Open Source Hardware Engineering

Instruction Manual

-

How to Build the

***<u>Inverted Bird Feeder</u>* Radiation Shield**

Version 4.0

February, 2011

Introduction

This document shows how to build the "Inverted Bird Feeder" -- a custom, fan-aspirated housing for temperature/humidity sensors which performs much better than a naturally aspirated shield. It looks kind of like an upside-down bird feeder which is where the name comes from. This design is being used by the author with an Oregon Scientific wireless temperature/humidity sensor. With appropriate modifications for sensor size and form factor, it will work with other brands of sensors too.

Using current internet and local store pricing, this can be built for a price around $60US plus applicable sales taxes and shipping costs. You may already have some of the materials in which case the cost would be less.

Features & Benefits

The key to this shield's excellent performance is a coaxial configuration which this author originally found on a web site in Greece here:

(http://users.otenet.gr/~meteo/project_radiation-shield.html)

Although this design is significantly different, it provided the initial idea to use a coaxial arrangement. Another feature of this design is that the exhaust air (which has been warmed by solar heating) is directed ***up and away*** from the air intake port, eliminating a source of error that has been a problem with some designs.

Figure 2 reveals the coaxial arrangement: one smaller pipe is centered inside a second larger pipe. The smaller pipe is shorter than the large pipe, so there is a gap at one end as shown. A DC powered axial fan mounted at the end of the large pipe sucks air through both pipes at the same time. The temperature sensor is mounted in the small pipe, in the airstream created by the fan.

Figure 3 depicts how solar radiation is presented with several barriers before it can alter the measured air temperature. First, solar radiation absorbed by the outer pipe's surface must be conducted through the wall of that pipe. The warmed inner wall must then transfer heat by convection across the air gap (this is hindered by air flow between the two pipes). Heat must then conduct through the wall of the inner pipe before finally being able to warm the sensed air temperature by convection again.

The polyethylene pipes used in this design are designed for water drainage and manufactured by the Hancor Company. They have a "triple wall" construction as shown in figure 1. This provides additional insulation, reducing the amount of heat that can be conducted through the pipe wall(s). As a result, this shield will perform better than a shield constructed of metal tubes.

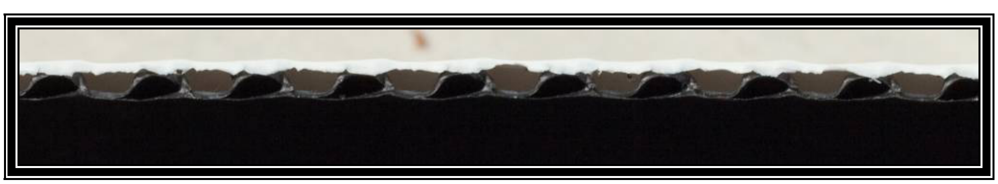

Figure 1. Hancor triple wall pipe cutaway view

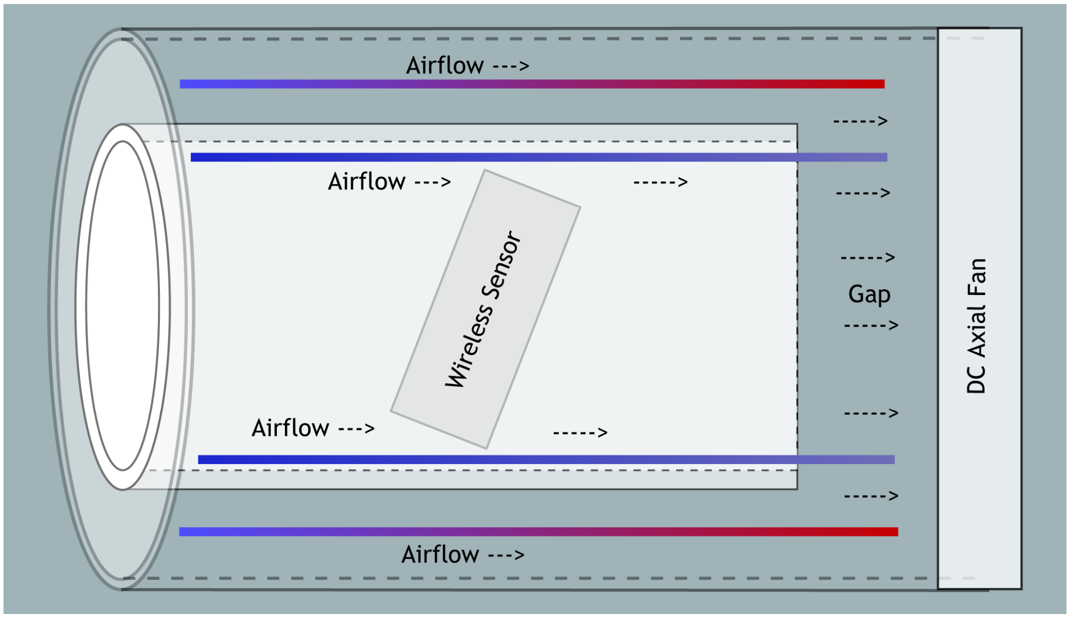

Figure 2. Coaxial Shield Concept

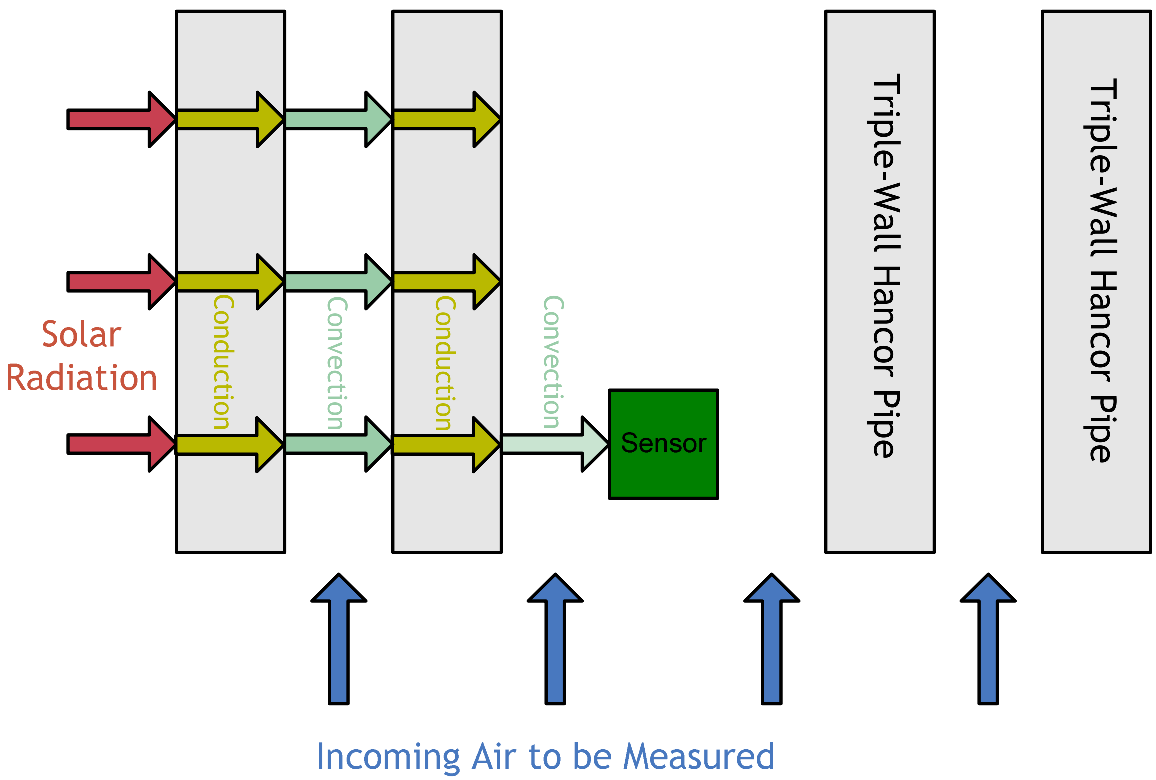

Figure 3. Heat transfer concepts

There is another advantage to this design. The surface of the outer pipe will be heated by the sun, and will in turn heat some of the nearby air. Another source of error is caused by aspiration of this heated air (just hanging around the outside of the outer pipe) into the air intake. This can occur for example in calm wind conditions. The design helps minimize this source of error since warmed air near the surface of the outer pipe will tend to get sucked into the gap between pipes instead of into the inner pipe (where the sensor is mounted).

A conceptual diagram of the shield is shown below in figure 4. By arranging two bowl-shaped pieces (actually, they are flower pot bases) as shown, protection from rain is provided while still causing the warmed exhaust air to be ejected upwards, away from the shield's air intake. The upward ejection of exhaust air is a significant improvement on other designs which tend to give exhaust air a downwards velocity component as it leaves the shield, thereby creating a risk of polluting the measurement air.

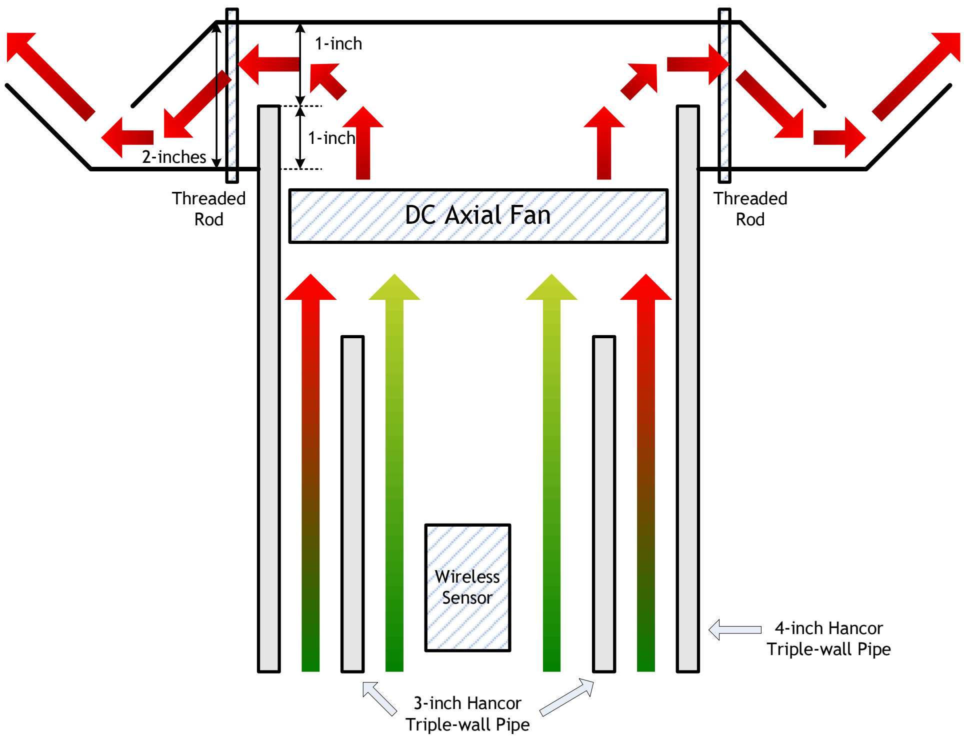

Figure 4. Inverted Bird Feeder cutaway view

The FPB Acronym

As mentioned above, the design uses two plastic bowls – flower pot bases. For the remainder of this document, they will often be referred to as "FBPs" to save a little typing.

Design Notes

A few notes are provided here about some of the design details. These notes may be useful for those wishing to modify this design and may also lead readers to ideas that could improve this design further. If you are not interested in the details and don't plan to modify the design, this section can be skipped.

The "Gap"

As shown in both figures 2 and 4, there is a gap between the end of the inner pipe and the fan. The purpose of this gap is to allow the fan to draw air equally through both air spaces – the inside of the inner tube where the sensor is mounted, and the annular gap between the two tubes.

The fan probably generates most of its airflow near the outer edges of the fan blades since they are moving faster than the portion of the blades near the center. The fan blade pitch varies with distance from the center to offset this behavior, but there may still be higher airflow near the outside edge.

If the inner tube extends all the way to the fan blades, the increased airflow at the outer edges could be restricted to the annular gap between tubes resulting in inadequate airflow through the inner tube. Moving the end of the inner tube away from the fan creates an area where airflow can redistribute itself resulting in more even airflow throughout the system.

These ideas have not been tested and could still be experimented with. For example, if it was discovered that there was not enough airflow in the annular gap, the inner tube could be lengthened. Or perhaps a longer gap than the one used here might be beneficial. An exercise left for the reader!

In comparison with a larger coaxial shield, it was discovered that this shield exhibits more temperature rise from solar radiation than the larger version. The difference seen has generally been 1 °F or less. While the cause is not fully understood, the prime suspect is the size of the annular gap between the two pipes. Increasing the outer pipe diameter or decreasing the inner pipe diameter would improve the performance if this guess is correct.

The Rain Shield

Three aspects of this design work together to keep rain away from the fan and sensor.

First there is the smaller flower pot base (or "FPB"), which completely covers the end of the larger pipe. No holes are drilled in this cover in the area where it covers the pipe. Holes attaching it to the larger FPB and mounting holes are drilled near the outside edge where any leaks will not find their way into the pipe.

Secondly the large FPB has a hole cut in it so that it slips snugly over the outer pipe. The outer pipe extends about 1-inch above the floor of the large pot base which creates a barrier wall that rain would have to splash over before getting into the top end of the outer pipe. Drain holes are drilled near the outer rim of the large pot base

Lastly, in combination the two FPBs only expose a small annular area (when viewed from above) where rain can land in the large FPB which makes it very unlikely that any splashes will find their way over the top of the pipe under the smaller FPB.

FPB Spacing

The spacing of 2-inches between FPBs in figure 4 is not arbitrary. There is one inch of space between the top of the outer pipe and the bottom of the covering small FPB. This distance was chosen to create an exit area for the exhaust air that is roughly equal to the cross-sectional area inside the outer pipe. The thinking is that if the exit area is the same as the pipe's flow area, then fan back pressure will not be significantly increased as the air makes the change in direction at the top of the outer pipe. This is simply a common-sense approach to managing back pressure and is not based on any technical airflow theory. Even with an equal exit area, back pressure is probably increased by the airflow having to make a change in direction; we're just crossing our fingers on this one.

The remainder of this document contains a parts list followed by instructions for fabrication and assembly of the inverted bird feeder.

Parts List

Although specific vendors are listed below, the author does not necessarily recommend these vendors. They were merely found as having typical internet-based prices for the parts required to build the radiation shield. The reader should do their own local and/or internet shopping to find vendors which are acceptable to them. To repeat: the fact that the author has listed a vender below does not constitute a recommendation to purchase from that vendor.

The smaller design uses these parts:

- 12-volt NMB 3610KL-04W-B30 fan (available from Newark Electronics for $13.25US), or Orion Fans OD9225-12MB
    - For quieter operation, NMB 3610KL-04W-B20 (also $13.25US from Newark) or Orion OD9225-12LB (available from Newark Electronics)
- 12-volt 6-watt power supply (a "wall wart") (for example, the CUI Inc. EPS120050, available from DigiKey for $5.93US)
- 14-inches of 4-inch Hancor triple-wall drain pipe ($8.00US for a 10-foot length)
- 6-inches of 3-inch Hancor triple wall drain pipe ($7.00US for a 10-foot length)
- 1 each, 4-inch drain pipe slip coupling ($1.67US)
- 1 each, 7-inch flower pot base ($2.00US)
- 1 each, 9-inch flower pot base ($3.00US)
- Hardware to mount flower pots with an approximately 2-inch spacing. Many options are possible and discussed below. Prices listed were taken from BoltDepot.com in February of 2011. This hardware is very inexpensive, so it might be a good idea to get some extras. The total price for all items listed below is $3.66US so the order could be doubled for extras with a total price of $7.32US (plus shipping). For example:
    - 3 each #8-32 x 2.5 inch long 18-8 stainless steel Phillips pan head machine screws ($0.22US each)
    - 6 each #8-32 18-8 stainless steel nuts ($0.05US each)
    - 12 each #8 and #12 18-8 stainless steel washers ($0.05US each)
    - 6 each #8 x 3/8 OD x 1-inch long nylon spacers ($0.35 each)
- A few feet of monofilament fishing line, 10 to 60-lb test ($3.00US each)

- 9 each, ¼-20 or ¼-28 by ½ to ¾-inch long bolts (hex head or socket head), stainless steel or plastic (nylon, for example). For example, ¼-28 by 5/8-inch socket head cap screws in 18-8 stainless from BoltDepot.com are $0.22US each for a total of $1.98US.

- 3 each, #6 electrical crimp lug for hanging the shield (optional)

- 1 square yard of mosquito netting ($4.00 US)

- Tie-wraps ($1.00US)

- Optional: Black and white spray paint

- Optional: 2-conductor, low voltage wiring long enough to reach from sensor location to power supply (minimum wire size: 26-gauge, price varies widely)

Parts List Notes

In some cases you may need to buy substantially more of something (like the Hancor pipe or monofilament fishing line) than is required in the design. The $60US estimate takes this into account. The shield can be built for a lot less money if you already have some of these items on hand or can obtain some small scraps.

The first two fans listed are roughly 2400 RPM and make a little more noise than the last two which run at 2100 RPM. The performance may be a bit better with the 2400 RPM fans but if noise is an issue the slower ones will work. The faster fans should create an overall flow around 420 feet per minute while the slower ones should create a flow in the neighborhood of 300 feet per minute. The exact airflow you get will also depend on how much air resistance the mosquito netting creates. The author has not tried the slower fans so it is not known how well they will work in this design.

One set of parts for bolting the two FPBs together with a 2-inch spacing is listed. There are many ways to accomplish this so feel free to use another approach if you are comfortable doing so.

The standoff material is preferably either stainless steel or nylon, with screws and washers of the same material. Aluminum standoffs are about half the price of stainless but might corrode over long periods of time. If the screws are made from a different metal than the standoffs, they should be compatible for purposes of galvanic corrosion. See the web site below or run an internet search for the words “compatible metals corrosion”.

http://www.engineersedge.com/galvanic_capatability.htm

For example, brass and stainless steel are compatible while stainless steel and aluminum are not. Threaded rod is available from nutty.com and standoffs can be found at fastenermarketplace.com.

For the shield pictured in the photos, I used stainless steel spacers 1.875-inches long with #6-32-by-2.5-inch long stainless screws. When these are secured to the smaller FPB with nuts, the total length is very close to 2 inches. See the section on final assembly for more on the assembly process. The parts list uses two 1-inch spacers put together on each screw and will result in a spacing a little larger than 2 inches which will also work fine.

The FPBs pictured in this document are made from soft, flexible plastic purchased from a local big-box home store. They are easy to cut and forgiving of slight dimensional misfits. FPBs are also available in hard plastic and these will be more difficult to cut and the cuts will need to be more precise. They will also work but more care is necessary during fabrication.

The shield is designed to be hung by wires, monofilament fishing line or similar. There are two ways to do this:

1. By drilling three small holes in the rim of the smaller FPB and stringing some wire or monofilament line through them. The wires or fishing line form an inverted tripod by which the shield can be hung.

2. By installing three electrical crimp lugs under the screw heads used to bolt the two FPBs together. In this case, wires or fishing line can be threaded through the crimping end of the lugs and the same sort of inverted tripod is created.

Don’t get ripped off!

Now it is time for an editorial comment on home stores. The author recommends purchasing the required hardware (bolts, screws, nuts, washers, etc.) from an internet site specializing in hardware. The big-box home stores are known for heavy price gouging when it comes to this type of merchandise and you will probably save money purchasing on the internet – even after paying for shipping. In the off chance there is a good industrial hardware store where you live, that may be a viable option as well. The Hancor pipe, associated fittings and FPBs may be purchased from any local source including home stores.

Fabrication

These instructions are split into two parts; fabrication and final assembly. The fabrication phase involves cutting and fitting parts in preparation for the final assembly process.

Main Outer Pipe

Start by cutting a 9-inch length of the 4-inch Hancor pipe. The easiest way to do this is using a compound miter saw (a.k.a. “chop saw”) with carbide tipped blade. The pipe in the following photos was cut with a utility knife which resulted in some ragged edges. Either way is totally acceptable.

Here’s a tip for cutting the Hancor pipe with a knife. You will notice that there appear to be “ribs” on the outside wall – this is where there is plastic connecting the inner and outer walls together. When cutting the pipe, stay in between the ribs as there is less overall plastic to cut through. The ribs also make good cutting guides to create a roughly square cut.

Next, drill two sets of three holes in the pipe. Measuring from the intake end of the pipe, one set is 1-inch over and the other set of three holes is at 5-inches. The exact location is not critical. These bolts will be used to clamp the inner 3-inch pipe in place so they just need to be located near the ends of the 3-inch pipe (which is 6-inches long). Each set of three holes is spaced evenly at 120º increments around the circumference of the pipe.

You want these holes just barely large enough so you can force-thread the bolts through the plastic pipe walls. Start with a drill that might be a bit too small. If using ¼-inch screws or bolts, start with a 13/64-inch (or even 3/16-inch) drill and enlarge the hole with successively larger drills until you can just thread the bolt into the hole. Thread each bolt through the pipe wall so it protrudes perhaps ¼ inch or so into the inside of the pipe. If you are using plastic (e.g. nylon) screws or bolts, it may be necessary to run a tap through the holes first depending on how strong the plastic threads are.

Figure 5. Main outer pipe with clamping screws installed.

Figure 5 shows the 9-inch length of pipe with six stainless steel cap screws threaded into the holes. I used ¼-28 by ½ inch long screws. These were just barely long enough to reach the 3-inch pipe and lock it into place. Longer screws (up to ¾-inch long) and/or a coarse thread (¼ - 20) should also work. The locations of the screws is measured from the intake end of the pipe.

Optionally, drill one or two more small holes (e.g. 1/16 inch or smaller) very close to the intake end of the 4-inch pipe, and then thread several feet of monofilament through these holes. Tie knots in the inside end of the line to keep it from slipping through the holes. These lines can be used as exterior tie-downs to secure the bottom end of the shield if it blows around too much in the wind. This option is not shown in the photographs.

Hacking the Fan

Now get ready to do some major cutting on the fan. This is the most difficult part of building the shield. You need to cut away enough of the mounting brackets so that the intake side of the fan will fit inside the 4-inch pipe. This translates to removing almost all of the mounting ears.

Identify the intake side of the fan; if it is not marked on the fan you may need to temporarily connect the fan wires to the power supply in order to determine the direction of air flow. Mark the intake side of the fan somehow so you don't forget which side needs to be cut down first.

Clips holding the fan wires may need to be removed to get the wires away from the part of the mounting ears that will be cut away. Use whatever technique seems best; I gently used a fine-toothed saw to make rough cuts on the fan brackets, and then finished with a bench-mounted grinding wheel. I worked at it slowly and did not have any problems with the plastic cracking or shattering.

The mounting ears on the exhaust side also need to be cut down – but not as much. They only need to fit inside of the 4-inch slip coupling. They should be large enough to prevent the entire fan from slipping inside the 4-inch pipe.

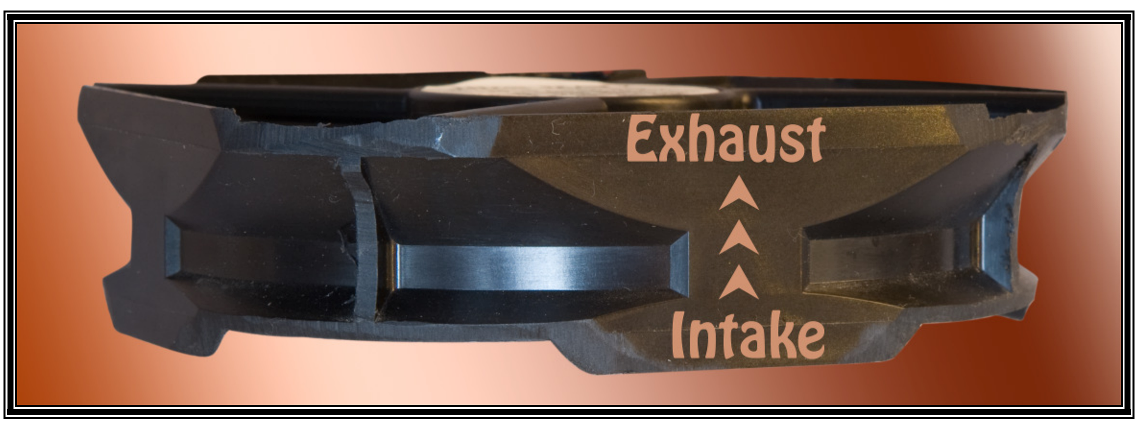

Figure 6. Fan trimming detail

Figure 6 shows the trimmed fan with the exhaust side on the top. You can see in this photograph that the intake side (on the bottom) is noticeably smaller than the exhaust side on the top.

Inner Pipe

Cut a 6-inch length of the 3-inch Hancor triple wall pipe. This is the inner coaxial pipe in which the wireless temperature sensor will be mounted.

Next, we'll drill a series of ten small holes in the 3-inch pipe and thread monofilament fishing line through them, creating a "cage" inside the pipe that will hold the wireless temperature sensor. There are two photos which help explain how this is done.

40-lb test line was used here, which has a 0.024-inch diameter. This heavier line is easier to work with, but thinner line should work too. Use a 1/16-th inch (or smaller); that works well with the 0.024-inch monofilament. Drill the holes between the ribs in the pipe to make threading the lines easier.

Figure 7 is a view from the intake (bottom) end of the 3-inch pipe. A total of five "wires" (which are actually monofilament fishing line) can be seen here.

The wire running from left to right is closest to the intake end of the pipe and forms the bottom of the cage, which the wireless sensor will rest on. The two holes for the cage bottom wire are drilled about one inch from the intake end of the pipe and 180º apart from each other around the pipe's circumference. These two holes can just barely be seen on the right side of figure 8.

The walls of the "sensor cage" consist of two sets of parallel wires. The lower pair (closest to the intake end of the pipe and the cage bottom) is labeled "L1" and "L2" in figure 7. The upper pair (nearest the exhaust end of the pipe) is labeled "U1" and "U2". The cage has no "top" because gravity will hold the sensor in place.

The OS sensor (THGN800) is about 3-1/2 inches tall and ¾ inch thick. The lower cage wires are located about 1-¾ inches from the intake end of the pipe and the upper wires are roughly 3-¾ inches from the intake end. If your sensor is a different size, the upper cage wires can be moved so they are near the top of the sensor.

The lower pair of cage wires are spaced apart from each other about ½ inch or a bit more – but less than the sensor thickness of ¾ inch. The same spacing is used for the upper pair of wires. This spacing means the cage wires will need to be stretched a little to get the sensor into the cage and this will keep it from bouncing around in there if the shield gets blown around in the wind a little bit (the wires labeled with ½-inch spacing in figure 5 are actually spaced closer to 5/8-inch). If your sensor has a different thickness, adjust the spacing of the cage wires accordingly.

Routing the fishing line through the holes to create the cage may appear a little complicated, so here's one way to do it (refer to figures 7 and 8 as necessary):

1. Cut a four or five foot length of fishing line from the spool.

2. Tie a double overhand knot about 12-inches from one end of the line.

3. Thread the long end of the line through the U2 hole from the outside, through the pipe and out the other U2 hole on the far side. Pull the line through until the knot is snug against the U2 hole on the near side – this can be seen in figure 5.

4. Route the line into the U1 hole on the far side (it's only ½ inch away from the U2 hole the line just came out of), then across the inside of the pipe and out the U1 hole on the near side.

5. Feed the line over to the L1 hole on the near side, through the inside of the pipe and out the L1 hole on the far side.

6. Route the line into the L2 hole on the far side (just ½ inch away), through the inside of the pipe and out the L2 hole on the near side.

7. Next, put the line through the cage bottom hole on the lower right side of the pipe as it is shown in figure 8. This line segment is clearly visible in the photo, leaving from the L2 hole and traveling down and to the right.

8. Fish the line through the inside of the pipe and out the other cage bottom hole (top right in figure 8).

9. Snug all the lines tight and then tie the two ends of the fishing line tightly together with a good monofilament knot (an improved clinch knot was used here). This knot is visible in figure 8 just above the ruler at about the 6.2 inches mark.

Figure 7. Sensor cage wire detail

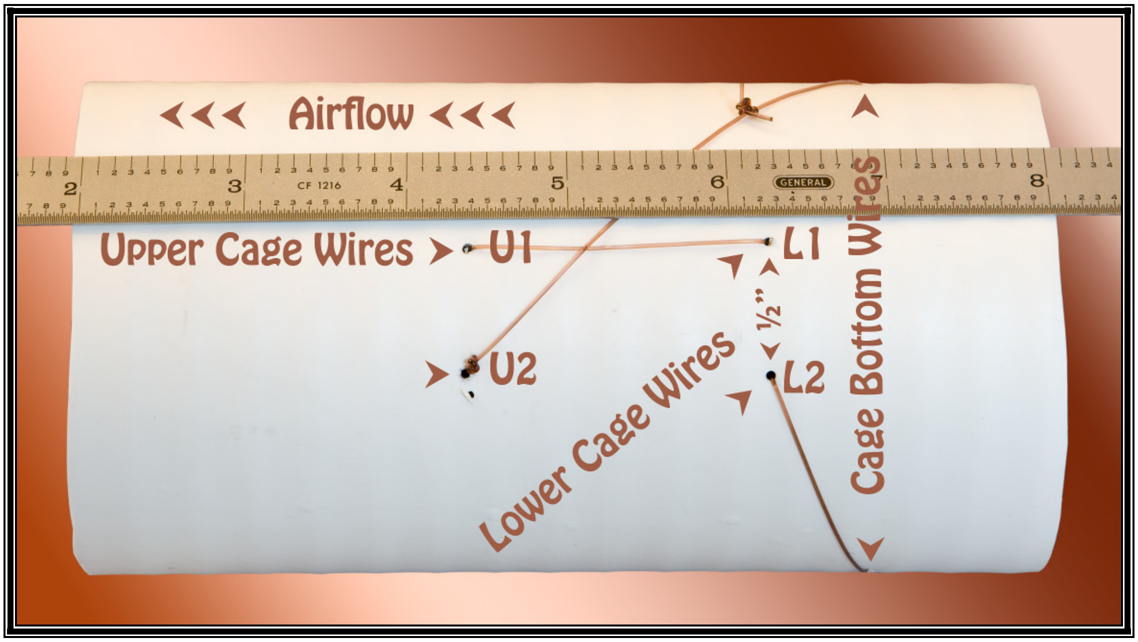

Figure 8. Cage wire routing detail

To summarize hole locations for cage wires to fit an OS wireless sensor (other than the THGN801):

- The two cage bottom holes are about 1-inch from the intake end of the pipe and 180º apart around the pipe circumference.

- Lower cage holes (L1, L2) are about 1-¾ inches from the intake. The space between L1 and L2 holes is a little less than ¾ inch.

- Upper cage holes (U1, U2) are roughly 3-¾ inches from the intake end. The space between U1 and U2 holes is also a little less than ¾ inch.

The THGN801 sensor is a little thicker than other OS sensors and you may want to space the holes a little more than ½ inch apart.

Flower Pot Bases

Carefully mark and cut a large hole centered in the 9-inch FPB which is just a tiny bit smaller than the outside diameter of the 4-inch pipe. You want the FPB to slip over the 4-inch pipe with some resistance. Depending on the material of which the FPB is made, the hole can be cut with a utility knife. For hard plastic, you will need to use a saw.

If the pot base is hard plastic, the hole will need to be cut precisely. It might be a good idea to make the hole slightly smaller than required (just 1/16 or 1/32-inch smaller) and then use a file to enlarge the rough hole to fit over the pipe. The resulting hole must not be so large that it fits over the outside of the 4-inch slip coupling. Also, for hard plastic pot bases, file a small notch somewhere in the circumference of the hole through which the two fan wires will pass.

Next, we'll drill three holes in each FPB that will be used with the standoff hardware to bolt them together. The holes in the large base need to line up closely with the holes in the small base. Holding the two FPBs together and centered (optionally, clamp them together), drill three holes for the threaded rods, screws or whatever hardware will be used to hold them together. The holes should be spaced evenly, roughly 120° apart and near the outside edge of the smaller 7-inch FPB. Don't make the hole too close to the outer rim or the spacer or standoff will not fit. After drilling the first hole, insert a threaded rod or screw through the hole in both bases before drilling the second hole. Also at this time, make a mark on both pot bases so that you can line up the holes later (the holes will probably not be on an exactly even spacing so you'll need these marks to orient the two bases correctly). Insert a threaded rod through the second hole in both bases before drilling the third hole. This process will help to ensure the holes line up properly with each other. In figure 15, you can see approximately where the holes are drilled in the small FPB.

Drill four ¼-inch holes in the 9-inch pot base very close to the outer rim. These are water drain holes. If you experience problems with them getting plugged up with debris, they can be enlarged to as much as ½ inch and more holes can be drilled. Just try to avoid turning the FPB into Swiss cheese.

Figure 9. Large FPB partially assembled

Figure 9 shows the large FPB partially assembled onto the shield. The base has been slipped down over a piece of 4-inch pipe and you can see that the large hole in the base is a relatively tight fit over the pipe. Also visible in the photo are the three standoff mounting holes and four water drain holes.

The remaining details shown in figure 9 will be discussed later in the final assembly section of this document.

One option for hanging the completed shield is to drill three small (1/16-inch or smaller) holes near or in the outer rim of the smaller 7-inch FPB; monofilament line or wire can be threaded through these holes and used to hang the sensor. These holes are visible (with monofilament line installed) in figures 15 and 16. The other hanging option is to use electrical crimp lugs under the standoff mounting screws; if you plan to use this option it is not necessary to drill these three holes.

If desired, paint the inside of the 7-inch FPB black. Paint all other surfaces of the two FPBs white. The black paint helps keep reflected solar radiation from getting into the top of the sensor tube. The outside of main 4-inch pipe can optionally be painted white. Do not paint the inside of the 4-inch pipe or any part of the 3-inch pipe.

Top Extension

Cut another length of 4-inch pipe that will protrude one inch when fully seated in the 4-inch slip coupling. The length will be approximately equal to one-half of the slip coupling length plus one inch.

In figure 10, the slip coupling is about 3-½ inches long and half of this is 1-¾ inches. The top extension should be one inch longer than half the coupling length, or about 2-¾ inches.

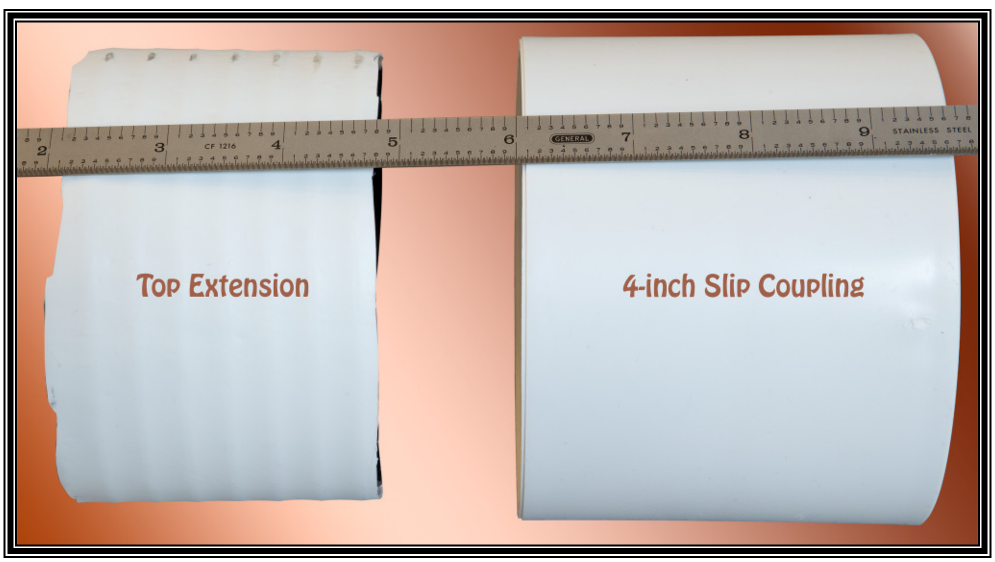

Figure 10. Top extension detail

Final Assembly

Slip the *intake* side of the fan into the *exhaust* end of the 4-inch pipe, as shown in figure 11. Fortunately, the fan wires are on the exhaust side of the fan in this example. If the fan wires are on the intake side of the fan, you will need to feed them around to the exhaust side. It might be necessary to notch the outside of the fan housing or drill a small hole in the pipe to make a path to route the wires.

Figure 11. Fan installation

Then, slide the 4-inch diameter top extension into the 4-inch slip coupling all the way until it bottoms out. The extension should be protruding about one inch from the end of the slip coupling. If not, then trim the top extension as necessary. Figure 12 shows the assembly after this step has been completed.

Next, slip the 4-inch coupling (with top extension) onto the exhaust side of the fan; push and wiggle the 4-inch pipe all the way into the coupling until it bottoms out. The fan wires should be routed up and out the end of the short piece of 4-inch pipe as shown in figure 13.

Holding the 4-inch pipe/fan assembly with top extension up, route the fan wires down the outside of the pipe and then slide the 9-inch FPB over the 4-inch pipe (with the rim pointing up) until it bottoms out against the 4-inch coupling. This will trap the fan wires between the 4-inch pipe and the 9-inch FPB and provides a convenient way to get the wires out of the shield without creating any holes where water can get in.

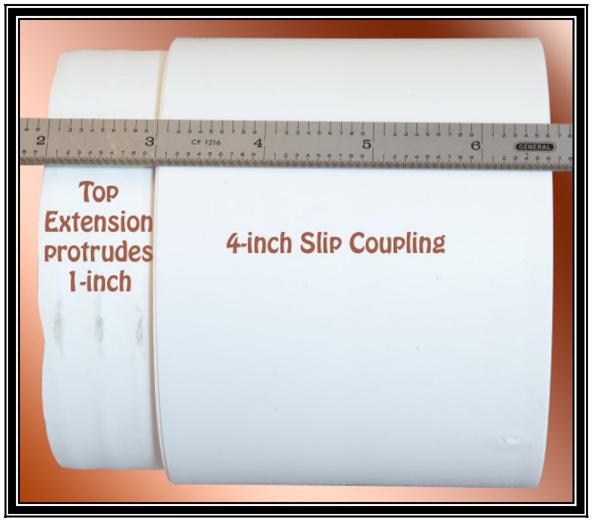

Figure 12. Top extension assembled into coupling

If using hard plastic FPBs, it may be necessary to file a notch in the FPB to make room for the wires to fit between the FPB and the 4-inch pipe. Be careful not to pinch or damage the wire insulation with the hard plastic FPB (this is not much of a concern with soft plastic FPBs).

Figure 14 shows the large FPB slipped over the top extension pipe with the fan wires exiting between the FPB and the pipe.

There are two options for securing the large FPB onto the top extension. The first option is just to install one or two tie-wraps tightly around the 4-inch pipe, trapping the FPB between the coupling and the tie-wrap(s) as seen in figure 21. The shield assembly will essentially be supported by the large FPB, so the tie wraps are required to keep the top extension pipe from slipping out of the large FPB.

The second option (recommended) is to install three hold-down bolts in the top extension pipe as shown in figure 9. With the large FPB fully seated against the slip coupling, take a marking pen and trace a line on the pipe where the large FPB intersects with the top pipe extension. Remove the large FPB and drill three holes for some ¼-28 by ½ inch long screws or bolts in the top extension pipe. Use the line you drew as a guide to place the edge of the hole such that the large FPB will be captured between the hold down screw and the slip coupling. Thread the screws into the top pipe extension once to create threads in the plastic pipe wall and remove them. Then slip the FPB over the pipe and install them again – it will take a little patience and you may need to use a pair of pliers to rotate them as the rim of the large FPB will interfere with your access to the screws. Figure 9 shows the hold down screws installed with a couple of tie-wraps added to provide some strain relief for the fan wires.

Also in figure 9, you can also see how a little bit of slack has been left in the fan wires as they go up and over the top extension pipe.

Figure 13. Slip coupling installed on top of fan

Top cover assembly

Using whatever standoff hardware you have chosen, the 7-inch FPB should be installed upside-down over the large pot base so that there is a gap of one inch between the top extension pipe and the small FPB. Use large washers to create a large contact area with the plastic FPBs. I used two different sizes of washer together for this purpose. Figures 15 and 16 show the assembled top cover.

For the example pictured in the photos, the bases were assembled together in this order using stainless steel hardware:

1. Install washers onto each of the three screws. If using crimp lugs for hanging the shield, install them first under the screw heads.

2. Insert each screw through the hole in the small pot base from its bottom side.

3. Install washers over the end of each screw on the inside of the FPB.

4. Slide spacers over each screw and secure tightly with a single nut (no washer is required under the nut).

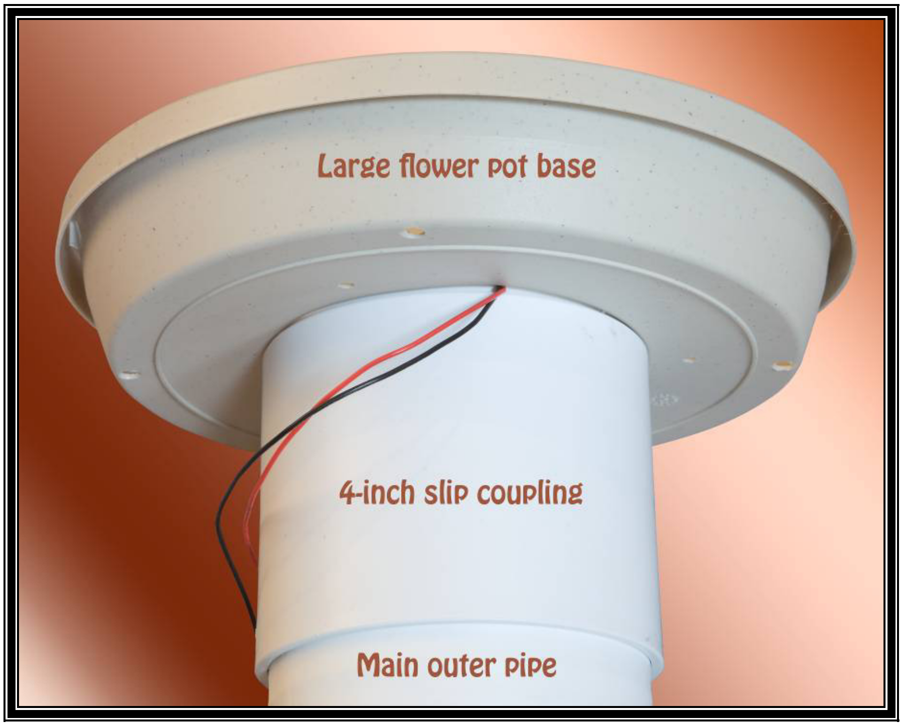

Figure 14. Fan wire routing

The smaller FPB now has three screws with spacers firmly attached to it. Having this as a separate assembly makes it easier to finish attaching it to the large FPB.

5. If not using crimp lugs for hanging the shield, thread monofilament line through the holes in the outer rim of the 7-inch base as shown in figure 16 to form an inverted tripod that will be used to hang the completed radiation shield. In this photograph, there is a single line that runs between two of the three holes, labeled “Monofilament loop”. The second line is tied around the first line using an “improved clinch knot” (commonly used with monofilament line).

6. Place the small FPB on a flat surface with the spacers pointing up (as in figure 15). Place large washers over the screws (they will rest against the already tightened nuts). Figure 9 shows these same large washers lying in the large pot base.

7. Slide the large FPB (with attached pipe pointing upwards) down over the screws on the small pot base. Be sure to line up the holes as they were marked earlier for easier assembly. Figure 17 shows the large FPB ready to be bolted in place.

8. Apply more large washers and nuts, tighten and this part of the assembly is complete.

Figure 15. Small FPB assembly

If you are using standoffs instead of spacers or just threaded rod the assembly process will be different, but the above description should give you an idea of how to proceed.

Coaxial Pipe Assembly

Slide the wireless sensor into its cage in the 3-inch inner pipe. From this point on, keep everything upright so the sensor does not slip out of the cage. If you install the sensor right-side up, the sensing end will be directly exposed to the incoming airflow. It will also be getting air that has not passed through much of the inner pipe yet and will have less temperature error. The sensor will respond to temperature changes faster. However, with the sensing end directly in the incoming airflow, it may also pick up dust and dirt in the incoming air more quickly. If this might be an issue, then install the sensor upside-down instead. It will respond more slowly to temperature changes and may pick up a little more temperature error due to heating of the walls of the inner pipe.

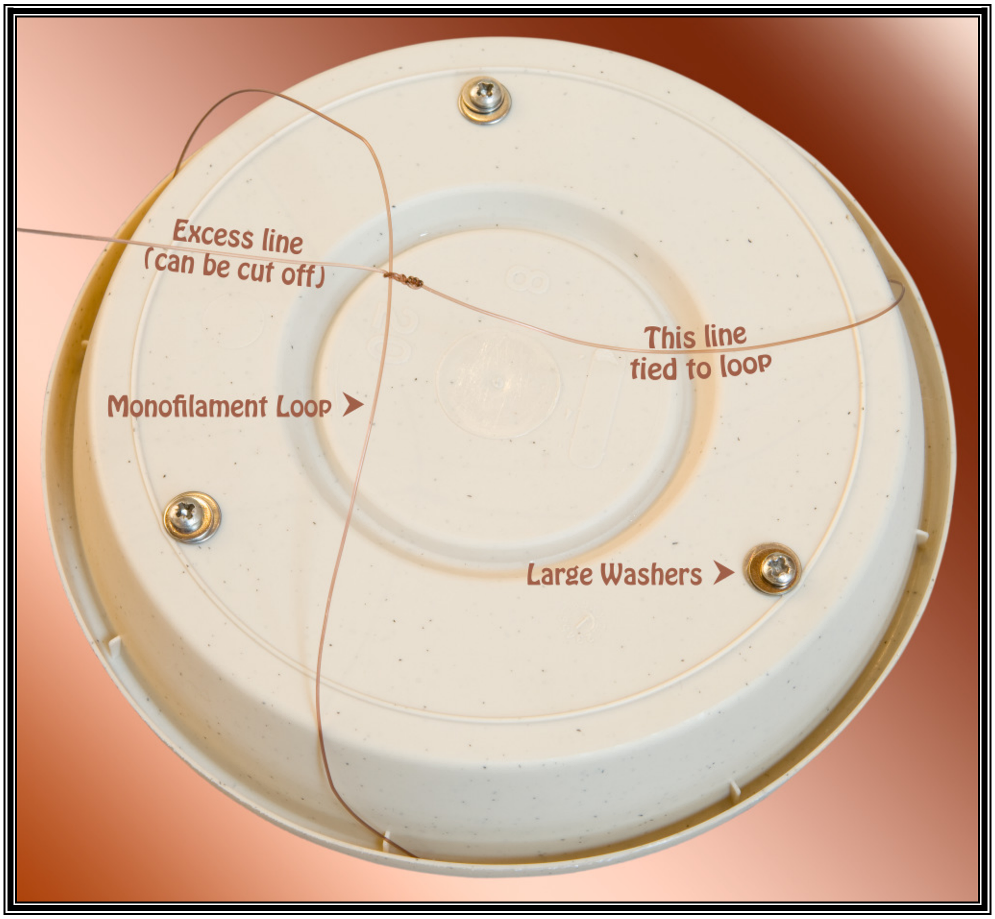

Figure 16. Small FPB detail

Insert the 3-inch pipe with sensor (pay attention to airflow direction) into the intake end of the 4-inch pipe and tighten the six screws or bolts to snugly hold the 3-inch pipe centered inside the 4-inch pipe. Don't over-tighten the bolts; they just barely need to make contact in order to secure the 3-inch pipe. The bottom ends of the two pipes (3-inch and 4-inch) should be flush with each other.

Figure 18 shows the two coaxial pipes assembled with the wireless sensor in place (sensing end down). Also visible are some of the sensor cage wires and the bolts clamping the inner pipe in place. This photo was taken with the assembly inverted, and tape had to be used to keep prevent the wireless sensor from falling out of its cage. During actual assembly, keep everything upright.

Cut a 9 or 10-inch diameter circle of mosquito netting and secure it over the intake end of the 4-inch pipe using tie-wraps. You can string multiple tie-wraps together if one is not long enough. As shown in figure 19, the tie wraps have been left a little bit loose. This allows them to be stretched up and over one of the bolt heads to help secure everything in place.

Figure 17. Bolting the two FPBs together

If you have attached one or more pieces of monofilament to the lower end of the 4-inch pipe, the ends of these lines will need to be threaded through holes in the netting as part of the assembly process.

There is no netting over the exhaust section of the shield, although you could add some. The author has not been running this new shield design for a long enough time to know if there will be problems with bugs and debris getting into the top of the assembly. One way to do that would be to take a large piece of netting and wrap it completely around the top of the assembly and secure it with tie wraps around the 4-inch slip coupling. That will not only cover the top opening but will keep bugs from getting in through the water drain holes as well. With this approach, the monofilament hanging wires will need to be threaded through the netting as part of the assembly process.

Connect low voltage wiring to the fan wires in some fashion. Options include soldering or crimping. Using some sort of automotive quick-disconnect connectors would be convenient. The 3.5mm round connector supplied with the power supply can be cut off if desired for connection to the wiring out to the fan. One of the wires coming out of the power supply is marked – either with a white or colored line, or with some ribbing formed into the insulation. You need to determine which wire is positive; a digital voltmeter is the best way. Lacking that, the fan is protected against reverse polarity, so just try connecting the wires to the fan arbitrarily and if it does not run the swap them.

Figure 18. Assembled concentric pipes

The 12-volt power unit is protected against short circuits and the fans are protected against reverse polarity, so there is not much you can do to damage the power supply or fans.

Replacing the sensor or changing batteries is easy. Remove the mosquito netting from the intake end of the pipe and loosen two of the six screws that hold the 3-inch pipe in place. The 3-inch pipe will drop out, providing easy access to the sensor.

The top side of the shield can also be covered with netting as shown in figures 20 and 21. In this case, the use of crimp lugs for hanging is recommended. Small holes are cut in the netting for the crimp lugs – the other option is to fish the monofilament hanging wires through the netting during installation and this is much more tedious.

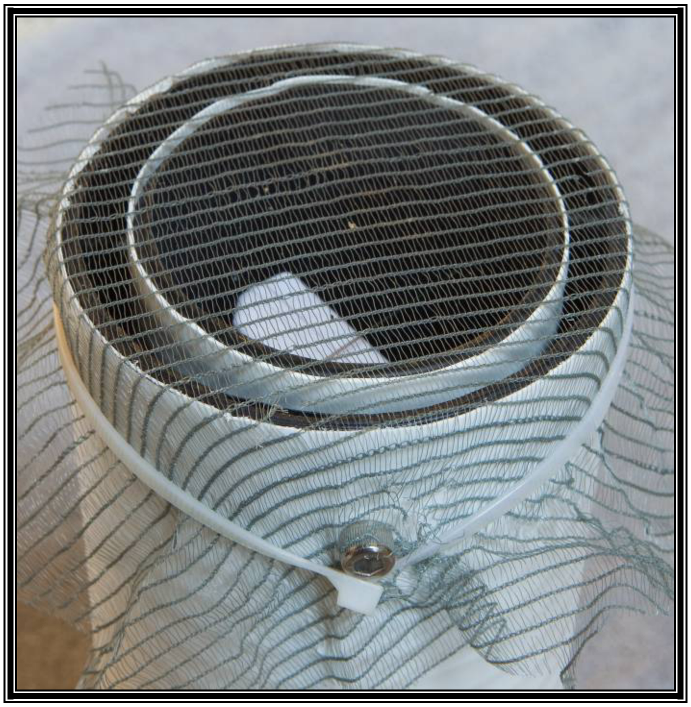

Figure 19. Mosquito netting detail

Figure 20. Mosquito netting on top with crimp lugs for hanging

Figure 21. Top mosquito net tie-wrap detail

Figure 22. Large FPB installation without hold down screws