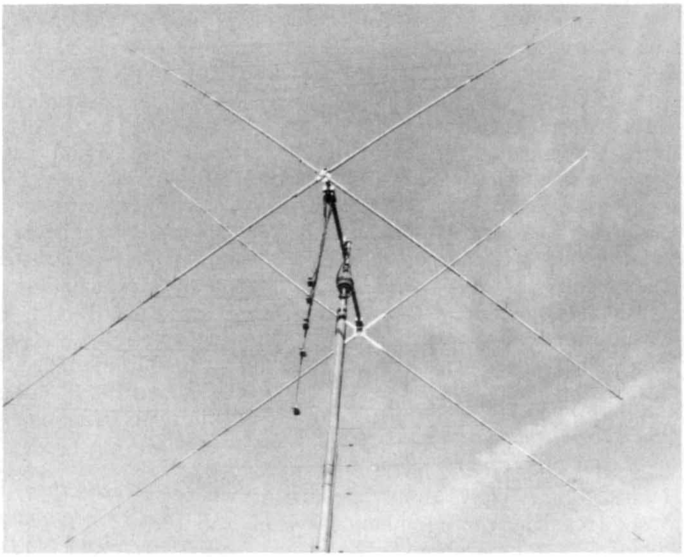
A Five-Band, Two-Element Quad for 20 through 10 Meters



Want a small antenna that covers *all* the ham bands between 14 and 29.7 MHz? Here's a solution with two alternatives for construction: using hardware-store parts or modifying an existing commercial triband quad.

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You have many choices when it comes to selecting a rotatable multiband, directional antenna. The most popular ones include Yagis with trapped or interlaced elements, log-periodic dipole arrays (LPDAs), log-Yagis and wire arrays, including the cubical quad. All have their advantages and disadvantages, and your choice will depend on many factors; but the basic objective is to select an antenna that performs well and is within your constraints of cost and availability of adequate support and rotating hardware.

If you intend to build your antenna, there are additional factors to consider, such as ease of construction with available materials, ease of adjustment, and weather-resistance. Another consideration, whether you buy or build your antenna, is appearance.

I needed a lightweight, small turning radius antenna, with good performance on the five bands from 20 through 10 meters, that could be easily adjusted for best performance after assembly. I computer modeled and studied trapped and interlaced Yagis, log-Yagis, and LPDAs before deciding on the quad. Computer modeling, in this case with *MN* version 3.5,[1] allowed me to try some "what-ifs" without cutting metal, snipping wire, climbing towers or crushing roof tiles (all to come later). I settled on a quad.

Why a Quad?

Quads are not for everyone. If your location is subject to ice storms or very high winds, you may want to select something else. Also, as one friend pointed out, many people consider the quad to be at least a "9" on the ugly scale of 10. Of course, as hams, we judge all antennas to be things of beauty, but here and there, others may not necessarily see things the same way!

But, if you enjoy challenging construction projects, and would like an antenna that performs well on all five bands from 20 through 10 meters, then this is the project for you. Conceptually, the multiband quad is a simple antenna, with separate driven and reflector loops for each band. In the case of the five-band, 20- through 10-meter quad, the driven and reflector arms each support five concentric wire loops. Two quad designs are described in this article, both nearly identical: one I constructed from scratch, and the other W6NBH built using modified commercial triband quad hardware. The principles of construction and adjustment are the same for both models, and the performance test results are also essentially identical. One of the main advantages of this design is the ease of (relatively) independent performance adjustment for each of the five bands.

Both models use 8-foot-long, 2-inch-diameter booms, and conventional **X**-shaped spreaders (with two sides of each quad loop parallel to the ground). The same basic techniques apply to a boomless design and to the conventional design in the diamond configuration. Many fine articles have been written on proven quad-construction techniques,[2-6] so this article discusses only those mechanical features that are different or especially important.

The Five-Band Quad as a System

Unless you are extraordinarily lucky, you should remember one general rule: *Any* quad must be adjusted for maximum performance after assembly. With two-element quads, this is especially true. Simple quad designs can be tuned by pruning and restringing the elements to control front-to-back ratio and SWR at the desired operating frequency. Since each element of this quad contains five concentric loops, this adjustment method could lead to a nervous breakdown!

Fig 1 shows that the reflectors and driven elements are each independently adjustable. After assembly, adjustment is simple, and although gamma-match components on the driven element and capacitors on the reflectors add to the antenna's parts count, physical construction is not difficult. The reflector elements are purposely cut slightly long (except for the 10-meter reflector), and electrically shortened by means of a tuning capacitor. The driven-element gamma-match networks set the lowest SWR at the desired operating frequency.

In general, with most multiband directive antennas, the designer can optimize any two of the following three attributes, at the expense of the third: forward gain, front-to-back ratio and bandwidth (where

[1]Notes appear on page 56.

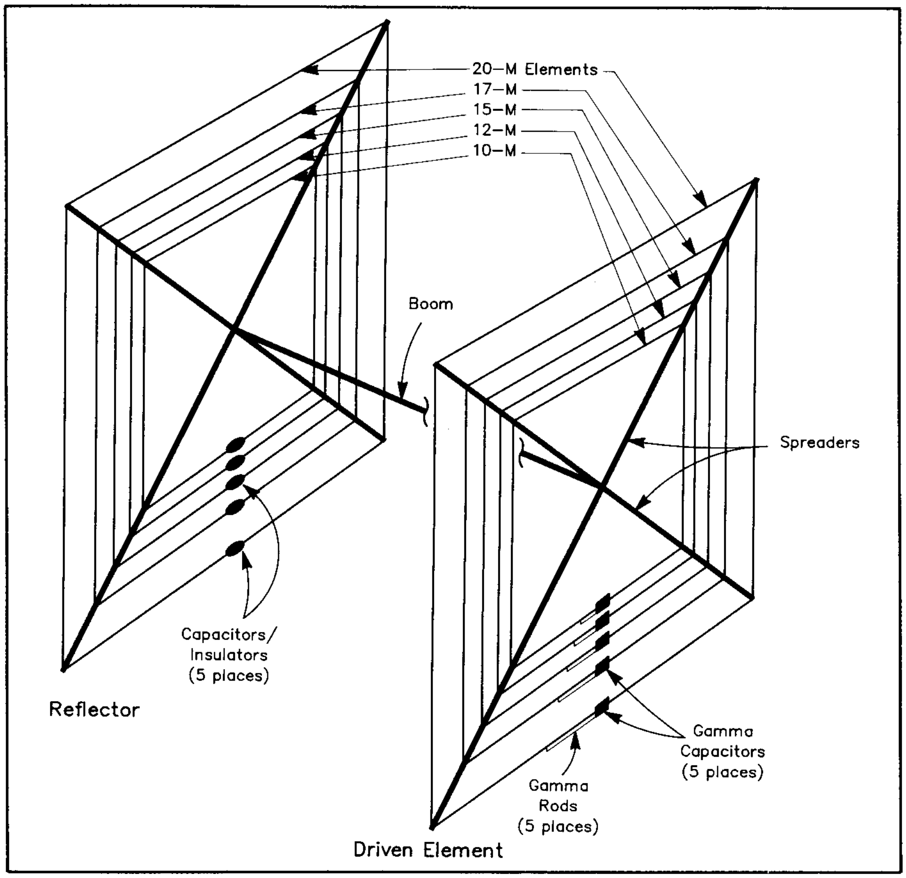

Fig 1—Mechanical layout of the five-band quad. The boom is 8 feet long; see Table 1 for all other dimensions.

Table 1

Element Lengths and Gamma-Match Specifications of the KC6T and W6NBH Five-Band Quads

KC6T Model

Band (MHz)	Driven Element Length (in.)	Gamma Match Length (in.)	Gamma Match Spacing	C_g (pF)	Reflector Length (in.)	C_R (pF)
14	851.2	33	2	125	902.4	68
18	665.6	24	2	110	705.6	47
21	568	24	1.5	90	604.8	43
24.9	483.2	29.75	1	56	514.4	33
28	421.6	26.5	1	52	448.8	(jumper)

W6NBH Model

Band (MHz)	Driven Element Length (in.)	Gamma Match Length (in.)	Gamma Match Spacing	C_g (pF)	Reflector Length (in.)	C_R (pF)
14	851.2	31	2	117	890.4	120
18	665.6	21	2	114	705.6	56
21	568	26	1.5	69	604.8	58
24.9	483.2	15	1	75.5	514.4	54
28	421.6	18	1	41	448.8	(jumper)

the SWR is less than 2:1). These three characteristics are related, and changing one changes the other two. The basic idea behind this quad design is to permit (without resorting to trimming loop lengths, spacing, or other gross mechanical adjustments):

- Setting the forward gain, bandwidth and front-to-back ratio by a simple adjustment after assembly. The adjustment can be made on a band-by-band basis, with little or no effect on previously made adjustments for the other bands.
- Setting the minimum SWR in any portion of each band, with no interaction with previously made front-to-back or SWR adjustments.

The first of the two antennas described, the KC6T model, uses aluminum spreaders with PVC insulators at the element-attachment points. (Fiberglass spreaders now cost between $30 and $40 each, so I shied away from them.) The second antenna, the W6NBH model, provides dimensions and adjustment values for the same antenna, but using standard triband-quad fiberglass spreaders and hardware. If you have a triband quad, you can easily adapt it to this design. When W6NBH built his antenna, he had to shorten the 20-meter reflector because the KC6T model uses a larger 20-meter reflector than W6NBH's fiberglass spreaders would allow. Performance is essentially identical for both models.

Mechanical Considerations

Even the best electrical design has no value if its mechanical construction is lacking. Here are some of the things that contribute to mechanical strength:

The Gamma-Match Capacitor

I used a small, air-variable, chassis-mount capacitor mounted in a plastic box (see Fig 2). A male UHF connector was mounted to the box, along with a screw terminal for connection to the gamma rod. The terminal lug and wire are for later connection to the driven element. The box came from a local hobby shop, and the box lid was replaced with a piece of 1/32-inch ABS plastic, glued in place after the capacitor, connector, and wiring had been installed. The capacitor can be adjusted with a screwdriver through an access hole. Small vent holes were drilled near corresponding corners of each end.

Enclose your gamma-match capacitor in such a manner that you can tape unwanted places closed so that for moisture can't be blown in during wind and rain storms. Also, the smaller the box, and the more sturdy the mount to the driven element, and the less likely you'll have to pick up gamma capacitor assemblies along with the leaves after a wind storm.

I constructed plastic gamma rod insulators/stand-offs from 1/32-inch ABS, cut 1/2 inch wide with a hole at each end. A knife was used to cut a slit between the hole and the side of each insulator so that one end could be slipped over the driven element and the other over the gamma rod. Use about four such insulators for each gamma rod, and mount the first one as close to the capacitor box as possible. Five-minute epoxy applied to the element and gamma rod at the insulator hole keeps the insulators from sliding around in the wind. If you intend to experiment with gamma-rod length, perform this gluing operation *after* you have made the final gamma rod adjustments.

Element Insulators

As shown in Fig 1, the quad uses insulators in the reflectors for each band to break

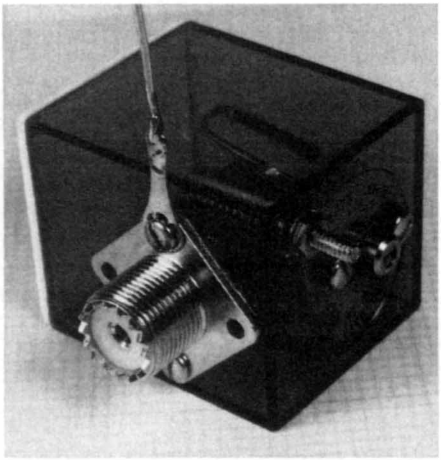

Fig 2—Photo of one of the feed-point gamma-match capacitor enclosures.

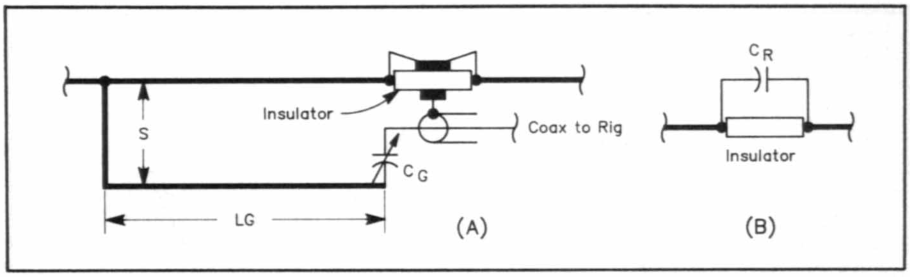

Fig 3—Gamma-match construction details (A) and reflector-tuning capacitor (C_R) attachment schematic (B). The gamma matches consist of matching wires (one per band) with series capacitors (C_g). See Table 1 for lengths and component specifications.

the loop electrically, and to allow for reflector adjustments. These insulators were also used to break up each driven-element loop so that element impedance measurements could be made with a noise bridge. In the driven-element loops, after the impedance measurements, the loops had to be closed again. The insulators are made from ¼ × 2 × ¾-inch phenolic stock. The holes are ½ inch apart. Two terminal lugs (shorted together at the center hole) are used in the driven element, and offer a convenient way to open the loops by removing one screw. Fig 3 shows these insulators and the gamma-match construction schematically. Table 1 lists the component values, element lengths and gamma-match dimensions.

Element-to-Spreader Attachment

Probably the most common problem with quad antennas is wire breakage at the element-to-spreader attachment points. There are a number of functional attachment methods; Fig 4 shows one of them. The attachment method with both KC6T and W6NBH spreaders is the same, even though the spreader constructions differ. The KC6T model uses #14 AWG, 7-strand copper wire; W6NBH used #18, 7-strand wire. At the drilling point for element attachment (see Fig 5), drill a hole through the spreader (both walls) using a #44 (0.086-inch) drill. Feed a 24-inch-long piece of antenna wire through the hole and center it for use as an attachment wire.

After fabricating the spider/spreader assembly, lay the completed assembly on flat ground and cut the element to be installed to the correct length, starting with the 10-meter element. Attach the element ends to the insulators to form a closed loop *before* attaching the elements to the spreaders. Center the insulator between the spreaders on what will become the bottom side of the quad loop, and using fingernail polish (or a similar substance), carefully measure and mark the element-mounting points. *Do not* depend on the at-rest position of the spreaders to guarantee that the mounting points will all be correct.

Holding the mark at the centerline of the spreader, tightly loop the attachment wire around the element and then gradually space out the attachment-wire turns as shown. The attachment wire need not be soldered to the element. The graduated turns spacing minimizes the likelihood that the element wire will flex in the same place each time under wind loading, thus reducing the chance of fatigue-induced wire breakage.

Feeding the Driven Elements

Each driven element is fed separately, but feeding five separate feedlines down the tower and into the shack would be costly and mechanically difficult. The ends of each of these coax lines also require support other than the tension (or lack of thereof) provided by the driven element at the feed point. I recommend that you use a remote coax switch on the boom approximately 1 foot from the driven-element spider assembly attachment point. I used a home-brew coax switch mounted in a weatherproof, cast-aluminum box; W6NBH used a commercial unit. Both switches are mounted on the booms with the connectors facing down.

At installation, the cables connecting the gamma-match capacitors and the coax switch help support the driven elements and gamma capacitors. The support can be improved by taping the cables together in several places. A single coaxial feed line (and a control cable from the remote coax switch, if yours requires one) is the only required cabling from the antenna to the shack.

The KC6T Model's Composite Spreaders

As I mentioned earlier, the cost of commercially available fiberglass spreaders varies from about $30 to $40 each, making home-brew quads expensive. If you live in an area with little or no wind, spreaders made from wood or PVC are practical but, if, like me, you live where winds can reach 60 to 80 mi/h, strong, lightweight spreaders are a *must*. Spreaders constructed with electrical conductors (in this case, aluminum tubing) can cause a myriad of problems with unwanted resonances, etc, and the problem gets worse as the number of bands increases.

To avoid these problems, I built composite spreaders made from machined PVC insulators at the element-attachment points. Aluminum tubing is inserted into (or over) the insulators 2 inches on each end. This spreader is designed to withstand 80 mi/h winds. The overall insulator length is designed to provide a 3-inch center insulator clear of the aluminum tubing. The aluminum tubing used for the 10-meter section (inside dimension "A" in Fig 5) is 1-1/8-inch diameter × 0.058-inch wall. The next three sections are 3/4-inch diameter × 0.035-inch wall, and the outer length is made from 1/2-inch diameter × 0.035-inch wall. The dimensions shown in Fig 5 are *attachment point* dimensions only—the tubing lengths vary depending on the dimensions of the insulators you use.

Attach the insulators to the aluminum using #6 sheet metal screws. Mechanical strength is provided by Devcon #S-220 Plastic Welder Glue (or equivalent) applied

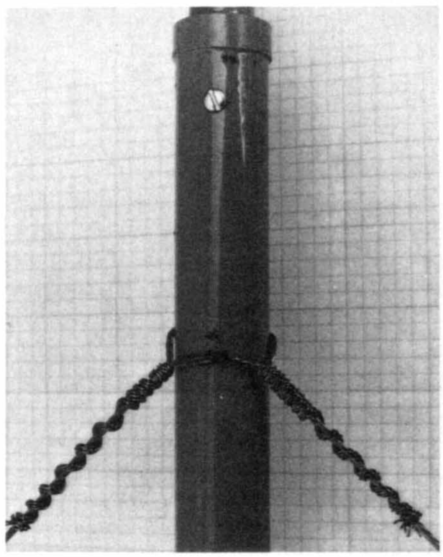

Fig 4—Attaching quad wires to the spreaders must minimize stress on the wires for best reliability. This method, described in the text, cuts the chances of wind-induced wire breakage by keeping the wire from repeatedly flexing in the same place.

liberally as the aluminum and plastic parts are jointed. Sunlight and PVC are not buddies, so paint the PVC insulators before mounting the elements to them. As you can see from Fig 5, an additional spreader insulator located about halfway up the 10-meter section (inside dimension "A") removes one of the structure's electrical resonances not eliminated by the attachment-point insulators. Because it mounts at a relatively high-stress point in the spreader, this insulator is fabricated from a length of heavy-wall fiberglass tubing.

Does the composite spreader work as well as the fiberglass spreader? You bet! Is it cheaper? Not unless you have a pretty good shop, including a lathe, or unless you can get a group of hams together to get volume discounts on aluminum tubing and/or machining services. The main objective of presenting the composite spreader is to show that fiberglass spreaders aren't a basic requirement—there are many other ways to construct usable spreaders. If you can lay your hands on a used multielement quad, even one that's damaged, you can probably obtain enough spreaders to reduce construction costs considerably.

Electrical Considerations

Gamma Rod

The gamma rod is made from a length of #12 solid copper wire (W6NBH used #18, 7-strand wire). Dimensions and spacings are shown in Table 1. If you intend to experiment with gamma-rod lengths and capacitor settings, I suggest you cut the gamma rod length about 12 inches longer than the length listed in the table. Fabricate a sliding short by soldering two small alligator clips back-to-back such that they can be clipped to the rod and the antenna element and easily moved along the rod/element. Note that gamma rod spacing varies by band. When you find a suitable shorting-clip position, mark the gamma rod, remove the clip, bend the gamma rod at the mark and solder the end to the element.

The W6NBH Model

As previously mentioned, this model uses standard 13-foot fiberglass spreaders, which aren't quite long enough to support the larger 20-meter reflector specified for the KC6T model. The 20-meter W6NBH reflector loop is cut to the dimensions shown in Table 1—12 inches shorter than that for the KC6T model. To tune the shorter reflector, a 6-inch-long stub of antenna wire (spaced 2 inches) hangs from the reflector insulator, and the reflector-tuning capacitor mounts on another insulator at the end of this stub.

Gamma-Match Capacitor

Use an air-variable unit of your choice. Approximately 300 volts can appear across this capacitor (at 1500 watts), so choose

	Dim	Driven	Reflector
	A	74.5	79.4
	B	85.4	90.9
	C	100.4	106.9
	D	117.6	124.7
KC6T:	E	150.4	159.5
W6NBH:	E	150.4	157.4

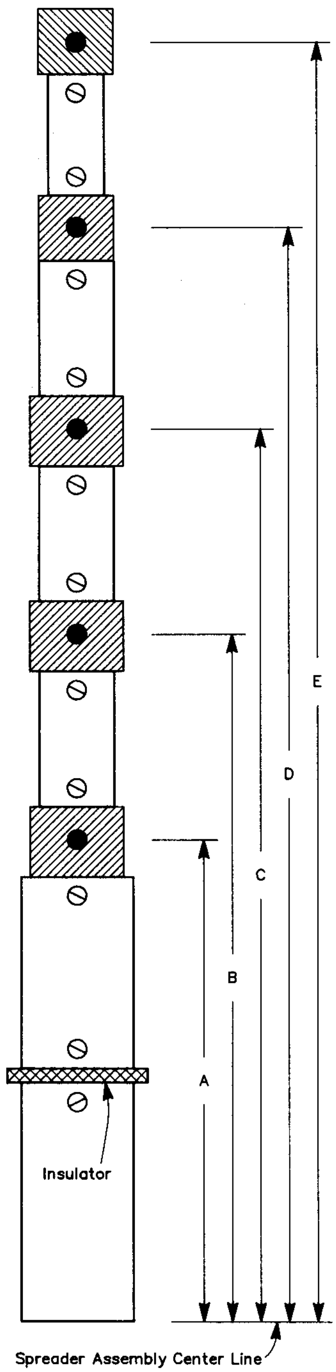

Fig 5—Spreader-drilling diagram and dimensions for the five-band quad. These dimensions apply to both spreader designs described in the text, except that most commercial spreaders are only a bit over 13 feet (156 inches) long. This requires compensating for the W6NBH model's shorter 20-meter reflector as described in the text.

plate spacing appropriately. If you want to adjust the capacitor for best match and then replace it with a fixed capacitor, remember that several amperes of RF will flow through the capacitor. If you choose disc-ceramic capacitors, use a parallel combination of at least four roughly equal-value units with a 1-kV rating. Any temperature coefficient is acceptable (NP0 units are not required).

Reflector-Tuning Capacitor

As with the gamma-match capacitor, if you plan to use fixed capacitors (recommended to reduce wind loading), use at least four roughly equal-value units (1-kV rating) in parallel.

Feed Line

Occasionally, just occasionally, something happens in hamming that is so bizarre that it becomes indelibly engraved in memory. One such event in my ham career involves experiencing an unexplained, very high (about 4:1) SWR on one band of a trapped HF antenna. Moving from one end of the band to the other did not produce any noticeable SWR change as measured at the shack end of the coaxial feed line. Adding 3 feet of coax at the shack end *cured the problem*, with the SWR meter now indicating about 1.3:1 and clearly showing normal variations as I scanned from one band edge to the other. What caused the problem? The feed line was almost exactly ¼ wavelength long electrically at 40 meters—the problem band. If the load (at the antenna) had been entirely resistive, and close to the characteristic impedance of the feed line, there would have been no such problem. If the load is reactive and the feed line is an odd electrical multiple of ¼ wavelength at the operating frequency—look out! You might have the same difficulty.

That's the bad news. The *good* news is that the problem is less severe with longer coax lengths (many odd multiples of ¼ wavelength). For a multiband antenna, this means that, if there is any likelihood of a such problem, it is more likely to occur at the lowest operating frequency than the highest. Lengths to avoid for each of the five bands from 20 through 10 meters can be calculated by:

$$L = n\,(246.1\ \mathrm{VF}) / f \qquad \text{(Eq 1)}$$

where VF is the velocity factor of your coax ($0 < VF < 1$), f is frequency in megahertz, and n is any odd integer.

Practically speaking, unless your antenna is on the roof, right above your shack, picking feed line lengths good for both 20 and 17 meters should be acceptable.

Adjustments

Well, here you are, with about 605 feet of wire just aching to be an antenna! Your antenna will weigh about 45 pounds (the W6NBH version is slightly lighter) and have about 9 square feet of wind area. If you choose to, you can use the dimensions and capacitance values given for the either of the two models; performance should be excellent. If you adjust the antenna for minimum SWR at the band centers, it should cover all of the lower four bands and 28-29 MHz with SWRs under 2:1; front-to-back ratios are given in Table 2.

Instead of building the quad to the dimensions listed and hoping for the best, you can adjust your antenna to account for most of the electrical environment variables of your installation. The adjustments are conceptually simple: You'll first adjust the reflector's electrical length for maximum front-to-back ratio (if you desire good gain, but are willing to settle for a narrower than maximum bandwidth), or accept some compromise in front-to-back ratio that results in the best bandwidth for your needs. You can make this adjustment by placing an air-variable capacitor (about 100 pF maximum will do) across the open reflector loop ends, one band at a time, and adjusting the capacitor for the desired front-to-back ratio. The means of doing this will be discussed later.

During these reflector adjustments, the driven-element gamma-match capacitors may be set to any value and the gamma rods may be any convenient length (but the sliding-short alligator clips should be installed somewhere near the lengths specified in Table 1). After completing the front-to-back adjustments, the gamma capacitors and rods will be adjusted for minimum SWR at the desired frequency. With this antenna, adjusting the reflector for minimum front-to-back ratio yields maximum bandwidth and good forward gain. Adjusting it for maximum front-to-back ratio cuts bandwidth and increases gain somewhat.

Adjustment Specifics

Do you need an antenna range to do the job properly? You bet, if you want to get meaningful gain figures and front-to-back ratios unaffected by surrounding objects and terrain. But tweaking the antenna at or near the installation site is possible and will yield the bandwidth and front-to-back ratios that you'll actually see and hear. So, the only real disadvantage of having to adjust the antenna without the benefit of an antenna range is that you can't actually *measure* forward gain.

My tower is alongside my house and I was able to crank it down to reach the reflector and driven-element adjustment points from the roof, without a ladder. I used a portable L-C-R meter for making capacitance measurements. I also successfully tried using a calibrated 100-pF air-variable capacitor (with a hand-drawn scale and wire pointer). As a matter of fact, I used the calibrated capacitor for adjusting the front-to-back ratio, then measured the adjusted capacitor with the L-C-R meter. Correlation was excellent. The capacitor can be calibrated on the bench, using your receiver, a known-value inductor and a dip meter (plus a little calculation).

I brought my transceiver to the roof with a length of coax that allowed me to reach the highest gamma-match capacitor box (10 meters) and still back away from the antenna about 10 feet or so to the rig, located on the roof. The harness of coax cables from the remote coax switch on the boom was disconnected from each driven element at the gamma-capacitor-box end.

The transceiver's S meter is used to determine nulls when adjusting for best front-to-back ratio. If you are lucky enough to have a ham friend a mile or so away, who is capable of putting out a few watts on each band of interest and, if you can turn the back of your antenna in his direction, the adjustment process is very simple. Remember, though, even a few watts can produce QRM; pick a quiet time for adjustments, and remind your buddy to identify his station during the tests.

To make the tests, simply clip the (calibrated) air-variable capacitor across the open ends of the desired reflector loop and while watching the S meter (tuned to the signal source), slowly adjust the capacitor. You'll find a *very* pronounced dip. Carefully tweak the variable capacitor for the desired front-to-back dip (or, for starters, just dip it to minimize the test signal) while observing the S meter. Do not depend on the sound from the speaker—the AGC in most receivers will keep the audio level nearly constant over a tremendous range of signal strengths.

I used an alternative method. I picked a good propagation day (and time) for the bands that the quad covers, and since the reflector pointed east when it was over my roof, I simply tuned in East Coast stations as my signal sources. Due to the nature of QSOs, this takes a bit longer, but works just fine. Either measure the calibrated capacitor, or read your home-brew calibration dial and install the fixed-capacitor equivalent across the insulator. The front-to-back adjustment for one band interacts very little with those for the other bands, but has a *big* effect on the correct gamma-match setting—both on the same band's driven element and adjacent bands' driven elements. Therefore, do *all* the front-to-back adjustments before adjusting the gamma match for each band. The adjustments can be started on any band; I started with 10 meters and worked toward 20 meters.

After completing the front-to-back adjustments, move to the driven-element adjustments. Connect the coax through an SWR bridge to the 10-meter gamma-match capacitor box. Use an SWR bridge that requires a watt or two (not more than 10 watts) for full-scale deflection in the calibrate position on 20 meters. Using the minimum necessary power, measure the SWR. Go back to receive and adjust the capacitor until (after a number of transmit/receive cycles) you find the minimum SWR. If it is too high, lengthen or shorten the gamma rod via the sliding alligator-clip short and make the measurements again.

Stand away from the antenna when making transmitter-on measurements. These adjustments have minimal effect on the previously made front-to-back settings, and may be made in any order. After making all the adjustments, reconnect your coax harness to the remote coax switch, and you are ready to roll!

Remember to take a good look at your new antenna after you climb down. It *is* beautiful, *isn't* it?!

Table 2
Measured Front-to-Back Ratios

Band	KC6T Model	W6NBH Model
14 MHz	25 dB	16 dB
18 MHz	15 dB	10 dB
21 MHz	25 dB	>20 dB
24.9 MHz	20 dB	>20 dB
28 MHz	20 dB	>20 dB

Acknowledgments

In any construction project, thanks are due for contributions from many sources, including QSOs with other antenna builders, casual conversations at club meetings, etc; important contributions are too numerous to itemize here. But I would particularly like to thank my wife, Diane, without whose patience and help with an endless supply of roof-repair goop, this project could not have been completed. Al Doig, W6NBH, provided just the right mix of gentle cajoling, encouragement and good ideas, and excellent comparative data. Thanks, Al.

Notes

[1]*MN* version 4.0 is now available from Brian Beezley, K6STI, 507½ Taylor St, Vista, CA 92084. Modeling of wire antennas can also be done using W7EL's program, *ELNEC*, available from Roy Lewallen, W7EL, PO Box 6658, Beaverton, OR 97007. Other software is also available for this application; see the advertisements in this issue for details.

[2]G. Hall, Ed, *The ARRL Antenna Compendium, Volume 1* (Newington: ARRL, 1985), pp 11-46.

[3]G. Hall, ed, *The ARRL Antenna Book*, 15th edition (Newington: ARRL, 1991), Chapter 12.

[4]P. Atkins, "Longer Life for Your Quad Antenna," Hints and Kinks, *QST*, Nov 1990, p 39.

[5]K. Wellenius and B. Wellenius, "A Light and Sturdy Quad for 10 and 15 Meters," *QST*, Jul 1991, pp 30-32.

[6]W. I. Orr and S. Cowan, *All About Quad Antennas*, third edition (Lake Bluff, IL: Radio Publications, 1988).

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