The Inverted-U as a Field Yagi

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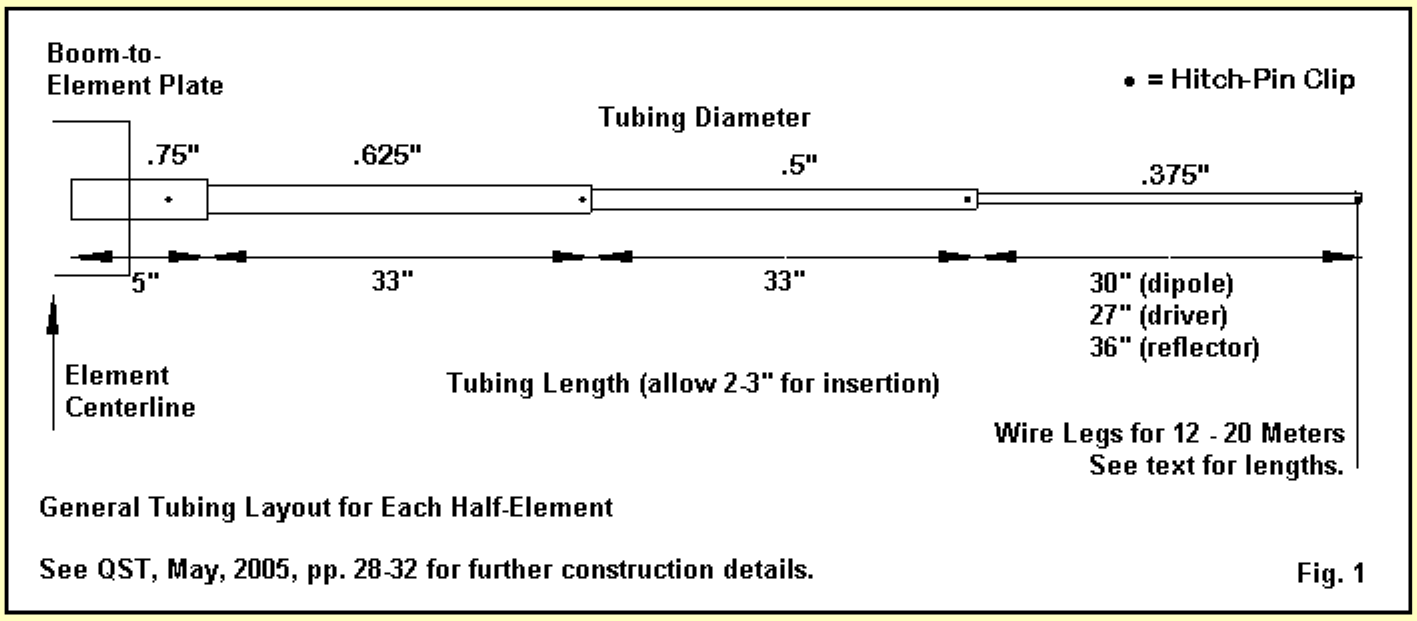
In May, 2005, *QST* published an article describing a simple field dipole using nested aluminum tubing, hitch-pin clips, and a simple center feedpoint assembly. ("The Inverted-U," pp. 28-32) Besides the use of techniques that allowed easy field assembly and disassembly, as well as compact storage and transport, the dipole featured the use of a 100" element length and aluminum fence wire (AWG #17) as vertical end tips to extended the total element length from its native 10-meter resonance to lower bands. Separate tips wires allowed coverage of 10 through 20 meters. **Fig. 1** shows the basic structure of the main horizontal element (actually, half of the element). Refer to the original article for additional construction details, including the use of hitch-pin clips and the method of holding the tip wires in place.



General Tubing Layout for Each Half-Element

See QST, May, 2005, pp. 28-32 for further construction details.

Fig. 1

Since the article appeared. I have received e-mails from individuals interested in developing the basic inverted-U into a 2-element Yagi. Within limits (that we shall explore as we move along) it is possible to develop an inverted-U Yagi. However, the first reminder at this point is the fact that the antenna physical design is aimed at short-term field use, not permanent home installation. Any long-term installation will need to check the tubing lengths against a program, such as YagiStress, to ensure that it will handle local wind loads. As well, the junctions of tubing sections will require more permanent fasteners for durable electrical contact and physical security.

The second reminder concerns the difference between designing a simple dipole and a 2-element Yagi. The dipole is easy. Starting with a 10-meter resonant element, we simple add tip wires for a desired band and trim the ends for a satisfactory SWR value at the operating frequency. Dipole patterns do not change much with SWR excursions, so we generally assume that the bi-directional pattern is satisfactory once we achieve the desired SWR reading. The original article shows some sample patterns that take into account the increasing vertical tip lengths as we lower the frequency. Other patterns account for the fact that maximum gain goes down and the elevation goes up if we place the antenna at a fixed height and lower the frequency of operation with longer tip wires.

A 2-element Yagi increases the complexity of the design considerably. The pattern shape changes rapidly with changes that may seem small when applied to a dipole. The best compromise among gain, front-to-back ratio, and feedpoint impedance rests on the interaction of the different lengths of the 2 elements (a driver and a reflector in this exercise) and the spacing of the elements. Since the elements are not linear, we have additional design decisions to make before we develop any dimensions.

As suggested in **Fig. 1**, I used the basic element structure of the inverted-U dipole as the foundation for designing 2-element Yagis. On 10 meters, the driver will be shorter and the reflector will be longer than the original 10-meter dipole. This arrangement allows the antenna to function as a 2-element Yagi of standard performance without the use of any tip wires. The decision also restricted the designs to field use. Changes of tubing sizes for stronger home versions of the antenna will require redesign, since element diameter affects the pattern shape as well as the feedpoint impedance. Once we enter the world of parasitic Yagis, pruning for resonance is a secondary field adjustment rather than the primary and sometimes the only adjustment needed with a dipole.

Since the antenna design is for field use, the feedpoint impedance should require no matching device that might require either assembly or adjustment in the field. Therefore, I used a 10-meter element spacing of 0.17 wavelength so that the feedpoint impedance would come as close as possible to 50 Ohms. The difference in the patterns between a more closely spaced driver-reflector Yagi and a 50-Ohm Yagi are numerically determinable but operationally insignificant. At a spacing of about 1/8 (0.125) wavelength, an optimized 2-element driver-reflector Yagi will show about a half dB more front-to-back ratio, about 0.1 dB more gain, and a feedpoint impedance in the low 30-Ohm range. Since 2-element driver-reflector Yagis (without reflector loading) have maximum front-to-back ratios in the 11-12-dB region, the convenience of a 50-Ohm feedpoint seemed warranted.

As a result of the decision to use a 50-Ohm Yagi design, the driver requires the same sort of construction that I used in the original inverted-U dipole. **Fig. 2** shows the general layout of the 2-element field Yagi. You can use the same plates designed for the dipole, although they will now attach to and hang under a boom. You can use a fairly lightweight boom, since each element will weigh only about 2 pounds (including the plate assembly and boom-to-element U-bolts). The original dipole used a length of non-conductive rod or tube inside the 0.75" short center tubes to effect the feedpoint gap. For the reflector, you can use a single center tube, since the reflector is a continuous element. In fact, if you wish to keep the smallest end tubing section shorter than the listed value, you can increase the length of the largest tube attached to the reflector plate. In this way, you can reduce the length of the nested tubes during storage and transport.

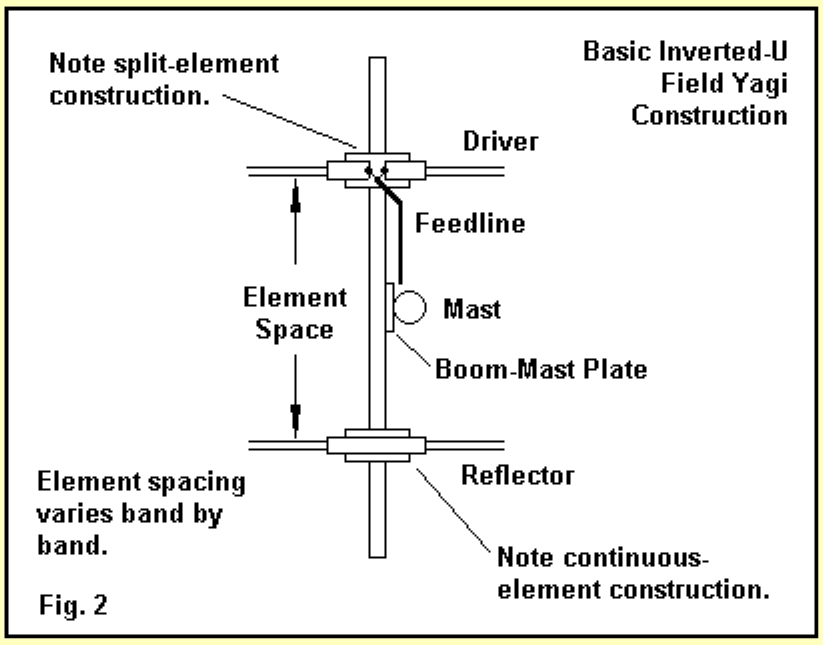


Fig. 2

Note in **Fig. 2** that the spacing will be variable. The optimal spacing grows physically wider to maintain the 0.17-wavelength element spacing. However, we encounter another design limitation. Because the elements have longer tip wires as we lower the operating frequency, the impedance increases more slowly with element spacing at lower frequencies. Therefore, we need to increase the spacing--up to about 0.19 wavelength at 20 meters. That fact, plus some others, may limit the utility of the design beyond 2 or 3 bands below 10 meters.

I also made a further design decision based on the intended application of the 2-element field Yagi. I set the tip-wire length for each band so that all 4 tip wires are interchangeable, that is, have the same length. This decision simplifies band changes in the field, since we do not need to locate a specific wire. As well, the core 10-meter elements remain constant and require no changes when we change frequency. However, this decision also restricts our ability to obtain the most optimal patterns from a 2-element Yagi with inverted-U elements.

Application decisions can have a far reaching effect on the design and its performance or shape. Although an inverted-U Yagi may have only limited use for field operators, the decision to retain the field-use features of the original inverted-U dipole determined a number of dimensions that a builder with other applications can change. For example, one might make both elements the same length and use driver and reflector tips with different lengths. Making both elements 196" long (98" per half-element) would require short tip wires on the reflector on 10 meters. For monoband applications in which the inverted-U element shape is simply a way to save horizontal space, one can use closer element spacing. The feedpoint impedance will drop, but there are a number of matching schemes available to raise it to 50 Ohms for the standard amateur coaxial cable--including beta and gamma networks as well as 1/4-wavelength sections. Before we close, we shall briefly examine some other alternatives based on some limitations that we encounter with the field-application design.

A Band-by-Band Look at Inverted-U Yagi performance

The inverted-U dipole showed bi-directional gain that gradually dropped (even in free space environments) due to the constant horizontal length and the increasing vertical tip-wire length as we moved from 10 to 20 meters. However, the 20-meter performance remained quite usable and the feedpoint impedance remained high enough to be directly compatible with coaxial cable feedlines. In contrast, the inverted-U Yagi, we must balance 2 element lengths and the spacing between them to yield acceptable 2-element Yagi performance. As well, driver-reflector Yagis show impedance levels that--for any reasonable spacing--remain lower than the impedance of the dipole. Hence, we shall encounter difficulties covering all 5 bands for which the dipole was applicable. To see how the limitations evolve, let's examine the performance of the inverted-U Yagi starting with 10 meters. The performance evolution may provide some insights into the operation of both 2-element Yagis and elements with the inverted-U shape.

For each band, we shall look at 3 essential sets of data. First will be a performance table that provides modeled data for the band edges and the design frequency--the passband center. The table will also include the critical figures for the wire tip lengths and the elements spacing required to arrive at the performance data. The listed tip-length values are from free-space models. Be prepared to make field adjustments to these lengths because the ground will interact with the elements at normal field heights. However, strive to keep all tips the same length. Next, we shall examine the free-space E-plane pattern for the modeled antenna. The free-space E-plane pattern is virtually identical to an azimuth pattern taken at any reasonable height above ground, although the latter requires a maximum gain adjustment of 5 to 6 dB, depending upon the actual antenna height. Finally, we shall look at the 50-Ohm SWR curve for the antenna and correlate its shape to the spot performance values in the table. The following table shows the tip lengths and other essential dimensions for the beam on each band.

Basic Dimensions of the Inverted-U Field Yagis
Basic Antenna: 10-Meter Yagi
Driver Length: 98" See Fig. 1 for element structure. All length adjustments
Reflector Length: 107" made to outer 3/8" diameter section.
AWG #17 aluminum fence-wire vertical end wires
(4 required for each band, all of equal length)

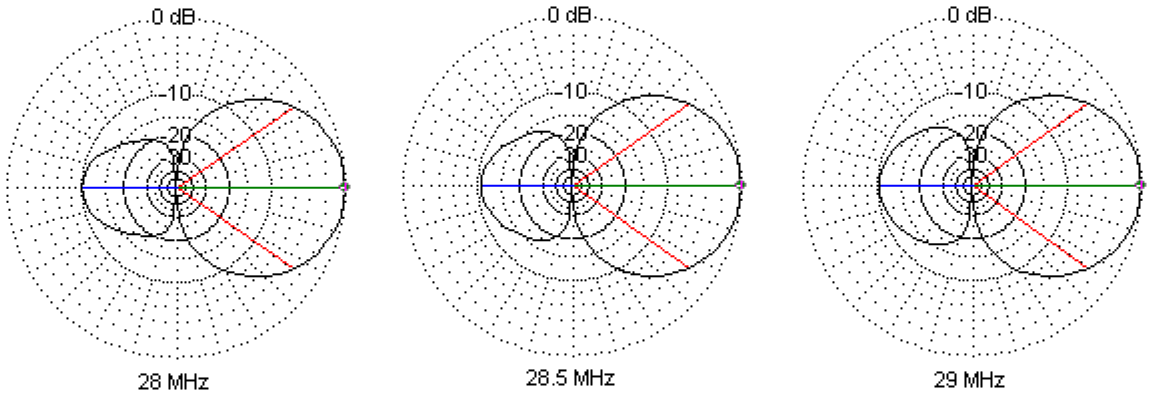
Band	**Wire Length (")**
10	**None**
12	**22.5"**
15	**50"**
17	**77"**
20	**127"**

10 Meters: The 10-meter passband is restricted to 28.0 to 29.0 MHz. We can redesign the beam to cover the entire 10-meter band (which extends to 29.7 MHz). However, the lower first MHz contains most of the non-AM activity that uses horizontal polarization. As noted from the start, the basic beam design requires no vertical tip wires, making the antenna indistinguishable from other 2-element Yagis in its class. The element spacing is 72" (6'), which yields a 50-Ohm feedpoint impedance.

Inverted-U Yagi 10-Meter Performance
No vertical end wires required
Driver Length: 196" Reflector Length: 214" Element Spacing: 72"

Frequency MHz	**Free-Space Gain dBi**	**Front-Back Ratio dB**	**Feedpoint Impedance R +/- jX Ohms**	**50-Ohm SWR**
28.0	**6.51**	**10.01**	**42.8 - j15.4**	**1.44**
28.5	**6.13**	**10.64**	**52.6 + j 1.8**	**1.06**
29.0	**5.79**	**10.14**	**61.4 + j17.7**	**1.46**

10 meters is the widest of the bands explored here. Like all 2-element driver-reflector Yagis, the gain decreases as the frequency increases across the passband. The design tries to reach peak front-to-back ratio about mid-band, and the value remains at or above 10 dB across the band. As shown by the patterns in **Fig. 3**, the 180-degree and worst-case front-to-back ratios are the same due to the shape of the rearward lobe.



Inverted-U Yagi: 10-Meter Free-Space E-Plane Patterns

Fig. 3

Fig. 4 provides the 50-Ohm SWR curve for the basic antenna. Note that the SWR values are virtually identical at both ends of the operating passband. Since both values are under 1.5:1, the array is suitable for use with equipment with sensitive fold-back or shut-down limits. From the curve shape, it is clear that we could have moved the design frequency to about 28.85 MHz and covered the entire band. However, the front-to-back ratio at each band edge would have been lower than the 10-dB figure shown.

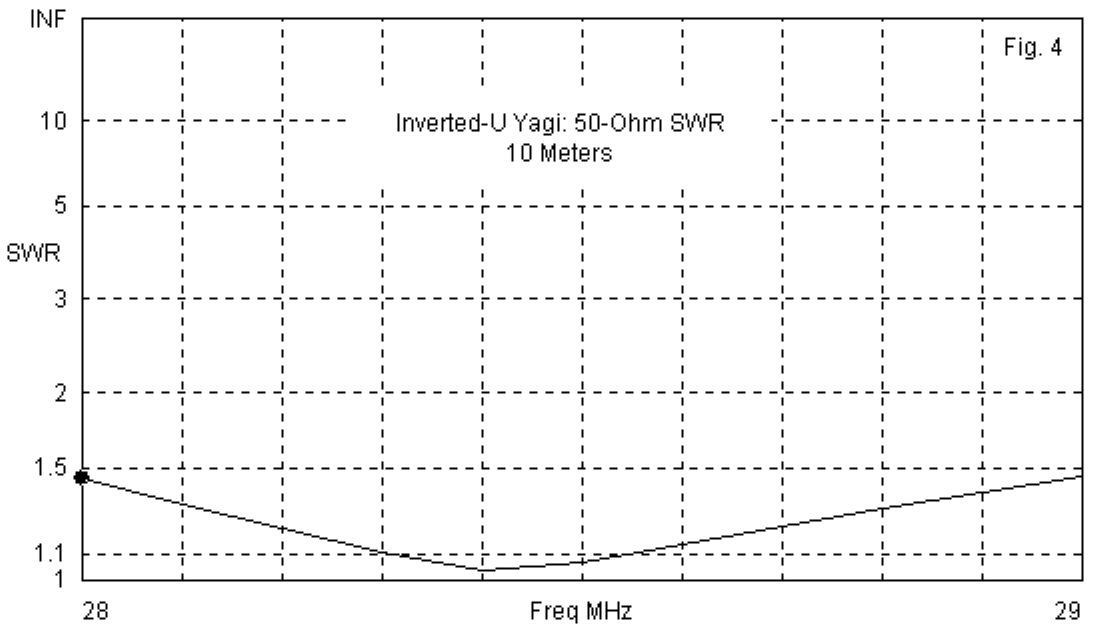


Fig. 4

Inverted-U Yagi: 50-Ohm SWR
10 Meters

12 Meters: The proximity of 12 meters to 10 meters and the narrowness of the passband (100 kHz) gives us some options that we shall not find on the lower bands. The optimal spacing for the array, with its 22.5" end wires, is about 82". However, with only a slight reduction in the feedpoint resistance (and a commensurate rise in the 50-Ohm SWR), we may use the same spacing that we set for 10 meters: 72". This option may simplify some field operations without jeopardizing performance. In fact, as shown by the table of modeled free-space values, the closer spacing may actually improve the performance numbers--although by an amount that we could not measure in the field.

Inverted-U Yagi 12-Meter Performance
Vertical end wires: 22.5"

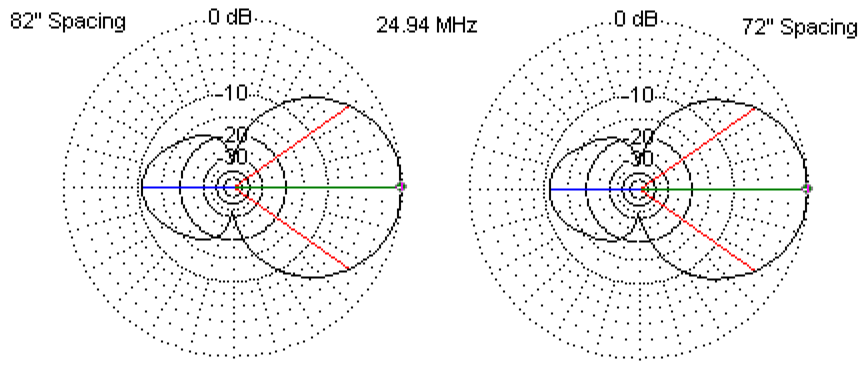
Driver Length: 196"   Reflector Length: 214" Element Spacing: 82"

Frequency MHz	**Free-Space Gain dBi**	**Front-Back Ratio dB**	**Feedpoint Impedance R +/- jX Ohms**	**50-Ohm SWR**
24.89	**6.28**	**10.59**	**47.7 - j 0.5**	**1.05**
24.94	**6.24**	**10.65**	**48.9 + j 1.5**	**1.04**
24.99	**6.19**	**10.69**	**50.0 + j 3.5**	**1.07**

Driver Length: 196"   Reflector Length: 214" Element Spacing: 72"

Frequency MHz	**Free-Space Gain dBi**	**Front-Back Ratio dB**	**Feedpoint Impedance R +/- jX Ohms**	**50-Ohm SWR**
24.89	**6.40**	**10.81**	**39.9 - j 1.7**	**1.26**
24.94	**6.35**	**10.88**	**41.06+ j 0.5**	**1.22**
24.99	**6.30**	**10.92**	**42.17+ j 2.6**	**1.20**

Because the band is so narrow, we may use a single E-plane pattern for the entire band. However, **Fig. 5** presents 2, one for each spacing option. The difference is almost undetectable. However, compare both plots with those for 10 meters. Note that the 12-meter side nulls (90 degrees away from the main forward heading) are not as deep as 10-meter nulls. Even with a short length of vertical tip wire on each element end, we see one of the main results of using inverted-U elements. Of course, at 12 meters. the reduction in the side nulls is not yet operationally significant.



Inverted-U Yagi: 12-Meter Free-Space E-Plane Patterns

Fig. 5

The SWR values for the two spacing options yield essentially straight-line SWR curves over the narrow 12-meter passband. See **Fig. 6**. In both cases, we have only a 2-3-Ohm change of resistance and about 4-Ohms change of reactance. The SWR values for the closer spacing are numerically higher than those for optimal spacing, but well within the range of excellent SWR performance. Indeed, even with the closer spacing, the SWR passband is broad enough to make initial and field adjustments quite easy.

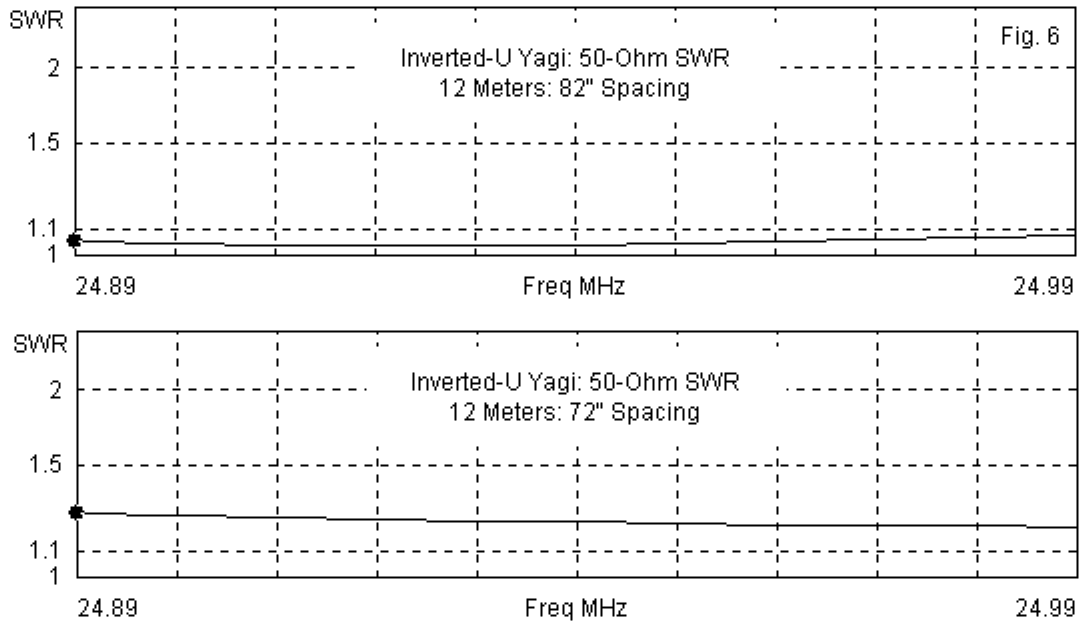


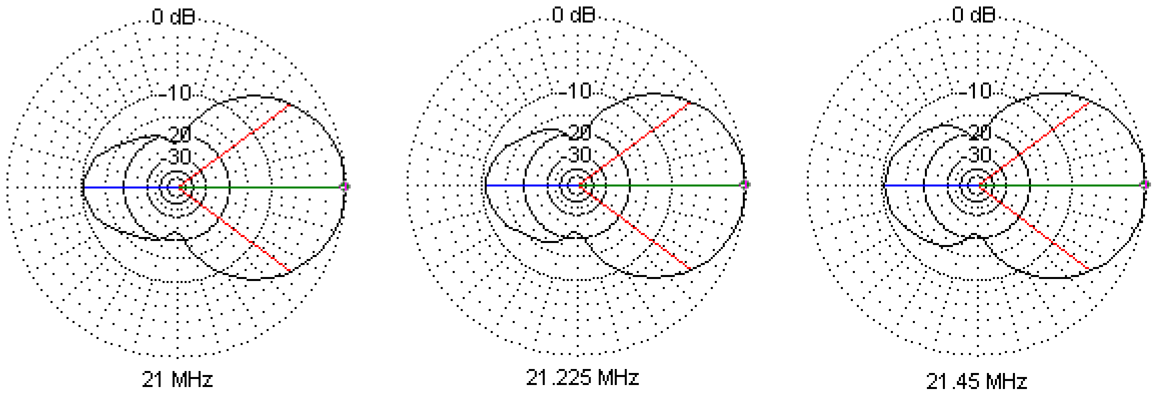
Fig. 6

15-Meters: 15 meters is a relatively wide amateur band and requires 50" tip wires to bring the antenna to optimal performance for the configuration. As well, the required spacing is 100" (8.3'), which is somewhat higher than the spacing needed for equivalent impedance performance on 10 meters. The spacing is about 0.19 wavelength, a fact that gives us a clue to one of the inverted-U Yagi's limitations. Lengthening the vertical wires as we decrease the operating frequency from band to band results in lower feedpoint resistance values for the same spacing when expressed as a fraction of a wavelength. We need a wider spacing to restore near-50-Ohm feedpoint resistance values, a requirement that gradually takes its toll on the basic performance values. However, because the increased proportion of vertical tip wire to horizontal element is also increasing, we cannot say precisely how much performance reduction results from each factor. As shown by the tabulated data, the reduction in maximum gain is noticeable, but not operationally serious.

Inverted-U Yagi 15-Meter Performance
Vertical end wires: 50"
Driver Length: 196"   Reflector Length: 214" Element Spacing: 100"

Frequency MHz	**Free-Space Gain dBi**	**Front-Back Ratio dB**	**Feedpoint Impedance R +/- jX Ohms**	**50-Ohm SWR**
21.0	**6.29**	**10.22**	**41.8 - j 4.0**	**1.22**
21.225	**5.99**	**10.65**	**47.8 + j 7.1**	**1.16**
21.45	**5.71**	**10.37**	**53.3 + j17.6**	**1.41**

The E-plane patterns, shown in **Fig. 7**, show the evolution of the side nulls, that is, a further decrease in depth. The null depth is now only 20-25 dB, compared to a value of over 40 dB or more for the basic 10-meter design. Beyond that fact, the patterns remain typical of 2-element driver-reflector Yagi designs.

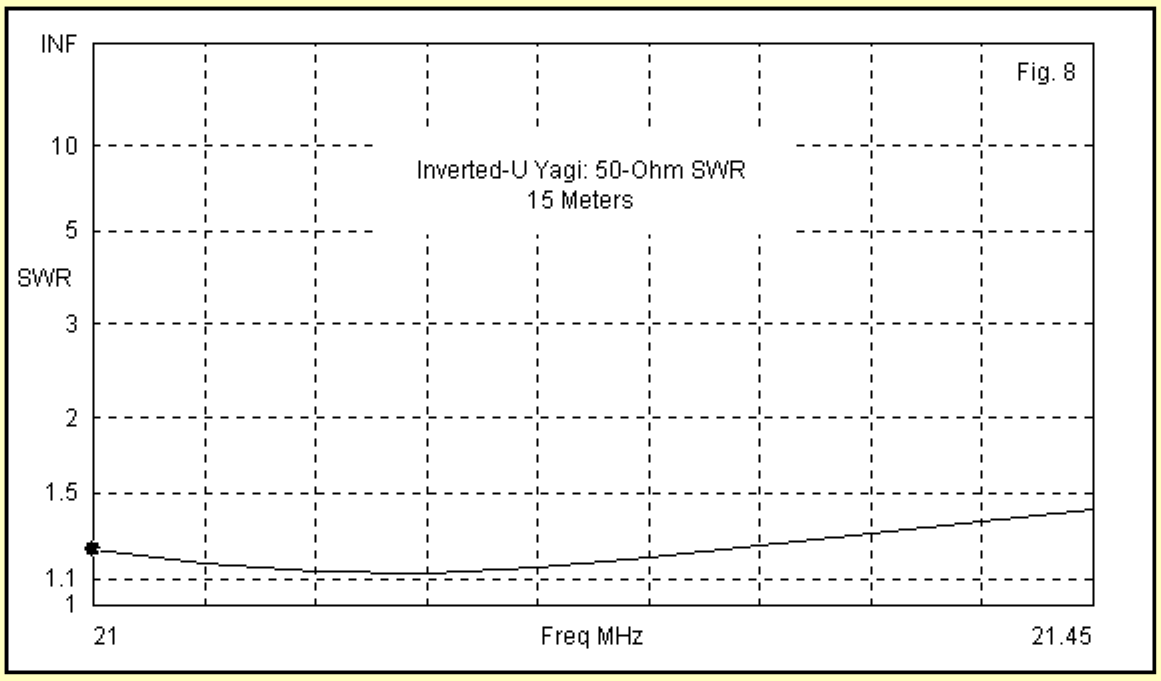


21 MHz
21.225 MHz
21.45 MHz

Inverted-U Yagi: 15-Meter Free-Space E-Plane Patterns

Fig. 7

The SWR curve for 15 meters is quite good, with band-edge values of 1.20 and 1.45 to 1. **Fig. 8** provides the pattern, with the tabular data showing the spot data. First, note that the range of resistance change has climbed to nearly 12 Ohms and the range of reactance is about 20 Ohms. Compare those values to the 10-meter values, even though 10 meters is a wider band. (Bandwidth is normally recorded as a percentage, using the total passband width divided by the band's center frequency and multiplied by 100 to arrive at a percentage.) Second, note that the resonant point of the driver has drifted downward in frequency. This situation suggests that there may be limits to balancing pattern shape and impedance performance using equal-length wire tips. Still, the 15-meter SWR value never rises to 1.5:1, giving us perfectly acceptable performance.

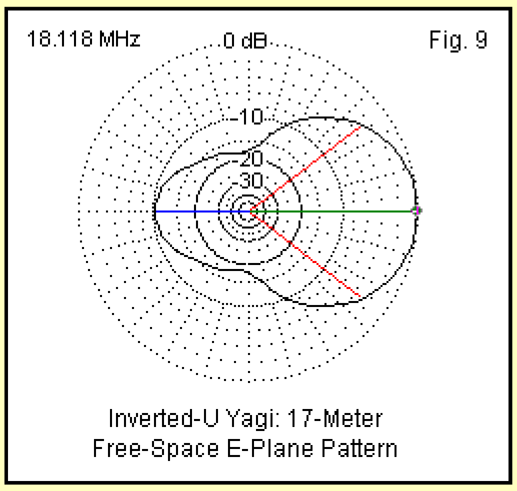


17 Meters: On 17 meters, the element spacing (or boom length) increases to 120" (10') to arrive at an input impedance of about 40 Ohms. As the tabulated data show, we begin to encounter significant changes in performance across even the 100-kHz passband, although the narrow band allows acceptable performance. The key question is whether we can increase the boom from 8.3' to 10' or whether we need to use narrower spacing and a matching network. The latter option might be applicable to a monoband version of the antenna used for a WARC-band only and having a small horizontal footprint.

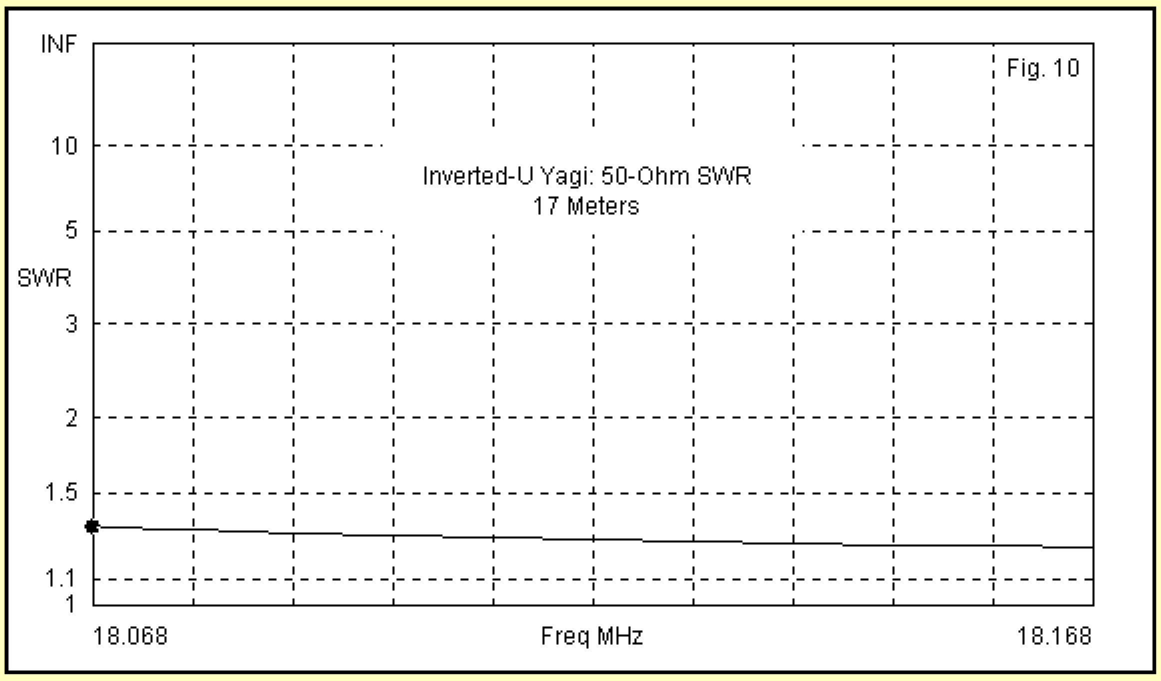
Inverted-U Yagi 17-Meter Performance
Vertical end wires: 77"
Driver Length: 196"   Reflector Length: 214"   Element Spacing: 120"

Frequency MHz	**Free-Space Gain dBi**	**Front-Back Ratio dB**	**Feedpoint Impedance R +/- jX Ohms**	**50-Ohm SWR**
18.068	**6.04**	**10.07**	**38.0 - j 2.5**	**1.32**
18.118	**5.95**	**10.26**	**39.6 + j 0.5**	**1.26**
18.168	**5.85**	**10.35**	**41.1 + j 3.5**	**1.23**

Fig. 9 shows the continuing evolution of the E-plane pattern. The side nulls are now only about 17 dB below the maximum gain level, which is, in turn, only about 7 dB more rejection than the front-to-back ratio. The pattern has changed from a pair of lobes--one forward, one rearward--into a pear-shaped affair.



Despite the longer boom and the reduced side rejection, the 17-meter version of the inverted-U Yagi does obtain a perfectly usable SWR curve, largely as a function of the narrowness of the 17-meter band. **Fig. 10** shows the curve--a virtual straight line--for the 50-Ohm SWR values.

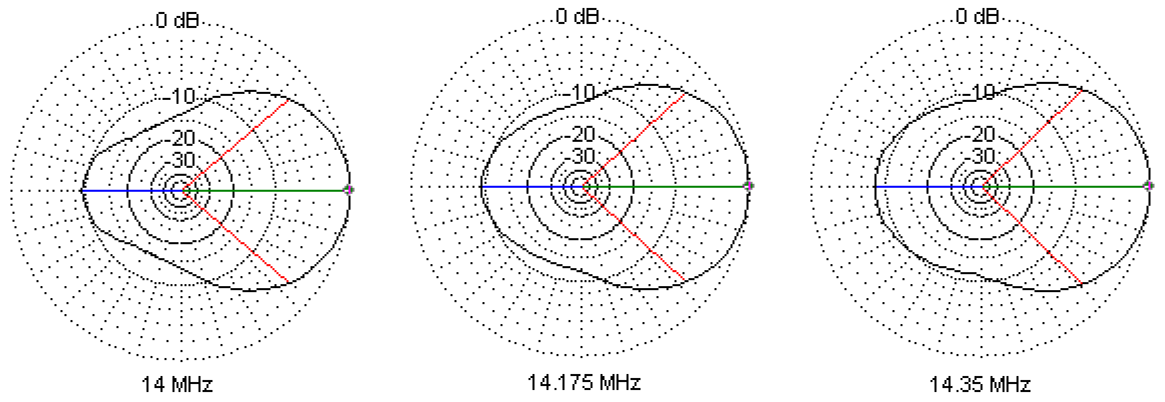


20 Meters: Whether or not the inverted-U Yagi, when built within the design constraints described at the beginning of this exercise, is suitable for 20-meter use depends on how much performance reduction we are willing to accept and how much boom length that we can accommodate. The tip wires are now 127" apiece. The boom required for adequate impedance performance rises to 160" (13.3'). As the tabulated data show, these factors add up to a highly noticeable decline in both gain and front-to-back ratio across the wider 20-meter band, with only adequate 50-Ohm SWR performance.

Inverted-U Yagi 20-Meter Performance
Vertical end wires: 127"
Driver Length: 196" Reflector Length: 214" Element Spacing: 160"

Frequency MHz	Free-Space Gain dBi	Front-Back Ratio dB	Feedpoint Impedance R +/- jX Ohms	50-Ohm SWR
14.0	**5.62**	**9.26**	**28.3 - j 5.1**	**1.80**
14.175	**5.02**	**9.24**	**34.1 + j 9.6**	**1.56**
14.35	**4.52**	**8.07**	**38.4 + j23.6**	**1.81**

As shown in **Fig. 11**, the pattern shape has lost almost all side rejection, with only a tapering gain value as we move from the front to the rear of the pattern. The absence of side rejection and the reduction in rear rejection is commensurate with the reduction in forward gain compared especially to the basic 10-meter version of the antenna that uses no element-end tip wires. However, we can also see that the pattern has taken a serious jump to lower performance from the 17-meter version of the antenna.



14 MHz 14.175 MHz 14.35 MHz

Inverted-U Yagi: 20-Meter Free-Space E-Plane Patterns

Fig. 11

Although we can use the 160" boom to produce a 50-Ohm SWR curve (shown in **Fig. 12**) that remains below 2:1, we cannot get the lowest value down to 1.5:1. Indeed, the antenna in this configuration would require a 35-Ohm cable (or 2 70-Ohm cables set up in parallel).

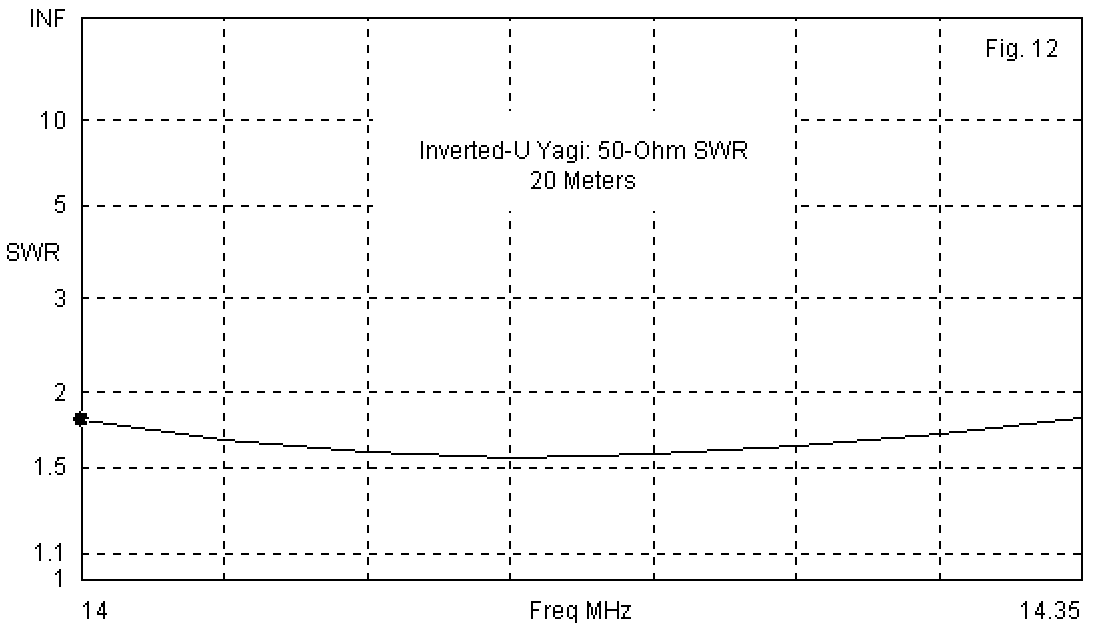


Fig. 12

Although the 20-meter version of the inverted-U dipole using exactly the same tubing structure was highly usable, we cannot say the same for the 20-meter version of the inverted-U Yagi. For the performance level attained and the mediocre SWR curve, the long boom seems almost unjustified.

Conclusion

The inverted-U driver-reflector Yagi, when built for field service, seems most apt as a 3-band and at most a 4-band antenna. Performance in all respects is quite good in terms of 2-element Yagi standards from 10 through 15 meters, with 17 meters a possibility if we wish to use a longer boom. However, 20-meter performance seems almost not worth the effort for most types of field operations.

Those who need a 17-meter or a 20-meter Yagi with a limited footprint do have some options. Suppose that we were to develop a 15-meter beam as the baseline. The element would be about 22' long compared to the 16-17' 10-meter elements. With a 15-meter baseline. the required wire tips for 17 and 20 meters would be considerably shorter, and performance would improve to about the levels of the 12- and 15-meter beams based on the 10-meter baseline.

Such a beam could serve either field or home applications, depending on the element diameter taper chosen for the array. Indeed, for any home or long-term installation, there are many handbook designs that will show element diameter taper schedules designed for the higher anticipated wind loads. The design exercise will then be to plug those 15-meter elements into a modeling program and to determine the most likely tip wire lengths required for either 17-meter or 20-meter performance. Such a beam would still use elements about 35% shorter than a full size 2-element 20-meter Yagi with relatively undetectable differences in performance. Since the exact dimensions will vary from one element diameter taper schedule to another--as well as with the selection of the desired element spacing and feedpoint impedance--we shall not attempt such a design in this exercise. Such a beam might well use stiffer wire for the tip sections, such as AWG #14 or AWG #12.

For the present exercise, it is sufficient, I think, to have shown the requirements for designing 2-element inverted-U Yagis using the 10-meter baseline. The exercise has alowed us to show the evolutionary factors in the design that offer potentially good performance, but over a more restricted range of frequency bands than the inverted-U dipole might serve. The exercise has also allowed us the chance to remind potential builders that long-term applications require stricter attention to strong and durable electrical and physical requirements in the construction process.

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