Log-Yagis simplified

A 12-foot (boom) antenna achieves 11-dB gain on 10 meters

Several articles on the design of log-periodic dipole and Log-Yagi antennas have made the Amateur fraternity quite conscious of their excellence for long-haul DXing. Their virtues are high gain, exceptional bandwidth, and a large capture area. In order to understand the mathematical concepts, rather than just copying a design, a series of simple functions have been derived that permits any interested Amateur to design his own Log-Yagi.

reflector considerations

Relatively close spacing is employed in these Log-Yagis. Purists may be dismayed by this approach, since approximately 0.5 dB would be lost in a *Yagi* of similar size. In the case of Log-Yagis, however, if such a lost exists it is dwarfed in importance by achievement of front to back ratios of up to 30 to 45 dB. Experimenters who have tried both the wide and close-spaced reflectors report that the close-spaced reflector shows no apparent loss in gain, but that the front-to-back is terrific. Interlacing Log-Yagis does show the loss of about 5 dB F/B when compared with monobanders.

Since I could find no published curves or data for using close-spaced reflectors, I decided to provide my own data at three spacings under 0.15 wavelength. The spacings were chosen to provide easily measured intervals of inches and fractions and result in 0.0765, 0.0854, and 0.1 wavelength. Efficient reflectors are made progressively longer as they are moved closer to the driven element or cell. Simple formulas can then be used to calculate reflector lengths based on the indicated spacing. Finally, the frequencies used for computation are based on the lower band-edge where wavelength is determined by 11808 ÷ f MHz, with the result in inches.

Reflector spacing versus required reflector length is as follows:

spacing	reflector length
0.0765λ	6190 ÷ f MHz
0.0854λ	6115.2 ÷ f MHz
0.10λ	6050 ÷ f MHz

director considerations

In addition to the reflector design needed to produce the best F/B ratio, the best broadband characteristics with constant gain were also considered. Because of perturbations within the log cell, it has been found that with spacings less than 0.12 wavelength the gain is not constant over the entire band. Spacings between 0.125 and 0.150 wavelength exhibit a relatively flat response if the director is adjusted to 95 percent of the longest cell element. The use of spacings of less than 0.125 require pruning or adjusting

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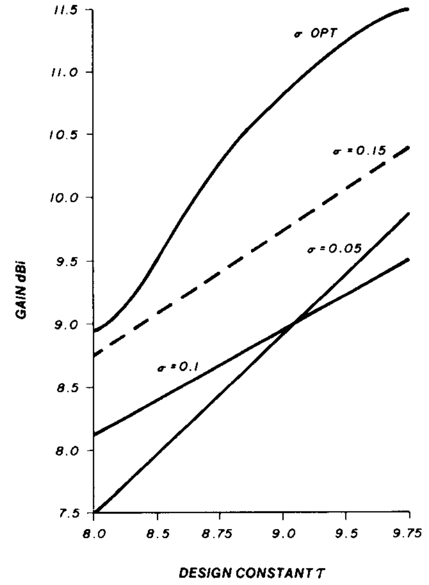

fig. 1. Gain (dBi) vs τ (from K4EWG curves).[1,2,3]

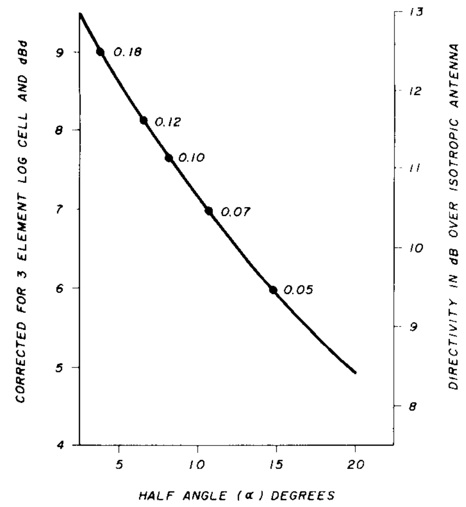

fig. 2. Extension and modification of Isbell's fig. 14.[4] [Curve for $\tau = 0.95$ only with approximate sigmas (σ).]

the director for best results in the portion of the band of interest.

average Yagi gain

Tests conducted using two Yagi parasitic elements with log-cell radiators show 4.3 to 4.6 dB gain over the cell alone. Reference in the text to average Yagi gain is based on a 4.5 dB average.

Second directors provide between 1 and 1.5 dB additional gain when spaced 0.15 to 0.2 wavelength from the first director. A third director seldom adds more than 0.5 dB gain.

the cell function

There are as many combinations of Log-Yagi configurations as imagination will allow. As this article is not a treatise on the construction of a single design, working examples are used to lead the builder through the simple design steps.

In the formulas presented, f is the frequency in MHz at the lower band edge, τ is the design constant between 0.85 and 0.97, and σ is the spacing constant between 0.05 and 0.19 used to determine cell length and gain. Half angle (α) is the angle formed between the boom and the taper formed by the element.

It should be noted that a τ near 0.95 produces higher gain, with virtually any σ, than is possible using the lower figures near 0.85, and is generally what I use. Bandwidth of the cells, even with high σ, are sufficient through 28 MHz to ensure coverage of the entire band.

Two curves are shown in **fig. 1** and **fig. 2** which enable the designer to reasonably determine cell gain. One represents the τ versus σ from K4EWG's work[1,2,3] and the other is from Isbell's[4] work using τ versus half angles. The Isbell curve has been modified by extending the curves to include half angles near 3 degrees.

Both curves are based on pure log-periodic cell design and their accuracy is not questioned. For Log-Yagi work, Isbell's curves appear to correlate closely if a correction factor of − 1.3 dB is applied.

Subtraction of 2.2 dB results in dBd — or gain over a dipole. For this reason, the left-hand figures on the modified Isbell curve have been corrected by 3.5 dB and shown as dBd.

Either curve shows that cell gains over a dipole, when added to the average Yagi gain, *provide a very efficient antenna on a relatively short boom.*

designing the antenna

Having waded through the basics that are pertinent to Log-Yagi design, you can proceed with the development of the antenna shown in **fig. 3** using simple formulas.

For the cell half-lengths in inches:

$$\ell 1 = 2820 \div f$$
$$\ell 2 = 1 \times \tau$$
$$\ell 3 = 2 \times \tau$$

Spacing between the elements is calculated by first multiplying the selected σ by four and again multiplying that quantity by the length of $\ell 1$. Stated as a formula: $\ell 1(4\sigma) = \ell 1 - \ell 2$ spacing. To calculate the

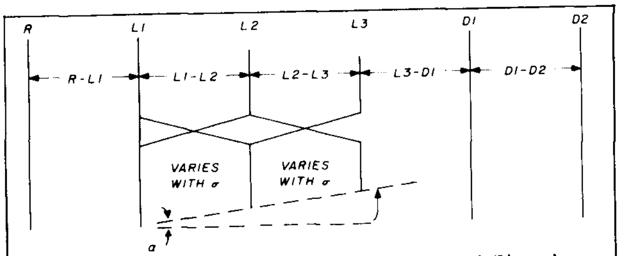

fig. 3. Log-Yagi consisting of cell (ℓ1, ℓ2, and ℓ3) and up to three parasitic elements.

$\ell 2 - \ell 3$ spacing multiply the $\ell 1 - \ell 2$ spacing by τ.

This completes the cell design and a total Log-Yagi can be designed from the data presented so far.

For example, a 28-MHz antanna with a τ of 0.95 and using a σ of 0.07 results in the following cell dimensions.

$$
\begin{aligned}
\ell 1 &= 2820 \div 28 = 100.71 \\
\ell 2 &= 100.71 \times 0.95 = 95.6786 \\
\ell 3 &= 95.6786 \times 0.95 = 90.895 \\
\ell 1 - \ell 2 &= (4 \times 0.07) \times 100.71 \\
&= 0.28 \times 100.71 \\
&= 28.1988 = (28.2) \\
\ell 2 - \ell 3 &= 28.2 \times 0.95 \\
&= 26.79 = (26.8) \\
\text{cell length} &= 55 \text{ inches}
\end{aligned}
$$

Continuing the design for the parasitic elements using 0.0765-wavelength spacing for the reflector and 0.15-wavelength spacing for the director we find:

$$
\begin{aligned}
R &= 6190 \div 28 \\
&= 221.07 \\
R - \ell 1 &= (11808 \div 28) \times 0.0765 \\
&= 421.7 \times 0.0765 \\
&= 32.26 = (32.25) \\
d &= (2 \times 100.71) \times 0.95 \\
&= 201.42 \times 0.95 \\
&= 191.349 = (191.35) \\
\ell 3 - d1 &= 421.7 \times 0.15 \\
&= 63.25
\end{aligned}
$$

The parasitic elements require 95.5 inches plus 2 inches each for mounting; when added to the cell length, this figure indicates that a boom of 154.5 inches, or 12.875 feet, is required. If the antenna was to have been designed for exactly a 12-foot boom, then this example must be changed by reworking the cell length or changing the director spacing. In the example given, reducing the director spacing to 0.125 wavelength results in a new spacing of 52.75 and the antenna fits a 12-foot long boom nicely.

The K4EWG curve indicates a cell gain of 9.2 dBi, or 7.0 dBd. To compute the half angle to check with the modified Isbell curve, we must calculate the cotangent (cot) of the half angle from the τ and σ used in our design as follows:

$$
\begin{aligned}
\cot \propto &= (4 \times \sigma) \div (1 - \tau) \\
\cot \propto &= (4 \times 0.07) \div (1 - 0.95) \\
&= 0.28 \div 0.05 \\
&= 5.6
\end{aligned}
$$

Cot 5.6 (5.614) resolves to a half angle (∝) of 10.1 degrees.

The gain on the modified Isbell curve indicates 8.8 dBi, or 6.6 dBd, for the cell alone. Cell gain of 6.6 plus 4.5 average Yagi gain renders a figure of **11.1 dBd total** gain for the Log-Yagi, or about 0.6 dB less than indicated by the other curve.

The two methods produce little difference in cell gain figures in the region between sigmas of 0.05 and 0.12, but even the lowest of gain figures equates to a power ratio of 12.6, which makes 100 watts as effective as 1.25 kW on a dipole.

wide-spaced cells

The previous design produced a high-gain antenna on a short boom. Surely some designers will be considering whether versions with longer booms and more directors are practical, particularly for those who have the space to erect them.

If all the constants remain the same except σ, which is increased, only the spacing between cell elements will change. The spacing for $\ell 1 - \ell 2$ becomes 68.5 inches and $\ell 2 - \ell 3$ is 65.063 inches for a cell length of 133.5 inches using a σ of 0.17.

Using this cell length with 0.15-wavelength director spacing and 0.0765-wavelength reflector spacing, the boom required would be a little over 19 feet long. If, however, the reflector spacing were changed to 0.0854 wavelength, the mechanical balance would be improved and the configuration would fit nicely on a 20-foot boom.

Using the previous formulas, the $\cot \propto$ is 13.6 and the half angle is 4.2 degrees. The modified Isbell curve shows a cell gain of 8.95 dBd and a total Log-Yagi gain of **13.45 dBd**. The 100 watts now looks like 2 kW on a dipole.

While straining for every dB possible, adding a second or third director could give a final figure of over 15 dBd.

tolerances

Two items left untouched by most other articles on this subject are the need for careful workmanship and the use of relatively finite measurement if the best results are to be attained. Inattention to detail or poor workmanship can cost you gain.

Tolerances should be held to 1/16 inch for element lengths and spacings up to 1/8 inch as high as 28 MHz. For metric measurement, 1 mm is an excellent tolerance figure (for both length and spacing).

By fastening the phase lines exactly 0.5 inch from the attachment end of the radiator, and maintaining equal lengths of each wire or strap in the phasing pairs, the builder is ensured of good electrical balance and his results will be repeatable time after time. The dimensions developed from the design effort are based on center-to-center spacing of all elements.

fine tuning the design

In many combinations of the three basic factors of design, it appears that some fractions make the measurement practically impossible. Other cases are noted where attaining the tolerance figures for construction is impossible.

Changing one or more of the factors even slightly can often resolve the problems. In the following example of a 14-MHz design, the original figures and finalized computations are explained:

original computation	final computation
$f = 14\ \mathrm{MHz}\quad \tau = 0.95$	$f = 14.0037214\quad \tau = 0.950341403$
$\sigma = 0.1791$	$\sigma = 0.1789265$
$\ell 1 = 201.42857$	$\ell 1 = 201.375$
$\ell 2 = 191.357$	$\ell 2 = 191.375$
$\ell 3 = 181.7893$	$\ell 3 = 181.875\ (181.8716)$
$\ell 1 - \ell 2 = 144.303$	$\ell 1 - \ell 2 = 144.125$
$\ell 2 - \ell 3 = 137.088$	$\ell 2 - \ell 3 = 137.0\ (136.968)$

First, the dimensions of $\ell 1$, $\ell 2$, and $\ell 3$ were difficult to measure. This was resolved by dividing 2820 by 201.375 for the new frequency. Although $\ell 2$ and $\ell 3$ could be considered within tolerance, it was desirable to see how τ would be influenced.

The figure of 191.3786 for $\ell 2$ after the frequency was changed was close to 191.375, so a new τ was developed by dividing 191.375 by 201.375 for $\tau = 0.950341403$, which helped make $\ell 3$ a more easily resolved figure.

Although the cell spacings were resolvable, I felt that reducing the sigma slightly would permit the use of integral inches for $\ell 2 - \ell 3$, and that the small change would not affect gain. By cut and try, I improved the dimensions and arrived at the new figure.

The results are dimensions well within the established tolerances. It is much more simple to redo the arithmetic than to try to measure uncommon fractions!

construction

I've tried various methods for mounting cell elements. Generally, the insulating material used in cell construction dictates the mounting method. When using polystyrene, Lucite, Plexiglass, or PVC tubing as insulators, strap them with stainless steel hose clamps. (If you use U-bolts, a cushioning material must be added.) With these insulators, I used 1-1/4 × 1-1/4 aluminum angle mounted to 4 × 4 plates for fastening to the boom (with muffler clamps). Most of the materials mentioned succumb to weathering of some sort in two to three years. PVC shows breakdown of insulation and the others get brittle and crack.

The best material is polycarbonate. Though this material is expensive, it has a tensile strength of 6000 psi, a breakdown characteristic of 360 volts per mil (0.001 inch), it retains its impact strength to −40 degrees F, and it has a temperature distortion point of over 260 degrees F. Polycarbonate with 1/8-inch wall can support a full-sized 14-MHz element, with two U-bolts spaced 6 inches apart, when the element is enclosed in a tube only 7 inches long with a gap between elements ends of 0.5 inch. There will be no noticeable sag at the element center.

guying

Single guy wires are satisfactory for small booms and on larger-diameter long booms with thick walls. The extra support provided by umbrella-type guying is recommended in most other cases. When the installation is close to salt water, or in areas where oxidation levels are high, stainless steel guys and turnbuckles are highly recommended. The 3/32-inch sailboat-shroud cable is adequate for most cases. For very heavy arrays, such as interlaces, 1/8-inch material is recommended. Dacron is the only rope material recommended for guys. This should be of the woven type, in diameters of 1/4 or 5/16 inch. Rope guys increase wind resistance considerably.

matching

Impedances of almost all configurations are between 35 and 48 ohms. Whether strap, rods, tubes, or wire is used for the phasing lines, their influence is small so far as matching capabilities are concerned.

K4EWG devised a matching stub for his design which is easily found by using 256 ÷ f. It is installed between $\ell 3$ and a 1:1 balun. Closing up the stub spacing or adjusting 1/8 inch at a time provides the best match.

On many occasions it is difficult to make such changes easily. A preferred method is to feed the antenna through a balun and slightly shorter stub, using a transformation in the feedline. This approach uses either an odd number of quarter wavelengths of 50-ohm feedline (corrected for velocity factor) or a single 50-ohm quarter-wave section between 70-ohm feedline and the balun end. In every case, it has been possible to reduce the VSWR to 1.3:1 or less across the band.

Though the standard computation for a quarter-wavelength section is 246 ÷ f multiplied by the line's velocity factor, my figure of 240 ÷ f low end, with correction for velocity factors, appears to provide the best broadband characteristic for this transformation.

about gain figures

I will be among the first to agree that antenna models do not guarantee the gain figures attributed to the designs of these Log-Yagis. Usually as much as 2.5 dB variation is noted.

Recent antenna testing by the NRL (Naval Research Lab) and others have verified that modeled antennas are but guidelines for the development of full-scale antennas, where certain performances are required over particular paths. Recent testing has been performed with full-scale antennas to determine "apparent gain" over such paths.

The use here of the idea of apparent gain is similar to its use in the development of "gain type" antennas for mobile use. For example, a 5/8-wavelength antenna by itself cannot produce a 3-dB improvement over an antenna 1/4-wavelength long. Apparent gain is accomplished by concentration of energy in a favorable direction or takeoff angle.

Apparent gain follows the design gain quite closely in Log-Yagi arrays. On long-haul paths of over 3000 miles, a comparison with a reference dipole yields results that are quite close to those derived by computations using the curves. The large capture area and non-symmetrical vertical pattern are no doubt contributors to its ability on such paths.

credits

Thanks goes to Peter Rhodes, K4EWG, for planting the original seed and for taking the time to discuss and verify the aspects of this new design; to WA3ELE for making the first long-boom wide-spaced array; and a special thanks to the model shop-workers who manufactured the antenna hardware.

references

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