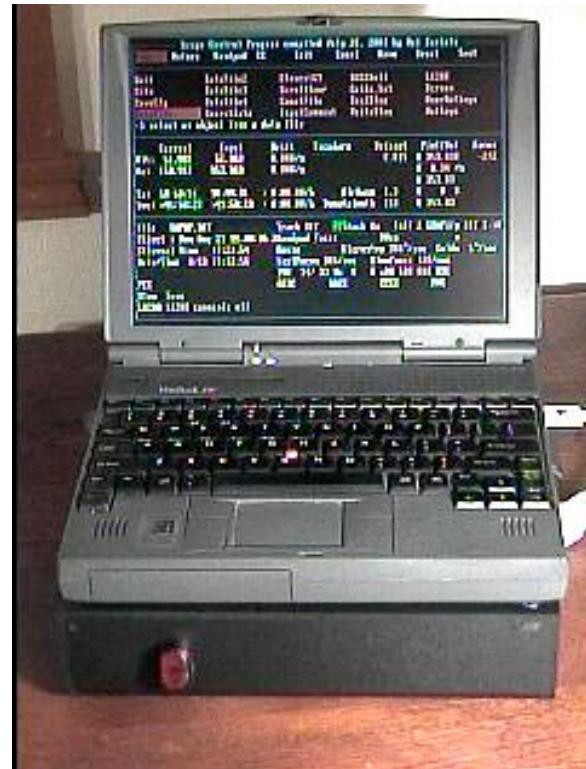
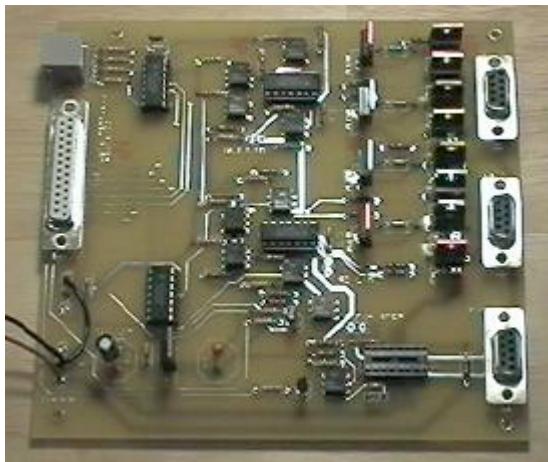


# BBAstroDesigns, Inc.

Formed October 2000 by Mel Bartels and Barbara Bajec,  
**BBAstroDesigns Inc.** <http://www.bbastrodesigns.com>  
aims to serve the amateur telescope making community,  
specializing in products for computer operated telescopes.

**Computer Operated Telescopes  
Stepper System Software, "Scope.exe"  
by Mel Bartels  
last revised May 1, 2006**

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## Safety Guide and Warning

You must exercise proper safety precautions, including the wearing of glasses and thick rubber lug shoes. Shock hazard! Bodily injury hazard! Any device using electricity is a shock and bodily injury hazard. You must hook up the device properly and follow all safety precautions, particularly when using electricity outdoors. If improperly hooked up or improperly operated, electronic components can shock, overheat, melt, and explode.

Peripheral equipment hazard! Any device electrically attached to a computer can damage the computer if hooked up improperly, or used improperly.

In particular:

- Never operate when the equipment or cabling is wet or moist, even if there is only a possibility that some of the equipment is wet or moist
- All grounding points must be connected to the battery (-) terminal before turning on any equipment; the grounds must never be disconnected while the unit is powered on (disconnecting any ground will force the current to search out a return path to ground, possibly by traveling through your body, causing shock and bodily injury)
- Power leads must be connected in proper order with the black ground wire connected before the red positive voltage lead
- Power leads must not be reversed: instant component failure is a certainty; components will overheat and can explode with violent force
- Do not exceed 12 volts DC power input: shorting more than 12 volts DC through your body can be lethal.
- The power supply (+ or positive voltage) lead can only be connected or switched on when the software scope.exe is executing, and if running under Windows, can only be connected or switched on if scope.exe is the foreground program

## Quick Start Guide

1. Re-read the Safety Guide and Warning
2. Attach the circuit board to the computer's parallel port using a straight through 25 pin serial cable
3. Attach the hand paddle to the circuit board
4. Using a small 12 volt battery, or two 6 volt dry cell batteries connected in series, attach the battery's (-) post to the circuit board ground, which will be the black lead
5. Turn on the computer
6. Enter the appropriate parallel port in the config.dat file: look near the end of the file for a line that starts PportAddr, and enter the desired lpt #, usually a 1
7. Run scope.exe, selecting either altazimuth or equatorial alignment
8. Attach the battery's positive (+) post to the circuit board's red lead
9. Check the hand paddle operation by pressing the hand paddle buttons in turn, verifying that scope.exe is reading the buttons properly
10. Using the optional LED tester unit, plug it into the altitude or the azimuth motor port (do not plug it into the field de-rotator port), then turn on tracking in scope.exe, and verify that a. the lights turn on and off in sequence from one side to the other, and b. no more than 2 lights are on at any one time
11. Verify motor movement by attaching a motor to the azimuth/right ascension port of the circuit board (the middle db-9 connector), then turn on tracking in scope.exe
12. Attach the other unipolar stepper motor to the altitude/declination port of the circuit board and verify movement by using the up button of the hand paddle
13. If using a bipolar field rotator motor, attach it to the field rotator port (the bottom db-9 connector, next to the raised IC), then set the altitude to 80 degrees in scope.exe

## Configuring the Stepper Software

Scope.exe requires a config.dat file. You can specify an alternative config.dat file by using the command line option -c, ie, scope.exe -c \temp\config.tmp

**Note: all variables, names, and strings are case insensitive, so DefaultBackground will work as will DefaultBackground**

The following variables set the display colors:

*DefaultBackground*

*DefaultColor*

*TitleColor*

*BorderColor*

*MenuColor*

*DisplayColor*

*SelectColor*

*CurrentColor*

*SelectBackground*

based on:

- BLACK=0,Both
- BLUE=1,Both
- GREEN=2,Both
- CYAN=3,Both
- RED=4,Both
- MAGENTA=5,Both
- BROWN=6,Both
- LIGHTGRAY=7,Both
- DARKGRAY=8,Foreground only
- LIGHTBLUE=9,Foreground only
- LIGHTGREEN=10,Foreground only
- LIGHTCYAN=11,Foreground only
- LIGHTRED=12,Foreground only
- LIGHTMAGENTA=13,Foreground only
- YELLOW=14,Foreground only
- WHITE=15,Foreground only
- BLINK=128,Foreground only

*ConfirmQuit*: set to 1 if you wish a confirming message before the program quits

*DisplayOpeningMsgs*: if set to zero, opening and closing messages are suppressed

*HorizonLimitFlag*: if 1, warn if selected object is below the horizon

*MoveHsMsgDeg*: how long of a slew allowed before a confirming message is displayed

*F9Hotkey*, *F10Hotkey*, *F11Hotkey*, *F12Hotkey*: optional user specified hotkeys; should only be set via the program; delete from config file if you wish to erase them

*InterfacePath*: location of controlling planetarium software program, ie, c:\guide\ also location of Project Pluto's planetarium DOS program, dosguide.exe

*UseMouseFlag*: if 1, use mouse to select menu items, datafiles, objects from datafiles, and move the scope in microstep, halfstep, and auxiliary motions.

*IACA\_Flag*: if 1, use IACA to communicate with other IACA aware programs

*GEMFlipPossible*: if 1 or on, GEM meridian flip can occur

*AutoGEMFlip*: if 1, the GEM flip will occur automatically when the scope is asked to traverse to the opposite hemisphere

*SafetyZoneFlag*: if 1 then safety zone for the GEM flip is ‘on’

*AutoGEMFlipOnFuzzDeg*, *AutoGEMFlipOffFuzzDeg*: values entered here, like 7.5 degrees, will give some fuzz or wiggle room so that the scope doesn't flip back and forth from hemisphere to hemisphere as you touch the centering buttons; enter values for when GEMFlip is on and for when GEMFlip is off

*Siderostat*: set to 0 if standard equatorial or altazimuth mount, set to 1 if you are using a siderostat or uranostat flat to focus light into a stationary telescope tube; you must set AzLowLimitDeg to about 90, AzHighLimitDeg to about 270, where due south is about 180, the difference between the limits must be 180 deg or less. This allows the altitude to exceed 90 deg, otherwise the flat mirror will attempt to flip upside down when aimed at northly objects.

*HomeAltDeg*, *HomeAzDeg*: these are the home, or park coordinates

*MsArcsecSec*: microstepping speed when the hand paddle is used to center objects, can be changed while the program is running

*AltFullStepSizeArcsec*, *AzFullStepSizeArcsec*: these are the step sizes for the altitude and azimuth steppers. The altitude is measured by using a precision level to set the tube horizontal, resetting alt to 0, then moving the scope via the motors until the precision level indicates the tube is exactly vertical. The ratio between the displayed alt and 90 degrees is the amount to adjust the step size by. Similarly, one complete turn in azimuth can be used to adjust the azimuth step size

*precessionNutationAberration*: 1 if you wish precession, nutation, and annual aberration corrections to be used with the equatorial coordinates, 0 if you wish these corrections ignored

*RefractFlag*: 1 if you wish refraction to be used, 0 if you wish refraction to be display only

*UseAltAzECFlag*: if 1, ALTAZEC turned on at program startup.

*UseAltAltECFlag*: if 1, ALTALTEC turned on at program startup.

*UseAzAzECFlag*: if 1, AZAZEC turned on at program startup.

*PointingModelFlag*: if 1, PMC turned on at program startup.

*HandPadPresentFlag*: if 1 then handpad present, if 0, then handpad not present and handpad is ignored. If the handpad is not connected or in an error condition at program startup, it is ignored.

*StartingHandPadMode*: sets starting handpad mode, also ending handpad mode saved at program exit to this variable: values are

- off: 0
- init auto on: 1
- init 1: 2
- init 2: 3
- init 3: 4
- polar alignment: 5
- analyze on: 6
- guide on: 7
- guide stay on: 8
- guide stay save on: 9
- guide stay rotate on: 10
- guide drag on: 11
- grand tour: 12
- scroll tour: 13
- scroll auto tour: 14
- record equat: 15
- toggle track: 16
- FR mode: 17
- focus mode: 18
- Auxiliary control mode: 19

*HandpadDesign*: 0 if standard handpad, 1 if using the four data lines to represent the four directions (no mode control or speed control available: this is for autoguiders that need simultaneous action in two directions, something not possible with standard handpad design)

*HandpadFlipUpDownWithGEMFlip*: if 1 then handpad will flip its up/down direction buttons when GEMflip is on to match the declination direction reversal that occurs when the GEMflip has occurred

*AltBacklashArcmin*, *AzBacklashArcmin*: these are backlash values (if both are 0, backlash is disabled). If backlash correction is desired, values should be positive. A negative value means that the motor will move in the opposite direction than expected in order to take up backlash

*ABacklashSignalPPortPin17*: if non-zero, then parallel port pin 17 used to signal the direction of the 'A' motor backlash: logical high if backlash direction is CCW, logical low if backlash direction is CW (can be used to control motorized counterweights); starting value is logical low

*AltLowLimitDeg*, *AltHighLimitDeg*, *AzLowLimitDeg*, *AzHighLimitDeg*: these limits are active only when HsTimerFlag is set to 1 (on); if HsTimerFlag is on and desiring to disable the alt limits, set both alt limits to 0; if HsTimerFlag is on and desiring to disable the az limits, set both az limits to 0

*GuideArcsecSec*: guiding correction speed, can be changed while the program is running

The following are drift rates that a star will be dragged across an autoguider with knife-edge detector. These autoguiders work by expecting the tracking rate to be slightly off guaranteeing that the star will always eventually move across the knife-edge. When the star crosses the knife-edge the autoguider gives it a little kick in the opposite direction, then waits for the star to reappear.

*GuideDragAltArcsecPerMin*

*GuideDragRaArcsecPerMin*

*GuideDragAzArcsecPerMin*

*GuideDragDecArcsecPerMin*

*HPUpdateDriftFlag*: if 1, then the drift is updated at the end of a handpaddle guiding session. Drift is calculated based on accumulated guiding corrections over the session and then automatically adopted.

*DriftAltArcsecPerMin*: starting value of altitude drift in arcseconds of angular movement per minute of time.

*DriftAzArcsecPerMin*: starting value of azimuth drift in arcseconds of angular movement per minute of time.

*DriftRaDegPerHr*: starting value of declination drift in degrees of angular movement per hour of time.

*DriftDecDegPerHr*: starting value of right ascension drift in degrees of angular movement per hour of time.

*PECFlag*: if 1, then PEC turned on at program startup time.

*AutoAltPECPin*: parallel port pin(s) that auto synchronization of altitude will be read from: must be 15, 16 or 17, or 10+12+13 (3 pin combination), or deleted from config.dat (default will be 17 then). If you use the 10+12+13, be careful not to simulate it by any of the following hand paddle key presses: UpKey + DownKey + CCWKey, or CCWKey + CWKey, or UpKey + RightKey, or DownKey + LeftKey

*AutoAltPECSyncOnFlag*: turns on automatic synchronization of the altitude PEC using the AutoAltPECPin pin of the parallel port

*AutoAltPECSyncLowHighFlag*: if 0, synch point occurs after +5 VDC has been applied, and at the moment ground is applied; if 1, synch point occurs when +5VDC is applied after pin has been grounded.

*AutoAltPECSyncDirFlag*: direction that alt PEC must be moving in order to trigger auto-sync: 0 = either direction, 1 = CCW direction, 2 = CW direction

*AutoAltPECDeBounce*: if 1 or on, then software will debounce the synchronizing signal: the debounce period ends when the PEC index is between the  $\frac{1}{4}$  and  $\frac{3}{4}$  point of the PEC cycle

*AutoAzPECPin*: parallel port pin that auto synchronization of azimuth will be read from: must be 15, 16 or 17, or 10+12+13 (3 pin combination), or deleted from config.dat (default will be 15 then). If you use the 10+12+13, be careful not to simulate it by any of the following hand paddle key presses: UpKey + DownKey + CCWKey, or CCWKey + CWKey, or UpKey + RightKey, or DownKey + LeftKey

*AutoAzPECSyncOnFlag*: turns on automatic synchronization of the azimuth PEC using pin 15 of the parallel port

*AutoAzPECSyncLowHighFlag*: if 0, synch point occurs when ground is removed from pin; if 1, synch point occurs when ground is applied.

*AutoAzPECSyncDirFlag*: direction that az PEC must be moving in order to trigger auto-sync: 0 = either direction, 1 = CCW direction, 2 = CW direction

*AutoAzPECDeBounce*: if 1 or on, then software will debounce the synchronizing signal: the debounce period ends when the PEC index is between the  $\frac{1}{4}$  and  $\frac{3}{4}$  point of the PEC cycle

*FullstepsPerPECArray*: This allows periodic correction for single through quad worms by tying the PEC sequence to an amount of fullsteps, not to a motor's single turn. Positive values in PEC.DAT indicate too much clockwise motion. Values are in tenths of an arc second. A total of 200 values per PEC are used regardless of number of fullsteps per PEC array. PEC must be synchronized by placing the motor shafts in the predetermined starting position and hitting the 'PEC on' keyboard menu item selection or by using the auto-sync option.

*PECIxOffset.A*, *PECIxOffset.Z*: index offsets of both axes between rotor position of 0 and synch point, for instance, if the current position coordinate is zero with the rotor in the up position, and you have 200 fullsteps for a PEC cycle, and if the PEC synch point occurs with the rotor in the down position, then the offset will be 100; leave at 0 until PEC is turned on and synchronized, at which point let the program determine these values

*FRStepSizeArcsec*: field rotation motor step size, set to 0 if you wish field rotation disabled

*SectoriedFRDrive*: if using a sectored field de-rotation drive, set to 1, otherwise field de-rotator motor may slew large angles after the scope finishes a slew.

*FRStepSpeedMilliSec*: speed of field rotation motor when slewed by hand paddle

*ReverseFRMotor*: reverse field rotation motor direction

*FocusMethod*: can be 0, 1, 2, or 3:

1. Connecting parallel port pins 16 and 17 to a pair of relays to control a small DC motor for focusing. Pin 16 focuses 'out' and pin 17 focuses 'in'. This can be operated with the field rotator concurrently.
2. As above in option 0, with the addition of parallel port pins 1 and 14 for slow speed control. Field rotation is disabled with this option.
3. Using the field rotation motor control circuit with a small stepper motor for focusing. This uses parallel port pins 1 and 14 for pulse and direction.
4. Adding a second MC3479 bipolar stepper control circuit with a small stepper motor for focusing. This uses parallel port pins 16 and 17 for pulse and direction. Both the field rotation

and focus motors can be operated simultaneously. Along with the altitude/declination and azimuth/hour angle motors, this means that four motors are controlled at the same time.

*ReverseFocusMotor*: if 1, then reverse direction of focusing motor

*FocusFastStepsSec*: if using bipolar stepper motor for focusing, then this value contains the fast speed setting in steps per second

*FocusSlowStepsSec*: if using bipolar stepper motor for focusing, then this value contains the slow speed setting in steps per second

*FocusPosition*: if using bipolar stepper motor for focusing, then this value contains the focuser position in steps

*MotorControlMethod*:

- 0 = pulse width modulation of unipolar stepper motors (if in doubt, pick this option),
- 2 = pulse and direction control, if option 2, set the fullstep size to the amount moved every motor pulse

*KeepAlivePPortPin*: set to the parallel port pin (1, 14, 16, or 17) you wish to use for input to a keep alive circuit; the pin will pulse at least 9 times per second; design the circuit so that the power supply to the motors is cut off if the pin fails to trigger after a short period of time.

*MotorWindings*: 4 or 5: number of windings that the stepper motors have; almost all have 4 windings, but the software can work with 5 phase motors such as those from Vexta if going with 5 phase motors then please observe the following notes:

An option is provided for driving 5-phase motors by using pins 16 and 17 for the fifth phases of the A and Z motors respectively. To use this option, set MotorWindings to 5 in CONFIG.DATA. Note that the choice of 4 or 5 phases for has no effect on the parallel port outputs for the field rotation motor.

The following changes in design or usage apply in the 5-phase case:

1. Driver circuitry must use H-bridge design. Refer to "Jones on Stepping Motors" at <http://www.cs.uiowa.edu/~jones/step/> or design data for the SGS Thompson L298 Dual Full Bridge Driver at <http://www.st.com/stoneline/books/pdf/docs/1773.pdf>
2. Interpretation of the 0's in the microstepping table above and in variables such as HsOut changes from "off" to "grounded" (see Jones).

*InvertOutput*: Original designed called for 7404 inverters to drive the transistors, hence InvertOutput 1 in the original config.dat (parallel port output goes high, hex inverters go low, and drive transistors turn off, hence the need to invert the output). In the original design, if opto-isolators were used, then InvertOutput 0 (parallel port output goes high, hex inverters go low, opto-isolators turn on pulling output low, hex inverters go high, and drive transistors turn on, hence no need to invert output). If using the printed circuit board, the pcb design uses 7408 and gates (parallel port output goes high, 7408 and gates go high, opto-isolators turn off allowing output to return to high, 7408 and gates go high, and drive transistors turn on, hence no need to invert the output). Screw this up and you will pump a lot of current through the steppers!

*ReverseAMotor*: set to 1 if you wish to reverse direction of the 'A' motor (the altitude or declination motor). This is equivalent to swapping winding leads 1 and 3.

*ReverseZMotor*: set to 1 if you wish to reverse direction of the 'Z' motor (the azimuth or right ascension motor). This is equivalent to swapping winding leads 1 and 3.

*HsRampStyle*: set to 0 if you wish the old simple ramp, and set to 1 if you wish the new 'S' shaped ramp curve, where the ramp starts slowly, speeds through the middle range, and slows down for the highest speeds at the end of the ramp.

*HsTimerFlag*: set to 1 if you wish to use IRQ 8 to time the halfstep slews, this allows for realtime updating of scope coordinates, keyboard interruption of slews, and altitude limit checking during a slew, otherwise if set to 0, halfsteps are timed by a delay loop with interrupts disabled to avoid interruption; using IRQ8 works perfectly in DOS, not at all in Win 3.x, and slowly in Win95

*MaxDelay*, *MinDelay*, *HsDelayX*: these set the slowest and fastest slew speeds:  
 when using IRQ 8 timing of halfsteps, ramp speed starts at *MaxDelay* and achieves highest speed at *MinDelay*; with interrupt 8 method of timing the halfsteps, speed can be converted to halfsteps per second by dividing *MaxDelay* and *MinDelay* into 1,000,000, so that a *MaxDelay* value of 1000 means 1000 halfsteps per second, and a *MinDelay* value of 200 means 5000 halfsteps per second.  
 when using delay loop timing of halfsteps with interrupts disabled, ramp speed starts at (**MaxDelay - MinDelay**) \* *HsDelayX* and achieves highest speed of **MinDelay \* HsDelayX**, where *HsDelayX* is used as a multiplier to keep the *MaxDelay* and *MinDelay* values reasonably sized on fast CPUs.

*HsRampX*: the amount of time to ramp up or ramp down is multiplied by *HsRampX*

*InterruptHs*: number of halfsteps before interrupts disabled if using delay loop timing of halfsteps

*HoldReps*: time to lock stepper rotors at beginning and end of slew to prevent shaft oscillation and overshoot

*HsOverVoltageControl*: for optional halfstep high speed slewing over-voltage control; if desired, enter a non-zero value. Control line is parallel port pin #17. Value entered here will be the Delay value at which the over-voltage control line will be toggled logical high. Pick a value between *MaxDelay* (slowest speed or greatest delay) and *MinDelay* (fastest speed or least delay between halfsteps)

*MaxConsecutiveSlews*: maximum number of consecutive slew attempts to reach a desired position. If slews cannot reach position, scope begins tracking. This prevents oscillations when *MsRepsTick* or PWM values are low and tracking speed exceeds maximum microstepping speed.

*MsPowerDownSec*: number of seconds before idle motor will power down during microstepping.

*PWMRepsTick*: count of pulse width modulations per bios clock tick. Set to average value of *PWMReps* displayed on screen.

*AvgPWMRepsTickOnFlag*: if 1, then auto-averaging of the *PWMRepsTick* will occur, based on the actual number of PWM repetitions per timer tick as averaged over 3.5 seconds; if 0, then the *PWMRepsTick* value as entered in the config.dat file will be used.

*MsDelayX*: repetition value of each value in the microstepping arrays, this allows for smaller arrays when needing large *PWM[]* values for fast PCs.

*MsPause*: the number of dummy loop repetitions at the end of every *PWM[]* loop. This allows for fine low voltage resolution when using a high voltage power supply

*Ms*: number of microsteps: up to 40 per each fullstep

*MaxIncrMsPerPWM*: maximum microstep increment per pulse width modulation. In order to microstep faster, microsteps can be skipped. Consequently, this sets the maximum microstepping speed. Microsteps can be skipped up to very roughly 4 per fullstep. For instance, if you have 20 microsteps per fullstep, then you can enter a value of 5 here. Consequently, this variable also controls the maximum microstepping or tracking speed. For instance, if you set it to 1, then your max microstepping speed will be the **PWMRepsTick \* 18** (ticks per second). The max value that you can set it to will be the number of microsteps in a halfstep, because the fastest the microstepping routine can work at is one halfstep per

PWM. (if the number exceeds MsHsToggleIncrMsPerPWM, the routine switches from microstepping per each PWM to halfstepping per each PWM)

*MsHsToggleIncrMsPerPWM*: while microstepping, the routine will switch into halfstep mode if necessary. This is toggled when the number of microsteps per each PWM repetition exceeds MsHsToggleIncrMsPerPWM. For instance, if the PMW repetitions per timer tick is 50, and if MsHsToggleIncrMsPerPWM is 5, and you ask the program to track at more than 250 (50\*5) microsteps per PWM, then the routine will toggle to halfstep movement. Max speed is still the # of microsteps per fullstep divided by 2, equivalent to halfstepping. In this example of 20 microsteps per fullstep, the max speed is 20/2 or 10 microsteps per PWM, or 500 (50\*10) microsteps per PWM. Overall speed in any case is still limited by MaxIncrMsPerPWM.

*MaxPWM*: maximum pulse width modulations, and consequently the maximum value that any PWM[] value can take. This can be set higher than PWM[0] so that PWM[1]... can be set higher than PWM[0] to ameliorate stepper motor cogging

*PWM[0] through PWM[19]* : These values sets the voltages for individual microsteps. In general, these values should reflect the ratios discussed earlier. If the microstepping is not smooth, adjust these values. If the motors become too warm and take too much current, increase MaxPWM, lower the PWM[0] through PWM[19] values, decrease MsDelayX and/or increase MsPause. When tracking, the steppers should draw no more than approximately 0.1 amp while still producing adequate torque.

The rotor is positioned based on the inverse square strength of two adjoining windings, for instance, PWM[0] 100 : 0

means that the first microstep has a current value for winding A of 100 and a current value for winding B of 0 positioning the rotor exactly over winding A, and,

PWM[10] 100 : 100

means that the 11th microstep has a current value for winding A of 100 and a current value for winding B of 100 positioning the rotor exactly between winding A and winding B, and,

PWM[19] 29 : 100

means that the 20th microstep has a current value for winding A of 29 and a current value for winding B of 100 positioning the rotor 9/10ths of the way between winding A and winding B (there is a slight deadband where a certain amount of counts, usually about 10, are needed for the motor to feel the current pulse at all);

here are the values for 20 microsteps:

PWM[0] 100 : 0	PWM[10] 100 : 100
PWM[1] 100 : 29	PWM[11] 98 : 100
PWM[2] 100 : 45	PWM[12] 95 : 100
PWM[3] 100 : 56	PWM[13] 88 : 100
PWM[4] 100 : 65	PWM[14] 81 : 100
PWM[5] 100 : 72	PWM[15] 72 : 100
PWM[6] 100 : 81	PWM[16] 65 : 100
PWM[7] 100 : 88	PWM[17] 56 : 100
PWM[8] 100 : 95	PWM[18] 45 : 100
PWM[9] 100 : 98	PWM[19] 29 : 100

Optional variables: *QSC ...*, which stands for QuarterStepCorrection: the '\_a' through '\_d' indicate the winding, and the extra '2' indicates the intermediate halfstep; enter corrective values in fullsteps, for instance, if the motor moves too far for the 'a' winding by 0.1 fullstep halfway through its range, and no other corrective actions are required, here is what the entries will look like for the 'a' winding (for windings 'b' through 'd', duplicate these entries, replacing the 'a' with the winding letter 'b', 'c', or 'd'):

```
QSC_a0 0 : 0
QSC_a1 0 : 0
QSC_a2 0.1 : 0
QSC_a3 0 : 0
```

Optional variables: *PWM\_...* which taken together allow compensation for current variation to each stepper motor winding. It has been discovered that the 8 output lines from the circuit may vary in output current thanks to variations in the parts themselves. In addition, there may be variations in motors. Some of the quarter step correction (QSC) issues may be due to variations in motor winding current. By allowing for individual current adjustment of each output line, one can tune every output line to give the same current. For instance, if one finds that the 2nd output line ('B' winding of the altitude/declination motor) reads a low current compared to the other output lines, the other lines can have their output current lowered by the software to compensate. Default is no compensation and config.dat does not need to be changed. If you wish to use output line/motor winding current compensation, add the following variables to config.dat. A value of 1 means output 100% of available current, a value of 0.5 means output 50% of available current, and so forth.

Here is what the entries will appear to handle a compensation for a disparate 'B' winding of the altitude/declination motor:

```
PWM_A_a_Comp 0.8
PWM_A_b_Comp 1
PWM_A_c_Comp 0.8
PWM_A_d_Comp 0.8
PWM_Z_a_Comp 0.8
PWM_Z_b_Comp 0.8
PWM_Z_c_Comp 0.8
PWM_Z_d_Comp 0.8
```

*PPortAddr*: parallel port address: enter a 1 or 2 or 3 for lpt port 1 through 3, or enter the base address in a 3 digit decimal form where portid lpt1 = decimal 888 (hex 378) lpt2 = decimal 632 (hex 278), monochrome video card = decimal 956 (hex 3BC)

*COM3Base*: com3 base address in decimal form (if entry not listed in the config file, will default to 0x3E8 in hex or 1000 decimal)

*COM3IRQ*: com3 interrupt from 3 to 15 (if entry not listed in the config file, will default to 4)

*COM4Base*: com4 base address in decimal form (if entry not listed in the config file, will default to 0x2E8 or 744 decimal)

*COM4IRQ*: com4 interrupt from 3 to 15 (if entry not listed in the config file, will default to 3)

*EncoderString*: options are:

- NoEncoders,
- BSeg = Bob Segrest unit,
- ResetViaR = MicroGuiderIII, Ouranos, StarPort, and types that support reset by 'R...',
- ResetViaZ = BBox, NGC types, and types that support reset by 'Z...',
- NoReset = SkyWizard and types that are not resettable,
- Ek = encoder box as designed by Dave Ek,
- Mouse = using encoders from mouse (turn off acceleration, etc in mouse driver)
- LM629Serial = use serial interface to LM629 servo controller

*EncoderComPort*: enter 1 or 2 for com1 or com2, ignored if using Mouse driver

*EncoderBaudRate*: baud rate to access the encoder interface box; normally 9600

*SerialWriteDelayMs*: millisecond wait after querying encoders before reading encoders; some wait is required, often 20-50 milliseconds

*AltEncoderCountsPerRev*, *AzEncoderCountsPerRev*: encoder counts per full revolution of the telescope mount; max of 65,534 with some encoder boxes having lower limits; if unable to set limits, then start scope.exe in serial test mode, turn on encoder box, enter commands from encoder box manual to manually

set the resolution, check manual for any confirmation commands, if successful, write down what you entered and what the encoder box returned and send to the author, exit scope.exe, restart scope.exe in normal mode - do not turn off encoder box - and continue with normal operation of the telescope

*AltEncoderDir, AzEncoderDir*: allows changing of direction that encoder counts up, set to 0 to reverse count direction

*EncoderErrorThresholdDeg*: if encoder readings compared to current coordinates exceed this threshold, then current coordinates reset to encoder readings; if 0, coordinates not reset no matter how great the discrepancy

*TrackEncoderErrorThresholdDeg*: as above, but the error threshold to be used when tracking or slewing is on

*MakeEncoderResetLogFile*: set to 1 if you wish encoder threshold violations to be recorded into the file "Encoders.txt"

*EncoderOffset.A, EncoderOffset.Z*: offsets of encoder position from scope position in radians; let the software calculate these values

*LX200ComPort*: enter 1 or 2 for the com port to receive LX200 styled commands from external PC; set to 0 if not used

*LX200BaudRate*: baud rate for LX200 control; normally 9600, but if possible to change the external controlling program, set the baud rate to highest speed for faster data throughput and consequent less impact on motor movement

*LX200MotionTimeoutSec*: if no LX200 stop motion command received, motion will stop in this many seconds

*LX200SlewHs*: if no slew stop received, slew distance in halfsteps

*LX200\_LongFormat*: start the program in emulate long format mode

*Current.Alt, Current.Az*: current telescope altazimuth coordinates in degrees

*AccumMs.A, AccumMs.Z*: current telescope altazimuth coordinates in accumulated microsteps; these are used for the telescope's starting and ending position. Calculate the current altazimuth coordinates in degrees by multiplying the accumulated microsteps \* the microstep size (which is fullstep size divided by number of microsteps).

*StartInitState*: This controls the startup state of the initializations. It operates exactly as the query at program startup:

- 0 means ask user per traditional menu options,
- 1 means adopt equatorial alignment,
- 2 means adopt altazimuth alignment,
- 3 means adopt no alignment at all, and
- 4 means to reuse last alignment.
- Any other option than 0 means that you will not be queried. This is a config.dat replacement for the query menu at startup time. Use it if your answer to the opening query is always the same. Default is 0, to query the user.

*OneInit, TwoInit, ThreeInit*: the stored initializations used to orient the telescope to the sky; these are written by the program; each line consists of Ra, Dec, altitude, azimuth, and sidereal time all in degrees

*ZIDeg*: elevation offset to horizon perpendicular

*Z2Deg*: optical axis error in same plane

*Z3Deg*: correction to zero setting of elevation (this can be set to zero permanently and the altitude offset function in the program used to make an automatic *Z3* correction)

*LatitudeDeg*: used only for rough initial altaz alignment

*CMOS\_RTC\_Access*: CMOS Real Time Clock access: 0 = direct port access, 1 = bios call access - use 1 only if machine locks up including during ATimes test (very rare - only one reported instance)

*LongitudeDeg*: your site's longitude, used to determine HAOffset and local sidereal time

*Tz*: used to determine sidereal time, the initialization process does not depend on sidereal time or longitude, instead relying completely on the time interval between initializations

*DST*: also used to determine sidereal time

*TestString*:

- NoTest = normal program execution,
- PreloadGuidexx.dat = preloads the program with guidealt.dat and guideaz.dat, then runs normally,
- Track = start 2 motor tracking with default value

### **Setting the altitude axis and azimuth axis fullstep size in the config.dat file**

Use the move/halfstep menu option to move the telescope a set amount of halfsteps. Assuming fullstep size of 3 arcseconds, and ability to measure angle change down to several arcminutes (8192 count per revolution encoders, or precision bubble), then execute at least 5,000 steps for 1% accuracy. If encoders are used, the program will automatically display the fullstep values for AltFullStepSizeArcsec and AzFullStepSizeArcsec that you should enter into the config.dat file. Try for 0.1% or 1 part in 1000 accuracy (move at least 50,000 steps, or roughly 45 degrees).

### **Setting the slew (halfstep) speed**

Because computer capabilities vary greatly and because of widely varying motor and scope mounts, it will be necessary to spend time optimizing the values relating to halfstepping in the configuration file, config.dat. I use a 486/100 laptop. Included is config.386, which were the values I used on my old 386/20 with 387 math coprocessor.

To set the halfstep slewing, try to set HsTimerFlag to 1, enabling the interrupt drive timing. The interrupt driven timing is independent of cpu speed, so regardless of the computer's speed, set MaxDelay to 2000, MinDelay to 500, and HsRampX to 5. MinDelay and MaxDelay can be converted to Hertz by dividing them into 1,000,000. For instance, if MaxDelay is 1000, then Hertz is 1000 or step frequency is 1000 steps per second.

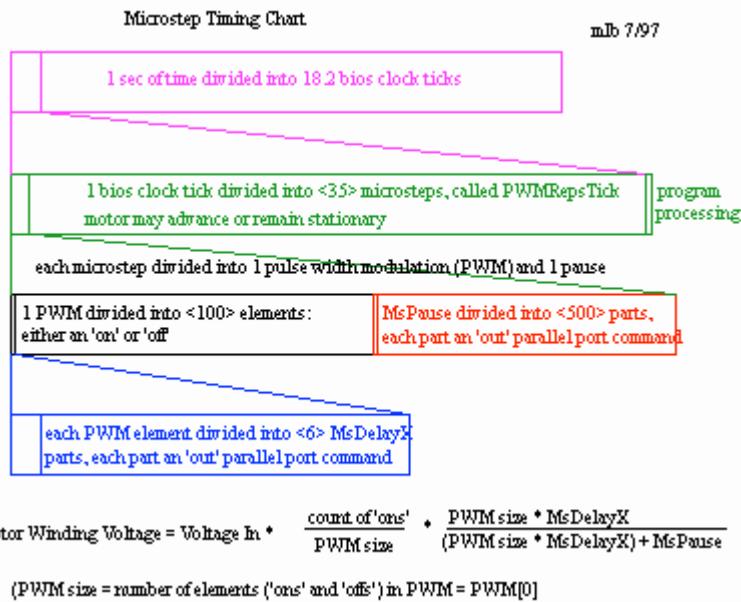
Be sure to run scope.exe after booting to DOS, or exiting Win95 to DOS. The motor's starting speed is set by MaxDelay, the fastest speed by MinDelay, and the time to ramp up and down set by HsRampX. Adjust to suit your combination of steppers, drive voltage, and scope's torque loading.

If the interrupt drive timing won't work and it is necessary to use the delay method of timing the halfsteps, set HsTimerFlag to 0. If you have a cpu close to a 386/20, start with MaxDelay 8000, MinDelay 3000, and HsDelayX 1. If you have a cpu close to a 486/100, change HsDelayX to 2. Speed starts at (MaxDelay - MinDelay)\*HsDelayX, and achieves fastest speed at MinDelay\*HsDelayX. HsDelayX is used as a multiplier to keep the MaxDelay and MinDelay values reasonable; otherwise the array size becomes too large. Again, adjust as necessary to fit the motors, the drive voltage, and the scope.

## Setting the microstepping parameters

To set the microstepping: start with the suggested PWM[] values ranging from 100 on down. Start with MsDelayX = 1, and MsPause = 0 if on a slower machine, and MsDelayX = 6 if on a faster machine. Adjust MsDelayX such that PWMRepsTick displayed (turn on tracking for a few seconds) is 20 to 40. People have reported mixed success with slow machines and PWMRepsTick values as low as 7. Values as high as 50 to 100 will also work. Find the MsDelayX value that results in smoothest motor rotation, adjusting MsPause to higher values possibly to 500 or more, to reduce voltage and current draw, and to smooth the motor rotation.

Here's how the microstepping is laid out:



To reverse motor direction, swap motor leads #1 and #3, or alternatively, #2 and #4. Finally, you can swap motor directions in the config.dat file.

Adjusting the microsteps:

The program handles microstepping up to 40 microsteps per fullstep.

For 10 microsteps per fullstep, the windings are combined as follows:

*; starting a line with ';' means a comment line*

<i>;rotor centered on winding</i>	<i>;rotor between windings</i>
PWM[0] 100	PWM[5] 100
PWM[1] 100	PWM[6] 85
PWM[2] 100	PWM[7] 70
PWM[3] 100	PWM[8] 55
PWM[4] 100	PWM[9] 35

For 20 microsteps per fullstep, the windings are combined as follows:

<i>;rotor centered on winding</i>	<i>;rotor between windings</i>
PWM[0] 100	PWM[10] 100
PWM[1] 100	PWM[11] 94
PWM[2] 100	PWM[12] 86
PWM[3] 100	PWM[13] 77
PWM[4] 100	PWM[14] 69
PWM[5] 100	PWM[15] 62
PWM[6] 100	PWM[16] 54
PWM[7] 100	PWM[17] 46
PWM[8] 100	PWM[18] 37

PWM[9] 100

PWM[19] 27

(this written with 10 microsteps per fullstep in mind)

Set TestString to Track in the config.dat file, and choose 1 microstep per second. Put a piece of masking tape on the motor shaft and watch it carefully for even spacing of the microsteps. If the step is too far apart, bring the voltages closer together. For instance, if the spacing between microstep #0 and #1 is too far, then lower PWM[9], if the motor hardly seems to move between #0 and #1, increase PWM[9]. Again, if the spacing between #3 and #4 is too large, then increase #3, or decrease #4, or a combination of the two. You can change the PWM[] values on the fly. When you get them the way you wish, copy the values to the config.dat file.

Here is a contributed method: "There is a way that I used to find the proper PWM numbers for the drive that can interest you:

I started first with approximate numbers in the software.

I mounted a 7.96" plastic rod on the shaft to get a 50" circumference or 0.025" per microstep.

I put the software in TestString = Track mode with 0.1 step per second.

I measure each microstep position with a micrometer head for 4 full steps.

I calculate the mean displacement for each microstep 0 to 1, 1 to 2 etc..

And more important I PUT THE CALCULATED DATA ON A GRAPHIC SHEET.

This gives me a nice smooth curve. I pickup the PWM numbers for 0.025", 0.050", 0.075" and so on. I put back these numbers in the config.dat file and restart the measurement and write down. The result was almost perfect. I had to change the numbers of only plus or minus 1."

Yet another suggestion from Juan Herrero: "I was going nuts trying to measure and adjust the variances between the microsteps in my Altaz controlled motors. I had 4 drinking straws taped end on end. Attached to the stepper motor shaft. The end of the 3' straw contraption, would only move a couple of millimeters per microstep. It was very difficult to take the measurements. And then...Mel decided to improve his software from 10 to 20 microsteps! How could I measure all those tiny steps ? Well yesterday I saw the light! Laser light that is. I went to RadioShack and got their cheapest laser pen pointer. Taped it to the motor shaft. And projected the beam on the wall. I can now measure microstep movements 20mm big! TA DA!"

Date: \_\_\_\_\_ Computer \_\_\_\_\_ Dir: \_\_\_\_\_ Scope.exe

Compiled: \_\_\_\_\_ Telescope \_\_\_\_\_ PCB \_\_\_\_\_

InvertOutput 0 0 for PCB

FR Step Size 2.25 for ½ step, 4.5 for full step

HSTimerFlag 1 for IRQ8 (DOS), 0 for Windows

Max Delay 2000 (DOS)

Min Delay 1000 (DOS)

HsDelayX N/A DOS, Multiplier for Windows slews

PWMRepsTick Shoot for 20-60

MsDelayX SlowPC=1, fast PC=6

MsPause Current Control during MS

Motor Current

PWM[0] a 100 Step0 = PWM[0]

PWM[1] b 100 Step1=PWM[1]+PWM[9]

PWM[2] c 100 Step2=PWM[2]+PWM[8]

PWM[3] d 100 Step3=PWM[3]+PWM[7]

PWM[4] e 100 Step4=PWM[4]+PWM[6]

PWM[5] f 100 Step5=PWM[5]+PWM[5]

PWM[6] g Step6=PWM[6]+PWM[4]

PWM[7] h Step7=PWM[7]+PWM[3]

PWM[8] i Step8=PWM[8]+PWM[2]

PWM[9] j Step9=PWM[9]+PWM[1]

SETUP: Pointer and scale on Motor, 10amp Range on Meter.

Calculate current to meet wattage limit on Motor:  $V=IR$ ,  $V_{Rated} * I_{Rated} = Watts_{Rated}$ ,

$I_{ops} = Watts_{Rated} / V_{ops}$

1. Start: Default PWM's, MsDelayX=1 for slow and up to 6 for fast,  
MsPause=0, PWMRepsTick=display in Track

2. Adjust MsDelayX till PWMRepsTick = 20 <-> 60 (may increase current) and motion is smooth.  
(Motion is smoother at lower PWM's, but current is higher and so is sound)

3. Adjust MsPause to get current within Motor Wattage Limits: (When current is too low, motion gets jerky)

Increase MsPause, Decrease PWM[x]'s or Decrease MsDelayX to Decrease current  
Decrease MsPause, Increase PWM[x]'s, or Increase MsDelayX to Increase current

4. Adjust PWM[x] Matrix for even steps (Larger PWM[x]'s decrease PWMRepsTick)

If spacing is too big: bring voltages closer together;

if spacing too small, increase the difference in voltages:

If the move between 0 and 1 is too big,

reduce [9] to decrease how much winding B pulls off centered on A

If motor barely moves between 0 and 1,

Increase [9] so winding B pulls it more off of centered on A

If spacing between [3] and [4] is too big,

increase [3] or decrease [4] (or both)

PWM (winding A) Step # PWM (winding B)

100 a 0--0-----0 a 100

100 b 1---1-----9 j \_\_

100 c 2---2-----8 I \_\_

100 d 3---3-----7 h \_\_

100 e 4-----4-----6 g \_\_

100 f 5-----5-----5 f 100

\_\_ g 6-----6-----4 e 100

\_\_ h 7-----7-----3 d 100

\_\_ i 8-----8-----2 c 100

\_\_ j 9-----9---1 b 100

5. Iterate 2-4 till current within wattage limit,

PWMRepsTick = 30-60, and motion is smooth/even

6. Adjust MinDelay and MaxDelay (and HsDelayX if Windows)

to allow smooth and fast slews with no buzzes (Min Delay = Buzz)

7. Copy these values into Config.dat

Bob Norgard has written a webpage on adjusting the microstep values. It is at  
<http://home.gci.net/~rnorgard/Scope/Microsteps>

Tom Krajci has an Excel spreadsheet to adjust the microstepping available at  
<http://www.egroups.com/Logon> and look at the scope-drive archives.

Andrew Martyn has an excellent microstep and QSC configuration page at  
[www.spin.net.au/~afmarty/index.html](http://www.spin.net.au/~afmarty/index.html)

## Program Display

```
+----- Scope Control Program compiled Nov 7, 2004 by Mel Bartels -----+
|File      Motors     Handpad   EC       Init     Coord     Move     Reset
+-----
|Quit        SaveCfg      DataFile      DataFile2      DataFile3
|DataFile4    ClosestGT    ScrollTour    InputComment    DOSShell
|Guide.bat    Hotkeys      ReadSlew      WriteSlew      LX200
|TestSerial   Screen
+-----
|--> quit the program
|    Current      Input      Drift      Encoders      Refract      FieldRot      Focus
|Alt: 30.028    30.028    0.000/m          0          A 315.562
|Az: 200.000    200.000    0.000/m          R 0.31 /m
|M 315.56
|Ra: 15:34:21  15:34:00  0:00:00/h      AirMass  2.0      M 0 0
|Dec: -13:44:45 -13:44:45 + 0:00:00/h  DomeAzimuth 200      G 0.00
+-----
|File           Track Off    FRTrack Off  Init 2      GEMFlip Off
|Object          Handpad Off          DUon      m
|Sidereal Time  16:45:21          Mouse      Microstep 300"/sec  Guide 5"/sec
|Date/Time 12/27 10:19:11          FastFocus 500/sec  SlowFocus 100/sec
|Pwm            / 37 Ms 0      0 b00 c00 000 QSC
|PEC             AZEC      AAEC      ZZEC      PMC
|Slew Done
|LX200 LX200 commands off
+-----
```

Use the cursor keys to select a menu item. Left-Right cursor keys select the main menu category and Up-Down cursor keys select the submenu item. Just under the menu selections, a more detailed description of the menu item's action is displayed.

The "Current" coordinates display where the telescope is currently pointing.

The "Input" coordinates display user input coordinates, ready for the telescope to be moved to, if "Move To/Equat" or "Move To/Altaz" is selected from the menu.

The "Drift" coordinates show the current drift rate in each axis.  
Encoder coordinates are displayed in degrees and in raw counts.

The "FieldRot" or field rotation shows one value if field rotation motor disabled, otherwise shows four values. The upper value is the current field rotation angle. The second value down is the rate of field rotation in degrees per minute. The next value down is the angle of the field rotation motor. The two numbers immediately below show the accumulated step count (clockwise adds, and counterclockwise subtracts), and the number of resets: all modulus 100. The final angle displayed under this line is the guide buttons rotation angle.

The "Focus" position shows the accumulated count of the focuser stepper. If no number is displayed, then the FocusMethod is set to something other than stepper motor control

The "AirMass" field shows the airmass number, or number of atmospheres that the telescope is aimed through.

The "DomeAzimuth" field shows the angle of the dome rotation in degrees.

The "File" area indicates which data file, or external program or device, has sent coordinates to the program.

If the coordinates have been reset because the encoder reset threshold values in the config.dat file have been exceeded, the "File" field will display a message stating the scope motion immediately preceding the

reset (enc.res.slew = encoder reset after slew, enc.res.on = encoder reset after tracking on, enc.res.off = encoder reset after tracking off), and a running count of the encoder resets for that particular scope motion.

The "Track" field shows if tracking is on or off.

The "TrackFRMotor" shows if the field rotation motor tracking is enabled/disabled.

The "Init" field shows how many initializations have been done so far.

The "GEMFlip" indicates if a german equatorial mount has been flipped across the meridian.

The "Object" area shows which object from the data file has been loaded into the input coordinates.

The "Handpad" field shows what handpad mode the program is currently in, and if that mode is active (for instance, if the mode is set to focus, and control of the focus motor is activated by the mode switch, then an 'on' will appear), if handpaddle auto-drift-update is on or off (DUon or DUoff), if guiding corrections saved to a file are finished then a "Fn" will appear, and further to the right, which buttons are being pressed and the switches' positions. C=clockwise button pushed, W=counterclockwise button pushed, U=up button pushed, D=down button pushed, m=speed switch in microstep position,H=speed switch in halfstep position, L=mode switch in left position, R=mode switch in right position, x = up, down buttons reversed.

The "Mouse" field shows the mouse mode: mouse modes include menu, where the traditional point and click is available, and various move modes, where mouse movement moves the telescope.

The "Microstep" field displays the current microstepping speed in arcseconds per second.

The "PWM" field shows the actual number of pulse width modulations per bios clock tick (there are about 18.2 clock ticks per second), and the averaged number of PWMs per timer tick that the program is currently using.

The "Ms" area shows the number of microsteps moved per timer tick (occurs 18.2 times per second) for altitude and azimuth motors, the winding from 'a' to 'd', the microstep within the winding for altitude and azimuth motors.

The "QSC" shows the current quarter step correction values for both motors.

The "Guide" field displays the current guiding speed in arcseconds per second.

The "FastFocus" displays the fast focus speed in steps per second.

The next area shows if the field rotation motor is moving "Fr+" or "Fr-", any auxiliary control lines activitated "A1" or "A14" or "A16" or "A17" and if the focus motor is moving "Ff+" (fast out) or "Ff-" (fast in) or "Fs+" (slow out) or "Fs-" (slow in).

The "SlowFocus" displays the slow focus speed in steps per second.

The "PEC" area, if PEC is on, shows the altitude and azimuth indexes and correction values in tenths of an arcsecond, respectively. In addition, if the auto-sync of altitude PEC or azimuth PEC is enabled, the PEC index at synch point is shown, and if an error, the PEC display is highlighted with the current selection color.

The "AZEC" shows the altitude vs azimuth error corrections in arcminutes.

The "AAEC" shows the altitude vs altitude error corrections in arcminutes.

The "ZZEC" shows the azimuth vs azimuth error corrections in arcminutes.

The "PMC" shows the pointing model error corrections for altitude and azimuth in arcminutes.

If using interrupt method to time the half steps, the "Slew" field will display the slew status, slew abort reason, the ramp half steps (1/2 of the total steps to move), the ramp up steps (steps taken while ramping up to max speed), the steps taken while at maximum speed up to the midpoint of the move, the remainder of the steps taken at maximum speed, the ramp down steps, and the current speed index (larger numbers = slow speeds, smaller numbers = high speeds).

If the menu option to display LX200 is turned on, then the LX200 field will show the history of commands received with an '\*' by the last command, and, the next line down will display the raw characters as received from the external device ouputting the lx200 protocol serial data.

### **LX200 supported commands**

Commands are displayed in abbreviated form on the LX200 line in scope.exe if the display LX200 is turned on as follows:

NA = no acknowledge yet received	RG = set motion rate to guide speed
AK = acknowledge received (indicates that external controlling program has queried for existence of lx200 device)	RC = set motion rate to centering speed
AA = align altaz	RM = set motion rate to find speed
AL = align land (turns off tracking)	RS = set motion rate to slew
AP = align polar	Sr = set right ascension
B+ B- B0 B1 B2 B3 = reticle brightness commands (ignored)	Sd = set declination
F+ = focus out	Sb = set brighter magnitude limit for find operation (value ignored)
F- = focus in	GF, GVF = get field (returns 100)
FQ = focus quit	Gq = get minimum quality of the find operation
FF = focus fast	GM GN GO GP get site info ("SCP" returned)St = set latitude (ignored)
FS = focus slow	Sg = set longitude (ignored)
GR Gr = get right ascension	SG = set GMT offset (ignored)
GD Gd = get declination	SM SN SO SP = set site number (ignored)
GA = get altitude	Sq = set minimum quality of the find operation
GZ = get azimuth	Sy GPDCO = sets the 'type' string for the FIND operation (ignored)
GS = get sidereal time	Sl = sets the larger size limit for the FIND operation (value ignored)
GL = get local time (24 hr format)	Ss = sets the smaller size limit for the FIND operation (value ignored)
Ga = get local time (24 hr format )	Sw = ???
GC = get current date Gc = get clock status	CM = synchronize scope
LI =return object info (ignored)	TQ = time quartz (ignored)
Lo = load object catalog from library (ignored)	U = toggle long format (coordinates)
Ls = load star catalog from library (ignored)	Un = unfinished command (no ending '#')
Mn = move north	Sf = set fainter magnitude limit for find operation (value ignored)
Ms = move south	SF = sets field (value ignored)
Me = move east	Sh = set current higher limit (value ignored)
Mw = move west	SS = set sidereal time
MS = start slew	SL = set local time
Q = stop slew	SC = set current date U0 = unknown command: first character uninterpretable
Qn = end motion north	U1 = unknown command: second character uninterpretable
Qs = end motion south	
Qe = end motion east	
Qw = end motion west	

U2 = unknown command: third character  
 uninterpretable  
 W1 through W4 = set site number (ignored)  
 Ig = ignored command

### **Customized LX200 commands**

commands starting with X are customized:

XgF gets focusing fast speed in deg/sec, format 999  
 Xgf gets focusing slow speed in arcsec/sec, format 999  
 Xgp gets focuser position, format 9999  
 XsF sets focusing fast speed in deg/sec, format 999  
 Xsf sets focusing slow speed in arcsec/sec, format 999  
 XGG get guiding rate in arcseconds per second, format 9999  
 XGM get MsArcsecSec  
 XGR get field rotation in degrees, format 999.99  
 XHa through XHt set handpadMode  
 XHL simulate press of handpad left mode key  
 XHR simulate press of handpad right mode key  
 XI1 initialize #1 with current altazimuth and input equatorial coordinates  
 XI2 initialize #2 with current altazimuth and input equatorial coordinates  
 XI3 initialize #3 with current altazimuth and input equatorial coordinates  
 XS set guiding rate in arcseconds per second, format 9999  
 XN set object name  
 XX unused in Scope II; used in scope.exe for clearing the LX200 display area

XGG = get GuideArcsecSec  
 XHa through XHz = set handpad mode 0 to 26 respectively  
 XHL = simulate handpad left mode key  
 XHR = simulate handpad right mode key  
 XI1 through XI3 = initialize point 1 through 3 using already sent equatorial coordinates  
 XSG = set GuideArcsecSec  
 XSM = set MsArcsecSec  
 XX = clear LX200 display area

### **Coordinates' display on the screen**

There are three main coordinates displayed: encoders, current, and input. The current coordinates show the scope's current position. The encoders coordinates show the positioning as relayed from the encoders. The input fields show coordinates that will be used if any of the move or reset to input menu items are selected. Inputting new equatorial coordinates does not change whatever inputted altazimuth coordinates are present, and visa versa.

### **Shortcut keys**

'1' selects 'move to equat'  
 '2' selects 'track on/off'  
 '3' saves current equatorial coordinates  
 '4' retrieve saved equatorial coordinates into the input fields  
 '5' saves current #2 equatorial coordinates  
 '6' retrieves saved #2 equatorial coordinates into the input fields  
 '7' read slew file from Guide6

'8' write slew file to Guide6  
 '9' input altaz  
 '0' reset to input altaz  
 'a' adds in the altitude offset to all initialization altitudes, adds in the altitude offset to the current altitude, and re-initializes  
 'b' begins an already loaded scroll file, and once started, 'l' continues onto the next scroll action, simulating a leftkey press of the handpaddle  
 'c' displays PEC graphically  
 'd' selects 'data file' menu item  
 'e' averages PEC analysis files and displays results graphically for the altitude axis  
 'f' averages PEC analysis files and displays results graphically for the azimuth axis  
 'g' selects menu item 'Guide.bat' (which calls Wguide.exe, passing it the current scope coordinates, the DOS 32 bit version of Guide)  
 'h' selects menu item hand paddle, toggling through handpad modes  
 'H' selects a hand paddle mode from a selection palette  
 'i' displays the initializations  
 'k' kills the inits  
 'l' reloads pec.dat file (when scrollfile is underway, 'l' simulates the handpad's leftkey press)  
 'm' selects microstepping speed  
 'n' slews to input altazimuth coordinates  
 'o' reset to input altazimuth coordinates  
 'p' selects PEC  
 'q' quits the program  
 'r' resets to input equat coord  
 's' selects scroll file  
 't' toggles tracking on/off  
 'u' altitude axis: graphically displays guiding efforts with respect to pec - gives options to save and update pec  
 'v' azimuth axis: graphically displays guiding efforts with respect to pec - gives options to save and update pec  
 'y' zeroes out the altitude pec array (does not save PEC.DAT)  
 'z' zeroes out the azimuth pec array (does not save PEC.DAT)  
 F1-F4 moves the scope with microstepping: F1 up, F2 down, F3 CCW, F4 CW  
 '' (the left apostrophe key in the upper left of most keyboards) selects the menu item 'Guide.bat'  
 '\$' or '[' or '{' gem meridian flip  
 '?' input equatorial coordinates  
 '<' handpad mode left key  
 '>' handpad mode right key  
 '&' restart scroll file  
 '@' toggle right handpad mode to reset equatorial in grand tour  
 '%' zero out backlash  
 '\*' do a three star polar alignment  
 User selectable Hotkeys: Use Cursor Left/Right and Up/Down to select function, then Hotkey highlighted function using F9-F12.

### **Equatorial Mount Startup**

1. select equatorial option at program startup; the scope will track accurately for any position in the sky, and, if the laptop's time and date is accurately set and the longitude value in the config.dat file accurately set then the scope will also slew accurately, but most likely these values will not be exactly accurate, so to refine the positioning:
2. center an object in the scope
3. enter object's coordinates via one of the data files, or manually if necessary

4. then do a reset to equat coordinates to inform the software where you are pointed; remember to never do any initializations at any time because it will confuse the original equatorial initializations at program startup time

Don Ware's polar alignment procedure is a part of scope.exe. Start with the telescope at least roughly polar aligned, and start the program using the equatorial alignment option. Then, follow the polar alignment instructions:

"Polar Alignment is split into five parts to allow operator intervention between stages. The process is started via the Init Menu or via hotkey '\*'. Subsequent stages are entered via hotkey '\*' or via the handpad left key.

**In Stage 0**, three stars are selected from the databases and the coordinates of the first star entered as input. After slewing to start#1, the operator then centers this star in the eyepiece with the handpad.

**In Stage 1**, a ResetEquatorial is executed, the coordinates of the second star entered as input and a slew to those coordinates executed. The operator then centers this star in the eyepiece using the handpad.

**In Stage 2**, the apparent coordinates of the second star are read and the offset of the polar axis calculated. Then a set of coordinates are calculated for the third star which are offset so that when the polar axis is moved to correct alignment the star will be centered in the eyepiece. A slew to these coordinates now takes place. The operator then adjusts the polar axis using altazimuth mount corrections only.

**In Stage 3**, a Reset Equatorial is performed using Star 3's correct coordinates. Finally, a slew back to the first star takes place.

**In Stage 4**, the operator is given the choice of repeating the process or of quitting. If the handpad is to be used, the Select HP Option "Polar Alignment" should be set prior to the start of the polar alignment process."

### Altazimuth Startup Sequence

there are several methods to initialize the scope with the sky -- they include:

- previously initialized + scope not moved,
- the instant eyeball initialization - good enough for visual tracking,
- tracking initialization,
- traditional 2 star initialization

#### **previously initialized + scope not moved:**

If the scope was previously accurately initialized and the scope has not been moved since then, pick altazimuth option 'reuse coordinates' at program startup.

If the encoder box has been left on, select 'reuse encoder coordinates' at program startup. You are set! If the encoder box was turned off, or if no encoders, then set the altitude and azimuth by

1. center object in eyepiece
2. enter object's coordinates via a data file or if necessary, manually
3. select reset to equat coordinates: this will update the altazimuth coordinates

#### **the instant eyeball initialization - good enough for visual tracking**

1. select option to adopt altazimuth alignment at program startup
2. enter best guess altitude and azimuth coordinates where scope is pointing, ie, if scope is horizontal and pointing to the south, enter 0 degrees altitude and 180 degrees azimuth
3. reset to altazimuth coordinates

This gives tracking accuracy good enough for visual purposes.

To improve (assumes that mount is fairly level, that timezone and longitude entered accurately in config.dat file, and that time/date of laptop is correct):

1. center object in eyepiece
2. enter object's coordinates via a data file or if necessary, manually
3. select reset to equat coordinates: this will update the altazimuth coordinates

#### **tracking initialization**

1. at program startup, select option to adopt no alignment
2. enter best guess altitude and azimuth coordinates where scope is pointing, ie, if scope is horizontal and pointing to the south, enter 0 degrees altitude and 180 degrees azimuth
3. reset to altazimuth coordinates
4. put handpad mode into init #1
5. enter an object's coordinates (typically a bright star from bstardat)
6. center object in eyepiece (use high powered illuminated crosshair eyepiece with barlow for most accurate results)
7. using handpad, init #1
8. put handpad mode into init #2
9. follow object with microstep movements using handpad for a minute or so
10. using handpad, init #2: scope now tracks accurately and can find nearby objects
11. hit shortkey 'i' to display the initialization results and check that the latitude is reasonable
12. continue to follow the object for a few more minutes
13. using handpad, init #2 once again
14. hit shortkey 'a' for altitude offset reset, answering yes
15. the initialization results (shortkey 'i') should show accurate latitude, differing from the real value for the site only by the mount's unlevelness
16. as objects further away from initialization object #1 are slewed to, continue to re-init #2 for increased accuracy of slewing across the sky

#### **traditional 2 star initialization**

1. at program startup, select option to adopt no alignment
2. enter best guess altitude and azimuth coordinates where scope is pointing, ie, if scope is horizontal and pointing to the south, enter 0 degrees altitude and 180 degrees azimuth
3. reset to altazimuth coordinates
4. put handpad mode into init #1
5. enter an object's coordinates (typically a bright star from bstardat)
6. center object in eyepiece (use high powered illuminated crosshair eyepiece with barlow for most accurate results)
7. using handpad, init #1
8. put handpad mode into init #2
9. enter another object's coordinates (typically a bright star from bstardat)
10. center object in eyepiece (use high powered illuminated crosshair eyepiece with barlow for most accurate results)
11. using handpad, init #2
12. hit shortkey 'i' to display the initialization results and check that the latitude is reasonable
13. hit shortkey 'a' for altitude offset reset, answering yes
14. the initialization results (shortkey 'i') should show accurate latitude, differing from the real value for the site only by the mount's unlevelness

#### **Your First Equatorial Initialization and Goto Run**

create a scroll file called startup.scr composed of these commands:

```
trackon
data_file bstars.dat
reset_equat
move_file messier.dat
prompt finished
```

the first command turns on tracking

the second command says to find an object from the bright star data file

the third command says to reset the telescope's position to the object's position

the fourth command says to move to a Messier object

and the last command displays a 'finished' statement indicating that the scroll file has finished

run scope.exe with the following command

*scope -x startup.scr*

this says to run scope and execute the scroll file startup.scr

answer 1. adopt an equatorial alignment and turn on the power supply to the motors when instructed

start the scroll file by pressing the left mode key on the handpad or the 'B' key on the keyboard  
as you do so, tracking will start

move onto the next scroll command via the left mode key or the '<' key on the keyboard which loads and displays the bstars.dat file, where you pick a nearby bright star

now center the telescope on the star using the handpad slew and microstepping speed switch and the four direction buttons

after centering, move onto the next scroll command via the left mode key or the '<' key on the keyboard which resets the telescope's coordinates to the star's coordinates

now move onto the next scroll command using handpad or keyboard, and select an object from the messier.dat file; the scope will slew to it

finish by moving on to the last scroll command which displays the finish command

exit the scroll function by pressing any key

### **Your First Altazimuth Initialization and Goto Run**

create a scroll file called startup.scr composed of these commands:

*data\_file bstars.dat*

*1i*

*trackon*

*data\_file bstars.dat*

*2i*

*move\_file messier.dat*

*prompt finished*

the first command says to find an object from the bright star data file

the second command says to initialize position #1 using the star's coordinates

the third command turns on tracking

the fourth command says to find another object from the bright star data file

the fifth command says to initialize position #2 using the star's coordinates

the sixth command says to move to a Messier object

and the last command displays a 'finished' statement indicating that the scroll file has finished

a. run scope.exe with the following command

*scope -x startup.scr*

this says to run scope and execute the scroll file startup.scr

b. answer 3. adopt no alignment and start from scratch and turn on the power supply to the motors when instructed

c. start the scroll file by pressing the left mode key on the handpad or the 'B' key on the keyboard  
as you do so, the program loads and displays the bstars.dat file, where you pick a nearby bright star

d. now center the telescope on the star using the handpad the four direction buttons and halfstep/microstep speed switch

e. after centering, execute the next scroll command to initialize position #1 via the left mode key or the '<' key on the keyboard

f. execute the next scroll command, setting up tracking to start as soon as the 2nd initialization is accomplished

g. move onto the next scroll command using handpad left mode switch or keyboard '<', and select the 2nd object from the bstars.dat file

h. center the telescope on the 2nd star by using the handpad as before

i. after centering, execute the next scroll command to initialize position #2 via the left mode key or the '<' key on the keyboard

j. now move onto the next scroll command and select an object from the messier.dat file; the scope will slew to it

k. finish by moving on to the last scroll command which displays the finish command

l. exit the scroll function by pressing any key

### The Handpaddle

The handpaddle has four momentary-on buttons that move the scope in altitude and azimuth. The center switch selects between fast halfstep slewing and smooth slow microstep centering.

The upper two momentary switches select different actions based on the software's current handpad status. 'Left' is the left mode key, and 'right' is the right mode key.



Handpad mode can be:

- o off: mode switch does nothing
- o init auto on: pressing either the left or right mode buttons inits the next available init, for instance, if init 1 already accomplished, then init 2 done, if all inits done, then closest init to the new init is replaced by the new init
- o init 1: pressing either the left or right mode buttons does an init # 1
- o init 2: pressing either the left or right mode buttons does an init # 2
- o init 3: pressing either the left or right mode buttons does an init # 3
- o polar alignment: steps through the polar alignment procedure for equatorial mounts – see the section on equatorial startup

- analyze on: if on, the handpad will save a position based on input equatorial and current altazimuth and sidereal time values to the analysis.dat for later mount error analysis
- guide on: pressing the left mode button puts the hand paddle into guide mode, where the push buttons act to move the scope very slowly in right ascension and declination by adding or subtracting from the current tracking rate - speed is set by GuideArcsecSec in the config.dat file - moving the switch momentarily to the right ends guide mode, and causes drift values to be calculated, put into use, and displayed - These drift values are used to null out any temporary residual drift due to imprecise initialization of a portable setup or imprecise mount construction, then the scope is moved back to the original Ra, Dec coordinates
- guide stay on: as 'guide on' but the scope stays put, adopting the new Ra, Dec coordinates of wherever the guiding corrections took the scope
- guide stay rotate on: when turned on by a press of the left mode hand paddle button, the program will rotate the hand paddle buttons by the guide rotate angle, which is slaved to the field rotation angle
- guide drag on: drift or drag values from the config.dat file are added to the current drift when the left mode button is momentarily pressed, and subtracted from the current drift values when the right mode switch is momentarily pressed; this is for knife edge autoguiders that rely on the guide star being constantly dragged back across the knife edge
- scroll tour: if the left mode button is pressed, this will cause the scope to continuously move through the scroll file; to stop move press the right mode switch or press any key on the keyboard
- scroll auto tour: if the left mode button is pressed, this will cause the scope to continuously move through the scroll file, repeating the scroll tour endlessly; to stop move press the right mode switch or press any key on the keyboard
- grand tour: the mode switch moves forward to the next object in the data file, or backwards to the previous object, depending if the left or the right mode button is pressed
- record equat: the mode switch will write the current scope equatorial coordinates to the record.dat file when either left or right mode button is pressed
- toggle track: the mode switch on the handpaddle can be used to turn tracking off and on (left button = on, right button = off)
- FRFocus mode: where the mode buttons activates/deactivates FR and focus motor control, where the up/down controls the field rotation motor and the CW/CCW controls the focus motor

## The Software

The software has gone through several reincarnations, starting as 6502 assembly code for the Commodore 64, when the Commodore 64 first came out (I bought my Commodore 64 for at the time incredible sales price of \$600, and with no floppy or tape drive, and had to reenter my programs everytime I turned the computer back on!). Unfortunately, the stalwart 2 megahertz 6502 processor could only muster recentering the object every couple seconds. The dream of an inexpensive amateur built altaz drive seemed far away, until the AT class machines arrived. The code was then rewritten in C. Later, the code went through its C++ object oriented life on a 386. Now, in interests of making the code as universal and easy to port, the code lives in ANSI C. Functions that are directly tied to low level hardware such as the parallel port and bios clock, use pointers to access the appropriate memory locations. For non-DOS machines, some modification of these parts of the code will be necessary.

The servo version of the software was started in May 2001.

The program is based on the popular two-star conversion algorithm, based on an Feb '89 Sky and Telescope magazine article by Toshimi Taki, to translate between altazimuth and equatorial coordinates. The scope need only be accurately aligned on two widely separated stars using a high power reticle eyepiece; there is no need to level the base. The scope can also be initially set on a planet, say, soon after sunset. After a couple of minutes of microstepping recentering, the scope is initialized on the same object again. The scope will continue to track the object, keeping it in the eyepiece field of view for an hour or two.

In addition, the program will use a third initialization point, for more accuracy than the two star initialization would otherwise give. Any of the three initialization positions can be reinitialized as often as wanted. All init positions are saved to a file for later analysis.

The conversion algorithm allows the input of mount construction errors. For instance, one altitude bearing may be a bit lower than its counterpart. Normally this would cause a pointing error, but the conversion algorithm will compensate once given the amount of the error. The program can refine the altitude angle based on the initialized positions. Per the original Taki routine, the starting azimuth can be any number. Now the starting altitude only needs to be set to within 10 degrees or so. This altitude offset algorithm was contributed by Dave Sopchak. This is the 'Z3' error (offset in elevation between the optical axis and the mechanical axis) so named by Taki. Taki's Z1 (axes non-perpendicularity) and Z2 (offset in horizon between the optical axis and the mechanical axis) errors are also calculated after at least three initializations are done.

The software is event driven by either keyboard or hand paddle input. If no events occur, then the scope moves to the current equatorial coordinates. If the coordinates remain unchanged, the scope tracks. If new coordinates are entered, the scope slews. Slews can only be interrupted by pressing or releasing a button on the handpad, and by the keyboard, and by the altitude or azimuth limits if the interrupt driven halfstepping option is turned on. Tracking should be paused if hot-keying out to another program. When the program is exited, the scope's altazimuth coordinates are saved along with any initialized positions.

The software handles backlash and handles periodic error correction, or PEC, for both axis. A 'guide' function is also included so that guiding for a minute or two nulls occasional tiny residual drift. Drift can be manually entered in both equatorial and altazimuth coordinates.

## Files Used

*scope.exe* - the executable program

*\*.c, \*.h* - source code

*config.dat* - the configuration file

*bstars.dat, messier.dat*, are object catalog files along with other *\*.dat* files too numerous to mention

*\*.scr* - scroll files

*\*.cdf* – comet definition files that include comet positions and equatorial drift values

*inithist.dat* - a history of all initializations, in degrees (Ra, Dec, Alt, Az, Sidereal Time, reason for init)

*analysis.dat* - a file of recorded positions triggered by the handpaddle that is used for later mount analysis

*analysis.err* - errors calculated from the analysis file

*altazec.dat* - correction file for altitude errors vs azimuth (rocker base levelness)

*altaltec.dat* - correction file for altitude errors vs altitude (altitude eccentricity, tube flexure)

*azazec.dat* - correction file for azimuth errors vs azimuth (azimuth eccentricity)

*pmc.dat* - a file containing corrections used by the pointing model corrections routine

*pec.dat* - the file used for periodic error corrections to the motors

*guidealt.dat and guideaz.dat* - a record of guiding corrections

*outguide.dat* - list of exit positions from Project Pluto Guide

*input.dat* - a record of all Ra, Dec, and name, that appear in the equatorial input fields

YYMMDDa through YYMMDDz.log, ie, 000313a.log - observer's log: a copy of the input.dat file, saved at program exit

*record.dat* - recorded scope equatorial scope positions via the handpaddle

*encoders.txt* - a recording of encoder threshold violations for each session

*trenc.txt* - file containing encoder readings per each microstep for all windings

*polealgn.txt* – file containing record of polar alignment procedure results

## Data object file layout

(a single blank space must start each line):

Ra\_hrs Ra\_min Ra\_sec Dec\_deg Dec\_min Dec\_sec name or comment  
ie,

12 23 14 33 53 09 test position

I have a conversion program available for the asking that will convert Megastar and Sky commander file formats to scope.exe's data file format.

For scroll file data layouts, see the webpage on operating the software - subpage scrolling.

Comet file layout (a single blank space must start each line):

Ra\_hrs Ra\_min Ra\_sec Dec\_deg Dec\_min Dec\_sec Drift\_Ra\_hrs Drift\_Ra\_min Drift\_Ra\_sec

Drift\_Dec\_deg Drift\_Dec\_min Drift\_Dec\_sec name or comment

ie,

07 14 31 +23 +12 +11 +00 00 +2 -00 -00 -1 31P Schwassmann-Wach

note that drift is per hour

## Main program execution loop

In detail, the sequence of events for each bios clock tick (which occurs about 18.2 times a second) is:

- add equatorial drift to current equatorial position,
- update a status field or work with the optional encoders: either a calculation or a direct write to video memory or reading the encoders or setting current coordinates to encoder coordinates,
- check for keyboard event, if none,
- check for handpad event, if none,
- check for IACA event, if none,
- check for LX200 events and process all accumulated commands since last bios clock tick, but if none,
- check to see if field rotation motor needs pulsing,
- then move to current equatorial coordinates by:
- calculate new altazimuth coordinates based on new sidereal time that was calculated when bios clock tick occurred,
- find difference between current altazimuth coordinates and newly calculated altazimuth coordinates,
- find distances to move in each axis and decide between microstepping or halfstepping, if microstepping,
- then check for backlash, if none,
- then spread microsteps over the bios clock tick by dividing # of microsteps into MsTicksRep, the count of PWM's per bios clock tick: if microsteps exceeds MsTicksRep, then reduce # of microsteps per fullstep up to halfstep, and if necessary, halfstep pulse the motors,
- continuously generate PWMs, checking for bios clock tick at end of each PWM: a PWM consists of outputting to parallel port an already calculated array of ons and offs to the stepper motors' windings,
- when bios clock tick occurs, PWMs end and new sidereal time is calculated,
- the field rotation motor calculations are done at the start of the microstepping function, and at the end of every PWM, a check is made to see if the field rotation motor needs pulsing,
- current altazimuth coordinates updated to reflect # of microsteps that actually occurred, current altitude coordinate updated to include refraction,
- current altazimuth coordinates updated to include any backlash compensations already moved,
- current altazimuth coordinates updated to include PEC based on steppers rotors' position,
- current altazimuth coordinates updated to include altazimuth drift,
- current altazimuth coordinates updated to include any guiding motions

## German Equatorial Mount Meridian Flip

The program handles GEM mounts and their required meridian flip. It does so by changing the altitude and right ascension in low level functions. Right Ascension is rotated by 180 degrees. The altitude is mirrored across the pole so that a declination of 80 is an altitude of 100 degrees .After a flip, the altitude will read in the range of +90 to +180 to higher values (-90 to -180 and lower if in the southern hemisphere). The Declination and Right Ascension will be calculated and displayed correctly. The hand paddle buttons are not automatically swapped in case autoguiders are wired in. However, the hand paddle buttons can be swapped after the GEM flip by selecting the menu option 'flipbuttons' in the control section.

**To do the flip automatically:**

1. Either turn on autogemflip in the config.dat file, or via the menu option: motors | autogemflip. The meridian flip will occur automatically, starting with a move to the pole, followed by the move across the meridian, ending with the move from the pole. You will have to cancel each slew in sequence if you wish to abort.
2. Or, select the menu option: move | gemflip.

**To do the flip manually:**

1. Turn off tracking.
2. Select the GEM flip menu option.
3. Position the telescope in declination so that the tube is roughly pointing at the celestial pole, for instance, a declination of 80+ degrees (-80 degrees if in the southern hemisphere).
4. If using the hand paddle to position the scope, or encoders are operational, the Ra and Dec should agree with the equatorial coordinates displayed before starting the GEM flip.
5. Move the scope 180 degrees in azimuth or 12 hours in right ascension.
6. Move the scope across the pole in Declination until the scope is roughly pointed properly.
7. Re-center the object.
8. If the hand paddle was not used to position the scope, or no encoders are present, you must do a 'reset to equat' to set the altazimuth coordinates properly.
9. The altitude will display a reading greater than 90 degrees (southern hemisphere users will see a reading below -90 degrees), and the Declination will display a reading less than 90 degrees (southern hemisphere users will see a reading greater than -90 degrees).
10. Tracking and goto functions can be resumed.
11. Hand paddle up down buttons can be reversed if desired by going into the menu section: control and selecting the flipbuttons option.

**Program startup and shutdown:**

You may start with the scope on either side of the meridian, and end with the scope on either side of the meridian. It is preferable to end with the scope on the same side of the meridian that you expect to start next time with. If you do not, read the next section.

**Synchronizing software and telescope to same side of meridian:**

1. turn off tracking
2. reverse the GEM flip (if it was off, turn it on, and visa versa)
3. enter appropriate input equatorial coordinates where the scope is actually pointing (if flip is off, RA should be less than sidereal time, if flip is on, RA should be greater than sidereal time)
4. do a 'reset to equat'

**Drift/Guiding/PEC**

After the initialization, typically high power tracking will show two residual errors.

The first is a slow steady drift, commonly a couple of arcseconds per minute of time. This is caused by small initialization errors such as not precisely centering the star in the crosshairs when initializing, and mount errors such as the azimuth and altitude axes not being exactly perpendicular.

The second is periodic error caused by the gearing, commonly the worm not being centered on its shaft or butting the gear properly. This shows as a slow oscillation of the star back and forth across the crosshairs. The program has both periodic error and drift error cancellation features.

The PEC, or periodic error correction, file consists of two columns. The first is a counter, 0 to 199, that indicates the index. The index is the resolution or number of steps that the PEC is divided into. Commonly this is spread over a single motor rotation or 200 fullsteps, but may be spread over any number of fullsteps. For instance, spreading the PEC over 400 fullsteps would cover the PEC caused by a double turn worm. Set the number of fullsteps that a PEC cycle will cover with the variable FullstepsPerPECArray. Mark a synchronization point on the motor shaft or the worm shaft that indicates the starting position, corresponding to an index of 0. Next to the index numbers in the PEC.DAT file are numbers that that

indicates the amount of PEC in tenths of an arcsecond to apply at each index. For instance, if a single turn worm causes 2.3 arcsecond of periodic error with the motor shaft at a 45 degree angle, then index 50 would have a value of 23 (assuming 200 fullsteps per motor revolution). See the PEC.TXT file to see how to enter these values. The altitude PEC comes first, with indexes of 0-199, then the azimuth motor comes with indexes of 0-199. Remember that you have 200 PEC values per axis, no matter how many fullsteps you spread the PEC over.

#### **PEC notes by Chuck Shaw:**

"I am Chuck Shaw. I recently finished converting my 14.5" f/5 dob into an AltAz system using Mel's plans and software. I concur, it is MUCH more of a "system" than I ever imagined!!!

I also just went through coming to grips with nulling out PE and I have a few "lessons learned" that might be helpful....

1. Use LOTS of power when running in Guide mode to build Guide.dat I used two barlows stacked into each other (a 1.7x and a 2.8x and a 12mm illuminated reticle eyepiece and an ~1808mm scope gives about 720x..... use AT LEAST that much if you can.... (Slightly defocused blobs are easier to guide with than points anyway!!)... You ARE using an illuminated reticle EP aren't you??? Do not try to keep a focused image of the star in the center of the box. Either defocus till the star fills the box, or put the star in the center of an intersection of two lines, or put it in a "corner" where its just touching two lines. Try different techniques to see which works best for you. I found the biggest source of inconsistencies in my data sets was ME and my poor guiding!!!!!! My reaction times usually had the wrong direction and were late..... (duh.....) :-) Play with the orientation of the handpaddle also to see if a "fly to" type of guiding is easier.....
2. Use the guide routine several times to nail the drift as well as possible BEFORE you try to write a file to capture PEC data.
3. For Azimuth data collection, be sure and aim the scope due south, near the celestial equator. This will minimize motion from Alt, and maximize the motion in AZ....
4. Shell out to DOS without stopping tracking after a Guide run, Do a "copy c:\guide.dat PE-AZ1.txt", then a copy "c:\PEC.txt guide.dat" (say YES to overwrite), then type exit and SHAZAM the scope will slew back to the star you were guiding on and you are ready for another run!!!! Name the next file PE-AZ2.txt, etc..... This allows you to capture several runs very quickly, and any system config changes between runs are minimized.
5. VERY CLOSELY inspect for any "wobble" in your worm bushing. I use 359:1 Byers gears. I had to make the bushings for the worms and discovered the bushing has a tiny bit more slop than it should (the clearance is about 0.001 and Byers tells me it should be about 0.00005). I decided to fabricate a "tailstock" out of a small aluminum angle and a brass machine screw. I ground a point on the end of the machine screw and it goes through the bracket and presses into the center ground dimple in the end of the worm. That made a HUGE difference in obtaining repeatable data. I think the problem was the worm's wobble was somewhat random. That, in turn changes the mesh slightly, and that induces PE.... If your worm is on a shaft with bearings/bushings at both ends, you still need to look for this!
6. Look at the couplings for the motor to worm. If they are flexible and you are using the motor bearings to stabilize the worm at all (if there is slop in the bushings you are in this category), you need to go to a precision coupling. I bought several commercial ones and found they were slightly out of round!!!! This in itself introduced PE!!! Thats OK though, since the Software will compensate for it.
7. Reinitialize the motor/worm positions in between runs to make VERY sure that you know what position corresponds to the 0 position in the guide.dat data I failed to do this a couple of times and got accurate but skewed curves..... You have to remember to turn off PEC and then back on after the shafts are positioned !!!!!

8. Remember the data take will NOT start at zero unless you time it that way. Do not try to get cute and time it, just start it and use your spreadsheet program to cut the four runs of data into separate columns and then move them up/down in the spreadsheet to line up the steps in each run. Then delete the step number columns (all but the far left one). Graph the 4 curves and throw out any that are obvious guiding errors. Then average the rest and you are there!!!

9. Remember after the data file is copied into a file called PEC.dat to reinitialize the shafts to their zero position. I keep forgetting to do this!!!! The system also seems to get lost after a couple of hours of operating.... An occasional reinit of the PEC alignment takes less than 15 sec and helps "clean up" things. I should not have to do this but.....

I have the sets of curves from my data takes I can send you. I was having the inconsistencies in taking data initially, and then the phase skewing till I stabilized the worms too.... perplexing, but a methodical working on each potential source of PE will find the culprit!!!

The performance of the system is simply astounding when all is completed..... I agree with Mel that software timing errors are the least likely culprit. Too many times I wanted to blame the software for problems but Mel has simply done too good of a job!!!! It was ALWAYS something I did!!!! (don'tcha hate it when that happens!???) :-)"

### **Updating the PEC data on the fly**

Much has been done to enhance the generation of periodic error correction on the fly. The two principal errors affecting guiding accuracy can be fixed at one time: the periodic error of the gear that the stepper connects to, and drift. The drift may need to be tweaked after pointing to another section of the sky. There are two methods to choose from: fixup an already generated PEC or generate a PEC from scratch. The PEC in use by scope.exe can be displayed by using the hotkey 'c'. If you wish to save this PEC to PEC.DAT, answer yes.

To synchronize the PEC with the motors, use the handpaddle to move both motors to their respective synchronization angle, then select 'p' or pec on/off on the keyboard. PEC is now synchronized with the motors and will remain synchronized unless the motors stall.

To generate PEC from scratch, or to fixup an already generated PEC, put the hand paddle into guide+save mode, and guide until at least two high beeps and two medium beeps are heard, preferably until a low beep is heard, indicating that the guide array has been filled. The higher pitched sound indicates each time the altitude motor crosses the synch point. It must cross twice in order to generate a full motor rotation of data. A medium pitched sound is used to indicate the azimuth motor's crossing of the synch point. Multiple rotations of the motor will yield multiple PEC analysis files. Better results may be obtained by focusing on only one axis, then repeating the entire procedure for the other axis.

If using an equatorial telescope, or using an altazimuth telescope where one axis is moving very slowly (altitude axis when on the meridian for instance), then you will have to either misalign the scope or find another section of the sky where both motors are moving at a nice rate.

Use the 'u' and 'v' hotkeys to inspect the just completed guiding corrections. If you wish the guiding corrections will be saved to PECAZxx.TXT or PECAZxx.TXT files, where 'xx' starts at '00' and is incremented for each file saved. This allows you to build several iterations of guiding corrections in order to average them for a more accurate PEC. In addition, the drift should shrink to zero as it is refined. Use the 'e' and 'f' hotkeys to read in all the PECAZxx.TXT or PECAZxx.TXT files, average them, then display the results graphically, including how the pec will look if the averaged files are added in.

Use the 'L' hotkey to reload PEC.DAT.

Set TestString to "PreloadGuidexx.dat" to preload guidealt.dat and guideaz.dat upon program startup. This gives an opportunity to analyze and pull out pec data from earlier guiding efforts.

### **Improve Local Finding/Tracking Accuracy**

Slew to a bright known star near the object.

Select new coordinates by using one of the data files, or by calling Guide.bat if available, or by inputting equatorial coordinates manually.

Choose Reset:equat - this will adjust the altazimuth coordinates of the telescope. Alternatively if you do not wish to change the altazimuth coordinates (for instance, you are using encoders and are positive that the encoders are working properly), choose to re-init #1 or #2 or #3 - this will update the initialization of the scope vs the sky and result in accurate movements near the initialization points.

Select Coord:equat to enter coordinates of new object to view.

Choose Move:equat to slew to object.

This nearby slew, if carefully done, will be accurate to the arcsecond level.

Alternatively, if you know the distance from one object to another, say, object 'x' is 1 degree north of object 'y', then center object 'y', and apply the coord:offset equat menu item then move:equat to make the precise offset movement.

### **Improving the initializations - Optimizing Goto and Tracking**

Most amateur telescopes point haphazardly. Sometimes the object is in the field of view and sometimes it's nowhere to be found. A telescope must be precisely built: axes perpendicular, round altitude bearings, matched rocker side bearing points, flat rocket base, rigid tube assembly, and coincident optical and mechanical axes. The most popular form of telescope, the manually pushed Dobsonian with teflon and formica bearings, does not require this kind of precision construction. Consequently, pointing accuracy generally falls between 1/4 degree and 1 degree. In addition, in a motorized scope, the motors and gear train introduce backlash and periodic errors in pointing and tracking. Consistent pointing to one arcminute is a worthy goal, giving confident centering of objects on small CCD chips and in high power eyepieces. If necessary, offsets accurate to arcseconds are easily obtained by first centering on nearby objects. Blind across the sky arcsecond accuracy enters a new realm. Here a whole barrel of corrective factors must be actively calculated and applied. While necessary for large professional scopes, this level of arcsecond accuracy is not needed by the serious amateur.

Errors to either eliminate by better design and construction, or by software compensation in order of importance and in order that they should be tackled:

- ✓ gear backlash
- ✓ gear periodic error correction (called PEC)
- ✓ for stepper motors, physical variations in the quarterstep spacings over the sequence of windings (called QSC for QuarterStepCorrection)
- ✓ drift
- ✓ atmospheric refraction
- ✓ axis misalignment (one side of the rocker is higher than the other) (called Z1 or axis misalignment)
- ✓ discrepancy between the optical and mechanical axis in the horizontal axis (called Z2 or azimuth offset)
- ✓ discrepancy between the optical and mechanical axis in the vertical axis (called Z3 or altitude offset)
- ✓ altitude vs. azimuth error correction (dobsonian rocker base levelness) (called ALTAZEC)
- ✓ altitude vs. altitude error correction (tube droop, altitude bearing unevenness) (called ALTALTEC)
- ✓ azimuth vs. azimuth error correction (azimuth drive gear eccentricity) (called AZAZEC)
- ✓ residual errors, captured as pointing model corrections (called PMC)

My software compensates for gear backlash. Move the motor in one direction until all backlash is taken up. Note the displayed Current Altitude or Azimuth value. In daylight, sight through the telescope at a distance sharp edged landmark. Carefully and slowly move the motor in the opposite direction until the telescope begins to move. Subtract the updated Current Altitude or Azimuth value in degrees to get the backlash value. Multiply by 60 and enter the resulting value in arcminutes in the configuration file.

My software offers extensive periodic error correction, called PEC. See the PEC webpage to learn how to map the periodic error and how to correct for it.

Telescope coordinates are translated to celestial coordinates using an alignment model. This model will be very simple in the case of an equatorially aligned telescope where altitude matches declination and azimuth matches hour angle (local sidereal time minus right ascension). For altazimuth telescopes, the modeling is more complex. Lesser used models include algorithms such as matching angular separation, and, more simply, tracking via automated following. More commonly used is a model based on spherical trigonometry formulae. These formulae call for entering the latitude and longitude of the observing location, precisely leveling the base, then finding stars using an accurate clock.

I use the model popularized by Taki. He uses a matrix of directional cosines to convert between telescope and celestial coordinates. The telescope pointing values are calculated from the telescope's altitude and azimuth, and time at the moment the object is precisely centered in the field of view. For instructions on how to initialize the telescope to the celestial sphere, see the operate software - equat startup, or, operate software - altaz startup webpages.

Drift is caused by pointing errors. Positions to track to, or, velocities to track by, are calculated based on assumptions of how the telescope is aligned to the sky. Inaccuracies in this alignment will cause the object to appear to slowly drift away from the center of the field. Drift can be nulled by setting my software in the guide + drift mode, and following an object for a couple of minutes. Centering the object, then pressing a button on the hand paddle, causes drift to be calculated and automatically adopted. Use drift nulling to precisely track an object for long exposure imaging on CCDs or film. Drift will slowly change as the telescope tracks for hours into a new portion of the sky. Drift should be set to zero before slewing to new object.

Refraction is caused by the atmosphere, making objects near the horizon appear higher in the sky than they really are. Don't turn this on unless you have an altazimuth mount that is reasonably level. Also, don't turn this on until backlash compensation is working.

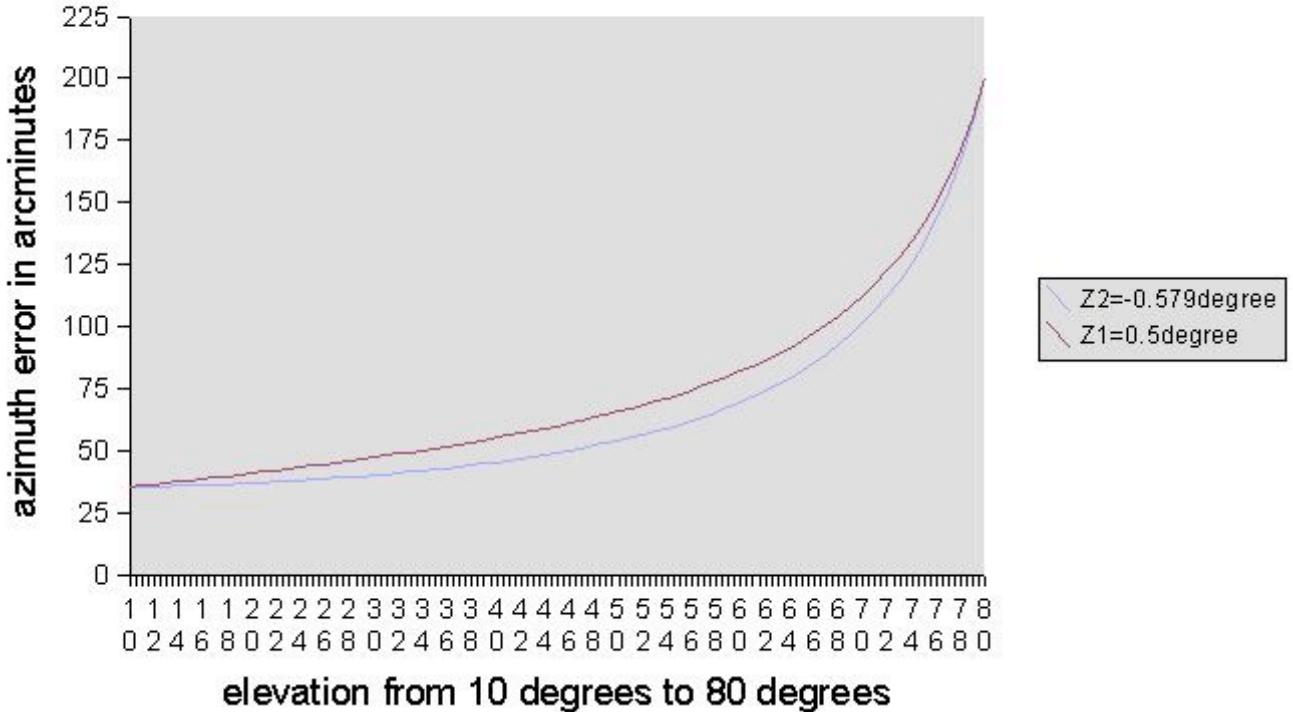
One advantage of the Taki routines is that the azimuth need not be precisely set at startup time. That is, one does not have to set zero azimuth precisely north or south. Instead, the routine relies upon the difference between azimuths. So the starting azimuth can be any value since we need only measure the change in azimuth as the telescope moves. Unfortunately, the starting altitude needs to be precisely known. However, by using the idea of matching the angular separation given by the celestial coordinates to the angular separation given by the telescope's coordinates, the correct altitude can be deduced. This means that the starting angle of neither axis need be precisely known at startup time. The altitude offset is typically done once each evening, as soon as the two stars are initialized. It is best to use two stars at about the same altitude with widely differing azimuths. The altitude offset is called Z3 by Taki. By investigating different scenarios, it is clear that deriving the altitude offset from two precise star positions is better than averaging discordant offsets from a group of casually taken star positions.

Z2 is the azimuth offset error, or the difference between optical and mechanical axis in the horizontal plane. Z1 is the degree of misalignment between the telescope's two axis. Think of one side of the rocker arms being higher than the other side: the axes are no longer exactly perpendicular. Z1 causes a growing azimuth error as the scope is moved towards the zenith, while Z2 is a constant azimuth error. However, as the scope is aimed further skyward, while Z2 itself stays constant, the effect on the scope's pointing is to make the azimuth error appear to grow. The lines of azimuth shrink as the scope approaches the zenith, so the apparent azimuth error increases. This mimics the Z1 or axis misalignment closely. Not only that, but investigating Taki's coordinate translation matrices shows that Z1 and Z2 are tangled and cannot be separated or solved for independent of each other. Instead, an iterative approach must be adopted, not only in Taki's routines themselves when converting from equatorial to altazimuth coordinates, but also in any routine that attempts to analyze sky positions to deduce the Z1 and Z2 errors.

Consider the following graph. Here I derived Z1 and Z2 errors that result if the scope is centered on a star at 10 degrees elevation, and on a star at 80 degrees elevation. Note that opposite Z2 mimics Z1. The difference between the Z1 and Z2 curves is very subtle, amounting to a handful of arcminutes at a between elevation. The challenge of calculating the proper Z1 Z2 is further compounded when considering that real world Z1 Z2 values are likely 1/4 to 1/2 of those used to generate the graph, that Z1 and Z2 are likely

present in some unknown mix, and, that the accuracy of azimuth measurements at high elevations is reduced by the cosine of the elevation. At 80 degrees elevation, measurements will be almost six times less accurate.

## Comparison of Z1 and Z2 errors



Measure Z1 and Z2 after the altitude offset and previously mentioned errors have been taken care of. Use a new set of three stars at about the same azimuth with differing altitudes from close to the zenith to the horizon - just the opposite of the best way to go about measuring Z3. Always avoid the equatorial and altazimuth poles for star alignments. These numbers will not change from night to night and can be measured once and stored in the configuration file. Changing the collimation, or moving the mirrors, or doing anything to change the horizontal angle between the optical and mechanical axis will necessitate re-measuring Z1 and consequently Z2. The Z3 - Z1-Z2 cycle can be repeated based upon another round of two and three star initializations.

While it may appear troubling that Z1 Z2 cannot be more assuredly and accurately determined, because the values are so easy to substitute for each other, the predictive ability is best served by using Z1 Z2 values that do result in the lowest rms pointing error.

The Z1Z1Z3 errors, the ALTAZEC errors, the ALTALTEC errors, and the PMC errors all rely on the analysis file. To view the analysis file, use the menu option graph analysis. If the analysis file looks OK, you can then proceed to correct for the next error in turn. The errors must be corrected for in order, though you may skip any of the error corrections.

To interactively change Z1, Z2, and Z3 while viewing the results, save a dozen analysis points, then go into the init - graph Z1Z2Z3 menu option.

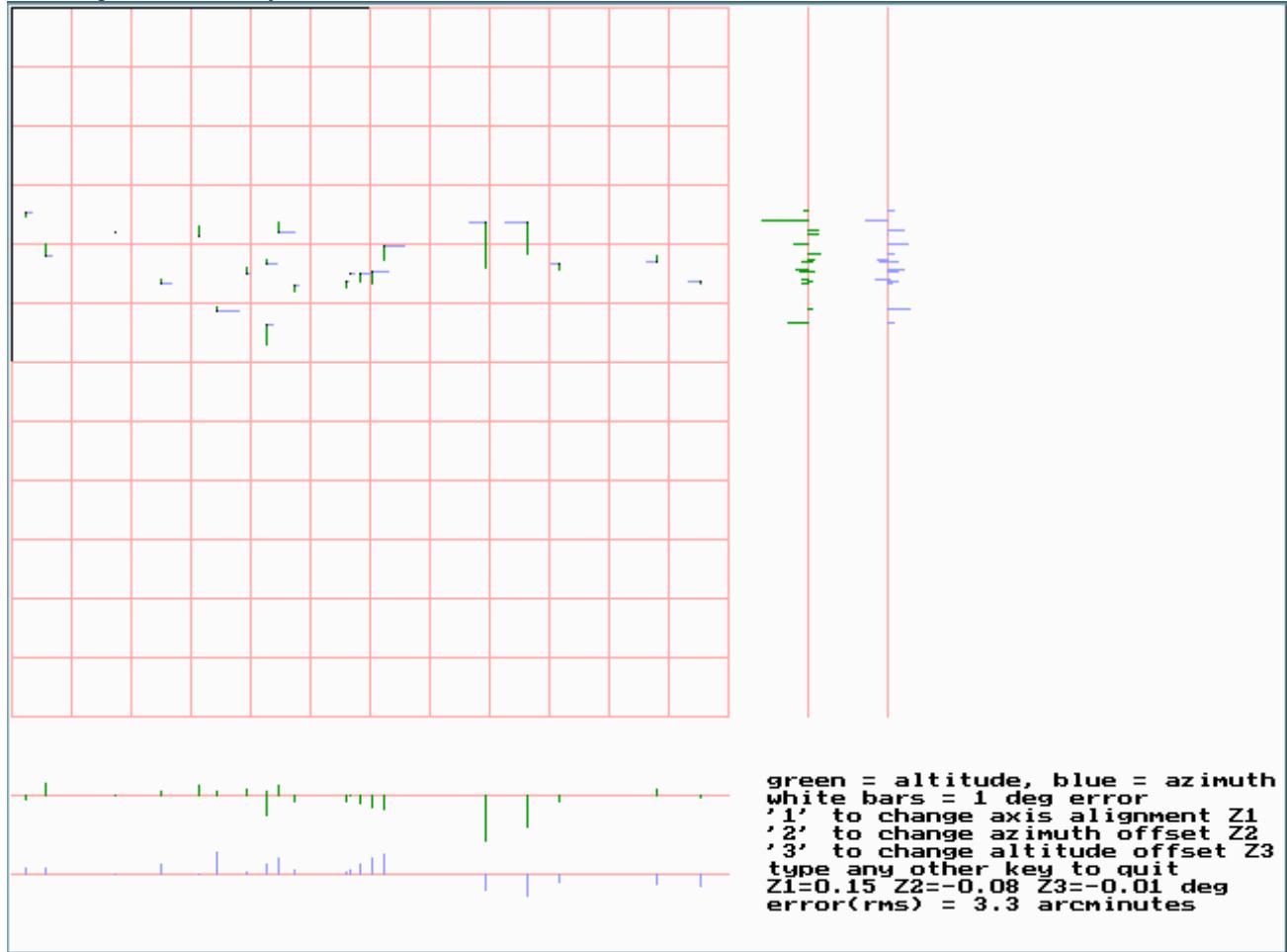
Five graphs are displayed:

1. a graph of altitude and azimuth errors plotted on a 30 degree grid pattern of altitude and azimuth, where green is altitude and blue is azimuth errors; an error bar up or to the right indicates that the scope aimed too high in value, azimuth is plotted left to right from 0 to 360 respectively, and altitude is plotted from top to

bottom, +180 to -180 respectively (areas above +90 and below -90 are for German equatorial mounts after they have been flipped across the meridian);

2. just to the right, a vertical graph of altitude vs. altitude errors, where the altitude errors are plotted based on the telescope's altitude;
3. to the far right, a vertical graph of azimuth vs. altitude errors, where the azimuth errors are plotted based on the telescope's altitude;
4. below the main grid, a horizontal graph of altitude vs. azimuth errors, where the altitude errors are plotted based on the telescope's azimuth;
5. at the very bottom, a horizontal graph of azimuth vs. azimuth errors, where the azimuth errors are plotted based on the telescope's azimuth;

Here's a plot of Tom Krajci's 16 inch - RMS error is about 3 arcminutes:



Looking at the far right graph, Z1 and Z2 can be analyzed. A tilt in this graph indicates that the Z1, mount axis misalignment, might be changed.

Users report that once Z3, Z1, and Z2 are nailed, Goto accuracy across the sky is significantly improved, placing objects in the center of the field at high powers.

After Z1, Z2, and Z3 are set, the ALTAZEC and ATLALTEC and PMC correction curves can be added. These must be either ignored or added in the following order:

Z1Z2Z3 correction

ALTAZEC correction

ATLALTEC correction

AZAZEC correction

PMC correction

General Pointing Model Corrections, called PMC, can now be analyzed and adopted. Generate a new analysis file by going to the menu option init / purge analysis, then making analysis points in a grid back and forth and up and down the sky, with points about 30 degrees apart. Go to the menu option init / graph PMC. Here you will see the errors displayed. If the errors look common sense, then you may generate the PMC by using the menu option init / AnalysisToPMC.

## **Grand Tour**

By putting the hand paddle in grand tour mode, and loading a data file, the scope can be commanded to move from object to object in the data file, by merely flicking the hand paddle mode switch to the left. This is useful for planned evening observations, and sequences of fields of objects such as galaxy clusters. By flipping the hand paddle mode switch to the right, the scope will return to the previous object.

To create data files for grand touring, you can manually edit your own files, naming them with the \*.dat extension. Follow the coordinate layout that you find in bstars.dat and messier.dat.

You can record positions that you visit during an observation run by using the handpad mode 'record equat'. Record a position by flipping the mode switch on the handpad.

You can also record positions if you use certain planetarium programs. Project Pluto's Guide's positions are automatically recorded when running Guide from inside scope.exe. Other programs' output can be run through data converter programs like ngcscope.

## **Data files**

A number of data files are available, many of them contributed by amateurs who have built the system. They include:

BSTARS (24 brightest stars)

MESSIER (messier catalog)

NGC0, NGC1, NGC2, NGC3, NGC4, NGC5, NGC6, NGC7 (ngc catalog)

IC (ic catalog)

5MAGSTAR (all stars 5 magnitude and brighter)

18TO2LOW, 0TO8HIG, 12TO18LOW, 0TO7LOW, 7TO12LOW, 9TO23HIG

A\_H\_BSC, I\_Z\_BSC (bright star catalog)

00000XL and 00000L (first file is all stars 6.5 mag and brighter north of -40 dec, the second file consists of stars only with Bayer (Greek) or Flamsteed (Arabic numeral) designations)

HICKSON (hickson galaxies)

PLANETS (run planets.exe to get current planet positions)

ARP (arp peculiar galaxies)

PN19TO23, PN00TO11, PN012TO1, PN17, PN18 (planetary nebulae catalog)

PALGC (palomar globular clusters)

constellation files designed by constellation abbreviation

multiple star files designed by 'MS....dat'

many more files can be found in the file repository of the scope-drive@yahoogroups.com group

## **Scrolling**

Scroll files are used to move through a series of scrolling, or 'fly-over' motions, and, are used to automate initializations, analyses, and other actions.

A scrolling flyover motion is a smooth microstepping action. By flipping the mode switch to the left and back to center, the scope will scroll to the next position in the \*.scr file, over the number of seconds shown in the \*.scr record. If the switch stays in the left position, the scope will automatically move from position to position. This is best used for scans of extended objects or fields such as the Cygnus Loop, and the Andromeda Galaxy.

Scope.exe can start with a scroll file. Use the syntax: scope.exe -x <scrollfilename>, ie, scope.exe -x nan.scr

In addition to the handpaddle mode switch, hotkeys can also be used:

'H' to bring up hand paddle modes  
 'm' to switch to scroll tour  
 'S' to load a scroll file  
 'B' to begin a scroll file  
 'L' to continue onto the next scroll action (simulates the leftkey of the handpaddle)  
 '<' to simulate the leftkey of the handpaddle  
 '>' to simulate the rightkey of the handpaddle

As of the May 12, 2000 version, it is not required to have two positions initialized before executing a scroll file, and starting a scroll file does not force tracking on anymore. This has implications for scrolling. For instance, some scroll actions do not make sense until the program has been initialized, or if the scope is not tracking.

In the scroll file, any line starting with a semi-colon ';' is ignored.

Here are the available commands:

- absolute move to altazimuth coordinates: written as abs\_altaz,
- offset move to altazimuth coordinates: written as off\_altaz,
- absolute move to equatorial coordinates: written as a,
- offset move in equatorial coordinates: written as o,
- drift values in altazimuth coordinates; written as drift\_altaz,
- drift values in equatorial coordinates; written as drift\_equat,
- initialize position 1: written as 1,
- initialize position 2: written as 2,
- initialize position 3: written as 3,
- initialize position 1 using input equatorial fields: written as 1i,
- initialize position 2 using input equatorial fields: written as 2i,
- initialize position 3 using input equatorial fields: written as 3i,
- slew to a data file's closest object to current equatorial position: written as f1,
- slew to a data file's closest object to current equatorial position that is not the same as the current equatorial position: written as f2,
- slew to a data file's closest object to current equatorial position that has not been visited in the current session: written as f3,
- turn tracking on: written as trackon,
- turn tracking off: written as trackoff,
- turn off pause and sound notification when moving to new scroll entry in auto scroll: written as auto\_scroll\_alert\_off,
- save a position for analysis: written as analyze,
- calculate and remove altitude offset: written as alt\_offset,
- turn on auto scrolling: written as auto\_scroll,
- turn off auto scrolling: written as auto\_scroll\_off,
- move motors to zero out PEC indeces, written as move\_zero\_pec,
- saves current equatorial coordinates, written as save1;
- retrieves the saved equatorial coordinates, written as restore1;
- adjust the microstepping speed, written as msarcsecsec,
- set the handpad mode, written as handpad\_mode,
- move in halfsteps: written as hs,
- new equatorial coordinates, written as new\_equat,
- new altazimuth coordinates, written as new\_altaz,
- prompts for input equatorial coordinates: written as set\_equat,
- prompts for input altazimuth coordinates: written as set\_altaz,
- resets to input equatorial coordinates: written as reset\_equat,
- resets to input altazimuth coordinates: written as reset\_altaz,
- resets to home coordinates: written as reset\_home,
- prompts for an object in the specified data file: written as data\_file,
- prompts for an object in the specified data file and moves to it: written as move\_file,
- displays a prompt on the screen: written as prompt

**Here are the commands' syntax:****Here's the format for a move to absolute altazimuth coordinates:**

```
abs_altaz <AltitudeInDecimalDegrees> <AzimuthInDecimalDegrees> <TimeForMove> <comment>
ie,
abs_altaz 45 100 0 <comment>
```

This will move the scope to altitude of 45 degrees, azimuth of 100 degrees. Since the time is zero seconds, halfstep slewing will be used. If the time to move allows for microstepping movement, then the scope will smoothly microstep over the allotted time to arrive at the appointed position.

```
For both absolute and offset altazimuth moves, a value of 9999 means to leave that motor untouched, ie
off_altaz 1 9999 10 <comment>
```

will move the scope up in altitude 1 degree over 10 seconds, leaving the azimuth motor as is

**Here's the format for a move to offset altazimuth coordinates:**

```
off_altaz <OffsetAltitudeInDecimalDegrees> <OffsetAzimuthInDecimalDegrees> <TimeForMove>
<comment>
ie,
off_altaz 1 1 10 <comment>
```

This will smoothly move the scope up in altitude 1 degree, over in azimuth 1 degree, over a time of 10 seconds.

**Here's the format to enter drift values for altazimuth coordinates:**

```
drift_altaz <DriftAltitudeInDecimalDegrees> <DriftAzimuthInDecimalDegrees>
<TimeForDriftInSeconds> <comment>
ie,
drift_altaz 1 0 60 <comment>
```

This will enter a drift in altitude of 1 degree over a time of 1 minute (60 seconds).

**Here's the format for a move to absolute equatorial coordinates:**

```
a <RaHr> <RaMin> <RaSec> <DecDeg> <DecMin> <DecSec> <TimeForMove> <comment>
ie,
a 23 0 0 15 10 0 10 <comment>
```

The 'A' indicates absolute positioning, here, the scope will scroll to 23:0:0, +15:0:0 over 10 seconds. If the telescope cannot microstep to the position over time given, it will immediately halfstep slew to the absolute position.

**Here's the format for a move to offset equatorial coordinates:**

```
o <RaHr> <RaMin> <RaSec> <DecDeg> <DecMin> <DecSec> <TimeForMove> <comment>
ie,
o 0 0 0 0 10 0 5 <comment>
```

The 'o' means offset coordinates, that is, the offset position will be added to the current scope position to arrive at the new target position, here 0:0:0, +0:10:0, or 10 arcminutes in declination will be added to the current position, so that over 5 seconds, the scope will scroll northward 10 arcminutes.

Here's an example that slews to a starting absolute position, then scrolls up and down in declination over various times, ending with a slew to the start of the smooth scroll motions:

```
a 23 0 0 15 10 0 10 AbsMove10sec
o 0 0 0 0 10 0 5 OffMove10'Dec5sec
o 0 0 0 0 10 0 8 OffMove 10'Dec8sec
o 0 0 0 0 -10 0 7 OffMove-10'Dec7sec
o 0 0 0 0 -10 0 0 OffMove-10'DecSlew
```

**Here's the format enter drift in equatorial coordinates:**

```
drift_equat <RaHr> <RaMin> <RaSec> <DecDeg> <DecMin> <DecSec> <TimeForDriftInSeconds>
<comment>
ie,
drift_equat 0 0 0 1 0 0 3600 <comment>
```

This will enter declination drift of one degree over an hour (3600 seconds).

**Here's the format for initializations:**

<init #> <RaHr> <RaMin> <RaSec> <DecDeg> <DecMin> <DecSec> <TimeForMove> <comment>  
ie,

1 10 8 22 11 58 0 0 <comment>

The '1' means init #1 using current altazimuth coordinates and sidereal time to equatorial coordinates  
10:8:22 11:58:0, the 0 seconds time being ignored.

ie,

2 10 8 22 11 58 0 0 <comment>

Here '2' means init #2, with the same format as the above init #1 example  
or to initialize #1 or #2 or #3 using whatever coordinates at that moment are in the input equatorial fields,

1i <comment>

2i <comment>

3i <comment>

after a long slew, some mechanical systems show slippage such that the object may or may not be centered;  
here's an example of how to center a messier object by first moving to the object's vicinity, then moving to  
the closest bright star, then after you center the star and init on it, you move back to the messier object

f1 messier.dat

f1 bstars.dat

2i

f1 messier.dat

**Here's the format to remove altitude offset:**

alt\_offset <comment>

Here's an example of a scroll file to automate the initialization process, where the scope is positioned on  
Regulus before the scroll file is started, then the observer inits #1 on Regulus, waits a minute, then inits #2,  
turns on tracking, then slews to the neighborhood of Spica, and after centering Spica, inits #2 on Spica,  
finally ending with calculating and setting the altitude offset to zero:

1 10 8 22 11 58 0 0 init1Regulus

2 10 8 22 11 58 0 0 init2Regulus

trackon turningtrackingon

a 13 25 12 -11 9 43 0 absSpica

2 13 25 12 -11 9 43 0 init2Spica

alt\_offset removingaloffset

**Here's the format for retrieving objects from data files:**

<object retrieval from data file option> <file name>

notice that a comment is not allowed after the file name,

ie,

f1 messier.dat

f2 messier.dat

f3 messier.dat

Here f1 retrieves then slews to the closest object to the current equatorial position from the messier.dat file,  
f2 retrieves and slews to the closest object as long as it does not match the inputted equatorial fields, and f3  
means to retrieve and slew the closest object that is not in the input.dat file, a history of all inputted  
equatorial values during the session.

Here's an example that immediately slews (since the time is 0 seconds) to 18:0:0 -24:0:0 then slews to the  
closest object in messier.dat, then slews to the closest object that is not currently inputted, then slews to the  
closest object that does not appear in the input.dat file:

a 18 0 0 -24 0 0 0 <comment>

f1 messier.dat

f2 messier.dat

f3 messier.dat

**Here's the formats for turning on and off tracking:**

```
trackon <comment>
trackoff <comment>
```

**Here's the formats for turning off the pause and beep when moving to a new scroll entry while auto scrolling:**

```
auto_scroll_alert_off <comment>
```

**Here's the format for analysis:**

```
analyze <comment>
```

Here's an example that builds an analysis file, by offsetting 1 hr in Right Ascension, then finding the closest star in bstars.dat, then analyzing; running this pattern a total of 3 times:

```
o 1 0 0 0 0 0 <comment>
```

```
f1 bstars.dat
```

```
analyze
```

```
o 1 0 0 0 0 0 <comment>
```

```
f1 bstars.dat
```

```
analyze
```

```
o 1 0 0 0 0 0 <comment>
```

```
f1 bstars.dat
```

```
analyze
```

**Here's the format to turn on auto scrolling:**

```
auto_scroll <comment>
```

**Here's the format to turn off auto scrolling:**

```
auto_scrol_offl <comment>
```

**Here's the format to move the motors so that the PEC indeces are zeroed out:**

```
move_zero_pec
```

**Here's the format to save the current equatorial coordinates:**

```
save1
```

**Here's the format to retrieve the saved current equatorial coordinates:**

```
restore1
```

**Here's the format to adjust the microstepping speed:**

```
msarcsecsec <speed> <comment>
```

```
ie,
```

```
msarcsecsec 100 <note>
```

**Here's the format to set the handpad mode:**

```
handpad_mode <mode number> <comment>
```

```
ie,
```

```
handpad_mode 5 <note>
```

**Here's the format for a halfstep slew:**

```
hs <#of altitude halfsteps> <# of azimuth halfsteps> <comment>
```

**Here's the format to set to new equatorial coordinates:**

```
new_equat <RaHr><RaMin><RaSec><DecDeg><DecMin><DecSec> <comment>
```

**Here's the format to set to new altazimuth coordinates:**

```
new_altaz <NewAltitudeInDecimalDegrees> <NewAzimuthInDecimalDegrees> <comment>
```

**Here's the format to input equatorial coordinates:**

```
set_equat <comment>
```

**Here's the format to input altazimuth coordinates:**

```
set_altaz <comment>
```

**Here's the format to reset to input equatorial coordinates:**

```
reset_equat <comment>
```

**Here's the format to reset to input altazimuth coordinates:**

```
reset_altaz <comment>
```

**Here's the format to reset to home coordinates:**

```
reset_home <comment>
```

**Here's the format to select an object from a specified data file:**

```
data_file <file_name>
```

**Here's the format to select an object from a specified data file and move to it:**

```
move_file <file_name>
```

**Here's the format to display a prompt on the screen:**

```
prompt <prompt_string_to_display>
```

Here's an example to build a ALTAZEC file (altitude vs azimuth, or rocker base levelness error correction file). Start by aiming the scope at an elevation of about 45 degrees, then do the first scroll action which will move the scope to a 5th magnitude star, then precisely center the star using high powered crosshairs, and do the next scroll action to analyze the pointing. Next, move the scope to the east about 5 degrees and repeat the scroll actions. Repeat this pattern of move, grab nearest 5th magnitude star, center it, and analyze it, as many times as desired:

```
f1 5magstar.dat
analyze
hs 0 6000 <comment>
f1 5magstar.dat
analyze
```

Here are some scroll file examples to help with portable scopes, by Tom Krajci:  
I had a blast over the weekend observing in the Lincoln National Forest, near Mayhill and Cloudcroft New Mexico at 7,000Ft with my scope. I also think I have learned a better way to optimize my mount pointing corrections.

Woe to us portable telescope users! It's next to impossible to reassemble the scope (especially plywood/truss tube scopes!) the same way every time you take it to an observing site. Mel's software gives

us great capabilities to correct for mount/pointing errors, but how should we use the software to quickly and correctly analyze the mount pointing errors?

Here's what I have come up with:

1. Set up the mount the same way, as closely as possible (for example - same leg of the ground board pointing due south, bubble level the base with reasonable care.)
2. Do a two star alignment the same way, every time...taking advantage of your mount's 'sweet spot.' (From previous testing of your scope, and comparing observing site lat/long to the 'derived' lat/long from 2 star init's...you should have found certain altitude/azimuth combinations for two star alignments that give you good results. For example, I like to use this scroll file for alignment:

```
trackon
abs_altaz 30 200 0
f1 00000000.dat
1i
abs_altaz 30 320 0
f1 00000000.dat
2i
altoffset
trackoff
```

When it works right I get repeatable 'derived' latitude that is within 0.01deg of the site's actual latitude.

3. Do a quick pointing analysis of stars at 180 az, at varying altitudes.

Here's a scroll file I use:

```
trackon
abs_altaz 25 180 0
f1 00000000.dat
analyze
abs_altaz 40 180 0
f1 00000000.dat
analyze
abs_altaz 55 180 0
f1 00000000.dat
analyze
abs_altaz 70 180 0
f1 00000000.dat
analyze
trackoff
```

Examine your pointing errors graphically...you will probably find that you need to tweak the value of Z2 to minimize the changing azimuth error that crops up at various elevations. Last night, during a calm spell, I got 0.5 arcmin RMS pointing error for my four star pointing analysis once Z2 was nailed to the nearest 0.01 degree. I find that Z2 varies a little bit every time I put the scope together...so this 'four star Z2 analysis' is needed to tune the pointing correction model. I also find this is a good way to quickly check to see if your step size in altitude is correct or not...if correct you'll get small/consistent/equal altitude errors at different altitudes...if step size is wrong, there will be a trend obvious in the graph...as you move higher the scope consistently points too high (or too low)..and the the higher the altitude the larger the error.

Hope this helps,Tom Krajci

### **Setting Backlash Values by Jerry Pinter**

Be sure to accurately (within an arcminute or less) determine the exact amount of backlash for each axis. Use a laser pointer attached to the scope, projecting a dot of light onto a wall. Start with both backlash settings (in scope.cfg) equal to 0. Using the handpad, move at slow speed for awhile in one direction, enough to takeup any backlash, stop, then read the altaz coordinates from the screen. Then reverse the motor direction on the handpad and stop immediately when the scope starts moving. Read the new altaz coordinate to determine the amount of backlash (in degrees). Repeat this several times and use the average value for each axis. Convert this to arcminutes and enter into scope.cfg. If one does not have a laser pointer, one can focus a cross-hair eyepiece on a stationary object on the horizon (house, tree, etc) to determine when the scope starts to move. The encoders could also be used if their precision is high enough. After entering the correct backlash parameters into scope.cfg, repeat the backlash test using the laser or encoders.

The scope should now "take up the slack" when direction is reversed during goto and tracking. For example, watch the current coordinates altazimuth display, along with the motor's display. You will see backlash either at zero or at maximum. Turn on tracking, and after a few moments to ensure that backlash is taken up, use the handpad to reverse direction. You will see the backlash in the motor display taken up in the opposite direction. When the button is released, you will see the backlash reverse takeup in the motor display, and observe that the current altazimuth coordinate for that motor remains unchanged during backlash takeup. This is the key to backlash compensation: even though the motors are spinning fast to take up the backlash, the scope is not moving with respect to the sky and thus the altaz coordinates do not change in value. Without backlash compensation, prior to every change of direction, the motors will spin and Scope II will think the scope is moving (and thus change the coordinates on the screen). However the scope with respect to the sky is not moving yet. This creates errors in pointing accuracy. Backlash can cause serious slewing, finding and tracking errors, especially if the backlash is a significant portion of the field of view.

For example, my (Jerry Pinter's) Cookbook CCD f.o.v. is about 15 arcminutes on my scope, and my backlash is about 7 arcminutes. Thus if I think I have an object nearly centered, without backlash compensation it may actually be 7 arcminutes off-center (depending on which way the motors last spun) which could be off the edge of the chip! Another problem is when doing initializations or "resetting" off a nearby bright star, if backlash is not compensated, then the scope may be pointing in error by the amount of backlash. Also, when tracking an object for CCD imaging, if the backlash is not compensated, then the object will drift across the image before the backlash is taken up. With backlash properly compensated for (as described above), everything is taken care of automatically. Scope II knows exactly where the scope is pointing during initialization, resets, and slews. When the scope slews to an object, the object will land on the CCD chip, and tracking will start immediately after the motors take out the slop, leaving the object in the same place within the field of view. It's important to have the scope balanced (alt axis) since any imbalance will tend to make the backlash appear only in one direction, which will screw up the backlash compensation.

### **Autoguide**

The computer controlled telescope can accept autoguider input via two methods:

**1. LX200 protocol:** scope.exe knows about the guiding commands available in the LX200 communications protocol. Simply hook up the serial port from the guiding computer via a null modem cable to the serial port being used as the LX200 communications port on the computer running scope.exe. Martin Niemi's superb quickcam autoguider will do this very inexpensively - see  
<http://www.ameritech.net/users/mniemi000/auto.html>

**2. Relay box:** The autoguider needs to supply a relay for each direction, or, a +5 VDC TTL signal for each direction, or, a serial connection sending LX200 protocol commands.

If using a relay box, wire the interface circuit such that when a relay closes, a +5VDC TTL signal is supplied as follows:

If using a control signal, tie the control signals so that the control signal going to logical high raises the input voltage to a +5VDC level as follows:

(this scheme mirrors the four direction buttons on the hand paddle)

up or north: to pin 13 of the parallel port, down or south: to pin 12 of the parallel port, left or counterclockwise: to pin 10 of the parallel port, right or clockwise: to pins 13 and 12 of the parallel port.

See following webpage for how Lenord Stage hooked up his SBIG SVD autoguider to the hand paddle:  
<http://www.dreamwater.com/biz/svdgoto/handpad.htm>

Here is how Juan Herrero hooked up his SBIG ST4 autoguider to the hand paddle:

Purchase a 2 female to 1 male phone wire adapter. Plug the male side to the control board.. Plug the hand paddle to one of the females. The other female will be for the ST-4. Purchase a phone wire with a male plug at one end to plug into the 2 to 1 adapter at the control board. At the other end of the wire. Install the correct computer plug to connect to the ST-4. You need to install 2 small signal diodes in two of the wires. Install the 2 diodes inside the computer plug.

The wire assignment is as follows:

ST-4 action	HAND PADDLE	PARALLEL PORT	ST-4 pins
+5v	white	n/a	----- 11, 5, 14, 8
-Az	yellow	10	----- 10
+Az	green	12	----- < ----- 4 *
+Az	black	13	----- < ----- 4 *
-Alt	green	12	----- 7
+Alt	black	13	----- 13

\* -----|<---- This symbol represents a diode and they are a must for thing to work.

Both the hand paddle and the ST-4 can be operated at the same time although conflicting simultaneous signals can be sent to the PC in this fashion, resulting in unpredictable actions.

#### To operate:

1. Put the telescope control program hand paddle mode into one of the guide modes. Set the speed of the guiding corrections by adjusting the microstepping guide speed.
2. Orient the autoguider by rotating it so that the autoguider's up and down correspond to the telescope's autoguider.
3. Calibrate the autoguider.
4. Initiate guide corrections by the telescope control program by momentarily flipping the hand paddle mode switch to the left and then center the switch.
5. Start the autoguider.

All guide functionality continues to exist with the autoguider on. For instance, in guide+stay mode, flipping the hand paddle mode switch momentarily to the right will calculate drift, and null the telescope's drift. Immediately re-initiate telescope control program guiding by momentarily flipping the hand paddle mode switch to the left and then center the switch. In guide+record mode, a record is kept of the autoguider's corrections.

The hand paddle can continue to be used. Pressing a direction button will add its guiding correction to the autoguider.

Guide arrangements include:

- piggyback guide scope
- off-axis guider
- intercept guider
- built-in guider chip ala ST7, ST8

## Interfacing with other programs

### To use Guide, a planetarium program by Project Pluto (Bill Gray):

1. Simply select 'guide.bat' option from scope.exe's menu. Make sure that the 'wguide.exe' program is in c:\guide.

Guide will show you where the scope is pointing, and upon exiting Guide, Guide's last coordinates will be displayed in the Input equatorial fields. Select move to input, or reset to input.

2. To run concurrently with Guide6.exe, the Win95 version of Guide, configure Guide6 by going to Settings, then Scope Control. Select an unused comm port, and pick 'altaz'. You will see a new drop down menu option appear, "Scope Pad". Select it. Be careful not to move the mouse as the cursor's position is used to send coordinates. To send coordinates from guide6.exe to scope.exe, select 'slew scope' on the scope pad menu. To receive coordinates into Guide6.exe from scope.exe, select 'slew guide'. To send coordinates from scope.exe to guide6.exe, use the hotkey '8', to receive coordinates into scope.exe from guide6.exe, use the hotkey '7'.

### Communicating With Other Programs

There are several methods to communicate with other astronomical software such as planetarium and control programs.

- via explicitly calling the DOS version of Guide
- via the serial/modem port using lx200 protocol commands
- via agreed upon slew files
- via the IACA

### Calling the DOS version of Guide via the menu option 'guide.bat' or the hotkey '' (left apostrophe), does the following:

- rewrites the startup.mar file that Guide uses to set its startup position
- exits to DOS and calls guide.bat, which launches Guide
- upon Guide's exit, Scope.exe reads startup.mar to ascertain the last coordinates that Guide used
- these coordinates are placed in the input equatorial fields

### Using the serial port to read and write lx200 protocol commands:

This is available if the lx200 serial port is set to 1 or 2 in the config.dat file.

Realtime display of lx200 commands processed and the character buffer is available if the menu option display LX200 is turned on.

Use a serial full null modem cable adapter to connect between the two serial ports.

Set the ports to 9600 baud, 8 databits, 1 stop bit, no parity.

It may be possible to use the modem. See <http://www.ghg.net/cshaw/modem.htm> for details.

**Scope.exe can also communicate via two agreed upon files**, using menu selections read slew and write slew or hotkeys '7' and '8'.

These files are located typically in the controlling planetarium program subdirectory, pointed to by the config.dat's InterfacePath variable, ie, c:\guide\

The file that is used to read in coordinates from the controlling planetarium program is called slew.dat and has two lines with the following format:

R <Ra degrees>  
D <Dec degrees>

The file that is used to write coordinates to the controlling planetarium program is called slew\_out.dat and has one line with the following format:

R <Ra degrees> <Dec degrees>

Any controlling program can thus add a little software to communicate with Scope.exe in this manner.

**Finally, the IACA can be used under DOS multitasking programs such as Windows 3.x:**

The Intra-Application Communication Area is a 16 byte area starting at 0040:00F0 that DOS sets aside to allow programs to communicate with each other; this area is used to exchange coordinates between the scope control program and graphically oriented CD-ROM planetarium programs such as Guide; the planetarium program's coordinates serve as input to the scope.

the scope program tells the planetarium program where the scope is pointing; coordinates are assumed to be precessed to the current date; each program, at startup, sets all coordinates initially to zero: this way, when non-zero coordinates are found, it can be assumed that the other program put them there; ie,

```
long iaca_ra = *(long far*) (0x4f0);
long iaca_dec = *(long far*) (0x4f4);
long scope_ra = *(long far*) (0x4f8);
long scope_dec = *(long far*) (0x4fc);
double scope_ra_in_decimal_hours = (double) scope_ra / 1.e+7;
double scope_dec_in_decimal_degrees = (double) scope_dec / 1.e+7;
```

## **PCB Testing Prior to Motor + Computer Hookup**

### **PCB voltage diagnostic as reference to ground**

running software with LED tester, parallel port test:

parallel port output pins to 7408 AND gates:  
logical high - 4.98 volts, logical low - 0.15

7408 AND gates to opto-isos:  
logical high - 4.60 volts, logical low - 0.47

opto-isos to TIP120:  
logical high - 5.07 volts, logical low - 0.21

TIPs:  
emitter logical high - 0 volts, logical low - 0  
collector logical high - 0.56 volts, logical low - VCC, eg, 12.3  
base logical high - 1.25 volts, logical low - 0.08

## **PCB checkout**

With the same concerns about my laptop's parallel port, here's how I tested my board. Starting with the driver board powered on and disconnected from the laptop, motors and handpad connected:

#1 Using volt meter, Black wire of multi-meter to Ground probe parallel pins with red wire looking for voltages higher than 5v, there should be none.

#2 Using a milli-amp meter, ground -> 100ohm resistor -> Black wire of meter, probe parallel pins with red wire recording milli-amp reading for each pin

- A) Pins 1 -9 should show very little to no current (Depending on invert option) \* See Note 1
- B) Pin 10 should show 50 milliamps only when Hand pad Left, Upper left, or Upper Right option button pressed \* See note 2
- C) Pin 11 should show 50 milliamps only when Slew Speed switch on
- D) Pin 12 should show 50 milliamps only when Hand pad Down, Right, Or Upper Right option button pressed \*see note 2
- E) Pin 13 should show 50 milliamps only when Hand pad Right, UP, or Upper Left option button pressed \*see note 2
- F) Pins 14 -17 should show very little to no current (Depending on Options)

H) Pins 18 - 25 should show no current

#3 using a milli-amp meter, +5vdc -> 100ohm resistor -> Red Wire of meter, probe parallel pins with black wire recording milli-amp reading for each pin

- A) pins 1-9 should show very little to no current (Depending on Invert option)
- B) Pin 10 should show 15.6 millamps with no hand pad buttons pressed \* see note 3
- C) Pin 11 should show 15.6 millamps slew speed switch off
- D) Pin 12 should show 15.6 millamps with no Hand pad buttons pressed \* see note 3
- E) Pin 13 should show 15.6 millamps with no Hand Pad buttons pressed \* see note 3
- F) Pins 14 -17 should show very little to no current (Depending on Options)
- G) Pins 18 - 25 should show 50 millamps of current

\* Note 1

While probing pins 2 - 9 in either step #2 or #3 depending on invert option, Also check to see if you stepper motors are turning on. In my case I could here the stepper motor 'Twitch' and it became very difficult to turn the shaft of the stepper motor.

\* Note 2

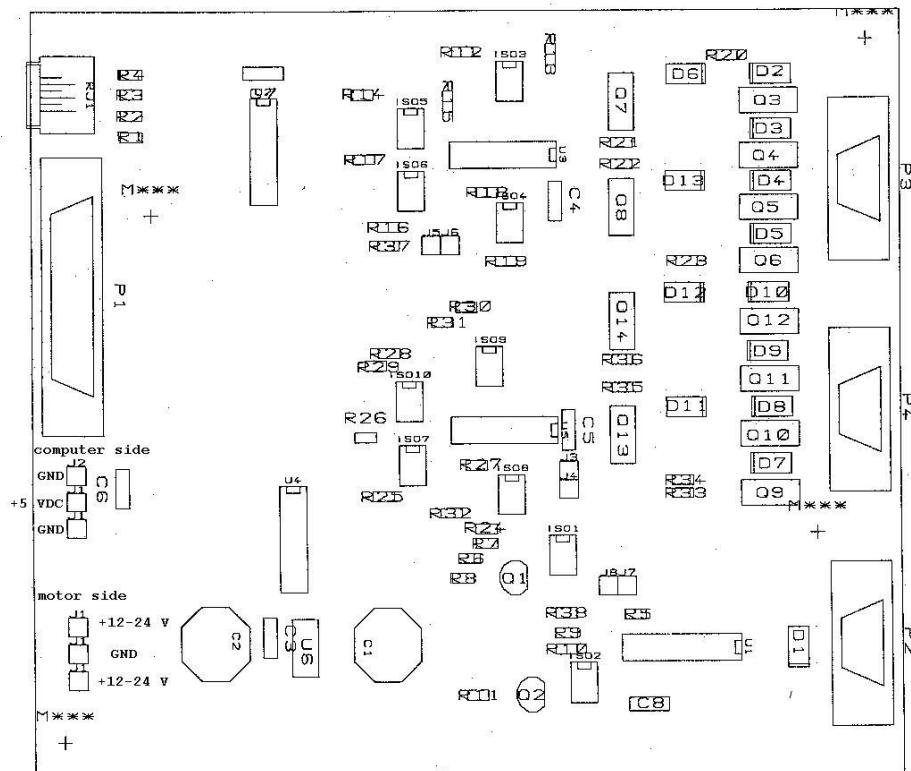
With the diodes in series and button pressed, you may only see 44 millamps of current (If I recall correctly)

\* Note 3

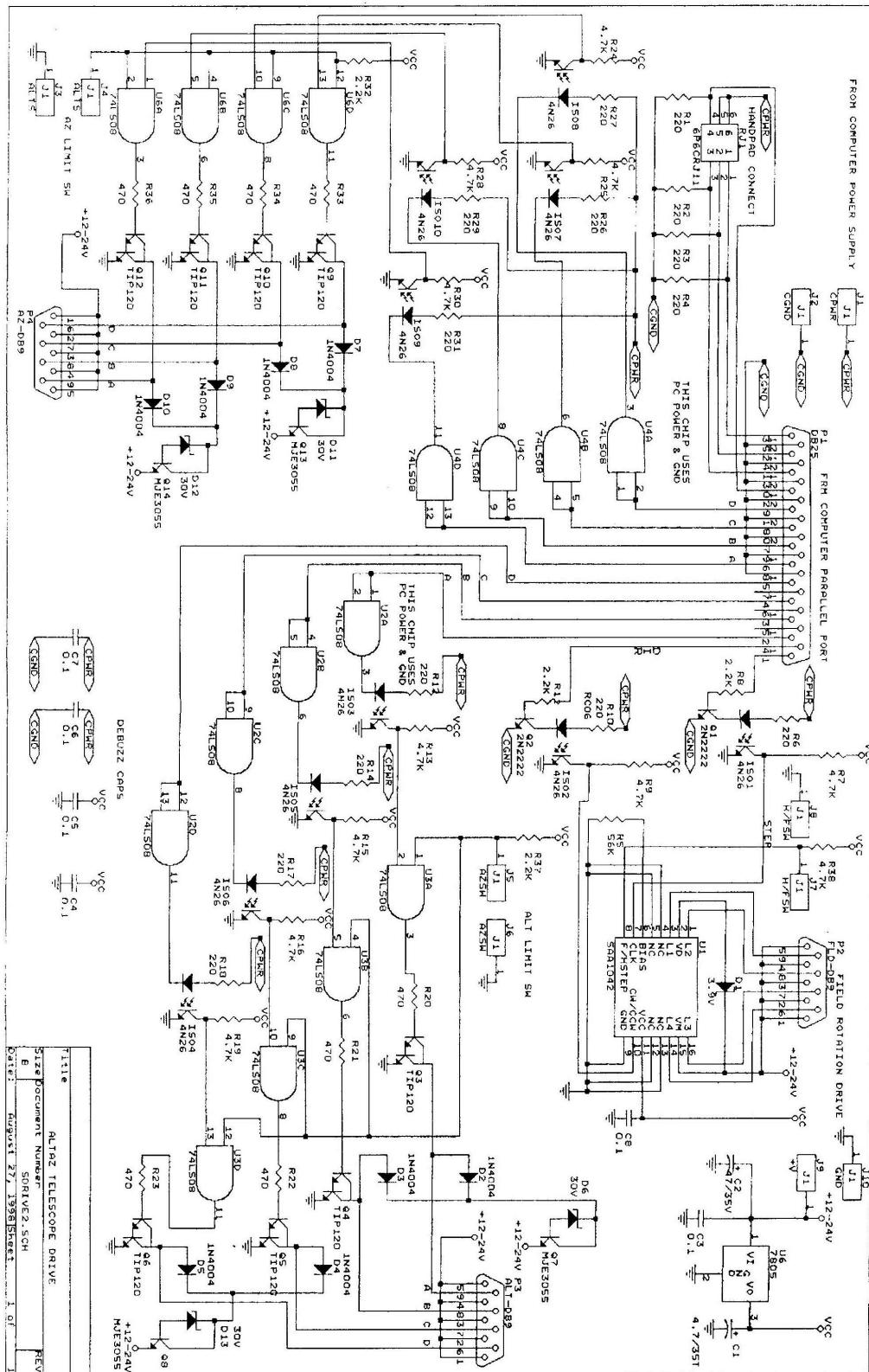
Again, with diodes in series and Key pressed, you may see 6 millamps of current. No key press should still be 15.6 milli-amps

Contributed by James Lerch, <http://Lerch.yi.org/atm> (James' Telescope Construction Webpage)

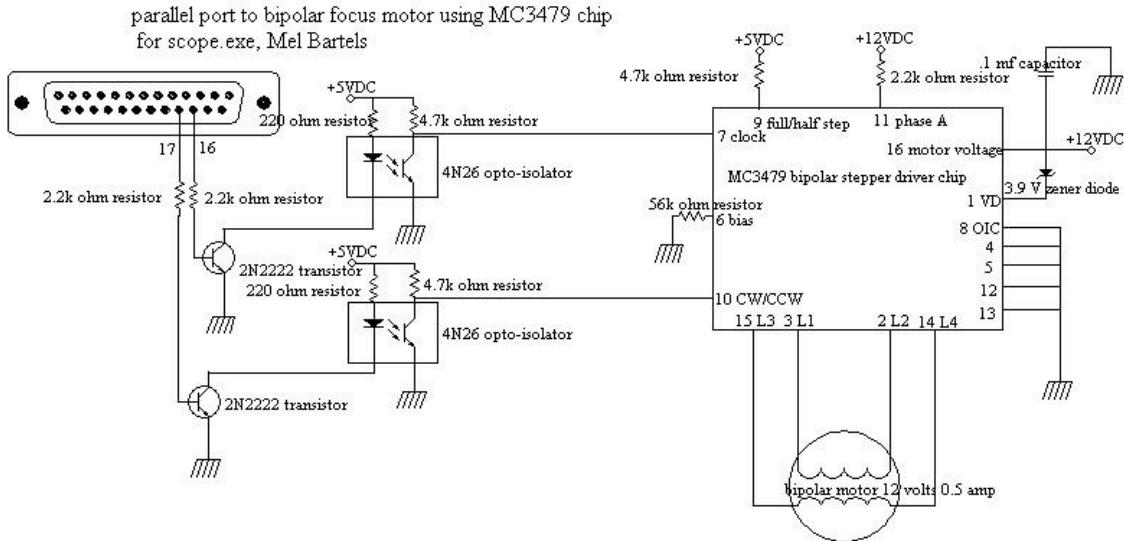
### PCB Parts Layout



## Circuit Diagram



## Focuser Motor Circuit Add-On



## Stepper Software Notes

config.dat settings:

set InvertOutput to 0 in config.dat.

Original designed called for 7404 inverters to drive the transistors, hence InvertOutput 1 in the original config.dat (parallel port output goes high, hex inverters go low, and drive transistors turn off, hence the need to invert the output).

In the original design, if opto-isolators were used, then InvertOutput 0 (parallel port output goes high, hex inverters go low, opto-isolators turn on pulling output low, hex inverters go high, and drive transistors turn on, hence no need to invert output).

This pcb design uses 7408 and gates (parallel port output goes high, 7408 and gates go high, opto-isolators turn off allowing output to return to high, 7408 and gates go high, and drive transistors turn on, hence no need to invert the output).

## Stepper Hardware Notes

### heatsinks:

no heatsinks are required on the power transistors as the software ensures that only the needed current is sent to the motors, for instance, 1 amp motors typically draw 0.1 amps while tracking and slewing; a heatsink on the 7805 voltage regulator might be required if you jumper it so as to power the computer side of the board and then use the board in poor ventilation or warm temperature (current draw with motors off at 12 VDC is 0.22 amps), or with higher drive voltages up to 24 VDC;

\*\*\* note by Pat Sweeney: I found that if the motors draw less than 1 amp each the transistors do not get hot while slewing or tracking. Currents of 4 or 5 amps while ramping up or down also are OK. If currents of around 2 amps per motor are expected. insure cooling via a small fan blowing on the TIP120s If currents much above 2 amps are expected I would suggest heat sinks But they must be electrically isolated. the collectors are tied to the tab on the TIP120s \*\*\*

#### **motor sizes and current limit:**

Use unipolar steppers in the range of 6 to 12 volts with amperage of 0.5 to 1 amps and winding or coil resistances of very roughly 5 ohms. Smaller and lighter motors will work also, even for rather large scopes. You can find these in old floppy drives, for instance. If the motor winding or coil resistance is 1 ohm or less, then the output power transistors will likely burn out in seconds. If you need to use more powerful motors of 1 to 3 volts with amperage up to 4 amps, then add either series power resistors, or better yet, install the current limiting add-on circuit designed by Jean-Charles Vachon.

#### **power/ground connections:**

the 6 holes for power and ground go as follows (board face up with the 6 holes to the lower left):

1. gnd 2. +5 vdc 3. gnd 4. +12 vdc 5. gnd 6. +12 vdc

for complete isolation, use separate computer and motor grounds, and supply an external +5.0 VDC source for the computer side or use the +5VDC output from pin 1 of the joystick port DB15; the vast majority of us will not require this total isolation, instead, tie computer and motor grounds together, and supply the computer +5 VDC from the 7805 power regulator (U6 - it will get hot supplying both sides of the board so consider a heat sink if not well ventilated or used in hot climate): do this best by jumping 1. gnd and 5. gnd together, then jump the bottom lead of the 7805 to 2. +5 vdc, and finally bring out two wires from 5. gnd and 6. +12-24 vdc for the ground and positive power connection respectively;

Be very careful when testing so as to not risk your computer's parallel port. Use a 6 volt drycell battery for motor voltage during initial testing.

\*\*\* note by Pat Sweeney: I left the computer 5volt supply separate from the 12 volt supply to isolate the parallel port from the drive circuit. If a catastrophic failure on the drive circuitry occurs there is the possibility of wrecking the parallel port on the computer. If + 5 volts is not available from the computer for this then I suggest using a small isolated DC to DC converter off the 12 volt side. I found that a 12 to 9 volt 250 mA DC to DC converter from JAMECO Part # 153736 for \$1.95, and, a 5 volt regulator will provide the isolation for my laptop. \*\*\*

#### **9/25 pin connectors:**

circuit board 9 pin and 25 pin connectors are straight (not angled) connectors; use thin flat cable to connect these to a set of connectors that you have mounted in the electronics box's face plate;

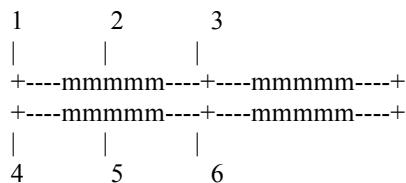
\*\*\* note by Pat Sweeney: you can mount all but the 25 pin parallel port connector from underneath on the solder side \*\*\*

### **Hooking up the stepper windings, by Chuck Shaw**

Any stepper motor with 5 or more leads will do. The stepper will have 4 windings and from 1 to 4 power leads. If a single power lead, then the inputs to all 4 windings are tied together inside the motor. If 8 total wires, then each winding has its own power lead.

You can puzzle out the leads if you use an ohmmeter. For instance, in a 5 lead stepper, the resistance of a winding to a winding lead will be double that of the power lead to any of the winding leads. If a 6 lead stepper, 2 windings are tied to a common power lead. Here, an ohmmeter will indicate which of the 3 leads belong together. Then for each of the grouping of 3 leads, you can use the rule of winding lead to winding lead giving twice the resistance of a power lead to winding lead.

The 6 wires are connected like so:



where the "m"s are the windings of the motor. If you have a volt/ohmmeter,

measure the resistance between each pair of wires:

pair	approximate resistance (ohms)
1-2, 2-3, 4-5, 5-6	40
1,2,3-4,5,6	infinite
1-3,4-6	80

Alternately, you can use a 1.5v battery and a red LED. It will glow dimmer across the 80 ohms than the 40 ohms. Chances are with your motor one set of 3 is 1-2-3 and the other set is 4-5-6.

Now, you have only to figure out the proper sequence. Here are some additional notes by Chuck Shaw on this subject:

If a 6 lead motor with red/blue powered by a white lead, and green/black powered by a yellow lead:

Tie White and Yellow together, and apply them to +12v

The signals from pins 6,7,8,9 go thru the circuitry to the bases of the transistors to turn them on/off

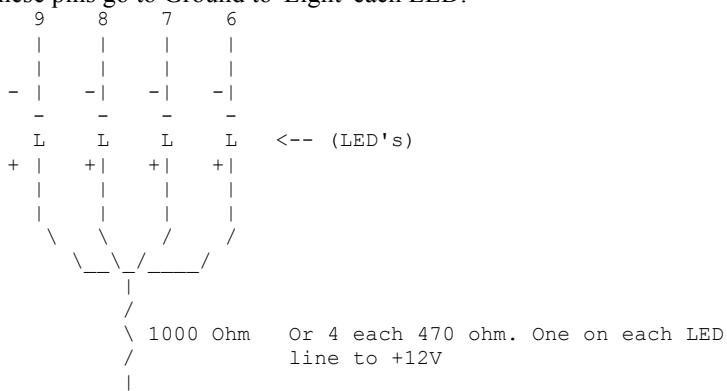
The 12v goes in via White/Yellow, and the circuit is completed to ground for a specific coil by setting the base for that coil's transistor high.

You can confirm the order that the pins are pulsed by using the Track test in config.dat (open config.dat, change the last line in the file to read "Track" rather than "NoTest" then resave config.dat. Run scope.exe and select a VERY slow rate). Rig a simple test set up to see which wire is "hot" by sending the power that would normally go thru the motor windings and send it thru a resistor and an LED and then to ground.

Build 4 of these, one for each pin output. Pay attention to the LED's polarity... The longer lead is usually "+" and the shorter one is the one that attaches to ground. The resistor should be sized to drop the 12v to 2 v (a 10v drop), assuming a 0.02 amp current thru the LED ( $V=IR$ ,  $10=(.02)(R)$ ,  $R=\sim 500$  ohms). Now use TestString = Track and watch the light show!!!! If you want to watch the output of the parallel port pins directly, the voltage will not be 12v dropped to 2, it will ~5v dropped to 2, so the resistor would be about 150 ohms. Note: you can keep this little test setup hooked up in parallel with the TIP120 outputs while the motor is running and hooked up too to verify which windings are being pulsed, and it makes a cool light show when the motors are driving the telescope too!!!!

(following diagram by Wayne Topa:)

These pins go to Ground to 'Light' each LED.



Pins 1-2-3-4-5 to +12V

This matrix assumes the pins are pulsed in the 6,7,8,9 order:

Test # / Results (Buzz, turn direction, etc)	6	8	7	9
1	blue	red	black	green
2	red	blue	black	green
3	blue	red	green	black
4	red	blue	green	black

The idea is to test and capture the results of the different combinations of pulsing windings.....

The software will pulse one coil from the Red/Blue pair, then pulse one from the Black/Green pair, then will pulse the other one from the red/blue pair, and finally will pulse the other one from the black green pair. Your challenge is to figure out what the order is within each pair.....

For 5 or 6 wire motors you are done!!! For 8 wire motors the test matrix gets bigger since you also need to identify the polarity of each winding in addition to its order!!!!!!

Here's the color winding order for Oriental Vexta motors.

1. red green blue black
2. green red blue black
3. green red black blue
4. red green black blue

In the end, you will not hurt anything by hooking up the stepper incorrectly. The motor will buzz or jump erratically. When you have the leads hooked up correctly, the motors will move smoothly during microstepping and halfstepping.

#### **A little checkout procedure for you to try:**

1. Disconnect everything from the parallel port, open config.dat with notepad and change the last line to read "TestParallelPort" to be able to run the parallel port test and save config.dat. Then start scope.exe and set the logical outputs to "high"
2. Measure the voltage from the "high" pins to ground. The high pins are 2,3,4,5,6,7,8,9 and should each all be about +5v with respect to the ground pins (18,19,20,21,22,23,24,25). Then set the logical outputs to "low" in scope.exe and verify the voltages all drop to zero on the previous +5v pins.....
3. If all of that was fine, hook up the PCB via the parallel port cable and turn on the power to the PCB. Do not have the LEDs or the motors attached to the output DB9 connectors.
4. Now, the idea is to set the logical outputs high as before, and trace the voltages along the PCB to the inputs to the first chip on the PCB.

Mel's circuit, when the Opto isolators are added, has the parallel port inputs initially going to a hex inverter, then to an optical isolator, then to a 2nd hex inverter, then to the base of the TIP120 transistors, then to the motor. Pat's circuit seems different. To start with, Pat only uses one Hex inverter and one opto isolator for each motor instead of two hex inverters and one opto isolator for each motor in Mel's version. Either system works, just be aware of the difference... On Pat's sheets 3of7 and 5of7, the parallel port goes to the Hex inverter first, then the opto isolator. However, on sheets 2of7 and 4of7, the circuit shows the parallel port goes to the opto isolator first, then the hexinverter..... Either order will work.

The thing to trace out, as the signal goes into the chip is which pin is connected to that output. If it was a +5v input, then the output should be 0 v. If the input is +5 and the putput is 0v, then toggle the parallel port to the other state and the input should go to zero and the putput should be +5.... Then follow that output from the first chip to the 2nd chip and do the same thing....

Repeat this for all 8 pins controlling the motors.....

If you trace the signals across the PCB from the parallel port and all is well, then look to the transistors. The circuit has +12v going to the motor, then through the winding, and then coming out and coming back to the transistor, where the transistor then closes and lets the circuit be completed to ground. You can test the transistors with your meter set to ohms. The transistor will be shorted (i.e. no resistance from pins 6,7,8,9 to ground, same config on both db9 connectors) NOTE, do NOT measure between any of the "HOT" pins on the DB9 (pins 1,2,3,4,5) to the ground pins while your meter is set to ohms... or "poof"... :-( To hook up the LED's, attach one led/470ohm resistor between pin 1 and 6, with the short lead on the LED attached to pin 6 (which goes to ground). Do the same for the other LED's (pin2 is +, pin 7 is neg), (pin 3 is +, pin 8 is neg), (pin 4 is +, pin 9 is neg).

With power ON to the PCB Box, toggle the parallel port outputs from low to high to low to high and the LED's should come on and off, etc. With the outputs set high, the LED's should be on, when they are set to low, the LED's should be off. If this is backwards, check the config.dat file for the optical isolator term....

If things still do not work right on the PCB, using the parallel port test, its a problem on the PCB. Check to see the orientation of the chips in sockets, etc... Also follow the +5 voltages from the regulators to see if

that voltage gets to the chips OK. Double check the orientation of the TIP120 transistors to make sure the leads are oriented correctly.....

If the parallel port does not act correctly we need to review the config.dat file settings.....

#### **Chris Rowland contributes the following:**

I have recently wired up an 8 wire motor made by Superior Electric, it is possible to work out the connections, even without a meter. The 8 wires are connected to 4 coils and you need to sort out not just which wires go to each coil but also which coils are in the same phase and which way round they need to be connected.

(1) Find the pairs of wires for each coil. There are two ways, one is to connect the wires to an ammeter and turn the motor. When you have the two ends of a coil you will see the meter needle move as the rotor moves. The other way is to short two wires and try to turn the rotor. When you have a coil the motor will be much more difficult to move and will also feel "notchy". The difference is obvious.

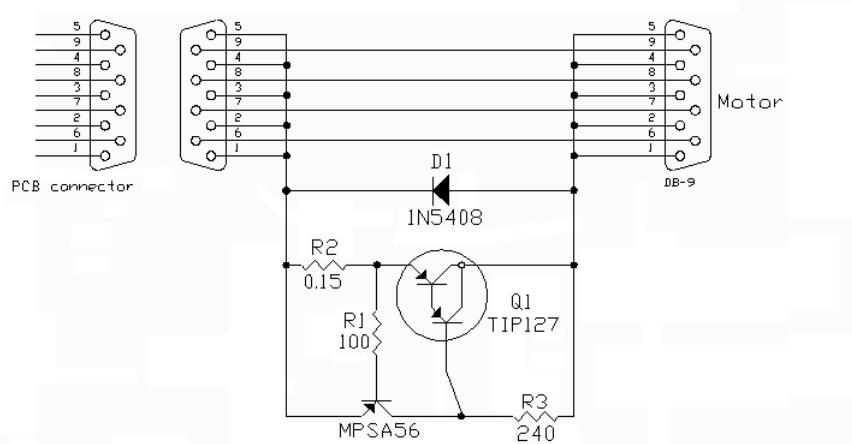
(2) Sort the pairs into two sets for the two phases. Connect two windings together in series and measure the current when you rotate the rotor as you did to find the windings. Try this for all the other windings, connected both ways round. When you have the two windings for the same phase, connected in the opposite direction, the current produced will be zero. It is easy to see this. If you don't have a meter then you can also use the same trick as above, when the two windings of the same phase are connected together there will be no additional resistance to movement. You now have the two windings for one phase but they are connected the wrong way round, reverse one of the windings. This will give you the common power connection and the two connections for one phase. (Phase A) Do the same for the other phase. (Phase B). Connect the common for the two phases to the power and the two phases to the drivers in the order ABAB. This should work, if you change the order of the Phase A or Phase B connections then the direction will change, if you are not in the ABAB (or BABA) order then the motor will not rotate correctly.

I hope this helps.Chris Rowland

Remember that the software expects the winding sequence to be A B A- B-, not the A A- B B- that some other controllers ask for. Here's a diagram contributed by Bob Rubendunst with the 9 pin connector pin numbers

#### **Current Limiting Modification**

by Jean-Charles Vachon [vachonjc@intlaurentides.qc.ca](mailto:vachonjc@intlaurentides.qc.ca)



New circuit inserted in series  
between the DB-9 of the PC board  
and a new DB-9 for the motor.

Jean-Charles Vachon  
May, 1999

modified slightly for presentation  
Mel Bortels

(the following is Jean-Charles' explanatory text, slightly edited)

In the depicted version, the 240 ohms resistor (R3) is connected to a common point with the TIP127 and diode 1N5408. Since there was no ground connection available, the motor itself was used as a return to ground. This is not as good as directly returning to ground, but there was no choice. On a new board this circuit, or a similar one, can be incorporated on the main PC board, or a ground connection can be added on the DB-9 connector.

The other version, not depicted, this resistor (R3) is 1000 ohms and connected directly to ground. This version is more effective.

Now, the current limit value is determined by R2, in my case 0.15 ohms for 4 amperes. This resistor should be a 5 watt. Any current can be chosen and it is calculated the following way:  $R2 = 0.6 / \text{desired current}$ . For example in my case I wanted 4 amperes maximum, so  $R2 = 0.6 / 4 = 0.15$  ohms. In a similar way, if you desire 3 ampere limitation the calculations are:  $0.6 / 3 = 0.2$  ohms, and so on.

If you use 24 volts I would raise R3 to 470 ohms in the first circuit and to 2200 ohms in circuit 2.

Transistor TIP127 does not heat, but in pure precaution I attached on the aluminium box, I used a medium size heatsink. I think it is better if used at 24 volts. This depends on the motors of course.

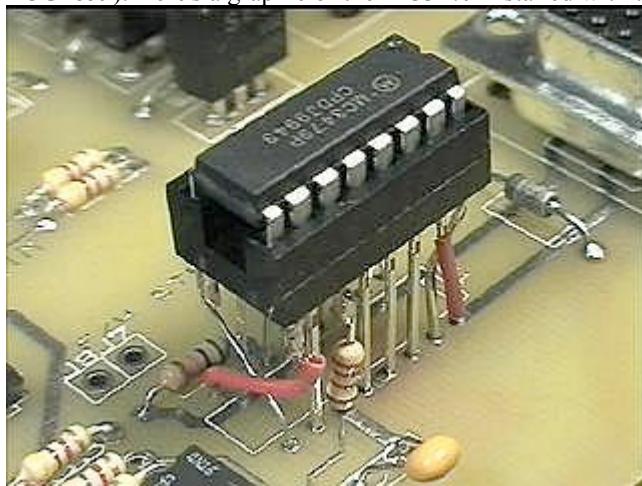
What the circuit does, is to limit the maximum current to the value presetted no mater what is the load, so as I discussed earlier, you will not end with astronomic currents near the 20 ampere mark.

Also see a stepper constant high current source circuit diagram and article at

[http://www.siliconchip.com.au/cms/A\\_30554/article.html](http://www.siliconchip.com.au/cms/A_30554/article.html)

### Stepper Field Rotator/Focuser

The optional field derotator/focuser chip can be added later. The circuit board was designed with the SAA1042 in mind. However, the now discontinued SAA1042 has been replaced by the MC3479 (or ECG1859). Here's a graphic of the MC3479 installed with the modifications on the pcb:



\*\*\* following note on how to hook up the MC3479 and ECG1859 by Bob Norgard \*\*\*

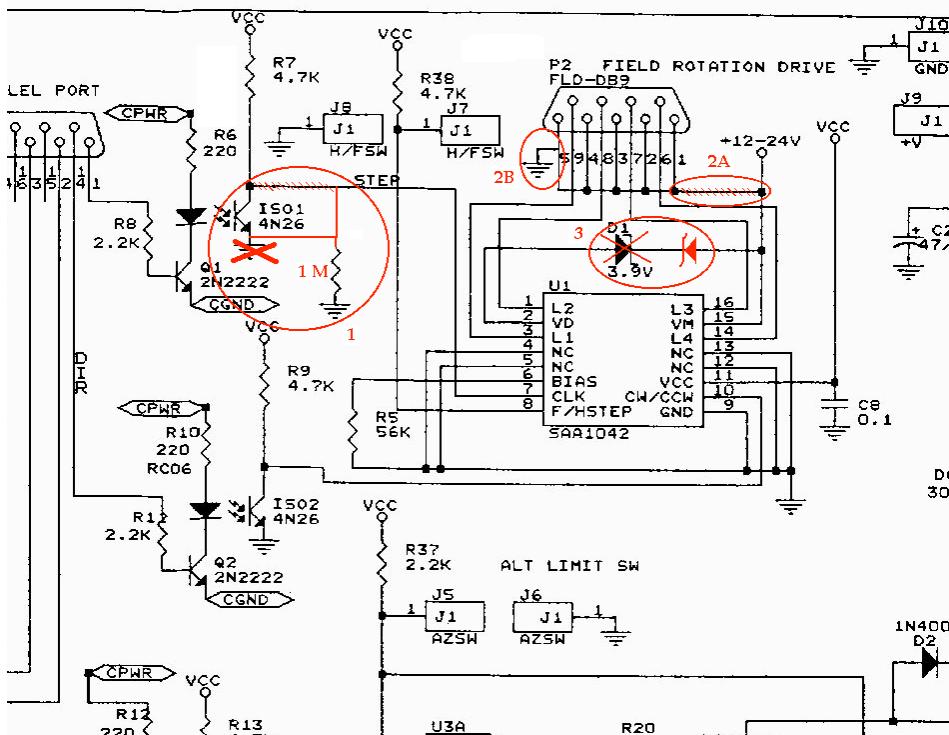
Three pairs of wires need to be reversed to make it function properly with the circuit board, plus a resistor needs to be added. Get a little daughter board designed to handle a single IC chip of 16 pins to float above the field derotator socket. Pins 1 & 2, 15 & 16, 8 & 9 need to be reversed. Cut 15 pieces of insulated 22 ga solid hookup wire 3/4 inch long. Take a 2k ohm 1/4w resistor and trim its leads to the same overall length. Solder one end of the resistor to pin #11 of the 16 pin socket. Additionally, the existing 56k bias resistor may not be optimum for different motors. Increase the resistance to lower current draw. The MC3479 handles up to 350 ma motors while the ECG1859 handles up to 500 ma motors. The stepper can handle larger amperage motors with Chuck Shaw's modifications mentioned below (be sure to still swap the 3 pairs of leads for the new chips).

Main Board ECG-1857 Board  
SAA1042 site

1*	2*	9*	8*
2*	1*	10	10
3	3	11	2K*
4	4	12	12
5	5	13	13
6	6	14	14
7	7	15*	16*
8*	9*	16*	15*

\* Note lead reversals and added 2K resistor!!!

I mounted the little board using 4 stand-offs inside the aluminum box that houses the rest of the drive circuitry. For testing purposes, I used a Mitsumi Electric M68SP-4 12V/33ohm stepper salvaged from an old floppy drive. It has 1.8 degree steps. The chip ran barely warm to the touch.



\*\*\* note by Pat Sweeney on the field derotator/focuser portion of the pcb \*\*\*

The schematic and silk screen does show the 3.9 volt zener in backwards. (sorry ) The rest of the circuit is OK. The chip is configured to drive a 2 phase bipolar stepper motor. (4 wire motor) I tested the circuit on a stepper that draws 200MA per winding and it seems to work properly. Only the pins 6,7,8, and 9 are used. Pins 1,2,3,4, and 5 can supply + 12 volts for external transistors to power a stepper that will draw more than 500MA. Ground for external transistors will have to be supplied from another location on the board.

### Soldering Tips

- orient the board so that the parallel port 25 pin connector is to the left
- the tip 120 transistors will face to the bottom, and the mje 3055 and 7805 voltage regulator will face to the left
- the diodes must be soldered so that their banded marking matches the diode marking on the pcb

- some capacitors have a long leg - these solder into the '+' marking
- all the opto-isolators solder in with the alignment marker to the top of the pcb, (alignment marker is to the upper left of the indented side)
- make sure you mount the 7408 AND gates so that the alignment marker is either to the top or to the right
- do not overheat components while soldering: solder one lead, then move onto the next part, returning later to solder the next lead
- double check all solder joints before applying power
- before mounting the 7408 AND gates, apply power and verify the ground and +5 VDC lines through the pcb, and particularly at each 7408 AND gate
- use a straight through 25 pin to 25 pin connector with male ends on each side to connect the parallel port to the pcb
- be careful to not cause a short if using metal screws to attach the DB9 connectors to the circuit board
- after mounting the 7408 chips and before attaching the stepper motors, use the parallel port test option of scope.exe to exercise the output lines and verify with a voltmeter that the 8 output lines to the 2 steppers are functioning properly

### Handpad



1 handpaddle plastic box Jameco 18921 (3.1"x2"x.9"ABS) \$2.25 or Mouser 546-1591BS-BK (4.4"x2.4"x1.2"ABS) \$3.34

6 push button momentary on switches Jameco 26622 \$.49

1 2-way switch Jameco toggle 21936 \$1.09

6 small diodes Jameco 35991 \$.40/10

1 RJ11 connector Jameco 124038 \$.95

Here's how Ned Smith built his handpad:

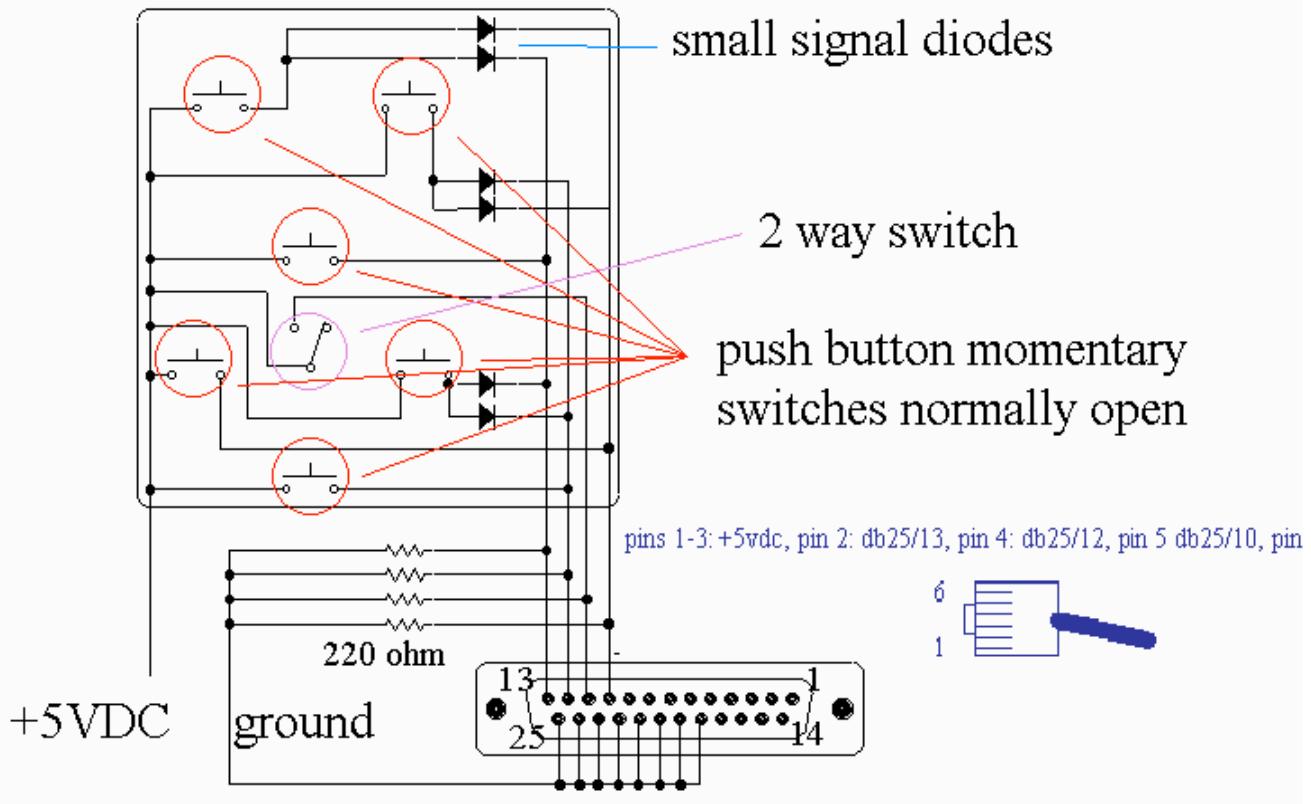
I used the following from TechAmerica (RadioShack): 910-1075 \$15.48 It is a 1 x 2.4 x 3.8 inch enclosure with a membrane

switch pad. It has a 3 x 4 switch array. I cut off one row to make a 3 x 3. This gives me Up, Down, Right, and Left. I used the upper R and L corners for the self-centering toggle switch. I only had to add SPDT to handle the two stepping rates. The membrane switches add about 50 ohms to the circuit which reduced the voltage at the connector. I used RJ12 connectors for the hand paddle to PCB enclosure and stepper motor to enclosure.

**Handpad Circuit Diagram**

# HandPaddle

## Circuit Diagram

**Handpad Cable**

cable: 10 foot length of flat 6 wire Jameco 103448 (\$.07/foot)

connectors: (2) RJ11 6p Jameco 79273 \$.15

Using RJ11 connector Jameco 124038 with straight through cable (comparing cable ends side by side with clips up, wiring is the same color sequence from left to right), hookup is:

pin number looking face-on to connector with clip on top:

\*\*\*\*\*

\*\*\*\*\*

\* rd wh ye \*

\* bk gr bl \*

\*\*\*\*\*

parallel port pin 13 is the yellow wire

parallel port pin 12 is the white wire

parallel port pin 11 is the red wire

parallel port pin 10 is the black wire

+5 VDC is the blue and green wires

Using RJ11 connector Jameco 124038 with crossover cable, hookup is:

pin number looking face-on to connector with clip on top:

```

*****
*****
* rd wh ye *
* bk gr bl *
*****
parallel port pin 13 is the black wire
parallel port pin 12 is the green wire
parallel port pin 11 is the blue wire
parallel port pin 10 is the yellow wire
+5 VDC is the white and red wires

```

### **PCB and Parts List**

Use the part numbers here and on the printed circuit board - any part numbers on other circuit diagrams do not necessarily correspond to the pcb.

All capacitors are in microfarads and all resistors are 1/4 watt: there is a fair degree of latitude in selecting parts.

- 1 C1 4.7/35V tantalum cap Jameco 33806 \$.35
- 1 C2 47/35V electrolytic cap Jameco 31114 \$.15
- 6 C3-C8 0.1 monolithic cap Jameco 25523 \$.15
- 1 D1 3.9V/1W zener Jameco 178765 \$.12, Allied 568-0135 \$.08
- 8 D2-5, D7-10 1N4004 diode Jameco 35991 \$.40/10
- 4 D6, D11-13 30V/1W zener Jameco 178925 \$.08, Allied 568-0045 \$.06
- 10 ISO1-10 4N35 optoisolator Jameco 41056 \$.35 (optional socket Jameco 112192 \$.08)
- 1 P1 DB25F connector Jameco 15165 \$.65
- 3 P2-4 DB9F connector Jameco 15780 \$.49
- 2 Q1-2 2N2222 transistor Jameco 28628 \$1.10/10
- 8 Q3-6, Q9-12 TIP120 transistor Jameco 32993 \$.65
- 4 Q7-8, Q13-14 MJE3055 transistor Jameco 25857 \$.65
- 14 R1-4, R6, R10, R12, R14, R17-18, R26-27, R29, R31 220 ohm resistor Jameco 30470 \$.89/100
- 1 R5 56k resistor Allied 526-1666 \$.29/200
- 11 R7, R9, R13, R15-16, R19, R24-25, R28, R30, R38 4.7k resistor Jameco 31026 \$.89/100
- 4 R8, R11, R32, R372.2k resistor Jameco 30314 \$.89/100
- 8 R20-23, R33-36 470 ohm resistor Jameco 31165 \$.89/100
- 1 RJ11 RJ11 connector Jameco 115836 \$.65
- 1 U1 MC3479 IC (replaces SAA1042) Jameco 25216 \$.5 (needed only if you will be doing field derotation or motorized focus control)
- 1 socket 16 pin Jameco 37372 \$.07 (needed only if you will be doing field derotation and using the SAA1042 chip; for the MC3479 chip use wire wrap socket Jameco 37410 \$1.09 with 2.2k resistor Jameco 30314 \$.89/100 as 3 pairs of wires need to be reversed and one lead replaced with the resistor)
- 4 U2-5 74LS08 IC Jameco 46375 \$.25
- 4 14 socket pin Jameco 37161 \$.06
- 1 U6 7805 regulator Jameco 51262 \$.29
- optional TO-220 heatsink for the 7805 Jameco 107297 \$.39 (heatsink compound Jameco 167249 \$7.95)
- (solder Jameco 141778 \$13.95)

### **Encoders**

The servo system utilizes encoders to report the servo motor position. External encoders that are placed on the telescope's two main axes can be added with a slave card. This gives the ability to detect drive slippage, observers pushing the scope out of position, and so forth.

For the stepper system, David Lane, author of The Earth Centered Universe (ECU), has designed an inexpensive serial interface for quadrature encoders. Called the MicroGuider 5 (MG5), complete details can be found at <http://www.nova-astro.com/>. Cost for the interface (ready to use), not including the encoders, is about \$75US (see the parts webpage for the encoders).

Bob Segrest has designed a very small PCB, you can contact him at [bobslan@erols.com](mailto:bobslan@erols.com).

Patrick Dufour offers a very compact commercial encoder interface box. See his WebPages at <http://www.microtec.net/pdufour/index.htm>, or reach him at Ouranos, 189, rue Du Foin, Saint-Augustin de DesMaures (Quebec), Canada G3A 2S6, Tel. 418-878-9426.

Dave Ek's box is a small very fast reading unit for nominal cost, details at <http://home.earthlink.net/~digicircles>

Finally, you can use the encoders from a mouse. Make sure that acceleration and multiplication settings are turned off via the mouse driver. Use the timer method of halfstepping instead of the delay method that temporarily turns off interrupts. For more on mouse encoders and telescopes, see <http://hscience.tripod.com/Atm.html>

If encoders are used, when tracking is off, if you grab the scope and move it by hand, the changing encoder values will update the current altitude and azimuth. When tracking is on, if the encoders differ from current altitude and azimuth, the situation is understood to be one of slippage of the drive shafts, or perhaps a wind gust moving the scope off position. The scope will slew back to the proper position and resume tracking. Do not intentionally move the scope by hand when tracking is on if the encoders are on. To illustrate this, the following is an incident that happened at a recent star party.

Greg Granville writes, "The 12.5" scope is working very nicely with this setup. I recently added encoders to the scope. At a star party a few weeks ago, a youngster was up on a ladder a few steps looking at NGC 4565. When coming down the ladder, he accidentally pushed the scope and caused it to slip on azimuth. He seemed a bit surprised when the scope responded by automatically moving back to the proper position!" The variables EncoderErrorThresholdDeg and TrackEncoderErrorThresholdDeg control the allowable difference between scope and encoder coordinates before a reset to encoder coordinates occurs. There are two variables since a tighter tolerance during slewing to a target position is often desired compared to the tracking reset tolerance. Set these to a value that represents at least one if not two or more encoder counts. At any time the scope can be reset to encoder coordinates via the 'reset to encoder menu option'. When a reset to encoder coordinates occur, if you wish encoder these threshold violations to be recorded, set the config.dat variable MakeEncoderResetLogFile to 1.

### Flywheels by Tom Krajci

Tonight I installed and tested flywheels on my stepper motors that drive my sixteen inch scope. The flywheels make a significant improvement in max speed slewing without stalling the motors. I can slew at 2.5 deg/second, and might be able to slew faster, but I'm afraid to slew faster with such a long tube! ;-) Based on the reading I've done in the last few days, I think almost all amateur scopes driven with Mel's stepper system can benefit from addition of flywheels. Why? The worm/coupling/whatever that's directly coupled to the stepper motors in amateur drive systems has a very low rotational inertia...far lower than the inertia of the stepper rotor itself...roughly the equivalent of the stepper running under no load. According to the literature I've reviewed (links from Mel's page) in some (many?) cases steppers don't perform well at the higher speeds under no-load conditions...resonance freq's are up high, near the speeds you want to slew at and the motor stalls.

Adding a flywheel (or adding friction, or adding viscous damping) can lower the motor's resonant frequency, and improve high speed performance.

My flywheels are very simple - 1/4 inch plate steel, cut into 2.25 inch squares by hacksaw, with the center hole drilled with a 1/4 inch drill. Balancing this thing? Put the flywheel on the drill shank and tap the shank...the flywheel will fall/settle with the heavy portion lowest...grind some of that away and test balance again until the flywheel won't settle into one position over any other. (Balance is not all that critical here...your steppers won't spin faster than about 10 times per second at max speed.)

The only tradeoff? You may have to ramp up/down the steppers a bit slower now, and perhaps start slewing at a slower speed, and perhaps lock the rotors after a slew for another .1 second or so.

There may be another flywheel improvement in some cases: it might smooth out microstepping motion. I say that because my motors are making less noise while microstepping now that I've added the flywheels. That's not proof that there's smoother motion, but perhaps an indication.

More good news from experimenting tonight. Now that I have a flywheel in place, I can use a smaller series resistor with my steppers (6V driven at 24V). This allows a bit more current...allowing even higher max slew speeds!

There seems to be a synergy between: over voltage driving of steppers, flywheels to control resonance (lower the fundamental frequency), and resistors to keep current within motor ratings so that resonance is controlled at lower speeds.

Before the flywheels I had to use 30 ohms series resistance to keep the motors from vibrating so much (they would stall at even the slowest speeds). With the flywheels I need only 10 ohms series resistance. I haven't even had to slow the ramp up/down speed...which means I can probably use an even heavier flywheel...which may mean a further increase in slew speed. Yikes! I'm already up to about 2.75 - 3 deg/sec! For now I'm satisfied with slew performance. Later I may experiment with heavier flywheels.

### **Stepper Motor Noise**

Stepper motors can run very quietly. They need not make any more noise when attached to the scope as when held in your hand. It's common star party etiquette to run a quiet operation, and you will make a good impression of your system.

The noise of the switching stepper motor windings is greatly amplified when attached to metal and wood mounts. The mount acts as a drum.

To run them quietly, isolate the stepper from wood and other resonant materials by a thin piece of rubber or styrofoam or something similar such as a mouse pad (neoprene). Use nylon screws or nylon bolts to attach the stepper to its mounting plate, further isolating the screws with rubber grommets. Use a short piece of automobile vacuum hose to attach the stepper to the input drive shaft of the gear reducer, leaving a gap of a millimeter between the shafts.

Another suggestion that receives rave reviews is to mount the motor with rubber standoffs, such as available from SmallParts.

Paul Shankland suggests using a PC wrist support made of a long strip of gel material. He goes on to say, "Cut away the hard rubber base revealing the material (color of vanilla pudding) underneath, with the cloth left on top - it's a tacky but cohesive firm gel, - looks like some synthetic blubber, and leaves a faint tacky residue - very resilient, absorbent, but of a resilience that with clamps, would not let the torque whip the steppers out of alignment. I think PERFECT for the job. I left the scope drive in my stateroom on the ship, so I took it in to toy with the damping qualities between bzillion meetings today and PRESTO- amazing quieting! BEST I have EVER heard!! Or not heard. The motors, about 95% haphazardly wrapped in the stuff, were sitting on a steel bench which amplifies noise heinously - but when I powered up the microstepping AND slewing, I thought the steppers were broken - I could not hear a thing!"

Here's a suggestion from Jean-Charles Vachon:

"I use a motor with a 2.25 inch square flange and I built around it walls leaving about 3/8 to 1/2 of an inch of space to put the wool.

"A word about the wool. Acoustic wool and insulation wool are not the same. Insulation wool has poor acoustic properties. Insulation wool is a low density wool in contrast to acoustic wool which is a high density wool.

"I would have to look for characteristics for acoustic wool. I do not remember by heart. It has been a long time I did not work with that. 7 years of retirement start to show. What I remember is that it is rated in pounds per square yard I believe. For instance in acoustic treatment we normally use 3, 3.5 and 4 pounds per square yard. The heavier the better is the product for acoustic treatment. If I am not mistaking acoustic tiles are around 3 pounds per yard which makes them excellent performers.

"A good way to see if the wool is firm enough is that it must stand up alone. The ceiling tiles are rigid enough for that. Now if you put this around the motor particularly the square flange the motor does not move. I am just returning from the basement to check that particular aspect, nothing moves.

"I also drive the motors with a gizmo called Wellnut. This is a rubber thing with 10/32" threads at one end and a rubber hole at the other. It has 3/4" in length. They are of all sizes. The one I use can accept, in its hole, the 1/4" shaft from the motor directly. The rubber is not hard and it makes an excellent universal joint that will accept and compensate for small misalignment between motor and worm.

"This is found at your hardware store and here cost 84 cents only. This is the best thing we found to couple the motors to the worm, thanks to Allan who made the discovery. I intend to use them as well for my optical encoders.

"With acoustic wool well in place the motors should not move.

"To give you an idea of the results I got here with that : the noise from the fan of my computer is louder than the motor I have treated with the wool.

A suggestion from Tom Krajei on reducing stepper motor noise:

"I've applied poster putty around my alt and az stepper motor bodies, and found that it's cut the motor noise by more than half. Poster putty is an adhesive putty that is used to hang lightweight objects on the wall without damaging wall paper, etc. It's sticky enough to stay in place, but the best advantage is that it's moldable to just about any shape, so I can get it into tight corners."

### **Parallel Port Interface**

The parallel port is an ideal interface for controlling telescopes, particularly with laptops in the field. The parallel port uses 8 bits of output, typically at port address 0x378. On the 25 pin connector, the 8 bits of output are on pins 2 through 9, from least significant to the most significant bit. These 8 bits of output are perfect for controlling the two stepper motors needed to drive a telescope in altazimuth mode. The parallel port cannot provide or sink large currents directly, hence, 74LS04 hex inverters are used to interface between the parallel port and the driver transistors.

The parallel port has 5 bits of input at port address 0x379. These input bits are on pins 15, 13, 12, 10, and 11 of the 25 pin connector, with pins 11 and 15 being inverted. Pin 15 activates bit 8, pin 13 activates bit 16, pin 12 activates bit 32, pin 10 activates bit 64 and pin 11 activates bit 128. Depending on which lines are raised high, the values can range from 8 through 248. In addition, the parallel port has 4 bits that can be either in or out at port address 0x37A. These 4 bits show up on pins 1, 14, 16 and 17 of the 25 pin connector. Bits 1, 14 and 17 are inverted. These values when read range from 0 to 15.

For more on the parallel port:

<http://baza.doc.ic.ac.uk/~ih/doc/par/>

<http://home.rmi.net/~hisys/parport.html>

<http://www.boondog.com/>

<http://www.lvr.com/files/ibmlpt.txt>

### **Stepper Motors**

Two methods of motorizing telescopes are open loop stepper motors and closed loop servo motors with tachometer or encoder feedback. With an open loop stepper motor system, the motors are commanded to move: there is no feedback that the movement took place. Stepper motors move in precise increments of (usually) 200 full steps per revolution. By conservatively rating the steppers, we can insure that the motors will never stall. The common dot-matrix printer positions the print head and paper in this manner. With servo motors we need some sort of feedback to tell us how the motor shaft is rotating. A tachometer or encoder will give us this information but at a price of more complex hardware and software. In practice, both methods work well. For our purposes open loop steppers will be easier to control over the wide range of scope characteristics and speeds needed by the altazimuth drive.

Perhaps the name 'stepper' is a misnomer; this type of motor was originally conceived to run on AC synchronous power. Instead of using smoothly varying AC, if DC is applied first to one winding, then to the next, the motor will move in step fashion, hence the name. When the DC is made to vary synchronously, in our case by a digital method called Pulse Width Modulation, the motor returns to its original smooth running state.

A typical stepper motor consists of a permanently magnetized rotor shaft shaped with radial teeth that rotate inside a stator that also contains teeth. Depending on how the stator's teeth are energized, the rotor will align itself in a particular orientation. The stator has four windings that energize various teeth. To drive a stepper, switch the current from one stator winding to the next.

A full step pattern, or excitation mode, goes like this:

full step # winding...

1	2	3	4
1	ON	OFF	OFF
2	OFF	ON	OFF
3	OFF	OFF	ON
4	OFF	OFF	ON

At each full step, the rotor aligns itself with the winding that is turned ON.

The halfstep pattern, or excitation mode, goes like this:

halfstep # winding...

1	2	3	4
1	ON	OFF	OFF
2	ON	ON	OFF
3	OFF	ON	OFF
4	OFF	ON	ON
5	OFF	OFF	ON
6	OFF	OFF	ON
7	OFF	OFF	ON
8	ON	OFF	ON

When adjacent windings are ON, the rotor positions itself between the two windings. Steppers move smoothly and are more resistant to resonance effects when halfstepping. Shaft oscillation occurs when the rotor snaps to the next winding during full stepping. The shaft will first overshoot, then undershoot, continuing a decaying oscillation. If the load on the shaft happens to have a harmonic period that matches the rotor's oscillation, a resonance develops between the motor and the load. This can destroy the stepper's ability to rotate at certain rates.

A much bigger improvement in rotor smoothness occurs when microstepping. In the past, amateur altazimuth stepper motor drive designs have sometimes failed because of induced vibration caused by coarse step resolution. With a PC directly controlling the voltage waveform of all four stepper motor windings, we can easily divide each full step into many microsteps.

Microstepping gives us five principal advantages:

running at resonance frequencies (allows low speed operation) that would otherwise jitter the stepper motor  
extending dynamic range towards lower frequencies (avoids ringing, noise, and vibration)

replace gearbox by extending the number of steps per motor shaft revolution

improved step accuracy

and lessened system complexity (much less complexity when microstepping as compared to a mechanical fix)

To microstep: winding A slowing ramps down in current following a cosine curve, while winding B slowly ramps up following a sine curve. Applying full current to winding A positions the rotor directly over winding A. Applying equal current to both windings A and B positions the rotor directly between winding A and B. Applying current to winding B that is 60% of winding A's current will position the rotor exactly 1/4 of the way between windings A and B. Because of the inverse square nature of the electromagnetic force, moving smoothly between windings A and B calls for a cosine/sine current pattern to be applied to the two windings.

Limitations on microstepping include absolute tooth error, typically 1/25 of a full step, and a deflection error caused by torque loading. The deflection error is at a minimum when the rotor is positioned on a winding and at a maximum when positioned between windings. If the torque loading is 10%, then the shaft's error when between windings will be 10% of a full step. Microstepping at 10 microsteps per full step is a reasonable compromise between smoothness and rotor position accuracy. More microsteps can translate into a smoother motion, but will not result in increased rotor position accuracy.

The PC uses the parallel port's eight output bits to simultaneously control the current waveform of the eight windings belonging to the two stepper motors. The current waveforms are generated using a technique called Pulse Width Modulation. Full current is turned ON for a certain time then turned OFF. The

cumulative effect of rapidly repeating ONs and OFFs to the motor is the same as if smooth average current was used. By adjusting the percentage of ON vs. OFF the resulting current can be controlled precisely. Torque remains high whatever the motor's speed since full current is applied during the ON time. For adequate current resolution, the sequence of ONs and OFFs will add to 100 or more. For illustration purposes, let's say that the total sequence per phase is 10. If winding A is controlled by bit #0 (control word output = 1), and winding B controlled by bit #1 (control word output = 2) of the control word, then the sequence of control words for a single full step with maximum average current (ignoring the other windings on bits #2 through #7) is:

sequence of control words output (10 pulses per phase):

---

phase #1: 1 1 1 1 1 1 1 1 1 1

phase #2: 2 2 2 2 2 2 2 2 2 2

For full stepping at half current:

sequence of control words output (10 pulses per phase):

---

phase #1: 1 1 1 1 1 0 0 0 0 0

phase #2: 2 2 2 2 2 0 0 0 0 0

For halfstepping at half current where the intermediate halfstep consists of both winding A and winding B on:

sequence of control words output (10 pulses per phase):

---

phase #1: 1 1 1 1 1 0 0 0 0 0

phase #2: 3 3 3 3 3 0 0 0 0 0

phase #3: 2 2 2 2 2 0 0 0 0 0

To microstep, we want to place the rotor at intermediate positions between windings A and B. To set the rotor 25% of the way towards winding B, the rotor must 'feel' winding B 1/3 as much, positioning itself 3 times closer to winding A than winding B. Since electro-magnetic fields propagate as the inverse square, the current supplied to winding B must be  $\text{sqr}(1/3)$  or about 60% of current to winding A:

sequence of control words output (10 pulses per phase):

---

winding A at 100% current: 1 1 1 1 1 1 1 1 1 1

+ winding B at 60% current: 2 2 2 2 2 2 0 0 0 0

= winding A + winding B: 3 3 3 3 3 3 1 1 1 1

Therefore, to microstep with four microsteps per full step with maximum current:

sequence of control words output (10 pulses per phase):

---

phase #1: 1 1 1 1 1 1 1 1 1 1 (A current = 100%, B current = 0%)

phase #2: 3 3 3 3 3 3 1 1 1 1 (A current = 100%, B current = 60%)

phase #3: 3 3 3 3 3 3 3 3 3 3 (A current = 100%, B current = 100%)

phase #4: 3 3 3 3 3 3 2 2 2 2 (A current = 60%, B current = 100%)

phase #5: 2 2 2 2 2 2 2 2 2 2 (A current = 0%, B current = 100%)

For 10 microsteps:

---

phase #1: 1 1 1 1 1 1 1 1 1 1 (rotor positioned on winding A, A current = 100%, B current = 0%)

phase #2: 3 3 3 3 1 1 1 1 1 1 (rotor positioned 9:1 times closer to A, A current = 100%, B current =  $\text{sqr}(1/9) = 33\%$ )

phase #3: 3 3 3 3 3 1 1 1 1 1 (rotor positioned 8:2 or 4 times closer to A, B current =  $\text{sqr}(1/4) = 50\%$ )

phase #4: 3 3 3 3 3 3 3 1 1 1 (rotor positioned 7:3 or 2.3 times closer to A, A current = 100%, B current =  $\text{sqr}(3/7) = 65\%$ )

phase #5: 3 3 3 3 3 3 3 3 1 1 (rotor positioned 6:4 or 1.5 times closer to A, A current = 100%, B current =  $\text{sqr}(2/3) = 82\%$ )

phase #6: 3 3 3 3 3 3 3 3 3 3 (rotor positioned 5:5 or equal distance from A and from B, A current = 100%, B current = 100%)

phase #7: 3 3 3 3 3 3 3 3 2 2 (opposite of phase #5)

phase #8: 3 3 3 3 3 3 3 2 2 2 (opposite of phase #4)

phase #9: 3 3 3 3 3 2 2 2 2 2 (opposite of phase #3)

phase #10: 3 3 3 2 2 2 2 2 2 (opposite of phase #2)

These ten values are defined in the software, written in C, as an array: PWM[0] through PWM[9]. In C, the first element of the array has an index or offset of 0.

Slight tweaking of the PWM values are necessary to reflect the finite on/off times of the power transistors, hex inverters, any opto-isolators used, the parallel port, differences in speed between PCs, and differences between motors and the torque loading.

Besides excessive vibration when full stepping, stepper motors have another limitation to overcome: they don't like to spin very fast. As the computer switches current to the windings ON and OFF, counter electromotive force (e.m.f.) is generated. When the source of the current is switched OFF, the collapsing magnetic field quickly moving through the winding generates a voltage spike that can destroy the power transistors.

A flyback diode prevents the voltage spikes by giving a path for the dying current to circulate back into the winding. However, this greatly slows the time for the current to collapse. The result is ever lowering torque as the motor tries to spin faster. A zener diode used with the flyback diodes allows just the voltage above the zener diode's rating to be returned to the power source. This prevents the extreme voltage spiking while avoiding the full braking action of the flyback diodes.

In combination with using higher voltage than the motor's continuous voltage rating, and smoothly ramping up the motor's spin, we can achieve speeds many times faster than otherwise. Rates up to 5,000 halfsteps per second can be achieved with modest torque. I use two 12 volt batteries in series to generate a total of 24 volts to operate 6 volt steppers. This gives enough voltage to run the steppers at a high speed. A single 12 volt battery also operates the steppers adequately. Current consumption for both motors combined is 0.1 amps while microstepping and 0.3 amps while slewing.

We want to set the stepper motor step size as a compromise between microstepping tracking resolution and a fast slew rate. Most stepper motors have 200 fullsteps per revolution. The reduction needed between motor and telescope is 360 degrees divided by the distance one stepper revolution covers. If 1/4 to 1/2 arc second per microstep, and 10 microsteps per fullstep, and 200 fullsteps per revolution, then one stepper revolution covers 500 to 1000 arc seconds. Dividing this into 360 degrees or 1,296,000 arc seconds calls for a reduction of 1300:1 to 2600:1 between motor and telescope. Our altitude bearing diameter divided by the drive shaft diameter gives a reduction of 5:1 to 100:1 for common sizes. This means that a gear reducer of 13:1 to 500:1 is needed between the stepper motor and the drive shaft.

If we adopt a microstep size of 1/4 arc second to 1/2 arc second where a fullstep is divided into 10 microsteps then the top slew speed is from 1 3/4 to 3 1/2 degrees per second. This is plenty fast to move such a large scope and give time to duck!

## Telescope Vibration

Vibration is a particular concern to telescope users. Not only are telescopes prone to vibration thanks to heavy weights at one or both ends, but whatever vibrations are present are highly magnified when looking through the eyepiece. That's why telescopes have massive mountings - to combat vibration. In the old days (1960's), the most popular type of amateur telescope was a 6 inch newtonian on a pipe mount. The rule of thumb was to focus, then stand back and count to twelve to let the vibrations quiet down.

Nowadays amateur telescopes are typically mounted on a Dobsonian mount - a form of an altazimuth mount much like a battleship's guns. An excellently designed and built Dobsonian telescope will quiet down in one second or less.

There are three sources of vibration: wind, hand touching, and motor drives. As the wind buffets a telescope, the scope's cross section, substantial thanks to its length, absorbs a surprising amount of energy, moving the telescope tube about its center of gravity imperceptibly. When the wind calms or momentarily swirls, the tube will spring back, setting up a vibration. Similarly when hand touching a telescope to focus an eyepiece or to make a positional adjustment, the telescope will spring back when the hand is let go.

Telescope users care about three principal characteristics of telescope vibration: the amplitude, the frequency, and the dampening time. The amplitude is the amount of back and forth movement. This can be measured at the eyepiece in arcminutes or arcseconds where the planet Jupiter is on average 45 arcseconds of size. The frequency is the number of vibrations per second. Most telescopes vibrate at a low

enough rate to be estimated by counting the shakes over a second or two. The dampening time is the amount of time in seconds that it takes for the vibration to come to a halt. An ideal telescope will have small amplitude and short dampening time. For instance, a Dobsonian telescope might have an amplitude of 1 arcminute, a frequency of 5 Hertz, and a dampening time of 1 second. Wooden and aluminum truss Dobsonian telescopes typically have a frequency of several Hertz, that is, they vibrate back and forth several times a second. The relatively slow speed is due to large masses at some distance from the center of gravity. The frequency can be increased by making the upper end lighter, by making the mirror box lighter, and by shorting the tube. Increasing the frequency is desirable as the overall dampening time will often shorten.

Vibration is absorbed by the ground and by the mount itself. A slightly soft surface such as grass or dirt will absorb vibration much better than concrete. But if the ground is too soft then it may act to amplify slow telescope vibrations. To promote absorption, sorbathane pads should be placed between the mount's feet and the ground. These pads absorb vibrations, prevent vibrations from traveling back into the telescope, and give the mount a slower characteristic resonant frequency. Wooden and aluminum mounts are somewhat flexible and therefore have more vibration absorbing ability. The frequency is lower with these mounts. In addition, these mounts suppress harmonics. The sorbathane pads respond slowly to vibration and therefore lower the natural frequency of the mount. Dangling chains from the upper end of the tube absorb vibration as they clang together. Another more common tactic is to place vibration absorbing material such as sorbathane, rubber, and leather between critical components of the mount.

While the hand can be a source of vibration moving and focusing the telescope, the hand can also be used to absorb vibration by touching the upper end while viewing.

Vibration caused by wind can be significantly reduced by removing as much as possible of the telescope tube's cross section. Instead of the completely encircled upper cage and shroud, amateur telescope makers have used single ring upper ends drilled with holes without shrouds to good effect in windy conditions. This will expose the diagonal to the wind, consequently an ordinary spider may no longer suffice. In windy conditions, the heavy diagonal causes the diagonal holder to very rapidly vibrate about the spider center in a back and forth rotational arc. Splitting the spider so that the four vanes come to two points forming what looks like two 'V's that are not quite touching, removes the ability of the diagonal to rotate about the diagonal's axis.

Finally, the motor tracking system can induce vibration. Any change from a completely smooth motor movement can induce vibration. This can come from the motor, from the motor coupling, and from the gearing. Very rarely if at all does the gearing cause vibration. But if a repeating or periodic error in the gearing is bumping or throwing the scope, and if the frequency of this error coincides with the natural resonant frequency of the mount, vibration not only would be induced but also amplified.

A coupler between the motor and the gearing is designed ease misalignment of the shafts and possibly absorb motor vibration. However even with a flexible coupler, badly misaligned shafts can cause vibration as they spin. The coupler itself can induce vibration also. If it is flexible, it might tighten and relax on its own accord, causing a sporadic jitter at the eyepiece. This can occur when the friction to rotate the output shaft is significant compared to the force required to twist the coupler. Here the coupler will tighten until finally it can transmit enough torque, at which point the shaft will skip ahead and the coupler will relax and shaft movement will cease until the coupler is wound up again. The coupler can also indirectly cause vibration if the motor control feedback is on the opposite end of the coupler from the motor. The feedback algorithm will have a varying delay caused by the twist up of the coupler introduced, causing it to feed large control signals to the motor first one way, then the other way. These control signals can cause the motor to transmit large oscillatory movements through the coupler into the telescope mount. Typically in servo motor systems, the overall gearing reduction is less, putting a premium on the coupler. So couplers for servo systems should be rigid, particularly if geared lightly and if the motor control feedback is on the other side of the coupler. The coupler can be somewhat flexible in highly geared servo systems and in stepper motor systems. The coupler should be as short as possible otherwise the windup effects mimic a long spring.

With modern servo systems, the control system can induce very slight vibrations. The pulse width modulation often used to control the motor velocity might be felt. The control system algorithm may have periodicities and the feedback loop may induce vibration under certain load conditions.

With stepper systems and their typically highly geared drivetrain, a somewhat flexible coupler can help smooth out any jerkiness in the stepper motor as it moves from step to step. Stepper motors snap from step to step when operating in fullstep or halfstep mode. This causes a jittery motion in the eyepiece that can be quite objectionable. A good test for this is to turn the drive off and on to see if there is any difference in the image quality. Another way to test is to put fingers lightly on the eyepiece. Jittery and higher speed oscillations can often be felt, if not downright heard by the ear.

Metal tubed telescopes such as refractors don't have the natural frequency absorbing characteristics of wood and aluminum Dobsonian mounts. Metal tubed telescopes also tend to not only vibrate at the lower frequencies caused by the entire tube shaking, but also tend to vibrate at higher frequencies and at harmonics of lower frequencies. This is manifested in the eyepiece as a very high speed wobble, perhaps only detectable by a frame to frame analysis by a camcorder, by the drive off and on test, or possibly by the finger test. Ideas to try to cure high speed vibrations include placing a piece of dampening material between tube and cradle, significantly beefing up the mount, and not allowing potential sources of vibration to occur. These include stomping around the scope, wind, pulling and shaking of cables, and nearby car and rail traffic.

Joseph Zigelinski suggests EAR products at <http://www.earsc.com> for noise absorbent materials.

## Drive Gear Ratios

The goal is to match the individual motor encoder ticks to an angular distance of 1/10 to  $\frac{1}{4}$  arcsecond. Considering that the controller's accuracy is typically at worse a tick or two, this keeps the tracking deviation at an acceptable value. The total ticks per axis revolution is then 5,184,000 to 12,960,000. If the motor's encoder outputs 2048 quadrature decoded ticks per motor shaft revolution, a further 2500 to 6300 reduction is required. For many equatorially mounted drives with 359:1 single turn worm and gear sets, a further 10 to 24 reduction is required. For roller drive altazimuth mounts with a 50:1 final roller reduction, a further 50 to 250 reduction is required. For those with home made gearing of 1000, a further 2 to 6 reduction is required. These further reductions can be answered by gearheads on the motors or by small gear reduction assemblies.

Torque is the work required to move the gear's input shaft. Gearing a motor down increases its torque subject to some loss and limitations in the gearing itself. Inertia is the work required to accelerate the moving mass, and can be handled by gearing down, where the inertia varies as the inverse square of the gear ratio.

## Mechanical Aspects of the Drive

Rigid dobsonian mounts offer large bearing surfaces to attach drives. The scope can be driven using one of several different methods. A direct-drive system is composed of a threaded rod pressed against the rim of a large drive circle. Threads are impressed into the rim of the drive circle either by JB-Weld, wood putty, or fiberglass. See an article of mine in Sky and Telescope magazine, April, '79 for a description of this method. My article was inspired by an earlier article in June '74 Sky and Telescope.

Many modern professional scopes use large circular rollers driven by machined shafts. These avoid the errors inherent in worm and gear drives. Worm and gear errors include periodic and erratic errors. Periodic errors are caused by the elliptical shape of the gear and by mis-centering of the worm on its shaft. Erratic errors are caused by tooth to tooth differences and by backlash when the drive changes direction.

By using a gear reducer in the preliminary stage and a roller drive for the final stage, the errors present in the gear reducer are divided by the ratio of the final roller. For instance, if the gear reducer has an error of one arc minute, and the final roller drive ratio is 30:1, then the actual error present at the eyepiece will be two arc seconds.

The bearing surfaces should be converted to ball-bearings riding underneath Formica in smaller scopes, and aluminum or galvanized metal sheet in larger sizes. Face the altitude bearing rims with thin strips of aluminum. Substitute a drive shaft or drive hub for one of the four altitude bearing points. Attach a gear reducer powered by a stepper motor to this drive shaft. The azimuth drive is a drive shaft with a conical machined end that rides underneath the rocker bottom, faced with a thin metal plate. The other two contact points are ball bearings. Since the rollers are very large, the scope has a very high inherent stiffness. One advantage of a dobsonian over an equatorial is that gravity naturally tensions the rollers and drive shafts.

On the left is a metal drawer roller, and on the right is a 3/4 inch caster ball bearing transfer unit - \$2 and \$5 respectively at the local hardware store.



Here is a view of the altitude axis and a view of the azimuth of a typical roller drive with small palm sized gear reducer in front of the stepper motor. Notice how the azimuth axis is slightly tipped and the end of the drive shaft is conical.



For more, see the following websites:

Make your own drive gear: <http://easyweb.easynet.co.uk/~chrish/worms.htm>

And Eric Greene's cast your own drive gear: <http://ngc1514.com/Computer/azimuth.html>

Tom Krajei's making your own drive gear: <http://ngc1514.com/Computer/tom.html>

Rex Kindall's gear made from side by side nylon threaded rods

[http://www.geocities.com/kindellism/Nylon\\_Worm\\_Gears.html](http://www.geocities.com/kindellism/Nylon_Worm_Gears.html)

Jan VanGestel's threaded rod driven 20 inch

<http://home.wanadoo.nl/jhm.vangastel/Astronomy/50cmscope/computerized.htm>

Gary Wolanski's homemade aluminum gears <http://www3.telus.net/gwolanski/Gearcutter.html>

Lew Cook's unusual declination drive <http://www.geocities.com/lcoo/eng29.htm>

Mark Rice's homemade threaded rod drive <http://homepage.ntlworld.com/ecliptic/worm.htm>

Moldable bearings: <http://www.moglice.com/index.html>

Don Clement's cable drive <http://mysite.verizon.net/res0owmd/id4.html>

Don Cement's flexible threaded rod drive: <http://mysite.verizon.net/res0owmd/id5.html>

Titolo Pagina toothed belt drive <http://web.tiscali.it/robertopipitone/page18.html>

Charlie Stark's friction drive system with manual push option using a DobDriverII

[http://www.astrosurf.com/altaz/ddalter\\_e.htm](http://www.astrosurf.com/altaz/ddalter_e.htm)

Dan Gray's timing belts as gears <http://www.siderealtechnology.com/28inch/index.htm>

Vincent Steinmetz's study of belt drives <http://xmrvs.free.fr/ep/index.htm>

## Creating Your Own Gears

You can mold teeth into the rim of a circle or arc, then press a threaded rod against the teeth for a smooth drive system. Because many teeth touch at any one time, errors in threads and teeth are averaged out, and there is no backlash. In the late 1970's I used such a drive on a 10 inch fork mounted reflector to take long exposure cold camera images on film. See Sky and Telescope April 1979 for my article.

I used wood putty to form the threaded impression, dunking the threaded rod in WD40 for a release agent. I worked the threaded rod around the rim. In use, grease helped reduce the drive friction. This idea came from Roger Tuthill and earlier amateurs who experimented with nylon and other materials. In Roger's case, he created a long split nut that was clamped around the threaded rod, linearly pulling a tape that was wrapped around a drum that was attached to the shaft. Here's the 10 inch in action:



## Making Your Own Drive Gears by Tom Krajci

In the last couple weeks I've been having some success with an inexpensive drive idea...for those that want motorized tracking, but don't want to shell out the \$\$\$ for a Byers gear set, and don't mind tinkering/building.

- Make a sector of plywood or plastic (cut it with a router or jigsaw)
- Wrap some nylon threaded rod around the sector (can be pre-bent to the sector radius in boiling water)
- Apply JB weld in a fillet on both sides of the nylon threaded rod, let dry
- Remove threaded rod (nylon won't stick to the JB Weld very strongly, even without a release agent)
- Trim/clean up the rough edges

Presto...a large sector drive! How big? Mine is about 11 inch radius. You can make yours larger if you want. (This may not work very well on smaller radii unless you use finer/thinner threaded rod.) I used 5/16 -18 threaded rod. Use the same diameter/pitch threaded rod (nylon, brass, steel?) for the worm.

Attach to a stepper or synchronous motor.

Wanna make a continuous worm? Do it in two steps. First mold a partial section on the disk. Then, the second molding step is the rest of the disk...with the ends of the threaded rod firmly meshed into the ends of the first molded worm gear section. Can this really work? It did for me...on the first try...a seamless/continuous 21 inch diameter worm gear with 1187 teeth.

I've been able to find nylon threaded rod in six foot lengths. That can make a pretty big worm! ;-) With a big enough worm you can use a "direct drive" system....which means low/zero backlash, and only one source of periodic error (one worm meshing with one worm gear, no reduction gear train). One motor, one worm, one big worm gear. Choose whatever worm gear size and threaded rod pitch will meet

your design needs.

If done carefully, this is easily good enough for wide angle imaging. I have not tested it for longer focal length photography possibilities, but periodic error in my first version is smooth, not jerky. I bet an autoguider could handle it better than many mass produced, inexpensive drive units!

Currently I'm using these gears to drive my sixteen inch, f/6 dobsonian. With surplus steppers rated at 6 volts, driven at 24 volts, using a small flywheel to smooth rotor resonance problems (lower fundamental resonance freq of the rotor), and some series resistors for current limiting at low step rates...I can halfstep slew this large telescope at 2.75-3 degrees per second. Duck!

PS. Is this an original idea? Nope. See Sky & Tel ATM articles from 1974 and Mel's article from April 1979. The difference is that nylon threaded rod is now easily available.

### **ALT/AZ Conversion Lessons, by Chuck Shaw**

The following paragraphs address the things I had to consider and work out the details for in changing the drive system of my 14.5" f/5 Newtonian from a Dob on an Equatorial Platform to a computer controlled Alt/Az/FR system. The intent of this article is to add to the experience base on this type project for use by other ATM'ers.

All the basic design plans and software used were based on the superb design and software by Mel Bartels (<http://zebu.uoregon.edu/~mbartels/altaz/altaz.html>). A significant amount of time was spent picking Mel's brains, and also another "hero" of the ATM world, Andy Saulietis, for his design thoughts, the use of his machine shop, and the Field Rotator hardware design and fabrication support (ISS@pvtnetworks.net). My deepest thanks to both these guys for the patience and help and generous support provided!!!

In retrospect, the project was more involved than I thought it would be when I started. Certainly not unacceptably more involved, but its not just a long weekend's worth of tinkering in the garage either. The biggest thing that soaked up time was the machine shop work for the gear mounting hubs and pressure-plates and the drive rollers and the field rotation system. The modifications to the rocker box actually went quickly, but the build up of the drive system components was done slowly since there was a lot of "design thinking" along the way. The electrical subsystem was quite straight-forward. I did not etch a circuit board (even though there are links to the design on Mel's Homepage) since I am comfortable with doing point to point wiring. If several folks are building systems at the same time, using etched boards would probably be a smart move if tasks are divided up.... The "tuning" of the system was quite involved (as most hardware/software integration activities turns out to be!). It was also one of the most satisfying stages of the project. The first step was just to learn the ins and outs of the software and the "theory" behind how Mel designed things. This was also quite enjoyable for me to learn about (and undoubtedly a GREAT relief to Mel when I finished so the flood of questions would slow down!!) I think learning about new things is a key to satisfaction as an ATM'er..... Certainly not REQUIRED, but I think it is a fun part of the overall experience. This learning about things and the act of passing it on to others is really what prompted me to write this info down.

Bottom line, the system is simply amazing! It was CERTAINLY more than worth the effort to change the drive system to this Alt/Az/FR configuration for the uses I want for it. However, as with most things, it takes USING it to make using it second nature.

### **WHY???**

This was a question that my wife often wanted to ask but was far too tactful to actually voice. My motivation for doing the conversion was to minimize the polar alignment time required for imaging with my ccd camera (since imaging with unguided tracking requires much more precise tracking than visual observing). I used to spend an hour or so tweaking the polar alignment of my equitorial platform to get consistant 30 second unguided tracking imaging. Now, in less than 10 minutes I have a system that provides consistant 1 minute unguided tracking and I have gone as long as 4 minutes unguided!!! That allows me to set up and perform some imaging on week nights and still get done in time to get to work the next day!!!

Besides the more obvious enjoyment of simply playing with astrophotography, the need to do imaging stems from the fact my sky at home in suburban Houston Texas is usually about 3rd magnitude. That means visual observing of deep sky objects is rather disappointing. To "see" anything, I need to use my ccd

camera to pull it out of the skyglow. That means tracking, etc, etc..... In addition, even with good tracking with my equitorial platform, under a 3rd magnitude sky doing star hops can be a real challenge.....The GOTO capability of a computer controlled system can be a lifesaver! Even though as a veteran "Dob Operator" I still think being able to star hop to anything in the sky is a basic skill any observer needs to have, you have to balance that against the frustration of trying to star hop without seeing all the stars you need to do the hop..... So, to all my buddies that say I have gone soft when I resort to using the Computer to move the scope for me, I say "YES, and I LOVE IT!!!"

Now, on to how all this came about:

### **WHERE TO START???**

There is a management approach that lays out all the "stuff" that needs to be done for a project and then draws what is referred to as the "critical path" through all the individual pieces. (I suspect this approach was originally developed, after the fact, by the guy that first built a "big" boat in his basement.....) However it originated, it is an EXCELLENT thing to do! When I went through it, I found that I needed to do the things that would change the balance and dimensions of the OTA first, then let that define the size of the rockerbox, which then defined the groundboard size and configuration. When I did this, I came up with the following order of doing things:

#### **UPDATE THE OTA (Optical Tube Assembly) "SUB-SYSTEM":**

1. Update Sec Cage
  - ✓ Upgrade Focuser to a Ball Bearing model to carry the extra weight of slide/ccd camera
  - ✓ Build a Field Rotation System to rotate the focuser/camera
2. Shorten Truss Tube assembly (to move the focus back out by the amount the focuser was moved in the sec cage due to the Field Rotation gear diameter needing more "clearance")
  - ✓ Shorten tubes and modify attach plates to shorten overall length of upper truss assembly
  - ✓ Shorten Elastic straps on lower end of Light Sock (due to shorter OTA)
3. Rebalance OTA for CCD Ops: (Slide/CCD Camera/wires/ filter wheel/finder/Telrad)
  - ✓ Radial (Y axis) Balance 1st
  - ✓ THEN Longitudinal (X axis) Balance

#### **UPDATE THE ROCKER BOX "SUB-SYSTEM":**

1. Build/Attach Altitude Bearing Trunions to OTA
  - ✓ Build Altitude Bearing Trunions and cover with metal on circumference.
  - ✓ Attach Altitude Bearing Trunions to OTA Center Ring
2. Modify Rockerbox sides to accomodate larger diameter Altitude Bearing Trunions
  - ✓ Measure required height of pivot point to clear the Encoder and wires on the Az Bearing Stud. Add about an inch to be conservative.....
  - ✓ Scribe sides and cut circles for altitude bearings. Put center of vertical optical axis directly above az axis. (remember the clearance is less when the OTA is non-vertical as the bottom edge swings by!!)
  - ✓ Mount 3 idler bearings to carry altitude trunions (4th support point is the altitude drive roller)
3. Fabricate Alt Drive Roller system:
  - ✓ Fabricate Ring Gear Hub/Clutch System for worm&ring Byers Gear (Same for Az system)
  - ✓ Fabricate Worm Mount: (same for Az System)
  - ✓ Mount Motor/Worm Mounting Plate to Aluminum Angle Bracket (same for Az system)
  - ✓ Fabricate and Mount "Tailstock" for Worm Gear to stabilize worm (same for Az system)
  - ✓ Fabricate Alt Drive Roller
  - ✓ Mount Alt Drive Roller Assembly to side of Rockerbox
4. Modify Rockerbox for Az Drive Roller system:  
Build new bottom to Rockerbox:
  - ✓ Two 24" dia 3/4" plywood disks glued together.

- ✓ 10ga galvanized steel sheet 24" dia circle (Jigsaw metal blade, lots of cutting oil, and go slow)
- 5. Add mounting shelves to sit Laptop on (attach on front of rockerbox and make wide enough to sit laptop on sideways) and for eyepieces (attach on observer side of rockerbox)

### BUILD A NEW GROUND BOARD "SUB-SYSTEM":

1. Fabricate Azimuth Drive Roller System:
  - ✓ Drive hub, motor mounting, and gear mountings all the same as for Alt Drive
  - ✓ Fabricate a Tapered Az Drive Roller
  - ✓ Graphically lay out angle required for taper on end of Drive Roller
2. Fabricate Azimuth Axis "axle"
  - ✓ Use a 3/4" Pipe Floor Flange and 3/4" Pipe Nipple and coupling and Tapered Roller Bearing (1" ID)
  - ✓ Length of pipe nipple: Height of Drive Roller Plus thickness of Rocker box base Plus cap thickness
3. Fabricate Idler Bearings and Brackets:
  - ✓ Two Bearings, each 120 degrees apart from Az Drive Roller
  - ✓ Fabricate "jacks" to elevate the rockerbox up off of the idlers and Az drive roller when being transported.
  - ✓ Properly locate, align, and mount the components on the ground board.

### BUILD THE DRIVE ELECTRONICS "SUB-SYSTEM":

1. Build up motor drive circuit section for Alt and Az Drive Motors
2. Build up motor drive circuit section for FR Motor (SAA1042)
3. Build wiring harnesses for Az and Alt Drive Motors for rockerbox.
4. Build wiring harness for OTA: (FR Motor, Dew Heaters)

### UPGRADE THE DRIVE ELECTRONICS:

(OK to delay this till system is up and running without it)

1. Build MG III Circuit
2. Mount Encoders for Alt and Az (Direct Drive)
3. Build cables for serial port and two encoders.

### Design Details and Fabrication Notes:

Once the overall "Plan" was developed, the devil was in the details.....

#### 1. OTA DESIGN AND FABRICATION:

##### Balance:

Balance Weight Attach/Adjust System (X and Z axis, no need for Y axis).

The coordinate system I refer to on the scope has the "X" axis along the long axis of the OTA. The "Y" axis is side to side through the altitude axis. the and "Z" axis is vertical when the tube is lowered parallel to the ground.

Having the system on ball bearings means it MUST be able to be balanced very accurately to avoid slippage on the drive rollers. Since my scope is a truss tube design. I elected to have a #2.5 balance weight on a clamp that I can slide along the tubes. With a lightweight eyepiece, the weight must be all the way forward towards the secondary cage to balance in the "X" axis. Heavier eyepieces require sliding the eyepiece back towards the Primary. With my CCD camera and Eyepiece slide mounted, the weight gets removed.

The scope also needs to be balanced in the "Z" axis since as the elevation changes the moments on either side of the altitude axis change. Again, the same weight clamp for the "X" axis will work, just move it to a different tube to change its Z position.

Unlike for a German Equatorial Mount, there is no need to balance the OTA (and rockerbox) in the "Y" axis to a high degree of balance as long as the ground board is "reasonably" level.

#### **Critical Path to find Balance Point:**

The need to add a Field Rotation System for longer image tracking times in any part of the sky added weight to the secondary cage. Since I refuse to add "large" counterweights (been there, done that, my back still hurts from lugging extra weights around!!) I needed to finish the secondary cage first to be able to rebalance the OTA. The configuration change of adding the FR system also required moving the focuser further away from the Primary to allow room for the 8" diameter gear that the focuser mounts on to be mounted in the secondary cage. To keep the focal plane from being pulled into the focuser too much, that required shortening the truss tubes (which helped correct the heavier secondary cage, but not enough by itself). Once the OTA balance point was found (default state was a lightweight eyepiece and a "small" counterweight all the way forward), then the rockerbox sides could be marked and cut to match the altitude trunion circles and to allow for clearance under the OTA as it swings up towards the zenith. The clearance needs to accommodate the wires going to the AZ motor as well as the Az encoder. Keep this as small as practical, but I would never end up with less than 1" of margin since it seems there is always something else that ends up getting added to eat up that clearance... Also remember that the clearance is the smallest as the edge of the scope swings past the azimuth axle, not when the scope is vertical!

#### **Reassembly Pins/Templates:**

An important requirement to meet for the system to be able to provide accurate tracking is to have the X, Y, and Z axes of the scope all orthogonal, and their relationship well defined (and aligned) with respect to the Altitude and Azimuth Axes of the rockerbox. With a truss tube system small differences in Reassembly can make enough of a difference to change collimation and small axis shifts with respect to each other. To compound this, my scope is actually a DOUBLE truss configuration (a true serurrier truss) to allow the balance point to be near the center along the X-axis but not require a physically large mirror box (i.e. The altitude trunions are attached to a "ring" that has truss tubes going aft to the mirror box, and also forward to the secondary cage).

To make VERY sure that the system is able to be reassembled to exactly the same configuration as far as spacing between components, a number of brass screws were inserted in the mirror box, center ring, and secondary cage and then their heads cut off, leaving small brass pins in the wood. Their exact locations were defined with an aluminum template made from a 1/2" wide, 1/16" thick aluminum bar long enough to reach between the components (secondary cage, center altitude axis ring, and Primary Mirror cell). Once the scope is assembled, the template allows small adjustments in the truss tube attachment clamps to "tweak" the configuration. The result is virtually no re-collimation is needed when the scope is reassembled. And the mechanical alignment of the OTA, being very repeatable, assures the Alt and Az axes relationship for the rockerbox keep their relationship to the OTA axes. This use of a template requires a very slight bit more "hassle" during assembly, but in reality the extra activity to use it is in the noise, and the precision it provides more than compensates. More "stock" truss tube dobs might be able to get away without a template since precision cut tubes inserted into precision located sockets (with bottoms) actually form their own templates.

#### **Vertical Alignment Hard Stop**

The scope.exe software needs to be told when the scope is either perpendicular or parallel to the azimuth axis as part of the initialization process. I think the simplest way to do this is to have the scope aimed vertically (parallel to the azimuth axis actually, since the platform does not have to be level). To make sure this is so, I have an adjustable hard stop to be able to rotate the scope up and against the stop. The adjustable hard stop is mounted on the inside of the front panel of the rockerbox. The spin align technique allows me to measure this position to a very high (arc second) accuracy and once adjusted it is very repeatable.

### **Spin Alignment Technique...(Optical and Mechanical Axis alignment)**

As mentioned previously, the OTA and the Alt/Az axes need to be aligned very carefully. There is actually a very simple and straightforward technique for doing this alignment that Andy Saulietis showed me. With the scope aimed vertically (not necessarily vertical as with using a bubble level, but instead make it parallel to the Azimuth axis) with the OTA against the hard stop and secured there with a bunjee cord, suspend a video camera above the scope, looking down into the OTA. Position it just off set from the secondary mirror to look past it down towards the Primary. Set the focus at infinity (and turn off autofocus). Take the camera video feed and send it to a monitor/TV convenient to the scope. At the eyepiece, you need to have a pinhole light source and have it located at the focal plane. An easy way to do this is to cut the end off of a plastic 35mm film can and punch a small hole (less than 1/16" dia and as round as possible) in the lid. Re-install the lid on the film can and tape it to a small flashlight (the lid towards the flashlight). Then just insert the film can into the focuser and rack the focuser in/out till the lid is at the focal plane. All of this will result in a collimated light beam being shone at the camcorder. To initially get the system looking at the light dot, use low power zoom. Once you have the light dot in the FOV, use as much magnification as possible (I used a 200mm telephoto lens afocally projected onto my camcorder objective lens with the camcorder set at a zoom of 6x).

As the scope is rotated in Azimuth, the small dot of light will describe a circle on the TV screen. Pick 4 "cardinal" points with respect to the ground board. to use as reference (i.e. call them N, S, E, and W, or 0, 90, 180, and 270). The idea is that you will adjust one of the altitude sectors fore and aft along the "X" axis of the OTA, then rotate the rockerbox to see if that made the circle smaller. Ultimately it will collapse into a line from a circle when the side to side tilt of the OTA's "X" axis is finally made orthogonal to the Altitude axis (and perpendicular to the Azimuth axis). The next step is to adjust the altitude hard stop on the front of the rockerbox that limits the OTA altitude to 90 degrees. Adjust it in the same manner as for the altitude sector adjustment till the motion due to the tube not being parallel to the azimuth axis in altitude collapses to nothing.

By going back and iterating the adjustments once or twice, and by using as much magnification as possible, you will end up with the dot probably describing a small figure 8. This is due to any small astigmatism in the metal plate on the bottom of the rocker box that forms the bearing surface and any "noise" in the bearings or bearing surface. The actual angular errors can be measured quite accurately, especially if you use high magnification. The size of the dot (actually the subtended angle) can be calculated by measuring the actual size of the pinhole in the film can lid and using the formula:  $(P/F)x(206.265)=D$  where P is the dia of the pin hole, F=focal length of the Primary Mirror, D=arc sec that the Dot image subtends. Then, the distance the dot wanders from the "center" of the figure it describes can be measured in terms of dot diameters on the TV screen, and then multiplied by the calculated angular size of the dot.

### **Field Rotation System**

Is FR needed or not? For visual use only, field de-rotation is certainly not required. If you limit your photography to looking east or west field rotation is very small and it is not required. Other areas of the sky have varying degrees of field rotation and the sensitivity to it is a function of the exposure lengths. An article in Sky and Telescope (Sept 1992, page 312) shows you how to calculate how much field rotation you will experience for different places in the sky. Another way to calculate it is the following formula:  $FRR=W\cos Z\cos L/\cos A$  where FRR is the field rotation rate, W=earth rate (15.041 deg/hr=72.9 urad/sec), Z=object azimuth, L=observer latitude, and A=object altitude. CCD photography allows you to track and stack images. As long as the individual images do not show trailing due to FR, there are software packages such as "SuperFix" and "Mira" that allow images to be derotated before being stacked. Richard Berry has developed a very powerful derotation scheme that is quite easy to use for Cookbook images (it is an updated version of his quite powerful track and stack software MULTI245). So, FR can be done in software or in hardware. If you do intend to do a lot of astrophotography or longer duration film astrophotos, I recommend building in the system mechanically since the software derotation cannot correct individual long exposure images that get smeared by field rotation which is, of course, worse for long film shots than for the generally shorter ccd exposures. If you cannot decide if you need a mechanical FR system , remember that adding a mechanical FR system later will add weight to the secondary cage. You will need to either allow for shifting the altitude trunions forward to re-balance the scope (i.e. you should make the

clearance under the scope bigger than what is needed initially to allow for this shift aft later) or commit to adding counterweights to avoid moving the altitude sectors.

## **2. ROCKERBOX DESIGN CONSIDERATIONS:**

### **Azimuth and Altitude Trunions and Bearings**

#### **Sizes:**

The larger the diameter of the trunions, both Az and alt, the better the drive ratios available and, in my opinion, the better the stability of the scope. I use 24" diameter trunions on my 14.5" f/5 Newtonian for both Altitude and Azimuth bearings. The Altitude trunions are 180 degree sectors (360 degree circles cut in two). Andy Saulietis likes to have two alt drive rollers (one for each alt trunion). To keep them running perfectly together, he connects them with a common drive shaft. This works very well, but slightly complicates the disassembly of the rocker box if that is desired. I have a requirement for my rockerbox to be able to be disassembled into small components so I can fit everything into the back of my standard size Plymouth Voyager without removing the rear seat, only folding it down, so I opted not to use the dual drive rollers.

#### **Rockerbox Disassembly requirements (single or double drive roller consideration):**

Andy advocates two drive rollers to avoid any "torque" put into the OTA from only driving one roller under one altitude trunion. He is convinced that the torque, while small, is still enough to detract from unguided astrophotography. When Andy is convinced about something, its usually the way it really is.... To drive one roller under each altitude trunion and drive them perfectly together, you need to connect the two rollers with a common drive shaft. This means the altitude trunions have to be big enough to allow this drive roller connection linkage to clear the OTA. This can result in pretty large trunions! I wanted my rockerbox to be able to be disassembled to take up less room in the car when being transported. To do this the mechanical system to mount the rollers has to either be one piece to maintain structural alignment between the rollers, or be a bit more complicated to be able to be disassembled with the rockerbox. I elected to initially build my system with only one roller and I have to admit, I have not seen any tracking errors that I would attribute to torque from only driving one altitude trunion. Thats not to says its not there, but I cannot see it, even in my CB245 ccd images with up to 4 minute unguided tracking. So, my suggestion is to initially build with only one drive roller under one trunion and see if that works for you. You can always build larger trunions later and a second drive roller, but I am betting you will not have a problem only using one. I did hedge my bets against slippage though. I have a turnbuckle attached from an axle bolt that is along the altitude axis. It extends down to the rockerbox. I tighten it a bit when there is a breeze blowing or the OTA balance is not perfect in the altitude axis. Another alternative in order to drive both sectors is to use two motors and drive rollers, one for each trunion. The "base" of the transistors for the corresponding (i.e. same) motor windings for each of the two motors should get tied together so the same pulse from the computer to send current to one motor goes to the other motor at the same time. I have used this for equatorial platform drives that have two drive rollers and it works quite well. However, till I see otherwise, driving a single drive roller under only one of the two altitude trunions seems to work well.

#### **Materials:**

Wooden disks, carefully cut with a router, are plenty accurate for the Altitude Trunions. Mine are two layers of 3/4" plywood glued together. They need to be faced with metal to provide a more durable and uniform surface for the drive roller and idlers bearings. Aluminum works fine, but a much better alternative is 22 gage stainless steel. Get the metal yard to cut it into the right width strips and a bit longer than the circumference. The Azimuth bearing surface on the bottomm of the rockerbox can be aluminum or stainless or galvanized steel. I chose 10 ga galvanized steel since it is very flat, and very cheap. Aluminum can wear too fast if you are using steel idler bearings, and stainless can get expensive in addition to not being flat if its been stored in a roll.

### **Altitude Sector Position adjustments:**

One of the best suggestions I was given was from Andy Saulietis. He said to make one Altitude trunion permanently attached, and the other be "adjustable" in both the X axis (along the OTA's optical axis) and the Z axis (top to bottom of the OTA when the OTA is parallel to the ground). The adjustment in the Z axis is easy to do just by loosening the bolts attaching the trunion. But the act of loosening them will allow the tube to slip in position (assuming the holes in the sector are oversize and covered with larger fender washers). To manage this slippage, attach a hangar bolt into the trunion so that it is parallel with the long axis of the OTA and going forward towards the secondary mirror end of the tube. Also attach a metal plate or block attached to the OTA that the hangar bolt goes thru with a nut on both sides of the plate/block. With the tube vertical, and the attach bolts for the trunion loosened, the weight of the tube is carried by the hangar bolt attached to the plate/block on the OTA. Very precise adjustments of the position of the trunion can be done using his scheme when performing the "spin align" technique for making sure the optical and mechanical axes are properly aligned.

If the scope is to be used for astrophotography, another adjustment that should be performed during the building process is to shim the attachment of the altitude trunions to the OTA so that they describe two parallel planes on either side of the OTA. All of this assumes that the rockerbox has some type of side to side restraints installed to make sure the sides of the OTA do not interfere with the rockerbox and the trunions stay centered on the drive and idler rollers. While not mandatory for visual work, this shim adjustment will prevent the OTA from shifting from side to side as the elevation changes due to the side restraints riding against the trunions and "pushing" the scope laterally. In addition, if they are not parallel the trunions may bind at one point, and be too free at another. So, shim the trunions as well as you can, and then install two restraints (teflon blocks or even better, two small roller bearings on angle brackets) on one side so they bear against the outside surface of the trunion. On the other side of the rockerbox, install one bearing, but this time make it spring loaded so that the plane that the OTA will describe in elevation (Altitude) will be defined by the one trunion's side riding against the two fixed side restraints. A small bit of extra trouble to install, but well worth the extra effort, especially if the scope may occasionally not be sitting on level ground.

### **Azimuth "Axe" and "Coupling Nut"**

Another great suggestion from Andy Saulietis was to use a "hollow" azimuth axle to be able to feed wires through it. Make it from a 3/4 inch (ID) pipe nipple screwed into a floor flange. A tapered roller bearing is mounted into the bottom of the rockerbox ("V" shape of the bearing down). The ID of the bearing should be 1". The unmachined pipe OD is slightly more than 1" so that when turned down in a lathe it fits with very little play. Then turn around the pipe/flange in the lathe and face the bottom of the flange to end up with a flange surface that is perfectly orthogonal to the pipe side surfaces. Use a "coupling" for the "nut" on top to be able to screw down against the top of the tapered roller bearing to increase the effective "weight" of the scope to eliminate any az roller slippage (no problem for heavy scope, but lighter scopes can slip). The coupling will also allow the wires to pass through it. Use an aluminum electrical conduit coupling and you can more easily cut it in half to make it shorter for better clearance from the bottom of the rockerbox..

### **Use of Azimuth roller under rockerbox vs "pinched roller" system**

Mel Bartels' basic design calls for a "tapered" roller under the rockerbox's base. This allows the weight of the scope to be used to help eliminate slippage. Andy uses, in one of his designs, flat rollers on the bottom of the rockerbox, and a machined surface on the top and outside edges of a ring of metal that these bearings ride on. The azimuth axle and bearing keep the rockerbox and its bearings riding on the metal ring base.. The drive motor and roller are mounted on the front of the rockerbox so that the drive roller is against the machined outside edge of the ring. To engage the drive, the mounting plate and bearing for the drive roller are pulled back against the outside edge of the ring. This design trades off machining a tapered roller and then locating it along the radius to the center of the azimuth bearing surface very accurately against machining the base ring, but only having to deal with cylindrical surfaces. Since machining a taper is not that difficult, and Mel's system more effectively uses the weight of the scope to avoid slippage rather than just mechanical pressure, I opted for Mel's design. While fine for visual work, belts or chain type systems

simply have too much play in them for very accurate unguided astrophotography (my goal with this system) and tape/cable drives have to be rewound (which Murphy's Law requires to typically happen 1/2 way thru an astrophotography exposure!)

### **Idler Bearings**

#### **Azimuth idler bearings:**

I used two roller bearings as idler bearings under the azimuth base plate surface of the rockerbox. The two idlers and the az drive roller are set 120 degrees apart and are adjusted so that they are all at the same height. The idlers run on an axle bolt running between two pieces of aluminum angle. Make sure the axle bolt is aimed very precisely at the azimuth axis to avoid "skidding" of the idler bearing on the rockerbox bearing surface. My two idlers are at a different radius from the center of the az axis so they do not run along the same track on the surface of the rockerbox bottom surface as the drive roller uses. This is to insure any damage or wear on the surface of the rockerbox base caused by the very hard idler bearing outer race will not affect the machined drive roller.

#### **Alt Bearing Height (inset vs surface mount):**

I chose to "inset" the drive roller and the idlers for the altitude trunions into the sides of the rockerbox to allow a smaller clearance between the altitude trunions and the radius I cut out of the sides of the rockerbox, and to simplify mounting the idlers (i.e. only the upper limb of the idler bearings and the altitude drive roller are "inside/above" the scribed altitude trunion circle). They ride on axles between plates thru bolted through the rockerbox sides. This was not only for esthetics, but if the drive system fails, I still have the old teflon pads from pre-drive system days and they can slip in on thin shims to lift the alt trunions off of the drive roller and idlers to return the scope to its original "dob" feel.....

#### **Alt Bearing "Spread" under Alt trunions:**

For a conventional dob, spreading the alt teflon pads further apart increases the alt axis "friction" and moving them closer decreases the force needed to move in altitude. With roller bearings, the force is effectively the same no matter what the "spread". So, move them as far apart as possible to increase stability. Build the mounting system for the altitude drive roller first, and mount that as far out as possible. Let that define where the idler that is on the opposite side of the rockerbox is mounted. The other two idlers are mounted to give the largest "spread" under each altitude trunion as possible.

### **Drive System Gear Reduction**

#### **Gearboxes vs Worm Drives vs Drive Rollers vs Drive Belts (accuracy reqmt's vs simplicity):**

This area requires a bit of thinking on the builder's part. "Good" gearboxes are expensive and still seem to have periodic errors (and not always smooth ones either!). However, they are a simple solution. Worm drives are less expensive, but you have to fabricate a hub for the gear, and a mounting system for the worm. Someone without access to a lathe would have to get the work done by a machine shop, which could cost more than using gearboxes.... Also, getting the worm and gear mesh set up perfectly to minimize periodic error sometimes can really be a pain. If you go this way, be sure to get the bushing blocks for the worms along with the worms. The best worm config is one that has the worm in the middle of a shaft, so that bearings can be used on BOTH ends of the worm. The shaft needs to be long enough to get the bearings far enough away from the gear to clear the gear..... If you use a bushing material, the clearances must be no more than about 0.00075 inch. An alternative if the worm has a shaft only on one end is to fabricate a "tailstock" from a brass machine screw ground to a point and mounted in a small bracket so that it can be inserted into the center ground hole in the end of the worm. This will steady the worm on that end. The motor will probably have good bearings and a good coupling between the worm and motor will provide support on that end. Watch out for couplings with too much clearance for the shafts or for "flexible" couplings. This will allow the worm to move and will induce periodic error that is not entirely repeatable

(maybe this should be called random error rather than periodic?). Again, this is primarily a caution for astrophotography.

A system without gears avoids many of the problems with the previous two systems. An aluminum disk with a hub that is set-screwed to a shaft and a bronze or brass roller pressed hard against it should have no periodic errors. There must be a fair amount of pressure to eliminate slippage, so all shafts need to run in ball bearings to control rolling friction. Even well lubricated bushings will have too much friction when the drive roller is pressed hard against the disk. This is also a simple system to clutch. Just a quick release cam pushing against one of the bearing blocks supporting the drive roller will decouple the system. Again, you need access to a machine shop to fabricate the disk/hubs, but this should be much cheaper than the hubs and pressure-plates for the worm gear systems. With all of this going for it, what is the down side?? There are only two that are of consequence. The first is the susceptibility of the system to contamination changing the drive rates. The rollers need to be kept as clean as possible. Initially, its a good idea to use something like valve grinding compound to "lap" the roller surfaces into each other, but when accuracy is needed, the surfaces need to be kept clean and dry. The second concern is inadvertant "skidding" of the surfaces against each other. This is different than slippage. Skidding would happen if the OTA was moved with the system "in gear". The problem is a small flat spot gets easily made on the smaller diameter drive roller. If that roller is brass or bronze, it will happen much easier than if steel. However, the steel roller will be more susceptible to slippage. This system is probably the best one overall to use if you take care to avoid the skidding and contamination problems.

The drive belt system is probably the easiest system to build. For a purely visual use system, it is also probably more than adequate for a light weight OTA. However, for photographic tracking accuracy, a drive belt is simply not accurate enough. This is true whether the belt is something like a cogged belt or a chain drive. A continuous steel tape might be the exception to this, but the joint in the band would have to be VERY good.... The same concerns for contamination and slippage would be present, but the skidding problem would probably not be of concern.

With all these options, the biggest factors for the builder will be what level of access to a machine shop the builder has and how accurate of a system you need (visual is much more forgiving than unguided astrophotography). I built worm drive systems for my Alt and Az drives, using surplus 4" Byers Gears originally made for Byers CamTrack systems. They were advertised to have 4-7 arc/sec of periodic error. In reality the final configuration had closer to 40 arcsec of PE. (due to the gear and worm themselves, plus bearing slop and any slight misalignment of the worm mesh). When divided by my 12:1 final ratio for my drive roller to sectors, this dropped to about 3-4 arc sec. The scope.exe software PE correction PEC) routine was able to reduce this to an undetectable amount of PE at the Altitude and Azimuth Axes. The gears also required machine shop time to build hubs and pressure plates to capture the gears and form a "clutch" system. The configuration works extremely well, but in retrospect I think I will go with drive roller reduction for any future systems due to its simplicity, lack of PE, and much less cost.

### **Gear Diameter considerations:**

The gears for the worm gears for my system are slightly larger than 4" dia. For the Alt drive roller, this posed no problem in mounting the worm and stepper motor just below the gear. A block of several thicknesses of plywood was built with the bottom piece of plywood forming a "shelf" that the motor and worm bearing bracket could mount on. The same approach as used for the Azimuth drive, with the thickness of the ground board making up two of the thicknesses of the block. The motor and worm were mounted below the gear to keep the motor low. In retrospect, the motor and worm could have been mounted to touch the gear at the 9 o'clock position instead of the 6 o'clock position on the gear and saved a thickness of plywood in overall height at the cost of slightly more complicated construction. The dia of the gear for the Azimuth drive also required the drive shaft connecting the gear to the tapered drive roller be long enough to have the gear outside the 24" dia disk for the base of the rockerbox. Since the original rockerbox simply had the formica removed from the bottom and a 24" dia disk (made of two thicknesses of plywood) was screwed to the bottom, the corners of the rockerbox were high enough to clear the gear. If the rockerbox did not have this extra height, the drive shaft would have to be slightly longer to have the gear clear the corners.

### **Drive System Disengage Requirements (to clutch or not to clutch?):**

Normally, the software (scope.exe) keeps track of where the mount is aimed by keeping track of the commanded steps sent to the stepper motors, and via occasional positional updates on targets with known positions. However, because of the very high gearing ratio I am using, which makes slews to objects rather "stately" in their speed (and my general impatience in getting the scope slewed to the next object) I elected to add the optical encoders to both Alt and Az systems and clutches on the systems to be able to disengage and move the scope manually and then re-engage the motors. The Printed Circuit Board for the MicroGuider III system from David Lane is simple to build. I bought the Z80 microprocessor, the RAM, and the EPROM from Dave, along with some other misc chips he happened to have on hand (which are also all readily available from DigiKey, Newmark, Allied, etc.). The Encoders are 2048 count encoders which the MGIII reads in quadrature to get 8192 counts per turn. This whole project added a total of about \$160 to the cost of the conversion and was WELL worth it!!

To take advantage of the encoders ability to update the computer's knowledge of where the scope is aimed so you can manually move the scope, you have to also have some sort of clutch system to disengage and then re-engage the motors. With an all drive roller reduction, having the motor and 1/4" shaft on a moving carriage with a screw adjustment to press the small shaft against the larger disk (which is on the shaft that has the drive roller on the other end) works fine. The shaft with the drive roller and large disk should run in two pillow blocks, with collars to react lateral loads. An over center lever (like on a bicycle front axle) is faster than the screw adjustment for the motor carriage. The small shaft needs to be of something rather soft, like brass, and be suspended between two bearings (do NOT just use the motor's bearing, the forces needed to keep things from slipping are too large!).

For gearbox systems, they can be clutched to the drive shaft holding the drive roller with a simple collar that slips over both the drive roller and the gearbox output shaft. The collar needs to have a strong set screw in one end and a thumbscrew in the other end to be loosened (as the clutch). If the collar also functions as a size adapter (different size gearbox output shaft size than drive roller shaft) put the thumbscrew in the end with the larger shaft for better mechanical advantage and less torque required to tighten the thumbscrew.

Minimize the "play" in the collar since that will be a source of PE.

Worm gear drive systems have a different challenge. The motor and worm need to be carefully adjusted so the mesh of the worm is correct (to avoid excessive backlash and periodic error). This means, after all those adjustments, you do NOT want to disengage the worm from the gear as the clutch system.

I considered not using any clutching system, and only doing my slews with the drive motors. I also considered no clutches and just moving the scope manually and allowing the sectors to "skid", counting on the encoders to detect any slippage.. Since I wanted to minimize slippage for astrophotography, anything I did to minimize slippage would work against this way to manually reposition. In addition, I was a bit concerned about damaging the drive roller surface. Even a very small flat spot would show up in an unguided ccd image. So, the challenge was to come up with a very simple clutch system.

The approach I took is similar to the traditional mounting scheme for the gear. Namely, to capture the gear between two "hubs" that get pressed together. The hubs are machined to fit the recesses in the inner flange/hole of the gear. One hub is set screwed to the drive shaft going to the drive roller. The other hub's center hole is slightly oversize and is free to move up against the gear, or to move away to "declutch" the system. The free (outer) hub then has a small disk slipped over the drive shaft out side the hub. This disk has three machine screws through it that press onto the outer hub. One of the machine screws should be a thumbscrew. Then, outside the disk, is a collar that is set screwed to the shaft to complete the assembly. To tighten the two hubs together, simply snug up the thumbscrew. This will take up any "slack" in the stack of components trapped between the inner hub (set screwed to the shaft) and the collar (also set screwed to the shaft). Very little tension on the thumbscrew is needed. The clutching action is very fast and very strong. Unlike normal worm and gear clutches on equatorial mounts, which use a fiber washer to allow the slippage to be modulated, this system should not use any washer nor any lubrication between the hubs and the gear. You want it either totally engaged, or totally free, and to be quick and simple for either operation!

### **Drive Roller Ratios:**

With the Byers gears giving a 359:1 gear reduction, and Mel's advise to have at least a 7:1 final drive roller ratio (drive roller dia to trunion dia), the ideal size would have been 3" dia for the drive rollers. Andy Saulietis had some bronze boat propeller shaft material that was 2" diameter. That gave a 12:1 final drive

ratio and a 4308:1 ratio (359x12) for alt or az to stepper motor reduction. For a 1.8 deg motor step size (200 steps per turn), that results in approximately a 1.5 arc sec scope movement for each full step of the motor. Slews using the motors are not fast, but are plenty fast for me. However, I usually declutch and manually slew when the move is very big anyway since I also added the optical encoders. There is simply NO detectable motion in the eyepiece at ANY magnification when I am using my Compaq 486SL25 laptop. This laptop lets me use value of about 90 for the number of pulses sent per bios clock tick to the motors. The motion looks just like a DC motor's smooth motion at that rate. When I use a slower ZEOS 386-SL20 (no math co-processor), the fastest rate I can send pulses is about 7 per bios clock tick. This is still plenty fine unless I am at really high power, when there is a tiny oscillation seen in the eyepiece. I do not even notice it anymore. However, I usually use the 486 to drive the scope. I suspect a 386 with a math co-processor would not have a problem sending the higher rate for the pulses, but the bottom line is that even a 286-16 is probably adequate if some of the bells and whistles in the software are turned off (using config.dat).

To get a comfortable 1 deg/sec slew rate with my gear ratios the stepper would have to turn 2400 full steps per sec, or 4800 1/2 steps per sec. While not slow, Mel assured me the flyback diodes in his driver circuit would allow that if the motors had enough voltage available. As it turns out it all works just as advertised!!!! As a matter of fact, I have test run the motors up to 8000 1/2 steps per second!! Cylinders of the bronze shaft material were cut and bored to fit the 3/4" steel drive shafts, and then machined using the drive shafts themselves as mandrels. The cylindrical Alt roller is just a touch wider than the 1.5" wide stainless bands that surface the alt sectors, and the tapered az roller is about 2" long with a 5 deg taper. The taper is needed so that all portions of the drive roller turn at the right radius and do not slip. If it was a cylinder, only one portion of the az drive roller would roll at the right speed without slippage. Any place closer to the az axis would be rolling too fast, and if further out, too slow. Thinking about it a different way, the circumference of the path the inside edge of the drive roller describes is shorter than the circumference the outside edge describes. But since the inside and outside edges rotate at the same rate, they need to be different diameters to describe the correct length circumferences. Looking at it a third way, the drive roller is simply a section out of a cone that has its tip at the center of the lower surface of the rockerbox bottom plate. Some simple geometry will allow you to calculate the angle you need, based on the diameter of the roller and how far out the roller rolls from the center of the az axis. The Sin of this angle is the Radius of the outside (larger dia) end of the drive roller divided by the distance this outside edge is located from the center of the az axis.. In case you have a tough time with doing the calculations for this, aim your Java enabled browser at the following URL for a handy dandy calculator to do it on line:

<http://www.shopstuff.com/trigcalc/trigcalc.html>. In reality, it was much easier to machine the taper on the roller to as close to the 5 deg as possible, then measure the actual angle cut, and then, given the measured outside diameter and the angle use the trig relationship above to determine how far to put the drive roller outer edge away from the center of the az axis. Make sure the drive shaft is aimed EXACTLY at the center of the az axis to avoid slippage from skidding (slipping a long piece of the steel shafting through the pillow blocks and lining it up with the azimuth axis makes this a simple task). The angle the drive shaft has to make with horizontal is the same as the taper. Shine a light opposite to the drive roller and look for light between the roller and the bottom surface of the rockerbox to make sure the roller is mounted to the right angle. Also make sure the entire scope is sitting on the rockerbox (or the same weight is on the bearings) since the system will probably flex a bit and not have the roller rolling flat against the surface when loaded down.

### **Worm gear mesh adjustments**

The bane of worm gears is the mesh alignment requirements. Good alignment is required to minimize the periodic error in the system. The worm will need to be centered on the gear side to side and along the "axis" of the worm. Too much pressure and the friction will be too high and the stepper motors will stall at faster slew rates (because the available torque decreases as the motors speed up.). Too little pressure and there is backlash in the system. Byers has used a spring loaded the mounting for the worm against the gear for some systems. This will work fine for lighter weight systems, but the danger is when the system is back driven (i.e. the OTA is bumped or is out of balance) you run the risk of the worm "skipping" out of mesh and potentially damaging the softer gear teeth. The best way I have found is to remove the motor and hand turn the coupling to "feel" for minimizing friction while maximizing the mesh pressure and "eyeballing" the alignment. The good news is Mel's software will allow you to measure whatever Periodic error is in the

system when you are done, and then correct for it. My system uses the 4" diameter Byers gears they made for the camtrack system. They were advertised to have about 4 arcsec of periodic error. The azimuth gear set runs, uncorrected at about 7 arc sec of PE, but the altitude gear set has about 10-12. This is after the system has been through a 12:1 final drive roller reduction.....so the actual gear errors are 12x those values!!!! However, the bottom line is the OTA sees virtually no periodic error when tracking thanks to the PEC software correction..... amazing!!! You also want to lubricate the worm and gear surfaces that mesh, as well as the worm shaft in its bushing. I use fishing reel lubricant (that contains teflon). You can get it in most sporting goods departments. Spray on dry lube also works well and picks up less dirt.

## Motors

### Voltage requirements

This was one of the more puzzling tradeoffs during the build process. Based on reading about steppers (probably too much reading about steppers) I concluded that 6 volt motors run at 12 volts with dropping resistors of a wattage and resistance the same as the windings would allow high RPM, lots of torque, and not be in any danger of too much current in the windings. As it turns out, the resistors are simply not required for my motors due to Mel's pulse width modulation scheme. By increasing MsDelayX you can decrease the current fed to the motors. My motors are rated for 6v and 1.2 amps. That is 7.2 watts. To keep the same wattage to the motors, that means at 12v the current needs to be limited to 0.6 amps. It was a simple matter to put an ammeter in series with the power supply and vary MsDelayX to decrease the current. Once again, Mel's software is the way to go!!!! The normal operating current that goes to the motors while tracking is about 0.1 amp each. High speed slews start out at about 1.0 amp each and quickly drop to about 0.2 to 0.3 amps each during the slew. I am sure there are motor/voltage combinations that would require the dropping resistors in series with the windings to prevent the steppers from "buzzing" at some particular speed range. If you run into that, its no big deal to add the ceramic power resistors in series with the windings. But I suggest trying it without it first.

### How many wires???

Stepper motors are a bit mystical to those not familiar with them. Actually they are quite simple. Mel has an excellent explanation on his website. However, they come in 4 wire, 5 wire, 6 wire and 8 wire versions..... You want to use motors that are unipolar with Mel's driver design, so stay away from the 4 wire models (which are bipolar). The terms unipolar and bipolar refer to whether the motor always has the current going through each coil in the motor always in the same direction (unipolar) or requires that the current be reversed in the sequence on alternate pulses to each coil (bipolar). The bipolar motors work well, but Mel's software and circuit assumes the motors are unipolar.

Each winding (coil) in the motor has two wires coming from it. For 8 wire motors, both wires from all 4 coils all come out the motor. Use an ohmmeter to find which wires go together. Since the 4 coils in a unipolar motor are oriented opposite to each other, often the "opposite" coils will have one end tied to each other, so now you have 3 wires coming out for two coils, for a total of 6 wires. Use your ohmmeter to find the three wires that are all connected to each other. The wire coming out from the two ends of the coils that are tied to each other will have the same resistance when measured to the other two wires. The other two wires will have twice that much resistance when measured between the two of them (the path goes through both coils). Five wire motors have one end of all four coils tied together. Find the common wire (quite often the black wire) with your ohmmeter in a similar fashion by comparing resistances and remembering that the resistance will be twice as high if you are not going through the common wire.

Mel's software pulses the coils in sequence. Assuming windings A and C are opposite to each other (and tied together on one end for 6 wire motors), and B and D are tied in a similar fashion, hook up winding A to the first output from the parallel port/hexinverter/transistor string. Then hook up winding B. You have a 50:50 chance that the coil you are calling coil B is actually B and not D. If the motor just buzzes and does not turn when you try to run it, reverse these two wires. Then hook up C (you have the same 50:50 chance its actually C and not A). If the motor buzzes when started, and you have swapped the wires to B and D, then try to swap A and C. If it still buzzes and does not turn, go back and undo the swap you did for A and C.

For figuring out 5 or 8 wire motors, the process is basically the same, except you do not have the luxury of a 6 wire motor having already divided up the windings into two groups. All that is required is to keep trying different combinations of the order the wires get hooked up in and the fervent belief that one of them WILL work!. Build a matrix to show the 16 different combinations, get something cold to drink, and then go play..... You can cheat a bit by assuming the color coding of the wires will give a clue as to which windings are opposite pairs of coils.

### **Direction of rotation**

This is, unfortunately, not arbitrary. However, during the fabrication activity, it does not matter. After things are put together, the handpaddle "up/down" PB's can be used to see which direction things move. I suggest that the encoders, if already built into the system, NOT be turned on for these tests, since they can confuse things if they are backwards. If the scope moves in the expected direction, smile and think about being that lucky at Las Vegas. Do the same for Azimuth with the CW/CCW PBs). If things move in the opposite direction, you need to swap the two wires for the motor windings (both wires on each winding). For the encoders, drive the scope with the motors and watch the display for Alt/Az for the current and encoder fields. They should move in the same direction. If not, simply reverse the two channels on the encoders (one wire is +5v, one wire is ground, the remaining two are the data channels). A later version of Scope.exe has made this even simpler, since the readout can be reversed in the software.  
The field rotation motor direction is changed with the same trick of swapping motor winding wires. The direction of rotation is, for a Newtonian, in the same sense as you are looking at the sky. At the North Celestial Pole, the field rotation system should be turning the focuser counter clockwise. As you look at the southern skies, the field rotation is clockwise. Things change somewhere in the middle (but don't worry about where for now, the software knows and that's all that counts!!!)

### **Wheelbarrow Handles vs built in wheels (like Mel's original design)**

Since I do not have a permanent place to leave the scope set up, I end up rolling things into the garage when done, and then out into the driveway or back yard to use the scope (or load things into the back of the pickup or van to drive to a dark sky). I did not build my scope to be light, since I knew I would be primarily imaging with it and wanted as much stability as possible. So, I have always had detachable wheel barrow handles with pneumatic tires to roll the scope/rockerbox/platform around. When I converted to the alt/az drive system I decided to stay with the removable handles versus the built in wheels like Mel had in his earlier design. In order to not damage the azimuth drive surface by bouncing the surface against the drive roller and/or the idler bearings, I put 4 wooden disks under the metal azimuth plate. The disks are actually "pads" that have a carriage bolt thru them with a washer and nut capturing the pad at the head of the carriage bolt. Then the carriage bolt goes thru a t-nut in the top of the ground board. To relieve the weight of the rockerbox/scope from the bearings and drive roller, I simply screw the wooden pads/carriage bolts out till the bolts/pads start to lift the rockerbox. Works great! The wheelbarrow handles are attached to the rockerbox with two home-made "thumbscrews" that are "captured" on the handles and screw into t-nuts in the rockerbox sides. They are quick to release and remove. However, quite often when operating in the driveway where the grass cannot drag against the wheels, I get lazy and just leave them in place.

### **Base Board**

#### **Baseboard size requirements**

In the interest of economy I copied the clever design that was used for the telescope called "Hercules" that I found in the links from Mel's website. Its worth the time to check it out, if for nothing else than to see a really impressive scope!

#### **Foot locations (load paths)**

In order to make sure that any flexure in the ground board is not a problem, make very sure that the "feet" that you put under the ground board are under the two idler bearings and under the pillow blocks for the Azimuth roller.

## **Level**

Even though the ground board does NOT have to be level for the system to operate properly, having the ground board reasonably level will help things work smoothly if the rockerbox is not well balanced. I have a Laptop hung on the front, a reasonably heavy altitude drive roller assembly and an eyepiece shelf on one side, and a power supply, electronics box, and MGIII electronics box all on the other side. The result is the rockerbox is out of balance with the "front" a bit heavy. When the system is level this makes no difference. I attached a small bullseye level to the ground board for an easy reference.

## **3. ELECTRICAL SYSTEM DESIGN CONSIDERATIONS:**

### **Opto Isolators or not???**

Mel's design has the option to include opto isolators to better protect the parallel port of the controlling computer. Even though the danger to the computer is minimal when running the motors at low voltages, I decided to take no chances. The cost of the isolators was peanuts compared to the cost of a repair job if any back emf, shorts, static electricity, etc, etc, etc became a factor....(Yes, on occasion I also wear a belt AND suspenders...)

### **Board Layout (additional FR circuitry)**

Mel's website also points to some fine work by folks on etched circuit boards. However, these boards do not include the field rotation circuitry. While its true that the FR portion of the circuit could be built on a daughterboard added to the system, I am comfortable doing point to point wiring, even though it is not as "neat" as using a PC board, so I elected to not go to the trouble and modest expense of etching a circuit board. If several people were building systems together, where you could farm out work to each other, then I think it would be a smart move to use etched boards.

### **Cooling**

I added a small 12v fan in the electronics box to make sure there would never be any thermal problems. I was a tiny bit concerned the fan might cause a vibration I would see, but that is not the case.

### **Mounting location on Rockerbox**

I decided to mount the electronics on the side of the rockerbox, opposite to the side that the altitude drive roller and motor were mounted on to help balance the rockerbox. I fabricated a box from a base of  $\frac{1}{2}$ " plywood, with a top and sides from plexiglass (so the circuitry can be seen). Mounted on the rockerbox means everything turns together, with the only thing that needs to be tended being a single power wire leaving the telescope. Initially I had the power supply sitting inside the rockerbox. However, the heat it generates was a concern to me for maintaining good imaging (since the scope is a truss tube type of configuration). So, I moved the power supply to the side of the rockerbox so any heat generated would be away from the OTA.

### **Connectors (CJ vs DIN vs DB)**

I elected to use the modular connectors used for phones for the encoders, with CJ plugs for the 12v power connections from the power supply (they are polarized and have a large current carrying capability). I used round DIN 6 plugs for the connections from the electronics box to the motors for their large pin size and the fact they are polarized. I also used a DIN 6 plug for the handpaddle plug, and in retrospect that was a mistake. I should have used a different type plug to avoid confusion and potentially plugging in the hand controller to a motor socket. The connection to the parallel port is, of course, a standard DB25 ribbon cable and connections. I also make a habit of unplugging all the wires to everything when the scope is not in use and is stored in the garage. The reason is a friend's scope was nuked by a close lightning strike. Even though

the scope was not hit, the EMI from the close strike obviously induced enough current in the plugged in wiring to destroy the electronics, and the encoders (with the wiring harness acting like an antenna).

### **Cable harnesses/wire sizes/types**

Instead of building a single wiring harness that runs everywhere on the scope I elected to have separate wires run from the box to the 3 motors and two encoders. This allows me to remove any component and its wiring for bench testing if the situation arises. The wire sizes are 20ga for the motors and 8 conductor 22 gage stranded telephone wire for the handpaddle. My Alt and Az motors are 5 wire motors, and I could not find 6 conductor wire that was the right size, so I used two 3 conductor wires run as a pair to each motor. That gives me 6 conductors (an extra if I need one). My FR motor is a 6 wire motor, but I tied the two return lines together so again, I only use 5 conductors up to that motor too. The extra wire going up to the secondary cage will eventually carry power for a dew control system.

### **Power inputs (110vac vs 12vdc)**

The entire system runs on 12v. I elected to mount a small 12v power supply on the side of the rockerbox beside the electronics box. That way I simply plug in to 110v for the whole scope and laptop brick, or into a 12v battery and run the laptop on internal batteries. Since I am usually imaging with my ccd camera (which requires 110v power) I rarely use just a 12v input. But its there when I do need it.

## **4. COMPUTER SUPPORT DESIGN CONSIDERATIONS**

### **Laptop vs Microprocessor (Interactive vs Black Box)**

After having built the system as designed by Mel Bartels, and after having used a system designed around a microprocessor by Tangent Instruments, I have to say I much prefer the more interactive system designed by Mel. The Tangent system (that Andy Saulietis uses in his design) works superbly. The tracking is GREAT, and the system is very easy to use. So why do I prefer Mel's system? The difference is in the need for accuracy in the mechanical systems. The Tangent system, because it is very limited in its interaction with the operator, cannot easily compensate for mechanical imperfections. Andy does not have a problem with that since he is a master machinist and his telescope mechanical systems are all high precision. However, the rest of us, even if we do know how to use a lathe and mill and other fun machine shop tools will usually not end up with the precision of an Andy Saulietis mechanical system. Therein lies the beauty of Mel's software... You can correct for backlash, periodic error, mechanical misalignment and even poor initial alignment to the stars. The costs for the two systems are almost exactly the same if you use an inexpensive, bottom end laptop like I use (which is MORE than adequate). All of this also begs the issue of also having a GO-TO capability along with the Grand Tour and Scroll Tour capabilities with Mel's system that are not there with the Tangent system.

### **Where to Mount the Computer?**

Instead of having a desktop computer/monitor (even a very cheap one) I elected to use an inexpensive laptop. I actually have two inexpensive laptops (one for the telescope drive and one I already had for the ccd camera). A cheap laptop can be found for \$200-\$300 that will be more than adequate and has the added benefit of being able to do other "laptop things" too when not driving the scope! I built a small, removable shelf for the front of the rockerbox to sit the laptop on. Some velcro on the bottom of the laptop and matching strips on the shelf keep things in place. The laptop actually sits sideways so I can see the screen and use the keyboard from my observing position. I also have a small 12v light with a potentiometer to dim it for seeing the keyboard easier. The laptop 110v-12v power brick rides inside the rockerbox and plugs into the same cord that the telescope power supply plugs in to. With the laptop riding on the rockerbox there are no wires, etc to chase or trip over as the scope is rotated in azimuth. I had tried to mount the laptop/shelf on the side of the rockerbox, but I found when looking up at higher elevations (near zenith) the laptop was actually in the way of my standing near enough to the scope to see into the eyepiece..

## 5. SOFTWARE

I run Windoze 95 on my desktop machine, but my laptops are pretty minimal, so I have elected to stay with Windows 3.11 and DOS 6.22 on them (yes I have two, one I use for the drive system and one to run my Cookbook245 ccd camera. At the prices they go for today, bottom end laptops like I have are really not such a big deal to have/use). For my laptops I have taken advantage of the "menu" function in DOS to have an option to be able to boot straight to DOS and have Scope.exe in the autoexec.bat file. It makes it really simple to operate the laptop in the field! Check "help" in DOS for how to set up using menu.

Perhaps a word about attention to details is in order too. Computers seem like they NEVER do what you WANT them to do, but they almost ALWAYS do what you TELL them to do..... What this translates to is typos you might make in config.dat or elsewhere will, quite often look like hardware problems, or you will think the software is screwed up when you have gone back and checked your wiring 10 times... Be prepared to get REALLY methodical in troubleshooting, especially with config.dat. Take the time to read the excellent info on Mel's website explaining each part. It will seem bewildering at first, but when the lights start coming on you are in for a rush as things start working right!!! This system and design are simply outstanding!!!!

The secret to getting the most of this system is in getting the hardware and software "tuned" to each other. Mel has a LOT of info on his website on this, so I will not try to duplicate info he has already written. Instead, this section will cover the software from a "user's" standpoint rather than a programmer or author's standpoint.

In all the software "tuning" activities, keep a "Master" copy of config.dat, config.sys, autoexec.bat, and pec.dat off to the side. Also make a "Working Master" copy, and then finally a "Working" copy. Make your "experimental" changes to the working copy. When you make an adjustment that works and you want to stay with, write it in a log (notebook, etc) so you can look back at what worked and what did not. Also, when something works save it to the working master (but not the "Master" master till you are totally done). In this way you can always go back one version and try something different. Also, only make ONE change at a time!!!! Otherwise, you will not be able to tell which change made things different. Its slightly slower and a bit more tedious, but I assure you the end result will be easier to arrive at!!

### **PC's System Software**

I run Scope.exe on one of two low end laptops I obtained for just this purpose (actually one for the scope drive and one for my Cookbook 245 ccd camera). One is a 386SL20 (a ZEOS Contenda sub-notebook), and the other is a 486SL25 (a Compaq LTE Lite 4/25c). The Zeos does not have a math co-processor, but the Compaq does. Both machines have DOS 6.22 and Windows 3.11 loaded. The default machine I use for the drive is the Compaq, since it runs a bit faster and allows me to use a higher number of pulses per bios clock tick (PwmRepsTick) which allows the steppers to run a bit smoother (even though the ZEOS's performance is acceptable). The message is most any machine will do, especially for visual work.

It is critically important to not have anything else running at the same time. Since Scope.exe does not run as well in a windows shell on the machines I use, I simply boot into DOS and start Scope.exe using the autoexec.bat file. DOS 6.22 has a clever capability called "menu" that allows you to effectively have a different Config.sys and Autoexec.bat for booting into different configurations. You get a menu presented to you during the boot process right after DOS starts. You get to build the menu. To find out how to do this, drop to a DOS prompt and type "help menu" or "menu?" to get all the info you will need.

### **Config.sys**

The config.sys I have for running scope.exe does not load any other drivers in order to save conventional memory. I also keep it as the default configuration that the system boots to.

### **Autoexec.bat**

Autoexec.bat gets called after config.sys, and then the menu operation calls the appropriate section of autoexec.bat (the menu option in config.sys sets a constant called "%config%" that provides hooks in autoexec.bat). Make sure each section ends with a "GOTO End" statement and that there is an ":end" statement at the end.

## **Directory Structure**

Scope.exe needs all the files it uses in the same directory as the program. Rather than put that directory in the path statement and then just run scope.exe, have autoexec.bat do a "cd\XXX where XXX is the directory where scope.exe lives. That way the files that scope.exe writes will go into the same directory as scope.exe.

## **Power Management**

Mel told me several times but I was (as usual) slow to listen: Turn OFF all power management for a laptop. This consumes CPU time and if you have a slower machine it will really screw up trying to get the motors to run smoothly. Turn it off in config.sys AND autoexec.bat, AND in the bios setup if its an option there (my Compaq uses an F10 during boot up to access this bios setup, my ZEOS uses F2, and my desktop uses the DEL key...the message to this: Bios is where you find it I guess)

## **Config.dat Constants**

The real beauty of Mel's software lies in its ability to compensate for mechanical imperfections. The old war between the hardware and software developers had a major victory with scope.exe in my opinion. All of the customizing of how the system runs and the ability to run different test modes is captured in an ascii file called "config.dat". This file has to be in the same directory as scope.exe. It can contain "remarks" lines that are quite handy for making notes to yourself (and that already have notes from Mel). These lines all start with a semi-colon (;). Mel has done an excellent job in providing information on each of the portions of config.dat, so rather than try and duplicate what he wrote, I will try and add WHY I configured my system the way I have. When tweaking config.dat you have to exit to DOS (do a "Q" from the menu or follow the specific directions for the test mode you are running). You can then use the DOS editor to call up and modify config.dat by simply typing "edit config.dat". Use the "Alt" key to use the menu on the DOS editor to save the changes (or just do an Alt-x and hit yes when asked if you want to save the changes), then just type scope.exe to return to scope.

## **Opto Isolators**

The logic on this one seems backwards, but if you DO use Opto-isolators, set the value to a "0". I added Opto-isolators since I figured the tiny bit of added hassle to add them was well worth the extra protection for the laptop's parallel port.

## **Test Modes**

Take advantage of using the test modes that Mel has provided. They have grown in number and power to help sort out problems. It is a bit of a hassle to have to quit and then change the config.dat file and then restart things to change test modes, but after a couple of times it goes really quick. After you quit scope.exe, type "edit config.dat" (make sure you are still in the directory where all the files are first!). A simple DOS editor will bring up the file. Make your changes (page up/down for fast scrolling) and do an Alt-F then an Alt-S to save and then an Alt-F followed by an Alt-X to quit (Don Halter points out you can just do the Alt-F, then Alt-X and say "yes" when it asks to save the file). Then type "scope" and hit return and you are off and running again.

## **Test Serial Port (Test 1)**

This test needs to use an UPPER CASE Q not a lower case q to interrogate the encoders. Holding it down gives constant interrogations like test 2 does.....

### **Parallel Port Test (test 5)**

This is a VERY handy tool to use to check the circuit to trace a "one" or a "high" output on the parallel port pin through the entire system all the way to the power transistor output (as well as toggling the output to a "0" or a "low" to watch the changes). You can easily see the inversions done at the opto-isolators and hex inverters to make sure they are working (and wired) correctly. If you decide just to look at the output of the parallel port itself, with nothing but your meter attached looking for the +5v high output, you may not get the right readings when toggling back to low. This is because the impedance of the output pins may not pull the voltage down. If you do not get a low reading when toggling to low, put a 10k ohm resistor between the pin and ground and then toggle the port to low. The resistor will allow the voltage to quickly bleed off, but is high enough resistance to not allow any current to speak of to flow and over load the port when its set high. My Compaq does not need this, but my Zeos does.....

### **Handpaddle test (Test 6)**

This was a big confidence builder to confirm the handpaddle was working right. Different switch combinations will toggle different bits on/off. Just look for the changes..... If no changes happen, make sure you are getting 5v to the handpaddle.. then check to see if all the diodes are wired in the right direction.

### **Rate Test (Test 8 )**

This was probably the most useful test mode for me during the "tuning" process. It is used to set the combination of PwmRepsTick/PWM[x]/MsDelay/MsPause values to get the smoothest motor motion at the least current values. You can also test to see if the flyback diodes are doing their job and allowing the stepper to spin very fast by specifying very high rates. For the slower speeds (like one microstep/sec), also set the option active to show what microstep is being commanded. You need this to tell which PWM values need to be adjusted. Watch the display and count with it, THEN, while keeping the counting cadence going move your eyes to a cardboard pointer taped to the armature of the motor. Use a negative sign for the rate to reverse directions.

### **Microstep Optimizing:**

This was probably the biggest single consumer of time after I had the drive system completed. It was far from drudgery since the scope was quite usable, but just not yet "perfect".... While you do not need to fully understand the ins and outs of the relationships of the constants, if you go to the trouble of building a system like this, it is very rewarding to also understand WHY it operates the way it does. Mel deserves some type of award for patience after all the questions I sent him on this area (Thanks again Mel!!). The bottom line is most of the explanations he passed to me have found their way into his webpage, so I will not attempt to duplicate them here. But there are a few simple principles that Mel drummed into my head that when you read his page you need to be sensitive to:

Make a pointer and cardboard clock face like Mel suggests to attach to the motor and shaft to be able to see the tiny-ist motions of the motor shaft. Use a magnifying glass to watch it as you get closer to the final configuration and are running at 1/2 to one microstep/sec.

### **The overall routine is quite simple to follow:**

Initially adjust PwmRepsTick to about 20, MsDelay to 1, and MsPause to 0 (for a fast machine like something that runs at more than 66 mhz, set MsDelayX to 5 or 10 initially).

Play with the sequence of values for PWM[xxx] in the PWM Matrix to get the smoothest movement (by this I mean that all the microsteps are the same size) even though during the first several iterations the movement may not be smooth, especially at the lower stepping rates.

Now look at the current the motor is drawing (put your ammeter in series with the +12v feed to the common wire for the motor windings (remember to initially use the 10amp config on your meter till things

are trimmed to low current levels..)). Run scope.exe in normal mode (TestCode 0) and start tracking. As the motor runs, note the current reading. Stop and increase MsPause if the wattage rating of your motor has been exceeded (Volts x Amps = Watts). My 6v motors are rated at 1.2 amps/phase. That equates to 7.2 watts. However, I am running them at 12v to get the extra "kick" you get from the higher voltage. So,  $7.2 \text{ watts} / 12 \text{ v} = 0.6 \text{ amps}$ . That means you need to adjust MsPauseX till the current reading is no higher than 0.6 amps when the system is in track mode. Think of MsPause as adding PWM pulses that are of zero current value, so the net effect is the total current is reduced by adding the "dummy" pulses). Also, during this step, note the PWM value displayed on the screen. In the next step you will set PwmRepsTick to this value.

Once you have the current down to where it needs to be, go back to test mode 8 and run the motor very slowly while watching the pointer movement. The PWM[xxx] values will probably have to be slightly tweaked to get the motion smooth again. While adjusting things in Config.dat, also update the PwmRepsTick value to that observed in the previous step. The idea is to have PwmRepsTick in config.dat set to about the same value as shown on the display (the display shows what the computer CAN do for PwmRepsTick. More accurate tracking will result with PwmRepsTick and the display reading the same.) You will need to note the screen value during each iteration that you end up with the system using the normal scope.exe display and then tweak config.dat accordingly.

If you raise the PWM values in the matrix, the displayed PWM value will decrease (within a bios clock tick the computer can get fewer PWM's in if they are large. Small PWM values will result in higher PwmRepsTick values. If the actual PWM reps are too low (i.e. less than 20-30) then adjust the size of PWM[0] and all the rest to smaller values and rebalance the PWM array to get smooth motion at the lower starting values. Don't go toooooo low with PWM[0] or you lose the available "range" to vary the PWM values you may need to get smooth motion (i.e. using a PWM[0] of 100 gives you 100 units to choose from for the remaining PWM values for the matrix. If you use a value of 50 for PWM[0], then you only have 50 units to spread the remaining PWM values across).

## PWM Profile

This series of values is really the heart of the tuning process to get smooth motion from the stepper motor. Remove a motor and cut out a cardboard disk about 8" in diameter, make marks around the circumference about  $\frac{1}{4}$ " apart, cut a  $\frac{1}{2}$ " hole in the center and slip it over the motor shaft and tape it to the motor.. Then cut out a cardboard pointer with a sharp point on the end that is about 4" long and use a hole punch to make a hole to slip the motor shaft thru and then tape the pointer to the shaft. The result should look like a clock with one hand. The marks around the edge of the disk are to provide an easy visual reference for judging the motion of the pointer.

Use the tracking test mode to run the motor at a constant rate. Make it as slow as possible so you can see the individual microsteps. I use either 0.5 or 1 sec/step and also use a magnifying glass to watch the end of the pointer.

Too large of a value for PWM[0] and the actual "PWM reps" value goes down, which makes the motor motion jerky (I think of it as more small PWM's can get crammed into a bios clock tick than large ones, but small PWM's lose the range of numbers available to do fine tuning on the even-ness of the step sizes which makes the motion uneven). Start with a value of PWM[0] = 100 and go from there. If the actual PWM rate goes way up from playing with other variables, remember to look at the individual microstep movements again, since they may no longer be smooth at that different PWM rate.

As you watch the pointer, think of what the two windings that are "pitted against each other" are doing. At the first microstep, the first winding (A) is 100% on, and the second winding (B) is 100% off. This aligns the motor totally to winding A. At the  $\frac{1}{2}$  way point (step 5) both windings are on the same value, and the rotor position is held  $\frac{1}{2}$  way between the two windings. At the end of the full step, B is at 100% and A is off, so things are lined up with B. Then it starts again....

To divide things up into finer movements, Mel uses 10 steps, and suggests winding A on at 100% for the first 5 of them. You can certainly vary both A and B (I tried to use two sine waves overlapping) but in the end Mel's way usually always proves the easiest!!! In each of the first 5 steps, the current to B is slowly increased each step till at step 5, you are in the middle, and the rotor is at the  $\frac{1}{2}$  way point. Then B stays on at 100% and the current for A is slowly decreased till things are all lined up on B.

So, when watching the relative step sizes, if the first couple of steps are too big, you may get "pulled" too much by B and get too close to the  $\frac{1}{2}$  way point too quickly. That makes the middle steps look too small.

Or, if the first steps are too small, then the middle steps will look too big when they center the rotor when both have the same current. For this reason, if the middle steps are too big, I first adjust the first steps (and the last ones) to be bigger. It will take a bit of playing with it to get a feel for which steps to adjust. It really helps to remember that the middle steps are centering the rotor. Small changes make a great deal of difference, and do not worry of the differences in each PWM value are not equal intervals in order to get equal movements in each microstep. They will almost assuredly NOT be equal numeric intervals to get equal physical movements. I have two laptops (a Compaq 486SL25 and a ZEOS 386SL20) and the two machines require quite different PWM profiles to get the same motion from the same electronics box/motors..... Take the time to play with this since it will make a BIG difference in the smoothness of your tracking (besides the "hoot" you'll get when it starts running as smooth as a DC motor!!)

As an example, the PWM Profile for my ZEOS (386SL20) which can only get up to 12 PWMRepsTick but otherwise runs just fine and the Profile for my Compaq LTE Lite 4/25 (486SL25) which runs at a VERY smooth 90 PWMRepsTick rate are: for .....ZEOS---Compaq

```
PWM[0].. 100---- 100
PWM[1].. 100---- 100
PWM[2].. 100---- 100
PWM[3].. 100---- 100
PWM[4].. 100---- 100
PWM[5].. 99----- 100
PWM[6].. 75----- 95
PWM[7].. 60----- 88
PWM[8] ..45-----82
PWM[9].. 26----- 62
```

### **AltFullStepSizeArcsec (and AzFullStepSizeArcSec)**

This is where you tell your system how far it moves per FULL step (not micro step). Start off with the calculated values from when you designed the gear ratios and drive roller ratios. But, you want to MEASURE things and enter a value of at least 7 significant figures!!! The tracking accuracy is dependent on this... Fortunately, its easy and fun to do. First, get a 2x4 about 8ft long. Tape a piece of paper to each end with a DARK line on it. This 2x4 will form a long ruler that you will drive the scope side to side at (AZ slews) and then up and down at (Alt Slews). Measure the distance between the two lines VERY accurately. Mount the board at least 50 ft away on something like a step ladder. Then measure the distance to the board from the Altitude AXIS and to the Azimuth AXIS of the drive. Then aim the scope at one of the lines. Use a laser collimator taped to the OTA, or an eyepiece with a reticle, or the edge of the FOV of an eyepiece. Use as much power as you can pile on (double up on barlows, etc.) When aimed at the starting line, do an "Input Altaz", with all zeros (just hit returns), then do a "Reset to Altaz" to have the program "swallow" what you just entered. Then, slew the scope to where the other line is centered in the FOV (or at the same edge of the FOV, or the laser dot is on the next line). Go SLOW when approaching the line and do NOT reverse directions if you overshoot!!! (Just do another run going the other direction). The "current" Alt or Az reading will tell you how far the telescope "thinks" it moved. Write this down and do a "Reset to Altaz" and drive back to the other line and take that data. Repeat this several times so you can average the distance the scope thinks its moving. Turn this into arc sec (multiply the degrees by 3600) and then divide by the Config.dat constant that was being used by scope.exe during the tests to see how many steps the drive counted when it moved.

Now, a little trigonometry.... divide the distance between the two lines on the board by the distance from the Altitude AXIS (or Azimuth AXIS) of the drive. This will give the tangent of the angle the scope actually moved. Take the arctan of that value to get the tangent (arcsin will also work for long distances away). Now, take that angle and divide it by the number of steps you calculated in the preceding paragraph and use that as your new constant in config.dat. Pretty cool, eh??? After entering the new value, repeat the test to verify the angle that scope.exe calculates for the motion is what you calculated with your trigonometry exercise.

Rotate the board to vertical on the step ladder and repeat the process using altitude slews instead of azimuth slews. The difference in tracking accuracy will be VERY noticeable after these updates are made to both axes!

If the mounting system for your encoders is not a 1:1 system or is a drive roller liked system, do this same exercise to measure the altitude and azimuth encoder accuracies. For the constants AltEncoderCountsPerRev (and for Az). If the directions are wrong when the encoders are looked at (i.e. it says you are going down when you are going up, etc.) toggle the AltEncoderDir value.

### **FRStepSizeArcSec**

Remember that if you are using an SAA1042 chip to drive the stepper motor, you can be using  $\frac{1}{2}$  step mode (which will cut the step size down by 50%). The motor will run quite warm using an SAA1042 since the motor spends a lot of time on each step or  $\frac{1}{2}$  step with both windings powered. I use a 12v motor that draws .3 amps per phase and it gets really warm/hot..... seems to be happy though.... Wish I could tap that warmth to help fight dew! If you are not doing photography, unplug the connector to the FR motor and save the power since FR is not needed for visual work.

### **MaxDelay (MinDelay)**

These values determine how fast the high speed slews are and how fast the ramp up and ramp down speeds are. A larger value for MaxDelay will mean the ramp up starting speed and the final ramp down speed will be slower. A larger value for MinDelay will mean the top speed the motors get to in the slews will be slower. There is a point for each motor where as the speed increases (and the available torque decreases) that the motor cannot drive the load on it. It will let you know by making the most awful buzzing sound.... Simply increase MinDelay to slow it down a bit and try again. (that buzzing sound is REALLY irritating!). It may be that if you are running your motors at higher than their rated voltage, there is a speed that the motors accelerate up through where they "buzz" no matter what you do. In that case, you may have to add dropping resistors in series with the motor windings to drop the current to the windings while they are running slower than top speed (where the impedance of the windings will also serve to limit current). Some motors will need this and some will not. Good luck!!

### **PPortAddr**

There are actually three values to choose from. Compaq computers seem to need to use the value of 956 to address LPT1... Maybe others do too? Check the outputs of the parallel port using test mode 5 and if things do not toggle, try a different parallel port address.

### **EncoderErrorThresholdDeg**

This constant and the one for Track can make the drive go nuts if set wrong. This constant should be pretty tight (but not less than the size of a single encoder count). This is the threshold for using the encoders to tell where the scope is aimed instead of the counts from the motors and is used when tracking is off, the motors are de-clutched, and you manually slew the scope. The TrackEncoderThresholdDeg is used when tracking is ON. I suggest you open this up to about 1.0 degree. If too tight, and the encoder and motor counts get out of sync by not too much, the scope will hunt between the two values and will go beserk. This usually happens when you gently push against the eyepiece while viewing and will scare you to death!!!!

### **LongitudeDeg, Tz, and DST**

These are pretty self explanatory and help the scope get a good start at figuring out where it really is. They do not have to be super accurate for the Longitude. The Time Zone is good to have right, as is whether or not you are on Daylight savings time (!=yes). For fun, watch where scope.exe calculates your position, its amazingly accurate!

### **PWMRepsTick**

Work to get this to at least 20-30 or higher. The higher the value the smoother the microsteps and the finer the ability to control current. This is the maximum number of pulses that can be sent during each bios clock tick. Each microstep is made up of a constant stream of PWM pulses to the motors, but with varying values

to each winding to get the smooth motion. The other values mentioned control how many of the pulses are really just "fill data" (i.e. have a value of zero) or are multipliers for very fast CPU's.

### **MsPause**

I think of this as "fill data" during each microstep's sets of pulses (PWM's). A higher value (up to the value of PWM[0]) will fill more and more of the time the microstep is sending PWM's with "offs", which lowers the total amount of current sent to the motors. This is my primary tool for setting the current that goes thru the motors.

### **MsDelayX**

Increasing this value will increase voltage to the motors because more time is spent doing the "On's" by a factor equal to MsDelayX. For slower CPU's, I found it was better to leave MsDelayX = 1 and simply vary MsPause to vary the current to the motors.

### **PEC**

This is a REALLY powerful capability of this software!!!! There is an EXCELLENT writeup on determining what values to use in the PEC table by Joe Garlitz at <http://www.orednet.org/~jgarlitz/pec.htm> that I was able to contribute some suggestions to on how to capture the data, so I will not duplicate that here. This is really a satisfying exercise to go thru and then watch the periodic error simply go away!!!! You just need to remember to USE it!! Also, periodically thru the evening (especially after long motor driven slews) its a good idea to stop tracking, cycle PEC off, reorient the motors to the "zero point" and restart PEC since its possible, over time, to lose count of exactly where the motors are after several hundred thousand motor micro steps! This re-initializing PEC takes about 10 seconds and is worth it (if you're getting tracking errors and you don't know where they came from, try it).

### **Opening and Closing Messages**

Every time I have been tempted to turn off these extra little messages, I forget to do what they say..... Thanks for having them there Mel!!!! I suggest you leave them enabled since at 3am you will probably be a bit fuzzy and may forget to do what they remind you to do!

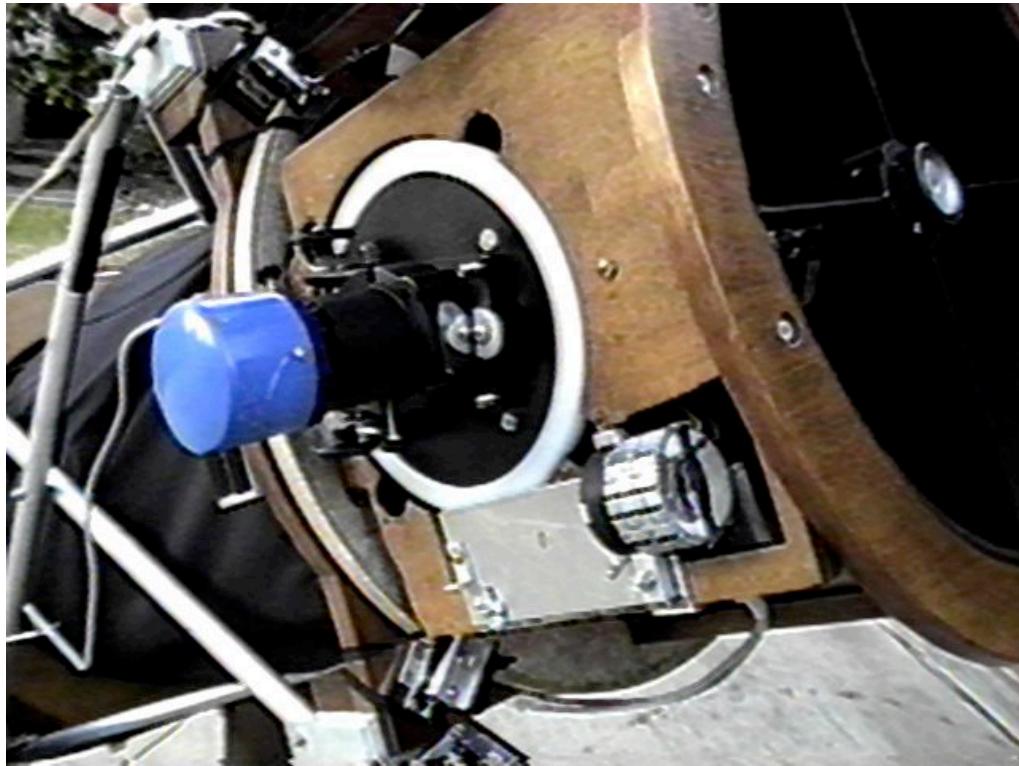
### **Scope Ops Cue Card (Hot Keys)**

I think its a GREAT idea to make some notes to yourself about the hot keys and tape them to the drive near the keyboard. Things like starting and stopping tracking are easy, as is turning on and off PEC, and toggling the handpaddle routines, and calling up data files, but snapshotting the equatorial coordinates and resetting to them and retrieving past stored ones I never seem to remember..... If I get around to it I will make mine a bit more presentable and add it to these notes to get you started.....

### **One last comment...**

Mel Bartels has made his design and software available as freeware to all of the rest of us, and he spends a LOT of time working to explain it and share it with everyone. Mel deserves some type of hero medal for that! The best thing I think we can do is to continue that spirit of sharing what we have learned and developed with each other. That's what motivated me to write down my "Lessons Learned" in this article, and make it available to everyone, and I have seen the same by lots of other folks. Let's keep up that attitude and we all profit in the end! Clear skies to all, and thanks again Mel!!!

**Image Plane Derotation System by Chuck Shaw**

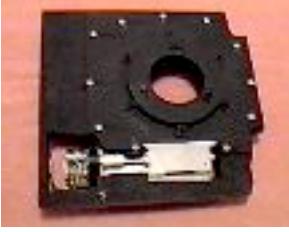


The motor is an SAIA 48 step, 12v stepper motor with a 50:1 gearbox, turning a 240:1 worm gear (HDPE Gear made by Andy Saulietis). The focuser is an Astro Systems, Phase 4 focuser. Each step of the motor rotates the image plane gear 2.25 arcseconds.

The worm gear can swing downward, out of mesh with the 8" dia HDPE gear, to allow manual re-positioning of the camera to adjust the framing of targets, or the software can drive the motor to reposition the camera for fine tuning of the framing.

The normal camera I use is a CB245. The camera in the photo is a greyscale QuickCam.

The field rotation assembly is basically a flange on the rear (inside) of the gear that rides on two 4" ID bearings. The bearings are held by a ring mounted in a plate screwed to the rear of the wooden slat in the secondary cage. The flange has a rear plate that is screwed to the end of the flange and squeezes the two bearings together in the bearing plate, capturing the gear/flange on the plate.

The mounting plate and bearing ring (backside, away from focuser) 	The mounting plate and bearing ring (Top side, towards focuser) 	Flange attached to rear of gear 
Rear Plate (attaches to inner end of flange on gear to capture bearings and bearing ring onto flange) 	Disassembled FR system 	FR system together with the secondary cage slat that the plate attaches to (on the rear) and the worm/motor assembly. 
Sec cage slat with the assembled FR system mounted to it, ready to be mounted in the sec cage. 	View of inside of the assembled sec cage slat, ready to be mounted to the sec cage. Silver screws attach the plate to the rear of the sec slat. 	The inside of the secondary cage has a "closeout" panel made of aluminum flashing. The following photo shows the inside of the secondary cage, the closeout panel, and the adjustment screws and their locking clamps on the Rear Plate of the Field Rotation bearing assembly. 

### Spin Alignment

By installing a pinhole light source of a known diameter pinhole size in the focuser at the focal plane, and then suspending a video camera over the scope, focused at infinity, looking down into the scope parallel to the optical axis (offset to the side from the secondary mirror), you can spin the scope around the azimuth axis and be able to adjust the vertical stop in the inside of the front panel of the rocker box to have the scope be perfectly aligned with the azimuth axis in that plane when the scope is against that adjustable stop. By adjusting the "fore and aft" position of the altitude trunions along the Optical Tube Assembly (OTA), the side to side tilt of the scope can be made to be parallel to the azimuth axis in that plane. The alignment in each plane can be accurately and easily measured in terms of arc seconds.

With the scope aimed vertically (not necessarily vertical as with using a bubble level, but instead make it parallel to the Azimuth axis) with the OTA against the hard stop and secured there with a bungee cord, suspend a video camera above the scope, looking down into the OTA. Position it just off set from the secondary mirror to look past it down towards the Primary. Set the focus at infinity (and turn off autofocus). Take the camera video feed and send it to a monitor/TV convenient to the scope. At the

eyepiece, you need to have a pinhole light source and have it located at the focal plane. An easy way to do this is to cut the end off of a plastic 35mm film can and punch a small hole (less than 1/16" diameter and as round as possible) in the lid. Re-install the lid on the film can and tape it to a small flashlight (the lid towards the flashlight). Then just insert the film can into the focuser and rack the focuser in/out till the lid is at the focal plane. All of this will result in a collimated light beam being shone at the camcorder. To initially get the system looking at the light dot, use low power zoom. Once you have the light dot in the FOV, use as much magnification as possible (I used a 200mm telephoto lens afocally projected onto my camcorder objective lens with the camcorder set at a zoom of 6x).

### Spin Alignment Setup



The telescope is aimed vertically and is up against the adjustable hardstop on the inside of the front panel of the rockerbox.

The video camera is suspended above the telescope aimed parallel to the optical axis with its focus set at infinity, autofocus turned off, and its video output sent to a nearby monitor. (The huge ladder holding the camcorder is used by Larry Mitchell to climb to the eyepiece on his 36" dob!!)

A pinhole light source is inserted into the focuser and is positioned at the focal plane.

Al Kelly (in the white shirt) is rotating the scope about the azimuth axis, from one "90 deg" position to the next.

Dick Miller (in the green shirt), is marking the path of the white dot (the image of the pinhole light source) with a water soluble pen on the TV monitor, and annotating the path described by the dot with the rotation position of the mount.

The side to side adjustments (on one of the altitude trunions) and the fore and aft vertical stop adjustment (the adjustable stop inside the rockerbox front panel) are adjusted till the dot describes the smallest circle possible. Then the adjustments are "locked" in place.

The remaining displacement is measured in terms of diameters of the dot image. The angular size of the diameter of the dot image is calculated from the pin hole size and the focal length of the Primary mirror and camcorder optics, thus allowing you to express the displacement of the dot's path (the mount's misalignment) in arcseconds.

Altitude Trunion adjuster. The bolts holding the trunion to the trunion-box are loosened and the nuts on the adjuster bolt allow the OTA to move "fore & aft" to adjust the side to side misalignment.



The small flashlight and 35mm film canister used for a pinhole light source. Punch a small round hole in the lid and measure its diameter as accurately as possible. Cut the end from the canister, re-install the lid, and tape the flashlight to the lid.



Photo of the flashlight/film canister inserted into the focuser. Adjust the focuser till the lid/pinhole is at the focal plane.

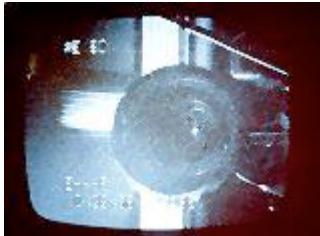


The adjustable hard stop on the inside of the front panel of the rockerbox. (a carriage bolt in a wooden plug, secured to the rockerbox via a t-nut and jam-nuts/washers)



As the scope is rotated in Azimuth, the small dot of light will describe a circle on the TV screen. Pick 4 "cardinal" points with respect to the ground board. to use as reference (i.e. call them N, S, E, and W, or 0, 90, 180, and 270). The idea is that you will adjust one of the altitude sectors fore and aft along the "X" axis of the OTA, then rotate the rockerbox to see if that made the circle smaller. Ultimately it will collapse into a line from a circle when the side to side tilt of the OTA's "X" axis is finally made orthogonal to the Altitude axis (and perpendicular to the Azimuth axis). The next step is to adjust the altitude hard stop on the front of the rockerbox that limits the OTA altitude to 90 degrees. Adjust it in the same manner as for the altitude sector adjustment till the motion due to the tube not being parallel to the azimuth axis in altitude collapses to nothing.

Video on TV screen showing the reflected image of the secondary mirror and the lighted dot from the pinhole.



By going back and iterating the adjustments once or twice, and by using as much magnification as possible, you will end up with the dot probably describing a small figure 8. This is due to any small astigmatism in the metal plate on the bottom of the rocker box that forms the bearing surface and any "noise" in the bearings or bearing surface.

The actual angular errors can be measured quite accurately, especially if you use high magnification. The size of the dot (actually the subtended angle) can be calculated by measuring the actual size of the pinhole in the film can lid and using the formula:  $(P/F)x(206.265)=D$  where P is the diameter of the pin hole, F=focal length of the Primary Mirror, D=arc sec that the Dot image subtends. Then, the distance the dot wanders from the "center" of the figure it describes can be measured in terms of dot diameters on the TV screen, and then multiplied by the calculated angular size of the dot.

## Contributors

A large number of friends have contributed greatly to the project.

Larry Bell derived a formula to correct coordinate conversion hysteresis when large values of Z1 and Z2 are used.

Richard Berry suggested the 3 star initialization routine.

Renato Bonomini contributed the eyepiece and eyepiece focusing code.

Jack Brindle and a small group are actively working on a Mac port loosely based on the computerized dob project.

Doug Brown contributed code and circuitry plans for 5 phase stepper operation.

Tom Cathey worked with me on the encoders.

Marcello Cucchi and friends contributed a program that generates a planetary positions data file.

Gilles Cotes contributed NGC/IC data files.

Donald J. D'Egidio contributed the AL\_DblSt.dat and AL\_Urban.dat data files (Astronomical League's double star and urban club object lists).

Ben Davies contributed precession/nutation/annual aberration formula and code.

Dale Eason contributed fast video routines and interrupt timed slewing, in addition to the Messier and stars to 5 mag data files.

Dave Ek contributed the altitude offset algorithm.

Mark Ewert contributed code for site configuration.

Bill Gray worked closely with me to integrate "Guide" with scope.exe.

Berthold Hamburger designed a PCB.

David Hutchinson contributed custom LX200 commands.

Rex Kindell worked on most of the data files, checking the declination minus situation; also contributed the solarsys.exe program..

Tom Krajci helped with the pointing error corrections, homemade worm gears, and contributed the bright stars catalogs.

Jerry Pinter contributed many of the object data files and worked with me developing backlash routines.

David Lane helped me integrate his MGIII encoder project with my system.

Bob Norgard contributed the NTE1857 replacement of the SAA1042 chip: its wiring and notes.

Vicent Peris contributed the Hickson Compact Galaxies, Palomar Globulars, Arp's Peculiar Galaxies, Catalog of Planetary Nebulae, and SAC60 by constellation data files.

Jon Rock showed how to use the mouse encoders.

Chris Rowland for source code on unique PWM values for the 2nd motor, and for many additional scroll commands.

Bob Segrest developed a microprocessor based encoder interface of great speed.

Chuck Shaw helped develop the field de-rotation system, spent time debugging the autogeneration of PEC routines, and has worked to develop a set of configuring instructions.

Pat Sweeney developed a PCB for the project.

Dave Sopchak contributed the iterative altitude offset algorithm.

Jean-Charles Vachon contributed the current limiting circuit.

Don Ware contributed the Flamsteed data sets along with NGC and IC1-5 data sets; and source code to read forwards/backwards through the data files; and the user defined hotkeys; and the polar alignment method for equatorial mounts..

Mark Williams contributed the autosynchronization of PEC idea and code.

Members of the scope-drive@yahoogroups.com list have contributed many ideas including hardware circuitry and operation suggestions.

Many other amateurs have made suggestions and worked with me to perfect parts of the system.

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