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VHF Log-Periodics and the "Log -Scan 420"

If you have been planning an antenna system for the VHF or UHF bands, you shouldn't overlook the log-periodic array. This antenna features high gain, wide bandwidth and reproduceability.

The new look in antennas is here. Soon VHF log-periodic antennas will be replacing yagi arrays of practically all types, and also replacing old standbys such as the collinear, helix, and corner reflector. This revolution has already been taking place in the television antenna business for several years and there are good reasons why.

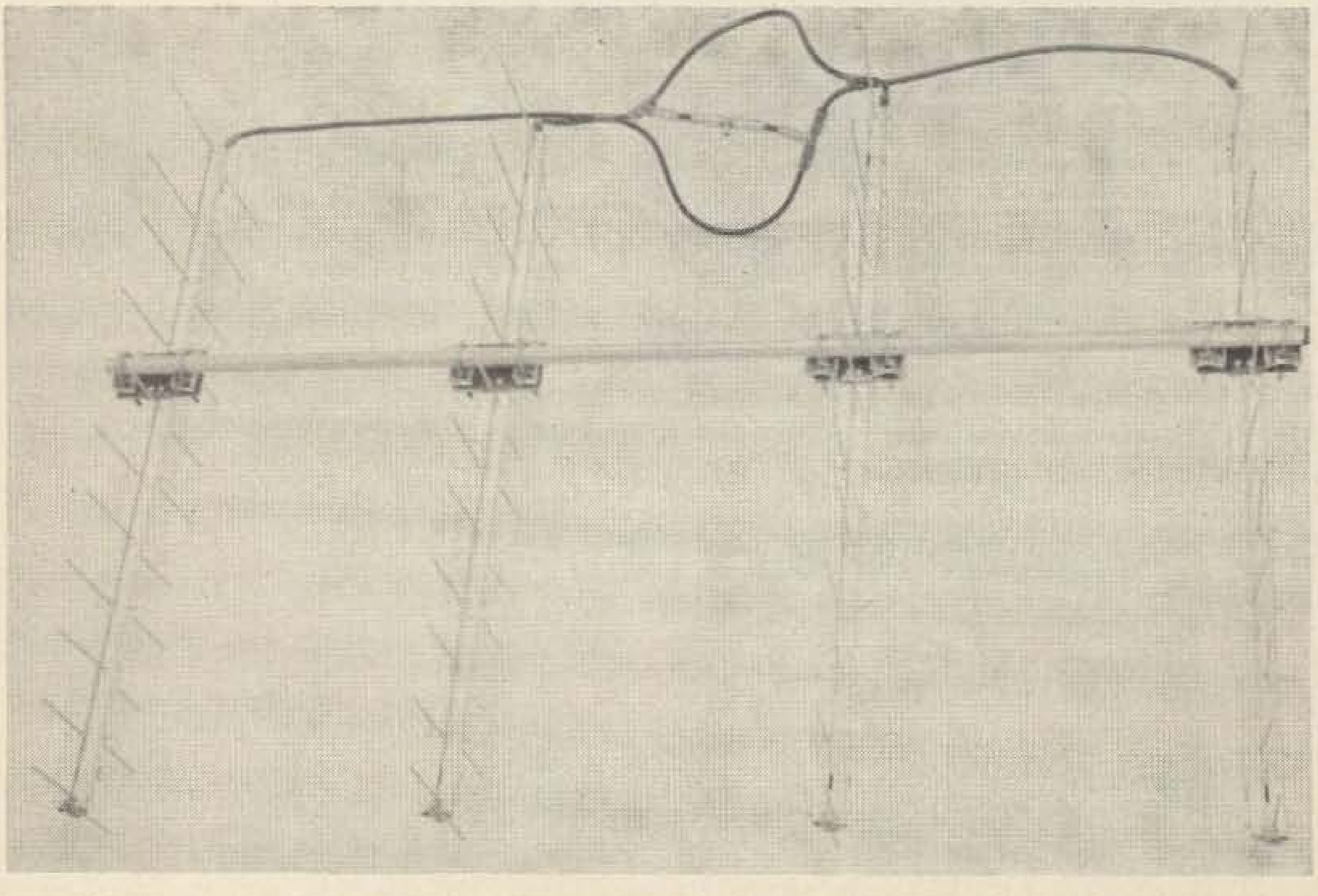
First of all, do not be led astray on the subject of gain. Not many people interested in antennas presently know that log-periodics having about 1.5:1 bandwidths can deliver just as much gain as yagis the same size and having only a few percent bandwidth. This, as well as other new data, has been accumulated in the last few years and the properties of the planar (flat) log-periodic have been under investigation recently. Only lately has it become evident that log-periodics with small apex angles can yield as much as 12 dB gain.

Construction details of the "Log-Scan 420" are presented later in this article. This antenna serves as an excellent example of the advantages of the log-periodic. Here is a summary of its characteristics:

a. Gain: 16-17 dB over an isotropic.
b. Bandwidth between 1.5:1 SWR points: 50 MHz.
c. Size: 14¼" wide, 65" high, 41" deep.
d. Input impedance: 50 ohms unbalanced.
e. Matching section or tuning adjustments necessary after construction: *none.*

As you can see, the antenna is ideal not only for general work on 420, but is just the thing for the ever-growing amateur television fraternity. Let's compare it with its nearest competitor, the yagi.

A stacked array of four yagis of the same overall size would have 1.5λ length booms, seven to nine elements per yagi, and each yagi would exhibit about 11 dB gain. With a stack of the above dimensions, a gain increase of only 4-5 dB would result because some aperature overlap occurs. However, even with fullwave stacking (height of 80"),



The "Log Scan 420" array built by K4GYO. Each antenna in this array exhibits about 11.5 dB gain; the entire array yields about 17 dB.

a total array gain of over 16.5 dB is unlikely. Advantage of the yagi in gain: little or nothing.

Mechanically, the yagi has the advantage of fewer booms and elements, but from every other standpoint, the log-periodic array has the upper hand. For instance: a 50 MHz bandwidth, compared to a 1 to 2 MHz bandwidth of the yagi. Even with special techniques, bandwidth of more than 10 MHz for the yagi array cannot be achieved without going to twin- or triple-driven elements at the expense of array size and/or gain. Also, log-periodics are not sensitive to tuning effects caused by element and boom diameter. Nor do small (less than 2%) variations in element lengths from those intended have much effect on gain and input impedance. In addition, no balun, delta, tee or gamma match is needed to couple the antennas to the coax phasing harness or feed line. The log-periodic design can be adjusted to provide a good match directly to coax of any impedance; this eliminates any tuning or pruning, and effectively reduces the weatherproofing problem to zero. More about these factors later.

What advantages does the planar log-periodic offer over dishes and corner reflectors? One word: size. The "Log-Scan" has the gain of a dish 7 feet in diameter, or of any other screen reflector antenna of about the same area. It also has about the same gain as a 32-element collinear 62 inches square. The reason is that, like the yagi, the traveling-wave structure of the log-periodic multiplies the effective capture area it exhibits, to equal a reflector antenna of much larger size (whose capture area approximately equals the reflector area). The simplicity of transmission-line matching doesn't offer too much advantage over the dish or corner reflector, but does when compared to the problems encountered with a 32-element collinear in a high humidity area.

Designing your own

Log-periodics have the extraordinary feature of being truly wide-band structures, with their electrical properties repeating at intervals occuring at a ratio equal to the factor τ, as the frequency is changed. The τ factor is the factor by which the next higher set of elements on the antenna decreases in length, relative to any one set. If, for example, an array had a τ factor of 0.9, and the longest set of elements were 100 inches

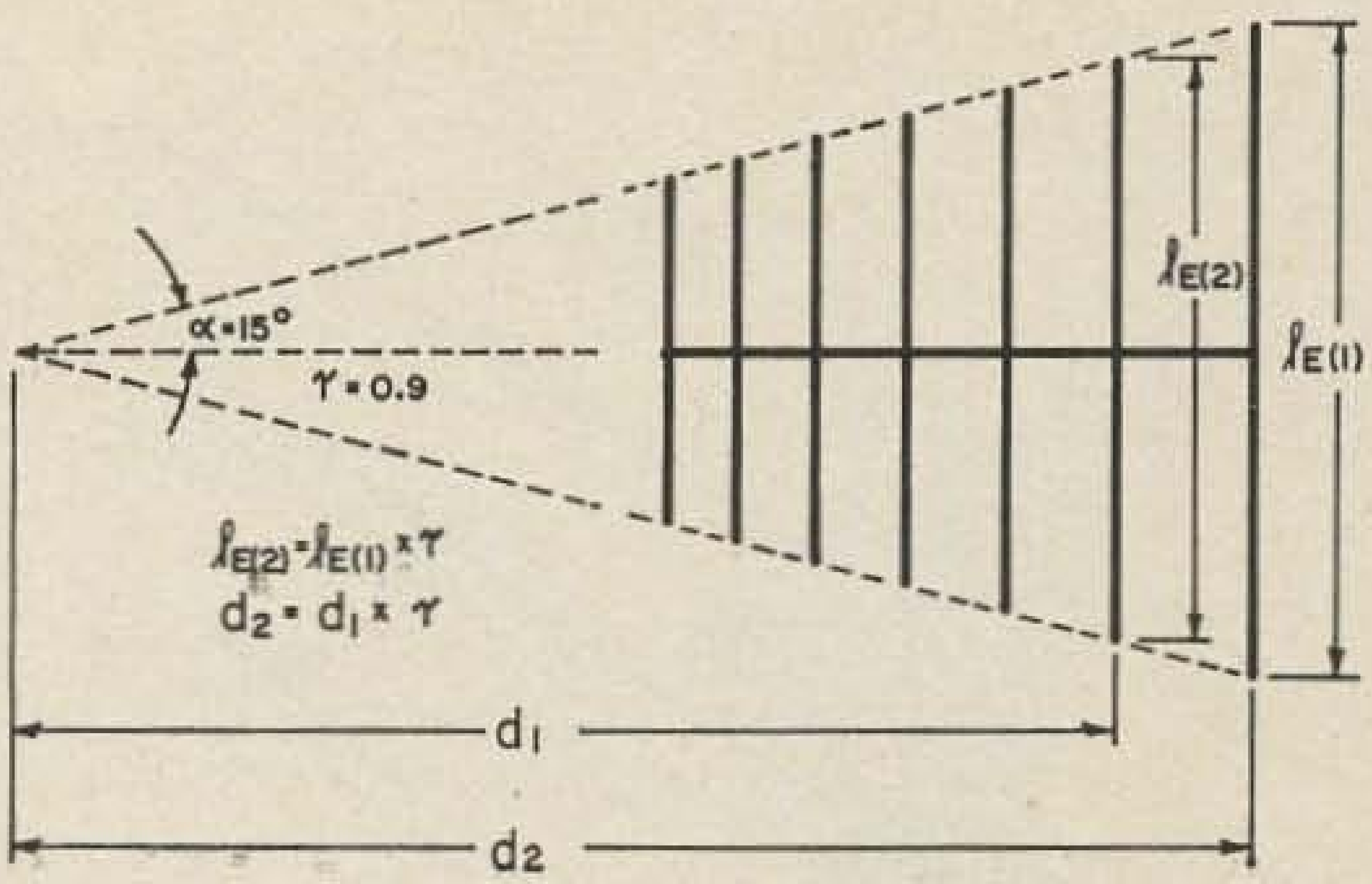


Fig. 1. The planar log-periodic antenna. The τ factor determines the relationship between subsequent element lengths and spacing. The α angle is the apex half-angle shown here. Both of these factors control the available gain of the array.

long, the second set would be 90 inches, the third set, 81 inches, and the fourth set, about 73 inches. The τ factor is usually chosen above 0.7 so the properties of the antenna repeat close enough together percentage-wise so there is no appreciable variation in them. A log-periodic can be made to cover 10:1 frequency ranges or more. However, to cover, say, a 100:1 range, it would be necessary to scale down the diameters of the elements and booms in inverse proportion to the increase in frequency.

The low cutoff frequency occurs when the *longest* set of elements is about 0.47 wavelengths long. The high cutoff frequency occurs when the *shortest* set is about 0.38 wavelengths (for that frequency). If it is desired to maintain gain and pattern closely over all of a given band, the cutoff frequencies should be set 10% below and above the band limits for τ factors of 0.9 and above; 20% for smaller factors.

The α angle is the apex half-angle, as shown in **Fig 1.** The τ factor and α angle together control the available gain; it being higher for a smaller α angle (which means a longer boom) and a higher τ factor (which means more sets of elements).

It can be seen why an antenna can be duplicated with different element and boom diameters than the original, without affecting the performance. All that will happen is that the high and low cutoff frequencies will be shifted slightly. This factor makes building log-periodics much easier than building and adjusting yagis.

Looking at **Fig. 2,** it can be seen that the planar log-periodic is actually a balanced transmission line with elements fed from along its length. Notice that each set of

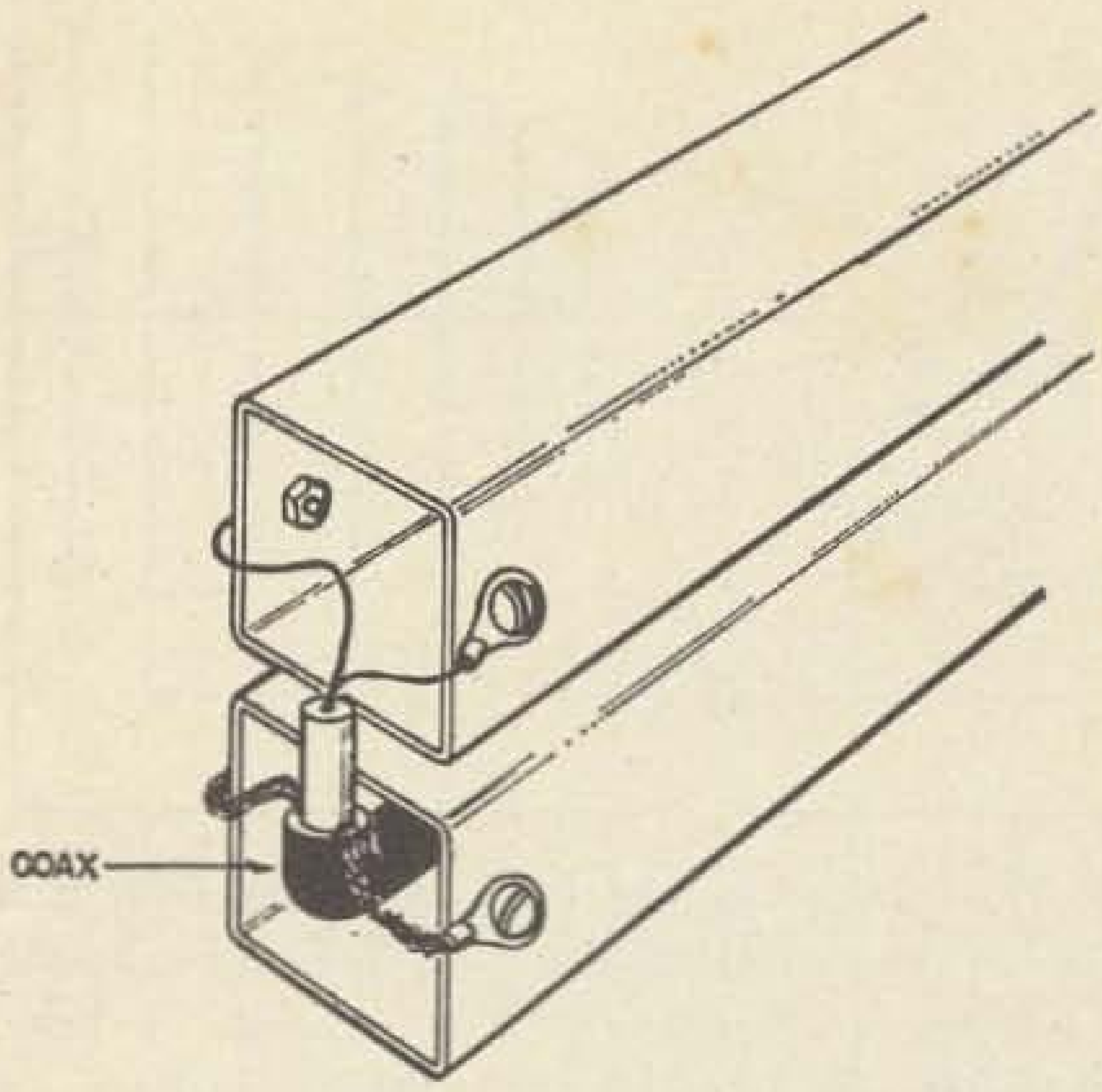


Fig. 2. Method of feeding the log periodic with coaxial feedline. The coaxial line is fed through one of the booms and connected to both.

elements is reversed in feed polarity from the previous set. The antenna will not work unless this is done. The antenna structure is fed at the high-frequency end, and its feed impedance appears somewhat less than the characteristic impedance of the boom structure. It is possible to match impedances from 50 ohms to 200 ohms by adjusting the boom spacing. The only restriction is that low impedances should be used only with high τ factors, although the reverse isn't true.

The L-P balanced structure can be fed by coax, without using a separate balun, by feeding the coax through one of the booms from the back of the antenna. The shield of the coax is connected to the carrier boom only at the very front, and the center conductor is connected to the end of the other boom by the shortest possible path. Currents on the other surfaces of the booms drop almost to zero toward the rear of the antenna, and the boom completely shields the coax from antenna fields along its length. The coax can be taken from the rear of the boom to the mast at about a 45 degree angle, without producing noticeable effect on antenna pattern, or line SWR. Notice that *both* booms must be insulated from the support mast and should be spaced from it by at least twice the gap between the booms.

It should be kept in mind that the smallest possible booms should be used for building VHF arrays, because this will lessen the amount by which the halves of an element set are out of line with each other. The fact that the halves are not directly in line causes some shift in polarization away from horizontal. This can be minimized by using high τ factors and by using square booms with the elements inboard toward each as far as possible. This was done in the "Log-Scan" (see **Fig. 9**)

The gain is related to the α angle and τ factor as shown in **Fig. 3** on the left scale. Antennas will work with other combinations of α and τ, but these combinations are optimum for maximum gain. **Fig. 3** also allows estimates of the size of an antenna for a given gain and bandwidth.

Let us design a L-P array as an example. Suppose that you wanted to build a fairly high gain L-P to cover 144-225 MHz, including 2 meters, channels 7-13, and 1¼ meters. The antenna is to have as much gain as possible without exceeding a boom length of 10 feet (l_B). First, calculate how many wavelengths at 144 MHz are equal to 10 feet:

$n = l_B \times f_{lower}/985$

$= 10 \times 144/985 = 1.46$

Then calculate the bandwidth ratio, BW:

$BW = f_{upper}/f_{lower} = 225/144 = 1.56$

Then, going to the graph, draw a straight line from 1.56 on the right scale, through 1.46 on the center scale, and find its intersection on the left scale. Roughly, $\alpha = 4.5$ degrees and $\tau = .95$. The gain available is 11.5 dB. This gain is equivalent to a 2-meter yagi of the same length, with a typical bandwidth between 1.5:1 SWR points of 2 MHz —not even enough for the whole amateur band!

The next step is to calculate the longest element length. This length , l_{E1}, is equal to 0.47 at the lower cutoff frequency:

$l_{E(1)} = 0.47 \times 985/f_{lower}$

$= 0.47 \times 985/144 = 3.22$ feet

The second set of elements has a length of:

$l_{E(2)} = l_{E(1)} \times \tau$

$= 3.22 \times 0.95 = 3.06$ feet

The rest of the element lengths are calculated in turn by multiplying each length by τ to obtain the next length. To know how many sets are needed, calculate the ideal shortest element, $l_{E(n)}$; equal to 0.38 τ at the high cutoff frequency:

$l_{E(n)} = 0.38 \times 985/f_{upper}$

$= 0.38 \times 985/225 = 1.66$ feet

Then continue the original table of elements until a length of less than 1.66 feet is reached. This is the shortest element needed (don't necessarily use 1.66 feet).

To determine the location of each element, start by determining the distance d_1 from the longest (and rearmost) element, to what would be the apex if the frequency coverage extended to infinity (see **Fig. 1**):

$d_1 = l_{E(1)}/2 \times \text{cotangent } (\alpha)$

(where $\alpha = 4.5°$)

$= 3.22/2 \times 12.77 = 20.59$ feet

The second element will be a distance d_2 from the apex:

$d_2\ d_1 \times \tau$

$= 20.59 \times .95 = 19.55$ feet

The table is continued, the same way as the element length table was, until finished. The last distance subtracted from 20.59 feet gives the exact boom length needed, except for adding perhaps a half inch at each end to hold the end elements. This won't be exactly 10 feet, but can be adjusted by changing τ a small amount and recalculating both distances and element lengths.

Next, choose a transmission-line impedance. If, for example, you decide on 50 ohms, a value of about 60 to 100 ohms should be tried for the characteristic impedance of the boom structure. The spacing will be much less than the boom width in this case. Decide what the smallest boom diameter is that is practical to use, and, fit your coax through. For circular booms, the approximate spacing can be found from a table in most handbooks showing the characteristic impedance of parallel-wire lines as a function of relative spacing. If square booms are used, you may have to guess a little, because, as yet, I haven't been able to find a formula for the impedance of square-conductor transmission lines. I have found by experiment that spacing of about 20% of the width of a square boom, gives a characteristic impedance close to 50 ohms for the finished antenna.

If it is desired to stack a pair of the antennas such as just designed, the coax should have impedance close to 100 ohms (91 ohms), and the boom structure should end up being between 110- and 180-ohm characteristic impedance. The coax cables are then brought out equal distances from the rear of each boom, and joined in a tee connector. The lengths of the individual cables are unimportant, so long as they are equal, in order to maintain proper radiation phasing. At this junction, the feed impedance will be close to 50 ohms. This combining method is, of course, frequency-independent and can also be used with three or four stacked antennas if 150 or 200 ohm coax can be obtained (those available may be relatively lossy). All feed lines should be the same

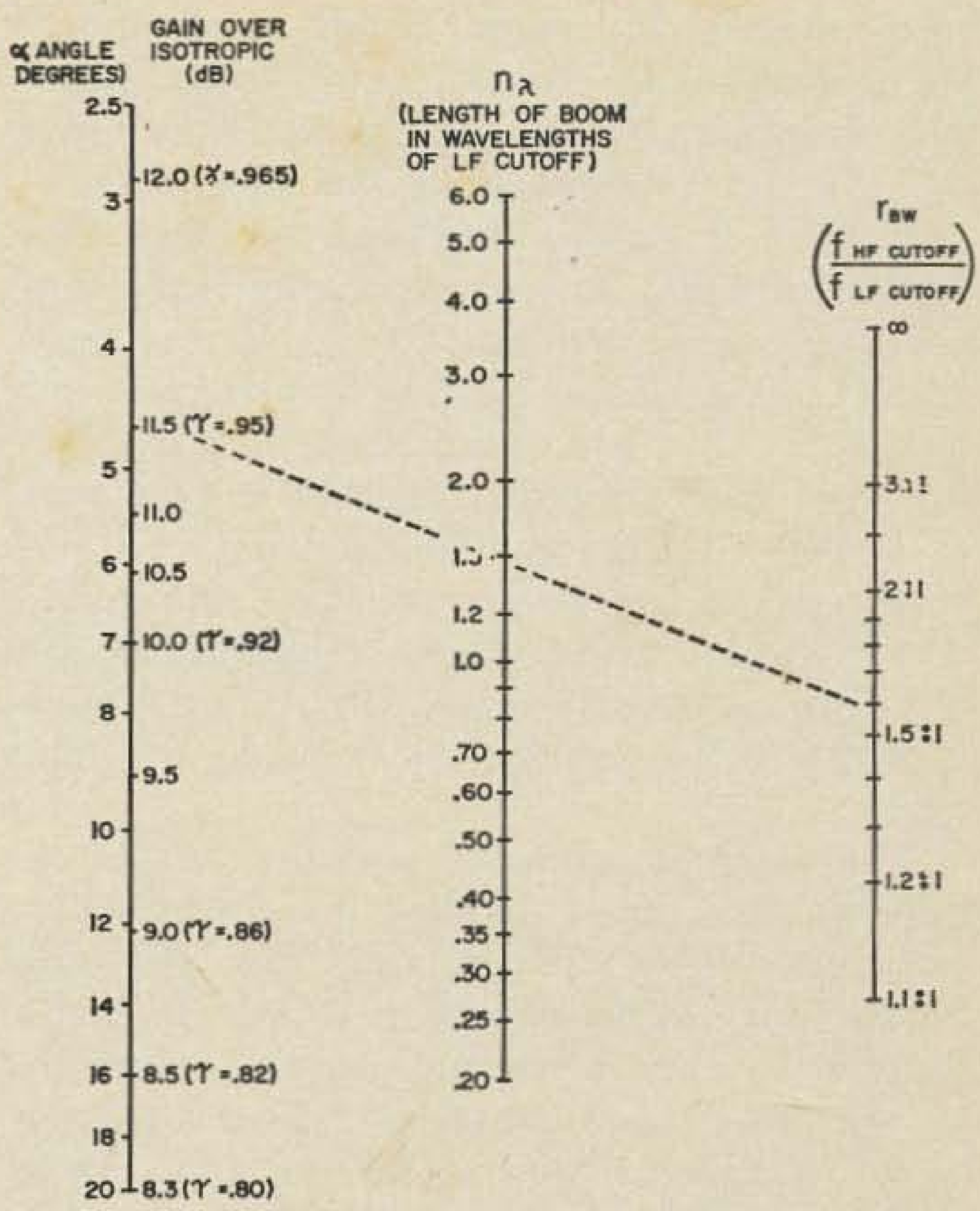


Fig. 3. Design nomograph for log-periodic antennas. When the bandwidth ratio is known ($f_{hf\ cutoff}/f_{lf\ cutoff}$), the length of the boom, α angle and gain over an isotropic can be found. For example, for an L-P for 144 to 225 MHz, the bandwidth ratio is 1.56. A boom is available which is ten-feet long (1.46 λ at 144 MHz). What α angle and τ factor are required? The dotted line indicates an α angle of 4.5 degrees and τ factor of 0.95; gain is approximately 11.5 dB.

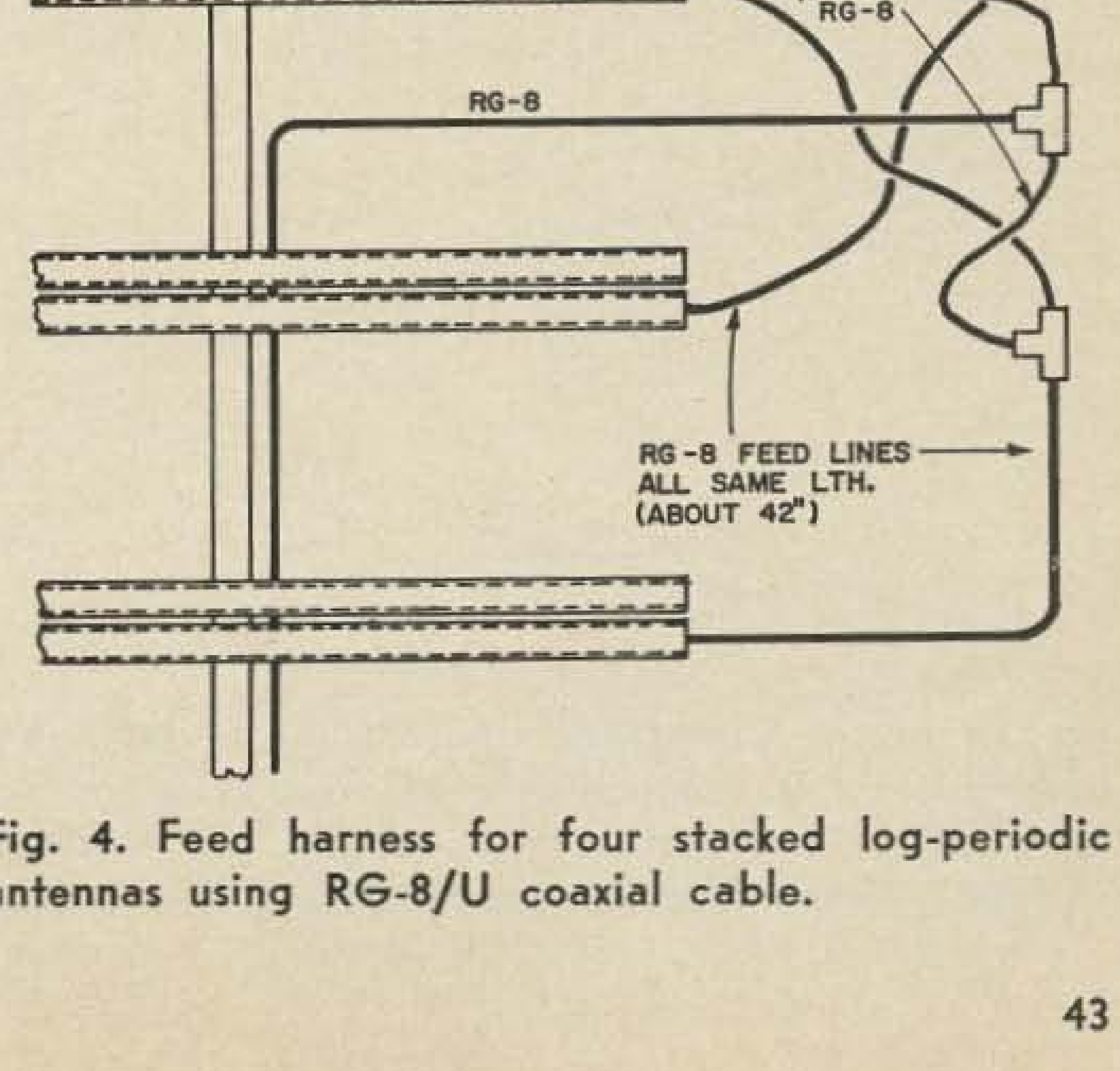


Fig. 4. Feed harness for four stacked log-periodic antennas using RG-8/U coaxial cable.

type, exactly the same length, and should all be hooked in parallel at the same point. The formula for paralleled resistors gives the driving impedance at this point.

With L-P arrays designed for less than 20% bandwidth, ¼-wave matching transformers can be used instead of the above method. The "Log-Scan" has all four L-P sections adjusted for, and fed with, 50-ohm coax. Then the feed lines are tee'd together in two pairs, as shown in **Fig. 4.** The resulting two impedances of 25 ohms are fed through ¼ wave, 50 ohm transformers to obtain two 100 ohm impedances. These are paralleled again in a third tee, getting us back to 50 ohms again.

The stacking of L-P's and the results obtainable are fairly similar to the stacking of yagis. With L-P's having less than 20% bandwidth, all sections can simply be made parallel to each other and spaced according to the same considerations found to apply when stacking yagis. The original "Log-Scan" employs ¾ wave stacking distances (some might prefer a full wavelength). When

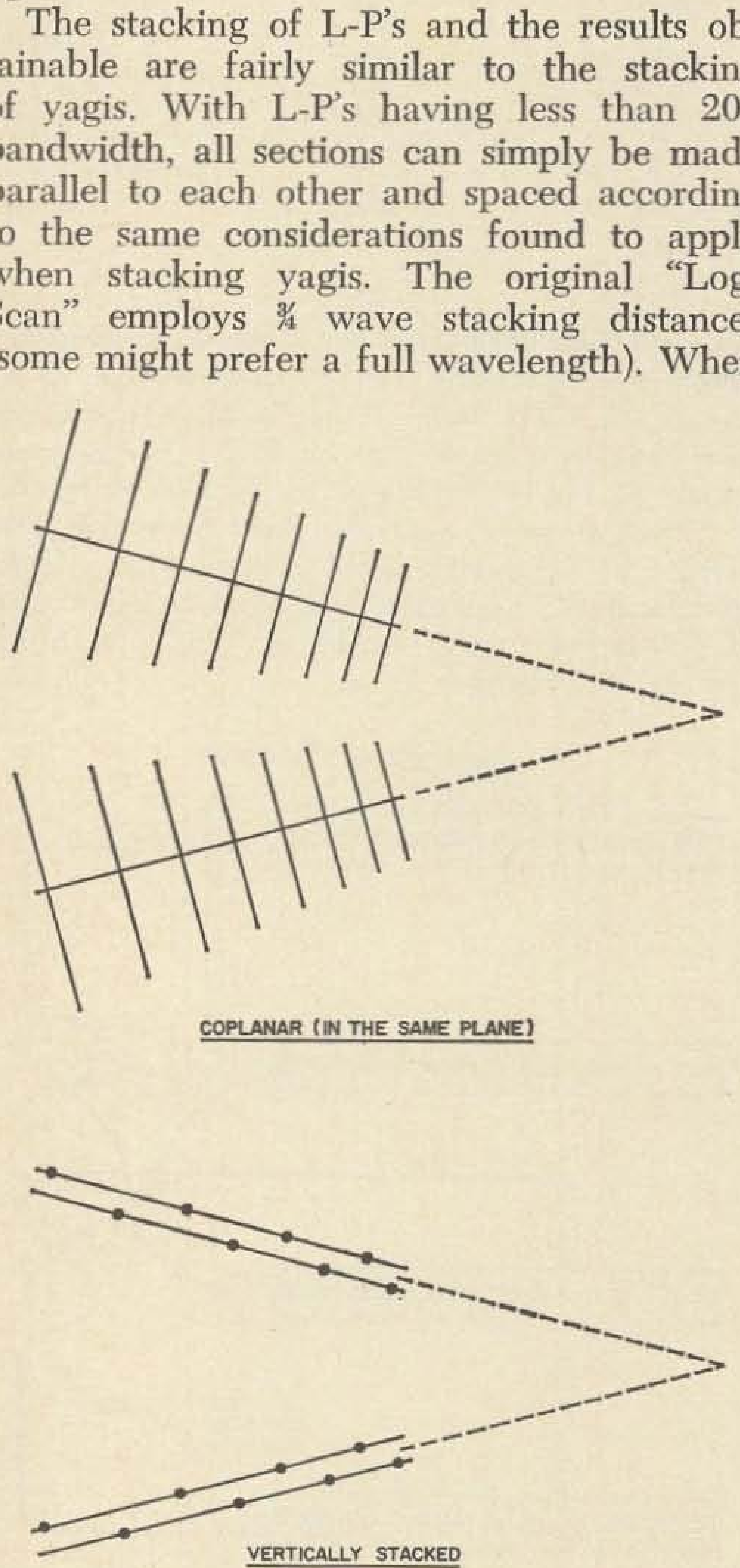
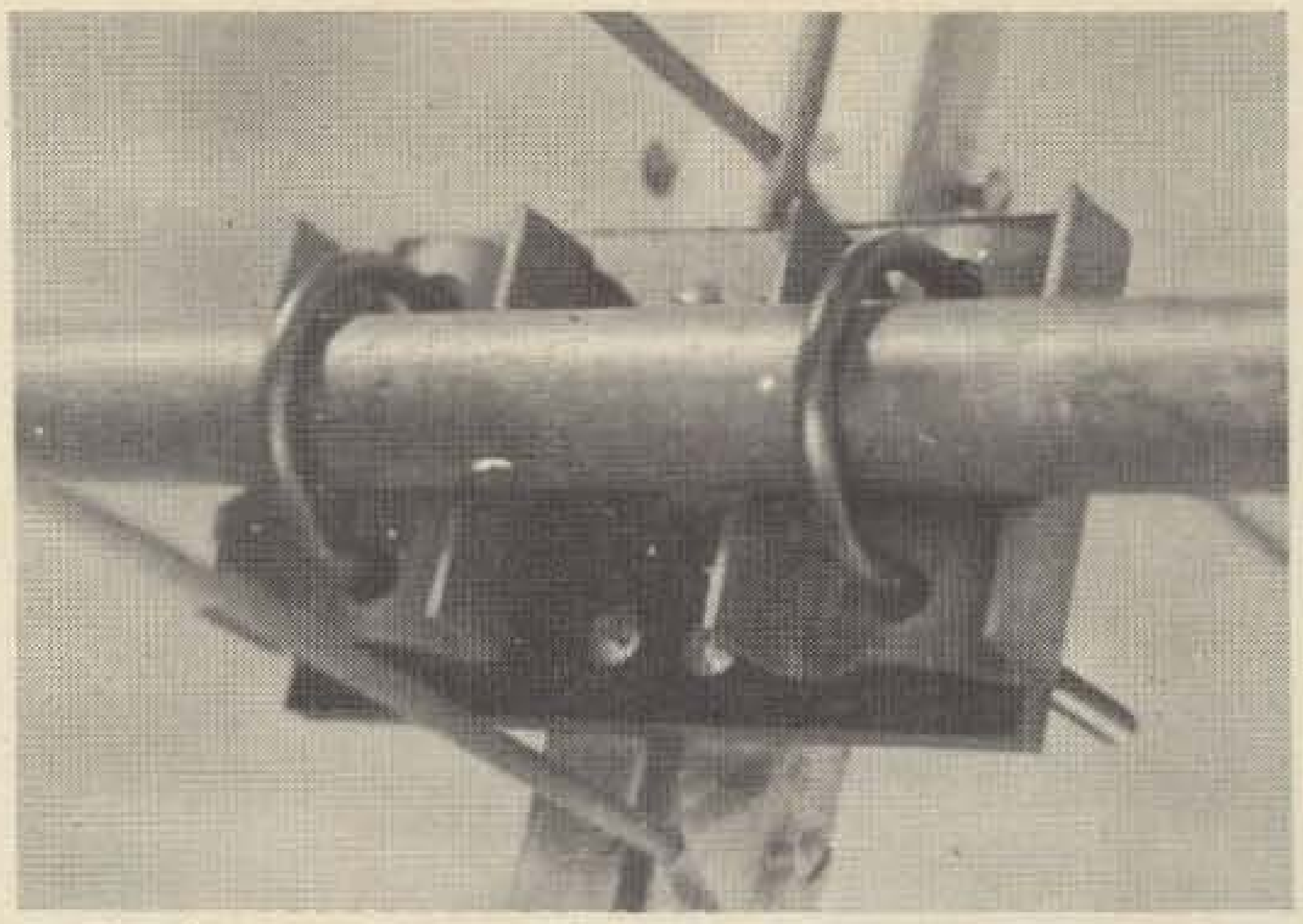


Fig. 5. Method used for stacking log-periodic antennas. Note in the vertically stacked drawing that each set of elements in the antenna are reversed in feed polarity from the opposite set.



Method of mounting the individual "Log Scan 420" log-periodic antennas to the mast. A piece of phenolic is used to insulate the booms from each other and from the mast.

arrays of more than 20% bandwidth are to be stacked, however, they should be tilted toward each other, as shown in **Fig. 5.** This keeps the "active" zones of the stacked antennas at a constant wavelength separation, regardless of the frequency, thus insuring a constant pattern shape. The amount of tilt should be that necessary to bring the (imaginary) apexes together. Up to perhaps six or eight antennas can be stacked by this method, and gains as high as 20 dB are *thought* possible. The angle between stacked sections should be something between two and four times α, which gives approximately ½-wave to a full-wave spacing. It will be necessary to use smaller (2α) angles for larger numbers of elements and larger α angles. When four antennas are to be stacked in a 2 x 2 array, they take on the appearance of a pyramid. Such arrays have been built for UHF TV reception, and, on a larger scale, for satellite tracking.

Be sure, when stacking either L-P's or yagis, that they all have the same side upward. Otherwise, when two are stacked, the phasing is 180 degrees out and a null instead of a peak will occur in the desired direction. With three or more antennas stacked, all sorts of peculiar but undesirable patterns will result if one or two are inadvertently turned over.

L-P's can be made to cover two different frequency ranges if you want to shorten the boom and eliminate a band in the middle. Just leave off the elements shorter than necessary for the lower band, and put the longest highband element where the next low-band element would have been. It is also possible to change the α angle and τ factor in mid-band, so that higher gain can be obtained at the higher frequencies. Neither trick seems to mess up the SWR curves or patterns in the desired ranges.

Cross-polarized L-P's may be constructed by using a structure of four booms, as shown. The outputs of the two feed cables, if they are kept the same length, can be combined in a hybrid ring to give right- and left-hand circular polarization. Special wideband hybrids have been developed for use with L-P arrays and the like, which work over frequency ranges on the order of 2:1 and more.

Getting it working

After you have designed your antenna and have built the two halves, the best procedure is to temporarily mount them together in some way so you can put the antenna out in the clear and make an SWR test on it. The tests should be made with several spacing values, to see what spacing appears to give the best average SWR. If you are building an array, this only need be done with one section; the results are very repeatable. If you don't have SWR equipment, a good guess at the spacing will most likely give SWR values not more than 50% higher than the best obtainable. This is another advantage of the L-P over the yagi. For amateur TV transmitting work, an SWR of 1.3:1 or less, is desirable to keep from transmitting "ghosts". It is possible to obtain this SWR over 20 MHz, or more, at 432 MHz by adjustment of the boom spacing (see **Fig. 7**).

If the antenna is to be side-mounted on the mast, the SWR curve should be checked unmounted, to set the spacing, and then mounted and rechecked. The mast should be as slim as possible in the case of 420 MHz antennas. The preferable way to mount small L-P's is from the rear. Dielectric masts, rather than metal, might be used more successfully for the side mounting. The final test of the effect of side mounting the antenna, is to confirm that the main pattern lobe is on the axis of the boom. If it is desired to rear mount an L-P, the booms can be extended back about ¼ wave (at the lower cutoff frequency) past the rear element and shorted together on a mounting plate. Side mounting is as much a problem at 420 with yagis as with L-P's, and rear mounting can sometimes help solve pattern problems.

Building the "Log'Scan 420"

If the specifications for this array created interest in building one, the required aluminum from a local jobber will cost about

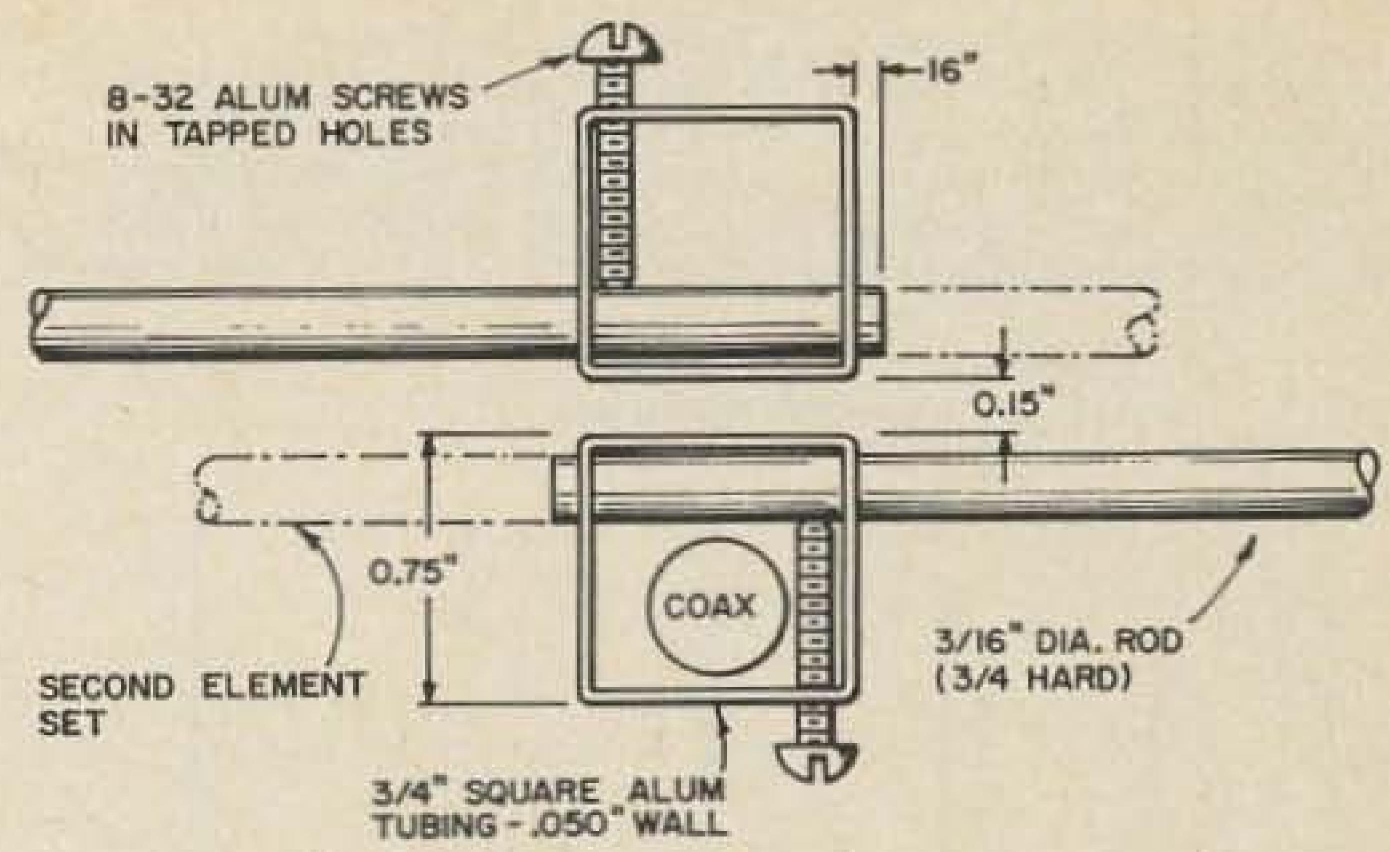


Fig. 6. Method of mounting the antenna elements to the booms used in the "Log Scan 420" log periodic. Clearance for the coax feedline is provided by installing the screws next to the wall of the boom.

$10.00. The boom material is ¾ inch square stock with .050 wall—preferably ¾ hardened. The elements are 3/16 inch rod, ¾ hardened. The elements are made long enough to pass through the boom and protrude about 1/16 inch on the opposite side. Each of the four identical sections requires two 41½ inch long boom pieces and about 13 feet of rod (multiply by four to build the array). The lengths and locations of the elements are given in **Fig. 8.** Note that the elements are not centered on the booms, but are moved toward the other boom as far as possible.

Elements are held in place by aluminum 8-32 machine screws which are threaded through the boom as shown in **Fig. 6.** They should be as close to the wall as possible, to leave room for the RG-8/U feed cable. These screws can put quite a bit of pressure on the elements to insure good contact with the boom; this is important. Since I was worried about corrosion, I rechecked the complete SWR plot after the array had been up some months in the humid, corrosive atmosphere near Cape Kennedy, and found no change.

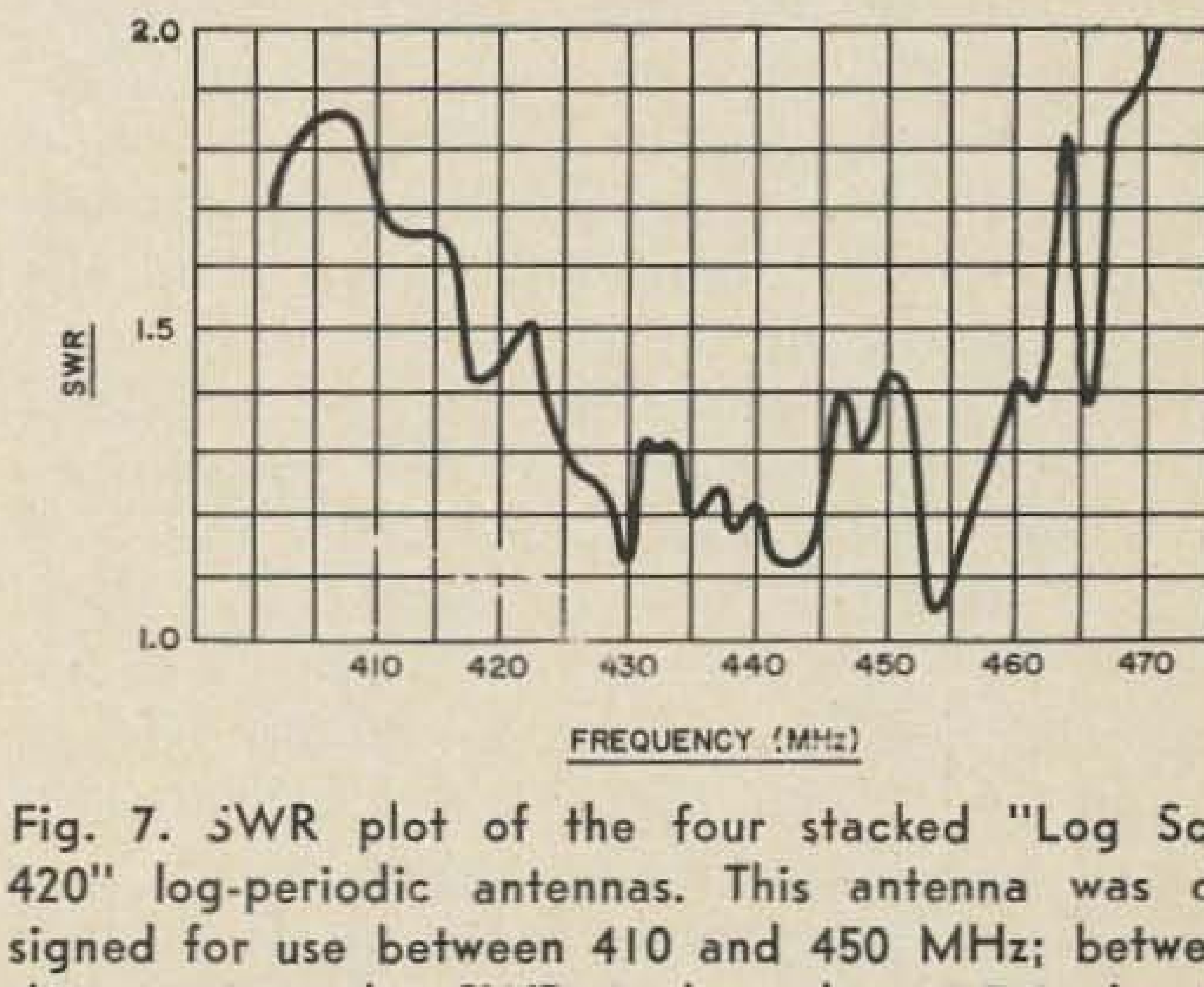


Fig. 7. SWR plot of the four stacked "Log Scan 420" log-periodic antennas. This antenna was designed for use between 410 and 450 MHz; between these points the SWR is less than 1.7:1. In the 420 MHz amateur band, the SWR is less than 1.5:1.

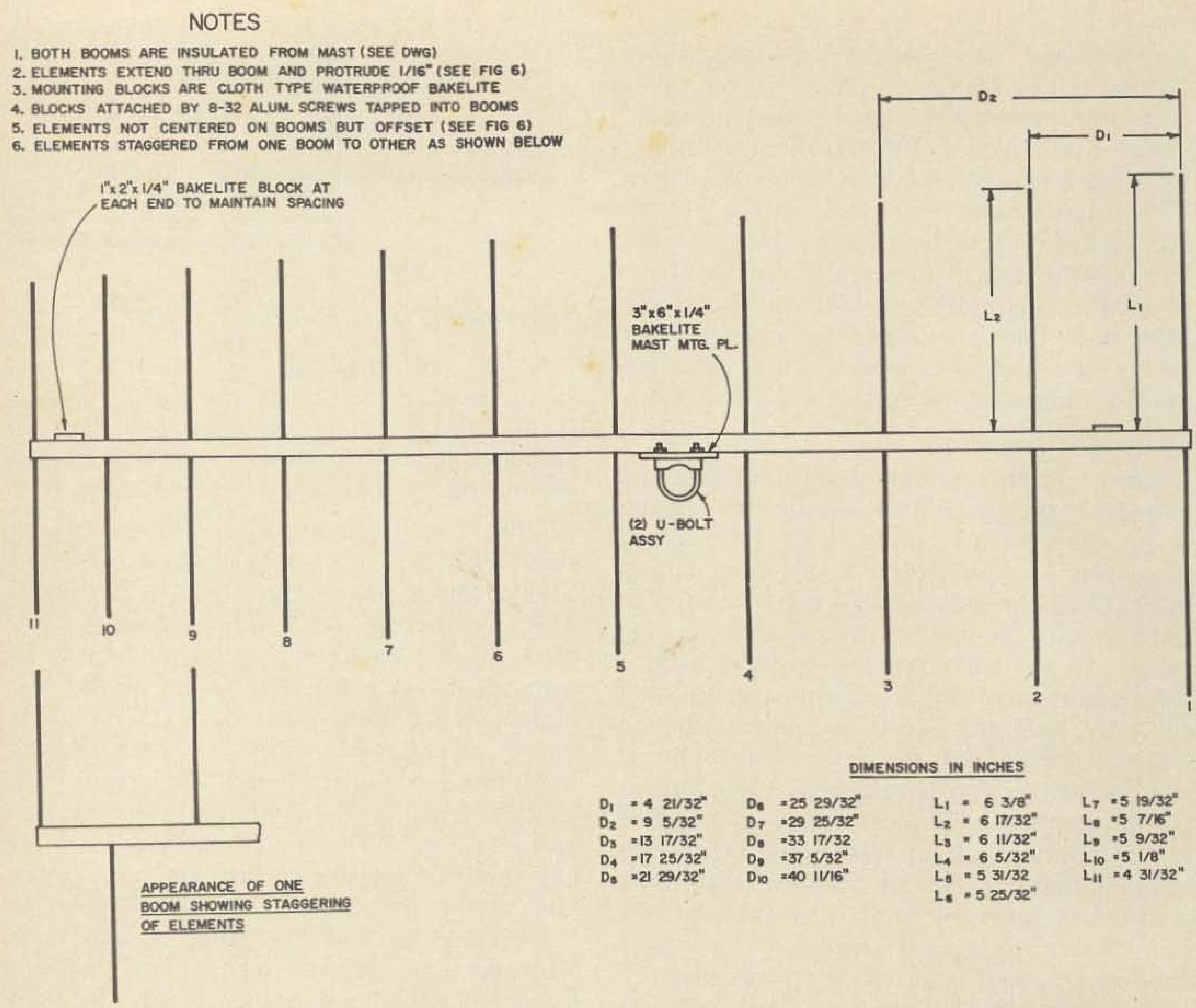


Fig. 8. Top view of a log-periodic antenna exhibiting about 12 dB gain. When four of these antennas are stacked, approximately 17 dB gain is possible. The SWR from 420 to 450 MHz, when fed with 50-ohm coaxial cable, is less than 1.4:1. L1 should be 6¾" long, not 6⅜" as shown.

The ideal antenna would be all welded, and while this might add $30–$60 to the cost of the array, it would virtually last forever.

The mast mounting assembly (four needed), shown in the photograph, is made from a piece of waterproof bakelite, ¼ x 3 x 6 inches, and two TV-type U bolts and clamps. Near each end of the boom pair, an additional piece of bakelite, ¼ x ¾ x 2 inches, is used (on the side opposite the mast mounting) to hold the booms in alignment at the proper spacing of 0.150 inches. Both mast mounting plates and end supports are held on by aluminum machine screws tapped into the boom. Tho lower boom carries the feed cable, and these screws should be offset toward the upper boom to leave as much room as possible. The cable should be run through the boom *before* the elements, set screws, and supports are installed.

The cable attaches to the front of the antenna with lugs, keeping the lead lengths as short as possible. All exposed parts of the cable outside of the jacket, and all of the area around the lugs and attachment screws should be covered with RTV silicon rubber to insure that moisture cannot cause trouble. Tape or other protection should be used on the cable where it leaves the rear boom, to prevent fraying of the cable jacket.

The sections are stacked 21 inches apart, and each cable should extend about 42 inches from the rear of the boom. Match cable lengths and types.

Type N connectors, UG-21/U, should be used on all cables. The cable matching section, which was explained earlier, is shown in **Fig. 4.** Each ¼-wave transformer is 4 inches overall length, leaving about 1 inch of jacket showing between the UG-21/U connectors. Triple-female tee connectors, type UG-28A/U are used for the three tees. The length of conductor inside each tee constitutes part of each ¼ wave transformer, and has been taken into account in the length calculation (which has been verified by measurement). The 4-inch sections must be made from solid dielectric RG-8/U; foam dielectric would require a shorter length. Recommended antenna feed line for lengths under 60 feet is foam RG-8/U, which has a loss of about 3.9 dB per 100 feet; over 60 feet, RG-17/U or ½-inch foam Heliax, both with a loss of 2.3 dB per 100 feet; and over 100 feet, ⅞ inch Heliax, with a loss of 0.8 dB per 100 feet.

Each section of the array has a 50-ohm impedance, and can be tested for SWR if you wish to verify that all sections are electrically identical. Needless to say, a single section can be used as an antenna with 12 dB gain. The individual SWR curves are fairly similar to the overall array plot in **Fig. 7.** If you wish to obtain the lowest SWR at any one part of the 420 band, it will be necessary to scale the antenna element lengths and location distances slightly, in one direction or the other. I would also recommend one additional set of elements at the low end and two additional sets at the high end, if the antenna must have equally good front-to-back ratio and patterns over the entire band.

The τ factor for the array is 0.97 and the α angle is 2.5 degrees. The design horizontal beamwidth is about 40 degrees, and the vertical beamwidth, about 20 degrees. The low frequency cutoff was designed as 410 MHz; the high cutoff, as 450 MHz.

Actual performance of the "Log-Scan" has indicated it works well. The beam is lined up with the boom axis as it should be, and the horizontal beamwidth is close to 40 degrees. The vertical beamwidth has not yet been measured, but the gain appears to be about right when compared to several yagi antennas. The high and low frequency cutoffs shown in **Fig. 7** are within a few percent of the design cutoffs.

I started building L-P's with the design and construction of a 110-300 MHz single planar log-periodic. Patterns and gain were both good. It has an α of 15 degrees and apparent gain of about 8.5 dB. The second log-periodic I built was a 50-300 MHz planar with two different τ factors, the change to a larger factor being made at 100 MHz. It does a good job on three amateur bands, all of the VHF TV, FM, the 225 MHz telemetry band, and quite a bit more. I am already convinced—try one yourself and be convinced, too.

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