Chapter 11

HF Yagi Arrays

Along with the dipole and the quarter-wave vertical, radio amateurs throughout the world make extensive use of the Yagi array. The Yagi was invented in the 1920s by Hidetsugu Yagi and Shintaro Uda, two Japanese university professors. 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 endfire multielement array. 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 spacing them 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 **Fig 1**. In the VHF and UHF spectrum, Yagis employing 30 or more elements are not uncommon, with a single reflector and multiple directors. See Chapter 18 for details on VHF and UHF Yagis. Large HF arrays may employ 10 or more elements, and will be covered in this chapter.

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 the directly driven multielement arrays considered in Chapter 8, where 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.

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, described in detail for the amateur audience the fundamental mathematics involved in modeling Yagis. His book *Yagi Antenna Design* is highly recommended for serious antenna designers. 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

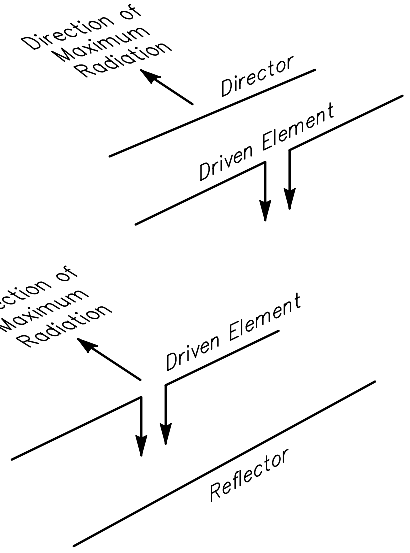


Fig 1—Two-element Yagi systems using a single parasitic element. At A the parasitic element acts as a director, and at B as a reflector. The arrows show the direction in which maximum radiation takes place.

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.

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, SWR or pattern measured at a single frequency gives very much insight into the overall performance of a particular Yagi. Poor designs have been known to reverse their directionality over a frequency band, while other designs have excessively narrow SWR bandwidths, or overly “peaky” gain response.

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 which are optimized for a good balance between gain, pattern and SWR over various amateur bands, and which are designed to survive strong winds and icing.

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 Chapter 8.

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* in amateur literature, 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 over 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. See Chapter 3, “The Effects of the Earth.”

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.

RESPONSE PATTERNS—FRONT-TO-REAR RATIO

As discussed in Chapter 2, for an antenna to have gain, it must concentrate energy radiated in a particular direction, at the expense of energy radiated in other directions. Gain is thus closely related to

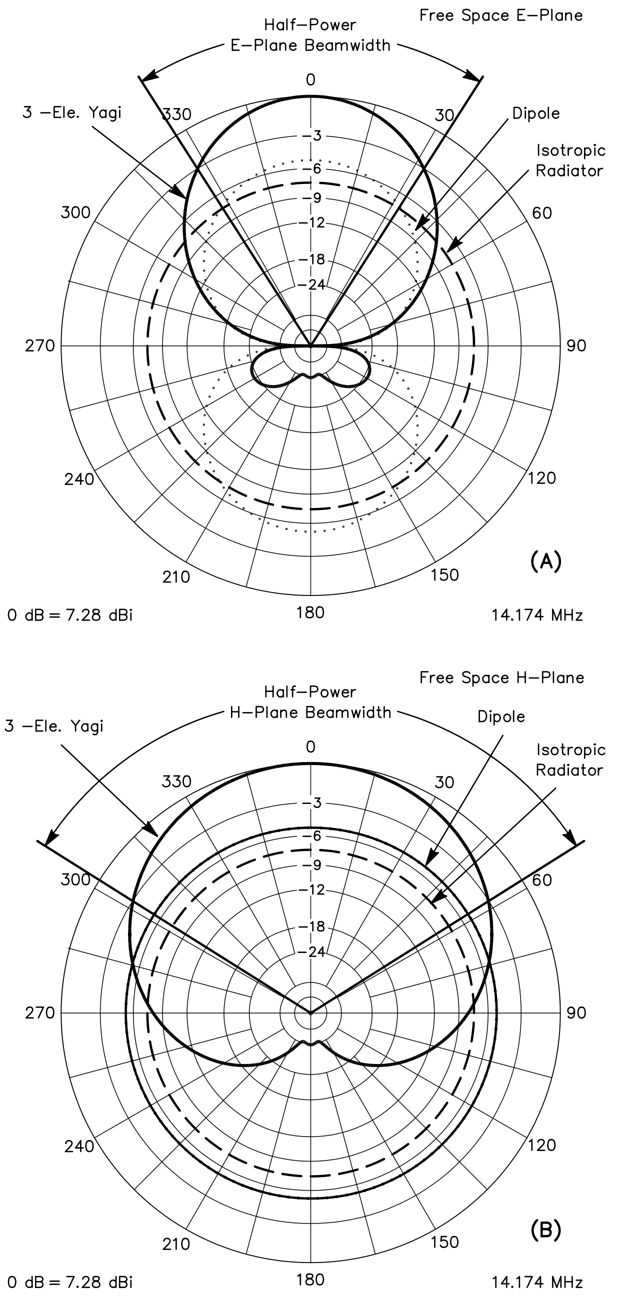


Fig 2—E-plane (electric field) and H-plane (magnetic field) response patterns for 3-element 20-meter Yagi in free space. At A the E-plane pattern for a typical 3-element Yagi is compared with a dipole and an isotropic radiator. At B the H-plane patterns are compared for the same antennas. The Yagi has 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°.

an antenna's directivity pattern, and also to the losses in the antenna. **Fig 2** shows the *E-plane* (also called *E-field*, for electric field) and *H-plane* (also called *H-field*, for magnetic field) pattern of a 3-element Yagi in free space, compared to a dipole, and an isotropic radiator. These patterns were generated using the computer program *NEC*, which is highly regarded by antenna professionals for its accuracy and flexibility.

In free space there is no Earth reference to determine whether the antenna polarization is horizontal or vertical, and so its response patterns are labeled as E-field (electric) or H-field (magnetic). For a Yagi mounted over ground rather than in free space, if the E-field is parallel to the earth (that is, the elements are parallel to the earth) then the antenna polarization is horizontal, and its E-field response is then usually referred to as its *azimuth* pattern. Its H-field response is then referred to as its *elevation* pattern.

Fig 2A demonstrates how 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. The gain is in the forward direction on the graph at 0° azimuth, and the forward part of the lobe is called the *main lobe*. For this particular antenna, the angular width of the E-plane main lobe at the half power, or 3 dB points compared to the peak, is about 66°. This performance characteristic is called the antenna's azimuthal *half-power beamwidth*.

Again as seen in Fig 2A, this antenna's response in the reverse direction at 180° azimuth is 34 dB less than in the forward direction. This characteristic is called the antenna's *front-to-back ratio*, and it describes the ability of an antenna to discriminate, for example, against interfering signals coming directly from the rear, when the antenna is being used for reception. In Fig 2A there are two sidelobes, at 120° and at 240° azimuth, which are about 24 dB down from 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, Fig 2A demonstrates that F/R is 0 dB. Fig 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°.

Fig 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. Fig 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.

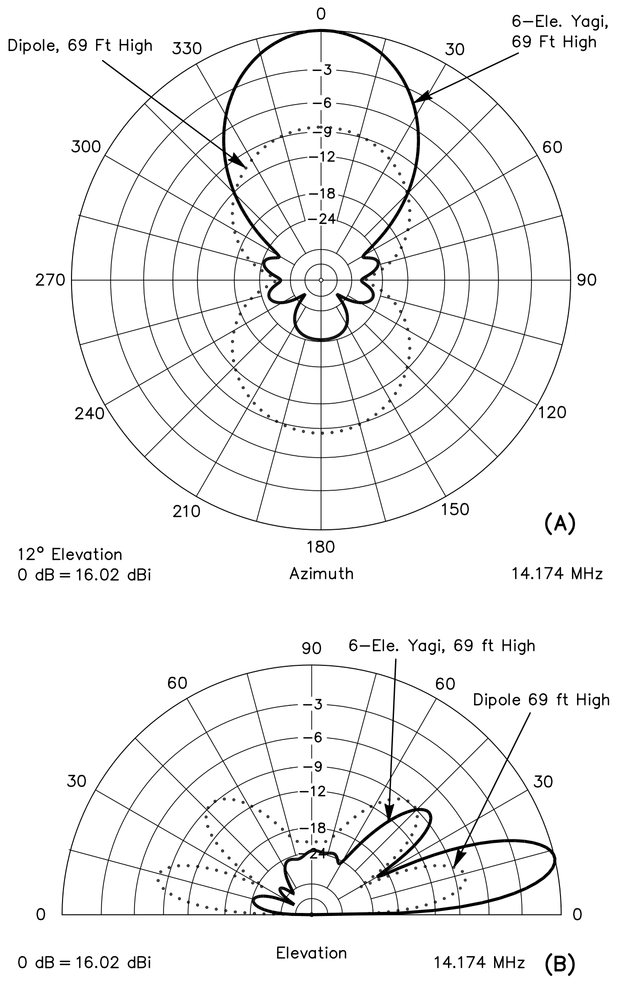


Fig 3—Azimuth pattern for 6-element 20-meter Yagi on 60-foot long boom, mounted 69 feet over ground. At A, the azimuth pattern at 12° elevation angle is shown, compared to a dipole at the same height. Peak gain of the Yagi is 16.04 dBi, or just over 8 dB compared to the dipole. At B, the elevation pattern 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.

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 Fig 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 earth. 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 under 35 feet at 14.2 MHz, heights that are not difficult to achieve for most amateurs. Some advanced computer programs can optimize Yagis at the exact installation height.

DRIVE IMPEDANCE AND SWR

The impedance at 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 ex-

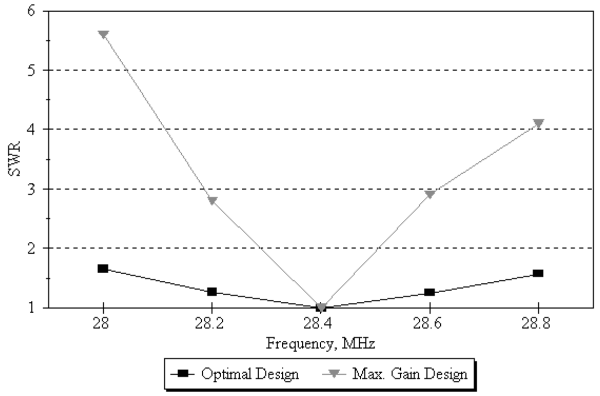


Fig 4—SWR over the 28.0 to 28.8-MHz portion of the 10-meter band for two different 3-element Yagi designs. One is designed strictly for maximum gain, while the second is optimized for F/R pattern and SWR over the frequency band. A Yagi designed only for maximum gain usually suffers from a very narrow SWR bandwidth.

tent by the presence of ground. In some designs which 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 cable. **Fig 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, which has been 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 probably want to advertise an antenna with the narrow-band SWR curve shown in Fig 4!

Yagi Performance Optimization

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.

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.

DESIGN VARIABLES

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

1. The physical length of the boom

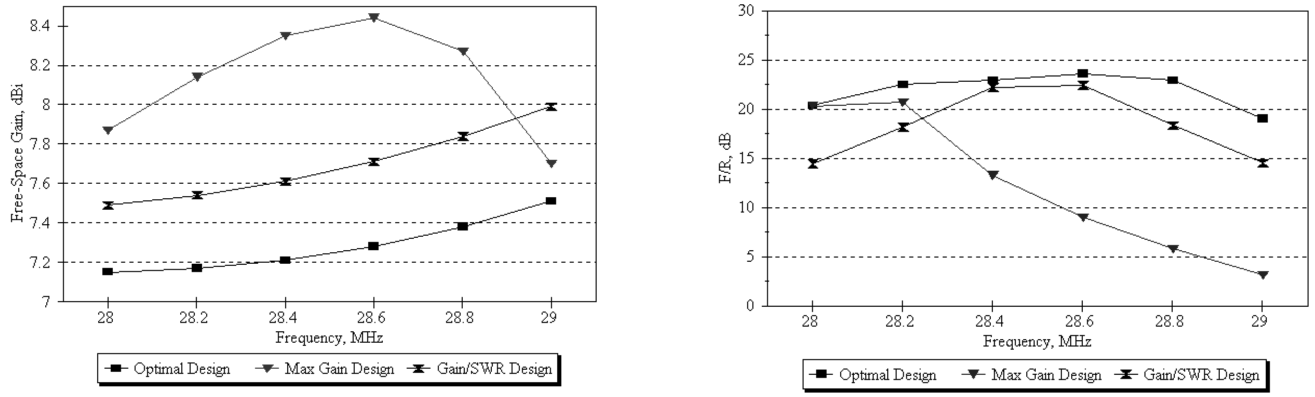
2. The number of elements on the boom
3. The spacing of each element along the boom
4. The tuning of each element
5. The type of matching network used to feed the array.

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 spread the response out over a frequency band.

Fig 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.



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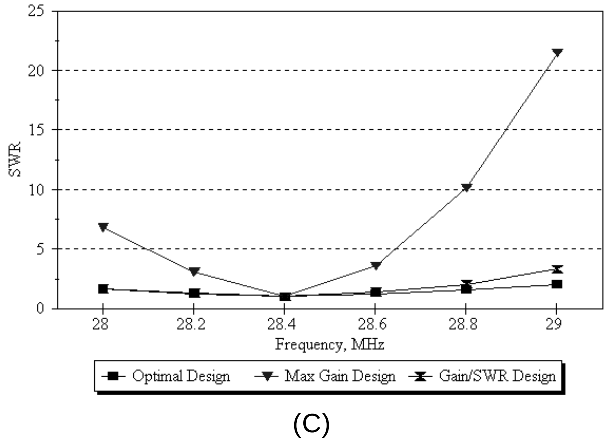


(C)

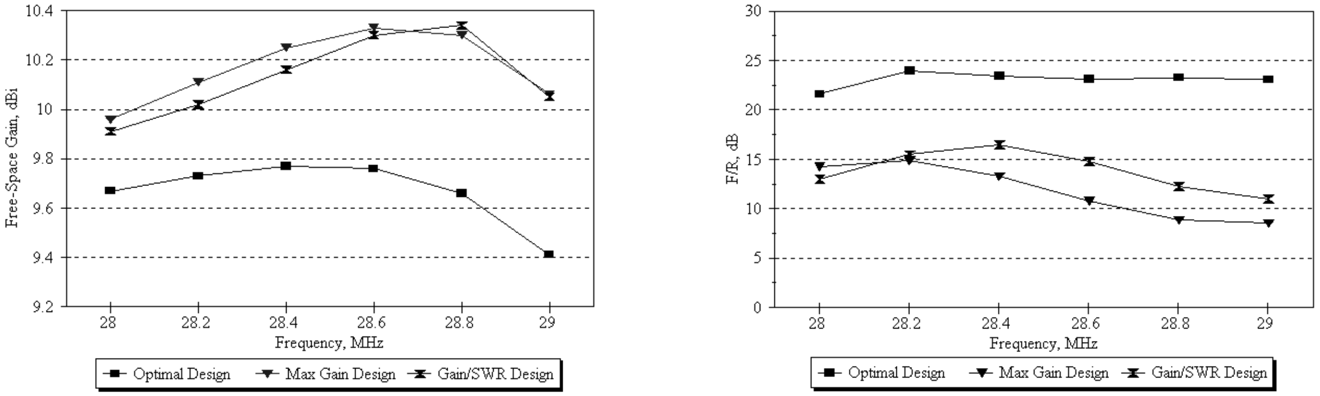
Fig 5—Comparisons of three different 3-element 10-meter Yagi designs using 8-foot booms. At A, gain comparisons are shown. The Yagi designed for the best compromise of gain and SWR sacrifices an average of about 0.5 dB compared to the antenna designed for maximum gain. The Yagi designed for optimal F/R, 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.

Fig 5B shows the F/R over the frequency band for these three designs, and Fig 5C shows the SWR curves over the frequency band. Antenna 1, the design which 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.

Fig 6A shows the free-space gain versus frequency for the same three types of designs, but for a bigger 5-element 10-meter Yagi on a 20-foot boom. Fig 6B shows the variation in F/R, and Fig 6C



(A) (B)

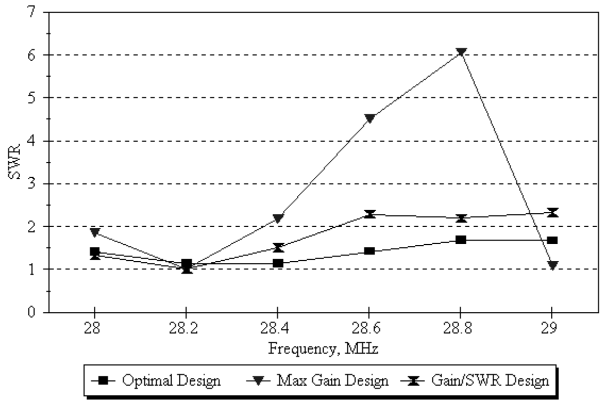


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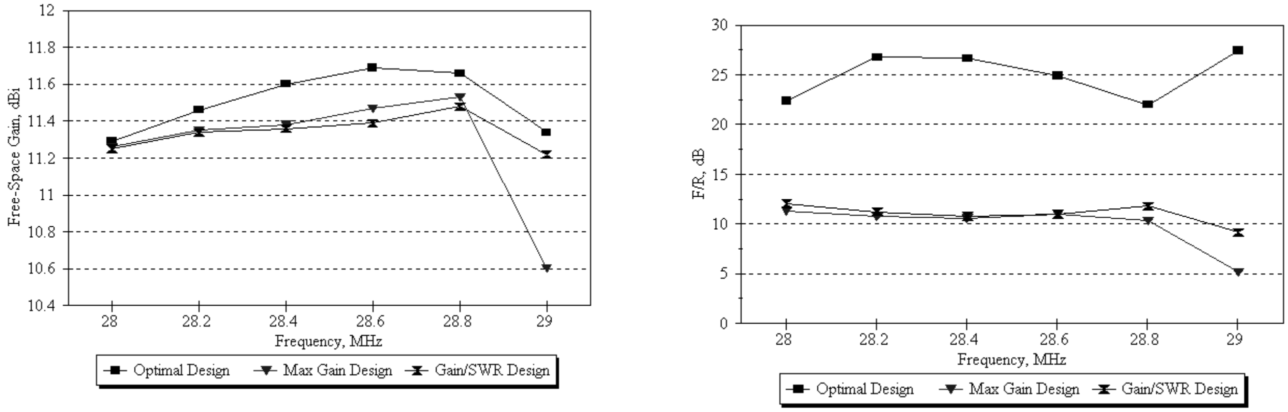
Fig 6—Comparisons of three different designs for 5-element 10-meter Yagis on 20-foot booms. At A, the gain of three different 5-element 10-meter Yagi designs are graphed. The difference in gain between the three antennas narrows because the elements can be stagger-tuned to spread the response out better 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.

shows the SWR curves versus frequency. Once again, the design which 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.

Fig 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 broadbanding the response over the whole band, while sacrificing only 0.3 dB of gain compared to the maximum-gain design.



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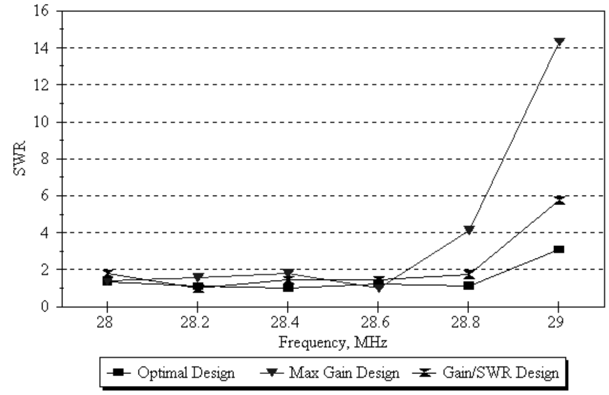

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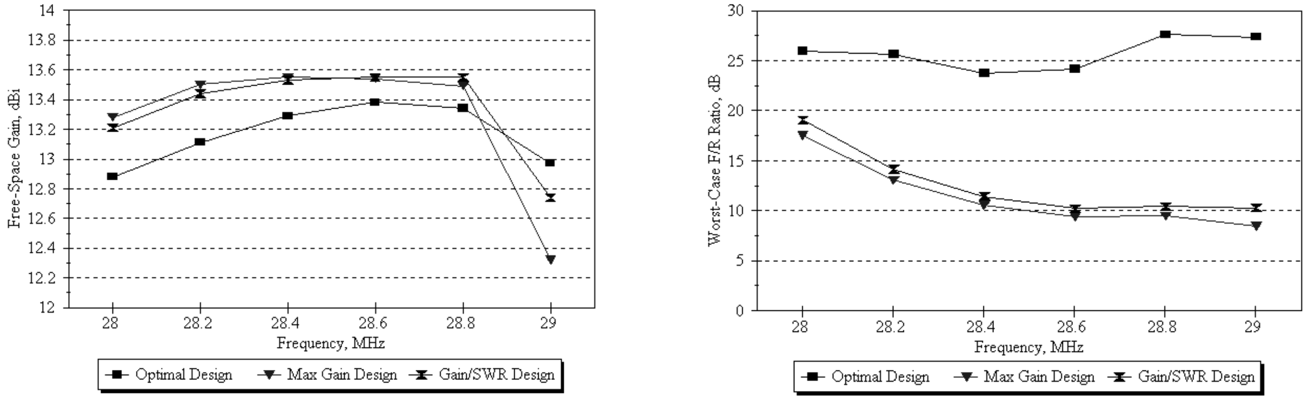
Fig 7—Comparisons of three different 6-element 10-meter Yagi designs on 36-foot booms. At A, gain is shown over the band. With more elements and a longer boom, the tuning can be staggered even more to make the antenna gain more uniform over the band. This narrows the gain differential between the antenna 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.



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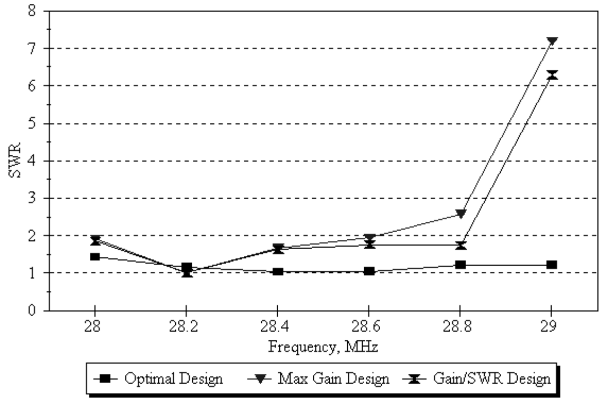

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Fig 8—Comparisons of three different 8-element 10-meter Yagi designs using 60-foot booms. At A, gain is shown over the frequency band. With even more freedom to stagger-tune elements and a very long boom on which to place them, the average antenna gain differential over the band is now less than 0.3 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.

Fig 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 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 anten-

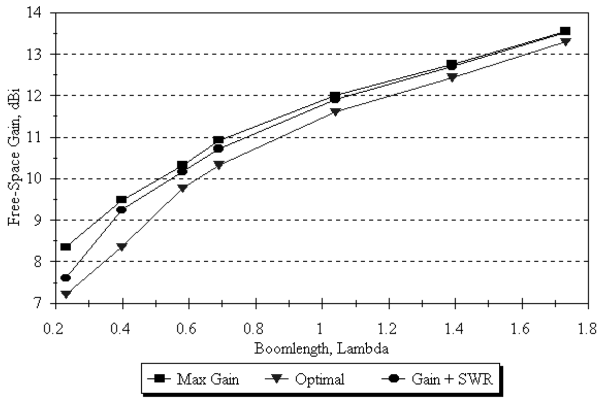


Fig 9—Gain versus boom length for three different 10-meter design goals. The goals are: (1) designed for maximum gain across band, (2) designed for a compromise of gain and SWR, and (3) designed for optimal F/R, SWR and gain across the 28.0 to 28.8 MHz portion of the 10-meter band. The gain difference is less than 0.5 dB for booms longer than approximately 0.5 λ.

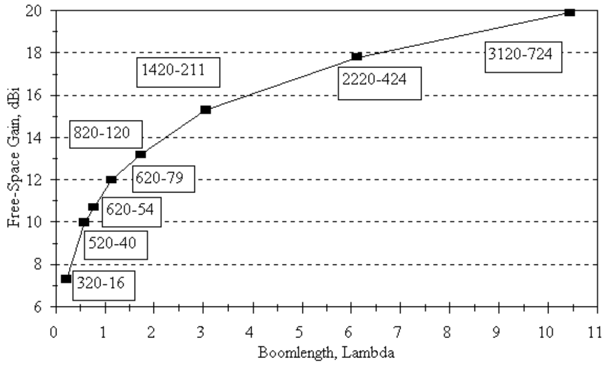


Fig 10—Theoretical gain versus boom length for 20-meter Yagis designed for optimal combination of F/R, SWR and gain across the entire 14.0 to 14.35 MHz band. The theoretical gain approaches 20 dBi for a gigantic 724-foot boom, populated with 31 elements. Such a design on 20 meters is not too practical, of course, but can readily be achieved on a 24-foot boom on 432 MHz.

nas which have mediocre rearward patterns, but which lose relatively little gain compared to the maximum gain case, at least for designs with more than three elements.

However, designing a Yagi for a 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. **Fig 9** summarizes the forward gain achieved for the three different design types versus boom length, as expressed in wavelength. Unless otherwise stated, 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, **Fig 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 are the prototypes for the theoretical 14-MHz long-boom designs. See Chapter 18 for VHF and UHF Yagis.

OPTIMUM DESIGNS AND ELEMENT SPACING

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. **Fig 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 windvanes, punishing, and often breaking, the rotators trying to turn, or hold, them in the wind. One successful solution to windvaning has been to employ "dummy elements" made of PVC piping. These nonconducting elements are placed on the boom close to the last director so the windload is equalized at the mast-to-boom bracket. In addition, it may be necessary to insert a small amount of lead weight at 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 $^1/_8$ inch results in performance remarkably consistent with the computations, without any "tweaking" or fine-tuning when the Yagi is on the tower.

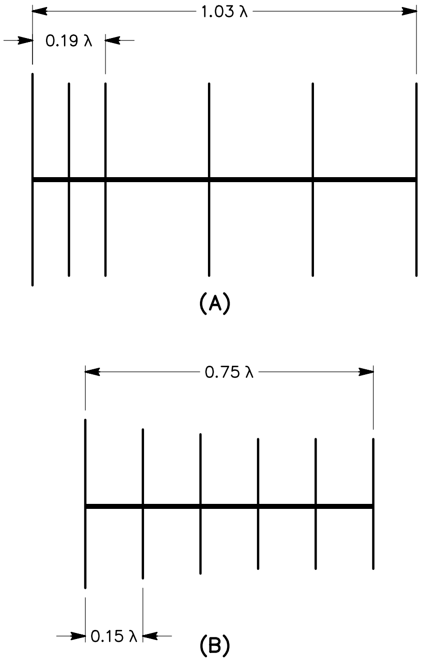


Fig 11—Tapering spacing versus constant element spacing. At A, illustration of how the spacing of the reflector, driven element and first director (over the first 0.19 λ of the boom) of an optimally designed Yagi is bunched together compared to the Yagi at B, which uses constant 0.15 λ spacing between 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 from 28.0 to 28.8 MHz.

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. See the section entitled "Antenna Frequency Scaling," and "Tapered Elements" in Chapter 2 of this book for details about element tuning as a function of tapering and element diameter. 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 operator. 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 section entitled "Construction with Aluminum Tubing" in Chapter 20 of this book shows details of tapered telescoping aluminum elements for the upper HF bands. In addition, the ARRL book *Physical Design of Yagi Antennas*, by Dave Leeson, W6QHS, describes the mechanical design process for all portions of a Yagi antenna very thoroughly, and is highly recommended for serious Yagi builders.

Specific Yagi Designs

The detailed Yagi design tables which follow are for two taper schedules for 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 $^1/_4$-inch radial ice. The medium-duty elements are designed to survive winds greater than 80 mph, or 60-mph winds with $^1/_4$-inch radial ice.

For 10.1 MHz, the elements shown are capable of surviving 105-mph winds, or 93-mph winds with $^1/_4$-inch radial ice. For 7.1 MHz the elements shown can survive 93-mph winds, or 69-mph winds with $^1/_4$-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 Fig 27 of Chapter 18, and as described in the ARRL book *Yagi Antenna Design*. 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 tuning is determined by the length of the tip, since the inner tubes are fixed in diameter and length.

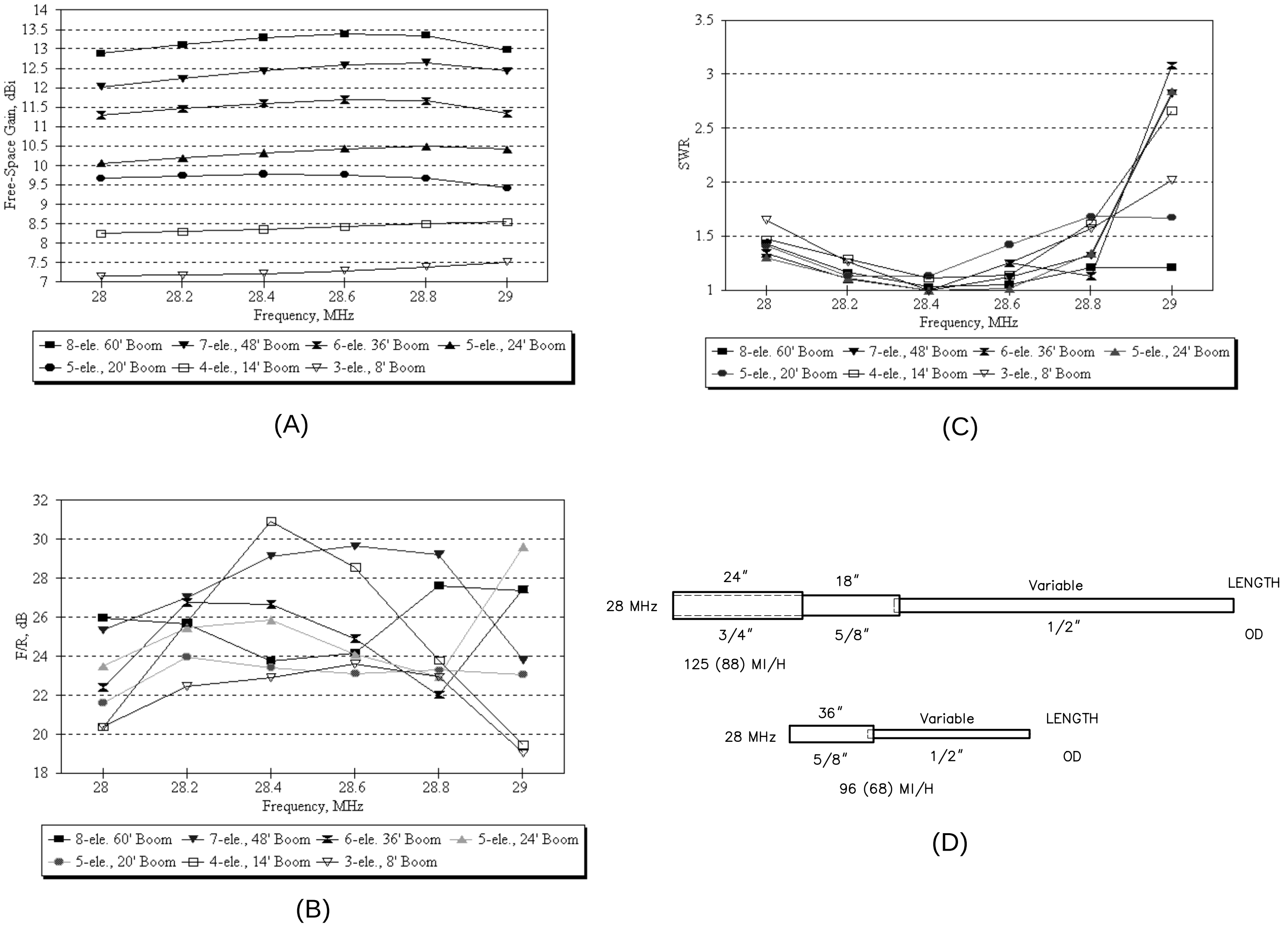
Note: Each design shows the dimensions for *one-half* of each element, mounted on one side of the boom. The other half of each element is the same, mounted on the other side of the boom. The use of a tubing sleeve inside the center portion of the element is recommended, so that the element is not crushed 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 Fig 11 in Chapter 20 of this book. Each antenna is designed with a driven-element length appropriate for a gamma type of matching 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!

10-METER YAGIS

Fig 12 describes the electrical performance of seven optimized 10-meter Yagis with boom lengths between 8 to 60 feet. The end of each boom includes 3 inches of space for the reflector and last-director mounting plates. Fig 12A shows the free-space gain versus frequency for each antenna; 12B shows the front-to-rear ratio, and 12C shows the SWR versus frequency. Each antenna 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.

Fig 12D 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 $^1/_4$ inch of radial ice. The medium-duty design can handle 96-mph winds with no icing, and 68-mph winds with $^1/_4$ 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 is centered on the plate, held by two galvanized U-bolts with saddles. Another set of U-bolts with saddles is used to secure the mounting plate to the boom. Electrically each mounting plate is equivalent to a cylinder, with 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. These dimensions are used in the computer modeling program to simulate the effect of the mounting plate.

The second column in **Table 1** 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 3 inches extra space at each end, the reflector is actually placed 3 inches from the end of the boom. For example, in the 310-08.YAG design (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.



(A)

(C)

(B)

(D)

Fig 12—Gain, F/R and SWR performance versus frequency for optimized 10-meter Yagis. At A, gain is shown versus frequency for seven 10-meter Yagis whose booms range from 8 feet to 60 feet long, and which have been optimized for better than 20 dB F/R and less than 2:1 SWR over the frequency range from 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 $^{1}/_{4}$-inch radial ice. The medium-duty elements can survive 96-mph winds without icing, and 68-mph winds with $^{1}/_{4}$-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.

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 310-08.YAG, the heavy-duty reflector tip, made out of $^{1}/_{2}$-inch OD tubing, sticks out 66.750 inches from the $^{5}/_{8}$-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 $^{1}/_{8}$-inch OD tubing is 69.750 inches long for the reflector. The medium-duty reflector tip has 71.875 inches protruding from the $^{5}/_{8}$-inch OD tube, and is 74.875 inches long overall. As previously stated, the dimensions are not extremely critical, although measurement accuracy to $^{1}/_{8}$ inch is desirable.

The last column in each variable tip columns 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 310-08.YAG antenna. Note that the heavy-duty elements require a correspondingly longer torque compensator than do the medium-duty elements.

Table 1
Optimized 10-Meter Yagi Designs

Three-element 10-meter Yagi, 8-foot boom

Element	*Spacing*	*Heavy-Duty Tip*	*Medium-Duty Tip*
File Name		*310-08H.YAG*	*310-08M.YAG*
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.YAG*	*410-14M.YAG*
Reflector	0.000"	64.875"	70.000"
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.YAG*	*510-24M.YAG*
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.YAG*	*610-36M.YAG*
Reflector	0.000"	65.750"	70.875"
Driven Element	37.000"	57.625"	62.875"
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.YAG*	*710-48M.YAG*
Reflector	0.000"	65.375"	70.500"
Driven Element	37.000"	58.125"	63.375"
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.YAG*	*810-60M.YAG*
Reflector	0.000"	65.000"	70.125"
Driven Element	42.000"	57.375"	62.625"
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 in inches. See Fig 12D 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 are one-half of total length, centered on boom.

Table 2
Optimized 12-Meter Yagi Designs

Three-element 12-meter Yagi, 10-foot boom

Element	*Spacing, inches*	*Heavy-Duty Tip*	*Medium-Duty Tip*
File Name		*312-10H.YAG*	*312-10M.YAG*
Reflector	0.000"	69.000"	73.875"
Driven Element	40.000"	59.125"	64.250"
Director 1	74.000"	54.000"	59.125"
Compensator	12" behind Dir. 1	13.625"	12.000"

Four-element 12-meter Yagi, 14-foot boom

Element	*Spacing, inches*	*Heavy-Duty Tip*	*Medium-Duty Tip*
File Name		*412-14H.YAG*	*412-14M.YAG*
Reflector	0.000"	66.875"	71.875"
Driven Element	46.000"	60.625"	65.625"
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.YAG*	*512-20M.YAG*
Reflector	0.000"	69.750"	74.625"
Driven Element	46.000"	61.750"	66.750"
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.YAG*	*612-30M.YAG*
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	72.000"	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.YAG*	*612-40M.YAG*
Reflector	0.000"	67.000"	71.875"
Driven Element	46.000"	60.125"	65.125"
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.YAG*	*712-54M.YAG*
Reflector	0.000"	67.125"	72.000"
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 in inches. See Fig 13D for element telescoping tubing schedule. Torque compensator element is made of 2.5" OD PVC water pipe placed 12" behind the last director. Dimensions shown for compensators are one-half of total length, centered on boom.

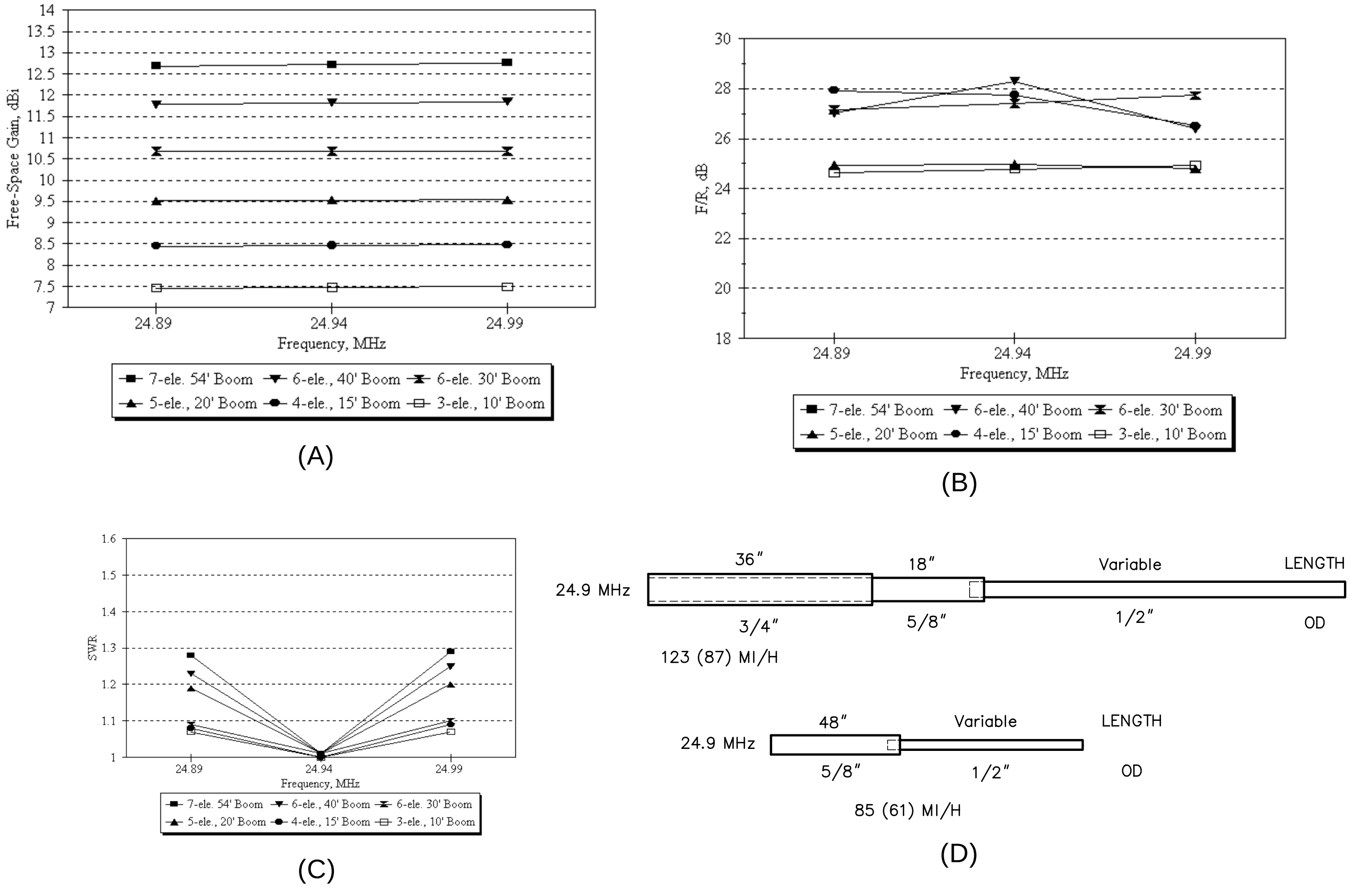
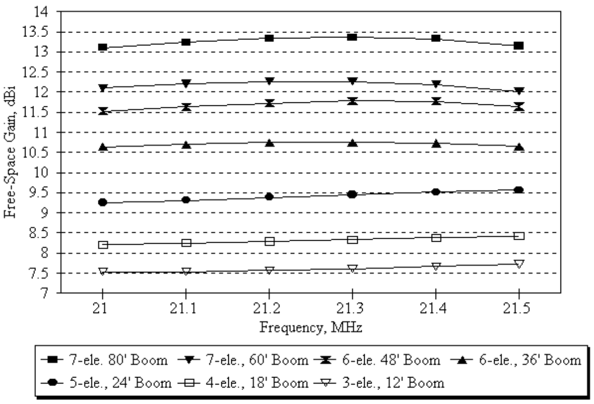


Fig 13—Gain, F/R and SWR performance versus frequency for optimized 12-meter Yagis. At A, gain is shown versus frequency for six 12-meter Yagis whose booms range from 10 feet to 54 feet long, and which have been optimized for better than 20 dB F/R and less than 2:1 SWR over the narrow 12-meter band from 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 $^1/_4$-inch radial ice. The medium-duty elements can survive 85-mph winds without icing, and 61-mph winds with $^1/_4$-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.

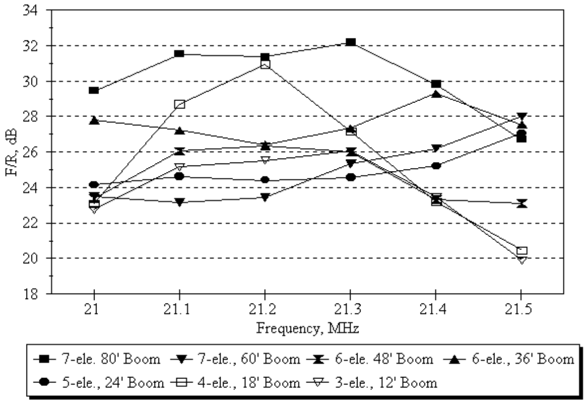
12-METER YAGIS

Fig 13 describes the electrical performance of six optimized 12-meter Yagis with boom lengths between 10 to 54 feet. The end of each boom includes 3 inches of space for the reflector and last director mounting plates. The narrow frequency width of the 12-meter band allows the performance to be optimized easily. Fig 13A shows the free-space gain versus frequency for each antenna; 13B shows the front-to-rear ratio, and 13C shows the SWR versus frequency. Each antenna 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.

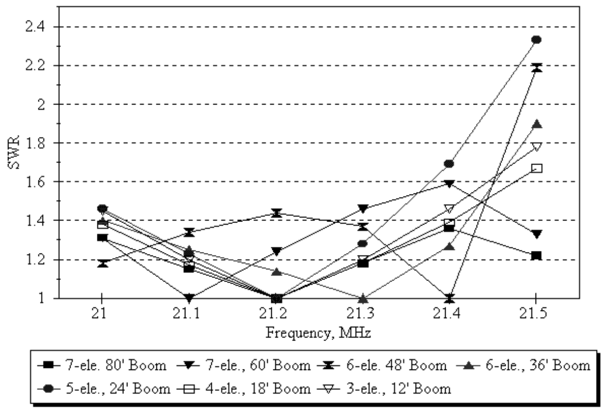
Fig 13D shows the taper schedule for two types of 12-meter elements. The heavy-duty design can survive 123-mph winds with no icing, and 87-mph winds with $^1/_4$ inch of radial ice. The medium-duty design can handle 85-mph winds with no icing, and 61-mph winds with $^1/_4$ inch of radial ice. The element-to-boom mounting plate for these Yagis is a 0.375 inches thick flat aluminum plate, 5 inches wide by 6 inches long. Electrically, each mounting plate is equivalent to a cylinder, with an effective diameter of 2.9447 inches for the heavy-duty element, and 2.8568 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.



(A)

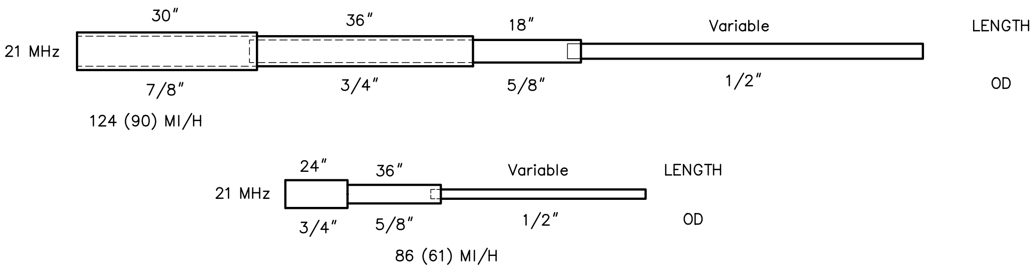


(B)



(C)

Fig 14—Gain, F/R and SWR performance versus frequency for optimized 15-meter Yagis. At A, gain versus frequency is shown for seven 15-meter Yagis whose booms range from 12 feet to 80 feet long, and which have been optimized for better than 20 dB F/R and less than 2:1 SWR over the frequency range from 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 $^{1}/_{4}$-inch radial ice. The medium-duty elements can survive 86-mph winds without icing, and 61-mph winds with $^{1}/_{4}$-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.



(D)

15-METER YAGIS

Fig 14 describes the electrical performance of seven optimized 15-meter Yagis with boom lengths between 12 feet to a spectacular 80 feet. The end of each boom includes 3 inches of space for the reflector and last-director mounting plates. Fig 14A shows the free-space gain versus frequency for each antenna; 14B shows the worst-case front-to-rear ratio, and 14C shows the SWR versus frequency. Each antenna 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.

Fig 14D 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 $^{1}/_{4}$ inch of radial ice. The medium-duty design can handle 86-mph winds with no icing, and 61-mph winds with $^{1}/_{4}$ 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. Electrically, each mounting plate is equivalent to a cylinder, with 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.

Table 3
Optimized 15-Meter Yagi Designs

Three-element 15-meter Yagi, 12-foot boom

Element	*Spacing*	*Heavy-Duty Tip*	*Medium-Duty Tip*
File Name	*12' boom*	*315-12H.YAG*	*315-12M.YAG*
Reflector	0.000"	61.375"	83.750"
Driven Element	48.000"	49.625"	72.625"
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.YAG*	*415-18M.YAG*
Reflector	0.000"	59.750"	82.250"
Driven Element	56.000"	50.875"	73.875"
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.YAG*	*515-24M.YAG*
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.YAG*	*615-36M.YAG*
Reflector	0.000"	61.000"	83.375"
Driven Element	53.000"	51.375"	74.250"
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"

Six-element 15-meter Yagi, 48-foot boom

Element	*Spacing*	*Heavy-Duty Tip*	*Medium-Duty Tip*
File Name		*615-48H.YAG*	*615-48M.YAG*
Reflector	0.000"	60.500"	83.000"
Driven Element	48.000"	50.875"	72.875"
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.YAG*	*715-60M.YAG*
Reflector	0.000"	59.750"	82.250"
Driven Element	48.000"	51.375"	74.250"
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"

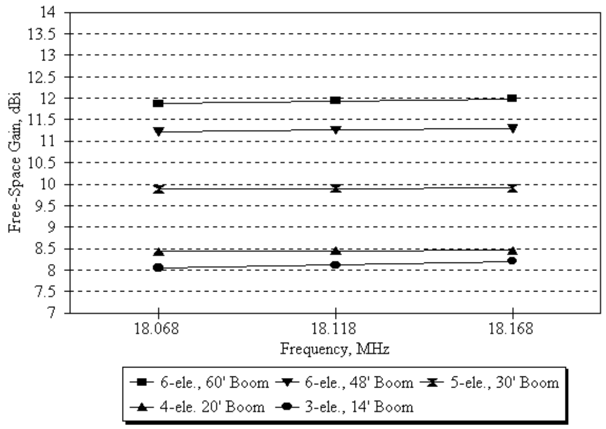
Eight-element 15-meter Yagi, 80-foot boom

Element	*Spacing*	*Heavy-Duty Tip*	*Medium-Duty Tip*
File Name		*815-80H.YAG*	*815-80M.YAG*
Reflector	0.000"	60.625"	83.125"
Driven Element	56.000"	51.250"	74.125"
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 14D 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 are one-half of total length, centered on boom.

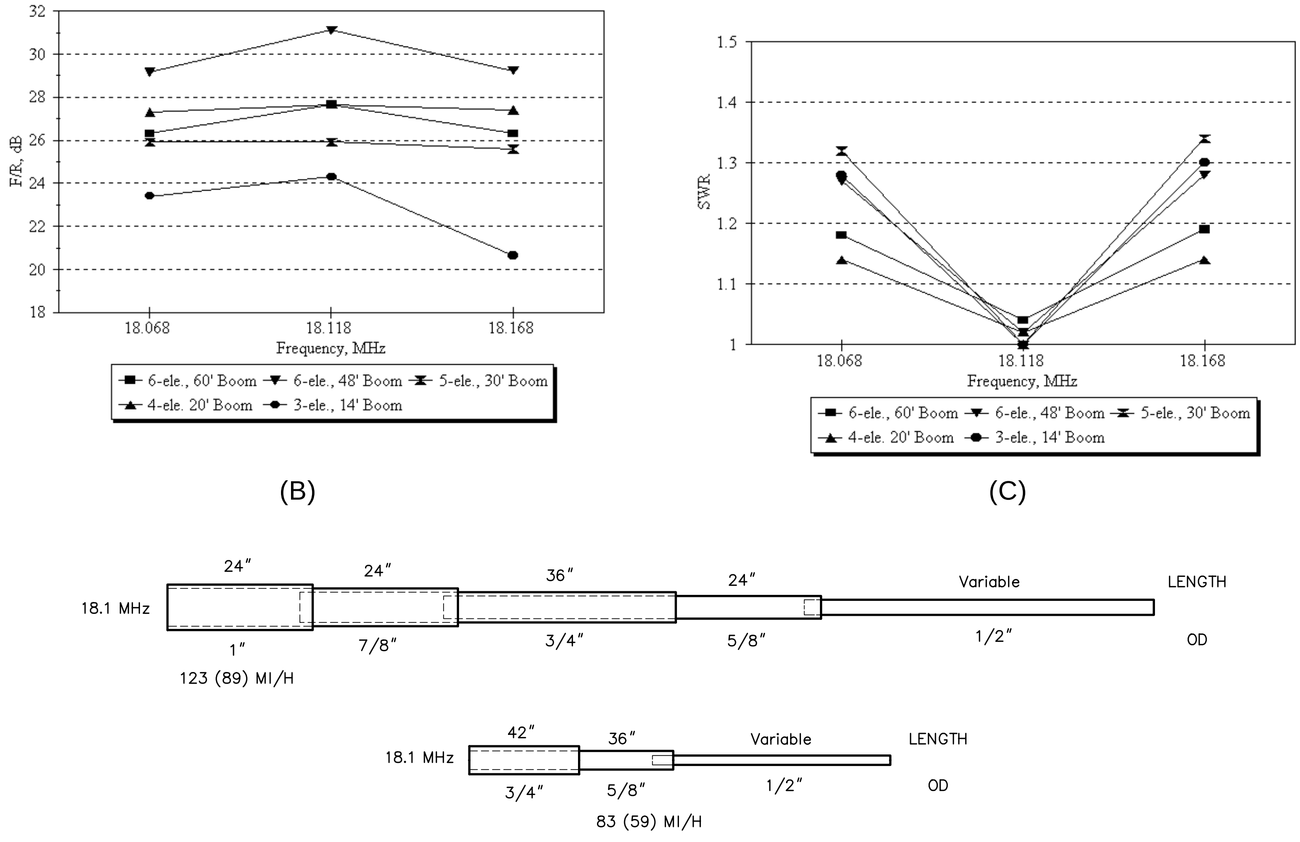
17-METER YAGIS

Fig 15 describes the electrical performance of five optimized 17-meter Yagis with boom lengths between 14 to a heroic 60 feet. As usual, the end of each boom includes 3 inches of space for the reflector and last director mounting plates. Fig 15A shows the free-space gain versus frequency for each antenna; 15B shows the worst-case front-to-rear ratio, and 15C shows the SWR versus frequency. Each antenna 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.



(A)

Fig 15—Gain, F/R and SWR performance versus frequency for optimized 17-meter Yagis. At A, gain versus frequency is shown for five 17-meter Yagis whose booms range from 14 feet to 60 feet long, and which have been optimized for better than 20 dB F/R and less than 2:1 SWR over the narrow 17-meter band from 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 17-meter elements is shown. The heavy-duty elements can withstand 123-mph winds without icing, and 89-mph winds with 1/4-inch radial ice. The medium-duty elements can survive 83-mph winds without icing, and 59-mph winds with 1/4-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.



(B)

(C)

(D)

Fig 15D 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 $^1/_4$ inch of radial ice. The medium-duty design can handle 83-mph winds with no icing, and 59-mph winds with $^1/_4$ 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. Electrically, each mounting plate is equivalent to a cylinder, with 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.

Table 4

Optimized 17-meter Yagi Designs

Three-element 17-meter Yagi, 14-foot boom

Element	*Spacing*	*Heavy-Duty Tip*	*Medium-Duty Tip*
File Name		*317-14H.YAG*	*317-14M.YAG*
Reflector	0.000"	60.125"	88.250
Driven Element	65.000"	56.625"	81.125
Director 1	97.000"	48.500"	77.250"
Compensator	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.YAG*	*417-20M.YAG*
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.YAG*	*517-30M.YAG*
Reflector	0.000"	61.875"	89.875"
Driven Element	48.000"	52.625"	81.125"
Director 1	52.000"	49.625"	78.250"
Director 2	93.000"	49.875"	78.500"
Director 3	161.000"	42.500"	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.YAG*	*617-48M.YAG*
Reflector	0.000"	62.250"	90.250"
Driven Element	52.000"	52.625"	81.125"
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

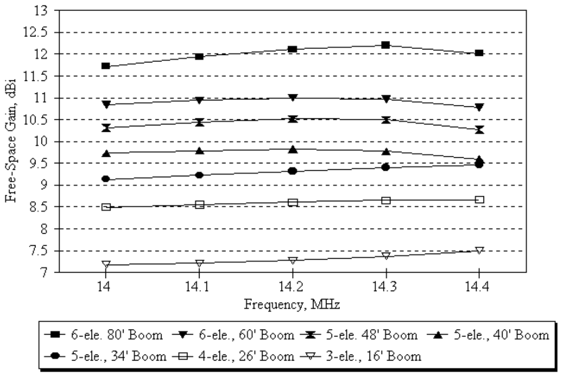
Element	*Spacing*	*Heavy-Duty Tip*	*Medium-Duty Tip*
File Name		*617-60H.YAG*	*617-60M.YAG*
Reflector	0.000"	61.250"	89.250"
Driven Element	54.000"	54.750"	83.125"
Director 1	54.000"	52.250"	80.750"
Director 2	180.000"	46.000"	74.875"
Director 3	235.000"	44.625"	73.625"
Director 4	191.000"	41.500"	70.625"
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 from 18.068 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 are one-half of total length, centered on boom.

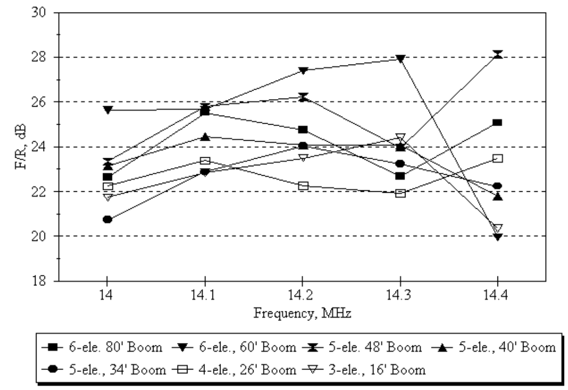
20-METER YAGIS

Fig 16 describes the electrical performance of seven optimized 20-meter Yagis with boom lengths between 16 to a giant 80 feet. As usual, the end of each boom includes 3 inches of space for the reflector and last director mounting plates. Fig 16A shows the free-space gain versus frequency for each antenna; 16B shows the front-to-rear ratio, and 16C shows the SWR versus frequency. Each antenna 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.

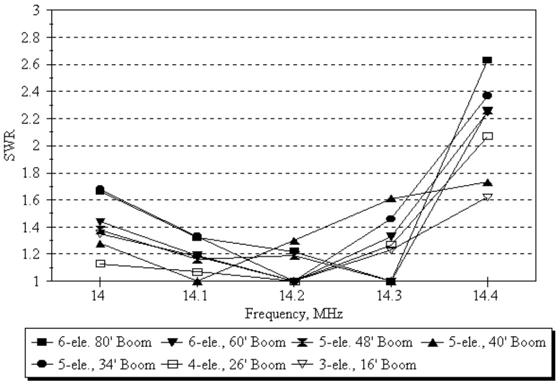
Fig 16D shows the taper schedule for two types of 20-meter elements. The heavy-duty design can survive 122-mph winds with no icing, and 89-mph winds with $^1/_4$ inch of radial ice. The medium-duty design can handle 82-mph winds with no icing, and 60-mph winds with $^1/_4$ inch of radial ice. The element-to-boom mounting plate for these Yagis is a 0.375-inch thick flat aluminum plate, 6 inches wide by 8 inches long. Electrically, each mounting plate is equivalent to a cylinder, with 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.



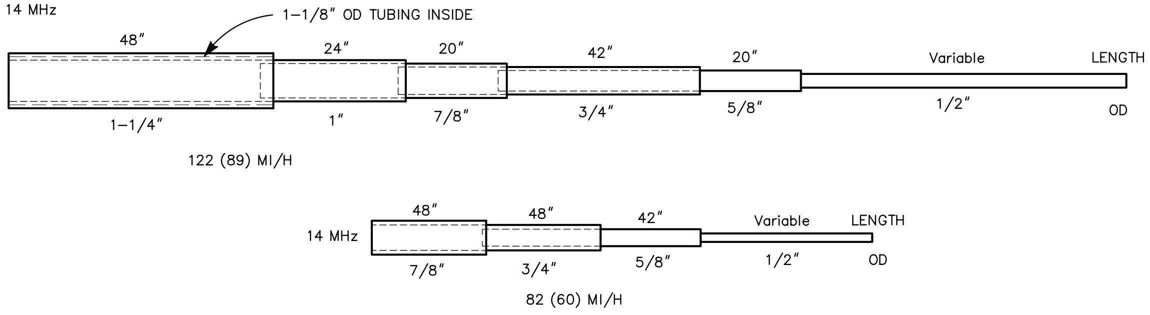
(A)



(B)



(C)



(D)

Fig 16—Gain, F/R and SWR performance versus frequency for optimized 20-meter Yagis. At A, gain versus frequency is shown for seven 20-meter Yagis whose booms range from 16 feet to 80 feet long, and which have been optimized for better than 20 dB F/R and less than 2:1 SWR over the frequency range from 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 $^1/_4$-inch radial ice. The medium-duty elements can survive 82-mph winds without icing, and 60-mph winds with $^1/_4$-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 5

Optimized 20-Meter Yagi Designs

Three-element 20-meter Yagi, 16-foot boom

Element	*Spacing*	*Heavy-Duty Tip*	*Medium-Duty Tip*
File Name		*320-16H.YAG*	*320-16M.YAG*
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.YAG*	*420-26M.YAG*
Reflector	0.000"	65.625"	76.875"
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.YAG*	*520-34M.YAG*
Reflector	0.000"	68.625"	80.750"
Driven Element	72.000"	52.250"	65.375"
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.YAG*	*520-40M.YAG*
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.YAG*	*520-48M.YAG*
Reflector	0.000"	66.250"	78.500"
Driven Element	72.000"	52.375"	65.500"
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.YAG*	*620-60M.YAG*
Reflector	0.000"	67.000"	79.250"
Driven Element	84.000"	52.375"	65.500"
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.YAG*	*620-80M.YAG*
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"

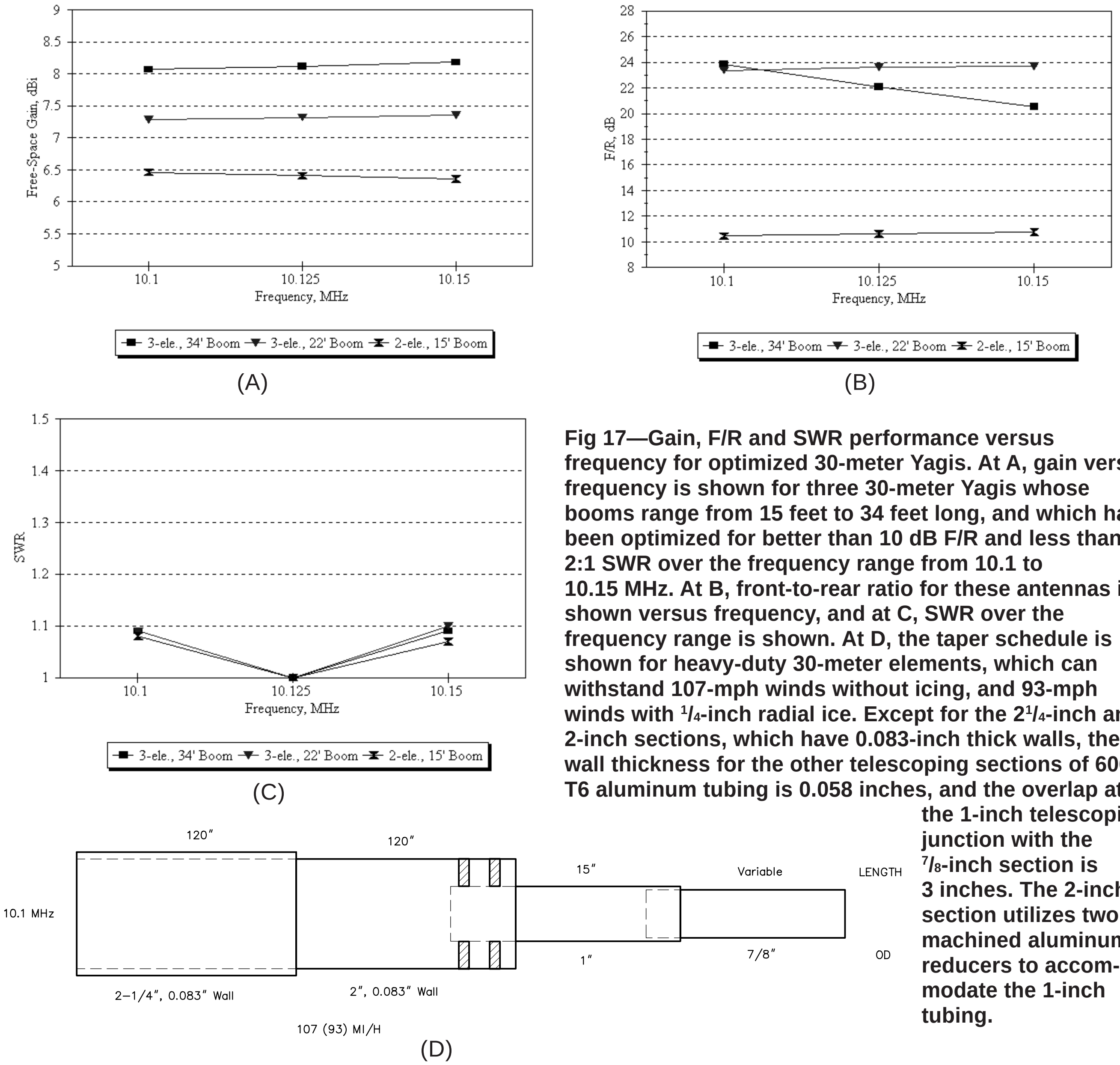
These 20-meter Yagi designs are optimized for > 20 dB F/R, and SWR < 2:1 over entire frequency range from 14.000 to 14.350 MHz, for heavy-duty elements (122-mph wind survival) and for medium-duty (82-mph wind survival). Only element tips are shown. See Fig 16D for element telescoping tubing schedule. 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 are one-half of total length, centered on boom.

30-METER YAGIS

Fig 17 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. Fig 17A shows the free-space gain versus frequency for each antenna; 17B shows the worst-case front-to-rear ratio, and 17C shows the SWR versus frequency.

Fig 17D shows the taper schedule for the 30-meter 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 $^1/_4$ 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. Electrically, each mounting plate is equivalent to a cylinder, with 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.



(A)

(B)

(C)

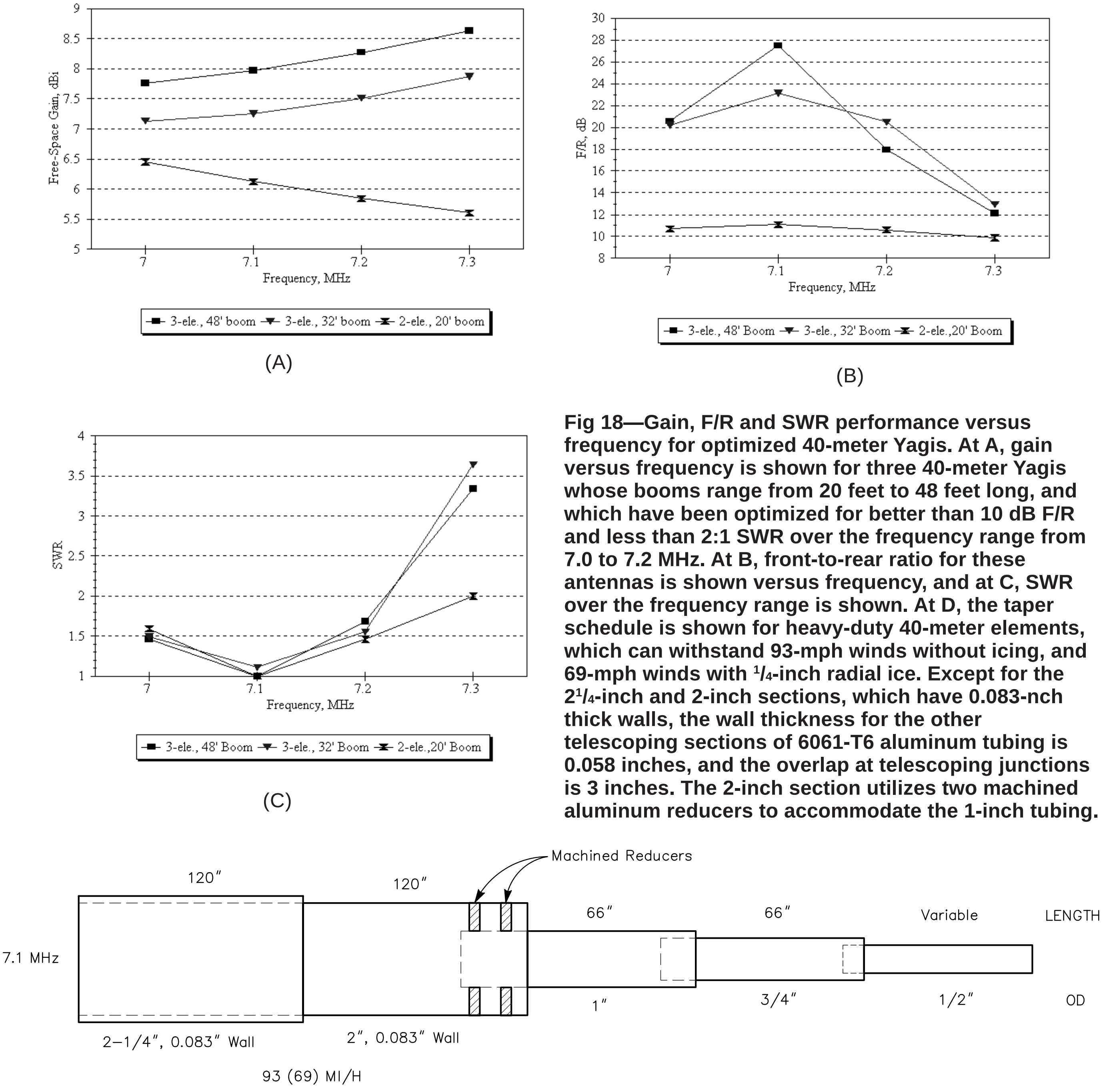
(D)

Fig 17—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 from 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 $^1/_4$-inch radial ice. Except for the $2^1/_4$-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 $^7/_8$-inch section is 3 inches. The 2-inch section utilizes two machined aluminum reducers to accommodate the 1-inch tubing.

40-METER YAGIS

Fig 18 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. Fig 18A shows the free-space gain versus frequency for each antenna; 18B shows the front-to-rear ratio, and 18C shows the SWR versus frequency.



(A)

(B)

(C)

(D)

Fig 18—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 from 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 93-mph winds without icing, and 69-mph winds with $^1/_4$-inch radial ice. Except for the $2^1/_4$-inch and 2-inch sections, which have 0.083-nch thick walls, the wall thickness for the other telescoping sections of 6061-T6 aluminum tubing is 0.058 inches, and the overlap at telescoping junctions is 3 inches. The 2-inch section utilizes two machined aluminum reducers to accommodate the 1-inch tubing.

Table 6
Optimized 30-Meter Yagi Designs

Two-element 30-meter Yagi, 15-foot boom

Element	*Spacing*	*Heavy-Duty Tip*
File Name		*230-150.YAG*
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		*330-22.YAG*
Reflector	0.000	59.375
Driven Element	135.000	30.375
Director 1	123.000	19.625

Three-element 30-meter Yagi, 34-foot boom

Element	*Spacing*	*Heavy-Duty Tip*
File Name		*330-34.YAG*
Reflector	0.000"	53.750"
Driven Element	212"	26.625"
Director 1	190"	14.500"

These 30-m 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 17D for element telescoping tubing schedule. All dimensions are in inches. No torque compensator element is required.

Table 7
Optimized 40-Meter Yagi Designs

Two-element 40-meter Yagi, 20-foot boom

Element	*Spacing*	*Heavy-Duty Tip*
File Name		*240-20.YAG*
Reflector	0.000"	85.000"
Driven Element	240.000"	25.500"

Three-element 40-meter Yagi, 32-foot boom

Element	*Spacing*	*Heavy-Duty Tip*
File Name		*340-32.YAG*
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		*340-48.YAG*
Reflector	0.000"	79.375"
Driven Element	300.000"	50.625"
Director 1	270.000"	27.500"

These 40-m 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 18D for element telescoping tubing schedule. All dimensions are in inches. No wind torque compensator is required.

Fig 18D 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 $^1/_4$ 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. Electrically each mounting plate is equivalent to a cylinder, with 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.

Modifying Hy-Gain Yagis

Enterprising amateurs have long used the Telex Communications 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, and Hy-Gain proudly points out that many of their monobanders are still working after more than 30 years. 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 optimum, particularly over an entire amateur band. Newer Hy-Gain designs are electrically superior to the older ones, but because of their 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.

Fig 19 shows the computed gain, F/R ratio and SWR for a 24-foot boom, 10-meter optimized Yagi (modified 105BA) using Hy-Gain hardware. **Fig 20** shows the same for a 26-foot boom 15-meter Yagi (modified 155BA), and **Fig 21** shows the same for a 34-foot boom (modified 205BA) 20-meter Yagi. **Tables 8** through **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 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.YAG*
Reflector	0.000"	54.500"
Driven Element	85.000"	50.125"
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.YAG*
Reflector	0.000"	58.500"
Driven Element	72.000"	52.000"
Director 1	72.000"	62.250"
Director 2	74.000"	61.875"
Director 3	190.000"	54.750"

See disk file for torque compensator information.

Table 9

Optimized Hy-Gain 15-Meter Yagi Designs

Optimized 155BA, Five-element 15-meter Yagi, 24-foot boom

Element	*Spacing*	*Element Tip*
File Name		*BV155CA.YAG*
Reflector	0.000"	62.625"
Driven Element	48.000"	64.875"
Director 1	48.000"	63.875"
Director 2	82.750"	61.625"
Director 3	127.250"	55.000"

See disk file for torque compensator information.

Table 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.YAG*
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	122.250"	44.750"

See disk file for torque compensator information.

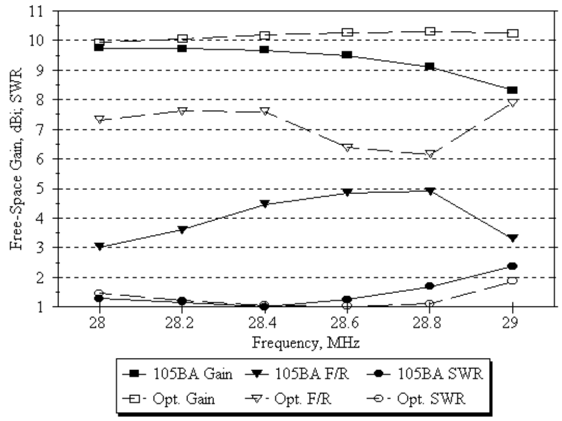


Fig 19—Gain, F/R and SWR over the 28.0 to 28.8 MHz range for original and optimized Yagis using Hy-Gain hardware. Original 105BA design provided excellent weight balance at boom-to-mast bracket, but compromised the electrical performance somewhat because of non-optimum spacing of elements. Optimized 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 10.

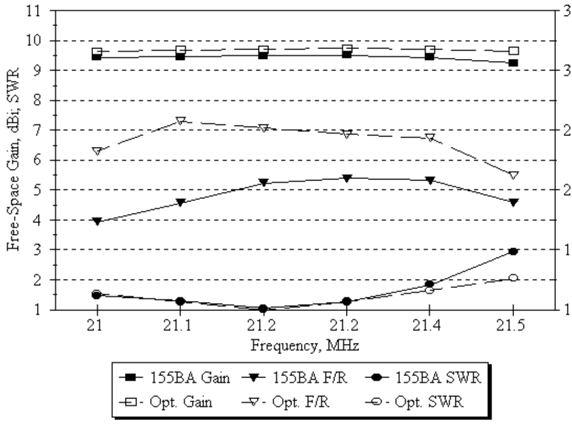


Fig 20—Gain, F/R and SWR over the 21.0 to 21.45 MHz band for original and optimized Yagis using Hy-Gain hardware. Original 155BA design provided excellent weight balance at boom-to-mast bracket, but compromised the electrical performance somewhat because of non-optimum spacing of elements. Optimized 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 9.

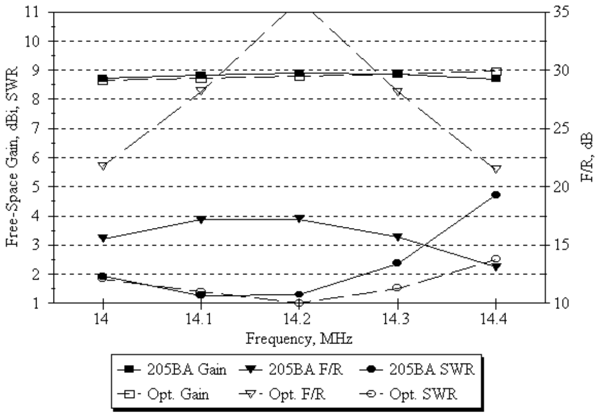


Fig 21—Gain, F/R and SWR over the 14.0 to 14.35 MHz band for original and optimized Yagis using Hy-Gain hardware. Original 205BA design provided good weight balance at boom-to-mast bracket, but compromised the electrical performance because of non-optimum spacing of elements. Optimized design requires a 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 8.

Stacked Yagis

Parasitic arrays are commonly stacked either in broadside or collinear fashion to produce additional directivity and gain. In HF amateur work, the most common broadside stack is a vertical stack of identical Yagis on a single tower. This arrangement is commonly called a *vertical stack*. At VHF and UHF, amateurs often employ collinear stacks, where identical Yagis are stacked side-by-side at the same height. This arrangement is called a *horizontal stack*, and is not usually found at HF, because of the severe mechanical difficulties involved with large, rotatable side-by-side arrays. **Fig 22** illustrates the two different stacking arrangements. In either case, the individual Yagis making up the stack are generally fed in phase. There are times, however, when individual antennas in a stacked array are fed out of phase in order to emphasize a particular elevation pattern. See Fig 4 in Chapter 17 for such a case where elevation pattern steering is implemented for a repeater station.

The following material on stacking Yagis has been condensed from an article in February 1994 *QST* by R. Dean Straw, N6BV, and Fred Hopengarten, K1VR, where they described their two different stacks of triband Yagis.

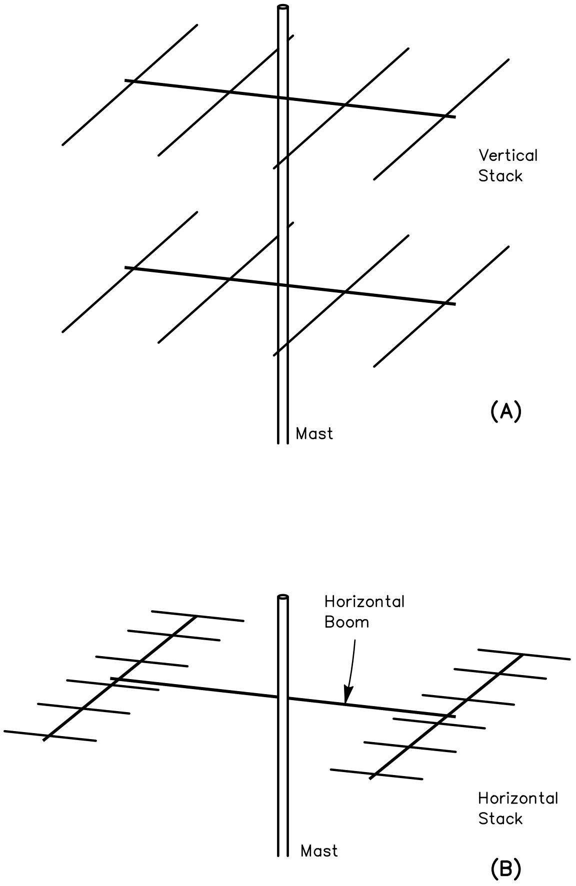


Fig 22—Stacking arrangements. At A, two Yagis are stacked vertically (broadside) on the same mast. At B, two Yagis are stacked horizontally (collinear) side-by-side. At HF the vertical stack is more common because of mechanical difficulties involved with large HF antennas stacked side-by-side, whereas at VHF and UHF the horizontal stack is common.

STACKS AND WIDE ELEVATION FOOTPRINTS

Detailed studies using sophisticated computer models of the ionosphere have revealed that coverage of a wide range of elevation angles is necessary to ensure consistent DX or contest coverage on the

HF bands. These studies have been conducted over all phases of the 11-year solar cycle, and for numerous transmitting and receiving QTHs throughout the world. **Table 11** is an example of such a study using a program called *IONCAP* for the path from New England to both Western and Eastern Europe. It lists the statistical range of elevation angles covering 99% of the time that signals arrive. This is for the whole 11-year solar cycle. Different tables are required to describe paths from New England to other parts of the world, and to describe the paths from other transmitting sites to various parts of the world. [See Chapter 23, "Radio Wave Propagation," for additional elevation angle information for other parts of the world.]

Fig 23 shows the computed elevation response for various combinations of Hy-Gain TH7DX triband Yagis on 10 meters, calculated using the *MNC* version of the *MININEC* computer program. The highest curve is for a stack of three TH7DXs at heights of 90, 60 and 30 feet, placed on one tower above flat ground with an average conductivity and dielectric constant. Overlaid on the same graph are the elevation patterns for a single TH7DX at 70 feet, representing a fairly common station setup. Also shown is the pattern for a single TH7DX at 40 feet, the pattern for a stack of two TH7DX tribanders at 70 feet and 40 feet on one tower and the pattern for a single 90-foot high dipole.

At 10 meters, the stack of three triband Yagis at 90, 60 and 30 feet has good coverage for low elevation angles, and good coverage out to about 11° elevation, where its pattern crosses that of the single 40-foot-high antenna. At an elevation of 2°, the stack of three has 8 dB more gain than the single 40-foot-high antenna, but only 2 dB of gain over the stack of two antennas at 70 and 40 feet. For the range of angles needed to cover Western and Eastern Europe, the race between the stack of three and the shorter stack of two is pretty close. A single TH7DX on 10 meters at 90 feet suffers dramatically whenever the elevation angles are higher than approximately 9°, as commonly occurs into Western Europe during the strongest part of the 10-meter opening from New England.

Both of the stacks illustrated here give a wider *elevation footprint* than any single antenna, so that all the angles can be covered automatically without having to switch from higher to lower antennas manually. This is perhaps the major benefit of using stacks, but not the only one.

Fig 24 compares the 15-meter elevation responses for tribanders at the same heights as for

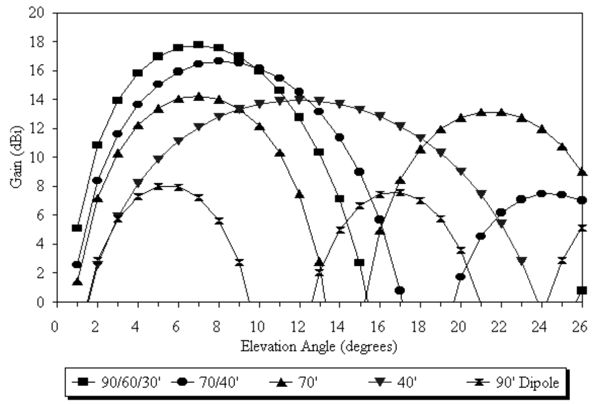


Fig 23—Comparison of elevation patterns for 10-meter TH7DX tribander combinations mounted over flat ground. The 10-meter stack of three at 90, 60 and 30 feet has an elevation footprint between 3.5° to 11° at its half-power points, and a peak gain of 17.8 dBi. The stack at 70 and 40 feet has a peak gain of 16.7 dBi at 8°, with coverage from 4° to 12.5° at its half-power points. A dipole at 90 feet might seem like a practical reference antenna for the stack of three Yagis. At 7° elevation, the 17.8 dBi gain of the stack of three is almost 10 dB greater than the gain of the 90-foot dipole. However, at 11°, where the dipole is in a null, the 14.6 dBi gain of the three-stack is 32 dB stronger than the dipole—this would be a gain of 32 dB! Clearly, it is difficult to measure a stack of Yagis directly against a single dipole. It would be fair, however, to use a stack of dipoles for comparison, or to compare the stack's gain to a free-space dipole. By definition, the use of dBi compares the stack's gain to that of a single free-space isotropic radiator.

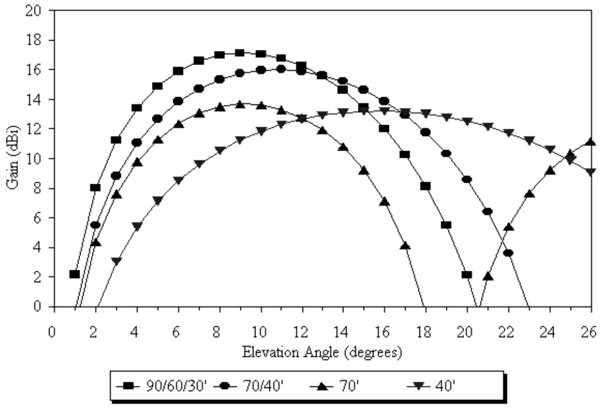


Fig 24—Comparison of elevation patterns for 15-meter TH7DX tribander combinations mounted over flat ground. The stack at 90, 60 and 30 feet yields an excellent footprint over the range of 4° to 14° at its half-power points, with a peak gain of 17.1 dBi. The stack at 70 and 40 feet has a peak gain of 16.0 dBi at 11°, with coverage from 5° to 17° at its half-power points. Like the 10-meter stack of three, the stack of two TH7DXs is very close in overall performance, except for lower gain at very low angles, where the higher top antenna comes into play in the stack of three.

Table 11
Range of Elevation Angles from New England to Europe

Band	*Elevation Angles for W. Europe*	*Elevation Angles for E. Europe*
80 meters	16° - 33°	12° - 30°
40 meters	5° - 21°	3° - 17°
20 meters	3° - 17°	1° - 13°
15 meters	3° - 13°	1° - 12°
10 meters	4° - 13°	1° - 12°

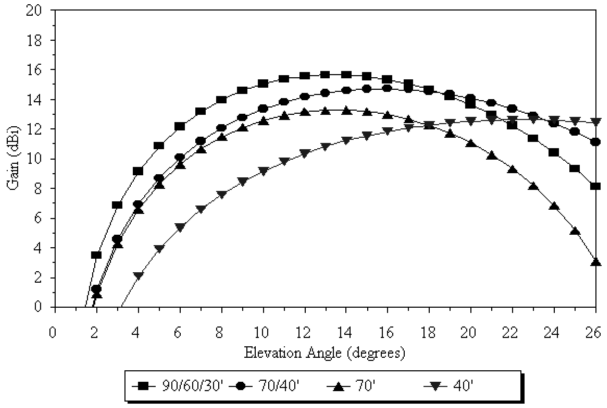


Fig 25—Comparison of elevation patterns for 20-meter TH7DX tribander combinations. The peak gain for the 90, 60 and 30-foot stack is 15.7 dBi at 13° elevation. The 3 dB elevation coverage is from 6.5° to 21.5°. The peak gain for the stack of two at 70 and 40 feet is 14.7 dBi at 16°, and the 3-dB elevation coverage is from 7.5° to 25°. The stack of three has proven to be an extremely effective antenna.

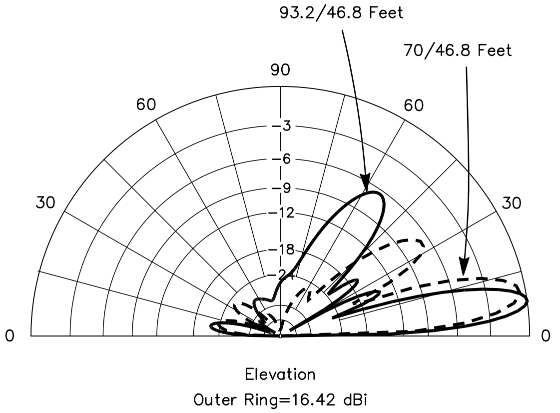


Fig 26—The effect of stacking distance on elevation patterns for 15-meter TH7DXs. The stack at 93.2 and 46.8 feet (one wavelength spacing) has a lower peak elevation angle (because of the top antenna's height) and just slightly more stacking gain than does the stack at 70 and 46.8 feet. The exact distance between practical HF Yagis is not critical to obtain the benefits of stacking. For a stack of tribanders at 90, 60 and 30 feet, the distance in wavelengths between individual antennas is 0.87 λ at 28.5 MHz, 0.65 λ at 21.2 MHz, and 0.43 λ at

10 meters. Here, the best system is also the stack of three at 90, 60 and 30 feet, followed by the stack of two at 70 and 40 feet. For most of the time, the single Yagi at 70 feet is down from the stacks by at least 3 dB. The stack of three at an elevation of 8° has a gain of about 7 dB over the single tribander at 40 feet. Again, either 15-meter stack gives a wider elevation footprint than any single antenna does.

Fig 25 shows the 20-meter elevation response for the same triband antennas. The edge in favor of the bigger stack narrows somewhat compared to the other antennas, mainly because the 30-foot spacing (0.43 λ) between antennas in the stack is more of a compromise for gain on 20 meters than for the upper bands. However, the stack of three still gives a gain of 6 dB over the single 40-foot-high tribander at a 10° elevation angle, and has a wider elevation footprint than any single antenna.

STACKS AND COMPRESSION OF THE FORWARD AND REARWARD ELEVATION LOBES

The basic principle of a stacked array is that it concentrates energy from higher angle lobes (which don't contribute much to communications anyway) into the main elevation lobe. The stack squeezes down the main elevation lobe, while maintaining the frontal lobe azimuth pattern of a single Yagi. This is the reason why many state-of-the-art contest stations are stacking arrays of relatively short-boom antennas, rather than stacking long-boom, higher-gain Yagis. A long-boom HF Yagi narrows both the azimuthal pattern and the elevation pattern, making pointing of the antenna more critical, and making it more difficult to spread a signal over a wide azimuthal area, such as all of Europe and Asiatic Russia at one time.

The compression of the higher angle lobes has another desirable effect, beyond that of creating more gain. It reduces QRM from high-angle signals arriving from the direction in which the antenna is pointed, and from high-angle signals coming from other directions, such as local QRM. A stack also squeezes down the elevation response of the rearward lobe, just like the forward lobe. On the negative side, however, the front-to-rear ratio of a stack is often degraded compared to that of a single, optimized Yagi, although this is not usually a severe problem.

By definition, a stack of triband Yagis has a constant vertical spacing between antennas in terms of feet or meters, but not in terms of wavelength. There is a great deal of folklore and superstition among amateurs about stacking distances. *There is nothing magical about stacking distances for practical HF Yagis*. The gain gradually increases as spacing in terms of wavelength is increased between individual Yagis in a stack, and then decreases slowly once the spacing is greater than about 1.0 λ. The difference in gain between spacings of 0.5 λ and 1.0 λ for a TH7DX Yagi amounts to only a fraction of a decibel.

Fig 26 shows the elevation patterns for two 15-meter TH7DXs stacked at 70 and 46.8 feet (half-wavelength spacing), and at 93.2 and 46.8 feet (one-wavelength spacing). The elevation footprint for the higher stack has slightly more gain at lower angles, as expected, and the peak gain is just slightly higher, but the stack with the smaller spacing still has a good gain and a desirable pattern. The situation is different on VHF, where truly long-boom, high-gain designs are practical and desirable, and where stack spacing is correspondingly more critical because of complex mutual coupling and interaction between the antennas.

STACKS AND FADING

Both K1VR and N6BV have solicited a number of reports from stations, mainly in Europe, to compare various combinations of antennas in stacks and as single antennas. The peak gain of the stack is usually just a little bit higher than that for the best of the single antennas, which is not surprising. Even a large stack has no more than about 6 dB of gain over a single Yagi at a height favoring the prevailing elevation angle. Fading on the European path can easily be 20 dB or more, so it is very confusing to try to make definitive comparisons. They have noticed over many tests that the stacks are much less susceptible to fading compared to single Yagis. Even within the confines of a typical SSB bandwidth, frequency-selective fading occasionally causes the tonal quality of a voice to change on both receive and transmit, often dramatically becoming fuller on the stacks, and tinnier on the single antennas. This doesn't happen all the time, but is often seen. They have also observed often that the depth of a fading is less, and the period of fading is longer, on the stacks compared to single antennas.

Exactly *why* stacks exhibit less fading is a fascinating subject, for which there exist a number of speculative ideas, but little hard evidence. Some maintain that stacks outperform single antennas because they can afford *space diversity* effects, where by virtue of the difference in physical placement one antenna will randomly pick up signals that another one in another physical location might not hear. This argument is difficult to argue with, and equally difficult to prove scientifically.

A more plausible explanation about why stacked Yagis exhibit superior fading performance is that their narrower frontal elevation lobes can discriminate against undesired propagation modes. Even when band conditions favor, for example, a very low 3° elevation angle on 10 or 15 meters from New England to Western Europe, there are signals, albeit weaker ones, which arrive at higher elevation angles. These higher-angle signals have traveled longer distances on their journey through the ionosphere, and thus their signal levels and their phase angles are different from the signals traversing the primary propagation mode. When combined with the dominant mode, the net effect is that there is destructive and constructive fading. If the elevation response of a stacked antenna can discriminate against signals arriving at higher elevation angles, then in theory the fading will be reduced.

STACKS AND PRECIPITATION STATIC

The top antenna in a stack is often much more affected by rain or snow precipitation static than is the lower antenna. N6BV and K1VR have observed this phenomenon, where signals on the lower antenna by itself are perfectly readable, while S9+ rain static is rendering reception impossible on the higher antenna or on the stack. This means that the ability to select individual antennas in a stack can sometimes be extremely important.

STACKS AND AZIMUTHAL DIVERSITY

Azimuthal diversity is a term coined to describe the situation where one of the antennas in a stack is purposely pointed in a direction different from the main direction of the stack. During most of the time in a DX contest from the East Coast, the lower antennas in a stack are pointed into Europe, while the top antenna is often rotated toward the Caribbean or Japan. In a stack of three identical Yagis, the first-order effect of pointing one antenna in a different direction is that one-third of the transmitter power is diverted from the main target area. This means that the peak gain is reduced by 1.8 dB, not a very large amount considering that signals are often 10 to 20 dB over S9 anyway when the band is open from New England to Europe.

THE N6BV/1 ANTENNA SYSTEM—BRUTE FORCE FEEDING

The N6BV/1 system in Windham, New Hampshire, is located on the crest of a small hill about 40 miles from Boston, and could be characterized as a good, but not dominant, contesting station. There is a single 120-foot high Rohn 45 tower, guyed at 30-foot intervals, with a 100-foot horizontal spread from tower base to each guy point so there is sufficient room for rotation of individual Yagis on the tower. Each set of guy wires employs heavy-duty insulators at 57-foot intervals, to avoid resonances in the 80 through 10-meter amateur bands. There are five Yagis on the tower. A heavy-duty 12-foot long steel mast with 0.25-inch walls is at the top of the tower, turned by an Orion 2800 rotator. Two thrust bearings are used above the rotator, one at the top plate of the tower itself, and the other about 2 feet down in the tower on a modified rotator shelf plate. The two thrust bearings allow the rotator to be removed for service.

At the top of the mast, 130 feet high, is a 5-element, computer-optimized 10-meter Yagi, which is a modified Create design on a 24-foot boom. The element tuning has been modified from the stock antenna in order to achieve higher gain and a better pattern over the band. At the top of the tower (120-foot level) is mounted a Create 714X-3 triband Yagi. This is a large tribander, with a 32-foot boom and five elements. Three elements are active on 40 meters, four are active on 20 meters and four are active on 15 meters. The 40-meter elements are loaded with coils, traps and capacitance hats, and are approximately 46 feet long. A triband 20/15/10-meter Hy-Gain TH7DX tribander is fixed into Europe at the 90-foot level on the tower, just above the third set of guys.

At the 60-foot level on the tower, just above the second set of guys, there is a "swinging-gate" side-mount bracket, made by DX Engineering of Oregon. A Hy-Gain *Tailtwister* rotator turns a TH7DX on this side mount. (Note that both the side mount and the element spacings of the TH7DX itself prevent full rotation around the tower—about 280° of rotation is achieved with this system.) At the 30-foot level, just above the first set of guys, is located the third TH7DX, also fixed on Europe.

All five Yagis are fed with equal lengths of Belden 9913 low-loss coaxial cable, each measured with a noise bridge to ensure equal electrical characteristics. At each feed point a ferrite-bead choke balun (using seven large beads) is placed on the coax. All five coaxial cables go to a relay switch box mounted at the 85-foot level on the tower. **Fig 27** shows the schematic for the switch box, which is fed with 250 feet of 75-Ω, 0.75-inch OD Hardline coaxial cable.

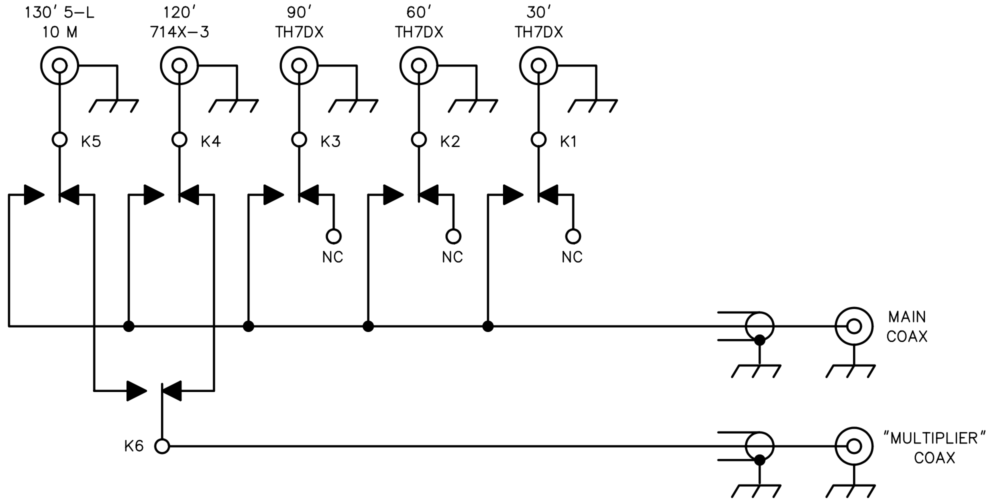


Fig 27—N6BV/1 switch-box system. This uses a modified DX Engineering remote switch box, with relay K6 added to allow selection of either of the two top antennas (5-element 10-meter Yagi or 40/20/15-meter triband 714X-3) as a "multiplier" antenna. There is no special provision for SWR equalization when any or all of the Yagis are connected in parallel as a stack fed by the Main coaxial cable. Each of the five Yagis is fed with equal lengths of flexible Belden 9913 coax, so phasing can be maintained on any band. The Main and "Multiplier" coaxes going to the shack are 0.75 inch OD 75-Ω Hardline cables.

The stock DX Engineering remote switch box has been modified by adding relay K6, so that either the 130-foot or the 120-foot rotating antenna can be selected through a second length of 0.75-inch Hardline going to the shack. This creates a *Multiplier* antenna, independent of the *Main* antennas. A second band can be monitored in this fashion while calling CQ using the main antennas on another band. Band-pass filters are required at the multiplier receiver to prevent overload from the main transmitter.

The 0.75-inch Hardline has very low losses, even when presented with a significant amount of SWR at the switch-box end. This is important, because unlike K1VR's system, no attempt is made at N6BV to maintain a constant SWR when relays K1 through K5 are switched in or out. This seemingly cavalier attitude comes about because of several factors. First, there are many different combinations of antennas which can be used together in this system. Each relay coil is independently controlled by a toggle switch in the shack. N6BV could not manage to devise a matching system that did not become incredibly complex because of the numerous impedance combinations used over all the three bands.

Second, the worst-case additional transmission line loss due to a 4:1 SWR mismatch when four antennas are connected in parallel on 10 meters is only 0.5 dB. It is true that a linear amplifier must be retuned slightly when combinations of antennas are switched in and out, but this is a small penalty to pay for the reduced complexity of the switching and matching networks. The 90/60/30-foot stack is used for about 95% of the time during DX contests, so the small amount of amplifier retuning for other antenna combinations is considered only a minor irritation.

WHY TRIBANDERS?

Without a doubt, the most common question K1VR and N6BV are asked is: "Why did you pick *tribanders* for your stacks?" Triband antennas were chosen with full recognition that they are compromise antennas. Other enterprising amateurs have built stacked tribander arrays. Bob Mitchell, N5RM, is a prominent example, with his so-called *TH28DX* array of four TH7DX tribanders on a 145-foot-high rotating tower. Mitchell employed a rather complex system of relay-selected tuned networks to choose either the upper stacked pair, the lower stacked pair or all four antennas in stack. Others in Texas have also had good results with their tribander stacks. Contester Danny Eskenazi, K7SS, has very successfully used a pair of stacked KT-34XA tribanders for years.

A major reason why tribanders were used is that over the years both authors have had good results using TH6DXX or TH7DX antennas. They are ruggedly built, mechanically and electrically. They are able to withstand New England winters without a whimper, and their 24-foot long booms are long enough to produce significant gain, despite trap-loss compromises. Amateurs speculating about trap losses in tribanders freely bandy about numbers between 0.5 and 2 dB. Both N6BV and K1VR are comfortable with the lower figure, as are the Hy-Gain engineers.

Consider this: If 1500 W of transmitter power is going into an antenna, a loss of 0.5 dB amounts to 163 W. This would create a significant amount of heat in the six traps that are on average in use on a TH6DXX, amounting to 27 W per trap. If the loss were as high as 1 dB, this would be 300 W total, or 50 W per trap. Common sense says that if the overall loss were greater than about 0.5 dB, the traps would act more like big *firecrackers* than resonant circuits! A long-boom tribander like the TH6DXX or TH7DX also has enough space to employ elements dedicated to different bands, so the compromises in element spacing usually found on short-boom 3 or 4-element tribanders can be avoided.

Another factor in the conscious choice of tribanders was first-hand frustration with the serious interaction that can result from stacking monoband antennas closely together on one mast in a Christmas Tree configuration. N6BV's worst experience was with the ambitious 10 through 40-meter Christmas Tree at W6OWQ in the early 1980s. This installation used a Tri-Ex SkyNeedle tubular crankup tower with a rotating 10-foot long heavy-wall mast. The antenna suffering the greatest degradation was the 5-element 15-meter Yagi, sandwiched 5 feet below the 5-element 10-meter Yagi at the top of the mast, and 5 feet above the full-sized 3-element 40-meter Yagi, which also had five 20-meter elements interlaced on its 50-foot boom.

The front-to-back ratio on 15 meters was at best about 12 dB, down from the 25+ dB measured with the bottom 40/20-meter Yagi removed. No amount of fiddling with element spacing, element tuning or even orientation of the 15-meter boom with respect to the other booms (at 90° or 180°, for example) improved its performance. Further, the 20-meter elements had to be lengthened by almost a foot *on each end of each element* in order to compensate for the effect of the interlaced 40-meter elements. It was a lucky thing that the tower was a motorized crankup, because it went up and down hundreds of times as various experiments were attempted!

Interaction due to close proximity to other antennas in a short Christmas Tree can definitely destroy carefully optimized patterns of individual Yagis. Nowadays, interaction can be modeled using a computer program such as *MN* or *MININEC* or *NEC*. A gain reduction of as much as 2 to 3 dB can easily result due to close vertical spacing of monobanders, compared to the gain of a single monoband antenna mounted in the clear. Curiously enough, at times such a reduction in gain can be found even when the front-to-back ratio is not drastically degraded, or when the front-to-back occasionally is actually *improved*.

Dave Leeson, W6QHS, mentions that the 10-meter Yagi in his 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. (We calculated that the free-space gain in the W6QHS 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! In private conversations, W6QHS has indicated that he would not repeat this kind of short Christmas Tree installation again.

Finally, in the N6BV/1 installation, triband antennas were chosen because the system is meant to be as simple as possible, given a certain desired level of performance, of course. Triband antennas make for less mechanical complexity than do an equivalent number of monobanders. There are five Yagis on the N6BV/1 tower, yielding gain from 40 to 10 meters, as opposed to using 12 or 13 monobanders on the tower.

THE K1VR ARRAY: A MORE ELEGANT APPROACH TO MATCHING

The K1VR stacked array is on a 100-foot high Rohn 25 tower, with sets of guy wires at 30, 60 and 90 feet, made of nonconducting Phillystran. Phillystran is a nonmetallic Kevlar rope covered by black polyethylene to protect against the harmful effects of the sun’s ultraviolet rays. A caution about Phillystran: Don’t allow tree branches to rub against it. It is designed to work in tension, but unlike steel guy wire, it does not tolerate abrasion well.

Both antennas are Hy-Gain TH6DXX tri-banders, with the top one at 97 feet and the bottom one at 61 feet. The lower antenna is rotated by a Telex Ham-M rotator on a homemade “swinging-gate” side mount, which allows it to be rotated 300° around the tower without hitting any guy wires or having an element swing into the tower. At the 90-foot point on the tower, a 2-element 40-meter Cushcraft Yagi has been mounted on a RingRotor so it can be rotated 360° around the tower.

After several fruitless attempts trying to match the TH6DXX antennas so that either could be used by itself or together in a stack, K1VR settled on using a relay-selected broadband toroidal matching transformer. When both triband antennas are fed together in parallel as a stack, it transforms the resulting 25-Ω impedance to 50 Ω. The transformer is wound on a T-200-A powdered-iron core, available from Amidon, Palomar Engineering, Ocean State Electronics or RadioKit. Two lengths of twin RG-59 coax (sometimes called Siamese or WangNet), four turns each, are wound on the core. Two separate RG-59 cables could be used, but the Siamese-twin cable makes the assembly look much more tidy. The shields of the RG-59 cables are connected in series, and the center conductors are connected in parallel. See **Fig 28** for details.

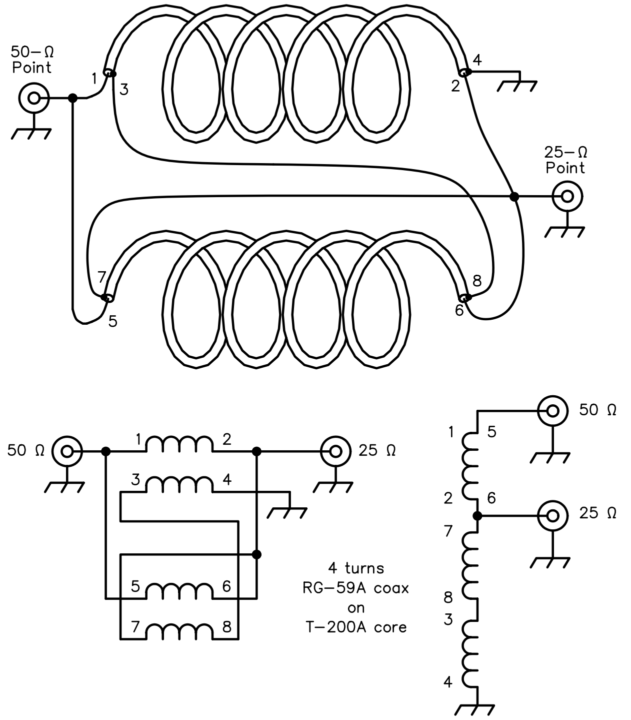


Fig 28—Diagram for matching transformer for K1VR stacked tribander system. The core is powdered-iron core T-200A, with four turns of two RG-59A or “Siamese” coax cables. Center conductors are connected in parallel and shields are connected in series to yield 0.667:1 turns ratio, close to desired 25 to 50-Ω transformation.

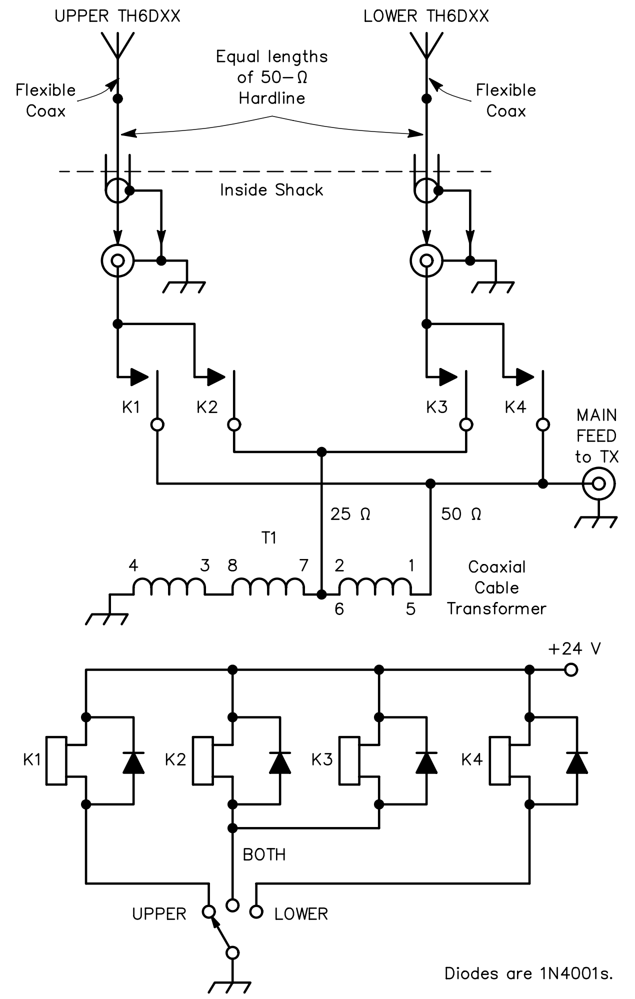


Fig 29—Relay switch box for K1VR stacked tribander system. Equal lengths of 50-Ω Hardline (with equal lengths of flexible 50-Ω cable at each antenna to allow rotation) go to the switch box in the shack. The SWR on all three bands for Upper, Lower or Both switch positions is very close to constant.

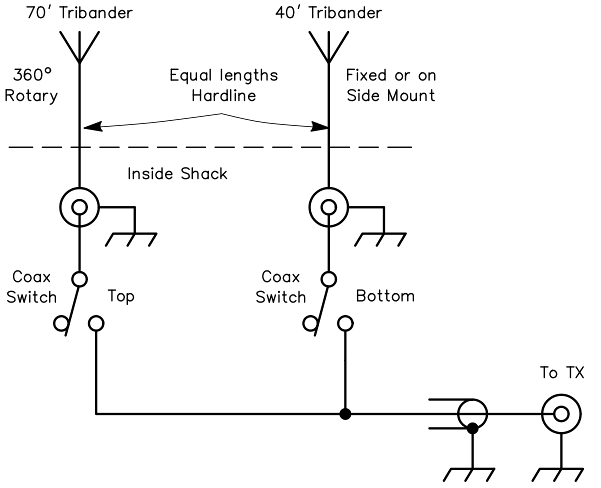


Fig 30—Simple feed system for 70/40-foot stack of tribanders. Each tribander is fed with equal lengths of 0.5-inch 75-Ω Hardline cables (with equal lengths of flexible coax at the antennas to allow rotation), and can be selected singly or in parallel at the operator’s position in the shack. Again, no special provision is made in this system to equalize SWR for any of the combinations.

Fig 29 shows the schematic of the K1VR switch box, which is located in the shack. Equal electrical lengths of 50-Ω Hardline are brought from the antennas into the shack and then to the switch box. Inside the box, the relay contacts were soldered directly to the SO-239 chassis connectors to keep the wire lengths down to the absolute minimum. K1VR used a metal box which was larger than might appear necessary because he wanted to mount the toroidal transformer with plenty of clearance between it and the box walls. The toroid is held in place with a piece of insulation foam board.

Before placing the switch box in service, the system was tested using two 50-Ω dummy loads, with equal lengths of cable connected in parallel to yield 25 Ω. The maximum SWR measured was 1.25:1 at 14 MHz, 1.3:1 at 21 MHz and 1.15:1 at 28 MHz, and the core remained cold with 80 W of continuous output power.

One key to the system performance is that K1VR made the electrical lengths of the two Hardlines the same (within 1 inch) by using a borrowed TDR (time domain reflectometer). Almost as good as Hardline, K1VR points out, would be to cut exactly the same length of cable from the same 500-foot roll of RG-213. This eliminates manufacturing tolerances between different rolls of cable.

K1VR’s experience over the last 10 years has been that at the beginning of the 10 or 15-meter morning opening to Europe the upper antenna is better. Once the band is wide open, both antennas are fed in phase to cast a bigger shadow, or footprint, on Europe. By mid-morning, the lower antenna is better for most Europeans, although he continues to use the stack in case someone is hearing him over a really long distance path throughout Europe. He reports that it is always very pleasant to be called by a 4S7 or HS0 or VU2 when he is working Europeans at a fast clip!

SOME SUGGESTIONS FOR STACKING TRIBANDERS

It is unlikely that many amateurs will try to duplicate exactly K1VR’s or N6BV’s contest setups. However, many hams already have a tribander on top of a moderately tall tower, typically at a height of about 70 feet. It is not terribly difficult to add another, identical tribander at about the 40-foot level on such a tower. The second tribander can be pointed in a fixed direction of particular interest (such as Europe or Japan), or it can be rotated around the tower on a side mount or a Ring Rotor. If guy wires get in the way of rotation, the antenna can usually be arranged so that it is fixed in a single direction. Insulate the guy wires at intervals to ensure that they don't shroud the lower antenna electrically. A simple feed system consists of equal-length runs of surplus 0.5-inch 75-Ω Hardline (or more expensive 50-Ω Hardline, if you are really obsessed by SWR) from the shack up the tower to each antenna. Each tribander is connected to its respective Hardline feeder by means of an equal length of flexible coaxial cable, with a ferrite choke balun, so that the antenna can be rotated.

Down in the shack, the two Hardlines can simply be switched in and out of parallel to select the upper antenna only, the lower antenna only, or the two antennas as a stack. See **Fig 30**. Any impedance differences can be handled as stated previously, simply by retuning the linear amplifier, or by means of the internal antenna tuner (included in most modern transceivers) when the transceiver is run barefoot. The extra performance experienced in such a system will be far greater than the extra decibel or two that modeling calculates.