Half-Length Dipoles (for 40 Meters)
Part 4: Basic Loaded-Element Parasitic Beams

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The two major strategies that we have used in shortening the linear span of a 40-meter dipole have been reshaping the full-length dipole and loading the half-length version. Of the various shapes used, the U configuration may have some application to more complex antenna arrays. Since the loaded elements are still essentially linear, they may have more direct application. Nevertheless, both reshaping and loading have significant consequences for the performance of more complex multi-element antennas.

Our final exercise in this series of notes will examine some of the consequences. The focal array will be a 2-element Yagi-Uda parasitic beam composed of a driver or driven element and a reflector element. We shall begin with a review of a full-size Yagi and then proceed to various alternatives that use shortened elements that we have previously explored. As in past episodes, we shall employ AWG #12 copper wire throughout, even though the 400" (33.33') main elements lend themselves to construction using aluminum tubing in sizes similar to those used in full-size 20-meter beams.

A Full-Size 40-Meter 2-Element Yagi

Two-element driver-reflector Yagis may use a variety of element spacing values. Although peak front-to-back ratio tends to occur with a spacing of 0.125 λ, the feedpoint impedance tends to be only about half the value at resonance (about 35 Ω) as the impedance of a single dipole (about 70 Ω). However, we may increase the spacing between elements to raise the impedance to a desirable level (usually 50 Ω) with only a few tenths of a dB loss in gain and less than 1 dB loss in front-to-back ratio. The exact spacing value depends upon the element diameter and the resulting level of mutual coupling between the two elements in the array.

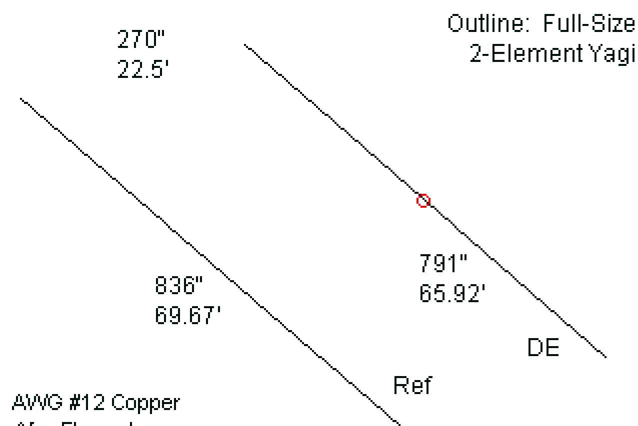


Fig. 1

Fig. 1 shows the outline of a full-size 2-element Yagi with a spacing of 270", about 0.145 λ. The element lengths reflect values necessary for relatively peak front-to-back performance and resonance at 7.115 MHz, slightly below the center of the band. We shall soon discover the reasons for moving the resonant frequency downward from the value used for single dipole elements. The overall performance of the Yagi in terms of free-space gain and front-to-back ratio appears in **Fig. 2**.

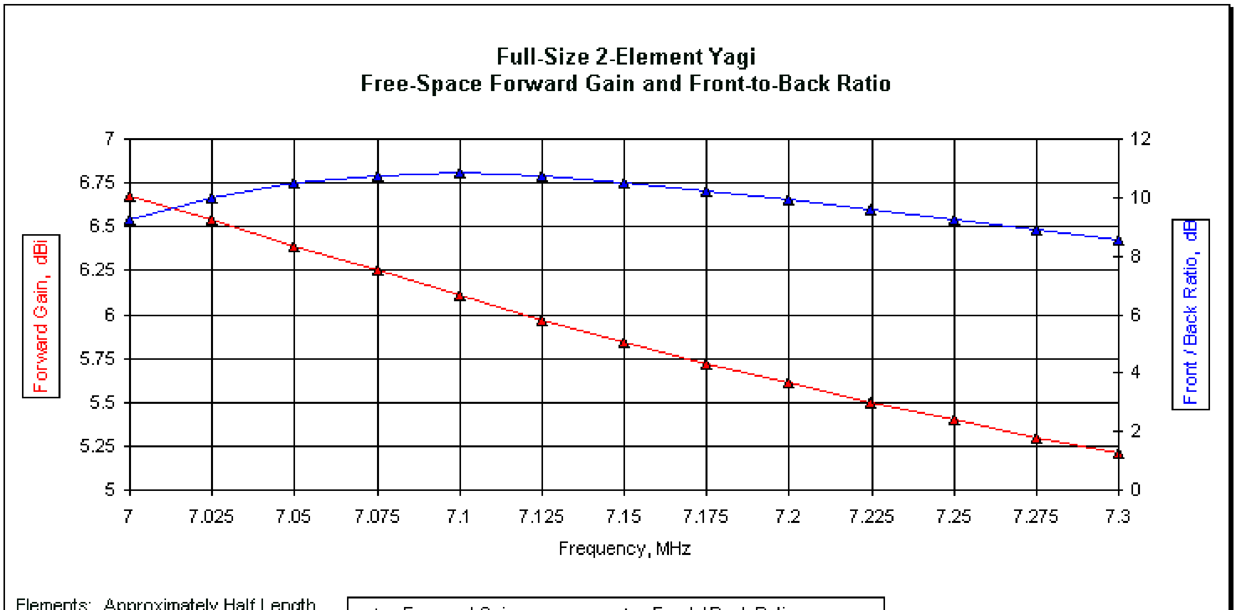


Fig. 2

Like all 2-element driver-reflector Yagis, the gain shows a continuously decreasing value across the passband. Fatter elements decrease the rate of descent, but the trend is endemic to this element configuration. In contrast, the front-to-back curve shows only modest value decreases as we move away from the peak value. Note that the front-to-back ratio decreases more rapidly below the design frequency than above it. With closer element spacing, the overall curve would be steeper: wider spacing tends to increase the operating bandwidth of the antenna in terms of basic performance parameters.

We find a similar pattern in the 50-Ω SWR sweep for the full-size Yagi. At 7.115 MHz, the impedance is 50.5 – j0.3 Ω. The impedance is about 70% of the value for a single dipole and handy for directly matching the antenna feedpoint impedance to the characteristic impedance of 50-Ω coaxial cable. Using a design frequency lower than the arithmetic band center allows the antenna to achieve a 2:1 SWR or better across the entire band. Like the front-to-back curve, the SWR curve is steeper below the design frequency than above it. Wider spacing would raise the resonant impedance and broaden further both the SWR and the front-to-back ratio curves.

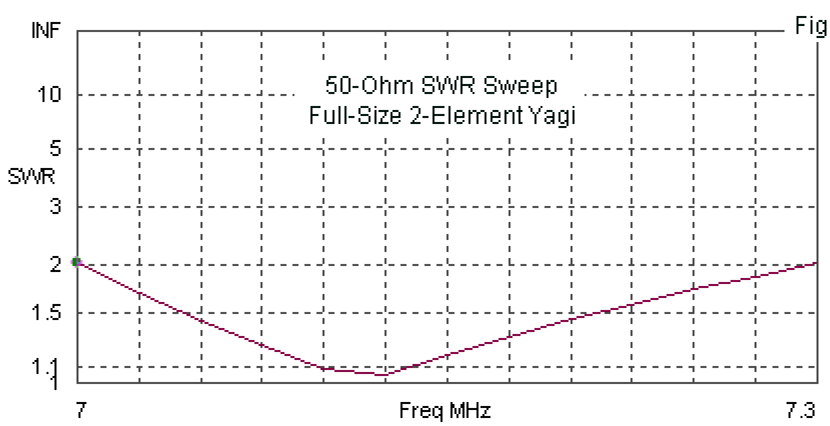
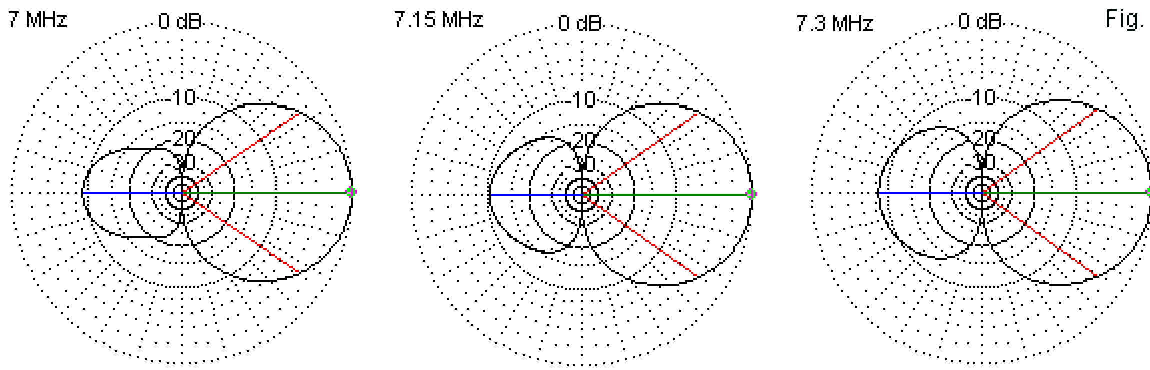


Fig. 3

The full-size Yagi provides relatively even performance across the entire band, as suggested by the free-space E-plane pattern in **Fig. 4**. The only exception, of course, is the forward gain, which decreases by a total of about 1.5 dB across the 300 kHz of the 40-meter band.

Fig. 4



Free-Space E-Plane Patterns
Full-Size 2-Element Yagi

The 2-element full-size driver-reflector Yagi is a very serviceable array on almost any amateur band. The front-to-back ratio is never outstanding in this configuration due to limitations of how the relative element geometry affects the current magnitude and phasing on the rear element for spacing values greater than 0.1 λ. We may obtain better results with closer spacing or by using a driver-director configuration, but the feedpoint impedance tends to drop to very low values and the operating bandwidth for all the performance parameters becomes very narrow.

The full-size Yagi provides a baseline of data to which we compare corresponding data for short-element Yagis that use one or another form of loading. Specifically, we shall examine Yagis with half-length elements that use center loading, mid-element loading, and hat loading. One general error that is common to less experienced attempts to create short-element Yagis is the tendency also to shrink the element spacing. The basic rules of element spacing do not change when we shorten elements. Wider spacing increases operating bandwidth, especially with respect to the front-to-back ratio and the SWR coverage. As well wider spacing yields higher feedpoint impedance values than closer spacing. Since many of our loaded dipoles already show low impedances, sustaining a usable feedpoint impedance value is significant to a successful short-element beam.

A Half-Size 40-Meter 2-Element Yagi with Center-Loaded Elements

The first of our Yagis using half-length (400”) elements employs center loading. The outline, roughly in scale to the sketch of the full-size Yagi, appears in **Fig. 5**. The first notable feature is the fact that neither element is precisely 400” long. In general, we can usually obtain slightly better performance from a center-loaded pair of elements by setting the load values at the same level on each element and then making small adjustments to the element length. This practice also corresponds to actual antenna construction. We can usually more easily change the two element lengths than we can change the loading inductors. The required loading inductors for the sample beam are close to but not identical with the inductors used in the preceding episode with a single dipole element. When constructing a 2-element driver-reflector beam—with or without loading—fine adjustment is a normal procedure.

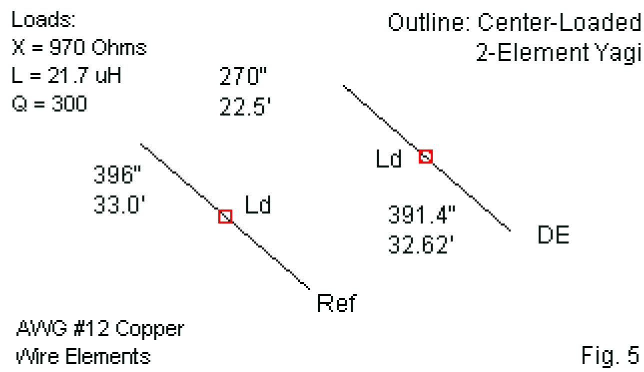


Fig. 5

Center loading severely reduces the operating bandwidth of a Yagi, even with loads with Q values of 300, as used in the sample array. The performance sweep for the center-loaded Yagi extends only from 7.05 to 7.25 MHZ, but the operating range is even more restrictive. At the low end of the gain and front-to-back graph in **Fig. 6**, we see a pair of minimum values for gain and for the front-to-back ratio. At the frequency of minimum value, we find a pattern reversal.

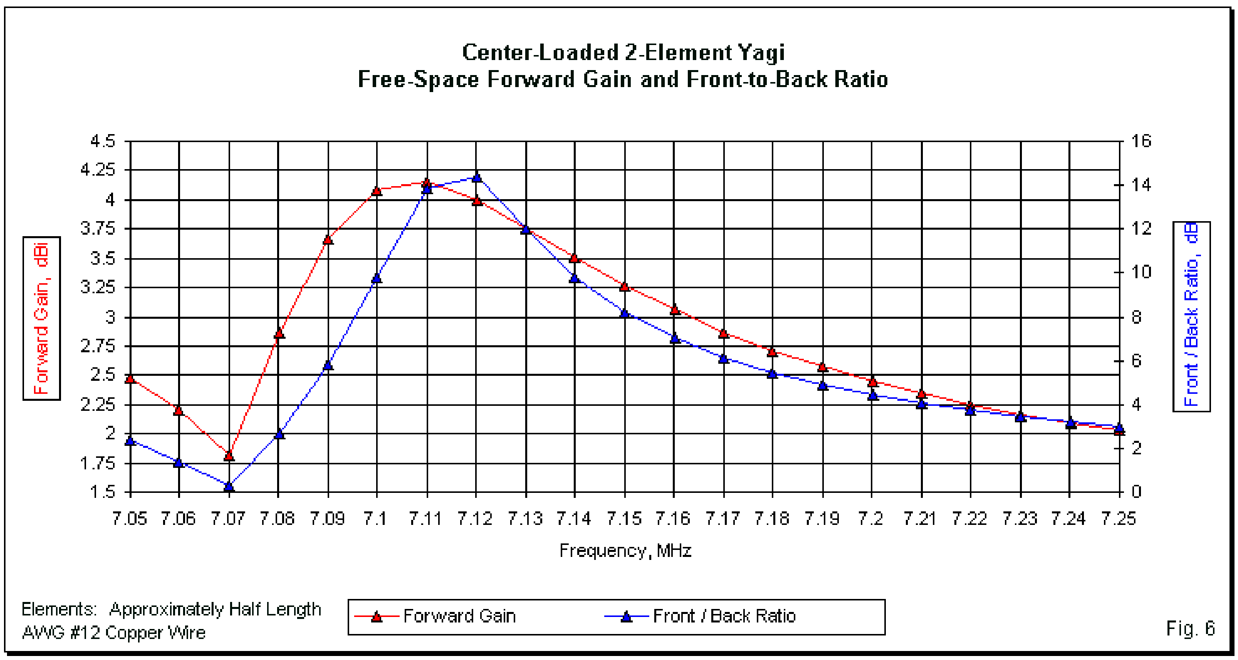


Fig. 6

Like the full-size Yagi, the center-loaded Yagi with half-length elements shows much steeper curves for both gain and front-to-back ratio below the design frequency (7.115 MHz) than above it. As well, the peak values of both curves are notable. Element loading with a finite value of Q (and hence with losses associated with the loading element resistance) reduces the maximum gain that we can achieve from the array. The full-size Yagi obtains a peak gain of well over 6 dBi, but the maximum gain for the center-loaded short-element Yagi is about 4.15 dBi. By the upper end of the frequency sweep, the gain has decreased to simple dipole levels.

In contrast, the peak front-to-back ratio improves with element loading. The full-size Yagi achieves a peak front-to-back ratio of slightly less than 11 dB, but the center-loaded version reaches almost 15 dB. The 4-dB difference is operationally noticeable and has led new beam users to mistake rearward quieting for forward gain. The front-to-back ratio aids reception by attenuating signal strength away from the desired communications target, but only forward gain provides that target with a stronger signal from one's transmitter.

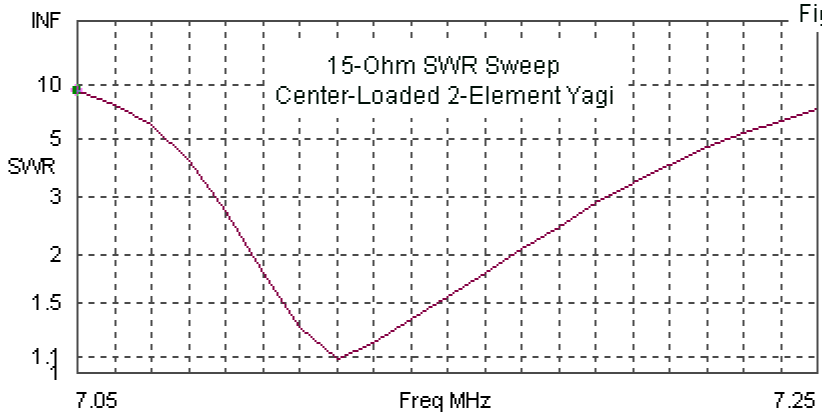


Fig. 7

Many of the points about gain and front-to-back ratio at frequencies away from the design frequency become moot when we examine the SWR curve in **Fig. 7**. Assuming that we have a suitable low-loss means of transforming the 15-Ω resonant feedpoint impedance to match the impedance of our feedline, the SWR bandwidth remains very narrow. The center-loaded short-element Yagi covers only about 70 kHz with less than a 2:1 SWR referenced to the resonant impedance.

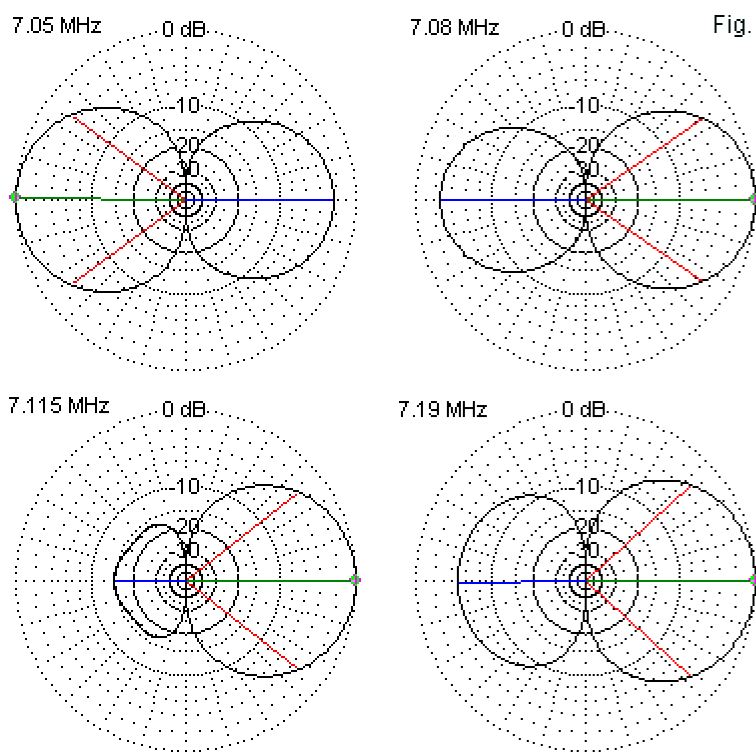


Fig. 8

Free-Space E-Plane Patterns
Center-Loaded 2-Element Yagi

The free-space E-plane patterns in **Fig. 8** are also revealing. The set includes a pattern for 7.05 MHz, a frequency below the minimum gain and front-to-back values that we saw in **Fig. 6**. The pattern direction reversal is very evident, indicating a useless portion of the band for this particular beam design. The remaining patterns include an optimal pattern at the design frequency. Both above and below the design frequency, the patterns quickly degrade. The normalized plots show the rapid reduction in the front-to-back ratio, as the rearward lobe quickly grows. To see the reduction in forward gain, read these plots in conjunction with the gain and front-to-back graph.

In practical terms, adjusting this type of beam so that the most significant performance parameters (gain, front-to-back ratio, and SWR) roughly coincide in frequency can be a somewhat daunting task, since small changes of dimension can yield large changes in the peak frequency for a given performance specification. Designing and constructing a center-loaded short-element Yagi is not a task for the newer antenna builder.

A Half-Size 40-Meter 2-Element Yagi with Mid-Element-Loaded Elements

With adjustments to the feedpoint impedance, the mid-element loaded dipole performance is similar to the center-load version. Therefore, we would expect that a short-element driver-reflector Yagi using mid-element loading should perform similarly to its center-loaded counterpart. Our expectation will not be disappointed.

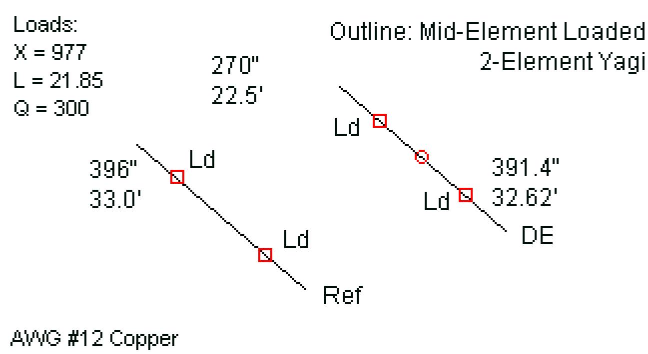


Fig. 9

Fig. 9 outlines the sample mid-element loaded Yagi. The element lengths are identical to those used with the center-loaded antenna. As a result, the required load values are slightly higher than those used in the dipole that we examined in the preceding episode. The present beam also retains the same 22.5' element spacing as the full-size and center-load Yagi beams. The element spacing results in a beam that is, with shortened elements, still under square by a ratio of 3:2. (A version of the beam using tubular elements might have slightly wider spacing, but not to a significant degree that would change the ratio of element length to element spacing.)

The performance of the mid-element loaded Yagi follows the trends set by the center-loaded version, although some details differ. **Fig. 10** graphs the free-space gain and the front-to-back ratio from 7.05 to 7.25 MHz. The gain exceeds that of the center-loaded Yagi by a few hundredths of a dB, obviously a trivial amount. Contrarily, the front-to-back ratio does not quite reach the same peak values, but again, not by an amount that would register operationally. The gain and front-to-back ratio reach minimum values near the lower limits of the frequency sweep. As well, the upper end of the sweep shows values that decrease nearly to simple dipole levels.

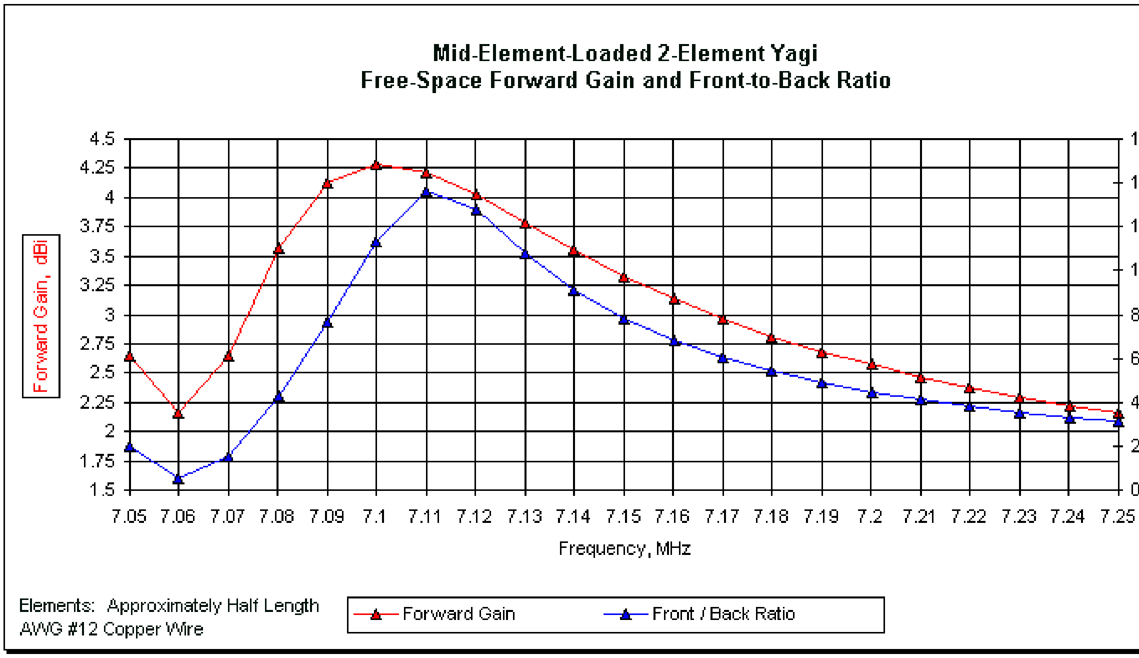


Fig. 10

The resonant feedpoint impedance of the sample mid-element loaded Yagi is very close to 30 Ω. The SWR curve referenced to this value appears in **Fig. 11**. The 2:1 SWR passband extends from about 7.09 to 7.16 MHz, a 70-kHz span that matches the narrow passband of the center-loaded Yagi. Nevertheless, a matching system designed to transform 30 Ω to 50 Ω, rather than going from 15 Ω to 50 Ω, might show lower losses under most circumstances. However, the exact results would depend in part on the precise matching system used.

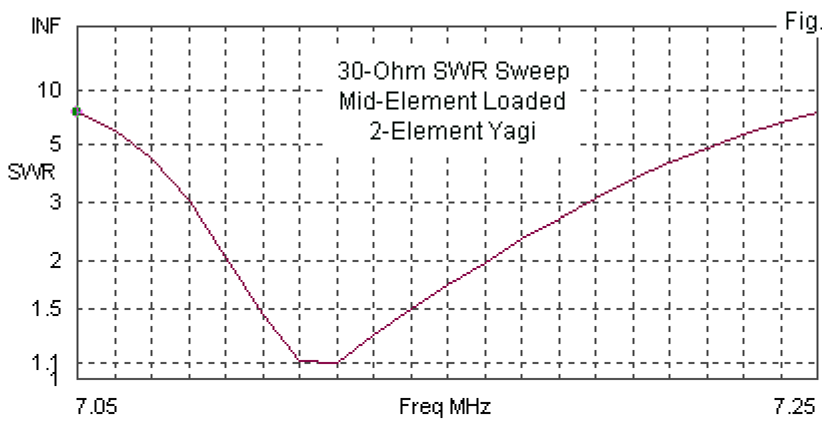
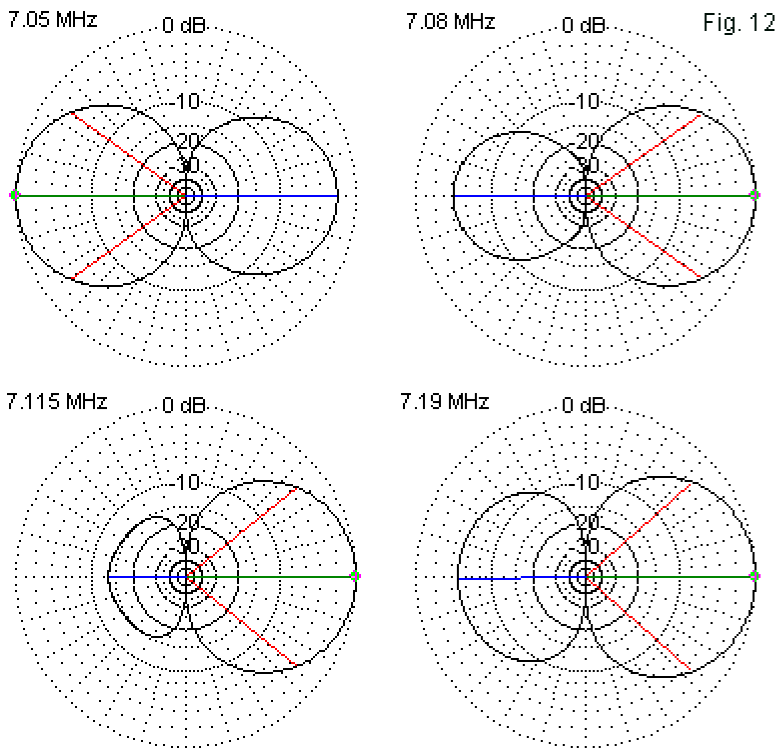


Fig. 11

Further evidence for the practical operational equivalence of the center-loaded and the mid-element loaded short-element Yagis appears in the collection of free-space E-plane patterns in **Fig. 12**. The pattern for the low end of the frequency sweep shows a clear direction reversal. For both loaded Yagis, the front-to-back ratio at 7.05 MHz is in the vicinity of 2 dB. The remaining three patterns replicate those of the center-loaded Yagi, with differences only in minor detail. As the gain graph shows, the forward performance for 7.08 and 7.19 MHz is well below the peak value at the design frequency. The mid-element loading Yagi is a performance twin to its center-loaded brother in every category except the basic feedpoint impedance.



Free-Space E-Plane Patterns
Mid-Element-Loaded 2-Element Yagi

Mid-element loading of the half-length elements does add a structural complication to the beam structure. It not only offsets the weight of the loading solenoids from the support boom, but as well multiplies by 2 the numbers of loading elements that may one day suffer from the effects of daily and seasonal weather. In addition, mid-element loading precludes the use of inductively link coupling between the driver element and the feedline.

A Half-Size 40-Meter 2-Element Yagi with Hat-Loaded Elements

One interesting feature of both inductively loaded Yagis is the fact that their respective feedpoint impedance values are very close to the values obtained from single dipole antennas with the same systems of loading. The impedance values stand in contrast to the full-size 2-element Yagi, which showed a feedpoint impedance about 20 Ω below the value we would obtain from a single full-length resonant wire dipole. Our interest in this difference emerges as we turn to a hat-loaded short-element Yagi.

For a sample hat or end-loaded Yagi, let's use elements that employ a spoke+perimeter wire. The outline of the sample array appears in **Fig. 13**. The hat spokes are 46.5" long (93.0" from tip to tip). We can reduce the length of the spokes by adding more of them, although the performance of the resulting beam would not change. The change from inductive loading to the use of end hats also requires different element dimensions, with a shorter driver and a longer reflector. The reflector-to-driver length differential is 22", compared to 4.5" for the loaded Yagis and to 35" for the full-size Yagi. As was the case for the inductively loaded Yagi elements, the hat size remained constant, and the element lengths underwent adjustment to bring the array to its peak performance. The model used 7.115 MHz as the design frequency.

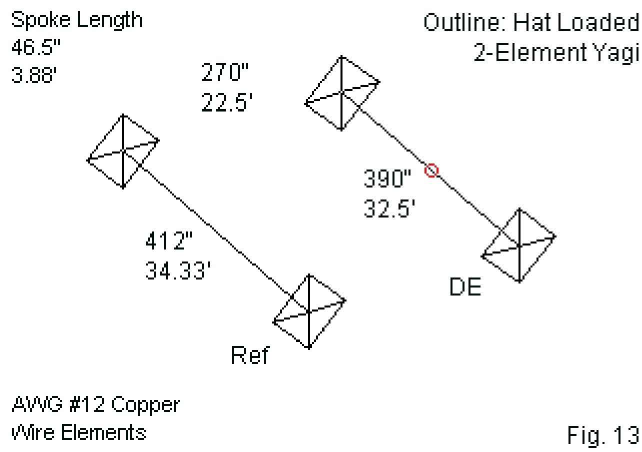


Fig. 13

Despite being somewhat ungainly, the use of end hats on the shortened elements increases the operating bandwidth of both the gain and front-to-back curves, as shown in **Fig. 14**. However, the curves do not match those of the full-size Yagi. For example, the full-size Yagi peak gain occurs below the lowest frequency in the sweep. For the hat-loaded Yagi, the peak gain is within the passband, although near the low end. As well, the hat-loaded Yagi gain curve is steeper, with the gain at the upper end about 0.7 dB lower than for the full-size Yagi. At the design frequency (7.115 MHz), the gain is about 5.9 dB, only about 0.1 dB less than we obtained from the full-size version and far above the values that emerge from the inductively loaded Yagis.

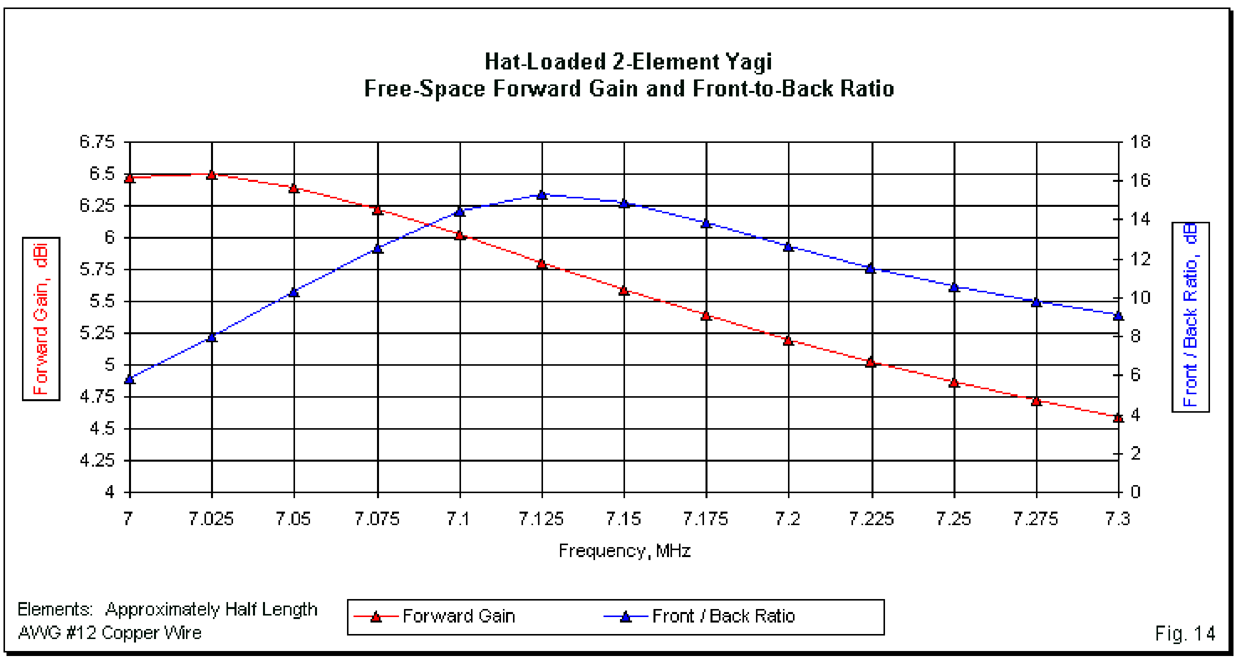
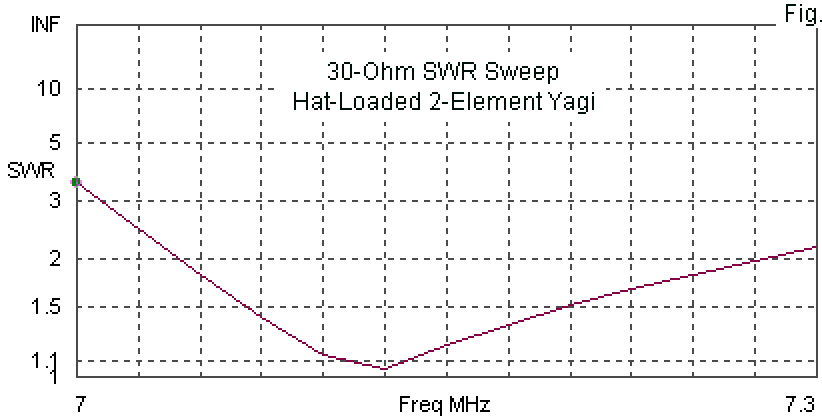


Fig. 14

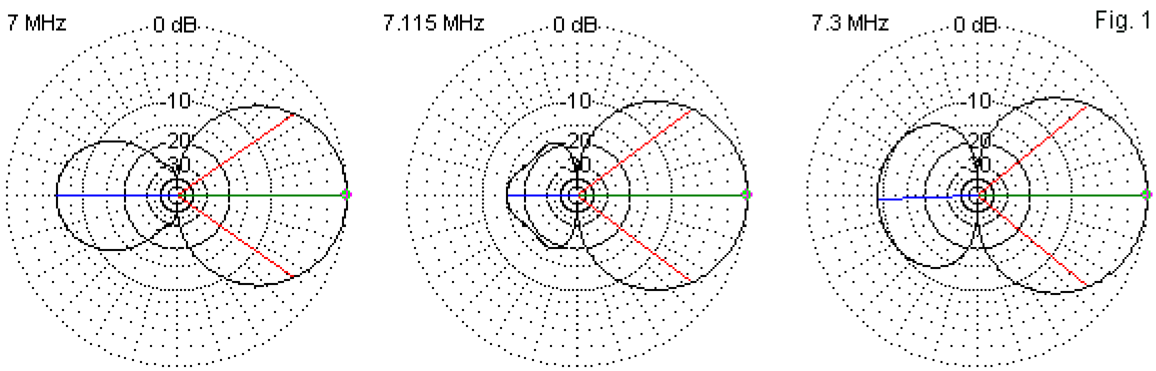
The SWR curve also is much steeper on both sides of the peak value. The peak value is close 15.5 dB and occurs close to the design frequency. This value exceeds the peak value of the full-size Yagi by over 4.5 dB. However, the band-edge values are between 6 dB and 9 dB, while the full-size Yagi yield values close to 8 dB at both ends of the band. Even though the hatted Yagi does not fully match the performance of the full-size Yagi, it exceeds the performance of the inductively load Yagis with similar element length by a wide margin, especially when we move away from the design frequency.

Fig. 15



The resonant impedance of the hatted short-element Yagi is just over 30 Ω. The hatted dipole showed a value close to 50 Ω. Hence, the feedpoint behavior of the hatted Yagi is similar to that of its full-size counterpart. In fact, the loadless driver element might be amenable to the use of a gamma match, as well as beta and series matching techniques to transform the antenna impedance to the usual 50-Ω value. **Fig. 15** displays the SWR sweep for the Yagi design. The 2:1 SWR passband extends from about 7.04 to 7.25 MHz, a 210 kHz spread that is three times wider than for either inductively loaded Yagi. As usual, the SWR curve below the design frequency is steeper than above it, but both partial curves are steeper than the corresponding segments of the SWR curves for the full-size Yagi.

Fig. 16



Free-Space E-Plane Patterns
Hat-Loaded 2-Element Yagi

As we would expect, the sample free-space E-plane plots in **Fig. 16** do not show the uniformity of the comparable plots for the full-size Yagi. Nevertheless, they are far superior, especially at the band edges, to the plots for the inductively loaded Yagis. The hatted short-element Yagi provides the improved front-to-back ratio at the design frequency without the severe reductions in gain and operating bandwidth suffered by the inductively loaded versions.

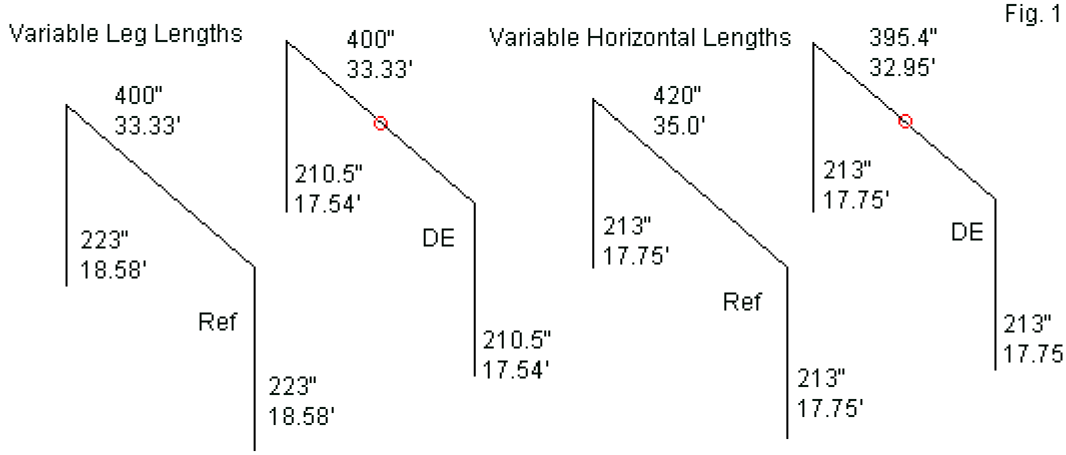
Of all the half-length element Yagis, the hatted version holds the highest performance potential. At the same time, it offers the greatest mechanical challenge: the requirement for substantial structures at the element ends. As a consequence, the history of amateur Yagi design contains many examples of inductively loaded Yagis (and the counterpart linear-loaded Yagis), but few examples of hatted element versions.

A Half-Size 40-Meter 2-Element Yagi with U-Shaped Elements

While reviewing the methods of reshaping full-length dipole element to fit the linear space of a half-length installation space, we noted the potential of the U-shaped element. It supplied fairly good gain and maintained a feedpoint impedance close to 40 Ω. The element might be useful as an alternative to the low-impedance inductively loaded elements and present fewer structural problems than end hatting the elements of a beam.

If we use our standard element spacing of 270", we can form a U-shaped Yagi in two ways. As sketched on the left in **Fig. 17**, we can maintain 400" center horizontal sections and allow the driver-reflector length variations to show up in the length of the vertical legs. Alternatively, as shown on the right, we can maintain equal vertical leg lengths and vary the length of the horizontal center section. In both cases, the total driver wire is 821" (68.42'), while the total reflector length is 846" (70.5').

Fig. 17



Two Versions of a U-Shaped 2-Element Yagi

Regardless of which technique we use, the performance of the resulting 2-element Yagi is virtually identical. **Fig. 18** graphs the gain and the front-to-back ratio across the entire 40-meter band. Between the two versions of the beam, the maximum difference in gain is less than 0.1 dB. The variation in front-to-back ratio is less than 0.4 dB. Both of the maximum variations occur at band edges. At the design frequency, the reported gain values are 6.06 and 6.08 dBi, with front-to-back values of 10.6 and 10.7 dB.

In many ways, the gain curve resembles the corresponding curve for the hatted Yagi. The peak gain value occurs just within the 40-meter band. The slope is also similar as we increase the operating frequency. The key difference is that the average gain across the band is about 0.5 dB lower with the U-shaped elements.

With the U-shaped Yagi elements, the front-to-back ratio is 3 to 4 dB lower than with end hats. The peak value is only about the same as for the full-size Yagi. However, unlike the full-size Yagi, the U-shaped Yagi shows front-to-back values that decrease relatively rapidly both above and below the peak frequency.

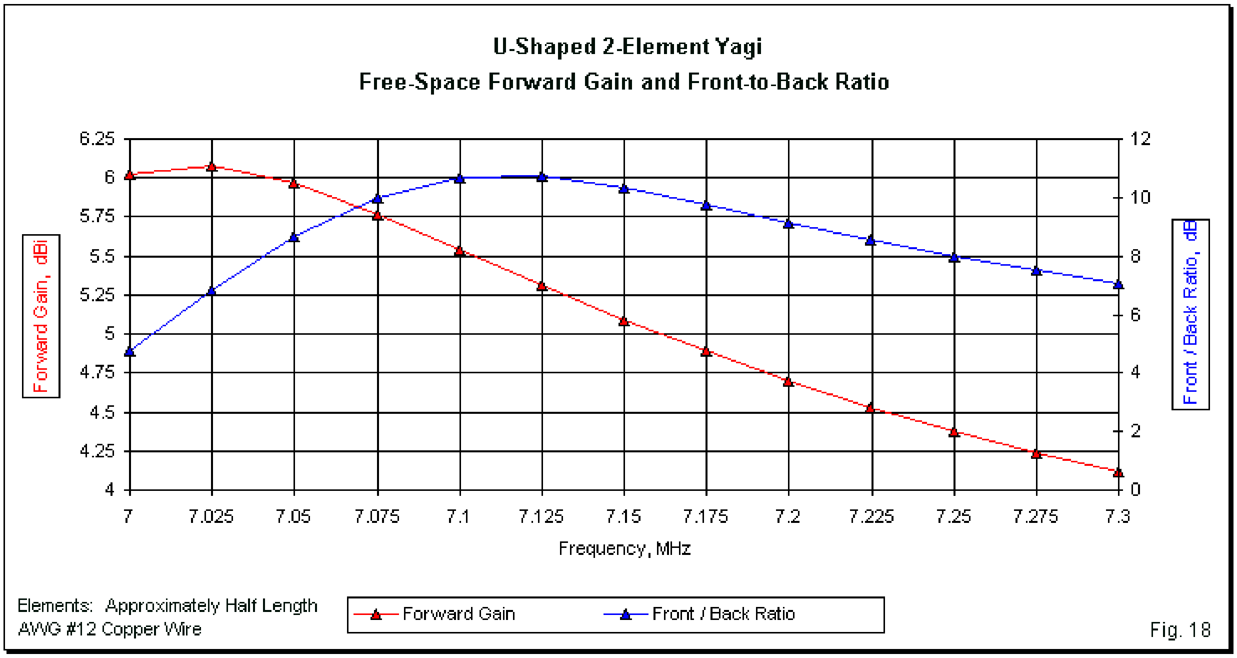


Fig. 18

The vertical legs of the U-shaped elements provide the key reason why the Yagi does not reach the peak front-to-back values of the other beam with shortened main elements. In the end-hatted Yagi, there is almost no radiation from the end assembly. However, the vertical legs of the U-shaped Yagi show considerable current. The legs therefore radiate to some degree endwise to the element center sections, reducing both the front-to-side nulls and the overall beam front-to-back ratio.

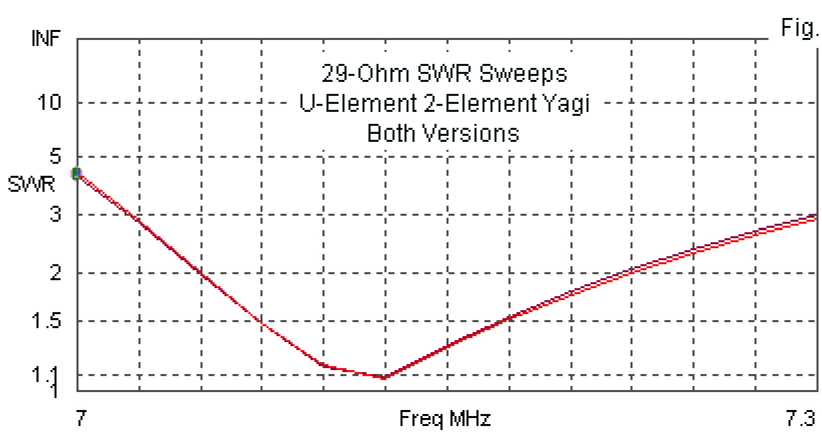


Fig. 19

To confirm the electrical identity of the two versions of the U-shaped Yagi, **Fig. 19** overlays the 30-Ω SWR sweeps for both versions. The curves are very similar to those for the end-hatted Yagi, but the 2:1 SWR passband extends only from 7.05 to 7.225 MHz. This 175-kHz span covers about 58% of the band, as it is defined for U.S. operation. The passband is certainly wide enough to cover the smaller European version of the 40-meter band.

The consequences of radiation from the vertical legs of the U-shaped Yagi appear clearly in the gallery of free-space E-plane patterns in **Fig. 20**. As we increase the operating frequency across the band, the front-to-side ratio steadily decreases from about 22 dB down to barely 12 dB. There is no significant difference between the pattern shapes for the two different versions of the array, since the differences in leg length are relatively small.

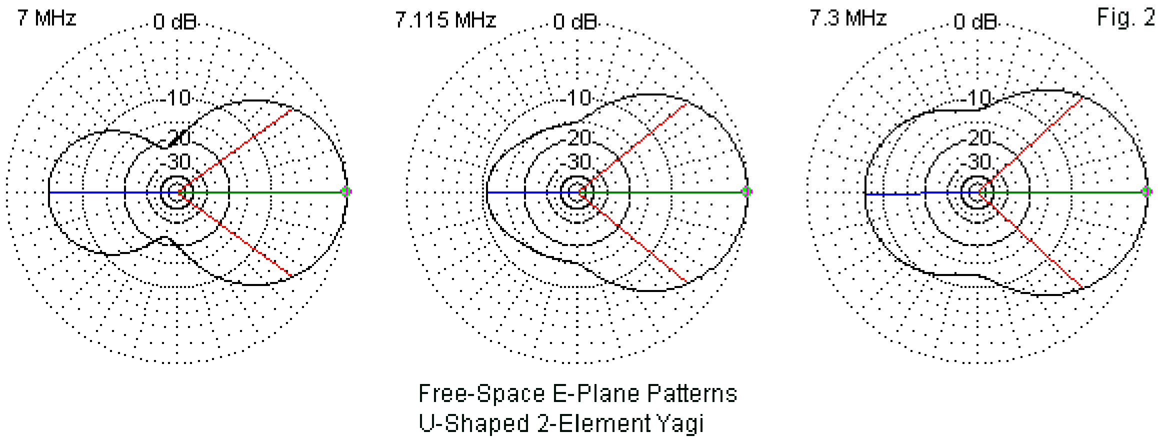


Fig. 20

Free-Space E-Plane Patterns
U-Shaped 2-Element Yagi

Although limited in performance relative to the end-hatted Yagi, the U-shaped parasitic array has a key advantage: structural simplicity. The vertical legs require some form of pinning to hold them in position and their tips must be well above a height that anyone can reach under any circumstances. Nevertheless, they add no support requirements, since the single-wire legs add very little weight to the two elements.

The VK2ABQ Square

There is a way to employ U-shaped elements horizontally and to remain close to the specified half-length center sections. The Moxon rectangle has become one of the standard monoband 2-element parasitic beams over the last 2 decades. The Moxon has, when properly designed, a direct 50-Ω feedpoint and would cover 40 meters with less than a 2:1 SWR ratio. The Moxon consists of two elements folded so that the tails of each element point toward a common point, with a precise gap between the ends of the tails. It makes use of the parallel (inductive) coupling between the long sections of the elements and the tip-to-tip (capacitive) coupling between the ends of the tails. While a Moxon rectangle is always a useful wire beam to consider, it violates our basic requirement that restricts us to elements about half as long as a linear full-size element. Moxon elements are about 70% of full-size when measured from one side of the beam to the other.

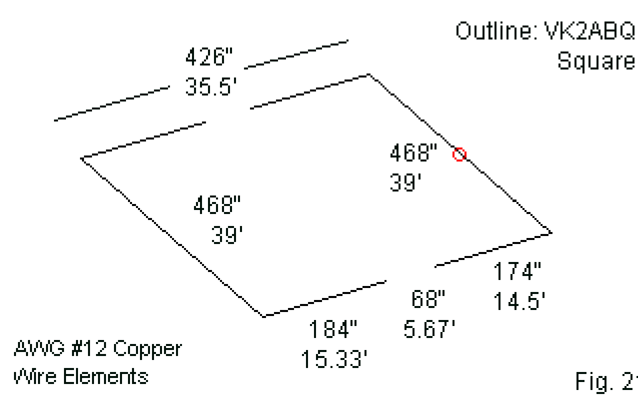


Fig. 21

Fig. 21 presents an alternative to the standard Moxon rectangle in the form of a beam that actually provided the foundation for the rectangle. The VK2ABQ square uses the same general principles as the Moxon, but with a shape that is more nearly square. The dimensions show the imperfection of the square shape necessitated by the process of optimizing the array for maximum performance. The foundation of the array in two U-shaped elements is clearly apparent.

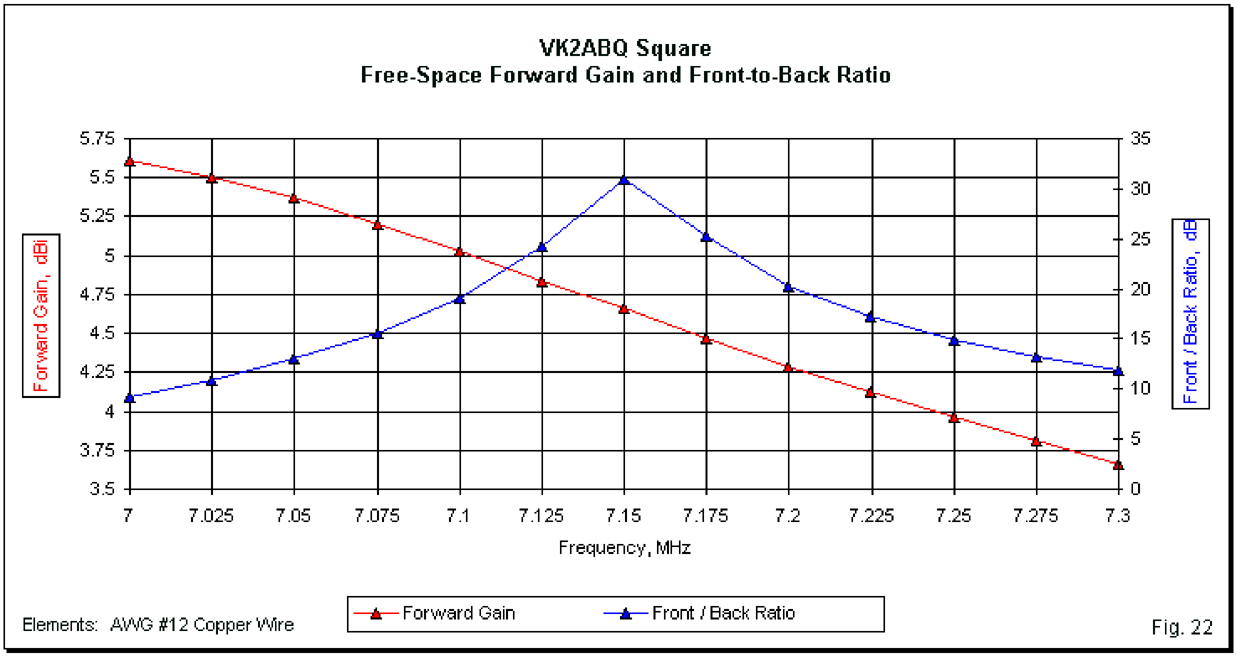


Fig. 22

Like any 2-element driver-reflector array, the square shows a descending gain curve, traced in **Fig. 22**. The square shape yields less gain than the rectangular Moxon shape in which the parallel high-current sections of the elements are more closely spaced. Like the Moxon, the square exhibits the very high peak front-to-back ratio at the design frequency. Although the values fall sharply both above and below the design frequency, the values are fairly good at both ends of the band

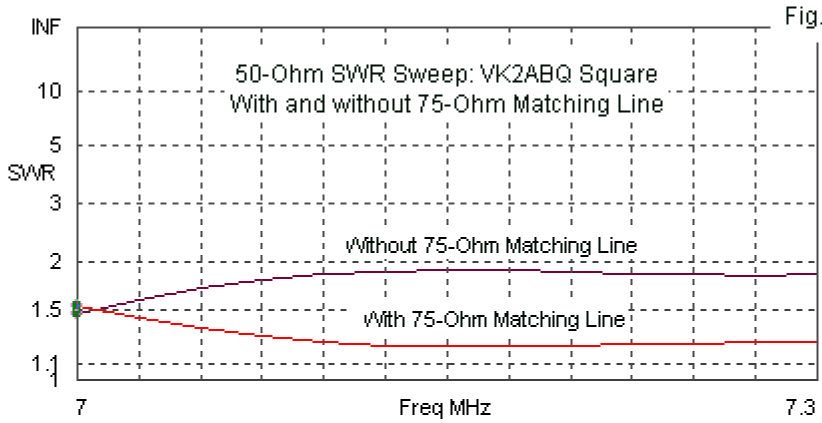


Fig. 23

The SWR sweep in **Fig. 23** provides two 50-Ω curves. One line tracks the SWR at the antenna feedpoint, which shows a 95-Ω impedance at the design frequency. However, the square shape demonstrates one of its key advantages. The impedance does not change significantly from one end of the band to the other. Hence, the curve is very flat. The lower curve results from adding a 75-Ω matching section that transforms the somewhat high antenna feedpoint impedance to a lower value. At the 7.15-MHz design frequency, the transformed impedance is about 60 Ω using a ¾ λ section of 75-Ω cable. Any odd multiple of a quarter wavelength (accounting for the line's velocity factor) will perform the necessary transformation.

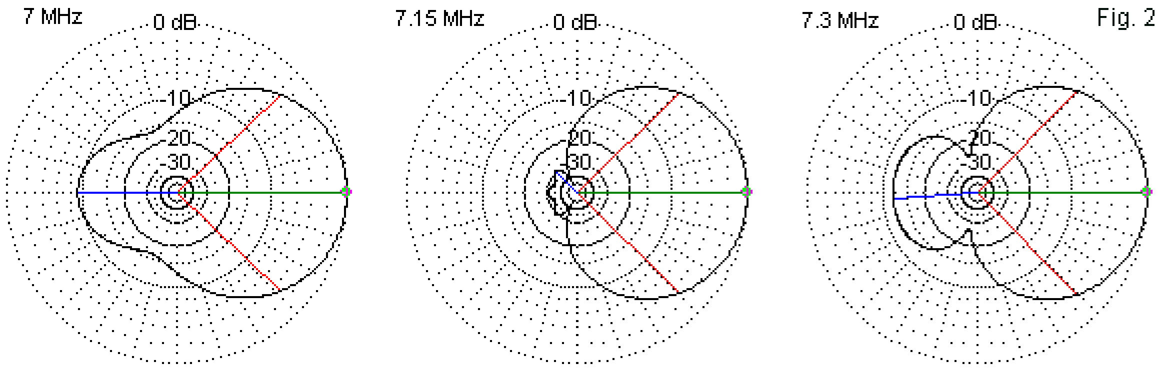


Fig. 24

Free-Space E-Plane Patterns
VK2ABQ Square

Fig. 24 provides a selection of free-space E-plane patterns across the 40-meter band. The evolution of the rearward lobe structure is clearly apparent. In all cases, radiation from the tails of the horizontal U-shaped elements is apparent. It shows up in the displacement of the side null. Even inductively loaded Yagis show a side null at about 90° to the main forward direction. However, the side null for the VK2ABQ square is closer to 120° away from the main forward heading of the array. Be certain to read the patterns in conjunction with the graph of gain levels, since each pattern is normalized.

Although the VK2ABQ square has lesser gain than either the hatted Yagi or the U-shaped Yagi, it offers full-band coverage with significant directivity and a very tame SWR curve. It requires 4-corner support, but a similar requirement attaches to virtually all of the wire beams that we have examined in these notes.

Conclusion

We have explored a fair sample—but certainly not all possible—parasitic beams using a driven element and a reflector that meet our basic requirement of needing only about half the linear space of a full-size Yagi. Each version has some advantages and disadvantages, but the weight that we assign them depends upon our operating needs and desires. More significantly, as we varied the technique for forming a directive beam, we discovered that we could overcome many limitations of using half-length elements. Unfortunately, we cannot overcome all of the limitations within a single design. The more familiar that we are with the variations, the better chance that we have to make the correct selection for our particular installation site and operating goals.