Reversible Wire Beams for Lower HF Use

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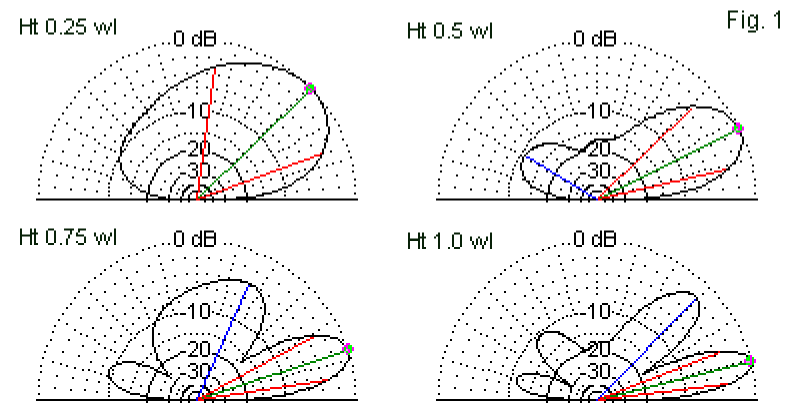
Rotatable directional beams for the lower HF region (from 30 meters downward) tend to be rare, heavy, and expensive. Many operators choose instead to use wire beams, despite their fixed orientation. One partial way around the limitation is to build a reversible wire beam. We can accomplish this feat with varying degrees of electrical complexity by switching sections of elements or using loading components.

In these notes, we shall examine 5 different but inter-related ways of achieving the goal of reversibility with the minimum of complexity. Some designs may require more real estate, but basic construction will only involve stringing and supporting elements. Any remote switching that we do will occur outside the antenna geometry. We shall look at two designs that use shorted stubs to load driver elements to become electrically long enough to serve as reflectors in 2-element beams: one Moxon rectangle and one Yagi. Then we shall look at an alternative reversible 2-element Yagi that requires 3 wires. The next step is to extend that technique to a 3-element Yagi with 5 wires. Finally, we shall reduce the wire count to 4, using an idea passed along to me by Bill Desjardins, W1ZY.

Some Directional Beam Basics

Although we may apply the general ideas in these notes to any of the bands in the lower HF region (or even to 160 meters), we shall focus on 40 and 30 meters, using test frequencies of 7.15 and 10.125 MHz. 30 meters is a band that is ideal for a reversible wire beam, because we can usually manage a 50-foot height. However, the band is so narrow that we do not receive a full impression of wire-beam capabilities and limitations unless we also include 40 meters.

One limitation of horizontal beams is strictly frequency-related. The height of a beam determines to a significant measure its performance potential, and we measure the height in wavelengths. In the lower HF region, height is normally a fraction of a wavelength, since even at 30 meters, a wavelength is about 100'. At 40 meters, that same 100; is only about 0.7-wavelength. **Figure 1** shows selected elevation patterns at different heights from 0.25 wavelength up to 1.0 wavelength for a 2-element Yagi. At the lowest height, the beam is best used as a directional NVIS antenna. The lowest usable height for reliable DX work may be about 3/8-wavelength **Table 1** provides performance data at 0.125-wavelength increments.



Effects of Beam Height on Its Elevation Pattern

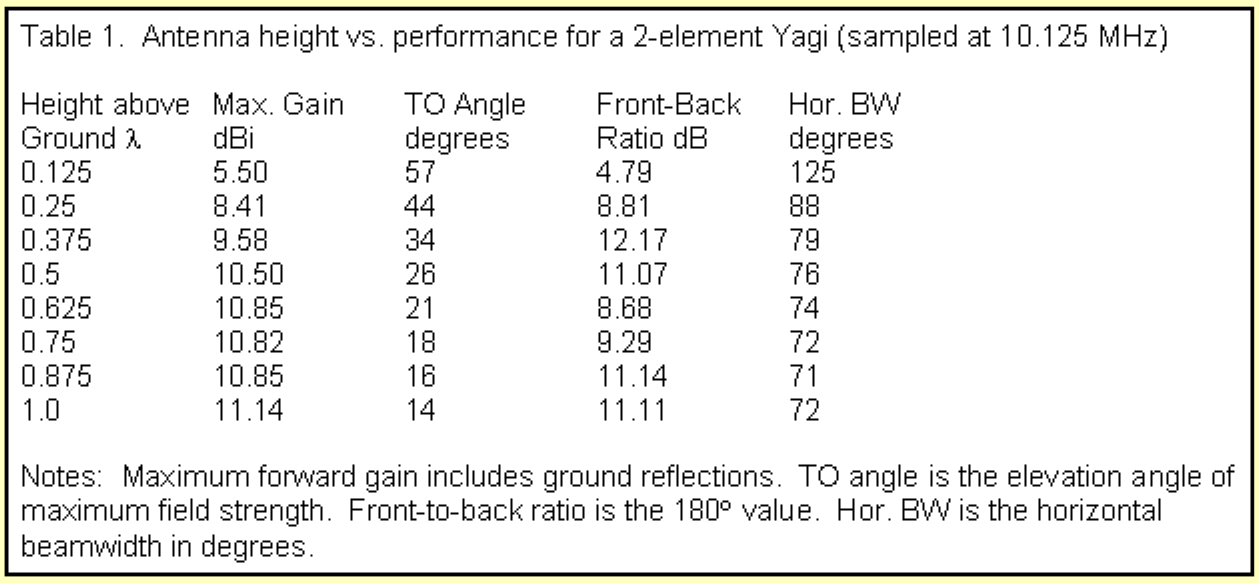


Table 1. Antenna height vs. performance for a 2-element Yagi (sampled at 10.125 MHz)

Height above Ground λ	Max. Gain dBi	TO Angle degrees	Front-Back Ratio dB	Hor. BW degrees
0.125	5.50	57	4.79	125
0.25	8.41	44	8.81	88
0.375	9.58	34	12.17	79
0.5	10.50	26	11.07	76
0.625	10.85	21	8.68	74
0.75	10.82	18	9.29	72
0.875	10.85	16	11.14	71
1.0	11.14	14	11.11	72

Notes: Maximum forward gain includes ground reflections. TO angle is the elevation angle of maximum field strength. Front-to-back ratio is the 180° value. Hor. BW is the horizontal beamwidth in degrees.

Note that the rise in forward gain is not smooth as we increase height. As well, the front-to-back ratio fluctuates with height, reaching its maximum value at ½-wavelength intervals beginning at 3/8 wavelength (with the second maximum value at about 7/8 wavelength. The value curves grow ever smoother as we exceed a 1-wavelength height, but such heights are impractical for most reversible wire beam builders.

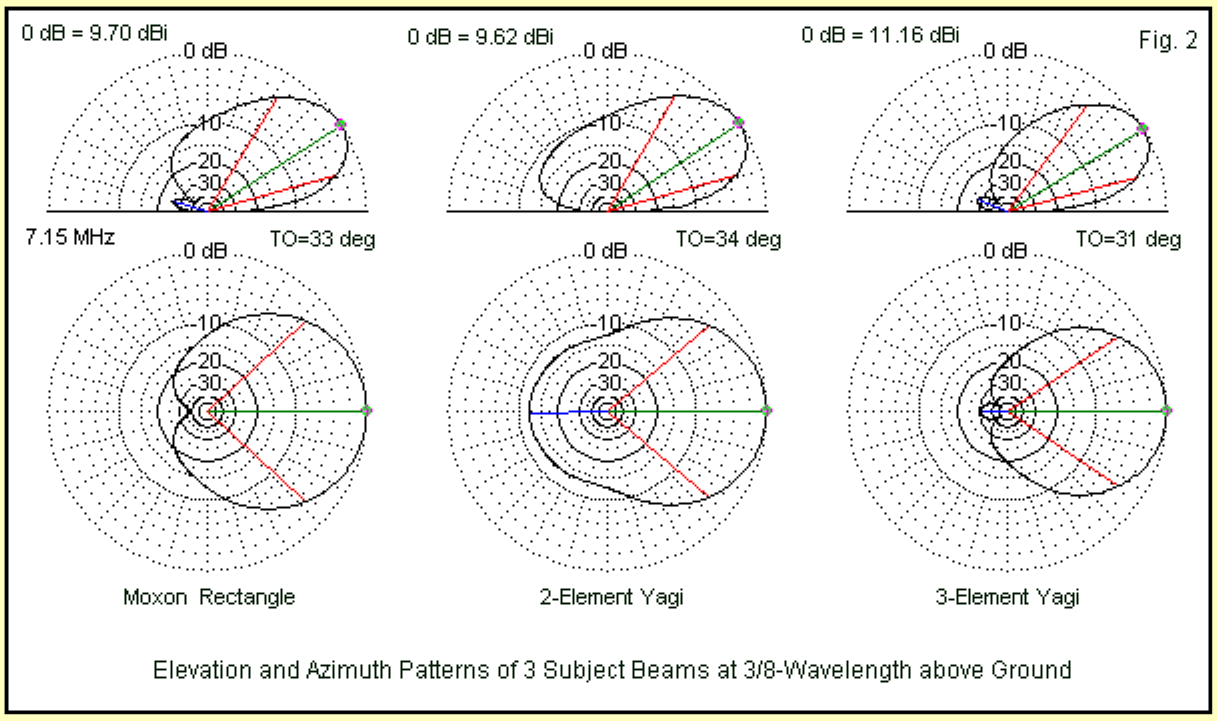


Fig. 2

Moxon Rectangle

2-Element Yagi

3-Element Yagi

Elevation and Azimuth Patterns of 3 Subject Beams at 3/8-Wavelength above Ground

The performance that we can obtain depends on the beam that we select. Most wire antenna beam builders choose a directional beam over a bi-directional antenna to obtain freedom from rearward QRM. Different beam designs are better or worse in this department. **Figure 2** shows the elevation and azimuth patterns of 3 different beams at a height that maximizes the front-to-back ratio: 3/8 wavelength. The standard 2-element Yagi barely achieves 12 dB. The Moxon rectangle and the 3-element Yagi do far better. Similar relationships would show up at all heights, but the patterns for a height of 3/8-wavelength are simply more vivid. As we shall see, however, the front-to-back ratio will not be our only consideration if we choose to build a reversible beam.

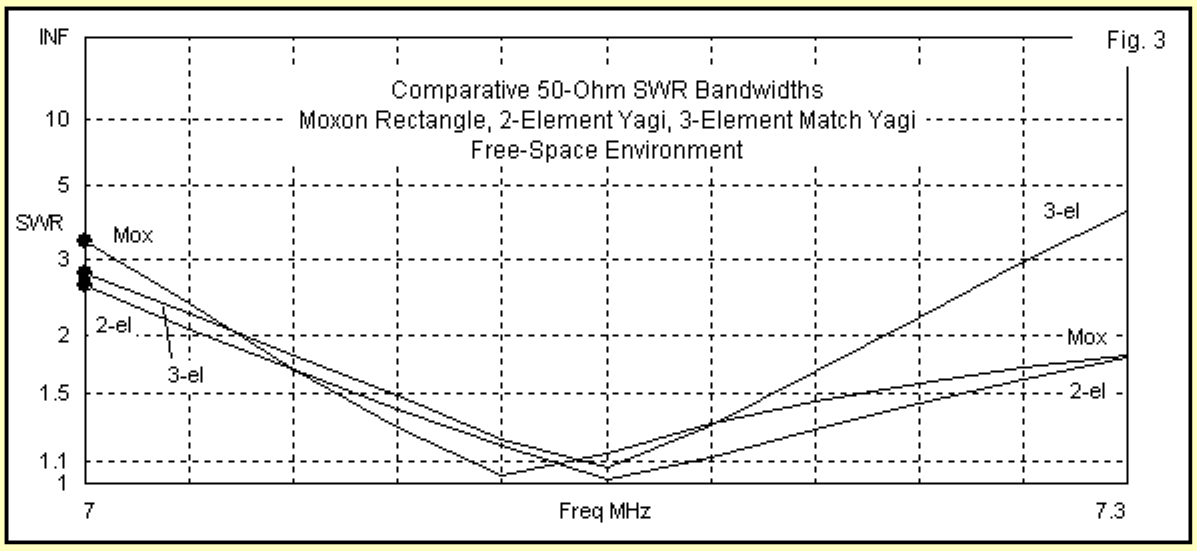


Fig. 3

Comparative 50-Ohm SWR Bandwidths
Moxon Rectangle, 2-Element Yagi, 3-Element Match Yagi
Free-Space Environment

All wire beams will fail to cover a band as wide as 40 meters. **Figure 3** overlays 50-Ohm SWR patterns for the 3 subject beams. The Moxon rectangle and the 2-element Yagi have natural 50-Ohm feedpoint impedances. For greater gain in the 3-element Yagi, I selected a design with a 30-Ohm feedpoint impedance and fitted it with a Regier series matching system using 50-Ohm and 75-Ohm cables to arrive at 50 Ohms. However, the SWR curve does not significantly change its 2:1 SWR bandwidth in the conversion. All three beams manage to cover a little over half of 40 meters. Hence, for most bands (with the exception of the 50-kHz 30-meter band), the builder will have to select the preferred portion of the band. Unlike simple dipoles, the directional beams will change their gain and front-to-back properties with frequency within any of the wider bands. 2-element (reflector-driver) beams shows a descending gain value with rising frequency, while a beam with at least one director will show a rising gain value with increasing frequency. Perhaps the more critical parameter is the front-to-back ratio, which tends to go to pot for the subject beams at about the limits of the 2:1 SWR values.

The final factor that limits the utility of a reversible beam is geographic. Reversible beams are useful only if there are desired communications target areas at approximate 180° bearings relative to the beam. In Tennessee, a reversible beam would cover most of Europe on one side and the VK and ZL regions in the other. Only if you are comparably situated should you consider a reversible beam.

The Survey Elements

Our short survey of techniques of easily reversing beams will use 4 elements. Of course, there will be text, along with a general outline of the beam under discussion. The outline graphic will also show a free-space E-plane pattern for reference and comparison apart from any particular height above ground. We shall also examine parts of two tables. **Table 2** lists the dimensions of each beam, while **Table 3** provides free-space performance data at the design frequencies.

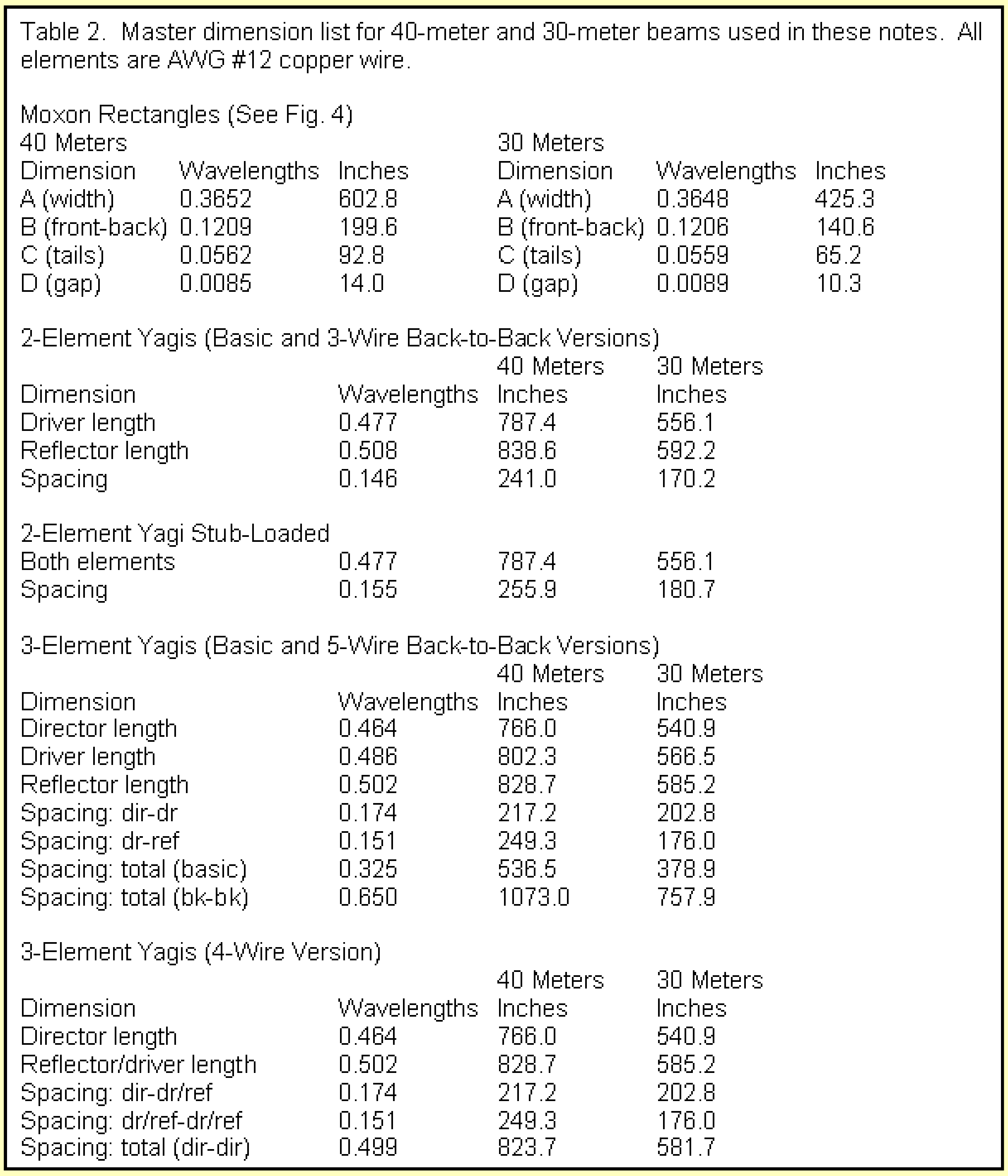


Table 2. Master dimension list for 40-meter and 30-meter beams used in these notes. All elements are AWG #12 copper wire.

Moxon Rectangles (See Fig. 4)

40 Meters Dimension	Wavelengths	Inches	30 Meters Dimension	Wavelengths	Inches
A (width)	0.3652	602.8	A (width)	0.3648	425.3
B (front-back)	0.1209	199.6	B (front-back)	0.1206	140.6
C (tails)	0.0562	92.8	C (tails)	0.0559	65.2
D (gap)	0.0085	14.0	D (gap)	0.0089	10.3

2-Element Yagis (Basic and 3-Wire Back-to-Back Versions)

Dimension	Wavelengths	40 Meters Inches	30 Meters Inches
Driver length	0.477	787.4	556.1
Reflector length	0.508	838.6	592.2
Spacing	0.146	241.0	170.2

2-Element Yagi Stub-Loaded

Both elements	0.477	787.4	556.1
Spacing	0.155	255.9	180.7

3-Element Yagis (Basic and 5-Wire Back-to-Back Versions)

Dimension	Wavelengths	40 Meters Inches	30 Meters Inches
Director length	0.464	766.0	540.9
Driver length	0.486	802.3	566.5
Reflector length	0.502	828.7	585.2
Spacing: dir-dr	0.174	217.2	202.8
Spacing: dr-ref	0.151	249.3	176.0
Spacing: total (basic)	0.325	536.5	378.9
Spacing: total (bk-bk)	0.650	1073.0	757.9

3-Element Yagis (4-Wire Version)

Dimension	Wavelengths	40 Meters Inches	30 Meters Inches
Director length	0.464	766.0	540.9
Reflector/driver length	0.502	828.7	585.2
Spacing: dir-dr/ref	0.174	217.2	202.8
Spacing: dr/ref-dr/ref	0.151	249.3	176.0
Spacing: total (dir-dir)	0.499	823.7	581.7

All modeled wire beam designs in **Table 2** use AWG #12 copper wire. Design techniques call for slightly different dimensions for the 30- and 40-meter Moxons, even when one measures the elements in terms of wavelengths. However, for the wire Yagis, you may use the same dimensions in wavelengths on both bands. If you design the Yagis for 40 meters, you may simply scale the element lengths and the spacing values for 30 meters. The failure to compensate for the constant element diameter only lowers the resonant frequency a bit on 30 meters, but the 50-Ohm SWR does not reach 1.5:1 on this narrow band. On 40 meters, the design frequency is 7.15 MHz. You may rescale the design upward or down ward within the band without regard to the element diameter and not incur any adverse effects.

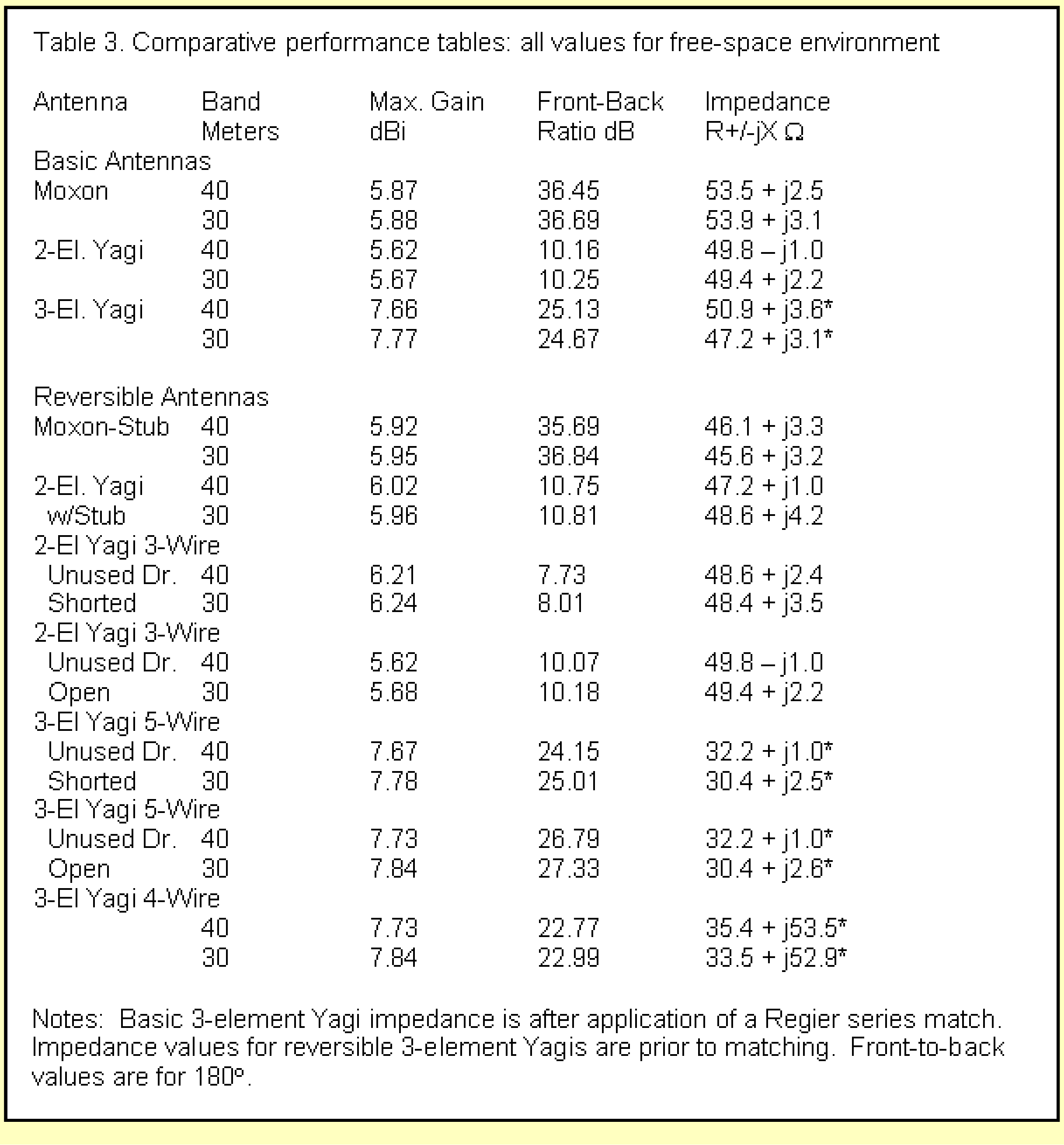


Table 3. Comparative performance tables: all values for free-space environment

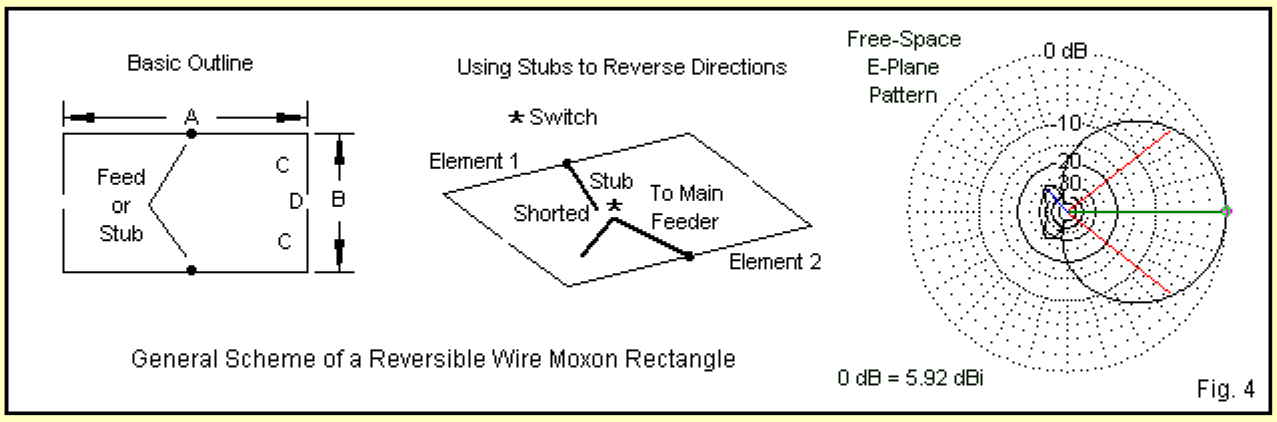
Antenna	Band Meters	Max. Gain dBi	Front-Back Ratio dB	Impedance R+/-jX Ω
Basic Antennas				
Moxon	40	5.87	36.45	53.5 + j2.5
	30	5.88	36.69	53.9 + j3.1
2-El. Yagi	40	5.62	10.16	49.8 – j1.0
	30	5.67	10.25	49.4 + j2.2
3-El. Yagi	40	7.66	25.13	50.9 + j3.6*
	30	7.77	24.67	47.2 + j3.1*
Reversible Antennas				
Moxon-Stub	40	5.92	35.69	46.1 + j3.3
	30	5.95	36.84	45.6 + j3.2
2-El. Yagi	40	6.02	10.75	47.2 + j1.0
w/Stub	30	5.96	10.81	48.6 + j4.2
2-El Yagi 3-Wire				
Unused Dr.	40	6.21	7.73	48.6 + j2.4
Shorted	30	6.24	8.01	48.4 + j3.5
2-El Yagi 3-Wire				
Unused Dr.	40	5.62	10.07	49.8 – j1.0
Open	30	5.68	10.18	49.4 + j2.2
3-El Yagi 5-Wire				
Unused Dr.	40	7.67	24.15	32.2 + j1.0*
Shorted	30	7.78	25.01	30.4 + j2.5*
3-El Yagi 5-Wire				
Unused Dr.	40	7.73	26.79	32.2 + j1.0*
Open	30	7.84	27.33	30.4 + j2.6*
3-El Yagi 4-Wire				
	40	7.73	22.77	35.4 + j53.5*
	30	7.84	22.99	33.5 + j52.9*

Notes: Basic 3-element Yagi impedance is after application of a Regier series match. Impedance values for reversible 3-element Yagis are prior to matching. Front-to-back values are for 180°.

The free-space performance values in **Table 3** allow a direct comparison from one beam's potential to another's. The top section of the table provides data on the modeled performance of non-reversible forms of each beam to permit an evaluation of the performance of reversible versions. You may revise the EZNEC models for the options to place each beam at the height that you plan to use before you reach any final conclusions. The Yagi performance data include some special entries labeled "Unused Driver Open" and "Unused Driver Shorted." We shall explain those notations as we move through the various Yagi designs.

The Stub-Loaded 2-Element Moxon Rectangle

The Moxon rectangle is a 2-element driver-reflector parasitic beam that uses two forms of element coupling to arrive at the design-frequency patterns shown in **Figure 4**. Not only do we have coupling between the parallel portions of the elements, but as well between the ends of the element tails. For versions of the rectangle requiring a 50-Ohm feedpoint impedance and using a uniform element diameter throughout, a design aid is available in the form of a spreadsheet at http://www.cebik.com/content/trans/ant-design.html. (The spreadsheet also contains design aids for monoband quad beams and 3-element Yagis.)



General Scheme of a Reversible Wire Moxon Rectangle

Fig. 4

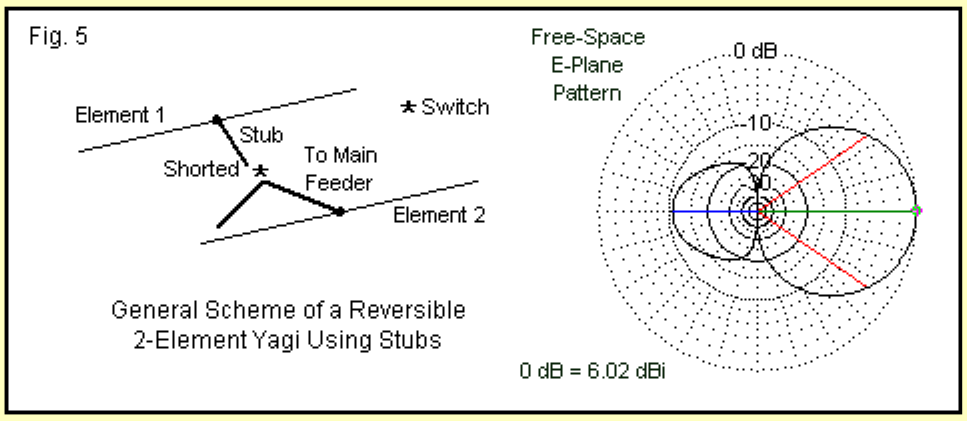
Ordinarily, the Moxon rectangle reflector tails are longer than shown in **Figure 4** and in **Table 2**. However, to make the beam reversible, we use two identical driver elements along with the prescribed gap between element tails. To the center of each element we connect a section of 50-W coaxial cable. At any one time, one section of cable connects to the main feedline, also a 50-Ohm cable. The other section we short to form a j65-Ohm inductive reactance. At 40 meters, the stub's electrical length is 240.4", while at 30 meters, the electrical length is 169.8". Both lengths of coax are more than long enough to reach a center point, even using a cable with a 0.66 velocity factor (and shortening the physical length accordingly). Since the cables are for independent elements, a remote DPDT switch or relay changes each coax function. It is possible to use long lines that reach the shack for these functions. By careful calculation (including the line's velocity factor), we can determine long line lengths that will serve as the required stub. In fact, we can also make the lines long and tune out the excess inductive reactance with a capacitor. This type of system would place all switching inside the warmth of the shack. However, these refinements are beyond the scope of these introductory notes.

As shown in the performance data in **Table 3**, the one drawback of using stubs to reverse the direction of a wire Moxon rectangle is a decrease in the feedpoint impedance. The resistive impedance drops by about 8 Ohms relative to an independent version of the antenna. Squaring the rectangle a small amount by shorting dimension A and increasing the tail length, C, of both elements would raise the impedance, but at a slight cost in forward gain, plus a refiguring of the required shorted stub reactance.

The Stub-Loaded 2-Element Yagi

We may apply the same technique to a 2-element Yagi, as shown in **Figure 5** and in the tables. Because we wish to preserve the 50-Ohm impedance of the array once we install a coax section on each driver element, we increase the element spacing from 0.146 wavelength to 0.155 wavelength. The shorted reflector stub provides j75 Ohms inductive reactance. On 40 meters, the coax (electrical) length is 258.8", while on 30 meters, the length is 182.3". The two coaxial cable lengths allow an easy mid-point meeting for switching cable functions from driver to stub and back again, even allowing for the line velocity factor.

Fig. 5



General Scheme of a Reversible 2-Element Yagi Using Stubs

The switched version of the antenna slightly outperforms the independent 2-element Yagi for interesting reasons. First, the physical proportions of the elements differ. Second, a loaded reflector provides slightly better front-to-back values than a full-size reflector. Nonetheless, we would be very hard pressed to notice the difference in operation.

Whether you choose a Moxon rectangle or a Yagi, the stub-loaded switched beam provides the most compact route to a reversible beam. I have seen 3-element Yagis with switched elements, normally a function swap between the director and the reflector. Often such beam use open stubs for the director to provide capacitive reactance to shorten the element's electrical length. The driver remains unswitched. Hence, each parasitic element switches between open and shorted modes, with potential length changes for each mode. Since these cables are weighty, some designs have used lumped components. In most cases, the switch systems are more complex than the ones used for the 2-element beams. As well, few Yagi 3-element designs provide peak performance with equal spacing between each pair of elements, and very often they also require a matching network to raise a low feedpoint impedance (perhaps 25 Ohms) to the main feedline value. We may keep our switching simple if we have enough land to add some further wire elements.

The 3-Wire 2-Element Yagi

One way to simplify switching is to begin with a common reflector element. For 2-element Yagis, we then add a driver on each side of the reflector. As shown in **Table 2**, the spacing of the elements returns to the value of the independent beam. The net result, as shown in **Figure 6**, is essentially two 2-element Yagis with a common reflector. Instead of switching loading stub lines, this design simply switches the feedline. We can handle this task at the antenna level or we can bring the two feedlines to the shack and use a simple mechanical switch.

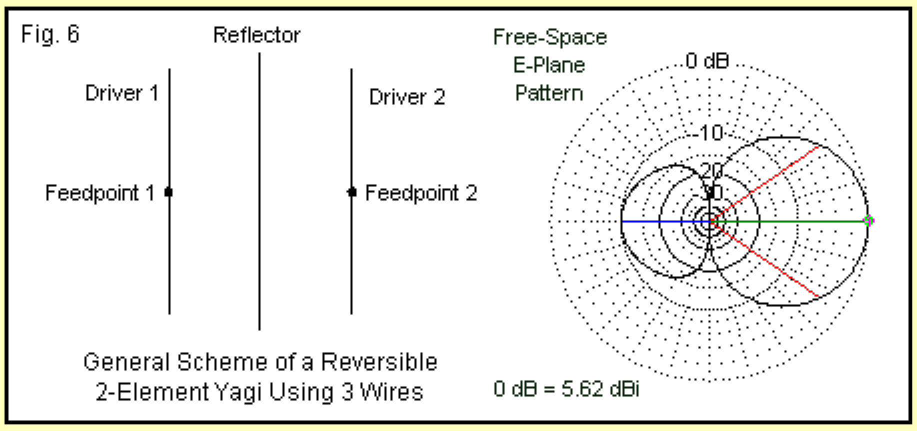


Fig. 6

General Scheme of a Reversible 2-Element Yagi Using 3 Wires

The 2-element reflector-driver Yagi has a limitation. As shown by the modeled data in **Table 3**, the performance changes according to whether the unused driver is shorted across the feedpoint or left open. The open connection provides the better front-to-back ratio. (The free-space E-plane pattern in **Figure 6** shows the results of an open unused driver.) When the front-to-back ratio depends wholly on a reflector element, the unused element exerts a greater effect on the reflector performance (that is, on the current magnitude and phase angle), than when we have a parasitic beam with at least one director.

Obtaining an open condition in the unused driver is a simple matter electrically if we switch at the antenna level. However, the arrangement may prove to be mechanically complex. We may also achieve the desired condition with a switch at the shack end of the feedlines if we attend to the cable lengths. If the feedlines are an odd multiple of a quarter-wavelength, then shorting the unused line will produce an open circuit at the feedpoint. An even multiple of a quarter-wavelength will require an open line end to yield an open circuit at the feedpoint. (In calculating the line lengths, of course, be sure to include the line's velocity factor.)

The 5-Wire 3-Element Yagi

The 3-wire reversible beam for 2-element Yagis becomes a 5-wire reversible beam for 3-element Yagis. Such an array requires considerable open ground, as the dimensions in Table 2 and the outline in **Figure 7** reveal. In the process, we gain an advantage but acquire a disadvantage.

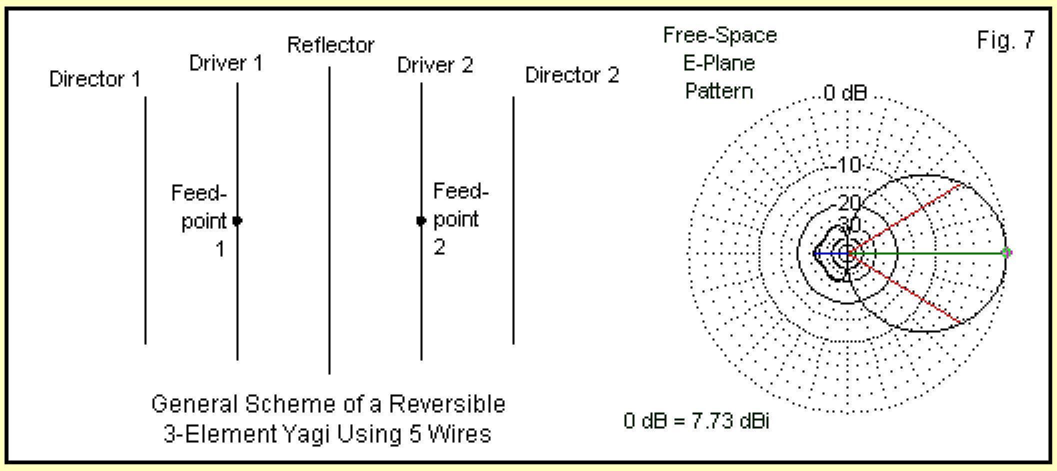


Fig. 7

General Scheme of a Reversible 3-Element Yagi Using 5 Wires

The "bad" news first: to make the effort of installing a 3-element wire beam worthwhile, we need to select a design that provides significant gain over the 2-element Yagis. The data in **Table 3** show that the design provides 1.5 to 2 dB additional forward gain over either 2-element beam. In the process, the feedpoint impedance drops to about 30 Ohms. Therefore, we require a matching system to reach 50 Ohms in order to achieve the widest possible operating bandwidth. We can easily achieve the match using common 50-Ohm and 75-Ohm coaxial cable sections in a Regier series match. We shall not go into the required calculations for this type of match in this set of notes. However, you can download a spreadsheet that includes the Regier series match within a collection of common matching systems at http://www.cebik.com/content/trans/ant-match.html. (The collection includes 3 types of series matches, the beta match, 2 versions of gamma-match calculations, and the matchline-and-stub system. Like the antenna design aid, the spreadsheet appears in both Quattro Pro and Excel formats.) The series matching system transfers matching complexities from the feedpoint junction to the transmission line itself. Therefore, it adds no further weight to the system.

The "good" news is that the front-to-back ratio of a 3-element Yagi is largely a function of the director and not the reflector element. Therefore, as is clear from the data in **Table 3**, the state of the unused feedpoint makes almost no difference to the array performance in either direction. With a series match in place, it is likely that switching at the shack may be the easiest way to handle directional changes for the array.

The 4-Wire 3-Element Yagi

W1ZY determined that he did not have the real estate needed for the 5-wire beam. He also reasoned that he could feed the driver with parallel transmission line and use his antenna tuner to arrive at the impedance needed by his equipment. Therefore, he opted for the scheme shown in **Figure 8**. As the free-space E-plane pattern suggests, he lost no performance in his truncated 4-wire version of the reversible 3-element Yagi.

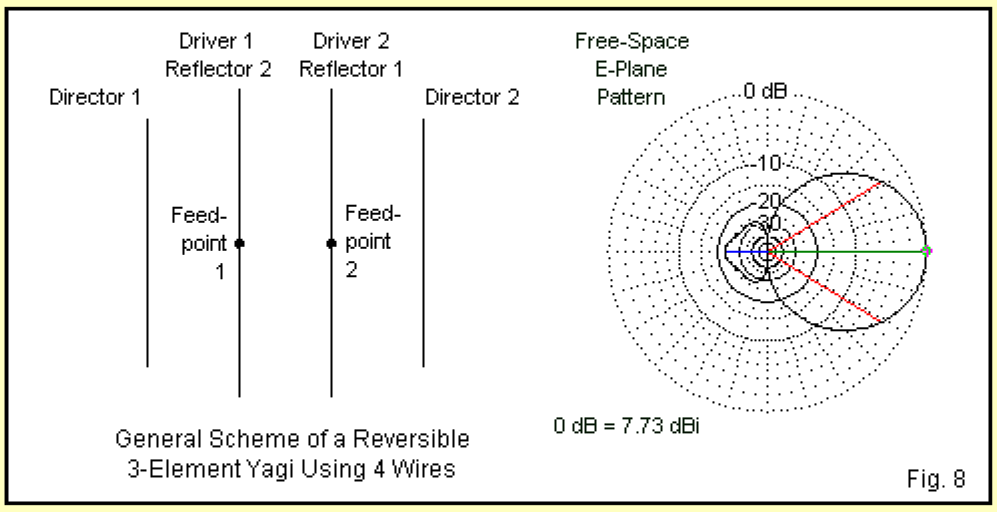

General Scheme of a Reversible 3-Element Yagi Using 4 Wires

Fig. 8

The dimensions in **Table 2** reveal that the elements consist of 2 directors and 2 "reflectors." I place the word reflector in quotation marks, because each of these two elements trades functions as we swap directions. One of the two elements becomes a reflector. The element between it and a director becomes the driver. The driver length makes little difference to beam performance. (In fact, J-poles have been used as 3-element Yagi drivers.) Driver length becomes critical only if we are seeking a particular feedpoint impedance. In this design for a reversible beam, parallel feedline allows the use of a driver impedance with a considerable reactive component. Therefore, we may do the work of 5 elements with only 4 and still obtain full 3-element Yagi performance in each direction.

For optimal performance, we must observe some cautions with the 4-wire reversible beam. First, in order to function correctly as a reflector, the unused driver must be shorted across the feedpoint by a relay or by a precisely cut line. With the reflector open at the center, the beam loses almost a full dB of forward gain and most of the high front-to-back ratio shown in the free-space E-plane pattern in **Figure 8**.

Second, as the SWR increases at the feedpoint, even low-loss parallel lines begin to show detectable losses. The values at the feedpoint (about 35 + j50 Ohms) are not fatal. But losses over a 100' length of line may exceed 0.5 dB. As well, the values that appear at the tuner terminals may exceed the matching range. At 40 meters, the use of one of the modern low-loss coax cables may prove to match parallel line loss with an easier match at the tuner. In addition, the low-loss coax lines need no spacing between each other to prevent unwanted coupling. Nevertheless, in both cases, the lines require cutting to a length that-with the switching system used-will ensure a closed circuit at the active reflector (inactive driver) center.

Conclusion

We have looked at 5 of many variations on the theme of creating a reversible horizontal wire beam for the lower HF region. The options that we explored are among the simplest electrically, although some of them required a considerable open area for implementation. The chief goal of these notes has been to show that for the budget-minder operator with a penchant for using wire, a reversible beam is not only possible, but both feasible and practical.

However much we tried to simplify the designs, we could not eliminate all electrical complexities. A reversible beam requires a switch somewhere along the line to change directions. As well, the unused element or the loading stub require attention to both line length and the switched condition at the line end. These matter are generally considerations that we wrestle with during installation. When operating, we may change directions as quickly as we can flip a switch.

There are numerous variations on the design shown as examples. Perhaps the most common tendency would be to think of the elements in the form of inverted-Vs. This option has two constraints and one advantage. The advantage is the ability to provide a strong support along the centerline for the cable hanging from the elements. One of the constraints is the necessity to redesign the elements to suit the new configuration. To base the design on a few guesses derived from the linear designs shown here or elsewhere seems a bit careless when good design tools are readily available.

The second constraint concerns performance. Inverted-V elements will reduce the front-to-side ratio of the beam patterns. In addition, V elements will also lower the effective height of the antenna. In the lower HF region, we are already height challenged with respect to obtaining a low-enough elevation angle for superior DX performance. At a certain (unspecified) point, lowering the ends of a horizontal beam may elevate the TO angle too much. In such cases, one might wish to consider one of the many directional vertical arrays, especially below 40 meters. Reversible beams are both possible and practical, but they will not overcome the limits that we briefly examined at the beginning of these notes.

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