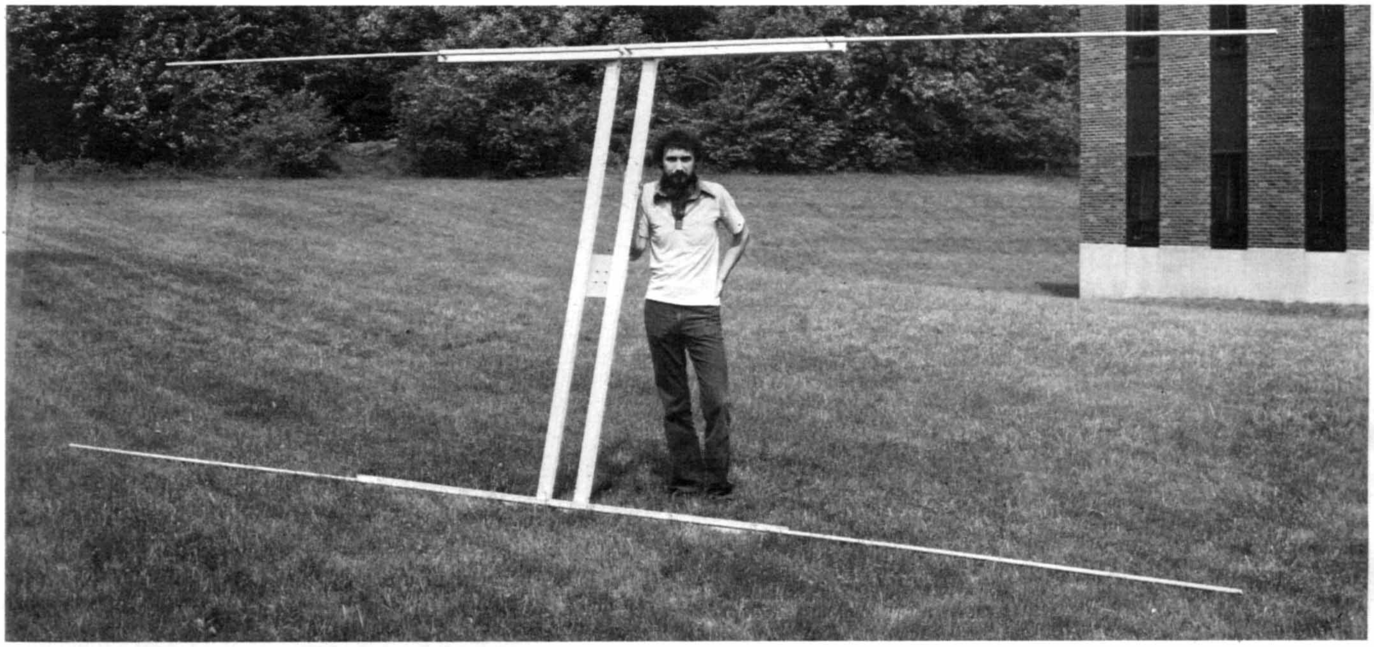
• *Basic Amateur Radio*

Simple Gain Antennas for the Beginner



You need not be a structural engineer or invest an absurd amount of money to build a beam type of antenna. Good performance can be obtained with simple antennas made from some very ordinary materials.

By Doug DeMaw,* W1FB

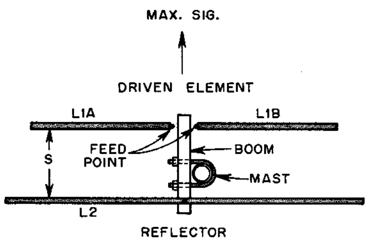
Let's refer to the antennas discussed here as inexpensive types rather than cheap ones. There's a difference! Cheap denotes inferiority, but an inexpensive antenna can be superior in performance. We will focus our attention this month on directional antennas that can provide gain. The expression "superior performance" has significance here. "Superior to what?" we might ask. Well, a gain antenna with directivity is superior to a wire antenna (Basic Radio, May 1981 *QST*, pp. 26-29) that has no gain and may exhibit mediocre directivity. What's the advantage of this superior style of antenna? The answer is, rejection of unwanted QRM off the sides and back of the antenna, plus some forward gain. The gain provides the same effect as increasing the transmitter output power, and all of us can use a few extra dB (decibels) when the going gets difficult on our favorite ham band!

*Senior Technical Editor, ARRL

Directivity and Gain

For the purpose of this discussion let's think of directivity as an antenna characteristic that permits us to concentrate the radiated signal energy in a favored direction. With a properly designed beam type of directional antenna the energy radiated off the *sides* of the antenna will be substantially lower (20 to 30 dB typically) than off the front of the antenna. Similarly, the response from the back side of the beam will be much lower than off the front, typically 10 to 20 dB. Nice way to reduce QRM (interference), eh?

The expression "gain" will refer to the effective increase in the power of the transmitted wave or signal. For example, if we had a 100-W output power from the transmitter, and increased it to 200 W, our signal would be 3 dB louder in the other station's receiver. (A 3-dB increase is just discernible to the human ear.) Now, if our *beam antenna* had a 3-dB gain characteristic, our 100-W transmitter would sound like a 200-W rig to the other station. If the gain antenna could produce a 9-dB signal enhancement (a forward gain of 9 dB or greater is not uncommon), our 100-W transmitter would be equivalent to an 800-W transmitter connected to a half-wave dipole antenna (no gain with a dipole). We can see from this that it would cost less to improve our signal strength with an antenna than to do it at the expense of a big power amplifier. From a moral point of view we would be helping to reduce consumption of precious natural fuel, and the monthly utility bill would be more acceptable! Finally, your signal might end up somewhat louder than the others (when several stations call a particular one) if you are using a gain antenna. This does not mean that the dog-eat-dog concept should be endorsed, but there is a definite advantage in being loud (or louder) in a crowded amateur band when the DX is rolling in! A stronger signal will also help you to *hold* the frequency on which you're having a QSO: Unwanted CQers won't survive long on your frequency if you have a robust signal!



$$L1A + L1B = \frac{474}{f(MHz)} \text{ FT.}$$

0.3048 × FT. = M
L1, L2 DIA. = 0.5-1.25 IN. (13-32 mm)

$$L2 = \frac{495}{f(MHz)} \text{ FT.}$$

S = 0.15 λ (WAVELENGTH) FT.

$$\lambda = \frac{984}{f(MHz)} \text{ FT.}$$

GAIN ≈ 5.4 dB
Z = 25Ω
F/B RATIO ≈ 15 dB

DESIGN EXAMPLE (21.1 MHz):

$$L1A + L1B = \frac{472}{21.1} = 22.37 \text{ FT. (6.8 M)}$$

$$L2 = \frac{495}{21.1} = 23.46 \text{ FT. (7.1 M)}$$

S = 0.15 × 46.6 = 7.0 FT. (2.1 M)

Fig. 1 — Basic design data for a 2-element hf-band Yagi antenna. (Gain figures are theoretical.)

Yagi-Uda Antennas

Perhaps the most common of the amateur gain antennas is the Yagi, which at its inception was known as the Yagi-Uda antenna, named after the Japanese inventors who developed it. Nowadays we hams refer to it simply as a "Yagi." It consists of two or more conductive elements, with the simplest type containing a driven element (radiator) that is one half wavelength long electrically, and a reflector (longer) or director (shorter). Fig. 1 shows one type of simple 2-element Yagi. In this example we find a driven element (split) and a reflector. The term "driven" means that power is fed to it. The reflector is called a "parasitic" element because it is not connected to the rf power source (transmitter). A director is also a parasitic element.

The simple antenna of Fig. 1 is easy to build and will work nicely for DXing on 20, 15 or 10 meters, depending on which band we design it for. The theoretical forward gain with the "S" spacing given will be roughly 5.4 dB. This would be equivalent to increasing the transmitter output power from 100 W to 350 W in the favored direction of the beam!

The various characteristics specified in Fig. 1 depend on the diameter of the beam elements, the spacing "S" and the height of the antenna above ground. For this discussion we will assume that the diameters of the driven element and reflector are between 0.5 and 0.75 in. (13 and 19 mm). However, wire could be used instead of tubing (if supported properly). We could also use tubing that is greater or smaller in diameter than that specified. The conductor cross-sectional area has a direct effect on the electrical length of the elements and on the *bandwidth* of the antenna. The bandwidth is generally thought of in amateur work as the frequency over which the VSWR (voltage standing-wave ratio) is 2:1 or less. The larger the antenna elements are in diameter, the lower the Q (quality factor) of the antenna, and hence the greater the bandwidth. The highest Q would be obtained when using, say, no. 16 wire as opposed to large-diameter tubing. Whatever conductor we may choose to use for the beam elements can be employed satisfactorily. Some experimenting may be necessary, however, to get maximum performance. This can be done by observing a field-strength meter (see "measurements" chapter of the *Handbook*) and adjusting spacing "S" and the element lengths for maximum forward gain from the beam. The dimensions given in Fig. 1 will yield good performance without any adjustments.

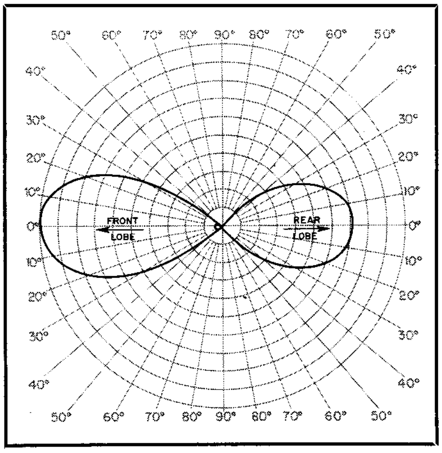


Fig. 2 — Directivity characteristics of a horizontally polarized 2-element Yagi antenna. The major (front) lobe is at the left.

Beam Radiation Patterns

All directional antennas exhibit a specific radiation pattern. The approximate pattern for the 2-element Yagi of Fig. 1 when mounted for horizontal polarization is shown in Fig. 2. There are two *significant* lobes. The larger one at the left is in the favored direction of the beam. The rear lobe is shown at the right in Fig. 2. It is much lower in magnitude, which gives us what is known as a *front-to-back ratio*, expressed in decibels. A typical theoretical ratio for a 2-element Yagi that uses a driven element and a reflector is 15 to 16 dB. The spacing "S" (Fig. 1) has a marked effect on the front-to-back ratio.[1] We can envision the pattern shown in Fig. 2 as one we would see if we were directly above the antenna, looking toward ground. We are assuming also that our eyes could see the rf (radio frequency) energy as it was radiated from the antenna.

Very deep nulls are observed directly off the sides of the beam antenna, as indicated in Fig. 2. This gives us what is known as the front-to-side ratio of the beam, based on field-strength measurements that are taken in decibels. It can be seen that maximum rejection takes place off the sides of the antenna, but that approximately 15 dB of rejection is also available off the rear of the antenna. These ratio characteristics aid us in rejecting QRM from all directions other than the favored one. Therefore, a beam that had no gain, or even had a loss, would be useful if it had a front-to-back and front-to-side ratio.

Another important radiation characteristic is depicted in Fig. 3. This is known as the *radiation angle*. We are concerned here with the angle at which the lobe leaves the antenna, respective to ground. Since we are bouncing our signal off the ionosphere in an oblique manner to work distant DX, the lower the radiation angle, the greater the distance we can work. This phenomenon is known as "skip." The vertical pattern in Fig. 3 is that of a 2-element Yagi of the type shown in Fig. 1. The height above ground is 1.25 wavelengths. The radiation angle of the main lobe is 12° for the height specified. The rear lobe is approximately the same in degrees. We can also see two *minor* (higher) lobes in Fig. 3. These are useful for working DX that is closer in, depending upon band conditions (propagation) at a given time of the day. These smaller

[1]Notes appear on page 35.

lobes have radiation angles that are between 30° and 40°.

Impedance Matching

The feed point of any antenna has a characteristic *radiation resistance* in ohms. This is referred to commonly as the feed-point impedance. To have maximum transfer of power from the feed line to the driven element we must have a *matched condition.* That is, if the feed point is 50 Ω, we should use a feed line that has a 50-Ω characteristic impedance. If the antenna feed impedance is nonstandard with respect to available types of feed lines, then we must include some type of matching network or device between the antenna feed point and the feed line. This can be done in a number of ways.

Various matching systems for Yagi antennas are described in detail in *The ARRL Antenna Book.* The reader is referred to that publication for tutorial guidance. But, for our immediate interest, we will consider a simple technique that will give us a reasonably close match between 75-Ω coaxial feed line and the antenna of Fig. 1. With the dimensions specified in the diagram we will have an antenna feed impedance of roughly 25 Ω. An easy way to obtain the required 2:1 transformation ratio is to insert a *quarter-wavelength transformer.* If we insert a quarter wavelength of 50-Ω cable between the feed point and a 75-Ω feed line, the system will be closely matched, and the system VSWR will be close to 1:1 (optimum).

Our matching transformer will be cut to a length dictated by the velocity or propagation factor of the cable we use for the transformer. Sections of transmission line that are cut for a particular wavelength dimension will always be shorter than a free-space length for the same frequency. This is because the insulating material in the feed line has a pronounced effect on the electrical length of the line. The matching transformer in Fig. 4 must be 7.69 ft (2.34 m) long for 21.1 MHz (Fig. 1), whereas the free-space dimension for one quarter wavelength would be 11.65 ft (3.55 m). This is because the velocity factor of RG-8/U cable is 0.66. Hence, 0.66 × 11.65 = 7.69 ft, or 7 ft, 8-1/4 in. The 75-Ω line (RG-11/U or RG-59/U) can be any convenient length. RG-58/U can also be used for the matching transformer. The larger coax cables will be best for reduced feed-line losses and high-power operation. The required impedance of the cable used in the matching transformer is determined by:

$$Z_o = \sqrt{Z_r Z_s}$$

where

Z_o = impedance of the cable used in the transformer.

Z_r = antenna feed-point impedance.

Z_s = characteristic impedance of the feed line.

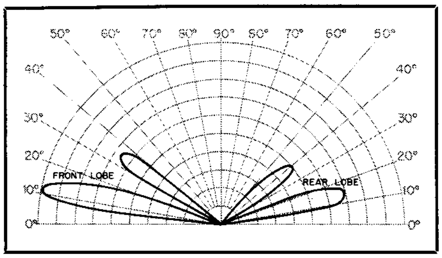


Fig. 3 — Major and minor lobes of a 2-element Yagi showing the radiation angles of the lobes (see text).

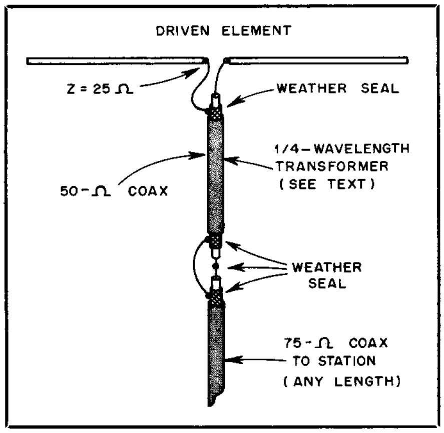


Fig. 4 — Method for using a quarter-wavelength matching transformer between the antenna feed point and the transmission line. The illustration shows how to effect a close match between a 25-Ω antenna and a 75-Ω feed line.

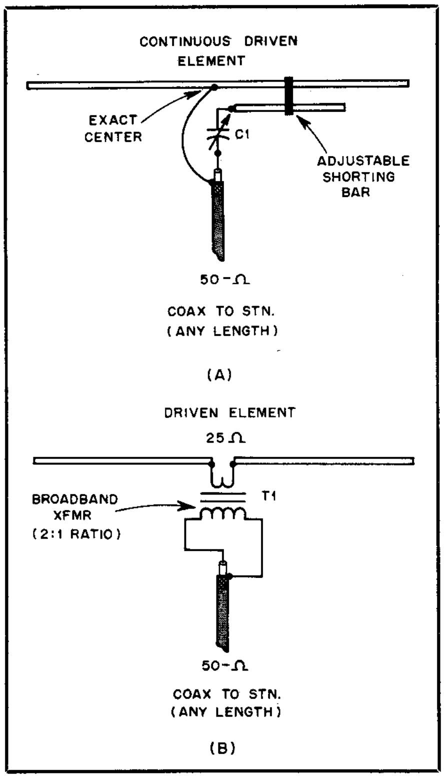


Fig. 5 — A gamma match is shown at A for use with a continuous length of conductor as the driven element. T1 at B is a broadband toroidal transformer that can be used to match 25 Ω to 50 Ω in this example. A split driven element (dipole) is used at B.

From this we find that the calculated impedance of the transformer coax cable is 43.3 Ω, using 25 Ω for Z_r and 75 Ω for Z_s. This will be close enough to the desired 50 Ω to provide a low VSWR. The VSWR can be calculated simply by:

$$VSWR = Z_o/R$$

where

Z_o = impedance of cable used for the transformer.

R = desired impedance of the cable (43.3 Ω).

This yields a VSWR of 1.15:1 on the line, which is entirely acceptable. If we connected a 50-Ω feed line directly to the 25-Ω feed point of the antenna we would have a VSWR of 2:1 as a best-case condition. Although we would probably work plenty of DX with a VSWR this high or slightly higher, we would lose even more transmitter power in the feed line. Furthermore, if our solid-state transmitter contained an SWR protective circuit, the output power would be reduced automatically by that circuit.

Other Matching Schemes

If the driven element in Fig. 1 were not split (continuous length of tubing or wire) we could employ a *gamma match* of the kind shown in Fig. 5A. Its length and the setting of C1 would be adjusted to provide a VSWR of 1:1. Simple formulas for calculating the dimensions of a gamma match are given in *The ARRL Antenna Book.* An alternative matching method is shown at B of Fig. 5. This involves the use of a toroidal broadband 2:1 matching transformer. Recent editions of *The ARRL Radio Amateur's Handbook* contain practical information on broadband-transformer design.

The matching technique illustrated in Fig. 4 requires the use of 75-Ω line to the ham shack. This means that a 50-Ω VSWR indicator will not yield accurate readings, since the line impedance is not right for the VSWR instrument. Transmitters with tubes and a pi network in the final-amplifier section will work fine into 75-Ω line. If the rig has a solid-state final amplifier designed for a 50-Ω load, there will be a slight power loss caused by the SWR-shutdown circuit. This is because when the 75-Ω cable is connected to the 50-Ω termination provided by the transmitter, a VSWR of 1.5:1 will be present. Chapter 19 of the 1981 *Handbook* contains data on building a simple 75-50 Ω broadband transformer that can be used between the VSWR indicator/transmitter and the 75-Ω line to correct the 1.5:1 mismatch condition. It can be used to solve the aforementioned problem.

Adding Yagi Elements

Although our intent in this article is to highlight the simple 2-element Yagi, we should mention the more popular 3-element version of this antenna. What will an additional parasitic element do for us? Basically, it will improve the front-to-back ratio and increase the forward gain. A beam pattern for a 3-element Yagi (director, driven element and reflector) is shown in Fig. 6. We can see that the back lobe is substantially smaller than that of the 2-element Yagi of Fig. 2. Also, the gain has increased to approximately 7.2 dB over a dipole. This would be like increasing our 100-W transmitter output power to 525 W, but without the aid of an amplifier.

With the antenna represented in Fig. 6 we would use a director-to-driven-element spacing of 0.1 wavelength. The height above ground for the pattern shown would be 0.5 wavelength. The beamwidth remains about the same as when using a 2-element Yagi. At a height of 0.5 wavelength the radiation angle is fairly high — about 28°, but by increasing the antenna height to 1 wavelength it becomes 12°, as is the case with the 2-element Yagi of Fig. 1. This illustrates the importance of antenna height versus DX capability. The spacing between the elements determines the feed-point impedance. With the antenna arranged for maximum gain we will find the feed impedance quite low — on the order of 10 Ω. By trading gain for element spacing we can raise the feed impedance considerably. But, it is better to adjust the Yagi for maximum gain and to use a matching system at the feed point. A gamma match is recommended for use with the 3-element Yagi. The driven element would then be a continuous length of tubing (Fig. 5A).

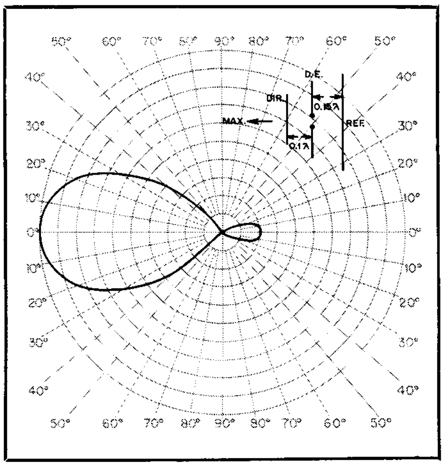


Fig. 6 — Radiation pattern for a 3-element Yagi. Note how much smaller the rear lobe is than that of the 2-element Yagi (Fig. 2). Also, the 3-element beam has greater forward gain than the 2-element one.

Simple 2-Element Yagi

A 2-element Yagi is easy to build and to erect. It is probably the best starting point for that first directional gain antenna. A number of construction methods are available to the builder. For example, one can obtain bamboo fishing poles, put a continuous wrapping of aluminum foil on the bamboo and use these poles as Yagi elements. This was described years ago in amateur literature as a "Catfish Beam." The aluminum foil can be taped firmly at intervals to affix it to the bamboo poles. The foil would of course have to be opened at the center of the driven element. Homemade aluminum clamps can be attached at the feed point (around the foil and poles) to provide a connection to the coax cable. Each clamp would be equipped with a screw, nut and solder lug for this purpose.

Aluminum tubing is expensive and sometimes hard to find. If you don't have a supply of it available, you can use thin-wall steel electrical conduit (aluminum conduit is also manufactured) for the Yagi elements. Of course this material will make the antenna much heavier than an aluminum version, and rust will form on the elements eventually. A coating of spar varnish or polyurethane lacquer can be applied to inhibit oxidation and rusting.

Fig. 7 illustrates a wooden frame we could build to serve as a foundation for tubing or wire Yagi antennas. Wooden elements "C" need not be nearly as long (about 0.33×) as the antenna tubing. They can be varnished to prevent deterioration from the weather. The hardware for holding the sections of the frame together can be 1/4-in./20 bolts. Items "B" are ceramic standoff cones. Other types of insulators can be used, such as plastic blocks. The insulating material must be strong enough to sustain the stress imposed by the driven element and director. A 1-in. (25.4-mm) pipe flange can be attached to plate "A" to allow the builder to employ 1-in. diameter water pipe as a mast.

Wire antenna elements can be used for the Yagi if wooden members "C" are as long as the wire elements. The weight of the antenna would be somewhat excessive if this were done, and could prove impractical for operation on 20 or 15 meters. At 10 meters and higher it should be an acceptable technique. For vhf Yagis we could use a single 2 × 2-in. (51 × 51-mm) section of wood as a boom, with 1/4-in. (6.3-mm) diameter tubing for the elements. Yagis with good performance on 144 MHz have been built in this manner by using coat-hanger wire for the antenna elements.[2] An 8- or 10-element 2-meter Yagi can be built inexpensively in this fashion.

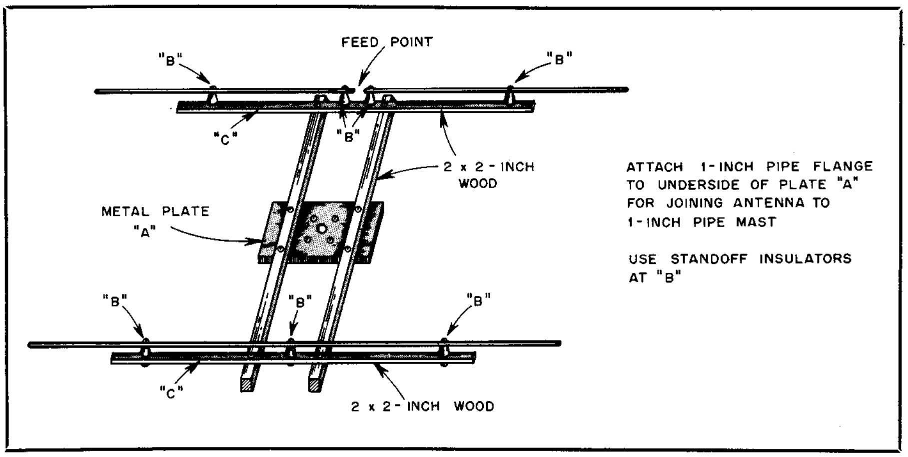


Fig. 7 — Details for building a wooden frame on which to assemble a 2-element Yagi. Readily available, inexpensive materials are specified. Some innovation will improve this design and perhaps reduce the cost. The cone insulators, B, can be replaced by blocks of plastic or phenolic material. Inches × 25.4 = mm.

Some Final Comments

Certainly there are other types of gain antennas we could have described in this article, but space doesn't permit such an in-depth treatment of the general subject. The intention was to present some fundamentals of gain-antenna design and performance.

Those who don't want to build a rotatable Yagi of the type shown in Fig. 7 may choose to construct a 2- or 3-element stationary Yagi from wire. It could be oriented toward Europe, Japan or some other favored direction. Antennas of this type have been used successfully on 160, 80 and 40 meters for many years. There is no reason why they wouldn't work nicely on 20, 15 or 10 meters as well.

The important consideration is to erect whatever type of Yagi we build as high above ground as possible, and well away from nearby conductive objects. An attempt should be made to match the antenna to its feed line to minimize losses and obtain a low VSWR. The DX awaits you, so perhaps now is the time to build your first Yagi! QST

Notes

[1]See *The ARRL Antenna Book*, chapter 4, 13th edition, for in-depth data on Yagi-antenna element spacing and conductor size.

[2]L. McCoy, W1ICP, "A Five-Element Two-Meter Beam for $1.50," *QST*, Oct. 1962, p. 17.