THE LOG-PERIODIC DIPOLE ARRAY

The log-periodic dipole array (LPDA) consists of a system of driven elements, but not all elements in the system are active on a single frequency of operation. Depending upon its design parameters, the LPDA can be operated over a range of frequencies having a ratio of 2:1 or higher, and over this range its electrical characteristics – gain, feed-point impedance, front-to-back ratio, etc. - will remain more or less constant. This is not true of any Multielement Directive Array Antenna, for either the gain factor or the front-to-back ratio, or both, deteriorate rapidly as the frequency of operation departs from the design frequency of the array. And because the antenna designs discussed earlier are based upon resonant elements, off-resonance operation introduces reactance which causes the SWR in the feeder system to increase.

As may be seen in Fig.1, the log-periodic array consists of several dipole elements which each are of different lengths and different relative spacings. A distributive type of feeder system is used to excite the individual elements. The element lengths and relative spacings, beginning from the feed point for the array, are seen to increase smoothly in dimension, being greater for each element than for the previous element in the array. It is this feature upon which the design of the LPDA is based, and which permits changes in frequency to be made without greatly affecting the electrical operation. With changes in operating frequency, there is a smooth transition along the array of the elements which comprise the active region.

A good LPDA may be designed for any band, hf to uhf, and can be built to meet the amateur's requirements at nominal cost: high forward gain, good front-to-back ratio, low VSWR, and a boom length equivalent to a full sized three-element Yagi. The LPDA exhibits a relatively low SWR (usually not greater than 2 to 1) over a wide band of frequencies. A well-designed LPDA can yield a 1.3-to-l SWR over a 1.8-to-1 frequency range with a typical directivity of 9.5 dB. (Directivity is the ratio of maximum radiation intensity in the forward direction to the average radiation intensity from the array. Assuming no resistive losses in the antenna system, 9.5 dB directivity equates to 9.5 dB gain over an isotropic radiator or approximately 7.4 dB gain over a half-wave dipole.

Basic Theory

The LPDA is frequency independent in that the electrical properties such as the mean resistance level, R_O, characteristic impedance of the feed line Z_O, and driving-point admittance Y_O, vary periodically with the logarithm of the frequency. As the frequency f_1 is shifted to another frequency f_2 within the passband of the antenna, the relationship is $f_1 = f_1 / \tau$, where

τ = a design parameter, a constant; τ <l.0. Also

$f_3 = f_1 / \tau^2$

$f_4 = f_1 / \tau^3$

•

•

•

$f_n = f_1 / \tau^{n-1}$ (Eq. 1)

$n = 1, 2, 3, \ldots n$

f_1 = lowest frequency

f_n = highest frequency

The design parameter τ is a geometric constant near 1.0 which is used to determine the element lengths, ℓ, and element spacings, d, as shown in Fig. 1. That is,

$$\ell_2 = \tau \ell_1$$
$$\ell_3 = \tau \ell_2$$
$$\vdots$$
$$\ell_n = \tau \ell_{(n-1)} \qquad \text{(Eq. 2)}$$

where ℓ_n= shortest element length, and

$$d_{2\longleftrightarrow 3} = \tau \; d_{1\longleftrightarrow 2}$$
$$d_{3\longleftrightarrow 4} = \tau \; d_{2\longleftrightarrow 3}$$
$$\vdots$$
$$d_{(n-1)\longleftrightarrow n} = \tau \; d_{(n-2)\longleftrightarrow (n-1)} \qquad \text{(Eq.3)}$$

where $d_{2\longleftrightarrow 3}$ = spacing between elements 2 and 3.

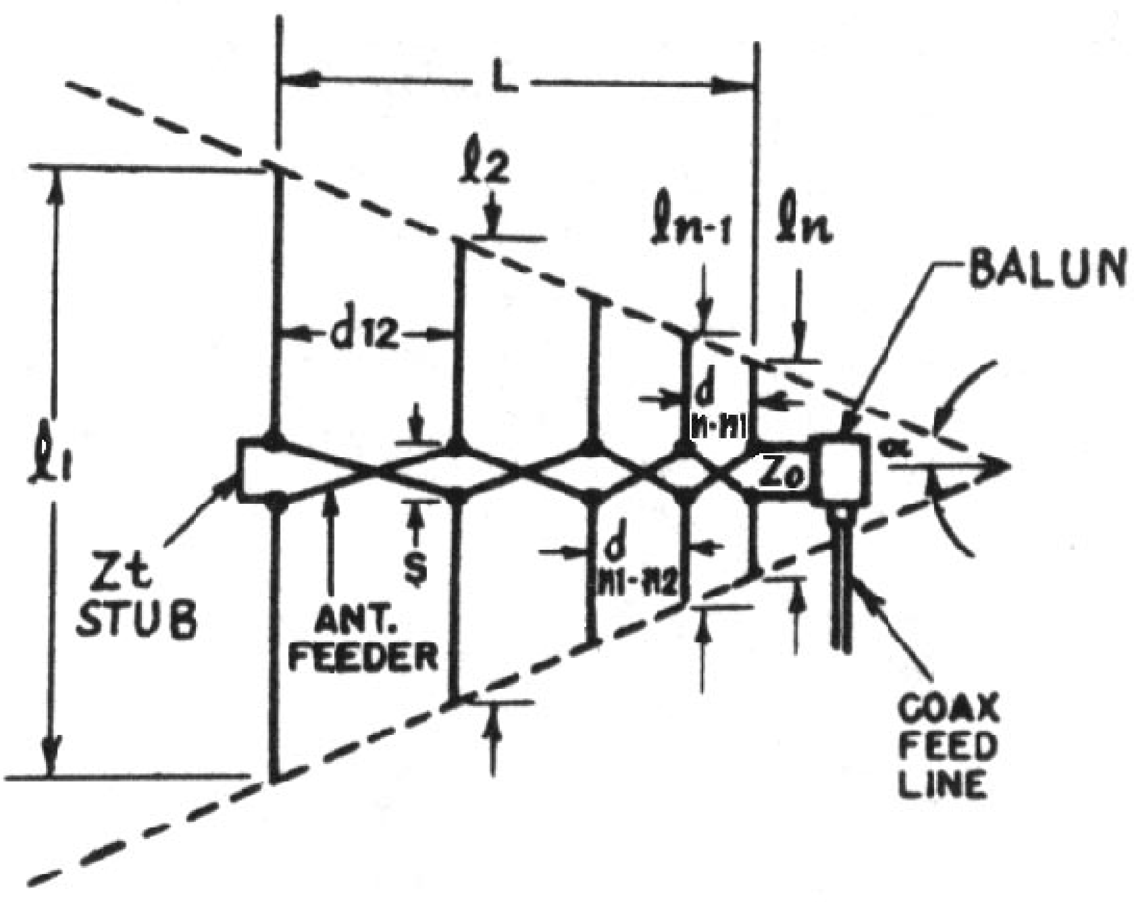


Fig. 1 — Schematic diagram of log-periodic dipole array, with some of the design parameters indicated. Design factors are:

$$\tau = \frac{\ell_n}{\ell_{n-1}} = \frac{d_{n,n-1}}{d_{n-2,n-1}}$$

$$\sigma = \frac{d_{n,n-i}}{2\ell_{n-1}}$$

$h_n = \frac{\ell_n}{2}$, where

ℓ = element length
h = element half length
d = element spacing
τ = design constant
σ = relative spacing constant
S = feeder spacing
Z_O = characteristic impedance of antenna feeder

Each element is driven with a phase shift of 180° by switching or alternating element connections, as shown in Fig. 1. The dipoles near the input, being nearly out of phase and close together nearly cancel each others' radiation. As the element spacing, d, expands there comes a point along the array where the phase delay in the transmission line combined with the 180° switch gives a total of 360°. This puts the radiated fields from the two dipoles in phase in a direction toward the apex. Hence a lobe coming off the apex results.

This phase relationship exists in a set of dipoles known as the "active region." If we assume that an LPDA is designed for a given frequency range, then that design must include an active region of dipoles for the highest and lowest design frequency. It has a bandwidth which we shall call β_{ar} (bandwidth of the active region).

Assume for the moment that we have a 12-element LPDA. Currents flowing in the elements are both real and imaginary, the real current flowing in the resistive component of the impedance of a particular dipole, and the imaginary flowing in the reactive component. Assume that the operating frequency is such that element number 6 is near to being half-wave resonant. The imaginary parts of the currents in shorter elements 7 to 12 are capacitive, while those in longer elements 1 to 6 are inductive. The capacitive current components in shorter elements 9 and 10 exceed the conductive components hence, these elements receive little power from the feeder and act as parasitic directors. The inductive current components in longer elements 4 and 5 are dominant and they act like parasitic reflectors. Elements 6, 7 and 8 receive most of their power from the feeder and act like driven elements. The amplitudes of the currents in the remaining elements are small and they may be ignored as primary contributors to the radiation field. Hence, we have a generalized Yagi array with seven elements comprising the active region. It should be noted that this active region is for a specific set of design parameters (τ = 0.93, σ = 0.175). The number of elements making up the active region will vary with τ and σ. Adding additional elements on either side of the active region cannot significantly modify the circuit or field properties of the array.

This active region determines the basic design parameters for the array, and sets the bandwidth for the structure, β_s. That is, for a design frequency coverage of bandwidth β, there exists an associated bandwidth of the active region such that

$$\beta s = \beta \ x \ \beta_{ar} \quad \text{(Eq. 4)}$$

where β = operating bandwidth $= \frac{f_n}{f_1}$ (Eq. 5)

f_1 = lowest frequency in Megahertz
f_n = highest frequency in Megahertz

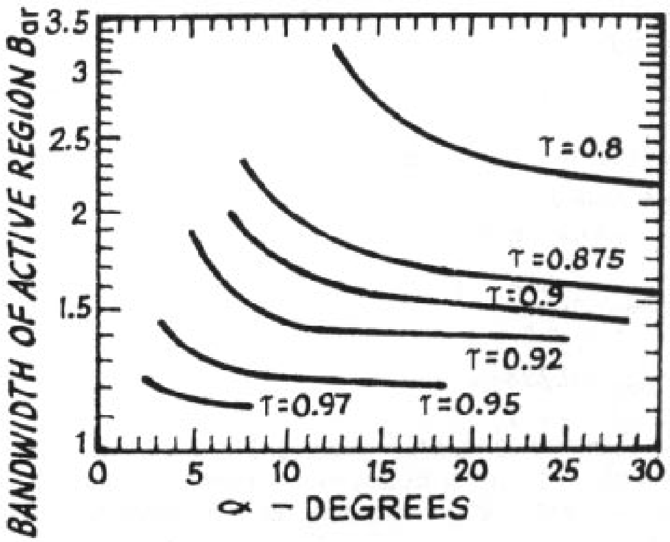


Figure 2

β_{ar} varies with τ and α as shown in Fig. 2. Element lengths which fall outside β_{ar} play an insignificant role in the operation of the array. The gain of an LPDA is determined by the design parameter τ and the relative element spacing constant σ. There exists an optimum value for σ, σ_{opt}, for each τ in the range $0.8 \le \tau < 1.0$, for which the gain is maximum; however, the increase in gain achieved by using σ_{opt} and τ near 1.0 (i.e., τ = 0.98) is only 3 dB above isotropic (3 dB*i*) when compared with the minimum σ ($\sigma_{\min} = .05$) and τ = 0.9, shown in Fig. 3.

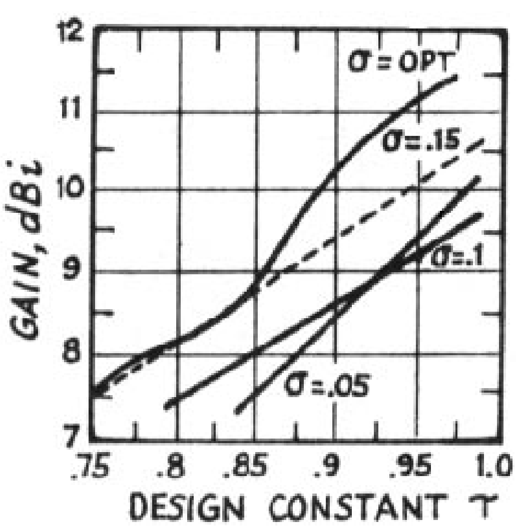


Figure 3

An increase in τ means more elements and optimum σ means a long boom. A high-gain (8.5 dB*i*) LPDA can be designed in the hf region with τ = 0.9 and σ = .05. The relationship of τ, σ, and α is as follows:

$$\sigma = (1/4)(1-\tau)\ \cot \alpha \qquad \text{(Eq. 6)}$$

where $\alpha = 1/2$ the apex angle

τ = design constant
σ = relative spacing constant

$$\text{also}\quad \sigma = \frac{d_{n,\ n\,-\,1}}{2/_{n\ -\ 1}} \qquad \text{(Eq. 7)}$$

$$\sigma_{opt} = 0.258\tau - .066 \qquad \text{(Eq. 8)}$$

The method of feeding the antenna is rather simple. As shown in Fig. 1, a balanced feeder is required for each element, and all adjacent elements are fed with a 180° phase shift by alternating element connections. In this section the term *antenna feeder* is defined as that line which connects each adjacent element. The *feed line* is that line between antenna and transmitter. The characteristic impedance of the antenna feeder, Z_o, must be determined so that the feed-line impedance and type of balun can be determined. The antenna-feeder impedance Z_o depends on the mean radiation resistance level R_o (required input impedance of the active region elements - see Fig. 4) and average characteristic impedance of a dipole, Z_a. (Z_a is a function of element radius a and the resonant element half length, where $h = \lambda/4$. See Fig. 5) The relationship is as follows:

$$Z_o = \frac{R_o 2}{8\ \sigma'\ Z_a} + R_o \sqrt{\left(\frac{R_o}{8\ \sigma'\ Z_a}\right)^2 + 1} \qquad \text{(Eq. 9)}$$

where Z_o = characteristic impedance of feeder

R_o = mean radiation resistance level or required input impedance of the active region.
Z_o = average characteristic impedance of a dipole

$$= 120\ \left(\ell n\ \frac{h}{a} - 2.55\right) \qquad \text{(Eq. 10)}$$

h = element half length
a = radius of element

$$\sigma' = \text{mean spacing factor} = \frac{\sigma}{\sqrt{\tau}} \qquad \text{(Eq. 11)}$$

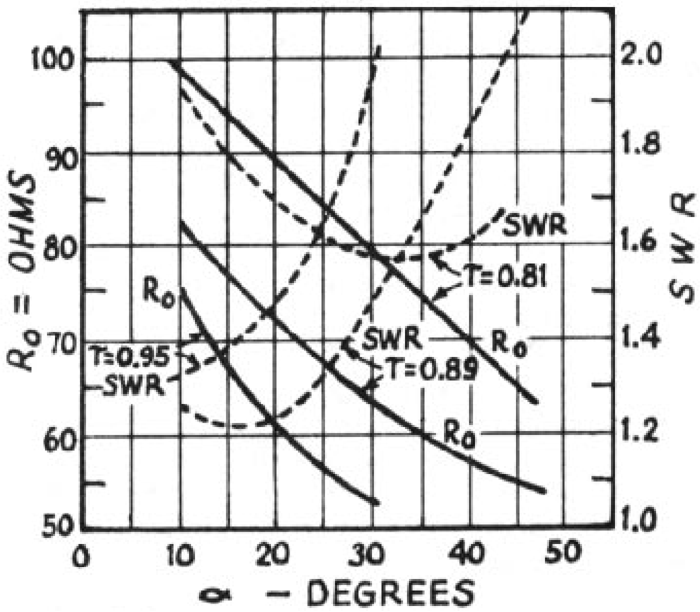


Figure 4

From Fig. 4 we can see that R_o decreases with increasing τ and increasing α. Also the VSWR with respect to R_o has a minimum value of about 1.1 to 1 at σ optimum, and a value of 1.8 to 1 at σ = .05. These SWR values are acceptable when using standard RG8/U 52-ohm and RG-11/U 72-ohm coax for the feed line. However, a one-to-one VSWR match can be obtained at the transmitter end using a coax-to-coax Transmatch. A Transmatch will enable the transmitter low-pass filter to see a 52-ohm load on each frequency within the array passband. The Transmatch also eliminates possible harmonic radiation caused by the frequency-independent nature of the array.

Once the value of Z_o has been determined for each band within the array passband, the balun and feed line may be chosen. That is, if Z_o = 100 ohms, a good choice for the balun would be 1 to 1 balanced to unbalanced, and 72-ohm coax feed line. If Z_o = 220 ohms, choose a 4 to 1 balun, and 52-ohm coax feed line, and so on. The balun may be omitted if the array is to be fed with an open-wire feed line.

The terminating impedance, Z_t, may be omitted. However, if it is used, it should have a length no longer than $\lambda\ \mathrm{max}/8$. The terminating impedance tends to increase the front-to-back ratio for the lowest frequency used. For hf-band operation a 6-inch shorting jumper wire may be used for Z_t. When Z_t is simply a short-circuit jumper the longest element behaves as a passive reflector. It also might be noted that one could increase the front-to-back ratio on the lowest frequency by moving the passive reflector (No. 1 element) a distance of 0.15 to 0.25 λ behind element No. 2, as would be done in the case of an ordinary Yagi parasitic reflector. This of course would necessitate lengthening the boom. The front-to-back ratio increases somewhat as the frequency increases. This is because more of the shorter inside elements form the active region, and the longer elements become additional reflectors.

Design Procedure

A systematic step-by-step design procedure of the LPDA follows. This procedure may be used for designing any LPDA for any desired bandwidth.

1) Decide on an operating bandwidth β be tween f_1, lowest frequency and f_n, highest frequency, using Eq. 5.

2) Choose τ and σ to give a desired gain (Fig. 3).

$$0.8 \le \tau \le 0.98$$
$$0.5 \le \sigma \le \sigma_{opt}$$

The value of σ_{opt} may be determined from Eq. 8.

3) Determine the apex half-angle α

$$\cot \alpha = \frac{4\sigma}{1 - \tau}$$

4) Determine the bandwidth of the active group β_{ar} from Fig. 2.

5) Determine the structure (array) bandwidth βs from Eq. 4.

6) Determine the boom length, *L*, number of elements, *N*, and longest element length, ℓ_1.

$$L = \left[\frac{1}{4}\left(1 - \frac{1}{\beta_s}\right) \cot \alpha\right] \lambda_{\max} \qquad \text{(Eq. 12)}$$

$$N = 1 + \frac{\log \beta_s}{\log\left(\frac{1}{\tau}\right)} \qquad \text{(Eq. 13)}$$

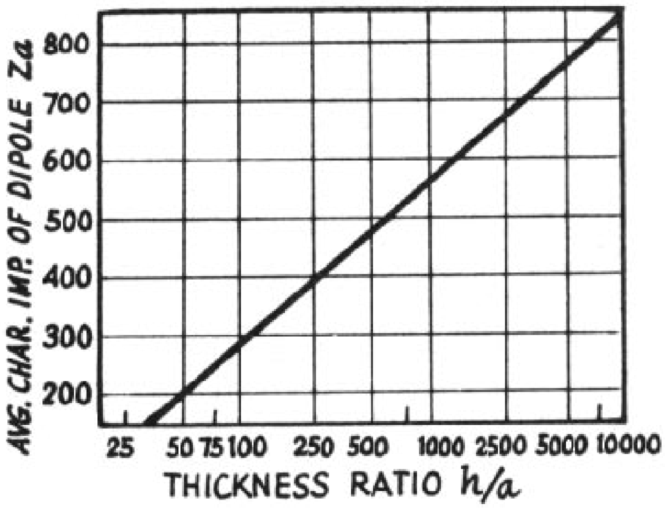
$$\ell_1 = \frac{492}{f_1}$$

where $\lambda_{\max}$ = longest free-space wavelength = $984/f_1$. Examine *L*, *N* and ℓ_1, and determine whether or not the array size is acceptable for your needs. If the array is too large, increase α by 5° and repeat steps 2 through 6.

7) Determine the terminating stub Z_t. (Note: For hf arrays short out the longest element with a 6-inch jumper. For vhf and uhf arrays use: $Z_t = \lambda_{\max}/8$

8) Once the final values of τ and σ are found, the characteristic impedance of the feeder Z_o must be determined so the type of balun and feed line can be found. Use Eq. 9. Determine R_o from Fig. 4, Z_a from Fig. 5 and σ' from Eq. ll. Note: Values for *h* /*a*, Z_a, and Z_o must be determined for each amateur band within the array passband. Choose

the element half-length h nearest $h = \lambda/4$, at the center frequency of each amateur band. Once Z_o is found for each band, choose whatever combination of balun and feed line will give the lowest SWR on each band.



9) Solve for the remaining element lengths from Eq. 2.

10) Determine the element spacing $d_{1\leftrightarrow 2}$ from

$$d_{1\leftrightarrow 2} = \tfrac{1}{2}\left(\ell_1 - \ell_2\right) \cot \alpha \qquad \text{(Eq. 14)}$$

and the remaining element-to-element spacings from Eq. 3.

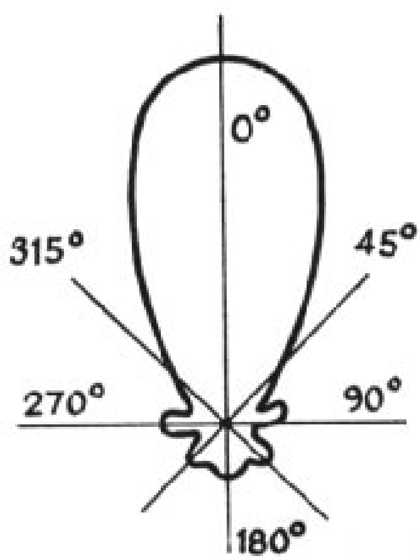


Fig. 6 — Measured radiation pattern for the lowest frequency band (14 MHz) of a 12-element 13-30 MHz log-periodic dipole array. For its design parameters, τ = 0.9 and σ = .05. The measured front-to-back ratio is 14.4 dB at 14 MHz, and increases to 21 dB at 28 MHz.

This completes the design. The measured radiation pattern for a 12-element LPDA is shown in Fig. 6.

There are several high-gain array possibilities using this type of antenna as a basis. Tilting the elements toward the apex will increase the gain 3 to 5 dB. Adding parasitic directors and a reflector will increase both gun and front-to-back ratio for a specific frequency within the passband. The LPDA-Yagi combination is very simple. Use the LPDA design procedures within the set of driven elements, and place parasitic elements at normal Yagi spacings from the LPDA end elements. Use standard Yagi design procedures for the parasitic elements. An example of a single-band high-gain LPDA-Yagi would be a two- or three- element LPDA for 21.0 to 21.45 MHz with the addition of 2 or 3 parasitic directors and one parasitic reflector. The combinations are endless.

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THE LOG-PERIODIC DIPOLE ARRAY

The antenna system shown in Figs. 7, 8, 9, 10, 11 was originally described in QST for November, 1973.

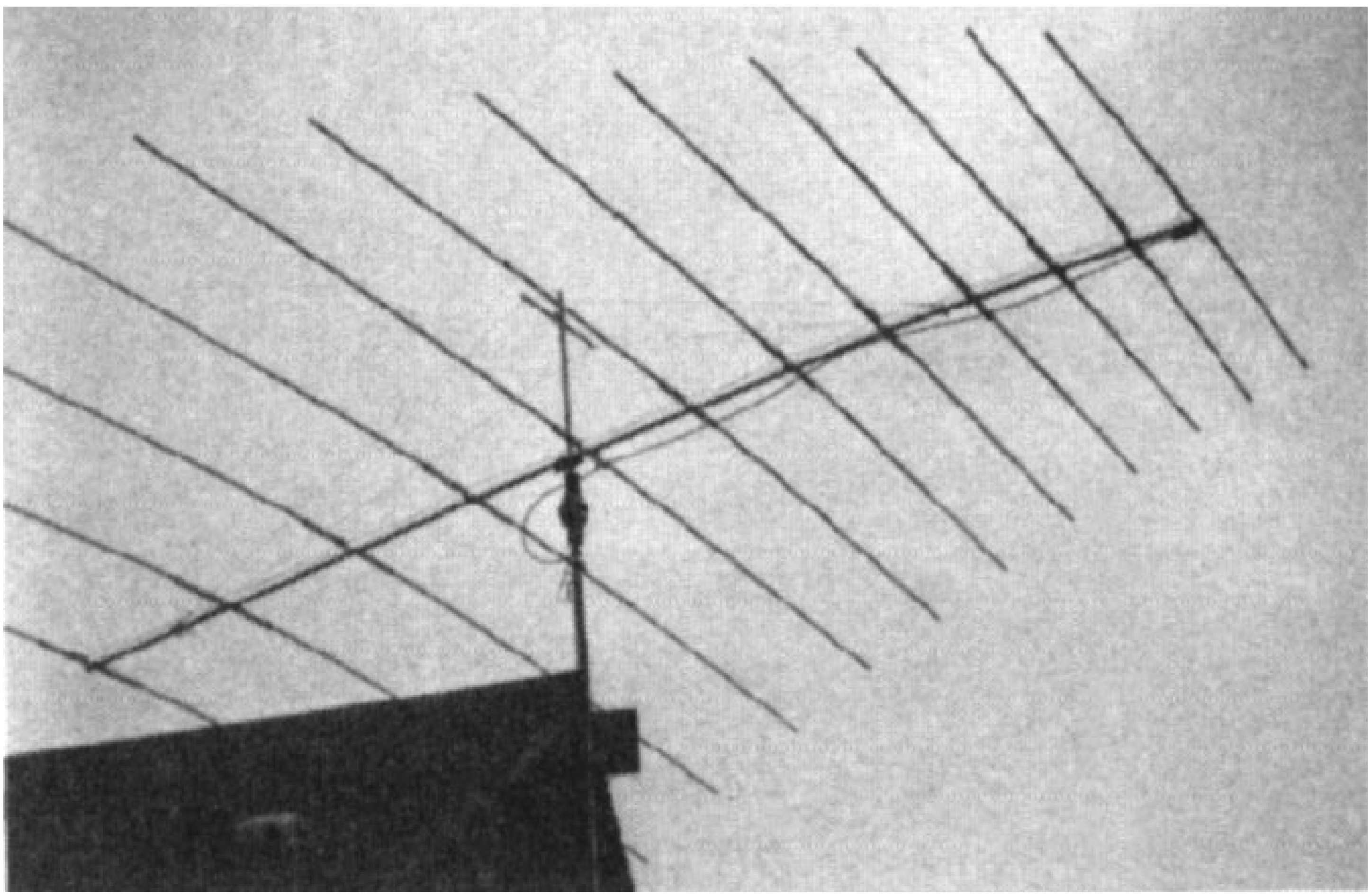

Figure 7

The characteristics of the triband antenna are:

Frequency range, 13-30 MHz
Half-power beamwidth, 43° (14 MHz)
Operating bandwidth, β = 30/13 = 2.3
Design parameter τ = 0.9
Relative element spacing constant σ = .05
Apex half-angle α = 25°, cot α = 2.0325
Bandwidth of active group, β_{ar} , = 1.4
Bandwidth of structure, βs = 3.22
Boom length, *L* = 26.5 ft

Longest element ℓ_1 = 38 ft (a tabulation of element lengths and spacings is given in Table I) Total weight, 116 pounds
Wind-load area, 10.7 sq. ft
Required input impedance (mean resistance),

R_o = 67 ohms,

Z_t = 6-inch jumper No. 18 wire

Average characteristic dipole impedance:

$Z_{a\ 14\ MHz}$ = 450 ohms;

$Z_{a\ 21\ MHz}$ = 420 ohms;

$Z_{a\ 28\ MHz}$ = 360 ohms

Mean spacing factor σ' = .0527
Impedance of the feeder:

$Z_{o\ 14\ MHz}$ = 95 ohms;

$Z_{o\ 21\ MHz}$ = 97 ohms;

$Z_{o\ 28\ MHz}$ = 103 ohms

Using a toroid balun at the input terminals and a 72-ohm coax feeder the SWR is 1.4 to 1 (maximum).

The mechanical assembly uses materials readily available from most local hardware stores or aluminum supply houses. The materials needed are given in Table II. In the construction diagIam, Fig. 8, the materials are referenced by their respective material list number. The photograph shows the overall construction picture, and the drawings show the details. Table III gives the required tubing lengths to construct the elements.

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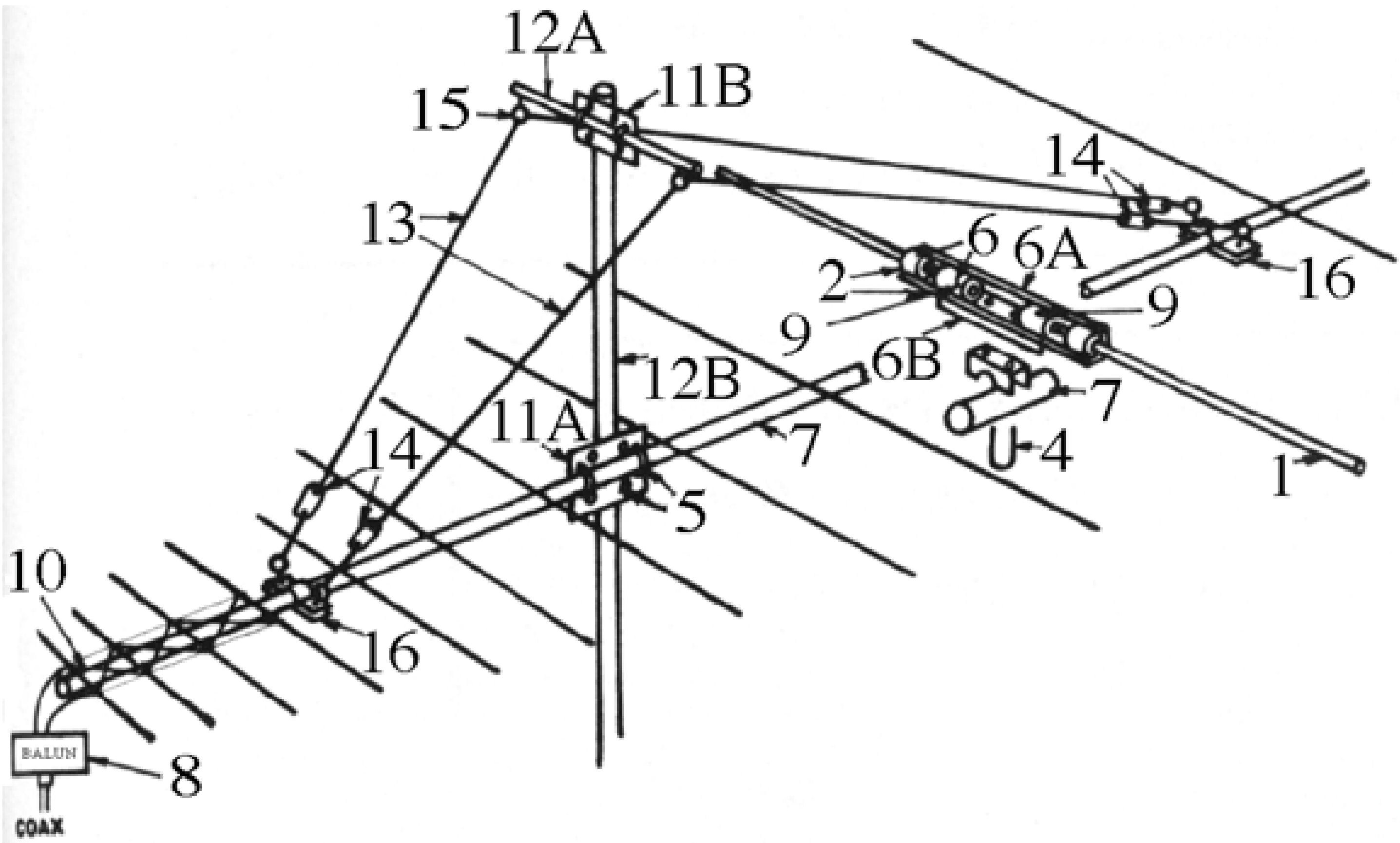

Fig. 8 — Construction diagram of log-periodic array. Figure 9 and 10 are shown the method of making electrical connection to each half element, and at D is shown how the boom sections are joined.

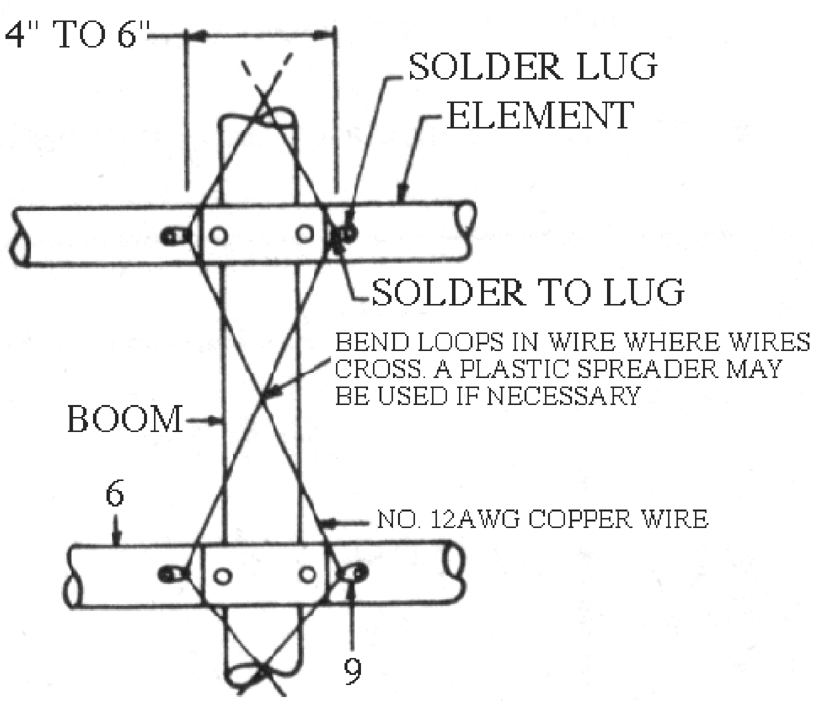

Figure 9

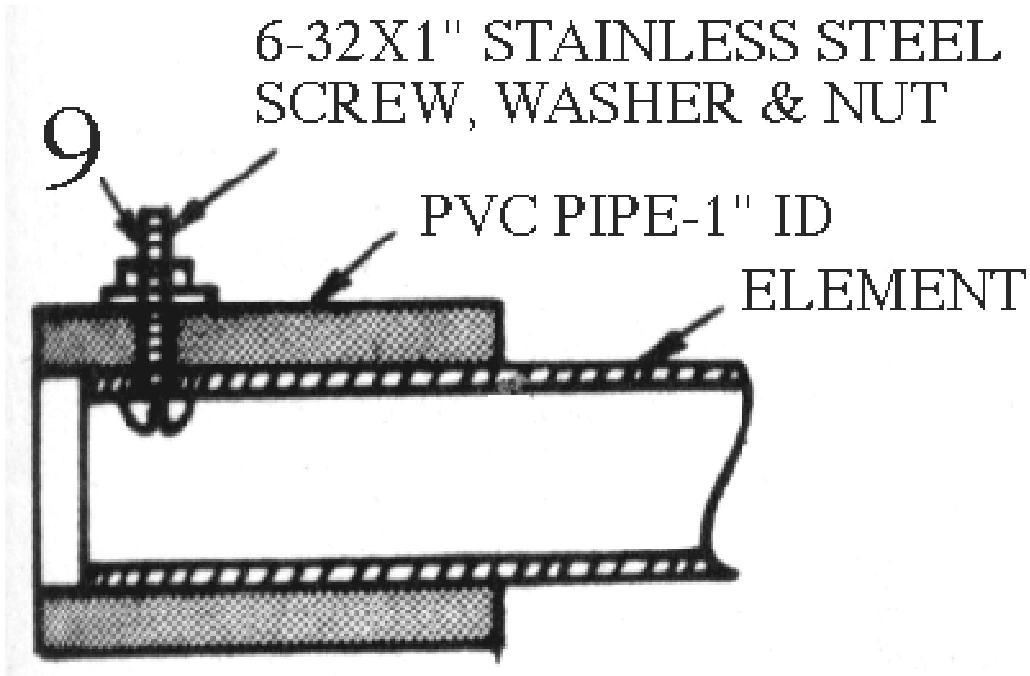

Figure 10

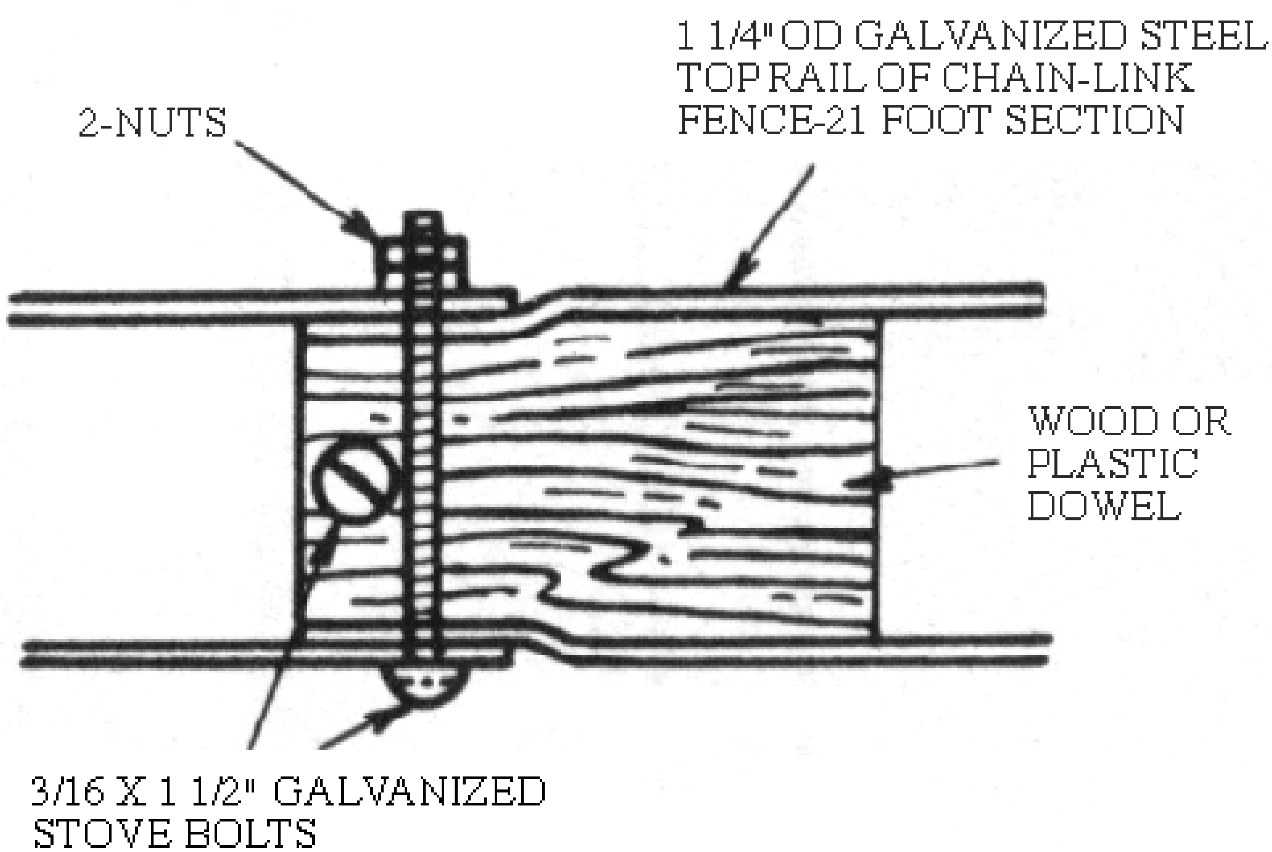

Figure 11

TABLE I ARRAY DIMENSIONS, FEET

Element #	ℓ_n	h	$d_{n \leftrightarrow 1,\, n}$	(spacing)	nearest resonant
1	38.0	19	0		
2	34.2	17.1	3.862 =	$d_{1 \longleftrightarrow 2}$	14 MHz
3	30.78	15.39	3.475 =	$d_{2 \longleftrightarrow 3}$	
4	27.7	13.85	3.13	•	
5	24.93	12.465	2.815	•	
6	22.44	11.22	2.533	•	21 MHz
7	20.195	10.098	2.28	•	
8	18.175	9.088	2.05	•	
9	16.357	8.179	1.85	•	28 MHz
10	14.72	7.36	1.663	•	
11	13.25	6.625	1.496	•	
12	11.924	5.962	1.347 =	$d_{11 \longleftrightarrow 12}$	

TABLE II MATERIALS LIST for Figure 8

	Material Description	Quantity
1.	Aluminum tubing—.047" wallthickness	
	1" — 12' or 6' lengths	126 lineal feet
	7/8"—12' lengths	96 lineal feet
	7/8"—6' or 12' lengths	66 lineal feet
	3/4"—8' lengths	16 lineal feet
2.	Stainles steel hose clamps — 2" max.	48 ea.
3.	Stainles steel hose clamps — 1-1/4" max.	26 ea.
4.	TV - type U-bolts	14 ea.
5.	U-bolts galvanized type	
	5/16" X 1-1/2"	4 ea.
	1/4" X 1"	2 ea.
6.	1" ID polyethelene water servire pipe - 160 psi test approx. 1-1/4" OD	20 lineal feet
	A. 1-1/4" X 1-1/4" x 1/8" aluminum angle — 6′ lengths	30 lineal feet
	B. 1" X 1/4" aluminum bar — 6' lengths	12 lineal feet
7.	1-1/4" top rail of chain-link fence	26.5 lineal feat
8.	1:1 toroid balun	1ea.
9.	6—32 X 1" stainless steel screws	24 ea.
	6—32 stainless steel nuts	48 ea.
	No. 6 solder lugs	24 ea.

10.	No. 12 copper feeder wire	60 lineal feet
11.		
	A. 12" X 8" X 1/4" aluminum plate	1ea.
	B. 6" X 4" X 1/4" aluminum plate	1ea.
12.		
	A. 3/4" galvanized pipe	3 lineal feet
	B. 1 “ galvanized pipe – mast	5 lineal feet
13.	Galvanized guy wire	50 lineal feet
14.	1/4 X 2 turnbuckles	4 ea.
15.	1/4" X 1-1/2" eye bolts	2 ea.
16.	TV guy clamps and eye bolts	2 ea.

TABLE III—ELEMENT MATERIAL REQUIREMENTS

Element #	1" tubing		7/8" tubing		3/4" tubing		1-1/4" angle	1" bar
	Lth.	Qty.	Lth.	Qty.	Lth.	Qty.	Lth.	Lth.
1.	6'	2	6'	2	8'	2	3'	1'
2.	6'	2	12'	2	-	-	3'	1'
3.	6'	2	12'	2	-	-	3'	1'
4.	6'	2	8.5'	2	—	—	3'	1'
5.	6'	2	7'	2	-	-	3'	1'
6.	6'	2	6'	2	-	-	3'	1'
7.	6'	2	5'	2	-	-	2'	1'
8.	6'	2	3.5'	2	-	-	2'	1'
9.	6'	2	2.5'	2	-	-	2'	1'
10.	3'	2	5'	2	-	-	2'	1'
11.	3'	2	4'	2	-	-	2'	1'
12.	3'	2	4'	2	-	-	2'	1'