A 3½ Band Yagi

KC6T builds an elegant 10/15/20 meter triband beam, with bonus "backwards" coverage of 12 meters.

Bill Stein, KC6T

Some years ago I had a great time constructing a five band, 2 element cubical quad antenna.[1] But I have always wanted to try my hand at a competitive multiband Yagi, one that could be constructed with commonly available materials. Because of my space limitations, a 14 foot maximum boom length was placed on my list of wants, along with the ability to operate on at least 10, 15 and 20 meters. In addition, I expanded the list to include full legal-limit operation, a wide SWR bandwidth and low losses consistent with moderate antenna weight and wind loading.

The usual suspects were considered, including log-Yagi designs, the Log Periodic Dipole Array (LPDA), the traditional trapped antenna and open-sleeve designs—each having its own advantages. I modeled the antenna configurations using *EZNEC*,[2] and ended up combining features found in two basic antenna types: a trapped tribander and an open-sleeve design.

- It is a tribander, covering all of the 20 and 15 meter bands, and 1 MHz of the 10 meter band, with a wide SWR operating bandwidth, low losses and a competitive gain and front-to-back ratio.
- It also operates on 12 meters, but with a level of SWR across the band that is high enough to require a tuner. Here it also has a competitive gain and front-to-back ratio—but the pattern is *reversed*. The front for this portion of the antenna is the back of the triband portion. So I call this my "3½ band antenna."
- It weighs about 65 pounds, has a calculated wind loading (at 45° to the boom) of 121 pounds at 70 mph, and has a center of weight balance and a center of wind balance that are very close to each other.
- Boom length is 14 feet, with a turning radius of 18 feet.
- The antenna features 3 elements with a single, low-loss 15 meter trap in each element half (of the 15 and 20 meter elements), plus an open-sleeve, parasitically driven 4 element, 10 meter array—this is effectively a 3 element array as well.
- It has a single coaxial feed line, coupled to the driven element through a commercially available choke balun. It needs no feed-point matching system, such as a beta or hairpin match.
- A wide SWR operating bandwidth is achieved without trap losses usually encountered with conventional trapped antennas. More on this later.
- The number and length of the individual element parts takes into consideration that 6 foot lengths of aluminum tubing may be more economical in the quantities required.
- The antenna is shown schematically in Figure 1.

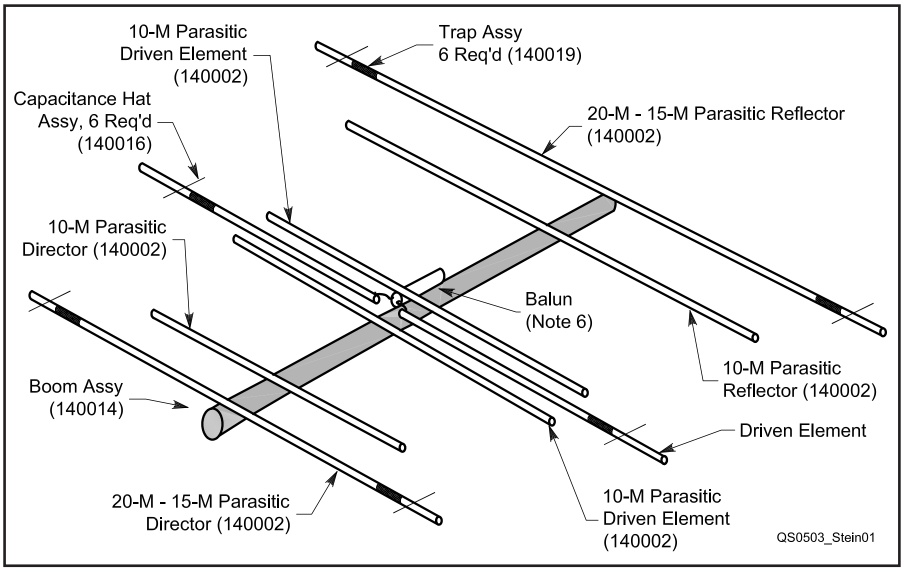


Figure 1—Schematic layout of KC6T 3½ band beam. Numbers in parentheses refer to drawings available on the ARRLWeb.[3]

Why Use Traps?

There is much discussion about lossy traps in today's ham community and about the advantages of a trapless antenna. There is an excellent selection of commercial antennas available that include arrays of 2 element antennas on a common boom, log periodic dipole arrays (LPDA), hybrid log-Yagi systems, the familiar triband trapped array and others. All choices incorporate trade-offs—whether they be mechanical sturdiness versus weight, gain versus boom length, operating SWR bandwidth versus gain bandwidth, the number of bands in a single antenna array versus other performance figures—and this antenna is no different. Traps can be lossy—but even the mechanical joints where antenna sections are joined together can be lossy, especially after some weathering. What is interesting is just how lossy a system might be and what, if anything, can be done about the losses.

With a conventional trapped triband Yagi each element half has two traps. The trap closest to the boom is a parallel L-C circuit that resonates in the 10 meter band. It acts to *disconnect* the portion of the element extending beyond the proper length for 10 meter operation. When I operate on 15 meters, the 15 meter trap

[1]Notes appear on page 37.

acts in the same way but the 10 meter trap (which is still in the circuit) acts as a loading coil, shortening the required physical length of the 15 meter section for resonance. The loading also causes the SWR bandwidth of the resulting 15 meter antenna to be somewhat narrower compared to an unloaded antenna. When I operate on 20 meters, both traps act like loading coils, resulting in more physical shortening of the required 20 meter elements and further narrowing of the SWR bandwidth on 20 meters. Trap unloaded Q has an effect on these properties, but regardless of the Q, the trade-offs tend to make the operating SWR bandwidth more limited compared to a full-size antenna system. Adding more bands by adding more parallel-resonant traps in series compounds the problem further.

This antenna uses only a single, high-Q trap in each element half for the 15 and 20 meter bands. This improves SWR bandwidth on these bands significantly, while minimizing the total losses attributable to traps. The calculated total trap losses for all six traps is about 0.1 dB, and the operating SWR bandwidth is the whole 20 meter band and most of the 15 meter band.[4,5] The 10 meter portion of the antenna is an open-sleeve driven array with no traps that yields an operating SWR bandwidth of 1 MHz.

Figure 2—The trap assembly is shown in various stages of fabrication. The mechanical components are detailed in the drawing package available on the ARRLWeb site. This photo shows the 50 pF NPO capacitor attached to its trap terminal, complete with a flexible wire. The coil form and insert are also shown. Although this particular design used a shrink-sleeve cover, the final design used two coats of gray epoxy paint instead.

Figure 3—The area around the boom-to-mast plate for the KC6T beam. The Cal-Av Labs balun is mounted under the rearward 10 meter open-sleeve driver. All elements are mounted on the boom-to-element plates using cast acrylic-insulating blocks.

Trap Construction

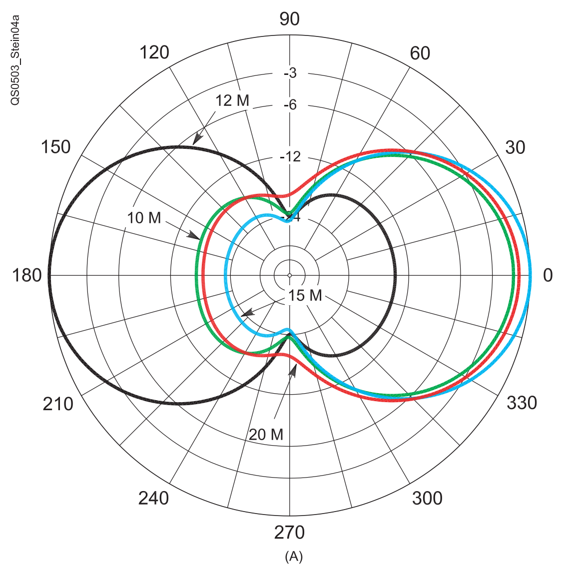
Careful attention to the step-by-step instructions will permit trap construction with a minimum of difficulty, since all six traps are identical. The completed trap consists of a 10 turn inductor[6] wound on a 3/4 inch schedule 40 PVC water pipe coil form and a parallel-connected 50 pF, 7500 V NP0 transmitting capacitor.[7] PVC is not the ideal material from which to make the coil form in terms of electrical losses, but it is readily available and more than strong enough.

Figure 2 shows a trap assembly in various phases of construction. In this early model I used shrink sleeving over the completed assembly, but this was not included for the final design. Heat from the shrinking operation caused the PVC to take a slight set, resulting in loosened electrical connections.

A complete set of fabrication drawings for this antenna can be downloaded from the ARRLWeb.[8] Preparation of the PVC forms and other trap components is detailed in these drawings. The basic idea is to make the coil form from 3/4 inch PVC and the inserts from 1/2 inch PVC. The inserts are split axially with a single-width hacksaw blade, then placed in a fixture and drilled for 5/8 inch ID holes. The fixture is simply a 3/4 inch diameter piece of PVC that is also split axially with a single-width hacksaw blade cut and then held together with a pair of hose clamps until the insert has been drilled.

After you have fabricated the trap components, start construction by assembling the transmitting capacitor to the trap terminal/capacitor mount. Attach a flexible multi-strand copper lead, about 8 inches long, to the second capacitor terminal. Next, install one of the coil-form inserts into the end of the coil form that has a single hole through the sidewall. Press the coil form in until it is flush with the end of the coil form. Insert the capacitor/terminal tube assembly into the opposite end of the coil form, terminal tube first. Gently press the assembly terminal tube through the installed coil form insert until the terminal tube extends beyond the coil form by 2 1/2 inches. Do not force the terminal through the insert, since damage to the capacitor may result. If required, redrill the bore of the installed insert until the capacitor terminal tube can be inserted with moderate pressure. Feed the capacitor flexible wire lead through the inside hole at the open end of the coil form.

Now install the remaining coil form insert into the open end of the coil form and press in the plain terminal tube until it extends beyond the coil form by 2 1/2 inches. Using 5 minute epoxy and a small screwdriver, apply the glue to the aluminum reinforcement pieces and insert them until they are flush with the inside end of the terminal tubes. Allow the glue to set. Using the end holes in the coil form as a guide, drill the appropriate size hole through the coil form insert, the terminal tube and the reinforcement tube. This gives a screw on each end of the coil form to electrically connect the terminal tubes, the capacitor and the coil. A #8 pan-head self-tapping screw could be used, although I prefer to use #8-32 stainless-steel machine



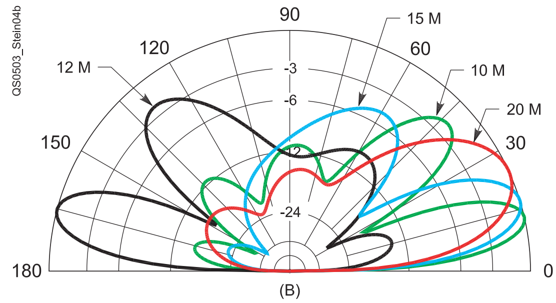


Figure 4—At A, azimuth plots for the four frequency bands covered by the KC6T beam. The response for the 12 meter band is reversed compared to the 10/15/20 meter bands. At B, elevation plots for the same bands at a height of 37 feet above flat ground.

screws and washers, requiring me to use the correct size drill and tap. These screws also act to secure the terminal tubes to the coil form assembly.

Form an "eye" in one end of the coil wire and attach to the terminal screw on the capacitor side of the coil form. Carefully route the first turn to provide for the main body of coil turns to be away from the internal capacitor body. Wind 10 turns as evenly as possible, forming another eye to terminate the coil on the opposite end of the coil form. Trim off excess length from the flexible wire from the internal capacitor and attach a terminal lug. Attach the lug to the adjacent coil terminal.

Using a grid dip oscillator, carefully adjust the trap windings until the assemblies resonate between 21.175 and 21.200 MHz. This is done by either squeezing or prying apart the coil turns as evenly as possible. In this process, a coil should be as far removed from metallic working surfaces or other electrical components as possible. Make sure that the coil forms and coils are free of grease and dirt. Then use masking tape to cover the exposed trap terminals. Paint the assemblies with two coats of epoxy spray paint, allowing the first coat to dry thoroughly before applying the second. Remove the masking tape when the trap assemblies are completely dry.

When installing the trap assemblies to their respective elements, the screw terminals should be oriented toward the ground (facing down). The end of the coil form through which the capacitor flexible wire protrudes should also be oriented toward the antenna element tip. This arrangement provides a convenient drain for any moisture that might appear inside the trap coil form.

Remaining Antenna Components

I made the boom-to-mast plate from a T-6061 $^{5}/_{16}$ inch thick aluminum blank, $17^{3}/_{4}$ inches long by 9 inches wide. It is a complex part because the center of weight and wind load is where the driven element and the close-spaced 10 meter parasitic driven elements are all located. This plate does not permit the mast to extend above the boom of the antenna. See Figure 3 for a close-up of the center of the boom.

All U bolts are 2 inch by $^{5}/_{16}$ inch. I fabricated and installed a pair of metal strips for each boom-to element plate as insurance that they will remain aligned perpendicular to the boom, even though this was probably overkill.

I made the element-support insulators from cast acrylic material that has a UV inhibitor. Figure 3 shows how each element is supported on an insulator. Notice how the balun[9] is fitted underneath the rear 10 meter parasitic driven element. The insulators are attached to the element-to-boom plates with #10-32 stainless-steel screws, as are the elements attached to the insulators.

A generous amount of overlap between the telescoping aluminum tubes is used for mechanical strength. The trapped driven element is split at the center for the antenna feed point. An insulating coupler is inserted inside the two halves. I used a fiberglass tube but you could also use a solid acrylic plastic rod with a 1 inch OD. The two center holes (#18 drill through) are provided for two #8-32 stainless-steel machine screws, nuts and washers to connect the two feed wires from the balun.

The center sections of the parasitic elements are reinforced with smaller OD aluminum tubing, as is the center of the boom. Reinforcement pieces ("BE" in the drawing package) provide added strength to the boom wall where the four outer elements are attached. An additional 8 inches of 2 inch OD tubing will be required to make the four pieces needed.

All boom-to-element support plates are made from $^{3}/_{8}$ inch thick, 2 inch wide 6061-T6 aluminum. A different boom-to-element plate is used for the trapped driven element, while the remaining six elements use the same design for their plates.

The two outer boom sections are each attached to the boom's center section with a $^{1}/_{4}$-20 stainless-steel machine bolt, lock washer and nut. After placing the two internal boom reinforcement sections ("BE"), drill a small hole through the outer boom section and reinforcement, add a small sheet-metal screw to hold each of the reinforcement sections in place during assembly of the boom to the boom-to-mast plate.

I used a capacitance-hat assembly shown in the drawing package. An even simpler capacitance hat is also suggested in that package. The design of the balun mount depends on the balun you choose to use. To keep feed lines short at the attachment point to the trapped driven element, choose a balun that will fit along the top of the boom. Mine was mounted underneath the rearmost 10 meter parasitic driven element.

Buying the Aluminum Tubing

The required quantity of tubing de-

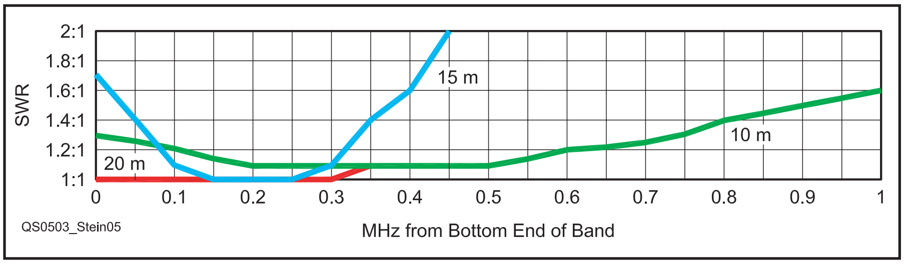


Figure 5—Measured SWR plots across the 10/15/20 meter bands at a height of 37 feet.

pends on the number of antennas being fabricated but also on the available lengths of each piece. In general, longer tubing lengths will result in less scrap. But shipping costs and minimum-order requirements may more than offset any scrap material savings. Six-foot lengths of tubing can be shipped for modest cost by UPS. I chose to buy tubing in these lengths as a reasonable trade-off between (large) minimum quantities, shipping costs and tubing prices.[10]

Antenna Assembly

When you assemble each element, remember to use conductive compound at all the tubing interfaces. The trap assemblies are inserted in the appropriate element section until the trap body is flush against the mating antenna element sections. Place the capacitance-hat assemblies on the ends of the trapped elements where shown.

The boom center section (2 inch diameter by 72 inches long) has internal reinforcement pieces ("BC"). Note that these are *not* placed in the center of the 2 inch diameter center portion of the boom. Assemble the element insulators to the element-to-boom plates and then mount the elements to their respective element plates. Then install the completed element assemblies to the boom. Install the boom-to-element plate reinforcement parts ("BE"). These help keep the boom from being crushed by the element plate-to-boom U bolts. Assemble the boom-to-mast clamp to the boom and double-check the element-to-element spacings. Finally, install the balun to the boom such that the balun body passes under the rear 10 meter parasitic driver. Connect the short balun leads to each side of the split driven element.

Antenna Adjustment

Figure 5 shows the measured SWR curves across the frequency bands covered. This shows a slightly narrower SWR operating bandwidth for the 15 meter band than the computer model, but the 20 and 10 meter SWR data are in close agreement with the calculated values. The 12 meter SWR performance shows the need for an antenna tuner. Most transceiver tuners will do an adequate job.

If you wish to move the frequency at which the lowest SWR occurs, you may do so, using the information in the drawing package. Because the 10 meter portion of this antenna is parasitically driven, changes in the lengths of both the 15 and 20 meter elements will have minimal effect on the 10 meter performance. But changes to the 15 meter section will affect the SWR characteristics of the 20 meter section.

Calculated azimuth and elevation patterns are shown in Figure 5. The performance of the Yagi on 12 meters is quite respectable, even though the forward direction is off the backside of the antenna.

On 10 meters the spacing between the trapped driven element and the two 10 meter open-sleeve driven elements is quite sensitive. The SWR on 10 meters can be shifted to another frequency by altering the length of the two 10 meter parasitic driven elements equally, and altering the 10 meter director and reflector proportionally. For example, the lengths of each 10 meter element half-length are:

- Parasitic reflector: 111 inches
- Parasitic driven: 100 inches
- Parasitic director: 96 inches

If you decide to shorten the driven element by 1 inch (99/100 = 99% of the original length):

- New parasitic reflector: 0.99 × 111 inches = 110 inches
- New parasitic driven: 99 inches
- New parasitic director: 0.99 × 96 inches = 95 inches

The SWR characteristics for the 15 meter band can be shifted in frequency by the same means suggested for 10 meters. A shift in the SWR characteristics for 20 meters section can best be accomplished for small changes by changing each of the 20 meter element lengths after the trap by the same length. Thus if you shorten each tip of the 20 meter driven element by 1 inch, you should also shorten each tip of the 20 meter reflector and director by 1 inch.

The Final Installation

I mounted my antenna at 37 feet, using a guyed tubular crank-up tower—a vintage Tristao model. You may find this antenna to be a mechanical challenge to fabricate, but for your efforts you will be rewarded with electrical stability and good performance. So far my antenna has been in place over 3 years. It has survived a 75 mph windstorm and has worked some DX toughies. It has not shown any changes in its SWR characteristics.

Acknowledgments

My thanks to the many ham antenna enthusiasts and experimenters I have contacted, each willing to exchange their views and antenna experiences during many enjoyable QSOs. My special thanks to my wife, Diane, who encouraged me to design and build this antenna. She put up with a huge number of hours spent over a hot computer and a similarly large number of hours spent fabricating and installing this beauty on my tower.

Notes

[1]"A Five-Band, Two Element Quad for 20 through 10 Meters," W. Stein, *QST*, Apr 1992, p 52.

[2]*EZNEC 3.0*, Roy Lewallen, W7EL, PO Box 6658, Beaverton, OR 97007; **www.eznec.com**.

[3]See **www.arrl.org/files/qst-binaries/stein_yagi.zip**.

[4]See Note 2.

[5]*Reference Data for Radio Engineers*, Howard W. Sams & Co., 6th edition, 1975, pp 6-4 to 6-8.

[6]#8 solid aluminum ground wire is available in 40 foot lengths from RadioShack, catalog no.15-035.

[7]Available from Surplus Sales of Nebraska, 1502 Jones St, Omaha, NE 68102. Their Web site is **www.surplussales.com**.

[8]See Note 3.

[9]The balun I used was a Model EB-1, manufactured by CAL-AV Labs Inc, 1802 W Grant Rd, #116, Tucson, AZ 85745, purchased at HRO.

[10]I purchased aluminum tubing in 6 foot lengths from Texas Towers, 1108 Summit Ave #4, Plano, TX 75074.

Photos by the author.

Bill Stein, KC6T, was first licensed in 1954, and enjoys both ragchewing and chasing DX, operating CW, SSB and PSK31. He is an active designer and homebrewer, having built not only antennas, but also a microcontroller based SWR/power meter, a solid-state audio record/playback device integrated with his HF transceiver, and the usual solid-state keyer projects. He is especially fond of restoring and operating vintage ham equipment. Bill received his BSE from UCLA in 1958, and spent most of his career working in the computer peripherals field. For the last 7 years, Bill has been self-employed as a consultant to management and is involved with industrial electronic products. You can reach the author at **steinwa@earthlink.net**.