A NEW DESIGN METHOD FOR LOW SIDELOBE LEVEL LOG-PERIODIC DIPOLE ANTENNAS

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***Abstract*- A new design procedure for log-periodic dipole arrays is presented in this paper. In this method, either the scale factor or the number of dipole elements is selected, after the boom length, and the operating frequency region are specified. The procedure is applied iteratively, in conjunction to the Numerical Electromagnetic Code, to produce a design with low sidelobe levels. With this new procedure, the antenna designer has more control over the boom length; in older techniques, the boom length and the element spacing were dependent on previous calculations, which frequently resulted on unreasonable values.**

Results for several designs are presented, showing the peak gain to peak-sidelobe level ratio, and the antenna gain as a function of frequency, for different scale factors and boom lengths, for a frequency range of 13 to 30 MHz.

I. INTRODUCTION

Log-periodic dipole array (LPDA) antennas are truly broadband structures which can be fabricated to operate over almost any frequency band [1]. These structures commonly present excellent VSWR characteristics over the design bandwidth. However, the radiation characteristics have not been exceptional for most designs; this is particularly true when the designed antenna is placed over ground. The peak gain to peak sidelobe level ratio for these antennas varies from poor to average (10-15 dB).

The design procedure for the LPDA relies mostly on the use of design curves and a series of calculations to obtain the scale factors, τ, σ and α, the dipole element lengths, the spacing between elements, and the boom length. Since the boom length is a result of the design process, an unreasonably large value can be obtained for the boom length, and the procedure must be repeated until a reasonable boom length is obtained. Sometimes, after the procedure is completed, and the antenna dimensions are specified, it is found that the antenna radiation pattern is unacceptable.

For the purpose of improving the design procedure of log-periodic antennas, a new method is presented in this paper. The new design procedure requires as inputs the frequency band of operation, the boom length, L, and either the scale factor, τ, or the number of dipole elements, N. The resulting design is simulated numerically to verify the gain, and peak gain to peak sidelobe level ratio.

This paper presents a comparative study of the peak gain to peak sidelobe level ratio and antenna gain for different scale factors, and boom lengths. Computer simulations were performed using NEC [2].

The results reported show that this new procedure can yield very good designs. Peak gain to peak sidelobe level ratios in the order of 25-30 dB are possible, while maintaining good VSWR characteristics, and reasonable antenna dimensions.

Two design examples are presented, one following the standard handbook procedure, and one following the new procedure developed here. The resulting array sizes are then compared with each other.

II. BACKGROUND

A. Basic Theory

Log-periodic antennas were introduced by DuHamel and Isbell in 1955 [3,4], as a modification to the equiangular log-spiral antenna characterized by Rumsey [3,4]. Isbell then introduced the LPDA, the most widely used log-periodic structure [4]. The LPDA consists of a sequence of parallel dipoles, with successively increasing lengths outward from the feed point at the apex [5], as shown in Fig. 1 [6]. The feed lines cross over between adjacent elements to provide a 180° phase shift between elements. This phase reversal is necessary to produce a beam pointing in the direction of the smallest elements. In this way, interference from the longer elements is avoided, and the smaller elements act as director elements as in the Yagi-Uda array.

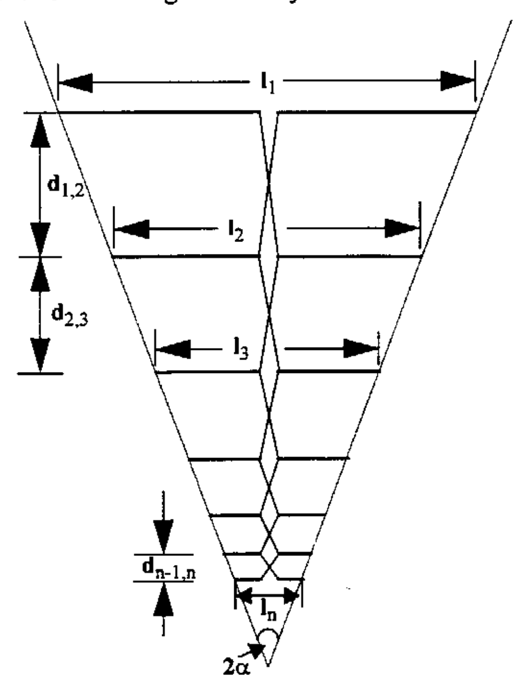

Fig. 1. Log-periodic dipole array geometry

Note from Fig. 1 that the dipole lengths increase along the structure so that the angle α is constant. The geometry of the log-periodic antenna is chosen so that the electrical properties repeat periodically with the logarithm of the frequency [4]. The length and radius of the dipole elements, and the inter-element spacing are scaled so that [7]

$$\tau = \frac{l_{i+1}}{l_i} = \frac{d_{i,\,i+1}}{d_{i-1,\,i}} \tag{1}$$

where l_i is the length of dipole i, and $d_{i,i+1}$ is the distance between the centers of dipoles i and i+1. Since in practice it is difficult to find wires or tubing with different exact radii, then either only one radius, or a few different radii can be used in the antenna manufacturing without significantly degrading the antenna performance [8].

This self scaling property stated in (1), implies that the array has the same radiating characteristics at frequencies related by a factor τ, e.g., at frequencies $f_1, f_2=\tau f_1, f_3=\tau^2 f_1$, etc.

Not all the elements in the array are active at a given frequency. The elements slightly smaller than a half wavelength constitute the active region, since they support much more current that the rest of the elements.

The frequency band of operation is roughly determined by the frequencies at which the longest and shortest dipoles are half-wavelength resonant, i.e. [5]

$$l_1 = \frac{\lambda_1}{2} \quad \text{and} \quad l_N = \frac{\lambda_N}{2} \tag{2}$$

where l_1, and l_N are the longest and shortest dipoles, respectively, and λ_1 and λ_N are the wavelengths corresponding to the lower and upper frequency limits, respectively.

The other two parameters that characterize the LPDAs are the spacing factor, σ, and the angle, α. The angle α forms an imaginary wedge that bounds the dipole elements, as shown in Fig. 1. The scaling factor τ, the spacing factor σ, and the angle α are interrelated and are given by [4]

$$\sigma = \frac{d_{i,\,i+1}}{2l_i} = \frac{1-\tau}{4\tan\alpha} \tag{3}$$

$$\alpha = \tan^{-1}\left(\frac{1-\tau}{4\sigma}\right) \tag{4}$$

B. Present Handbook Design Procedure

The design procedure is well known, and details on the procedure are available in the literature [8-12]. A short summary of this method is presented in the following paragraphs.

The antenna gain, radiation pattern, and input impedance, depend upon the spacing factor, σ, and the scale factor, τ. The constant gain contours are given by [4], and are plotted as function of σ and τ in Fig. 2. Note that these contours are reduced by 1.5 dB from the original contours presented by Carrel in [13]. This reduction is an average correction for the error made by Carrel in the calculation of the E-plane pattern [3].

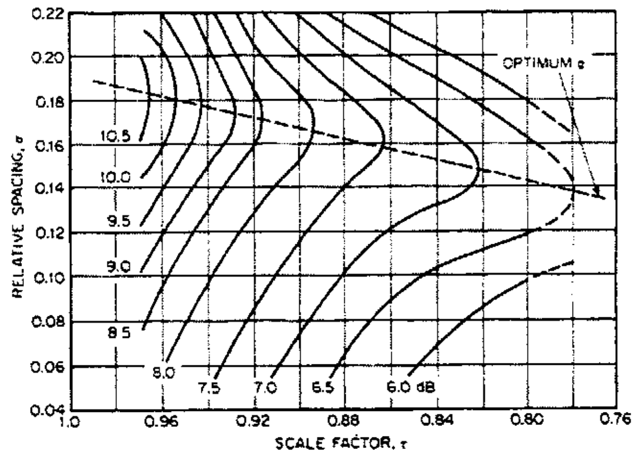

Fig. 2. Gain contours for a log-periodic dipole array (from [4], after Reference [14])

For this procedure, first the antenna bandwidth is selected. Then, the values for σ and τ are found using Fig. 2 and the desired antenna gain; the value of α is found from (4). The lengths of the longest and shortest elements are calculated using (2), and the rest of the element lengths are found from (1). The inter-element spacings can be found from (3), and, finally, the boom length is found by adding all the inter-element spacings.

C. Example

It is desired to design a LPDA that operates between 13 and 30 MHz, with a gain of at least 10.5 dBi, and peak gain to peak sidelobe level ratio of at least 15 dB.

Using Fig. 2, σ=0.179, and τ=0.964, and from (4), 2α=5.75°. After applying (2), and (1), the dipole element lengths were calculated. The LPDA antenna designed required 24 elements. The spacings were then calculated from (3), and the boom length turned out to be 65.364 m. Selected values of the dipole lengths and the inter-element spacings are shown in Table I.

Note the excessively long boom length that resulted from this design procedure. A new design technique is developed in order to produce LPDAs with excellent electrical characteristics, while having a reasonable size and fewer elements than those obtained in this case.

III. LPDA Antenna Design

A. New Design Procedure

The new design methodology is simplified from that of the standard procedure, by taking advantage of the log-periodic properties of the antenna structure. In the new procedure, the boom length is specified beforehand, to ensure a physically realizable design is obtained. The classical design methodology has the boom length as an output parameter, and therefore, there is the possibility of obtaining a design that is not physically realizable.

TABLE I: SELECTED LENGTHS AND SPACINGS FOR LPDA ANTENNA

i	Dipole Length, l_i (m)	i-1,i	Spacing, $d_{i-1,i}$ (m)
1	11.12	1,2	4.13
2	10.72	2,3	3.98
23	5.15	22,23	1.91
24	4.97	23,24	1.84

The new design procedure takes the boom length, L, the frequency range of operation, $f_L<f<f_H$, and either the scale factor, τ, or the number of dipole elements, N, as input parameters. The dipole lengths, l_i, the inter-element spacings, $d_{i-1,i}$, and either N or τ, are then calculated.

The resulting design is then simulated numerically to verify that the gain, and the peak gain to peak sidelobe level ratio comply with the specifications. The procedure is explained in detail in the following paragraphs.

1. Specify the boom length, L, the lowest operating frequency, f_L, and the highest operating frequency, f_H.

2. Set $f_1=f_L$, and $f_N=1.5f_H$, to ensure smooth high frequency characteristics.

Recall that the dipole lengths are given by

$$\begin{aligned} l_1 &= \frac{\lambda_1}{2} = \frac{c}{2f_1} \\ l_2 &= \tau l_1 = \tau\frac{c}{2f_1} = \frac{c}{2f_2} \\ l_i &= \tau^{i-1}l_1 = \tau^{i-1}\frac{c}{2f_1} = \frac{c}{2f_i} \\ l_N &= \tau^{N-1}l_1 = \tau^{N-1}\frac{c}{2f_1} = \frac{c}{2f_N} \end{aligned} \tag{5}$$

and that the spacing between dipole elements is given by

$$\begin{aligned} d_{2,3} &= \tau d_{1,2} \\ d_{3,4} &= \tau d_{2,3} = \tau^2 d_{1,2} \\ d_{i-1,i} &= \tau^{i-2}d_{1,2} \\ d_{N-1,N} &= \tau^{N-2}d_{1,2} \end{aligned} \tag{6}$$

where l_i is the wavelength at frequency f_i, l_1 is the longest dipole element, l_N is the shortest dipole element, $d_{i-1,i}$ is the spacing between elements i-1 and i, and c is the speed of light in a vacuum.

Therefore, rearranging (5),

$$\frac{l_N}{l_1} = \frac{f_1}{f_N} = \tau^{N-1} \tag{7}$$

3. Specify either τ or N.

If τ is specified, taking the logarithm of (7)

$$(N-1)\log\tau = \log\left(\frac{f_1}{f_N}\right) \tag{8}$$

$$N = \frac{\log\left(\frac{f_1}{f_N}\right)}{\log\tau} + 1 \tag{9}$$

If N is specified, then, rearranging (8),

$$\log\tau = \frac{\log\left(\frac{f_1}{f_N}\right)}{(N-1)} \tag{10}$$

$$\tau = 10^{\frac{\log\left(\frac{f_1}{f_N}\right)}{(N-1)}} \tag{11}$$

4. Find the spacing between the two largest elements, $d_{1,2}$.

Recall that L is the sum of all inter-element spacings,

$$L = d_{1,2} + d_{2,3} + \ldots + d_{N-1,N} = \sum_{i=2}^{N} d_{i-1,i} \tag{12}$$

Using (6), (12) becomes

$$L = d_{1,2} + \tau d_{1,2} + \ldots + \tau^{N-2} d_{1,2} \quad (13)$$

$$= d_{1,2} \sum_{i=0}^{N-2} \tau^i$$

Equation (13) can be simplified as

$$L = d_{1,2}\left[\frac{\tau^{N-1} - 1}{\tau - 1}\right] \quad (14)$$

Therefore,

$$d_{1,2} = L\left[\frac{\tau - 1}{\tau^{N-1} - 1}\right] \quad (15)$$

5. Find the dipole lengths using (5), and the spacing between elements from (6).

6. Simulate the resulting antenna design, and examine the peak gain to peak sidelobe level ratio, and the antenna gain.

7. Repeat the procedure by changing L, τ or N, until the design meets the specifications.

In the next section, a LPDA antenna is designed following the aforementioned procedure.

B. Example

Design a LPDA as specified in Section II-B, but with a minimum peak gain of 12 dBi over average ground, and a peak gain to peak sidelobe level ratio greater than 20 dB.

1. f_L=13 MHz, f_H=30 MHz, L=7.3, 9.14, 11, 12.8, 14.6 m.

2. f_1=13 MHz, f_N=1.5(30)=45 MHz.

3. τ=0.85, 0.87, 0.89, 0.91, 0.93, 0.95; N=9, 10, 12, 14, 18, 25.

The scale factor, τ, (or the number of elements) is varied for each boom length case. The resulting antenna design for each case is modeled using NEC 3. In the simulation, the antenna is placed 16.8 m above ground with relative permittivity ε_r=13.0, and conductivity σ=5.0 mS/m. The boom is modeled as a transmission line, of characteristic impedance Z_0=200 Ω, connecting the dipole elements. The peak gain to peak sidelobe level ratio is recorded for elevation angles of 0° to 40°, and its largest value is plotted against frequency. The antenna gain is also plotted against frequency.

Results are shown for the case of L=14.6 m. Figures. 3 and 4 show the peak gain to peak sidelobe level ratio, and the antenna gain, respectively, for τ=0.85, 0.87, 0.89. Figures 5 and 6 show the peak gain to peak sidelobe level ratio, and the antenna gain, respectively, for τ=0.91, 0.93, 0.95.

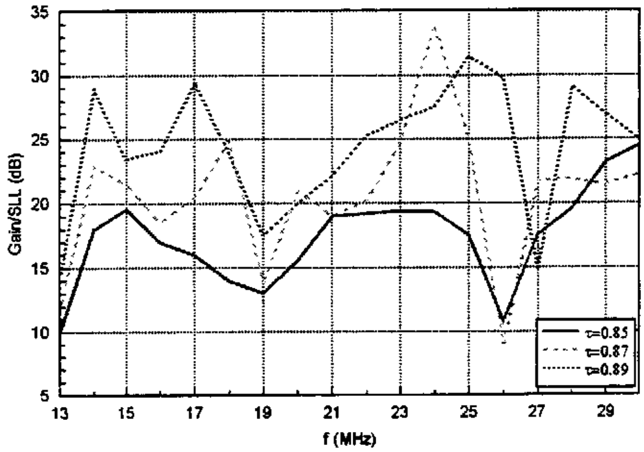

Fig. 3. Peak gain to peak sidelobe level ratio for L=14.6 m and h=16.8 m.

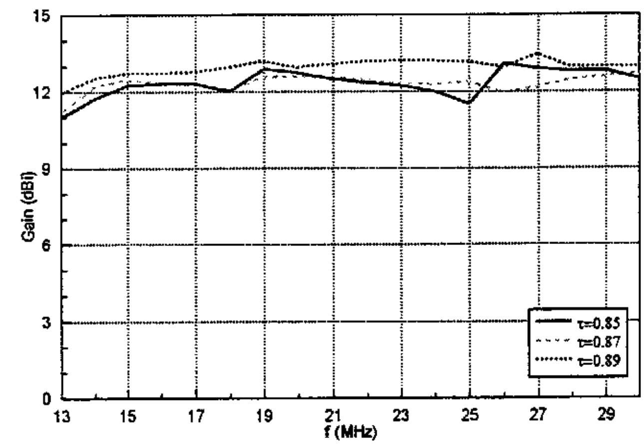

Fig. 4. Gain for L=14.6 m and h=16.8 m.

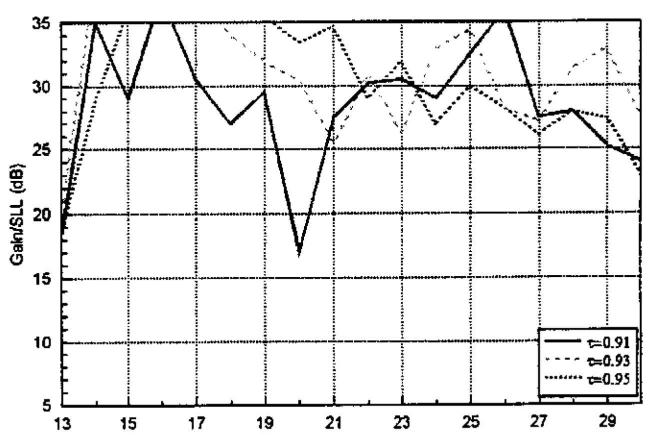

Fig. 5. Peak gain to peak sidelobe level ratio for L=9.14 m and h=16.8 m.

Note that as τ increases, so does the peak gain to peak sidelobe level ratio. The condition of having a peak gain to peak sidelobe level ratio greater than 20 dB is met only for

τ=0.93, and τ=0.95. However, increasing τ from 0.93 to 0.95, increases the number of elements by seven.

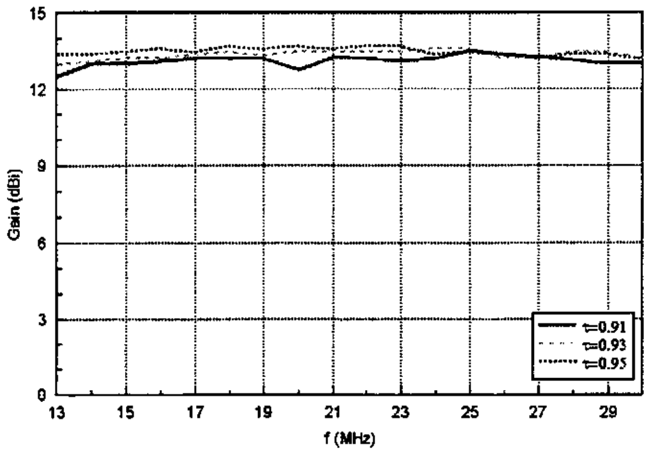

Fig. 6. Gain for L=9.14 m and h=16.8 m.

For smaller boom lengths, the peak gain to peak side-lobe level ratio criterion was met for other values of τ, and numbers of elements.

The antenna gain is very flat over the entire frequency band, having a value of about 13 dBi. As the boom length is shortened, the gain slightly decreases. Therefore, a scale factor, τ=0.93, is selected, yielding an 18 element LPDA. Selected values for the dipole lengths and inter-element spacings are presented in Table II. All dipole elements have a radius of 12.7 mm.

TABLE II: SELECTED LENGTHS AND SPACINGS FOR LPDA ANTENNA

i	Dipole Length, l_i (m)	i-1,i	Spacing, $d_{i-1,i}$ (m)
1	11.54	1,2	1.44
2	10.73	2,3	1.34
17	3.61	16,17	0.48
18	3.33	17,18	0.45

Figures 7-12 show representative azimuth and elevation patterns calculated with NEC for the selected design, at 14.2, 21.2, and 28.5 MHz. Fig. 13 shows that a VSWR of less than 1.4 was obtained for the entire frequency band.

Note that the gain of this antenna is higher than the one expected for the antenna designed with the traditional method. This improvement over the standard handbook method was achieved with a smaller number of elements, and a shorter boom length. If the LPDA antenna with minimum gain of 12 dBi was to be designed with the traditional method, the number of elements would increase to 43, and the boom length would be almost twice the original value computed for the antenna with 10.5 dBi gain.

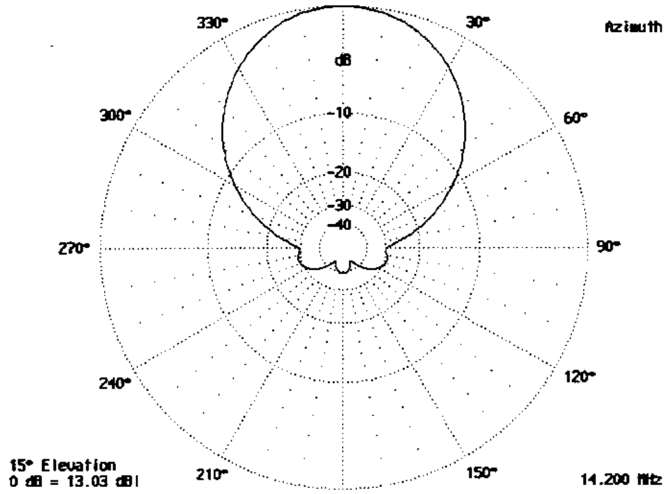

Fig. 7. Azimuth pattern for f=14.2 MHz and h=16.8 m.

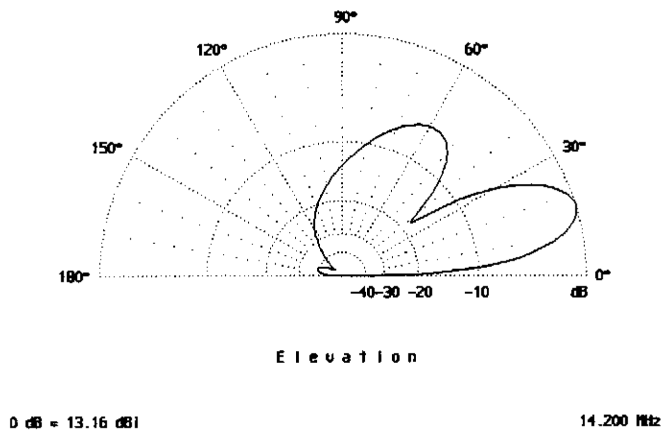

Fig. 8. Elevation pattern for f=14.2MHz and h=16.8 m.

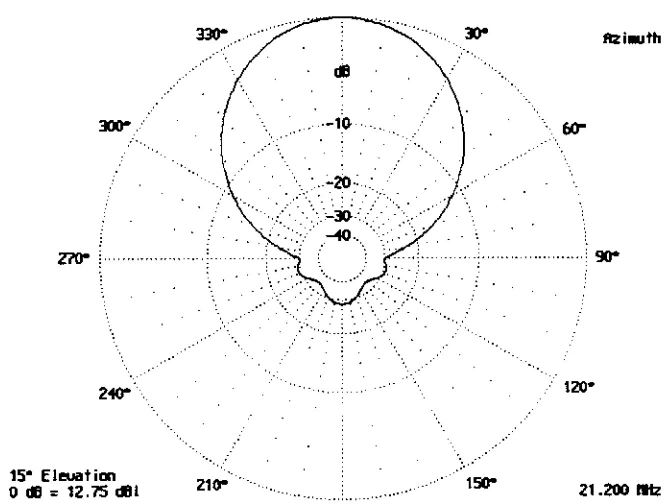

Fig. 9. Azimuth pattern for f=21.2 MHz and h=16.8 m.

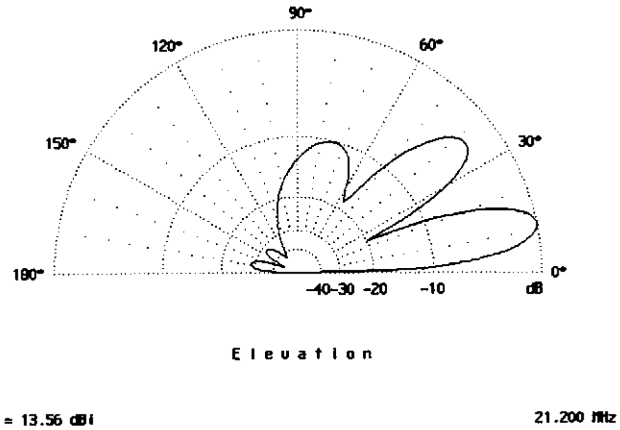

Fig. 10. Elevation pattern for f=21.2 MHz and h=16.8 m.

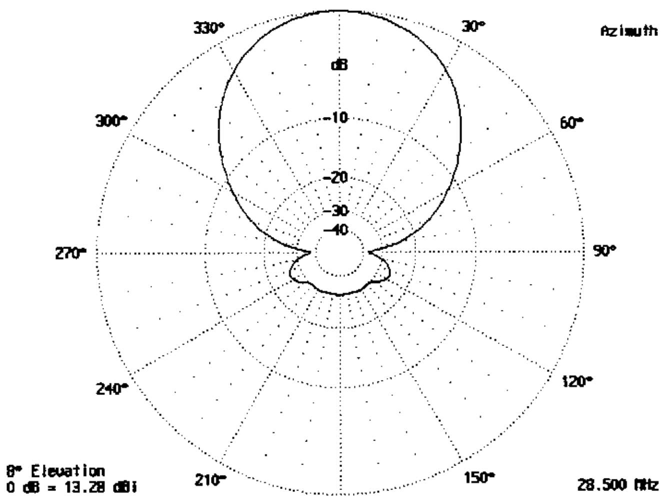

Fig. 11. Azimuth pattern for f=28.5 MHz and h=16.8 m

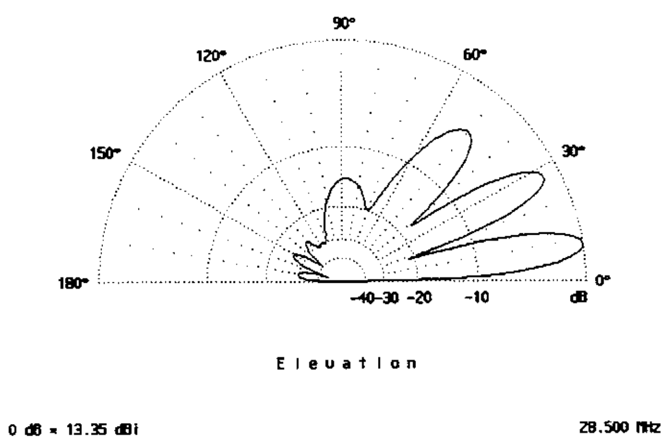

Fig. 12. Elevation pattern for f=28.5 MHz and h=16.8 m.

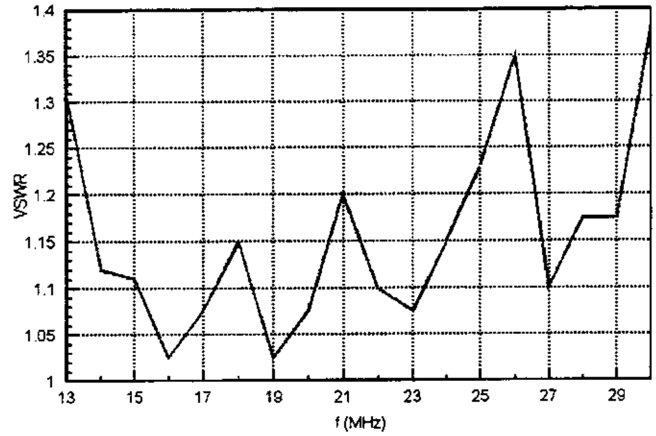

Fig. 13. VSWR for final design, τ=0.93, L=14.6 m, and h=16.8m.

IV. Conclusions

A new procedure for the design of log-periodic dipole array antennas has been developed. In this new procedure, the boom length is selected beforehand. Specifying the boom length as the first step in the design procedure, ensures that impractical values for the boom length do not arise.

An antenna was designed following both the old and the new procedures. It was shown that the new design technique produced a smaller antenna size, and a fewer number of elements than the old procedure, while maintaining excellent radiation and VSWR characteristics.

It was also shown that the peak gain to peak sidelobe level ratio increases as the τ factor is increased, for a given boom length. The antenna gain was very flat over the frequency band of interest, and it increased slightly for larger values of τ, and L.

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