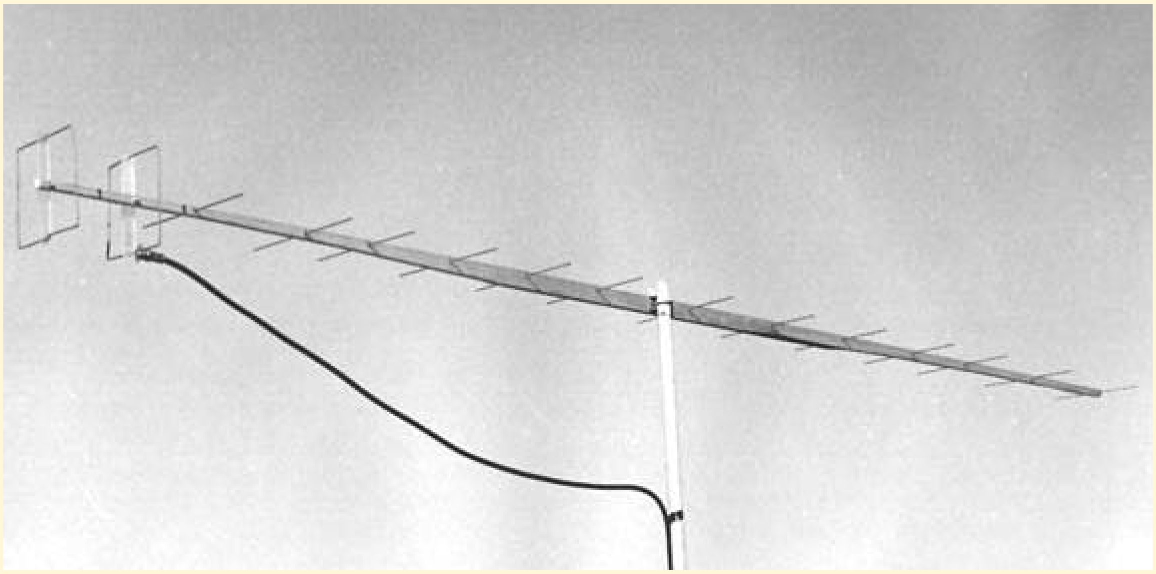


The Quagi Antenna Turns 30

By Wayne Overbeck, N6NB
www.n6nb.com

It has been 30 years since the VHF-UHF Quagi antenna--a combination of the desirable features of a Yagi and a cubical quad--was developed and the design was first published in the newsletter of the Southern California VHF Club, a forerunner of today's Western States Weak Signal Society.

After the first prototype Quagi antennas were measured for gain at the 1972 West Coast VHF Conference in Santa Clara, Calif., word began to spread about these simple and easy-to-duplicate but effective antennas. The original 8-element design was published in the April, 1977 issue of *QST* magazine. A follow-up article in *QST* for February, 1978 described the 15-element 432 MHz version (shown above). A third article, describing Quagi antennas for 1296 MHz, appeared in the August, 1981 *QST*.

The antenna, which is usually built with little more than hardware-store materials, became popular in many parts of the world. The original design was republished in amateur radio publications in countries as diverse as the former Soviet Union and India. Thousands of them have been built over the years.

Some Quagi history

The Quagi was originally designed on the K6YNB/N6NB backyard antenna range in 1972, with the assistance of Will Anderson, WB6RIV/AA6DD (check out the 1972 photo of Will at the end of this article). Later work on the larger Quagi designs was done in a city park and on a beach in an attempt to get away from reflections and obstructions that made the task of optimizing the antenna design in a small backyard more difficult.

What originally inspired the development of the Quagi antenna was the need for a low-cost, high-gain antenna for moonbounce communications. Some of the commercial

In this era of computer-optimized antenna designs, many radio amateurs are amazed that anyone would actually set up a home antenna range and perform the tedious job of designing an antenna one element at a time.

Computer modeling has revolutionized the way radio amateurs look at antennas. Armed with one of the powerful software packages that have come along in recent years, it is possible to design more antennas in a day than could be designed in a lifetime on an antenna range. Consequently, actual field measurement of antennas--using the classic scientific method of experimental research--has gone out of fashion.

However, computer modeling has its limitations. It is not always possible to model all of the variables that come into play with real-world antennas. And the modeling process has pitfalls even for the experts. Well-known software producer Brian Beezley, K6STI, published an article in Vol. 4 of the *ARRL Antenna Compendium* called "An Adventure in Antenna Modeling," in which he described his own frustrating attempt to design an antenna with exceptional low-angle radiation. Concluding, he said this: "In the end I decided to write up this fiasco for several reasons. First, I wanted to demonstrate how foolish it's possible to become when you get carried away with computer modeling. Powerful software is no substitute for common sense. Second, I wanted to point out how easy it is to draw invalid conclusions when you ignore the limitations of antenna-modeling algorithms."

Roy Lewallen, W7EL, another well-known modeling software author, said much the same thing in a February, 1991, *QST* article, "MININEC: The Other Edge of the Sword." He cited an example of an amateur whose computer modeling showed that a dipole less than a foot above a poor ground yielded 45 decibels gain over a dipole. Of that amateur, Lewallen said, "...he recognized that the answer was ridiculous, but sometimes we're not so lucky and the errors are tougher to spot."

Well then, how can a radio amateur who wants first-rate antenna performance be certain an antenna is really working as it should--or design a brand-new antenna?

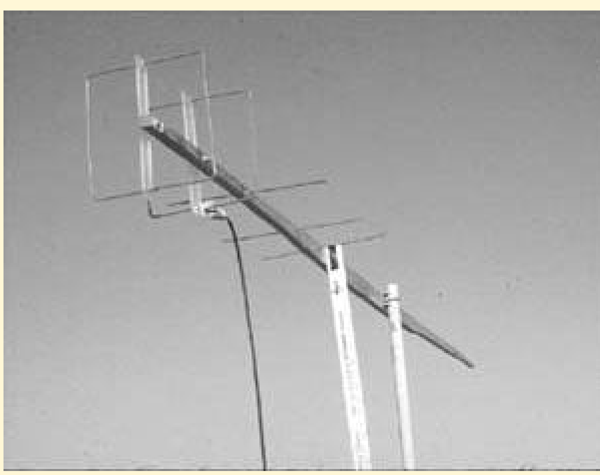
One answer is to measure the antenna's gain against a known reference. Antenna gain measuring sessions have been conducted at VHF/UHF conferences since the 1950s. Often these sessions, in which antennas are sometimes measured side by side as shown in the 1977 photo at left, are conducted by antenna experts using professional quality signal sources and measuring instruments. But any amateur willing to invest some time can set up an antenna range somewhere and obtain accurate antenna gain measurements with nothing more sophisticated than a low-power transmitter, a receiver and an audio VU meter. I published an article in *QST* in October, 1977, called "Measuring Antenna Gain with Amateur Methods" to describe the procedures for doing this.

Because so few amateurs do actual gain measurements today, it seems worthwhile to summarize what that article said here.

The article said that any clear area can be an antenna range. The trick is to avoid obstructions and reflections: if the received signal is louder when the antenna is pointed away from the source, there is a problem.

To conduct comparison tests, two antennas are placed side by side on masts of the same height, using equal length feedlines. A steady signal (a carrier) is generated perhaps 40 wavelengths away, and it is detected on a CW/SSB receiver that is *not* overloaded but has its AGC disabled. Then a VU meter can be used to indicate the difference in received signal strength of the two antennas. As a precaution, the two antennas are swapped so that antenna #1 goes on the mast and uses the feedline formerly used by antenna #2. Given some care in measurements and a stable path, it is possible to determine the difference in the gain of the two antennas down to a fraction of a decibel.

Once the experimenter has confidence in the integrity of the antenna range, it's quite possible to dispense with the receiver and VU meter and use a signal source plus a field strength meter such as the one shown in the photo at right (which also shows an assortment of elements of varying lengths, including one mounted on a meter stick for use in antenna design work).



Incidentally, although this test setup is most practical with VHF/UHF antennas, the same principles work at HF as well if one can obtain the right hardware (e.g., a tower trailer to support a reference antenna beside each antenna being tested). Also, new antennas can be designed using these antenna range principles. A variety of element length and spacing combinations can be tried until the best results are achieved. While this is far more tedious than computer modeling, it does produce repeatable, practical real-world results. The Quagi antenna was designed in this fashion in 1972.

In the original Quagi development at 222 MHz, Will and I first started working with cubical quad-style loop elements until we were satisfied that we had loops that were performing as they should. Then we added elements, first using loops and then rod directors. We tried various lengths for each new element and adjusting the spacing for maximum gain. The addition of each new element, of course, required us to re-check the previous elements for length and spacing, monitoring the gain of the antenna during each change. After a lot of painstaking experimentation, we arrived at the designs for 144, 222 and 432 MHz that were eventually published. The 1296 antennas were designed five years later at N6NB's antenna farm in Woodland Hills, which was the forerunner of the Tehachapi Mountain antenna farm.

Quagi construction notes for 144, 222 and 432 MHz

The original Quagi antennas used wooden booms (1x2 or 1x3 Douglas Fir, tapered at both ends to reduce the weight and wind load), but any other nonconductor (e.g., fiberglass, Plexiglas or even taped bamboo) can also be used. If an aluminum boom is used, the elements should be mounted on insulators above or below the boom (not passed through a metal boom). Many builders have used small pieces of hardwood moulding to mount the directors atop an aluminum boom.

432-MHz, 15-Element, Long Boom Quagi Construction Data

Element Lengths, Inches	*Interelement Spacing, Inches*
R—28	R-DE—7
DE—26-5/8	DE-D1—5-1/4
D1—11-3/4	D1-D2—11
D2—11-11/16	D2-D3—5-7/8
D3—11-5/8	D3-D4—8-3/4
D4—11-9/16	D4-D5—8-3/4
D5—11-1/2	D5-D6—8-3/4
D6—11-7/16	D6-D7—12
D7—11-3/8	D7-D8—12
D8—11-5/16	D8-D9—11-1/4
D9—11-5/16	D9-D10—11-1/2
D10—11-1/4	D10-D11—9-3/16
D11—11-3/16	D11-D12—12-3/8
D12—11-1/8	D12-D13—13-3/4
D13—11-1/16	

Boom: 1 × 2-in. × 12-ft Douglas fir, tapered to 5/8 in. at both ends.
Driven element: No. 12 TW copper wire loop in square configuration, fed at bottom center with type N connector and 52-Ω coax.
Reflector: No. 12 TW copper wire loop, closed at bottom.
Directors: 1/8-in. rod passing through boom.

The driven element and reflector are mounted on nonconductive spreaders such as dowel rods or strips of Plexiglas to avoid interaction. The driven element has a coaxial connector (an SO-239 or type-N connector, which is preferable at UHF) at the center of the bottom side of the element and is fed directly with 50-Ohm coaxial cable. In the original design, covered solid #12 TW house wire was used for the quad-style elements. The use of other types of wire, or even removing the insulation, may change the resonant frequency enough that the length has to be adjusted. Suggestion: build the antenna to the dimensions shown in the chart and run an SWR curve, noting the SWR above and below the desired operating frequency. If it is lowest below the desired frequency, the driven element should be made shorter--or longer if the SWR is lowest above the desired frequency. The reflector should then be adjusted in length a similar amount. *Many builders have used THHN wire, which is more readily available than type TW now. They generally report that the resonant frequency is higher than expected, which means the loop elements have to be lengthened slightly for THHN wire. Tests in 2003 indicated that each wire loop should be about one percent longer than the original dimension if THHN wire is used.*

Fine-tuning of the element length is usually not needed for the directors, provided they are made of 1/8-inch aluminum rods, brass welding rods or something similar--as long as the boom is a nonconductor or the elements are mounted on insulators above or below the boom. If the elements pass through a metal boom (even with insulating sleeves), the length will have to be adjusted experimentally (have fun!). The director lengths are tapered from longest (closest to the driven element) to shortest (at the front of the antenna).

Although the quad loops are square or circular, the antenna is linear in polarization, not circular. If it is fed at the bottom, the antenna will be horizontally polarized. Feed the antenna on either side for vertical polarization (and then mount the directors vertically, not horizontally.

Some builders have tried baluns to correct the imbalance in this quad-style feed arrangement. In many cases, a balun introduces losses so great that it's better to live with the unbalanced feed than to try to correct it. Feedline radiation can be reduced by placing toroids on the feedline at the antenna. Also, the feedline should run away from the feedpoint along the boom or below it--and then down the supporting mast perpendicularly to the elements to avoid interaction problems.

A phasing harness is needed if two or more Quagi antennas are stacked for additional gain. The simplest way to feed multiple bays is with a commercial power divider and equal-length 50-ohm feedlines from the power divider to each antenna. An alternative method is to feed each pair of antennas with odd quarter-wavelength multiples of 75-ohm coaxial cable going to a T connector and with 50-ohm cable from that point to the station. Most amateur radio refer

With a little practice, these antennas can be mass-produced in large quantities at low cost. I have built as many as 16 of them for e.m.e. work in less than a day.

Performance? Quagi antennas have been measured for gain at VHF conferences many times. If well built, the 8-element model usually comes in between 12 and 13 dBd. forward gain over a dipole, while the 15-element model is around 14-15 dBd. gain. These antennas have been used by a number of record-setting VHF-UHF contest stations, sometimes in portable applications like the one shown in the photo here.

This photo, taken in 1976 at Utah Pass, Utah shows an installation of six Quagi antennas (two each for 144, 222 and 432 MHz) plus a Yagi for 50 MHz.

Note: All lengths are gross lengths. See text and photos for construction technique and recommended overlap at loop junctions. All loops are made of no. 18 AWG solid-covered copper bell wire. The Yagi-type directors are 1/16-in. brass brazing rod. See text for a discussion of director taper.

Feed: Direct with 52-ohm coaxial cable to UG-290 connector at driven element; run coax symmetrically to mast at rear of antenna.

Boom: 1/4-in.-thick Plexiglas, 30 in. long for 10-element quad or quagi and 48 in. long for 15-element quagi.

10-Element Quagi for 1296 MHz

Element	*Length (in.)*	*Construction*	*Element*	*Interelement Spacing (in.)*
Reflector	9.5625	(loop)	R-DE	2.375
Driven El.	9.25	(loop)	DE-D1	2.0
Director 1	3.91	(brass rod)	D1-D2	3.67
Director 2	3.88	(brass rod)	D2-D3	1.96
Director 3	3.86	(brass rod)	D3-D4	2.92
Director 4	3.83	(brass rod)	D4-D5	2.92
Director 5	3.80	(brass rod)	D5-D6	2.92
Director 6	3.78	(brass rod)	D6-D7	4.75
Director 7	3.75	(brass rod)	D7-D8	3.94
Director 8	3.72	(brass rod)		

15-Element Quagi for 1296 MHz

The first 10 elements are the same lengths (inches) as above, but the spacing from D6 to D7 is 4.0 in. here; D7 to D8 is also 4.0 in.

Director 9	3.70	D8-D9	3.75
Director 10	3.67	D9-D10	3.83
Director 11	3.64	D10-D11	3.06
Director 12	3.62	D11-D12	4.125
Director 13	3.59	D12-D13	4.58

Notes concerning the 1296 MHz antenna design

At 1296 MHz, even small variations in the dimensions can have a dramatic effect on the antenna's performance. In the original design, the reflector loop was overlapped by 1/8 inch and soldered together after being fitted through holes drilled in a plexiglas "spreader" mounted on the boom. The driven element loop was soldered to a standard UG-290 chassis-mount BNC connector. One end of the 9.25-inch loop was pushed as far as it would go into the center pin and soldered. Then the loop was shaped and threaded through a plexiglas spreader. Finally, the other end was fed into one of the four mounting holes on the BNC connector and soldered. In most cases, the best VSWR was obtained if the end of the wire just passed through the hole so that it was flush with the opposite side of the connector. These lengths can be optimized if a reflected power meter that works at 1296 MHz is available: the length of the driven element can be adjusted slightly for lowest reflected power. If a major change has to be made, the reflector should be adjusted a comparable amount. The loop elements were shaped into a square; the exact shape did not appear to be critical.

The directors were made as follows. Using 1/16-inch brass welding rod, one director was cut just slightly shorter than four inches and then filed down as needed. Then another was cut and filed to the shortest dimension, as well as that could be determined with a good ruler. Finally, all of the intermediate elements were filed so that they tapered evenly in length from the longest (3.91 inches) to the shortest (3.59 inches in the case of the 15-element model).