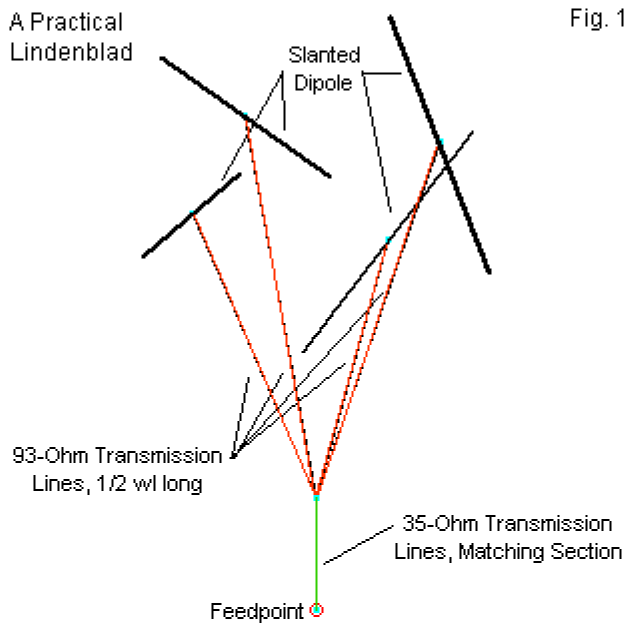
The Practical Lindenblad

L. B. Cebik, W4RNL (SK)

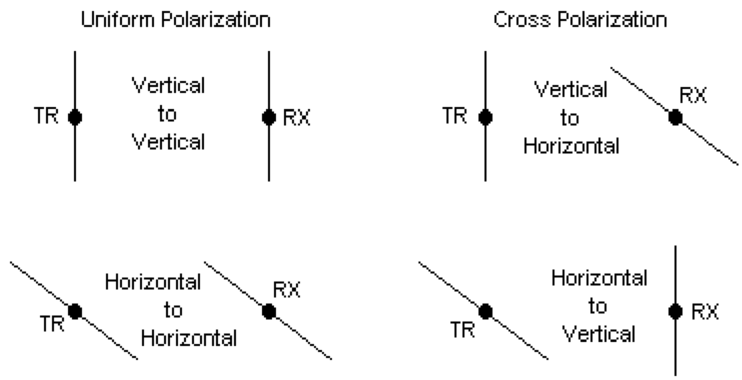
In a fairly recent article ("Notes on Fixed Satellite Antennas"), I called attention to the original Lindenblad array (in contrast to the modified Lindenblad used as a fixed satellite antenna by some amateurs). **Fig. 1** provides an overview of the array, along with the lines necessary to a. feed all of the dipoles in phase and b. match the resulting impedance to the standard amateur 50-Ω feedline. Granted that the pattern is roughly omni-directional. Granted that the polarization in the X-Y plane (parallel to ground) is roughly circular. Still, one might fairly ask what utility the antenna might have if one does not plan to broadcast TV or FM signals from the Empire State Building, the antenna's original home.



The answer is fairly straightforward: the Lindenblad can serve as an omni-directional all-mode, all-polarization antenna for local communications on at least 6 and 2 meters. At present, if we wish to have the same features for local vertically polarized services, we need to have at least a vertical dipole or ground-plane monopole. Horizontally polarized services call for a separate antenna. The simplest omni-directional antenna may be a turnstiled pair of dipoles. The Lindenblad can rid us of half the required support assemblies at a cost of one more dipole.

Some Polarization Basics

We often associate antenna polarization with the plane of an antenna, using a dipole as a standard. If the dipole is parallel to the ground, we call it horizontally polarized, and if it extends toward the sky, we call it vertically polarized. We can live with this oversimplification for a few moments to consider the antenna situations shown in **Fig. 2**. We may have transmitting and receiving dipoles that are aligned with each other--either vertically or horizontally--or we may face the problem of having them at 90° to each other--called cross polarization. Very often, we encounter simple handbook statements that tell us one simple fact: alignment is good for signal strength, but cross-polarization is bad. Rarely do we find a demonstration of the phenomenon.



Common Polarization Situations

Fig. 2

I set up a small modeling experiment. I created two dipoles and placed them 1 mile (5280') apart. I fed one and then recorded the current on the center segment of the other. The dipoles are at 52 MHz and are 20' above average ground. The transmitting power is not important except for one facet: it should be the same for all cases. As well, the receiving data is not 100% accurate, since in each case, we would normally translate the segment current into a corresponding voltage or power based on the impedance of the receiving dipole's center segment. However, for the present demonstration, these supplementary calculations are both unnecessary and distractions, since we are looking for rather gross differences.

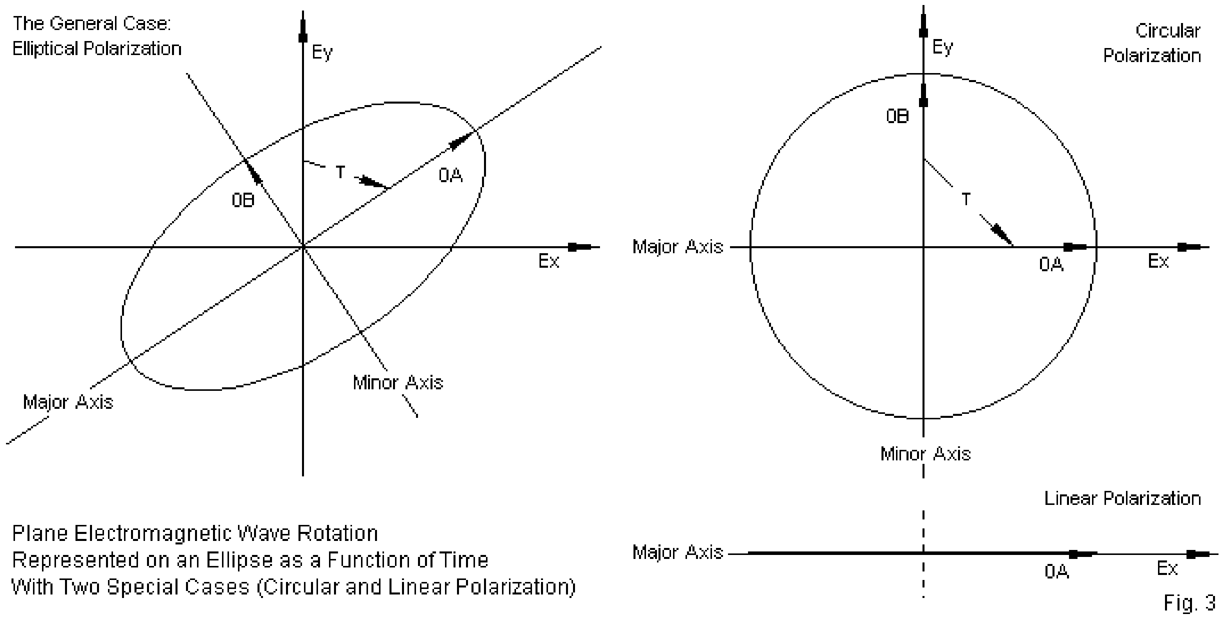
Table 1. Aligned and cross polarized signal strengths.

Polarization	Receiving Dipole Current
Vertical to Vertical	5.8e-4
Vertical to Horizontal	2.0e-10
Horizontal to Horizontal	5.1e-4
Horizontal to Vertical	4.0e-10

Notes: All antennas are ½-λ long and centered 20' above average ground. Distance: 1 mile. Transmitted power constant.

Table 1 shows the results of our initial experiment. With the selected transmitting power level, we find the received current to be between 4e-4 and 5e-4 A when the elements are aligned. When the elements are cross polarized, the receiving current drops to between 2e-10 and 4e-10 A, a 6-order change of value. Little wonder that we do not need high precision in the numbers when we have such a large value change. Of course, the modeled situation presumes only level ground between the antennas with no ground clutter. Buildings, terrain, and natural growth can create reflections, refractions, and diffractions that are sufficient to lower the differential considerably. Nevertheless, we cannot count on such phenomena in every direction.

Another statement that often greets us in all of its simplicity is that circular polarization can overcome many of the problems of cross-polarization. However, most handbooks readily available to amateurs do not provide any background on what polarizations really is in the first place. In fact, most amateurs think that perhaps there are just 3 polarizations: vertical, horizontal, and circular. Therefore, let's step backward one pace and examine **Fig. 3**. Although our account will be woefully shy of complete, it will at least put the familiar polarization labels into a unified context.



Plane Electromagnetic Wave Rotation
Represented on an Ellipse as a Function of Time
With Two Special Cases (Circular and Linear Polarization)

Fig. 3

The oval on the left is a means of representing the rotation of a plane electromagnetic wave when referred to a central point and tracked in time--very tiny increments of time. The figure forms an ellipse, and every possible form of polarization of plane waves forms some variation of an ellipse. Every ellipse has a long or major axis and a short or minor axis. For a given situation, these axes may or may not align with the graph axes--and in most cases do not. Hence, relative to the Y-axis, the major ellipse axis forms an angle, τ, the tilt angle in the line from the radiation table. NEC likes to count the size of all its angular quantities in terms of +180° to -180°. Textbooks (for example Balanis, *Antenna Theory: Analysis and Design*, 2nd Ed. (Wiley, 1997), pp. 64-73) like to calculate the axial ratio (AR) this way:

AR = Major Axis/Minor Axis = 0A/0B

This method gives the axial ratio a possible range of 1 to infinity. To confine the numbers, NEC reverses the equation:

AR = Minor Axis/Major Axis = 0B/0A

The result is equally valid, but the number range is now from 1 down to nothing.

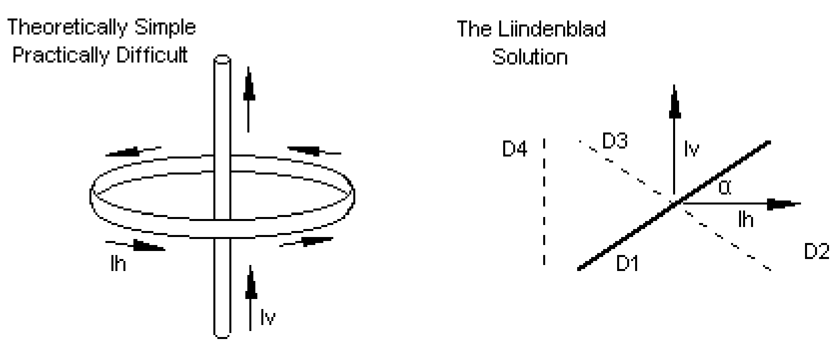
If the major and minor axes are identical in strength, as in the top-right part of **Fig. 3**, then we obtain perfect circular polarization. Rarely is a radiation pattern in any direction so perfect that 0A and 0B are exactly equal. Even if we find the same numbers carried to 2 decimal places being identical, the circle may have a very tiny elliptical shape. So for nearly perfect circular polarization entries, expect almost any value for the angle. Quite frankly, even nearly perfect circular polarization is very rare in antennas. Perfectly circular polarization would have an AR value of 1.0. Those who absolutely must have circular polarization in the antenna industry have gone to bifilar and quadrifilar helical windings in their efforts to overcome the shortcomings of our simple monofilar helices.

If we have only a single component or if we have two components that are essentially in phase or exactly 180° out of phase, then we obtain the crushed ellipse of the lower right corner in **Fig. 3**. This situation yields linear polarization, and it is quite common. NEC may show the tilt angle in such cases as 0°, 90°, or -90°, depending on its internal conventions of substituting values for vanishing quantities. However, the tilt angle becomes largely irrelevant for linearly polarized elements and antennas. The critical quantity is the axial ratio, which is zero. Actually, NEC will call polarization linear wherever the major axis value is many orders of magnitude larger than the minor axis. What we call vertical and horizontal polarization are simply two orientations of linear polarization. Due to the potential for cross-polarization of linearly polarized antennas, the orientation is very significant, but only for linearly polarized antennas in point-to-point or direct-path communications. The ionosphere skews polarization and therefore reduces its importance.

If a circularly polarized antenna has an advantage for VHF point-to-point communications, it lies in the antenna's ability to receive signals equally well (in a very rough sense) from linear sources that are either vertical or horizontal. As well, it can transmit effectively to either type of linear antenna used at the receiver. Hence, it promised (in the 1940s) to be an effective TV and FM transmitting antenna for the New York City area, regardless of the type of receiving antenna used by the TV viewer (who had yet to be classified as a mere TV consumer).

The Lindenblad Solution to Circular Polarization

The origins of our subject array lie in the pioneering work of N. E. Lindenblad, who first proposed the antenna design almost off-hand in a broad article on television transmitting antennas. (See N. E. Lindenblad, " Antennas and Transmission Lines at the Empire State Television Station," *Communications*, vol. 21, April, 1941, pp. 10-14 and 24-26.) After World War II, Brown and Woodward (who made numerous contributions to VHF and UHF antenna design) developed the idea in detail from Lindenblad's patent papers. (See G. H. Brown and O. M. Woodward, "Circularly Polarized Omnidirectional Antenna," *RCA Review*, vol. 8, June, 1947, pp. 259-269.) They envisioned possible aviation uses for the antenna. The overall goal for the antenna was omni-directional coverage in the X-Y plane (parallel to ground) with circular polarization.



Evolution of the Lindenblad Array

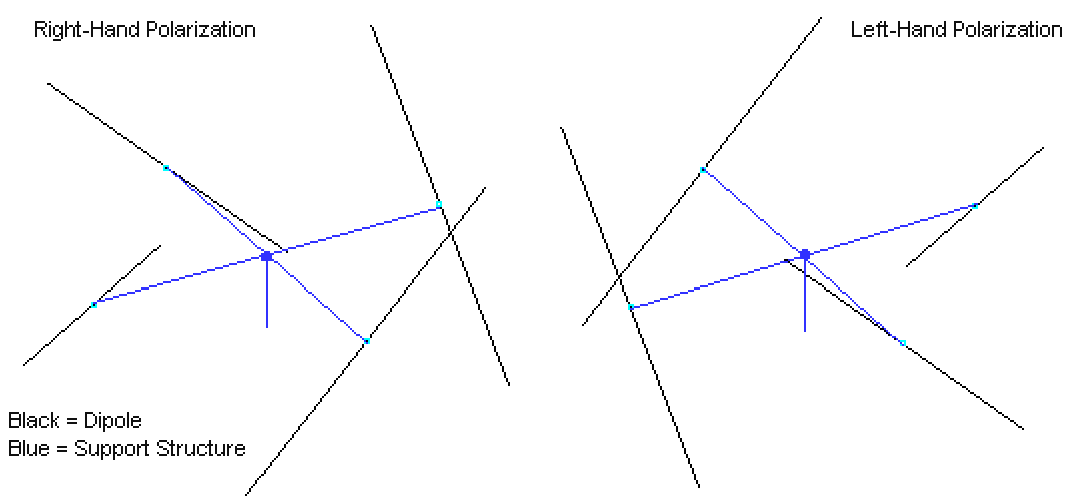
Fig. 4

Fig. 4 shows on the left the fundamental principle behind the Lindenblad dipole array. To achieve circular polarization, we need vertically and horizontally polarized components--shown as currents in the wires--such that they result in exactly equal fields at any distance from the antenna in any direction. The sketch shows right-hand circular polarization. The conceptual diagram is almost impossible to realize as a physical antenna. Lindenblad reasoned that an array of tilted dipoles, fed in phase, would approximate the ideal situation. The right side of **Fig. 4** shows the solution, highlighting 1 of the 4 dipoles. If we select the proper angle for the dipole relative to the horizontal (α), then the vertical and horizontal components will be equal. The design is subject to limitations, since we have facing dipoles. The tilt angle, α, depends in part on the distance between facing dipoles. In terms better suited to calculation, the required tilt angle depends upon the radius of the circle connecting the feedpoint positions of the dipoles. Since the fields between adjacent dipoles overlap, the required tilt angle for the dipole also depends on whether we measure fields tangential to the dipole faces or at angles that bisect two dipoles. **Table 2** shows a few of the Brown-Woodward tilt-angle calculations.

Table 2. Calculated Tilt Angles for Dipoles in a Lindenblad Dipole Array

Radius In λ	Tilt Angle Relative to the Horizontal Facing Dipole	Between Dipoles
0.0833	15°	15° 22'
0.166	30°	32° 55'
0.25	45°	55°

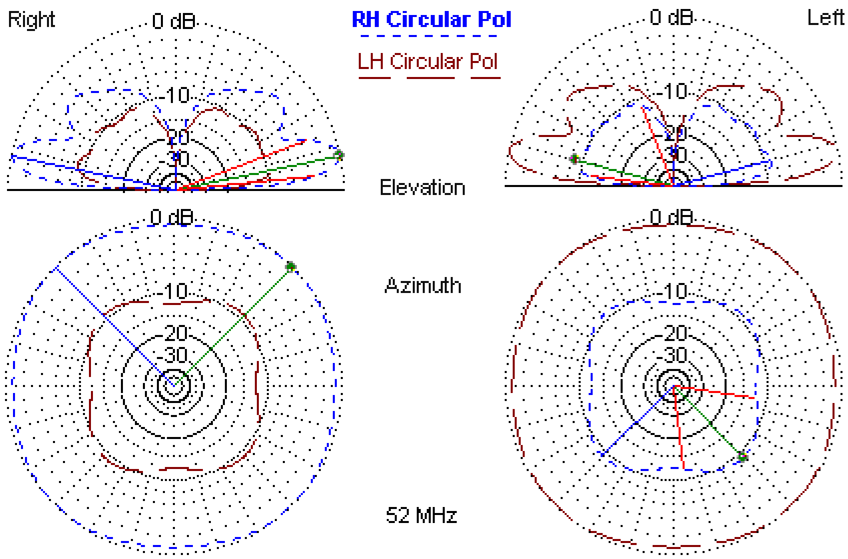
In the original version of the Lindenblad, we feed all 4 dipoles in phase to produce the circular polarization in the X-Y plane, that is, in every direction from the array and parallel to the ground. (The modified Lindenblad for satellite reception uses progressive quadrature feed to produce circular polarization overhead.) We may produce versions of the array with right-hand and with left-hand polarization simply by reversing the angle of the dipoles. The two arrays in **Fig. 5** are based on an array radius of 0.25-λ. This radius yields close to the best gain and azimuth circularity for the array. (I have seen amateur versions of the antenna with very close spacing, that is, a small array radius, without any adjustment to the 45° dipole tilt.)



Right-Hand and Left-Hand Lindenblad Arrays

Fig. 5

For reference, **Fig. 6** provides elevation and azimuth patterns for both versions of the antenna. These patterns differ from the usual patterns that emerge from NEC by showing only the left-hand and the right-hand circularly polarized components of the total field. Creating the patterns requires post-NEC-core calculations, since NEC itself does not directly provide a tabular output for these patterns.



Elevation and Azimuth Patterns: Right-Hand and Left-Hand Lindenblads
20' above Average Ground at 52 MHz

Fig. 6

The patterns are identical except for a reversal of color in the outer and inner rings. The legend tells us which pattern is for the right-hand component and which for the left. The fact that the inner ring is significant compared to the outer ring provides us with another important fact. The polarization from a Lindenblad is not truly circular in these far-field patterns, but is instead elliptical. The axial ratio for these patterns is between 0.45 and 0.55. However, see the final special note (at the end) on the level of polarization circularity when we use ground-wave analysis instead of far-field analysis. These patterns suffice to show us that reversing the tilt of all dipoles in the array does change the sense of the polarization between the right-hand and the left-hand options.

The utility of a Lindenblad as an all-mode, all-polarization antenna depends on two factors. We shall eventually look at how we can cover the entirety of 6 meters and of 2 meters with a single array per band. At present, we shall confine ourselves to what happens when we pair a Lindenblad with the various standard antennas that we find. **Table 3** provides the results of our initial experiment when we substitute a Lindenblad at one or both ends of the transmit-receive path.

In all cases, the current on the receiving dipole has the same order of magnitude as when we receive a signal from a linear source aligned with a linear receiving antenna. Since the Lindenblad is an open structure (in contrast to something like an axial-mode helical antenna pointed at us), it even receives (or transmits) well relative to a Lindenblad constructed for the opposite circular polarization. In fact, when we have two Lindenblads of opposing circular polarization, it is the dipole on the far side of the receiving array that records the highest center-segment current magnitude.

Table 3. Right-hand Lindenblad array with various sources.

Source	Receiving Antenna	Receiving Dipole Current
Vertical	Lindenblad	4.0e-4
Horizontal	Lindenblad	4.6e-4
Lindenblad	Vertical	3.3e-4
Lindenblad	Horizontal	2.9e-4
Lindenblad	Lindenblad (both right)	4.7e-4
Lindenblad	Lindenblad (opposing)	3.9e-4

Notes: All antennas are ½-λ long and centered 20' above average ground. Distance: 1 mile. Transmitted power constant.

Like all antennas designed for service in the X-Y plane, the Lindenblad shows increased gain and a reduced elevation angle as we raise it above ground. **Table 4** lists representative figures for an array at different heights. Notice that the elevation beamwidth of the lowest lobe decreases in step with the elevation angle of maximum radiation. The gain values are for the azimuth pattern corners at a 45° angle to the dipole facing headings. The gain difference within the azimuth pattern is about 1 dB from maximum to minimum.

Table 4. Critical Performance Data for an Original Lindenblad Array at Various Heights above Average Ground

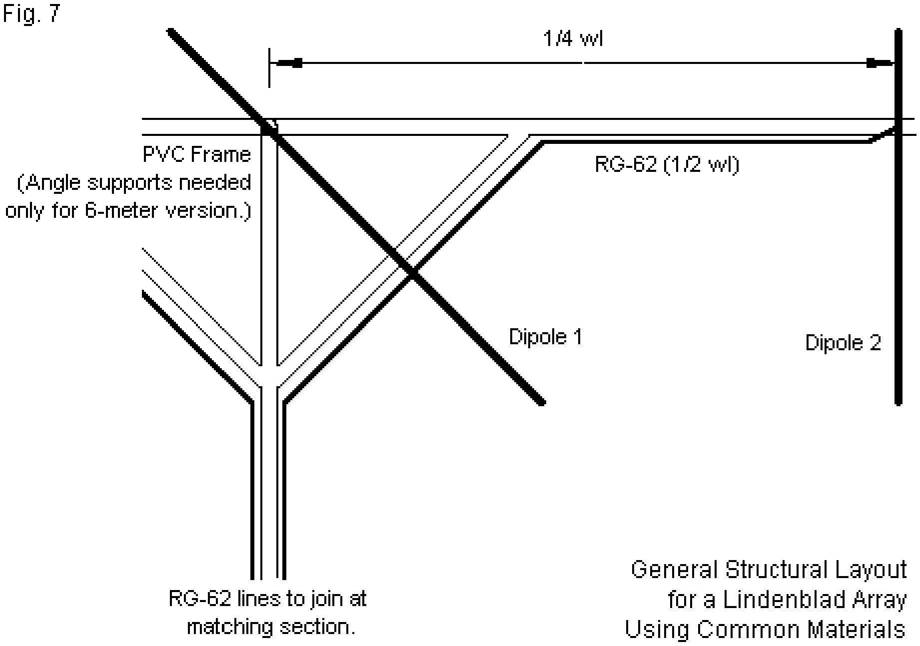
Height (λ)	Gain (dBi)	Elevation Angle Of Peak Gain	Beamwidth (degrees)
1	5.28	13	16
1.25	5.51	11	12
1.5	5.72	9	10
1.75	5.83	8	9
2	5.96	7	7
3	6.18	5	5
5	6.45	3	3
10	6.73	1.5	1.5

Practical Lindenblad Arrays for 6 and 2 Meters

A practical Lindenblad array for amateur use (using relatively common materials) requires attention to the three main parts of the system: 1. the antenna elements and their support, 2. the coaxial lines used to feed each dipole in phase with the others from a common source, and 3. the final matching section to allow the use of the ubiquitous 50-Ω amateur feedline. We shall provide a few notes on each part of the system.

The dipole elements use standard construction, with a center gap for the attachment of the feed cable. The designs call for 3/8" diameter aluminum tubing for the 6-meter version and 1/8" rod for the 2-meter version. The 6-meter dipoles are each 107" long (or 106.95" to be precise to my modeling work). The 2-meter elements are 38.1" long. Since the dipole length produces resonance, changing the array radius from 0.25-λ to some other value or adapting the array to progressive quadrature feed for satellite use will require a revision to the dipole lengths.

Fig. 7



General Structural Layout
for a Lindenblad Array
Using Common Materials

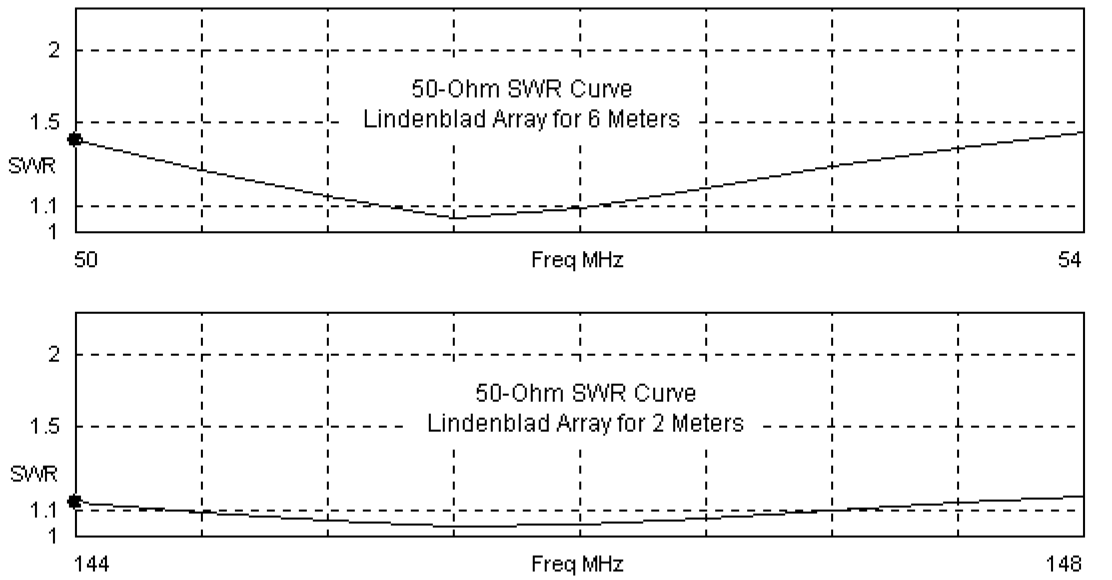
Fig. 7 shows one possibility for a support structure, with only 2 of the dipoles partially visible. A central hub, perhaps consisting of a PVC 4-way connector, connects 4 support arms each ¼-λ long. At 52 MHz, a quarter-wavelength is about 56.75" long or just under 5'. At this frequency, you may wish to add an angular support using PVC Y-connectors. At 146 MHz, ¼-λ is only 20.21", and the support arm should need no bracing.

At the design frequency in the middle of each band, the resonant impedance of each dipole in the environment that consists of all 4 dipoles is about 105 Ω. To feed them in phase, we need 4 transmission lines, each the same length. The closest common feedline is RG-62, with a 93-Ω characteristic impedance and a velocity factor of 0.84. To replicate the dipole feedpoint impedance at the opposite end of each line and still reach the center of the array, we may use lines that are electrically ½-λ. At 52 MHz, we need lines that physically are 91.8" long, while at 146 MHz, the lines should be 32.7" long. Since the lines are in parallel at the connector, the net resonant impedance is about 26 Ω.

To match the usual 50-Ω feedline used by radio amateurs, we need a matching section. The length will be approximately--but not exactly--1/4-λ electrically. The required characteristic impedance is close to 35 Ω. RG-83 exists but is rare. The more common approach is to use parallel sections of RG-59, with 70-Ω impedance. Simply solder together at each end the two braids and the two center conductors. Tape or glue the outer jackets together for a mechanical bond.

To obtain the best SWR curves for each band, we need to use line lengths that exceed ¼-λ. The electrical length of the 52-Ω line should be about 75", while the length of the 2-meter cable should be about 26". The exact electrical length is not critical, so +/-2" at 52 MHz and +/-1" at 146 MHz will yield good results. With the specified lengths, the cables produce the SWR curves shown in **Fig. 8**.

Fig. 8

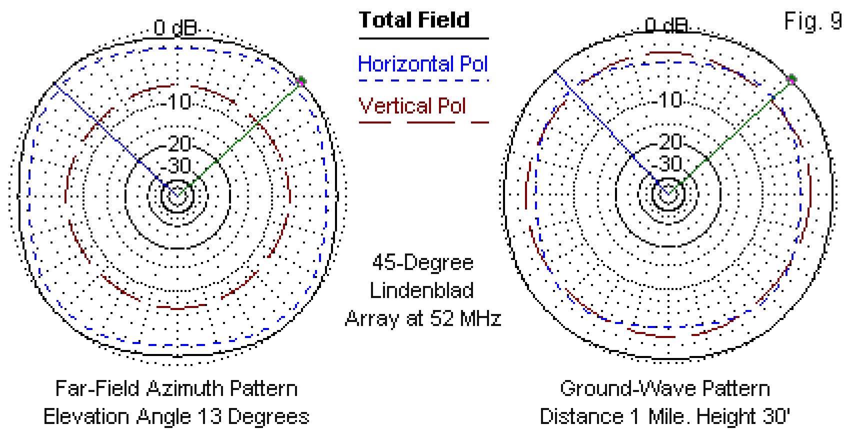


I have not given the physical lengths of the cables, because RG-59 comes in several variations with different velocity factors that range between 0.66 and 0.83. Multiply the required electrical length by the velocity factor of the line used to arrive at the necessary physical length. However, since velocity factors vary a small amount from one batch of coax to another, be prepared to trim this line for the best SWR curve.

The original Lindenblad performance characteristics have a broader bandwidth than the SWR. At a 20' height, the gain of the 52-MHz version varies by less than 0.4 dB across the 6-meter band. On 2 meters, at the same physical height, the gain varies by less than 0.05 dB. The difference in the variation is a function of the difference in the bandwidth when measured as a percentage of the center frequency. 6 meters is 7.7% wide, while 2 meters is only 2.7% wide. Because we are feeding all of the dipoles in phase, the polarization remains intact, with no significant variation between the right-hand and the left-hand components. (The modified Lindenblad used for satellite service does not have the same properties, because progressive quadrature feeding requires the use of narrow-band techniques, such as ¼-λ lines, to establish the phase differential.)

Special Note: Far-Field (RP0) vs. Ground-Wave (RP1) Patterns

If you model the Lindenblad array using the specifications shown in these notes, the results may lead you to make some incorrect adjustments to the design under certain circumstances. Many entry-level versions of NEC only produce far-field patterns. In fact, **Fig. 6** used the far-field pattern to show the difference between left-hand and right-hand polarization. Since we were not directly concerned with the relative strengths of the two fields except to note a major difference, this use was harmless. However, if we look at the relative strengths of the vertical and the horizontal components of the Lindenblad array within the far-field pattern taken at the TO angle or elevation angle of maximum radiation, we may derive an incorrect perspective on what the antenna is doing and what it is designed to do. See the left side of **Fig. 9**.



Vertical and Horizontal Components of
Far-Field and Ground-Wave Patterns

The far-field pattern shows the vertical and horizontal components of the total field pattern. We can convert the graphic lines into numerical values in several ways, two of which appear in **Table 5** in the left set of columns. One way is to use the NEC reports of the gain in dBi for the components. An alternative method is to look at the conventionalized field strength values. (Because a far-field pattern uses a conventionalized field strength measure calculation when the user does not specify a specific distance from the antenna, these field strength values are not comparable to other field strength values that do use a specified distance from the antenna. However, the values are useful for internal comparisons, the kind that we are making here.) For both types of measures, we find that the horizontal component is very significantly stronger than the vertical component.

Table 5. Some comparative measures of vertical and horizontal components in the far-field and the ground-wave patterns of a 45° Lindenblad array. (See Fig. 9) Antenna height is 20' above average ground. Ground-wave distance = 1 mile, observation height = 30'.

	Far-Field Pattern (TO angle 13°)				Ground-Wave Pattern	
	Component Gain		Relative Field Strength		Relative Field Strength	
Azimuth Heading Degrees	Vertical Gain dBi	Horizontal Gain dBi	Vertical F-S V/m	Horizontal F-S V/m	Vertical F-S V/m	Horizontal F-S V/m
0	-2.00	2.91	4.26e-2	7.49e-2	1.05e-3	0.90e-3
45	-2.39	4.29	4.07e-2	8.72e-2	1.00e-3	1.49e-3

The semi-natural tendency of any modeler would be to tweak the model until the vertical and the horizontal values are about equal. The pattern in **Fig. 9** and the data in **Table 5** show that we obtain different values in-line with the antenna elements (0°) and between the antenna elements (45°), as predicted by the array originators. So we cannot expect to bring the values into perfect alignment, but we might reduce the differences to a level that we can call negligible. To save you the work of tweaking the model, a tilt angle of 60° relative to the horizontal or to ground will do the job. However, we would not accomplish anything useful by this exercise.

The Lindenblad's main use was and is for point-to-point or ground-wave communications. The array developers based their calculations and tests on the ground-wave properties of the antenna. If we wish to obtain a better portrait of the polarization properties of the array, that is, the relative strengths of the vertical and the horizontal components, we must use the ground-wave or RP1 capability of NEC. I used a distance of 1 mile (5280' or 63360") for the ground-wave distance. I also presumed an observation height of 30' (360"), although any reasonable height will do so long as it is not very close to the ground. The antenna remained as originally modeled with a 45° tilt to each dipole. The results appear in the right-side pattern in **Fig. 9** and in the right set of columns in **Table 5**.

The two component patterns interweave with each other. The data on field strength confirm the interweaving. (The data here are in RMS, so the values in the original NEC output report will be 1.414 times these EZNEC tabular values.) The result is that for point-to-point communications, the vertical and horizontal components of the total field are about as equal as we can make them with a single setting of the tilt angle of the dipoles in the array. Hence, if we could convert the values into a polarization pattern set, the array under these ground-wave conditions would show nearly perfect circularity with a right-hand sense, and the left-hand component of that kind of pattern would diminish almost to the vanishing point.

The bottom line of this special note has several entries. First, the original Lindenblad array is well designed for its intended point-to-point use. For a radius of about 1/4-λ, the 45° tilt provides nearly equal sensitivity to both vertically and horizontally linear polarized signals. Second, tweaking the antenna design for equal strength components in the far field at the TO angle would not yield beneficial results for 2 reasons. First, for ground-wave communications, the antenna would have a vertical bias or a horizontal weakness. Second, ionospheric propagation tends to skew the polarization of a signal, and so the equalization of components at high angles would not necessarily result in better skip-distance reception (for which the antenna was not designed in the first place). Finally, when modeling an antenna, it pays to use the right modeling software facility to evaluate the antenna's performance within the sphere of its intended use.

Conclusion

The original Lindenblad array is a circularly polarized array in the X-Y plane. The polarization is actually elliptical, but the difference from true circularity of the radiation pattern does not significantly affect its performance as a local area all-mode, all-polarization antenna. It is not an antenna for everyone, but for those who wish to use a single antenna for local communications on bands that use both vertical and horizontal linear polarization, the array may serve quite well. In-phase-feeding of the dipoles simplifies construction and gives the antenna relatively broadband characteristics that enhance the chances for successful replication with normal assembly care.