The K4EWG Log Periodic Array

By Peter D. Rhodes, K4EWG
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Since the publication of my original paper in *QST* in 1973[1] (also republished in *The ARRL Antenna Book*[2]), I have done extensive HF work with these arrays using tubing elements.[3,4] This article represents practical solutions to certain problems which result from the electrical and physical constraints of HF log periodic dipole arrays.

The goals of this article are as follows:

1) Minimize the number of elements without sacrificing gain and/or SWR for the desired bandwidth.

2) Apply W2PV taper correction to the element lengths.[5]

3) Minimize boom length.

4) Simplify construction by removing the cross-wire feeder system and lumped balun.

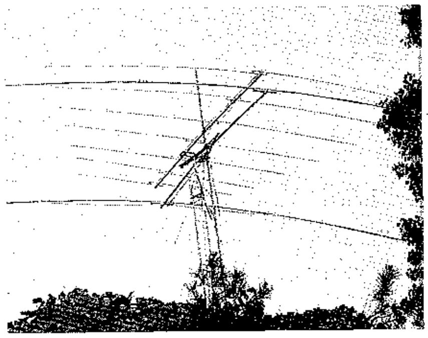
5) Simplify the assembly by using "plumbers delight" techniques.

6) Reduce the weight of the 14-30 MHz array.

I will not repeat the design for the LPDA, as it can be found in the latest *ARRL Antenna Book*. However, it is sufficient to say that the LPDA performs as a frequency independent (broadband) array. When designed properly, it will provide the equivalent gain of a 3-element Yagi with a 15-dB front to back ratio on all bands within the array passband. Fig 1 depicts a typical LPDA with the specified design parameters. If the design constant τ is near 1.0, more elements are required. If the element-spacing constant σ is greater than 0.1, a longer boom is required. A balance must be struck if goals 1 and 3 are to be satisfied.

I define this process as the *Logarithm Periodicity Method*. Basically this method determines a specific design constant τ which will permit element lengths to be chosen so their discrete resonances occur at or near a desired band (for example 14, 18, 21, 25, 28 and 29 MHz).

Fig 2 relates the H-plane (vertical) and E-plane (horizontal) half-power (3 dB) total beamwidths in degrees.[6] Notice that the E-plane beamwidth is almost constant at 60° to 55° for $0.8 < \tau < 0.92$ and $0.05 < \sigma < 0.13$. Also, notice that the H-plane beamwidth varies from 85° to 155° under the same ranges of τ and σ.

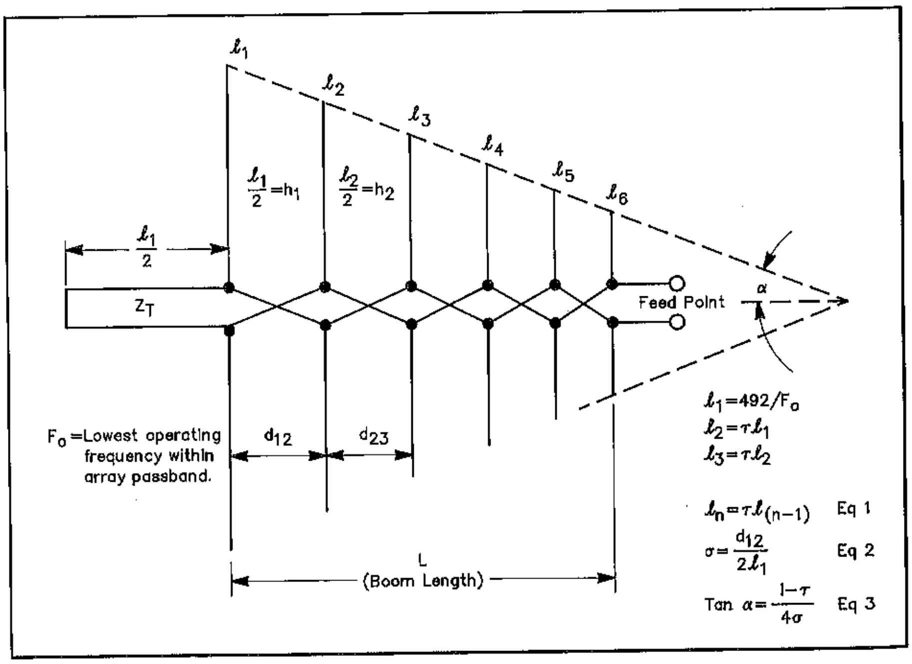


K4EWG Log Periodic Array atop the 120-foot tower (40-meter beam visible below). *(photos by the author)*

The directivity in dBi can be computed using

$$G_{dB} = 10 \log \frac{41{,}253}{E^\circ H^\circ} \qquad \text{(Eq 4)}^{7}$$

It is not my intention to enter a gain controversy. However, Lawson states that the 3-dB total beamwidth is 100° in the H plane and 68° in the E plane for his 3-element Yagis on a 0.3-λ boom.[8] Using Eq 4, this represents a directivity of 7.83 dBi. I have found that the gain of a 3-element monoband Yagi is quite impressive, particularly when one considers a single small antenna approximating such gain for five bands! Both τ and σ (relative spacing constant) can be chosen from Fig 2, so that a directivity of 7 to 8 dBi can be realized. Since the E-plane beamwidth is almost



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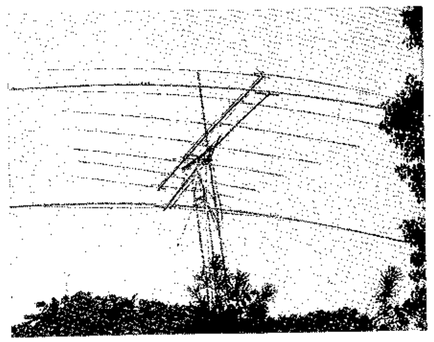

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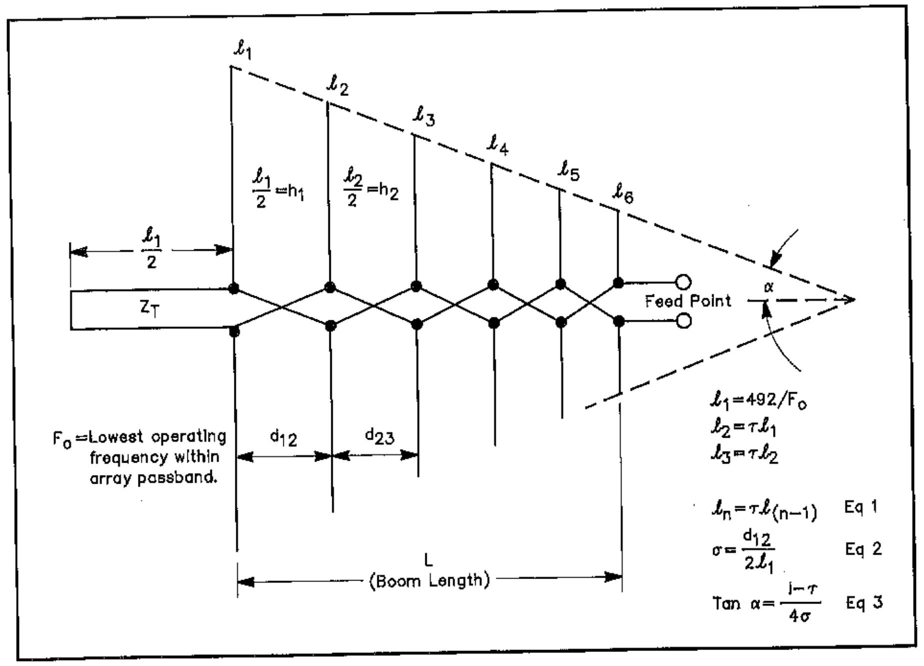

Fig 1—A typical log periodic dipole array.

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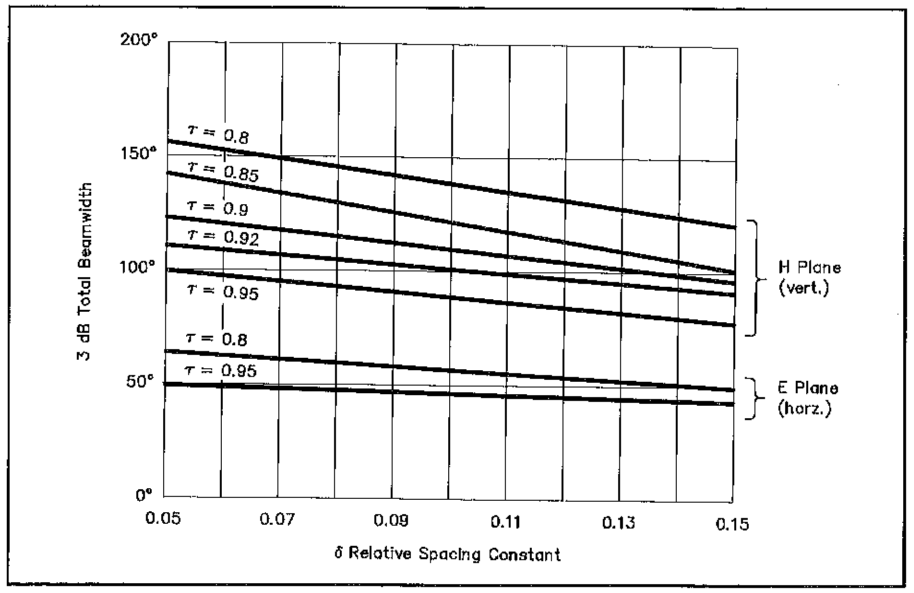


Fig 2—E- and H-plane versus half-power beamwidth.

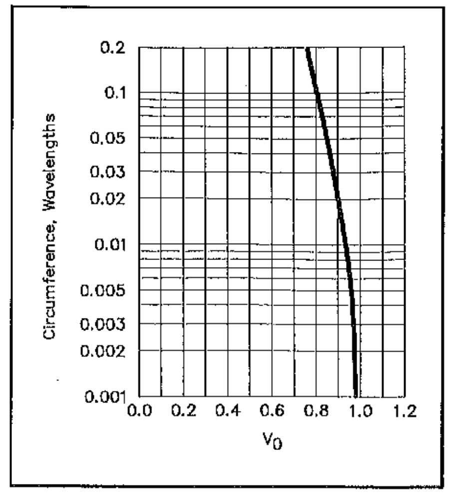


Fig 3—Element pipe circumference in wavelengths versus velocity factor V_0.

The log periodic dipole array has the characteristic of repeating all electrical qualities such as directivity, impedance, front-to-back ratio, SWR and E- and H-plane 3-dB points at intervals of $\log(1/\tau)$. That is to say, there is a relationship between F_1 and F_2.

$$F_2 = [1 + \log(1/\tau)]F_1 \qquad \text{(Eq 5)}$$

$$F_3 = [1 + \log(1/\tau)]^2 F_1$$

where F = array frequencies of periodicity

Let $R = [1 + \log(1/\tau)]$

Then $F_2 = RF_1$

and $F_3 = R^2F_1 = RF_2$

$$F_n = R^{(n-1)}F_1 = RF_{(n-1)} \qquad \text{(Eq 6)}$$

Also,

$$1/\tau = \log^{-1}\frac{F_2}{F_1} - 1$$

$$1/\tau = \log^{-1}\frac{F_n}{F_{n-1}} - 1 \qquad \text{(Eq 7)}$$

Let's consider a 14-30 MHz LPDA with 7 to 8 dBi gain and determine the *least* number of elements required. From Fig 2, τ ranges from 0.850 (σ = 0.05, H = 137°) to 0.920 (σ = 0.07, H = 109°). Given this range of τ, we can proceed to iterate and optimize the periodicity of the array. I will use 1-inch diameter pipe as a referenced normalized length for all elements. Referring to Fig 3[9] at 14.0 MHz, a 1 inch diameter pipe has 0.003-λ circumference and the velocity factor V_0 = 0.94. The resonant frequency of ℓ_1 is f_1, which is also the first periodic frequency of the array, F_1.

$$\therefore F_1 = f_1 = V_0F_0 = 0.94 \times 14.0 = 13.160 \qquad \text{(Eq 8)}$$

where F_0 = lowest desired operating frequency within the array passband in MHz

Also,

$$\lambda_1 = \frac{11,808}{f_1}$$

= free-space wavelength of f_1 and/or F_1 (Eq 9)

Combining Eqs 5 and 8, we can formulate Table 1. As you can see, trial no. 3 looks especially promising. In order to speed up the design process, the discrete dipole element resonant frequencies, f_1 to f_n (specific ham band frequencies), are related to an average τ. For example, if you choose τ = 0.85 (Table 1) with a 14-30 MHz array passband (F_0 = 14, f_n = 30), Eq 10 will determine that seven elements are required (a 7-element array).

$$n = \frac{\log\frac{0.822\,F_0}{F_n} + 1}{\log \tau} \qquad \text{(Eq 10)}$$

where
n = number of elements
nth element = 0.411 λ_n
$\lambda_n = 984/F_n$

Table 1
Array Periodic Frequencies for Different τ Values
F_1 to F_n = Array periodic frequencies within the array passband.

Trial No.	*Trial* τ	*1 + log (1/τ)*	F_1	F_2	F_3	F_4	F_5	F_6	F_7	$F_8 \to F_n$
1	.82	1.08619	13.160	14.294	15.526	16.864	18.317	19.896	21.610	etc →
2	.83	1.08092	13.160	14.225	15.376	16.620	17.965	19.419	20.990	
3	.85	1.070581	13.160	14.088	15.083	16.148	17.287	18.508	19.814	

Table 2
Element Half Lengths

$f_1 = 13.160$	$\ell_{Eq\,1} = \frac{0.94 \times 5904}{13.16} = 210.857$ inches
$f_2 = 15.433$	$\ell_{Eq\,2} = \tau[\ell_{Eq\,1}] = 179.801$ inches
$f_3 = 18.100$	$\ell_{Eq\,3} = \tau[\ell_{Eq\,1}] = 153.318$ inches
$f_4 = 21.224$	$\ell_{Eq\,4} = 130.737$ inches
$f_5 = 24.891$	$\ell_{Eq\,5} = 111.481$ inches
$f_6 = 29.190$	$\ell_{Eq\,6} = 95.061$ inches
$f_7 = 34.232$	$\ell_{Eq\,7} = 81.060$ inches
	$\ell_{Eq\,n} = \tau\,[\ell_{Eq\,n-1}]$ (Eq 12)

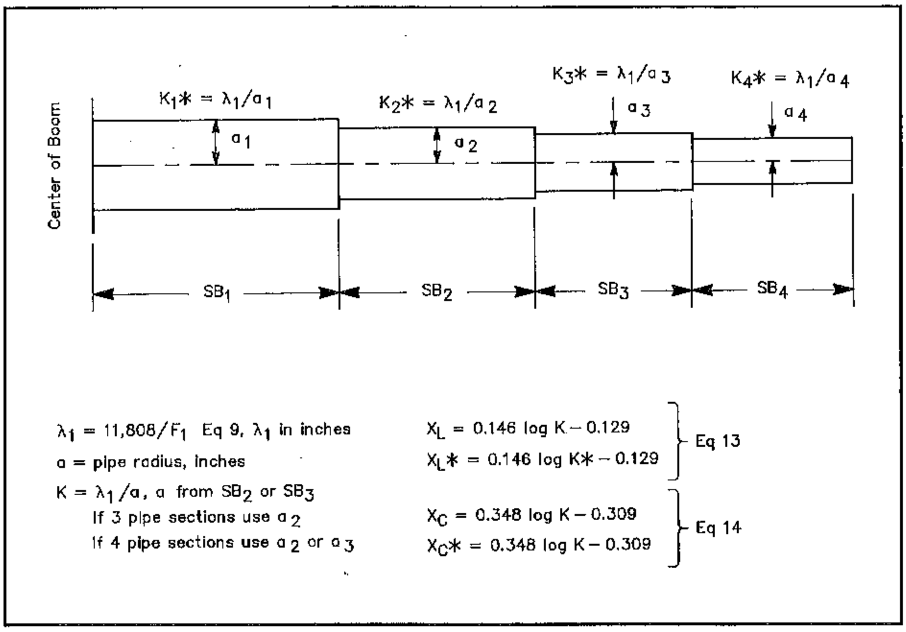
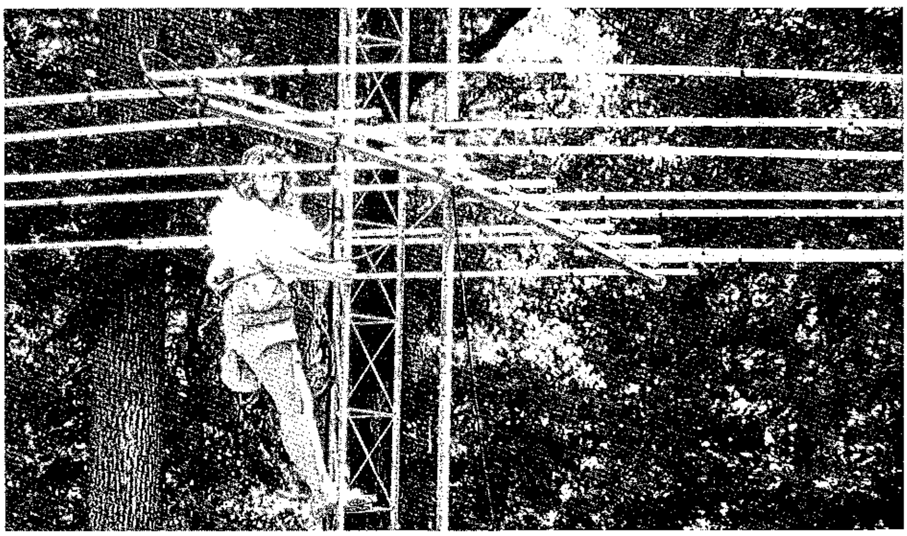


Fig 4—Taper section for half-element length. Hold all inner sections at a fixed length and vary the end section as needed.



K4EWG Log Periodic Array before being raised to the top of the tower, with XYL Tana assisting.

Since dipole ℓ_1 is resonant at 13.160 MHz, desired (element) dipole frequencies may be assigned as follows.

$F_1 = f_1 = 13.160$ MHz
f_2 = unknown
$f_3 = 18.100$
$f_4 = 21.250$
$f_5 = 24.891$
f_6 = unknown
f_7 = unknown

Then $\tau_{3\text{–}4} = \frac{18.100}{21.250} = 0.85176$

$$\tau_{4\text{–}5} = \frac{21.250}{24.891} = 0.85372$$

The average value of τ is

$$\tau_{AVG} = \frac{\tau_{3\text{–}4} + \tau_{4\text{–}5}}{2} = 0.85274$$

and $f_n = \frac{f_{n-1}}{\tau}$ (Eq 11)

Then, using Eq 11 and the averaged τ, we have

$$f_2 = \frac{f_1}{\tau_{AVG}} = 15.432$$

$$f_6 = \frac{f_5}{\tau_{AVG}} = 29.189$$

$$f_7 = \frac{f_6}{\tau_{AVG}} = 34.230$$

Of course, once a final τ has been found, Table 1 could be repeated for that specific τ to examine the F_1 to F_n frequency periodicity over the entire array passband. Obviously, it is desirable that the five 14-30 MHz ham bands fall at or near these periodic frequencies. The final τ used in the K4EWG Array design was 0.85271318.

Now, using the W2PV approach to the taper corrections, I have chosen 1-inch outside diameter pipe for the electrically normalized lengths. I will call these *element half lengths*, ℓ_{Eq}, per W2PV's designation. (See Table 2.)

Hence,

$$\ell_{Eq} = \frac{V_0\,5904}{f_1},\ V_0 = 0.94 \text{ (Fig 3)},\ F_1 = f_1,$$

and $f_n = F_n$.

Derivation of the taper correction equations can be simplified. However, the element taper should not exceed 0.125 inch in diameter for adjacent pipe to pipe telescoping sections within the element. Hence, a light or smooth taper eliminates the tedious m and $f(\theta)$ calculations.

The simplified method can be under-

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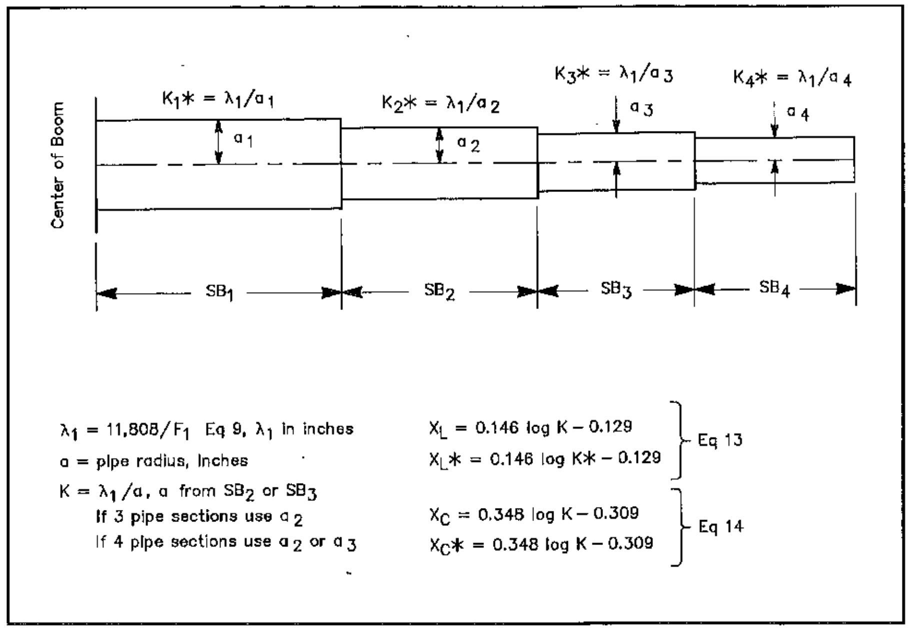

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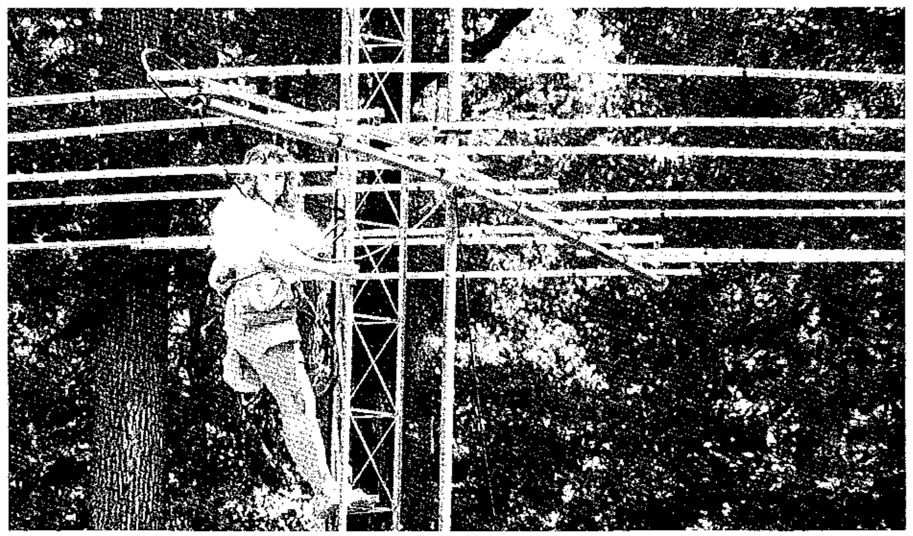

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The simplified method can be understood using Fig 4 and the associated equations from W2PV's earlier paper.[10]

Table 3
Taper Equation for ℓ(K4EWG Array)
SB_2 is normalized section.

Sect. No.	*SB inches*	*2a inches*	*K**	$XL*/XL_2$	$XC_2/XC*$	*SA inches*	$K_2 = \lambda_1 / a_2 = 1{,}794.13$
1	16	1.125	1595.14	0.9784	—	15.655	$X_{C2} = 0.3461$
2	64	1.000	1794.53	0	0	64.000	$X_{L2} = 0.8234$
3	60	0.875	2050.89	—	0.9761	58.565	$f_1 = F_1 = 13.160$ MHz
4_1	70	0.750	2392.70	—	0.9468	66.489	$\lambda_1 = 897.24$ in., $a_2 = 0.5$ in.
4_2	84	0.750	2392.70	—	0.9468	79.787	$SA = (X_L^* / X_{L2})SB = (X_{C2} / X_C^*)SB$

$SB_{TOTAL} = 224$ in., trial no. 1 — $\ell_{Eq} = 218.006$, trial no. 1
$SB_{TOTAL} = 210$ in., trial no. 2 — $\ell_{Eq} = 204.709$, trial no. 2

For example, to find taper equation ℓ_1 in the K4EWG Array, choose SB_2 as normalized pipe section, $a_2 = 0.5$ inch, and $\lambda_1 = 897.264$ inches.

By looking carefully at Table 3, you'll see that SB_4 (the last pipe) was varied in length while all other pipes were fixed. Also, you will see that it would require 224 inches total length for the tapered element to have the same resonance as a 1-inch diameter pipe 218.006 inches in length. Trial no. 2 reveals 210 inches tapered to 204.709 inches for the 1-inch pipe.

The Taper Correction Formula

The taper correction formula is

$$\eta = P\ell_{Eq} + q \qquad \text{(Eq 13)}$$

where
η = physical half length of the tapered element
ℓ_{Eq} = equivalent cylinder length, Table 3

$$P = \frac{\eta_1 - \eta_2}{\ell_{Eq\,1} - \ell_{Eq\,2}} \qquad \text{(Eq 14)}$$

and

$$q = \frac{\eta_2 \ell_{Eq\,1} - \eta_1 \ell_{Eq\,2}}{\ell_{Eq\,1} - \ell_{Eq\,2}} \qquad \text{(Eq 15)}$$

Note: Numbers 1 and 2 refer to trial selections 1 and 2 for the end pipe, not to be confused with element designations ℓ_1 and ℓ_2.

Since the elements are mounted above the boom using a single muffler clamp, there is very little, if any, need for boom-to-element mounting taper adjustment. Lateral element to boom stability is enhanced by the cross connecting hose clamps at the feed pipe for each element (Fig 5). If the elements are mounted by plates and U bolts as specified by Lawson, a plate taper must be developed for each element and included in the element taper schedule for section SB_1.[5]

Table 4
Taper Equations for K4EWG Array

Element No.	*Physical Half Lgth Inches*	*Taper Correction Eq for $\ell/2 = h$*	*Pipe Section – Inches* 1.125	1.00	0.875	0.750
1	216.473	$1.0529\,\ell_{Eq1} - 5.5318$	16	64	60	76½
2	183.898	$1.0344\,\ell_{Eq2} - 5.6767$	16	64	60	43⅞
3	155.606	$1.0261\,\ell_{Eq3} - 1.7074$	16	64	60	15⅝
4	132.494	$1.0269\,\ell_{Eq4} - 1.7611$	16	64	52½	—
5	113.065	$1.0278\,\ell_{Eq5} - 1.5174$	16	64	33$\frac{1}{16}$	—
6	95.911	$1.0287\,\ell_{Eq6} - 1.8758$	16	64	15$\frac{15}{16}$	—
7	82.476	$1.0297\,\ell_{Eq7} - 0.9879$	16	32	34½	—

$\ell_{Eq\,1-6}$ from Table 2. Use 8-inch minimum pipe overlay

The taper schedule for the K4EWG Array is given in Table 4. Boom length minimization is simplified by use of Fig 2. Actually, σ can range from 0.05 to 0.08 with little change in array gain. Now,

$$\tan\alpha = \frac{1 - \tau}{4\sigma} = \frac{\ell_1 - \ell_n}{L}$$

and

$$\sigma = \frac{d_{12}}{2\ell_1} \qquad \text{(Eq 2)}$$

where d_{12} = spacing ℓ_1 to ℓ_2

Rearranging,

$$d_{12} = \frac{(1 - \text{tau})\,\ell_1\,L}{\ell_1 - \ell_n}$$

where L = boom length, same dimensions as ℓ.

Using the K4EWG Array as an example: L = 20 feet, $d_{12} = 4.78$ feet and $\sigma = 0.0674$.

A 20-foot boom length is quite a reduction from my earlier design of 26.5 feet.[1,2] Since $\tau = 0.8527$ and $\sigma = 0.0674$, the H-plane beamwidth is approximately 130° from Fig 2, giving a gain of 7.61 dBi from Eq 4.

The cross feeder is not necessary. It is, however, necessary to switch feeder connections electrically as shown in Fig 1 for end-fire (toward shortest element) directivity. If the switching were not done, broadside directivity (perpendicular to the plane of the array) would occur.[11] I have accomplished this switching as shown in

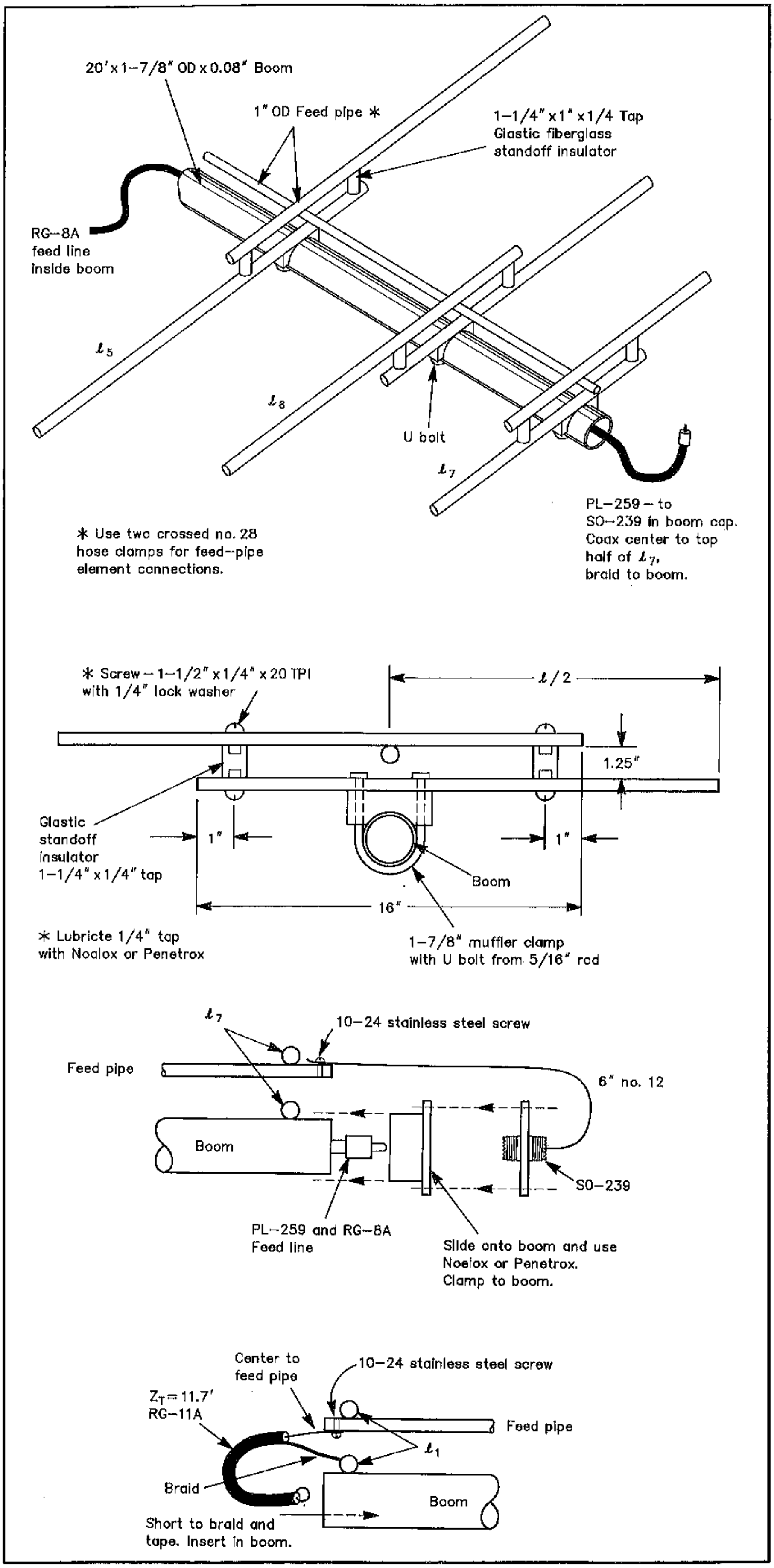
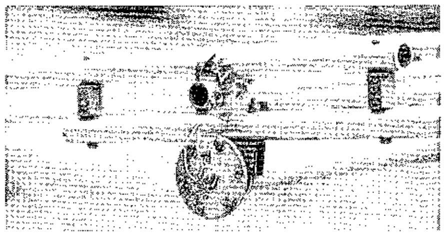


Fig 5—Mechanical detail of K4EWG Array.



Close-up detail of feed point.

Fig 5 (patent pending). I define this feeding system as *Eccentric Linear Feeding for Log Periodic Dipole Arrays* (patent and trademark pending).

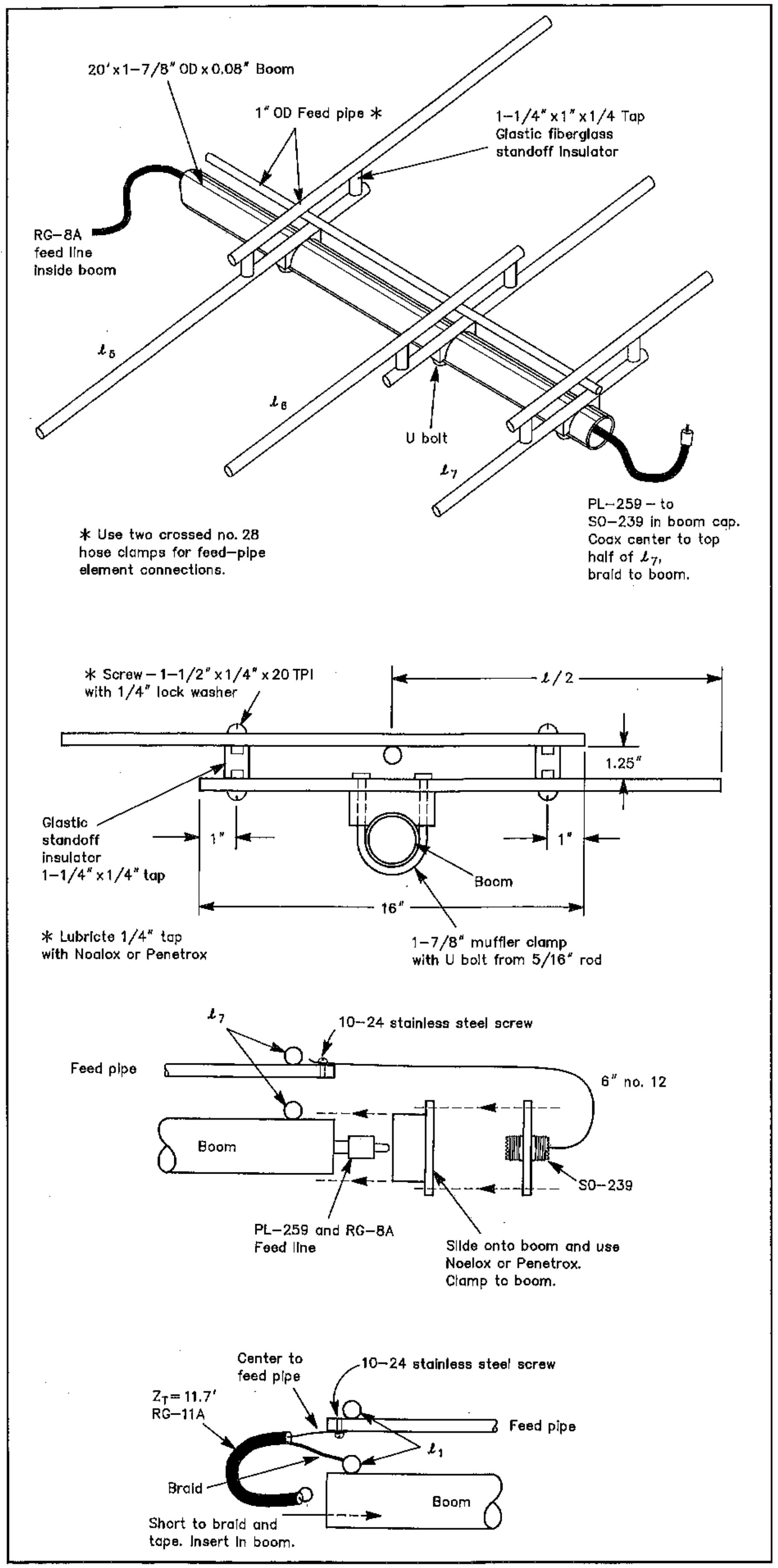
Examination of Fig 5 and the accompanying photos reveals that goals 3, 4, 5 and 6 are satisfied (the total completed weight of the K4EWG Array is 56 lb). The lumped balun is not necessary since the feeder is unbalanced by design. Also the coax runs through the boom, which acts as a decoupling device for any unbalanced currents on the outside of the coax.

I will not develop the Z_0, or characteristic impedance, since it can be determined from the published data in the *ARRL Antenna Book*[1,2]. However, the SWR at the feed point of this array is listed for each of the five bands in Table 5. Needless to say, they are quite acceptable and are primarily due to the periodicity and feeder design approach. A summary of materials used in the K4EWG Log Array can be found in Table 6.

Astute readers will note that I have also listed SWR figures for the 10-MHz band.

Table 5
SWR Versus Frequency (MHz) for K4EWG Array

Freq MHz	*SWR at Antenna*
10.1	2.0
10.15	2.0
10.2	2.5
14.0	1.7
14.2	1.5
14.5	1.4
18.0	1.4
18.2	1.2
18.4	1.2
21.0	1.0
21.2	1.1
21.5	1.2
24.5	1.2
24.9	1.1
25.1	1.0
28.0	1.4
28.5	1.5
29.0	1.2
30.0	1.2



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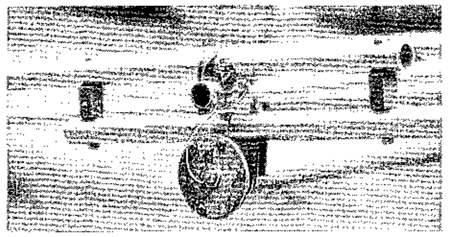

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Fig 5 (patent pending). I define this feeding system as *Eccentric Linear Feeding for Log Periodic Dipole Arrays* (patent and trademark pending).

Examination of Fig 5 and the accompanying photos reveals that goals 3, 4, 5 and 6 are satisfied (the total completed weight of the K4EWG Array is 56 lb). The lumped balun is not necessary since the feeder is unbalanced by design. Also the coax runs through the boom, which acts as a decoupling device for any unbalanced currents on the outside of the coax.

I will not develop the Z_0, or characteristic impedance, since it can be determined from the published data in the *ARRL Antenna Book*[1,2]. However, the SWR at the feed point of this array is listed for each of the five bands in Table 5. Needless to say, they are quite acceptable and are primarily due to the periodicity and feeder design approach. A summary of materials used in the K4EWG Log Array can be found in Table 6.

Astute readers will note that I have also listed SWR figures for the 10-MHz band.

Table 5
SWR Versus Frequency (MHz) for K4EWG Array

Freq MHz	*SWR at Antenna*
10.1	2.0
10.15	2.0
10.2	2.5
14.0	1.7
14.2	1.5
14.5	1.4
18.0	1.4
18.2	1.2
18.4	1.2
21.0	1.0
21.2	1.1
21.5	1.2
24.5	1.2
24.9	1.1
25.1	1.0
28.0	1.4
28.5	1.5
29.0	1.2
30.0	1.2

Table 6
Materials List for K4EWG Log Array

Aluminum tubing—6061ST—0.047 in. wall thickness elements
1.125 in. OD—192 in. (2 ea—8 ft pcs)
1.000 in. OD—1,224 in. (17 ea—6 ft pcs)
0.875 in. OD—816 in. (10 ea—6 ft pcs, 1 ea—8 ft pcs)
0.750 in. OD—312 in. (3 ea—8 ft pcs, 1 ea—4 ft pcs)
1.875 in. OD—240 in. (1 ea—20 ft pcs—0.08 in. wall)

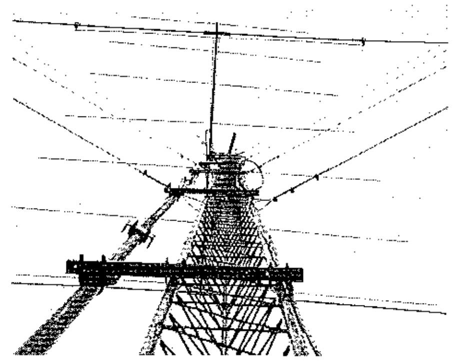
Clamps
11 ea—1⅞ in. muffler clamps (U bolts not used for elements)
28 ea—no. 28 stainless steel hose clamps
7 ea—5⁄16 in. × 12 in. threaded rod (bend to form U bolts for elements)

Miscellaneous
1 ea ¼ in. × 8 in. × 12 in. aluminum boom to mast plate
44 ea—no. 6 stainless steel sheet metal screws
1 ea—boom cap, aluminum, homemade
1 ea—SO-239 coax connector
4 oz.—Noalox or Penetrox
28 ea—¼ × 1½ in. stainless steel screw, 20 TPI and ¼ in. SS lock washers
1 ea—Z_τ, 11.7 ft RG-11A inserted inside boom, Z_τ = 0.33 ℓ_1
14 ea—1¼ × ¼ in. tap Glastic standoff insulator*

*Glastic Manufacturing Co, Cleveland, Ohio, tel 216-486-0100. Distribution Headquarters: Electrical Insulation Supplies, 1255 Collier Rd NW, Atlanta, GA 30318, tel 404-355-1651 (Glastic part number 2165-1B).

(Now we have a 6th band on one antenna!) Operation on 10 MHz is possible due to the loading effect of Z_τ on ℓ_1. Z_τ is a shorted quarter wave section for 14.0 MHz and, therefore, it acts like an open circuit at that frequency. At higher frequencies, most of the RF energy is radiated by the elements within the active region of dipole elements. Therefore, Z_τ receives very little energy from the feeder. At 10.1 MHz, however, Z_τ provides an inductive loading reactance for ℓ_1, making it resonant at 10.1 MHz. Surprisingly, ℓ_2 contributes as part of a 10-MHz active region and endfire directivity occurs with τ near 0.6, ℓ_1 to ℓ_2. Of course, with such a low τ the gain is not comparable to the design array passband (14-30 MHz), but it is interesting to see what extremes can be tolerated in such arrays. The log periodic array exhibits an interesting quality in that elements shorter than the nearest resonant element ($\tau > 0.75$) carry 80% of the radiated energy.[6] The array simply "wants to work"! Z_τ also provides a dc ground for lightning protection.

My previous papers have dealt with the technical and electrical aspects of such arrays. I'd like, however, to diverge from my normal closings and relate a brief note of nontechnical interest. After completing the array I left it sitting on the saw horses (approximately 3 feet above ground) and put it on the air. While due respect is given for propagation and my location, a single hour of operation resulted in numerous QSOs while running only 100 watts. Some of the stations worked included D68TW and 3B8CF (21 MHz CW), TA3F and VU2AU (21 MHz SSB), TY1OR (14 MHz CW), DL9JI (10 MHz, CW) and five Siberian stations on 21 MHz CW. I was surprised at how well this array performed so close to the ground! Subsequent to the "saw horse QSOs," I have been enjoying the antenna in its proper location on the tower at about 120 feet.



Ground view of tower assembly and antennas. Note the rotator mast pipe visible at left.

At the time of writing of this paper, I am building a second K4EWG Log Periodic Array which will stack 0.6 λ at 14 MHz (42 feet) under the top array (120 feet). It will be interesting to vary stacking distances with such arrays and plot the E- and H-plane patterns. As can be seen in the photos, the rotator is ground mounted with a 2-inch outside diameter pipe mast running along the entire length of the tower. Such a mast simplifies stacking arrays and I must credit my good friend, Bill Maxson, N4AR, for this neat idea. However, I'll leave the stacking details for another paper.

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