Horizontal Bi-Directional Wires

L. B. Cebik, W4RNL (SK)

In the last set of notes, we discussed some of the options for bi-directional wire broadside arrays based on the vertical dipole. Since we should be fair to horizontal wires, this collection of notes will focus on bi-directional wire arrays that have their roots in the horizontal dipole. Just as the last collection was incomplete, so this one will be even further from exhaustive. Once we have some basic arrays available to use, the permutations and combinations form an endless progression. However, we can look at the various types of arrays.

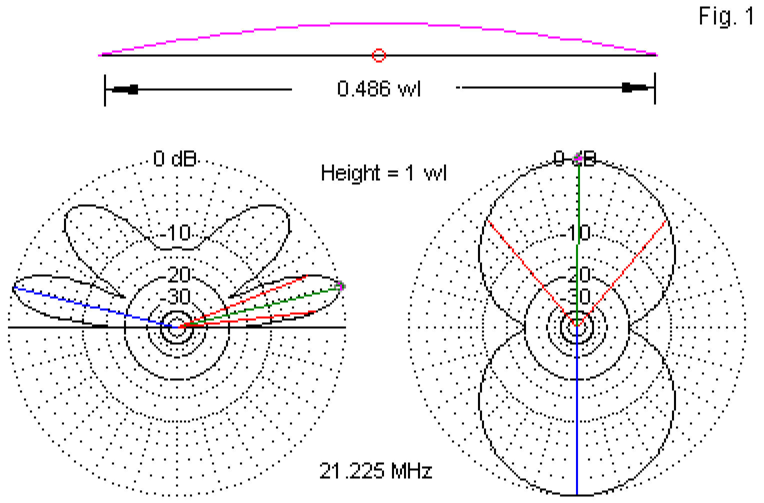
To be effective, a horizontal array should be well above ground. Although we might disagree on the minimum height for horizontal arrays, placing all arrays at 1 wavelength above ground for the top wire (if the array has a vertical dimension) will keep us well above the minimum. In the preceding notes, I set a height of 50' as a limit of sorts, since most serious array users can usually arrange 60' support posts, trees, or surplus telephone poles. The physical height restriction leads us to 15 meters, more specifically, a uniform test frequency of 21.225 MHz for all comparative horizontal array data. A wavelength at this frequency is 46.34'. To unify further the modeling conditions, the ground will be average, that is, have a conductivity of 0.005 s/m and a relative permittivity of 13. All antenna elements will use AWG #12 (0.0808" diameter) copper wire. As a result, we can more directly compare the reported performance characteristics for the antennas included in these notes.

Traditionally, we categorize arrays as collinear, end-fire, or broadside. These categories are not mutually exclusive, but they do give us a convenient way of grouping our subject antennas. However, we must begin with a baseline.

The Standard Antennas

No antenna is more fundamental to amateur (and other) antenna work than the ½-wavelength resonant dipole. **Fig. 1** shows the outline of the antenna. Superimposed on the antenna is the distribution of the current magnitude along the wire's length. (Adding the current phase would create difficult viewing problems with some of our antennas.) Note that the dipole is electrically resonant, which requires a physical length that is 0.486 wavelength for #12 copper wire at the specified height above average ground. The resonant length of a dipole will vary with the height above ground, especially below about 1.25 wavelengths.

Fig. 1



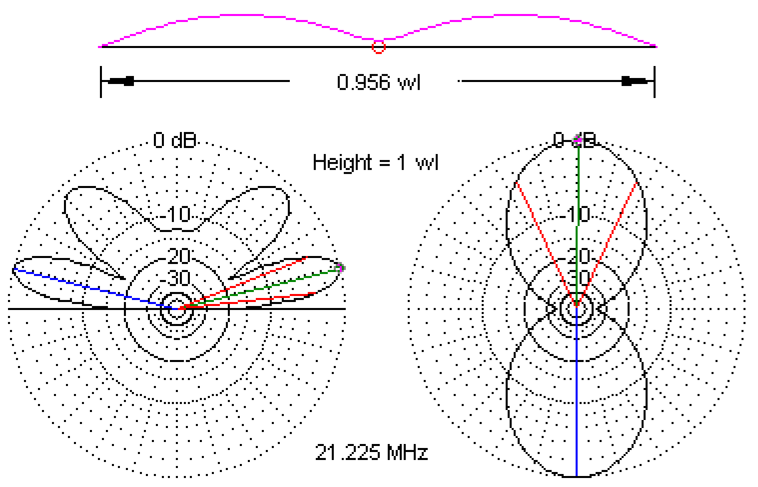
General Outline and Elevation and Azimuth Plots
Resonant (Half-Wavelength) Dipole

Horizontal wire antennas tend to have an elevation angle of maximum radiation (or TO angle) that depends on the antenna's height more than any other factor. Hence, all of the basic antennas whose performance reports appear in **Table 1** have a TO angle of 14°. The dipole data in the table give numerical meaning to the plots on **Fig. 1**. Note the wide (79°) beamwidth for a standard dipole. A triangle of dipoles would suffice to cover the entire horizon. The dipole gain of 7.6 dBi becomes the baseline against which we may measure the gain of all subsequent arrays.

Table 1. Modeled 15-meter standard wire antenna performance characteristics

	Gain dBi	TO Angle	Beamwidth	Feedpoint impedance
½-λ dipole (See Fig. 1.)				
	7.62	14°	79°	72.0 + j0.3 Ω
1-λ doublet (See Fig. 2.)				
	9.23	14°	51°	4464 - j1.8 Ω
Extended double Zepp (See Fig. 3.)				
	10.67	14°	36°	230.6 - j1023 Ω (L = 1.20 λ)
	10.78	14°	33°	153.5 - j781.6 Ω (L = 1.25 λ)

Notes: 1. All antennas are bi-directional. 2. Gain is maximum at the TO angle (or elevation angle of maximum radiation. 3. Beamwidth is the half-power value for each of the 2 lobes. 4. Impedance values are the resistive and reactive series values. 5. See the indicated figures and the text for the physical description of the individual arrays and their elements. 6. Test frequency is 21.225 MHz. Ground is average (conductivity = 0.005 S/m; relative permittivity = 13). 6. These notes apply to all subsequent tables of modeled performance figures.



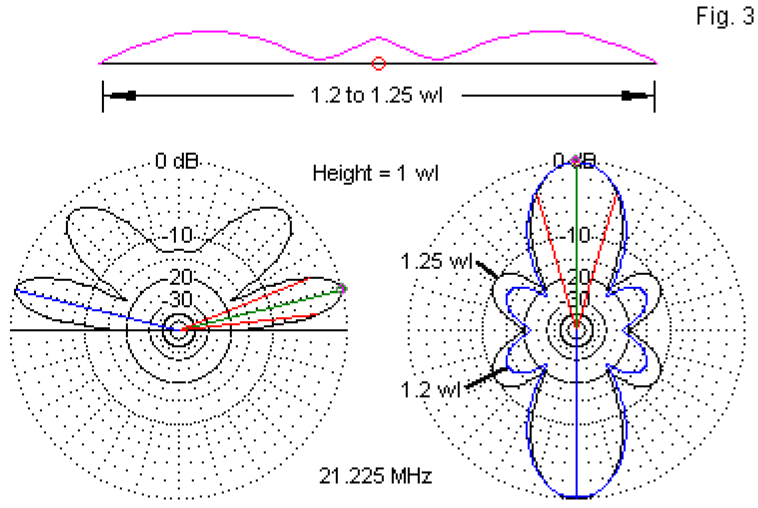
General Outline and Elevation and Azimuth Plots
Resonant One-Wavelength Doublet

The second standard antenna can go by several names. The table and **Fig. 2** both refer to a 1-wavelength center-fed doublet. An equally apt way to refer to the antenna is as a collinear array of 2 half-wavelength wires. The current magnitude curve on the antenna outline shows why this name has good sense, since we observe two complete cycles of current rise and fall. Like the dipole, the physical length will be shorter than the electrical length. For the test conditions, we obtain resonance with a length of 0.956 wavelength of wire. Finding the resonant length of a center-fed 1-wavelength wire is tedious in modeling and virtually impossible with real wire. The resonant point occurs at a very high value of resistive impedance, where the reactance changes in a very short space from very inductive to very capacitive. Hence, there is an air of artificiality about the reactance number in the table, although the resistive part is a good indicator of what to expect at the feedpoint. One way to bring the impedance down to a value that is more amenable to our coaxial ways is to use a ¼-wavelength section of 450-Ohm line.

The pattern and the gain value are both very real and usable. The 1-wavelength wire provides about 1.6 dB additional gain relative to a dipole under equal conditions, but at a cost in the beamwidth. The longer wire has a beamwidth of about 51°. A triangle of 1-wavelength wires will not cover the horizon.

The third standard wire antenna is the extended double Zepp (EDZ). We operate this antenna off resonance. We sometimes say that the antenna is non-resonant, but there is another use for this term. Many traveling wave and frequency-independent antennas show no cyclical appearance of resonant frequencies as we operate the antenna over a large frequency range. Many texts call these antennas non-resonant in contrast to antennas like a center-fed wire of fixed physical length. This antenna is resonant in the sense of showing cyclical re-appearance of zero reactance at the feedpoint as we sweep through a wide frequency range. So we may be content in calling the EDZ an off-resonance antenna. **Fig. 3** shows the current magnitude distribution for a physical length of 1.25 wavelength. The antenna qualifies as a collinear array.

Fig. 3



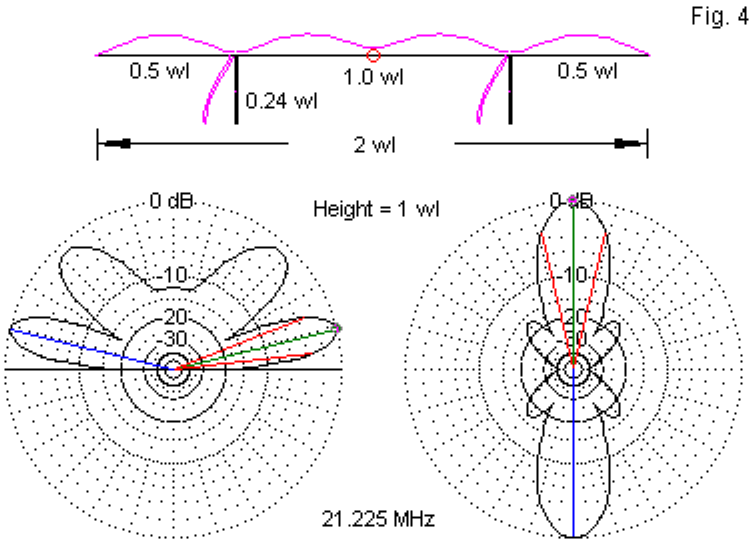
General Outline and Elevation and Azimuth Plots
Extended Double Zepp (EDZ) Antenna/Array

As we increase the length of a center-fed wire beyond 1 wavelength, we find that the gain increases until the length passes the 1.25-wavelength mark. However, the azimuth patterns and the tabular data show us other dimensions of what is occurring. As we move from about 1.2 wavelengths to 1.25 wavelengths, the resistive and capacitively reactive components of the feedpoint impedance decrease. (The gain changes only by about 0.1 dB.) Offsetting the reduction in the feedpoint impedance is the growth of the sidelobes that give an EDZ azimuth pattern its distinctive look. With a length of 1.2 wavelengths, the sidelobes are about 13 dB lower in gain than the main lobe. By a length of 1.25 wavelengths, the sidelobes have grown by 3 dB. At a total length of about 1.5 wavelengths, the side lobes would be as strong as or stronger than the main or broadside lobe. As well, the beamwidth continues to shrink as we lengthen the wire and increase the peak gain. Hence, the EDZ represents a sort of limit to the length of collinear arrays unless they employ techniques to correct phasing along the wire.

Collinear Arrays

One technique that allows us to obtain increased gain with straight wires is to introduce at critical points along the wire a phase-changing stub. Consider a 2-wavelength center-fed wire, such as the one shown in **Fig. 4**. We see 4 complete half-wavelength current cycles. However, if we had just used a continuous length of wire. The phasing of the current at the outer half-wavelength sections would have been 180° out of phase for producing a simple broadside pattern. Indeed, we would see for such a wire a 4-lobe pattern that forms a cloverleaf. By introducing ¼-wavelength shorted transmission-line sections, we change the phase of the current at the beginning or inner end of the outer sections so that the radiation adds to the radiation of the center section. The result is a narrow main beam (the width is 26°) with over 1 dB gain over the EDZ. The tabular data for the collinear arrays appears in **Table 2**, for comparison with the patterns in the relevant figures.

Fig. 4



General Outline and Elevation and Azimuth Plots
Collinear Array Using 1/2-Wavelength Sections

Table 2. Modeled15-meter collinear array performance characteristics.

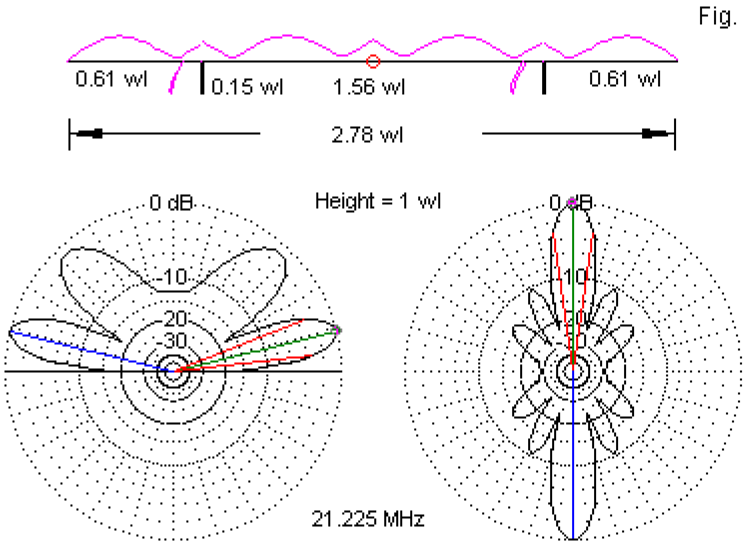
Gain dBi	TO Angle	Beamwidth	Feedpoint impedance
Collinear array based on ½-λ sections (See Fig. 4.)			
11.97	14°	26°	2189 + j28.9 Ω
Collinear array based on 5/8-λ sections (See Fig. 5.)			
13.50	14°	16°	250 - j733.3 Ω
Bi-square array (See Fig. 6.)			
10.29	20°	63°	3344 - j100.4 Ω

Notes: See Table 1.

Like a 1-wavelength wire, which is what we find at the center of our collinear array that uses ½-wavelength sections, the feedpoint impedance is very high. As well, the azimuth pattern shows small EDZ-like sidelobes that are normal to very closely spaced ½-wavelength sections--in this case, the end sections relative to the longer inner section of the array.

We need not limit ourselves to using ½-wavelength sections as the basis for a collinear array. As shown in **Fig. 5**, 5/8-wavelength section will work as well and provide additional gain. The collinear array shown uses such sections and has a total length of 2.78 wavelengths to achieve a peak gain of 13.5 dBi, about 1.5-dB higher than the comparable array using ½-wavelength sections. However, the beamwidth has shrunk to 16°. This array is for point-to-point communications.

Fig. 5

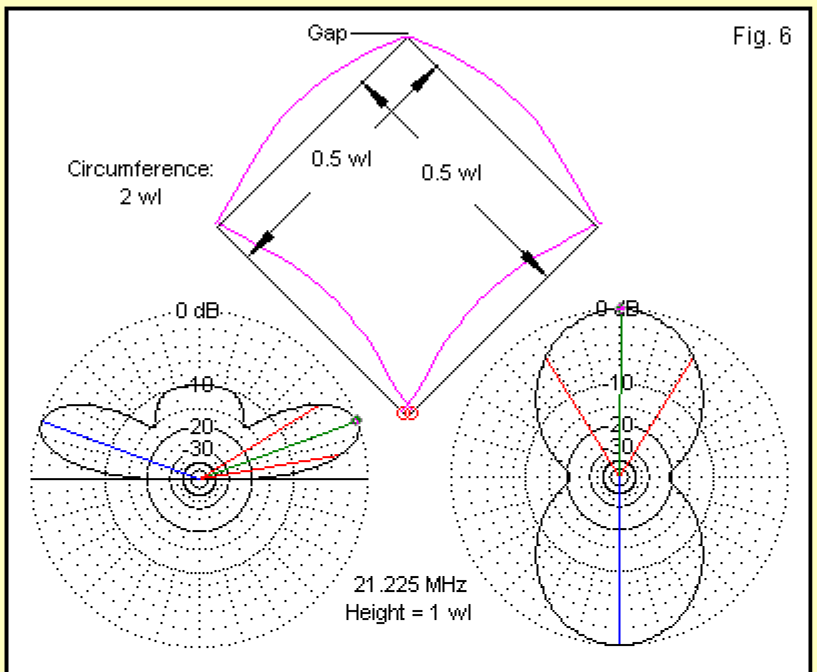


General Outline and Elevation and Azimuth Plots
Collinear Array Using 5/8-Wavelength Sections

The array shows twice as many sidelobes because we have--in effect--a doubled EDZ structure. The inner section is slightly over 1.5 wavelengths, which seems long for an EDZ. However, if you examine the current magnitude curve on the outline sketch, you will see that it requires the added current rise not only at the feedpoint, but also at the location of the phasing lines. Because these regions are already reactive, the phasing lines can be shorter to effect the required phase reversal--in this instance, about 0.15 wavelength. The feedpoint impedance is normal for an EDZ-type antenna. Moreover, despite the high increase in array complexity, it still shows a TO angle of 14° that owes to its 1-wavelength height above ground.

In the models for both of the collinear arrays, the phase lines are physical wire structures and not NEC TL constructs.1 The non-radiating TL lines are most accurate at high current regions of an antenna where the current changes very slowly over appreciable distances along the wire. They become less accurate in regions of the antenna in which the current changes rapidly over short distances. Since both collinear arrays show relatively low currents at the phase-line locations, physical lines are necessary for best accuracy in the models. The modeled line wires should be the same diameter as the antenna element wire, and the spacing should not be excessively close.

The final sample of a collinear array takes an odd turn--upward. The bi-square array is a center-fed 2-wavelength wire with the ends turned upward to form a square that is ½ wavelength on a side. However, the wire ends do not meet, but leave a gap. **Fig. 6** shows the general outline and the current magnitude curves for each of the 4 wires. Because we have set a 1-wavelength limit for the top structure, the low point for the array is about 0.3 wavelength above ground. The net effect is to raise the TO angle of the array as a whole. A useful rule of thumb for any array consisting of multiple wires in the vertical plane is that the effective height of the array is about 2/3 the way up the array from the low point to the high point. Hence, the effective height of the bi-square in the illustration is about 0.75 wavelength.

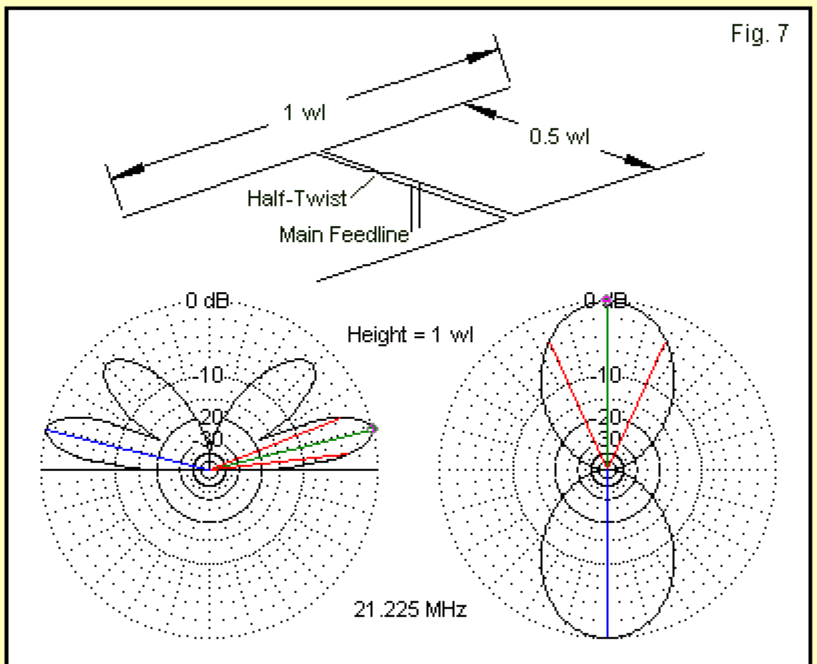


General Outline and Elevation and Azimuth Patterns
Bi-Square Array

The bi-square has a beamwidth of about 63°, although its gain is about halfway between the values for the 1-wavelength and the EDZ arrays, both of which antennas exhibit narrower beamwidths. If you compare the elevation pattern for the bi-square with those for the other two relevant wires, you will discover that the bi-square lacks most of the upper structure or second elevation lobes that characterize the elevation patterns of the single wire antennas. The bi-square lends itself to single-support mounting, and you may place two such antennas at right angles on the support, switching to the one that yields best signal strength.

End-Fire Arrays

If a set of elements radiates in the plane of the elements with the lobes broadside to the element wires, then we have an end-fire array. Among basic arrays, we need only one sample: the W8JK "flat-top" array, developed by John Kraus, W8JK. The antenna has many incarnations using various element lengths and forms and using many spacing distances. In general, the longer the elements, for a given spacing, the higher will be the gain. Equally generally, the closer the spacing, the higher the gain will be. Hence, every W8JK is a compromise based on best achieving a particular set of goals for the antenna.



General Outline and Elevation and Azimuth Plots
15-Meter W8JK "Flat-Top" End-Fire Array

Fig. 7 shows the outline of the 15-meter version that we shall examine. It uses a pair of 1-wavelength elements (or collinear ½-wavelength elements) spaced ½ wavelength apart. Between the elements, we find two phase lines of equal length meeting at a central point where we attach the main feedline. Note that the elements require a 180° phase difference, so one and only one of the phase lines receives a single half-twist. The modeled impedance data in **Table 3** rests on the use of 450-Ohm phase lines with a velocity factor of 0.9. Other line values will produce other impedances. The 15-meter patterns in **Fig. 7** are very clean with a bi-directional gain similar to that of a 2-element reflector-driver Yagi.

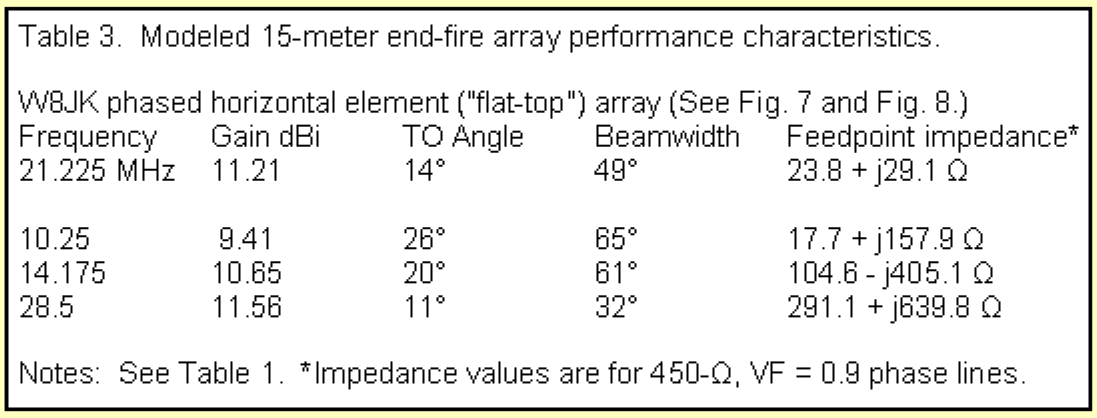


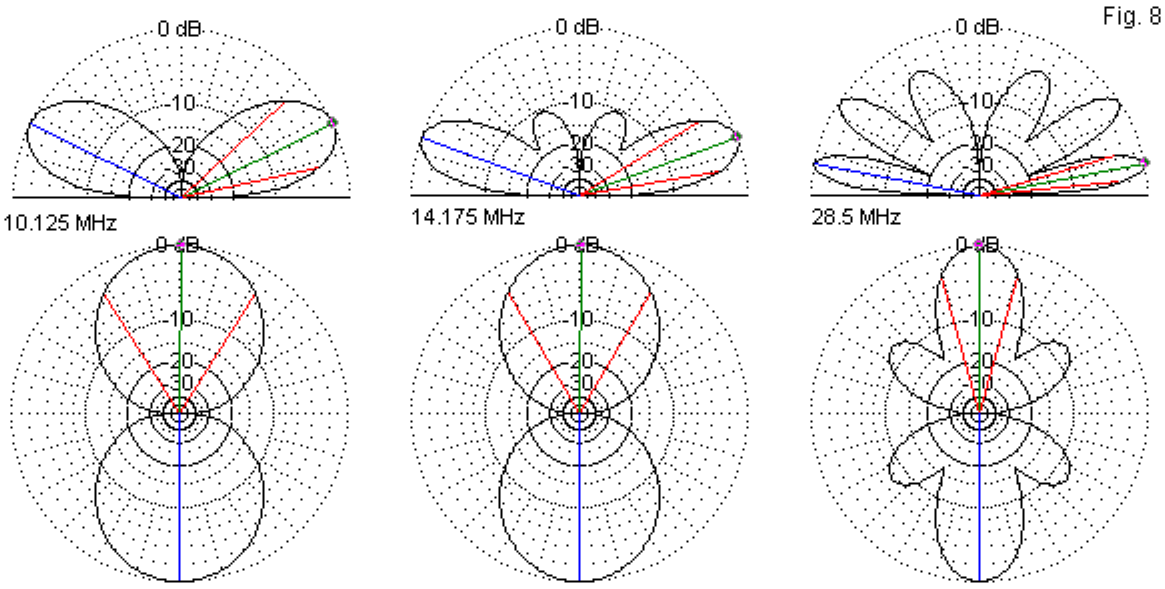
Table 3. Modeled 15-meter end-fire array performance characteristics.

W8JK phased horizontal element ("flat-top") array (See Fig. 7 and Fig. 8.)

Frequency	Gain dBi	TO Angle	Beamwidth	Feedpoint impedance*
21.225 MHz	11.21	14°	49°	23.8 + j29.1 Ω
10.25	9.41	26°	65°	17.7 + j157.9 Ω
14.175	10.65	20°	61°	104.6 - j405.1 Ω
28.5	11.56	11°	32°	291.1 + j639.8 Ω

Notes: See Table 1. *Impedance values are for 450-Ω, VF = 0.9 phase lines.

Fig. 8



Elevation and Azimuth Patterns of 15-Meter W8JK Bi-Directional Array
on 30, 20, and 10 Meters

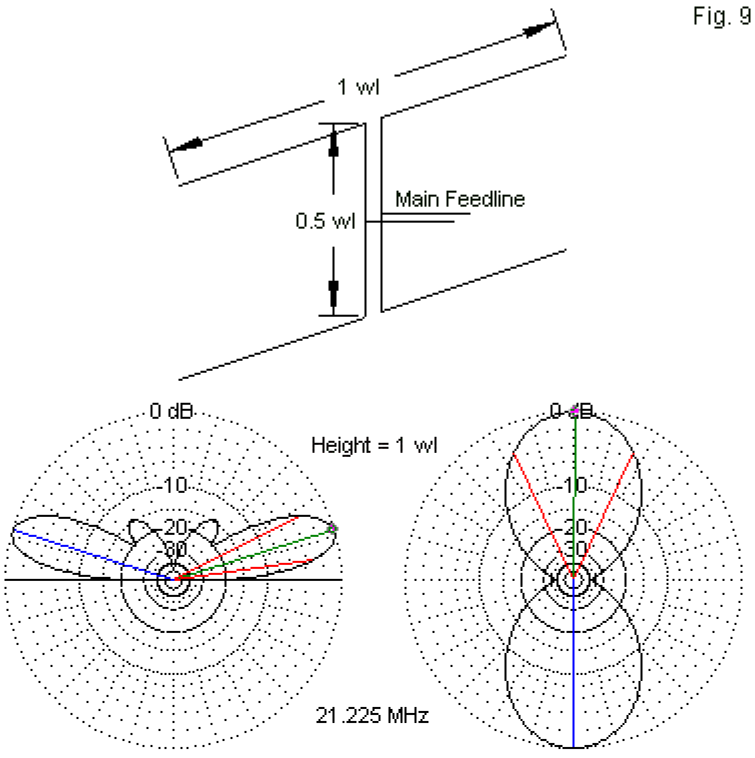
The selection of the element length and spacing for this sample becomes apparent from the patterns in **Fig. 8**. As we raise the operating frequency, the spacing increases to lower the gain, but the element lengths increase to raise it. Lowering the operating frequency produces opposite effects. The result is an array that one might use over several bands with remarkably similar performance. The remaining gain changes are largely a function of the antenna's changing height when measured in wavelengths.

The W8JK first emerged in 1937. For other configurations, see Kraus' *Antennas*, 2nd Ed., p. 458, as well as innumerable articles in *QST* over the years since the antenna first appeared. The array also lends itself to becoming part of more complex array systems.

Broadside Arrays

If the main radiation lobes of an antenna are at right angles to the plane of the elements, then we have a broadside array. Standard HF horizontally polarized arrays tend to require a vertical plane for the elements for broadside use, although NVIS operations might set the element in a horizontal plane for straight-up radiation. The most common simple 2-element broadside array for 15-meter and other upper HF bands is the Lazy-H, shown in **Fig. 9**. Like the W8JK, the elements are 1-wavelength long and spaced vertically ½-wavelength apart. However, we feed the elements in phase, so we do not twist either of the two phase-lines. (An alternative feeding system brings the main feedline to the bottom element. The line connecting the elements receives a half twist to produce a 360° phase change in the 180° phase line. The resulting feedpoint impedance is very high and requires a matching section.) **Table 4** provides the modeled data for the center-fed version of the array. The impedance reports rest on the use of 600-Ohm phase lines having a velocity factor of 1.0.

Fig. 9



General Outline and Elevation and Azimuth Plots
Lazy-H Broadside Array

Table 4. Modeled 15-meter broadside array performance characteristics.

Lazy H phased horizontal element ("flat-top") array (See Fig. 9 and Fig. 10.)

Frequency	Gain dBi	TO Angle	Beamwidth	Feedpoint impedance*
21.225 MHz	12.32	17°	49°	33.8 + j5.1 Ω
14.175	8.47	25°	74°	662.6 - j527.7 Ω
28.5	13.45	12°	27°	1540 + j1851 Ω

Notes: See Table 1. *Impedance values are for 600-Ω, VF = 1.0 phase lines.

With elements at ½ wavelength and 1 wavelength above ground, the lazy-H out-performs the W8JK on 15 meters, even though the effective height is only a bit over 0.8 wavelength. The increased gain is partly a function of suppressing the upper lobe structure that we see in the W8JK pattern as a result of the lazy-H's vertical stack of elements at a ½-wavelength spacing. Like the W8JK, we can use the lazy-H on other bands, as shown both in the tabular data and the patterns of **Fig. 10**. Even though the elements are not spaced for maximum vertical lobe suppression on other bands, the elevation patterns show good reduction in higher angle lobes compared to a flattop array. As we lower the operating frequency, the height of the lower wire in the lazy-H grows closer to the ground when measured as a fraction of a wavelength. Hence, the bi-directional pattern for 30 meters does not appear, since it would be weaker than a simple dipole at 46' above ground and have a higher TO angle. Nevertheless, the antenna is operable on that band. Unlike the W8JK, the lazy-H shows considerable variation in gain as we move from one band to the next.

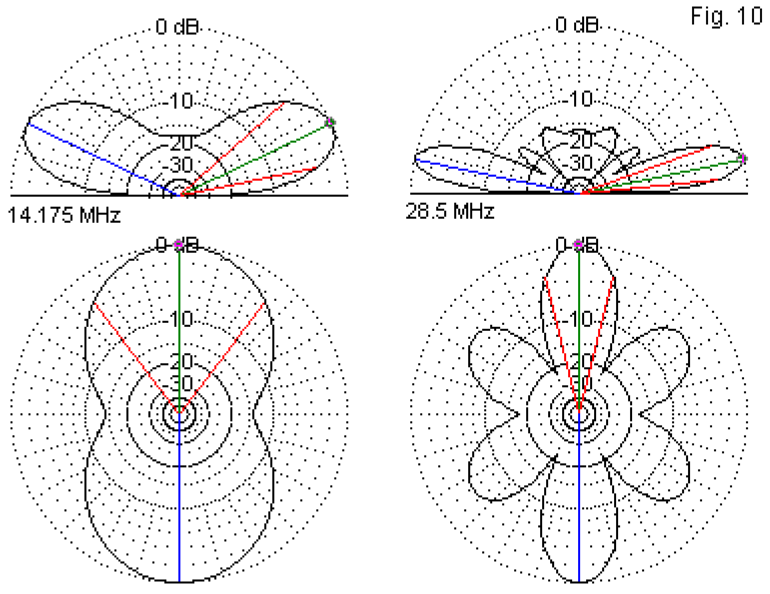


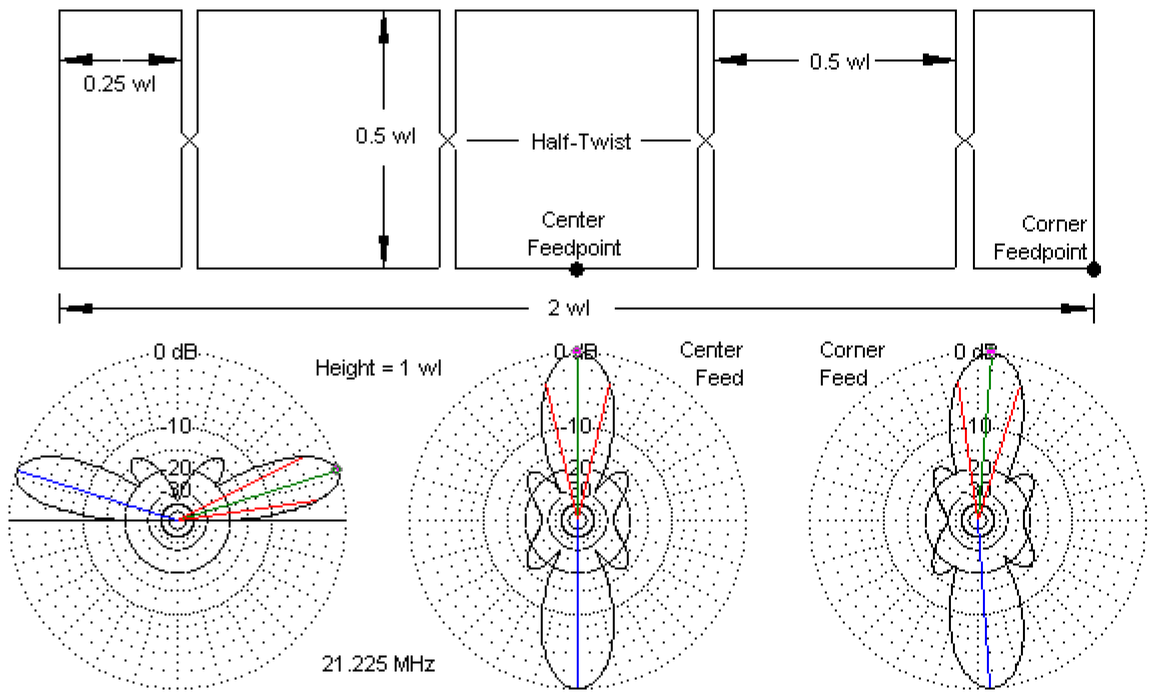
Fig. 10

Elevation and Azimuth Plots of 15-Meter Lazy-H Bi-Directional Array on 20 and 10 Meters

The pattern for 28.5 MHz calls for a brief note. Using elements that are 1-wavelength long for 15 meters produces a 10-meter pattern with very strong sidelobes, since the elements are over 1.3-wavelengths long on that band. Instead of beginning with a standard 15-meter design, we might have design for 10 meters a lazy-H that uses 1.25-wavelength elements with 5/8-wavelength spacing--about 44' and 22', respectively. The result would not change the 10-meter gain significantly, but it would yield an EDZ-type pattern with lower sidelobe content. As well, the antenna would operate over the same frequency range as our sample. This is the so-called expanded or extended lazy-H.

The lazy-H is the foundation for many more complex arrays. In principle, we may combine the lazy-H and the W8JK into a 4-element array. The lazy-H also finds extensive use in commercial array construction for short-wave broadcasting. Consider a vertical bay of elements fed in phase, with as many element at ½-wavelength spacing as vertical supports will allow. Now place further columns of such arrays next to each other. Finally, place a large screen between ¼-wavelength and ½-wavelength behind the rows and columns of antennas. In the late 1920s, we would have called the antenna a billboard array. If we reduce the element lengths to about ½-wavelength and use special wide-band forms of dipole elements, we end up with the modern dipole directional array. By staggering the feed current phase angle from one vertical bay to the next, we can actually slew the direction of the main lobe without ruining the overall characteristics of the antenna pattern. This brief account of modern dipole arrays overlooks a myriad of both electrical and mechanical engineering feats necessary to implement such an array, but it does show the fundamental place of the lazy-H among broadside arrays.

Our final sample broadside array is a curtain, one that passed out of use long ago. Nevertheless, it serves well as a sample of an antenna that continues to attract amateur attention for its pattern properties. In **Fig. 11** we have the outline of a 3-section Sterba curtain, first reported in antenna literature in 1931. Basic to the design are the ½-wavelength by ½-wavelength inner sections, with end sections that are ¼-wavelength wide by ½-wavelength high. We may use as many inner sections as we desire, but a centered feedpoint requires an odd number. The lines between sections are critical: they must be ½-wavelength long parallel transmission lines with a half-twist in each line to keep the top and bottom wires in phase with each other. The sample places the bottom wire ½-wavelength above ground to keep the array within our maximum height limits.



General Outline and Elevation and Azimuth Patterns
3-Section Sterba Curtain

Fig. 11

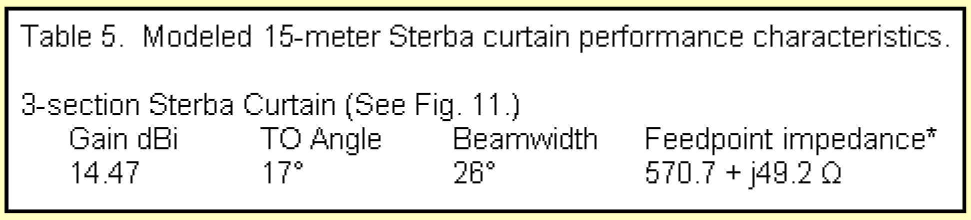


Table 5. Modeled 15-meter Sterba curtain performance characteristics.

3-section Sterba Curtain (See Fig. 11.)

Gain dBi	TO Angle	Beamwidth	Feedpoint impedance*
14.47	17°	26°	570.7 + j49.2 Ω

Table 5 provides the modeled data to accompany the patterns in **Fig. 11**. Like the lazy-H, the elevation pattern shows good suppression of higher-angle lobes. The figure shows two azimuth patterns to accommodate the two most common feedpoints for Sterba curtains: the center of the lower element structure and the corner. The table includes only one data set, since there is no significant difference in the gain, the beamwidth, or the feedpoint impedance. A 600-Ohm feedline would handle either central or corner feeding very effectively. With central feeding,

we have a bi-directional pattern that is exactly broadside to the array itself. However, if we feed that antenna at a corner, we bend the pattern by nearly 5° in the direction of the feedpoint. For such a large array (even though only 2-wavelengths or about 92' long), copper losses are sufficient to distort the pattern direction, although one might compensate through a tedious task of making slight dimension alterations.

Like a lazy-H that uses a bottom feedpoint and a ½-wavelength half-twist phase-line, the Sterba curtain is a monoband antenna. On other frequencies, it becomes simply a semi-random collection of wire. As well, the Sterba requires a great quantity of wire. Consider once more the collinear array that used half-wavelength sections. If we stack a pair of these antennas vertically, the total array length and height will be the same as for a Sterba curtain. However, we require only a single phase-line between the two to connect the feedpoints to the main feedline. The resulting array (with wires at ½-wavelength and 1-wavelength heights) will have a gain of nearly 15 dBi, but with a very great saving in wire.

Another Interim Conclusion

For the wire fans, horizontal bi-directional arrays offer considerable potential in the form of relatively simple, reliable, and inexpensive arrays. In the upper HF region, such antennas have a long-term home if we use care in the ones we select. The lazy-H and the W8JK may be the most flexible arrays in terms of potential multi-band use. However, we must consider the impedances at the tuner end of the main feedline. In some cases, a low antenna feedpoint impedance may create significant line losses, even in parallel lines. We may need to change dual phase-line lengths and impedances to arrive at the best compromise efficiency level on all bands. Monoband arrays with very high impedances will likely require matching sections to arrive at the lower impedances of common coaxial or parallel transmission lines. Simple antennas can present not-so-simple feeding challenges.

Likewise, we must use care in our selection of an array in terms of the gain-vs.-beamwidth question. If we had just one friend with whom we wish to communicate (or two friends at 180° separation), then we might use gain alone as our desideratum. However, in most cases, we shall want to balance gain against coverage. Hence, it is likely that we shall have to trade some gain to obtain adequate beamwidth.

Just when we might think we have reached an ending, someone has whispered to me, "How do we convert a bi-directional array into a directional array?" It turns out that, even here, we have options.

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