Subject: Cone Horn Construction
Memo: 22, Rev 13
From: Glen Langston, Sue Ann Heatherly, Kevin Bandura
Date: 2020 February 3

Our Milky Way galaxy is visible from your own back yard, when observed with your own simple radio telescope. Here your are given step by step instructions on construction of a sensitive horn radio telescope for discovering the structure of our Milky Way Galaxy, through observation of neutral hydrogen atoms. The telescope we are constructing can trace the motions of the arms of our galaxy. Your horn needs sensitive amplifiers which increase the signal to the level needed for our digital signal processor. Our measurements show significant improvement in the feed gain is achieved by proper placement of the feed probe..

We've made significant progress in increasing the sensitivity of this telescope, but the process of perfecting the feed horn and probe has been slow. The first memo on this topic in the LightWork series is memo 3, dated 2015 July 28

Radio telescopes are constructed in a great many different ways, and this horn construction guide can certainly be enhanced. *Please contribute your own guides to telescope construction!*

Background

As a part of an education and training program for high school students just entering college, our group has been providing materials and tools for students to build their own radio telescopes. These students were successful in building telescopes! **Figure 1** shows a group performing their first observations with the telescope they named "Alexander". These students designed their own telescope base and structure for holding the horn. They were giving a figure similar to the figures included in this document for building their horn. We've used their experience to make some slight improvements to the designs presented here.

***Figure 1**: High school graduates with their first radio telescope, completed in July 2017. The telescope was designed and constructed by these students, based on rough sketches and an example telescope we'd built in advance of their arrival at the National Science Foundation's Green Bank Observatory.*

Note that the telescope is big, but light, and is portable, so can be taken to astronomy events. Since the telescope electronics can be powered by the laptop used to take the data, the telescope can be taken to remote sites for observations.

We have designed and constructed all the electronics and receiving section for this radio telescope. Our system consists of electronics

Figure 2: Large Parts of Cone Horn (Left). *The Bubble Wrap and green foam board are 4-feet tall. The cone legs are 39-inches long segments of grey conduit. The red ruler is 4 feet long. The galvanized 6-inch to 8-inch pipe reducer is by the ruler.*

The completed horn, attached to the resonant cavity and telescope base is at right.

The completed horn has an area of 0.52 square meters.

attached to a 6" diameter, 1 foot long stove pipe. We need to add collecting area to increase sensitivity.

We've tried a number of horn designs, using reflective foam insulation and other materials. Here we're presenting a design that is very durable. The horn is relatively large but light weight. The major parts used to construct the horn are shown in **Figure 2**. This horn is made from mylar coated bubble wrap, used for home insulation. Legs are cut from electrical conduit and the top is made from 3/4 inch thick foam board. This foam is found to be very transparent to radio waves significantly, so is ideal for this application. A horn without a lid would be more sensitive, but we've found that such a horn soon fills up with leaves, bugs, snow and rain. The bottom of the horn is a 6-inch to 8-inch duct work pipe reducer. This part was chosen because it easily fits onto the 6-inch stove pipe we're using as the resonant cavity to collect the radio signals. This part is also relatively strong and allows firmly attaching the legs. The completed horn is also shown in **Figure 2.** This horn is a later generation than the one shown in **Figure 1.**

We used a web page to calculate the sizes of the cuts to the bubble wrap. The web page is shown in **Figure 3**. In order for the horn to efficiently direct the radio waves into the receiver, the horn should have a fairly narrow opening angle.

The cone you are creating is designed to be attached to a 6-inch diameter stove pipe. The cone will attach to the crimped end of the stove pipe. To give the cone some strength, the bubble wrap horn is attached to a pipe "reducer", which reduces the diameter from 8-inches to 6-inches. All the stove pipe parts are galvanized to prevent rusting. The reducer has a total length of 7-inches to allow a smooth transition. The bubble wrap part of the cone is 33.8-inches high and 32-inches wide at the wide end. The total height of the cone is 42-inches.

The width of the cone was set to allow the cone to fit through standard size doors. This cone design also has the advantage that the lid can be removed and the cone collapsed to a width of about 10 inches, for storage or transport.

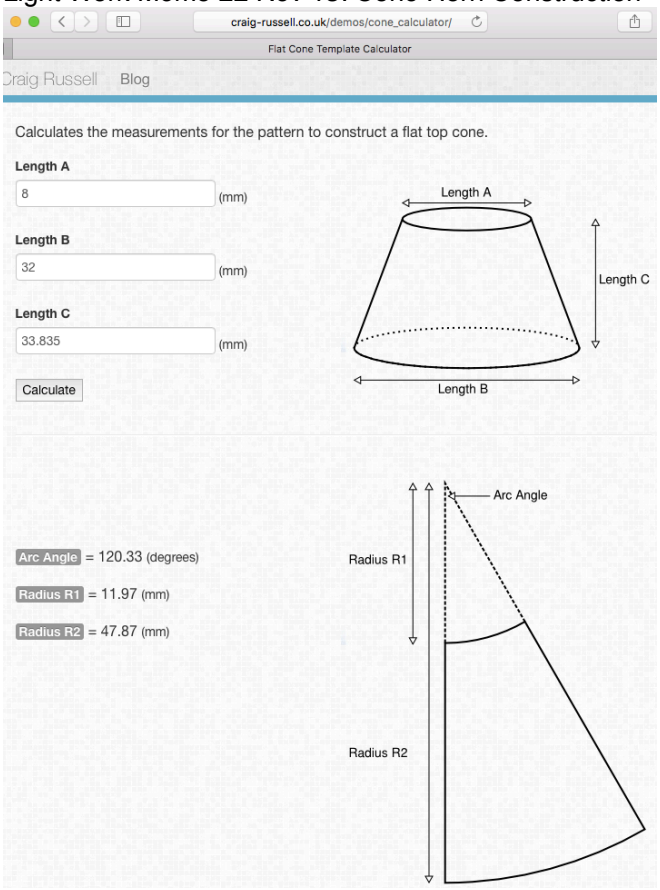


Figure 3: *Web page with calculator with values required to create a cone from a flat sheet.*

The web site notes units in mm, but the cone dimensions scale to any units. Assuming 8-inch diameter small end and 32-inch diameter large end, the cone must be 33.8-inches high to yield an arc of 120 degrees. This size is convenient for producing a hexagon shaped top.

The widest possible cone that can be created with 48-inch wide sheet is 36-inches wide, with 8-inch bottom and 120 degree arc.

See appendix for description of how to cut this cone shape.

From web-site:

http://craig-russell.co.uk/demos/cone_calculator/

The shape of the cut of the bubble wrap was first done by trial and error, but it was found that a better job could be done by calculating the cone shape. We used the web page shown in **Figure 3.** Like everything about building a radio telescope, different sizes and shapes are possible, each design having its own advantages and disadvantages. Notes on different designs are given in the appendix and also in other *LightWork Memos.*

Part Number	Part Name	Unit Cost	Number	Part total	
1	Galavanized 8" to 6" reducer	16.01	1.00	$16.01	
2	Bubble Wrap Role 4-feet x 25-feet	38.00	0.33	$12.67	3 Telescopes
3	Drywall Screws, 2-inch	0.05	6.00	$0.30	
4	Silver Muffler Tape	6.00	1.00	$6.00	
5	10ft long, 1in diameter conduit	2.35	2.00	$4.70	
6	Assorted 6-32 Metal Screws	10.00	1.00	$10.00	
7	Lock Nuts for 6-32 Screws	3.00	1.00	$3.00	
8	Sheet Metal Screws	0.05	2.00	$0.10	
9	Pipe Strap	1.35	1.00	$0.45	3 Telescopes
10	Miscellaneous 1/2 plywood pieces	1.00	1.00	$1.00	
11	Foam Insulation Board 4-feet x 8-feet	16.00	0.33	$5.33	3 Telescopes
and/or					
12	36-inch, 1/4-inch diameter threaded rod	2.89	3.00	$8.67	

Table 1: *Cone Horn Parts list with costs (as of Winter 2020).*

Two of the more expensive parts, the foam board and bubble wrap, can be used to make 3 telescopes.

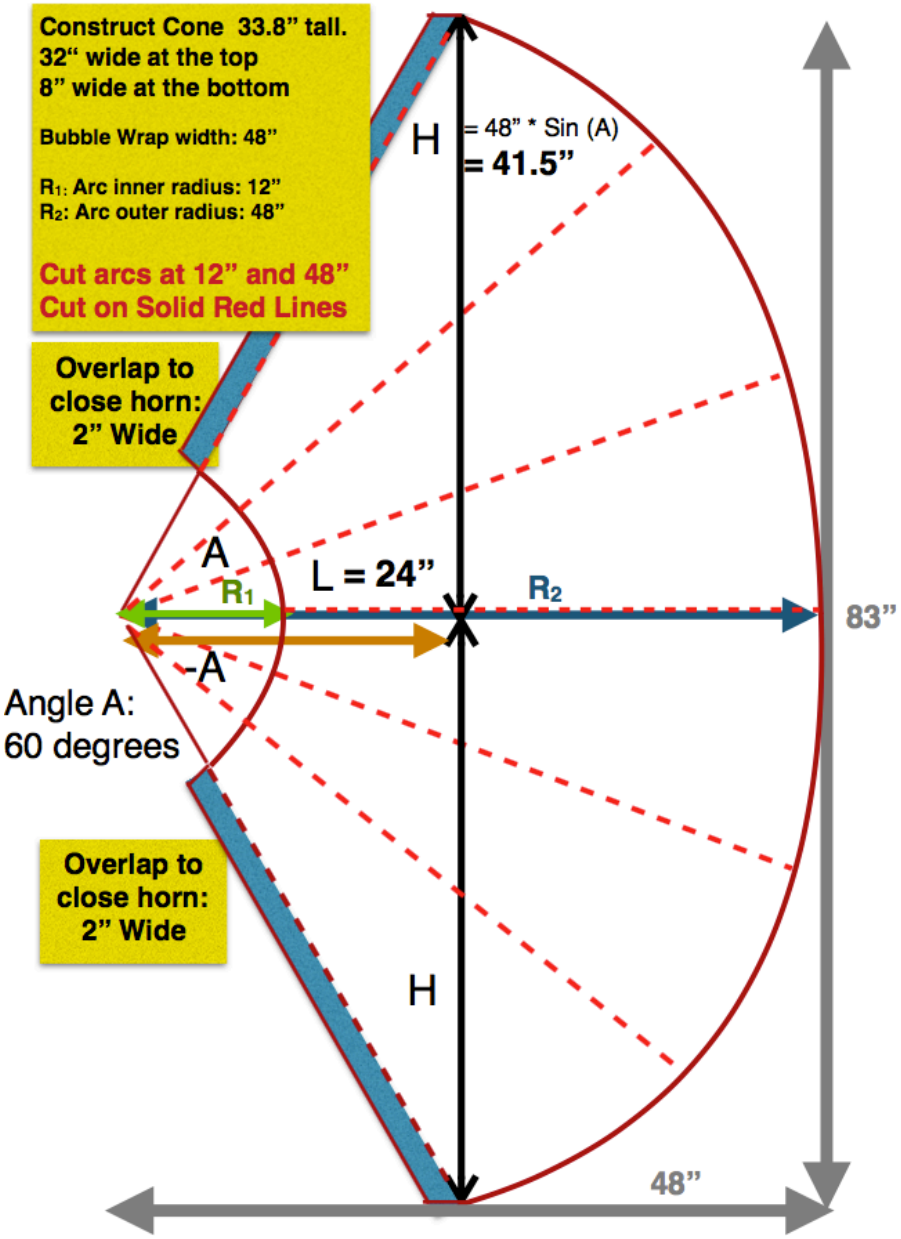


Figure 4: *Create the horn from a 48-inch wide by 83-inch piece of mylar (silver) bubble wrap. The solid red line shows the places to cut. The dashed red lines show the locations of the legs*

First draw a dashed line across the bubble wrap sheet, 41.5 inches from the short edge. The left edge of this line is the center of the two arcs drawn on the bubble wrap. The arcs are two parts of circles with 12 and 48 inch radius, easily drawn with a 4 foot ruler.

Put one ruler edge at center of the circle and the other at the top of the sheet. Draw marks at 12 and 48 inches. Rotate the ruler and mark all along the arcs.

The positions of the six legs of the horn are shown with dashed lines. The legs are placed every 20 degrees on the arc. Draw the leg positions on both sides of the mylar sheet

Components

The horn is constructed from components listed in **Table 1**. The main part of the cone is constructed from a 4-foot wide sheet of bubble wrap, which is held open by six legs. Obtain all parts in this list.

The legs are constructed from two 10-foot lengths of plastic electrical conduit, normally used to protect electrical wiring. This material was chosen because it is stiff, but bendable, and is not expensive. The 10-ft long conduit sections have a 3 inch ends that are wider than the rest of

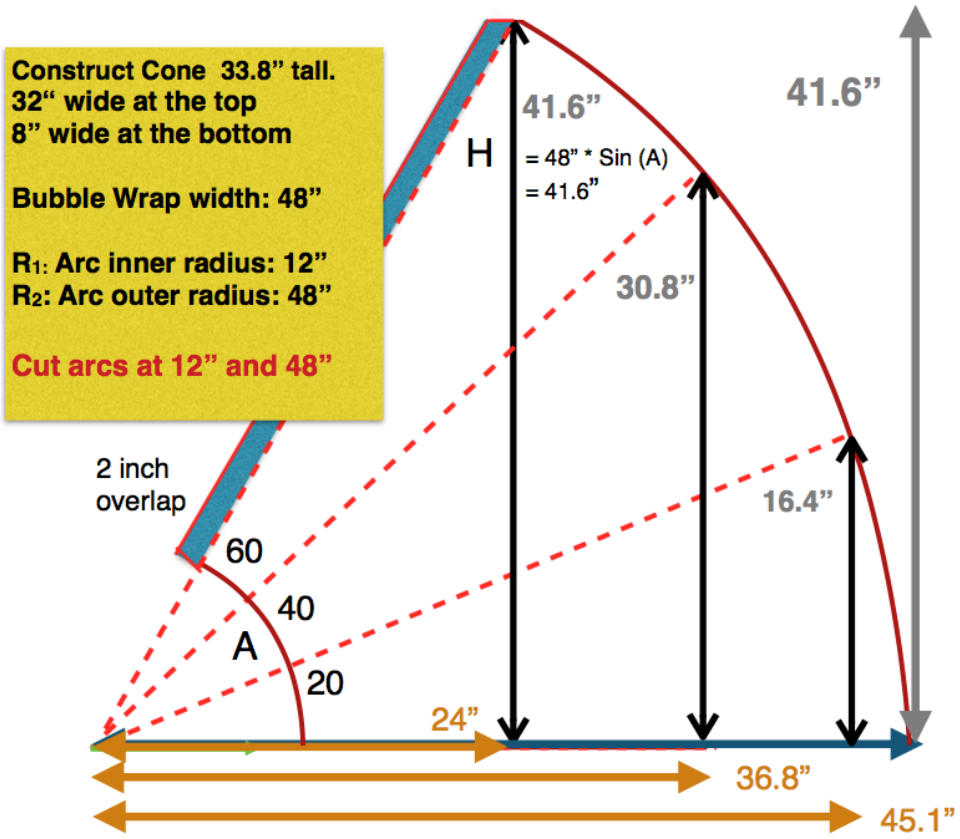


Figure 5: *Zoom in on the top half of the bubble wrap horn. The measurements are from the middle line of the bubble wrap. The center of the arc is on the left side of the sheet. The x and y coordinates of the leg positions are shown with dashed lines.*

Draw all marks on the sheet before cutting.

The horn is closed with the overlap pieces which is between 1.5 and 2 inches wide on both sides.

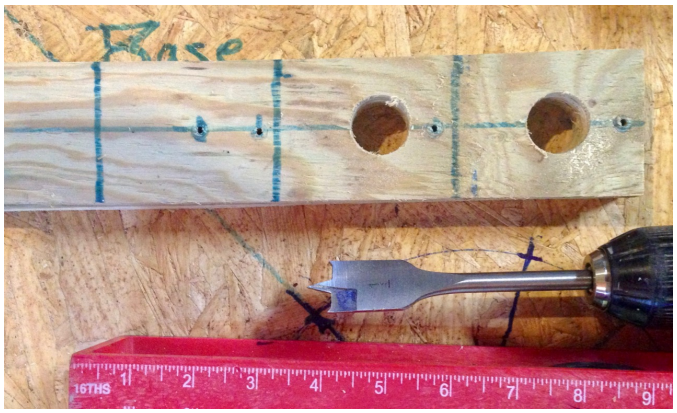
the conduit. Cut these 3 inch sections off, leaving 117-inches of conduit. Cut both conduits into thirds, creating 6 legs, each 39-inches long.

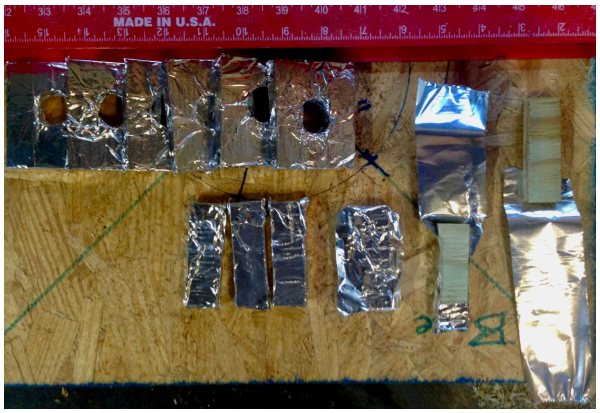
Take a permanent marker and measure 41.5 inches from the edge of the wrap. Mark a point on the left side of the wrap. This is the center for the inner and outer arcs. Draw an arc 12 inches long and another 48 inches long. Draw a line across the bubble wrap 41.5 inches from the edges. This will be the location of one leg.

Figure 5 shows the measurements needed to mark the locations of the other legs. Measure over 45.1 inches. Then measure up 16.4 inches. This should be a point on the outer arc. Draw a line from this point to the arc center. This is the position of a leg. Then measure down 16.4 inches. This will be another point on the outer arc. Draw a line from this point to the arc center. This is another position for a leg.

Next measure over 36.8 inches from the arc center and up 30.8 inches. This is another point on the outer arc. Draw a line from the point to the arc center. This is the 4th leg. Now measure down 30.8 inches and draw a line for the 5th leg. Finally measure over 24 inches from the arc center and up 41.5 inches. This should be on the edge of the bubble wrap. Draw a line to the arc center. This is the position of the 6th leg. From this edge. draw a line parallel to the 6th leg but two inches over. This is the overlap, used to seal the cone.

Draw lines for each of the six legs, from the outer arc to the inner arc. The conduit legs will be placed on these lines. Now cut around the out side edges of the bubble wrap.





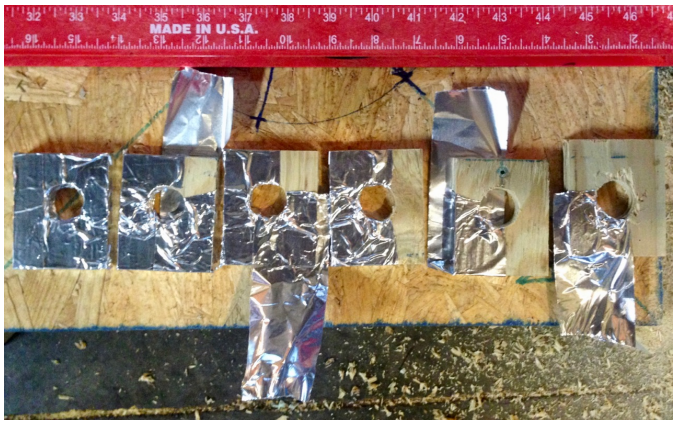


Figure 6: Steps for making attachments for legs and end caps to hold lid on. The upper left shows steps for making the 6 end caps. These are made two at a time by placing two lengths of 2.5-inch wide plywood strips on top of each other. Mark the strips every 3 inches, then draw a center line. At 1/4-inch from each edge and 1 1/4-inch mark spots for drilling with 1/8 inch drill bit.

After drilling the 1/8 inch pilot hole for the larger hole, use a space bit to drill the 1.25 inch wide hole for the conduit.

Wooden Parts for Cone Lid

A 12 wooden parts are used to attach the lid to the top of the cone. Each attachment is a pair of wooden parts. The inside part is a rectangular piece of wood, 2.5 inches long by 1.25 inch wide, 1/2 inch thick plywood. The outer attachment is a rectangle 3 inch long, by 2.5 inch wide 1/2 inch thick plywood. We will drill holes in the outer attachments. Figure 6 shows the series of steps to drill the holes and cover the attachments with muffler tape.

Attach the legs to the outside edge of the cone.

Starting from the middle of the bubble wrap sheet, place the first leg of the horn on the center. Align end of the leg with the small end of the bubble wrap. The leg will extend a few inches beyond the top of the wrap.

Attaching the legs to the Bubble Wrap.

The narrow (bottom) part of the cone is attached is 8 inches in diameter. It is attached to the pipe reducer by bolts and lock nuts. Place a leg on the line from inner to outer arc, alining conduit with the edge of the wrap.

Measure 3 inches from the end of the conduit and drill a 5mm wide hole (7/16 inches) through the conduit and bubble wrap. From the inside of the cone, insert a M5x35mm bolt with 12mm washer through the hole. The washer is inside the cone to spread the tension over a larger

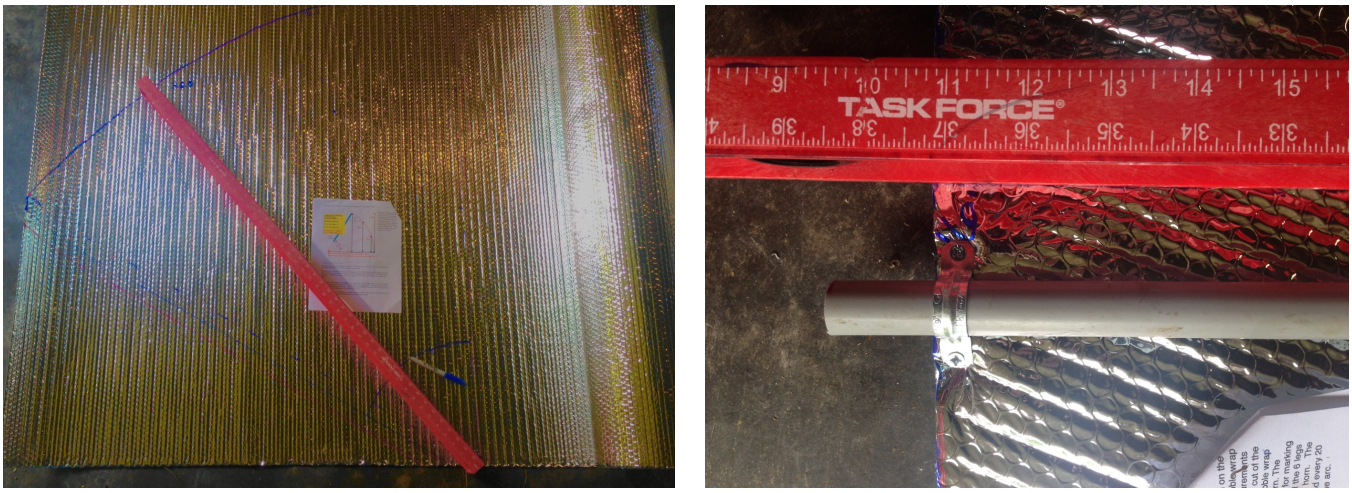


Figure 8: *Steps of cutting wrap and attaching pipe legs. The upper left figure shows drawing the inner and outer arcs, the 1.5-2-inch overlap on both sides and measuring and marking the leg positions. Starting with the center pole, add the inner piece of the lid plywood part.*

area of the bubble wrap.. Bolt the bubble wrap to the conduit using a M5 lock nut. Measure 18 inches from the inner arc and drill another 5mm wide hole. Repeat attachment of bubble wrap to conduit using another M5x35mm bolt with washer. At the outer arc the conduit will extend beyond the edge of the bubble wrap. Take one of the 2.5inch by 1inch pieces of wood and use 1/2inch wood screws to attach the wooden part to the inside of the cone.

Finally at the inner arc, measure 0.75 inches from the edge and drill a 4mm hole.

Attaching Cone to Pipe Reducer

The cone is bolted to a pipe reducer to allow separating the horn into two parts. The galvanized pipe reducer has no crimped ends, and is 6-inches in diameter on the small end, 8-inches in diameter on the large end. The reducer is 7-inches tall. The horn is attached to the large end by six 2-inch long bolts. The bolt diameter is not critical, use bolts between 3mm and 4mm. The imperial 6-32 bolts have a diameter of 3.5mm. Use lock washers or locking nuts with these bolts.

The circumference of the large end of the reducer is C = 8-inches * pi = 25.1-inches. The bolts are placed every 25.1/6 = 4.2-inches apart.

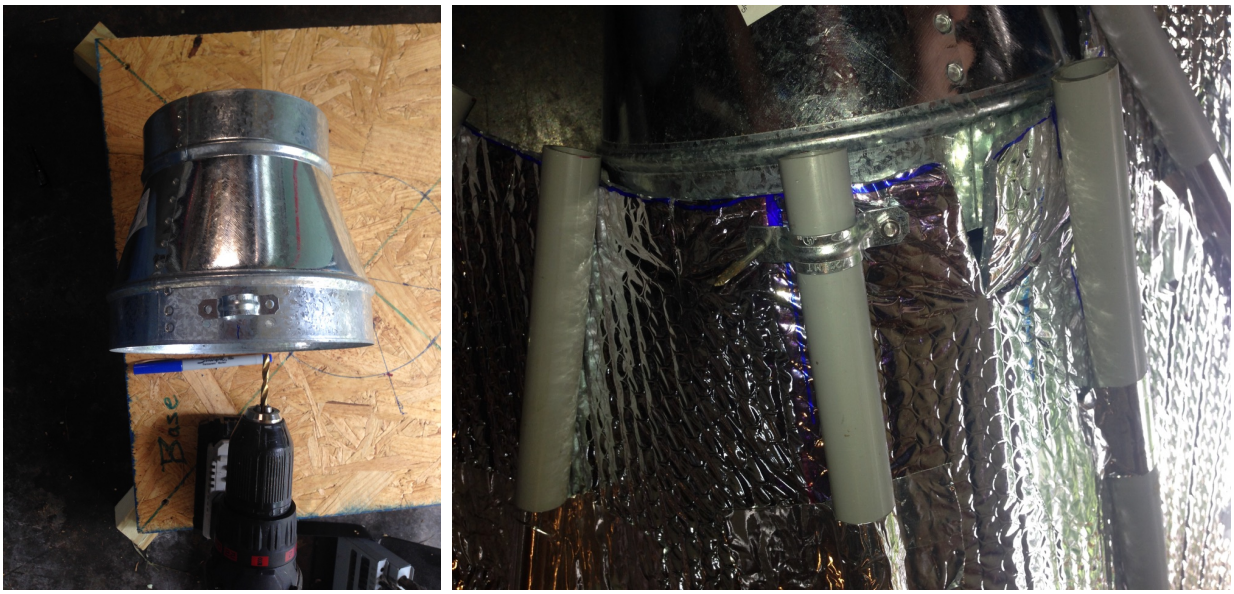


Figure 8*: Drilling the holes in reducer for conduit straps. Attaching the first (center) leg to the reducer. 6 pairs of holes are needed for the 6 legs.*

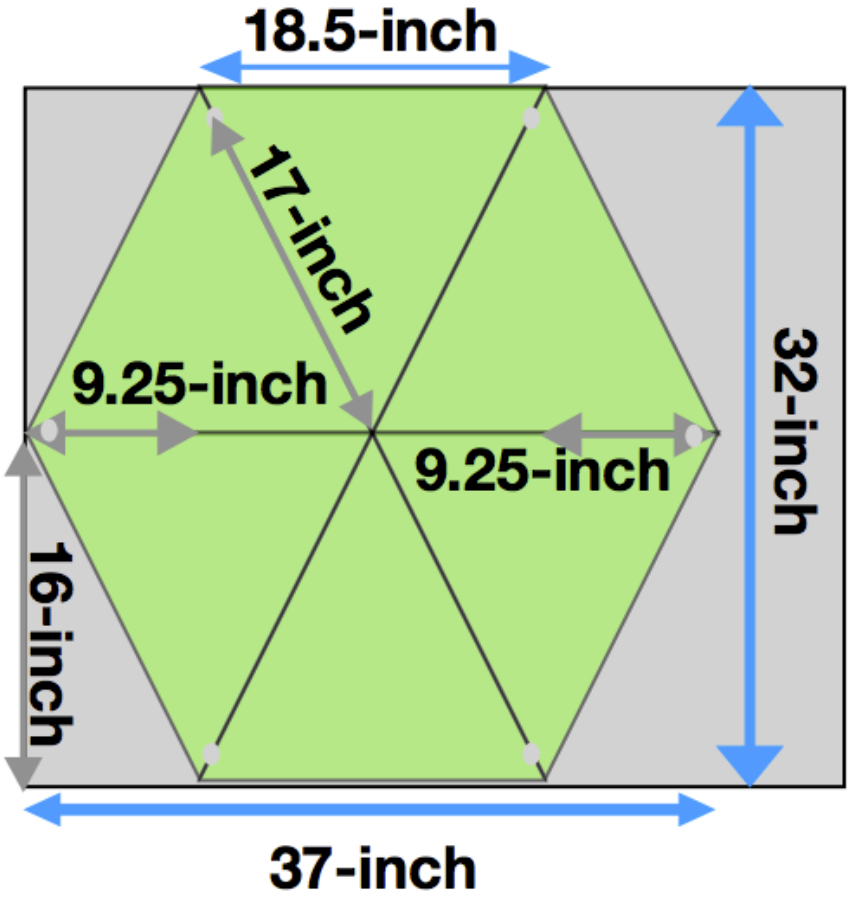


Figure 9: *Cone Lid Construction guide for creating a large foam hexagon. The part is created from 1/3 of a 8 ft sheet of 3/4 inch thick foam insulation. The largest dimension is 37 inches and the hexagon is 32 inches wide in three directions. The support legs feed through 6 holes on the edge of the hexagon. The holes are 1-inch in diameter, 17-inch from the center of the hexagon.*

Draw lines for the border, then use an knife to cut along the edges. Folding the foam after cutting will yield straight edges.

Pick a spot on the reducer adjacent to the place where the reducer outer band is welded together. Mark the placements of all six of the holes drilled in the reducer, 1-inch from the edge of the reducer.. Check that all six of the are separated by the same distances. Drill the six holes for attaching the legs.

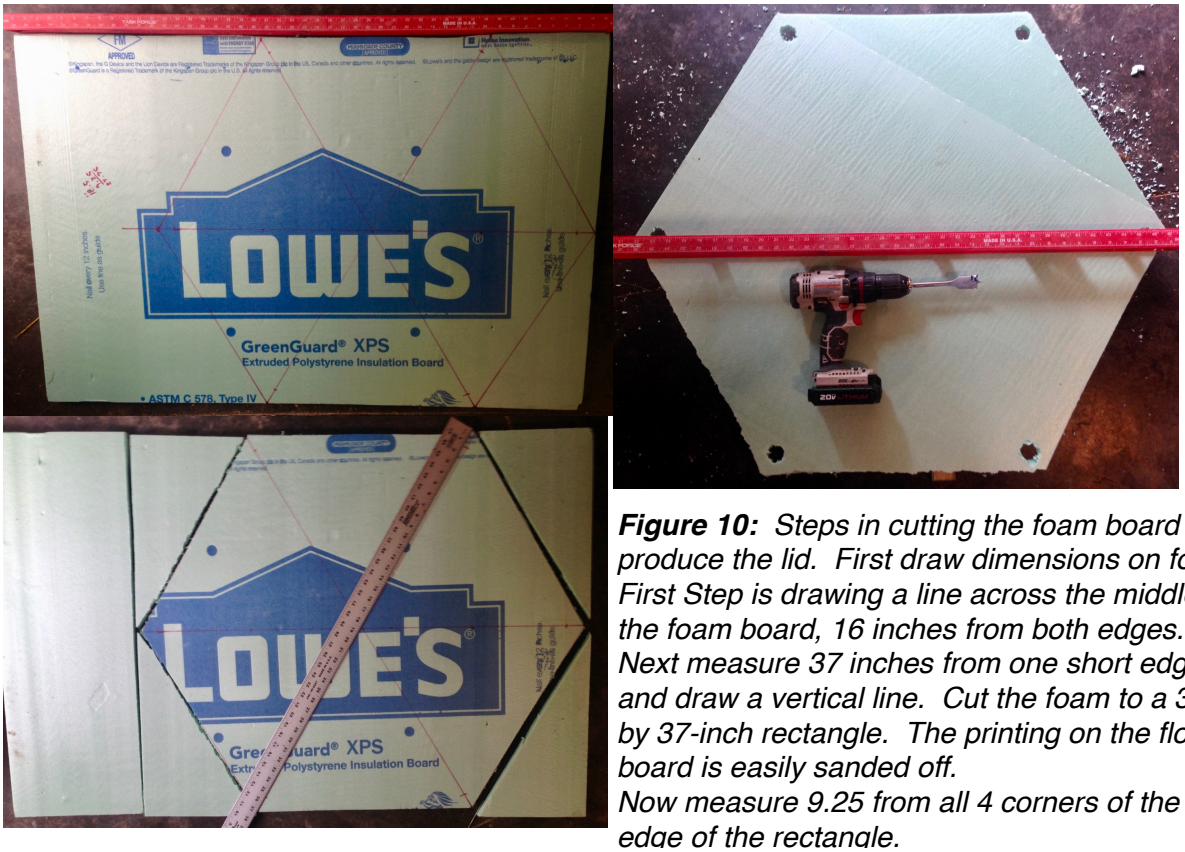


Figure 10: *Steps in cutting the foam board to produce the lid. First draw dimensions on foam. First Step is drawing a line across the middle of the foam board, 16 inches from both edges. Next measure 37 inches from one short edge and draw a vertical line. Cut the foam to a 32 by 37-inch rectangle. The printing on the float board is easily sanded off.*
Now measure 9.25 from all 4 corners of the long edge of the rectangle.

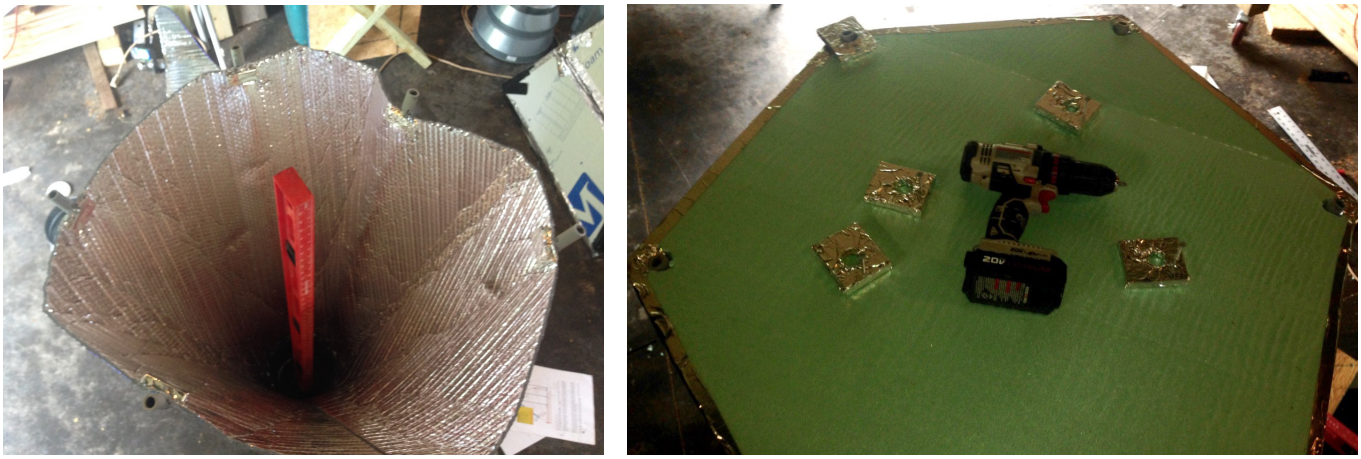


Figure 12: *Horn attached to reducer, but no cap yet. At right the horn lid is being attached to the legs. Because of the symmetry of the horn, the lid can act as a table, for light weight items.*

Create wooden pieces to Attach Legs and Lid to Cone

The legs are attached to the cone by electrical conduit straps screwed to wooden pieces. The wooden pieces are small 1 by 3 inches, and should be covered with silver tape to be reflective

Figure 13: *Completed horn! The horn has the lid on top and the pipe reducer on the bottom. Because of the symmetry of the horn, it acts as (tippy) table. The lid connectors are screwed through the lid to small pieces of wood 3 inches from the ends of the legs.*

to radio waves. You need six of these to attach to the six legs. Figure 8 shows the process of cutting the wooden parts.

The cone lid is attached to get cone by sticking the legs through the cone lid. The cone lid is held down by 3 by 5 inch pieces of wood with a 1.25 hole drilled through each. The hole is centered one 1.25 inches from the edge of the wooden rectangle.

Cone lid

The cone is a six-sided, hexagon-shaped, lid constructed from foam insulation. This foam insulation is transparent to radio waves, and does a good job of keeping rain, snow, leaves and bugs out of the horn.

We've chosen a 32 inch wide lid, so that three lids can be cut from a single 4-ft by 8-ft sheet. We're using 3/4-inch thick foam. Half-inch to 1-inch thick foam board would also work. Figure 5 shows the dimensions of the lid. The lid is held in place by end caps constructed from 2.5-inch wide, 3-inch long pieces of plywood. The lid is screwed on by six 2-inch long drywall screws.

Before assembly of the green foam on the horn, sand the printing off of the foam. This print may attenuate the signal and increase the system temperature. After sanding, fold the silver muffler tape around the lid edges to give it strength. Then place tape inside the holes for the legs, to strengthen the lid further. Try to keep tape from blocking much of the inner part of the lid. The legs attach to the lid through holes in the lid. These are drilled with a 1inch wide drill bit. Mark spots 18 inches from the center of the lid along each of the six directions to the corners

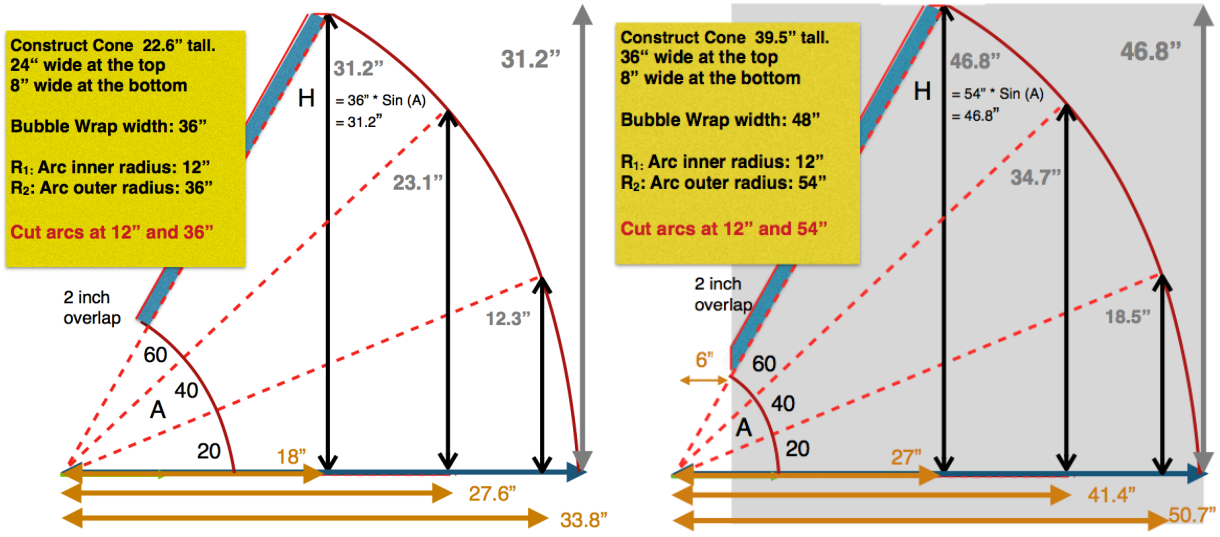


Figure 14: *Bubble wrap measurements for constructing a 24 inch wide cone (left) and 36 inch wide cone (right). These measurements are from a point defining the center of the arcs to be cut. For the 24 inch cone, the point is at the edge of the bubble wrap. For the 36 inch diameter cone, the point is 6 inches off of the bubble wrap. To draw the arcs, tape the bubble wrap to the floor and mark the center point on the floor. (Note the 24 inch cone leg positions happen to each have only 3 digits: 12.3", 23.1" and 31.2")*

of the lid. Then insert small pieces of metal tape around the inside of each hole. This is to strengthen the connection of lid to cone.

The lid tops are screwed into the wooden pieces attaching each leg to the cone using 2 inch dry wall screws. The long edge of the wooden tops should extend out side of the lid, to protect the foam if the cone tips over.

Conclusion

The completed bubble wrap horn greatly increases the sensitivity of the telescope, by increasing the collecting area. The bubble wrap horn is very durable. I've had mine in operation outside, in snow, wind, sun and rain, for years and it worked well.

Attach your cone to your receiver and start discovering!

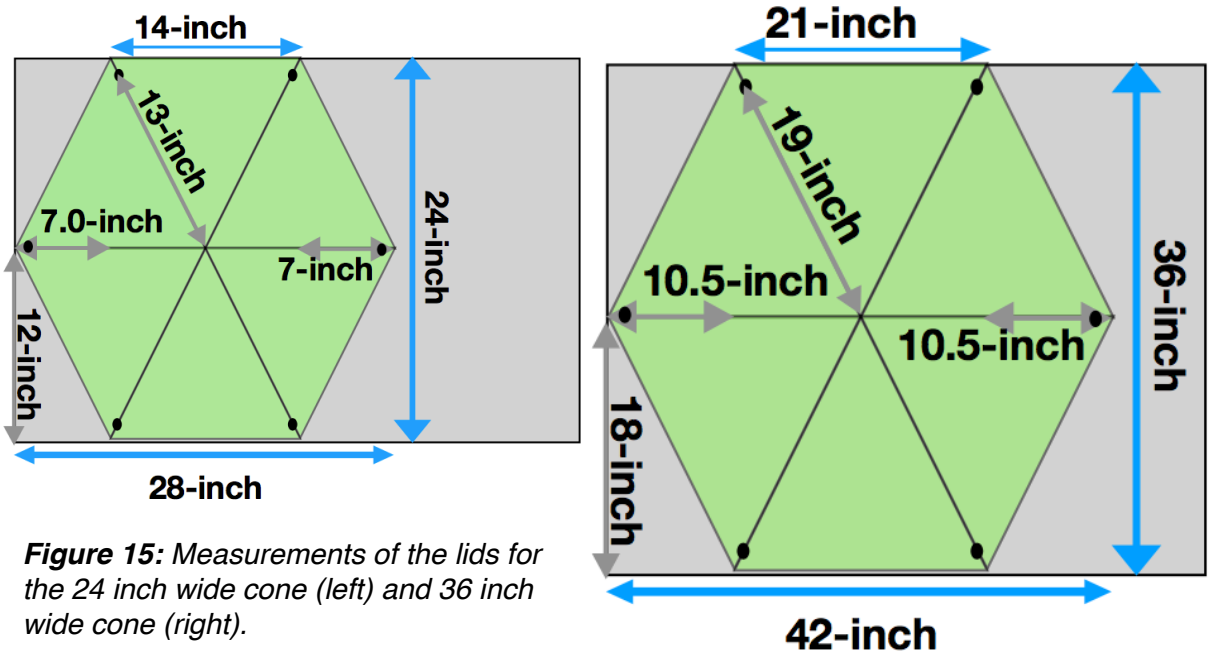


Figure 15: *Measurements of the lids for the 24 inch wide cone (left) and 36 inch wide cone (right).*

Appendix A: Different size horns

Bigger horns yield more sensitive telescopes, but at the cost of more difficulty in transport. Smaller horns are better for in-class demos and still yield good results. In this appendix, we describe the process of creating two more horn sizes. One is a little bigger, 36 inches in diameter, which is the biggest that can be created from a 48 inch wide sheet of bubble wrap. The other horn is a little smaller, 24 inches in diameter, which is more convenient for transport. This 24 inch size has the advantage that 4 horns can be built from a single 4 by 8 foot wide piece of green foam.

Figure 5 shows zoom in the 32 inch wide cone measurements, with measurements for positioning the legs. In figure 14, we recalculate those values for 24 and 36 inch wide horns. I've rounded numbers a little bit for measuring convenience.

All these horns are cut from a 120 degree wedge of bubble wrap. The 24 inch wide horn has an inner radius of 12 inches and an outer radius of 36 inches. To create this horn, a sheet of 36 inch wide bubble wrap is needed (or cut from a 48 inch sheet). The piece must be 2*36*sin(60 degrees) = 2 * 31.18 = 62.35 inches long. The legs will be attached at 36*sin(20 degrees) = 12.3 inches and 36*sin(40 degrees) = 23.14 inches.

The 36 inch wide horn is cut from a 48 inch piece of bubble wrap and the inner radius is still 12 inches. The outer radius is 54 inches, which is longer than the 48 inch bubble wrap is wide, so a mark must be placed on the floor 6 inches from the bubble wrap. Draw arcs 12 inches and 54 inches in diameter from that point. The piece of bubble wrap must be 2*54*sin(60 degrees) long = 2 * 46.75 inches = 93.5 inches long. The legs must be attached at 54* sin(20 degrees) = 18.5 inches and 54*sin(40 degrees) = 34.7 inches.

Figure 9 shows the horn lid measurements for the 32 inch wide cone. The lids for the smaller and larger cones are scaled from these measurements. Figure 15 shows the measurements for the 24 and 36 inch wide cones.

For the 24 inch wide cone, the equal lateral triangles sizes are 12/sin(60 degrees) = 14 inches (rounded). The lid is twice this size, 28 inches wide. Figure 15 shows the lid dimensions for the 24 and 36 inch wide cones.

The legs for the horns are 3 inches longer than the difference between the outer and inner radii. For the 24 inch wide horn, that is 36-12 + 3 = 27 inches. For the 36 inch wide horn the legs are 54-12+3 = 45 inches long.

Note the *area* of the horn opening is the critical parameter for comparing sensitivity of your telescope. For the 36" wide horn, the area is pi * r * r = 3.14 * 1.5 * 1.5 = 7 square feet. For the 24 inch wide horn, the area is 3.14 square feet. So, observations with the 36" wide horn are more than *twice* as sensitive as with the 24" wide horn. (In metric units the areas of the 24 and 36 inch wide horns are 0.29 and 0.66 square meters.)

Finally, one last note on constructing horns. If you happen to have a 36 inch wide piece of bubble wrap, you *could* make a 28 inch wide cone. This cone has an outer radius of 42 inches.

I'll leave it to you to calculate the other measurements needed to create the cone and lid. A teacher/leader could also ask you to find the measurements needed to create a 28 inch wide horn, to test your skills!

Appendix B: 8 Inch diameter circle for marking holes to attach legs to Reducer.