The M3KXZ 2-Element Vertical Phased Array

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In July, 2006, Pete Millis, M3KXZ, published to the internet an array of 2 vertical antennas that he calls "'No-counterpoise' antenna: 2-element phased array." You can find his article at http://www.outsideshack.com/no_counterpoise_phased_array.pdf. The latest incarnation follows a 1-element version of the antenna.

The antenna is interesting in several respects. First, it uses a very simple structure and common materials that you can obtain from Radio Shack and hardware sources. Pete uses speaker wire and PVC supports for the vertical elements. Perhaps the only specialized antenna items are the baluns that he winds on ferrite cores and the encased 4:1 balun he uses at the center of the 2-element version of his array. However, we shall have occasion to evaluate the need for these items as we look into the antenna.

The second significant aspect of the antenna is its performance. A single element length covers a spread of bands, for example, 20 meters to 6 meters using a total length of 25'. The normal limit for either a 1/4-wavelength monopole or a 1/2-wavelength dipole is about 2.5:1, which would suggest a cut-off of about 35-36 MHz, if the original antenna is cut for 14 MHz. Once a monopole exceeds about 5/8-wavelength or a dipole exceeds 1-1/4-wavelengths, the main radiation is no longer broadside to the wire. For a vertical antenna, the long lengths result in very high angle radiation, rather than the low angle radiation that we normally need. However, the M3KXZ antenna and array yield very usable patterns from 20 through 6 meters. In addition, the gain of the antenna is close to the gain available from either vertical dipole/doublets or from elevated monopoles with radials on all bands.

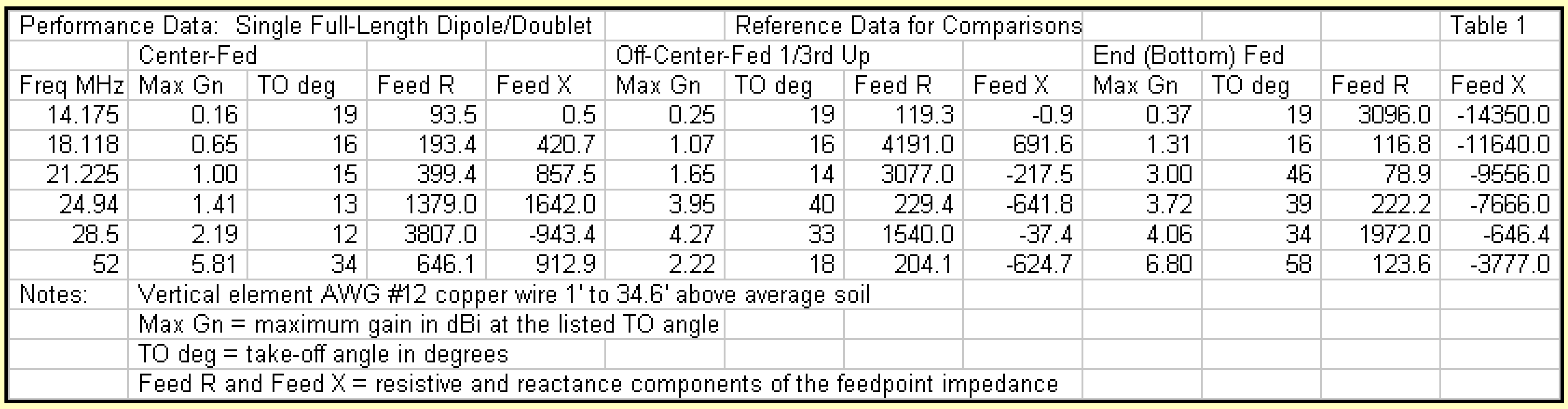
For these reasons, it seems that the antenna in both its 1-element and 2-element versions deserves a closer look, if only to understand its operation better. As well, if one wanted to replicate his antenna using different materials, we shall need to look at some of the pieces in his arrangement.

A Frame of Reference

As a basic for evaluating the behavior and performance of the M3KXZ antenna and array, let's first catalog comparable data for a more familiar antenna, the straight vertical wire element. Since we shall look at the 20-6-meter version of the M3KXZ antenna, we may cut the wire for 20 meters. We shall use AWG #12 copper wire and place the lower end 1' above the ground, the height that we shall use for the other elements. However, a straight wire that is vertical requires a top height of 34.6'. For our basic work, we shall use average ground as the soil throughout.

We have 3 choices for feeding our vertical wire. We might select the center, which would be natural for a 1/2-wavelength dipole. Of course, the wire becomes a doublet as the length grows longer than 1/2-wavelength and the current peak and voltage minimum no longer occur at the center of its length. Alternatively, we might select a feedpoint based on the M3KXZ design, that is, a position 2/3 of the distance down from the antenna top, considering the 12.5' fold back in the M3KXZ design as the lower 1/3 of the antenna. Finally, we might place the feedpoint at the lower end of the antenna.

Table 1 summaries some of the key performance data for each of the three versions of the vertical wire at the center of all amateur bands from 20 through 6 meters.

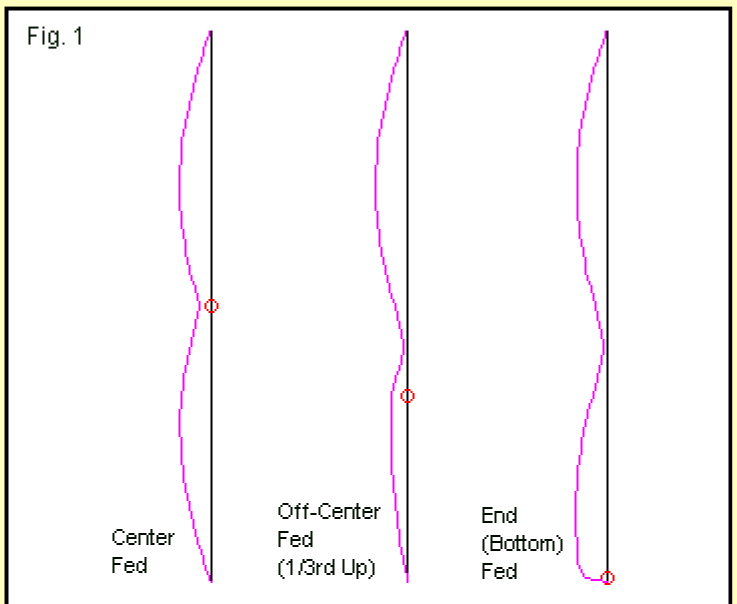


Performance Data: Single Full-Length Dipole/Doublet						Reference Data for Comparisons						Table 1
	Center-Fed				Off-Center-Fed 1/3rd Up				End (Bottom) Fed			
Freq MHz	Max Gn	TO deg	Feed R	Feed X	Max Gn	TO deg	Feed R	Feed X	Max Gn	TO deg	Feed R	Feed X
14.175	0.16	19	93.5	0.5	0.25	19	119.3	-0.9	0.37	19	3096.0	-14350.0
18.118	0.65	16	193.4	420.7	1.07	16	4191.0	691.6	1.31	16	116.8	-11640.0
21.225	1.00	15	399.4	857.5	1.65	14	3077.0	-217.5	3.00	46	78.9	-9556.0
24.94	1.41	13	1379.0	1642.0	3.95	40	229.4	-641.8	3.72	39	222.2	-7666.0
28.5	2.19	12	3807.0	-943.4	4.27	33	1540.0	-37.4	4.06	34	1972.0	-646.4
52	5.81	34	646.1	912.9	2.22	18	204.1	-624.7	6.80	58	123.6	-3777.0
Notes:	Vertical element AWG #12 copper wire 1' to 34.6' above average soil											
	Max Gn = maximum gain in dBi at the listed TO angle											
	TO deg = take-off angle in degrees											
	Feed R and Feed X = resistive and reactance components of the feedpoint impedance											

As we would expect, the feedpoint impedance values (Feed R and Feed X) differ widely among the antenna versions. More significant for eventual comparative purposes is the performance of each version. None of the three can sustain a low elevation angle for the main radiation lobe across the range of bands covered by the survey. Moreover, we find differences within each band depending on the feedpoint position, and the differences involve more than small changes in the maximum gain. For an example, we may use 24.94 MHz. The center-fed version produces a main lobe at 13 degrees elevation. The off-center-fed version's main lobe is at 40 degrees, while the end or bottom-fed version main lobe is at 39 degrees elevation.

The radiation pattern differences result from differences in the current magnitude distribution along the wire on this band--and on any other band where the wire is longer than 1/2 wavelength. **Fig. 1** shows the differences that occur on 12 meters. Most evident is that the current minimum occurs ever lower on the structure as we move from center feeding to bottom-end feeding. As well, but to a lesser degree, the differences in the current curve between the off-center-fed and the end-fed version play a role in the ultimate shape and strength of the pattern lobes for the vertical wire.

Fig. 1



Current Magnitude Distribution on Reference Element at 24.94 MHz with Different Feedpoint Positions

Only the center-fed version of the straight wire doublet manages to cover 20 through 10 meters with the man lobe at a low elevation angle. The other versions give way to having their main lobes at higher and generally undesired elevation angles well under 10 meters. Despite our interest in the radiation patterns, we shall also discover that the impedance columns of **Table 1** will hold importance as we attempt to see what lies behind the behavior of the M3KXZ antenna.

Some M3KXZ Antenna Basics

The full 2-element array appears in **Fig. 2** in outline form. I have selected the 20-6-meter version for a detailed look. A single-element version of the antenna would simply omit the second element and the two phase-lines marked TL1 and TL2.

Main Elements of the M3KXZ 2-Element Phased Vertical Array

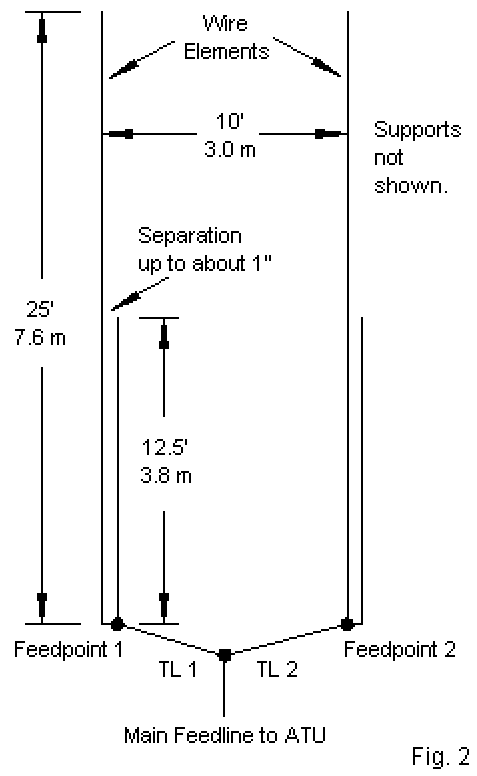
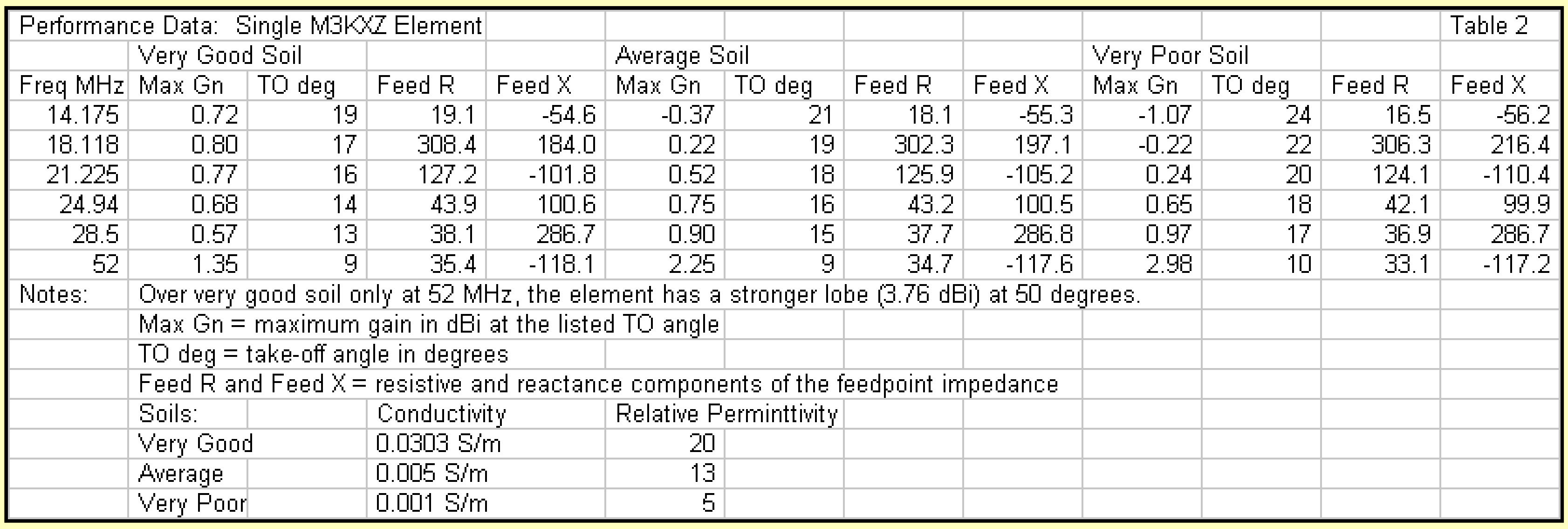


Fig. 2

In modeling the antenna, I departed from the original, which uses speaker wire. To yield adequate models, I spaced the AWG #12 copper wires 1" apart in the lower half. Parallel wires at this separation have a transmission-line impedance of about 400-450 Ohms. Although I have seen no tests of insulated speaker wires, the characteristic impedance of a pair is likely to fall into the 75-100-Ohm range, due to both the spacing and the relative permittivity (dielectric constant) of the insulation between them. In addition, Pete twines the wire along a length of PVC for support, but without introducing any significant inductance. Although we can view his elements as essentially straight, we should understand at the outset that all models will be only approximations of his antenna.

We should also enter a modeling caution to those who may wish to replicate the models used in this study. The separation between the long and the short sections of the element is 1". Although one would normally use 1" segment lengths for the remainder of the model, there is a different overriding consideration. Very closely spaced wires in NEC are subject to errors, even when we precisely align the segment junctions. In order to obtain a fair set of comparisons between the M3KXZ element and the straight wire element, it is necessary to adjust the segmentation to obtain an average gain test (AGT) score that is as close to 1.00 as may be feasible. For the models used here, 120 segments in the long section and 60 segments in the short section produced an AGT score of 1.004, indicating that gain and impedance values will be very much on a par with those drawn from the straight wire element with its essentially perfect AGT score. AGT values below near-perfect will yield low gain and high impedance reports, while AGT scores above near perfect will yield values that are too high for the gain and too low for the impedance. For very closely spaced wires, the segmentation density alone is enough to yield gain values up to 1.5 dB off the mark. Hence, close attention of the model's AGT score is essential, especially when comparing the performance of models have different geometries.

Before we turn to the full phased array, let's see what we might obtain from a single M3KXZ element. **Table 2** lists the NEC-4 reports from the model, which places the 25' element at a height of 1' above ground. I placed the antenna over a range of soils from very good to very poor in order to determine if the soil quality had a significant bearing on performance, given the close proximity of ground to the lower end of the element.

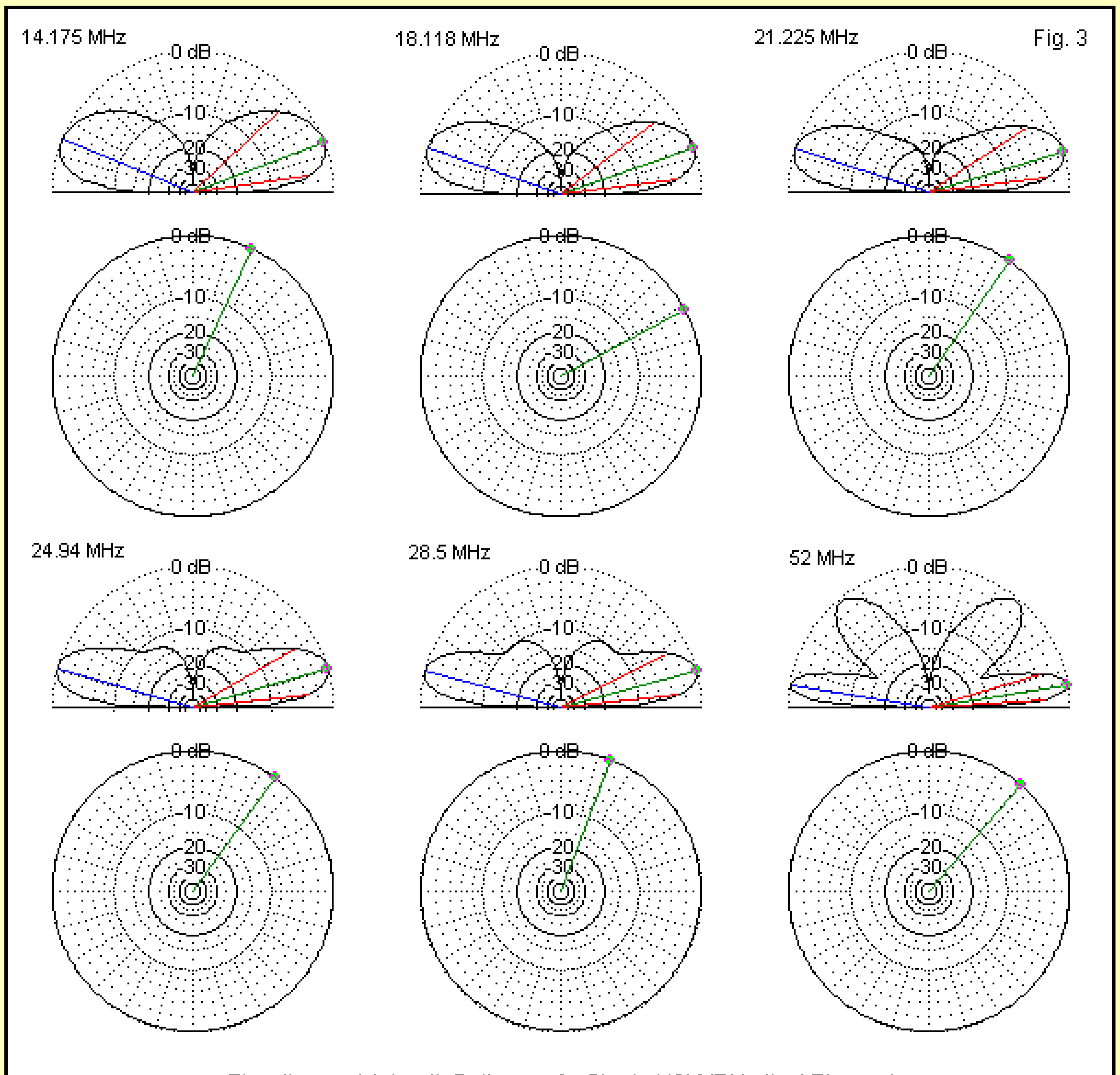


Performance Data: Single M3KXZ Element												Table 2
	Very Good Soil				Average Soil				Very Poor Soil			
Freq MHz	Max Gn	TO deg	Feed R	Feed X	Max Gn	TO deg	Feed R	Feed X	Max Gn	TO deg	Feed R	Feed X
14.175	0.72	19	19.1	-54.6	-0.37	21	18.1	-55.3	-1.07	24	16.5	-56.2
18.118	0.80	17	308.4	184.0	0.22	19	302.3	197.1	-0.22	22	306.3	216.4
21.225	0.77	16	127.2	-101.8	0.52	18	125.9	-105.2	0.24	20	124.1	-110.4
24.94	0.68	14	43.9	100.6	0.75	16	43.2	100.5	0.65	18	42.1	99.9
28.5	0.57	13	38.1	286.7	0.90	15	37.7	286.8	0.97	17	36.9	286.7
52	1.35	9	35.4	-118.1	2.25	9	34.7	-117.6	2.98	10	33.1	-117.2
Notes:	Over very good soil only at 52 MHz, the element has a stronger lobe (3.76 dBi) at 50 degrees.											
	Max Gn = maximum gain in dBi at the listed TO angle											
	TO deg = take-off angle in degrees											
	Feed R and Feed X = resistive and reactance components of the feedpoint impedance											
	Soils:		Conductivity		Relative Perminttivity							
	Very Good		0.0303 S/m		20							
	Average		0.005 S/m		13							
	Very Poor		0.001 S/m		5							

If we examine the gain and TO angle columns of **Table 2** under average soil, we discover that on all bands through 10 meters, the M3KXZ element yields competitive gain values and TO angles that are only slightly worse than those we gather from the center-fed straight wire. The M3KXZ element TO values are slightly higher largely because the top height is about 30% lower than the top height of the center-fed doublet. Nonetheless, all of the TO angles shown in the table are suitably low, although they do vary with the ground quality.

There is an incidental but interesting pattern to note. We normally think of ground losses as increasing as soil quality decreases so that as we move toward bad soils, the gain of a vertical element decreases. However, this thinking has a frequency limit. The old thinking applies in small amounts from 20 through 15 meters. However, on 12 meters, maximum gain occurs over average soil. Above 12 meters, maximum gain occurs over very poor soil. The trend reversal is accompanied by a shrinkage in the differential in gain as we change soil, but the reversal is quite real.

Soil quality changes do not make a large difference in the feedpoint impedance at the antenna base, where the short and the long wires meet. However, the range of feedpoint impedances is considerable. Hence, the use of a coaxial cable between the antenna base and the antenna tuner may prove a considerable loss source unless the length is very short. With the possible exception of 10 meters, all of the impedances fall within the easily matched range of a remote antenna tuner place at the element feedpoint. Otherwise, the use of parallel feedline--suitably elevated from the ground to prevent unwanted coupling--may be necessary. However, the very low impedance on 20 meters may incur some losses even with parallel feedlines.



Elevation and Azimuth Patterns of a Single M3KXZ Vertical Element

Fig. 3 provides a gallery of elevation and azimuth patterns for the bands covered by the array. Although the azimuth patterns all appear to be quite circular, note the shifting angle of the line that indicates the bearing of maximum gain. Any antenna with a fold-back--including the well-known J-pole--will exhibit at least a slight pattern distortion due to radiation from the two wires in the fold-back region. The closer that we space the wires, the less will be the distortion, and with the 1" spacing, the differential is never more than about 0.03 dB. However, as the shifting line bearings show, the distortion will change a bit from one band to the next. The fact is not operationally significant, but will prompt some further investigation.

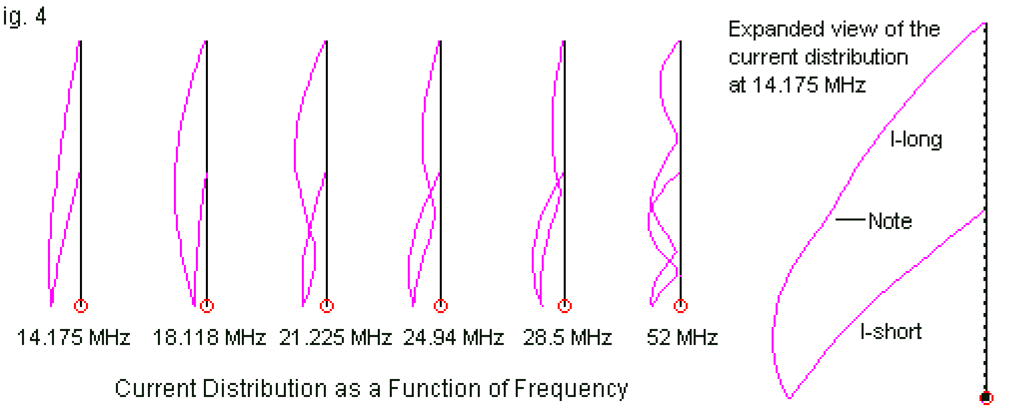
The elevation patterns reveal one of the most essential aspects of the antenna's performance, the well-behaved radiation at low angles with very little higher-angle radiation until we reach 52 MHz. At the upper limit of the operating spectrum, the second elevation lobe nearly equals the gain of the lower lobe over average ground, and over very good soil, the second lobe at an angle of 50 degrees is actually stronger. However, the low-angle gain remains serviceable. For comparison, a straight vertical dipole fed 1/3rd of the way up its length shows a considerable upper-angle lobe on 15 meters, and at 12 and 10 meters, the higher second lobe dominates the pattern.

The well-behaved patterns are one of the effects of the 12.5' fold-back. That fold-back is not just a convenient way of feeding the antenna at a point 1/3 of its total length (25' plus 12.5'). For example, if we feed a 20-meter vertical dipole at the 1/3rd point, we obtain resistance values ranging from 100 to 3100 Ohms, and reactance values from -600 to +700 Ohms. The values shown in **Table 2** are far tamer than they are for an off-center-fed straight dipole--or for any of the other versions of the straight-wire element in **Table 1**.

In fact, the fold-back forms a transmission line section that is 12.5' long. Whatever impedance appears at the junction of the single-wire top section and the beginning of the double-wire section undergoes a transformation according to the electrical length of the double section and its characteristic impedance. Note once more that modeling requirements have dictated a 1" spacing, and that the characteristic impedance is not the same as it would be for the speaker wire. Hence, the impedance numbers in **Table 2** are only representative. As well, they do not account for the transmission-line velocity factor of the insulated speaker wires used in the original.

Fig. 4 presents a collection of current magnitude distribution graphs taken from the EZNEC models. At the far right, I have expanded the 20-meter graph in order to show that the current magnitude undergoes a small but noticeable shift at the point where the top single wire meets the double-wire section. The jog indicates that below the junction, the graph is showing a combination of both radiation and transmission-line currents.

Fig. 4



Current Distribution as a Function of Frequency
M3KXZ Vertical Element

The remainder of the current magnitude graphs show that we should not try to apply a simplistic J-pole or end-fed Zepp model to the situation. As the patterns show, the junction between the top and bottom sections does not occur at a maximum voltage, minimum current point on any band. As well, the double-line length is not 1/4-wavelength on any band, although it comes close on 10 meters. Therefore, the impedance transformation differs for each band in terms of both the impedance at the section junction and the amount of transformation that occurs in the lower section. One might use a number of means to roughly calculate the start and end values for the transformation, but given the higher characteristic impedance in the model relative to the speaker wire used in the original, such an exercise might prove to be operationally useless. For any given installation, the most practical effort is to measure the impedance at the feedpoint for every planned frequency of operation.

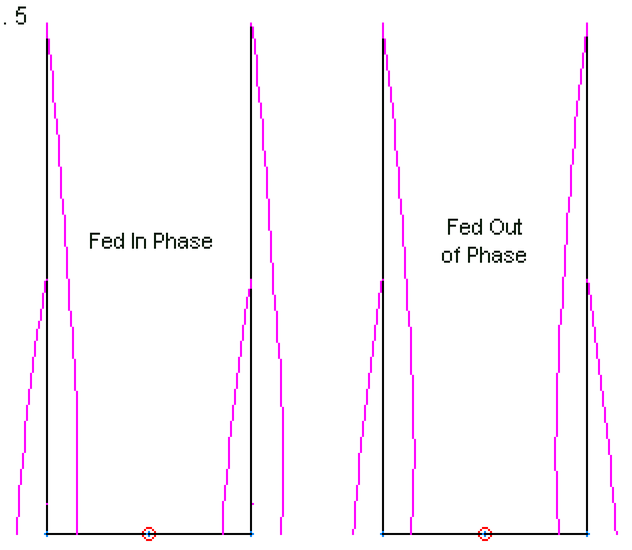
One consequence of the lower double-wire or transmission-line section is that the dominant radiation currents do not follow the patterns that they would in a straight dipole/doublet, whatever the feedpoint. Hence, M3KXZ has found essentially an antenna designer's grail or silver bullet: an arrangement of wires that extends the range of desirable pattern formation beyond its normal limits while sustaining good gain for an antenna of its type and leaving quite workable feedpoint impedance values.

The 2-Element M3KXZ Phased Array

The 2-element version of the M3KXZ antenna, shown in **Fig. 2**, consists of 2 elements connected by equal lengths of a transmission line, with a common junction for connection to the main feedline. For the 25' version of the antenna, intended to cover 20 through 6 meters, the spacing between elements is 10'. The spacing is not accidental, since at 52 MHz, it represent about 0.53-wavelength, the maximum that we would wish to space phase-fed elements.

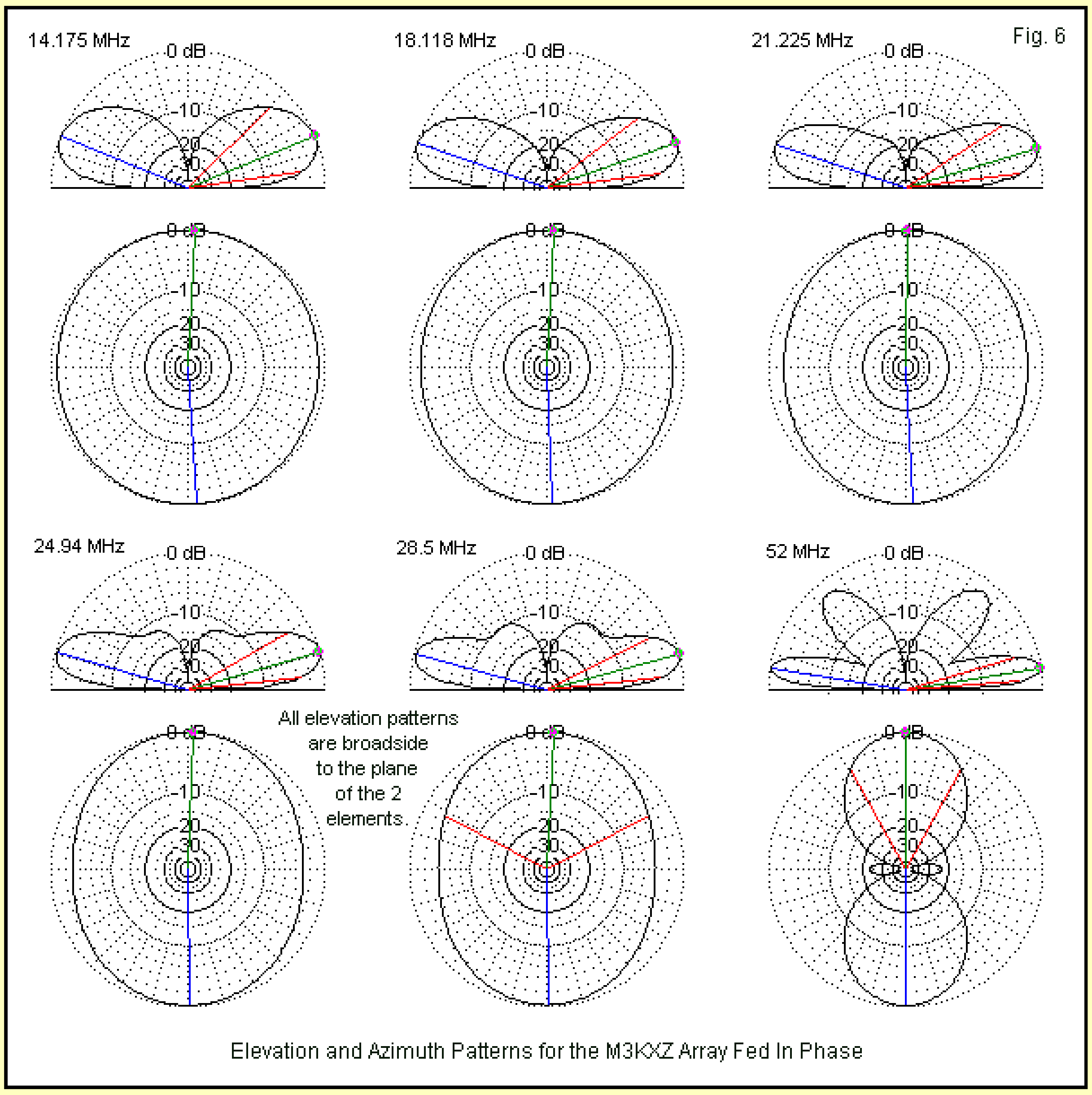
Since we shall ultimately feed the antenna at a center point between the two elements, we have two choices of phasing. We may connect the two lines so that each long-section wire goes to the same side of the junction for in-phase feeding. Alternatively, we may give one (and only one) of the two lines a half twist so that connections to long-section wires go to opposite junction points and thus end up with out-of-phase feeding. The original design used plugs and jacks at the center junction box to allow a quick reversal of the junction connections. A remote switch might achieve the same goal with control transferred to the equipment location. **Fig. 5** shows the differences in the current distribution curves that result from the alternative feedpoint connections.

Fig. 5



Current Distribution on the M3KXZ Array
When Fed in Phase and Out of Phase

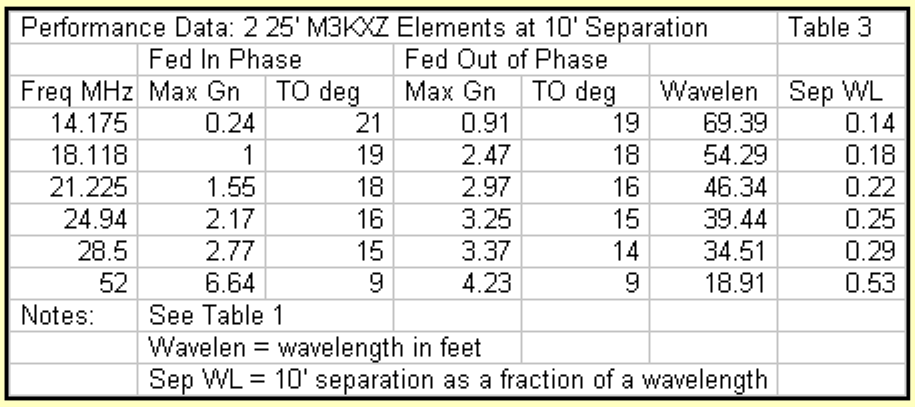
In-phase feeding of the two elements results in a broadside azimuth pattern relative to the plane of the two elements, comparable to the patterns that we obtain from converting a lazy-H into a standing-H. The gain yielded by the pattern over the gain of a single element is a function of the narrowing beamwidth in the plane of the array. The elevation pattern is not materially affected by the dual feed. How much gain increase and beamwidth reduction we obtain is a function of the spacing between the elements measured in wavelengths at the frequency of operation. Gain increases slowly from virtually single-element performance at very close spacing to maximum with a spacing that is just over 0.5-wavelength. With an exact 0.5-wavelength spacing, the azimuth pattern is a perfect figure-8. Gain continues to increase with slightly wider spacing, but small sidelobes develop in the plane of the elements. Above about 0.55-wavelength spacing, the sidelobes grow so fast that the gain broadside to the antenna decreases.



Elevation and Azimuth Patterns for the M3KXZ Array Fed In Phase

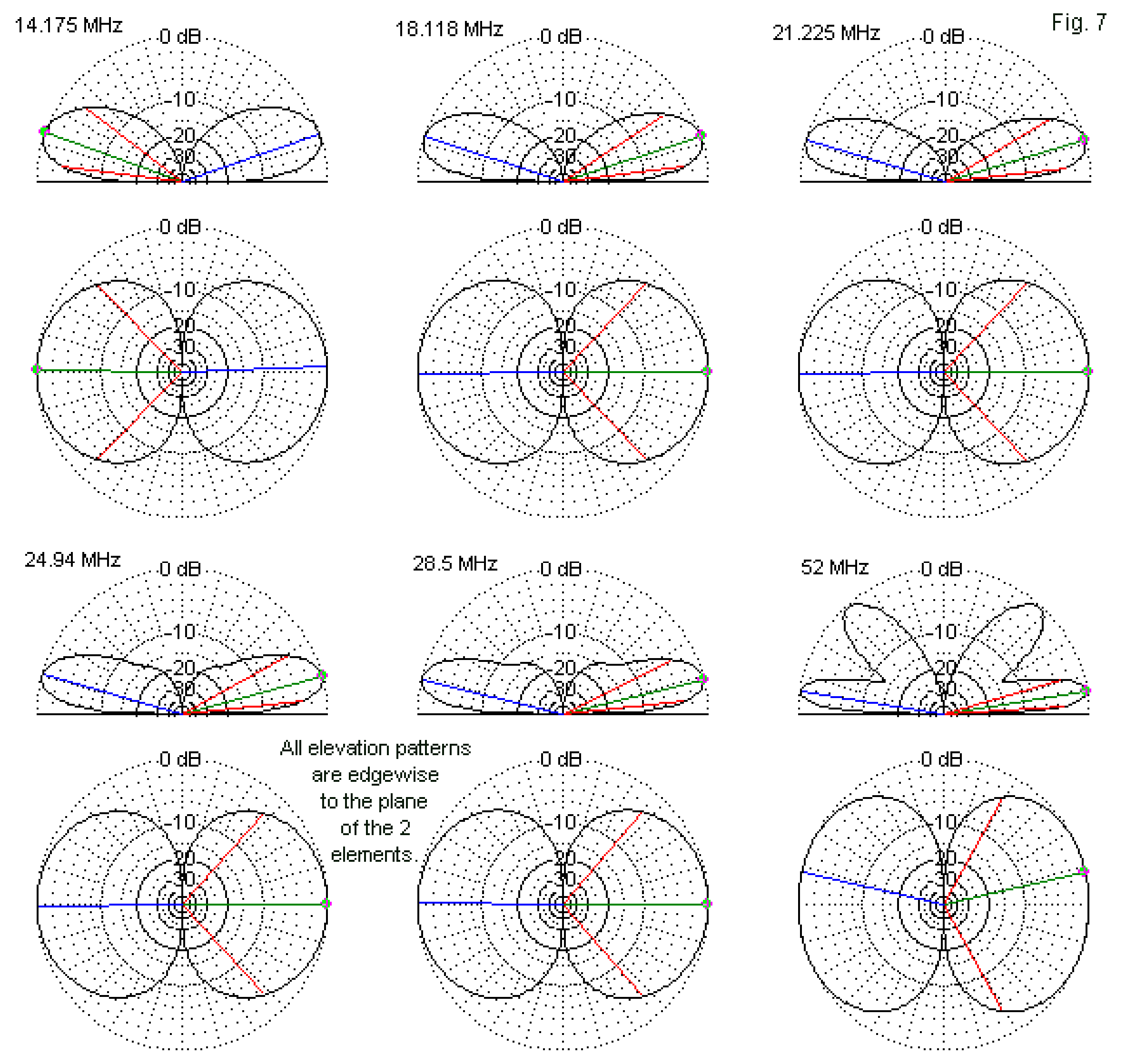
Fig. 6 provides a gallery of elevation and azimuth patterns for the model of the 25' M3KXZ array with the 10' spacing between elements. Note that the elevation patterns, taken broadside to the plane of the two elements, do not differ significantly from the single-element elevation patterns. The azimuth patterns do not show relative gain values. Instead, each pattern uses the outer ring as the pattern limit to reveal more clearly the pattern shapes. If we look at the azimuth pattern for 52 MHz, we can see the beginnings of the sidelobes that develop as a result of the 0.53-wavelength spacing between elements. However, at lower frequencies, the spacing between elements is considerably less than the 0.5-wavelength ideal. As a results, as we move down in frequency, the patterns become more circular, indicating both broader beamwidth values and lower gain values. At 20 meters, where the spacing is only about 0.14-wavelength, we should expect--and we obtain--very little gain increase over a single element.

Table 3 provides 2 sets of performance values, both sets taken over average ground. The left-most columns give the modeled gain and TO angle for the patterns in **Fig. 6**. You may compare these values to the values obtain for a single M3KXZ elements over average ground in **Table 2**. At 20 meters, the gain advantage only about 0.6 dB due to the close spacing of the in-phase-fed elements. At 10 meters, the gain advantage of the 2-element array increases to about 1.9 dB as the spacing increases to nearly 0.3-wavelength. At the more nearly ideal spacing on 6 meters, the gain advantage jumps to about 4.4 dB, with a commensurate decrease in the beamwidth of the two broadside lobes.



Performance Data: 2 25' M3KXZ Elements at 10' Separation						Table 3
	Fed In Phase		Fed Out of Phase			
Freq MHz	Max Gn	TO deg	Max Gn	TO deg	Wavelen	Sep WL
14.175	0.24	21	0.91	19	69.39	0.14
18.118	1	19	2.47	18	54.29	0.18
21.225	1.55	18	2.97	16	46.34	0.22
24.94	2.17	16	3.25	15	39.44	0.25
28.5	2.77	15	3.37	14	34.51	0.29
52	6.64	9	4.23	9	18.91	0.53
Notes:	See Table 1					
	Wavelen = wavelength in feet					
	Sep WL = 10' separation as a fraction of a wavelength					

The table's center columns provide modeled values for the performance of the array when fed out-of-phase by giving one of the two equal-length lines a single half-twist. The method of feeding is a simple evolution from the W8JK array that we usually see in horizontal form. The same principles apply. The antenna becomes a bi-directional endfire array with the main radiation in the plane of the elements. **Fig. 7** provides a gallery of elevation and azimuth patterns as they apply to out-of-phase feeding of the two elements with their 10' spacing. The elevation patterns are taken in the plane of the elements.



Elevation and Azimuth Patterns for the M3KXZ Array Fed Out of Phase

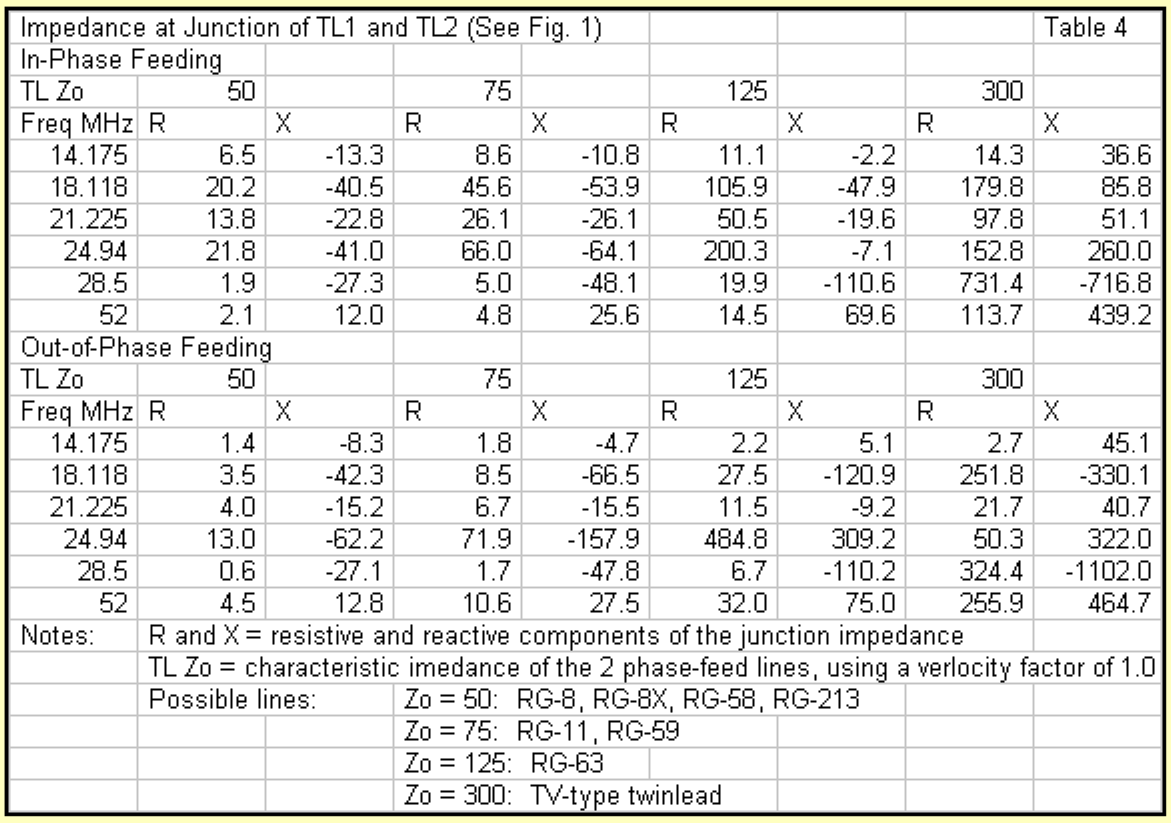
Except for the 52-MHz plot, the azimuth patterns all show comparable beamwidths. If we compare the out-of-phase gain values to the in-phase values, we find a sudden jump and a leveling off, so that we show only a slow rise in gain as we increase the operating frequency. The behavior of an end-fire out-of-phase fed array differs considerably from the in-phase-fed version. Two general rules apply. First, the closer the element spacing, the higher the gain will be over a single element. This trend gives precedence to 20 and 17 meters, where element spacing is closest. Second, the gain advantage increases as we increase the element length relative to an initial length. This trend gives precedence to the higher frequencies, where the M3KXZ elements are electrically longer. The broadening of the beamwidth at 52 MHz suggests that at higher frequencies (and therefore longer element electrical lengths), the pattern will break into 4 lobes, ruining the bi-directional characteristic of the antenna with out-of-phase feeding. The net result of combining the two trends is a much tighter grouping of gain figures for the out-of-phase version relative to the broadside in-phase version of the array.

The purpose of switching the phase of feeding is to obtain maximum possible gain from two fixed vertical elements in the direction of the signal. An in-phase/out-of-phase switch at the junction of the two lines marked TL1 and TL2 in **Fig. 2** provides a means of switching the axes of the bi-directional beaming. The beamwidths of the lobes in each version are complementary so that little or none of the horizon is excluded from performance equal to or better than the omni-directional patterns of a single element. Of course, in the 2-element phased version of the M3KXZ array, the elevation patterns retain their low TO angles.

Thus far, the M3KXZ array displays considerable ingenuity in providing low-angle vertically polarized radiation over a wide passband. However, the array faces one final challenge: feeding the system and matching the junction impedance for either phase condition to the equipment. Here, we can use the modeled elements only with great caution. M3KXZ constructed his entire system with speaker wire, an inexpensive but dubious choice for outdoor durability. Speaker wires generally carry no rating for performance under the summer-to-winter weather extremes, and so the quality of such wires will vary from one maker to another, depending upon the quality of the insulation. In addition, such wires carry no rating for their characteristic impedance at RF frequencies. However, similar wires with standard "poly-plastic" insulations usually show an impedance in the 75- to 100-Ohm range. Due to modeling limitations, we have had to use a lower or double-wire section composed of bare wires 1" apart, for a characteristic impedance in the 400- to 450-Ohm range. Therefore, the impedance transformation that occurs in this section from the junction with the single-wire upper section and the end feedpoint will differ from the transformation obtained in the original version.

Adding phase lines to a central junction is another matter. We may sample a variety of lines, that is, a range of characteristic impedance values, by using the TL facility within NEC. The line impedance will not change the antenna radiation pattern, but it will change the impedance that we obtain at the junction of the two lines under each of the phasing conditions. In creating a survey of values, I have simply used a velocity factor of 1.0 for two reasons. First, the element feedpoint impedance values are already off their marks if we use a double-wire section with a difference characteristic impedance. Second, common feedlines tend to come in several versions, each with a specific velocity factor.

Nevertheless, we can obtain a view of the type and size of the feedpoint impedance challenge using two 5' lengths of transmission line to a central junction. For the survey, I selected characteristic impedance values of 50, 75, 125, and 300 Ohms. The 50-Ohm value is for the most common variety of coaxial cable. 125-Ohms is the value for RG-63, a very useful but often overlooked cable. 75-Ohm covers both some common coaxial cables and so-called twisted pairs of insulated wires. 300 Ohms, of course, applies to common TV-type parallel feedline. **Table 4** provides the results of the survey, where R and X are the impedance components at the junction of the two cables (TL1 and TL2) under each phasing condition.



Impedance at Junction of TL1 and TL2 (See Fig. 1)								Table 4
In-Phase Feeding								
TL Zo	50		75		125		300	
Freq MHz	R	X	R	X	R	X	R	X
14.175	6.5	-13.3	8.6	-10.8	11.1	-2.2	14.3	36.6
18.118	20.2	-40.5	45.6	-53.9	105.9	-47.9	179.8	85.8
21.225	13.8	-22.8	26.1	-26.1	50.5	-19.6	97.8	51.1
24.94	21.8	-41.0	66.0	-64.1	200.3	-7.1	152.8	260.0
28.5	1.9	-27.3	5.0	-48.1	19.9	-110.6	731.4	-716.8
52	2.1	12.0	4.8	25.6	14.5	69.6	113.7	439.2
Out-of-Phase Feeding								
TL Zo	50		75		125		300	
Freq MHz	R	X	R	X	R	X	R	X
14.175	1.4	-8.3	1.8	-4.7	2.2	5.1	2.7	45.1
18.118	3.5	-42.3	8.5	-66.5	27.5	-120.9	251.8	-330.1
21.225	4.0	-15.2	6.7	-15.5	11.5	-9.2	21.7	40.7
24.94	13.0	-62.2	71.9	-157.9	484.8	309.2	50.3	322.0
28.5	0.6	-27.1	1.7	-47.8	6.7	-110.2	324.4	-1102.0
52	4.5	12.8	10.6	27.5	32.0	75.0	255.9	464.7
Notes:	R and X = resistive and reactive components of the junction impedance							
	TL Zo = characteristic imedance of the 2 phase-feed lines, using a verlocity factor of 1.0							
	Possible lines:		Zo = 50: RG-8, RG-8X, RG-58, RG-213					
			Zo = 75: RG-11, RG-59					
			Zo = 125: RG-63					
			Zo = 300: TV-type twinlead					

The number of cases in which we obtain very low impedances, regardless of the characteristic impedance values for the phasing lines, raises a strong question about using a 4:1 balun at the junction of the two lines. Converting an impedance that is already well below 50 Ohms down to an even lower values seems to make little sense, especially if one uses the 50-Ohm main feedline shown in the originator's sketches. 4:1 baluns come in numerous designs, some of which may prove to suffer losses when used with high reactive components or when used outside the range of their winding's characteristic impedance. The result may be artificially favorable impedance values at the terminals that may disguise what is actually occurring within the device. There are few values in **Table 4** that would benefit from even an accurate 4:1 downward impedance transformation.

In addition, the author uses 1:1 baluns supposedly to force equal currents on to the short and long sections. Actually, the current imbalance on each side of the feedpoint is part of what allows the array to achieve its broadband characteristics. A balun or choke might be more applicable at each element feedpoint if TL1 and TL2 are both coaxial cables, where transmission-line currents are inside the cable between the center conductor and the inner side of the braid, and common-mode currents are on the outside of the braid. Indeed, parallel transmission lines may not be the most ideal phase lines for the array.

The author also correctly notes that he obtains good impedance matches between whatever impedance the array presents at the junction--after transformation down the 50-Ohm main feedline--via his antenna tuner. We shall bypass any losses incurred by the impedance mis-match between the cable's impedance and the load impedance at the phase-line junction. The low-impedance loads, if transferred to a tuner, present challenges of their own.

Depending upon the type of network used, low-impedance loads sometimes result in acceptable but imperfect impedance matches, where the best obtainable SWR value at the tuner is perhaps 1.3:1 to 1.6:1. These conditions generally indicate a limit to the range of the components within the tuner relative to the impedance at the terminals. In the table, note that many modeled values show much higher reactive components than resistive components. Although the match is acceptable, the efficiency of power transfer may not be as high as we too often presume. If the network has a low loaded or operating Q (Terman's "delta" term from the 1940s), we may find a difference in the settings required for resonance (that is, for zero reactance), for maximum power transfer, and for impedance matching. As the circuit's delta increases to about 10, these settings resolve to a single point. However, so long as tuners continue to lack any form of relative output indicator, we cannot easily tell if the impedance match that we obtain is also the point of maximum efficiency.

The junction of the two phasing lines is a balanced feedpoint. Ideally, the array might be fed at that feedpoint by a remote, balanced, weatherproof ATU with a very wide range of impedance matching capabilities. Such tuners are not generally available, although we can press existing components into service. In general, placing the tuner at the balanced feedpoint that joins the two phase-lines allows the use of a 50-Ohm cable to the equipment with minimum loss. At the input to the tuner we likely should install a common-mode current attenuator, such as an unun or a ferrite bead choke. System ground should occur at the equipment side of the unun or the choke, not either at the tuner output or at the tuner input. (The tuner input is likely to have a common ground system with the output, and we would want the tuner to "float." Grounding the braid of the coax at the equipment side of a ferrite bead choke would provide for static discharge.)

Conclusion

The M3KXZ antenna and array constitute an ingenious arrangement of element parts that achieves low-angle vertically polarized radiation over an extended operating bandwidth that common configurations cannot match. The 2-element version of the array offers some gain and pattern shaping for bi-directional operating. Even with improved materials designed for both RF service and durability through seasonal weather cycles, the antennas are inexpensive. Moreover, they a relatively short for a given frequency range, adding to their neighborhood acceptability.

The challenges presented by the antenna and the array revolve around the matching and the feed system. Increased attention to these details may result in a very serviceable, wide-band vertical array.

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