A Short Boom, Wideband 3 Element Yagi for 6 Meters

L. B. shows us how to craft an easy to reproduce 6 meter Yagi that covers the whole band.

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Although there are many 2 and 3 element Yagi designs for 6 meters, few do justice to the needs of the FM operator who requires some gain and directivity from 51 to 54 MHz. The 3 element design described here will actually cover the entire 6 meter band (a bandwidth of about 7.7%) with reasonable performance and a 50 Ω SWR of less than 2:1. The short 3 foot boom is a further attraction. Figure 1 is a photograph of a completed Yagi mounted on a PVC test mast.

Beam Design and User Expectations

Evaluating a beam design requires an appreciation of three ingredients: your needs on a particular band, general beam antenna behavior and reasonable expectations to have of a beam once installed. Your requirements for a beam on 6 meters change depending on your operating goals. If you only use CW, SSB or digital modes, then you tend to operate in the lowest MHz of the band and can use a beam with a narrow operating bandwidth. If you wish to use FM and want some directivity, however, then you need a wideband design with good performance from 51 to 54 MHz.

Moreover, the beam should be vertically polarized, which normally translates into a beam with vertically oriented elements. FM activity generally relies on point-to-point signal paths. Cross polarization of the sending and receiving antennas may result in weak signals or no signals at all. As shown in Figure 1, the present antenna is designed for broadband 6 meter service using vertically oriented elements.

Older designs for a truly wideband Yagi depend on the spacing between the driver and the reflector elements to obtain their broad coverage. The wider spacing produces a beneficial side effect — it raises the feed-point impedance to about 50 Ω so that the user can make a direct connection between the feed line and the antenna without needing to add a matching network. However, these designs carry a penalty. The lower gain 2 element driver-reflector Yagi needs a 3.5 foot boom, while the higher gain 3 element Yagi's boom is over 6 feet long. The design here has three elements, but uses a boom less than 36 inches long. Figure 2 shows its outline, while Figure 3 is a photo of the prototype beam.

To obtain higher gain and a shorter boom, you might turn to a driver-director Yagi design. Unfortunately, these designs have quite low feed-point impedances and very narrow operating bandwidths. Broadening the operating bandwidth of a driver-director design involves redesigning the driver, using two elements with a simple phase line between them. Now you have a beam that competes with the 3 element standard Yagi, but does so on a much shorter boom.

A driver-director design (in fact, any Yagi with one or more directors) has another advantage over the 2 element driver-reflector Yagi if you consider your needs on the band. A driver-reflector Yagi shows its highest gain

Figure 1 — The prototype 3 element wideband phase-fed Yagi on the test mast. Note that this mast is nonconductive to avoid interactions with the nearby driver elements.

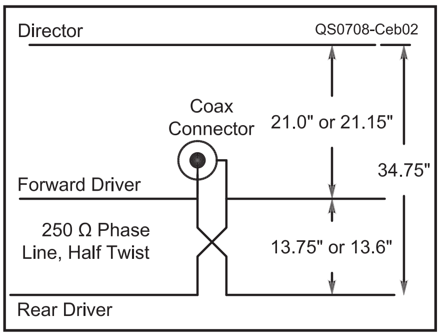

Figure 2 — General outline of the 3 element wideband short-boom Yagi for 6 meters.

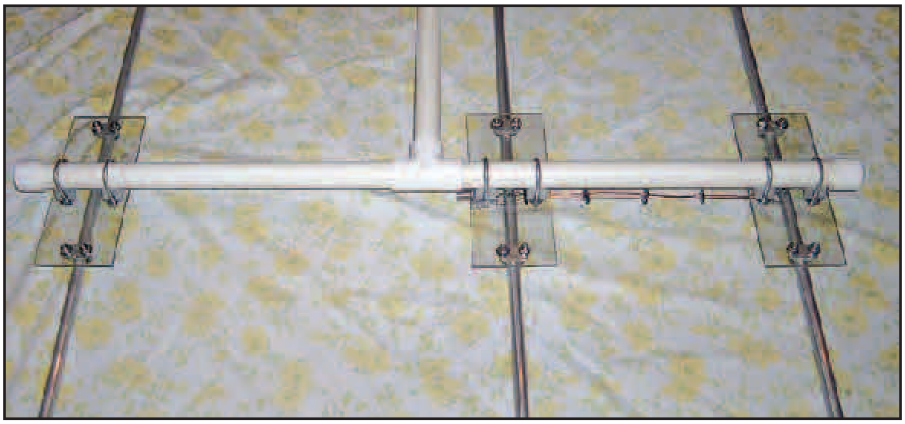

Figure 3 — Photo of the entire central beam structure, including the PVC boom and mast stub.

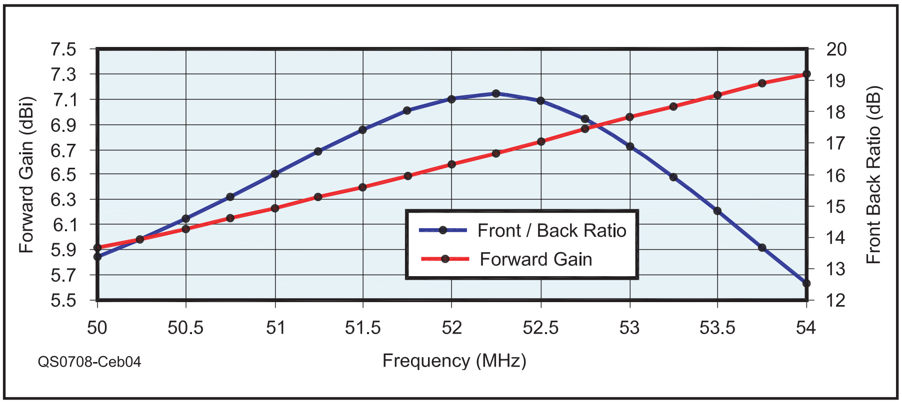

Figure 4 — Modeled free space gain and 180° front-to-back ratio of the 3 element wideband short-boom Yagi for 6 meters.

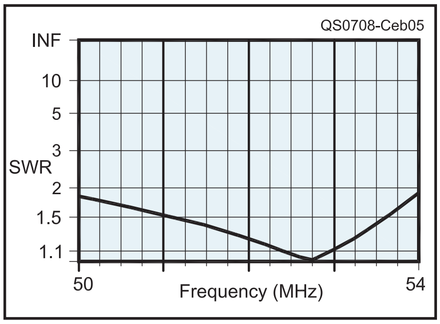

Figure 5 — Modeled 50 Ω SWR curve for the prototype 3 element wideband short-boom Yagi for 6 meters. The array requires no matching network and uses ⅝-½ inch elements with bare wire phase line. The measured SWR was identical to the modeled SWR.

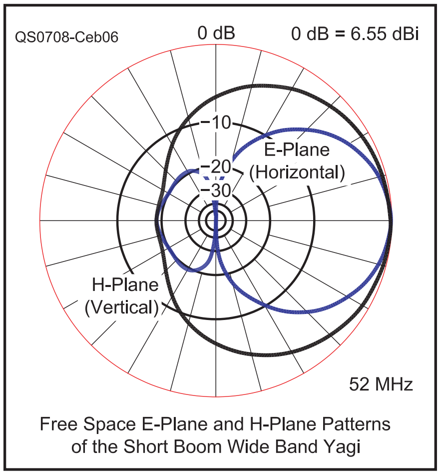

Figure 6 — Free-space E-plane (horizontal) and H-plane (vertical) patterns for the 3 element wideband short-boom Yagi at 52 MHz.

Table 1
Dimensions of the Yagi for Different Construction Methods

Tapered-Element Version Using 0.625"/0.5" Elements; 250 Ω (Open Wire) Parallel Phase Line

0.625" Inner Sections = 24" Each Side of Center or 48" Total; Add 2" to Tip Lengths for Insertion

Element	*Total Length*	*Tip (0.5") Length*	*Spacing from Rear Element*
Rear Driver	110"	31"	—
Forward Driver	103.5"	27.75"	13.75"
Director	101"	26.5"	34.75"

Tapered-Element Version Using 0.625"/0.5" Elements; 250 Ω RG-63 Phase Line

0.625" Inner Sections = 24" Each Side of Center or 48" Total; Add 2" to Tip Lengths for Insertion

Element	*Total Length*	*Tip (0.5") Length*	*Spacing from Rear Element*
Rear Driver	108.5"	30.25"	—
Forward Driver	104"	28"	13.75"
Director	101"	27"	34.75"

Uniform-Element Version Using 0.5" Elements; 250 Ω (Open Wire) Parallel Phase Line

Element	*Total Length*	*Spacing from Rear Element*
Rear Driver	108.9"	—
Forward Driver	102.6"	13.6"
Director	99.8"	34.75"

Tapered-Element Version Using 0.5"/0.375" Elements; 250 Ω (Open Wire) Parallel Phase Line

0.5" Inner Sections = 24" Each Side of Center or 48" Total; Add 2" to Tip Lengths for Insertion

Element	*Total Length*	*Tip (0.375") Length*	*Spacing from Rear Element*
Rear Driver	111"	31.5"	—
Forward Driver	104.6"	28.3"	13.6"
Director	102"	27"	34.75"

Tapered-Element Version Using 0.5"/0.375" Elements; 250 Ω RG-63 Phase Line

0.5" Inner Sections = 24" Each Side of Center or 48" Total; Add 2" to Tip Lengths for Insertion

Element	*Total Length*	*Tip (0.375") Length*	*Spacing from Rear Element*
Rear Driver	109"	30.5"	—
Forward Driver	105"	28.5"	13.6"
Director	102"	27"	34.75"

at the low end of the band, with decreasing gain as you increase the frequency. Figure 4 shows the modeled performance of the prototype antenna from 50 to 54 MHz. Like a longer standard 3 element Yagi, the gain shows a rising curve so that we have maximum gain in the FM section of the band. The graph also shows the anticipated front-to-back performance, which varies from nearly 13 dB at the band edges to a peak value of over 18 dB.

The final critical operating parameter is the 50 Ω SWR across the band. The present design requires no additional matching network. Instead, it connects directly to a 50 Ω transmission line (although I always recommend the use of a common-mode current attenuator, such as a ferrite bead choke or a 1:1 balun at the feed-point). Figure 5 shows the modeled SWR curve for the entire 6 meter band. (The test antenna curve overlaps the modeled curve too closely to justify a second line on the graph.)

Newer amateurs who read *QST* often get a wrong impression of Yagi patterns, because almost all beam patterns for HF appear with the elements horizontal (or in the E-plane). E-plane patterns differ from H-plane patterns (when the elements are vertical). Figure 6 overlays the E-plane and H-plane free-space patterns of the phased-driver design at 52 MHz to show the difference. The E-plane pattern shows a limited beamwidth and very deep nulls 90° from the axis of maximum forward gain. The H-plane pattern has the same forward and rearward gain maximums, but has a much broader beamwidth and no side nulls at all. The H-plane pattern generally represents the azimuth pattern that we should expect from a vertically oriented Yagi. Because the beamwidth is so great, the forward gain of a vertical beam over ground will be less than the forward gain of a horizontal Yagi at the same height. However, the gain of each beam over a similarly oriented dipole will be just about the same (a bit over 4 dB).

Design and Construction of the 3-Element Broad-Band Short-Boom Beam

The Boom

The 3 element short boom wideband Yagi consists of two elements that serve as a phased pair of drivers. Forward of the driver pair is a single director element. All versions of the beam have a total length of 34.75 inches from the center of the rear element to the center of the director. Therefore, you need a boom that is perhaps 38 to 40 inches long, depending upon your construction methods. An aluminum tube and a schedule-40 PVC 1 inch nominal tube are equally effective, since we shall insulate and isolate our elements from the boom with mounting plates. The prototype employed a PVC-pipe boom with a T connector for the boom-to-mast connection. The stub slips inside my main test mast, which uses 1¼ inch nominal PVC.

Element Dimensions

Table 1 lists five separate sets of dimensions for the beam, since amateurs generally have access to different material stocks. The first two sets use ⅝ inch diameter inner sections with ½ inch outer or tip sections. The middle set uses uniform-diameter ½ inch tubes throughout. The final two dimension sets use ½ inch inner sections with ⅜ inch diameter tips. The prototype in the photos uses the first set of dimensions. However, the only change in performance among the dimensions is that the fattest elements provide a very slight improvement in the SWR curve at the band edges.

Table 1 illustrates two important facts for newer beam builders. First, small design changes, such as a change in the phase line structure or a change in element diameter, can alter beam performance enough to

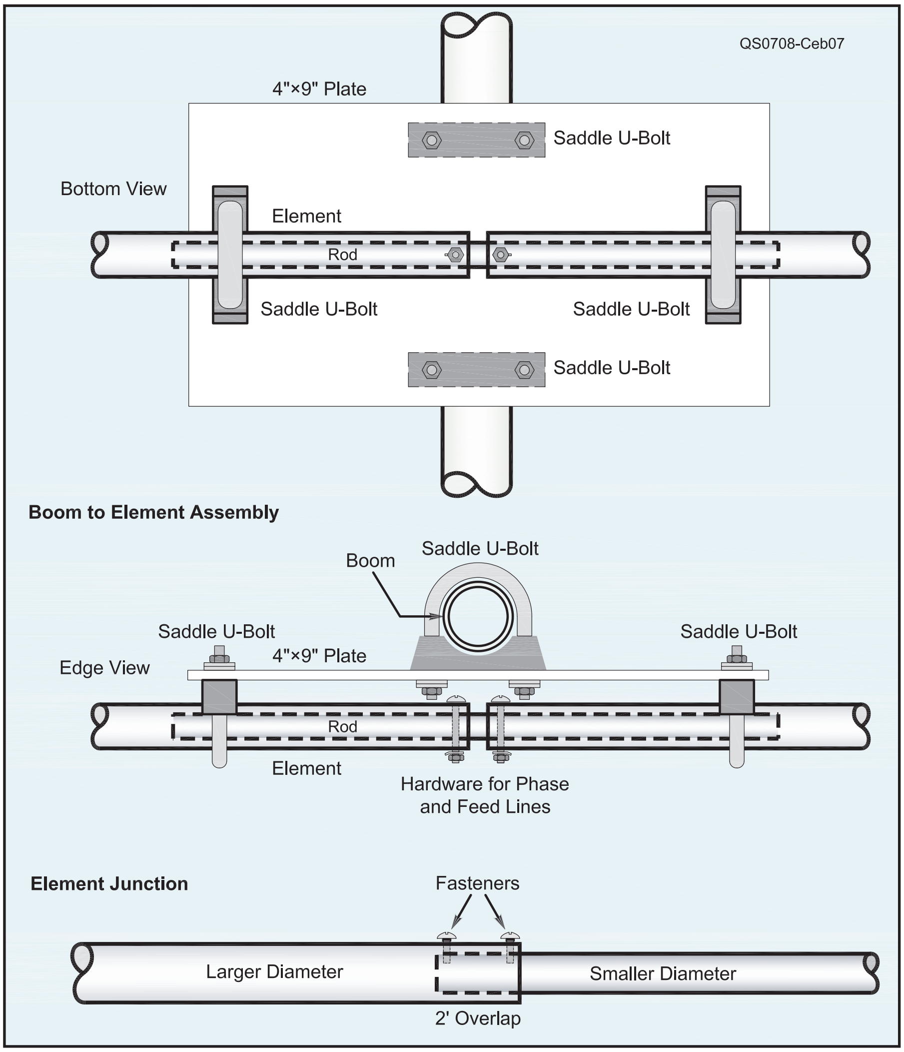

Figure 7 — Some construction details for the prototype array, including the junction of element sections and the element to boom plate assembly. The sketches apply to driver elements; omit the gap for the director.

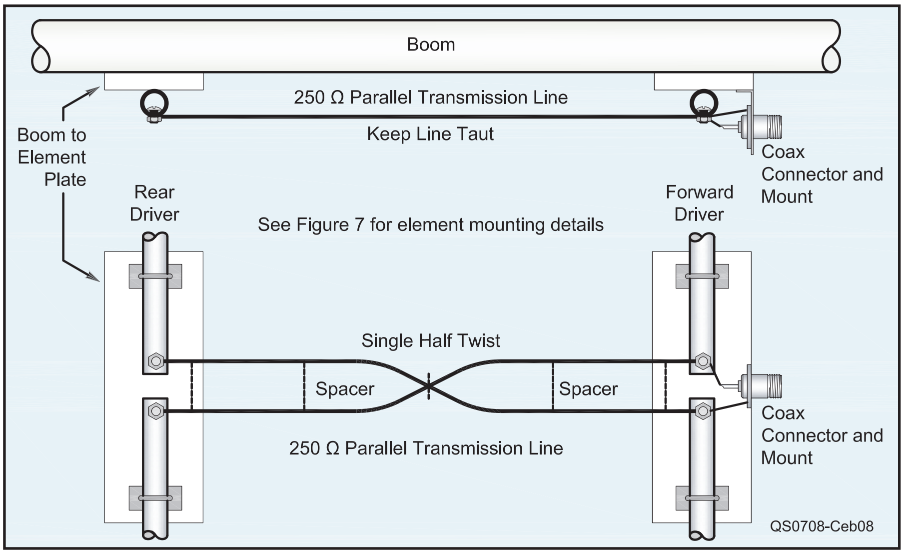

Figure 8 — The basic structure of the array feed-point and the phase lines. Except for the spacers, the same structure applies to the use of RG-63 cables for the phase lines.

require a complete redesign of the element lengths. (Element spacing is usually less critical.) Second, tapered element diameters require added length to be electrically equivalent to uniform diameter elements, even if the average diameter of the tapered element is larger than the diameter of the uniform element. Changing just the lengths of inner and tip sections can require an adjustment to the total element length for equivalent electrical performance.

If you use one of the tapered-diameter schedules, add about 2 inches to the tip lengths shown in Table 1 for insertion into the inner element section. See the bottom of Figure 7 for a typical junction. Sheet metal screws or aircraft rated rivets are among the most useful fasteners to ensure long term contact between element sections. I prefer high-quality 6063-T832 drawn aluminum tubing, available from Texas Towers and similar sources, since it is available in outer diameter increments of ⅛ inch in the US. The 0.058 inch wall thickness (just under 1⁄16 inch) allows a smooth fit but a tight joint.

Element-to-Boom Mounting

For the element-to-boom junctions, I prefer to use ¼ inch thick polycarbonate plates. For 6 meters, 9 by 4 inch plates are more than large enough. As shown in Figure 7, the chief fasteners are U-bolts with saddles, available from DX Engineering, as one source. I use saddles to prevent the U-bolt from crushing the element and to provide a space between the element and the plate. For the driver elements, you need additional hardware to handle the phase lines. The element U-bolts have a spacing of ¾ inches, while the boom U-bolts are around 1 inch to 1¼ inch tubes. Like all of the hardware (including lock washers) in the beam, the U-bolts are stainless steel.

The sketch shows a gap between element halves for each driver. The feed line and the phase line connect to each side of the gap. The exact size of the gap is not critical, although very close spacing will help keep the phase lines properly spaced. The gap is part of the overall element length and not in addition to it. To keep the element halves aligned with only two U-bolts at the plate ends, I used a length of ½ inch diameter fiberglass rod, the length of the plate, inserted into the ⅝ inch inner element sections. Almost any ½ inch diameter non-conductive rod or stiff tubing will do, although wood is susceptible to moisture.

For the director, you may use either of two mounting methods. If you do not over tighten the U-bolts, you may use a single 48 inch length of tubing for the inner element section. If you wish to guard against crushing, you can use two 24 inch lengths with an insert of

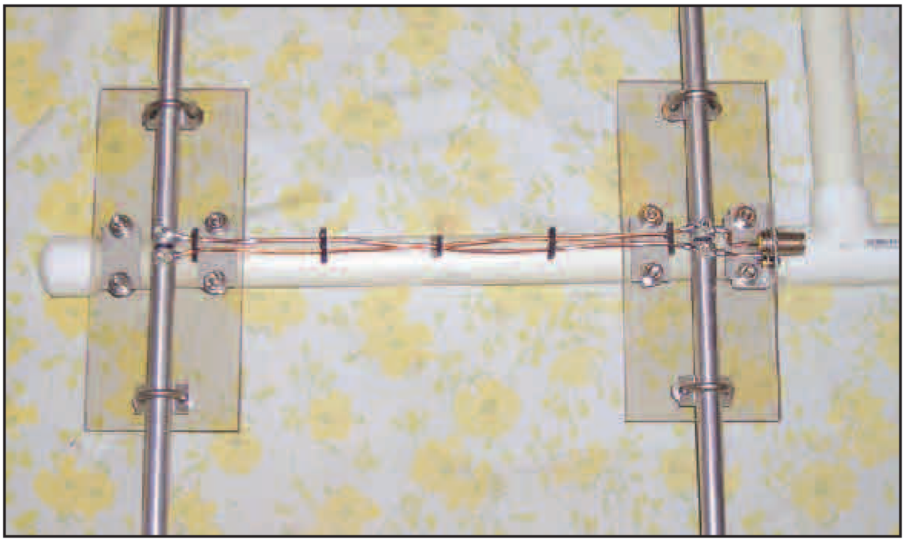

Figure 9 — A close-up photo of the phase line and driver assembly. Note the half twist in the line and the periodic spacers.

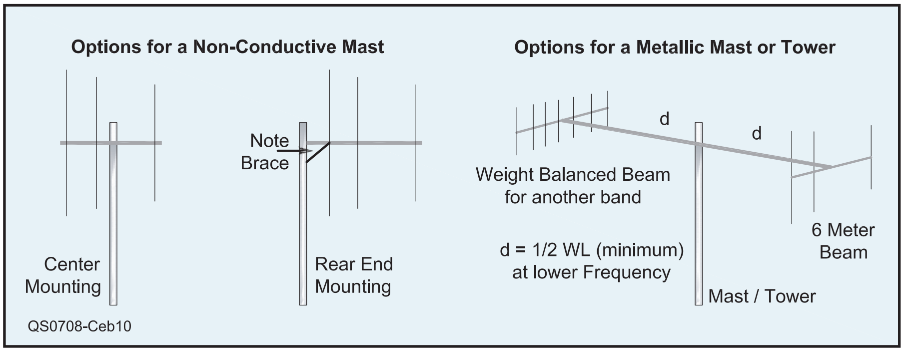

Figure 10 — Some mounting options for the 3 element wideband short-boom Yagi for 6 meters.

Table 2
250 Ω Open Wire Transmission Line Dimensions

AWG Wire Size	*Wire Diameter*	*Center-to-Center Spacing*
#14	0.0641"	0.262"
#12	0.0808"	0.330"
#10	0.1019"	0.416"
#8	0.1285"	0.525"

the next smaller aluminum tubing size that is as long as the plate. Sheet metal screws work well to ensure continuity in the element.

The Phase Lines

Since you need only 13.75 inches of phase-line (plus a bit extra for connections to the elements), you likely should make your own. Table 2 lists the center-to-center spacing for 250 Ω lines using common bare copper wire, arranged by AWG size. You will need spacers about every 3 inches to maintain the wire spacing accurately. The best way to make spacers is to drill the wire holes in a long strip of polycarbonate, Plexiglas or similar plastic. Cut the spacers to size after you complete the drilling. Do not make the holes too large; you want a tight fit. A drop of superglue at each hole will lock the spacers in place. The velocity factor of this phase line will be very close to 1.0.

I do not recommend using 300 Ω TV twinlead as the phase line. Even high quality 300 Ω line has a velocity factor of about 0.8 to go with its characteristic impedance that is already 20% higher than optimal. Using a taut line will make the TV phase line about 25% longer electrically than the value needed to create the right conditions for the drivers to operate well. Two elements with a phase line use a fairly critical combination of element dimensions and spacing — along with equally critical values of phase-line characteristic impedance and electrical length — to get the job done. This involves dividing the current at the feed point so that each driver element receives the correct current magnitude and phase angle for maximum gain from the pair (in the presence of the director element) — while yielding a 50 Ω feed-point impedance.

There is an alternative way to construct the phase-line. RG-63 coax (available from such sources as The Wireman, **thewireman.com**) has a characteristic impedance of 125 Ω. Cut two 13.75 inch sections. At each end, solder the braids together and tape them to prevent contact with the elements. You then use only the center conductors to make the phase-line connections (with the single half-twist, of course). The line now forms a series-connected dual coax cable with an impedance of 250 Ω. Since RG-63 has a velocity factor of 0.84, you must adjust the lengths of the two driver elements to compensate. In Table 1, you will find alternative dimensions for both the ⅝-½ inch and the ½-⅜ inch versions of the array. These variations on the design produce performance that is indistinguishable from the versions that use bare wire phase lines.

Figure 8 shows the connection scheme for the phase lines and the feed point. I used #8 bolts and nuts through each driver at the gap, along with ring solder lugs to fasten the phase line between doubled nuts on the bolts. Very short leads go from the forward driver connections to a coax connector mounted on a small plate that I fastened to the element mounting plate. Once I completed all final adjustments, I coated all exposed connections with one of the liquid plastics that substitutes for electrical tape. The close-up photo in Figure 9 of the phase line structure was taken before I weather-sealed the connections.

The Boom-to-Mast Connection

Although the prototype uses a PVC boom and mast, standard 1 inch or 1¼ inch aluminum tube is also suitable as a boom material. However, to minimize the metallic mass in the immediate vicinity of the forward driver, I recommend a polycarbonate plate with stainless steel U-bolts to fasten the boom to the mast. Figure 10 shows some alternative methods of mounting the beam. The two sketches at the left apply to non-conductive masts that extend at least a small distance below the tip of the lower element halves. Rear end mounting is feasible, since the beam is relatively light. However, a 45° brace is necessary to reduce boom sag.

The sketch at the right of Figure 10 shows an alternative that allows the use of a metal cross boom that is at right angles to the elements. If you have a beam for another band that is weight-balanced with the 6 meter beam, you can set up the dual mounting scheme by allowing enough room between the beams. I recommend a total starting distance of 1 λ at the lower frequency. You can then shorten the distance in small increments while maintaining proper weight distribution until you begin to notice interactions. Some pattern distortions may occur before you encounter disturbances to the feed-point impedance.

Adjustment and Performance

The beam design emerged from *NEC* software with the Leeson corrections enabled to accurately account for the tapered diameter elements on most versions of the array.[1] I tried to be as careful in the shop as at the computer. Consequently, the test version of the antenna required no post-construction adjustments. Indeed, the measured SWR curve is so close to the modeled version that I checked it several times to ensure that I was not wishfully seeing numbers that did not exist. The predicted SWR minimum occurs at about 52.75 MHz, while the prototype showed the lowest value at 52.8 MHz (give or take the tolerances of my test meters). If your minimum SWR point is lower in frequency, extend the tips of both drivers in ⅛ inch increments. If the minimum frequency is too high, shorten the driver tips in the same manner. The director, if properly constructed, should not need adjustment. Also be certain that you do not have too much metal in the boom to mast plate and that it is not too close to the forward driver. The prototype's all PVC boom and mast stub, coupled with the PVC upper section of the test mast, eliminated this concern.

The beam appears to perform just as expected, with significant forward gain (about 4 dB) over a vertical dipole (at the same height) and good rearward quieting. A gain of 4 dB can make the difference between signals that fall below or rise above the FM threshold of reception. The present design is perhaps the smallest Yagi of which I am aware that provides this level of performance.

In fact, the design is adaptable to other frequency bands that need good performance over a wide operating bandwidth. The first MHz of 10 meters and the entire 40 meter band are two such examples. Although a 40 meter version falls outside the limits of my shop and test facilities, I'll bet that I can build a horizontal version for 10 meter use in time for the new sunspot cycle.

[1] *EZNEC* models for all five versions of the array in Table 1 are available at the ARRL Web site at **www.arrl.org/files/qst-binaries/Cebik0807.zip**.

*Licensed since 1954, L. B. Cebik, W4RNL, is a prolific writer on the subject of antennas. Since retiring from teaching at the University of Tennessee, LB has hosted a Web site (***www.cebik.com***) discussing antennas — both theoretical and practical. He has written more than 15 books, including the ARRL course on antenna modeling. Serving both as a technical and an educational ARRL advisor, he's also been inducted into both the QRP and QCWA Halls of Fame. LB can be reached at 1434 High Mesa Dr, Knoxville, TN 37938 or at* **cebik@cebik.com**.