

CONSTRUCTION AND ASSEMBLY

Now down to the work that is really fun and rewarding. I will describe the way that I assembled my tracking system but you will probably want to substitute some of your own ideas. I have broken the construction and assembly into pieces that are labeled on [\(figure 8\)](#).

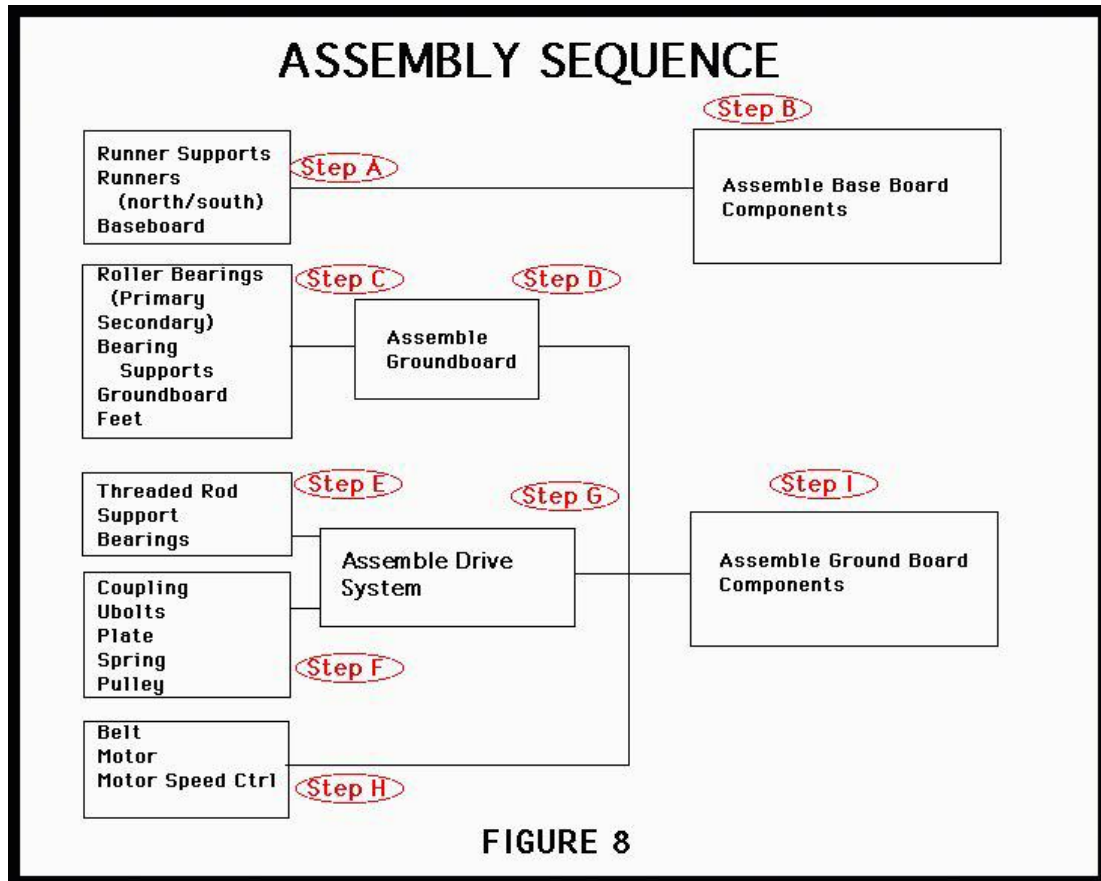


FIGURE 8

The diagram [\(figure 8\)](#) is for organization of your thoughts, and does not have to be done in the order that I have written. At each step I will describe the following components of the construction and assembly: Plans, Materials, Fabrication, Finishing, Assembly.

STEP A

RUNNERS (NORTH AND SOUTH)

-PLANS

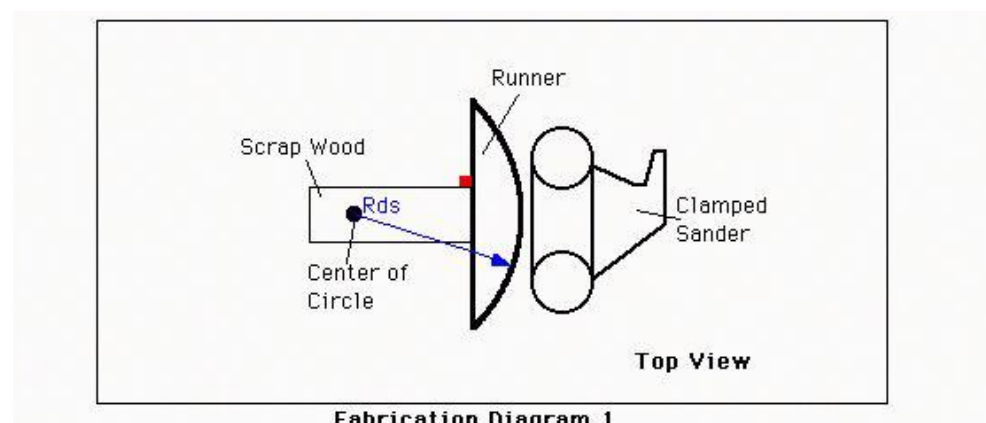
The dimensions of the runners are given on the spreadsheet. Remember that the runners are actually cut-off segments of circles. The radius of the North runner is R_{nb} , and the radius of the south runner is R_{sb} . The north runner has a larger radius and is wider than the south runner, but the height of the runners is the same. Before you do any cutting on the runners make sure that the runners fit under the groundboard. For example; if your runners are 4 inches high and you have your reference line drawn at 2.25 inches below the groundboard, the runners will not fit correctly.

-MATERIALS

I am an avid woodworker so I used 1"; thick Cherry boards that I had on hand. A few other choices would be maple or sycamore. Keep in mind that if you use wood you will have to take care that you don't ding the surface that the bearing runs on. Any imperfections in the runner surface will show up in the eyepiece. If you have access to someone who can work with aluminium, this would be a more durable choice.

-FABRICATION

1. Lay out the dimensions on your material. I recommend that the flat edge of the material be lined up with the flat edge of the runner, that way you only have to cut the curved surface.
2. Cut the curved surface with a bandsaw or saber saw. There is no reason to be very accurate with this first cut because we will clean that up later. Do not cut on the line, but make sure that the entire line is visible.
3. Temporarily tack your runner to a scrap piece of wood shown in ([fabrication diagram 1](#)) Use a square to make sure that the scrap piece of wood is perpendicular to the runner's flat surface.



4. Mark the center of the circle (Rnb) on the scrap piece of wood and drive a nail through it. This will let the runner rotate at the radius that you want (Rnb).

5. Clamp a belt sander so that it just barely touches the rough-cut runner. Turn on the sander and slowly rotate the runner so that it grazes the sander. Repeat this process until there is no resistance when you rotate the runner past the sander. Move the sander a very small distance closer to the runner and repeat until you have sanded exactly up to, but not all the way through your curved line. Use a square to make sure that the newly sanded surface is perpendicular to the other surfaces. The runners are the most important pieces to the correct movement of your system. Take your time and make them as accurate as you can.

-FINISHING

1. Sand all surfaces. Carefully sand the curved surface and the flat surfaces that touch the bearings with fine sandpaper.

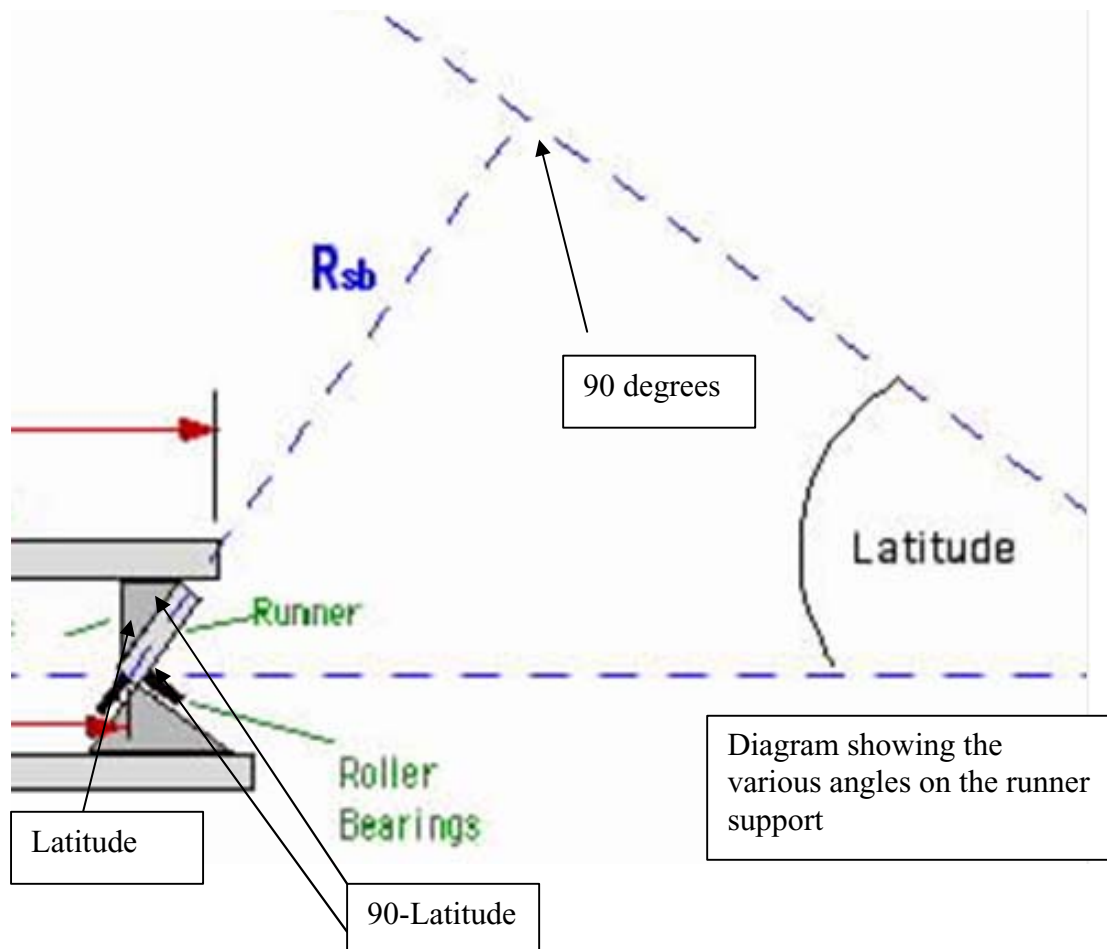
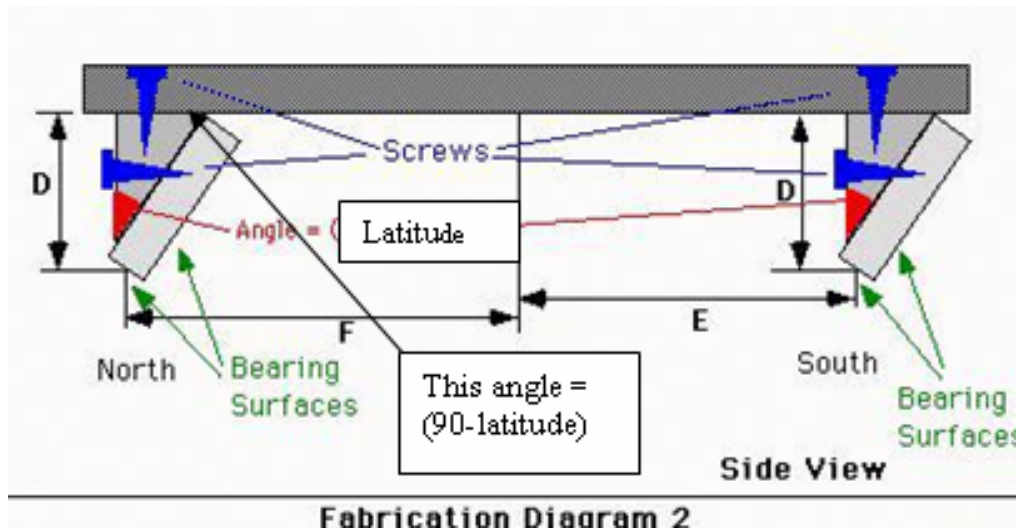
2. Apply at least 2-3 coats of polyurethane. This will seal the wood from the moisture that it will see in the field and make it look great.

3. Re-sand the bearing surfaces with extremely fine grit sandpaper. (400-grit wet-dry paper worked well for me) If you sanded through the polyurethane to the wood, apply another coat of polyurethane and repeat. Once you have a smooth surface, rub it down with .000 Steel Wool. Your bearing surface should have a polished appearance. These surfaces are the first step in creating rock solid images. Take your time.

RUNNER SUPPORTS

-PLANS

The supports attach the runners to the groundboard, and at the correct angle. The geometry is indicated in (fabrication [diagram 2](#)). Make the support thick enough so that you have enough room for your attachment hardware to penetrate the support.



-MATERIALS

The material for the supports is your choice. Since I used 1" thick cherry on the runners, I used the same for the supports.

-FABRICATION

I have a nice tip that will help you make accurate angled cuts without using the "not so accurate" devices on power equipment. Carefully draw a right triangle on a piece of thick paper or cardboard. The angles should be (latitude) and (90-latitude). Cut this out and take it to the shop to use as a template when setting up the angle on a table saw or other equipment. Make it at least 12" long so that it is easy to handle.

-FINISH

2-3 Coats of polyurethane. Smooth finish is only needed for esthetics.

BASEBOARD

-PLANS

The baseboard is the surface that your telescope will set on. The length and width is "C" as shown on (figure 4). The "C" dimension should be larger than your telescope base, but not too much larger.

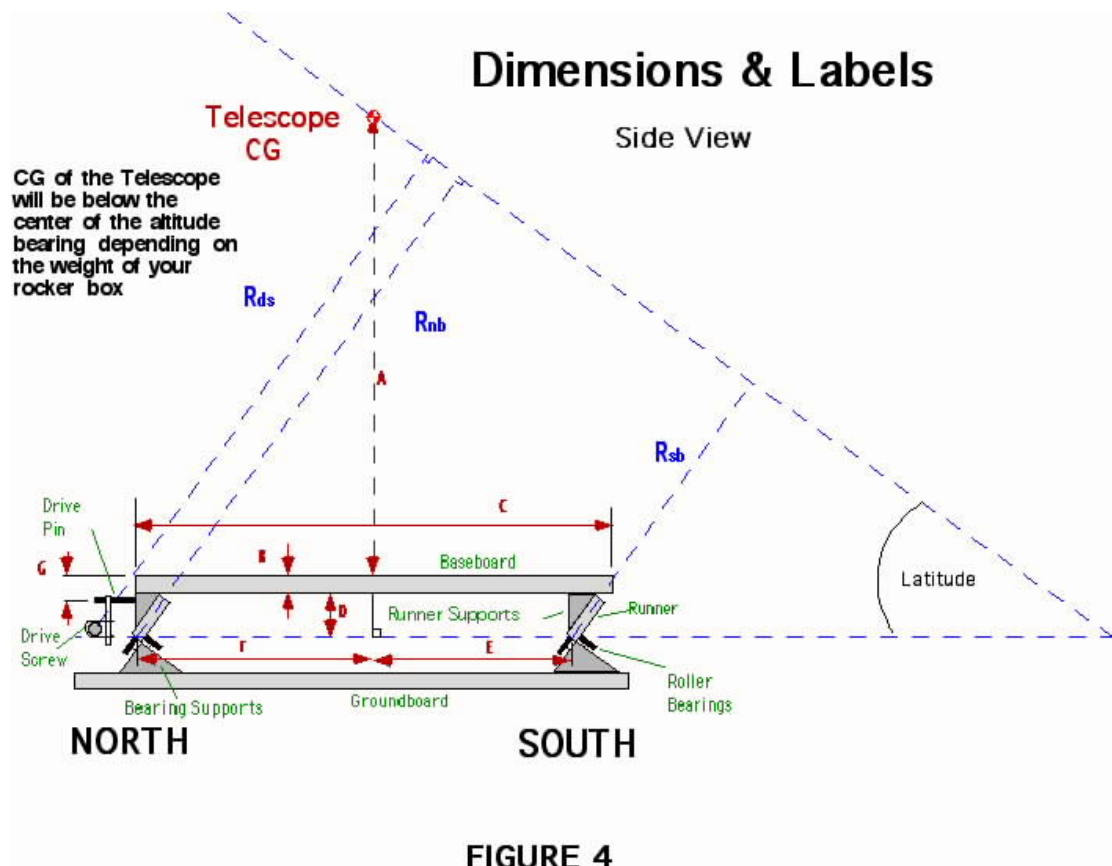


FIGURE 4

-MATERIALS

I used .75 inch particle-board for the groundboard and baseboard. Particle-board is a stable material as long as it remains dry (you must be careful to seal it well), but it is also surprisingly heavy. I would think that plywood would be a suitable choice also. If you are able to obtain Aluminum in the size you need, that would reduce the weight. Keep in mind that we all like things light so that they are easy to carry, but if it is too light, it will not be as stable.

-FABRICATION

Cut the square piece with a table saw or circular saw. If you use a circular saw, clamp a 2x4 near the line to make the cut straight and accurate. Make sure that your baseboard is absolutely square. It is not necessary for the operation of the system, but it will help when you start lining up your components during assembly.

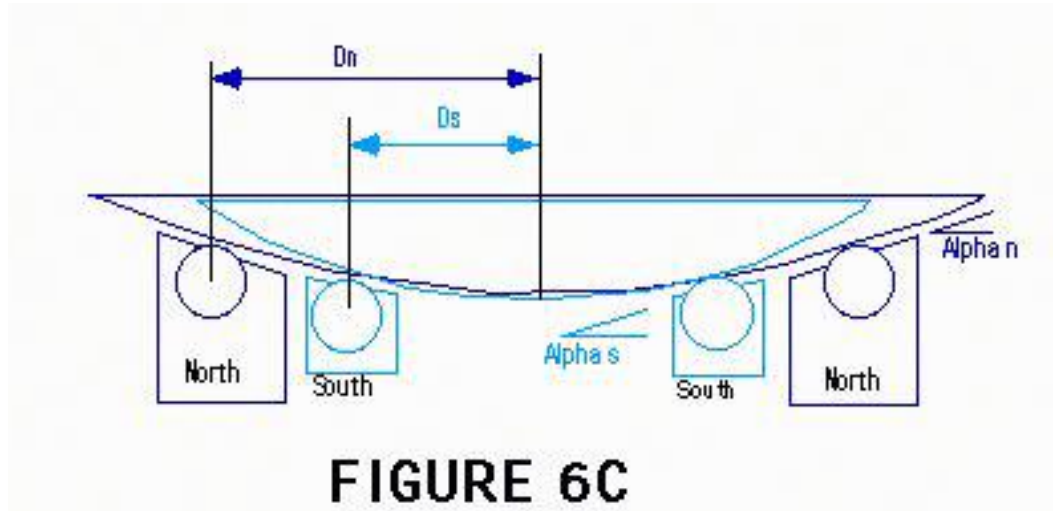
-FINISH

I gave all surfaces 3-4 coats of a water-based, black enamel paint. It is vital that the particle board be completely sealed to keep moisture out. I also added another step that made the edges more durable, and pretty. I applied some formica (lamine) to the edges using contact cement. If you have used a router and a laminate trimmer bit, this would be self explanatory. If you have not used a router, I would recommend just filling any cracks and voids with putty and painting it to make it look better.

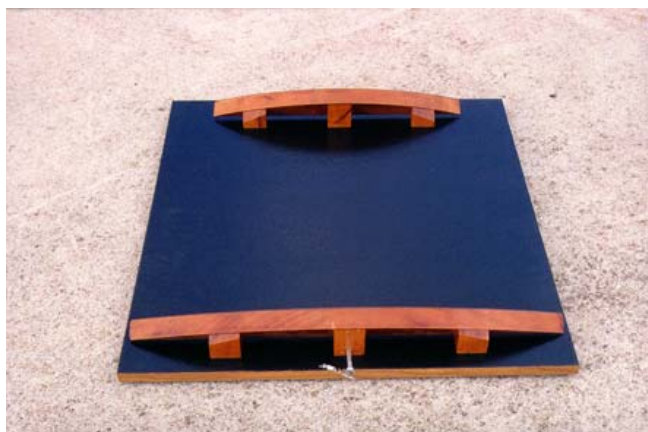
STEP B (Assembly of Baseboard)

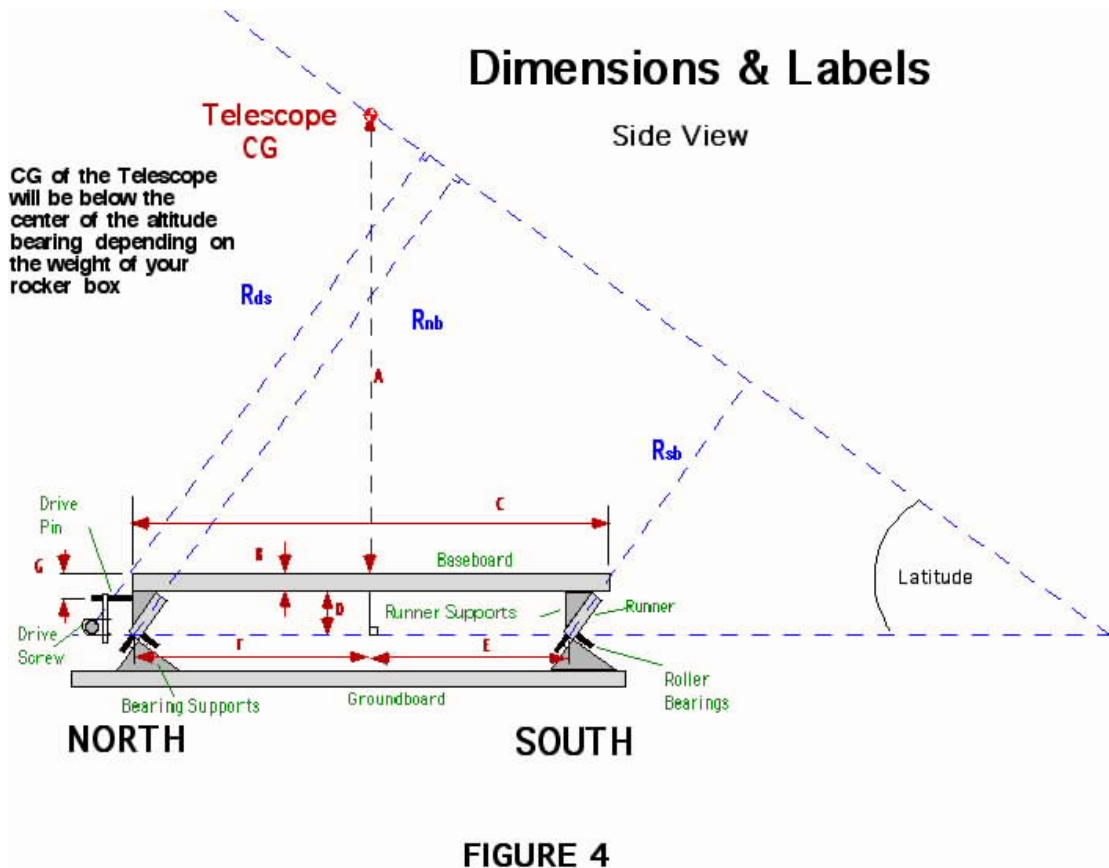
-ATTACH SUPPORTS TO RUNNERS

1. A roll of two-way (carpet) tape is invaluable in this step. Place the tape on the support so that you are able to stick it to the runner, but will be able to remove it when you want to reposition the support. I marked the runner exactly where I wanted the supports to be located, and marked the center of the supports so that they would be easy to line up. It works out nicely for alignment if you place the supports exactly above the location where the primary bearing will be located. ([figure 6C](#))



2. Temporarily stick the supports to the runner and turn it upside down ([P5, runners](#)) Make sure that the flat side of the runner is parallel to the baseboard and that the centerline of the curved surface on the runner is the distance D_s in ([figure 4](#)) Use the centerline of the curved bearing surface for this measurement because that is where the bearing will contact the runner.





3. Once you have your geometry set drill a pilot hole and screw the runners and supports together. I highly recommend screws for attaching everything. Screws are reversible, nails are not. Recessing the screw heads is not necessary, but it does look professional.

-ATTACH RUNNER ASSEMBLIES TO THE BASEBOARD

1. Again, apply carpet tape to the top of the support so that it can be positioned and repositioned on the baseboard. Also mark the center of the sides of the baseboard. Since it is hard to mark on black paint, place some wide masking tape to the baseboard in the necessary areas and mark on the tape. You can easily peel the tape (and the marks) off later.
2. Line the runner up so that it is parallel to the edge of the baseboard
3. The centerline of the curved surfaces should be the distances "E" and "F" from the center of the baseboard. ([figure 4 above](#))
4. Attach the supports to the baseboard using screws.

STEP C

ROLLER BEARINGS (PRIMARY AND SECONDARY)

-PLANS

The primary and secondary bearings may be the same size, but the size is arbitrary. I made my bearings the same thickness as the thickness of my runner so that the load would be well distributed. I had my bearings custom made by a friend who runs a machine shop, but I'm sure that most people don't have that kind of connections. Lowe's, Home Depot or other stores of that type should have a selection of bearings to choose from.

-MATERIALS

If you made your runners out of wood, I would suggest a softer material such as plastic for the bearings. I had my bearings made out of Delrin (kind of like hard Teflon). If you used metal runners, I think that metal bearings would be better. You want to closely match the hardness of the runner to the hardness of the bearing.

-FABRICATION

This is the way I made my bearing. The bearing itself is a disk with a hole drilled in the exact center. The hole is countersunk to accept the bolt that I bought. I bought a curved washer that would let the bearing run on a small surface rather than directly on the bearing support. (Fabrication Diagram 3) This washer reduces the friction on the bearing. The area of the bolt that touches the bearing should not have threads on it, but should be a straight shaft. For good bearing operation, it is a good idea to polish the bolt shaft so that there is little friction between the bolt and the bearing. Do not over tighten the bolt.

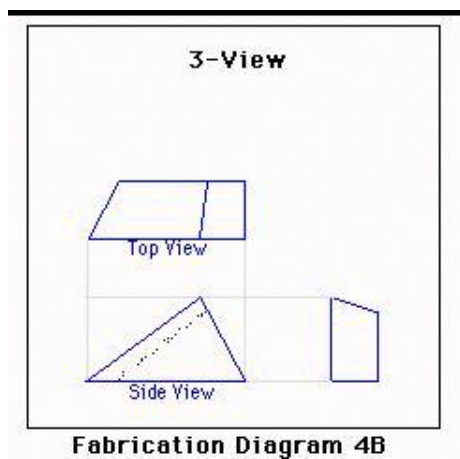
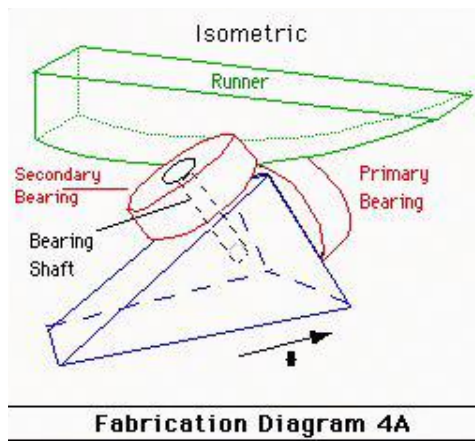
-FINISH

None

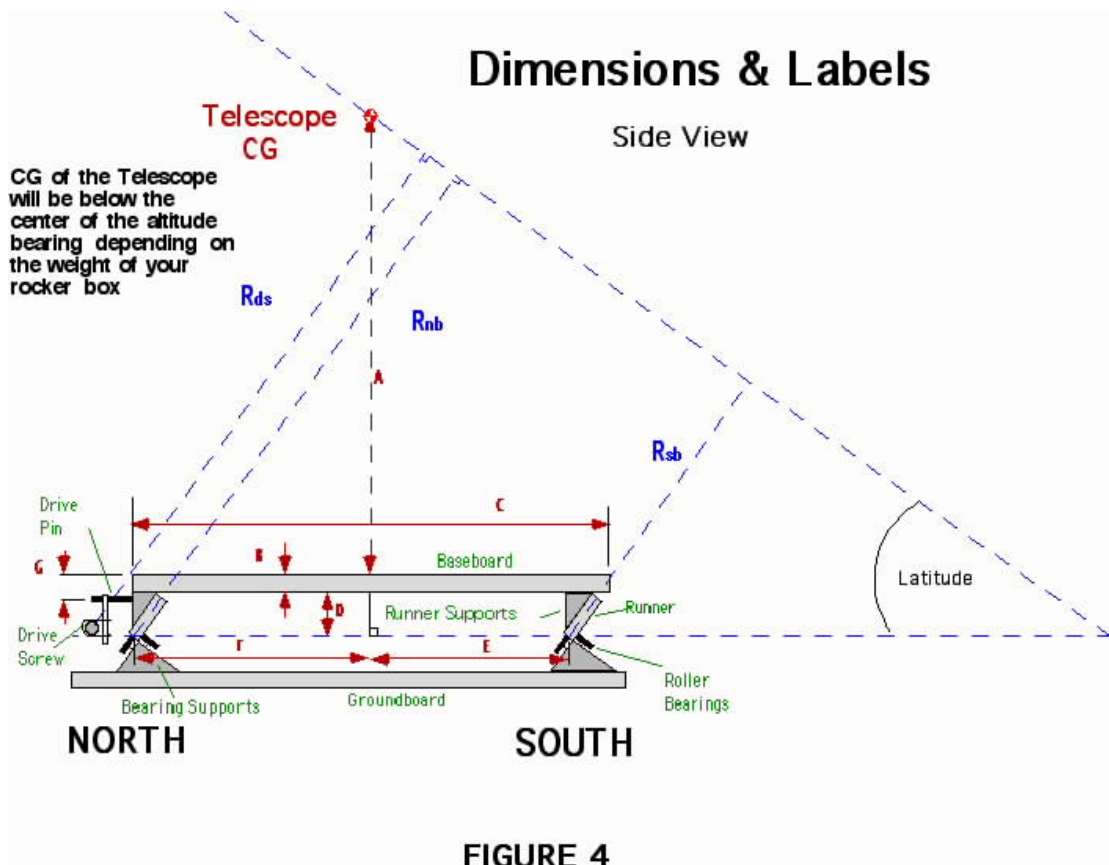
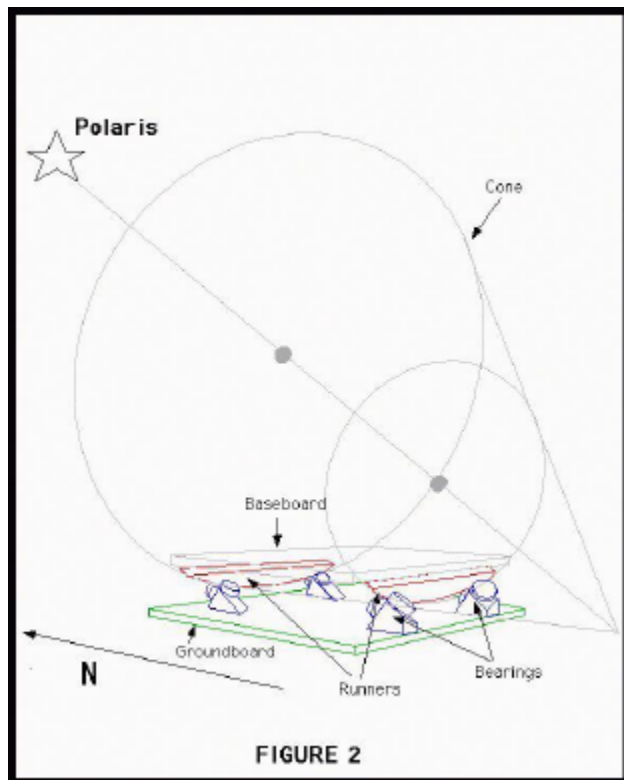
BEARING SUPPORTS

-PLANS

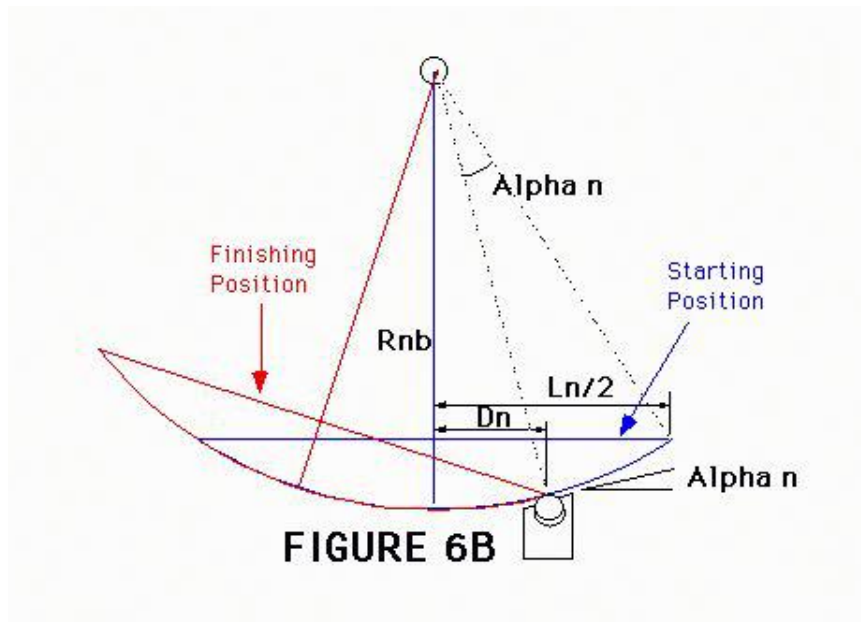
Most of the parts so far could be understood by seeing a side or top view alone, but this one is a little more difficult. I have included a couple of figures and pictures to help you "picture" how this part works. Look at (fabrication [diagram 4A](#) and [diagram 4B](#)) and ([P6, Bearing](#)).



The necessity for this somewhat complex geometry is for lining up the bearing shafts correctly. The shaft of the primary bearing should be pointing in the same direction as the center of our imaginary cone ([figure 2](#)), ([figure 4](#)).



The shaft of the secondary bearing should be oriented 90 degrees from the primary bearing ([figure 4 above](#)), AND pointed at the centerline of the imaginary cone ([figure 6B](#)).



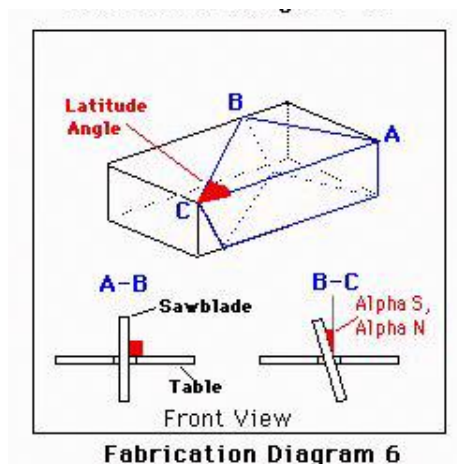
See (fabrication Diagram 5) for correct angles on side and front view. Please note that all 4 bearing supports will be different.

-MATERIALS

I recommend wood for the bearing supports, such as maple or cherry. You may have to glue up a few boards in order to get a thick enough part. The thickness of the support is also arbitrary, but I wouldn't use less than 2.5 inches.

-FABRICATION

1. Lay out the side view of the triangle on the block of wood. ([fabrication diagram 6](#))



2. Set the angle of the table saw blade to Alpha-N or Alpha-S.

3. Set the miter fence of the saw at the latitude angle. This is another place that you can use the template.

4. Make Cut B-C

5. Reset the Saw blade angle to 90 degrees (straight up and down)

6. Set the miter fence to (90-latitude) degrees.

7. Make cut A-B

-FINISH

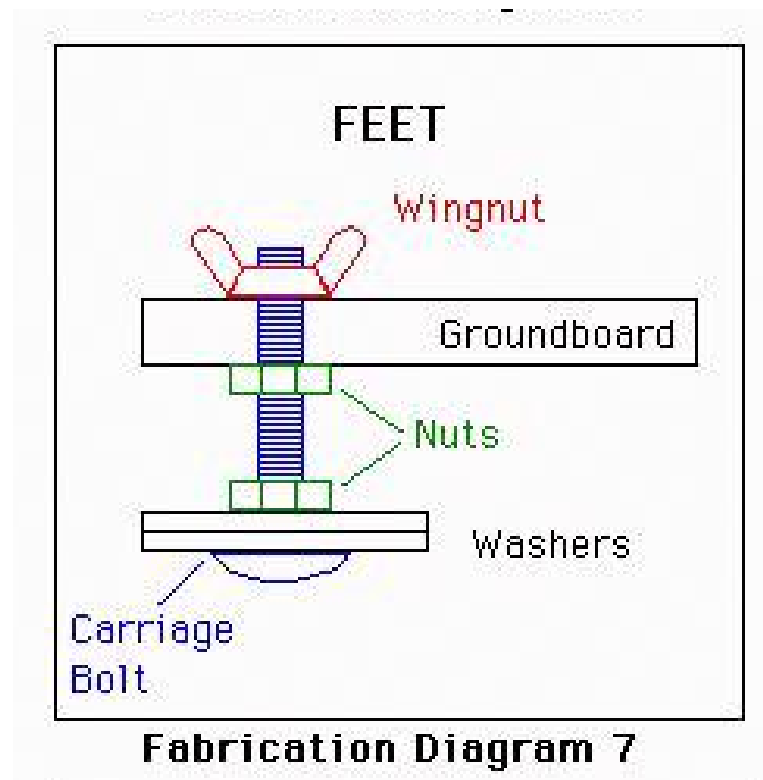
Multiple coats of Polyurethane, all sides.

GROUNDBOARD

-The groundboard should be made using the same process as the baseboard. The only change is the dimensions. The width should be the same as the baseboard, but the length should be several inches longer than the baseboard. This extra length is necessary for a location of the motor mount and drive system

FEET

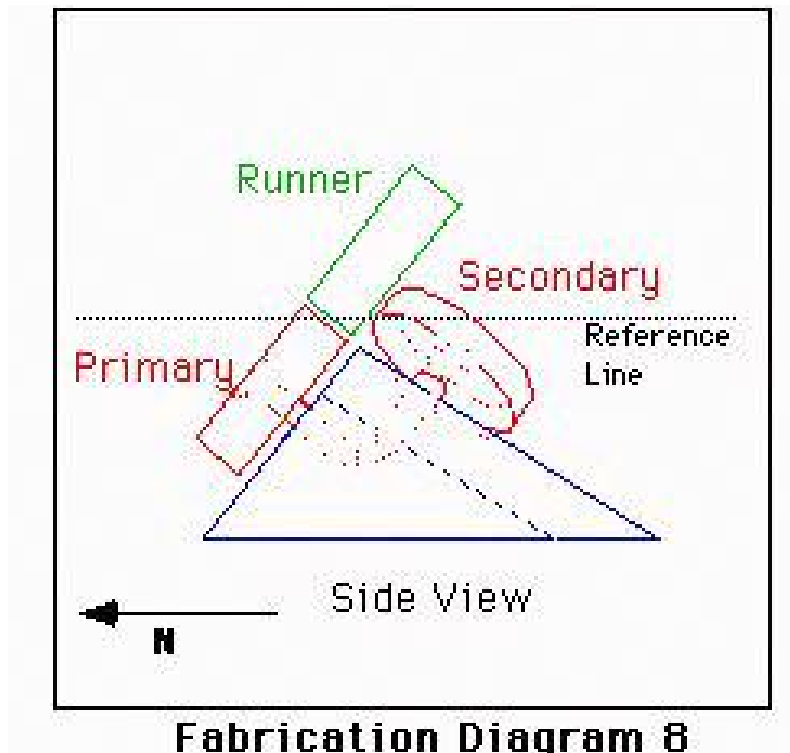
Assemble the bolts and nuts in (fabrication [diagram 7](#)). You may want to use either 3 or 4 feet. Something with three feet is easier to level, but 4 is more stable.



STEP D

BEARING ASSEMBLIES

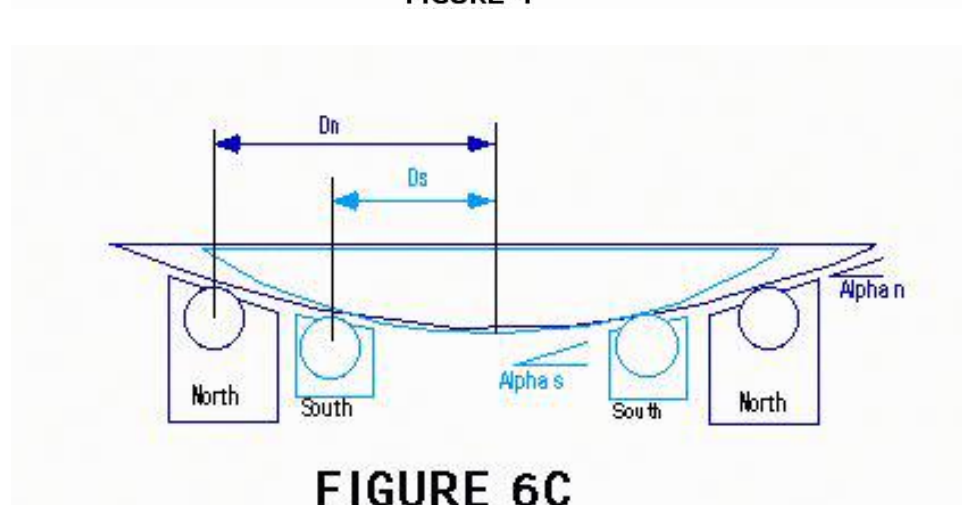
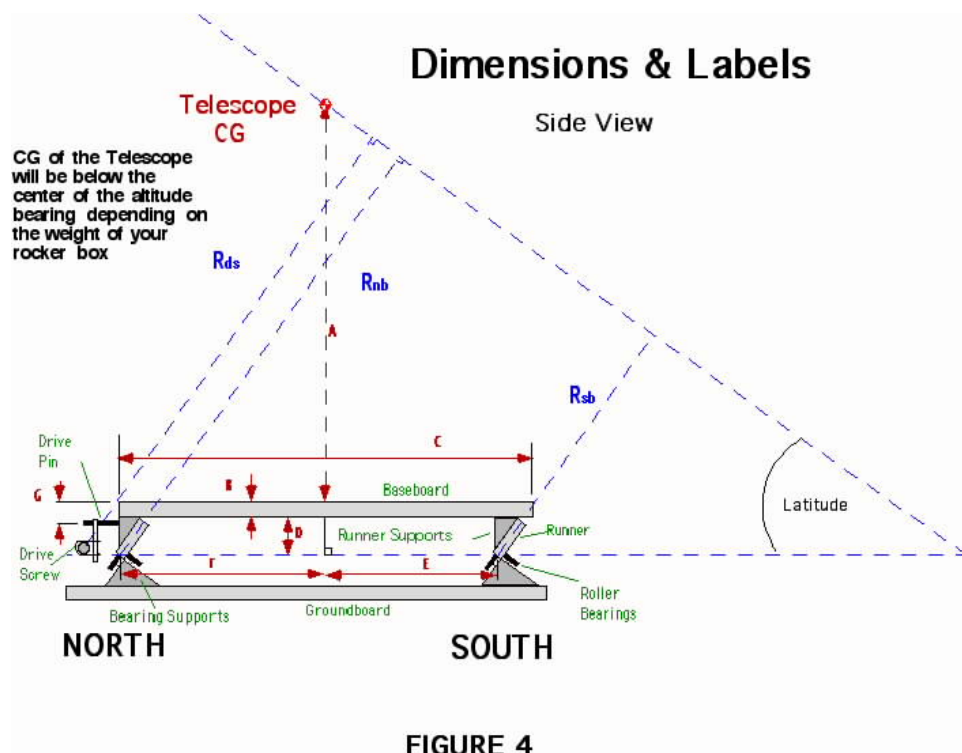
1. Line up primary bearing shaft so that the bearing will touch the runner edge (fabrication [diagram 8](#)).



2. Drill a hole in the north bearing support perpendicular to the surface. Use a jig of some sort to make sure that the hole is square to the surface.
3. Mount shaft of bearing into hole to check alignment.
4. Line up secondary shaft so that the bearing will touch the backside of the runner (fabrication [diagram 8](#)).
5. Drill a hole in the north bearing support perpendicular to the surface. Use a jig of some sort to make sure that the hole is square to the surface. Remember that the shaft of this bearing will point toward the central axis of our imaginary cone, and not straight up.
6. Mount shaft of bearing into hole to check alignment. Use the runner for the fit-check. The surfaces of the bearings should make complete contact with the runner surfaces. Make sure that the bearings are not tilted so that they touch at a single point.

GROUNDBOARD ASSEMBLY

1. I highly recommend two people for this part of the assembly. The work is not heavy, but the extra pair of hands will be invaluable.
2. Place masking tape on the groundboard at the approximate locations that the bearing assemblies will sit. This will let you to make marks on the groundboard that you will use for alignment.
3. Apply carpet (2-way) tape to the bottom of the bearing supports and place them in the locations that you called out in your dimensions ([figure 4](#)), ([figure 6C](#))



4. Set the completed baseboard (with runners) on the bearing assemblies and check the fit. This is where the two people come in handy. The carpet tape is not strong enough to make the bearing assemblies stick if the entire weight of the baseboard is placed on it. If the bearing assemblies don't stick well enough to the groundboard, try using hot-glue. It sticks very well, but has to be scraped off every time you reposition the bearing assemblies. Make sure that as the runners can rotate back and forth, they make complete contact with every bearing surface. I doubt that any one calculations will be good enough to make this work on the first try.

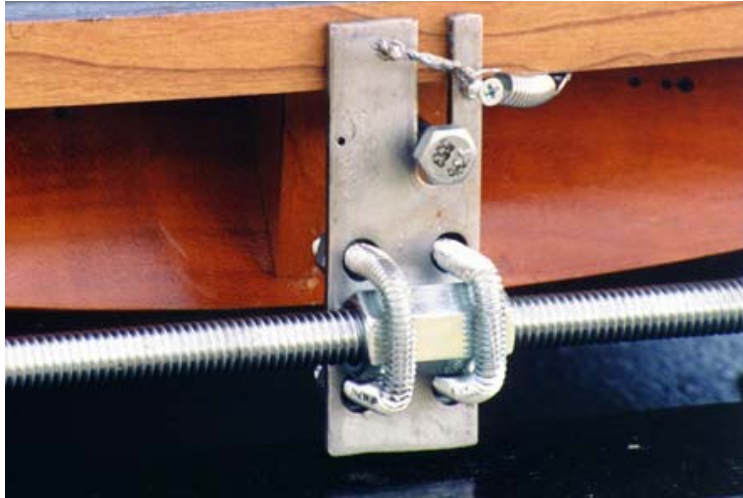
5. Pick up the baseboard and reposition the bearing assemblies. Retry step 4 until the runners can rotate from side to side without rotating off one or more of the bearing assemblies.

6. Screw the assemblies in place from the bottom.

7. At this point I encourage you to give your system it's initial test. Set the telescope on the baseboard and rotate the assembly back and forth. If your baseboard assembly had a tendency to rotate off one of the bearing assemblies by a small amount, the weight of the telescope and mount may be enough to make better contact. Use your latitude angle template to set your telescope at the latitude angle. The scope should theoretically be pointed at Polaris. Now as you rock your assembly back and forth on the bearings, the telescope tube should rotate about the center of the tube and not translate from side to side. I'm sure that you will enjoy this immensely. By now you have worked long and hard and it is the first sign that you are on your way to success!

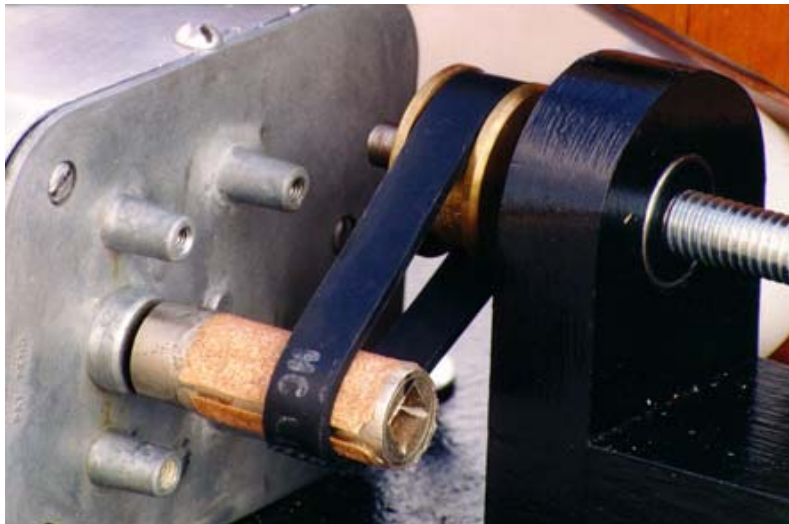
STEP E

[THREADED ROD \(P2, Drive\)](#)



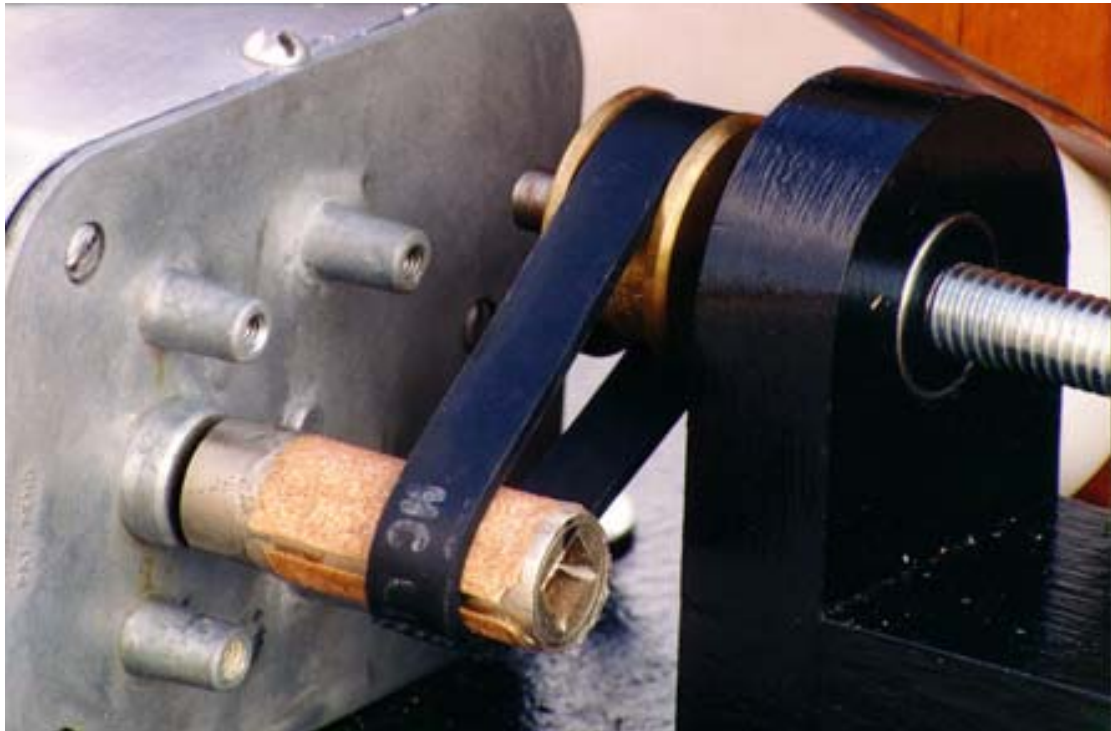
You can buy a threaded rod at most hardware stores. You can choose the rod diameter and threads/inch so that your calculations in the spreadsheet turn out the way you want them. The threaded rod is a portion of an economical worm gear that you will build yourself. Buy at least 2 feet of length.

[THREADED ROD BEARINGS \(P2, Belt\)](#)



You can buy these at a well-supplied hardware store such as Lowes. I actually ended up buying mine at a power-tool repair shop. For \$10 I bought a pair of high speed encased ball bearings. Make sure that your threaded rod will fit inside the center of your ball bearings.

THREADED ROD SUPPORTS (P2, Belt)



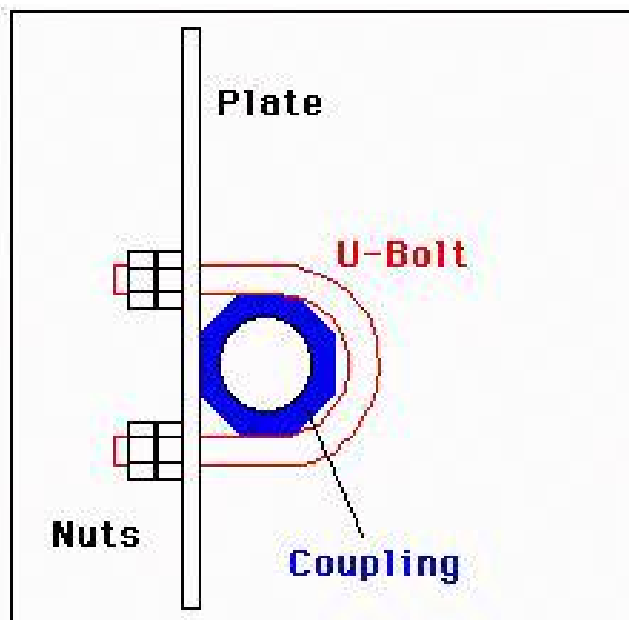
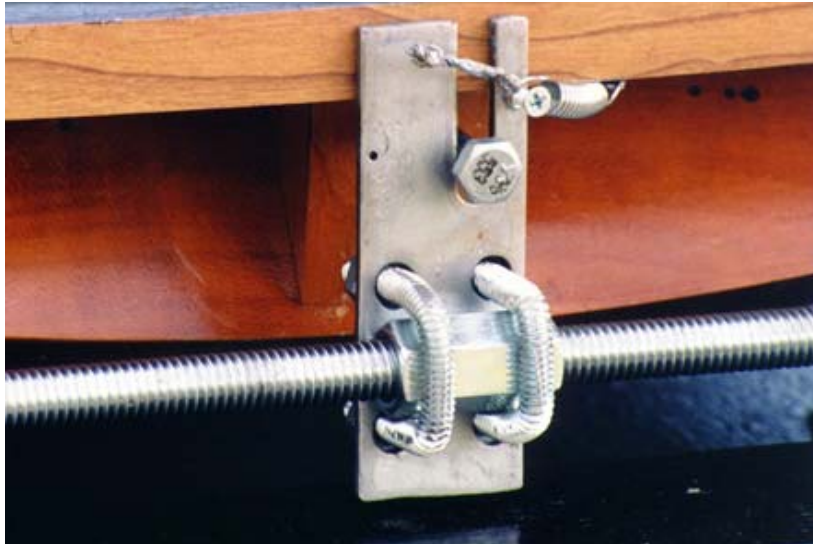
Build a small frame to hold the threaded rod. Attach your bearings to the supports and put the threaded rod through the center. I again recommend using screws to attach this so that you can disassemble the system in order to add the other parts.

STEP F

COUPLING

Buy 2 of these at the hardware store when you buy your threaded rod. Rod couplings are usually used to connect two threaded rods, but they look like really long nuts (about 4 times longer than a regular nut).

UBOLTS (P2, Drive) (fabrication [diagram 9](#))

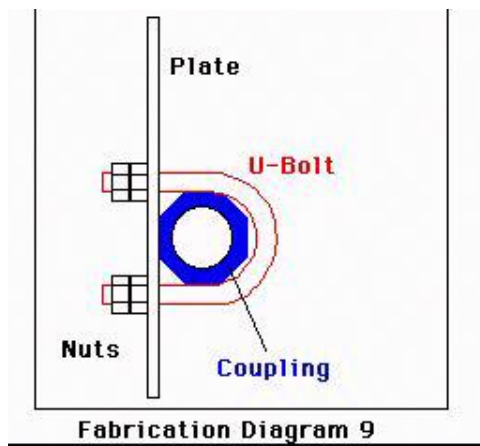
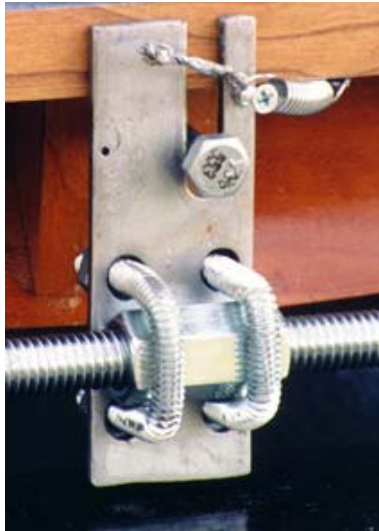


Fabrication Diagram 9

You need two of these to attach your coupling to the plate. I could not find any with the correct radius, so I bent some bolts around one of the couplings. That is the reason I said to buy 2 of them. When you use one of the couplings to bend the u-bolts around, it messes up the appearance of that coupling, so you have another for good looks. (Plus I had to buy them in a package of two!) Buy 8 nuts that will fit the U-bolt

so that you can attach the U-bolts to the plate and the coupling.

PLATE (P2, Drive) (fabrication diagram 9)



This is a simple metal plate with a groove in it. The drive pin, which is attached to the baseboard, rides in the groove and transfers the motion of the rod into the motion of the baseboard. The drive pin will be at its lowest position when in the center of the travel, and will be at its highest position at the ends of the travel.

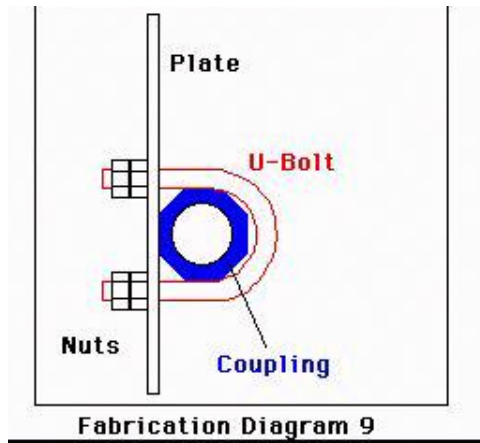
PULLEY and BELT

I decided to use a pulley to connect the motor to the threaded rod. Since my neighbor was custom making my pulley to fit on my threaded rod, I could choose exactly the diameter of pulley I wanted. If you make or buy a pulley, make sure that it is crowned in the middle so that the belt will not slip off. This gave me a lot of flexibility, but you may not have access to a "free" machinist. If you have access to spur gears, this may be the way you would want to drive your system.

The belt that I used came from a vacuum cleaner that I bought from a vacuum/sewing machine supply store.

STEP G

1. Assemble the U bolts, coupling and plate as shown in (fabrication [diagram 9](#)) and ([P2, Drive](#))



2. Thread the coupling assembly onto the threaded rod.
3. Place the threaded rod in its support brackets. Make sure that the threaded rod has enough length beyond the bearing to attach your pulley or spur gear.
4. Attach the assembly to the groundboard using screws. Place the assembly as close to the front runner of the baseboard as possible.
5. Insert the Drive pin into the front runner support of the baseboard. I used a .25 inch lag screw, and left the head on it. As the coupling assembly travels down the threaded rod, the plate will have a tendency to flop forward or backward. ([P2, Drive, above](#)) If the plate goes one way, it is stopped by the front portion of the baseboard. If it goes the other way, it is constrained by the bolt head. A small amount of play is necessary.
6. Attach a small, stiff spring between the drive pin and the plate. This will help to keep the drive pin in constant contact with the plate at all times.

STEP H

MOTOR & SPEED CONTROL

I had difficulty finding a motor that would work for this application, mostly because I was too cheap to buy something brand new. There are plenty of motors out there that will work, but finding an inexpensive (or free) one was hard for me. Here are some things to consider

D/C: A D/C motor is very portable and will work easily in the field. The trade off is that you will have to buy a battery with enough amps that will run the motor, and carry the battery with you. This is an option that many people take and is worth looking at.

A/C: An A/C motor is what I ended up using. The obvious drawback is that you have to stay close enough to an outlet to plug it in. I ended up using A/C because I was going to use my tracking system in my back yard. Instead of recharging and lugging around a battery, I just un-reel my extension cord. My reasoning goes like this. Most objects that you would view at high power are bright objects, and I only use the tracking system on high power. Therefore: I use my tracking system in my somewhat light polluted back yard to look at bright objects, but I don't take it with me to a dark site because I don't need it at low power. I found this to be true so far, but I admit that the over-riding reason for my A/C motor decision was that someone gave me an A/C motor for free! By the way you can buy 12v D/C to A/C converter that is not terribly expensive. The motor that I used was a 3 RPM motor from a barbecue spit.

Torque: Make sure that the motor you buy has enough torque to move your tracking system. The first motor I bought was too wimpy and I had to send it back. I realize that a perfectly balanced system will not require much torque, but I needed a little extra to move the weight of a reflecting telescope and it's dobsonian mount. You don't have to be off far on your CG measurements and calculations to generate a reasonable amount of torque.

Speed: The spreadsheet should tell you what the rotational speed of the threaded rod should be (in RPM). If you use a pulley, remember that the speed of the rod will be influenced by the different diameters of the pulleys that you use. Example. If your pulley is .50 in diameter and your motor shaft is .25 in diameter, your rod will rotate at 1/2 the speed of the motor. If you use spur gears, you will run into the same affect. Speed Control: No matter how good your workmanship and calculations are, you will want some manual control of your speed to adjust the system once it is working. If you choose a D/C motor, a simple resistor circuit will do it for you. I used a ceiling fan speed control (variable speed, not 3-speed) to control my A/C motor. Beware, a simple resistor circuit will not work on most A/C motors.

STEP I (attaching motor)

In step G you should have assembled the drive system and should be able to rotate the baseboard by manually rotating the threaded rod with your fingers. All that is left to do is to attach the motor to the groundboard, and slip the belt onto the pulley and the shaft of the motor. After the system has reached the end of its travel, you will have to reset the drive system for another pass. I simply take off the drive belt (it stretches a little) and rotate the threaded rod with my fingers until the coupling is back in its original starting position. You may want to attach the motor in a way that allows you to swing the motor out of the way to make it easier to remove the drive belt.

CALIBRATION (Polar alignment in use)

You need to be able to level your tracking system, and have it pointed at true North.

Before going out in the field, place a mark on the exact center of the north edge of top of the tracking system. Glow in the dark paint is good to use. Also place a mark on the center of the telescope base.

1. Place a level on the groundboard without the baseboard attached. Adjust the feet until the ground board is leveled. A small \$3 bubble level does the trick for me.
2. Now that the groundboard is level, assemble the baseboard and telescope. Use a low power eyepiece and put Polaris in the center.
3. Now look at the two marks that you made on the tracking system and the telescope base. If the two marks do not line up, you are not lined up on true north.
4. Rotate the base of the telescope to line up the marks. Use your eyepiece again to find Polaris and repeat steps 2-4 until the lines match up.
5. Put in your highest magnification eyepiece and locate any guide star or planet.
6. Note the direction of the motion of the object in view.
7. Turn on the tracking system and note the direction that the object now. If the object only slows down, turn up the speed of the motor. If the object reverses direction, slow the motor down.
8. Once you have "frozen" the object in view, feel free to move the telescope in any direction. No matter what the orientation of the scope, the tracking system should take the "motion" out of what you are looking at. Once an hour or so you will have to reset the system when it reaches the end of it's travel. Keep Looking Up.

TIPS

I tend to use my scope in the same place in my yard, so I devised a very simple way to set up my tracking system without having to calibrate it every time.

1. Set up and calibrate the tracking system.
2. Mark the location of the feet on the ground.
3. The next day, drive some small diameter PVC pipes into and flush with the top of the ground. Place a PVC coupling on the top of these pipes. Again, pound these down until they are slightly higher than ground level.
4. Now use a level and pound down the higher couplings until they are all level with each other.

5. You now have an inexpensive, "leveled" pad that you can drive the lawn mower over. No concrete, no rust, no mess!

IMPROVEMENTS

CHARLES CARLSON chcarlo@du.edu. You might be interested in our one major innovation (which I believe others have used): buying rollerblade wheels. We bought the hardest available rollerblade wheels (they come in different degrees of hardness, we found out) and the ballbearing hubs produce perfectly smooth, frictionless rotation. We were also able to find 12vdc motors at a local electronic specialty shop with gearboxes that produce very slow rpms with very high torque. We get extremely precise control with Atlas model railroad power packs - the basic model (about \$30) is all that's needed. The shaft RPM comes out very close to the figure predicted by your spreadsheet program.