Notes on Reversible Yagi Arrays

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Many hams in the U.S. are fortunately located so that good amateur radio target area lie in a 180-degree (or close to it) line. In Tennessee, Europe is northeast and Australia and New Zealand are southwest. If I were content to work these regions as my predominant interest, then I would not need a tower, rotator, and the other paraphernalia that goes with a high gain beam. I might set up a bi-directional array, such as an extended Lazy-H. However, if I wish some protection from QRM coming from the wrong direction. I might opt instead for a system of wire Yagis.

The reversible wire Yagi array has been around for a long time. There are many ways to construct such arrays, including fancy switching systems in the wire elements, reflector and director loading stubs, and even reflector and director loading using lumped components. These techniques all use the minimum number of wires and electrically or electro- mechanically alter their electrical lengths within the array. We can either change directions using these methods or we can change the properties to peak performance within a given band.

In these notes, we shall explore some alternatives that trade the complexity of such system for the use of some additional wire.

Wire Yagis are noted by their good performance potential combined with a relatively narrow bandwidth. In exchange for the light weight of AWG #12 or #14 wire, we suffer with a smile the narrower bandwidth characteristics that thin elements provide. As well, thicker elements provide some gain increase due to the larger surface area of the elements. A larger surface area has lower skin-effect losses and allows somewhat higher mutual coupling over a broader frequency range between elements. Parasitic arrays, of course, depend upon the mutual coupling between elements. It is not unfair to think of thin wire arrays as being "half-band" beams on 40 through 20 meters. On 160 and 80, their coverage can be even narrower.

In most cases, stringing one or two extra wires within the space allocated to a wire beam may be easier than arranging for complex switching mechanisms that require weather protection. From this premise arose a different sort of reversible beam based on the fact that wires behind the reflector of a Yagi have little influence on the performance of wires ahead of the reflector. Instead of switching within the wires of a Yagi, let's just build two Yagis back-to-back, using a common reflector.

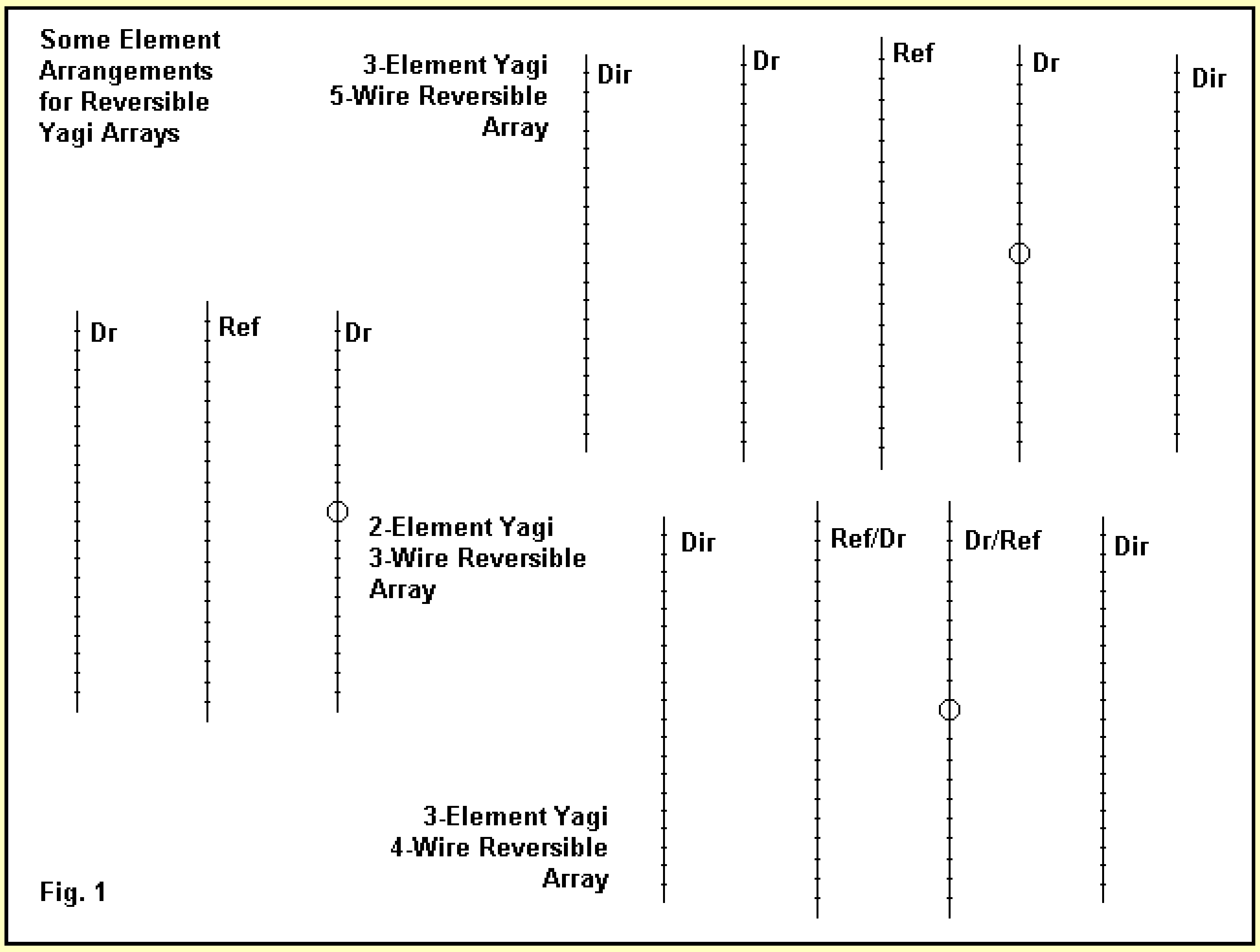
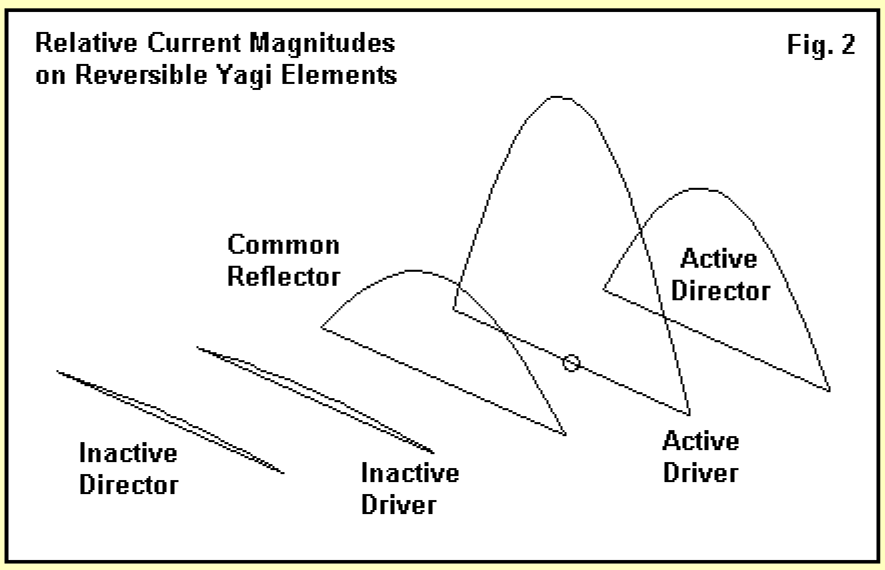


Fig. 1 shows two common and one less common configuration of reversible Yagis. On the left is a 3-wire, 2-element Yagi, consisting of a reflector and a driver for each direction. We can increase performance by using a 5-wire, 3-element reversible Yagi, as shown on the upper right. Under special conditions--that we shall explore later--we might even cut the number of wires to 4 and still have a reversible 3-element Yagi. The lower right portion of the diagram shows the layout and the space that we save by using only 4 wires, since all three outline are approximately the same scale.



It is not difficult to satisfy oneself that a reversible Yagi of this sort actually works. **Fig. 2** shows the relative current magnitudes on each of the elements of a 5-wire array when the right driver is active and radiation is to the right, relative to the sketch. The reflector is normally active, but the inactive driver and inactive director have very low current levels, indicating their relative inertness. If we switch the active driver to the on the left, with radiation also to the left, then the right driver and director would become nearly inert.

The beauty of the system is that to make such a reversible Yagi, we do not need to design from scratch. If we already have a good design for a 2- or 3-element Yagi, we can make a reversible Yagi simply by adding the driver and other elements--if present--on the opposite side of the reflector. We do not need to alter the original Yagi design to achieve the same performance in two directions. (Remember, however, that we do not get the two directions at once, but only serially as we change the active driver.)

A 2-Element, 3-Wire Yagi Array

Among the simplest arrays from which to create a reversible Yagi is the simple reflector-driver version of the Yagi. Although modest in performance, a 2-element Yagi provides very noticeable gain over a wire dipole, along with enough front-to-back ratio to satisfy many operating needs.

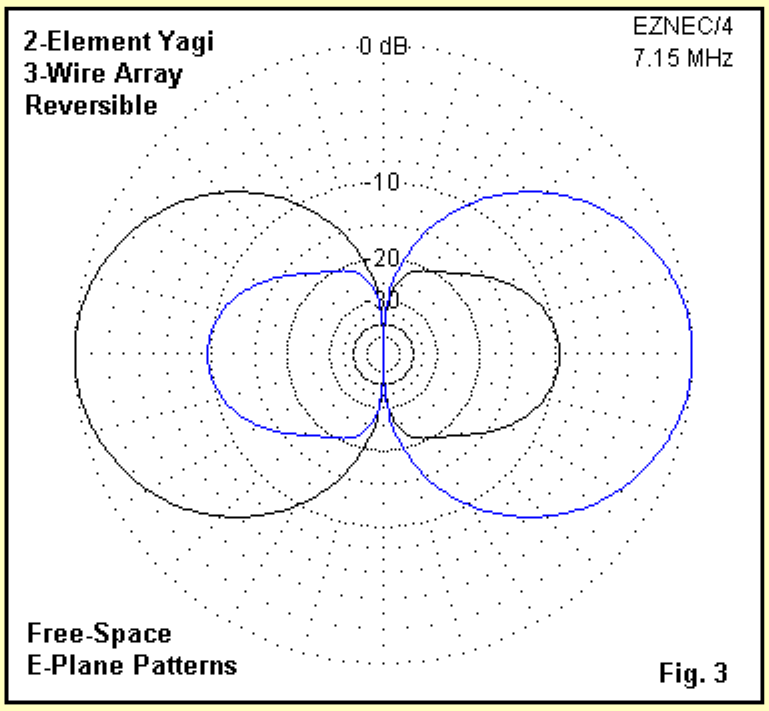


Fig. 3 shows the two patterns of a reversible 2-element Yagi using 3 wires. Although these patterns are representative of performance on any of the HF bands, the examples that we shall use are all designed for 7.15 MHz. The design frequency free-space gain is a bit over 6.2 dBi, with nearly 10 dB of front-to-back ratio.

The dimensions that I used to obtain these values will appear in terms of fractions of a wavelength. This notation will make it simple for anyone to change the design frequency to either the upper or lower end of 40 meters. As well, the values should hold without significant adjustments if we scale them up to 30 or 20 meters or down to 80 meters, all the while using the AWG #12 copper wire of the original design. The only exception to this generalization is that gain will decrease on lower frequency band and increase on higher frequency bands, largely due to the change in wire diameter as a fraction of a wavelength.

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Dimensions of a 3-Wire, 2-Element Yagi Reversible Array

Element	Length (wl)	"Boom" Length (wl)	Inter-Element Spacing (wl)
Driver 1	0.476	0	--------
Reflector	0.502	0.146	0.146
Driver 2	0.476	0.292	0.146

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The total "boom" length (where the idea of a boom means a virtual boom) is less than 0.3 WL, which is considerably less than the 0.5 WL width of the array. Hence, in many situations, if one can accommodate the width of a 2-element wire beam, the total "boom" length is usually not a great space problem.

Performance, of course, is not constant across the entire 40-meter band. **Fig. 4** presents the gain and front-to-back curves for the array. A review of **Fig. 3** will make it clear that the 180-degree and worst-case front-to-back ratios are identical for this array.

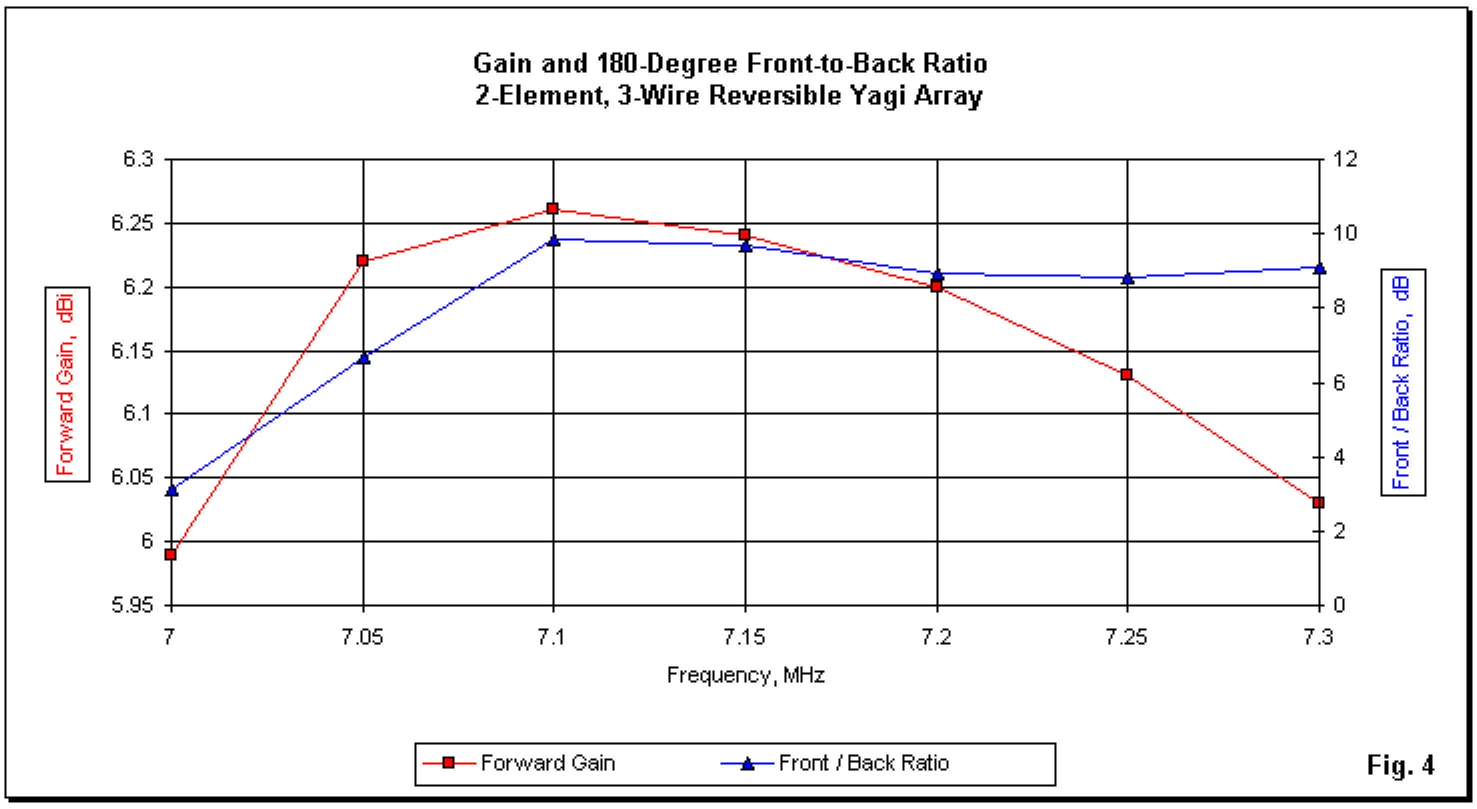

Fig. 4

Both the gain and front-to-back ratio fall off more rapidly below the design frequency than above it. Hence, any such 2-element wire Yagi (reversible or not, requires a choice on the part of the builder relative to a favor operating region of the band. Redesigning the array for about 7.05 MHz would cover the CW portion of the band with peak performance, while designing for about 7.2 to 7.25 MHz would yield the same results for the SSB portion of the band. Overall, the peak free-space gain is 6.26 dBi, with a minimum value of 5.99 dBi. The gain spread might be acceptable, but the front-to-back ratio is unlikely to satisfy most operators below the design frequency. The peak front-to-back ratio approaches 10 dB, but falls to a mere 3 dB 150 kHz below the design frequency. Above the design frequency, it remain relatively constant.

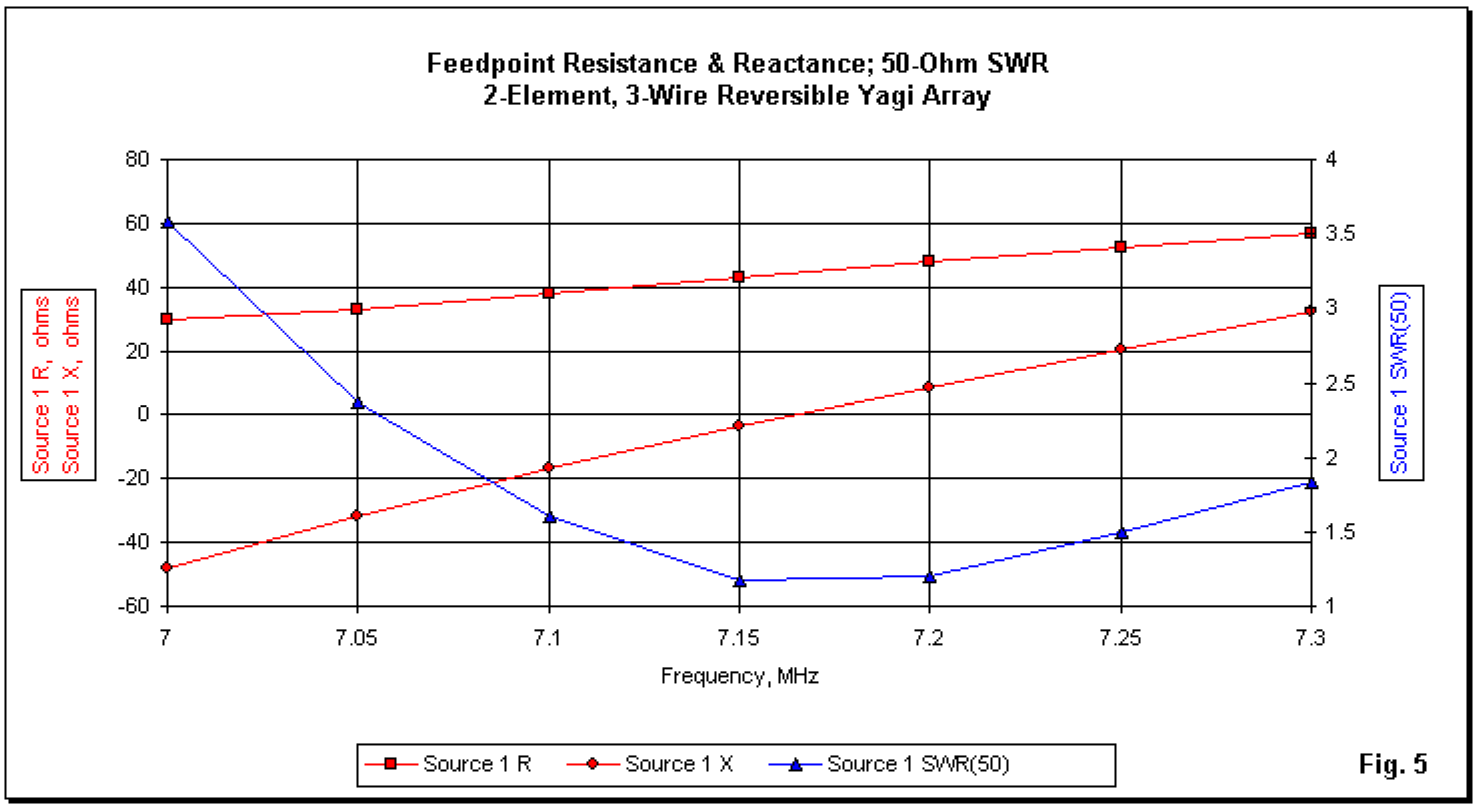

Fig. 5

One of the benefits of the 2-element Yagi is that its feedpoint resistance and reactance vary in such a way as to make the SWR curve generally follow the gain and front-to-back curves. As **Fig. 5** shows, the 50-Ohm SWR is acceptable for nearly 2/3 of the ham band, and the favorable segment of the band is at and above the design frequency. Hence, redesigning the array for either the upper or lower portion of the band becomes a simple matter of adjusting the dimensions.

I have given free-space patterns and values in order to make fair comparisons among the total number of arrays that we shall cover. Any give array will vary in performance according to its height, with heights below 1/2 WL subject to the greatest variation. Hence, if you anticipate building an array such as this one or the others that we shall touch upon, it may be wise to model it first at the intended height of operation.

A 3-Element, 5-Wire Yagi Array

If we expand our basic Yagi to 3 elements, we can obtain additional gain and improved front-to-back ratio. As well, we improve the isolation of the inactive or rearward elements. In a reflector-driver design Yagi, the two elements interact so as to mutual control the forward gain, the front-to-back ratio, and the driver feedpoint impedance. If we add a director to the system, it tends to take control of the forward gain and front-to-back ratio, leaving the reflector-driver relationship to control the feedpoint impedance of the array. Since the pattern-shape controlling elements are at an increased distance from each other, the isolation between the two halves of our reversible array increases.

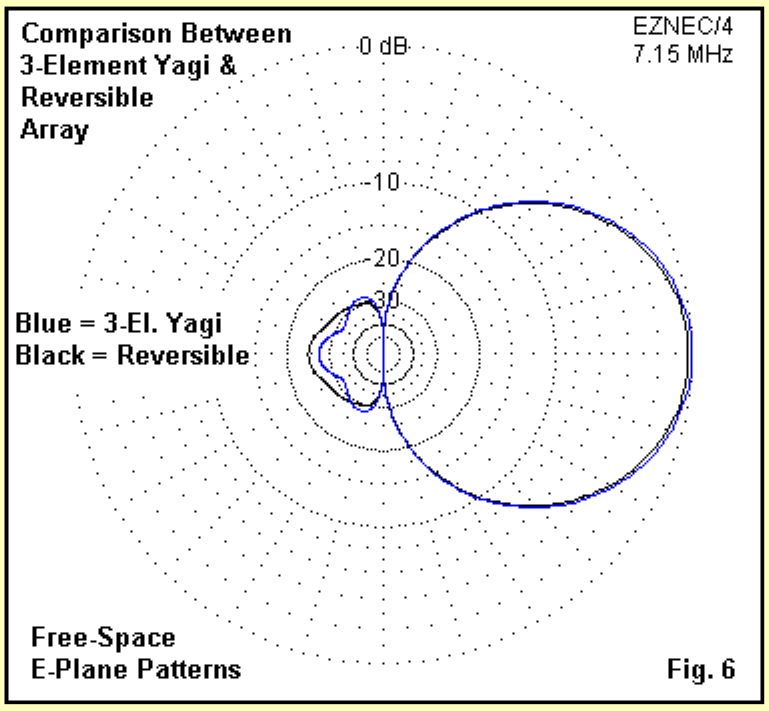

Fig. 6 compares the free-space E-plane patterns for a 3-element wire Yagi that is identical to one half of the reversible array to the 5-wire array itself. As the pattern shows, there is little or nothing to choose between the two patterns. The average gain and front-to-back ratio peak of the two arrays differ by less than 0.1 dB in each parameter.

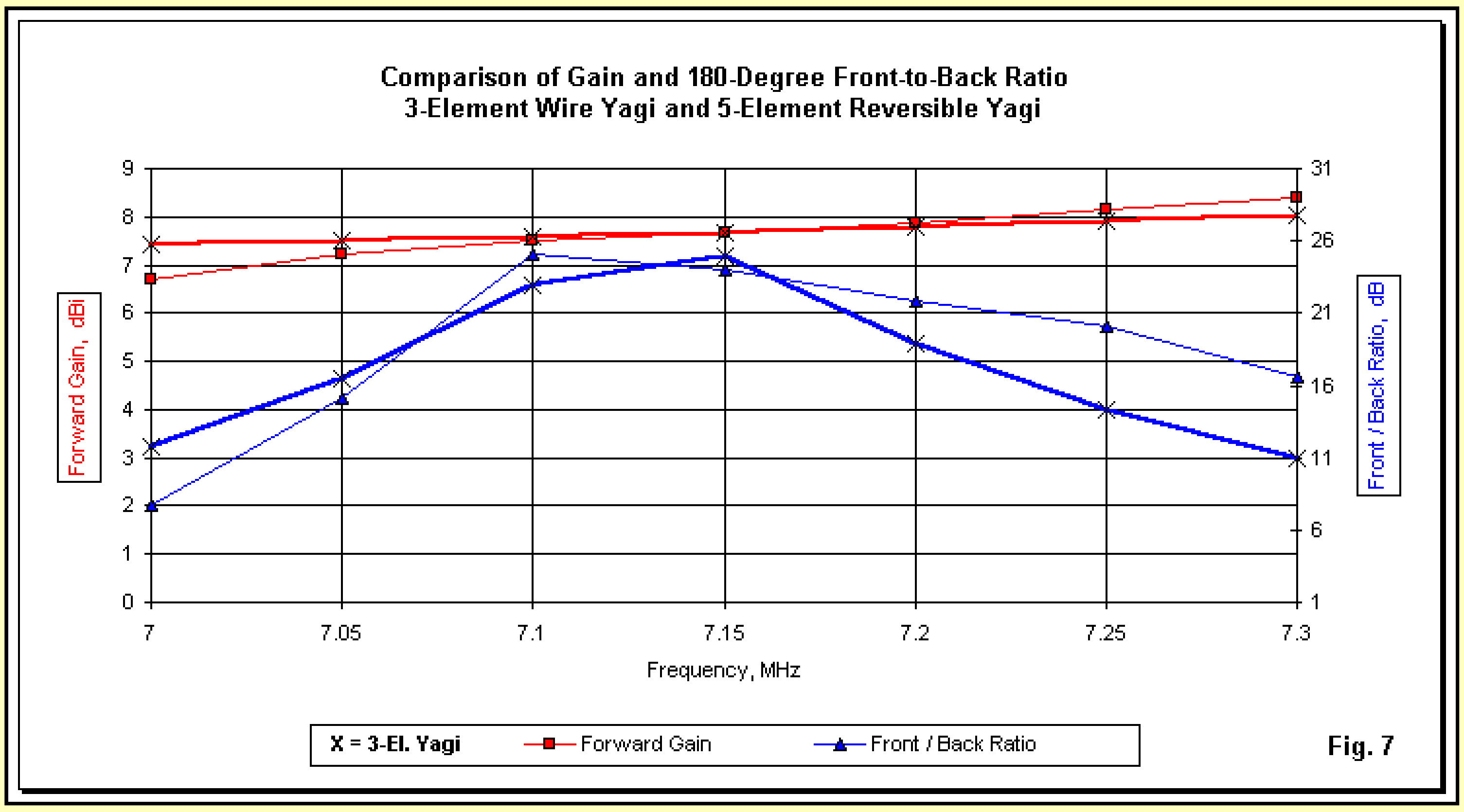

Fig. 7 compares the gain and front-to-back curves across the entire 40-meter band. The gain of the independent Yagi is slightly flatter, although the difference is more numeric than significant. Combining two Yagis into a reversible array does move the peak front-to-back ratio by about 50 kHz, although the reversible array has a slower fall-off rate above the design frequency.

The free-space gain of the array at the design frequency is about 7.6-7.6 dBi, with a front-to-back ratio that exceeds 24 dB. Both of these values are worthy increases relative to the 2-element, 3-wire reversible Yagi we explored earlier.

The following table lists the dimensions of the array, once more using fractions of a wavelength as the unit of measure.

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Dimensions of a 5-Wire, 3-Element Yagi Reversible Array

Element	Length (wl)	"Boom" Length (wl)	Inter-Element Spacing (wl)
Director 1	**0.464**	**0**	**--------**
Driver 1	**0.486**	**0.174**	**0.174**
Reflector	**0.502**	**0.325**	**0.151**
Driver 2	**0.486**	**0.476**	**0.151**
Director 2	**0.464**	**0.650**	**0.174**

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Perhaps the major item of interest in the dimension chart is the fact that the reversible 3-element Yagi is more than twice as long ("boom" length) as its 2-element Yagi counterpart, but without an increase in the side-to-side dimension. The virtual boom is now significantly longer than the length of the longest element. It therefore requires considerably more real estate, not to mention adding dimensions to the meas of supporting the wire elements.

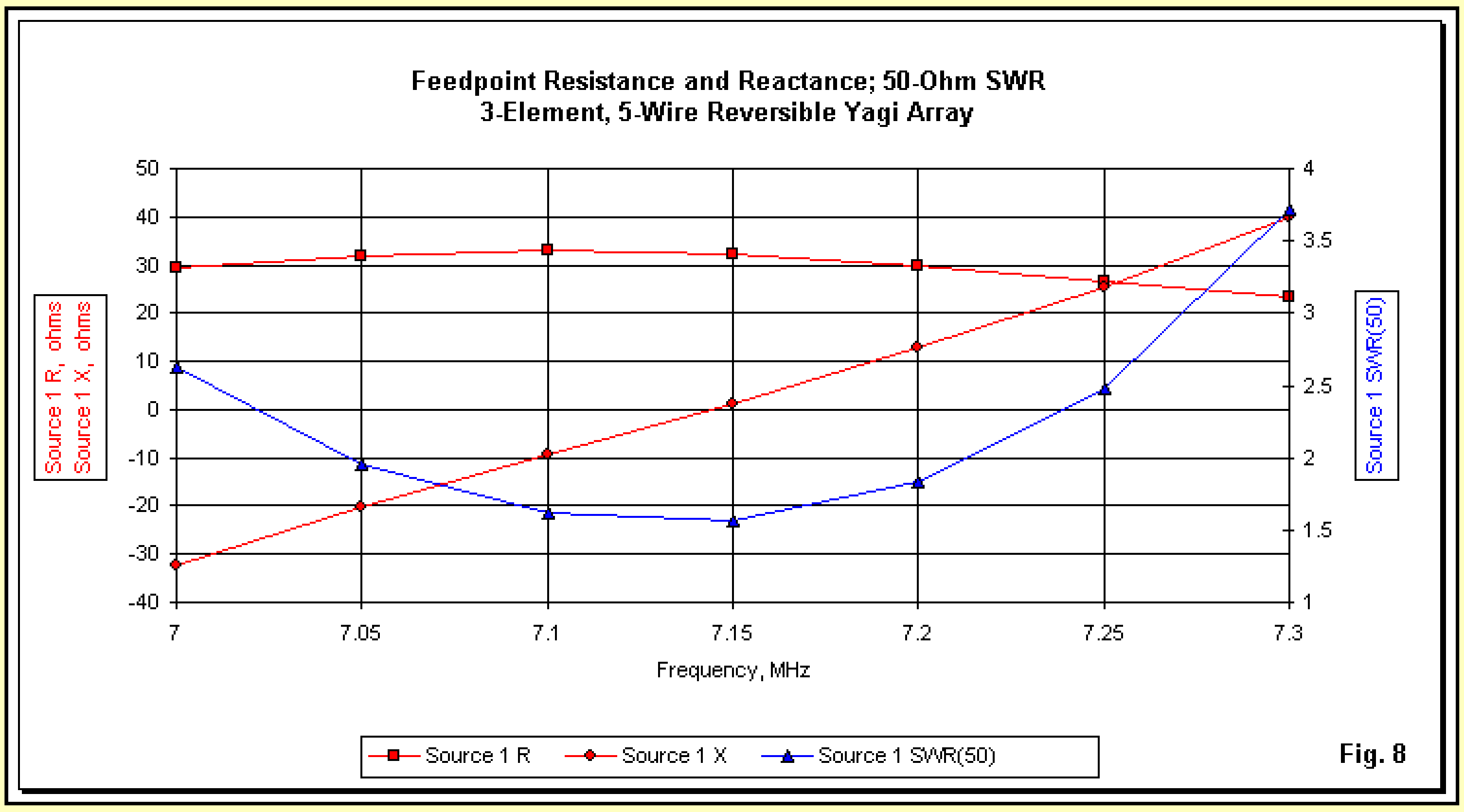

Fig. 8

The 5-wire reversible array is designed for a feedpoint resistance of about 30 Ohms. At the design frequency, the array is resonant. As **Fig. 8** reveals, we obtain a 50-Ohm SWR under 2:1 from about 7.05 MHz to about 7.21 MHz, just over half the 40 meter band. Since the resistance makes a very small excursion, one might adjust the minimum SWR position to virtually anywhere in the band simply by adjusting the lengths of the two driver elements. The change of reactance across the band is virtually linear, making adjustment predictions fairly reliable.

However, the 50-Ohm SWR never falls below about 1.5:1. For many applications that employ sensitive SWR detection systems, the entire SWR curve may be unsatisfactory. Hence, the use of an antenna tuner is recommended. At 40 meters and below, coax losses tend to be very low. Hence, a simple network tuner will generally suffice. The one danger in this tuning procedure is that one may lose sight of the fact that the front-to-back ratio falls off as one moves away from the design frequency, especially at the lower end of the band. Like the 2-element Yagi array, this reversible 3-element Yagi is a half-band antenna on 40 meters. If we forget this fact due to the ease of obtaining a match with an antenna tuner, we shall have to rely upon QRM to remind us.

A 3-Element, 4-Wire Yagi Array

Bill Desjardins, W1ZY, called my attention to his modification of the 5-wire reversible Yagi design, one that he has used. I have not seen other references to the modification, but they may exist. Instead of using 5 wires for a 2-way 3-element beam, let's use only 4.

By referring to **Fig. 1** and some of the general properties of 3-element Yagis, you can follow the reasoning behind Bill's design. We need a reflector, driver, and director in each direction. Yagis of 3 elements or more become insensitive to the driver length (within reason) relative to other performance parameters, such as gain and the front-to-back ratio. Since we are likely to need an antenna tuner even with the 5-wire design, why not plan for one from the beginning. There is no reason why the driver cannot be the same length as the reflector, if we can accept the increase in inductive reactance that the increased driver length entails. Since we must switch drivers anyway in order to change beam directions, we can let the inner wires of the array do double duty as both reflectors and drivers. Hence, we cut down the overall "boom" length by one notch and the number of wires goes to 4.

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Dimensions of a 4-Wire, 3-Element Yagi Reversible Array

Element	**Length (wl)**	**"Boom" Length (wl)**	**Inter-Element Spacing (wl)**
Director 1	**0.464**	**0**	**--------**
Driver/Reflector	**0.502**	**0.174**	**0.174**
Reflector/Driver	**0.502**	**0.325**	**0.151**
Director 2	**0.464**	**0.499**	**0.174**

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The dimensions shown are optimized somewhat from Bill's initial design. Indeed, except for the driver length, they replicate the values for each Yagi in the 5-wire design. Where the designs differ most is in the overall "boom" length, which has shrunk from 0.65 wl down to 0.5 wl. In fact, the array now makes an almost perfect square.

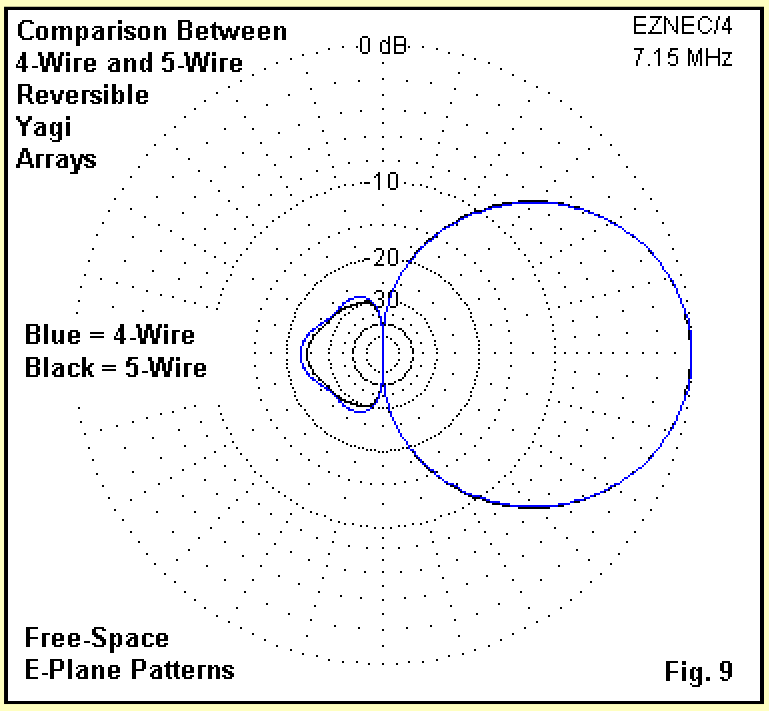

Fig. 9

The immediate question is whether the 4-wire array performs as well as the 5-wire version. **Fig. 9** tells the story. There is no significant difference in either the forward gain or the front-to-back ratio between the two variations on the 3-element reversible Yagi concept. The gain at the design frequency is about 7.7 dBi, with a front-to-back ratio of 23 dB. **Fig. 10** plots the free-space gain and the front-to-back ratio across 40 meters. The curves closely resemble those we saw in **Fig. 7**, in the comparison between a single 3-element wire Yagi and the 5-wire reversible model.

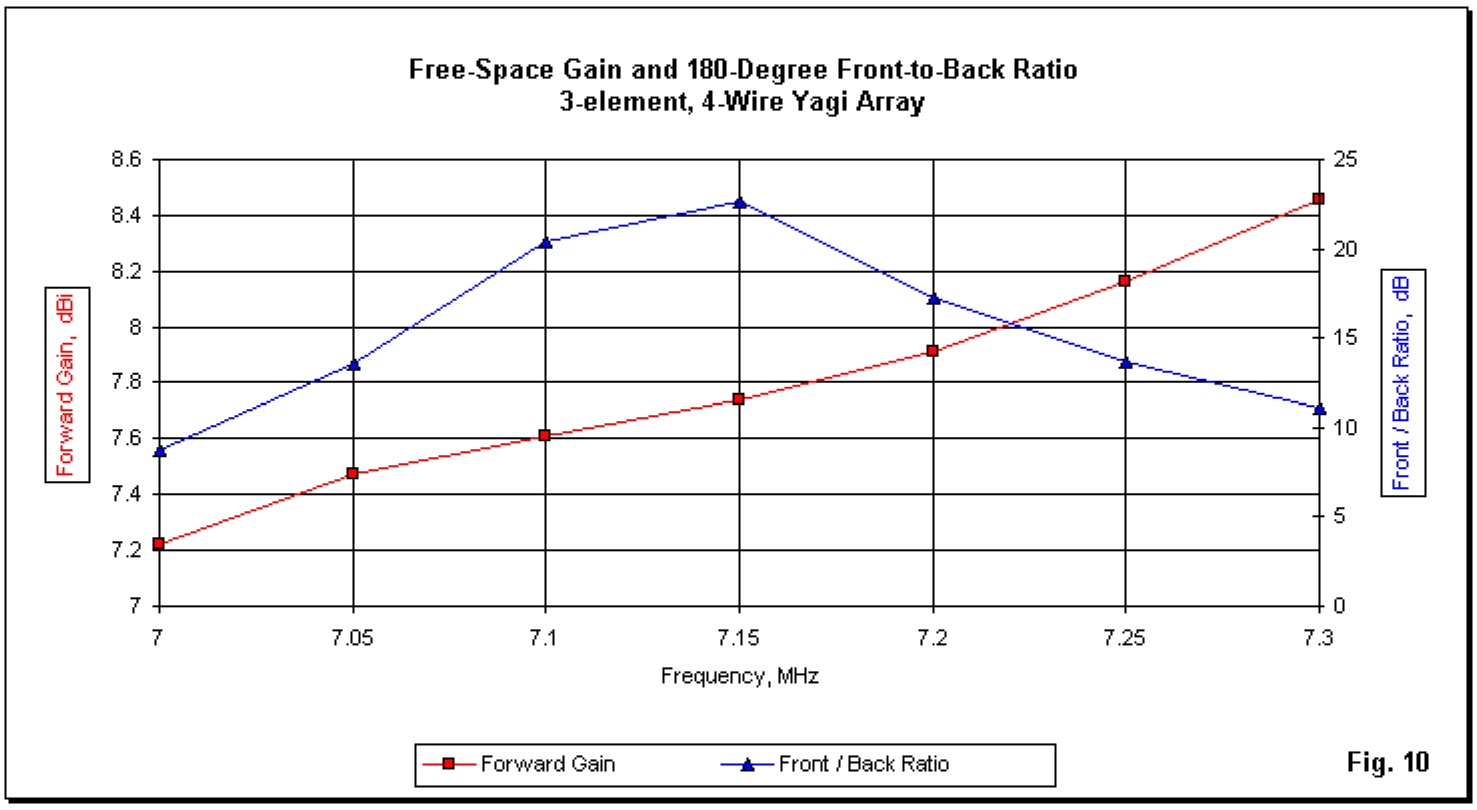

Fig. 10

Because the driven element of the 4-wire design is intentionally long, an SWR curve would provide little or no information. However, the feedpoint resistance and reactance curves in **Fig. 11** may be helpful in understanding operation of the antenna. As with the 5-wire array, the reactance increases virtually linearly with frequency. However, it is purely inductive and reaches zero only well below the lower band edge. The resistance changes slowly, but does decrease above the design frequency. Hence, the 35-Ohm value that occurs at 7.15 MHz, drops to about 25 Ohms at the upper band edge.

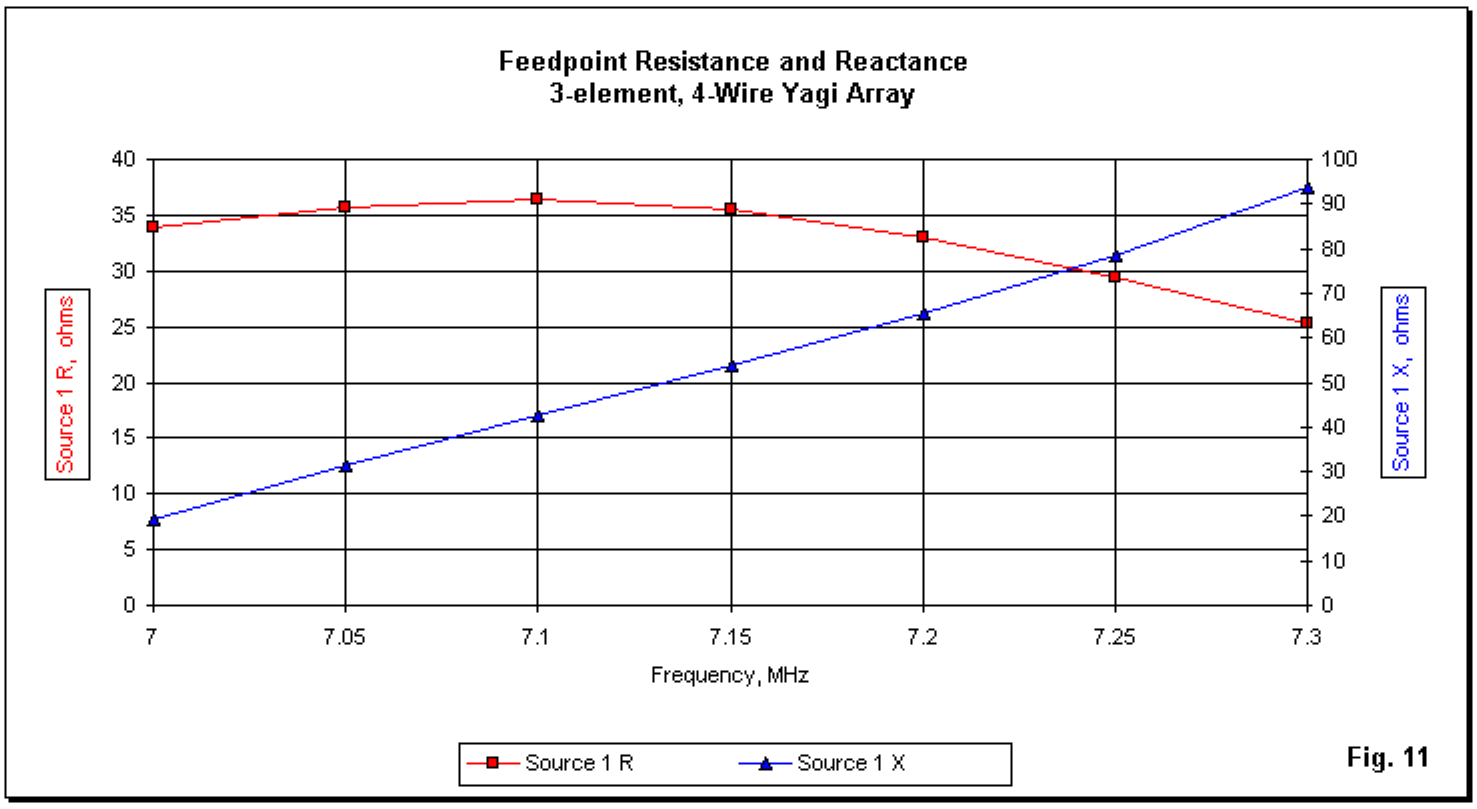

Fig. 11

The values listed are those that occur at the driver terminals. The value obtained at the terminals of an antenna tuner will vary with both the characteristic impedance and the length of the transmission line used. Since basic impedance at the design frequency is fairly low (35 + j 50 Ohms), some users may prefer a low impedance coaxial cable, accepting the coax matched and additional SWR losses. Other users may prefer to use parallel transmission line in order to hold the losses as low as possible. However, with a line impedance of 400-600 Ohms, the excursions in impedance will be much greater, thereby increasing the chances that the tuner may see values that fall outside its tuning range--or its efficient tuning range. Of course, one cure for terminal impedance values outside of a tuner's range is to change the length of line from the antenna to the tuner. If you pre-calculate the likely terminal impedance, be certain to include the line velocity factor in the calculations.

Switching Directions

Switching directions with any of the arrays involves two facets. One is to switch the active driver element. The other is to ensure that the inactive element has a low or zero impedance across the feedpoint terminals. The second facet of switching is less important with the 3-and 5-wire designs, but it is critical to the 4-wire array. Since the inactive driver functions as the reflector, there must be effective continuity across the terminals.

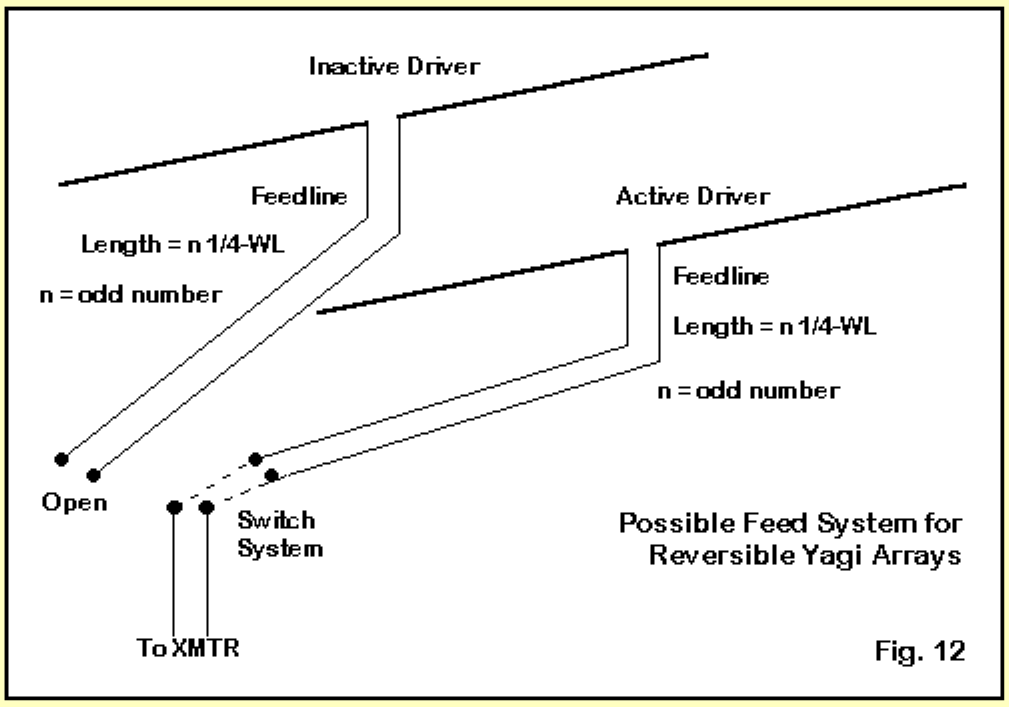

Fig. 12 shows one way to accomplish the double task. A simple switch--DPDT--switches the pair of leads from the antenna to the transmitter or antenna tuner. If the lines from the switch to the antenna are an odd multiple of 1/4 wl (taking into account the velocity factor of the line), then an open circuit at the switch end of the line will appear as a short circuit (or close to it) at the antenna end of the line.

So long as the length condition is met, the lines may be any length and even reach to the shack for indoor switching. Such a system eliminates any problems of weatherproofing the switch. However, the lines from the switch to their respective drivers should be well separated if one uses open wire transmission line. The object is to avoid interactions between the lines, in addition to the usual precaution of avoiding interactions between the lines and other objects along the run from shack to antenna.

Whichever type of reversible array that you choose, assuming that your circumstances make one of them attractive, concentrate on achieving the highest mounting level feasible. Like any horizontally polarized array, the reversible beams perform best when above 1/2 wl.

Of the 3 arrays, perhaps the 4-wire design of W1ZY is most attractive for its ability to pack 3-element Yagi performance in two directions in only about 0.2 wl more boom length than required for 2-element performance. However, the 3-wire, 2-element design will show up very well if one has only had a single wire dipole to use in the past. The reversible beam concept in the forms indicated eliminates the need for sophisticated remote switching in weatherproof containers, which may make Yagi performance more accessible to the average builder.

The arrays are also part of a larger collection of bi-directional and reversible arrays. Lazy-Hs and extended-Lazy-Hs offer good gain with relatively narrow beamwidths. They take only the ground space of a single wire, but their demands extend vertically instead. For the individual with less ground space than even a 2-element reversible array requires, there is the reversible Moxon rectangle, described in a number of sources and forms. It is even possible to design a reversible array for 160 meters, one that is frequency nimble within the band as well a reversible in direction. But that is an exercise at least 2 to 3 orders of magnitude beyond the simple designs we have explored here. Despite its complexity, that array will only perform to the level of the simpler designs in 4 and 5 wires that we have examined. So if you can live with a half-band on 40 or 20 (or all of 30 meters), then one of these designs may increase your DX effectiveness--at least in two directions.

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