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Chapter 11

HF Yagi and Quad Antennas

11.1 YAGI ANTENNAS

Along with the dipole and the quarter-wave vertical, radio amateurs throughout the world make extensive use of the Yagi antenna, more accurately referred to as a Yagi array. Hidetsugu Yagi and Shintaro Uda, two Japanese university professors, invented the Yagi in the 1920s. Uda did much of the developmental work while Yagi introduced the array to the world outside Japan through his writings in English. Although the antenna should properly be called a *Yagi-Uda* array, it is commonly referred to simply as a *Yagi*.

The Yagi is a type of end-fire multielement array as described in the **Multielement Arrays** chapter. At the minimum, it consists of a single *driven element* and a single *parasitic element*. These elements are placed parallel to each other on a supporting boom some distance apart. This arrangement is known as a 2-element Yagi. The parasitic element is termed a *reflector* when it is placed behind the driven element, opposite to the direction of maximum radiation, and is called a *director* when it is placed ahead of the driven element. See **Figure 11.1**. In the VHF and UHF spectrum, Yagis employing 30 or more elements are not uncommon, with a single reflector and multiple directors. See the **VHF and UHF Antenna Systems** chapter for details on VHF and UHF Yagis. Large HF arrays may employ 10 or more elements and will be covered in this chapter.

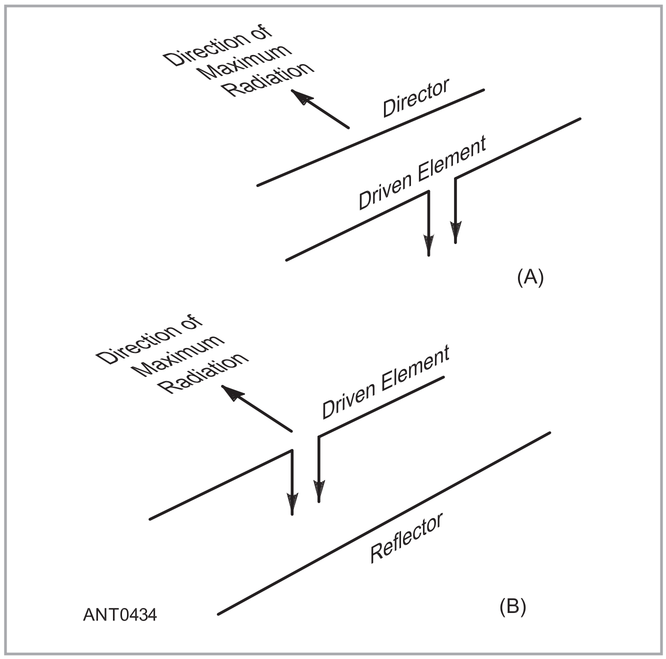


Figure 11.1 — Two-element Yagi systems using a single parasitic element. At A the parasitic element acts as a director, and at B as a reflector. The arrows show the direction in which maximum radiation takes place.

11.1.1 HOW A YAGI WORKS — AN OVERVIEW

The gain and directional pattern of a Yagi array is determined by the relative amplitudes and phases of the currents induced into all the parasitic elements. Unlike directly driven multielement arrays in which the designer must compensate for mutual coupling between elements, proper Yagi operation *relies on* mutual coupling. The current in each parasitic element is determined by its spacing from both the driven element and other parasitic elements, and by the tuning of the element itself. Both length and diameter affect element tuning.

The following discussion is quite over-simplified but serves to illustrate the basic process by which the Yagi antenna creates its radiation pattern. Begin with a dipole driven element resonant at the operating frequency and a single parasitic element configured as a reflector, slightly longer than the driven element. Current in the driven element creates a radiated electromagnetic field (the *direct field*) that induces a current in the parasitic element. That induced current causes a *re-radiated field* just as if the current was caused by a transmitter connected to the element. The re-radiated field combines with the direct field from the driven element to create the antenna's radiation pattern.

Three things determine the phase relationship between the current in the reflector and in the driven element. First, the direct field at the reflector slightly lags the field at the driven element because the direct field must travel from the driven element to the reflector. Second, the induced current is 180° out of phase with the direct field at the location of the reflector. Third, the reflector element is slightly longer than a resonant length and so its self-impedance is inductive, creating additional phase lag in the induced current relative to the direct field.

The combination of phase lags due to the direct field's travel time, the 180° phase inversion for induced current, and the reflector's inductance cause the re-radiated field to partially cancel with the direct field from the driven element along a line from the driven element through the reflector. (Imagine the boom extending beyond the reflector — that is the line being referred to.) This creates the rear null in the Yagi radiation pattern. Similarly, the fields reinforce each other in the opposite direction to the forward direction as shown in Figure 11.1.

The situation is reversed in the case of a director element. The phase lag from travel time and the inversion in the induced current act the same as for the reflector. The director element is slightly shorter than resonant however and so has a capacitive self-impedance, creating a phase lead. The combination results in the fields reinforcing in the forward direction and cancelling in the opposite direction.

Two-element Yagis are useful antennas but even more directivity (gain) can be obtained by adding additional parasitic elements. Additional reflectors are rarely used because field cancellation to the rear of the antenna leaves too little field for them to improve directivity. Thus, multiple directors are used to increase directivity as you will see in practical Yagi designs later in the chapter.

The actual situation is of course far more complicated than this simplistic view of Yagi operation. In a real Yagi, the mutual coupling between all elements must be considered, including between the parasitic elements. This makes determining the optimum spacing and element length for a desired radiation pattern quite involved mathematically and best left to software modeling programs.

11.1.2 YAGI MODELING

For about 50 years amateurs and professionals created Yagi array designs largely by "cut and try" experimental techniques. In the early 1980s, Jim Lawson, W2PV (SK), described in detail for the amateur audience the fundamental mathematics involved in modeling Yagis. His book *Yagi Antenna Design* (now out of print) is highly recommended for serious antenna designers as is his series of articles in *Ham Radio* (see Bibliography). The advent of powerful microcomputers and sophisticated computer antenna modeling software in the mid 1980s revolutionized the field of Yagi design for the radio amateur. In a matter of minutes, a computer can try 100,000 or more different combinations of element lengths and spacings to create a Yagi design tailored to meet a particular set of high-performance parameters. To explore this number of combinations experimentally, a human experimenter would take an unimaginable amount of time and dedication and the process would no doubt suffer from considerable measurement errors. With the computer tools available today, an antenna can be designed, constructed and then put up in the air, with little or no tuning or pruning required.

A very popular modeling program for amateur use is *EZNEC* by Roy Lewallen, W7EL (**www.eznec.com**). *EZNEC* is well-suited to model Yagi antennas. There are several Yagi antenna models included on this book's CD-ROM, and *EZNEC* is discussed in more detail in the **Antenna Modeling** chapter.

The *YW* Modeling Program

Included on this book's CD-ROM, the *YW* modeling program developed by Dean Straw, N6BV, is designed to evaluate monoband Yagi antennas. (*YW* stands for *Yagi for Windows*.) *YW* results compare very closely with Brian Beezley's *YO* or *YA* programs (no longer sold in the amateur market) and with *NEC*-based programs, such as *EZNEC*, *NEC-Win Plus* or *NEC-4*. *YW* is a special-purpose program, designed strictly for monoband Yagis. It has the advantage of running many times more quickly than general-purpose programs such as *NEC* but it has some attendant limitations.

YW evaluations over ground are done over flat "perfect" ground. Mutual impedances between Yagi elements and the ground are not specifically taken into account in *YW*, so calculations for antennas mounted less than approximately $\lambda/8$ above ground are likely to be inaccurate. Antennas mounted in the presence of other nearby antennas or mounted very low to the ground are the specialties of method-of-moment programs like *EZNEC*. Despite these caveats, *YW* will get you very close to a final design — one where you can simply cut the elements and expect that your Yagi will work as advertised.

11.2 YAGI PERFORMANCE PARAMETERS

There are three main parameters used to characterize the performance of a particular Yagi — *forward gain*, *pattern* and *drive impedance/SWR*. Another important consideration is mechanical strength. It is very important to recognize that each of the three electrical parameters should be characterized over the frequency band of interest in order to be meaningful. Neither the gain, the SWR nor the pattern measured at a single frequency gives very much insight into the overall performance of a particular Yagi.

Poor designs have even been known to reverse their directionality over a frequency band, while other designs have excessively narrow SWR bandwidths, or gain that peaks excessively in the band. Finally, an antenna's ability to survive the wind and ice conditions expected in one's geographical location is an important consideration in any design. Much of this chapter will be devoted to describing detailed Yagi designs that are optimized for a good balance between gain, pattern and SWR over various amateur bands, and that are designed to survive strong winds and icing.

11.2.1 YAGI GAIN

Like any other antenna, the gain of a Yagi must be stated in comparison to some standard of reference. Designers of phased vertical arrays often state gain referenced to a single, isolated vertical element. See the section on "Phased Array Techniques" in the chapter **Multielement Arrays**.

Many antenna designers prefer to compare gain to that of an *isotropic radiator in free space*. This is a theoretical antenna that radiates equally well in all directions, and by definition, it has a gain of 0 *dBi* (dB isotropic). Many radio amateurs, however, are comfortable using a dipole as a standard reference antenna, mainly because it is *not* a theoretical antenna.

In free space, a dipole does not radiate equally well in all directions — it has a figure-eight azimuth pattern, with deep nulls off the ends of the wire. In its favored directions, a free-space dipole has 2.15 dB gain compared to the isotropic radiator. You may see the term *dBd*, meaning gain referenced to a dipole in free space. Subtract 2.15 dB from gain in dBi to convert to gain in dBd.

Assume for a moment that we take a dipole out of "free space," and place it one wavelength above the ocean, whose saltwater makes an almost perfect ground. At an elevation angle of 15°, where sea water-reflected radiation adds in phase with direct radiation, the dipole has a gain of about 6 dB, compared to its gain when it was in free space, isolated from any reflections. This and other related effects are addressed in the chapter **Effects of Ground**.

It is perfectly legitimate to say that this dipole has a gain of 6 dBd, although the term "dBd" (meaning "dB dipole") makes it sound as though the dipole somehow has gain over itself! Always remember that gain expressed in dBd (or dBi) refers to the *counterpart antenna in free space*. The gain of the dipole over saltwater in this example can be rated at either 6 dBd (over a dipole in free space), or as 8.15 dBi (over an isotropic radiator in free space). Each frame of reference is valid, as long as it is used consistently and clearly. In this chapter we will often switch between Yagis in free space and Yagis over ground. To prevent any confusion, gains will be stated in dBi.

Yagi free-space gain ranges from about 5 dBi for a small 2-element design to about 20 dBi for a 31-element long-boom UHF design. The length of the boom is the main factor determining the gain a Yagi can deliver. Gain as a function of boom length will be discussed in detail after the sections below defining antenna response patterns and SWR characteristics.

11.2.2 RADIATION PATTERN MEASUREMENTS

Figure 11.2 compares the E-plane and H-plane pattern of a 3-element Yagi in free space to those of a dipole and an isotropic radiator. (See the **Antenna Fundamentals** chapter for definitions and conventions associated with measurement of radiation patterns.) These patterns were generated using *NEC-2* modeling software. Figure 11.2A shows that this 3-element Yagi in free space exhibits 7.28 dBi of gain (referenced to isotropic), and has 5.13 dB gain over a free-space dipole. For this particular antenna, the half-power beamwidth is about 66°.

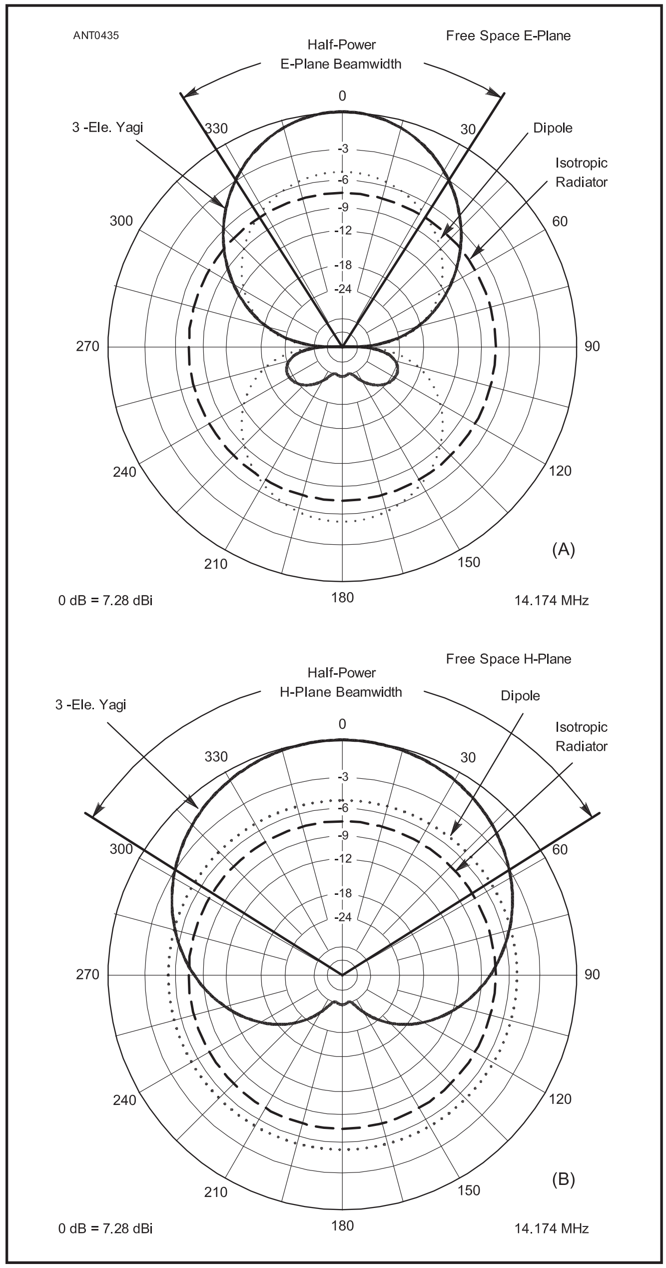


Figure 11.2 — E-Plane (electric field) and H-Plane (magnetic field) response patterns for 3-element 20 meter Yagi in free space. At A the E-Plane pattern for a typical 3-element Yagi is compared with a dipole and an isotropic radiator. At B the H-Plane patterns are compared for the same antennas. The Yagi has an E-Plane half-power beamwidth of 66°, and an H-Plane half-power beamwidth of about 120°. The Yagi has 7.28 dBi (5.13 dBd) of gain. The front-to-back ratio, which compares the response at 0° and at 180°, is about 35 dB for this Yagi. The front-to-rear ratio, which compares the response at 0° to the largest lobe in the rearward 180° arc behind the antenna, is 24 dB, due to the lobes at 120° and 240°.

Front-to-Back Ratio

Again as seen in Figure 11.2A, this antenna's front-to-back ratio is 34 dB comparing response at 180° to that in the forward direction at 0°. (The ratio of the forward response to the averaged response over the entire 180° rearward section is called the *front-to-rear ratio*.) In Figure 11.2A there are two sidelobes, at 120° and at 240°, which are about 24 dB below the peak response at 0°. Since interference can come from any direction, not only directly off the back of an antenna, these kinds of sidelobes limit the ability to discriminate against rearward signals. The term *worst-case front-to-rear ratio* is used to describe the worst-case rearward lobe in the 180°-wide sector behind the antenna's main lobe. In this case, the worst-case front-to-rear ratio is 24 dB.

In the rest of this chapter the worst-case front-to-rear ratio will be used as a performance parameter, and will be abbreviated as "F/R." For a dipole or an isotropic radiator, Figure 11.2A demonstrates that F/R is 0 dB. Figure 11.2B depicts the H-field response for the same 3-element Yagi in free space, again compared to a dipole and an isotropic radiator in free space. Unlike the E-field pattern, the H-field pattern for a Yagi does not have a null at 90°, directly over the top of the Yagi. For this 3-element design, the H-field half-power beamwidth is approximately 120°.

Figure 11.3 compares the azimuth and elevation patterns for a horizontally polarized 6-element 14-MHz Yagi with a 60-foot boom mounted one wavelength over ground to a dipole at the same height. As with any horizontally polarized antenna, the height above ground is the main factor determining the peaks and nulls in the elevation pattern of each antenna. Figure 11.3A shows the E-field pattern, which has now been labeled as the Azimuth pattern. This antenna has a half-power azimuthal beamwidth of about 50°, and at an elevation angle of 12° it exhibits a forward gain of 16.02 dBi, including about 5 dB of ground reflection gain over relatively poor ground, with a dielectric constant of 13 and conductivity of 5 mS/m. In free space this Yagi has a gain of 10.97 dBi.

The H-field elevation response of the 6-element Yagi has a half-power beamwidth of about 60° in free space, but as shown in Figure 11.3B, the first lobe (centered at 12° in elevation) has a half-power beamwidth of only 13° when the antenna is mounted one wavelength over ground. The dipole at the same height has a very slightly larger first-lobe half-power elevation beamwidth of 14°, since its free-space H-field response is omnidirectional.

Note that the free-space H-field directivity of the Yagi suppresses its second lobe over ground (at an elevation angle of about 40°) to 8 dBi, while the dipole's response at its second lobe peak (at about 48°) is at a level of 9 dBi.

The shape of the azimuthal pattern for a Yagi operated over real ground will change slightly as the Yagi is placed closer and closer to ground. Generally, however, the azimuth pattern doesn't depart significantly from the free-space pattern until the antenna is less than 0.5 λ high. This is just over 17 feet high at 28.4 MHz and just below 35 feet at 14.2 MHz — heights that are not difficult to achieve for most amateurs. Some advanced modeling programs can optimize Yagis at the exact installation height.

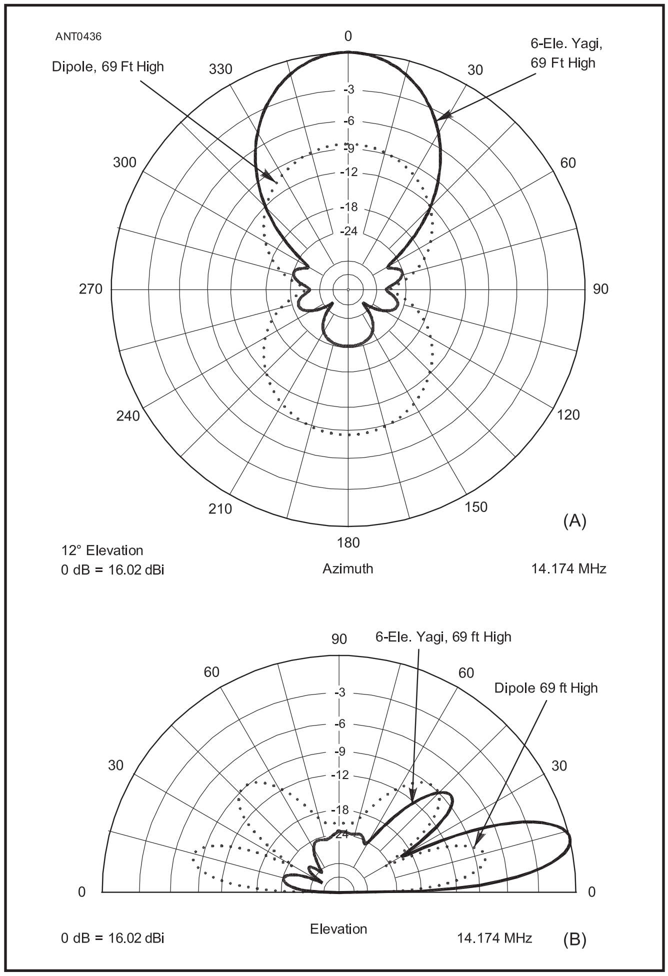


Figure 11.3 — Azimuth pattern for 6-element 20 meter Yagi on 60-foot long boom, mounted 60 feet over ground. At A, the azimuth pattern at 12° elevation angle is shown, compared to a dipole at the same height. Peak gain of the Yagi is 16.04 dBi, or just over 8 dB compared to the dipole. At B, the elevation pattern for the same two antennas is shown. Note that the peak elevation pattern of the Yagi is compressed slightly lower compared to the dipole, even though they are both at the same height over ground. This is most noticeable for the Yagi's second lobe, which peaks at about 40°, while the dipole's second lobe peaks at about 48°. This is due to the greater free-space directionality of the Yagi at higher angles.

11.2.3 FEED POINT IMPEDANCE AND SWR

The impedance at the feed point of the driven element in a Yagi is affected not only by the tuning of the driven element itself, but also by the spacing and tuning of nearby parasitic elements, and to a lesser extent by the presence of ground. In some designs that have been tuned solely for maximum gain, the driven-element impedance can fall to very low levels, sometimes less than 5 Ω. This can lead to excessive losses due to conductor resistance, especially at VHF and UHF. In a Yagi that has been optimized solely for gain, conductor losses are usually compounded by large excursions in impedance levels with relatively small changes in frequency. The SWR can thus change dramatically over a band and can create additional losses in the feed line. **Figure 11.4** illustrates the SWR over the 28 to 28.8 MHz portion of the 10 meter amateur band for a 5-element Yagi on a 24-foot boom, tuned for maximum forward gain at a spot frequency of 28.4 MHz. Its SWR curve is contrasted to that of a Yagi designed for a good compromise of gain, SWR and F/R.

Even professional antenna designers have difficulty accurately measuring forward gain. On the other hand, SWR can easily be measured by professional and amateur alike. Few manufacturers would want to advertise an antenna with the narrow-band SWR curve shown in Figure 11.4!

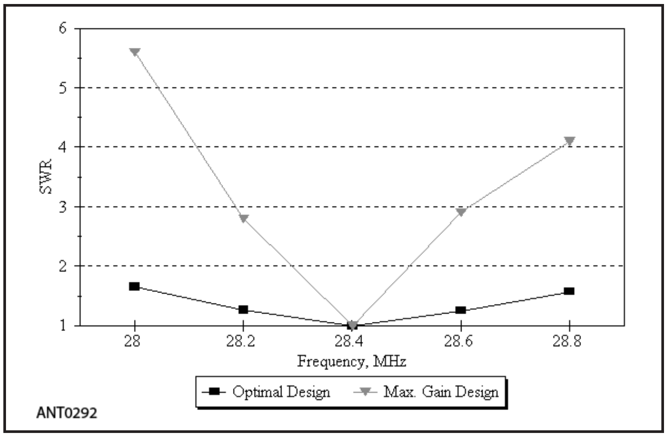


Figure 11.4 — SWR over the 28.0 to 28.8 MHz portion of the 10 meter band for two different 3-element Yagi designs. One is designed strictly for maximum gain, while the second is optimized for F/R pattern and SWR over the frequency band. A Yagi designed only for maximum gain usually suffers from a very narrow SWR bandwidth.

Direct Feed Yagis

By carefully adjusting the position and tuning of the Yagi elements by using modeling software it is possible to create an antenna design for which the feed point impedance is close to 50 Ω and can be fed directly with coaxial cable. The tradeoff is usually a small amount of gain, but such *direct feed* designs are becoming increasingly common with no compromise in performance. Direct feed designs are somewhat more complex mechanically as the driven element must be insulated from the boom. This includes designs that require beta or hairpin matching.

Choke Baluns

The use of a choke or current balun is good practice for any Yagi with a balanced driven element, regardless of feed point impedance. To be sure, many Yagi antennas provide adequate performance without a balun at the feed point but obtaining top performance from the antenna requires decoupling or isolation of the feed line from the antenna. If a choke balun is *not* used, interaction between the outer surface of the coaxial cable shield and the antenna can affect feed point impedance and result in significant common-mode current on the shield. Re-radiation from the common-mode current can fill in the radiation pattern nulls, degrading front-to-side and front-to-back performance. Common-mode current on the feed line can also result in RF-related problems in the station. (See "Common-Mode Transmission Line Currents" in the **Transmission Line System Techniques** chapter.)

11.3 MONOBAND YAGI PERFORMANCE OPTIMIZATION

11.3.1 YAGI DESIGN GOALS

The previous section discussing driven-element impedance and SWR hinted at possible design trade-offs among gain, pattern and SWR, especially when each parameter is considered over a frequency band rather than at a spot frequency. Trade-offs in Yagi design parameters can be a matter of personal taste and operating style. For example, one operator might exclusively operate the CW portions of the HF bands, while another might only be interested in the Phone portions. Another operator may want a good pattern in order to discriminate against signals coming from a particular direction; someone else may want the most forward gain possible, and may not care about responses in other directions.

There are only a few variables available to adjust when one is designing a Yagi to meet certain design goals. The variables are:

1) The physical length of the boom
2) The number of elements on the boom
3) The spacing of each element along the boom
4) The tuning of each element
5) The type of matching network used to feed the array.

For elements that are created from telescoping tubing sections, the lengths of individual sections (called the taper schedule) affects antenna performance as well. Taper schedule is usually varied in order to provide mechanical strength and is not considered a primary electrical design variable.

Extensive computer modeling of Yagis indicates that the parameter that must be compromised most to achieve wide bandwidths for front-to-rear ratio and SWR is forward gain. However, not much gain must be sacrificed for good F/R and SWR coverage, especially on long-boom Yagis. Although 10 and 7-MHz Yagis are not rare, the HF bands from 14 to 30 MHz are where Yagis are most often found, mainly due to the mechanical difficulties involved with making sturdy antennas for lower frequencies. The highest HF band, 28.0 to 29.7 MHz, represents the largest percentage bandwidth of the upper HF bands, at almost 6%. It is difficult to try to optimize in one design the main performance parameters of gain, worst-case F/R ratio and SWR over this large a band. Many commercial designs thus split up their 10 meter designs into antennas covering one of two bands: 28.0 to 28.8 MHz, and 28.8 to 29.7 MHz. For the amateur bands below 10 meters, optimal designs that cover the entire band are more easily achieved.

The performance requirements for Yagis used at VHF and UHF are similar to those of HF Yagis but place more emphasis on reduction of side lobes due to the importance of lowering received noise above 30 MHz. In addition, there are differences in feed point matching and considerations of losses are handled differently. These topics are addressed in the **VHF and UHF Antenna Systems** chapter. The remainder of this chapter will focus on HF designs unless specifically noted otherwise.

11.3.2 GAIN AND BOOM LENGTH

As pointed out earlier, the gain of a Yagi is largely a function of the length of the boom. As the boom is made longer, the maximum gain potential rises. For a given boom length, the number of elements populating that boom can be varied, while still maintaining the antenna's gain, provided of course that the elements are tuned properly. In general, putting more elements on a boom gives the designer added flexibility to achieve desired design goals, especially to broaden the response across a frequency band.

Figure 11.5A is an example illustrating gain versus frequency for three different types of 3-element Yagis on 8-foot booms. The three antennas were designed for the lower end of the 10 meter band, 28.0 to 28.8 MHz, based on the following different design goals:

Antenna 1: Maximum mid-band gain, regardless of F/R or SWR across the band

Antenna 2: SWR less than 2:1 over the frequency band; best compromise gain, with no special consideration for F/R over the band.

Antenna 3: "Optimal" case: F/R greater than 20 dB, SWR less than 2:1 over the frequency band; best compromise gain.

Figure 11.5B shows the F/R over the frequency band for these three designs, and Figure 11.5C shows the SWR curves over the frequency band. Antenna 1, the design that strives strictly for maximum gain, has a poor SWR response over the band, as might be expected after the previous section discussing SWR. The SWR is 10:1 at 28.8 MHz and rises to 22:1 at 29 MHz. At 28 MHz, at the low end of the band, the SWR of the maximum-gain design is more than 6:1. Clearly, designing for maximum gain alone produces an unacceptable design in terms of SWR bandwidth. The F/R for Antenna 1 reaches a high point of about 20 dB at the low-frequency end of the band, but falls to only 3 dB at the high-frequency end.

Antenna 2, designed for the best compromise of gain while the SWR across the band is held to less than 2:1, achieves this goal, but at an average gain sacrifice of 0.7 dB compared to the maximum gain case. The F/R for this design is just under 15 dB over the band. This design is fairly typical of many amateur Yagi designs before the advent of computer modeling and optimization programs. SWR can easily be measured, and experimental optimization for forward gain is a fairly straightforward procedure. By contrast, overall pattern optimization is not a trivial thing to achieve experimentally, particularly for antennas with more than four or five elements.

Antenna 3, designed for an optimum combination of F/R, SWR and gain, compromises forward gain an average of 1.0 dB compared to the maximum gain case, and about 0.4 dB compared to the compromise gain/SWR case. It achieves its design objectives of more than 20 dB F/R over the 28.0 to 28.8 MHz portion of the band, with an SWR less than 2:1 over that range.

Figure 11.6A shows the free-space gain versus frequency for the same three types of designs, but for a bigger 5-element

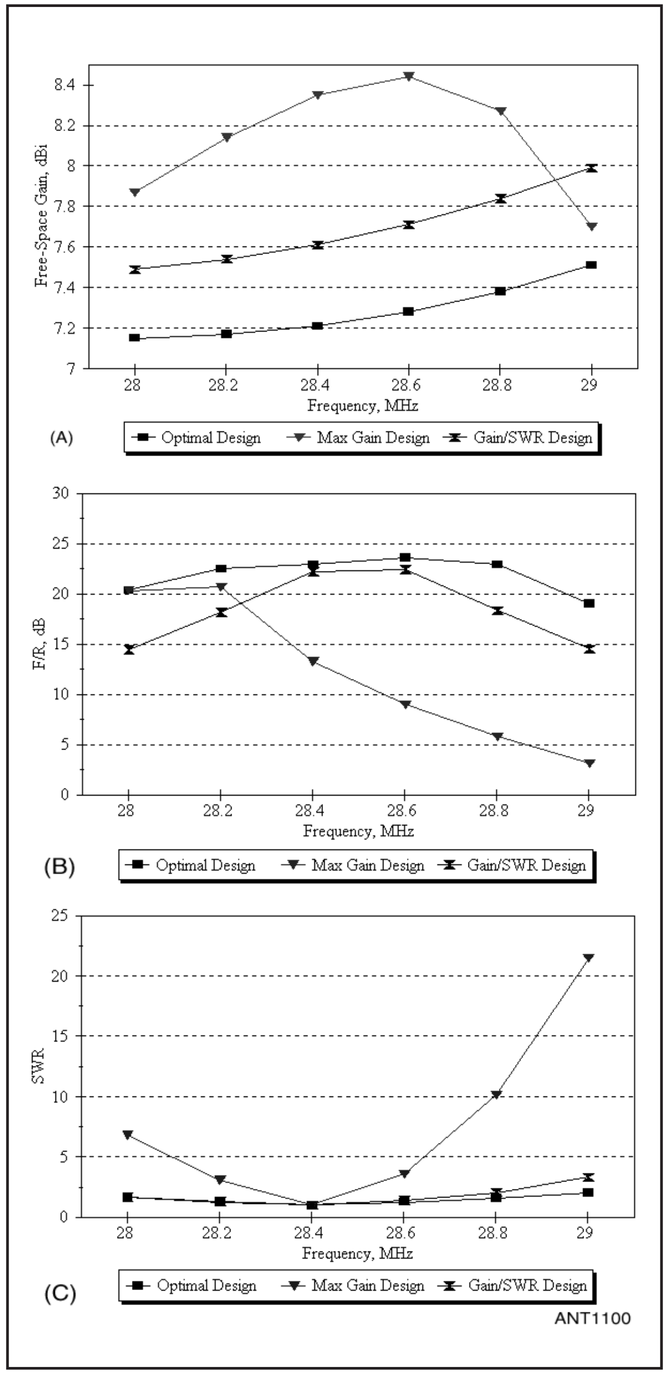


Figure 11.5 — Comparisons of three different 3-element 10 meter Yagi designs using 8-foot booms. At A, gain comparisons are shown. The Yagi designed for the best compromise of gain and SWR sacrifices an average of about 0.5 dB compared to the antenna designed for maximum gain. The Yagi designed for optimal F/R, gain and SWR sacrifices an average of 1.0 dB compared to the maximum-gain case, and about 0.4 dB compared to the compromise gain and SWR case. At B, the front-to-rear ratio is shown for the three different designs. The antenna designed for optimal combination of gain, F/R and SWR maintains a F/R higher than 20 dB across the entire frequency range, while the antenna designed strictly for gain has a F/R of 3 dB at the high end of the band. At C, the three antenna designs are compared for SWR bandwidth. At the high end of the band, the antenna designed strictly for gain has a very high SWR.

10 meter Yagi on a 20-foot boom. Figure 11.6B shows the variation in F/R, and Figure 11.6C shows the SWR curves versus frequency. Once again, the design that concentrates solely on maximum gain has a poor SWR curve over the band, reaching just over 6:1 toward the high end of the band. The difference in gain between the maximum gain case and the optimum design case has narrowed for this size of boom to an average of under 0.5 dB. This comes about because the designer has access to more variables in a 5-element design than he does in a 3-element design, and he can stagger-tune the various elements to spread the response out over the whole band.

Figure 11.7A, **B** and **C** show the same three types of designs, but for a 6-element Yagi on a 36-foot boom. The SWR bandwidth of the antenna designed for maximum gain has improved compared to the previous two shorter-boom examples, but the SWR still rises to more than 4:1 at 28.8 MHz, while the F/R ratio is pretty constant over the band, at a mediocre 11 dB average level. While the antenna designed for gain and SWR does hold the SWR below 2:1 over the band, it also has the same mediocre level of F/R performance as does the maximum-gain design.

The optimized 36-foot boom antenna achieves an excellent F/R of more than 22 dB over the whole 28.0 to 28.8 MHz band. Again, the availability of more elements and more space on the 36-foot long boom gives the designer more flexibility in broad-banding the response over the whole band, while sacrificing only 0.3 dB of gain compared to the maximum-gain design.

Figure 11.8A, **B**, and **C** show the same three types of 10 meter designs, but now for a 60-foot boom, populated with eight elements. With eight elements and a very long boom on which to space them out, the antenna designed solely for maximum gain can achieve a much better SWR response across the band, although the SWR does rise to more than 7:1 at the very high end of the band. The SWR remains less than 2:1 from 28.0 to 28.7 MHz, much better than for shorter-boom, maximum-gain designs. The worst-case F/R ratio is never better than 19 dB, however, and remains around 10 dB over much of the band. The antenna designed for the best compromise gain and SWR loses only about 0.1 dB of gain compared to the maximum-gain design, but does little better in terms of F/R across the band.

Contrasted to these two designs, the antenna optimized for F/R, SWR and gain has an outstanding pattern, exhibiting an F/R of more than 24 dB across the entire band, while keeping the SWR below 2:1 from 28.0 to 28.9 MHz. It must sacrifice an average of only 0.4 dB compared to the maximum gain design at the low end of the band, and actually has more gain than the maximum gain and gain/SWR designs at the high-frequency end of the band.

The conclusion drawn from these and many other detailed comparisons is that designing strictly for maximum mid-band gain yields an inferior design when the antenna is examined over an entire frequency band, especially in terms of SWR. Designing a Yagi for both gain and SWR will yield antennas that have mediocre rearward patterns, but that lose relatively

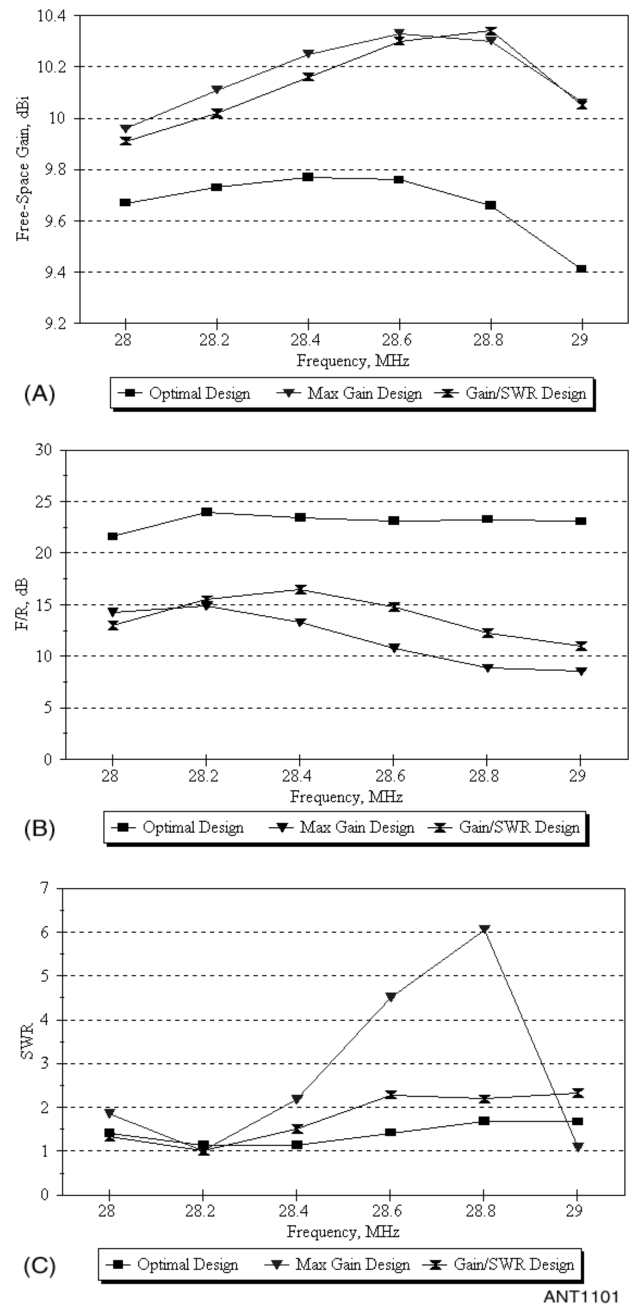


Figure 11.6 — Comparisons of three different designs for 5-element 10 meter Yagis on 20-foot booms. At A, the gain of three different 5-element 10 meter Yagi designs are graphed. The difference in gain between the three antennas narrows because the elements can be stagger-tuned to spread the response out better over the desired frequency band. The average gain reduction for the fully optimized antenna design is about 0.5 dB. At B, the optimal antenna displays better than 22 dB F/R over the band, while the Yagi designed for gain and SWR displays on average 10 dB less F/R throughout the band. At C, the SWR bandwidth is compared for the three Yagis. The antenna designed strictly for forward gain has a poor SWR bandwidth and a high peak SWR of 6:1 at 28.8 MHz.

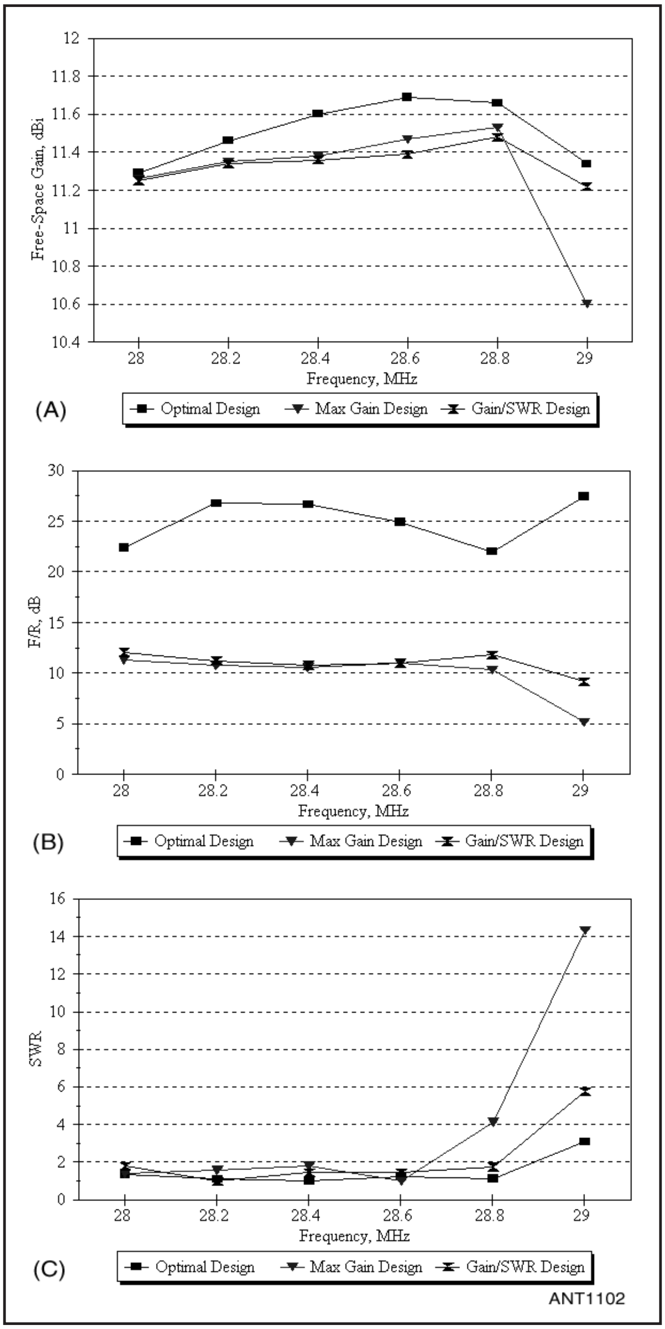


Figure 11.7 — Comparisons of three different 6-element 10 meter Yagi designs on 36-foot booms. At A, gain is shown over the band. With more elements and a longer boom, the tuning can be staggered even more to make the antenna gain more uniform over the band. This narrows the gain differential between the antenna designed strictly for maximum gain and the antenna designed for an optimal combination of F/R, SWR and gain. The average difference in gain is about 0.2 dB throughout the band. At B, the F/R performance over the band is shown for the three antenna designs. The antenna designed for optimal performance maintains an average of almost 15 dB better F/R over the whole band compared to the other designs. At C, the SWR bandwidth is compared. Again, the antenna designed strictly for maximum gain exhibits a high SWR of 4:1 at 28.8 MHz, and rises to more than 14:1 at 29.0 MHz.

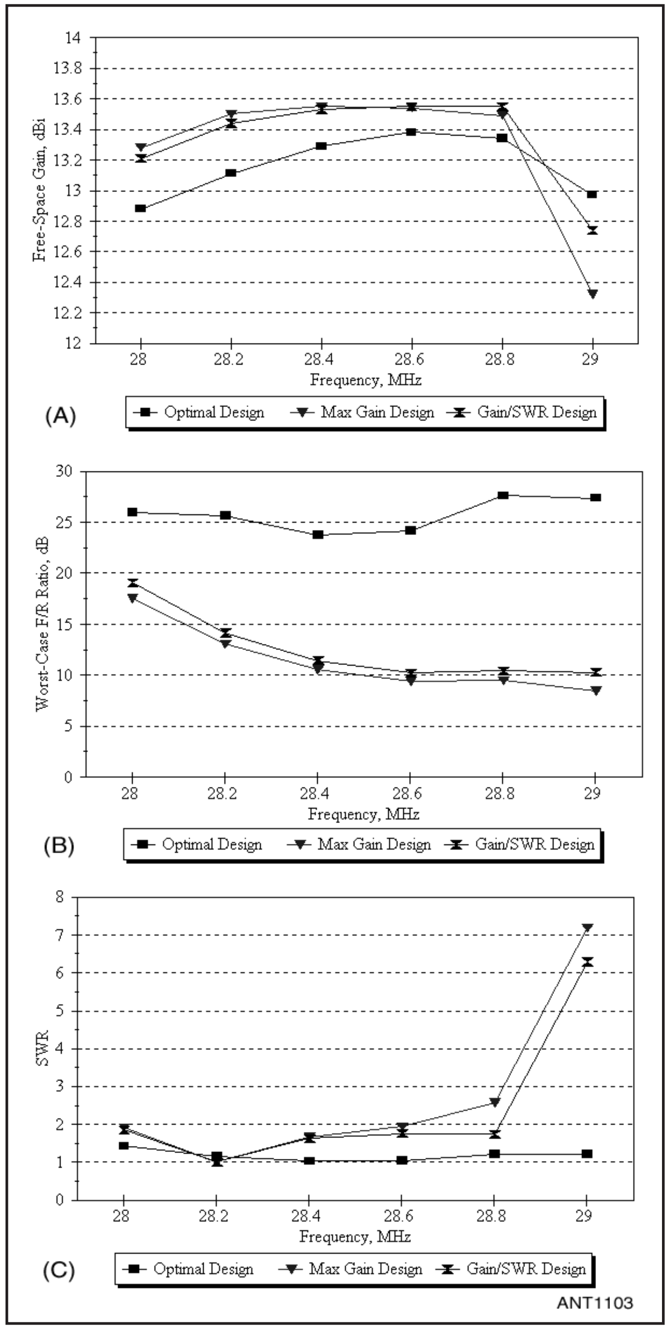


Figure 11.8 — Comparisons of three different 8-element 10 meter Yagi designs using 60-foot booms. At A, gain is shown over the frequency band. With even more freedom to stagger-tune elements and a very long boom on which to place them, the average antenna gain differential over the band is now less than 0.2 dB between the three design cases. At B, an excellent 24 dB F/R for the optimal design is maintained over the whole band, compared to the average of about 12 dB for the other two designs. At C, the SWR differential over the band is narrowed between the three designs, again because there are more variables available to broaden the bandwidth.

little gain compared to the maximum gain case, at least for designs with more than three elements.

However, designing a Yagi for an optimal combination of F/R, SWR and gain results in a loss of gain less than 0.5 dB compared to designs designed only for gain and SWR. **Figure 11.9** summarizes the forward gain achieved for the three different design types versus boom length, as expressed in wavelength.

Except for the 2-element designs, the Yagis described in the rest of this chapter have the following design goals over a desired frequency band:

1) Front-to-rear ratio over the frequency band of more than 20 dB

2) SWR over the frequency band less than 2:1

3) Maximum gain consistent with points 1 and 2 above

Just for fun and to illustrate what an imaginative antenna designer can do with modeling software, **Figure 11.10** shows the gain versus boom length for theoretical 20 meter Yagis that have been designed to meet the three design goals above. The 31-element design for 14 MHz would be wondrous to behold. Sadly, it is unlikely that anyone will build one, considering that the boom would be 724 feet long! However, such a design *does* become practical when scaled to 432 MHz. In fact, a K1FO 22-element and a K1FO 31-element Yagi described in the **VHF and UHF Antenna Systems** chapter are the prototypes for the theoretical 14-MHz long-boom designs.

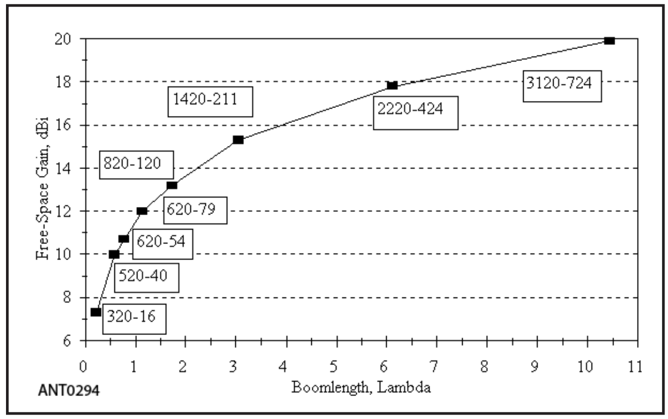


Figure 11.10 — Theoretical gain versus boom length for 20 meter Yagis designed for optimal combination of F/R, SWR and gain across the entire 14.0 to 14.35 MHz band. The theoretical gain approaches 20 dBi for a gigantic 724-foot boom, populated with 31 elements. Such a design on 20 meters is not too practical, of course, but can readily be achieved on a 24-foot boom on 432 MHz.

11.3.3 OPTIMIZED DESIGNS AND ELEMENT SPACING

Two-Element Yagis

Many hams consider a 2-element Yagi to give "the most bang for the buck" among various Yagi designs, particularly for portable operations such as Field Day. A 2-element Yagi has about 4 dB of gain over a simple dipole (sometimes jokingly called a "one-element Yagi") and gives a modest F/R of about 10 dB to help with rejection of interference on receive. By comparison, going from a 2-element to a 3-element Yagi increases the boom length by about 50% and adds another element, a 50% increase in the number of elements — for a gain increase of about 1 dB and another 10 dB in F/R.

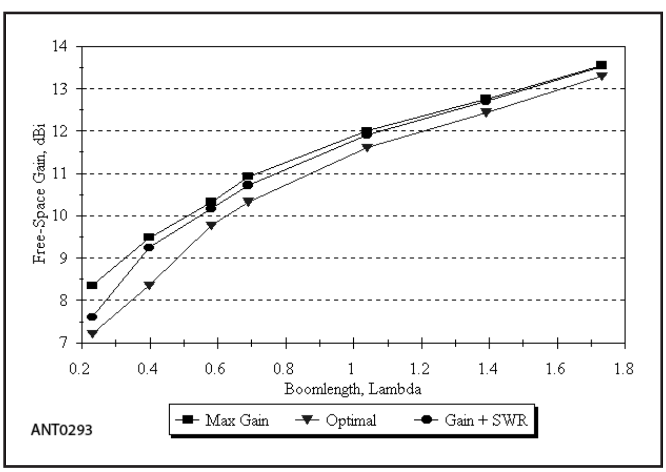


Figure 11.9 — Gain versus boom length for three different 10 meter design goals. The goals are: (1) designed for maximum gain across band, (2) designed for a compromise of gain and SWR, and (3) designed for optimal F/R, SWR and gain across 28.0 to 28.8 MHz portion of 10 meter band. The gain difference is less than 0.5 dB for booms longer than approximately 0.5 λ.

Element Spacing in Larger Yagis

One of the more interesting results of computer modeling and optimization of high-performance Yagis with four or more elements is that a distinct pattern in the element spacings along the boom shows up consistently. This pattern is relatively independent of boom length, once the boom is longer than about 0.3 λ.

The reflector, driven element and first director of these optimal designs are typically bunched rather closely together, occupying together only about 0.15 to 0.20 λ of the boom. This pattern contrasts sharply with older designs, where the amount of boom taken up by the reflector, driven element and first director was typically more than 0.3 λ. **Figure 11.11** shows the element spacings for an optimized 6-element, 36-foot boom, 10 meter design, compared to a W2PV 6-element design with constant spacing of 0.15 λ between all elements.

A problem arises with such a bunching of elements toward the reflector end of the boom — the wind loading of the antenna is not equal along the boom. Unless properly compensated, such new-generation Yagis will act like wind vanes, punishing and often breaking, the rotators trying to turn, or hold, them in the wind. One successful solution to wind-vaning has been to employ "dummy elements" made of PVC pipe. These non-conducting elements — called *torque compensators* — are placed on the boom close to the last director so the wind load is equalized at the mast-to-boom bracket. Flat plates can also be installed on the boom to oppose the turning force from the elements.

Along with an unbalanced wind load, the weight balance

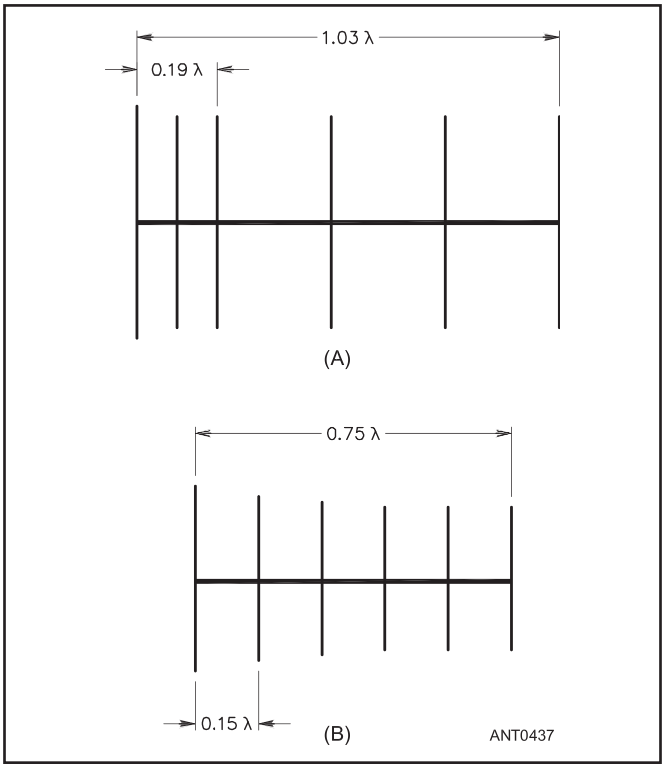


Figure 11.11 — Tapering spacing versus constant element spacing. At A, illustration of how the spacing of the reflector, driven element and first director (over the first 0.19 λ of the boom) of an optimally designed Yagi is bunched together compared to the Yagi at B, which uses constant 0.15 λ spacing between all elements. The optimally designed antenna has more than 22 dB F/R and an SWR less than 1.5:1 over the frequency band 28.0 to 28.8 MHz.

point is likely to be different than wind load balance point. The solution is generally to place a small amount of lead or iron inside one end of the boom in order to balance the antenna weight.

Despite the relatively close spacing of the reflector, driven element and first director, modern optimal Yagi designs are not overly sensitive to small changes in either element length or spacing. In fact, these antennas can be constructed from design tables without excessive concern about close dimensional tolerances. In the HF range up to 30 MHz, building the antennas to the nearest ⅛-inch results in performance remarkably consistent with the computations, without any "tweaking" or fine-tuning when the Yagi is on the tower.

11.3.4 ELEMENT TUNING

Element tuning (or *self-impedance*) is a complex function of the effective electrical length of each element and the effective diameter of the element. In turn, the effective length and diameter of each element is related to the taper schedule (if telescoping aluminum tubing is used, the most common method of construction), the length of each telescoping section, the type and size of mounting bracket used to secure the element to or through the boom, and the size of the Yagi boom itself. Note especially that Yagis constructed using wire elements will perform very differently compared to the same antenna constructed with elements made of telescoping aluminum tubing.

The process by which a modern Yagi is designed usually starts out with the selection of the longest boom possible for a given installation. A suitable number of elements of a given taper schedule are then placed on this boom, and the gain, pattern and SWR are calculated over the entire frequency band of interest to the designer. Once an electrical design is chosen, the designer must then ensure the mechanical integrity of the antenna design. This involves verifying the integrity of the boom and each element in the face of the wind and ice loading expected for a particular location. The chapter **Antenna Materials and Construction** discusses the details of tapered telescoping aluminum elements for the upper HF bands. In addition, the ARRL book *Physical Design of Yagi Antennas*, by Dave Leeson, W6NL, describes the mechanical design process for all portions of a Yagi antenna very thoroughly, and is highly recommended for serious Yagi builders. (This book is now out of print.)

11.4 MONOBAND YAGI DESIGNS

The detailed Yagi design tables that follow are for two taper schedules for HF Yagis covering the 14 through 30-MHz amateur bands. The heavy-duty elements are designed to survive at least 120-mph winds without icing, or 85-mph winds with ¼-inch radial ice. The medium-duty elements are designed to survive winds greater than 80 mph, or 60-mph winds with ¼-inch radial ice.

For 10.1 MHz, the elements shown are capable of surviving 105-mph winds, or 93-mph winds with ¼-inch radial ice. For 7.1 MHz the elements shown can survive 93-mph winds, or 69-mph winds with ¼-inch radial ice. For these two lower frequency bands, the elements and the booms needed are very large and heavy. Mounting, turning and keeping such antennas in the air is not a trivial task.

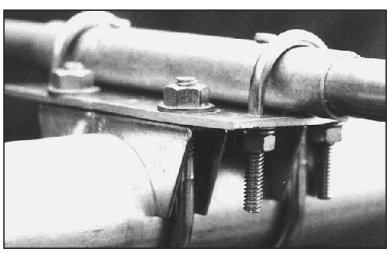
Each element is mounted above the boom with a heavy rectangular aluminum plate by means of U-bolts with saddles, as shown in **Figure 11.12A**. This method of element mounting is rugged and stable, and because the element is mounted away from the boom, the amount of element detuning due to the presence of the boom is minimal. The element dimensions given in each table already take into account any element detuning due to the boom-to-element mounting plate. For each element, the length of the tip determines the tuning, since the inner tubes are fixed in diameter and length.

The element-to-boom mounting plates are modeled as a short section of element equivalent to a cylinder with an effective diameter given for each antenna. These dimensions to simulate the effect of the mounting plate are incorporated in the files for the *YW* (*Yagi for Windows*) computer modeling program on the CD-ROM accompanying this book.

The second column in each design table shows the spacing of each element relative to the next element in line on the boom, starting at the reflector, which itself is defined as being at the 0.000-inch reference point on the boom. The boom for antennas less than 30 feet long can be constructed of 2-inch OD tubing with 0.065-inch wall thickness. Designs larger than 30 feet long should use 3-inch OD heavy-wall tubing for the boom. Because each boom has extra space at each end, the reflector is actually placed 3 inches from the end of the boom. For example, in the 310-08H.YW design (a 10 meter Yagi with 3 elements on an 8-foot boom), the driven element is placed 36 inches ahead of the reflector, and the director is placed 54 inches ahead of the driven element.

The next columns give the lengths for the variable tips for the heavy-duty and then the medium-duty elements. In the example above for the 310-08H.YW Yagi, the heavy-duty reflector tip, made out of ½-inch OD tubing, sticks out 66.750 inches from the ⅝-inch OD tubing. Note that each telescoping piece of tubing overlaps 3 inches inside the piece into which it fits, so the overall length of ⅛-inch OD tubing is 69.750 inches long for the reflector. The medium-duty reflector tip has 71.875 inches protruding from the ⅝-inch OD tube, and is 74.875 inches long overall. As previously stated, the dimensions are not extremely critical, although measurement accuracy to ⅛ inch is desirable.

(A)



(B)

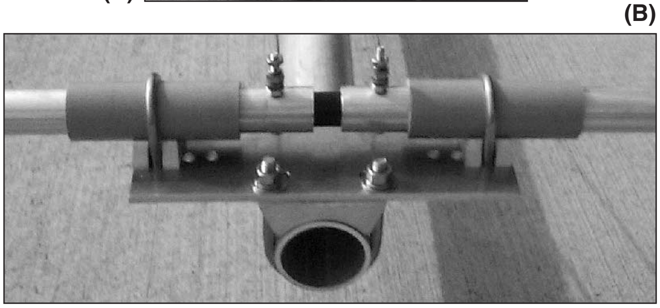


Figure 11.12 — Typical construction techniques for an HF Yagi. Photo A shows a typical element-to-boom clamp. U-bolts are used to hold the element to the plate and muffler clamps hold the plate to the boom. Photo B shows a hairpin match on a driven element insulated from a mounting plate that is attached to the boom with muffler clamps and saddles. Outdoor-rated gray PVC conduit sleeves insulate the element from the mounting plate. U-bolts hold the element on the plate. The feed line is connected to the two screws to which the hairpin inductor is attached. Note that the hairpin inductor's center point is attached to the boom at an electrically neutral point. All mounting hardware should be galvanized or stainless steel. The latter requires the use of an anti-seize compound to prevent thread galling.

The last row in each variable tip column shows the length of one-half of the "dummy element" torque compensator used to correct for uneven wind loading along the boom. This compensator is made from 2.5 inches OD PVC water pipe mounted to an element-to-boom plate like those used for each element. The compensator is mounted 12 inches behind the last director, the first director in the case of the 3-element 310-08H.YW antenna. Note that the heavy-duty elements require a correspondingly longer torque compensator than do the medium-duty elements.

Half Elements

Each design shows the dimensions for *one-half* of each element, mounted on *one side* of the boom. The other half of each element is symmetrical, mounted on the other side of the boom. The use of a tubing sleeve inside the center portion of the element is recommended, so that the element is not crushed by the mounting U-bolts. Unless otherwise noted, each section of tubing is made of 6061-T6 aluminum tubing, with a 0.058-inch wall thickness. This wall thickness ensures that the next standard size of tubing can telescope with it. Each telescoping section is inserted 3 inches into the larger tubing, and is secured by one of the methods shown in the **Antenna Materials and Construction** chapter, which also includes generic half-element designs rated for specific wind- and ice-loading conditions.

Matching System

Each antenna is designed with a driven-element length appropriate for a hairpin or *beta match* network. The driven-element's length may require slight readjustment for best match, particularly if a different matching network is used. *Do not change* either the lengths or the telescoping tubing schedule of the parasitic elements — they have been optimized for best performance and will not be affected by tuning of the driven element! (See the **Transmission Line System Techniques** chapter and the discussion on use of baluns in the previous "Direct Feed Yagis" section.)

Figure 11.12B is a photograph of the driven element for a 2-element 17 meter Yagi built by Chuck Hutchinson, K8CH, for the ARRL book *Simple and Fun Antennas for Hams.* The aluminum tubing on each side of the boom was 1-inch OD, and the two pieces were mechanically joined together with a ¾-inch OD fiberglass insulator. Chuck wound electrical tape over the insulator to protect the fiberglass from the sun's UV.

Three-inch lengths of 1-inch UV-resistant PVC conduit, split lengthwise, to make the grey outer insulators for the driven element. The aluminum plates came from DX Engineering, as did the stainless steel U-bolts and saddle clamps. These saddles ensured that the elements don't rotate on the 2-inch OD boom in heavy winds.

You can see the bolts used to pin the center fiberglass insulator to the aluminum tubing, while also providing an electrical connection for the #12 AWG hairpin inductor wire and for the feed line coax). Note that the center of the hairpin is connected to the boom using a grounding lug. The center of the hairpin inductor is electrically neutral and may be connected to boom to provide dc grounding and a measure of protection from static buildup.

11.4.1 10 METER YAGIS

Figure 11.13 describes the electrical performance of eight optimized 10 meter Yagis with boom lengths between 6 to 60 feet. The end of each boom includes 3 inches of space for the reflector and last-director (or driven element for the 2-element designs) mounting plates. Figure 11.13A shows the free-space gain versus frequency for each antenna; Figure 11.13B shows the front-to-rear ratio, and Figure 11.13C shows the SWR versus frequency. Each antenna with three or more elements was designed to cover the lower half of the 10 meter band from 28.0 to 28.8 MHz, with SWR less than 2:1 and F/R better than 20 dB over that range.

Figure 11.13D shows the taper schedule for two types of 10 meter elements. The heavy-duty design can survive 125-mph winds with no icing, and 88-mph winds with ¼-inch of radial ice. The medium-duty design can handle 96-mph winds with no icing, and 68-mph winds with ¼-inch of radial ice.

The element-to-boom mounting plate for these Yagis is a 0.250-inch thick flat aluminum plate, 4 inches wide by 4 inches long. Each element except for the insulated driven element, is centered on the plate, held by two stainless-steel U-bolts with saddles. Another set of U-bolts with saddles is used to secure the mounting plate to the boom. The mounting plate has an effective diameter of 2.405 inches for the heavy-duty element and 2.310 inches for the medium-duty element. The equivalent length on each side of the boom is 2 inches.

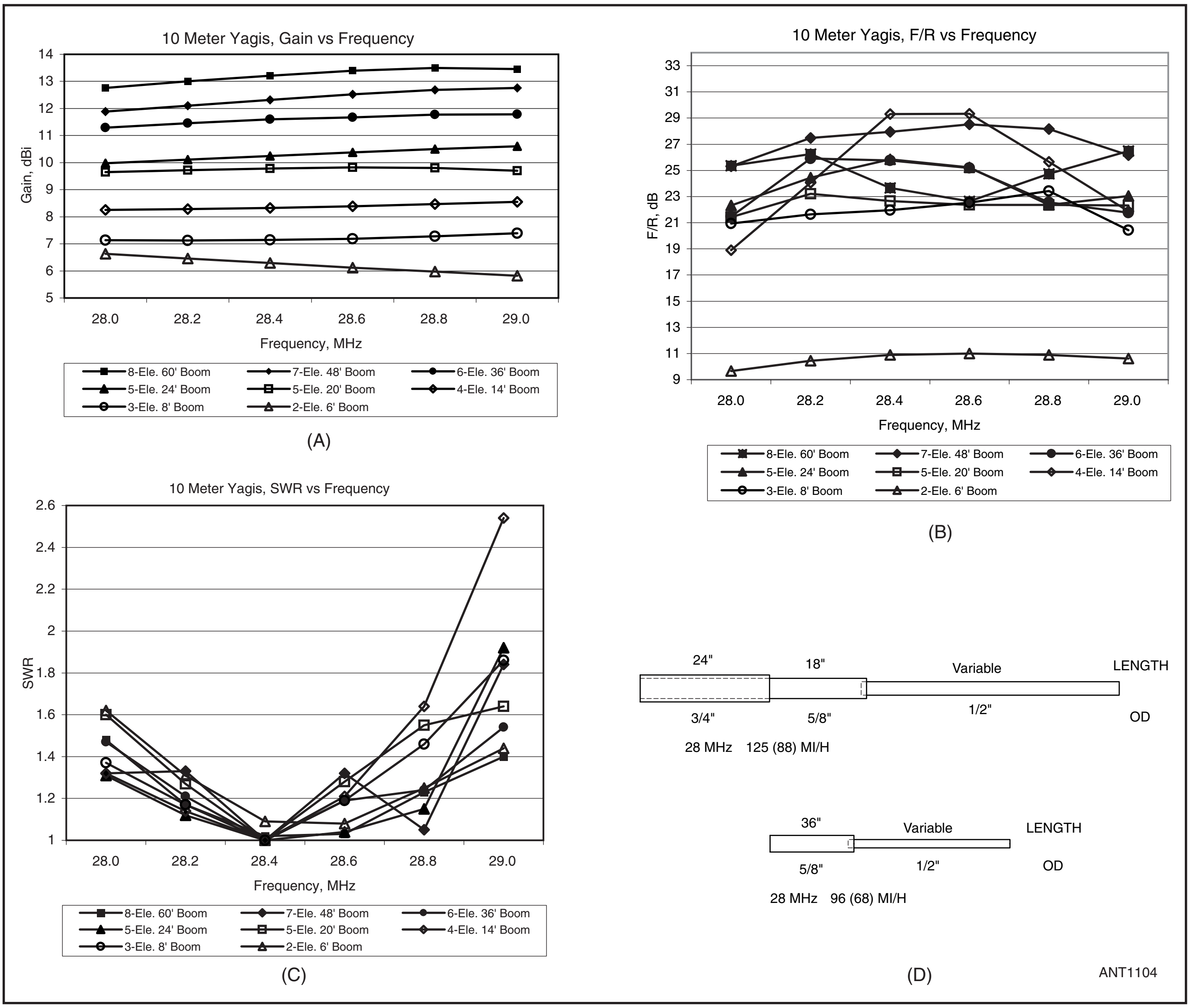


Figure 11.13 — Gain, F/R and SWR performance versus frequency for optimized 10 meter Yagis. At A, gain is shown versus frequency for eight 10 meter Yagis whose booms range from 6 feet to 60 feet long. Except for the 2-element design, these Yagis have been optimized for better than 20 dB F/R and less than 2:1 SWR over the frequency range 28.0 to 28.8 MHz. At B, front-to-rear ratio for these antennas is shown versus frequency, and at C, SWR is shown over the frequency range. At D, the taper schedule is shown for heavy-duty and for medium-duty 10 meter elements. The heavy-duty elements can withstand 125-mph winds without icing, and 88-mph winds with ¼-inch radial ice. The medium-duty elements can survive 96-mph winds without icing, and 68-mph winds with ¼-inch radial ice. The wall thickness for each telescoping section of 6061-T6 aluminum tubing is 0.058 inches, and the overlap at each telescoping junction is 3 inches.

Table 11.1
Optimized 10 meter Yagi Designs

Two-element 10 meter Yagi, 6 foot boom

Element	*Spacing*	*Heavy-Duty Tip*	*Medium-Duty Tip*
File Name		210-06H.YW	210-06M.YW
Reflector	0.000"	66.000"	71.500"
Driven Element	66.000"	57.625"	63.000"

Three-element 10 meter Yagi, 8 foot boom

Element	*Spacing*	*Heavy-Duty Tip*	*Medium-Duty Tip*
File Name		310-08H.YW	310-08M.YW
Reflector	0.000"	66.750"	71.875"
Driven Element	36.000"	57.625"	62.875"
Director 1	54.000"	53.125"	58.500"
Compensator	12" behind Dir. 1	19.000"	18.125"

Four-element 10 meter Yagi, 14 foot boom

Element	*Spacing*	*Heavy-Duty Tip*	*Medium-Duty Tip*
File Name		410-14H.YW	410-14M.YW
Reflector	0.000"	66.000"	72.000"
Driven Element	36.000"	58.625"	63.875"
Director 1	36.000"	57.000"	62.250"
Director 2	90.000"	47.750"	53.125"
Compensator	12" behind Dir. 2	22.000"	20.500"

Five-element 10 meter Yagi, 24 foot boom

Element	*Spacing, inches*	*Heavy-Duty Tip*	*Medium-Duty Tip*
File Name		510-24H.YW	510-24M.YW
Reflector	0.000"	65.625"	70.750"
Driven Element	36.000"	58.000"	63.250"
Director 1	36.000"	57.125"	62.375"
Director 2	99.000"	55.000"	60.250"
Director 3	111.000"	50.750"	56.125"
Compensator	12" behind Dir. 3	28.750"	26.750"

Six-element 10 meter Yagi, 36 foot boom

Element	*Spacing, inches*	*Heavy-Duty Tip*	*Medium-Duty Tip*
File Name		610-36H.YW	610-36M.YW
Reflector	0.000"	66.500"	71.500"
Driven Element	37.000"	58.500"	64.000"
Director 1	43.000"	57.125"	62.375"
Director 2	98.000"	54.875"	60.125"
Director 3	127.000"	53.875"	59.250"
Director 4	121.000"	49.875"	55.250"
Compensator	12" behind Dir. 4	32.000"	29.750"

Seven-element 10 meter Yagi, 48 foot boom

Element	*Spacing, inches*	*Heavy-Duty Tip*	*Medium-Duty Tip*
File Name		710-48H.YW	710-48M.YW
Reflector	0.000"	65.375"	70.500"
Driven Element	37.000"	59.000"	64.250"
Director 1	37.000"	57.500"	62.750"
Director 2	96.000"	54.875"	60.125"
Director 3	130.000"	52.250"	57.625"
Director 4	154.000"	52.625"	58.000"
Director 5	116.000"	49.875"	55.250"
Compensator	12" behind Dir. 5	35.750"	33.750"

Eight-element 10 meter Yagi, 60 foot boom

Element	*Spacing, inches*	*Heavy-Duty Tip*	*Medium-Duty Tip*
File Name		810-60H.YW	810-60M.YW
Reflector	0.000"	65.000"	70.125"
Driven Element	42.000"	58.000"	63.500"
Director 1	37.000"	57.125"	62.375"
Director 2	87.000"	55.375"	60.625"
Director 3	126.000"	53.250"	58.625"
Director 4	141.000"	51.875"	57.250"
Director 5	157.000"	52.500"	57.875"
Director 6	121.000"	50.125"	55.500"
Compensator	12" behind Dir. 6	59.375"	55.125"

These 10 meter Yagi designs are optimized for > 20 dB F/R, and SWR < 2:1 over frequency range from 28.000 to 28.800 MHz, for heavy-duty elements (125 mph wind survival) and for medium-duty (96 mph wind survival).
For coverage from 28.8 to 29.7 MHz, subtract 2.000 inches from end of each element, but leave element spacings the same as shown here. Only element tip dimensions are shown, and all dimensions are inches. See Fig 11.13D for element telescoping tubing schedule. Torque compensator element is made of 2.5" OD PVC water pipe placed 12 inches behind last director. Dimensions shown for compensators is one-half of total length, centered on boom.

11.4.2 12 METER YAGIS

Figure 11.14 describes the electrical performance of seven optimized 12 meter Yagis with boom lengths between 6 to 54 feet. The end of each boom includes 3 inches of space for the reflector and last director (or driven element) mounting plates. The narrow frequency range of the 12 meter band allows the performance to be optimized easily. Figure 11.14A shows the free-space gain versus frequency for each antenna; Figure 11.14B shows the front-to-rear ratio, and Figure 11.14C shows the SWR versus frequency. Each antenna with three or more elements was designed to cover the narrow 12 meter band from 24.89 to 24.99 MHz, with SWR less than 2:1 and F/R better than 20 dB over that range.

Figure 11.14D shows the taper schedule for two types of 12 meter elements. The heavy-duty design can survive 123-mph winds with no icing, and 87-mph winds with ¼ inch of radial ice. The medium-duty design can handle 85-mph winds with no icing, and 61-mph winds with ¼ inch of radial ice.

The element-to-boom mounting plate for these Yagis is a 0.375 inch thick flat aluminum plate, 5 inches wide by 6 inches long. The mounting plate has an effective diameter of 2.945 inches for the heavy-duty element, and 2.857 inches for the medium-duty element. The equivalent length on each side of the boom is 3 inches. As usual, the torque compensator is mounted 12 inches behind the last director.

11.4.3 15 METER YAGIS

Figure 11.15 describes the electrical performance of eight optimized 15 meter Yagis with boom lengths between 6 feet to a spectacular 80 feet. The end of each boom includes 3 inches of space for the reflector and last director (or driven

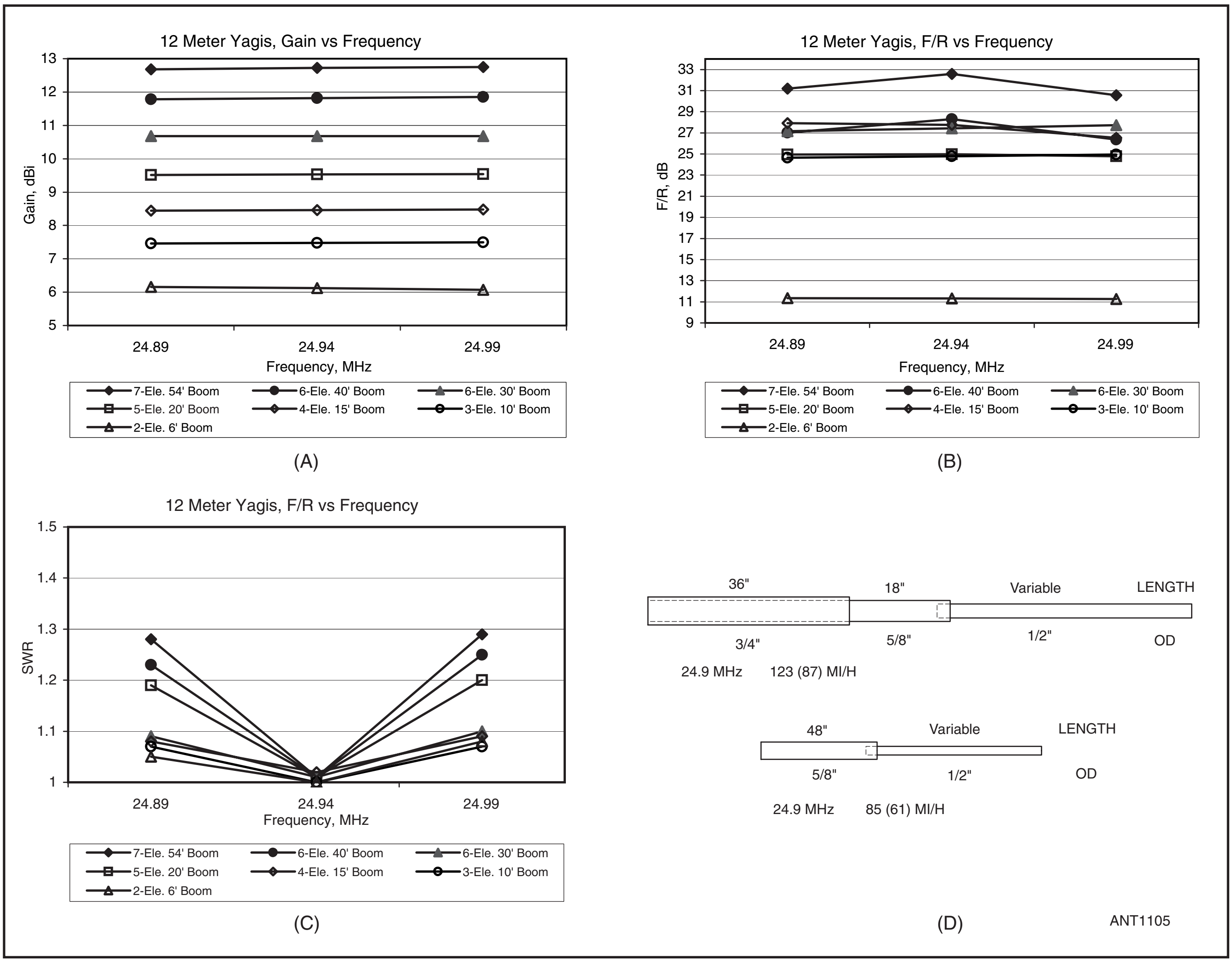


Figure 11.14 — Gain, F/R and SWR performance versus frequency for optimized 12 meter Yagis. At A, gain is shown versus frequency for seven 12 meter Yagis whose booms range from 6 feet to 54 feet long. Except for the 2-element design, these Yagis have been optimized for better than 20 dB F/R and less than 2:1 SWR over the narrow 12 meter band 24.89 to 24.99 MHz. At B, front-to-rear ratio for these antennas is shown versus frequency, and at C, SWR over the frequency range is shown. At D, the taper schedule for heavy-duty and for medium-duty 12 meter elements is shown. The heavy-duty elements can withstand 123-mph winds without icing, and 87-mph winds with ¼-inch radial ice. The medium-duty elements can survive 85-mph winds without icing, and 61-mph winds with ¼-inch radial ice. The wall thickness for each telescoping section of 6061-T6 aluminum tubing is 0.058 inches, and the overlap at each telescoping junction is 3 inches.

Table 11.2
Optimized 12 meter Yagi Designs

Two-element 12 meter Yagi, 6 foot boom

Element	*Spacing*	*Heavy-Duty Tip*	*Medium-Duty Tip*
File Name		212-06H.YW	212-06M.YW
Reflector	0.000"	67.500"	72.500"
Driven Element	66.000"	59.500"	65.000"

Three-element 12 meter Yagi, 10 foot boom

Element	*Spacing, inches*	*Heavy-Duty Tip*	*Medium-Duty Tip*
File Name		312-10H.YW	312-10M.YW
Reflector	0.000"	69.000"	73.875"
Driven Element	40.000"	60.250"	65.250"
Director 1	74.000"	54.000"	59.125"
Compensator	12" behind Dir. 1	13.625"	12.000"

Four-element 12 meter Yagi, 15 foot boom

Element	*Spacing, inches*	*Heavy-Duty Tip*	*Medium-Duty Tip*
File Name		412-15H.YW	412-15M.YW
Reflector	0.000"	66.875"	71.875"
Driven Element	46.000"	61.000"	66.000"
Director 1	46.000"	58.625"	63.750"
Director 2	82.000"	50.875"	56.125"
Compensator	12" behind Dir. 2	16.375"	14.500"

Five-element 12 meter Yagi, 20 foot boom

Element	*Spacing, inches*	*Heavy-Duty Tip*	*Medium-Duty Tip*
File Name		512-20H.YW	512-20M.YW
Reflector	0.000"	69.750"	74.625"
Driven Element	46.000"	62.250"	67.000"
Director 1	46.000"	60.500"	65.500"
Director 2	48.000"	55.500"	60.625"
Director 3	94.000"	54.625"	59.750"
Compensator	12" behind Dir. 3	22.125"	19.625"

Six-element 12 meter Yagi, 30 foot boom

Element	*Spacing, inches*	*Heavy-Duty Tip*	*Medium-Duty Tip*
File Name		612-30H.YW	612-30M.YW
Reflector	0.000"	68.125"	73.000"
Driven Element	46.000"	61.750"	66.750"
Director 1	46.000"	60.250"	65.250"
Director 2	73.000"	52.375"	57.625"
Director 3	75.000"	57.625"	62.750"
Director 4	114.000"	53.625"	58.750"
Compensator	12" behind Dir. 4	30.000"	26.250"

Six-element 12 meter Yagi, 40 foot boom

Element	*Spacing, inches*	*Heavy-Duty Tip*	*Medium-Duty Tip*
File Name		612-40H.YW	612-40M.YW
Reflector	0.000"	67.000"	71.875"
Driven Element	46.000"	60.125"	65.500"
Director 1	46.000"	57.375"	62.500"
Director 2	91.000"	57.375"	62.500"
Director 3	157.000"	57.000"	62.125"
Director 4	134.000"	54.375"	59.500"
Compensator	12" behind Dir. 4	36.500"	31.625"

Seven-element 12 meter Yagi, 54 foot boom

Element	*Spacing, inches*	*Heavy-Duty Tip*	*Medium-Duty Tip*
File Name		712-54H.YW	712-54M.YW
Reflector	0.000"	68.000"	73.000"
Driven Element	46.000"	60.500"	65.500"
Director 1	46.000"	56.750"	61.875"
Director 2	75.000"	58.000"	63.125"
Director 3	161.000"	55.625"	60.750"
Director 4	174.000"	56.000"	61.125"
Director 5	140.000"	53.125"	58.375"
Compensator	12" behind Dir. 5	43.125"	37.500"

These 12 meter Yagi designs were optimized for > 20 dB F/R, and SWR < 2:1 over frequency range from 24.890 to 24.990 MHz, for heavy-duty elements (123 mph wind survival) and for medium-duty (85 mph wind survival). Only element tip dimensions are shown, and all dimensions are inches. See Fig 11.14D for element telescoping tubing schedule. Torque compensator element is made of 2.5" OD PVC water pipe placed 12" behind last director. Dimensions shown for compensators is one-half of total length, centered on boom.

Table 11.3
Optimized 15 meter Yagi Designs

Two-element 15 meter Yagi, 6 foot boom

Element	*Spacing*	*Heavy-Duty Tip*	*Medium-Duty Tip*
File Name		215-06H.YW	215-06M.YW
Reflector	0.000"	62.000"	85.000"
Driven Element	66.000"	51.000"	74.000"

Three-element 15 meter Yagi, 12 foot boom

Element	*Spacing*	*Heavy-Duty Tip*	*Medium-Duty Tip*
File Name		315-12H.YW	315-12M.YW
Reflector	0.000"	62.000"	84.250"
Driven Element	48.000"	51.000"	73.750"
Director 1	92.000"	43.500"	66.750"
Compensator	12" behind Dir. 1	34.750"	37.625"

Four-element 15 meter Yagi, 18 foot boom

Element	*Spacing*	*Heavy-Duty Tip*	*Medium-Duty Tip*
File Name		415-18H.YW	415-18M.YW
Reflector	0.000"	61.000"	83.500"
Driven Element	56.000"	51.500"	74.500"
Director 1	56.000"	48.000"	71.125"
Director 2	98.000"	36.625"	60.250"
Compensator	12" behind Dir. 2	20.875"	18.625"

Five-element 15 meter Yagi, 24 foot boom

Element	*Spacing*	*Heavy-Duty Tip*	*Medium-Duty Tip*
File Name		515-24H.YW	515-24M.YW
Reflector	0.000"	62.000"	84.375"
Driven Element	48.000"	52.375"	75.250"
Director 1	48.000"	47.875"	71.000"
Director 2	52.000"	47.000"	70.125"
Director 3	134.000"	41.000"	64.375"
Compensator	12" behind Dir. 3	40.250"	35.125"

Six-element 15 meter Yagi, 36 foot boom

Element	*Spacing*	*Heavy-Duty Tip*	*Medium-Duty Tip*
File Name		615-36H.YW	615-36M.YW
Reflector	0.000"	61.000"	83.375"
Driven Element	53.000"	52.000"	75.000"
Director 1	56.000"	49.125"	72.125"
Director 2	59.000"	45.125"	68.375"
Director 3	116.000"	47.875"	71.000"
Director 4	142.000"	42.000"	65.375"
Compensator	12" behind Dir. 4	45.500"	39.750"

Seven-element 15 meter Yagi, 48 foot boom

Element	*Spacing*	*Heavy-Duty Tip*	*Medium-Duty Tip*
File Name		615-48H.YW	615-48M.YW
Reflector	0.000"	62.000"	84.000"
Driven Element	48.000"	52.000"	75.000"
Director 1	48.000"	51.250"	74.125"
Director 2	125.000"	48.000"	71.125"
Director 3	190.000"	45.500"	68.750"
Director 4	161.000"	42.000"	65.375"
Compensator	12" behind Dir. 4	51.500"	45.375"

Seven-element 15 meter Yagi, 60 foot boom

Element	*Spacing*	*Heavy-Duty Tip*	*Medium-Duty Tip*
File Name		715-60H.YW	715-60M.YW
Reflector	0.000"	59.750"	82.250"
Driven Element	48.000"	52.000"	75.000"
Director 1	48.000"	52.000"	74.875"
Director 2	93.000"	49.500"	72.500"
Director 3	173.000"	44.125"	67.375"
Director 4	197.000"	45.500"	68.750"
Director 5	155.000"	41.750"	65.125"
Compensator	12" behind Dir. 5	58.500"	51.000"

Eight-element 15 meter Yagi, 80 foot boom

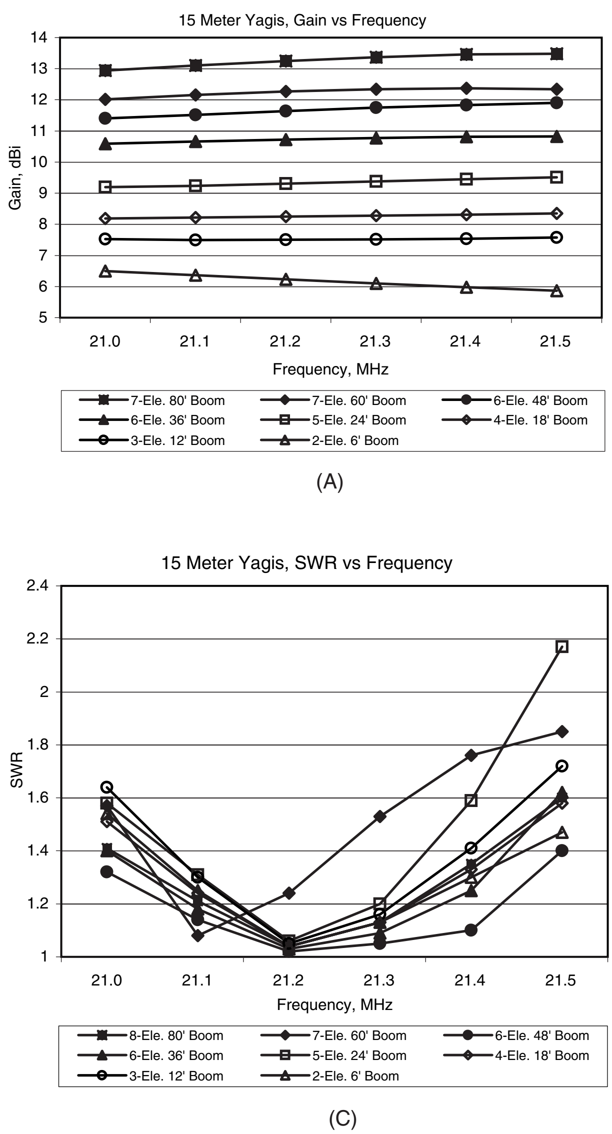
Element	*Spacing*	*Heavy-Duty Tip*	*Medium-Duty Tip*
File Name		815-80H.YW	815-80M.YW
Reflector	0.000"	62.000"	84.000"
Driven Element	56.000"	52.500"	75.500"
Director 1	48.000"	51.500"	74.375"
Director 2	115.000"	48.375"	71.500"
Director 3	164.000"	45.750"	69.000"
Director 4	202.000"	43.125"	66.500"
Director 5	206.000"	44.750"	68.000"
Director 6	163.000"	40.875"	64.250"
Compensator	12" behind Dir. 6	95.000"	83.375"

These 15 meter Yagi designs are optimized for > 20 dB F/R, and SWR < 2:1 over entire frequency range from 21.000 to 21.450 MHz, for heavy-duty elements (124 mph wind survival) and for medium-duty (86 mph wind survival). Only element tip dimensions are shown. See Fig 11.15D for element telescoping tubing schedule. All dimensions are in inches. Torque compensator element is made of 2.5" OD PVC water pipe placed 12" behind last director, and dimensions shown for compensators is one-half of total length, centered on boom.

element) mounting plates. Figure 11.15A shows the free-space gain versus frequency for each antenna; Figure 11.15B shows the worst-case front-to-rear ratio, and Figure 11.15C shows the SWR versus frequency. Each antenna with three or more elements was designed to cover the full 15 meter band from 21.000 to 21.450 MHz, with SWR less than 2:1 and F/R ratio better than 20 dB over that range.

Figure 11.15D shows the taper schedule for two types of 15 meter elements. The heavy-duty design can survive 124-mph winds with no icing, and 90-mph winds with ¼ inch of radial ice. The medium-duty design can handle 86-mph winds with no icing, and 61-mph winds with ¼ inch of radial ice.

The element-to-boom mounting plate for these Yagis is a 0.375-inch thick flat aluminum plate, 5 inches wide by 6 inches long. The mounting plate has an effective diameter of 3.0362 inches for the heavy-duty element, and 2.9447 inches for the medium-duty element. The equivalent length on each side of the boom is 3 inches. As usual, the torque compensator is mounted 12 inches behind the last director.



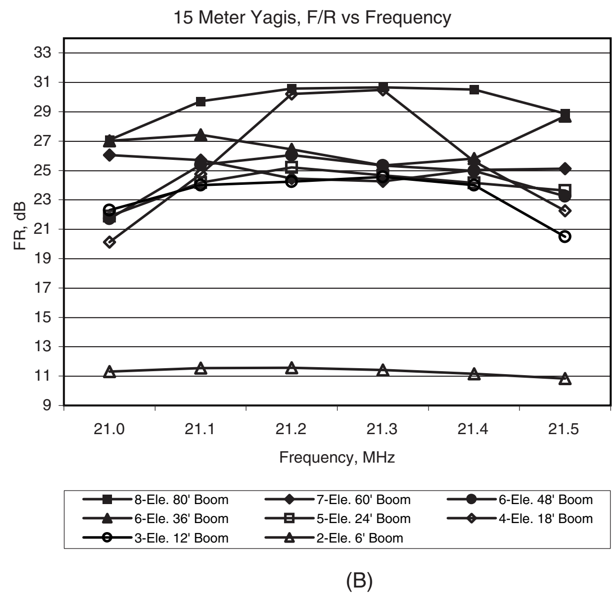
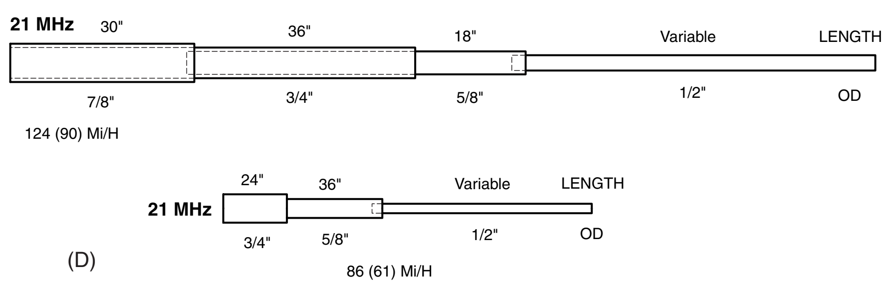


Figure 11.15 — Gain, F/R and SWR performance versus frequency for optimized 15 meter Yagis. At A, gain versus frequency is shown for eight 15 meter Yagis whose booms range from 6 feet to 80 feet long. Except for the 2-element design, these Yagis have been optimized for better than 20 dB F/R and less than 2:1 SWR over the frequency range 21.0 to 21.45 MHz. At B, front-to-rear ratio for these antennas is shown versus frequency, and at C, SWR over the frequency range is shown. At D, the taper schedule for heavy-duty and for medium-duty 15 meter elements is shown. The heavy-duty elements can withstand 124-mph winds without icing, and 90-mph winds with ¼-inch radial ice. The medium-duty elements can survive 86-mph winds without icing, and 61-mph winds with ¼-inch radial ice. The wall thickness for each telescoping section of 6061-T6 aluminum tubing is 0.058 inches, and the overlap at each telescoping junction is 3 inches.



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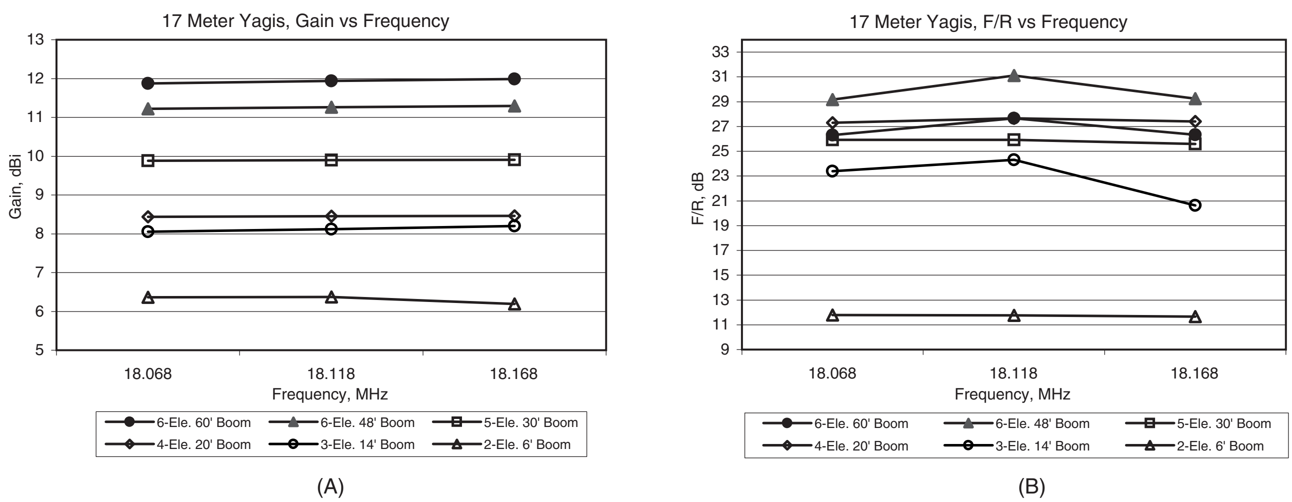
11.4.4 17 METER YAGIS

Figure 11.16 describes the electrical performance of six optimized 17 meter Yagis with boom lengths between 6 to a heroic 60 feet. As usual, the end of each boom includes 3 inches of space for the reflector and last director (or driven element) mounting plates. Figure 11.16A shows the free-space gain versus frequency for each antenna; Figure 11.16B shows the worst-case front-to-rear ratio, and Figure 11.16C shows the SWR versus frequency. Each antenna with three or more elements was designed to cover the narrow 17 meter band from 18.068 to 18.168 MHz, with SWR less than 2:1 and F/R ratio better than 20 dB over that range.

Figure 11.16D shows the taper schedule for two types of 17 meter elements. The heavy-duty design can survive 123-mph winds with no icing, and 83-mph winds with ¼-inch of radial ice. The medium-duty design can handle 83-mph winds with no icing, and 59-mph winds with ¼ inch of radial ice.

The element-to-boom mounting plate for these Yagis is a 0.375-inch thick flat aluminum plate, 6 inches wide by 8 inches long. The mounting plate has an effective diameter of 3.5122 inches for the heavy-duty element, and 3.3299 inches for the medium-duty element. The equivalent length on each side of the boom is 4 inches. As usual, the torque compensator is mounted 12 inches behind the last director.



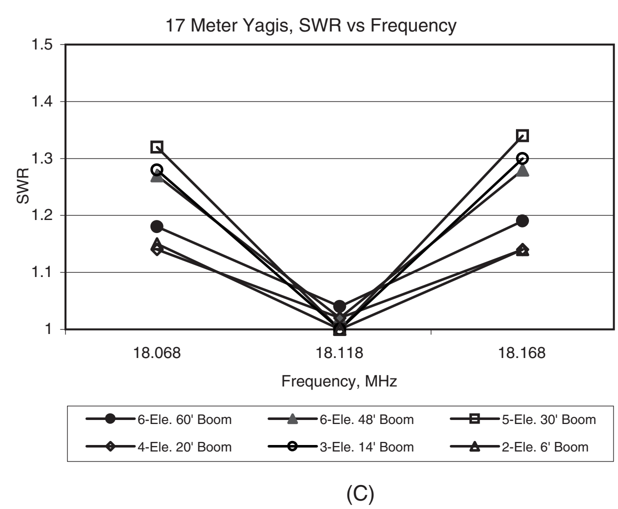


Figure 11.16 — Gain, F/R and SWR performance versus frequency for optimized 17 meter Yagis. At A, gain versus frequency is shown for six 17 meter Yagis whose booms range from 6 feet to 60 feet long. Except for the 2-element design, these Yagis have been optimized for better than 20 dB F/R and less than 2:1 SWR over the narrow 17 meter band 18.068 to 18.168 MHz. At B, front-to-rear ratio for these antennas is shown versus frequency, and at C, SWR over the frequency range is shown. At D, the taper schedule for heavy-duty and for medium-duty 10 meter elements is shown. The heavy-duty elements can withstand 123-mph winds without icing, and 89-mph winds with ¼-inch radial ice. The medium-duty elements can survive 83-mph winds without icing, and 59-mph winds with ¼-inch radial ice. The wall thickness for each telescoping section of 6061-T6 aluminum tubing is 0.058 inches, and the overlap at each telescoping junction is 3 inches.

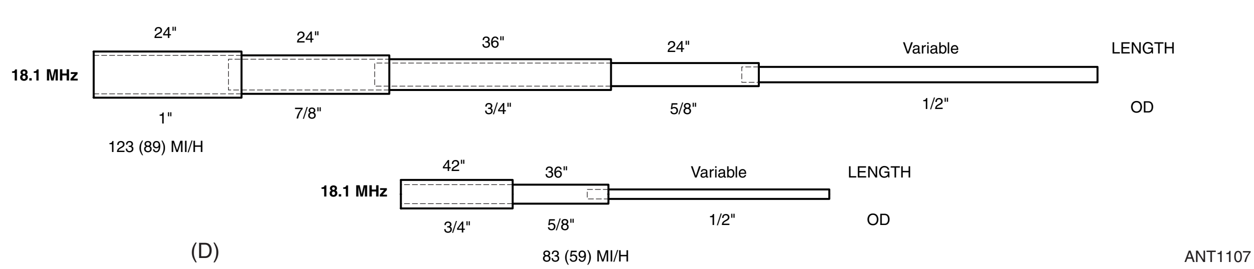


Table 11.4
Optimized 17 meter Yagi Designs

Two-element 17 meter Yagi, 6 foot boom

Element	*Spacing*	*Heavy-Duty Tip*	*Medium-Duty Tip*
File Name		217-06H.YW	217-06M.YW
Reflector	0.000"	61.000"	89.000"
Driven Element	66.000"	48.000"	76.250"

Three-element 17 meter Yagi, 14 foot boom

Element	*Spacing*	*Heavy-Duty Tip*	*Medium-Duty Tip*
File Name		317-14H.YW	317-14M.YW
Reflector	0.000"	61.500"	91.500"
Driven Element	65.000"	52.000"	79.500"
Director 1	97.000"	46.000"	73.000"
	12" behind Dir. 1	12.625"	10.750"

Four-element 17 meter Yagi, 20 foot boom

Element	*Spacing*	*Heavy-Duty Tip*	*Medium-Duty Tip*
File Name		417-20H.YW	417-20M.YW
Reflector	0.000"	61.500"	89.500"
Driven Element	48.000"	54.250"	82.625"
Director 1	48.000"	52.625"	81.125"
Director 2	138.000"	40.500"	69.625"
Compensator	12" behind Dir. 2	42.500"	36.250"

Five-element 17 meter Yagi, 30 foot boom

Element	*Spacing*	*Heavy-Duty Tip*	*Medium-Duty Tip*
File Name		517-30H.YW	517-30M.YW
Reflector	0.000"	61.875"	89.875"
Driven Element	48.000"	52.250"	80.500"
Director 1	52.000"	49.625"	78.250"
Director 2	93.000"	49.875"	78.500"
Director 3	161.000"	43.500"	72.500"
Compensator	12" behind Dir. 3	54.375"	45.875"

Six-element 17 meter Yagi, 48 foot boom

Element	*Spacing*	*Heavy-Duty Tip*	*Medium-Duty Tip*
File Name		617-48H.YW	617-48M.YW
Reflector	0.000"	63.000"	90.250"
Driven Element	52.000"	52.500"	80.500"
Director 1	51.000"	45.500"	74.375"
Director 2	87.000"	47.875"	76.625"
Director 3	204.000"	47.000"	75.875"
Director 4	176.000"	42.000"	71.125"
Compensator	12" behind Dir. 4	68.250"	57.500"

Six-element 17 meter Yagi, 60 foot boom

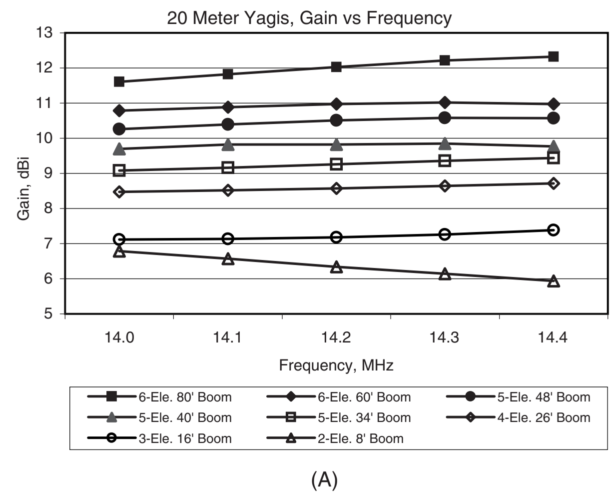
Element	*Spacing*	*Heavy-Duty Tip*	*Medium-Duty Tip*
File Name		617-60H.YW	617-60M.YW
Reflector	0.000"	61.250"	89.250"
Driven Element	54.000"	54.750"	83.125"
Director 1	54.000"	52.250"	80.750"
Director 2	180.000"	46.000"	74.875"
Director 3	235.000"	44.625"	73.625"
Director 4	191.000"	41.500"	70.625"
Compensator	12" behind Dir. 4	62.875"	53.000"

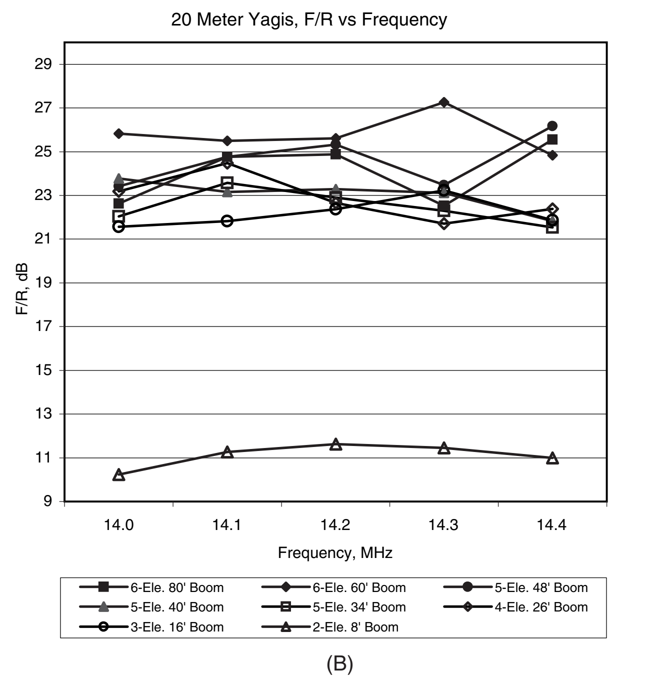
These 17 meter Yagi designs are optimized for > 20 dB F/R, and SWR < 2:1 over entire frequency range from18.068 to 18.168 MHz, for heavy-duty elements (123 mph wind survival) and for medium-duty (83 mph wind survival). Only element tip dimensions are shown. All dimensions are in inches. Torque compensator element is made of 2.5" OD PVC water pipe placed 12" behind last director, and dimensions shown for compensators is one-half of total length, centered on boom.

11.4.5 20 METER YAGIS

Figure 11.17 describes the electrical performance of eight optimized 20 meter Yagis with boom lengths between 8 to a giant 80 feet. As usual, the end of each boom includes 3 inches of space for the reflector and last director (driven element) mounting plates. Figure 11.17A shows the free-space gain versus frequency for each antenna; Figure 11.17B shows the front-to-rear ratio, and Figure 11.17C shows the SWR versus frequency. Each antenna with three or more elements was designed to cover the complete 20 meter band from 14.000 to 14.350 MHz, with SWR less than 2:1 and F/R ratio better than 20 dB over that range.

Figure 11.17D shows the taper schedule for two types of 20 meter elements. The heavy-duty design can survive 122-mph





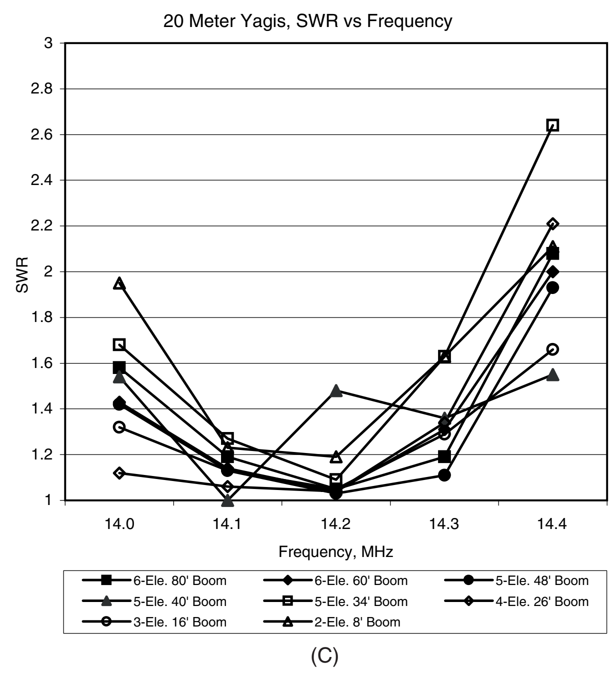


Figure 11.17 — Gain, F/R and SWR performance versus frequency for optimized 20 meter Yagis. At A, gain versus frequency is shown for eight 20 meter Yagis whose booms range from 8 feet to 80 feet long. Except for the 2-element design, these Yagis have been optimized for better than 20 dB F/R and less than 2:1 SWR over the frequency range 14.0 to 14.35 MHz. At B, front-to-rear ratio for these antennas is shown versus frequency, and at C, SWR over the frequency range is shown. At D, the taper schedule for heavy-duty and for medium-duty 20 meter elements is shown. The heavy-duty elements can withstand 122-mph winds without icing, and 89-mph winds with ¼-inch radial ice. The medium-duty elements can survive 82-mph winds without icing, and 60-mph winds with ¼-inch radial ice. The wall thickness for each telescoping section of 6061-T6 aluminum tubing is 0.058 inches, and the overlap at each telescoping junction is 3 inches.

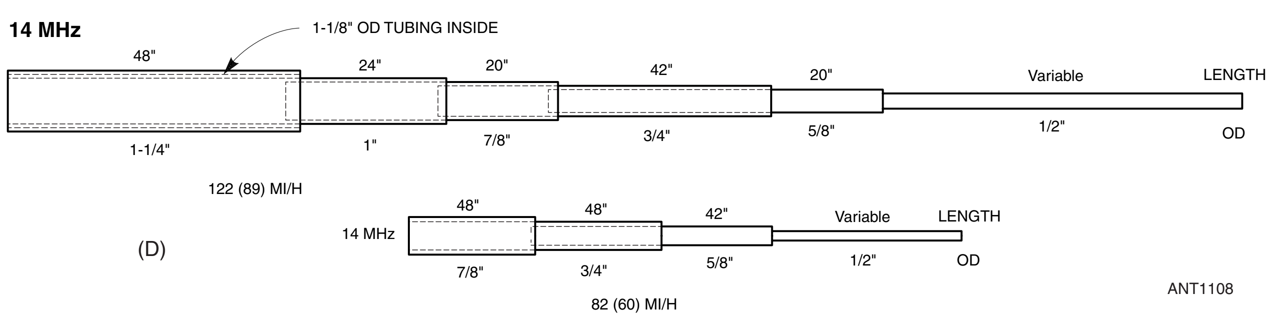


Table 11.5

Optimized 20 meter Yagi Designs

Two-element 20 meter Yagi, 8 foot boom			
Element	*Spacing*	*Heavy-Duty Tip*	*Medium-Duty Tip*
File Name		220-08H.YW	220-08M.YW
Reflector	0.000"	66.000"	80.000"
Driven Element	90.000"	46.000"	59.000"
Three-element 20 meter Yagi, 16 foot boom			
Element	*Spacing*	*Heavy-Duty Tip*	*Medium-Duty Tip*
File Name		320-16H.YW	320-16M.YW
Reflector	0.000"	69.625"	81.625"
Driven Element	80.000"	51.250"	64.500"
Director 1	106.000"	42.625"	56.375"
Compensator	12" behind Dir. 1	33.375"	38.250"
Four-element 20 meter Yagi, 26 foot boom			
Element	*Spacing*	*Heavy-Duty Tip*	*Medium-Duty Tip*
File Name		420-26H.YW	420-26M.YW
Reflector	0.000"	65.625"	78.000"
Driven Element	72.000"	53.375"	65.375"
Director 1	60.000"	51.750"	63.875"
Director 2	174.000"	38.625"	51.500"
Compensator	12" behind Dir. 2	54.250"	44.250"
Five-element 20 meter Yagi, 34 foot boom			
Element	*Spacing*	*Heavy-Duty Tip*	*Medium-Duty Tip*
File Name		520-34H.YW	520-34M.YW
Reflector	0.000"	68.625"	80.750"
Driven Element	72.000"	52.250"	65.500"
Director 1	71.000"	45.875"	59.375"
Director 2	68.000"	45.875"	59.375"
Director 3	191.000"	37.000"	51.000"
Compensator	12" behind Dir. 3	69.250"	56.250"
Five-element 20 meter Yagi, 40 foot boom			
Element	*Spacing*	*Heavy-Duty Tip*	*Medium-Duty Tip*
File Name		520-40H.YW	520-40M.YW
Reflector	0.000"	68.375"	80.500"
Driven Element	72.000"	53.500"	66.625"
Director 1	72.000"	51.500"	64.625"
Director 2	139.000"	48.375"	61.750"
Director 3	191.000"	38.000"	52.000"
Compensator	12" behind Dir. 3	69.750"	56.750"
Five-element 20 meter Yagi, 48 foot boom			
Element	*Spacing*	*Heavy-Duty Tip*	*Medium-Duty Tip*
File Name		520-48H.YW	520-48M.YW
Reflector	0.000"	66.250"	78.500"
Driven Element	72.000"	53.000"	66.000"
Director 1	88.000"	50.500"	63.750"
Director 2	199.000"	47.375"	60.875"
Director 3	211.000"	39.750"	53.625"
Compensator	12" behind Dir. 3	70.325"	57.325"
Six-element 20 meter Yagi, 60 foot boom			
Element	*Spacing*	*Heavy-Duty Tip*	*Medium-Duty Tip*
File Name		620-60H.YW	620-60M.YW
Reflector	0.000"	67.000"	79.250"
Driven Element	84.000"	51.500"	65.000"
Director 1	91.000"	45.125"	58.750"
Director 2	130.000"	41.375"	55.125"
Director 3	210.000"	46.875"	60.375"
Director 4	199.000"	39.125"	53.000"
Compensator	12" behind Dir. 4	72.875"	59.250"
Six-element 20 meter Yagi, 80 foot boom			
Element	*Spacing*	*Heavy-Duty Tip*	*Medium-Duty Tip*
File Name		620-80H.YW	620-80M.YW
Reflector	0.000"	66.125"	78.375"
Driven Element	72.000"	52.375"	65.500"
Director 1	122.000"	49.125"	62.500"
Director 2	229.000"	44.500"	58.125"
Director 3	291.000"	42.625"	56.375"
Director 4	240.000"	38.750"	52.625"
Compensator	12" behind Dir. 4	78.750"	64.125"

These 20 meter Yagi designs are optimized for > 20 dB F/R, and SWR < 2:1 over entire frequency range from 14.000 to 14.350 MHz, for heavy-duty elements (122 mph wind survival) and for medium-duty (82 mph wind survival). Only element tip dimensions are shown. See Fig 11.17 for element telescoping tubing schedule. All dimensions are in inches. Torque compensator element is made of 2.5" OD PVC water pipe placed 12" behind last director, and dimensions shown for compensators is one-half of total length, centered on boom.

winds with no icing, and 89-mph winds with ¼ inch of radial ice. The medium-duty design can handle 82-mph winds with no icing, and 60-mph winds with ¼ inch of radial ice.

The element-to-boom mounting plate for these Yagis is a 0.375-inch thick flat aluminum plate, 6 inches wide by 8 inches long. The mounting plate has an effective diameter of 3.7063 inches for the heavy-duty element, and 3.4194 inches for the medium-duty element. The equivalent length on each side of the boom is 4 inches. As usual, the torque compensator is mounted 12 inches behind the last director.

11.4.6 30 METER YAGIS

Figure 11.18 describes the electrical performance of three optimized 30 meter Yagis with boom lengths between 15 to 34 feet. Because of the size and weight of the elements alone for Yagis on this band, only 2-element and 3-element designs are described. The front-to-rear ratio requirement for the 2-element antenna is relaxed to be greater than 10 dB over the band from 10.100 to 10.150 MHz, while that for the 3-element designs is kept at greater than 20 dB over that frequency range.

As usual, the end of each boom includes 3 inches of space for the reflector and last director mounting plates. Figure 11.18A shows the free-space gain versus frequency for each antenna; Figure 11.18B shows the worst-case front-to-rear ratio, and Figure 11.18C shows the SWR versus frequency.

Figure 11.18D shows the taper schedule for the 30 meter

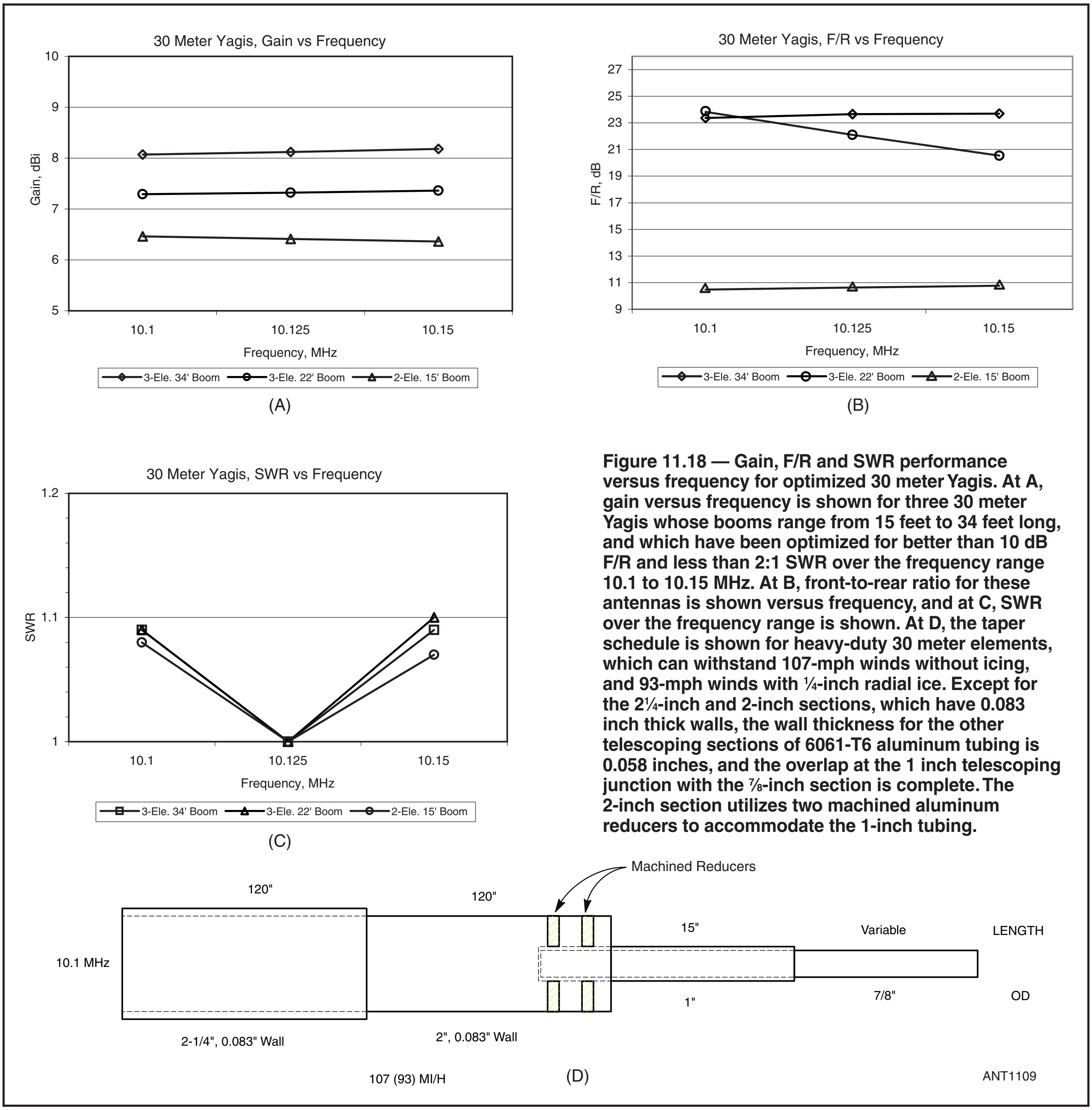


Figure 11.18 — Gain, F/R and SWR performance versus frequency for optimized 30 meter Yagis. At A, gain versus frequency is shown for three 30 meter Yagis whose booms range from 15 feet to 34 feet long, and which have been optimized for better than 10 dB F/R and less than 2:1 SWR over the frequency range 10.1 to 10.15 MHz. At B, front-to-rear ratio for these antennas is shown versus frequency, and at C, SWR over the frequency range is shown. At D, the taper schedule is shown for heavy-duty 30 meter elements, which can withstand 107-mph winds without icing, and 93-mph winds with ¼-inch radial ice. Except for the 2¼-inch and 2-inch sections, which have 0.083 inch thick walls, the wall thickness for the other telescoping sections of 6061-T6 aluminum tubing is 0.058 inches, and the overlap at the 1 inch telescoping junction with the ⅞-inch section is complete. The 2-inch section utilizes two machined aluminum reducers to accommodate the 1-inch tubing.

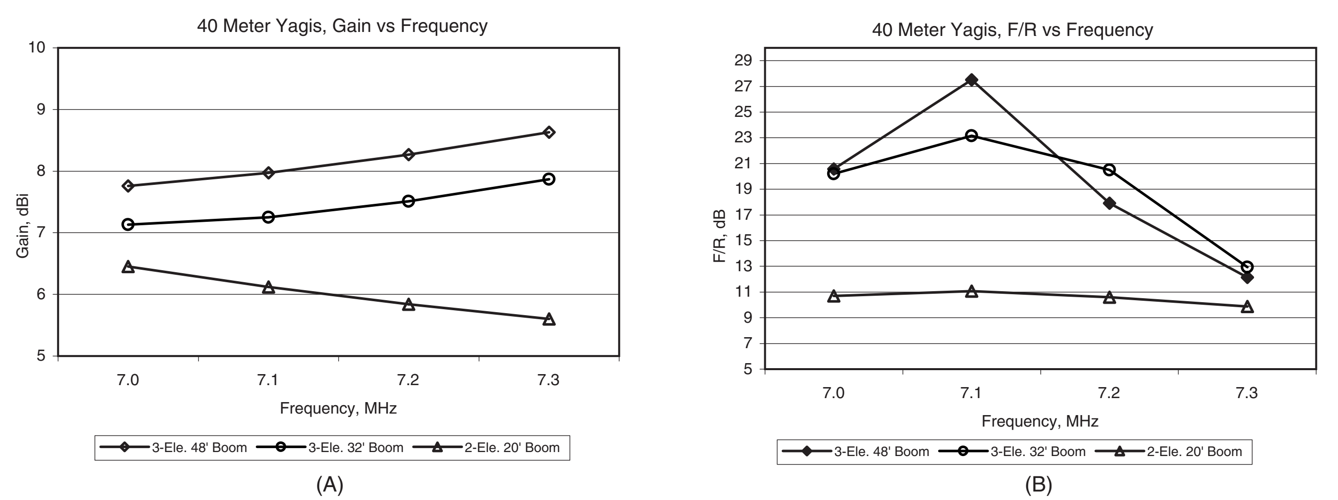
elements. Note that the wall thickness of the first two sections of tubing is 0.083 inches, rather than 0.058 inches. This heavy-duty element design can survive 107-mph winds with no icing, and 93-mph winds with ¼ inch of radial ice.

The element-to-boom mounting plate for these Yagis is a 0.500-inch thick flat aluminum plate, 6 inches wide by 24 inches long. The mounting plate has an effective diameter of 4.684 inches. The equivalent length on each side of the boom is 12 inches. These designs require no torque compensator.

11.4.7 40 METER YAGIS

Figure 11.19 describes the electrical performance of three optimized 40 meter Yagis with boom lengths between 20 to 48 feet. Like the 30 meter antennas, because of the size and weight of the elements for a 40 meter Yagi, only 2-element and 3-element designs are described. The front-to-rear ratio requirement for the 2-element antenna is relaxed to be greater than 10 dB over the band from 7.000 to 7.300 MHz, while the goal for the 3-element designs is 20 dB over the frequency range of 7.000 to 7.200 MHz. It is exceedingly difficult to hold the F/R greater than 20 dB over the entire 40 meter band without sacrificing excessive gain with a 3-element design.

As usual, the end of each boom includes 3 inches of space for the reflector and last director mounting plates. Figure 11.19A shows the free-space gain versus frequency for each antenna;



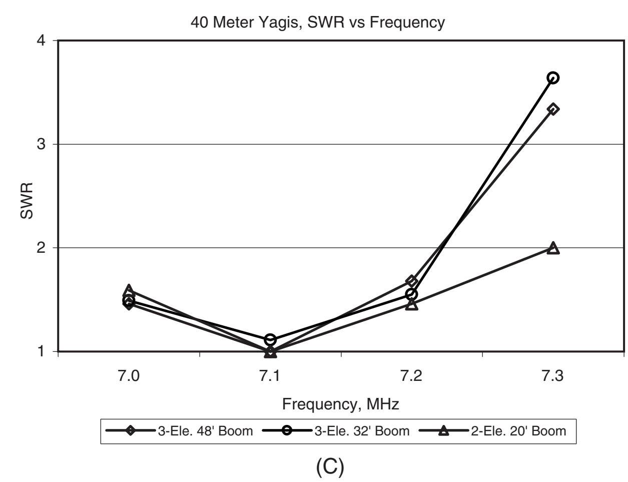


Figure 11.19 — Gain, F/R and SWR performance versus frequency for optimized 40 meter Yagis. At A, gain versus frequency is shown for three 40 meter Yagis whose booms range from 20 feet to 48 feet long, and which have been optimized for better than 10 dB F/R and less than 2:1 SWR over the frequency range 7.0 to 7.2 MHz. At B, front-to-rear ratio for these antennas is shown versus frequency, and at C, SWR over the frequency range is shown. At D, the taper schedule is shown for heavy-duty 40 meter elements, which can withstand 107-mph winds without icing, and 93-mph winds with ¼-inch radial ice. Except for the 2¼-inch and 2-inch sections, which have 0.083 inch thick walls, the wall thickness for the other telescoping sections of 6061-T6 aluminum tubing is 0.058 inches, and the overlap at the end telescoping junction is 3 inches. The 2-inch section utilizes two machined aluminum reducers to accommodate the 1-inch tubing.

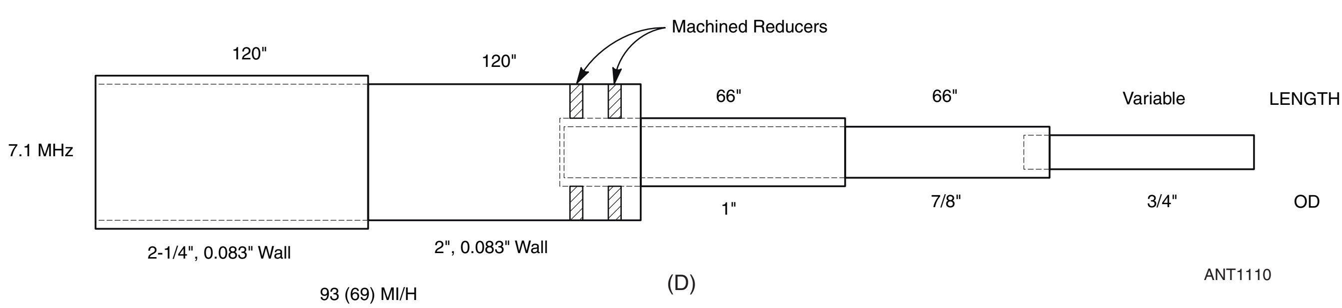


Table 11.6
Optimized 30 meter Yagi Designs

Two-element 30 meter Yagi, 15 foot boom

Element	*Spacing*	*Heavy-Duty Tip*
File Name		230-15H.YW
Reflector	0.000"	50.250"
Driven Element	174.000"	14.875"

3-element 30 meter Yagi, 22 foot boom

Element	*Spacing*	*Heavy-Duty Tip*
File Name		330-22H.YW
Reflector	0.000	59.375
Driven Element	135.000	35.000
Director 1	123.000	19.625

Three-element 30 meter Yagi, 34 foot boom

Element	*Spacing*	*Heavy-Duty Tip*
File Name		330-34H.YW
Reflector	0.000"	53.750"
Driven Element	212"	29.000"
Director 1	190"	14.500"

These 30 meter Yagi designs are optimized for > 10 dB F/R, and SWR < 2:1 over entire frequency range from 10.100 to 10.150 MHz for heavy-duty elements (105 mph wind survival). Only element tip dimensions are shown. See Fig 11.18D for element telescoping tubing schedule. All dimensions are in inches. No torque compensator element is required.

Table 11.7
Optimized 40 meter Yagi Designs

Two-element 40 meter Yagi, 20 foot boom

Element	*Spacing*	*Heavy-Duty Tip*
File Name		240-20H.YW
Reflector	0.000"	85.000"
Driven Element	234.000"	35.000"

Three-element 40 meter Yagi, 32 foot boom

Element	*Spacing*	*Heavy-Duty Tip*
File Name		340-32H.YW
Reflector	0.000"	90.750"
Driven Element	196.000"	55.875"
Director 1	182.000"	33.875"

Three-element 40 meter Yagi, 48 foot boom

Element	*Spacing*	*Heavy-Duty Tip*
File Name		340-48H.YW
Reflector	0.000"	81.000"
Driven Element	300.000"	45.000"
Director 1	270.000"	21.000"

These 40 meter Yagi designs are optimized for > 10 dB F/R, and SWR < 2:1 over low-end of frequency range from 7.000 to 7.200 MHz, for heavy-duty elements (95 mph wind survival). Only element tip dimensions are shown. See Fig 11.19D for element telescoping tubing schedule. All dimensions are in inches. No wind torque compensator is required.

Figure 11.19B shows the front-to- rear ratio, and Figure 11.19C shows the SWR versus frequency.

Figure 11.19D shows the taper schedule for the 40 meter elements. Note that the wall thickness of the first two sections of tubing is 0.083 inches, rather than 0.058 inches. This element design can survive 93-mph winds with no icing, and 69-mph winds with ¼ inch of radial ice.

The element-to-boom mounting plate for these Yagis is a 0.500-inch thick flat aluminum plate, 6 inches wide by 24 inches long. The mounting plate has an effective diameter of 4.684 inches. The equivalent length on each side of the boom is 12 inches. These designs require no torque compensator.

11.4.8 MODIFYING MONOBAND HY-GAIN YAGIS

Enterprising amateurs have long used the Hy-Gain "Long John" series of HF monobanders as a source of top-quality aluminum and hardware for customized Yagis. Often-modified older models include the 105BA for 10 meters, the 155BA for 15 meters, and the 204BA and 205BA for 20 meters. Newer Hy-Gain designs, the 105CA, 155CA and 205CA, have been redesigned by computer for better performance.

Hy-Gain antennas have historically had an excellent reputation for superior mechanical design. In the older designs the elements were purposely spaced along the boom to achieve good weight balance at the mast-to-boom bracket, with electrical performance as a secondary goal. Thus, the electrical performance was not necessarily optimal, particularly over an entire amateur band.

Newer Hy-Gain designs are electrically superior to the older ones, but because of the strong concern for weight balance are still not optimal by the definitions used in this chapter. With the addition of wind torque-compensation dummy elements, and with extra lead weights where necessary at the director end of the boom for weight-balance, the electrical performance can be enhanced, using the same proven mechanical parts.

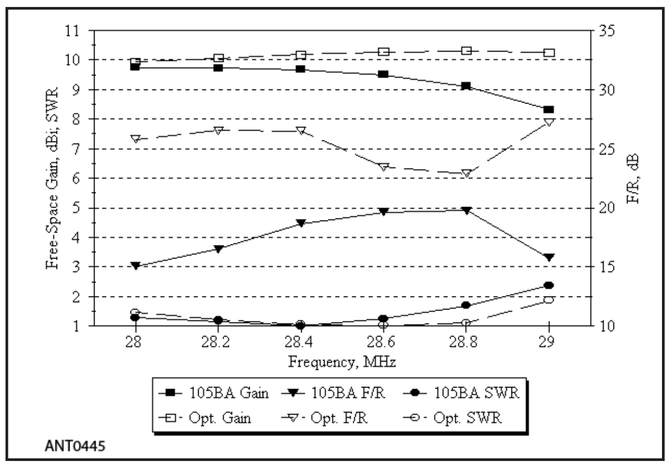


Figure 11.20 — Gain, F/R and SWR over the 28.0 to 28.8 MHz range for original and optimized Yagis using Hy-Gain hardware. Original 105BA design provided excellent weight balance at boom-to-mast bracket, but compromised the electrical performance somewhat because of non-optimum spacing of elements. Optimized design requires wind torque-balancing compensator element, and compensating weight at director end of boom to rebalance weight. The F/R ratio over the frequency range for the optimized design is more than 23 dB. Each element uses the original Hy-Gain taper schedule and element-to-boom clamp, but the length of the tip is changed per Table 11.8.

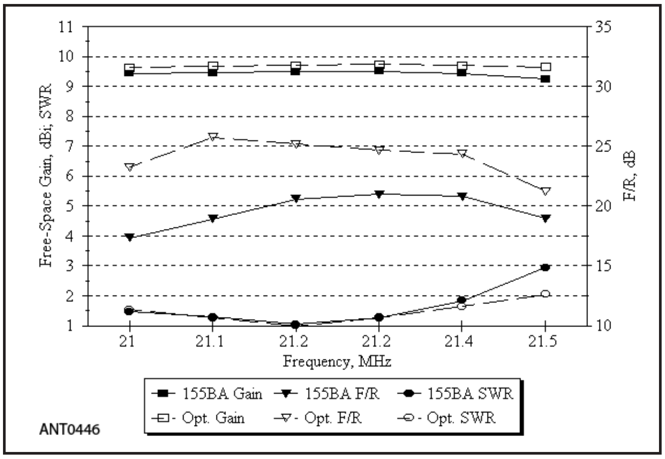


Figure 11.21 — Gain, F/R and SWR over the 21.0 to 21.45 MHz band for original and optimized Yagis using Hy-Gain hardware. Original 155BA design provided excellent weight balance at boom-to-mast bracket, but compromised the electrical performance somewhat because of non-optimum spacing of elements. Optimized design requires wind torque-balancing compensator element, and compensating weight at director end of boom to rebalance weight. The F/R ratio over the frequency range for the optimized design is more than 22 dB. Each element uses the original Hy-Gain taper schedule and element-to-boom clamp, but the length of the tip is changed per Table 11.9.

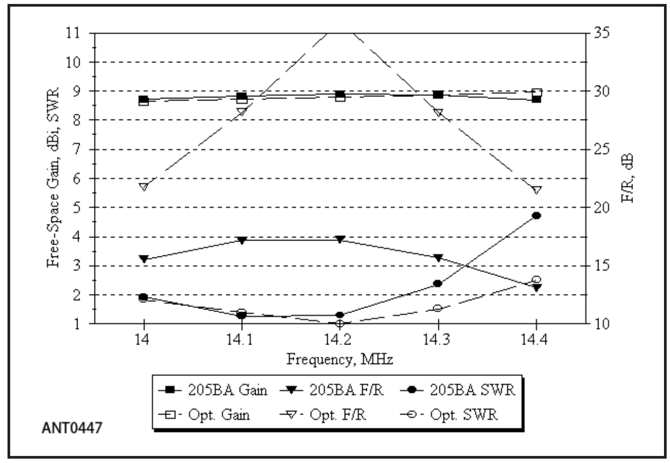


Figure 11.22 — Gain, F/R and SWR over the 14.0 to 14.35 MHz band for original and optimized Yagis using Hy-Gain hardware. Original 205BA design provided good weight balance at boom-to-mast bracket, but compromised the electrical performance because of non-optimum spacing of elements. Optimized design requires wind torque-balancing compensator element, and compensating weight at director end of boom to rebalance weight. The F/R ratio over the frequency range for the optimized design is more than 23 dB, while the original design never went beyond 17 dB of F/R. Each element uses the original Hy-Gain taper schedule and element-to-boom clamp, but the length of the tip is changed per Table 11.10.

Table 11.8
Optimized Hy-Gain 20 meter Yagi Designs

Optimized 204BA, Four-element 20 meter Yagi, 26 foot boom

Element	*Spacing*	*Element Tip*
File Name		BV204CA.YW
Reflector	0.000"	56.000"
Driven Element	85.000"	52.000"
Director 1	72.000"	61.500"
Director 2	149.000"	50.125"

Optimized 205CA, Five-element 20 meter Yagi, 34 foot boom

Element	*Spacing*	*Element Tip*
File Name		BV205CA.YW
Reflector	0.000"	62.625"
Driven Element	72.000"	53.500"
Director 1	72.000"	63.875"
Director 2	74.000"	61.625"
Director 3	190.000"	55.000"

Note that because the HyGain boom-to-element clamps require several inches of boom, the elements can't be mounted exactly at the end of the boom. Since the boom length of 34' is the same as the sum of element spacings, Director 3 cannot have a spacing of 190" and will have to be a few inches less. This does not result in a significant change in the antenna pattern according to designer Dean Straw, N6BV.

Figure 11.20 shows the computed gain, F/R ratio and SWR for a 24-foot boom, 10 meter optimized Yagi (modified 105BA) using Hy-Gain hardware. **Figure 11.21** shows the same for a 26-foot boom 15 meter Yagi (modified 155BA), and **Figure 11.22** shows the same for a 34-foot boom (modified 205BA) 20 meter Yagi. **Tables 11.8** through **11.10** show dimensions for these designs. The original Hy-Gain taper schedule is used for each element. Only the length of the end tip (and the spacing along the boom) is changed for each element.

Table 11.9
Optimized Hy-Gain 15 meter Yagi Designs

Optimized 155BA, Five-element 15 meter Yagi, 26 foot boom

Element	*Spacing*	*Element Tip*
File Name		BV155CA.YW
Reflector	0.000"	64.000"
Driven Element	48.000"	65.500"
Director 1	48.000"	63.875"
Director 2	82.750"	61.625"
Director 3	127.250"	55.000"

Table 11.10
Optimized Hy-Gain 10 meter Yagi Designs

Optimized 105BA, Five-element 10 meter Yagi, 24 foot boom

Element	*Spacing, inches*	*Element Tip*
File Name		BV105CA.YW
Reflector	0.000"	44.250"
Driven Element	40.000"	53.625"
Director 1	40.000"	52.500"
Director 2	89.500"	50.500"
Director 3	112.250"	44.750"

11.5 MULTIBAND YAGIS

So far, this chapter has discussed monoband Yagis — that is, Yagis designed for a single Amateur Radio frequency band. Because hams have operating privileges on more than one band, multiband coverage has always been very desirable.

Interlacing Elements

In the late 1940s, some experimenters tried interlacing Yagi elements for different frequencies on a single boom, mainly to cover the 10 and 20 meter bands (at that time the 15 meter band wasn't yet available to hams). The experimenters discovered that the mutual interactions between different elements tuned to different frequencies are very difficult to handle.

Adjusting a lower-frequency element usually results in interaction with higher-frequency elements near it. In effect, the lower-frequency element acts like a retrograde reflector, throwing off the effectiveness of the higher-frequency directors nearby. Element lengths and the spacing between elements can be changed to improve performance of the higher-frequency Yagi, but the resulting compromise is rarely equal to that of an optimized monoband Yagi. A reasonable compromise for portable operation was developed by VE7CA and is described in the **Portable Antennas** chapter.

Trap Multibanders

Multiband Yagis using a single boom can also be made using traps. Traps allow an element to have multiple resonances. The **Multiband Antennas** chapter provides details on trap designs. The general function is very similar to trap dipoles in which the traps act as open circuits or reactances that change the electrical length of the element at different frequencies.

Commercial vendors have sold trap antennas to hams since the 1950s and surveys show that after simple wire dipoles and multiband verticals, trap triband Yagis are the most popular antennas in the Amateur Radio service.

The originator of the trap tribander was Chester Buchanan, W3DZZ, in his March 1955 *QST* article, "The Multimatch Antenna System." On 10 meters this rather unusual tribander used two reflectors (one dedicated and one with traps) and two directors (one dedicated and one with traps). On 20 and 15 meters three of the five elements were active using traps. The W3DZZ tribander employed 12 traps overall, made with heavy wire and concentric tubular capacitors to hold down losses in the traps. Each trap was individually fine-tuned after construction before mounting it on an element.

Another example of a homemade tribander was the 26-foot boom 7-element 20/15/10 meter design described by Bob Myers, W1XT (ex-W1FBY) in December 1970 *QST*. The W1FBY tribander used only two sets of traps in the driven element, with dedicated reflectors and directors for each frequency band. Again, the traps were quite robust in this design to minimize trap losses, using 7⁄16-inch aluminum tubing for the coils and short pieces of RG-8 coax as high-voltage tuning capacitors.

Relatively few hams actually build tribanders for themselves, mainly because of the mechanical complexity and the close tolerances required for such antennas. The traps themselves must be constructed quite accurately for reproducible results, and they must be carefully weatherproofed for long life in rain, snow, and often polluted or corrosive atmospheres.

Traps, like any lumped-constant circuit, have some amount of loss which can be minimized with careful design. The primary compromise incurred in a trap multiband Yagi is the fixed element spacing on all bands. The usual tribander design is optimized for the middle band while the spacing is a bit too long for the highest band and a bit too short for the lowest band. Nevertheless, trap tribanders provide good performance in a compact package.

Christmas Tree Stacks

Another possible method for achieving multiband coverage using monoband Yagis is to stack them in a "Christmas tree" arrangement as in **Figure 11.23**. For an installation covering 20, 15 and 10 meters, you could mount the 20 meter monobander on the rotating mast just at the top of the tower. Then perhaps 9 feet above that you would mount the 15 meter monobander, followed by the 10 meter monoband Yagi 7 feet further up on the mast. Another configuration would be to place the 10 meter Yagi in between the lower 20 meter and upper 15 meter Yagis. Whatever the arrangement, the antenna in the middle of such a Christmas-tree always suffers the most interaction from the lowest-frequency Yagi.

Dave Leeson, W6NL, mentions that the 10 meter Yagi in a closely stacked Christmas Tree (15 meters at the top, 10 meters in the middle, and 20 meters at the bottom of the rotating mast) loses "substantial gain" because of serious interaction with the 20 meter antenna. (N6BV and K1VR calculated that the free-space gain in the W6NL stack drops to 5 dBi, compared to about 9 dBi with no surrounding antennas.) Monobanders are *definitely not* universally superior to tribanders in multiband installations.

Forward Staggering

Some hams have built multiband Yagis on a common boom, using a technique called *forward staggering*. This means that that most (or all) of the higher-frequency elements are placed in front of any lower-frequency elements — in other words, most of the elements are not interlaced. Richard Fenwick, K5RR, described his triband Yagi design in September 1996 *QEX* magazine. This uses forward-stagger and open-sleeve design techniques and was optimized using several sophisticated modeling programs.

Fenwick's tribander used a 57-foot, 3-inch OD boom to hold 4 elements on 20 meters, 4 elements on 15 meters and

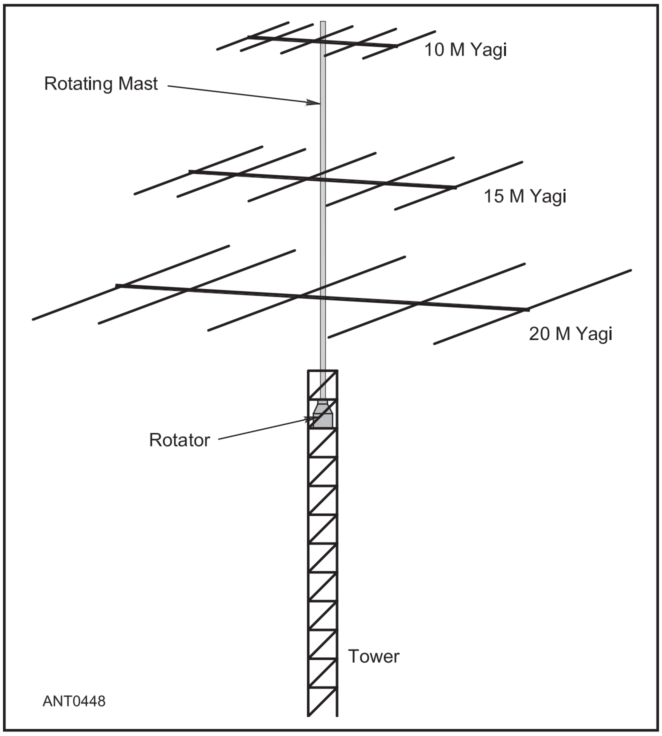


Figure 11.23 — "Christmas Tree" stack of 20/15/10 meter Yagis spaced vertically on a single rotating mast.

5 elements on 10 meters. **Figure 11.24** shows the element placement for the K5RR tribander. Most hams, of course, don't have the real-estate or the large rotator needed to turn such a large, but elegant solution to the interaction problem!

Force 12 C-3 "Multi-Monoband" Triband Yagi

Antenna manufacturer InnovAntennas/Force 12 (**www.force12inc.com**) also uses forward-stagger layouts and patented combinations of open- and closed-sleeve drive techniques extensively in their product line of multiband antennas, which they call "multi-monoband Yagis." **Figure 11.25** shows the layout for the popular Force 12 C-3 triband Yagi. The C-3 uses no traps, thereby avoiding any losses due to traps. The C-3 consists of three 2-element Yagis on an 18-foot boom, using full-sized elements designed to withstand high winds. (There is a pair of 10 meter driven elements for coverage of the full band.)

The C-3 feed system employs open-sleeves, where the 20 meter driver element is fed with coax through a common-mode current balun and parasitically couples to the closely spaced 15 meter driver and the two 10 meter driven elements to yield a feed point impedances close to 50 Ω on all three bands. Open-sleeve dipoles are discussed in the **Multiband Antennas** chapter.

Note the use of the forward-stagger technique in the

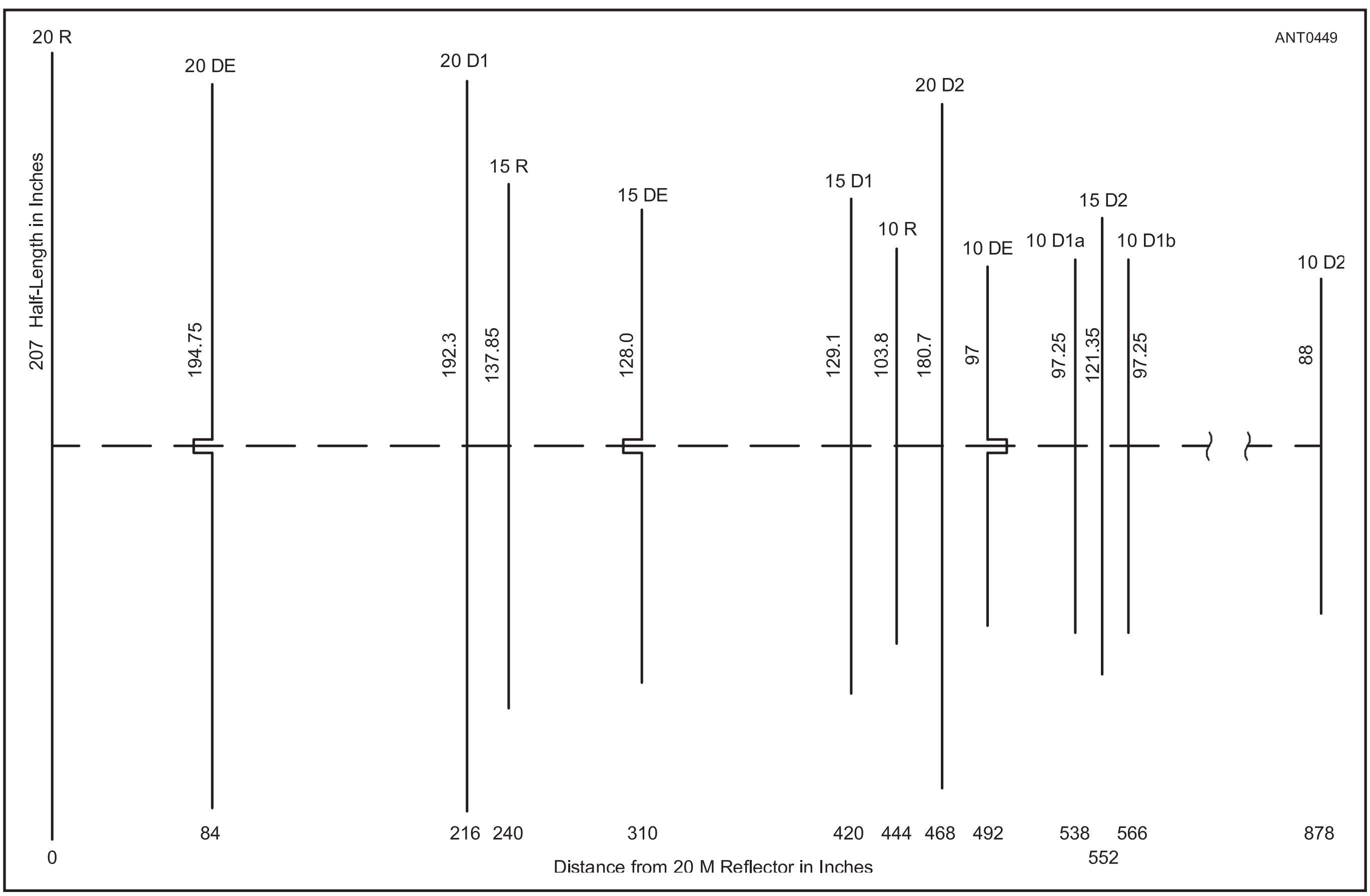


Figure 11.24 — Dimensions of K5RR's trap-less tribander using "forward stagger" and open-sleeve techniques to manage interaction between elements for different frequencies.

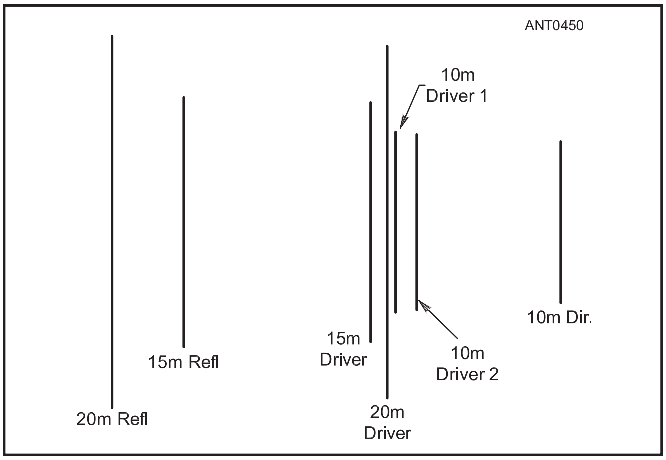


Figure 11.25 — Layout of InnovAntennas/Force 12 C3 multiband Yagi. Note that the 10 meter (driver/director) portion of the antenna is "forward staggered" ahead of the 15 meter (reflector/driver) portion, which in turn is placed ahead of the 20 meter (reflector/driver) portion. The antenna is fed at the 20 meter driver, which couples parasitically to the 15 meter driver and the two 10 meter drivers.

C-3, especially on 10 meters. To reduce interaction with the lower-frequency elements behind it, the 10 meter portion of the C-3 is mounted on the boom ahead of all the lower-frequency elements with the main 10 meter parasitic element (#7) acting as a director. The lower-frequency elements behind the 10 meter section act as retrograde reflectors, gaining some improvement of the gain and pattern compared to a monoband 2-element Yagi. A simplified *EZNEC* model of the C-3 is included on the CD-ROM accompanying this book.

On 15 meters, the main parasitic element (#2) is a dedicated reflector, but the other elements ahead on the boom act like retrograde directors to improve the gain and pattern somewhat over a typical 2-element Yagi with a reflector. On 20 meters, the C-3 is a 2-element Yagi with a dedicated reflector (#1) at the back end of the boom.

The exact implementation of any Yagi, of course, depends on the way the elements are constructed using telescoping aluminum tubing. The C-3 type of design is no exception.

11.6 SHORTENING YAGI ELEMENTS

Almost any technique that can be used to reduce the physical length of a dipole can also be used to shorten the physical length of a Yagi element. The tradeoffs are additional mechanical complexity and reduced performance with respect to forward gain and SWR bandwidth. As with shortened dipoles and monopoles, placement of the loading structures is critical to obtaining good performance and careful modeling is required. (Caution should be used in modeling wires that are very close to each other, junctions of large-diameter conductors, and other complex mechanical arrangements.)

Linear Loading

The most common size-reducing technique is *linear loading* and it can be applied to Yagis as well as dipoles and verticals. An example of linear loading for a dipole was presented by Lew Gordon, K4VX, in his July 2002 *QST* article. A very similar example of linear loading for a 2-element 20 meter Yagi can be found in a June 1976 *QST* article by Cole Collings, WØYNF.

Linear loading essentially consists of folding the antenna into a zig-zag pattern. Each back-and-forth folded segment radiates very little because the field from each of the folded conductors partially cancels that of the adjacent conductors. Nevertheless, the folding does extend the electrical length of the antenna. The effective length of the folded antenna is somewhat longer than if the section remained unfolded.

The Hy-Gain 402BA 2-element 40 meter Yagi was a popular linearly-loaded antenna with 46-foot elements. A full-size element on 40 meters is approximately 65 feet long, so linear loading provided a substantial reduction in size.

End Loading and Inductor Loading

The technique of adding capacitance hats near the end of an antenna to lower its resonant frequency is most often encountered in vertical ground-plane antennas for the lower HF bands. The technique can also be put to good use on HF Yagis as seen in the Cushcraft (**www.cushcraftamateur.com**) MA5B mini-beam for 20/17/15/12/10 meters. The capacitance hats on this multiband Yagi play a major role in reducing the longest element to a bit over 17 feet long — just over $\lambda/4$ on 20 meters.

The elements of the MA5B also use traps and that also helps reduce length by inserting inductance into the element below the trap's resonant frequency. The Cushcraft XM240 2-element 40 meter Yagi also uses a combination of capacitance hats and coils to reduce element size.

Inductors on large Yagis for 75/80 meters are used similarly to base loading in verticals. The same general concerns apply with the inductance and placement of the coil, as well as losses in the coil.

11.7 THE MOXON RECTANGLE

The Moxon design is becoming increasingly popular on the HF and low VHF bands. Two additional Moxon designs, one for 10 meters and another for 20 meters, are included on this book's CD-ROM.

L.B. Cebik, W4RNL (SK), has written extensively about the *Moxon rectangle*, an antenna invented by Les Moxon, G6XN (SK), derived from a design by VK2ABQ. The Moxon rectangle beam takes less space horizontally than a conventional 2-element Yagi design, yet it offers nearly the same amount of gain and a superior front-to-back ratio. And as an additional benefit, the drive-point impedance is close to 50 Ω, so that it doesn't need a matching section.

For example, rather than a "wingspan" of 17 feet for the reflector in a conventional 2-element 10 meter Yagi, the Moxon rectangle is 13 feet wide, a saving of almost 25%. The Moxon rectangle W4RNL created for *The ARRL Antenna Compendium, Vol 6*, had an SWR less than 2:1 from 28.0 to 29.7 MHz, with a gain over ground of 11 dBi. It had a F/B of 15 dB at 28.0 MHz, more than 20 dB at 28.4 MHz, and 12 dB at 29.7 MHz.

The Moxon rectangle relies on controlling the spacing (hence controlling the coupling) between the ends of the driven element tips and the ends of the reflector tips, which are both bent toward each other. See **Figure 11.26** which shows the general outline for W4RNL's 10 meter aluminum Moxon rectangle. The tips of the elements are kept a fixed distance from each other by PVC spacers. The closed rectangular mechanical assembly gives some rigidity to the design, keeping it stable in the wind. W4RNL described other Moxon rectangle designs using wire elements in June 2000 *QST*.

11.7.1 40 METER MOXON RECTANGLE

Dave Leeson, W6NL, has modified the Cushcraft XM240 2-element 40 meter Yagi to a Moxon Rectangle design shown in **Figure 11.27**. The W6NL Moxon Yagi is a high efficiency design that uses cross elements to provide both loading and the Moxon coupling. The upgrade of the XM240 to the W6NL Moxon consists of replacing the loading coil LCA sections with four new assemblies, each consisting of two new sections and the new tee loading element. The remaining parts are original Cushcraft.

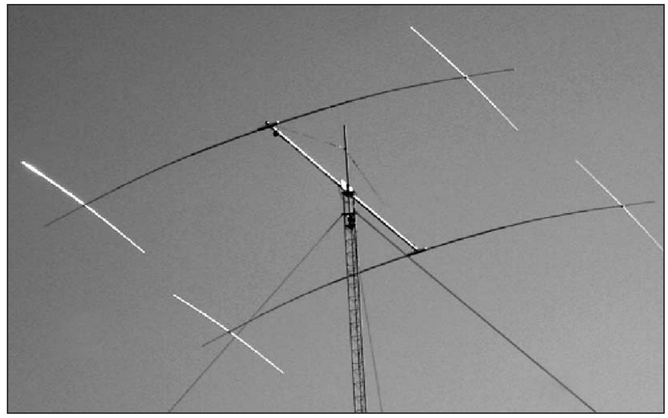


Figure 11.27 — A Cushcraft XM240 2-element 40 meter Yagi is modified by W6NL to become a Moxon Rectangle. The antenna is mechanically strengthened during the modification, as well. (Photo by Dave Leeson, W6NL)

The antenna has a gain of more than 10 dBi (including ground reflections) and a high front-to-back ratio (not specified by the designer). As is usual for Moxon designs, the SWR bandwidth is very good — more than 300 kHz with an SWR of less than 1.5:1.

Modifying the XM240 is described in detail in W6NL's design article, "Construction of W6NL Moxon on Cushcraft XM240," included on the CD-ROM for this book. The mechanical strength of the antenna is also improved as part of the modification procedure.

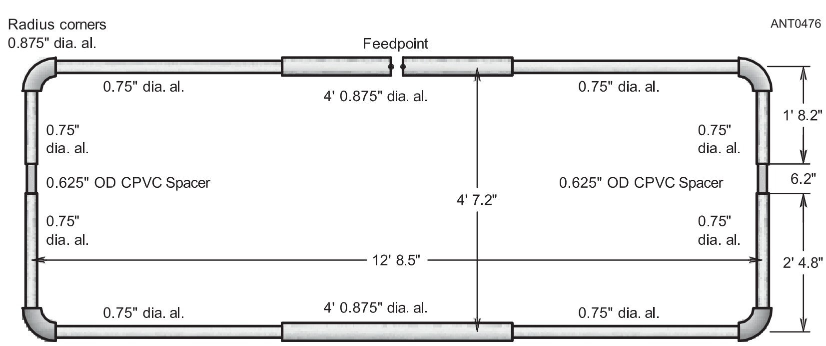


Figure 11.26 — General outline of the 10 meter aluminum Moxon rectangle, showing tubing dimensions.

11.8 QUAD ANTENNAS

The previous section discussed Yagi arrays as systems of approximately half-wave dipole elements that are coupled together mutually. You can also employ other kinds of elements using the same basic principles of analysis. For example, loops of various types may be combined into directive arrays. A popular type of parasitic array using loops is the *quad antenna*, in which loops having a perimeter of about one wavelength are used in much the same way as half-wave dipole elements in the Yagi antenna.

Clarence Moore, W9LZX, created the quad antenna in the early 1940s while he was at the Missionary Radio Station HCJB in Quito, Ecuador. He developed the quad to combat the effects of corona discharge at high altitudes. The problem at HCJB was that their large Yagi was literally destroying itself by melting its own element tips. This occurred due to the huge balls of corona it generated in the thin atmosphere of the high Andes Mountains. Moore reasoned correctly that closed loop elements would generate less high voltage — and hence less corona — than would the high impedances at the ends of a half-wave dipole element.

Figure 11.28 shows the original version of the two-element quad, with a driven element and a parasitic reflector. The square loops may be mounted either with the corners lying on horizontal and vertical lines, as shown at the left, or with two sides horizontal and two vertical (right). The feed points shown for these two cases will result in horizontal polarization, which is commonly used.

Quad designers may want to look up a copy of Bill Orr, W6SAI's *All About Cubical Quads* (now out of print) for a variety of design notes and ideas. Similarly, R. P. Haviland, W4MB's series of quad-related articles in *Ham Radio* and *QEX* are also worth reading. (See Bibliography.)

11.8.1 QUADS VERSUS YAGIS

Since its invention, there has been controversy whether the quad is a better performer than a Yagi. The three main electrical performance parameters of a Yagi are gain, response patterns (front-to-rear ratio, F/R) and feed point impedance/SWR. Proper analysis of a quad also involves checking all these parameters across the entire frequency range over which you intend to use it. Both a quad and a Yagi are classified as "parasitic, end-fire arrays." Modern antenna modeling by computer shows that monoband Yagis and quads with the same boom lengths and optimized for the same performance parameters have gains within about 1 dB of each other, with the quad slightly ahead of the Yagi.

Figure 11.29 plots the three parameters of gain, front-to-rear ratio (F/R) and SWR over the 14.0 to 14.35-MHz band for two representative antennas — a monoband three-element quad and a monoband four-element Yagi. Both of these have 26-foot booms and both are optimized for the best compromise of gain, F/R and SWR across the whole band.

While the quad in Figure 11.29 consistently exhibits about 0.5 dB more gain over the whole band, its F/R pattern toward the rear isn't quite as good as the Yagi's over that span of frequencies. This quad attains a maximum F/R of 25 dB at 14.1 MHz, but it falls to 17 dB at the bottom end of the band and 15 dB at the top. On the other hand, the Yagi's F/R stays consistently above 21 dB across the whole 20 meter band. The quad's SWR rises to just under 3:1 at the top end of the band, but stays below 2:1 from 14.0 to almost 14.3 MHz. The Yagi's SWR remains lower than 1.5:1 over the whole band.

The reason the Yagi in Figure 11.29 has more consistent responses for gain, F/R and SWR across the whole 20 meter band is that it has an additional parasitic element, giving two additional variables to play with — that is, the length of that

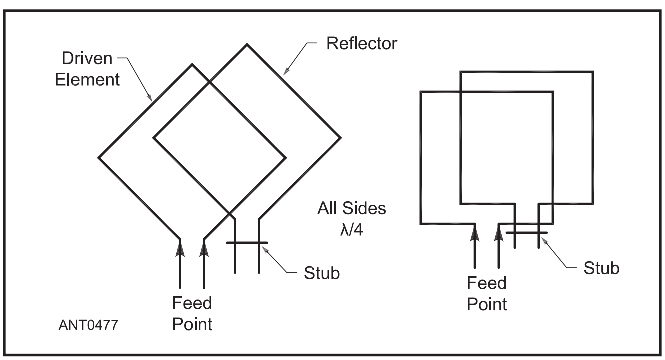


Figure 11.28 — The basic two-element quad antenna, with driven-element loop and reflector loop. The driven loops are electrically one wavelength in circumference (¼ wavelength on a side); the reflectors are slightly longer. Both configurations shown give horizontal polarization. For vertical polarization, the driven element should be fed at one of the side corners in the arrangement at the left, or at the center of a vertical side in the "square" quad at the right.

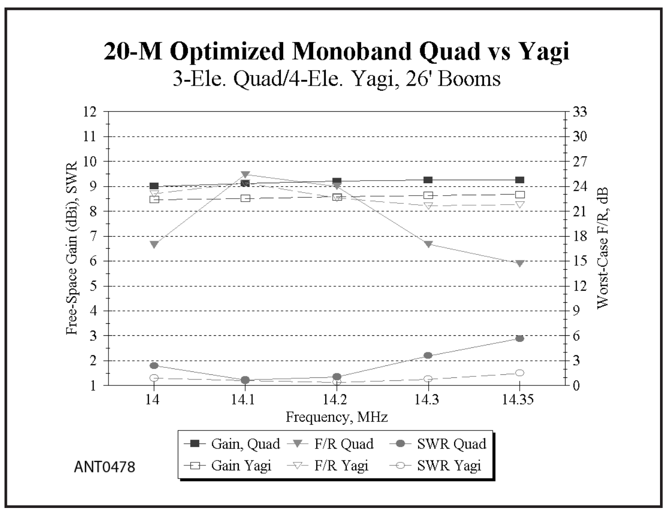


Figure 11.29 — Comparison of gain, F/R and SWR over the 14.0 to 14.35-MHz range for an optimized three-element quad and an optimized three-element Yagi, both on 26-foot booms. The quad exhibits almost 0.5 dB more gain for the same boom length, but doesn't have as good a rearward pattern over the whole frequency range compared to the Yagi. This is evidenced by the F/R curve. The quad's SWR curve is also not quite as flat as the Yagi. The quad's design emphasizes gain more than the other two parameters.

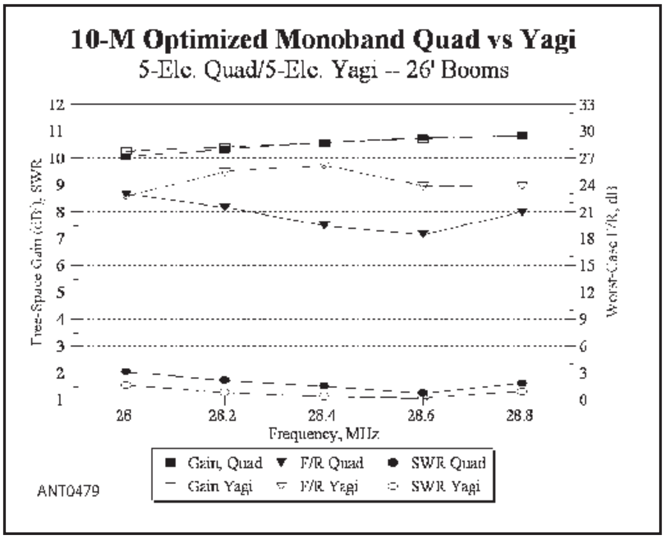


Figure 11.30 — Comparison of gain, F/R and SWR over the 28.0 to 28.8-MHz range for an optimized five-element quad and an optimized five-element Yagi, both on 26-foot booms. The gain advantage of the quad is about 0.25 dB at the low end of the band. The F/R is more peaked in frequency for the quad, however, than the Yagi.

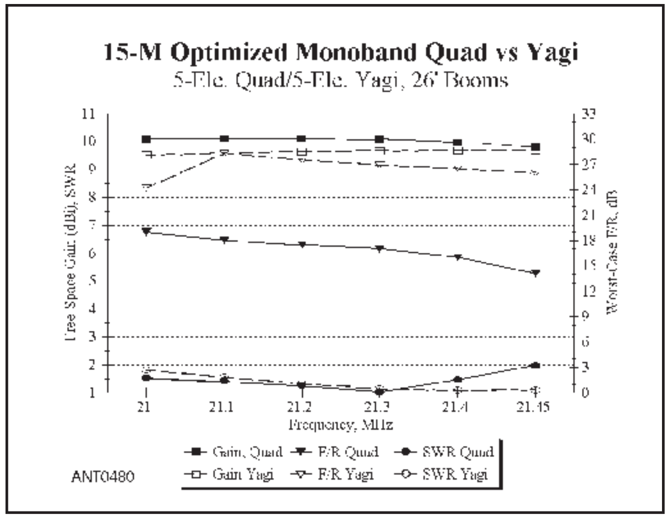


Figure 11.31 — Comparison of gain, F/R and SWR over the 21.0 to 21.45-MHz range for an optimized 5-element quad and optimized 5-element Yagi, both on 26-foot booms. The quad enjoys a gain advantage of about 0.5 dB over most of the band. Its rearward pattern is not as good as the Yagi, which remains higher than 24 dB across the whole range, compared to the quad, which remains in the 16-dB average range.

additional element and the spacing of that element from the others on the boom.

Yagi advocates point out that it is easier to add extra elements to a Yagi, given the mechanical complexities of adding another element to a quad. Extra parasitic elements give a designer more flexibility to tailor all performance parameters over a wide frequency range. Quad designers have historically opted to optimize strictly for gain and, as stated before, they can achieve as much as 1 dB more gain than a Yagi with the same length boom. But in so doing, a quad designer typically has to settle for front-to-rear patterns that are peaked over more narrow frequency ranges. The 20 meter quad plots in Figure 11.29 actually represent an even-handed approach, where the gain is compromised slightly to obtain a more consistent pattern and SWR across the whole band.

Figure 11.30 plots gain, F/R and SWR for two 10 meter monoband designs: a five-element quad and a five-element Yagi, both placed on 26-foot booms. The quad now has the same degrees of freedom as the Yagi, and as a consequence the pattern and SWR are more consistent across the range from 28.0 to 28.8 MHz. The quad's F/R remains above about 18.5 dB from 28.0 to 28.8 MHz. Meanwhile, the Yagi maintains an F/R of greater than 22 dB over the same range, but has almost 0.8 dB less gain compared to the quad at the low end of the band, eventually catching up at the high end of the band. The SWR for the quad is just over 2:1 at the bottom of the band, but remains less than 2:1 up to 28.8 MHz. The SWR on the Yagi remains less than 1.6:1 over the whole band.

Figure 11.31 shows the performance parameters for two 15 meter monoband designs: a five-element quad and a five-element Yagi, both on 26-foot booms. The quad is still the leader in gain, but has a less optimal rearward pattern and

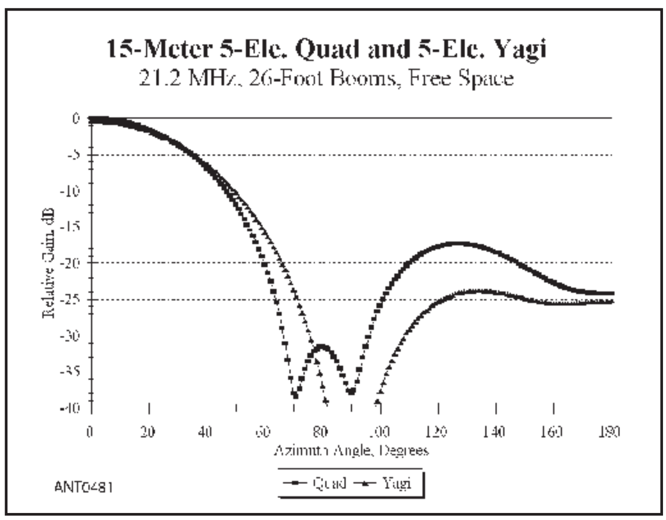


Figure 11.32 — Comparing the pattern of the 15 meter quad and Yagi shown in Figure 11.31. The quad has a slightly narrower frontal beamwidth (it has 0.5 dB more gain than the Yagi), but has higher "rear quartering" sidelobes at about 125° (with a twin sidelobe, not shown, at 235°). These sidelobes limit the worst-case front-to-rear (F/R) to about 17 dB, while the F/B (at 180°, directly at the back of the quad) is more than 24 dB for each antenna.

a somewhat less flat SWR curve than the Yagi. One thing should be noted in Figures 11.29-11.31. The F/R pattern on the Yagi is largely determined by the response at the 180° point, directly in back of the frontal lobe. This point is usually referred to when discussing the "front-to-back ratio."

The quad on the other hand has what a sailor might term "quartering lobes" (referring to the direction back toward

Table 11.11
Dimensions for Optimized Monoband Quads in Figs 11.29, 11.30 and 11.31, on 26-Foot Booms

	14.2 MHz	*21.2 MHz*	*28.4 MHz*
Reflector	73' 9"	49' 6"	37' 3"
R-DE Spacing	17' 8"	7'	6' 4"
Driven Element	71' 8"	47' 6"	35' 9"
DE-D1 Spacing	8' 3"	5'	5' 6"
Director 1	68' 7"	46' 8"	34' 8"
D1-D2 Spacing	—	6' 8"	6' 9"
Director 2	—	46' 10"	35' 2"
D2-D3 Spacing	—	7' 4"	7' 5"
Director 3	—	45' 8"	34' 2"
Feed method	Direct 50 Ω	Direct 50 Ω	Direct 50 Ω

the "quarterdeck" at the stern of a sailing vessel) in the rearward pattern. These quartering lobes are often worse than the response at 180°, directly in back of the main beam. **Figure 11.32** overlays the free-space E-Field responses of the 15 meter quad and Yagi together. At 21.2 MHz, the quad actually has a front-to-back ratio (F/B) of about 24 dB, excellent in anyone's book. The Yagi at 180° has a F/B of about 25 dB, again excellent.

However, at an azimuth angle of about 125° (and at 235° azimuth on the other side of the main lobe) the quad's "quartering lobe" is down only some 17 dB, setting the worst-case F/R at 17 dB also. As explained in the sections on Yagis, the reason F/R is more important than just the F/B is that on receive, signals can come from any direction, not just from directly behind the main beam.

Table 11.11 lists the dimensions for the three computer-optimized monoband quads shown in Figures 11.29, 11.30, and 11.31.

Cubical versus Concentric Quads

First — no quad is truly "cubical" in the sense of the distance between the elements being the same as the side of an element. That would place the elements λ/4 apart which is too widely spaced for good performance. The term "cubical quad" generally applies to multiband quads that maintain the same electrical spacing between elements on each band whereas "concentric quad" refers to a set of elements mounted on the spreaders in one plane, concentric to each other. (The two quad antennas shown in this chapter are concentric quads.)

The cubical quad with its consistent electrical spacing has a very slight performance advantage on the higher frequency bands but requires a special spreader mount at the center of the boom to hold the spreaders in the required tilted configuration. In fact, the boom of a true cubical quad is only inches long since the spreaders meet near the center. The cubical quad's spreaders, being both diagonal and tilted, must be a few percent longer than the planar spreaders of the concentric quad.

Quads Versus Yagis at Low Heights

Another belief held by some quad enthusiasts is that they need not be mounted very high off the ground to give excellent DX performance. Quads are somehow supposed to be greatly superior to a Yagi at the same height above ground. Unfortunately, this is mainly wishful thinking.

Figure 11.33 compares the same two 10 meter antennas as in Figure 11.30, but this time with each one mounted on a 50-foot tower over flat ground, rather than in theoretical free space. The quad does indeed have slightly more gain than a Yagi with the same boom length, as it has in free space. This is evidenced by the very slight compression of the quad's main lobe, but is more obvious when you look at the third lobe, which peaks at about 53° elevation. In effect, the quad squeezes some energy out of its second and third lobes and adds that to the first lobe. However, the difference in gain compared to the Yagi is only 0.8 dB for this particular quad design at a 9° elevation angle. And while it's true that every dB counts, you can also be certain that on the air you wouldn't be able to tell the difference between the two antennas. After all, a 10- to 20-dB variation in the level of signals is pretty common because of fading at HF.

11.8.2 MULTIBAND QUADS

On the other hand, one of the valid reasons quads have remained popular over the years is that antenna homebrewers can build multiband quads far more easily than they can construct multiband Yagis. In effect, all you have to do with a quad is add more wire to the existing support arms. It's not quite as simple as that, of course, but the idea of ready expandability

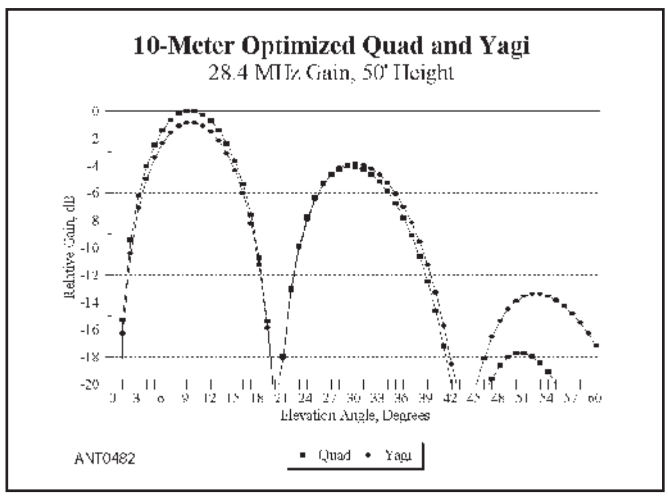


Figure 11.33 — A comparison on 10 meters between an optimized five-element quad and an optimized five-element Yagi, both mounted 50 feet high over flat ground and both employing 26-foot booms. There is no appreciable difference in the peak elevation angle for either antenna. In other words, a quad does not have an appreciable elevation-angle advantage over a Yagi mounted at the same boom height. Note that the quad achieves its slightly higher gain by taking energy from higher-angle lobes and concentrating that energy in the main elevation lobe. This is a process that is similar to what happens with stacked Yagis.

for other bands is very appealing to experimenters.

Like the Yagi, the quad does suffer from interactions between wires of different frequencies, but the degree of interaction between bands is usually less for a quad. The higher-frequency bands are the ones that often suffer most from any interaction, for both Yagis and quads. For example, the 10 and 15 meter bands are usually the ones affected most by nearby 20 meter wires in a triband quad, while the 20 meter elements are not affected by the 10 or 15 meter elements.

Modern computer modeling software can help you counteract at least some of the interaction by allowing you to do virtual "retuning" of the quad on the computer screen — rather than clinging precariously to your tower fiddling with wires. However, the programs (such as *NEC-2* or *EZNEC*) that can model three-dimensional wire antennas such as quads typically run far more slowly than those designed for monoband Yagis (such as *YW* included with this book). This makes optimizing rather tedious, but you use the same considerations for tradeoffs between gain, pattern (F/R) and SWR over the operating bandwidth as you do with monoband Yagis.

11.8.3 BUILDING A QUAD

The parasitic element shown in Figure 11.28 is tuned in much the same way as the parasitic element in a Yagi antenna. That is, the parasitic loop is tuned to a lower frequency than the driven element when the parasitic is to act as a reflector, and to a higher frequency when it is to act as a director. Figure 11.28 shows the parasitic element with an adjustable tuning stub, a convenient method of tuning since the resonant frequency can be changed simply by changing the position of the shorting bar on the stub. In practice, it has been found that the length around the loop should be approximately 3.5% greater than the self-resonant length if the element is a reflector, and about 3.0% shorter than the self-resonant length if the parasitic element is a director. Approximate formulas for the loop lengths in feet are:

$$\text{Driven Element} = \frac{1008}{f_{MHz}}$$

$$\text{Reflector} = \frac{1045}{f_{MHz}}$$

$$\text{Director} = \frac{977}{f_{MHz}}$$

These are valid for quad antennas intended for operation below 30 MHz and using uninsulated #14 AWG stranded copper wire. At VHF, where the ratio of loop circumference to conductor diameter is usually relatively small, the circumference must be increased in comparison to the wavelength. For example, a one-wavelength loop constructed of ¼-inch tubing for 144 MHz should have a circumference about 2% greater than in the above equation for the driven element.

Element spacings on the order of 0.14 to 0.2 free-space wavelengths are generally used. You would employ the smaller spacings for antennas with more than two elements, where the structural support for elements with larger spacings tends to become challenging. The feed point impedances of antennas having element spacings on this order have been found to be in the 40- to 60-Ω range, so the driven element can be fed directly with coaxial cable with only a small mismatch.

For spacings on the order of 0.25 wavelength (physically feasible for two elements, or for several elements at 28 MHz) the impedance more closely approximates the impedance of a driven loop alone — that is, 80 to 100 Ω. The feed methods described in the **Transmission Line System Techniques** chapter can be used, just as in the case of the Yagi.

Feeding the Multiband Quad

There are two approaches to feeding a multiband quad with several driven elements. If the driven elements are all on one set of spreaders the *combined feed* ties all of the elements together at a single feed point. This allows the use of a single feed line but creates a great deal of interaction between harmonically-related elements, reducing gain and F/B dramatically as described by L.B. Cebik in "Feeding the 5-Band Quad" (see Bibliography). Using separate feed lines to each driven element results in much less interaction and preserves the quad's performance.

A compromise that allows the use of a single feed line to the shack but separate feed lines for each element is to use a remote coax switch such as the Ameritron RCS-4 or RCS-8V (**www.ameritron.com**). The coax switch can be mounted on the antenna boom or mast and short feed lines run from the switch to the elements. The editor used just such a configuration for a number of years for a five-band 2-element quad with good results.

The impedance of the multiband quad driven elements varies quite a bit from the free-space value of a single loop. Cebik's article mentioned above shows that the feed point impedance varies from close to 50 Ω on 10 meters (the innermost element) to more than 100 Ω on 20 meters (the outermost element). If multiple feed lines are used, quarter-wave matching sections as described in the **Transmission Line System Techniques** chapter can be used to provide an acceptable SWR.

Mechanical Construction Issues

The most obvious problem related to quad antennas is the ability to build a structurally sound system. If high winds or heavy ice are a normal part of the environment, special precautions are necessary if the antenna is to survive a winter season.

Both multiband quad arrays use fiberglass spreaders. Bamboo is a suitable substitute (if economy is of great importance). However, the additional weight of the bamboo spreaders over fiberglass is an important consideration. A typical 12-foot bamboo pole weighs about 2 pounds; the fiberglass type weighs less than a pound. By multiplying the difference times 8 for a two-element array, times 12 for a three-element antenna, and so on, it quickly becomes apparent that fiberglass is worth the investment if weight is an important factor. Properly treated, bamboo has a useful life of three or four years, while fiberglass life is probably 10 times longer.

One step beyond the conventional fiberglass arm is the pole-vaulting arm. For quads designed to be used on 7 MHz, surplus "rejected" pole-vaulting poles are highly recommended. Their ability to withstand large amounts of bending is very desirable. The cost of these poles is high, and they are difficult to obtain.

Spreader supports (sometimes called *spiders*) are available from manufacturers such as Cubex (**www.cubex.com**). The expense of home-made spiders is about half that of a commercially manufactured equivalent. The homemade arm supports described for the multiband quad section below may be less likely to rotate on the boom as a result of wind pressure.

The physical sturdiness of a quad is directly proportional to the quality of the material used and the care with which it is constructed. The size and type of wire selected for use with a quad antenna is important because it will determine the capability of the spreaders to withstand high winds and ice. One of the more common problems confronting the quad owner is that of broken wires. A solid conductor is more apt to break than stranded wire under constant flexing conditions. For this reason, stranded copper wire is recommended. For 14-, 21- or 28-MHz operation, #14 or #12 AWG stranded wire is a good choice. Soldering of the stranded wire at points where flexing is likely to occur should be avoided.

You may connect the wires to the spreader arms in many ways. The simplest method is to drill holes through the fiberglass at the appropriate points on the arms and route the wires through the holes. Some amateurs have experienced cracking of fiberglass poles which might be a result of drilling holes through the material. However, this seems to be the exception rather than the rule.

Soldering a wire loop across the spreader, as shown in the designs below, is recommended. However, you should take care to prevent solder from flowing to the corner point where flexing could break it. A better method is to clamp a piece of plastic tubing to the spreader with a stainless steel hose clamp and run the wire through the tubing. This allows the wire to slide when the antenna flexes.

Every effort must be placed upon proper construction if you want to have freedom from mechanical problems. Hardware must be secure or vibration created by the wind may cause separation of assemblies. Solder joints should be clamped in place to keep them from flexing, which might fracture a connection point.

While a boom diameter of 2 inches is sufficient for smaller quads using two or even three elements for 14, 21 and 28 MHz, when the boom length reaches 20 feet or longer a 3-inch diameter boom is highly recommended. Wind creates two forces on the boom, vertical and horizontal. The vertical load on the boom can be reduced with a guy-wire truss cable. The horizontal forces on the boom are more difficult to relieve, so 3-inch diameter tubing is desirable.

Diamond or Square?

The question of how to orient the spreader arms has been raised many times over the years. Should you mount the loops in a diamond or a square configuration? Should one set of spreaders be horizontal, giving the loop a diamond shape as shown in Figure 11.28 on the left, or should the wire itself be horizontal to the ground (spreaders mounted diagonally in the fashion of an X) as shown at the right in Figure 11.28? From the electrical point of view, there is not enough difference in performance to worry about.

From the mechanical point of view there is no question which version is better. The diamond quad, with the associated horizontal and vertical spreader arms, is capable of holding an ice load much better than a system where no vertical support exists to hold the wire loops upright. Put another way, the vertical poles of a diamond array, if sufficiently strong, will hold the rest of the system erect. When water droplets are accumulating and forming into ice, it is very reassuring to see water running down the wires to a corner and dripping off, rather than just sitting there on the wires and freezing. The wires of a loop (or several loops, in the case of a multiband antenna) help support the horizontal spreaders under a load of ice. A square quad will droop severely under heavy ice conditions because there is nothing to hold it up straight.

Of course, in climates where icing is not a problem, many amateurs point out that they like the aesthetics of the square configuration. There are thousands of square-configuration quads in temperate areas around the world.

Another consideration will enter into your choice of orientation for a quad. You must mount a diamond quad somewhat higher on the mast or tower than for an equivalent square array, just to keep the bottom spreader away from the tower guys when you rotate the antenna.

Getting It Up the Tower

The many elements of a Yagi are hard enough to maneuver around guy wires but the quad's three-dimensional structure can make it a challenge to lift to the top of a tower. If the tower is a crank-up or tilt-over, it is much easier to get a quad mounted on the antenna mast. On a fixed, lattice-style tower with guys, you'll have to carefully work the antenna around each set of guy wires as it is raised. The tram technique described in the **Building Antenna Systems and Towers** chapter is highly recommended as the work to rig the tram pays off with a lot easier lift of the antenna over the guys.

Another technique used by builders of the more common concentric quads it to assemble each set of spreaders and elements separately on the ground and lift them one by one to the top of the tower where they are mounted to the boom one after another. This requires some planning but is a lot easier than lifting the entire assembled antenna, particularly when there are guy wires to contend with.

11.9 TWO MULTIBAND QUAD DESIGNS

This section describes two multiband quad designs. The first is a large triband 20/15/10 meter quad built on a 26-foot boom made of 3-inch irrigation tubing. This antenna has three elements on 20 meters, four elements on 15 meters, and five elements on 10 meters. **Figure 11.34** shows a photograph of the five-element triband quad. This is a *big* antenna!

The second project is a compact two-element triband quad on an 8-foot boom that covers 20, 17, 15, 12 and 10 meters. We call this a "pentaband" quad since it covers five bands. This antenna uses five concentric wire loops mounted on each of the two sets of spreaders. Either antenna may be constructed in a diamond or square configuration.

While the same basic construction techniques are employed for both multiband quads, the scale of the larger triband antenna makes it a far more ambitious undertaking! The large quad requires a strong tower and a rugged rotator. It also requires a fair amount of real estate in order to raise the quad to the top of the tower without getting tangled in trees or other antennas.

11.9.1 A FIVE-ELEMENT, 26-FOOT BOOM TRIBAND QUAD

Five sets of element spreaders are used to support the three elements used on 14 MHz, four elements on 21 MHz and five elements on 28 MHz. We chose to use four elements on 15 meters in this design (rather than the five we could have been employed on this length of boom) because the difference in optimized performance wasn't great enough to warrant the extra complexity of using five elements. The dimensions are listed in **Table 11.12**, and are designed for center frequencies of 14.175, 21.2 and 28.4 MHz.

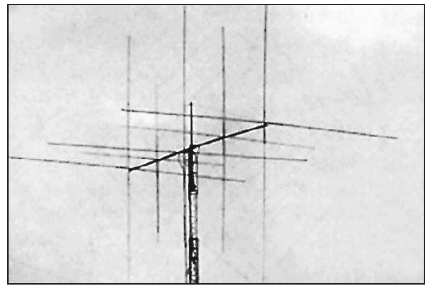


Figure 11.34 — Photo of the three-band, five-element quad antenna.

The spacing between elements has been chosen to provide good compromises in performance consistent with boom length and mechanical construction. You can see that the element spacings for 20 meters are quite different from those for the optimized monoband design. This is because the same set of spreaders is used for all three bands on three out

Table 11.12
Three-Band Five-Element Quad on 26-Foot Boom

	14.15 MHz	*21.2 MHz*	*28.4 MHz*
Reflector	72' 6"	49' 4"	36' 8"
R-DE Spacing	12'	12'	6'
Driven Element	71'	47' 6"	35' 4"
DE-D1 Spacing	14'	7'	6'
Director 1	68' 6"	46' 8"	34' 8"
D1-D2 Spacing	—	14'	7'
Director 2	—	46' 5"	34' 8"
D2-D3 Spacing	—	—	7'
Director 3	—	—	34'
Feed method	Direct 50 Ω	Direct 50 Ω	Direct 50 Ω

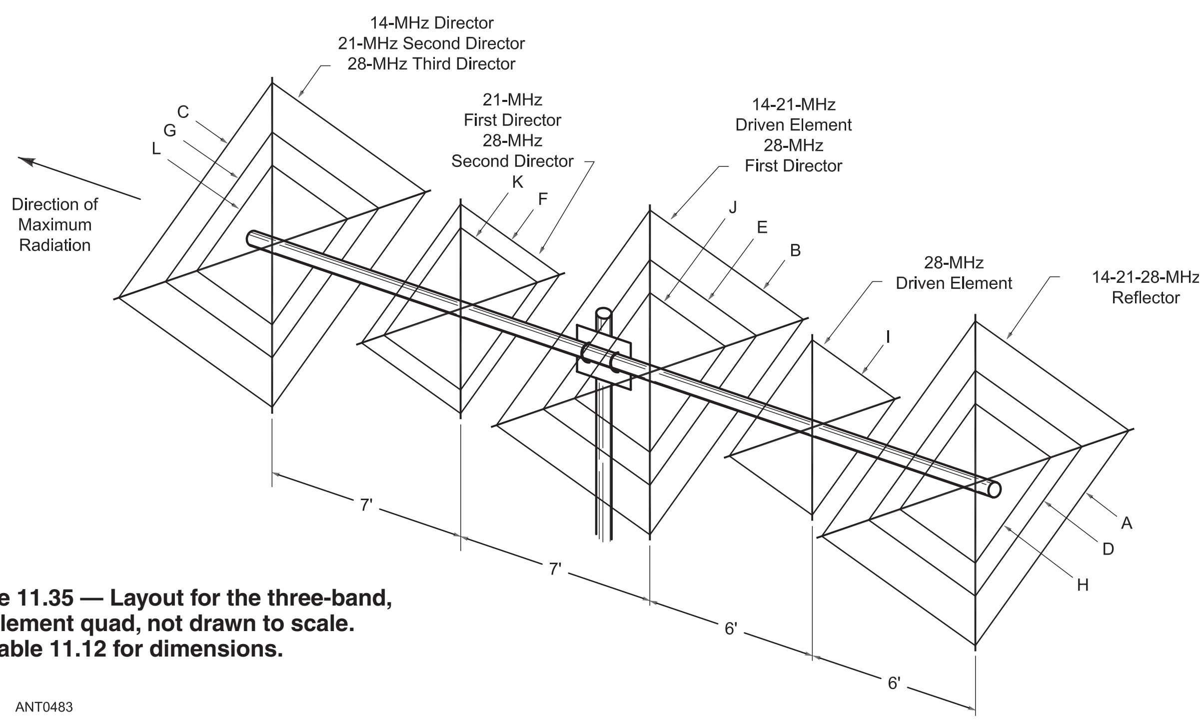


Figure 11.35 — Layout for the three-band, five-element quad, not drawn to scale. See Table 11.12 for dimensions.

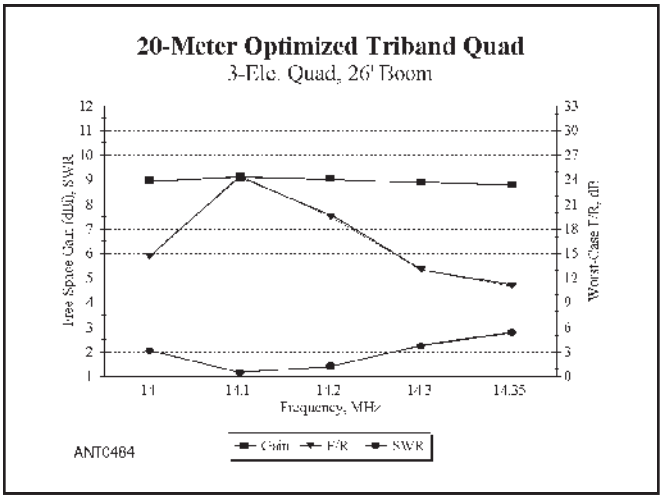


Figure 11.36 — Computed performance of the triband, five-element quad over the 20 meter band. The direct 50-Ω feed system holds the SWR below 2.8: 1 across the whole band. This could be improved with a gamma-match system tuned to 14.1 MHz if the builder really desires a low SWR. The F/R peaks at 14.1 MHz and remains above 10 dB across the whole band.

of the five elements, and the higher-frequency bands dictate the spacing because they are more critical.

Each of the parasitic loops is closed (ends soldered together) and requires no tuning. **Figure 11.35** shows the physical layout of the triband quad. **Figure 11.36** plots the computed free-space gain, front-to-rear ratio and SWR response across the 20 meter band. With only a few degrees of freedom in tuning and spacing of the three elements, it is impossible to spread the response out to cover the entire 20 meter band. The compromise design results in a rearward pattern that varies from a worst-case of just under 10 dB at the high end of the band, to a peak F/R of just under 19 dB at 14.2 MHz, in the phone portion of the band. The F/R is about 11 dB at the low end of the band.

The SWR remains under 3:1 for the entire 20 meter band, rising to 2.8:1 at the high end. The feed system for this triband quad consists of three separate 50-Ω coax lines, one per driven element, together with a relay switchbox mounted to the boom so that a single coax can be used back to the operating position. Each feed line uses a ferrite-bead balun to control common-mode currents and preserve the radiation pattern and each coax going to the switchbox is cut to be an electrical three-quarter wavelength on 15 meters. This presents a short at the unused driven elements since modeling indicated that the 15 meter band is adversely affected by the presence of the 20 meter driven element if it is left open-circuited. If you use RG-213 coax, the ¾-λ electrical length of each feed line is 23 feet long at 21.2 MHz. This is sufficient physical length to reach each driven element from the switchbox.

Figure 11.37 shows the free-space response for the 15 meter band. The rearward response is roughly 15 dB across the band. This is a result of the residual interaction

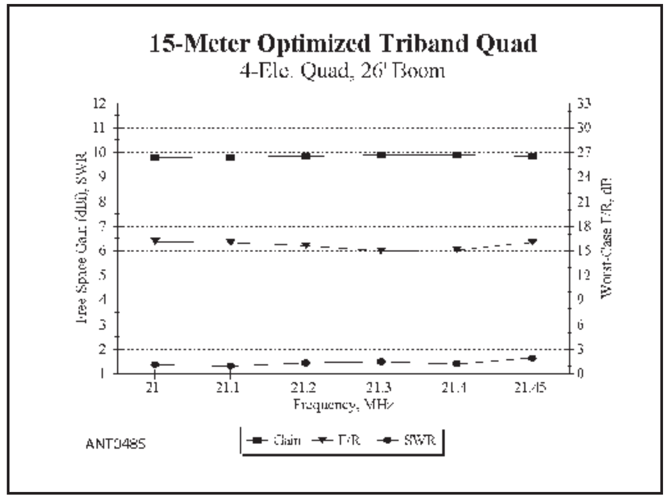


Figure 11.37 — Computed performance of the triband, five-element quad over the 15 meter band. There is some degree of interaction with the 20 meter elements, limiting the worst-case F/R to about 15 dB. The gain and SWR curves are relatively flat across the band.

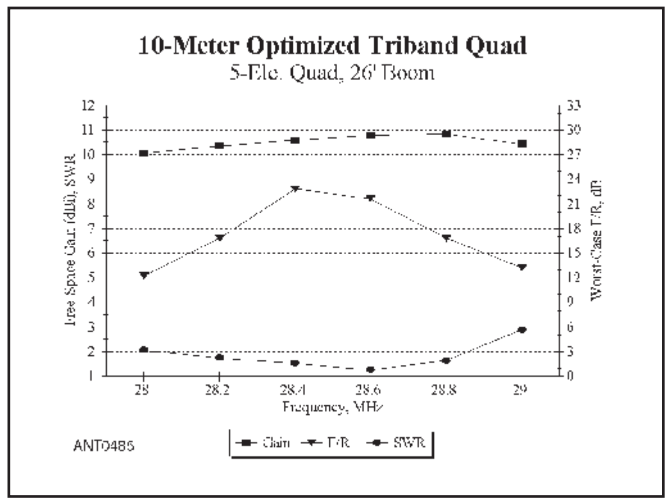


Figure 11.38 — Computed performance of the triband, five-element quad over the 10 meter band. The F/R is higher than 12 dB across the band from 28.0 to 29.0 MHz, but the SWR rises at the top end of the band beyond 2:1. The free-space gain is higher than 10 dBi across the band.

between the 20 meter elements on 15 meters, and no further tuning could improve the F/R. Note how flat the SWR curve is. This SWR characteristic is what gives the quad the reputation of being "wideband." A flat SWR curve, however, is not necessarily a good indicator of optimal performance for directional antennas like quads or Yagis, particularly multiband designs where compromises must be made by physical necessity.

Figure 11.38 shows the characteristics of the 10 meter portion of the two-element triband quad. The response favors the low-phone band, with the F/R falling to about 12 dB at the low end of the frequency range and rising to just about 23 dB at 28.4 MHz. The SWR curve is once again relatively flat across the major portion of the band up to 28.8 MHz.

Construction

A 3-foot length of steel angle stock, 1 inch per side, is used to interconnect the pairs of spreader arms. The steel is drilled at the center to accept a muffler clamp of sufficient size to clamp the assembly to the boom. The fiberglass is clamped to the steel angle stock with stainless steel hose clamps, two per pole. Each quad-loop spreader frame consists of two assemblies of the type shown in **Figure 11.39**.

Connecting the wires to the fiberglass is shown in **Figure 11.40**. The model described here has no holes in the spreader arms; the wires are attached to each arm with a few layers of plastic electrical tape and then wrapped approximately 20 times in a crisscross fashion with $\frac{1}{8}$-inch diameter nylon string, followed by more electrical tape for UV protection, as shown in **Figure 11.41**.

The wire loops are left open at the bottom of each driven element where the feed line coaxes are attached. All of the parasitic elements are continuous loops of wire; the solder joint is at the base of the diamond.

Although you could run three separate coax cables down to the shack, we suggest that you install a relay box at the

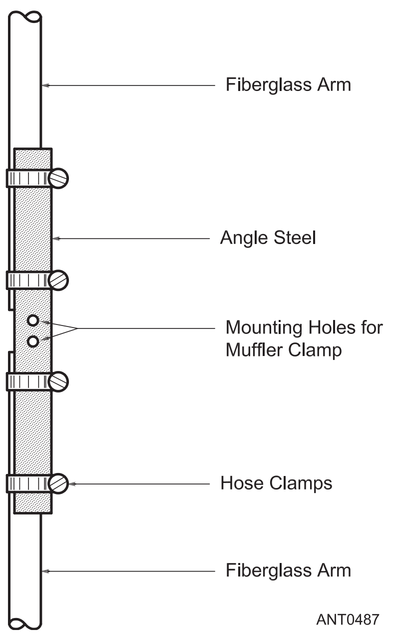


Figure 11.39 — Details of one of two assemblies for a spreader frame. The two assemblies are joined back-to-back to form an X with a muffler clamp mounted at the position shown.

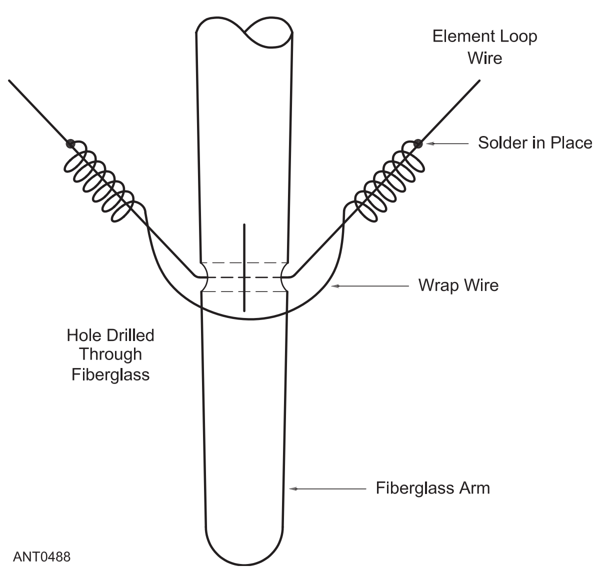


Figure 11.40 — A method of assembling a corner of the wire loop of a quad element to the spreader arm.

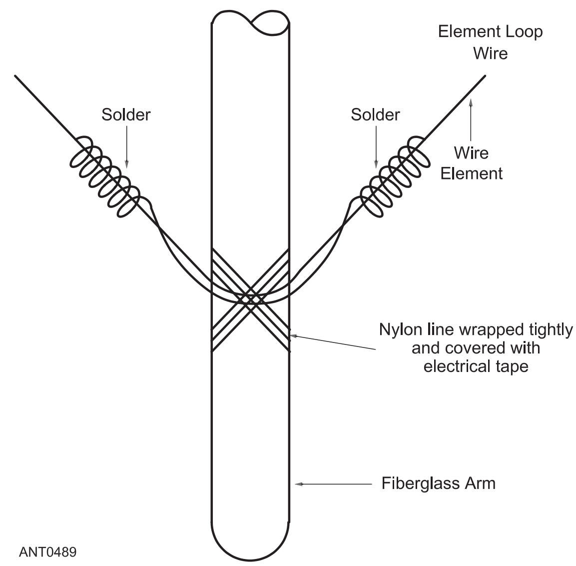


Figure 11.41 — An alternative method of assembling the wire of a quad loop to the spreader arm.

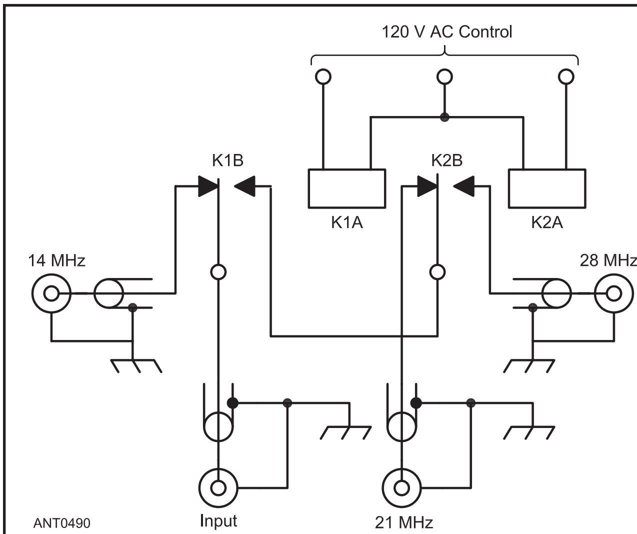


Figure 11.42 — Suitable circuit for relay switching of bands for the three-band quad. A three-wire control cable is required. K1, K2 — any type of relay suitable for RF switching, coaxial type not required (Potter and Brumfield MR11A acceptable; although this type has double-pole contacts, mechanical arrangements of most single-pole relays make them unacceptable for switching of RF).

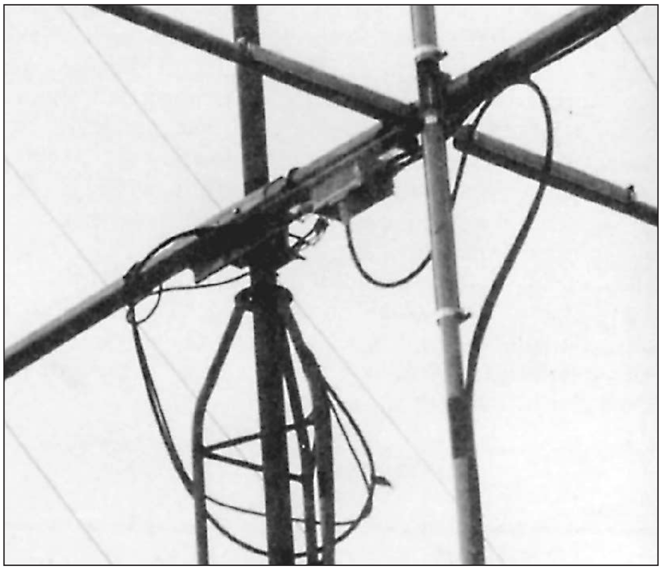


Figure 11.43 — The relay box is mounted on the boom near the center. Each of the spreader-arm fiberglass poles is attached to steel angle stock with hose clamps.

center of the boom. A three-wire control system may be used to apply power to the proper relay for changing bands. The circuit diagram of a typical configuration is presented in **Figure 11.42** and its installation is shown in **Figure 11.43**.

11.9.2 A TWO-ELEMENT, 8-FOOT BOOM PENTABAND QUAD

This two-element pentaband (20/17/15/12/10 meter) quad uses the same construction techniques as its big brother above. Since only two elements are used, the boom can be less robust for this antenna, at 2 inches diameter rather than 3 inches. Those who like really rugged antennas can still use the 3-inch diameter boom, of course.

This quad is very similar to those sold commercially by vendors such as Cubex who also sell hard-to-find parts for quads such as spreaders and the spiders that mount the spreaders to the boom. Readers may also want to review the article on improving the 2-element quad by Mees (see Bibliography).

Table 11.13 lists the element dimensions for the pentaband quad. The following plots show the performance for each of the five bands covered. The feed system for the pentaband quad uses five, direct 50-Ω coaxes, one to each driven element. These five coaxes are cut to be ¾-λ electrically on 10 meters (17 feet, 2 inches for RG-213 at 28.4 MHz). In this design the 10 meter band is the one most affected by the presence of the other driven elements if they are left un-shorted. The ¾-λ lines open-circuited at the switchbox are long enough physically to reach all elements from a centrally mounted switchbox. This length assumes that the switchbox open-circuits the unused coaxes. If the switchbox short-circuits unused coaxes (as several commercial switchboxes do), then use ½-λ long lines to feed all five driven elements (11 feet, 5 inches for RG-213 at 28.4 MHz).

The SWR curves do not necessarily go down to 1:1 because of this simple, direct feed system. If anyone is bothered by this, of course they can always implement individual matching systems, such as gamma matches. Most amateurs would agree that such a degree of complexity is not warranted. The worst-case SWR is less than 2.3:1 on each band, even with direct feed on 20 meters. With typical lengths of coaxial feed line from the shack to the switchbox at the antenna, say 100 feet of RG-213, the SWR at the transmitter would be less than 2.0:1 on all bands due to losses in the feed line.

Figure 11.44 shows the computed responses for the pentaband quad over the 20 meter band. With only two degrees of freedom (spacing and element tuning) there is not much that can be done to spread the response out over the entire 20 meter band. Nonetheless, the performance over the band is still pretty reasonable for an antenna this small. The F/R pattern peaks at 19 dB at 14.1 MHz and falls to about 10 dB at either end of the band. The free-space gain varies from about 7.5 dBi to just above 6 dBi, comparable to a short-boom

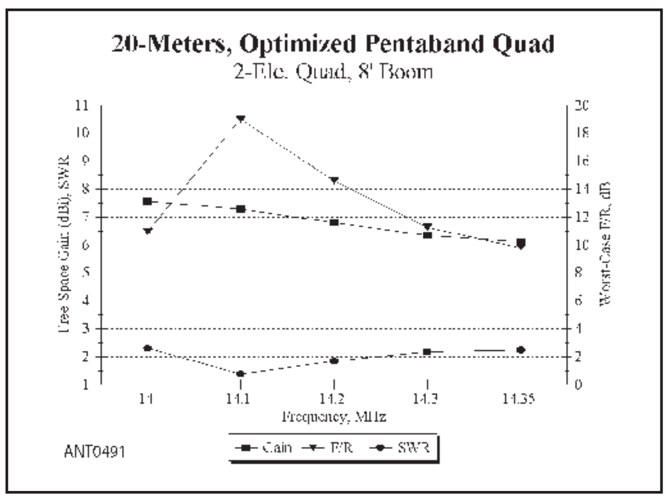


Figure 11.44 — Computed performance of the pentaband two-element quad on 20 meters. With the simple direct-feed system, the SWR rises to about 2.3:1 at the low end of the band. A gamma match can bring the SWR down to 1:1 at 14.1 MHz, if desired.

Table 11.13
Five-Band Two-Element Quad on 8-Foot Boom

	14.2 MHz	*18.1 MHz*	*21 MHz*	*24.9 MHz*	*28.4 MHz*
Reflector	72' 4"	56' 4"	48' 6"	40' 11¼"	37' 5½"
R-DE Spacing	8'	8'	8'	8'	8'
Driven Element	69' 10½"	54' 10½"	46' 7"	39' 10½"	34' 6"

three-element Yagi. The SWR curve remains below 2.3:1 across the band. If you were to employ a gamma match tuned at 14.1 MHz, you could limit the peak SWR to less than 2.0:1, and this would still occur at 14.0 MHz.

On 17 meters, **Figure 11.45** shows that the other elements are affecting 18 MHz, even with element-length optimization. Careful examination of the current induced on the other elements shows that the 20 meter driven element is interacting on 18 MHz, deteriorating the pattern and gain slightly. Even still, the performance on 17 meters is reasonable, especially for a five-band quad on an 8-foot boom.

On 15 meters, the interactions seems to have been contained, as **Figure 11.46** demonstrates. The F/R peaks at 21.1 MHz, at 19 dB and remains better than 12 dB past the top of the band. The SWR curve is low across the whole band.

On 12 meters, the interaction between bands is minor, leading to the good results shown in **Figure 11.47**. The SWR change across this band is quite flat, which isn't surprising given the narrow bandwidth of the 12 meter band.

On 10 meters, the interaction seems to have been tamed well by computer-tuning of the elements. The F/R remains higher than about 14 dB from 28 to 29 MHz. The SWR remains below 2.2:1 up to about 28.8 MHz, while the gain is relatively flat across the band at more than 7.2 dBi in free space. See **Figure 11.48**.

Overall, this pentaband quad is physically compact and yet it provides good performance across all five bands. It is competitive with commercial Log Periodic Dipole Array (LPDA) designs and triband Yagi designs that employ longer booms.

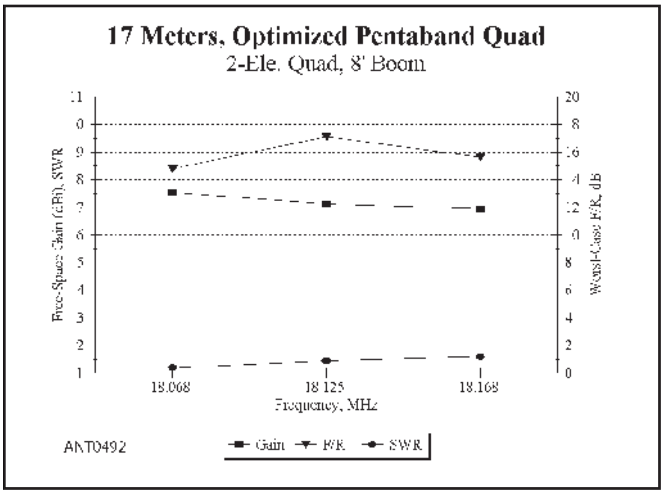


Figure 11.45 — Computed performance of the pentaband two-element quad on 17 meters. There is some interaction with the other elements, but overall the performance is satisfactory on this band.

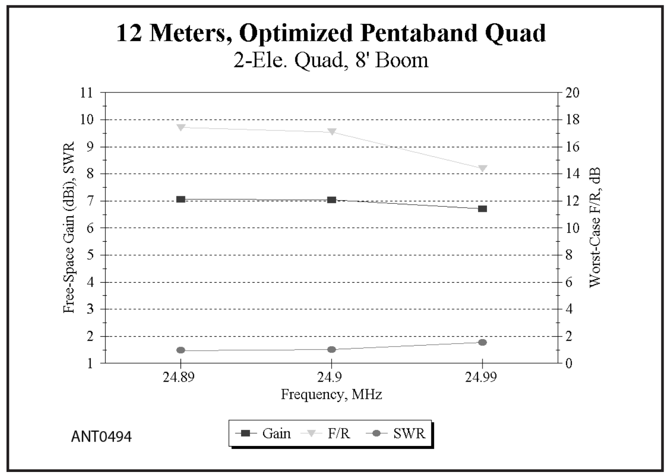


Figure 11.47 — Computed performance of the pentaband two-element quad on 12 meters.

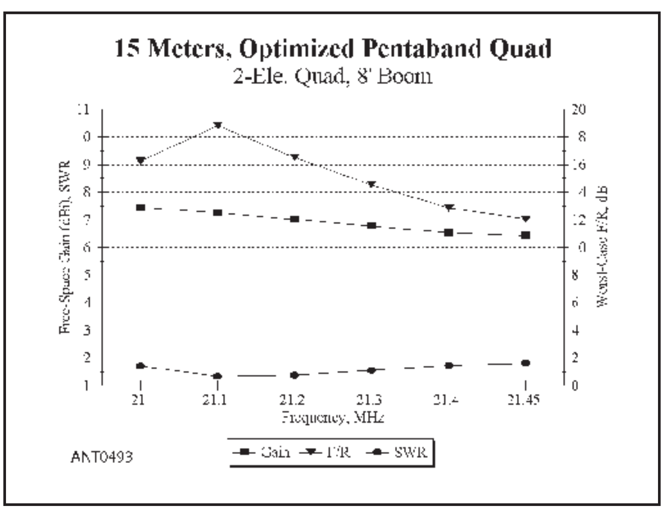


Figure 11.46 — Computed performance of the pentaband two-element quad on 15 meters. The performance is acceptable across the whole band.

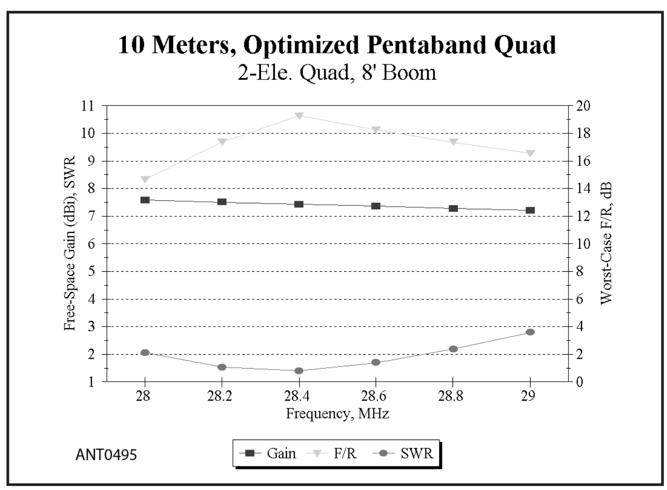


Figure 11.48 — Computed performance of the pentaband two-element quad on 10 meters. The SWR curve is slightly above the target 2:1 at the low end of the band and rises to about 2.2:1 at 28.8 MHz. This unlikely to be a problem, even with rigs with automatic power-reduction due to SWR, since the SWR at the input of a typical coax feed line will be lower than that at the antenna due to losses in the line.

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