Sneaking Up on 2-Element Common-Feed Quads
Part 1: Monoband Quad Beams as a Starting Point

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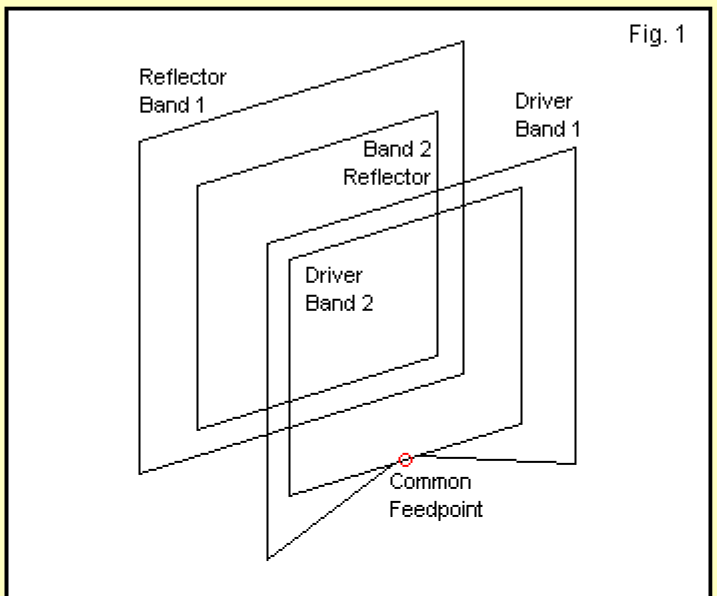
Among 2-element quad beam users a question lingers. Which feed system is superior: separate switched drivers or drivers brought to a common feedpoint? The common-feed system is easier for the user, since it eliminates an extra, usually remote, switch box. However, the separate-feed system is usually easier to design and test for proper operation. Many answers to the question abound, ranging from antenna maker claims that users cannot always confirm to simple feelings about the matter.

The common-feed 2-element quad is not a simple system, as **Fig. 1** tells us. We have the elements for at least 2 bands of operation. The elements interact simply by virtue of proximity. Moreover, we have additional interactions occasioned by the use of a common feedpoint. Finally, we can add to the equation the fact that we usually do not know to what we may be comparing either the common-feed or the separate-feed quad. Little wonder that the question tends to raise more heat than light.



Question: What Happens When We Use a Common Feedpoint for a Multiband Quad Beam?

Let's revise the basic question so that we can sort out the proper steps on the way to an answer. What happens when we create a multi-band quad and provide it with a common driver feedpoint for all bands?

First, we need a set of starting points, namely, monoband quads from which to build the multi-band quad. Every multi-band quad rests on a set of monoband quads which the multi-band design alters to compensate for element interaction. In many cases, the designer may not actually examine the monoband quads that underlie the more complex array, but those quads exist anyway. These notes will designate the monoband quads as the place to start so that we can compare multi-band designs and performance to them.

Second, we need to move in logical steps and "sneak up" on the common feed design. After reviewing the performance of the foundational monoband quads, we shall develop from them a series of multi-band designs that use separate feedpoints. These designs will use perfectly square loops for all elements so that the interactions exist at only one level: between reflector wires and driver wires that are equally spaced from each other for the entire perimeter. Only when we know the consequences of this step can we move on to the necessary distortions of the driver wires that occur when we use a common feedpoint.

Third, we must set some limits to the study--or we shall never reach a stopping point. One limitation is setting a frequency ratio between adjacent bands in any multi-band design. The closer 2 bands are in frequency, the greater that the element interaction will be. If the operating frequencies are too close, then seemingly inactive elements become very active, sometimes in unwanted ways. When operating on the lower of two frequencies, the seemingly inactive reflector element may form a director in the wrong direction relative to desired beaming. To hold interactions to an accountable level, I shall set a minimum frequency ratio of 1.3:1 between adjacent bands. This ratio allows combinations such as 17 and 12 meters, 20 and 15 meters, and 15 and 10 meters. However, it rules out adjacent bands in the upper HF region of the amateur spectrum. There are successful quad beams using these combinations, but they do not reveal their interactions as readily as more widely space bands. Remember that our goal is to understand what happens as we move toward a multi-band common-feed quad beam. It is not necessarily to design one that we might build.

I shall also limit the study (with one exception) to 2-band quad beams, simply to limit the number of different kinds of sample beams. Instead of examining all possible combinations of multi-band quads, we shall look at multiple examples of two-band quads with different frequency combinations in order to find the reliable trends in the physical shape and performance of these beams. These trends will be the keys to understanding what happens along the road to a common feedpoint. As well, the dual-band quads will give us an opportunity to explore an interesting feeding strategy.

One situation that I shall avoid is a combination of quads involving a 2:1 frequency ratio, such as a 20-meter and 10-meter dual-band quad. On 10 meters, both of the drivers will be at or near resonance and at or near a low impedance. Hence, we would encounter a greater-than-normal current split between the drivers. However, when used on 10 meters, the 20-meter driver has a circumference of about 2 wavelengths, and radiation is predominantly off the loop edge. The quad works best when radiation is broadside to the loop, a condition that occurs when closed loops are close to 1 wavelength in circumference. By avoiding the 2:1 frequency ratio, we by-pass the need for special compensations to overcome the conflict in pattern formation.

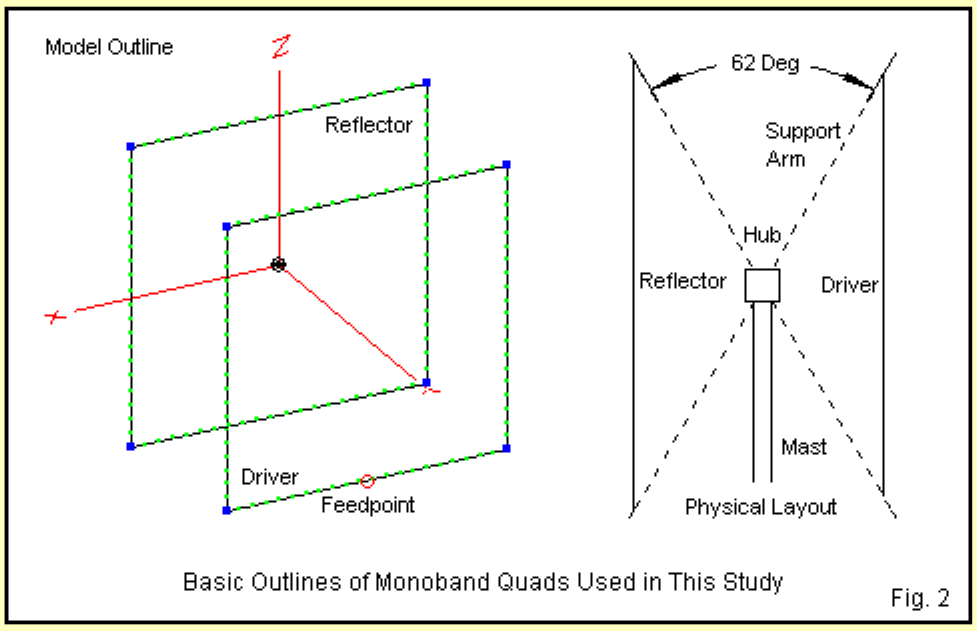
The final limitation will involve element spacing. Throughout the multi-banding exercises, I shall maintain the element spacing used in the monoband quads that form our starting points. This specification will result in spider rather than planar quad beams. Planar quad beams have advantages and disadvantages of their own. One primary example is the KC6T quad that I analyzed in volume 1 of *Cubical Quad Notes*. In terms of wavelengths, the spacing between elements changes as we change bands. Hence, we do not have a ready ability to relate the performance of the multi-band antenna to its root monoband quad components. By preserving element spacing and using what will amount to spider construction with sloping support arms, we can achieve the desired comparisons between original monoband quads and the modifications needed to make them work in various multi-band settings.

Getting Started: Monoband 2-Element Quads

The multi-element quad beam is essentially a parasitic array with relatively narrow-band performance characteristics. A 2-element driver-reflector design will show a characteristic reduction in forward gain with increasing frequency across the operating passband. This feature the quad shares with the Yagi. (Any well-designed parasitic array with at least one director will show a rising gain with frequency.) However, the key limitations involve the SWR and front-to-back ratio passbands. In Yagi design, 2-element driver-reflector arrays show a low but almost uniform front-to-back ratio across any of the upper HF bands. The SWR passband is often the chief design concern. To widen that passband, we need increased element spacing. The result is a very small reduction in gain at the design frequency, but a wider spread of usable frequencies in which to observe the gain curve.

Designing a monoband 2-element quad involves a number of compromises. In volume 2 of *Cubical Quad Notes*, I described a program and a programmed NEC-Win Plus model that provides optimized 2-element quad beams for any user-selected design frequency and element diameter. The designs rest on extensive hand optimization of models, along with extensive regression analysis to allow use of the designs on wire diameters ranging from 10E-2 through 10E-5 wavelengths and on frequencies from 3 to at least 300 MHz. A number of interested amateurs have added to the array of formats in which one may perform the calculations. For a list of available downloads, see http://www.cebik.com/quad/q2l2.html.

Fig. 2 shows the general model outline (using an EZNEC graphic), along with a side view of the quad's physical structure. The angle between the support arms is 62 degrees, that is, about 31 degrees each side of a vertical line drawn through the mast and hub. The precise angle will vary a bit from band to band.



Basic Outlines of Monoband Quads Used in This Study

Fig. 2

The angle for the (non-conductive) support arms varies according to the calculated spacing between the elements. The spacing, like all other quad dimensions, is a partial function of the element diameter as measured in wavelengths. In these exercises, I have standardized all quads to the very familiar AWG #14 (0.0641" diameter) copper wire. As measured in wavelengths, the element diameter changes from one band to the next. Since the wire is quite thin, the effects are small. However, the spacing may vary enough to change the overall angle between the reflector and the driver by as much as a full degree or so in the move from 20 down to 10 meters.

Based on the equations, I produced a series of models for the upper HF bands. The dimensions appear in **Table 1**. The spacing entry represents the full dimension. However, for modeling convenience, the loop dimensions appear as 1/2-side lengths. A full side length is twice the value shown, and the loop circumference is 8 times the value in the table. The dimensions are in inches. Multiply these dimensions by 0.0254 to obtain a result in meters.

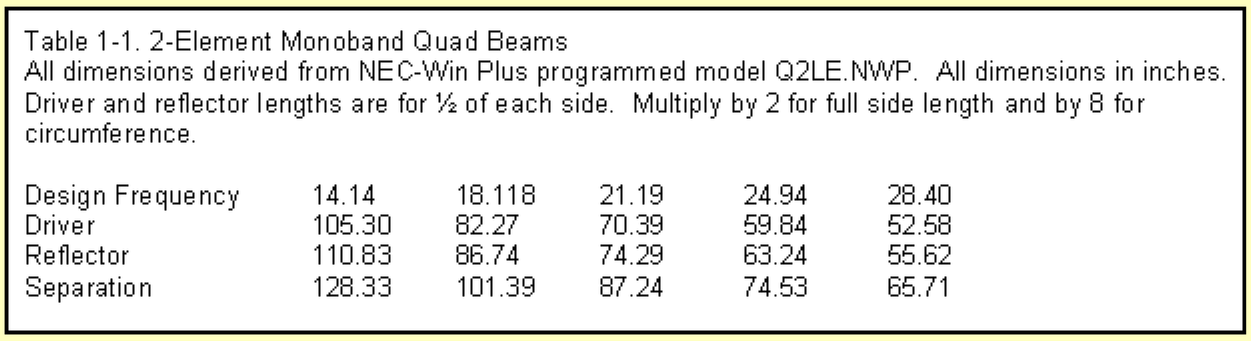


Table 1-1. 2-Element Monoband Quad Beams
All dimensions derived from NEC-Win Plus programmed model Q2LE.NWP. All dimensions in inches. Driver and reflector lengths are for ½ of each side. Multiply by 2 for full side length and by 8 for circumference.

Design Frequency	14.14	18.118	21.19	24.94	28.40
Driver	105.30	82.27	70.39	59.84	52.58
Reflector	110.83	86.74	74.29	63.24	55.62
Separation	128.33	101.39	87.24	74.53	65.71

These quad designs model very adequately on either NEC-2 or NEC-4. In fact, I remodeled each quad using EZNEC Pro/4 to check on the results of NEC-Win Plus, which uses NEC-2. The reported performance figures are insignificantly different. Although carrying out measurements in inches to 2 decimal places may seem to be beyond normal construction needs, the original model rests on spreadsheet calculations that carry them out to a dozen decimal places. Rounding to the nearest tenth of an inch is perfectly acceptable. Tenths may be easier to convert to the English system of eighths and sixteenths for use with a tape measure.

I selected this particular set of models as the monoband 2-element quads for our study since they provide the widest operating passband of any monoband 2-element quads in my experience. For example, the SWR bandwidth (using the design frequency resonant impedance as a standard) is well below 2:1, even on 10 meters (using the 28-29-MHz span as the antenna passband). However, the 180-degree front-to-back ratio shows a very high peak at the design frequency, but falls off rapidly.

On the narrow ham bands (17 and 12 meters), I used the band center as the design frequency. However, on the wider upper HF bands (20, 15, and 10 meters), I selected a frequency below the band center. The design frequency selection criterion was a relatively equal 180-degree front-to-back ratio at both band edges. The 20-meter design frequency is 14.14 MHz. On 15, the frequency is 21.19 MHz. On 10 meters, 28.4 MHz serves as the design frequency.

Although we shall look more closely at the performance curves for each monoband quad, **Table 2** summarizes the performance characteristics across the band. It lists the band-edge and band-center values. Where the design frequency is not also the center of the band, the table includes those values as well.

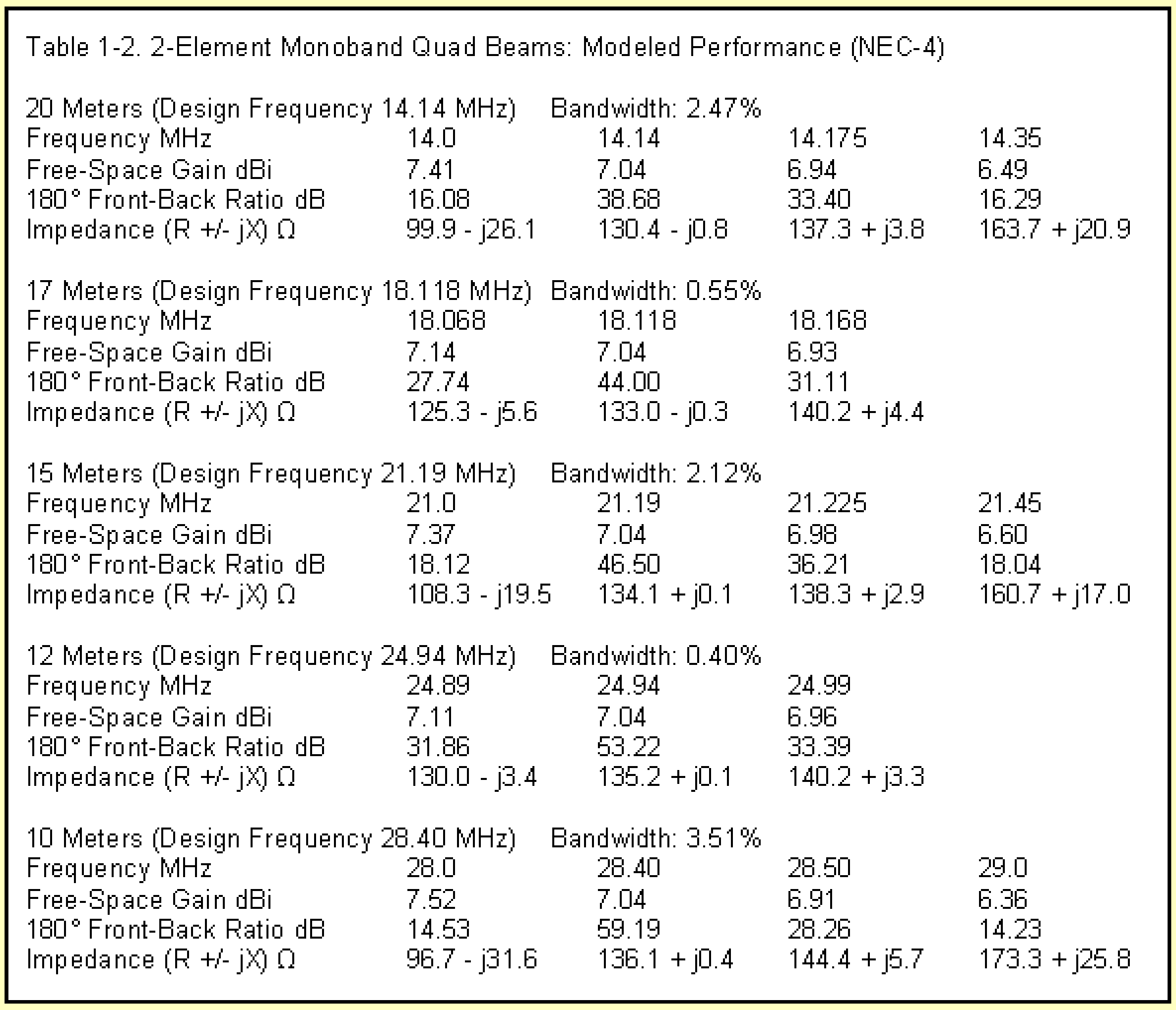


Table 1-2. 2-Element Monoband Quad Beams: Modeled Performance (NEC-4)

20 Meters (Design Frequency 14.14 MHz)	Bandwidth: 2.47%			
Frequency MHz	14.0	14.14	14.175	14.35
Free-Space Gain dBi	7.41	7.04	6.94	6.49
180° Front-Back Ratio dB	16.08	38.68	33.40	16.29
Impedance (R +/- jX) Ω	99.9 - j26.1	130.4 - j0.8	137.3 + j3.8	163.7 + j20.9
17 Meters (Design Frequency 18.118 MHz)	Bandwidth: 0.55%			
Frequency MHz	18.068	18.118	18.168	
Free-Space Gain dBi	7.14	7.04	6.93	
180° Front-Back Ratio dB	27.74	44.00	31.11	
Impedance (R +/- jX) Ω	125.3 - j5.6	133.0 - j0.3	140.2 + j4.4	
15 Meters (Design Frequency 21.19 MHz)	Bandwidth: 2.12%			
Frequency MHz	21.0	21.19	21.225	21.45
Free-Space Gain dBi	7.37	7.04	6.98	6.60
180° Front-Back Ratio dB	18.12	46.50	36.21	18.04
Impedance (R +/- jX) Ω	108.3 - j19.5	134.1 + j0.1	138.3 + j2.9	160.7 + j17.0
12 Meters (Design Frequency 24.94 MHz)	Bandwidth: 0.40%			
Frequency MHz	24.89	24.94	24.99	
Free-Space Gain dBi	7.11	7.04	6.96	
180° Front-Back Ratio dB	31.86	53.22	33.39	
Impedance (R +/- jX) Ω	130.0 - j3.4	135.2 + j0.1	140.2 + j3.3	
10 Meters (Design Frequency 28.40 MHz)	Bandwidth: 3.51%			
Frequency MHz	28.0	28.40	28.50	29.0
Free-Space Gain dBi	7.52	7.04	6.91	6.36
180° Front-Back Ratio dB	14.53	59.19	28.26	14.23
Impedance (R +/- jX) Ω	96.7 - j31.6	136.1 + j0.4	144.4 + j5.7	173.3 + j25.8

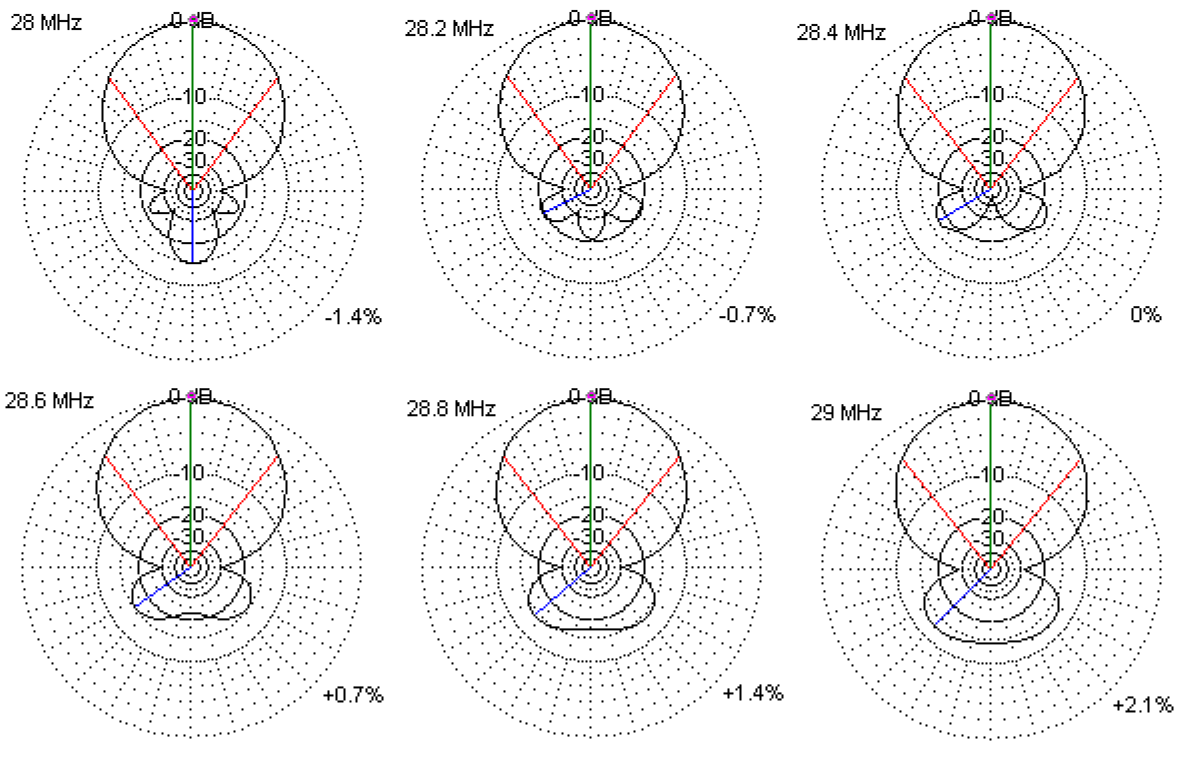
The design-frequency free-space gain is uniformly 7.04 dBi. The 180-degree front-to-back value at the design frequency tends to climb with frequency, as does the resonant feedpoint impedance. (The reported values result from using calculated figures and do not result from any further modifications to make them "fit" the desired outcome.) The front-to-back ratio at the band edges is about the same for each of the wider bands. (The narrow bands are too narrow and the front-to-back values are too high to be concerned about differences less than 5-6 dB.)

Each upper HF amateur band has a different bandwidth when measured as a percentage of the band-center frequency. The table lists those values as well. It is clear from these sample numbers that as the bandwidth increases, the band-edge front-to-back ratio becomes lower. Three-element Yagis on short booms (under 0.25-wavelength) are capable of about 20 dB front-to-back ratios across the wider ham bands. A 2-element quad may match the 3-element Yagi in gain (with a reverse gain curve relative to frequency), but it simply cannot sustain the front-to-back ratio.

What the numbers in the table cannot show is how the rearward pattern changes with frequency. (The forward lobe remains well-behaved throughout.) For that purpose, we need a useful gallery of E-plane patterns. **Fig. 3** supplies the need. More importantly, it shows the evolution of the rearward lobes as we move away from the design frequency.

Fig. 3

Note: Percentages are the bandwidth departure from the design frequency (= 0%).



A Gallery of Free-Space E-Plane Patterns for a Monoband 2-Element Quad Beam

I selected 10 meters for the gallery since that band gives us the widest operating passband of all the upper HF bands. The patterns show both the frequency and how much that frequency departs from the design frequency. Both 17 and 12 meters are so much smaller than the smallest increment of difference in the figure that we can expect their band-edge patterns to resemble the design frequency pattern with only a small loss on the direct rearward null. 20 meters is only about 70% as wide as 10, and 15 meters is only about 60% as wide as 10 meters. Hence, their band-edge patterns will be intermediate between the pair of patterns marking the farthest extremes on 10 meters.

One may debate my use of the 180-degree front-to-back ratio as the desideratum for choosing a design frequency. Admittedly, it is partially a function of modeling convenience, since that figure automatically appears in the basic NEC plot data collection produced by most implementations of the core. However, we should note a significant difference in the overall energy radiated to the rear quadrants both below and above the design frequency. Below the design frequency, we find only a small total area of rearward energy (remembering that we are dealing with only 2 dimensions and ignoring the third). In comparison, above the design frequency, we find a much larger and growing area of total rearward radiation. This condition correlates well with the decreasing forward gain (but continues to ignore the fact that a free-space pattern is actually a 3-dimensional affair). Nevertheless, the band-edge 180-degree front-to-back ratio values--and their equality at the band edges--will serve us well as markers of both similarity and of change when we develop dual-band quad beams.

We may collect further detail on the performance changes across each of the upper HF amateur bands by performing frequency sweeps. The graphs to follow emerged from AC6LA's EZPlots Excel function based on EZNEC sweep files. In each case, I subdivided the band into 10 segments to provide the smoothest curves feasible.

20 Meters

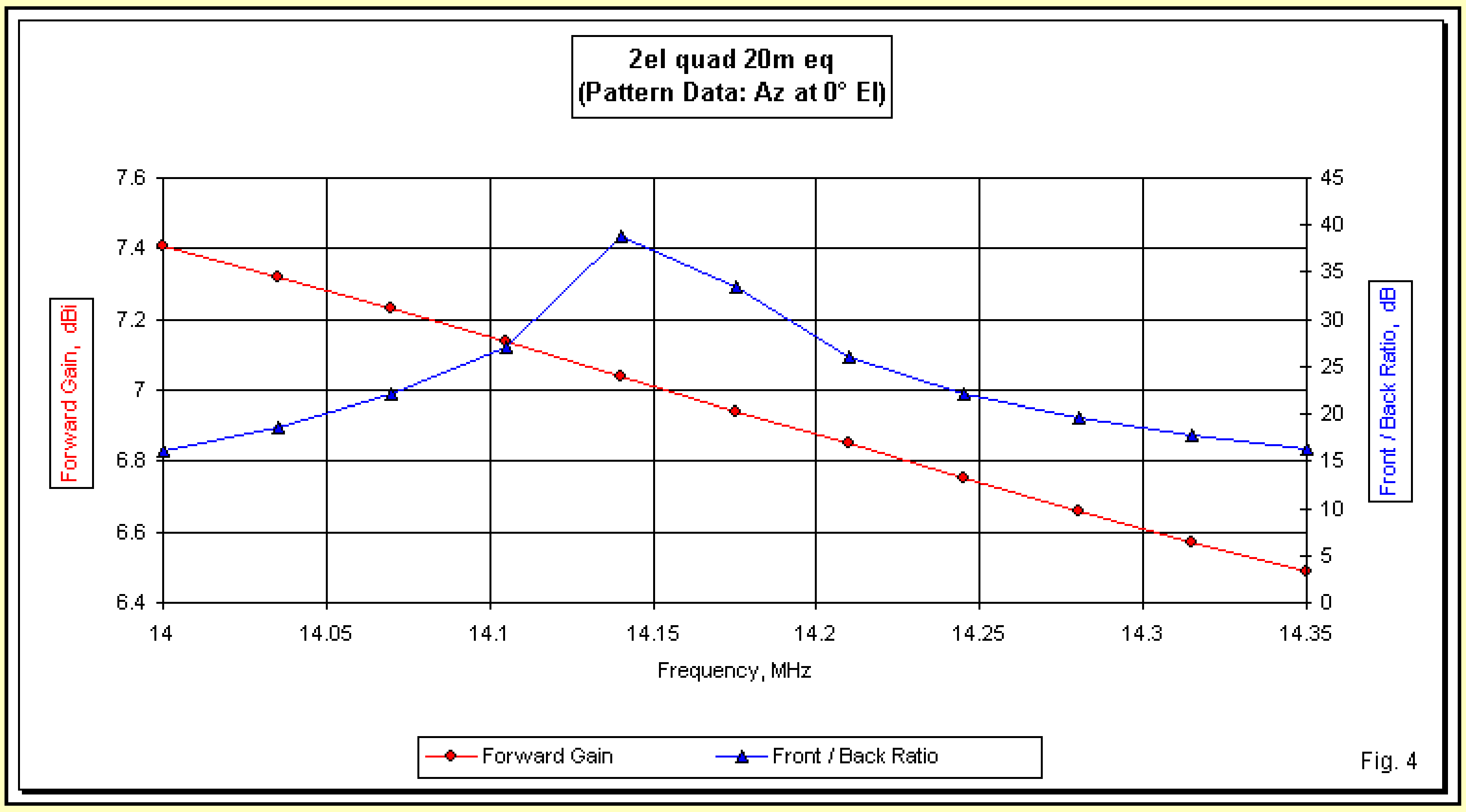


Fig. 4

The gain and front-to-back curves in **Fig. 4** show the performance on 20 meters. The gain curve is nearly, but not quite, linear in the gain reduction per unit of the passband. The rate of decline is about the same as the rate of climb for a short-boom 3-element Yagi using elements of the same diameter. (Since most Yagis would use fatter elements, practical Yagis of such design will show a somewhat shallower gain-rise curve, ranging from about 6.9 to 7.4 dBi.) The front-to-back ratio peaks at the design frequency and drops to about 16 dB at the band edges.

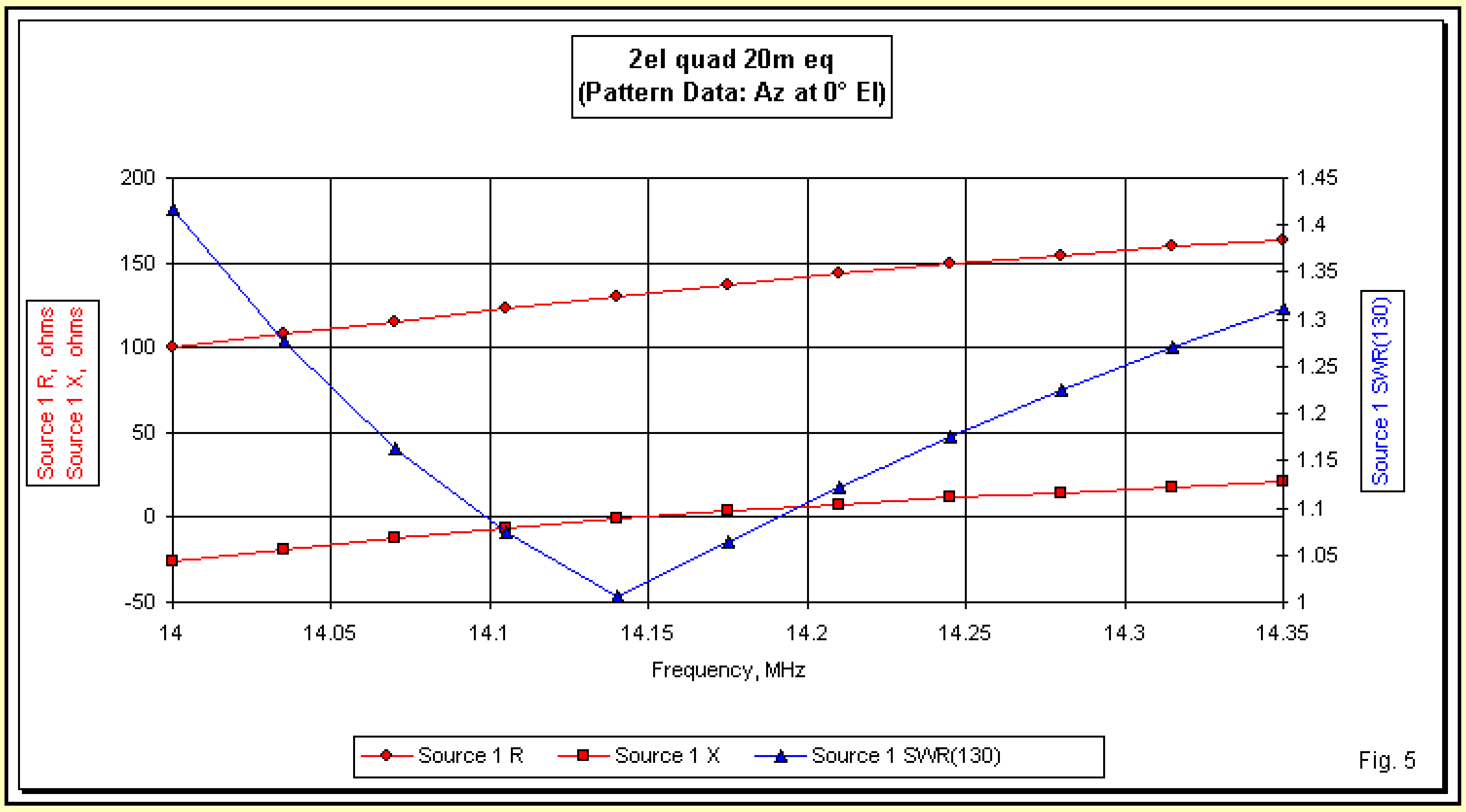


Fig. 5

The impedance curves in **Fig. 5** have a number of interesting features. The resistance and reactance curves almost parallel each other. Resistance rises about 64 Ohms across the band, while the reactance changes by about 47 Ohms. With AWG #14 wire on 20 meters, the resonant impedance is about 130 Ohms. Using this reference value, we can note that the SWR climbs more rapidly below the design frequency than above it. These features will repeat themselves in subsequent charts, especially for the wider bands.

17 Meters

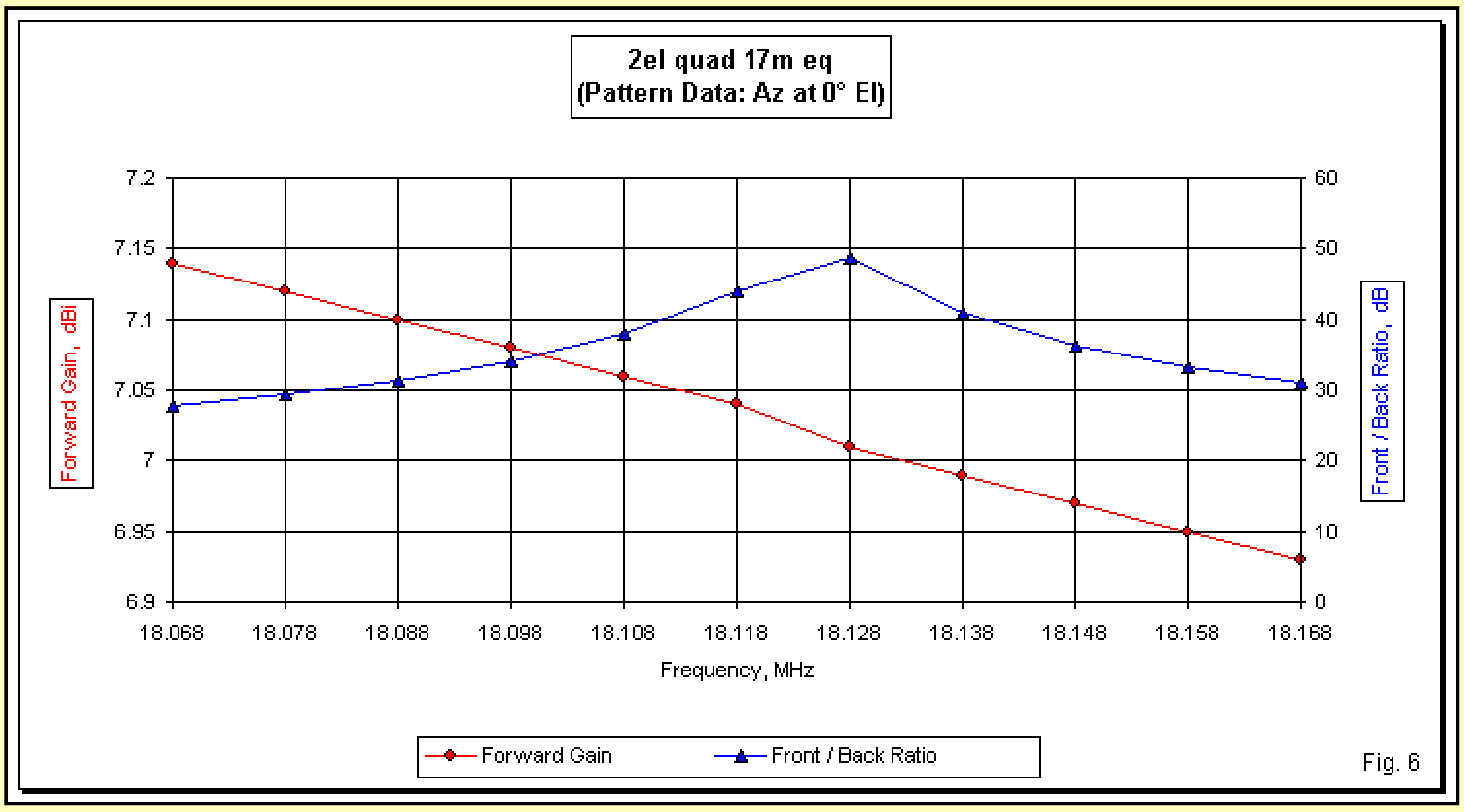


Fig. 6

The 17-meter band is only a bit over 1/2% wide. Therefore, we expect flatter gain and front-to-back curves than on the wider 20-meter band. **Fig. 6** does not disappoint us. The gain drop is only about 0.2 dB across the band. Because the graph spreads the smaller passband into 10 parts, the front-to-back curve appears flatter. However, it is every bit as steep as the 20-meter curve. However, the front-to-back value remains very high over the whole band, suggesting that the use of a 2-element quad may be well suited to the band.

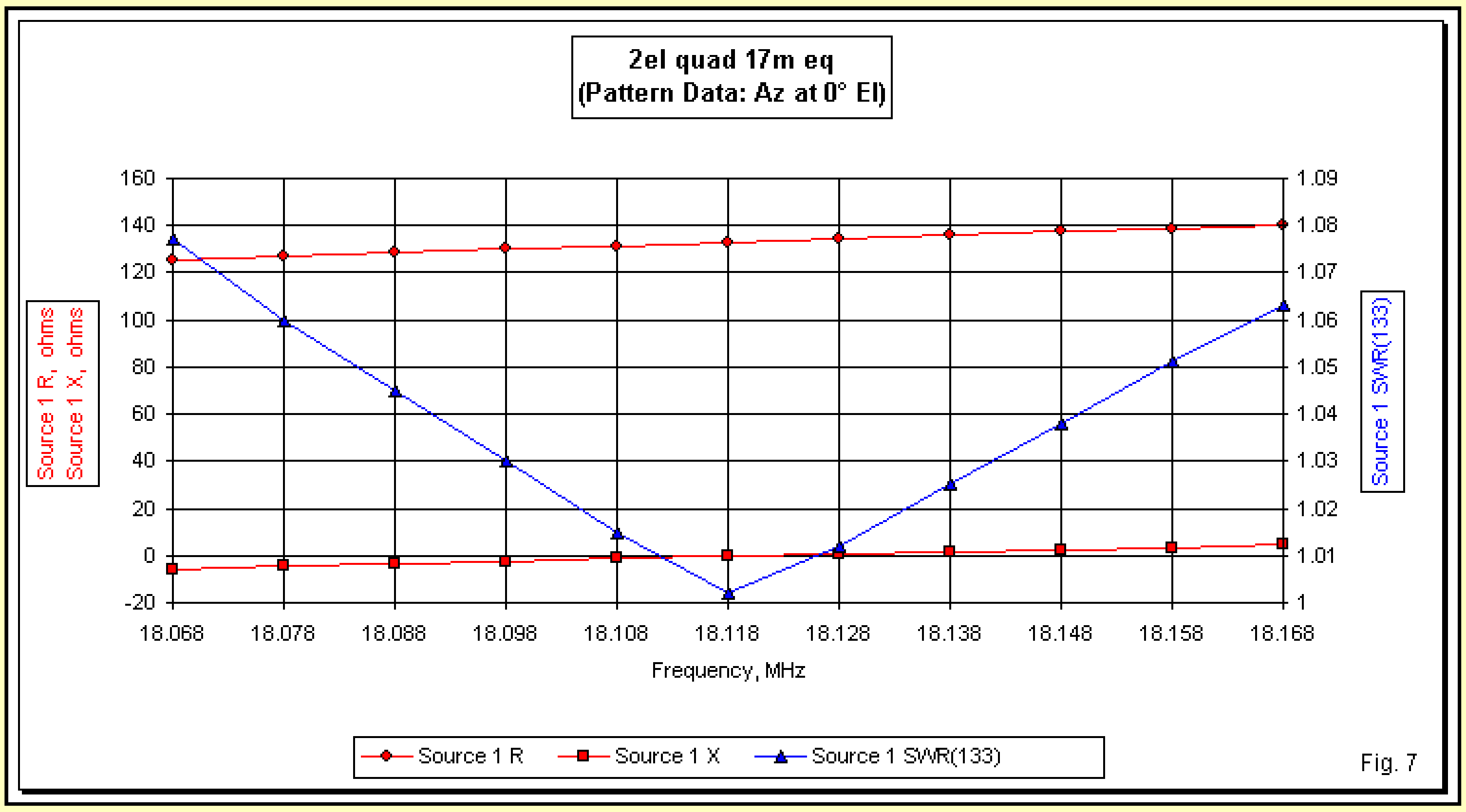


Fig. 7

Fig. 7 confirms the impression left by **Table 2** that the resistance, reactance, and 133-Ohm SWR are for all practical purposes flat across the band. Only automated graphing spreads the SWR values along the Y-axis. The spread is useful in showing that even over a narrow bandwidth, the SWR rises more rapidly below the design frequency than above it. In most cases, construction variables will result in greater SWR deviations than the changes shown in the graph.

15 Meters

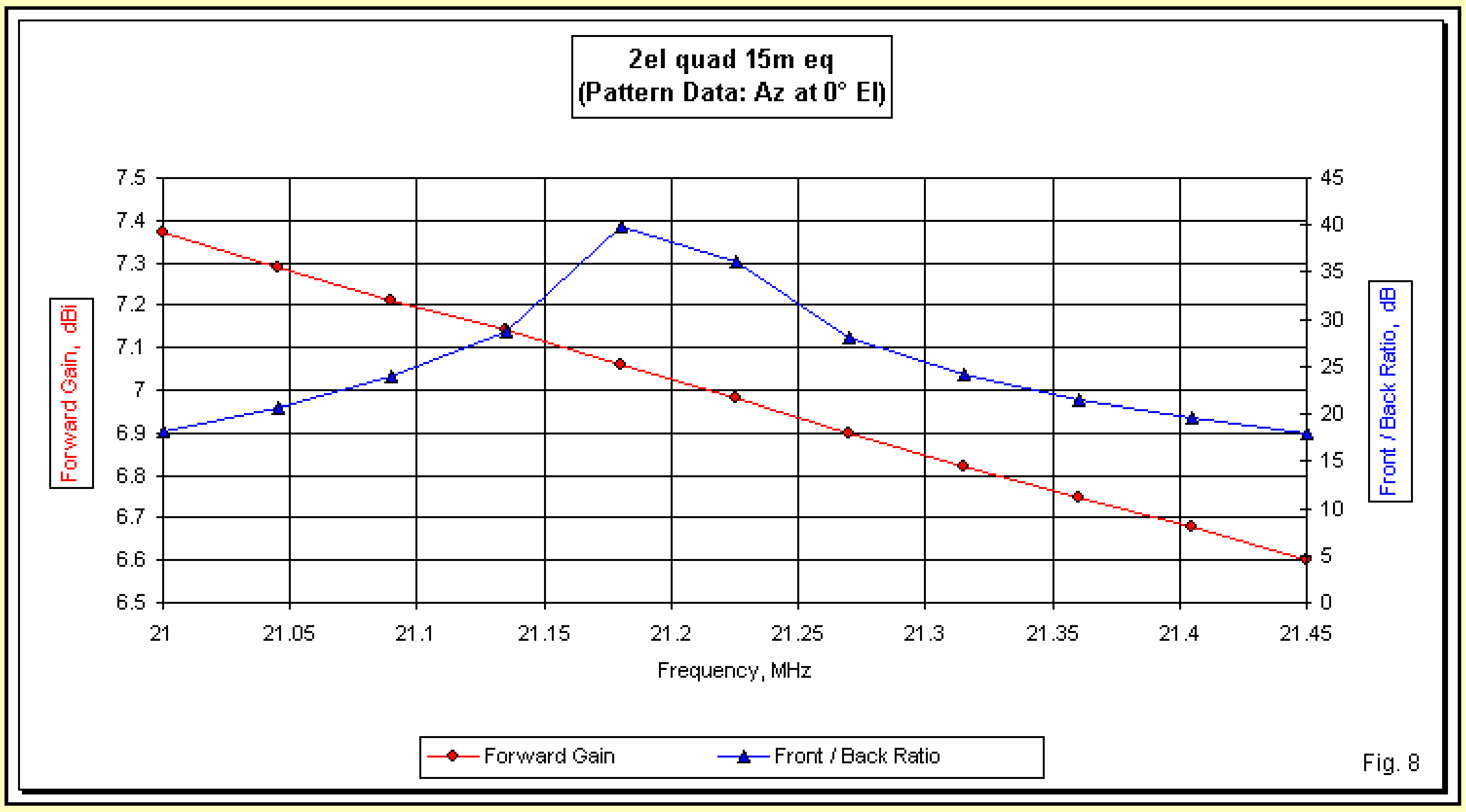


Fig. 8

15 meters returns us to a wider band, but not as wide as 20 meters when measured as a percentage of the band-center frequency. As shown in **Fig. 8**, the band is wide enough to replicate the 20-meter front-to-back pattern. Both bands show a more rapid decrease in the front-to-back value directly below the design frequency than directly above it. However, by the band edges, the ratio has dropped to about 18 dB on 15 (in contrast to about 16 dB on the slightly wider 20 meters where the wire is also slightly thinner as a fraction of a wavelength).

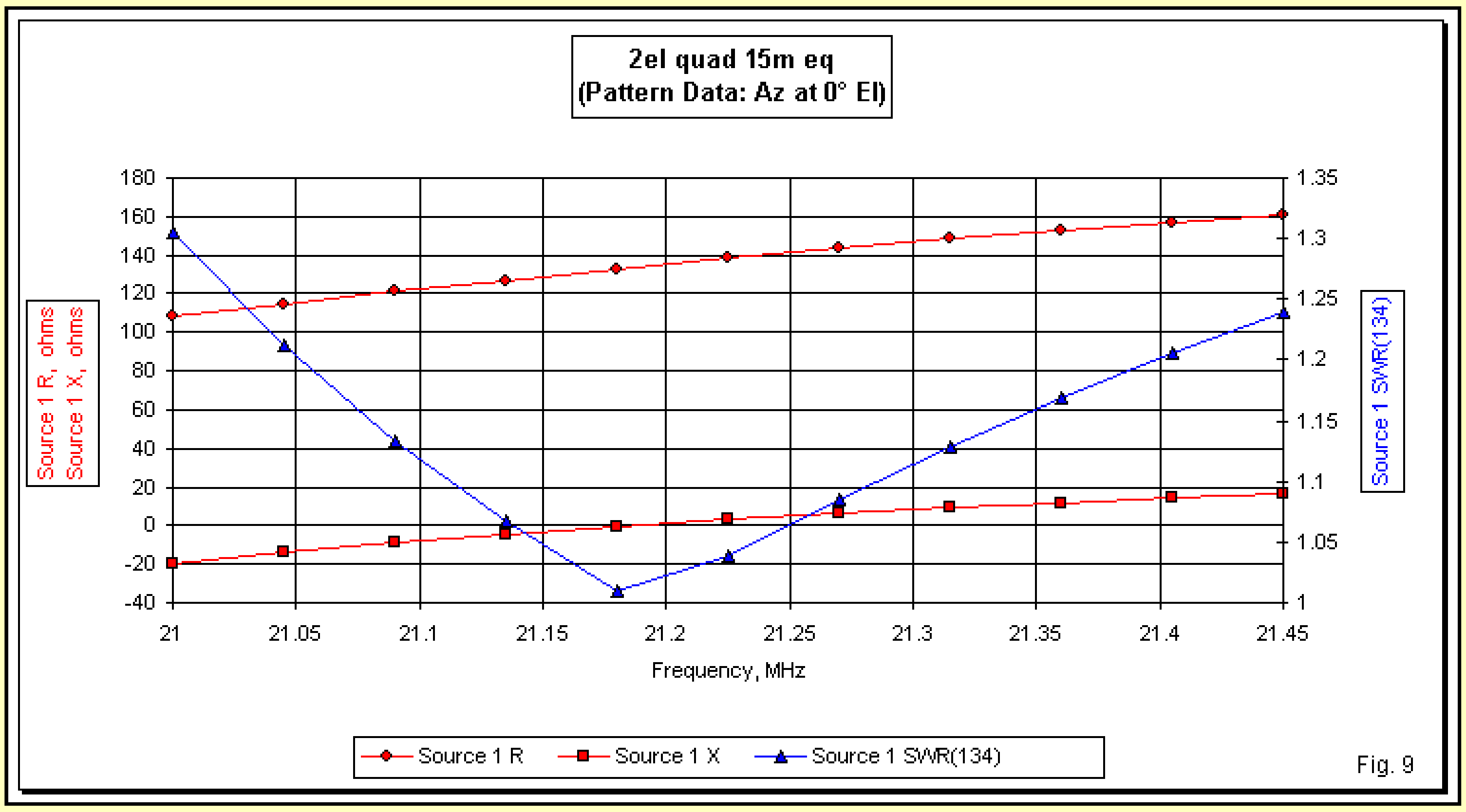


Fig. 9

As we might anticipate from the fact that 15 meters is slightly narrower than 20 meters, the range of resistance and reactance variation in **Fig. 9** is somewhat less than in **Fig. 5**. The resonant impedance is 134 Ohms. The "spooning" of the SWR curve results from the graph's use of 21.18 MHz as a sampling point, when the actual design frequency is 21.19 MHz.

12 Meters

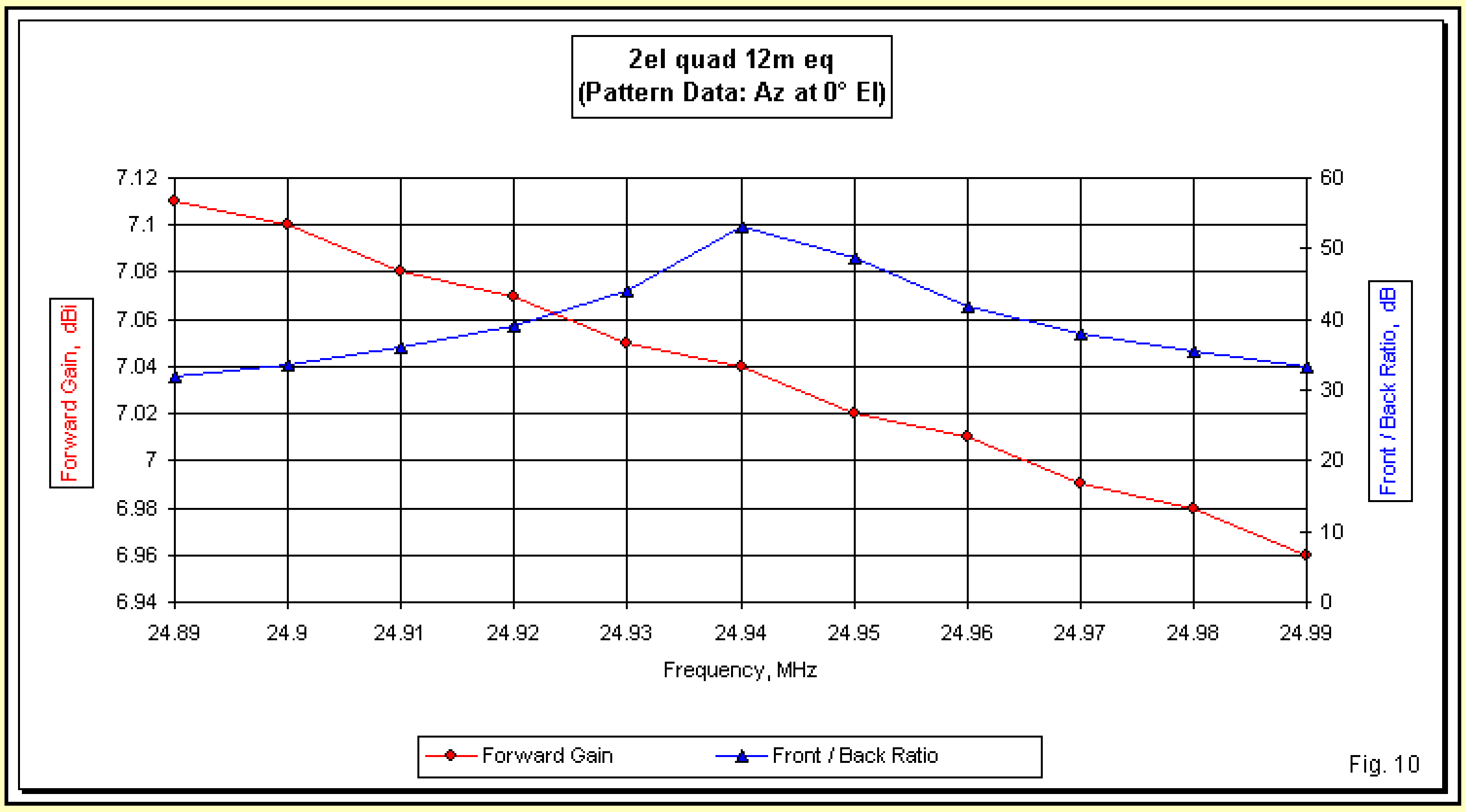


Fig. 10

12 meters is the narrowest of the upper-HF amateur bands, when we measure the passband as a percentage of the center frequency (24.94 MHz). Since the band is only 0.4% wide, graphs tend to have a stair-step quality due to the data, which is limited to 2 decimal places. Hence, the gain decrease across the band in **Fig. 10** appears somewhat uneven, since the total amount of change is only 0.15 dB. As well, the front-to-back ratio has room only to move slightly off of it peak value. However, if we had used a broader frequency scale, the front-to-back curve would closely resemble the corresponding curves for the wider bands.

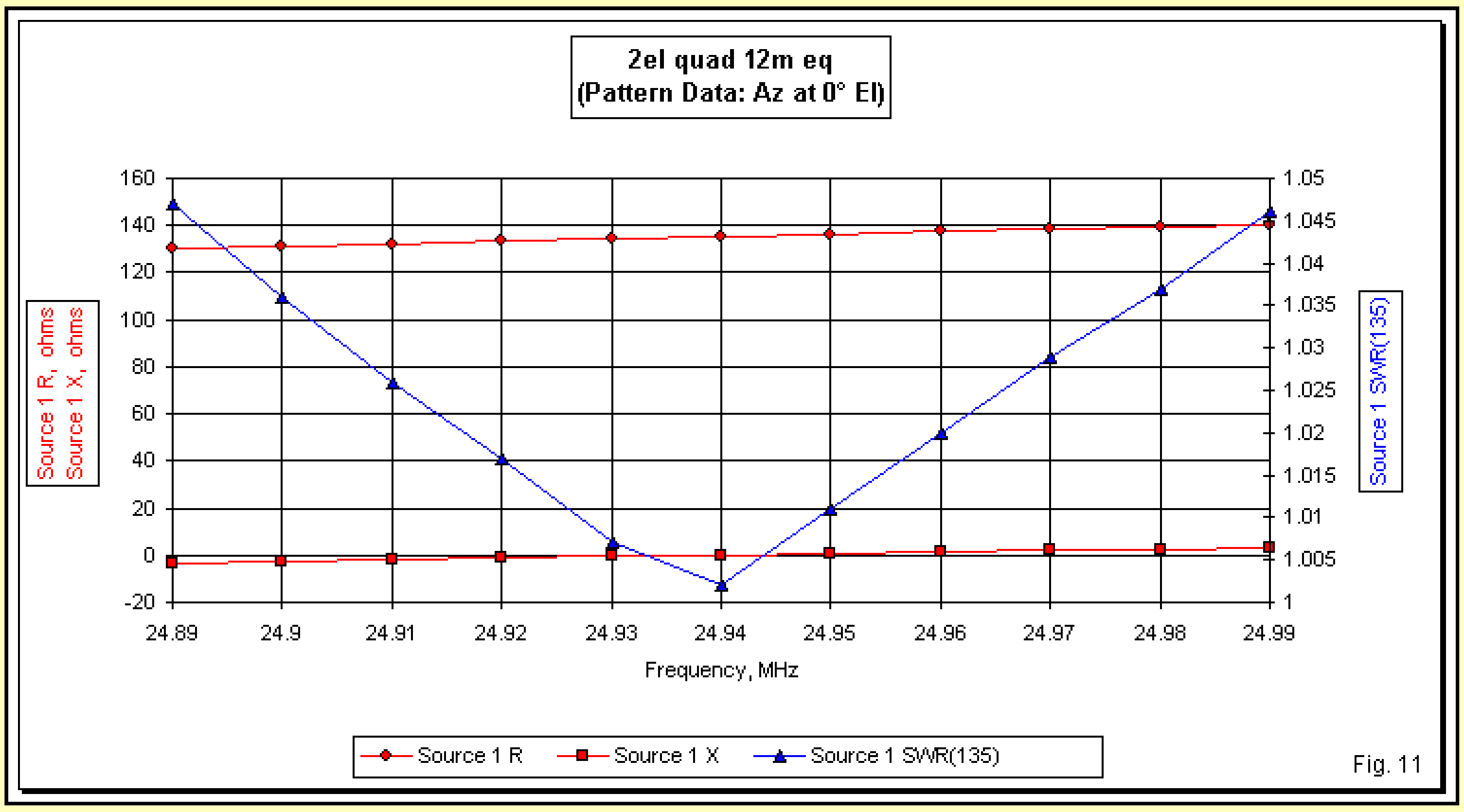


Fig. 11

The impedance curves in **Fig. 11**show barely any change in the resistance and reactance across the band. The resonant design-frequency resistance (135 Ohms) continues to rise as we move upward in frequency and the wire diameter grows when measured as a fraction of a wavelength. The SWR does not reach 1.05:1 within the band. Of course, construction variables suggest that a physical copy of this design might not show the perfection that we can easily obtain in the model.

10 Meters

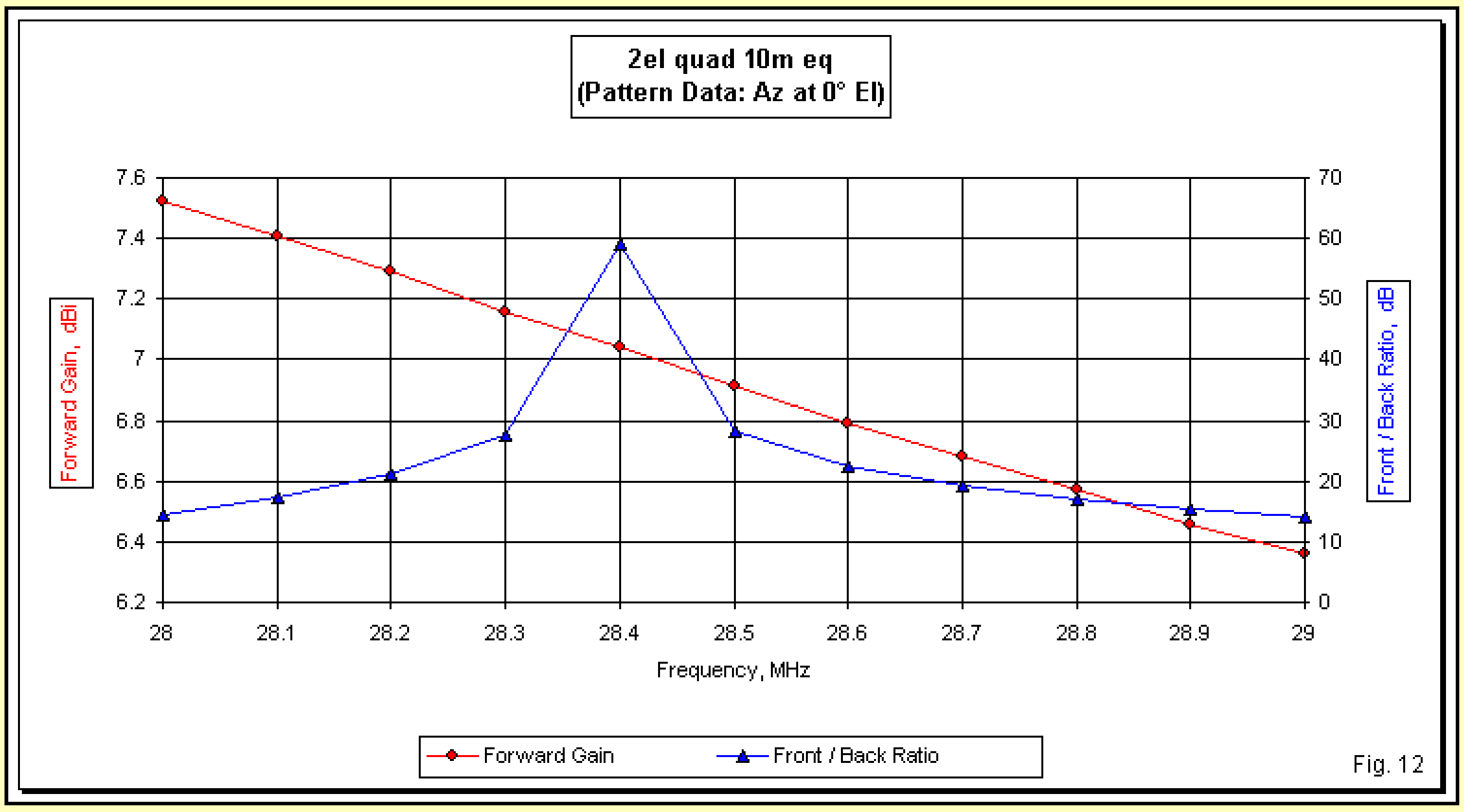


Fig. 12

With a bandwidth of about 3.5%, the first MHz of the amateur 10-meter band is the widest within our survey. Therefore, the gain shows the greatest range in **Fig. 12**. The 180-degree front-to-back ratio drops to a little over 14 dB at the prescribed band edges, even though its peak value is higher than on any other band. One usual marker of a high-performance array in amateur circles is a front-to-back ratio in excess of 20 dB. The 10-meter 2-element quad achieves this value for only about half the band (from 28.2 to 28.7 MHz). However, at the band edges, the front-to-back ratio is higher than we generally achieve with a 2-element driver-reflector Yagi.

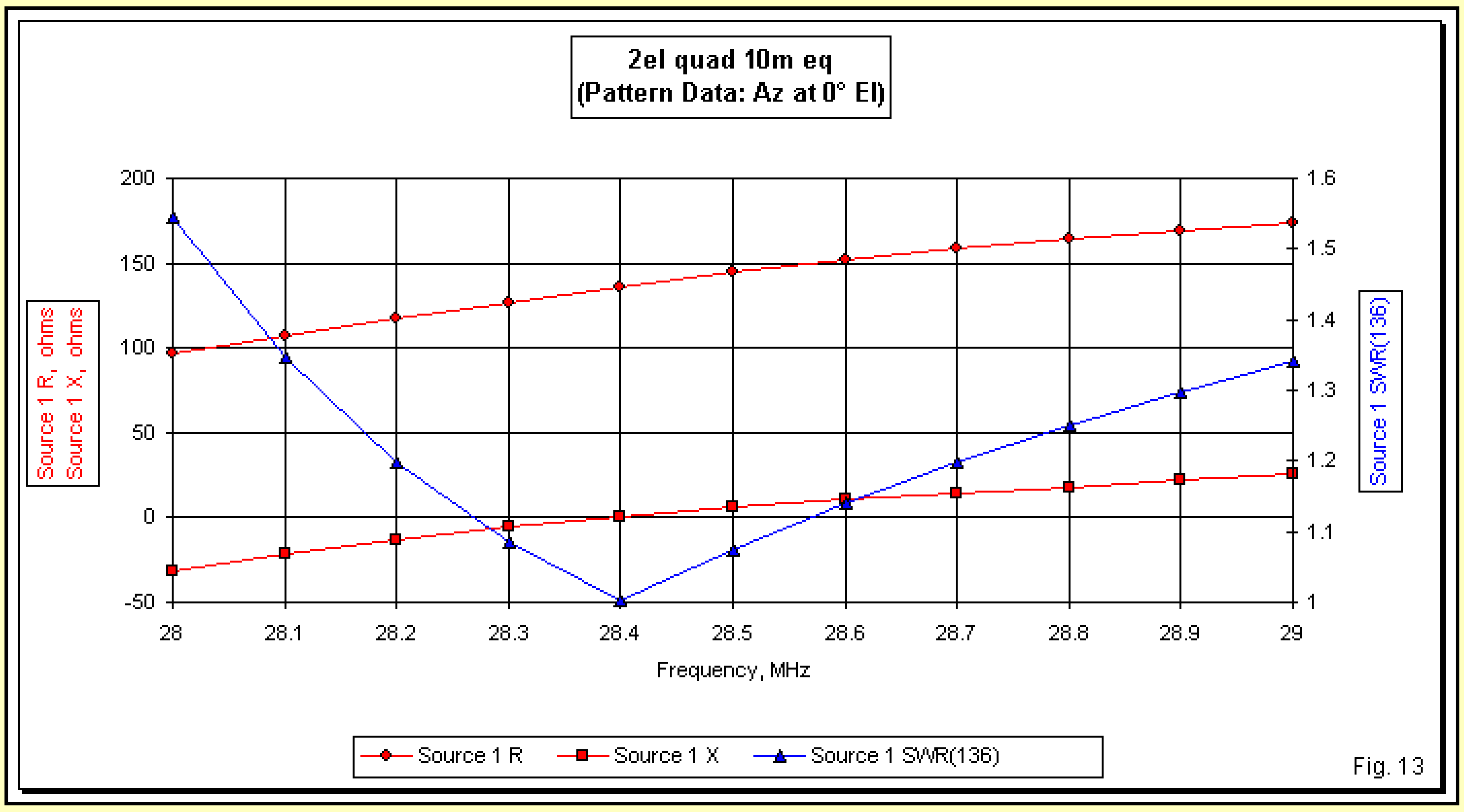


Fig. 13

I selected the design frequency to achieve approximately equal 180-degree front-to-back ratios at the band edges. As a consequence of this decision, the 136-Ohm SWR curve--while perfectly acceptable--does not result in equal values at the band edges, as shown in **Fig. 13**. However, a 2-element quad is a bit less sensitive to driver length changes than a 2-element Yagi. Therefore, we might change the driver length to equalize the band edge SWR value while leaving the reflector length to control the front-to-back peak frequency. However, significant changes in the driver length will require corresponding changes in the reflector.

The survey has included a collection of equation-designed monoband quad beams for each of the upper HF amateur bands. I have provided extensive information on the modeled performance curves in order to form a detailed baseline against which we can measure multi-band quads to come. However, before we leave the monobanders, we should address at least one or two practicalities. The first matter concerns construction. The models in this sequence presume that all support structures are non-conductive at the operating frequencies. The models also make square corners, although a very small curve at a physical corner to avoid wire crimping would create no operational problems. However, each corner attaches to a support arm. The method of fastening should involve only non-conductive hardware and other components. Metallic clamps, screws, and other fasteners--even if insulated from the element wire--can create 1-turn inductors that may detune the elements, especially since each such conductive fastener is multiplied by 4 for each element. The alternative to a wholly non-conductive fastening system is extensive field adjustment to restore the modeled conditions.

A second practicality involves feeding quads with feedpoint impedance levels that are considerably higher than standard coax feedline values. The most usual matching system is a simple 1/4-wavelength line using an intermediate characteristic impedance between the feedpoint impedance and the main feedline value. **Table 3** provides a sample table of the electrical length of 1/4-wavelength lines at each of the design frequencies. The physical length of the required line requires that we multiply the electrical length by the listed or (better) measured velocity factor of the actual line used. Coaxial cable velocity factors tend to range from about 0.66 to to about 0.80, depending on the dielectric material separating the center conductor from the braid.

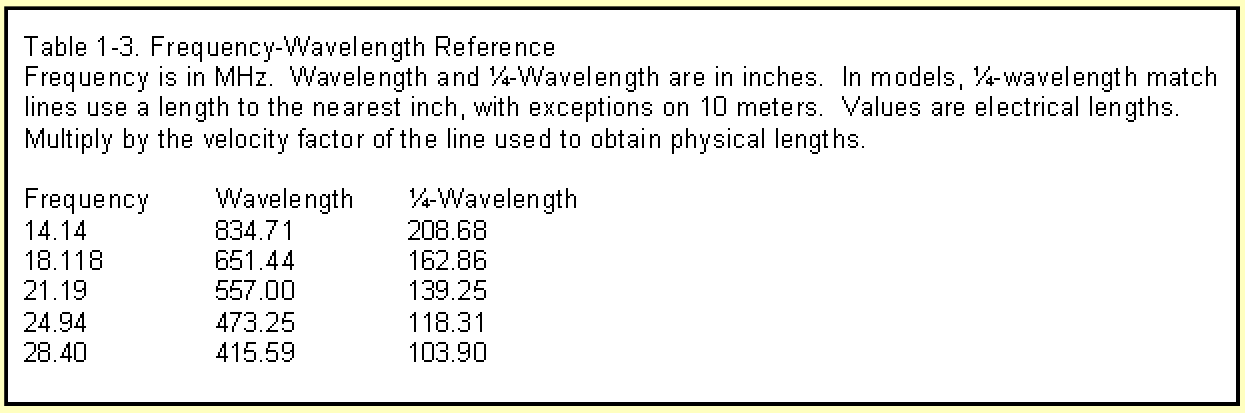
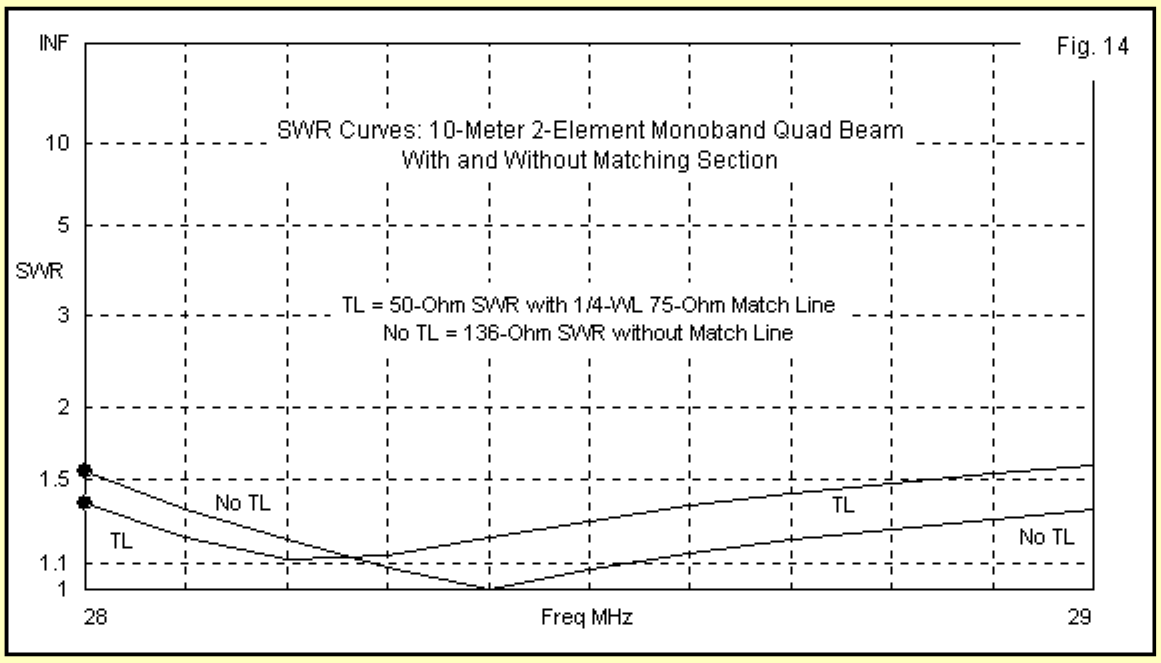


Table 1-3. Frequency-Wavelength Reference
Frequency is in MHz. Wavelength and ¼-Wavelength are in inches. In models, ¼-wavelength match lines use a length to the nearest inch, with exceptions on 10 meters. Values are electrical lengths. Multiply by the velocity factor of the line used to obtain physical lengths.

Frequency	Wavelength	¼-Wavelength
14.14	834.71	208.68
18.118	651.44	162.86
21.19	557.00	139.25
24.94	473.25	118.31
28.40	415.59	103.90

Ideally, the matching section characteristic impedance should be the geometric mean between the two terminal impedance values. We arrive at that value by taking the square root of the product of the terminal impedances. For the range of feedpoint impedances in our models and a presumed 50-Ohm main feedline, the ideal match line would have a characteristic impedance of about 80 to 82 Ohms. 75-Ohm line produces perfectly acceptable 50-Ohm SWR curves. **Fig. 14** shows the basic 10-meter SWR curve referenced to a 136-Ohm standard and a 50-Ohm SWR curve that results from using a 1/4-wavelength 75-Ohm match line. The values at any frequency differ, but the overall curve falls well within the range of acceptable SWR values. Remember that the matching system does not alter the antenna performance. Given the linear nature of the 1/4-wavelength match line, it does not add to the total feedline length and hence does not add any significant amount to line losses.



Conclusion to Part 1

We have changed the fundamental question that we pose to common-feedpoint multi-band quads. Instead of asking "Which kind of feed system is better?" we asked instead "What happens when we use a common feedpoint for a multi-band quad?" That simple change in question creates a large change in our approach to answers. Instead of directly modeling a common-feedpoint multi-band quad--and drawing all manner of conclusions that might raise more questions than they answer--we have spent the entirety of Part 1 laying a foundation for further steps in the exploration.

The monoband quads that we have examined--and to which we shall return continually--represent precisely designed 2-element quad beams having the widest operating bandwidth in all operating categories consistent with having a free-space design-frequency gain of at least 7 dBi. Each quad places the peak 180-degree front-to-back value and feedpoint resonance on the design frequency. For ease of future references, the design frequencies result in relatively equal front-to-back values at the upper and lower edges of the wider amateur bands.

As a practical matter, we may use any of the programs or models that encapsulate the equations derived from hand optimizing an entire system of quads in order to select a different design frequency. One reason for doing so might be to ensure having at least 20 dB of front-to-back ratio across a favored segment of one or another amateur band. The 2-element quad lends itself well to such operational choices. Indeed, if one only wishes to operate on a subsection of a wide amateur band, then one might even prefer other designs that sacrifice operating bandwidth for slightly more gain.

However, our goal is not to make such selections. Instead, I wish to establish a baseline that we can reliably use in assessing what happens when we attempt to construct multi-band quads. One criticism often leveled against multi-band quads--often based on experience with multi-band Yagis--is that the interaction between elements tends to narrow the operating bandwidth of the antenna on at least one of the bands involved. By starting with a wideband design, we may actually be able to evaluate that claim. As well, we may be able to determine whether the reduction--if actual--results from the basic multi-band process or from trying to use a common feedpoint. We may also note that the criticism that we have recorded is very non-specific in terms of naming which performance parameters might be subject to a narrowing bandwidth in a multi-band quad.

In one sense, then, we have not yet gotten anywhere in our quest to understand the effects of multi-banding quads and feeding the resulting beam. From a different perspective, we have laid a reasonable foundation for actually going some distance to answer our question. If our extended survey of monoband quad performance is the foundation, then the first floor of the multi-band quad edifice involves creating some quads using separate feedlines for each band. In that way, we may proceed with no shape distortion to any element.

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