CARR'S CORNER

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Finding antenna dimensions by scaling

Designing most standard antennas requires no great effort. For example, most hams know that the overall length of a half wavelength center-fed dipole is $468/F_{MHz}$ feet or $143/F_{MHz}$ meters. For example, if we want to design a dipole for, say, 14.250 MHz, we know that the length is 468/14.25 = 32.84 feet long. But this method falls down a bit when we try to design antennas that are more complex. For the sake of simplicity, however, let's look at the dipole problem first ... and, in the process, discover a simplified method for designing antennas.

Our simplified design problem is based on a simple procedure: *frequency scaling*. We find a design that meets our needs, but is at the wrong frequency, and then scale it. Scaling can be done by dividing the design frequency by the desired frequency, and then multiplying each of the lengths and spacings by this figure. For example if α is the scaling factor, we state that $\alpha = F_{DESIGN}/F_{DESIRED}$ and then multiply each length and spacing by α.

Consider our sample design of 14.25 MHz and 32.84 feet. Suppose we want to scale the antenna to 21.2 MHz? We can use the equations or we can scale it. For our example:

$$\alpha = F_{DESIGN}/F_{DESIRED}$$

$$\partial = 14.25 \text{ MHz}/21.2 \text{ MHz} = 0.6722.$$

To find the length of the desired antenna we need only multiply the length of the known antenna by α:

$$L_{NEW} = L_{KNOWN} \times \alpha$$

$$L_{NEW} = (32.84 \text{ feet})(0.6722)$$

$$L_{NEW} = 22.08 \text{ feet}$$

In the trivial case of the dipole we can easily check the result:

L = 468/21.2 = 22.08 feet

Rule: When using the scaling method, scale all dimensions and spacings of the antenna. In scaling a beam, for example, it does no good to scale the element lengths but not the spacings. *All* lengths and *all* spacings must be put through the scaling process.

The usefulness of scaling becomes apparent when you want to design complex antennas such as quad or yagi beam antennas. You often find successful designs in magazines and handbooks, but they are not on the frequency that you wish to use—or they might be on a completely different band. The answer is to use scaling. Let's consider an example. Bill Orr's (W6SAI) *Radio Handbook 18th Edition* (an oldie!) gives the dimensions for a two-element cubical quad antenna (**Fig. 1**) as follows.

For 21.250 MHz:

L1 = 11.8 feet
L2 = 12.1 feet
S = 5.56 feet

In the case of the cubical quad beam all four sides of each element are equal, so the circumference is four times L1 or L2. Now let's suppose we get our wildest wishes and are able to put up a 75-meter band cubical quad. The dimensions for 3.750 MHz can be found from scaling. The factor $\alpha = F_{DESIGN}/F_{DESIRED} = 21.250 \text{ MHz}/3.750 \text{ MHz} = 5.667$.

L1 = 11.8 feet x 5.667 = 66.87 feet

L2 = 12.1 feet x 5.667 = 68.57 feet

S = 5.56 feet x 5.667 = 31.51 feet.

The yagi beam antenna is very popular, and on some bands is relatively easy to build (on lower bands it might be easier to buy one, given the nature of the metalwork needed to make a safe and reliable antenna).

The basic three-element yagi antenna is shown in **Fig. 2**. Although three elements are shown here, it is also possible to build a two-element yagi or a yagi with more (even many more) elements than three. The reason for looking at the three-element version is that it provides a look at all three classes of elements: *driver* (or *"driven element"*), *reflector* and *director*. The driven element is a half-wavelength dipole, and is the only one that is connected to the transmission line from the receiver or transmitter. Because only one element is fed, the other elements are called *parasitic elements*, and the antenna is sometimes called a *parasitic beam* to distinguish it from *phased array beams* in which all elements are driven.

The gain achievable by the yagi depends on several factors, but in general, the following values are realized relatively easily:

No. of Elements	dBd	dBi
2	5.2	7.4
3	6.8	8.9
6	10.5	12.6

Table 1. Gain achievable by the yagi.

The driven element is little more than a half-wavelength dipole, fed in the center by coaxial cable. The

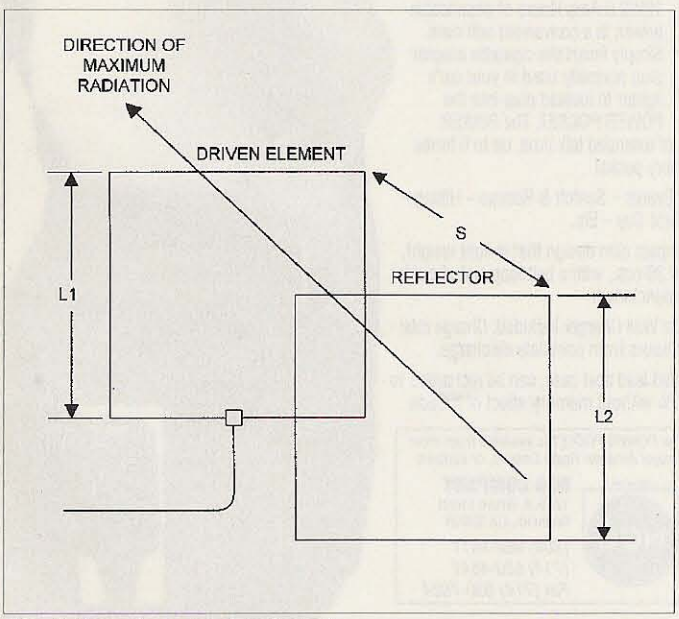

Fig. 1. Two-element cubical quad.

ELEMENT	ELEMENT LENGTH (λ)	POSITION (λ)
Reflector	0.49531λ	0λ
Driven Element	0.48598λ	0.13754λ
Director	0.46257λ	0.27508λ
$\lambda = 984/F_{MHz}$ feet or $\lambda = 300/F_{MHz}$ meters (Boom position uses reflector as reference, so sets position at zero)		
SPACING (S = ΔX) S1 0.13754λ S2 0.13754λ		

Table 2. Three-element beam spacing factors.

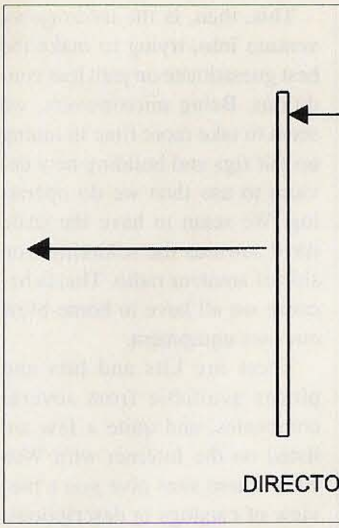

Fig. 2. Three-element yagi.

transmission line divides the driven element into two quarter-wavelength halves. The reflector and director are also half-wavelength, but being parasitic elements are not fed in the center or any other point. The parasitic elements are spaced (S) from the driven element about 0.131λ to 0.271λ (specific spacing is in **Table 2**).

The driven element is about half a wavelength long. The reflector is a few percent longer than the driven element, while the director is a few percent shorter. In some multi-element designs, additional reflectors or directors may be added to increase gain. As with all such yagi antennas, the directivity is towards the direction of the smallest element. In the example of **Fig. 2**, the directivity is from the driven element towards the director. In that direction, received signals are louder, and transmitter signals appear stronger to distant receivers.

Increasing the number of elements will increase the gain and narrow the beamwidth of the yagi antenna. Although there is a limit to the optimum number of antenna elements that can be fitted on a given size boom, the general rule is "the more the merrier." **Fig. 3** shows the layout for a very large beam of 19 elements laid out on a boom of about 5.6 wavelengths (λ). It is derived from one published in *The ARRL Antenna Book*. The gain is on the order of 15 dBd. It has an azimuthal beamwidth of 26 degrees, and an elevation beamwidth of 28 degrees. The feedpoint impedance is about 30 ohms.

This beam is designed using the scaling method. All elements and element positions (which also set the spacings) are related to a

Element	Length Factor (L)	Position Factor (P)
Reflector	1.087A	0P
Driven Element	1A	0.327A
Director D1	0.9989A	0.468A
Director D2	0.976A	0.732A
Director D3	0.959A	1.095A
Director D4	0.949A	1.552A
Director D5	0.939A	2.08A
Director D6	0.933A	2.673A
Director D7	0.929A	3.317A
Director D8	0.925A	4.01A
Director D9	0.920A	4.74A
Director D10	0.916A	5.507A
Director D11	0.911A	6.298A
Director D12	0.906A	7.106A
Director D13	0.902A	7.923A
Director D14	0.897A	8.746A
Director D15	0.893A	9.575A
Director D16	0.889A	10.41A
Director D17	0.885A	11.25A
Boom Length	11.25A	

Table 3. The normalized lengths of the elements and their positions relative to the reflector element.

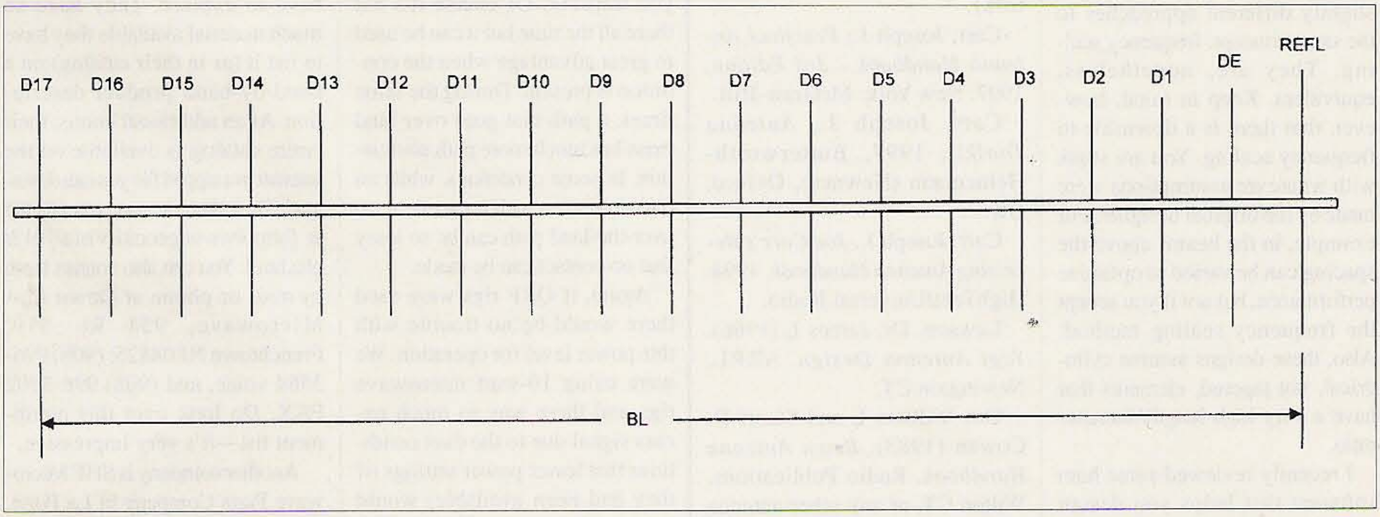

Fig. 3. Nineteen-element beam.