Subject: Radio Telescope Base Construction Guide
Memo: 21, Revision 6
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Summary: Science Aficionado Telescope Base Construction Guide.

This memo gives step-by-step instructions for building the base of a horn radio telescope for exploring our Milky Way Galaxy. The telescope base design is simple, allowing tilting in elevation. The design includes holes for quick, but precise, setting of the elevation angle in 5 degree increments. Usually the Science Aficionados will point the telescope North or South. This telescope base is a woodworking project that can be built in a morning, once tools and parts are obtained. Fully constructed the base is 32 1/2-inches tall, and is a little bigger than a two foot square. The telescope base parts cost roughly $70 (in Summer 2018).

Overall Goal

The Science Aficionado telescope is used for many student research projects. The first project the Aficionado will complete is detecting our Milky Way Galaxy. **Figure 1** shows two different telescopes designs, but both use this telescope base design.

Figure 1: *Two Science Aficionado Telescopes. At left, the front of two telescopes is shown. One telescope is constructed out of reflective foam sheets and the other is made of bubble wrap, held in shape by segments of conduit. At right, the rear of these two telescopes is shown. The telescopes can stand by themselves if there is no high wind. Because these telescopes were left outside, the base is weighed down with concrete blocks and bricks.*

Figure 2: Wood parts of Science Aficionado Telescopes, before assembly. *The pieces cut from a 48-by-19-inch plywood sheet are above the 4-foot long re ruler.. Below the red ruler are pieces cut from two 2x4s. Some of the tools are also shown, including tape measure, set of drill bits and electric drill..*

Figure 2 shows all the wood parts required for the base. The maximum base size was set to allow bringing the base inside a standard-sized door.

Please remember to wear all required safety equipment, including protective glasses, a dust mask and gloves. Watch your fingers when using power tools! Measure, mark, then check for anything in the path of the power tools, especially fingers and power cords.

Figure 3: *This figure is a zoom in on the lines to be drawn before cutting the sheet with a circular saw. The red ruler is 48 inches long.*

Item	Component	Unit Cost	Number	Part Cost
1	Board 2x4 x 8-feet treated	5.77	2	11.54
2	Plywood treated sheet	17.98	1	17.98
	1/2-in thick x 2-feet x 4-feet			
3	1/2-in screws, pan head	1.94	1	1.94
	Box of 50, only 24 needed			
4	1-1/2-in flat head screws	6.14	1	6.14
	Box of 50, only 24 needed			
5	Ceramic 3-in Deck screws, Flat head	5.53	1	5.53
	Box of 50, only 10 needed			
6	12-in 1/2-diamter threaded rod	1.57	1	1.57
7	Flat washer, 1/2-in hole	0.50	2	1.00
8	Wing nut 1/2-in diameter hole	1.28	2	2.56
9	Sheet Steel shelf brackets	1.48	4	5.92
	5.25-in x 7.63-in			
10	Stainless Steel Clamp	1.98	2	3.96
	(American Valve) 4 to 7-in diameter			
11	Spray Paint (Can)	3.98	2	7.96
	Total Parts Cost			$66.10

Table 1: Part list for telescope base, including costs of components. All parts needed are listed with costs per item, number of items and total cost. The wood screw parts listed by number of boxes. Two telescopes can be built with the boxes of screws.

Parts Required

The wood parts, shown in **Figure 2** are cut from 2 eight-foot long 2x4s and a sheet of 4 by 2 foot plywood. Since the telescope will remain outside for long periods, purchase pressure treated wood, if possible.

2x4 Parts Part Name	Length (In)	Length (cm)	Number of Pieces	Length Sum (in)	Length Sum (cm)
Base Cross Long Leg	30.0	76.0	1	56.0	142
Base Cross Side Legs	14.3	36.0	2		
Fork bottom Section	10.8	27.0	1	10.8	27
Fork Legs	27.0	67.5	2	54.0	135
Elevation Base	19.0	48.0	2	38.0	96
Total 2x4s				158.8	400
Total Length	13.2 feet		4 meters		

1/2 to 3/4 inch thick Plywood Sheet Parts

Part Name	Length (in)	Width (in)	Number of Pieces	Length (cm)	Width (cm)
Base	19	19	1	48	48
Protractor	19	19	1	48	48
Elevation Base Top	7	7	1	18	18
Elevation Base Bottom	7	5	1	18	13
Elevation Cross Supports	7	2	2	18	5
Fork Stop	10.75	3	1	27	8

Table 2: Parts list for wood components. These parts are cut from two 8-foot long 2x4s and a 48 inch by 19 inches sheet of plywood.

The parts lengths are given in imperial and metric units.

Figure 4: All plywood parts cut. *The telescope base and protractors are exactly the same size, 19-inches square. The smaller parts are for the elevation tilt part of the base.*

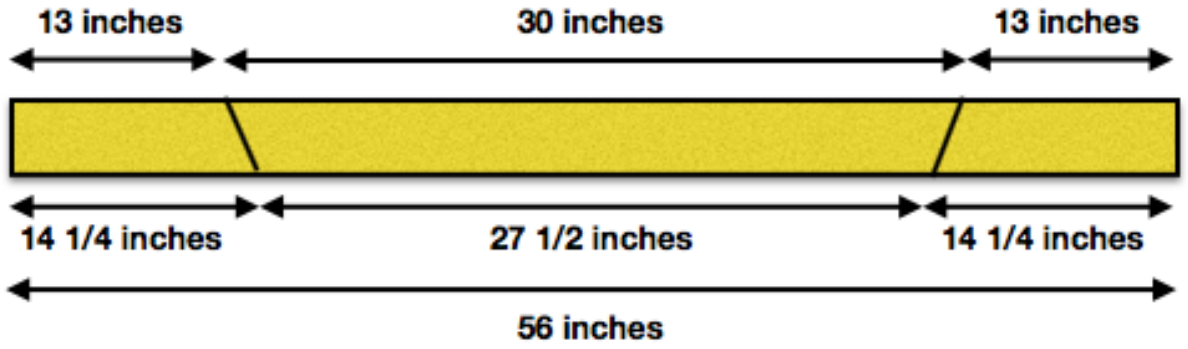

Figure 5: Cut the base legs from a 56-inch long part of a 2x4. *The two angle cuts of the 2x4 are measured and cut with a circular saw. Three pieces are cut from this board, two identical side pieces and the long cross piece. After assembly, this will be a 30 inch cross.*

The tools required are:
1. Electric Drill (battery powered is more convenient).
2. Circular Saw.
3. Ruler 4 feet long.
4. Tape Measure.
5. Square, for straight cuts of the 2x4s.
6. 5/8-inch spade wood drill bit.
7. Set of drill bits; including 1/8-inch and 9/16-inch drill bits.
8. Phillips screwdriver bit for drill.

The majority of the base is constructed from segments of two 2x4 by 8-foot long boards and one 4-by-2-foot sheet of 1/2-inch thick, pressure treated, plywood. If pressure treated is not available then regular plywood may be used, but should be completely painted. If 1/2-inch sheet is not available, then plywood as thick as 3/4-inch may be used without changes to the other measurements in **Table 2.**

Plywood Sheet Cutting Guide

In this section the steps needed to produce the plywood base parts are listed. The base parts are intended to allow pointing accuracy of roughly +/-1 degree. Given the size of the parts, the cutting accuracy needed is roughly 1/4-inch. This accuracy is easy to reach with hand tools. For each measurement draw the measurement line then cut on the measurement line, don't bother trying to keep the line. Here are the steps to cut the plywood sheet.

1. Draw marks 19 inches from the edge of the plywood sheet every foot along the board.
2. Draw a straight line along the entire length.
3. Using the circular saw, cut along the line to make a 48x19 inch rectangle.
4. Along both edges of the board draw marks at 19, 38, and 45-inches
5. Draw lines to connect the edge marks. The shortest segment will be 3-inches wide. See **Figures 3 and 4**.

Figure 6: Assembly of the cross pieces to make the base legs. *The image at left shows how the plywood base and protractor are used to square the base legs. At right, the base is shown attached to the legs.*

6. Use the circular saw to cut the shortest segment to make a 3 by 19 inch rectangle.
7. Use the circular saw to cut along the line at 38 inches to make a 7 by 19 inch rectangle.
8. Use the circular saw to cut along the line at 19 inches to make two 19x19 inches squares.
9. Take the 7x19 inch piece and draw lines along both edges at 7, 12, 14, and 16 inches
10. Draw lines connecting the edge marks. See **Figure 4.**
11. Starting with the smaller segments, cut along each of the lines to make one 3-by-7 inch segment, two 2-by-7 inch segments, one 5 by 7-inch segment and a 7 by 7-inch square.

2x4 Cutting Guide

Next we cut the two 2x4s into pieces to make the base legs and vertical pieces. The U.S. 2x4s are actually 1 1/2 by 3 1/2 inches in cross section. The measurements listed below assume this wood thickness. You will need to make small adjustments for different thicknesses of wood.

The longest parts are the two 27-inch long forks, which hold the elevation tilt part of the base

1. Take each of the two 2x4s and square the ends, taking off around an inch of wood, if then ends are not square with the long direction of the board. Draw lines and use the circular saw for the cuts.
2. From each of the two 2x4s, measure and cut 27 inch long segments, These are the two vertical pieces.
3. From a remaining 2x4, measure and cut one 56 length. This part is used to make the base cross piece legs This part will be assembled into a 30 inch square cross, with bottom slightly longer than the top. See **Figure 5.**
4. On one edge of this 56-inch long board, measure 13 inches from each end and mark.
5. On the other edge of this board measure 14 1/4-inches from each end and mark.

Figure 7: Drill holes in vertical pieces for Elevation Tilt. *The left image shows measurements 1 3/4-inches from all edges of the one of the 27-inch long vertical forks. The image on the right shows 5/8 inch holes drilled in both fork pieces with the spade drill bit.*

6. Now connect the two lines, to draw slightly diagonal lines.
7. Cut the board along these lines, resulting in three boards, to make the 4 legs of the short base table. Two legs are from the 30-inch board, measured on the long edge and two more legs are the 14 1/4-inch boards, again measured on the longer edges.
8. Place these 2x4s on the table (or floor) with the long edges down. Center one of the shorter legs in the middle the longer legs. The middle of the longer legs should be 13 3/4-inches from the top edge of the board. See **Figure 6.**

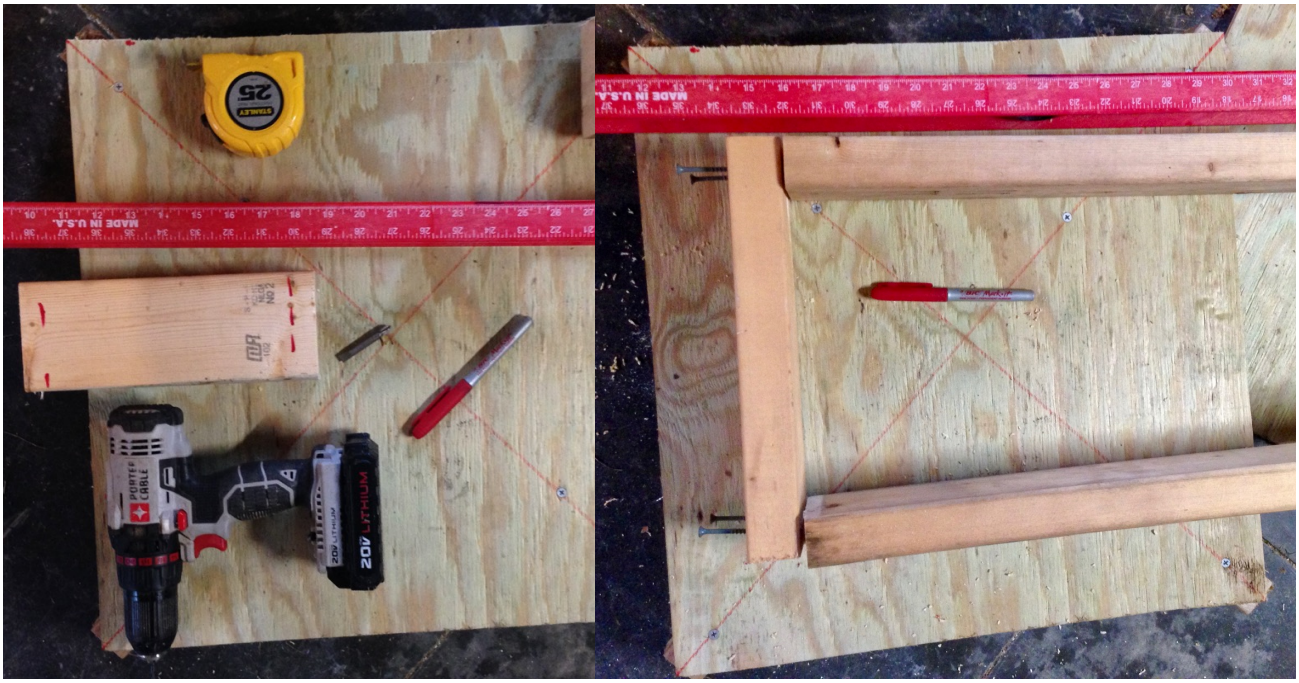

Figure 8: Preparation to Assemble vertical forks. *The base plate for the vertical forks is the 10 3/4 inch long 2x4. The image at left shows measuring and drilling the 4 holes used to attach the forks. The image at right shows four 3 inch deck screws ready to assemble the vertical fork. First attach the protract then install the base plate.*

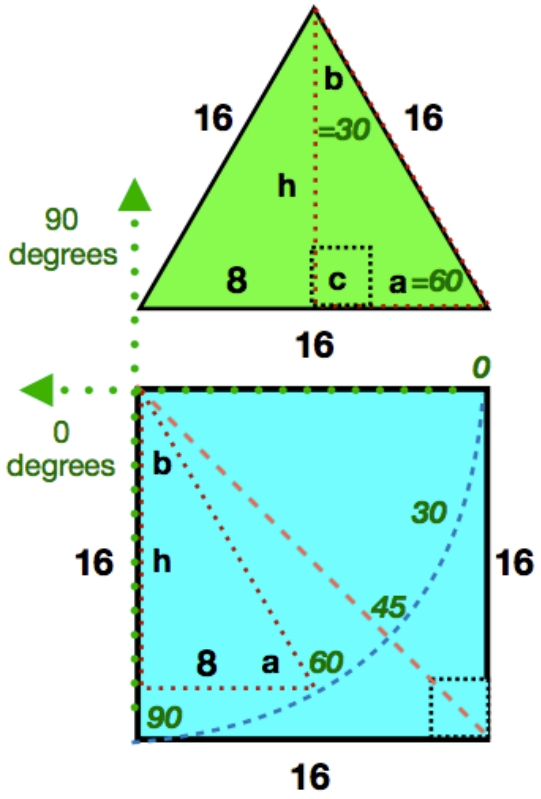

Figure 9: Angles in a triangle and a square. *Angles, measured in degrees, are defined by the fact that a right angle is **90** degrees, and that the sum of all angles in a triangle is 180 degrees. The top of the figure shows a triangle with 3 equal sides, each 16 inches long. Since the sides are equal, so are the angles. Each angle is 180/3 = **60** degrees. Angle **a = 60** degrees. A red dashed line is drawn from the top of the triangle to the middle of the bottom side. Angle **b** is exactly half of **a**, or **b = 30** degrees. Angles **a** and **b** add up to **90** degrees, so angle **c** is also **90** degrees.*

*The square has 4 sides, each 16 inches long and 4 right angles. Draw a line diagonally between the two opposite edges to divides **90** degrees in half, so the angle is **45** degrees. Since we want to measure where the horn is pointed, we making holes in the opposite end. Angle **0** is simple, just draw a mark at the right top side of the square. Angle **90** is just as simple, draw a mark at the bottom left of the square.*

*The square has a curved line, which is 16 inches from the top left. All our angle marks will be on this curved line. Angle **45** degrees is where the curved and diagonal lines cross.*
*Now we use the angles from the triangle to place **30** and **60** degrees on our protractor. Measure 8 inches from the left side to meet the 16 inch arc. This is half the 3 sided triangle, so the angle is **60** degrees. Do the same by measuring from the top down 8 inches to mark the **30** degree angle.*

9. Drill two holes, one above the other, in the middle of the longer leg, to prepare to attach the first short leg to the long legs.
10. Use two 3 inch screws to attach the long logs to the first short leg.
11. Place the other short 2x4 leg on the other side of the long legs, and drill two holes diagonally into the opposite sides of the short 2x4 leg, to prepare to complete the cross.
12. Screw two 3 inch screws to complete the cross.
13. Take the other 2x4 and measure and mark at 19, 38 and 48 3/4-inches.
14. Use the circular saw to cut straight along these lines. You are making two 19-inch long parts for the elevation tilt shelf and a 10 3/4-inch piece to connect the two vertical forks.

Next we need to drill the holes for the elevation axis. Since the 2x4s are actually 1 1/2 thick by 3 1/2 wide, we will measure half this distance, 1 3/4-inches from one end of each of the two forks and mark a point in the middle of the boards. See **Figure 7.**

15. Measure 1 3/4-inches from all sides of each of the two 27 inch long boards to draw a mark in the center of the board width.
16. Using a 1/8-inch drill bit, drill holes through the ends of the two 27-inch long boards
17. Using a 5/8-inch spade drill bit, drill half way through the two 27-inch 2x4s.
18. Flip the boards and finish drilling through the 2x4s. We flip the boards to avoid getting splinters on the sides of the boards when drilling.

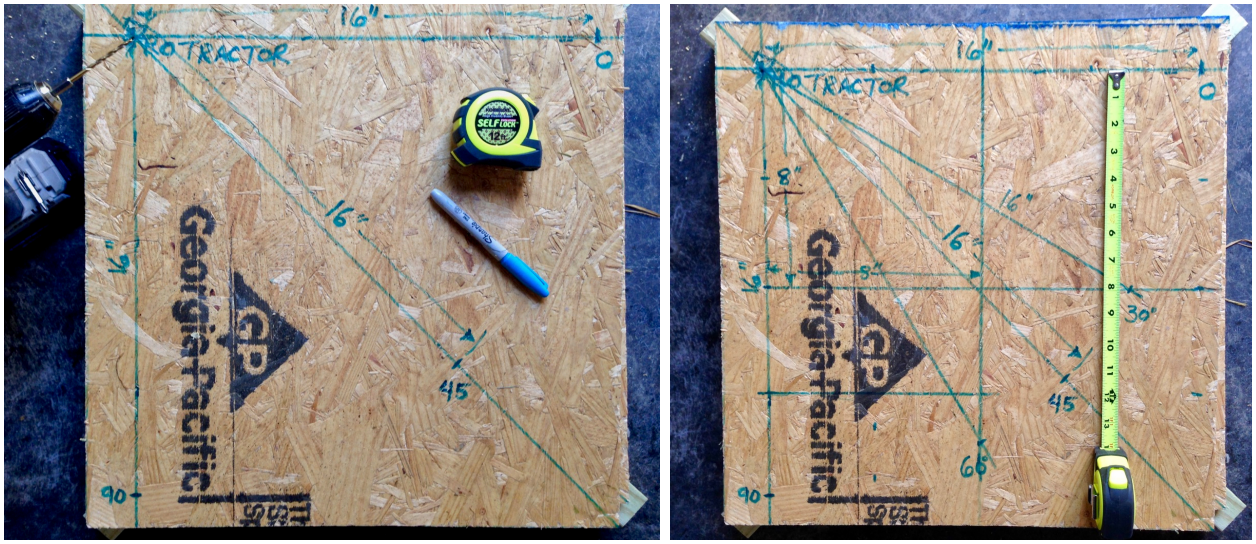

Figure 10: Drawing the first few Elevation Angle Marks. *The protractor is a 16 x 16-inch square drawn on the 19 x 19-inch square of plywood. To get a better understanding of angles, we'll just draw on the easy angles at 0 and 90 degrees. Then by drawing a diagonal line and measuring 16 inches we mark the 45 degree point, shown at left. By drawing lines 8 inches over from left and down from top of the 16-inch square, we find the 30 and 60 degree elevation points, as is shown at right.*

19. Next we start on parts for the elevation tilt shelf. Take the two 19-inch long 2x4s and repeat this process, measuring 1 3/4-inches from one end of each of the two boards. This is the same procedure as shown in **Figure 7**.
20. Measure 1 3/4-inches from the edge of the 2x4s, then mark each of the boards.

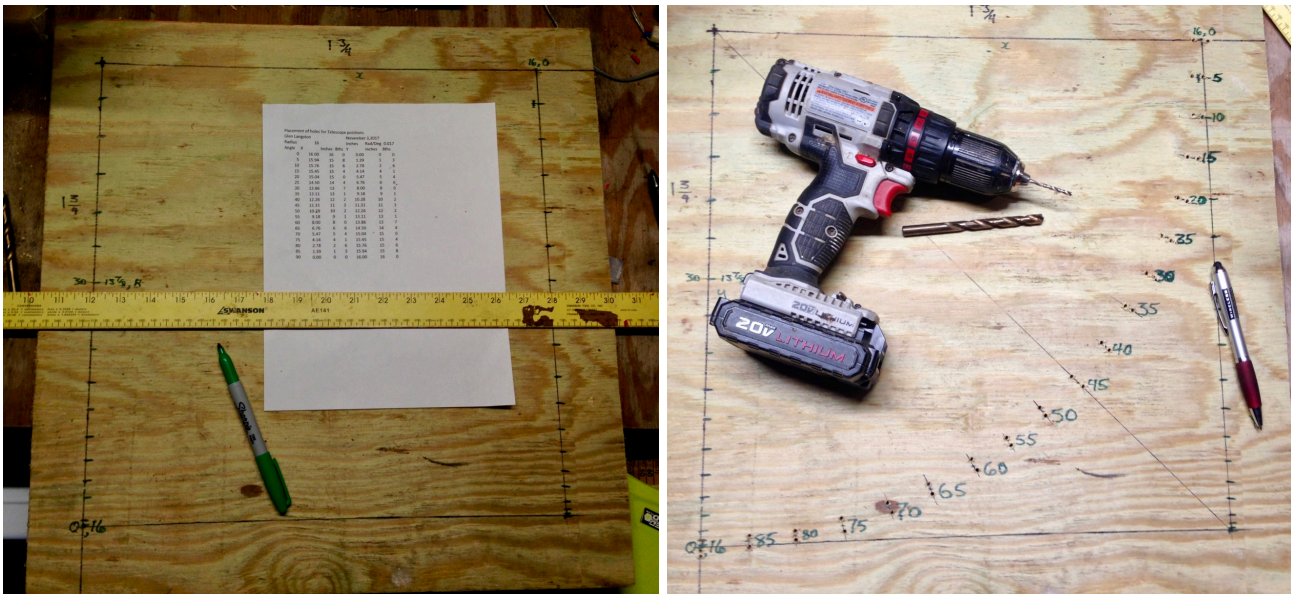

Figure 11: Measuring positions to drill protractor angles.. *The protractor is used to set the elevation angle for the observations. At left the image shows the first step in creating the protractor. A 16 inch square box is drawn on the protractor. The box is 1 3/4-inches from the upper and side edges, so that it will match one of the vertical forks when attached. At right, all the positions for angles between 0 and 90 degrees are drawn. Two pilot holes are pre-drilled on either side of the measured point. The two holes are separated by 1/4-inches.*

Angle	X	Inches	8ths	cm	Y	Inches	8ths	cm
0	16.00	16	0 /8	40.6	0.00	0	0 /8	0.0
5	15.94	15	7 /8	40.5	1.39	1	3 /8	3.5
10	15.76	15	6 /8	40.0	2.78	2	6 /8	7.1
15	15.45	15	4 /8	39.3	4.14	4	1 /8	10.5
20	15.04	15	0 /8	38.2	5.47	5	4 /8	13.9
25	14.50	14	4 /8	36.8	6.76	6	6 /8	17.2
30	13.86	13	7 /8	35.2	8.00	8	0 /8	20.3
35	13.11	13	1 /8	33.3	9.18	9	1 /8	23.3
40	12.26	12	2 /8	31.1	10.28	10	2 /8	26.1
45	11.31	11	3 /8	28.7	11.31	11	3 /8	28.7
50	10.28	10	2 /8	26.1	12.26	12	2 /8	31.1
55	9.18	9	1 /8	23.3	13.11	13	1 /8	33.3
60	8.00	8	0 /8	20.3	13.86	13	7 /8	35.2
65	6.76	6	6 /8	17.2	14.50	14	4 /8	36.8
70	5.47	5	4 /8	13.9	15.04	15	0 /8	38.2
75	4.14	4	1 /8	10.5	15.45	15	4 /8	39.3
80	2.78	2	6 /8	7.1	15.76	15	6 /8	40.0
85	1.39	1	3 /8	3.5	15.94	15	7 /8	40.5
90	0.00	0	0 /8	0.0	16.00	16	0 /8	40.6

Table 3: Positions for Protractor Slots*. The elevation axis angles are set by slots in the protractor. The protractor slots are at these X and Y positions. The first column in the table is the Elevation Angle. The X and Y coordinates are measured inside the 16 square, drawn on the protractor. The other column show measurements in 1/8 of an inch and centimeters (cm).*

21. Using a 1/8-inch drill bit, pre-drill holes through the ends of the two 19-inch long 2x4s. Next we'll make these holes bigger.
22. Using the 5/8-inch spade drill bit, drill half way through both the 19-inch 2x4s.
23. Flip the boards and finish drilling through the 2x4s.
24. On one of the two 19-inch boards measure 16-inches from the elevation axis and drill a 9/16-inch hole. This hole will be used to hold the elevation tilt shelf in at different angles.

Next we'll assemble the legs and base into a 4 inch tall table.

25. Place the 19x19-inch square plywood sheet on top of the base legs and center.
26. Take four 1 1/2-inch screws, placing them 1 inch from the 4 corners of the base table. Attach the square base to the legs, making a short table. Force the legs to match the points of the square, before screwing in place.
27. Prepare to assemble the vertical fork by taking the 10 3/4 inch 2x4 (called the **base plate**) and measure 3/4 inches and mark lines each end. Drill holes with 1/8 inch drill bit. Screw in four 3-inch long deck screws. **See Figure 10. Do not assemble the fork yet, as we must first create the protractor** (I put the fork together first, then realized couldn't attach the protractor).

Create the Elevation Angle Protractor

Our horn telescope has a resolution of about 15 degrees, so the pointing accuracy needed for our observations is about 5 degrees. We are making a protractor with pointing accuracy of plus or minus 1 degree, but with angles marked every 5 degrees. Some students have had questions about measuring angles, so lets look at angles in two simple shapes, a triangle and a square. See **Figure 11,** which shows an equal lateral triangle, which has three identical sides and a square, with four identical sides. First we'll make simple measurements to mark the first few angles, then use the **Table 3** to mark all 19 slots in our ***protractor.***

Figure 12: Drilling the protractor slots. *At left the image shows the protractor slots re-drilled with a 1/4 inch drill bit. First drill where you've previously drilled the 1/8 inch pilot holes. The slide the 5/16 inch drill bit between the two holes make a slot about 1/2 inch long. The slot is needed to account for any inaccuracy of assembly of the base. board. At right the assembled vertical forks with protractor install in-between the two forks.*

A ***protractor*** is used to measure angles, and we are creating a big protractor, drilled into the 19-inch square. The first step is to draw a 16-inch square on the protractor, offset from the edges of the plywood sheet by half the width of the 2x4, 1 3/4-inches. We've made a protractor several ways, and found the easiest is to simply make a square and measure all the positions along all edges, then draw marks where the positions cross. Since the protractor is symmetric the positions are the same up and down as right and left. The steps for creating the protractor are listed next.

28. Lay the 19-inch square on a table. Measure 1 3/4-inches from the top on the left and right edges. Draw a connecting the marks. (1 3/4-inches is half the width of the 2x4)
29. Measure 1 3/4-inches from the left side, on the board top and bottom. Draw a line connecting the marks.
30. The intersection of the two lines, on the upper left, is were the elevation axis will be placed. We'll call this the **origin**, for all other measurements.
31. Draw a diagonal line from the top left to bottom right of the square. Measure 16-inches from the origin along the diagonal line and mark that spot. This is the **45 degree** mark. See the left side of **Figure 10.**
32. Measure 16-inches along the top and mark that spot. That is the **0 degree** elevation angle.
33. Measure 16-inches down, along the left line and mark that spot. That is the **90 degree** elevation angle.
34. Measure over 8 inches from the left side of the drawn square, finding the spot on the arc 8-inches from the left. Mark this spot, which is **60 degrees.** See the right side of **Figure 10.**
35. Measure 8 inches down from the top line, again finding the place where 8-inches down is on the arc. This is the **30 degree** angle**.**
36. Measure down 16 inches from **0 degrees** and over 16-inches from **90 degrees,** marking that spot. Draw lines to complete the 16-inch square. See the left side of **Figure 11**.

Figure 13: Wood parts for Elevation Tilt Shelf.Drilling *The wood parts for the elevation tilt shelf for the horn are shown in the figure. The 2x4s have large, 5/8 inch diameter, holes drilled for the elevation axis. The on one of the two 2x4s a second hole, 5/16 inches in diameter, is drilled to enable setting the elevation.*

37. Now using a ruler, and starting from the origin, rotate a ruler to draw marks every few inches that are 16 inches from the origin, to make an arc from **0 to 90 degrees.**
38. Now measure the location of all other angles listed **in Table 2,** marking the positions on the left and right sides of the square. See the right side of **Figure 11.**
39. Using your ruler, find the place where the lines cross the arc, marking each angle. Bigger angles are at the bottom left of the square and smaller angles are on the top right.
40. You've completed the protractor measurements. Now take your drill and 1/8 inch drill bit and drill two holes, separated by 1/4-inch on either side of the marks, making two holes along the line connecting the mark to the **origin.**
41. Next take the 5/16-inch drill bit and drill all the holes again, making slots oriented in the direction of the **origin.**
42. Use the 5/16-inch drill bit to clear all wood between the two holes in each slot.
43. Use the 1/8-inch drill bit to drill a pilot hole at the top left of the square, making a hole at the **origin.**
44. Use the 5/8-inch spade bit to drill a bigger hole at the **origin** This competes the protractor!

Now we will mount the protractor on a vertical fork and assemble the remainder of the base.

45. Take one of the two vertical forks (27 inches long) and attach the protractor to the inside of the fork; The two 5/8 inch holes should align for the elevation axis. Use two 1 1/2-inch

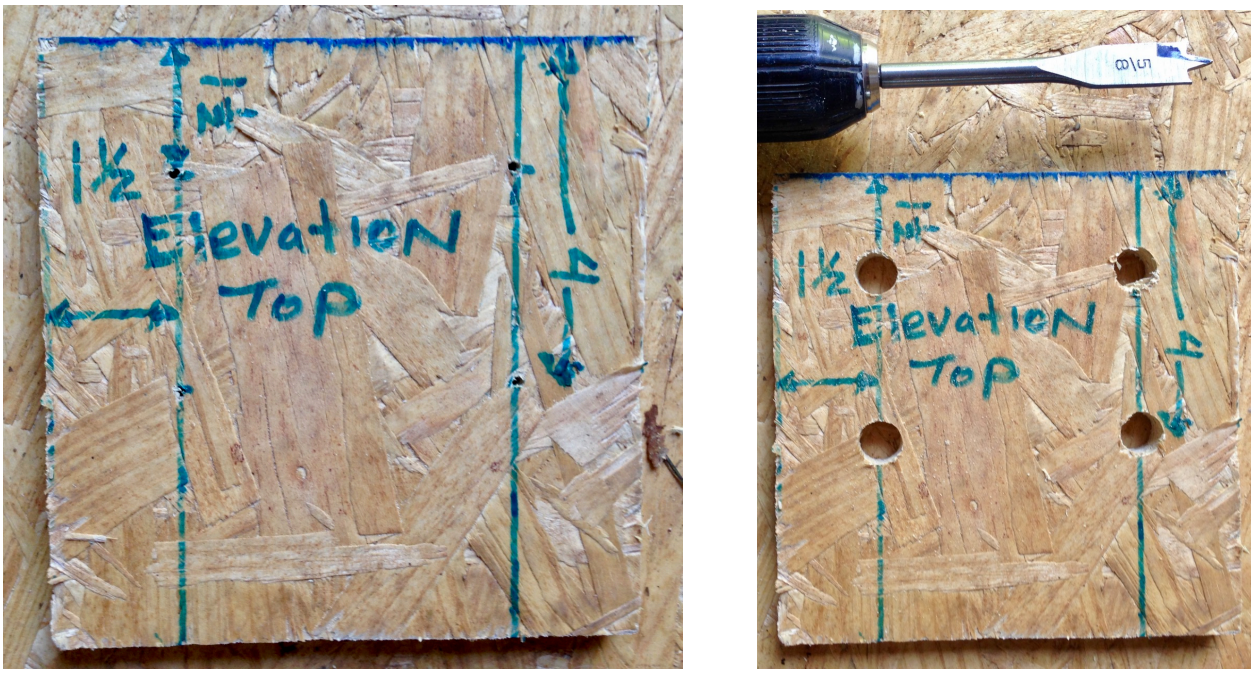

Figure 14: Drilling holes in Elevation top for Attaching horn. *The elevation shelf top has 4 holes for clamping the horn to the tilt shelf. First measure 1 1/2-inch and draw lines 1 1/2-inches from the edge of the two sides. Then with the 1/8-inch drill bit, pre-drill holes 1 1/2 and 4-inches from the front of the top base, as is shown on the left. Then use the 5/8-inch spade drill bit to make holes wide enough for the metal clamps, as shown on the right*

screws near the top of the protractor and two 1 1/2 inc screws near the bottom. See the left side of **Figure 12.**

46. Take the 5/16-inch drill bit and drill holes in the fork 2x4 through the **90 and 85 degree** slots.

Figure 15: Top of the elevation shelf completed. *The elevation base top is flush with the front of the elevation 2x4s. The 3-inch wide cross piece is between 9 and 12-inches from the front. Screw these both in with 1 1/2-inch screws. There is a 2-inch gap between the two cross pieces.*

Figure 16: Side view of the Elevation Tilt Shelf for Attaching horn. *One bottom part is the 5 inch wide cross piece, aligned with the two elevation axis holes. The other bottom part is a 2-inch wide cross piece, 12 inches back from the front of the shelf. Attach these pieces with 1 1/2-inch screws*

47. Take four 3-inch deck screws and attach the 10 3/4-inch base plate 2x4 to the bottom of the two vertical fork boards. Take the vertical fork and place in the center of the base plate along the direction of the two short legs.
48. Using the 1/8-inch drill bit, drill two holes along the middle of the base plate and 2 inches from the inside edges of the base plate. See **Figure 12.**
49. Take the vertical fork and place in the center of the base plate along the direction of the two short legs.

Figure 17: Completed elevation shelf and final base, painted and numbered. *At left the complete elevation shelf is shown with two large (7 inch diameter) stainless steel clamps for attaching the horn to the base. At right, the elevation shelf is attached via a 1/2 inch diameter threaded bar, 12 inches long. Use two washers and two wing nuts to hold the elevation axis in place. Paint and then number the elevation angles for each slot.*

50. Using the 1/8 drill bit, drill two holes along the middle of the base plate and 2 inches from the inside edges of the base plate.
51. Use two 3 inch screws to mount the vertical fork on the base, long the direction of the two shorter legs of the base. The screws should reach all the way to the shorter legs, underneath the base.
52. Place the four shelving braces on both sides of both vertical forks. Attach each shelf brace with six 1/2-inch pan head screws. See **Figure 12**, right side.

Elevation Tilt Shelf Part of the Base

The base is designed to allow tilting the horn to 19 different elevations. The remaining wood parts are assembled into shelf for holding the horn, while tilting to the angles on the protractor. All of the parts to assemble the elevation tilt part of the base are shown in **Figure 13**.

1. Take the elevation top and mark lines 1 1/2-inch from two opposite sides.
2. Mark points 1 1/2 and 4-inches from an edge. See **Figure 15**. We are preparing to drill holes to use to clamp the horn in place.
3. Drill the 5/8-inch diameter holes in the top.
4. Take the two 19-inch 2x4s and set on the table (or floor). Place the top base over the front edge, which has the two large holes in the 2x4s. Screw the top base to the 2x4s using four 1 1/2-inch screws.
5. Take a 3-inch wide cross brace and place 12-inches from the front of the elevation tilt shelf. Attach with two 1 1/2-inch screws
6. Flip the elevation shelf over and portion the 5-inch wide cross piece over the elevation axis, leaving 1 3/4 inches open in front. See **Figure 16.**
7. Attach a 2-inch cross piece to the bottom of the elevation shelf, 12 inches from the front of the shelf. See **Figure 16.**
8. Thread the two 7 inch diameter stainless steel clamps into the two pairs of holes in the elevation shelf.
9. Spray paint the base table, vertical forks and elevation tilt shelf the colors you've chosen.
10. This completes the elevation shelf. **See left side of Figure 17**

Finally we'll insert the elevation axis through the vertical forks and the elevation tilt shelf.

11. Align the Elevation axis on the shelf with the two holes in the vertical fork.
12. Place the 1/2-inch diameter rod through the holes.
13. Add washers and wing nuts to the two opposite sides of the elevation axis. This completes the Telescope base! **See right side of Figure 17.**

Conclusion

You've created your radio telescope base and are ready to begin observations. Your completed telescope base is shown in **Figure 17**. Assemble your horn and gather up your amplifiers and computers, it's time to start discovering the invisible universe!