Chase the Stars with a Camera

Eric Chesak

Who hasn't looked at the night sky and asked in awe, "How can I capture that?" A motor-driven star tracker won't let you grab a star, but it will let a camera track the "movement" of the stars so you can take spectacular photos. The trick involves setting the proper tracking rate and pointing the motor in the proper direction. Camera ready... "Beam us up, Scotty."

You want to take photos of the stars, but how do you do it with so little light? By far, the easiest method involves a fixed tripod and a camera that can "shoot" long exposure times. But as the focal length of a lens or a camera's exposure time increase, the possibility of star "trailing" becomes progressively more likely. Star trails, rather than pin-point stars, appear as arcs in long motionless exposures due to the apparent motion of the sky.

Eric Chesak describes how you can build a small "clock-drive" camera mount suitable for portable use and light enough in weight for travel. This star-tracker project requires some mechanical-design experience to lay out mechanical components, mount gears on shafts, fabricate a mounting frame or enclosure. A small metal lathe or milling machine will help greatly.

How It Works

The Earth rotates at one revolution per day and completes a revolution--called a Sidereal day--in 23.9344696 hours. So the camera mount must rotate at this rate to keep stars in "fixed" positions on film or on a camera's image sensor. So the first problem centers on how to achieve this rotation rate so your camera and the stars stay synchronized and images leave so star trails. Next, the equipment needs a mechanically stable platform.

It’s not easy to obtain a stable shaft rotation of one revolution every 23.934 hours. A system of large worm gears and an AC synchronous motors might solve the problem, but this approach is out of reach for an average hobbyist.

Eric solved the problem by using a geared stepper motor that drives a worm gear. The use of a stepper motor and commercial gears lets a builder use almost any ratio of motor and worm gear combinations. A simple stepper-motor controller circuit provides the precisely timed pulses to achieve a given rotation rate. The individual steps experienced by the camera mount are very small; less than three arcminutes, or 1/20 of a degree per step. So the non-continuous motion of the system is not evident in the photographs. (One arcminute is 1/60th of a degree.)

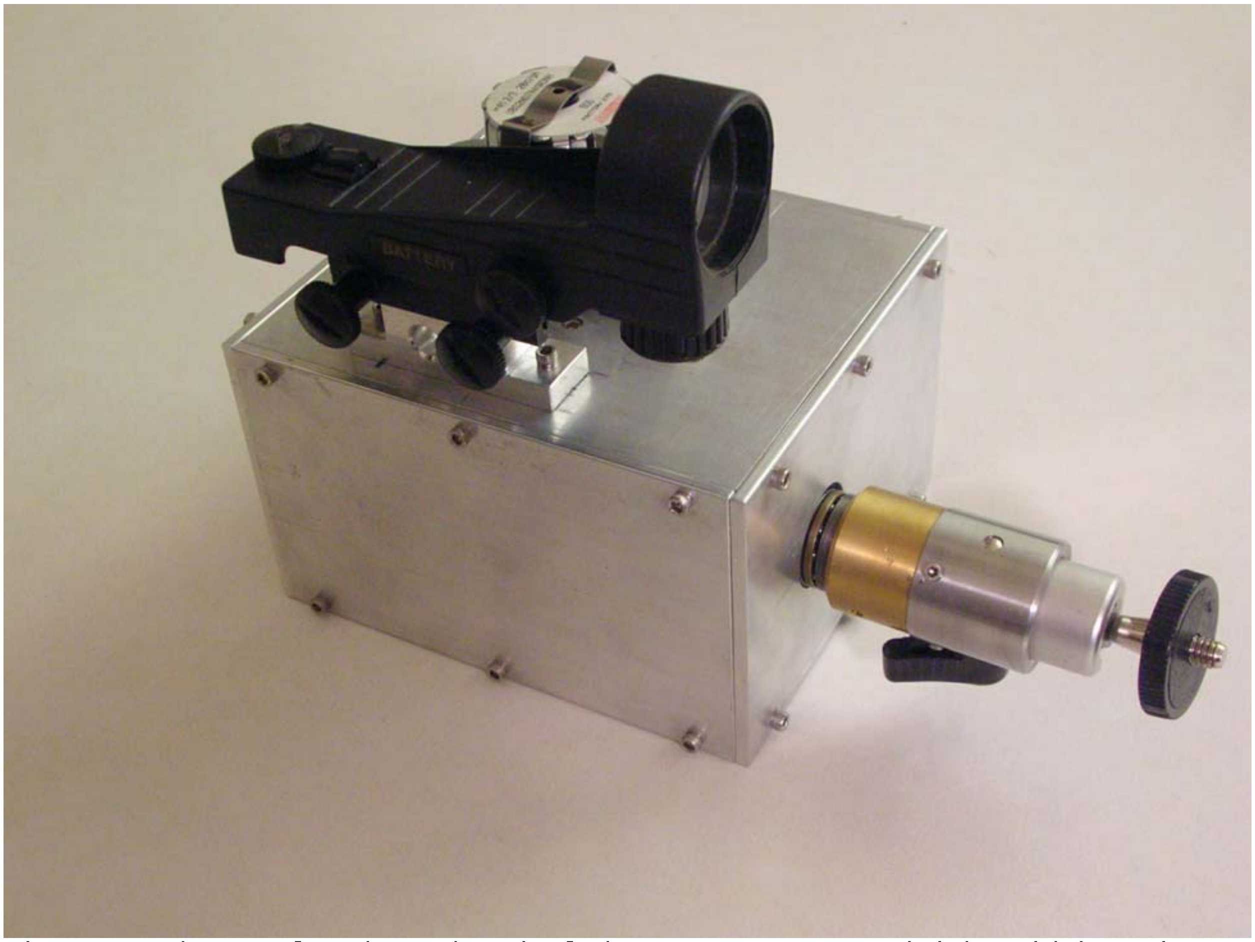


Figure 1. The completed tracker includes a camera mount (right side) a view finder and a stepper motor (behind the view finder).

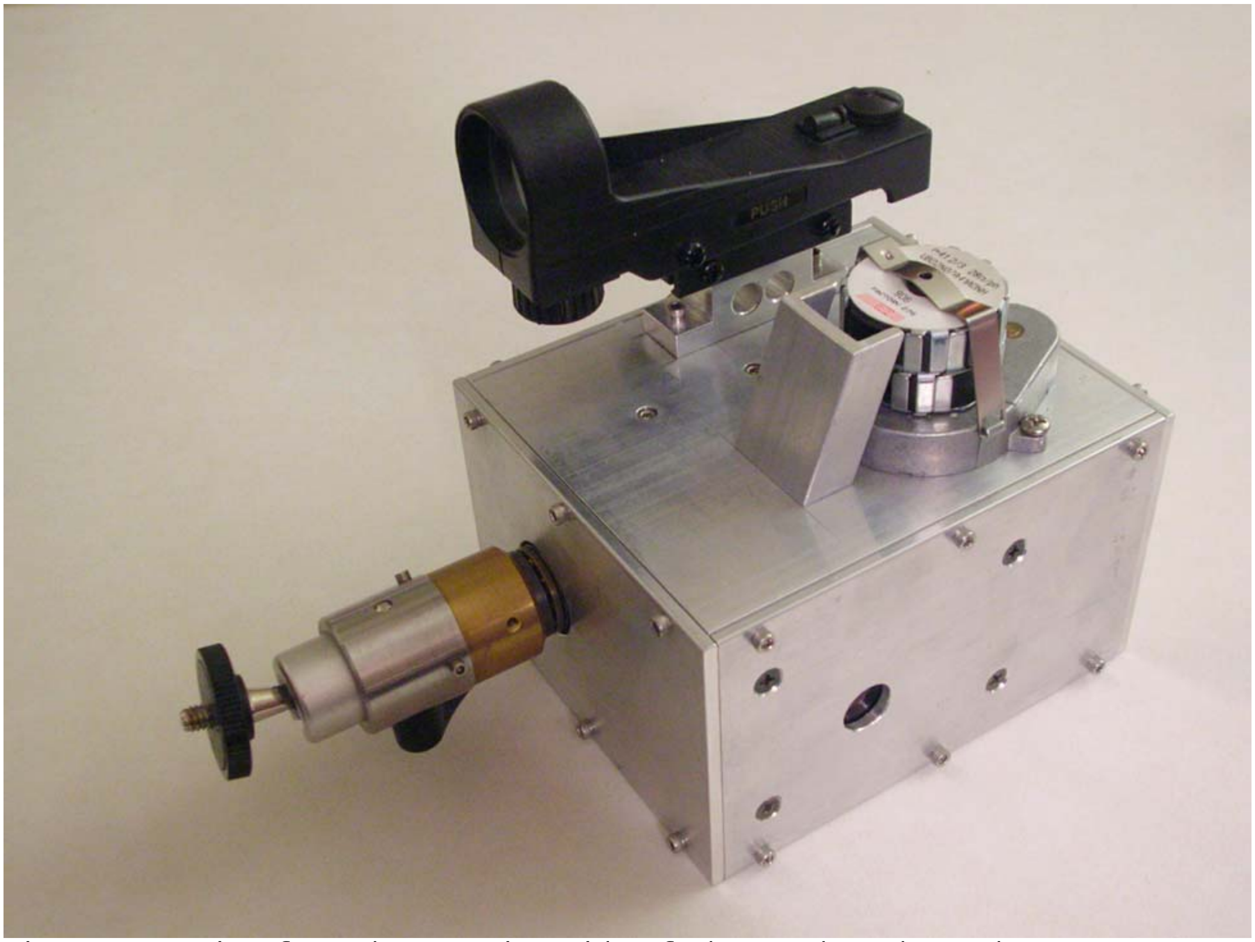


Figure 2. A view from the opposite side of the tracker shows the stepper motor and its attached gearbox.

Build Instructions

To start, obtain a worm/worm gear set. (A worm looks like a spiral on a shaft and the worm gear has machined "teeth" that fit into the spaces on the worm.) The more teeth on the worm gear, the better. Nearly any worm/worm-gear combination will work, however.

Stock Drive Products is one of the best places to locate gears, pillow blocks, and bushings. For regular worm gears, visit: https://sdp-si.com/eStore/Direct.asp?GroupID=270. And for the corresponding worms, visit: https://sdp-si.com/eStore/Direct.asp?GroupID=175.

Given the precision movements needed for astrophotography, you might wonder about using more-expensive anti-backlash worm gears. According to Eric, anti-backlash gears would be fine, but because the motor turns only in one direction there is no backlash worry about. It would be different if the motor turned back and forth. For information on anti-backlash gears, visit: https://sdp-si.com/eStore/Direct.asp?GroupID=210

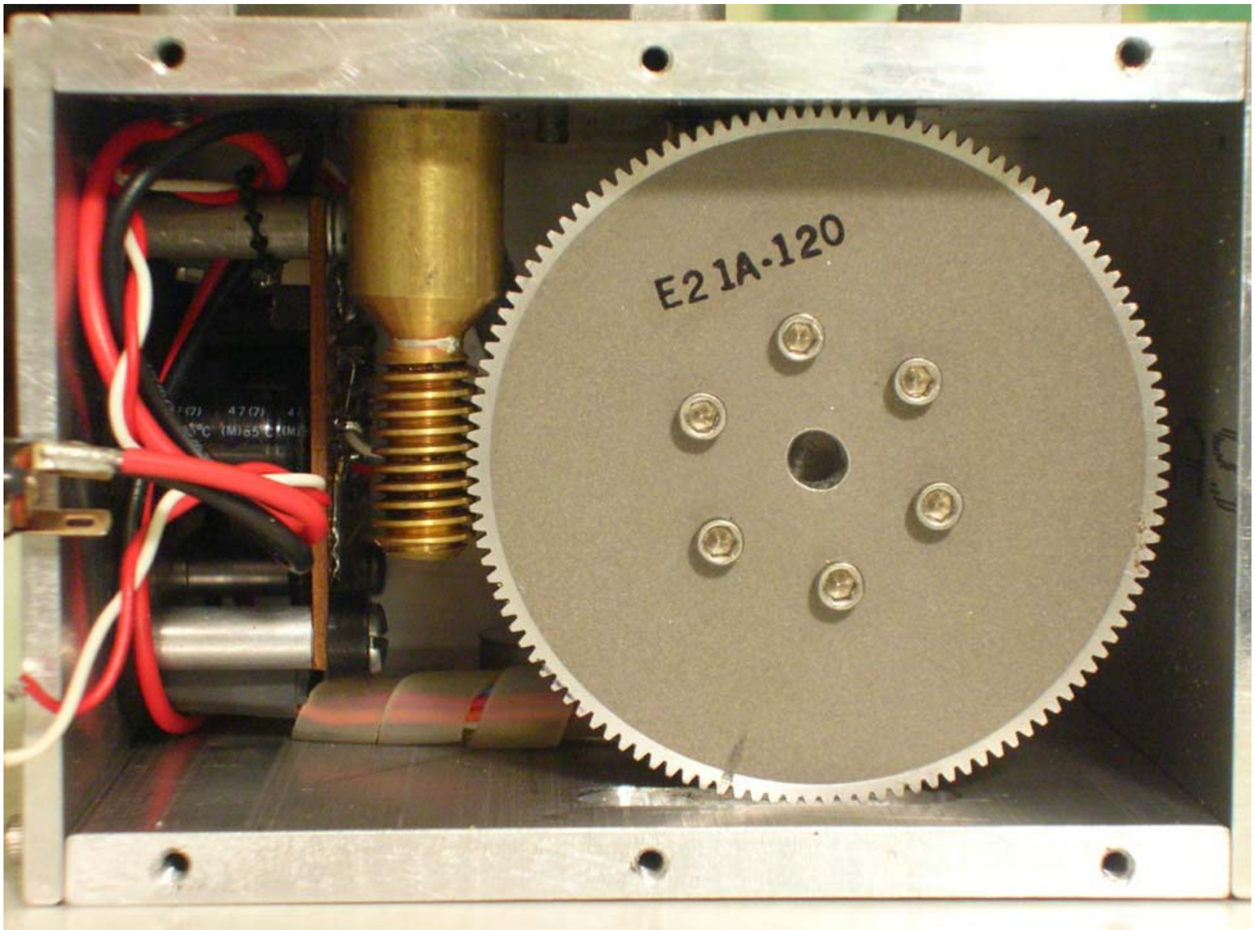


Figure 3. This close-up view shows the arrangement of the spiral worm, circular worm gear and electronics. Notice the milled slots in the top and bottom of the case that make space for the worm gear.

Geared Stepper Motors and Gear Calculations

You also need a geared unipolar (6-wire) stepper motor. Eric's stepper motor operated at 48 full steps per revolution, or 96 steps per revolution in half-step mode. Gears within this stepper motor provide 2000 full steps or 4000 half steps per revolution at the motor's output shaft. The worm gear described here has 120 teeth and a 41-2/3 ratio with the motor. A spreadsheet that accompanies this project lets you calculate the required steps and ratios for your own set-up. Download the spreadsheet, a large version of the schematic diagram at: www.gfreak.com/GF160/GF160_Tracker.zip. This file also includes full-size photos of the tracker mount and several of Eric's astrophotographs. (File size: 5.5 Mbytes.)

Any permanent-magnet geared stepper motor should work well. The higher the gear ratio, the better the system will work because you can use a higher step rate and thus reduce any lag, or time delay, between the steps which could cause star trailing in images.

Eric reported that his large equatorial mount, used with his telescope for deep sky astrophotography, uses Hurst stepper motors. Losmandy sells the the

Hurst geared stepper motors and a circuit board as part no. SM, listed in the "Replacement Parts for G-11 & GM 8G," at: www.losmandy.com/pricelist.html.

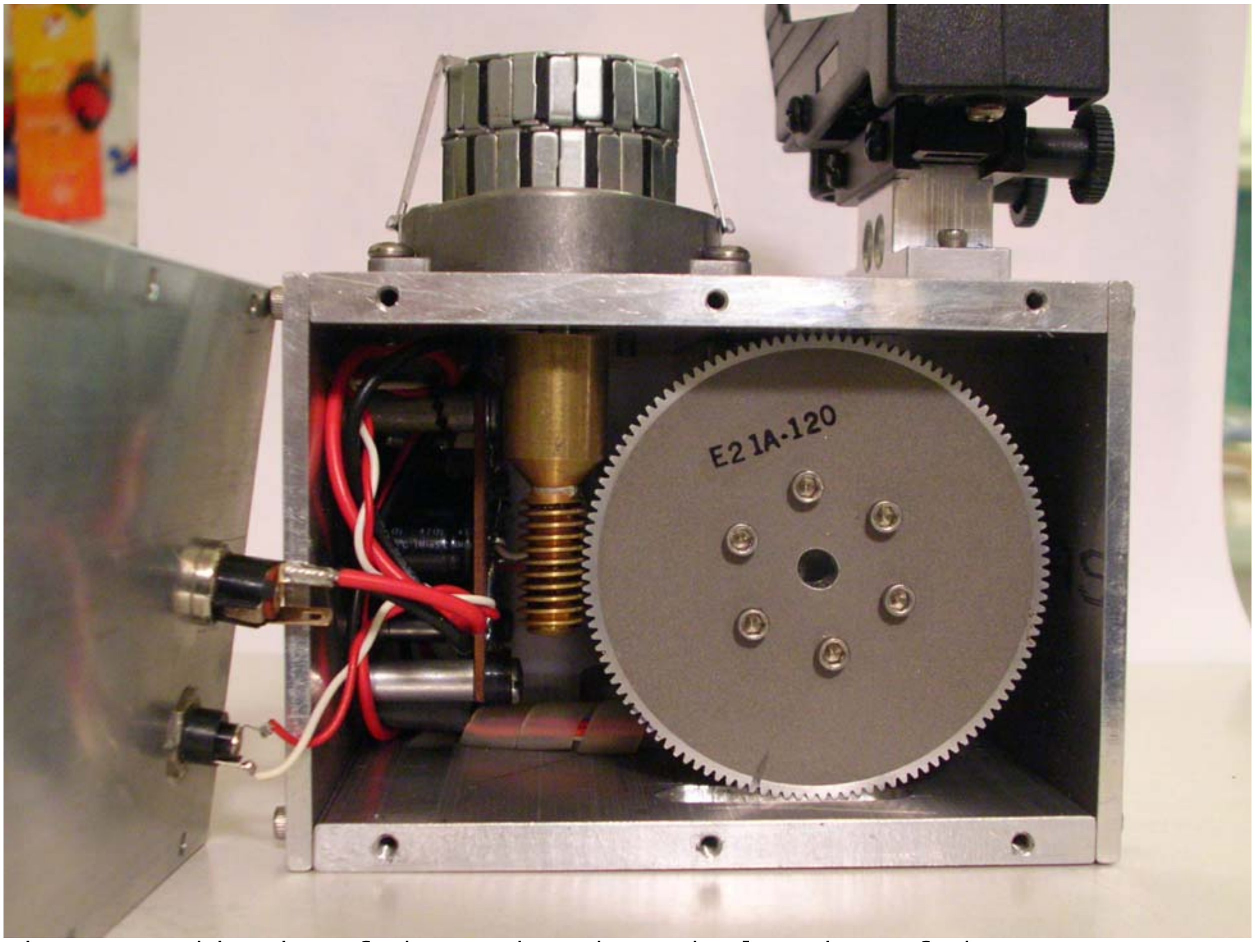


Figure 4. This view of the tracker shows the locations of the stepper motor and the view finder.

Find information about Hurst stepper motors at: www.hurst-motors.com/permanentmagnetdcstepper.html.

Any of these motors would work in the tracker. The size would probably depend on the required torque to move the camera. However, at very high step-down gear ratios, almost any motor provides enough torque. Here are links to the specific Hurst motor types:

Series 35 Geared: www.hurst-motors.com/lsg35geared.html
Series 42 Geared: www.hurst-motors.com/lsg42geared.html
Series AS, ABS Geared: www.hurst-motors.com/asabsgeared.html

SAIA-Burgess also manufactures geared stepper motors and has worldwide distributors. For information about the Rotational UBD Motors, visit: www.saia-motor.com/index.php?id=813. For information about compatible UGA-type gearboxes, visit: www.saia-motor.com/index.php?id=811.

Mounting Components

Eric's star tracker used a needle bearing block to support the rotating camera-drive shaft. Just about any combination of bearings and shafts would work as long as you have an appropriate and rigid mounting structure. Find information about mounted and flanged pillow bearings at: www.mcmaster.com/#mounted-bearings/=5hn29c.

Because rotations occur slowly, even a mounted bushing would work. However, you want as little "play" as possible in the shaft. For economy bearing blocks, visit: https://sdp-si.com/eStore/Direct.asp?GroupID=177, and for self-aligning press bearings, visit: https://sdp-si.com/eStore/Direct.asp?GroupID=1074.

Drive the Stepper Motor

In Eric's design--with the geared stepper motor driven in half-step mode and a 120-tooth worm gear--a pulse frequency of 5.57 steps per second provided the proper rotation rate of one main-shaft rotation every 23.9 hours. A Parallax BASIC Stamp BS-1 microcontroller (part no. BS1-IC) generated the stepper-motor pulses and a ULN2803 Darlington-array drove the stepper-motor coils as shown in the schematic diagram below. The BASIC Stamp 1 module is programmed in PBASIC 1.0, which is available as a free download from Parallax at: www.parallax.com. Eric used the Parallax BASIC Stamp 1 Serial Adapter (part no. 27111) to download code from his PC via a serial port to the BASIC Stamp 1 module. The company also offers a BASIC Stamp 1 starter kit.

Eric used only four of the eight ULN2803 outputs to drive the stepper-motor coils. He used the remaining four channels and four BS-1 outputs to operate four LEDs that indicate the on or off state of each motor coil. The LEDs indicate the motor operation, which is otherwise difficult to see because of its slow rotation rate.

The four connections between the motor and the ULN2803 include four diodes. If the stepper motor you choose includes similar diodes, you will not need those shown in the schematic. If in doubt, it cannot hurt the circuit to include the diodes.

Builders could substitute another type of microcontroller or even use a parallel-port output and their own software to create the quadrature pulses to drive the ULN2803 device. We leave the details to you.

Mechanical Components

The mechanical assembly requires some ingenuity and flexibility on the part of a builder because mounting the motor, gears, and other components relies heavily on the types of components selected or available. Eric placed his mechanics and electronics in a metal enclosure to keep dirt and moisture out of the motor and gear train.

You must buy or fabricate a camera clamp that will attach to the end of the worm-gear shaft. (Try Amazon.com and search for "ball head camera mount".) Most cameras can accept a short mounting screw with a 1/4-20 thread. Check the mount on your camera for any special requirements.

Optical Alignment

The star-tracker mechanism includes a view finder that lets a user properly align the shaft of the worm gear so the camera will rotate around the same "axis" as the Earth. You will need a small laser pointer to perform the initial alignment and you can use either of two mounting techniques. The Bill of Materials lists view finder suitable for this project.

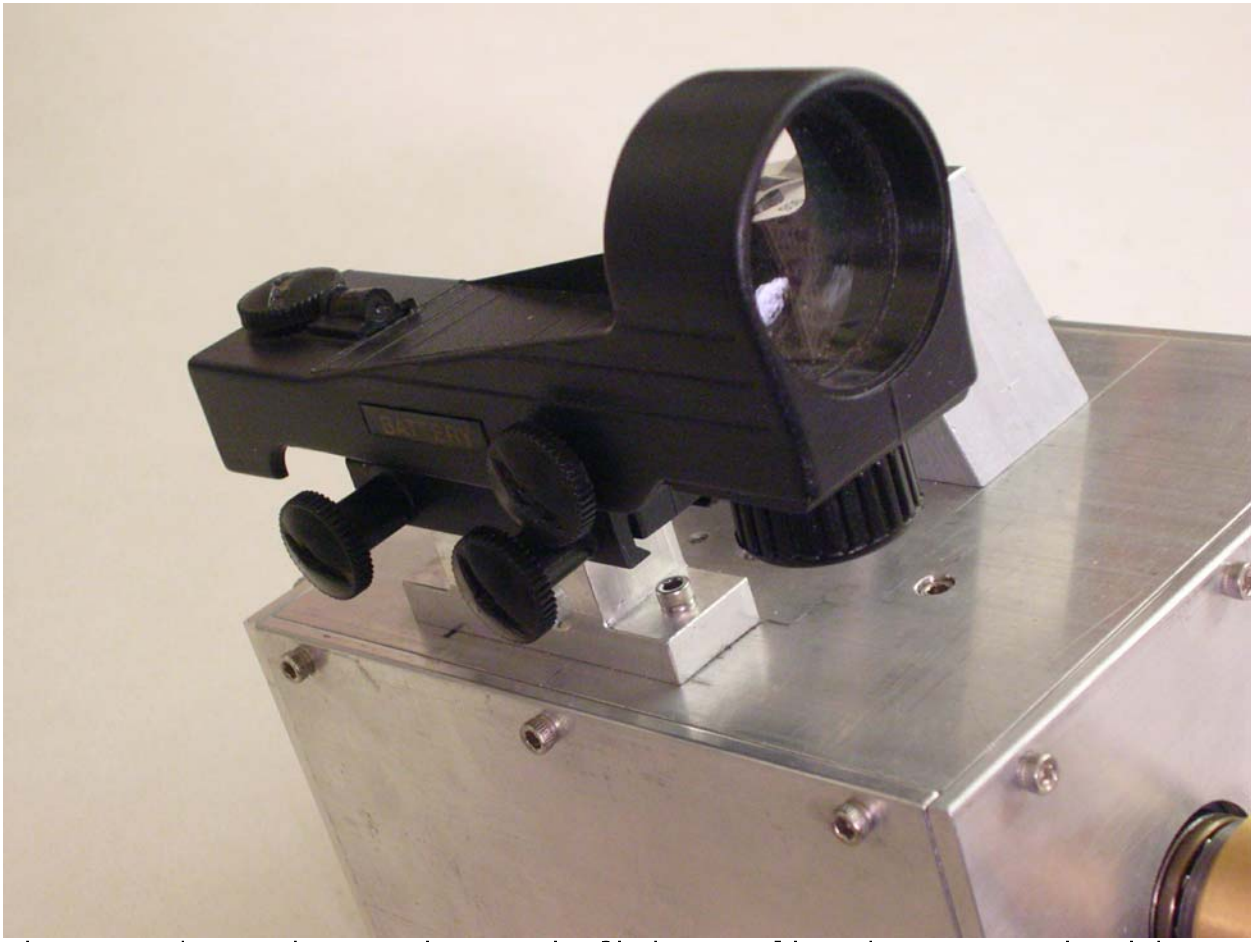


Figure 5. The tracker requires a viewfinder to align the camera axis with Polaris, the North Star.

The first technique uses a "V" block or clamp. This block has precision vees machined into two opposite sides. Place one vee on the shaft of the worm gear. Then place the small laser pointer in the other vee. The laser should point outward, away from the tracker assembly and you should have access to its on-off switch or button. Use a rubber band or masking tape to hold the laser pointer and the shaft firmly in the vee block. The laser pointer and the axis of the shaft should be very close to parallel. (Vee blocks are handy for holding round materials in a workshop. Visit Travers Tool Co. at www.travers.com and locate part no. 57-071-117, or visit ENCO at www.use-enco.com and locate part no. 420-5420.)

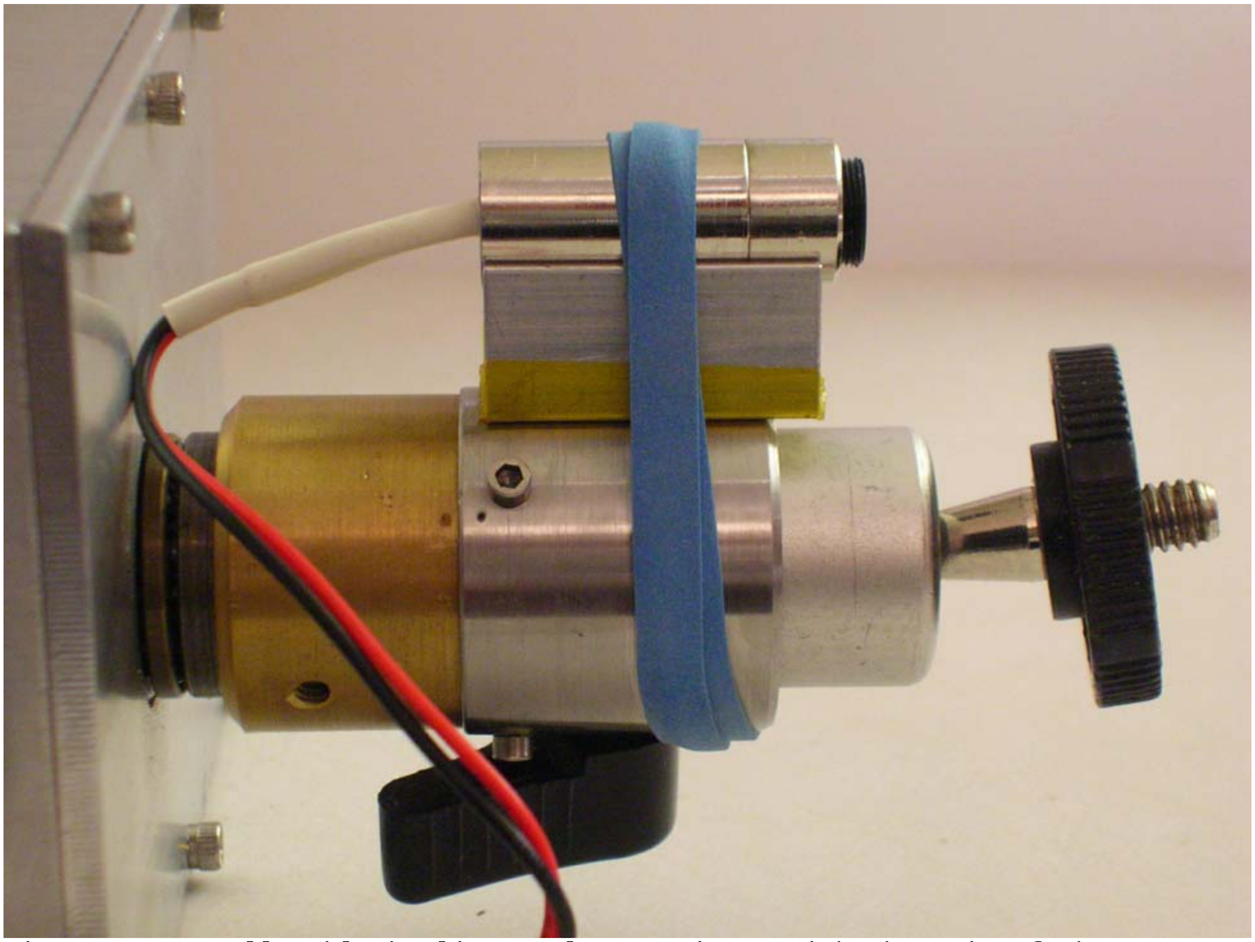


Figure 6. A small V block aligns a laser pointer with the axis of the motor-mount shaft.

The second technique uses two hexagonal 1/4-inch Allen wrenches to form a vee. Check the Allen wrenches to ensure they do not have nicks or burrs along their sides or edges. (It might be better to buy two new clean wrenches for a dollar or two apiece.) Clean the Allen wrenches to remove any oil or dirt. Place them on a flat surface and use a tiny amount of Superglue to hold them together tightly, flat side to flat side. After the glue dries, place the home-brew vee block on the shaft and mount the laser pointer parallel to the shaft. DO NOT glue the Allen wrenches to the worm-gear shaft. You can use acetone to dissolve the glue between the wrenches.

After you have secured the laser parallel to the worm-gear shaft, aim it at a distant target. A reflective traffic or street sign works particularly well because it produces a good reflection even at a long distance. Adjust the viewfinder so it aligns with the distant laser spot. Viewfinders have a center "spot" or use crosshairs to indicate their optical axis. Now you have the viewfinder set to align with the axis of the worm-gear shaft. Almost any viewfinder will work, but choose one that is easy to mount and align.

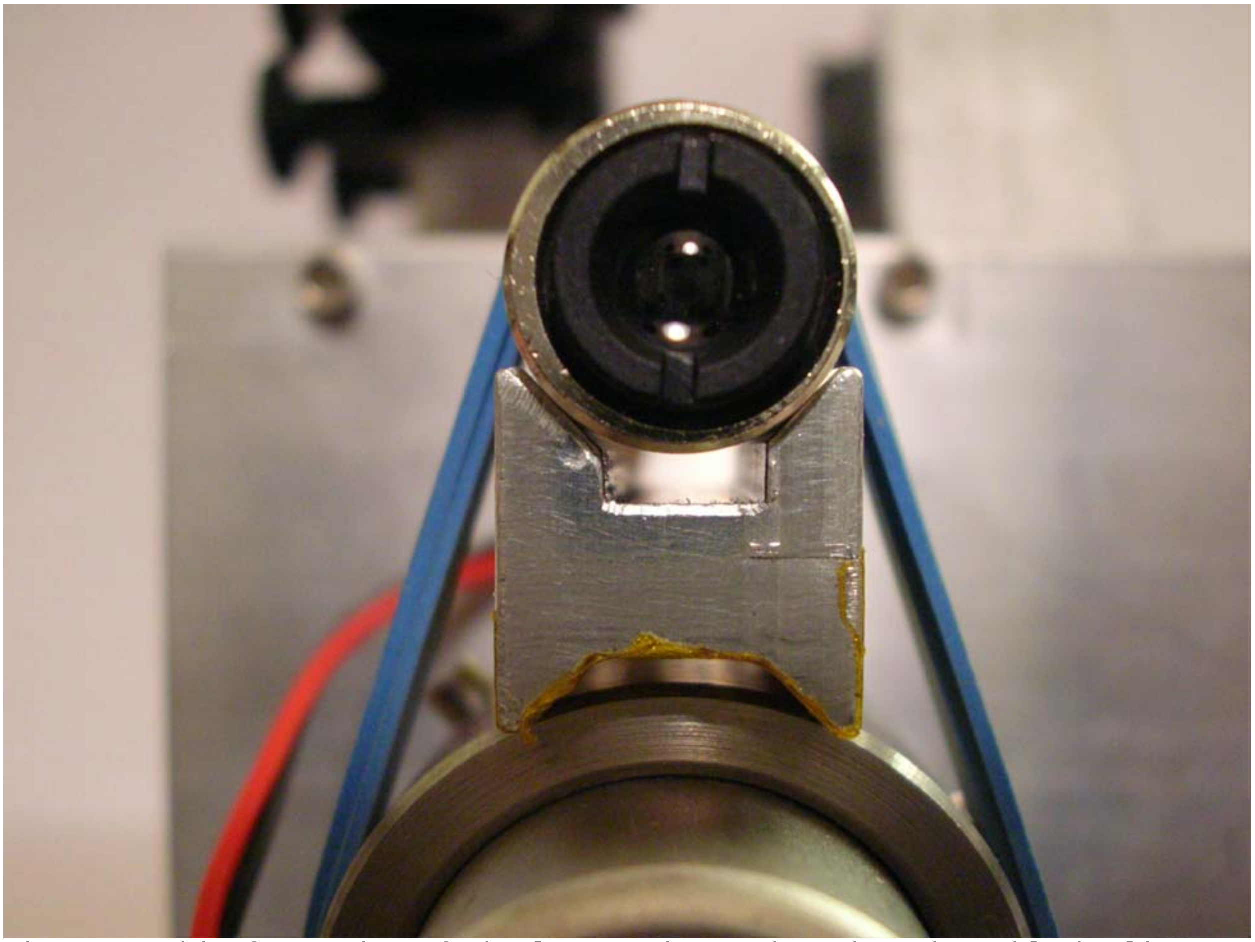


Figure 7. This front view of the laser pointer shows how the V block aligns the axis of the laser with that of the shaft.

After you align view finder with the laser pointer's dot, you can mount your star tracker on a good, all-metal tripod or similar solid mounting platform. (Remove the laser pointer and the vee block.) Then you need a star map to help you find Polaris, also known as the North Star. You can download a monthly star chart at Skymaps.com: www.skymaps.com/downloads.html or at Dan Bruton's Midnight Kite Web site: www.midnightkite.com/starcharts.html.

Or you can find a star map in *Astronomy* magazine or *Sky & Telescope* magazine. Visit your local library for issues.

Eric also recommends Roger W. Sinnott's spiral-bound "Sky & Telescope's Pocket Sky Atlas," available from Amazon.com for about $US 14.

Star Alignment

Locate the North Star, or Polaris, on the map. It's the star at the tail end of the Little Dipper, also known as Ursa Minor. Polaris lies very close to the Celestial North Pole (CNP) but not directly coincident with it. However, because Eric designed his tracker for wide-field use, an alignment of the tracker's worm-gear shaft with Polaris comes close enough and works very well.

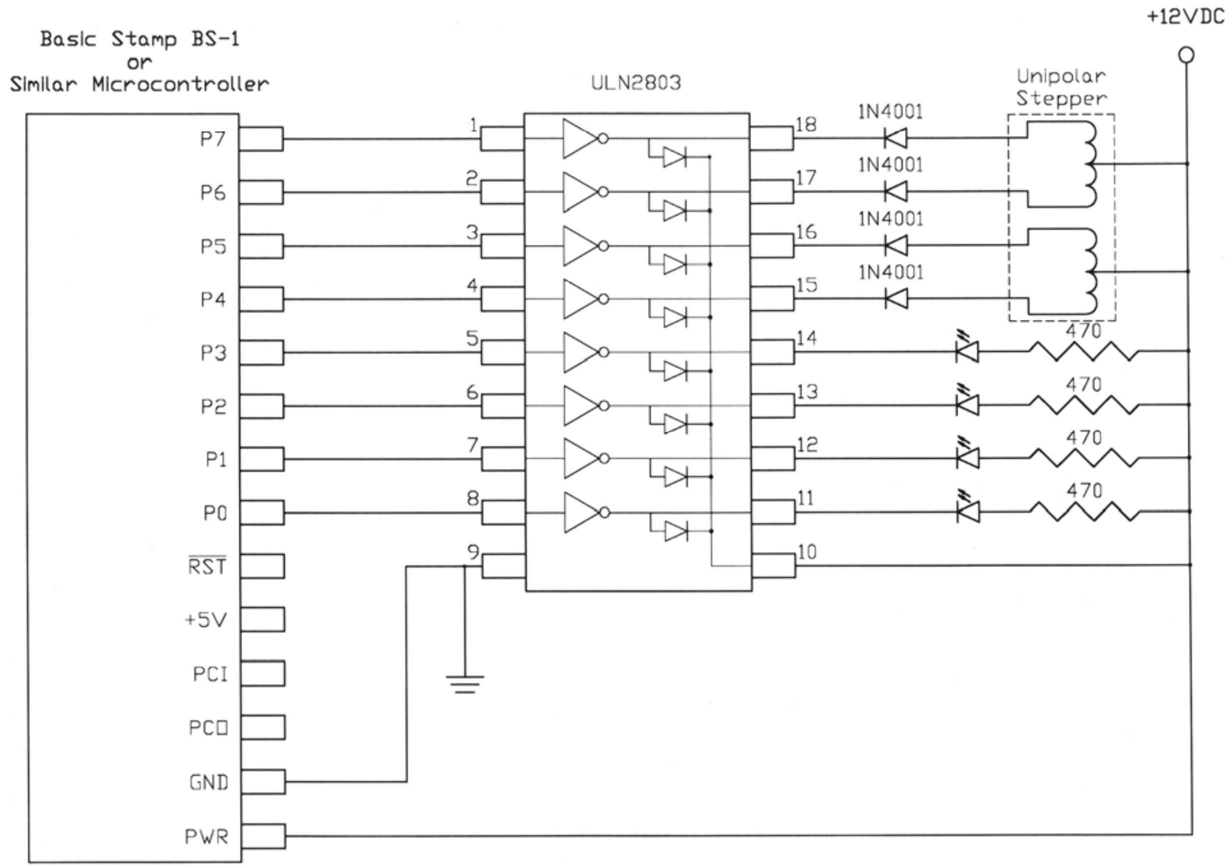
Eric noted he gets more accurate alignment when he loads the mount with the camera and lens before doing aligning the view finder with Polaris. This approach eliminates alignment error caused by any flex in the tripod or mount when you attach the camera and lens later.

There is no need to attempt to move the alignment to the axis of the CNP. Now, move the tracker so you have Polaris centered in the viewfinder. A general alignment should allow lengthy exposures for cameras with a focal length of 70 mm or lower. Eric reported using his mounts with a camera that offers 100-to-120-mm focal lengths, but he gets better results at shorter focal lengths. "For this design and a quick, non-precise polar alignment the mount is probably ideal for focal lengths below 70 mm," he noted.

BASIC Stamp 1 Program Listing

```
dirs=%11111111
abc:
 pins=%10101010
 pause 432
 pins=%10001000
 pause 432
 pins=%10011001
 pause 432
 pins=%00010001
 pause 432
 pins=%01010101
 pause 432
 pins=%01000100
 pause 432
 pins=%01100110
 pause 432
 pins=%00100010
 pause 432
goto abc
```

Schematic Diagram



For a larger version of this schematic diagram, go to:
www.gfreak.com/GF160/GF160_Tracker.zip.

Bill of Materials

Amt.	Description	Allied Part No.
1	ULN2803A, Darlington Array	248-9280
4	470-ohm Resistor, 1/4W	296-4768
4	Red LED	405-0053
1	Red Laser Pointer	245-0068
1	DC Power Connector	283-2551
1	Breadboard, 4x4 inches	977-1256
4	1N4001, 50V Diode	950-0466
1	5V, 1A Voltage Regulator	935-3020
1	Power Supply, 12V, 1.25A	653-0137
1	Power Supply Adapter Plug Clip	653-0260
1	Power Supply International Adapters	653-0003

Recommended finder scope or view finder:

Orion Telescopes and Binoculars, Model No. 07228, Orion EZ Finder II Telescope Reflex Sight. www.telescope.com.

Stellarvue, Model No. F1001, Stellarvue Red Dot Finder. www.stellarvue.com.

Astrophotographers or astronomy hobbyists can often find motors, view finders, and other used components at Astromart (www.astromart.com) and at Cloudy Nights Classifieds (www.cloudynights.com/classifieds/.

Reference:

For a tutorial about stepper motors, visit:
www.solarbotics.net/library/pdflib/pdf/motorbas.pdf

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