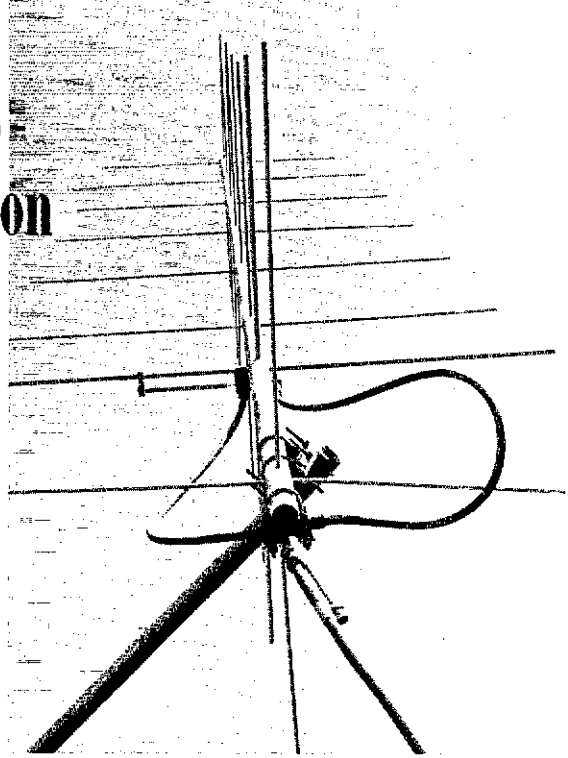
Crossed Yagi Antennas for Circular Polarization

BY KATASHI NOSE,* KH6IJ



Crossed-Yagi antenna used in ten satellite transponder stations which the author has built.

WITH THE ADVENT of space and satellite communications, amateurs should consider the effects of polarization and angle of elevation, along with the azimuth of either a transmitted or received signal. Normally, provisions for polarization are unnecessary on the hf bands, since the original polarization direction is lost after the signal passes through the ionosphere. A vertical antenna will receive a signal emanating from a horizontal one, and the converse is true when transmitting and receiving antennas are interchanged. Neither is it worth the effort to make provisions for tilting the antenna, since the elevation angle is so unpredictable. However, with satellite communications, the polarization changes and a signal that would disappear into the noise on a normal antenna, might be S9 on one that is insensitive to polarization direction. Angle of elevation is also important from the standpoint of tracking, and avoiding indiscriminate ground reflections which might cause nulls in signal strength.

Circular Polarization

The ideal antenna for random polarization, would be one with a circularly polarized radiation pattern. Two commonly used methods for obtaining circular polarization are the crossed Yagi and the helical antenna. The crossed Yagi is mechanically simpler to construct, but harder to adjust than its helical counterpart.

Polarization sense may also be a factor, especially if the satellite uses a circularly polarized antenna. In physics, clockwise rotation of an approaching wave is called "right circular polarization," but the IEEE standard uses the term "clockwise circular polarization" for a receding wave. Either clockwise or a counter-clockwise sense can be selected by reversing the phasing harness which will be mentioned in a later section.

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Mathematically, linear and circular polarization are special cases of elliptical polarization. Consider two electric-field vectors at right angles to each other. The frequencies are the same, but the magnitudes and phase angles can vary. If either one or the other of the magnitudes is zero, linear polarization results. If the magnitudes are the same and the phase angle between the two vectors (in time) is 90 degrees, then the polarization is circular. Any combination between these two limits gives elliptical polarization.

Crossed Linear Antennas

A dipole radiates a linearly polarized signal whose direction depends upon the orientation of the antenna. Fig. 1A and Fig. 1B are the electric field patterns of horizontal and vertical dipoles. If the two outputs are combined with the correct phasing (90 degrees), a circularly polarized wave results, and the electric field pattern is shown in Fig. 1C. Notice that since the electric fields must be identical in magnitude, the power from the transmitter must equally divide between the two

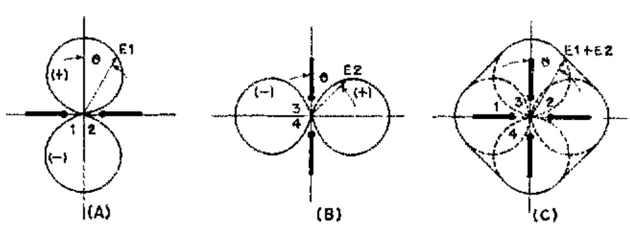
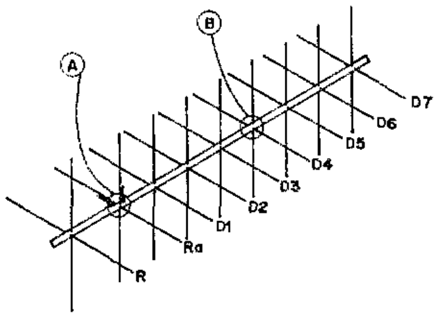


Fig. 1 — Radiation patterns looking head-on at dipoles.



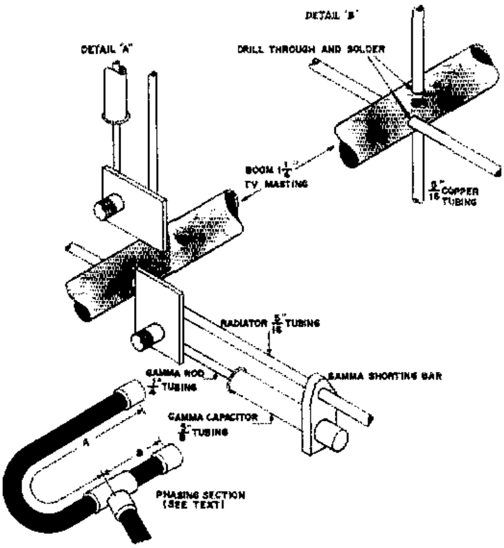


Fig. 2 — Construction details of a crossed Yagi antenna.

antennas, hence the gain of each one is decreased by 3 db, when taken alone in the plane of its orientation.

As previously mentioned, a 90-degree phase shift must exist between the two antennas. The simplest way to obtain the shift is to use two feed lines with one section a quarter wavelength longer than the other one. These two separate feed lines are then paralleled to a common transmission line which goes to either the transmitter or receiver. Therein lies one of the headaches of this system, since the impedance presented to the common transmission line by the parallel combination of the other two sections is one half that of either one of them taken alone (normally not true when there is interaction between loads, as in phased arrays). Another factor to consider is the attenuation of the cables used in the harness, along with the connectors. Good low-loss coaxial line should be used, and connectors such as type N are preferable to the uhf variety.

A Practical Antenna

After trying out various kinds of matching sections for high-power use (one kilowatt), it was found that the simplest one worked the best. It is shown in Fig. 2 as part of the final design for an antenna used in ten satellite transponder stations which the author has built.[1] The 90-degree phase shift is realized by making section "A" a quarter wave longer electrically, than section "B." The characteristic impedance of these sections should be such that, when paralleled, they match the main feed line.

RG-133/U (95 ohms), made by Consolidated Wire Co., is ideal but is a hard item to find. More commonly found in stock is RG-63/U (125 ohms). There was some mismatch when using RG-63/U with a 50-ohm main feed line, but it was not serious enough to warrant additional matching networks. Care should be taken when other types of coax are considered, especially if one is unfamiliar with them. For example, RG-111/U which has an impedance of 95 ohms might sound like a good one to use, but since it is a twin cable, it would be unsuitable.

Fig. 3 shows the electrical-network equivalent of a 3-element array, with a gamma-match feed system. *Lg* is the equivalent circuit of the gamma rod, which is resonated at the operating frequency by *Cg*, the gamma capacitor. The individual antenna elements can be represented by parallel L-C circuits. *La-Ca*, the equivalent circuit for the driven element, must resonate slightly higher than the operating frequency. *Lr-Cr* (reflector) should resonate lower than *La-Ca*, and *Ld-Cd* (director) should be higher than *La-Ca*.

Another factor that complicates the network is the mutual coupling among elements. This is shown in Fig. 3 as *Mra*, *Mrd*, and *Mad*. Also, antenna current (*Ir*) and gamma current (*Ig*) flow through a common section, making analysis even more difficult in a practical application. Unless a systematic approach is taken, one is liable to spend frustrating weeks trying to find the combination which will give the proper impedance (*Zin*) to match that of the phasing harness.

[1] Nose, "Using the ATS-1 Weather Satellite for Communications," *QST*, December, 1971.

Radiator length (Ra) in feet is given by:
Ra = 460/*f* (MHz)
Reflector length (R) equals:
Ra + 0.1 Ra
First director length (D1) is given by:
Ra − .05 Ra
Successive director lengths (D2...Dn) equal:
D2 = D1 − .01 D1
Dn = (Dn − 1) − .01 (Dn − 1)
Spacing between reflector and radiator — 0.2λ.
Spacings between first director, radiator, and between all other directors — 0.15λ.

Table I. Crossed-Yagi antenna element lengths and spacings.

Gamma-Match Tune-Up Procedure

The following method has proven useful in simplifying tune-up of the gamma match and antenna elements. One parameter should be kept fixed, while the rest of the adjustments are made, rather than varying all of them simultaneously. It was found convenient to use the length of the driven element as the fixed parameter. Its approximate dimensions can be found in Table I (along with those of the other elements), and the length should be slightly shorter than that given by the formula. Do not change the length, except for some minor pruning which will be mentioned later.

Once the antenna is assembled, the next step is to adjust the gamma rod and capacitor for minimum SWR. Table II shows some approximate settings and lengths for the gamma rod, capacitor, and shorting bar (see Fig. 4). The correct procedure in tuning would be to select an appropriate length for the gamma rod and capacitor sections from the Table, and then adjust the shorting bar and capacitor for a minimum SWR indication, with the capacitor adjusted last.

No matter how far off either the reflector or director lengths happen to be, the last few steps should at least get the SWR into the ball park. If not, then look for the following problems:

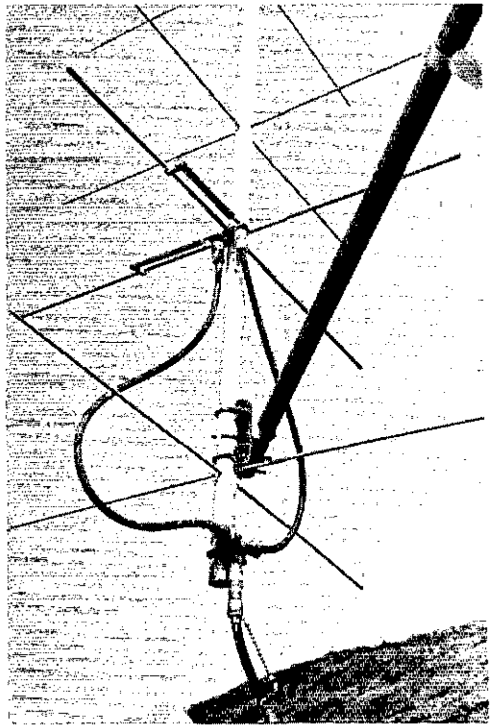
1) Poor rf source; use a signal generator or low power transmitter, *not* a grid-dip oscillator. Make sure that harmonic content is kept as low as possible in order to avoid erroneous readings on the SWR indicator.

2) Radiator length too far off, usually too long.

3) Poor Q of the gamma-match system. Use a coaxial-capacitor type (preferably one with as much air dielectric as possible) such as that shown in Fig. 4.

Frequency (MHz)	*Dimensions in inches (Fig. 4)*			
	W	X	Y	Z
135.6 (ATS-1 out)	6	4	6	1
146 (OSCAR 6 in)	5-3/4	3-3/4	5	1-1/2
149.2 (ATS-1 in)	5-1/2	3-1/2	4-3/4	2

Table 2. Approximate gamma-match dimensions.



Placement of phasing harness and T-connector is shown in lower half of photograph. Note that gamma match is mounted somewhat off-center for better balance of rf voltages on elements.

Finally adjust the director and reflector for maximum front-to-back ratio. This can be done by looking for minimum pickup with the back of the beam aligned with a test dipole as far away as practical. Final touch-up of the SWR can be accomplished by adjusting the length of the radiator, but by no more than one percent.

Unequal antenna currents can be equalized by offsetting the gamma section in the direction of the desired increase in antenna current. For more details, see previous articles by the author.[2,3]

Some authors have come up with various dimensions and formulas for the element lengths, gamma sections and spacings. Also, many amateurs have their own favorite designs. With so many

[2] Nose, "Adjustment of Gamma-Matched Parasitic Beams," *QST*, March, 1958.

[3] Nose, "Notes on Parasitic Beams," *QST*, March, 1960.

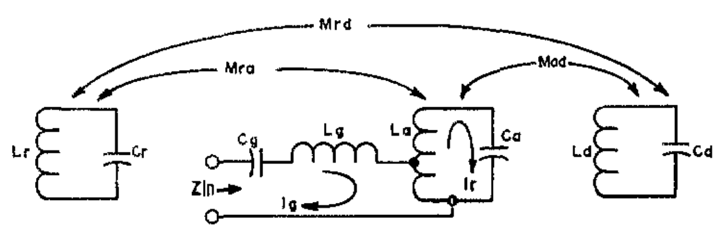


Fig. 3 — The equivalent circuit of a three-element gamma-matched array.

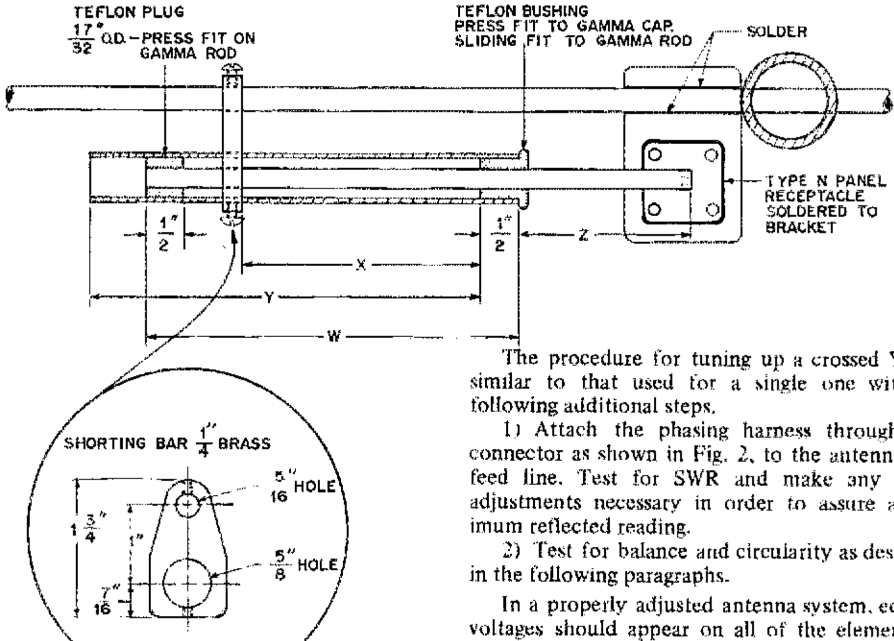


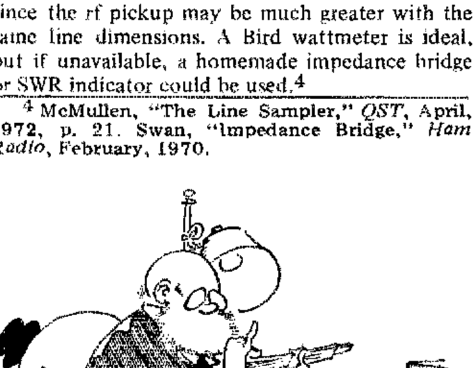
Fig. 4 — Gamma-match construction details.

variables, the problem becomes complex, and can have more than one satisfactory solution. When confronted with such a situation, a scientist often says that he will have to resort to a heuristic approach. What he really means is that he is going to use the old amateur cut-and-try method.

Final Tune-Up

The procedures used for tune-up and matching at vhf are similar to those for hf antennas, except that more care is necessary in the selection of test instruments. For example, a Monimatch designed for hf may burn out a diode if used on vhf, since the rf pickup may be much greater with the same line dimensions. A Bird wattmeter is ideal, but if unavailable, a homemade impedance bridge or SWR indicator could be used.[4]

[4] McMullen, "The Line Sampler," *QST*, April, 1972, p. 21. Swan, "Impedance Bridge," *Ham Radio*, February, 1970.



Sometimes a neuristic approach is necessary . . .

The procedure for tuning up a crossed Yagi is similar to that used for a single one with the following additional steps.

1) Attach the phasing harness through a T connector as shown in Fig. 2, to the antennas and feed line. Test for SWR and make any minor adjustments necessary in order to assure a minimum reflected reading.

2) Test for balance and circularity as described in the following paragraphs.

In a properly adjusted antenna system, equal rf voltages should appear on all of the elements. A practical method is to see how much detuning results from attaching a short piece of wire with an alligator clip to the ends of each element. A properly balanced element will show the same amount of detuning (SWR goes up or bridge null is upset) regardless of which end has the clip.

To test for coupling between the Yagi sections (there should be none), feed power into the horizontal Yagi alone, and see how much detuning results by attaching the wire-and-clip combination to the vertical Yagi. Repeat this procedure for each element. If there are no interactions, feed power into the vertical Yagi and see if there is any coupling from the horizontal one. In making any of these tests, while near the antenna, make sure that the *power is off to avoid possible injury!*

As a final test, tune in on a linearly polarized signal from a satellite such as the ATS-1, or even a repeater. Rotate the crossed Yagi on its axis and note if there is any signal variation. A good circularly polarized antenna should have no more than 1 dB variation, as one rotates the antenna.

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