A HIGH PERFORMANCE AIRBAND ANTENNA
FOR YOUR ULTRALIGHT / LIGHTSPORT AIRCRAFT

by Dean A. Scott   (revised March, 2018)

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 radio wave crest to another. 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:

$$c / f$$

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 inches 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, which is much more manageable.

"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 3dB (two times) more gain, a half-wave, 2.15dB (1.7 times), and a quarter-wave, 0.15dB. 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 twice as bright (3dB) 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 two to four foot long antenna 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. Instead of a sheet of metal, four stiff wires, each the same length as the main element, radiating straight out from the base of the antenna can be substituted.

There's just no good way to mount such a monstrosity 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 2dB 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 one or two 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, but only 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 that form 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 impedance at the antenna terminals, 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 two watts effective power, using a rubber ducky with a four watt handheld, you'll get the full four 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.
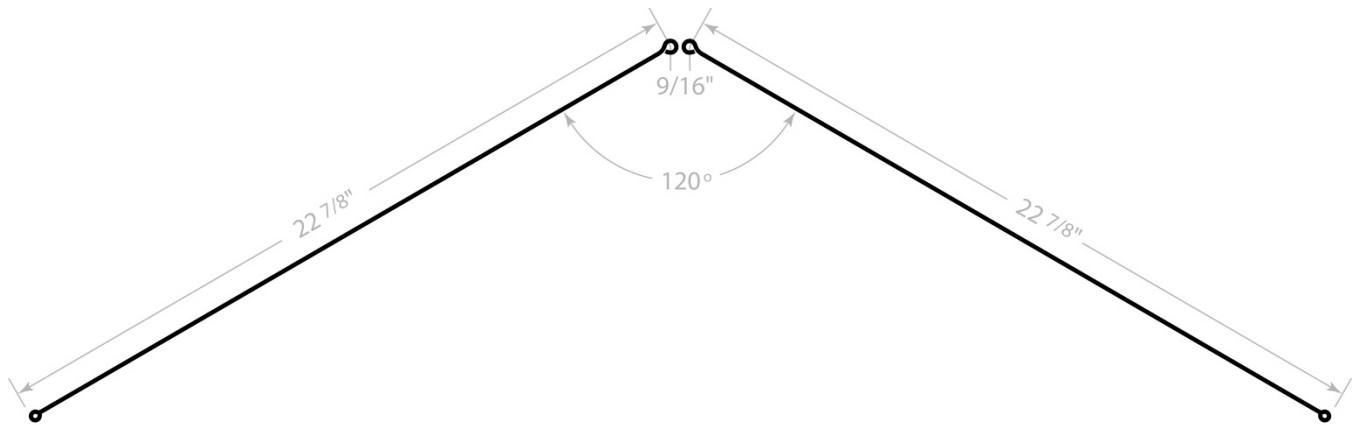
Figure 1 – Dimensions of the Inverted V antenna elements.

Any stiff wire that's around 2mm 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" (635mm) 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 center of the loop to the tip (for use on Unicom or to the length returned in the quarter wave formula on page one).

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 3/8" (9.5mm) thick. 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).
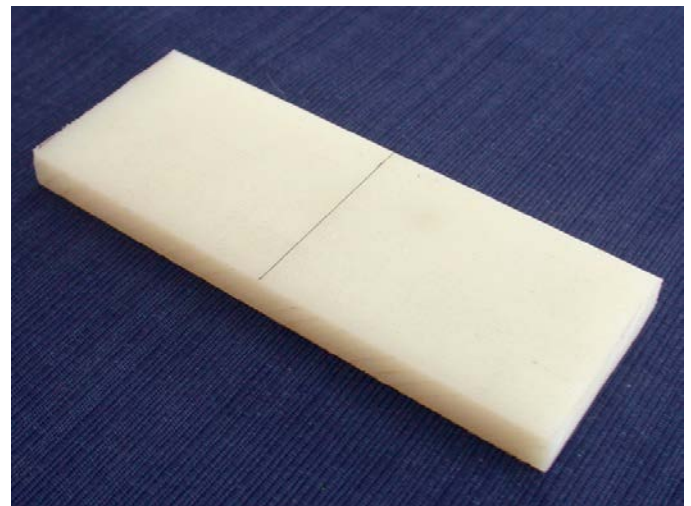

Figure 2 – Polypropylene or Nylon stock makes a good base for the antenna mounting block.

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).
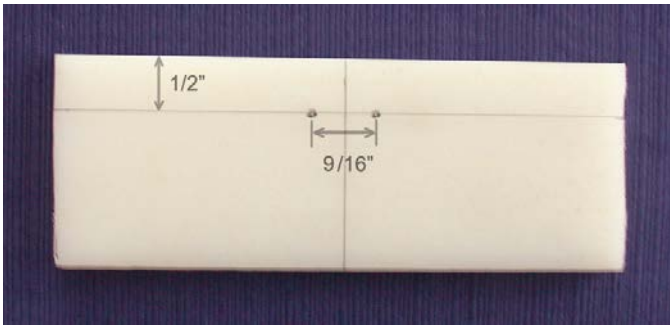
Figure 3 – Marking the antenna terminals.

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).
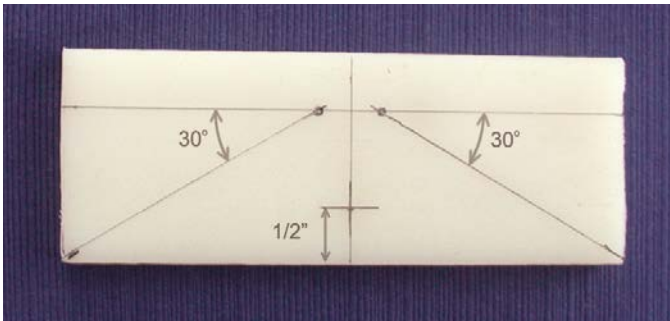

Figure 4 – Marking the 120 degree angle and BNC connector location.

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

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

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

Drill holes in the countersunk areas: 3/16" (5mm) for the antenna terminal screws and 3/8" (9.5mm) for the BNC connector (Figure 6).
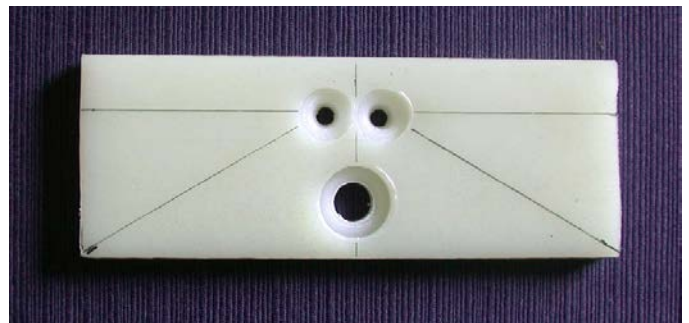

Figure 6 – All holes countersunk first and then drilled to size.

Step 7
Using a table saw or hand saw, 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. 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). Fill the grove with hot melt glue for added resilience.

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
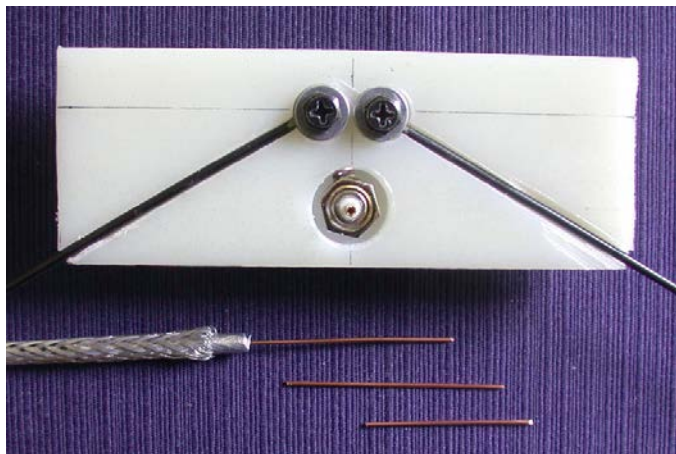Cut lengths of stiff, solid copper wire from the center conductor of RG-59 coax cable (Figure 9).

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).
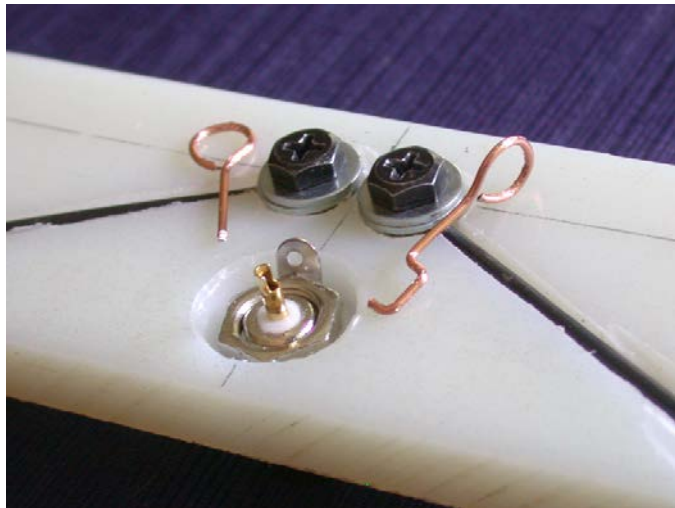

Figure 10 – Wires bent to connect the antenna terminals to the BNC connector.

Place each wire 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 tab goes to the other (Figure 11).
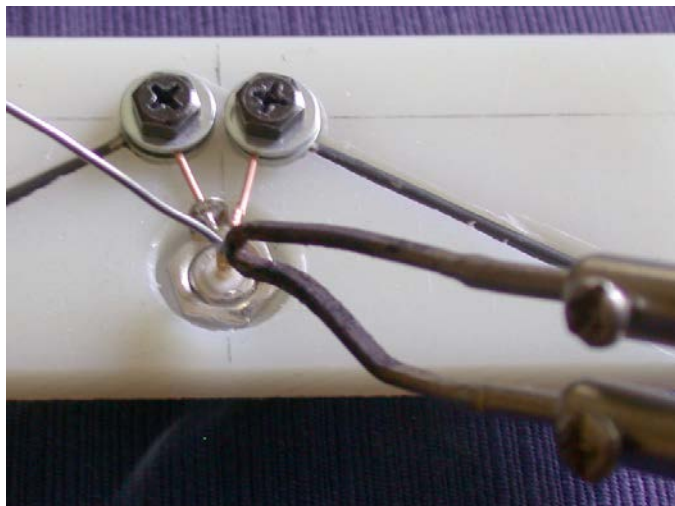

Figure 11 – Soldering the wires to the antenna terminals and BNC connector.

At this point, most would consider the antenna finished and ready for mounting, but it is not.

Connecting a 50 ohm coax cable to the antenna terminals creates an unbalanced electrical

condition, due to the unbalanced nature of coax cable.

The reason why is too complex to go into detail here, but suffice it to say it has to do with the way RF current flows on the surface of a conductor, not inside of 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 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!

These reflected and induced currents impede power from getting to and from the antenna elements. It also turns the cable itself into a radiating "antenna" element, as well.

We can prevent this unbalanced, 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.

The most efficient and easiest way to do this is to CHOKE (block) the flow of this current. We can do this by putting ferrite "beads," or cores, in a straight line on the coax cable. Typically, each core appears as around 300 ohms of inductive impedance to the RF energy flowing on the outside of the cable's sheild, so five in a line provides over 1,500 ohms of impedance, effectively blocking the reflected current and "converting" the unbalanced coax at the antenna terminals to balanced.

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
Cut the existing BNC connector off one end of your coax cable. Slip the ferrite cores on to the cable and re-terminate the cable with a new BNC connector (screw-on type is easiest).

Step 3
Secure the ferrites in place on the coax as near as possible to the antenna's BNC connector, using a wire zip tie at each end of the stack (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 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. This one tested at a 1:1.3 SWR at 122.7 MHz. At 118 MHz, the SWR was near 1:1. At 130 MHz, it jumped up to 1:5. So, I cut 1/4" off the end of each antenna element and retested. The results were better, but not perfect. I cut off another 3/16" and the antenna is now 1:1 from 120 – 124, a perfect 50 ohm match between antenna terminal impedance and coax cable, zero reflected current coming back down the cable shield,

indicating that the ferrite cores are doing their job of choking reflected current.

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.

GO FLY AND BE HEARD!

This completes the construction and assembly of your new antenna.

When this antenna is oriented **vertically as shown** (Figure 15), you get 360-degree, horizon-to-horizon coverage, according to the radiation pattern plotted in Figure 16. It's hard to see, but this polar pattern plot is shaped like a "lumpy donut," instead of a smooth, round ball, which would represent equal reception and transmission in all directions.

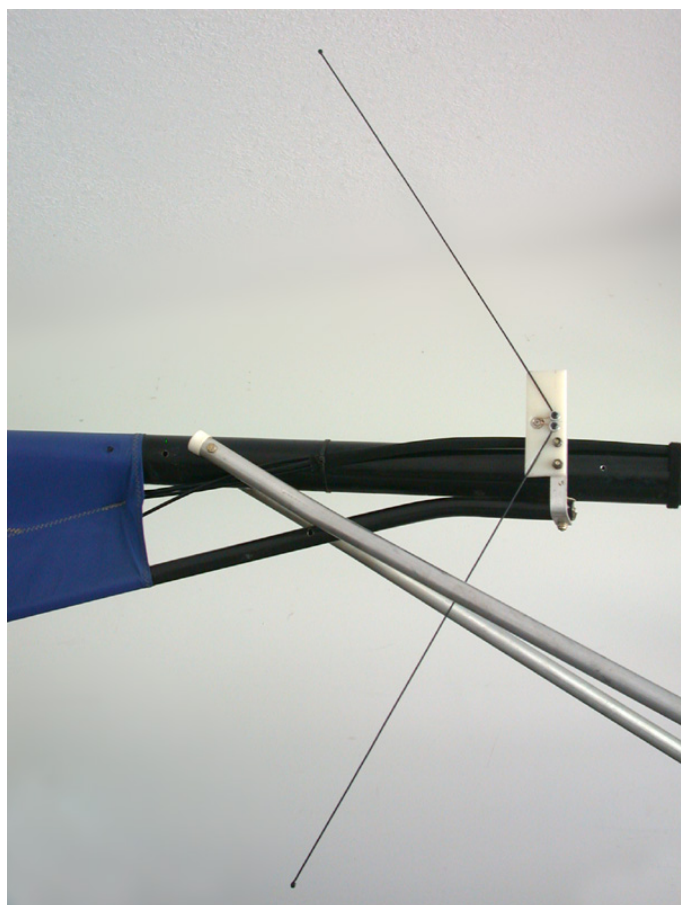Figure 14 – Antenna mounted using an L-bracket. Anything similar will work as well.

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

This "lumpy donut" shows that the antenna is about 60 times (-17 dB) **less** sensitive 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. Conversely you won't receive a very strong signal from them, either. Your best reception and transmission is going to be horizontally around you, extending 45 degrees down and up. Coincidentally, this is where 99% of all the planes and ground stations "live."

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
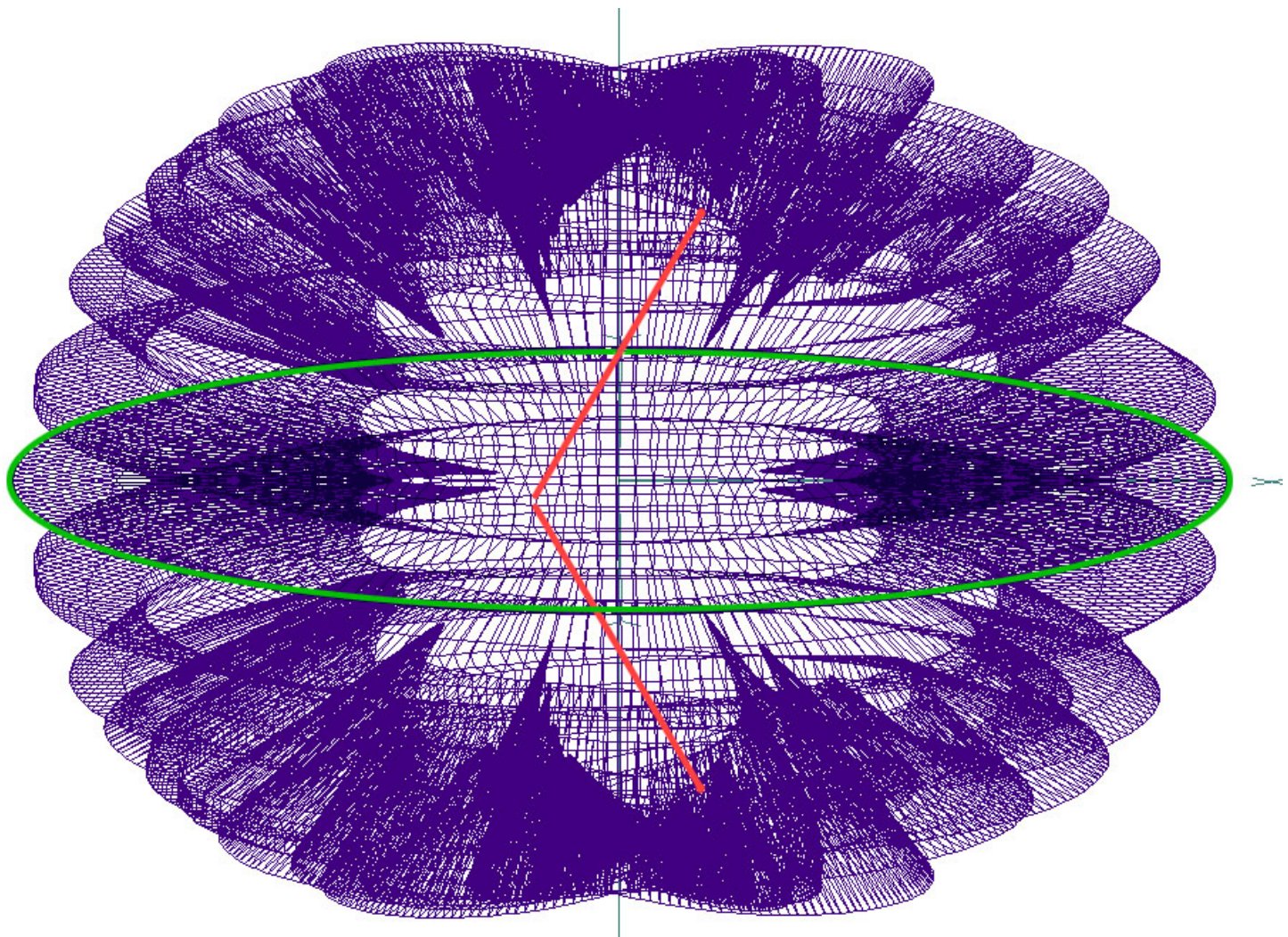

Figure 16 – 3D representation of the "crumpled donut-like" field strength surrounding the red vertically mounted antenna. The green circle represents the horizon where signal strength is at maximum, just what a pilot wants… 360 degree coverage.   Notice the puckered top and bottom "poles" jutting inward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