A HIGH PERFORMANCE AIRBAND ANTENNA FOR YOUR ULTRALIGHT / LIGHTSPORT AIRCRAFT

by Dean A. Scott, mfa (revision 3 September 2017)

In this article I present a simple, easy to construct, and easy to mount "Inverted V" half-wave dipole antenna that will significantly increase your range and clarity of communication in the aircraft radio band when compared to rubber-ducky and external commercial or homemade quarter-wave "whip" antennas. Basic radio frequency (RF) and antenna theory will be discussed to explain some of the reasons for the design.

To start, let's define the terms "half-wave" and "quarter-wave." These refer to the length of a metal conductor that resonates at a certain frequency in the radio spectrum. Specifically, a full-wave antenna is one whose length is the same as the distance from one crest to another of a radio wave. A half-wave would be half that length (crest to trough) and a quarter-wave would be half that again (crest to zero-crossing point). The length of a radio wave is determined by the equation:

*(c / f) * 12"*

where *c* is the speed of light, in millions of feet per second, and *f* is the radio frequency, in megahertz (MHz).

In the vacuum of space, electro-magnetic energy, such as light and radio waves, travels 983,568,960 feet in one second. However, due to complex interactions with a terrestrial environment (conductors, surrounding structures, the ground, and other wires connected to an antenna system) this speed is effectively reduced to 936 million feet per second. Divide 936 by 2 and you get the equation for a half wavelength in inches:

(468 / MHz) * 12"

For a quarter wavelength it is:

(234 / MHz) * 12"

Why are half- and quarter-wave antennas used rather than full-wave? Size. For instance, let's use the unicom airband frequency of 122.7 MHz. A full-wave antenna would be 7 feet 7-1/2" long! Try mounting THAT on your plane! The half-wave version is 45-3/4", but that's still cumbersome. The quarter-wave is 22-7/8" long. Much more manageable and thus why it is so offend used.

"But, doesn't more wire generate more signal?" Compared to an isotropic antenna (a mathematically prefect antenna that radiates in all directions equally), a full-wave has 3 dB (2 times) more gain, a half-wave, 2.15 dB (1.65 times), and a quarter-wave, 0.15 dB. So, yes, a full-wave antenna does give the most gain, but at the expense of size.

Gain is nothing more than a redistribution of a reference radiation pattern such that a certain direction is favored more in receiving and transmitting a signal than another. It's sort of like placing a mirror behind the sun; it becomes apparently brighter even though it is radiating the same amount of energy. The other half of the light traveling away from us is simply being reflected back to us.

Another question you may be asking is, "Why is your half-wave antenna better than the rubber ducky or single element whip I already have?"

First, the rubber-ducky antenna supplied with handheld radios is an inefficient design based on the low-gain quarter-wave (it's simply 23" or so of wire coiled into a spring). The reason they are supplied is because they are cheap to make, very robust (it's a bendy spring), and very few people like to carry around a radio that has a 2 to 4 foot long anenna sticking up out of it!

Second, your typical “whip” or quarter-wave antenna requires a ground plane to obtain optimum balance and performance, something a tube and fabric ultralight or light-sport aircraft just really doesn’t have. What’s a ground plane? It’s a flat expanse of metal around 4 feet in diameter that does what the name implies… simulates earth ground. If not a sheet of metal, then at least 4 stiff wires, each around 23” long, radiating straight out from the base of the main, 22-7/8”-long vertical antenna.

There’s just no good way to mount such a monstrousity on any sort of plane, not to mention the increased drag profile. Some may say that the metallic tube frame of a UL/LSA is a good enough ground plane, but RF theory and antenna design say otherwise. An aluminum skinned plane is a different story. A quarter-wave on them works just a well as this article’s design, so there wouldn’t be much gained by making the antenna presented here.

Third, a half-wave dipole does not require a ground plane and has 2 dB more gain than a whip or rubber ducky. It also doesn’t present much of a challenge to mount it compared to a whip (without a ground plane) and is just as easy to make.

Fourth and most importantly, this antenna is designed to perfectly match the impedance of your radio and coax cable for the best possible transfer of RF energy to and from the radio. It is also designed to counteract the imbalance created when the electrically balanced antenna is connected to the electrically unbalanced coax cable.

Your next question might be, “Sounds plausible, but how well does it perform?”

Consider this: Your handheld radio with a rubber-ducky antenna is only able to spit out not much more than 1 or 2 watts of power due to the antenna’s high Standing Wave Ratio (SWR) of 1:1.5 to 1:2. This reduces your transmission range to at best 5 miles and reception range to 15 - 20 miles.

How about when using an external quarter-wave whip antenna? Much better if the plane has enough metal surface for a ground plane, and the antenna is properly matched and tuned to the radio… maybe 15 miles transmit and 40 miles receive.

Using the antenna design presented here, you should obtain clearly received transmissions from over 60 miles away and be heard by others 30 miles away (line of sight)! So, let’s get down to business.

PART 1
ANTENNA ELEMENTS

Figure 1 shows the simple nature of this “Inverted V” half-wave dipole design. It’s made of two stiff wires, 22-7/8” long, forming a 120 degree angle. When used on Unicom and air-to-air communication frequencies (122 – 123 MHz), the element lengths and angle result in a 50 ohm terminal impedance, a perfect match for 50 ohm RG-58 coax cable.

Such an even match between the antenna, cable, and radio means that all possible power can flow through the system. So, instead of 2 watts effective power using a rubber ducky with a 4 watt handheld, you’ll get the full 4 watts with this design. A mismatch of impedances means power is wasted in the form of heat by the generation of standing waves in the coax cable.

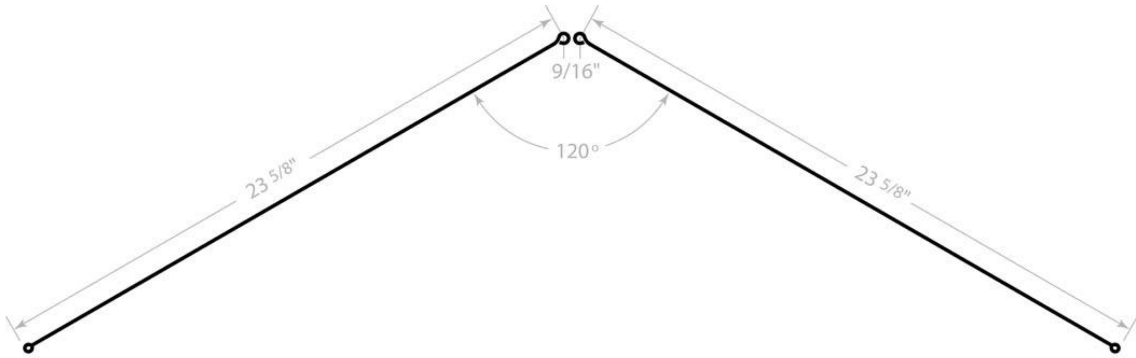

Figure 1 – Dimensions of the Inverted V antenna elements.

Any stiff wire that's around 2 mm in diameter (12 AWG), such as brass welding rods or even coat hangers, can be used. Since coat hangers were on hand, that's what I made mine from.

Step 1
Cut two 25" (634mm) lengths of wire rod.

Step 2
Form a loop with a 3/16" (5mm) inside diameter on one end of each rod using stout needle-nose pliers.

Step 3
Cut the rod so it measures 22-7/8" (581mm) from the end of the loop.

Step 4
Tape over the looped end and paint the antenna elements to protect from corrosion. Or, if already painted, scrape the paint off the loops, inside and out.

PART 2
FABRICATING THE MOUNTING BLOCK

These two antenna elements must be mounted so that they are held firmly in place at a 120 degree angle. **This angle is critical!** It sets the feed point impedance at 50 ohms. The mount must keep the elements electrically insulated from each other and all other metallic parts of the system and provide a robust, vibration-resistant way to connect the terminals to a coax cable. The following mounting block fits the bill perfectly.

Step 1
Obtain any sort of hard, dense plastic material that's 2" (50mm) wide by 5" (127mm) long by 1/4" to 3/8" (6mm – 9mm) thick or so. A good source for this would be a common kitchen cutting board. Draw a center line dividing the length of the block in half (Figure 2).

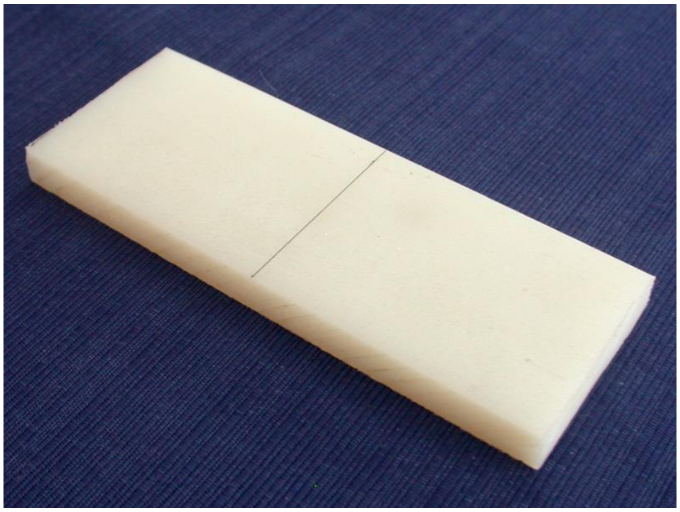

Figure 2 – Polypropylene or Nylon stock makes a good base for the antenna mounting block.

Step 2
Draw a line perpendicular to this that is 1/2" (13mm) below the top edge. On this line mark the locations of the two antenna terminals, one on either side of the center line and 9/16" (15mm) apart (Figure 3).

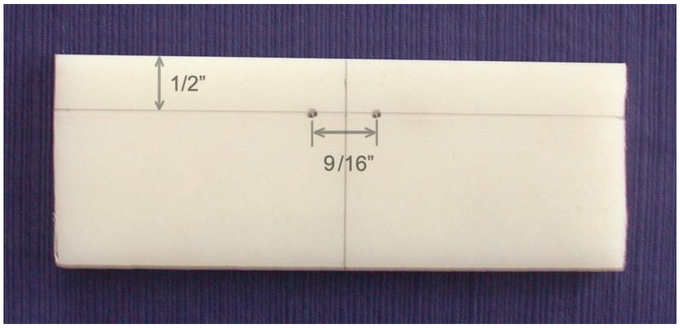

Figure 3 – Marking the antenna terminals.

Step 3
With the center point of a small protractor positioned directly over each terminal point, put a mark on the bottom edge of the block at the 30 degree line. Repeat for the other side.

Step 4
Draw a line connecting each mark to its respective terminal point to form a 120 degree angle.

Step 5
Draw a line 1/2" (13mm) up from the bottom of the block to mark the location for mounting a female panel-mount BNC connector (Figure 4).

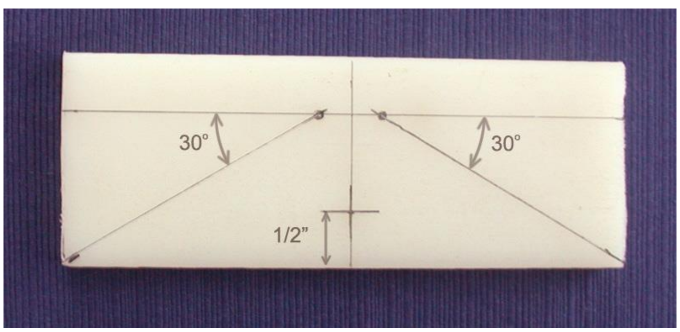

Figure 4 – Marking the 120 degree angle and BNC connector location.

Step 6
Drill these three locations with a small pilot hole. Countersink the antenna terminals with a 1/2" (13mm) wood bit about 1/8” (3mm) deep (Figure 5).

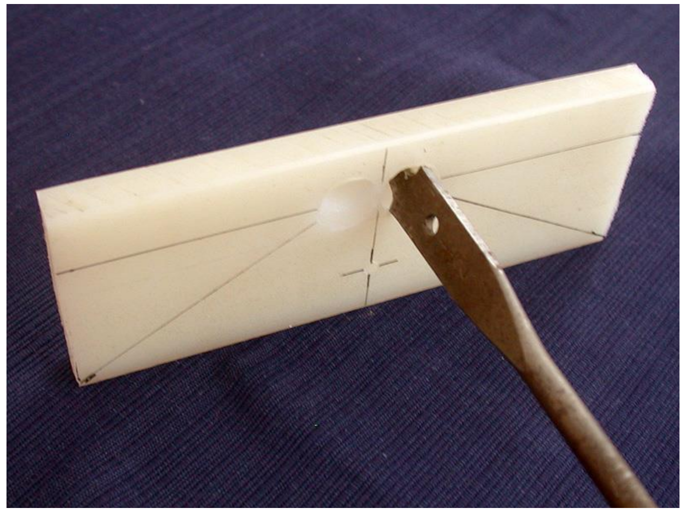

Figure 5 – Countersinking the two antenna terminal holes with a ½” wood bit.

Countersink the BNC connector hole by 1/4" (6mm) using a 11/16” (17mm) wood bit.

Drill the antenna terminal holes to size with a 3/16” (5mm) bit and the BNC connector with a 3/8” (9.5mm) bit (Figure 6).

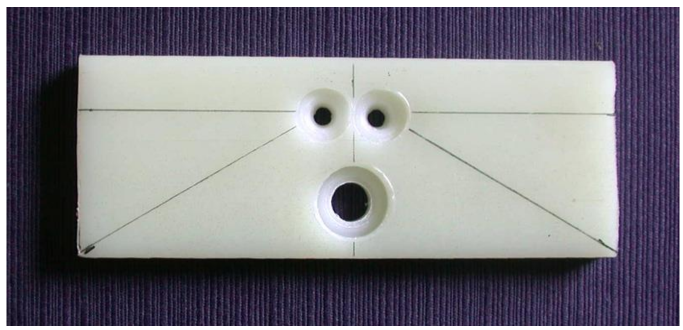

Figure 6 – All holes countersunk first and then drilled to size.

Step 7
Using a table saw or other means, cut grooves along the 30 degree angle lines that are 1/8” (3mm) wide and 1/8” (3mm) deep (Figure 7).

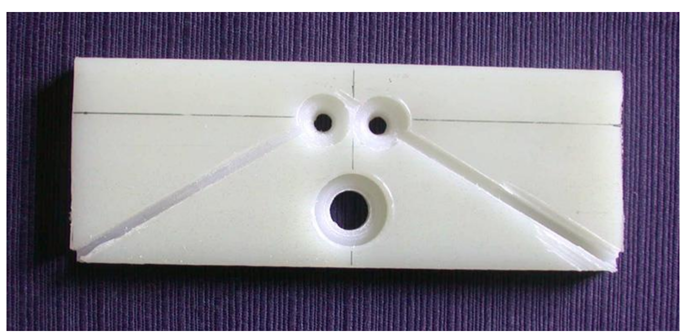

Figure 7 – Grooves for antenna elements cut into block.

PART 3
ASSEMBLY

Step 1

Attach the antenna elements to the block with 3/4" (19mm) long #10 machine screws or bolts. Place two flat washers onto the screw first, followed by an antenna element, then insert the screw into the block and secure with another flat washer, a lock washer, and a nut on the back side (Figure 8).

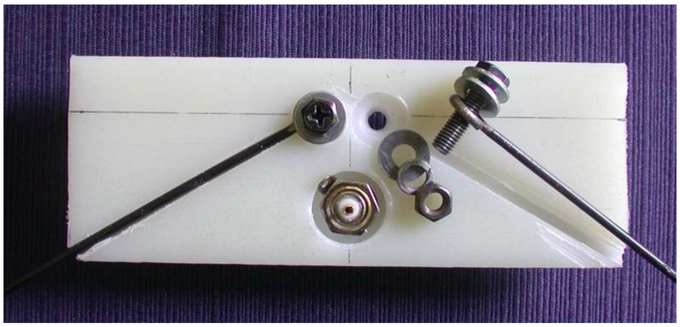

Figure 8 – Mounting the antenna elements and BNC connector.

Step 2

Place the female BNC panel-mount connector into the 3/8" hole so that the center terminal sticks up on the countersunk side. Tightly secure with the supplied solder tab washer and nut (Figure 8).

Step 3

Cut lengths of stiff, solid copper wire from the center conductor of television coax cable (Figure 9).

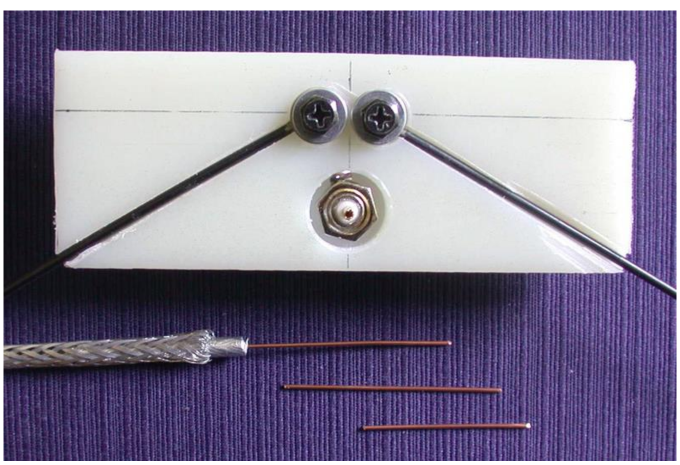

Figure 9 – A good source of stiff solid copper wire for antenna terminal connections is TV coax cable.

Make loops in the ends of each wire to fit the #10 machine screws and bend as needed to reach the terminals of the BNC connector (Figure 10).

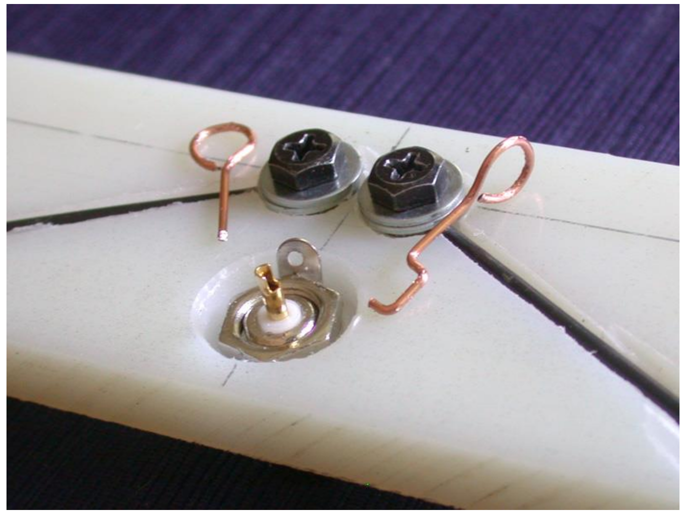

Figure 10 – Wires bent to connect the antenna terminals to the BNC connector.

Place each loop between the pair of washers of the antenna terminal screws and solder the other end to the BNC connector. The center conductor goes to one antenna element and the ground goes to the other (Figure 11).

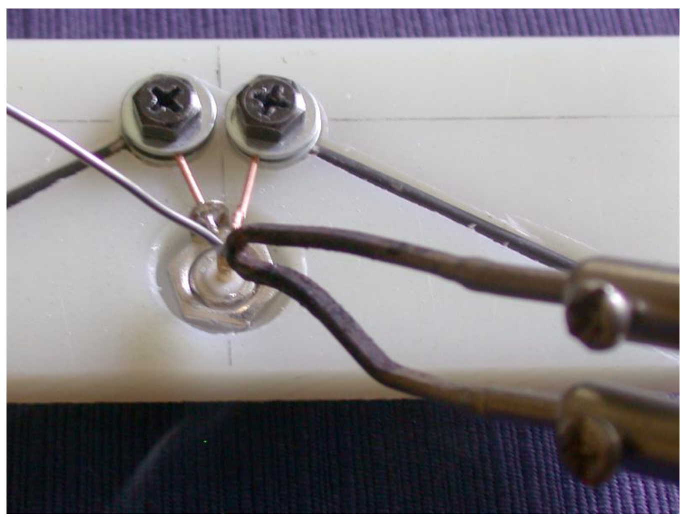

Figure 11 – Soldering the wires to the antenna terminals and BNC connector.

At this point most would consider the antenna finished and ready for mounting, but it is not. Connecting a BNC jack to the antenna terminals like this creates an unbalanced electrical condition due to the unbalanced nature of coax cable.

The reason why is too complex to deal with here, but suffice it to say it has to do with the way RF current flows only on the surface of a conductor, not in it, and how current flowing on the outside of the center conductor induces an equal and opposite current on the INSIDE of the cable's braided shield. Since the cable is electrically unbalanced, current reflects back from the end of the grounded antenna element, flowing down the cable on the OUTSIDE of the shield

Yes, two different currents are flowing on different sides of the same shield. Electrons buzzing around at radio frequencies are very strange critters!

This reflected current diverts power away from the antenna elements, turning the cable itself into a radiating element (antenna) as well. We can prevent this unbalancing reflected current from flowing on the outside of the cable by installing a device called a balun (**bal**anced to **un**balanced).

There are a few different ways of making a balun. All do the same thing; transform an unbalanced RF current flow to a balanced flow.

For those who read this article prior to this 2014 revision may remember that I used a variation of the Sleeve or Bazooka balun, called a Pawsey stub, because it was simple to construct from a bit of coax cable. HOWEVER, I've since learned that it is inherently unstable, detuning when it comes near anything conductive, thus rendering its use unsuitable for this application.

That Pawsey stub is known as a current choke, because it created a high impedance to current flowing on the outside skin of the coax cable's shield, choking it from getting back into the radio and turning the coax into an unpredictable antenna itself. The currents flowing on the inside surface of the shield were unaffected.

The NEW method presented in this revised article does this same current choking job much more effectively and easily.

Without going into more RF theory, one way to choke reflected RF current is to form a 6-turn, 2" diameter coil using the feed line coax itself at the antenna connection. However, this coil is hard to manage and mount securely, especially on an open-air UL.

Another way is to wrap the coax a few times around a ferrite toroid (doughnut) core, but again, the result is just as cumbersome to deal with. However, if one "straightens" out the windings around a toroid, you see that each turn is simply the coax passing through a single "tube" of ferrite. So, instead of a big 2" diameter ring with 4 or 5 turns of coax wrapped around it, you can put 5 smaller "beads" in a straight line on the coax. If each "bead" or core provides 300 ohms of impedance, then five in a line will provide over 1,500 ohms of reflected current choking impedance. In other words, the unbalanced coax will be "converted" to balanced at the antenna terminals.

PART 4
FERRITE CHOKE BALUN

Step 1

Purchase five Fair-rite brand #2631540002 ferrite cores or any similar item having 300 ohm impedance at 100 MHz (typically Mix 31) with an ID a bit larger than your coax. I purchased mine on-line from Newark Element 14. The ones below are 14.3mm OD x 6.35mm ID x 28.6mm long (Figure 12).

Figure 12 – Fair-rite brand #2631540002 ferrite cores.

Step 2
Get a male BNC connector (screw-on is ideal) to replace the existing one you will be cutting off, in order to slip the 5 ferrite cores on to your coax feed cable.

Step 3
Secure the ferrites in place on the coax as near as possible to the antenna's BNC connector using two wire zip ties (Figure 13).

Figure 13 – Five ferrite cores secured with wire zip ties at antenna connector end of coax feed line.

Step 4
Add some sort of abrasion and impact/vibration protection to the ferrites such as a length of cable mesh, electrical tape wrap, etc.

Step 5
Mount the antenna to your aircraft in a **VERTICAL orientation. No other orientation will work!** Figure 14 shows how an aluminum L-bracket is used to fasten the antenna block to an ultralight's main boom/keel tube.

Step 6
Finally, obtain an SWR meter and see how your new antenna performs. I didn't have such a meter when I built this antenna back in 2006. I now do and found that it was indicating 1:1.3 SWR at 122.7 MHz. At 118 MHZ the SWR was near 1:1. At 130 MHz it jumped up to an unusable 1:5 SWR. So, I trimmed 1/4" off the end of each antenna element and retested. Better. Another 3/16" off and the antenna was 1:1 from 120 – 124. Meaning, the 50 ohm coax feed line is a perfect match to the 50 ohm antenna terminal impedance AND that there was zero reflected current coming back down the cable shield, indicating that the ferrite cores were providing ample choke.

The meter also told me that all 4 watts of power from my Icom A4 radio was going into the antenna. None was being wasted or diverted.

Figure 14 – Antenna mounted using an L-bracket. Anything similar will work as well.

GO FLY AND BE HEARD!

This completes the construction and assembly of your new antenna (Figure 15).

When this antenna is oriented **vertically as shown**, you get 360-degree horizon-to-horizon coverage, according to the radiation pattern plotted in Figure 16. This polar pattern plot is shaped like a "crumpled donut" instead of a smooth round ball (a ball would represent equal reception and transmission in all directions).

This "crumpled donut" shows that the antenna is about 60 times (-17 dB) **less** sensitive

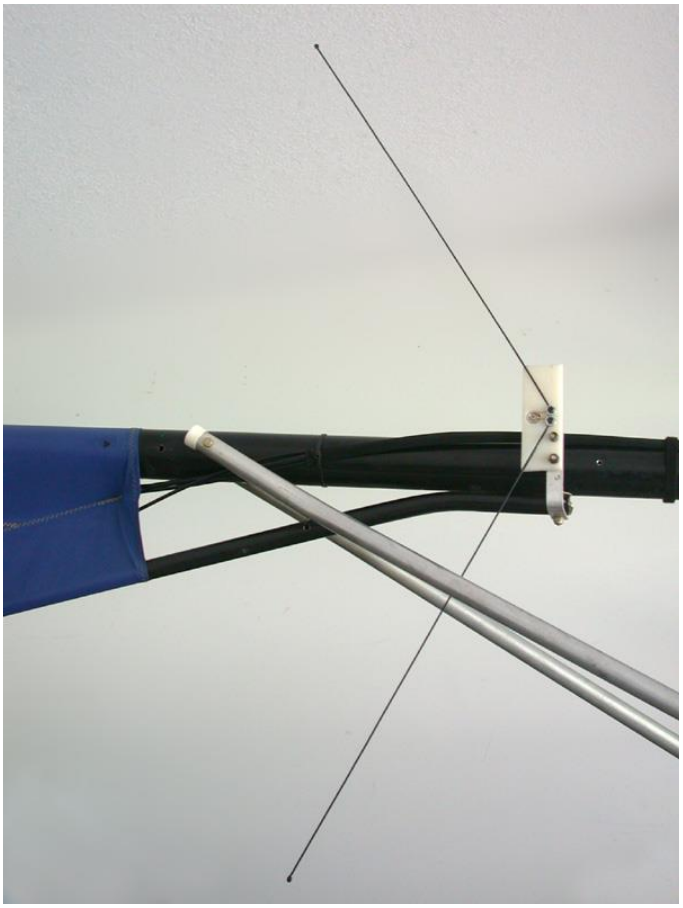

Figure 15 – Overall view of how the author's antenna is mounted to the boom of his Weedhopper [tm] Ultralight.

straight up and down and around 5 times (+7 dB) **more** sensitive out toward the horizon in all directions.

Theoretically, aircraft directly above and ground stations directly below you will not receive a very strong signal when you transmit and conversely you won't receive a very strong signal from them, either. Your best reception and transmission is going to be from 0 degrees (horizon) to 45 degrees down and up, where 99% of all the planes and ground stations live anyway.

The only thing left to do now is go out and fly and see if this antenna improves your reception and if others can more clearly hear you farther away.

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Dean Scott is a hobbyist in many general areas like electronics, which he blames on his dad who was a HAM operator. Professionally, he is an award-winning 3D animation artist and graphic designer with an MFA in 3D Computer Art. Of course, none of this qualifies him as an expert on the subject of this article, but it was fun doing it anyway and he hopes it helps someone out there. Contact him via email with questions or comments at: dascott@chrusion.com

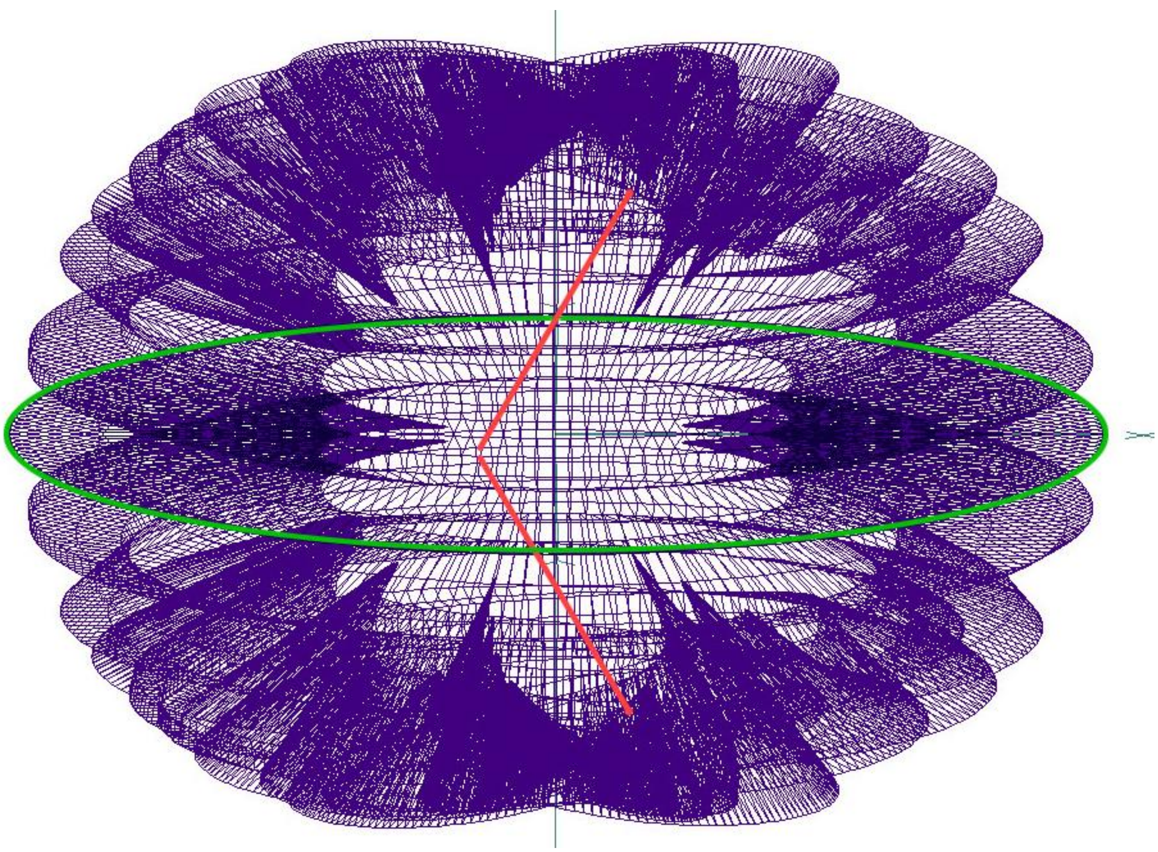

Figure 16 – 3D representation of the "crumpled donut-like" field strength surrounding the red vertically mounted antenna. The green circle represents the horizon where signal strength is at maximum, just what a pilot wants… 360 degree coverage. Notice the puckered top and bottom "poles" jutting inward toward the center. This indicates lower signal receive and transmit strength. Diagram generated by EZNEC 4.0.