loop-yagi antennas

Comparative data based on recent literature is presented on loop-Yagis versus conventional designs

The elements of a Yagi antenna can take a variety of shapes. The most common are linear designs, with elements arranged as in **fig. 1**; the square loop, as in the quad; or triangular loop, as in the delta loop. Less often seen are circular loops. Yagis having an element formed into a loop, usually of one-wavelength circumference, are called loop-Yagis.

The controversy of loop-Yagis versus linear, or conventional Yagis, has raged for many years. Feeding the controversy have been a number of articles making technical comparisons on a practical basis.[1,2] Usually, however, the choice is made on the basis of mechanical convenience, appearance, or plain dollars and cents. I'd like to draw attention to two recent papers that detail design methods for optimum-gain arrays: one for Yagis of conventional design;[3] the other for loop-Yagis.[4]

conventional yagi optimization

"Optimum Element Lengths for Yagi-Uda Arrays," by C. A. Chen and D. K. Cheng,[3] appeared in the January, 1975, issue of the IEEE journal, *Transactions on Antennas and Propagation,* and is the first paper of interest. (See also reference 5). An analytical method is described that begins with a given design; element lengths and spacings are then shuffled several times until the gain is optimized. Chen and Cheng refer to these adjustments as "length-spacing perturbation," The mathematics of the method are somewhat involved but are amenable to computer solution. Perhaps someone with the time and experience could write a program and oblige the amateur fraternity with published data.

Chen and Cheng[3] illustrated their technique by applying it to a six-element Yagi. This antenna consisted of a one-half-wavelength-long driven element, a reflector about 4% longer spaced a quarter-wave behind the driven element, and four directors spaced 0.31 wavelength apart, all 0.43 wavelength long. The gain of this initial array was 8.8 dBd (gain in dB referred to a dipole). The array parameters were then adjusted for maximum gain, using Chen and Cheng's procedures, ending with a gain of 11.25 dBd. In the process, the length increased from 1.49 to 1.69 wavelengths. (But this alone does not fully account for the gain increase of nearly 2.5 dB). That final figure puts the array in the same ballpark as loop Yagis of similar length, according to references 1 and 2. It also exceeds measured gains of published Yagi designs having more elements. The final design and its parameters are illustrated in **fig. 1**. Element lengths and spacings for various frequencies, which I computed are given in **tables 1** and **2**. I haven't tried the numbers in practice;

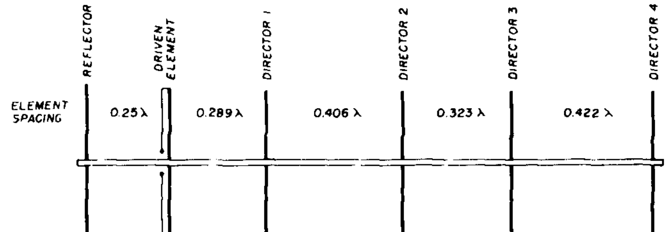

fig. 1. Optimized design of Yagi-Uda array by Chen and Cheng. Drawing is to scale: 1.75 inch (44.5mm) equals 1 wavelength. Element diameter is given as 6.738×10^{-3} wavelength.

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they are intended as a starting point for amateur experimentation.

Added benefits gained by the design method of Chen and Cheng are decreased sidelobe amplitude and slightly improved front-to-back ratio (with reference to the initial array). The frontal lobe is narrower as a result of the increased gain. Unfortunately, they make no comment on bandwidth, but bandwidth would be expected to be around 1% or less.

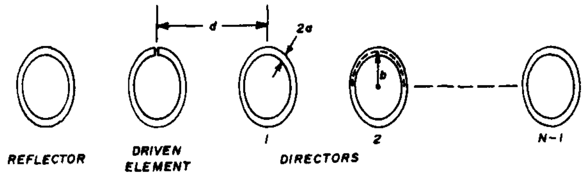

fig. 2. Loop-Yagi antenna (after Shen and Raffoul). Dimensions are loop thickness (*2a*), loop radius (*b*), and loop spacing (*d*).

table 1. Element lengths and diameters for selected frequencies based on the optimized Yagi-Uda antenna of fig. 1.

element	element length (λ)	element spacing (mm except as noted) frequency (MHz) 28.5	50.1	52.1	144.1	146.0	432.1	435.0
reflector	0.476	4.852m	2.760m	2.654m	960	947	320	318
dipole	0.452	4.607m	2.621m	2.520m	911	899	304	302
director 1	0.436	4.444m	2.528m	2.431m	879	868	293	291
director 2	0.430	4.383m	2.493m	2.398m	867	856	289	287
director 3	0.434	4.424m	2.517m	2.420m	875	864	292	290
director 4	0.430	4.383m	2.493m	2.398m	867	856	289	287
element diameter (mm)		69	39	38	14	14	5	5

loop-yagi design

The second paper of interest is "Optimum Design of an Yagi Array of Loops," by L. C. Shen and G. W. Raffoul.[4] They describe a quite simple design procedure. Equal element spacing and element diameter are used throughout. The reflector spacing could be made larger to improve front-to-back ratio (see reference 6).

The general form of the array is shown in **fig. 2**, and one proceeds as follows. The first parameter chosen is usually gain or array size. The curves in **fig. 3** (after Shen and Raffoul[4]) give bandwidth versus array size and gain (in dBd). Select an appropriate d/b (loop spacing/loop radius) ratio or an appropriate bandwidth for the array length chosen. **Table 3** (again after Shen and Raffoul) gives the L/λ and b/λ ratios for the d/b ratio just selected. Knowing the wavelength, you can then find b, followed by $2a$ (loop thickness), and thus the distance, d, between the loops. The number of elements (including the reflector) can be found by dividing the approximate boom length by d. The bandwidth decreases with array size (as expected); but even with a large array, the bandwidth is quite substantial.

example

To illustrate the procedure, here's an example. Calculate the wavelength from

$$\lambda = \frac{29050}{f}$$

where λ is wavelength (mm)
f is frequency (MHz)

If f = 433 MHz, wavelength = 671 mm

From **fig. 3**, choosing an array length of three wavelengths (3λ), the bandwidth is 13%, or 56 MHz, and the gain is 15 dBd. The a/b ratio is fixed at 0.01. Now, for a d/b ratio of 1.0, proceed as follows.

From **table 3**, b/λ = 0.142, and

loop radius = 0.142 × 671 = 95mm
loop circumference = 2π × radius = 600 mm
loop thickness = $2a$ = 0.02 × 95 = 2mm
loop spacing = 95mm (as d/b = 1.0)
number of elements = $N = \frac{\text{array length}}{d}$ = 21

table 2. Element spacing and array length for selected frequencies based on the optimized Yagi-Uda antenna of fig. 1.

element	element spacing (λ)	element length (mm except as noted) frequency (MHz) 28.5	50.1	42.1	144.1	146.0	432.1	435.0
reflector-dipole	0.250	2.548m	1.450m	1.394m	504	498	168	167
dipole — D1	0.289	2.946m	1.676m	1.611m	583	575	194	193
D1 — D2	0.406	4.138m	2.354m	2.264m	819	808	273	272
D2 — D3	0.323	3.292m	1.873m	1.801m	651	643	217	216
D3 — D4	0.422	4.302m	2.447m	2.353m	851	840	284	283
array length (m)		17.23	9.8	9.43	3.41	3.4	1.14	1.14

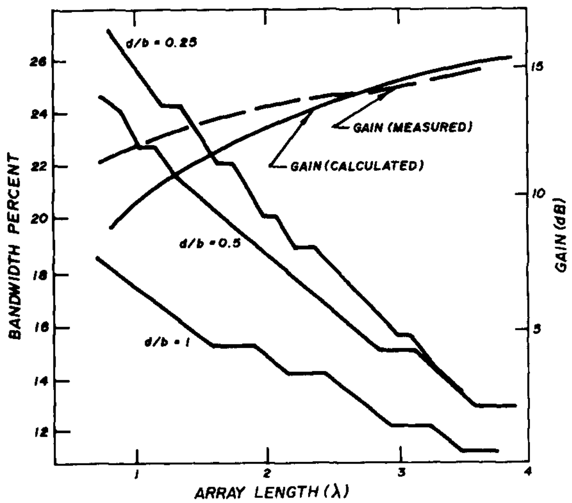

fig. 3. Design curves for loop-Yagi antennas (after Shen and Raffoul). Loop spacing/loop radius values (d/b) are used with table 3 data to obtain array length/wavelength ratio (L/λ) and loop radius/wavelength ratio (b/λ).

Thus the boom length is 2.02 meters. Summarizing,

frequency	=	433 MHz
array length	=	2.02m
gain	=	15 dBd
bandwidth	=	56MHz
loop diameter	=	190 mm
loop circumference	=	600 mm
loop thickness	=	2 mm
loop spacing	=	95 mm

comparisons

From an examination of **fig. 3**, a loop-Yagi 1.7 wavelengths long has a calculated gain of 11 to 12 dBd, which compares with the six-element Yagi by Chen and Cheng.[3] But the measured gain of the loop-Yagi is higher than the calculated gain by about 1 dB. Do loop-Yagis still hold the edge in performance? Maybe 1 dB is splitting hairs; a few practical comparison measurements may prove interesting.

table 3. Loop-Yagi antenna design data (after Shen and Raffoul). Ratio a/b is 0.01; L is array length.

d/b = 1.0		d/b = 0.5		d/b = 0.25	
L/λ	b/λ	L/λ	b/λ	L/λ	b/λ
0.73-0.87	0.146	0.78-0.98	0.142	0.81-1.00	0.140
0.88-1.44	0.145	0.99-1.45	0.140	1.01-1.40	0.138
1.45-2.55	0.143	1.41-1.99	0.138	1.41-1.80	0.137
2.56-3.36	0.142	2.00-2.51	0.137	1.81-2.18	0.135
3.37-4.03	0.140	2.52-3.28	0.135	2.19-2.55	0.135
		3.29-3.92	0.134	2.56-3.17	0.132
				3.18-3.65	0.131
				3.66-3.84	0.129

A loop-Yagi 1.7 wavelengths long, designed by Shen and Raffoul's method, has 12 elements. The obvious disadvantage is more hardware than an equivalent-size conventional Yagi; but the wide bandwidth is an advantage, and construction tolerances are relaxed. It would be an interesting exercise to adopt the length-spacing perturbation techniques of Chen and Cheng[3] to the loop Yagi designs of Shen and Raffoul.[4]

table 4. Representative data for an amateur-band loop-Yagi antenna. Dimensions may be used as a starting point for experimentation.

parameter	6 meters		2 meters		70 cm	
gain (dB)	>10	>11	>11	15	>11	14
loop radius (mm)	795	797	288	279	96	95
loop thickness (mm)	16	16	6	6	2	2
element spacing (mm)	795	797	288	279	96	95
number of elements	7	12	12	29	12	21
bandwidth (MHz)	9	7.8	22	16	65	56
loop circumference (mm except as noted)	5m	5.008m	1.81m	1.79m	604	600
physical length (mm except as noted)	5.6m	8.8m	3.2m	7.8m	1056	2013
array length (λ)	1	1.7	1.7	4	1.7	3

construction notes

Dimensions of a representative series of loop Yagi antennas appear in **table 4** for various amateur bands. Elements could be made from sheet metal, rod, or tubing providing the loop thickness is maintained; i.e., cross section equal to calculated loop thickness. The elements can be supported by a metal boom through the center of the loops, using insulated arms to support the elements. Alternatively, the elements can be supported at voltage nodes (current maxima); i.e. at the feedpoint. Etching the loops on fiberglass PC board would be an ingenious method of construction, although the effect of the fiberglass on the resonant frequency would have to be determined. Insulated boom material, such as PVC conduit, allows elements to be cemented in place using epoxy resin. For further information on loop-Yagis, see references 6, 7, and 8.

references

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