# *Eggbeater II* Omni LEO Antennas

Presented here is a high-performance, circularly polarized omni-directional antenna that is easy to build, easy to tune, inexpensive, and will work all the mode J Low Earth Orbit (LEO) satellites. I have built several of the traditional "eggbeaters" from plans floating around on the Internet, but was never satisfied with the overall performance. This design is the outcome of my investigations into methods of improving the performance of the "original" eggbeater without obviating the simple construction.

## Background:

The "eggbeater" antenna is an omni-directional antenna employing circular polarization to maximize signal capture from low Earth orbit (LEO) satellites. It is, basically, just two full wave loops fed in quadrature. Commercial versions are available from M2 Antennas. The garden-variety home-brew version employs a 90-degree "phasing" line to provide a fixed right-hand circular polarization (RHCP). It also uses, optionally, a pair of parasitic reflector elements to focus more of the radiation pattern overhead. This effect makes it a "gain" antenna, but that gain is at the expense of low-elevation reception. To the horizon it is linear-horizontally polarized. As the pattern rises in elevation, it becomes more and more RHCP.

My on-the-air observations about the excellent overhead performance of the eggbeater with radials led to some hunches, followed by experimentation, and resulted in the *Texas Potato Mashers* (Jan/Feb 1999 The *AMSAT* Journal). The TPM improved the coaxial gain of the eggbeater by re-shaping the loop into a square and moving the reflector closer to the driven element. It has been my workhorse LEO antenna ever since, but of course, it is a directional antenna.

Nevertheless, how to improve the eggbeater as an omni-directional antenna? A couple of data points worth noting are, compared to directly overhead, a typical LEO satellite has about 6 dB in free-space path loss at 30 degrees, and another 6 dB at the horizon. This implies an ideal omni-directional antenna would have an elevation pattern that was -6 dB from 30 degrees to 90 degrees--focusing the gain from the horizon up to 30 degrees elevation--where you need it the most--but without the deep overhead null presented by high-gain verticals.

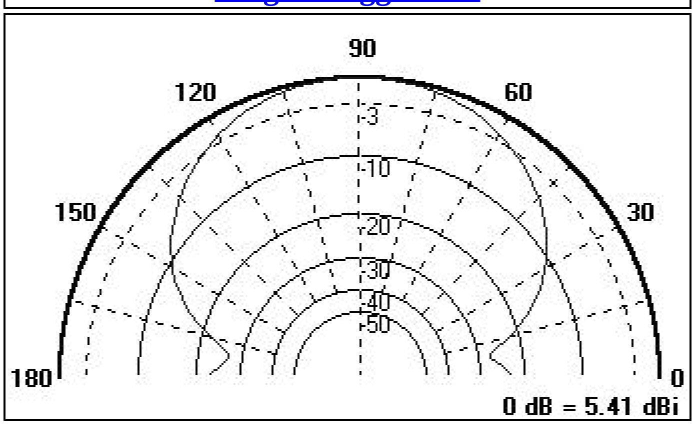
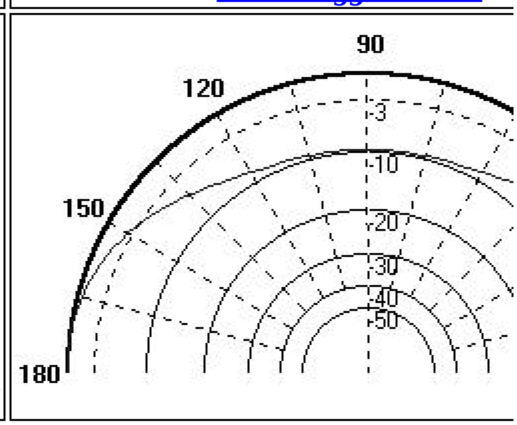
I've been pondering this design problem (how to easily build a better omni for satellites) ever since I read AA2TX's paper from the 1998 AMSAT Symposium ("An Omni-Directional Antenna for Receiving Mode-J, LEO Satellites"). Tony presents a novel and effective design and makes several thought-provoking points. It is recommended reading. His prototype design, however, may be difficult for the average back yard mechanic (a ham with two left thumbs) to reproduce.

## Design:

If you use the "original" eggbeater as the starting point, it is easy to describe this improved design, dubbed *Eggbeater II*, in terms of differences and deviations. The first distinction is it does not use a round "loop" for the driven elements. Instead, rectangles are formed. Modeling showed me why the original eggbeater never had an SWR below about 1.5:1. The input impedance of the round loops with reflector was close to 90 Ohms--too low. Starting with a square and "playing" with the shape allowed me to find a very good match at 100 Ohms, purely resistive. Since the two rectangle-loops are fed in-quadrature (but out of phase), the resultant feedpoint is very close to 50 Ohms with no reactance. The antenna is linearly polarized horizontally at the horizon and the pattern becomes more and more right-hand-circularly-polarized (RHCP) as the elevation pattern increases.

The second major distinction is the location of the reflector elements. They are placed not at the common 3/8-wavelength distance, but at slightly more than 1/2 wavelength below the driven elements. This placement helps "pull" the major lobes down to the horizon instead of "pushing" them overhead as in the original eggbeater design.

The free space elevation plots (NEC4Win) clearly depict the improvement of the new design over the "original" eggbeater. Note the gain is almost the same at 45 degrees, but the new design is 6 dB better at 30 degrees and about 10 dB better at 15 degrees. The real-world ground-based elevation patterns are also shown.

| | Original Eggbeater | K5OE *Eggbeater II* |
|---|---|---|
| **Free Space Elevation** |  |  |
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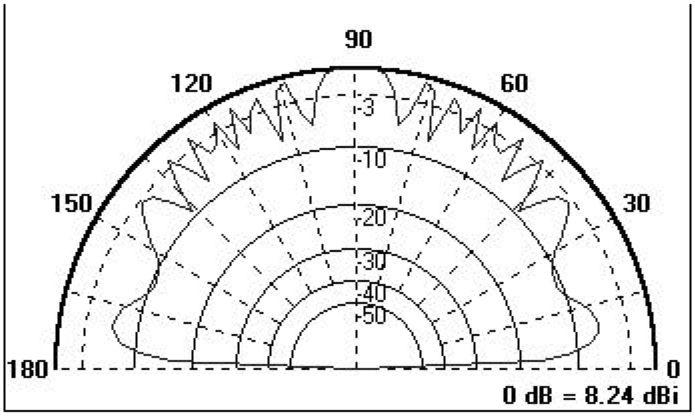
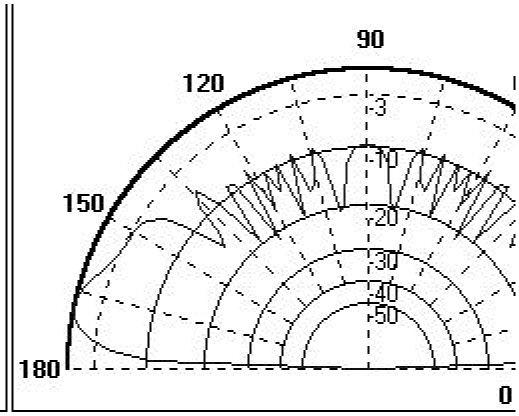
**Ground Based Elevation @ 35' (10.5 m)**




Of course, the trade-off is the new antenna exhibits -10 dB directly overhead. That is by design. Remember that 6 dB is gained in reduction of the satellite's path loss and 3 dB is gained in the improved circularity of the signal as the bird reaches higher elevations. How often does a satellite go above 75 degrees? Not very often; and the duration of it's stay in that high elevation is very brief. In short, you give up very little and theory predicts an almost constant signal level from 15 degrees to directly overhead.

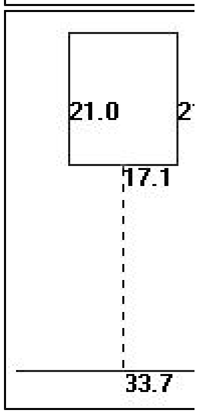
Construction: Common 1" PVC couplings and 6-32 stainless hardware are used. The loops are formed from # 10 copper wire with insulation left on (I strip 10/2 w/ground house wiring for the conductors, about $6.00 for a 25' box). The 70 cm loops are 6-3/4" (17 cm) wide by 8-1/4" (21 cm) tall; the 70 cm reflectors are 13-1/4" (33.5 cm) long and 13" (33 cm) below the driven elements. The 2 meter loops are 20" (51 cm) wide by 24-9/16" (63 cm) tall; 2 meter the reflectors are 39-1/2" (100.5 cm) long and 39-3/4" (101 cm) below the driven elements. I used 3/16" aluminum rod for the 2 meter reflectors. You could also try using 1/4" copper tubing as a suitable alternative.

These dimensions are very precise and will work well with #10 and # 12 wire (for 70 cm only), but you may want to make the loops slightly larger and trim the extra length based on your SWR readings. The # 10 wire on the 2 meter version is marginal, so using # 8 aluminum wire may be a good, if difficult to work, alternative. Unlike the original eggbeater, this new design provides an almost perfect 1.05:1 SWR.

**Dimensions: inches** | **centimeters**

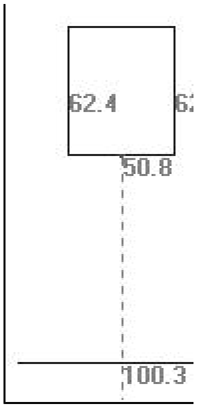
***70 cm Eggbeater II***

| Wire | X1 | Y1 | Z1 | X2 | Y2 | Z2 | Diam. |
|---|---|---|---|---|---|---|---|
| 1 | 0.000 | -3.375 | 0.000 | 0.000 | 3.375 | 0.000 | 0.008 |
| 2 | 0.000 | 3.375 | 0.000 | 0.000 | 3.375 | 8.250 | 0.008 |
| 3 | 0.000 | 3.375 | 8.250 | 0.000 | -3.375 | 8.250 | 0.008 |
| 4 | 0.000 | -3.375 | 8.250 | 0.000 | -3.375 | 0.000 | 0.008 |
| 5 | 0.000 | -6.625 | -13.000 | 0.000 | 6.625 | -13.000 | 0.008 |
| 6 | -3.375 | 0.000 | 0.000 | 3.375 | 0.000 | 0.000 | 0.008 |
| 7 | 3.375 | 0.000 | 0.000 | 3.375 | 0.000 | 8.250 | 0.008 |
| 8 | 3.375 | 0.000 | 8.250 | -3.375 | 0.000 | 8.250 | 0.008 |
| 9 | -3.375 | 0.000 | 8.250 | -3.375 | 0.000 | 0.000 | 0.008 |
| 10 | -6.625 | 0.000 | -13.000 | 6.625 | 0.000 | -13.000 | 0.008 |



**2 meter *Eggbeater II***

| Wire | X1 | Y1 | Z1 | X2 | Y2 | Z2 | Diam. |
|---|---|---|---|---|---|---|---|
| 1 | 0.000 | -10.000 | 0.000 | 0.000 | 10.000 | 0.000 | 0.008 |
| 2 | 0.000 | 10.000 | 0.000 | 0.000 | 10.000 | 24.565 | 0.008 |
| 3 | 0.000 | 10.000 | 24.565 | 0.000 | -10.000 | 24.565 | 0.008 |
| 4 | 0.000 | -10.000 | 24.565 | 0.000 | -10.000 | 0.000 | 0.008 |
| 5 | 0.000 | -19.750 | -39.750 | 0.000 | 19.750 | -39.750 | 0.015 |
| 6 | -10.000 | 0.000 | 0.000 | 10.000 | 0.000 | 0.000 | 0.008 |
| 7 | 10.000 | 0.000 | 0.000 | 10.000 | 0.000 | 24.565 | 0.008 |
| 8 | 10.000 | 0.000 | 24.565 | -10.000 | 0.000 | 24.565 | 0.008 |
| 9 | -10.000 | 0.000 | 24.565 | -10.000 | 0.000 | 0.000 | 0.008 |
| 10 | -19.750 | 0.000 | -39.750 | 19.750 | 0.000 | -39.750 | 0.015 |




A method I've developed to test resonance of the loops is to feed both in parallel, without the phasing line; connecting the 50 Ohm feedline to both loops. This provides a good resonance test without any impedance bump from the phasing/delay line. Simply connect the coax center conductor to any two adjacent loop ends and the coax shield to the other two adjacent loop ends. With the reflectors installed, test for SWR. If the SWR is above 1.5:1, follow this procedure:

- if SWR is better at lower frequency, make the loops slightly smaller and re-test
- if SWR is better at higher frequency, make the loops slightly larger and re-test

The reflector length is very critical, so measure it accurately. The distance is not so critical and can be adjusted a small amount to get the SWR perfect.

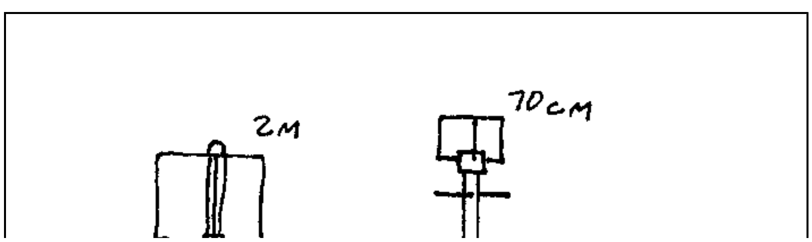
Finally, install the phasing/delay line. The phasing lines are made from RG-62 (93 Ohm, see notes below) coaxial cable. The connections from the coaxial cable to the loops are made using ring lugs and stainless steel 6-32 bolts/washers/nuts. See the phasing line sketch (view from bottom) for right-hand-circular-polarization connections. The 70 cm phasing line is 5-1/2" (13.5 cm) long and the 2 meter phasing line is 16-1/2" (41.5 cm) long. Cut the RG-62 about 2" (5 cm) longer than these measurements and leave 1" (2.5 cm) at each end to strip the insulation, peel back the braid, strip the center conductor, and attached the ring lugs. The ring lungs at one end of the phasing line can be shared with the 50 Ohm feedline (9913F or equal recommended) so that only four ring lungs are required.

Performance:

This antenna, mounted at 35' elevation, performed very well for an omni-directional design. At 5 degrees above the horizon, signals on FO-20 start to come alive. At 15 degrees, they are strong and clear--without a preamp AND with over 50' of feedline. The signals stay strong and pick up about 3-to-6 dB of strength up through 90 degrees. I believe this increase is due to the improved circularity as the pattern rises.The signals on AO-27 are much harder to capture and the horizontal polarization at the horizon is a definite penalty. I found the use of a preamp necessary. I got good copy on the bird once it reached about 15-20 degrees elevation--compared to 30-to-35 degrees on my original eggbeater. While I have not attempted to use this antenna for pacsats, I have monitored the signals on FO-29 while in mode JD and found I could copy at S3 or better from horizon to horizon (with preamp).

Field Day:

At right is an example setup for Field Day use. Total additional hardware required is three 10' sections of 1" schedule 40 PVC pipe and two 1" PVC tee's. I have these antennae built and



stored in the garage. They are
lightweight and can be carried out to the FD position, one in each hand. The 10' sections of pipe are stored separately and assembled onto the antennas out in the yard.

I operated 1B with these antennae this year (1999) and was able to make a QSO on every LEO using these (except RS-15, where I used my AO-10 beam for the uplink). FO-29 was easy, FO-20 was pretty workable but really crowded from 435.800 - 435.860, RS-13 (mode A) was great, but AO-27 was too much; I did make one QSO on AO-27, and I worked hard for it.

137 MHz WX Sat Dimensions:
At the request of EB5HDT, Miguel, I scaled the dimensions to 137 MHz. The loops should be built with # 8 AWG wire and the reflectors should be increased to about 1/4" diameter. The loops will be 54 cm wide by 66.5 cm high. The reflectors will be 107 cm long and 108 cm distance from the feed point. The RG-62 will be 45 cm long (plus 2.5 cm at each end). I have received good reports from several builders of this antenna.

RG-62 Coaxial Cable:
This 93 Ohm cable is not as commonly available as RG-8 or 9913F. In a pinch, you could substitute 75 Ohm cable such as RG-6, but expect to pay a price in feedpoint balance and SWR. For the 2 meter uplink, you may never tell the difference. For the 70 cm downlink, it could mean the difference between copy and no copy. I have heard the cable on automobile stereo antennas is RG-62, so you might want to try your local parts dealer (or WalMart) to see if a cheap replacement antenna-with-coax is an easy source. If you cannot find any of this cable, send me a SASE (5x7 manila envelope with 3 units of postage recommended) and I'll cut and send you one or both of the required cables.