A Short Boom, Wideband, Three Element Yagi for 10 Meters

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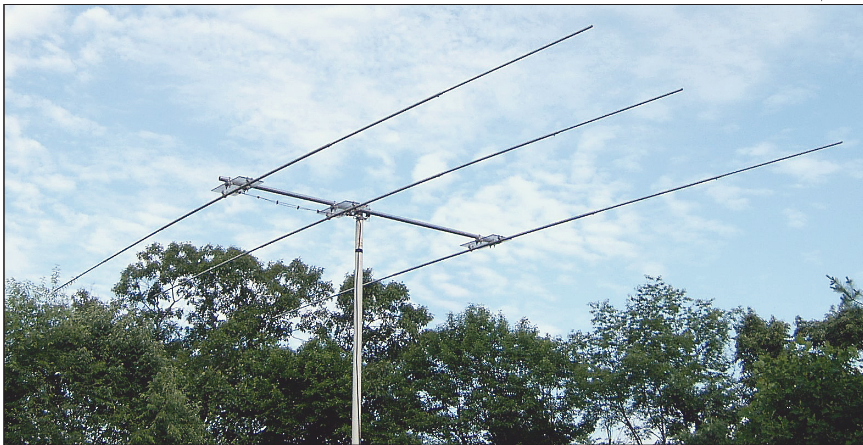

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Although there are many two and three element Yagi designs for 10 meters, most cover much less than the full band. For this Yagi, I set four requirements:

- The beam must show less than 1.5:1 SWR from 28 to 29 MHz.
- The driven element must use a direct 50 Ω feed with no matching network, such as a gamma or beta match, required.
- The antenna should have the shortest feasible boom length and turning radius.[1]
- Finally, the beam may require careful but not finicky construction.

When we combine all of these requirements, some of which are admittedly just builder/operator preferences, we find only a few candidates.

Traditional Yagi designs that are worth considering have been around since the 1980s. If we check the 10 meter performance of these antennas, we have a basis for comparison.

A normal wideband two element reflector-driver Yagi is about 5.5 feet long. The beam manages about 6.0 dBi free-space gain across the band with only 10 to 12 dB front-to-back ratio (F/B).

A wideband three element Yagi with a direct 50 Ω feed point is close to 11.5 feet long. It provides about 7.1 dBi free-space gain and averages about 20 to 21 dB F/B across the band.

Now suppose that we could find a way to achieve about 6.7 dBi gain with about 16 or 17 dB F/B and still keep the beam only 5.5 feet long. That beam would be worth at least a second look. The proposed design consists of a three element beam, but instead of the usual reflector, driven element and director configuration, it uses a close spaced dual driven element and a single director.

The differences among the beams amount to more than numbers. Figure 1 overlays the free-space E-plane (azimuth) patterns for the three antennas. The weaker gain of the two element design shows up almost as clearly as the poorer F/B. The gain deficit of the proposed design is far less evident. As well, even though the worst case F/B of the proposed design is a bit weaker, the average F/B is not too dissimilar from the rear pattern of the standard longer-boom three element Yagi.

[1]Notes appear on page 32.

The proposed design shares a possibly significant property with the standard three element Yagi. Both use directors and therefore show a rising gain value as we increase frequency across the band. As shown in Figure 2, this characteristic contrasts sharply with the descending gain curve of the standard driver-reflector two element Yagi.

All three small Yagi designs share a common trait — they cover the first MHz of 10 meters with less than 1.4:1 SWR. They all provide for a direct connection to a 50 Ω coaxial cable with no matching network (although a common-mode current balun is always a good idea). In fact, if we reset the element lengths for a slightly higher frequency (about 28.9 MHz), the beams will cover all of 10 meters (28-29.7 MHz) with less than 2:1 50 Ω SWR.

The Short-Boom Wideband Phase-Driven Three Element Yagi

The performance improvement over a standard two element wideband Yagi with the same boom length comes at a price — an extra element and a phase line. If we were working with a 40 meter Yagi, the third element would add a considerable load on the mast and rotator. At 10 meters, however, elements are much lighter. So a third element does not come close to stressing any part of the support system. The array that we are exploring has two driver elements spaced 25 inches apart with a single director 39 inches forward of the first driver. The total length is 64 inches plus a few inches at the boom ends. A 6 foot boom using 1.25 inch aluminum or similar material would serve very well. The antenna is short enough to allow for a PVC schedule 40 boom without significant sag. Let's examine the structure in small steps.

The Elements

We can build beams to be light or to withstand heavy winds. To give you a choice, I shall provide two sets of dimensions. One set uses heavier elements for wind loads up to about 90 to 100 mi/h. The lighter version might be rated to the 60 to 70 mi/h level.

The dimensions in Table 1 apply only to the two different element diameter taper schedules. If you change the material diameters or the interior lengths of wider tubing, the beam may not perform as advertised. Remember to add about 2 to 3 inches to the lengths of the smaller tubes to ensure sufficient material for a secure overlap.

Both versions provide essentially identical performance across the band. The gain varies from 6.4 dBi at 28 up to 7.1 dBi at 29 MHz. The F/B peaks at almost 18 dB at mid-band. Its lowest value is about 14.5 dB at 29 MHz.

The Overall Design

The general layout of the beam is shown in the lead photo. In this design, I started with a simple narrow band driver director array. All two element driver director Yagis have a very narrow bandwidth. I then changed the driver system to a pair of phased drivers in order to

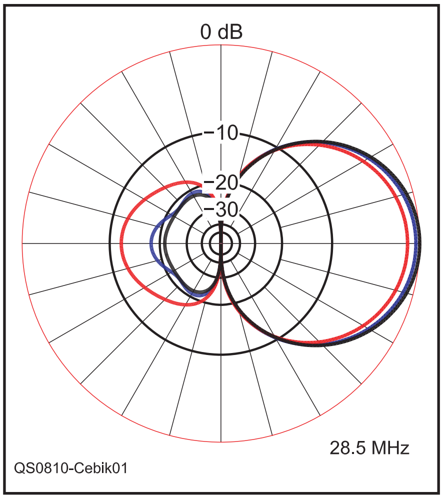

Figure 1 — Overlaid free space *EZNEC* E-plane (azimuth) patterns of the three wide-band Yagi designs for 10 meters at 28.5 MHz. Blue plot is the phased design, black the three element reflector/director and red a two element Yagi.

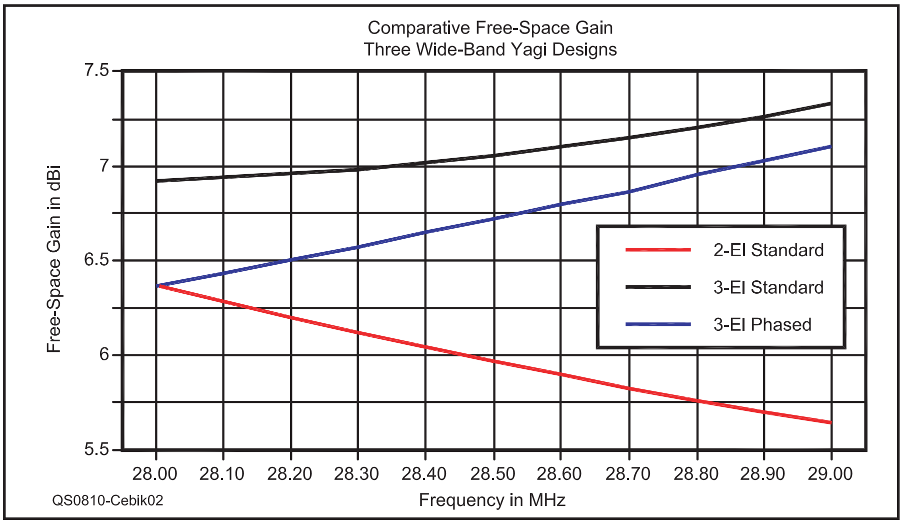

Figure 2 — 10 meter (28-29 MHz) free-space gain curves for the three wide-band Yagis. Blue plot is the phased design, black the three element reflector/director and red a two element Yagi.

broaden the antenna's operating bandwidth. By the judicious selection of element spacing, element length and the phase-line characteristic impedance, I ended up with a beam that spreads the relatively good driver director performance across the entire first MHz of 10 meters.

The phase line consists of a parallel transmission line with a 250 Ω characteristic impedance. The line requires one (and only one) half twist between the two drivers in order to provide the correct phasing for broadband service on 10. The coax connector — that is, the feed point for the main transmission line — goes on the forward driver. This position is convenient, since the position is fairly close to the mast.

Making Your Own Phase Line

Since you need only 25 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 some common bare copper wire.

You will need spacers about every 3 inches to accurately maintain the wire spacing. The best way to make spacers is to drill wire size holes in a long strip of plastic, such as polycarbonate. Then cut the spacers to size after you complete the drilling. Do not make the holes too large; you want a tight fit. If you do not deburr the holes, the spacer will tend to stay in place through all kinds of weather. The velocity factor of this phase line will be very close to 1.0.

You may already be tempted to substitute 300 Ω TV twinlead for the specified homemade line. I do not recommend the substitution. 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 a fairly critical phase line characteristic impedance and electrical length — to get the job done. The job 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.

Putting it all Together

There are many ways to construct Yagis. In this design, all of the dimensions apply to elements that are well insulated and isolated from a conductive boom. If you use a 6 foot section of aluminum tubing as a boom, you will need polycarbonate or similar nonconductive plates for the boom-to-element junctions. I prefer to use stainless steel U bolts with saddles to grip the boom and the elements without crushing them. I prefer them to the typical muffler style fixture with a U shaped saddle that contacts the tubing in two lines.

The director will be a continuous element, with no break in the center. Both drivers require a small gap (¼ inch is fine) for connections. Note that the gap is included in the tip to tip element length shown. Do not add the gap to the element length. I prefer to place a fiberglass rod inside the largest tube and extend it to the ends of the plate. This system has two advantages. First, it places an extra support under the element U bolts and it also aligns the whole element with only two element U bolts near the outer edges of the plate. Second, the rod allows good support for #6 or #8 stainless steel hardware that secures the connections to the phase line and to the coax connector leads. Figure 3 shows the general scheme (U bolts removed for clarity).

The side view shows the elements below the boom for best stability. As well, the boom helps to keep ice and snow off the phase lines. The bottom view shows the phase line and coax connection points. Keep the phase line taut. The sharp twist in the sketch will become in reality a gradual twist along the

Table 1

Dimensions of the Yagi for Different Construction Methods

Heavy Duty Version Using 0.75/0.625/0.5" Diameter Elements with 250 Ω Parallel Phase Line. Inner (0.75") 24", Mid (0.625") 18" Each Side.

Element	*Total Length*	*Tip (0.5") Length*	*Spacing from Rear Element*
Rear Driver	205"	60.5"	
Forward Driver	193"	54.5"	25"
Director	190"	53"	64"

Medium Duty Version Using 0.625/0.5/0.375" Diameter Elements with 250 Ω Parallel Phase Line. Inner (0.625") 36", Mid (0.5") 33" Each Side.

Element	*Total Length*	*Tip (0.375") Length*	*Spacing from Rear Element*
Rear Driver	206"	34"	
Forward Driver	194"	28"	25"
Director	191"	26.5"	64"

line length. There will be enough spacing between the phase line and the boom to minimize interaction if ¼ inch thick insulation plates and saddle U bolts are used.

The coax connector can sit on a small metallic plate attached to the forward edge of the forward driver plate. Just be sure that the screws you use to secure the coax connector plate do not contact the boom. Of course, all hardware should be stainless steel, which you can obtain from most home centers these days. I use stainless steel nuts to separate copper wire ring connections from the aluminum in the element.

Final Adjustments

Final adjustments should be negligible if you have constructed the phase line carefully. I performed initial tests with the antenna 10 feet above ground on a temporary mast. The usual test for determining correct construction is to sample the SWR across the operating passband (28.0 to 29.0 MHz, in this case). Modeling showed that the 50 Ω SWR curves vary only a little as you increase the height from about 10 to 33 feet (1 λ). Thus, you can be confident that any adjustments you make at a low test height will hold at the ultimate operating height.

For the initial tests, I left the ⅜ inch diameter tip sections unfastened. I fastened all other parts of the antenna in final form. I held the tip sections in place with electrical tape for possible adjustment. However, my prototype needed no changes in the lengths of the elements.

Performance

The antenna performs as modeled. The added gain over a two element driver reflector design is less evident than the improved F/B. The SWR measurements overlay the modeled curves in Figure 4 too closely to need a new chart.

Part of the successful translation of the design models to a physical antenna involves the use of high quality parts throughout. Home center tubing — when available — tends to use thinner walls than 6063-T832 tubing with 0.058 inch wall thickness. The latter nests very well so that sheet metal screws used as element section fasteners do not vibrate loose over the seasons. UV protected polycarbonate boom to element plates endure the sun for many years. Stainless steel hardware is weather impervious. Unless you are building a short-lived trial version of this (or virtually any) antenna, I do not recommend junk box materials.

There are only two HF amateur bands that might call for a design like the short-boom wideband three element phased-driver Yagi: 10 and 40 meters. In fact, this 10 meter version evolved from a 40 meter design exercise. I lack the shop space and the support system needed to build and test a 40 meter prototype. I have included all of the models referenced in these notes for availability on the ARRL Web site.[2] The 40 meter design that covers 7 to 7.3 MHz with under 1.5:1 50 Ω SWR is in the collection. When modeling these antennas in either *NEC-2* or *NEC-4*, be certain to apply the Leeson corrections. Even *NEC-4* will drift off the mark with the large element-diameter taper required by 40 meter elements. The Web material also includes additional figures and design details that should prove helpful to the builder.

The 10 meter version of the antenna is not for everyone. However, it supplies a Yagi design that fills a niche between standard two element and three element wideband Yagis. It improves performance while retaining the short two element boom. The wideband aspect of the design may prove as important in allowing for construction variations as it is in obtaining a low SWR across the band. Hence, it is a beam that the home craftsperson can — with care — successfully build.

Table 2
250 Ω 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"

Notes

[1]Turning radius is the distance from the mast to the farthest tip of any element.

[2]**www.arrl.org/files/qst-binaries/.**

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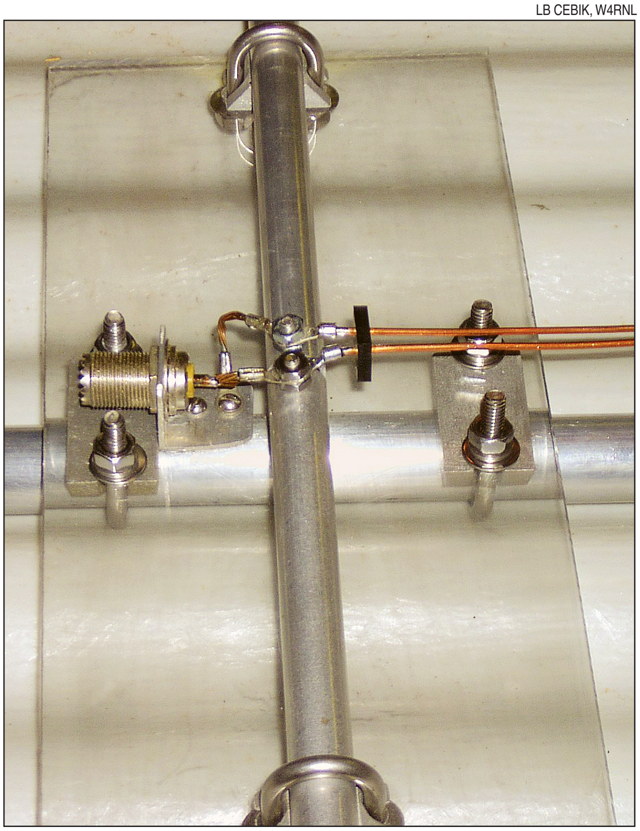

Figure 3 — Closeup view of the feed point assembly.

The last *QST* article authored by longtime contributor L. B. Cebik, W4RNL (SK)

L. B. Cebik, W4RNL, ARRL Technical Advisor and antenna authority, passed away in April 2008. He had submitted this article prior to his death and we publish it as a memorial to a life that added an immense amount of knowledge to the study of antennas by amateurs and professionals throughout the world.

Cebik was 68. An ARRL Life Member, he was known to many hams for the numerous articles he wrote on antennas and antenna modeling. He had articles published in most of the US ham journals, including *QST*, *QEX*, *NCJ*, *CQ*, *Communications Quarterly*, *Ham Radio*, *73*, *QRP Quarterly, Radio-Electronics* and *QRPp*.

Those of us who worked with L. B. along with the entire Amateur Radio community miss him very much. — *Joel R. Hallas, W1ZR, QST Technical Editor*