Why Not Use a 3-Band, 3-Element Quad?

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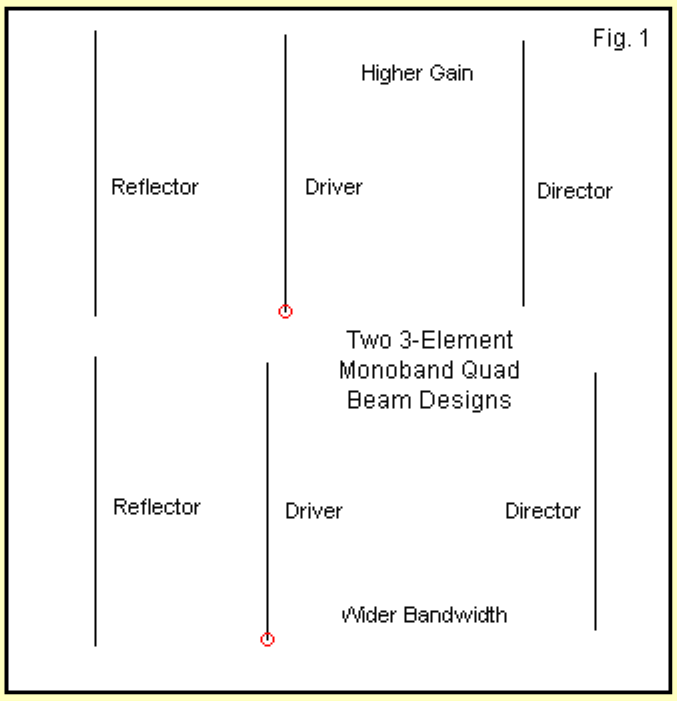
Although we can find a number of designs for 3-element monoband quad beams, we would have a difficult time uncovering tri-band or 5-band versions of them. There are both physical and electrical reasons for this lacuna in the range of available quad multi-band designs. We should spend at least a brief time discovering what the reasons are.

Monoband 3-Element Quads

Among 3-element quad beams, we can find both good and mediocre designs. In Volume 2 of *Cubical Quad Notes*, I offered computer programs for two types of 3-element monoband quads. One version stressed the widest obtainable bandwidth for both the front-to-back ratio and the SWR curve. The other version gave up bandwidth (but not altogether) in exchange for the maximum gain that we might obtain from 3 quad loops, commensurate with a reasonable front-to-back ratio at the design frequency. Both programs (along with a NEC-Win Plus NEC model that incorporated the equations) required only two input variables: the element (wire) diameter in the units in use and the design frequency. **Fig.1** shows the outlines of the two beam types to provide an idea of their proportions.



The wide-band version is about 19% longer than the high gain model. Despite the greater length, the wide-band driver is closer to the reflector than the corresponding element on the high-gain version. The wide-band director is also considerably smaller in circumference than the high-gain director.

The wide-band version may be the easier antenna to mount. If you draw a centerline through the elements to represent a boom, then the mid-point of the boom will fall just beyond the "r" in the word "driver." However, since there would be two elements and their support arms left of the midpoint, the actual position for the boom-to-mast plate would fall somewhere within the word "driver." Alternatively, some builders have placed additional weights inside the director end of the boom to provide a mast position closer to the boom mid-point.

The situation is a bit more precarious with the high-gain version of the antenna. Here, the mid-point of the imaginary boom line falls close to the "d" in "driver." Since support arms tend to be flexible and an element wire extends across the face of the support mast or tower, builders tend to use counter weights inside the director boom end to arrive at a balance point that maximizes the flexing space for the driver support arms and wire.

Because the data will be significant when we explore the electrical properties of attempted tri-band 3-element quads, let's quickly review the potential performance of both types of monoband quads. Since all bands provide similar performance, except for bandwidth issues, we can illustrate performance by reference to the widest of the upper HF bands, 10 meters. **Table 1** provides the dimensions for both antennas. All dimensions are in inches, and the table lists full side lengths and loop circumferences. The spacing dimension is referenced to the reflector.

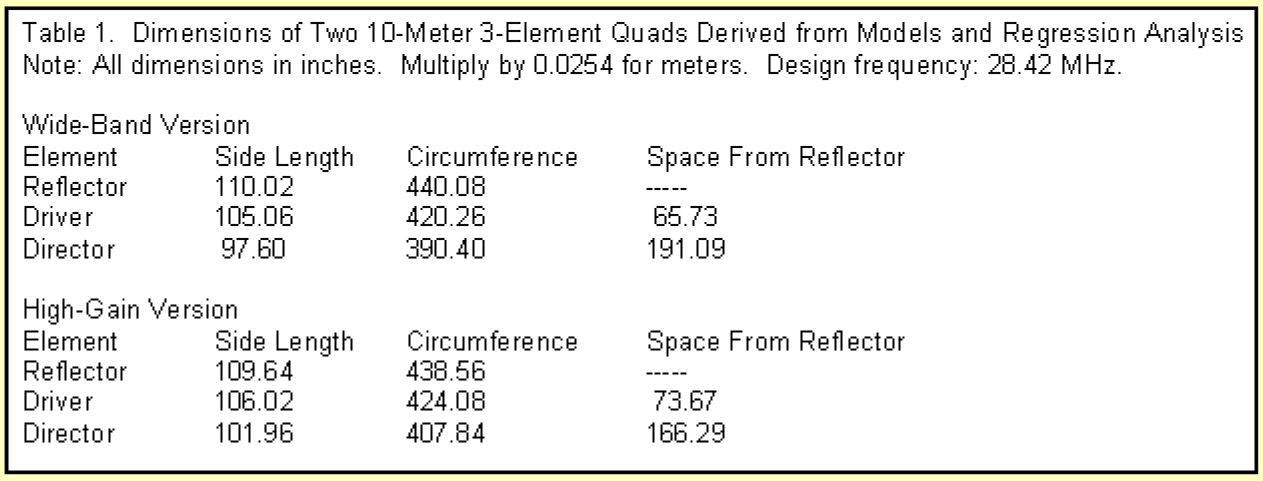


Table 1. Dimensions of Two 10-Meter 3-Element Quads Derived from Models and Regression Analysis
Note: All dimensions in inches. Multiply by 0.0254 for meters. Design frequency: 28.42 MHz.

Wide-Band Version

Element	Side Length	Circumference	Space From Reflector
Reflector	110.02	440.08	-----
Driver	105.06	420.26	65.73
Director	97.60	390.40	191.09

High-Gain Version

Element	Side Length	Circumference	Space From Reflector
Reflector	109.64	438.56	-----
Driver	106.02	424.08	73.67
Director	101.96	407.84	166.29

The modeled performance in free space for both beams represents close to the best obtainable for 3-element quads of each type. **Table 3** samples the performance at the band edges and at the design frequency. Note that the worst-case and the 180-degree front-to-back ratios are the same at the band edges and differ only in the middle portion of the band, where the rear lobe shows a characteristic "dimple." Also notable is the difference in beamwidth between the two designs. As gain increases, beamwidth decreases.

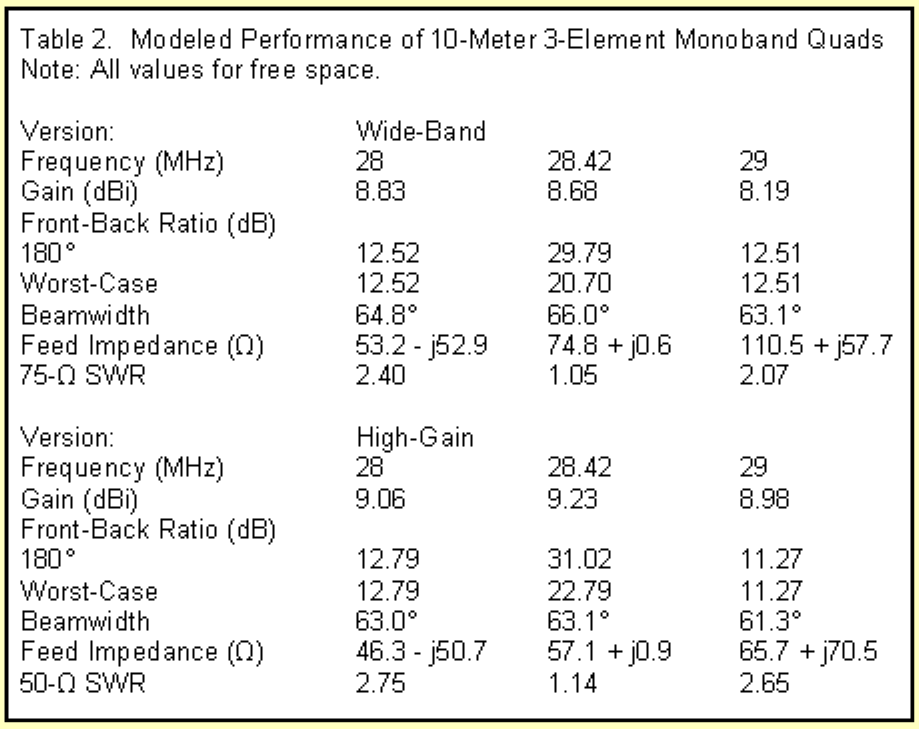


Table 2. Modeled Performance of 10-Meter 3-Element Monoband Quads
Note: All values for free space.

Version:	Wide-Band		
Frequency (MHz)	28	28.42	29
Gain (dBi)	8.83	8.68	8.19
Front-Back Ratio (dB)			
180°	12.52	29.79	12.51
Worst-Case	12.52	20.70	12.51
Beamwidth	64.8°	66.0°	63.1°
Feed Impedance (Ω)	53.2 - j52.9	74.8 + j0.6	110.5 + j57.7
75-Ω SWR	2.40	1.05	2.07
Version:	High-Gain		
Frequency (MHz)	28	28.42	29
Gain (dBi)	9.06	9.23	8.98
Front-Back Ratio (dB)			
180°	12.79	31.02	11.27
Worst-Case	12.79	22.79	11.27
Beamwidth	63.0°	63.1°	61.3°
Feed Impedance (Ω)	46.3 - j50.7	57.1 + j0.9	65.7 + j70.5
50-Ω SWR	2.75	1.14	2.65

We may correlate the main performance data in the table to the gain and 180-degree front-to-back curves for both models in **Fig. 2**. The high-gain version of the 3-element quad allows one to structure the design so that the maximum forward gain occurs at the design frequency, with lesser values at the band edges. Obtaining a high-gain curve of this shape with a Yagi is not normally possible. The high-gain quad model obtains in its 3 elements about the same gain as a long-boom 4-element Yagi. However, unlike Yagis that usually manage close to a minimum front-to-back ratio of 20 dB across the band, the quad shows the typically narrow-band nature of its front-to-back curve. The high-gain model manages 20-dB front-to-back ratio for only about 35% of the 10-meter band.

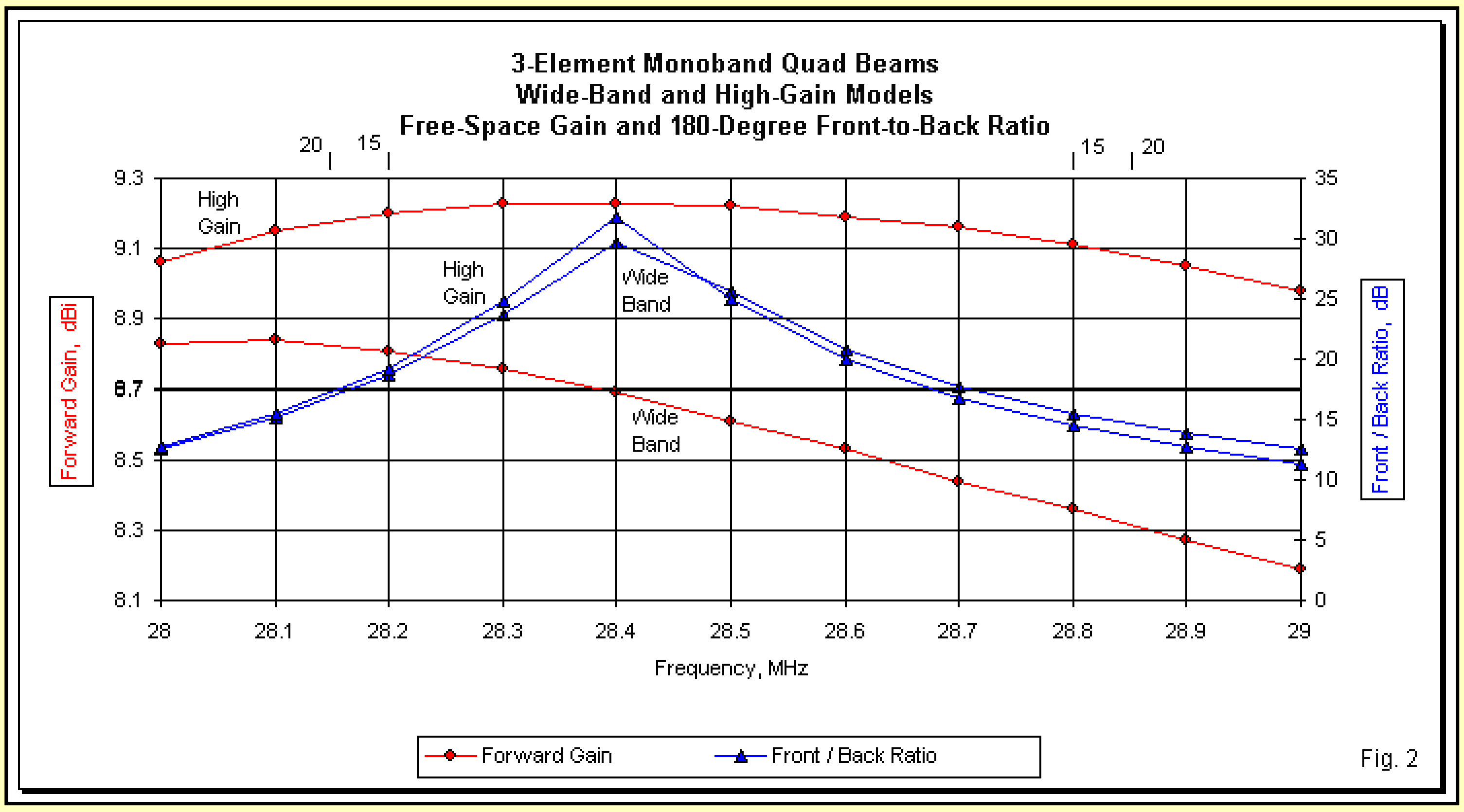


Fig. 2

The wide-band version of the 3-element quad trades gain for a more acceptable feedpoint impedance range. The trade-off results in a gain level that is about 0.55-dB lower than the high gain model at the design frequency. The design frequency free-space gain level is close to the value obtained from a short-boom 4-element Yagi. In addition, the wide-band model shows peak gain at the low end of the band, with a decreasing gain curve toward the high end. However, the minimum gain value is about 8.2 dBi, about 1.5-dB higher than the minimum value for a 2-element monoband quad on 10 meters. Interestingly, the front-to-back curves for both the wide-band and the high-gain versions of the antenna are very similar. Differences would fall below the operationally noticeable level.

The graph also contains a pair of marks at each end--along the upper edge. Since the curves for all 3-element quads derived from the equation models would be very similar, the marks show the curve limits for the 20-meter and the 15-meter amateur bands. You may extrapolate the likely gain and front-to-back values for each band by using these limiting marks. The impedance data in **Fig. 3** contains the same marks for similar extrapolations.

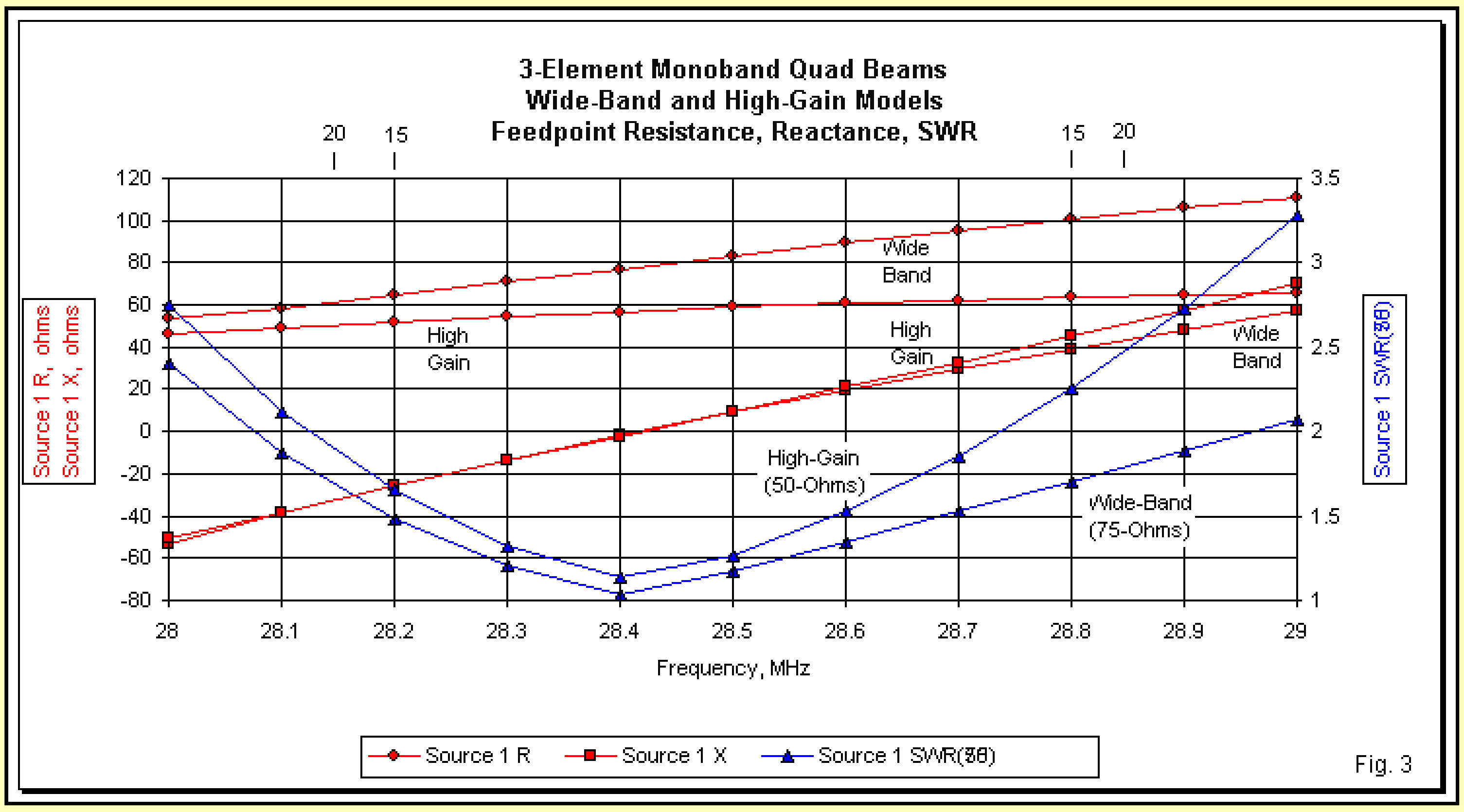


Fig. 3

The wide-band resistance curve centers at about 75 Ohms. Although the resistance change across the band is higher than the corresponding change for the high-gain model, the reactance shows a much lower total change from 28 to 29 MHz. Hence, the wide-band models shows a 75-Ohm SWR curve that covers about 900 kHz of the band with less than a 2:1 value. The same curve on 20 and 15 meters would show band-edge values well below 2:1.

The resonant impedance for the high-gain model is closer to 50 Ohms, allowing within the limits of the antenna a direct connection to the typical main feedline (with a common-mode current attenuator, of course). However, the total range of reactance across the band limits the 2:1 50-Ohm SWR operating bandwidth to about 600 kHz or about 60% band coverage. Since 20 meters is about 70% of the bandwidth of 10 meters, the curve would not quite allow 2:1 SWR use of that band. However, the curve would just about fit 15 meters, since it is about 60% of the bandwidth of 10 meters.

The monoband data will prove useful in evaluating the potential performance of any attempted tri-band 3-element quad. Tri-band 2-element quads managed to produce performance levels on each band that are similar to monoband values for each band. The key electrical question will be whether or not we can expect similar results from a tri-band 3-element quad.

Tri-Band 3-Element Quads: the Physical Questions

Typically, there are two ways of constructing a multi-band quad: the spider and the planar methods. The spider method uses the distance between elements as measured in wavelengths as a constant. Therefore, the physical spacing between elements varies from one band to the next. **Fig. 4** shows a possible arrangement of elements for a tri-band quad in which the drivers form a plane and the reflectors and directors vary their distance in inches, feet, or meters as we change frequency band. The model uses the wide-band version of the monoband quad as the basis for the elements shown.

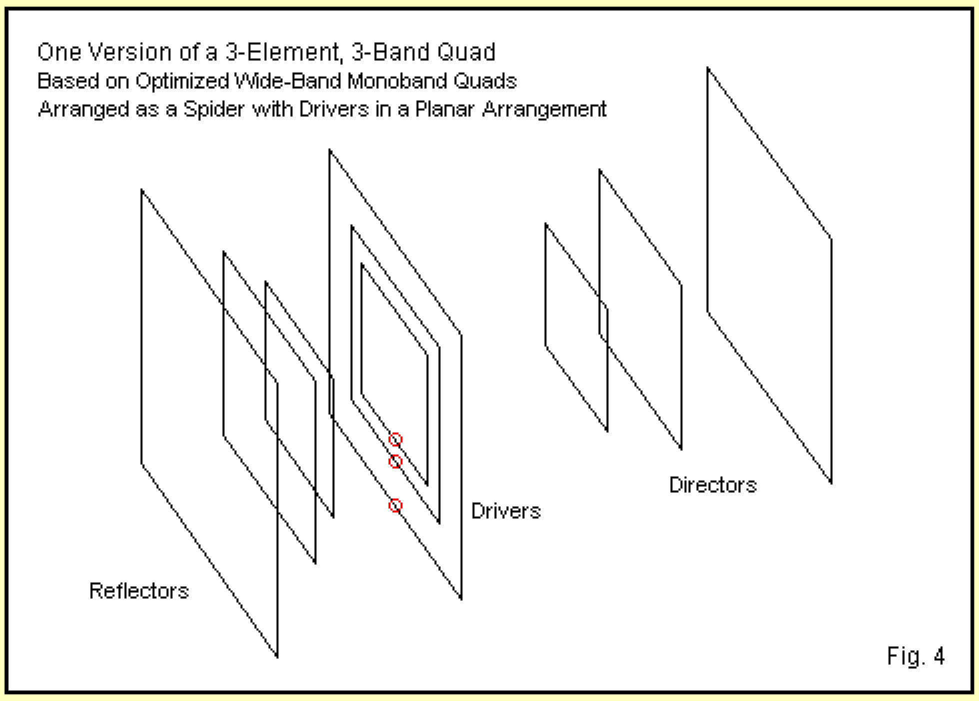


Fig. 4

The alternative construction method uses planar support arms for each elements. **Fig. 5** shows the general outline for such a quad in terms of the element placement. Since the element spacing would be optimal for only one of the 3 bands--at most--the element spacing values will vary according to the design compromises used to create the structure.

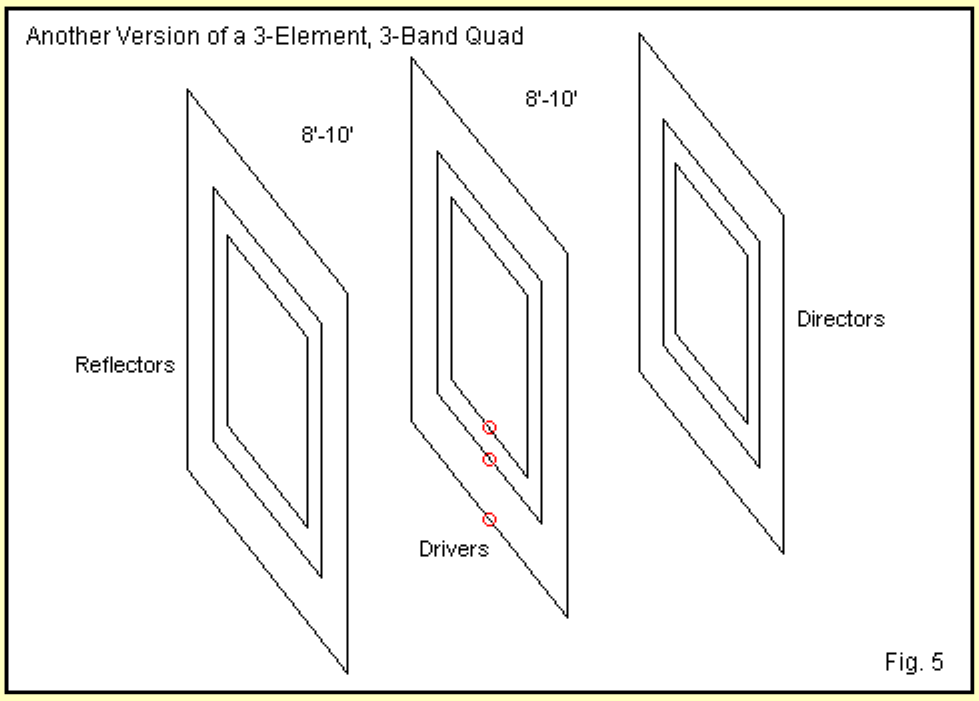
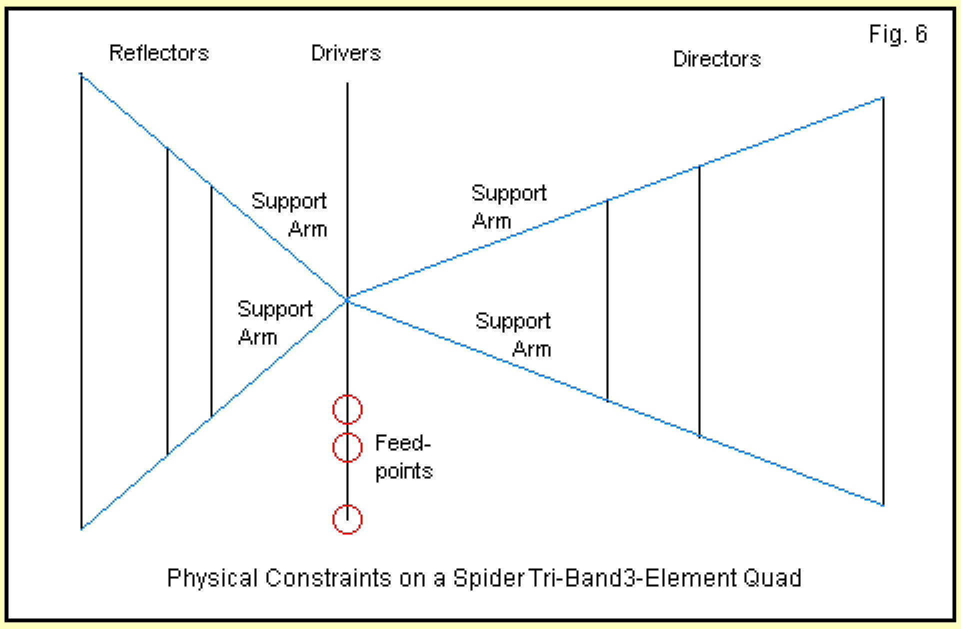


Fig. 5

At this juncture, we shall overlook performance questions to concentrate on the physical challenges presented by each design direction with constructing a tri-band 3-element quad. If we add support arms to the spider quad in **Fig. 4**, we obtain a sketch resembling the side view shown in **Fig. 6**.

Fig. 6



Physical Constraints on a Spider Tri-Band3-Element Quad

The optimal angles for the parasitic support arms exceed what is wise (or perhaps, even what is possible) using the wide-band quad as a model. Quad support arms must be relatively light and strong, a combination that gives the arms considerable flexibility. When we exceed certain angles (that vary with the arm structure), flexibility turns into sag that tension rods between pairs of forward and rearward arms cannot overcome. We can modify the structure somewhat, perhaps be using the high-gain design with its shorter overall front-to-back dimension. However, even this design would show support-arm angles that threaten serious sag, especially if we add an ice load to the array. The next strategy might be seriously to reduce the spacing between elements. However, this tactic will either reduce the operating bandwidth or reduce the performance level below 3-element expectations.

Physical Constraints on a Planar Monoband or Tri-Band 3-Element Quad

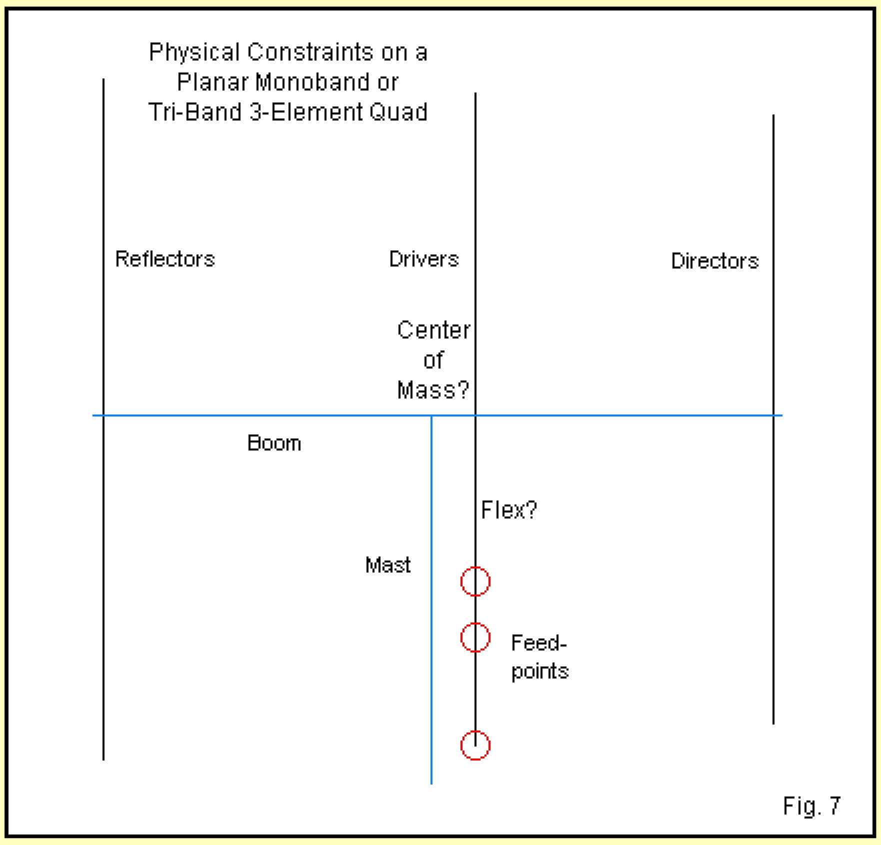


Fig. 7

Fig. 7 shows the fundamental difficulty with all planar 3-element quads. The compromises called for in the electrical performance of this type of multi-band array tend to place the driver very close to the support mast. Typical reflector-to-driver spacing values for upper HF multi-band quads are from 8' to 10'. However, driver-to-director spacing values use the same range. Support arm structures are lightweight and flexible. However, they still have some weight. Hence, even if we use different spacing values for the forward and rearward elements, we must adjust the mast-to-boom connection to compensate for the double X-structure on one side of the mast. The net effect is to put the driver elements in jeopardy of contacting the mast or tower during normal wind loads.

For the reasons outlined, we find few 3-element tri-band quad designs available. Most builders prefer to move from 2 to 4 elements. Virtually all 4-element quad designs use planar construction. Hence, the load on each end of the boom, relative to the mast or tower, is equal. The reflector and driver elements go to the rear, while the directors ride in front. It is still important to mount the quad at its center of mass rather than using the boom-length center point. However, even that adjustment leaves several feet of space between the mast and the nearest set of element wires.

Tri-Band 3-Element Quads: the Electrical Questions

There is more to dis-recommend a multi-band 3-element quad than just the mechanical details. Someone might well be able to overcome the physical constraints if the 3-element quad offered near-monoband performance on all bands, even if only in a 3-band version. However, we are unlikely to see such an antenna because the 3-element design--when multi-banded--presents some electrical problems.

To test the tri-band 3-element quad, I created a number of models using both planar and spider construction. All of the planar models failed to have either the gain or the bandwidth of the wide-band monoband 3-element quad. Since it is not possible in a finite lifetime to exhaust all of the possibilities, I cannot claim the survey to be exhaustive, although it has so far proven both exhausting and futile. Among spider models, the version of the antenna shown in **Fig. 4** and in **Fig. 6** proved to provide the best performance. **Table 3** samples that performance at the design frequencies. The table also lists the design-frequency monoband performance on all 3 bands to ease the task of making comparisons.

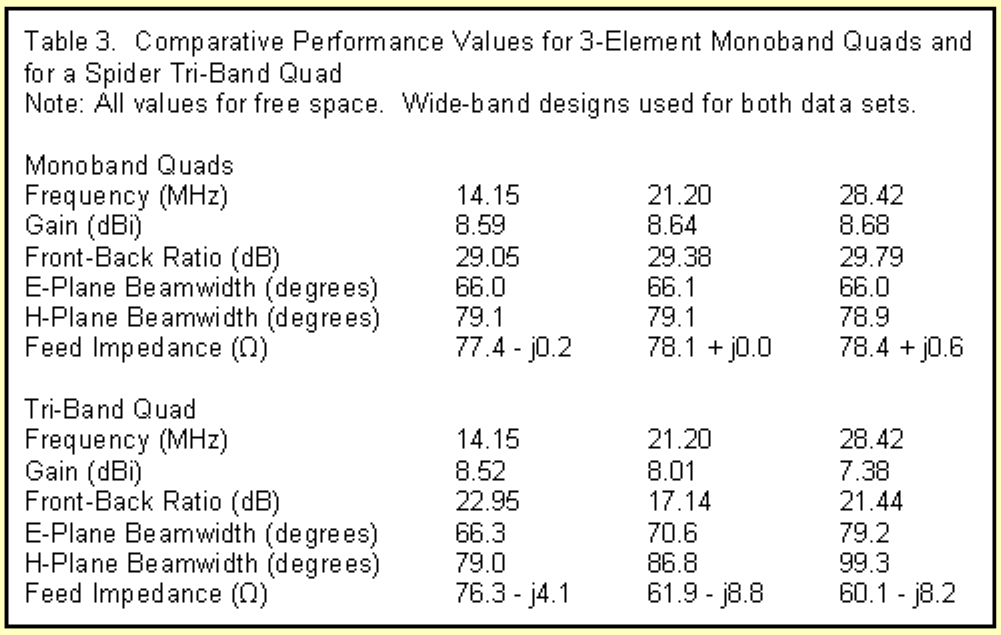
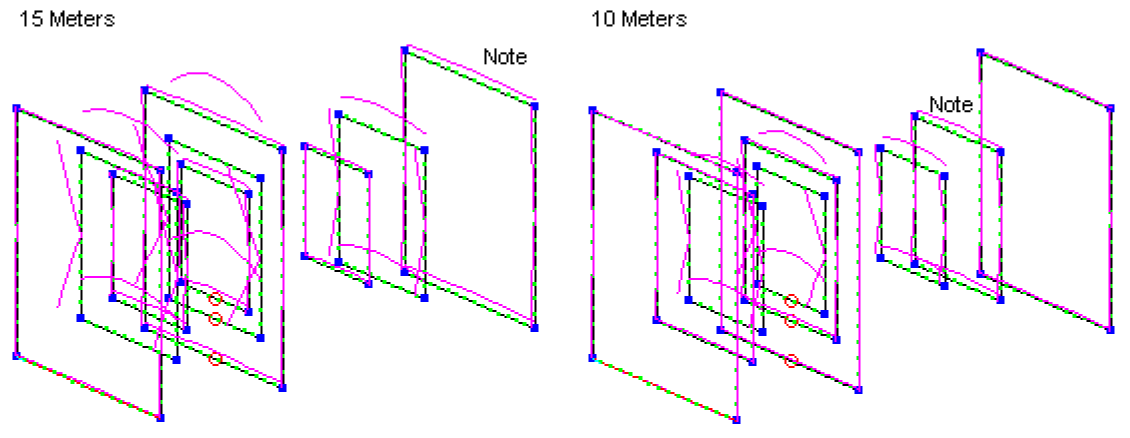


Table 3. Comparative Performance Values for 3-Element Monoband Quads and for a Spider Tri-Band Quad
Note: All values for free space. Wide-band designs used for both data sets.

Monoband Quads			
Frequency (MHz)	14.15	21.20	28.42
Gain (dBi)	8.59	8.64	8.68
Front-Back Ratio (dB)	29.05	29.38	29.79
E-Plane Beamwidth (degrees)	66.0	66.1	66.0
H-Plane Beamwidth (degrees)	79.1	79.1	78.9
Feed Impedance (Ω)	77.4 - j0.2	78.1 + j0.0	78.4 + j0.6
Tri-Band Quad			
Frequency (MHz)	14.15	21.20	28.42
Gain (dBi)	8.52	8.01	7.38
Front-Back Ratio (dB)	22.95	17.14	21.44
E-Plane Beamwidth (degrees)	66.3	70.6	79.2
H-Plane Beamwidth (degrees)	79.0	86.8	99.3
Feed Impedance (Ω)	76.3 - j4.1	61.9 - j8.8	60.1 - j8.2

The table clearly shows that we encounter a lower feedpoint resistance as we increase the frequency. However, the rate of decrease is lower than for 2-element tri-band quads. The reduced rate rests on a combination of factors, including the planar arrangement of the drivers and the fact that each driver has two elements that exert influence on the feedpoint impedance. Were it not for other factors, we might use this beam without further adjustment to the driver lengths.

Unfortunately, as we increase frequency, we also see a decline in the array gain. In fact, the 10-meter gain falls within the range that we can achieve with only 2 elements in a tri-band quad. As well, we also find a decrease in the front-to-back ratio. These numbers are not simply the product of a front-to-back peak that is on a different frequency. Rather, the decrease in front-to-back ratio is part of the same set of effects that yields the lower gain on each band above 20 meters. In fact, 20 meters is the only band on which we see near-normal (monoband) gain, and this fact provides a clue to what is happening.



Restrictions on Upper-Band Gain in a Tri-Band 3-Element Quad

Fig. 8

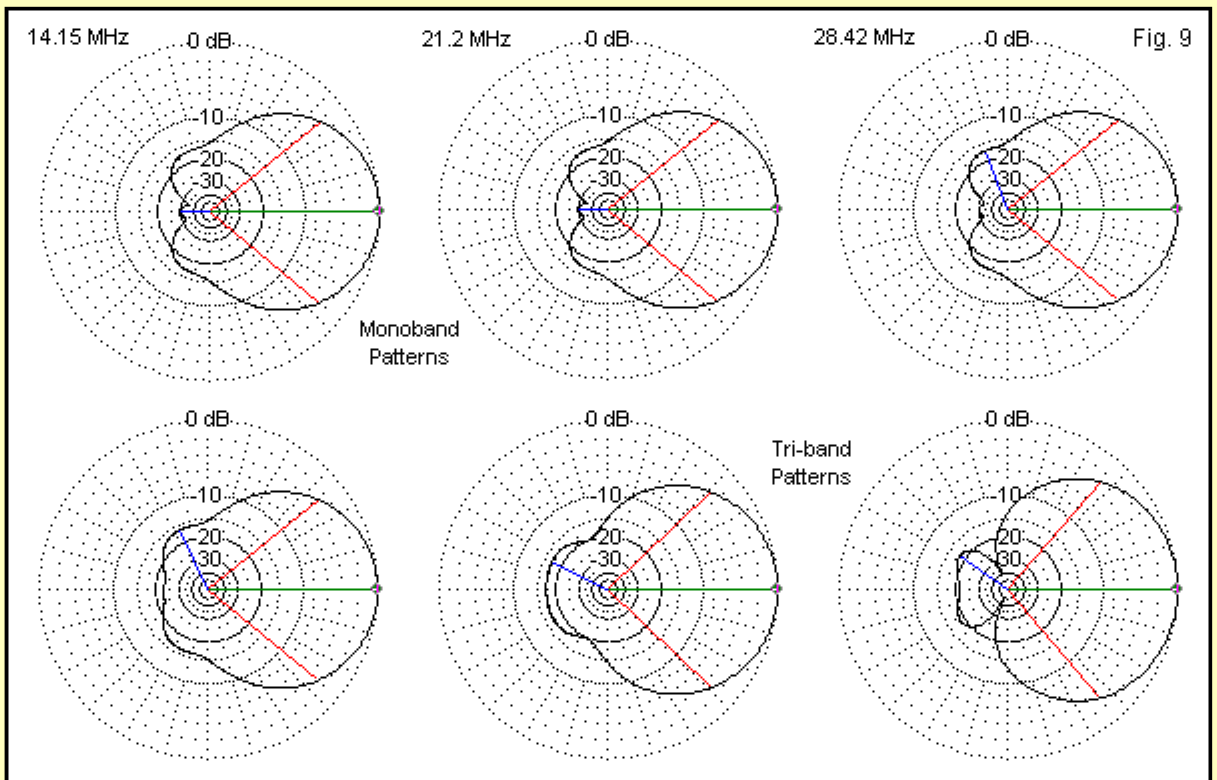
We can visualize the problem by examining **Fig. 8**, which shows the relative current magnitudes when we operate the array on 15 meters and on 10 meters. On the left, we find fairly high peak currents on the 15-meter elements, since the operating frequency is 21.2 MHz. There is one additional active element: the 20-meter director. Its current magnitude is over 1/3 the value of the 15-meter director current magnitude. Likewise, on 10 meters or 28.42 MHz, we find fairly high values of current magnitude on the 10-meter elements. As well, the 15-meter director is active at a current magnitude that is more than 1/2 the current magnitude of the 10-meter director.

Current magnitude is not the sole determiner of what occurs with these elements. We must also consider the phase angle of the current. In the monoband versions of these 3-element quads, we find a relative current magnitude on the reflector that varies between 0.81 and 0.86 across 20 meters. The corresponding current phase varies from 126 to 153 degrees. The director current varies from 0.23 to 0.36 in magnitude, with a phase angle range of from -133 to -151 degrees. At the design frequency, the current magnitudes and phase angles are about at the average of these ranges (0.85 at 140 degrees for the reflector and 0.29 at -140 degrees for the director).

In the tri-band design, at 14.15 MHz, the reflector values are 0.84 at 131 degrees and 0.27 at -149 degrees--well within the range shown for the monoband beam. However, at 21.2 MHz, the tri-band reflector current is down to 0.68 at 133 degrees, while the director current is 0.31 at -150 degrees. The reflector relative current magnitude is low. At the same time, the 20-meter director shows current values of 0.11 at -11.6 degrees. At 28.42 MHz, the 10-meter reflector current is 0.64 at 148 degrees. The 10-meter director current values are 0.36 at -135 degrees. While the combinations are not optimal, the key value is the low reflector relative current magnitude. At this frequency, the 15-meter director shows current values of 0.20 at 20 degrees.

If the parasitic element current magnitude and phase angle values are not radically out of line (with the possible exception of the 10- and 15-meter reflector magnitudes), then we may still be at a loss to explain why the forward gain drops so much, rather than just a little. The answer lies in understanding how currents and element functions go together. Clearly, reflector currents show a positive phase angle, while director currents show a negative phase angle in 3-element arrays. Although the exact number will change according to the precise design, the monoband ranges of magnitudes and phase angles give us ballpark values for any 3-element parasitic array. We should not neglect the driver current, which in all cases of this modeled sequence is 1.0 at 0 degrees. Essentially, phase angle values near zero yield a driver element, and the two directors with unintended activity are closer to zero degrees than to values appropriate to reflectors or directors. In effect, the parasitically active directors for the next higher band are radiating energy, but without the direct influence of the parasitic elements that have been cut for the band in use.

The energy must go somewhere. For the subject design, the energy tends to go "up" and "down" relative to the wires in the loop as much as it goes forward and backward. In other words, we end up with wider beamwidth values, not only in the E-plane, but as well in the H-plane. Re-examine the data in **Table 3**. The tri-band 20-meter beamwidth values are nearly the same as the ones we derived for the monoband beam. In fact, all three monoband 3-element quads have almost identical beamwidth values. However, when we move to 15 meters, the E-plane shows a 4.5-degree wider beamwidth, while the H-plane value increases by about 8 degrees. At 10 meters, relative to the monoband values, the E-plane beamwidth increases by about 13 degrees, while the H-plane beamwidth increases by over 20 degrees. **Fig. 9** provides a gallery of H-plane patterns that show clearly the increasing beamwidth as we operate the 3-element tri-band quads on the upper bands.



Design-Frequency H-Plane Patterns: Monoband Quads and Tri-Band Combination

The exact degree of pattern deformation, relative to a standard derived from the monoband pattern, will vary with the multi-band quad design. However, every planar and spider 3-element quad design that I have examined has shown the same basic phenomena. At 15 meters, the 20-meter director is active, and at 10 meters, the 15-meter director is active. In both cases, being active means having a current magnitude of at least 10% the value of the driver. The activity is sufficient to prevent the quad from reaching its monoband performance levels on the upper two band. Regardless of the precise design, the upper bands of a 3-element multi-band quad in some cases barely reach 2-element performance levels.

Planar 3-element, 3-band designs are at a further disadvantage. 2-element designs exhibit only slow changes of performance with variations in reflector-to-driver spacing. However, the driver-to-director spacing (and element circumference) in a 3-element quad reacts to smaller changes in spacing. Hence, a 3-element tri-band quad tends more readily to show that fact that the element spacing is optimal at best on only one of the 3 bands and often not on any of them. As a consequence, tri-band planar designs using 3 elements tend not to achieve a very significant gain over a 2-element quad. Optimized quad designs for the widest bandwidths easily show about 8.5 dBi free-space gain at mid-band. Optimized high-gain monoband quads top 9.0 dBi. A planar quad rarely achieves 7.8 dBi on any band.

I sampled tri-band 3-element planar quads using 3 different popular spacing values for boom lengths of 18' to 20'. One sample used 10' from reflector to driver and 8' from driver to director, while a second reversed those two numbers. A final sample used 10' for both the reflector-driver and driver-director spacing values. Although it may be possible to refine the performance further, **Table 4** shows the range of values at mid-band for the group of designs.

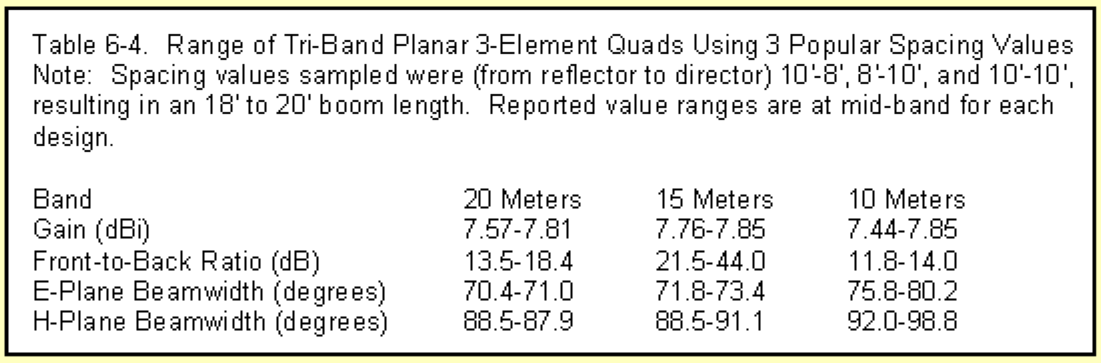


Table 6-4. Range of Tri-Band Planar 3-Element Quads Using 3 Popular Spacing Values
Note: Spacing values sampled were (from reflector to director) 10'-8', 8'-10', and 10'-10', resulting in an 18' to 20' boom length. Reported value ranges are at mid-band for each design.

Band	20 Meters	15 Meters	10 Meters
Gain (dBi)	7.57-7.81	7.76-7.85	7.44-7.85
Front-to-Back Ratio (dB)	13.5-18.4	21.5-44.0	11.8-14.0
E-Plane Beamwidth (degrees)	70.4-71.0	71.8-73.4	75.8-80.2
H-Plane Beamwidth (degrees)	88.5-87.9	88.5-91.1	92.0-98.8

The element spacing value range favors 15 meters over the other 2 bands. Hence, the overall 180-degree front-to-back ratio level is higher on that band. As well, the lowest gain value is higher than for either of the other bands. The planar design also suffers in beamwidth in both the E- and the H-planes. Optimized monoband designs showed about a 66-degree E-plane beamwidth and a 79-degree H-plane beamwidth. As the table shows, all of the beamwidth values for the tri-band planar design are higher. In addition, the values increase with increasing operating frequency. Finally, the H-plane beamwidth shows considerable growth as the operating frequency increases. Given the associated physical challenges of a 3-element planar multi-band quad construction, most builders have concluded that there is no great sense in deriving 2-element performance from 3 elements.

Conclusion

The only definitive point that these notes establish is that multi-band 3-element quads present both physical and electrical challenges that most quad builders find perhaps too daunting. Whether there are any sure-fire ways to overcome both sets of challenges, I frankly do not know. To this point, I have discovered none. Apparently, most quad builders have not found these ways either, since 3-element multi-band quads are far more rare than 4-element multi-band quads.

With 4 elements, a quad presents no major mounting problems other than the weight of the elements and their support arms. As well, the presence of the second director overcomes to a large measure the pattern distortions that tend to prevent 3-element quads from reaching monoband performance on the upper bands. Nevertheless, 4-element quads present their own challenges--and sometimes the means to overcome them. Virtually all 4-element quads use planar construction. The result will inevitably be that some bands have compromise performance values that emerge from using a boom length that is either too short or too long for optimal wide-band performance. At the same time, the presence of three parasitic elements per band allows the builder to offset some loop dimensions to increase the operating bandwidth with an acceptable SWR value. The challenge lies in finding the correct combination that yields operating bandwidth and reasonable performance that is worth the construction and adjustment effort. Many quad builders have found the benefit-cost ratio favorable in 4-element designs while finding the ratio unacceptable for 3-element multiband quad designs.

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