2-Element Quads as a Function of Wire Diameter
Part 3: Fatter elements from "Mere Wire"

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In Part 1 of this series, I suggested that there might be a way to simulate large diameter elements in 2-element quads by using wire. The object was to allow the same performance as a thick tubular element without the very high increase in weight associated with such elements. Quad structures are rarely designed to handle anything but wire.

In this part, let's re-examine the reasons for wanting to use fat elements in our quads. Then let's perform a modeling test to see if we can get the simulation to work well.

Why a Fat-Element Quad?

The simplest way to get a handle on why fatter elements are beneficial to 2-element quads is to examine the performance of a couple of optimized designs. The design frequency will be 28.5 MHz. The design passband will be 28-29 MHz: we shall be interested in performance across that span, and not just at the design frequency.

The element diameters chosen are 0.0641" and 0.5". The thinner wire corresponds to #14 AWG copper wire, perhaps the most popular quad element material used in the US. The half-inch size is arbitrary, but sufficiently larger to show major performance differences--differences that can make a difference in operation across the designated passband.

Each beam was designed using the automated program presented in Part 2 of this series. The #14 version uses a spacing of 0.158 wl. The driver circumference is 1.012 wl long, while the reflector length is 1.071 wl. The design frequency resonant impedance is 136.1 Ohms. The 0.5" diameter version requires a spacing of 0.164 wl. The driver is 1.020 wl long, while the reflector is 1.103 wl long. The resonant impedance at the design frequency is 141.1 Ohms.

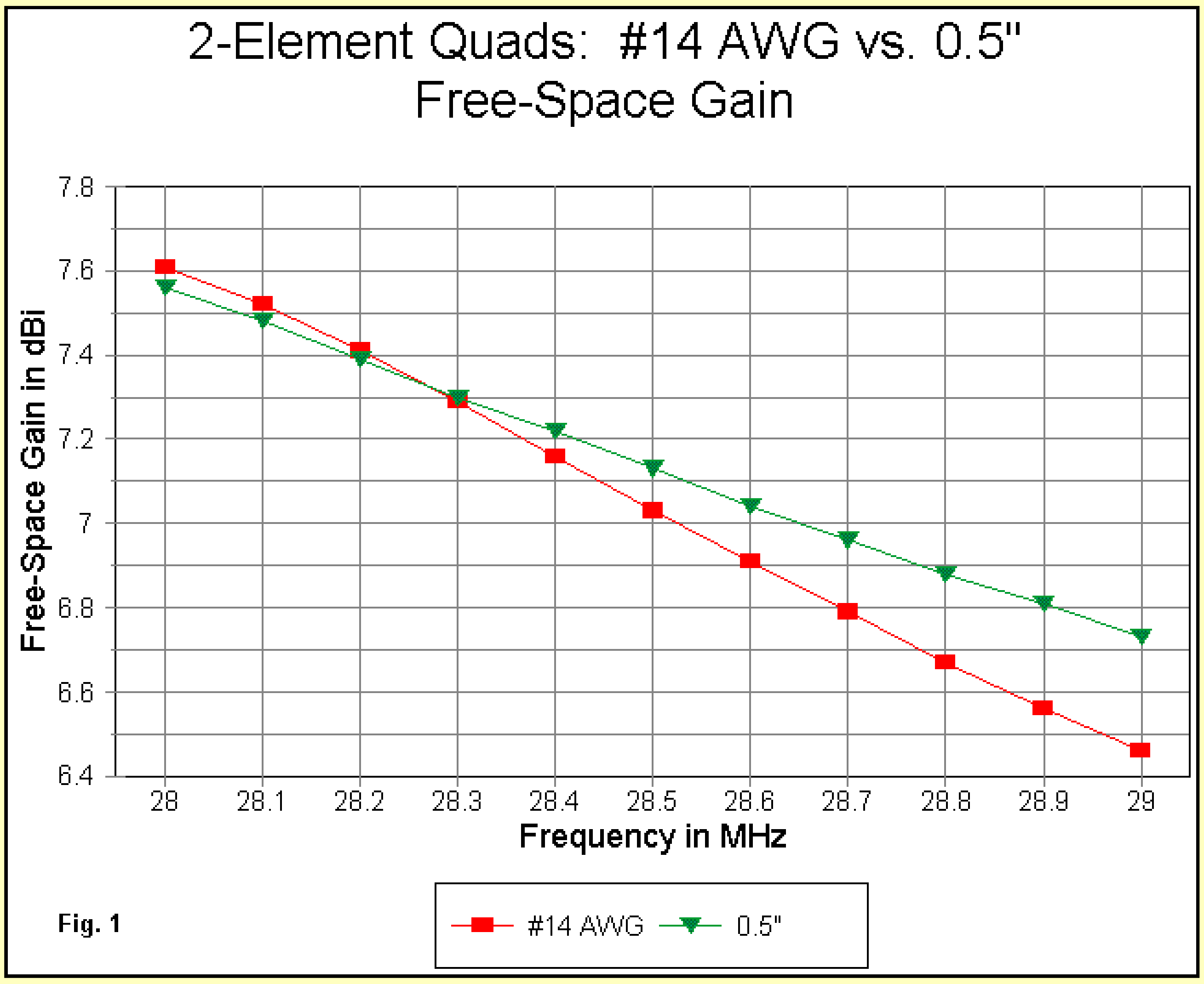

Fig. 1

Fig. 1 shows the gain curves for the two quads. As we have noted, the thinner the wire size for a 2-element quad, the closer in frequency are the maximum front-to-back and the maximum gain points. Hence, the #14 quad starts at a higher gain, being closer to the gain peak. However, the gain of the #14 version decreases more rapidly across the passband of interest in this exercise. In contrast, the 0.5" version has a lower rate of change across the band, which tends to even up gain performance between band edges. If gain were the only parameter in question, then there would likely be no reason to work with fatter elements. However, we should also look carefully at the front-to-back curve, shown in **Fig. 2**.

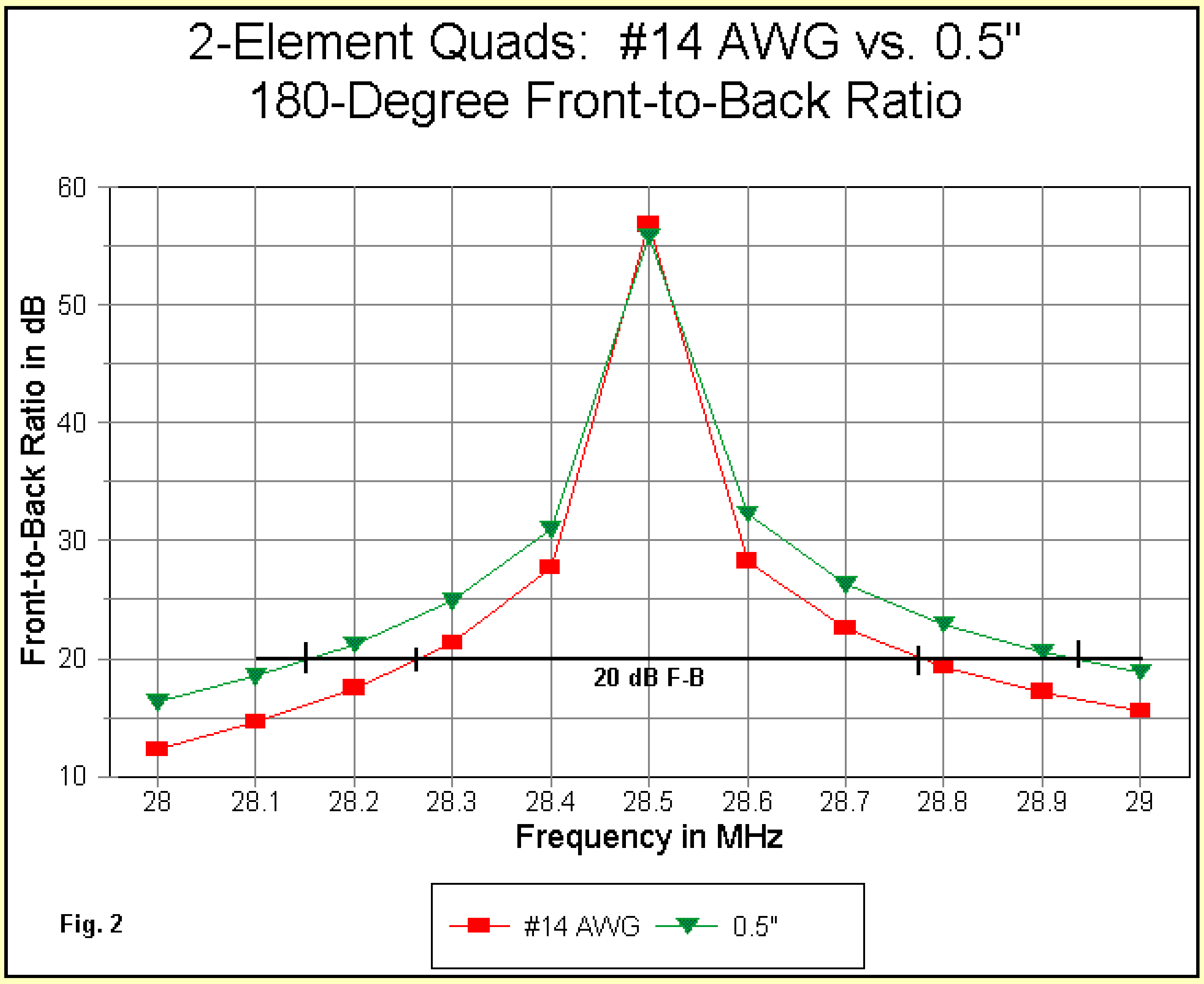

Fig. 2

It is tempting to focus on the front-to-back peak, which is the same for both antennas. However, of much greater importance is the front-to-back ratio toward the band edges. The front-to-back ratio of the #14 antenna is barely 12 dB at 28 MHz and 16 dB at 29 MHz. 20 dB front-to-back ratio is a common amateur standard. For the #14 version, we achieve this goal only between 28.26 and 28.78 MHz. In contrast, the 0.5" version of the antenna shows better than 20 dB front-to-back ratio between 28.15 and 28.94 MHz, a 50% improvement in bandwidth between the 20-dB markers. At 28 MHz, the 0.5" antenna improves the front-to-back ratio by 4 dB over the #14 version, while at 29 MHz, the improvement is 5 dB.

The operational improvements are sufficiently large to encourage us to try to obtain them. We may not want to go to exceptional lengths mechanically to acquire the improved performance, but if we could modify the standard quad support structure in minor ways, the modifications might be worth the work.

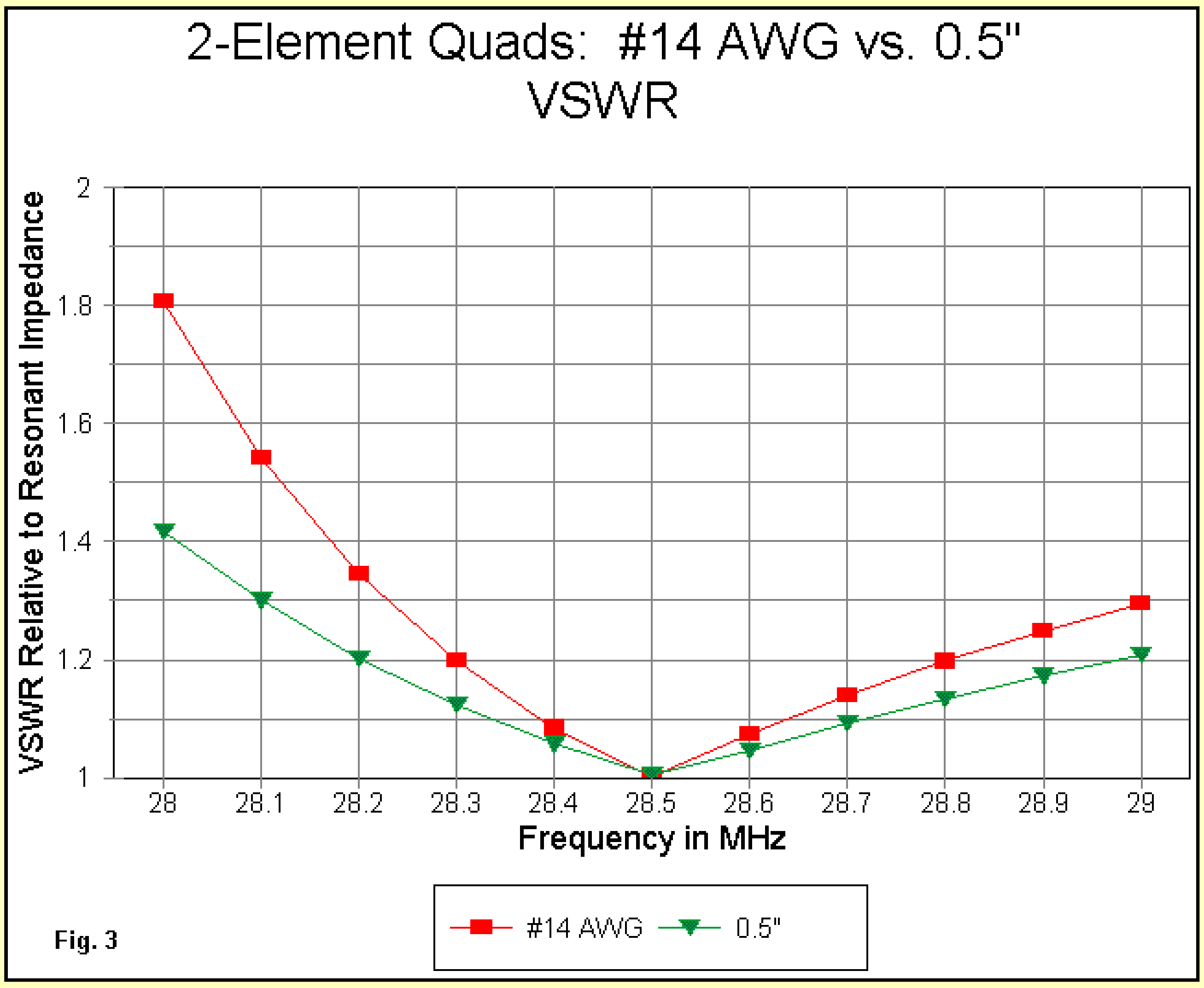

Fig. 3

To complete the record, **Fig. 3** shows the comparative SWR curves of the two antennas, each referenced to its own resonant feedpoint impedance. Once more, we see the more rapid increase in SWR below design frequency than above it. Since the SWR never reaches 2:1, we might be satisfied with either curve. However, for very long coax runs, the 0.5" curve is superior in reducing line losses.

How Can We Obtain Fat Element Performance from Wire?

For any fat element, we may construct an equivalent element from 2 wires spaced by a distance that is not at all arbitrary. When using relatively thin wire to simulate very thick elements, a three wire scheme may be required, but the transition from #14 to 0.5" on 10 meters is far from needing the added wire.

For linear elements, such as used in Yagis, the technique is simple. We may take each element and find its resonant frequency. Then we construct a wire pair (shorted at the ends and the center) of the same length as the tubular element. We adjust the spacing until we arrive at the same resonant frequency. For most simple arrays of linear elements, the spacing used for one element will generally suffice for all of them.

The dual wire element will have a higher material loss than the original tubular element, since its surface area is smaller. However, the performance of a parasitic array depends more upon the inter-element coupling than on material loss (within limits, of course). The dual wire element restores the level of coupling that is reduced in the move from a fat to a thin element. Hence, the modeled performance of Yagis using thick tubular elements and their dual wire equivalents is generally within 0.1 dB gain and indistinguishable with respect to the front-to-back ratio and the impedance curve. These factors apply not only to the design frequency, but as well across the passband.

For 2-element quads, with their closed element geometry, the construction of a 2-wire equivalent requires a different procedure--more of a trial and error technique. Constructing a 2-wire element for each of the quad's elements requires a trial spacing of the wires and then adjustment of the overall loop sizes to bring the antenna to resonance and to maximum front-to-back ratio at the design frequency. The feedpoint impedance at resonance is a good indicator that the wire spacing is correct: it should be about the same as the fat-element antenna being simulated.

There are two main ways to construct dual-wire elements, shown in **Fig. 4**.

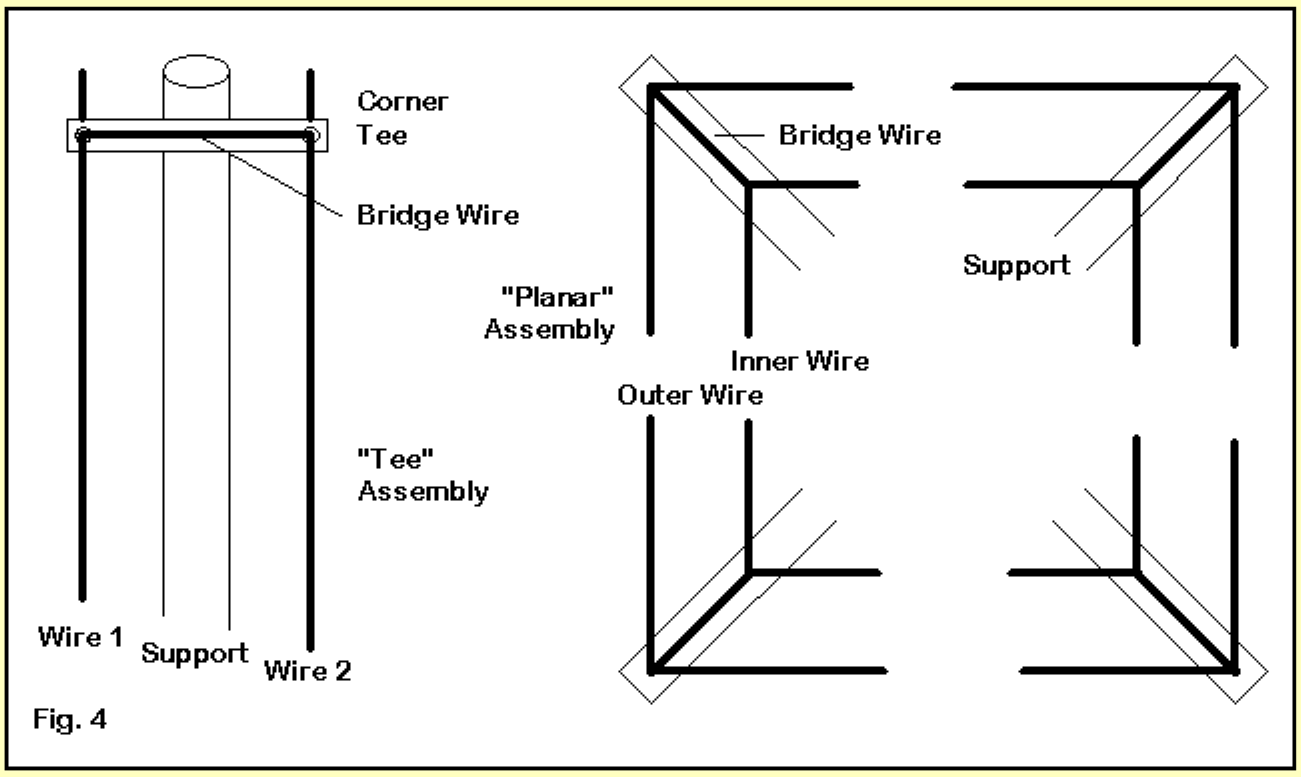

Fig. 4

One method, shown on the left, involves placing a cross-piece at the loop support point--a sort of Tee-configuration. Then, for each element, identical loops are built, spaced by the desired amount. At each corner (minimally), bridge wires between loops are required to ensure that each loop in the element has the same current distribution. The mid-point between loops in each element--where the support arm is--represents the point for measuring the spacing between elements.

The second method is to construct loops in the same plane. This method is illustrated on the right in **Fig. 4**. The two loops for each element will have different circumferences, one larger and one smaller than the reference length used to calculate them. Once more, bridge wires are necessary at the corners (at least) to ensure equal current distribution along the wires of each loop. In this planar construction method, each element is a constant distance from the other.

For our test antenna, I finally settled on a wire spacing of 5" for both the Tee and the planar models. To show what is necessary in quad element adjustment for the simulated fat elements, the following table may be useful.

Antenna	**#14 Single**	**0.5" Single**	**#14 Tee**	**#14 Planar**
Element Spacing	**0.158 wl**	**0.164 wl**	**0.164 wl**	**0.164 wl**
Driver Length	**1.012 wl**	**1.020 wl**	**1.003 wl**	**1.003 wl**
Refl. Length	**1.071 wl**	**1.103 wl**	**1.107 wl**	**1.107 wl**
Resonant Impedance	**136.1 Ohms**	**141.1 Ohms**	**142.1 Ohms**	**141.8 Ohms**

For the Tee configuration, the actual spacing is +/- 2.5" for each of the loops. For the planar configuration, the actual loop lengths are 4 x +/-2.5" for each loop. From the perspective of resonance and maximum front-to-back ratio at the design frequency, it makes no difference whether one uses the Tee or the planar configuration. The results are the same to 4 significant figures, with differences only in the 5th digit for numerical fussiness on my part.

More interesting at this point is the fact that each of the dual-wire antennas requires a smaller driver and a larger reflector than the 0.5" antenna which they simulate. In fact, the dual-wire driver is even smaller than that required for the more closely spaced single #14 antenna. Whether these loop size adjustments will affect performance remains to be seen.

Modeling dual wire elements involves great care. The 5" spacing at 10 meters presses the limits of NEC-2. To ensure equal current distribution in the driver, one must model a single wire of at least three segments, with the source placed at the center. Then, 1 segment wires move at right angles to the center feed wire to the required spacing limit. For 5" spacing, these wires were each 2.5" long. Since NEC prefers that wires meeting at angles have similar segment lengths, 2.5" became the standard segment length for the entire model. The planar model required different levels of segmentation for the inner and outer loops in order to keep the segment junctions parallel with each other. In the end, the models required between 645 and 670 segments. This level of segmentation still provided a large segment length to wire diameter ratio, also desirable for accuracy.

Even with such care, the NEC-2 models pressed the core limits for the close spacing of wires. Initial NEC-2 models showed a systematic 0.3 dB gain deficit relative to the 0.5" model. Applying the average gain test in NEC-Win Plus to all of the models produced values of 1.002 for both of the single wire models. However, the dual-wire models yield values 0.969. Values close to 1.000 indicate a precise model within the limits of the test (which is a necessary, but not a sufficient condition of model adequacy). For many general purposes, values as low as 0.96 and as high as 1.04 are considered very good. However, for correlating models, especially when one design is a proposed substitute for the other, the average gain test values were considered inadequate.

The models were reconstructed in NEC-4, which is, while not perfect, considerably better than NEC-2 with respect to close wire situations. Unfortunately, the average gain test was not available in the version of NEC-4 used. However, the gain deficit dropped to 0.1 dB. I suspect, but cannot prove, that the remaining deficit is a function of the core and not a real difference between antennas. (Proof will have to await the next generation of modeling cores.) Part of my suspicion arises from the fact that the dual wire models virtually eliminate material loss as a source of reduced gain. The single #14 wire quad has an efficiency of 97.9% as a function of wire composition, including skin effect. The 0.5" model has an efficiency of 99.7%. Both dial-wire antennas have efficiencies of 99.0%.

We shall look separately at the performance of the Tee and the planar versions of the dual-wire 2-element quad. The reason will become apparent before we are done.

The Dual-Wire Tee Model

Fig. 5 presents a sketch of the elements of the dual-wire quad in the Tee configuration (where "Tee" refers to the unseen supporting structure). The structure, including the feedpoint modeling, are apparent from the sketch.

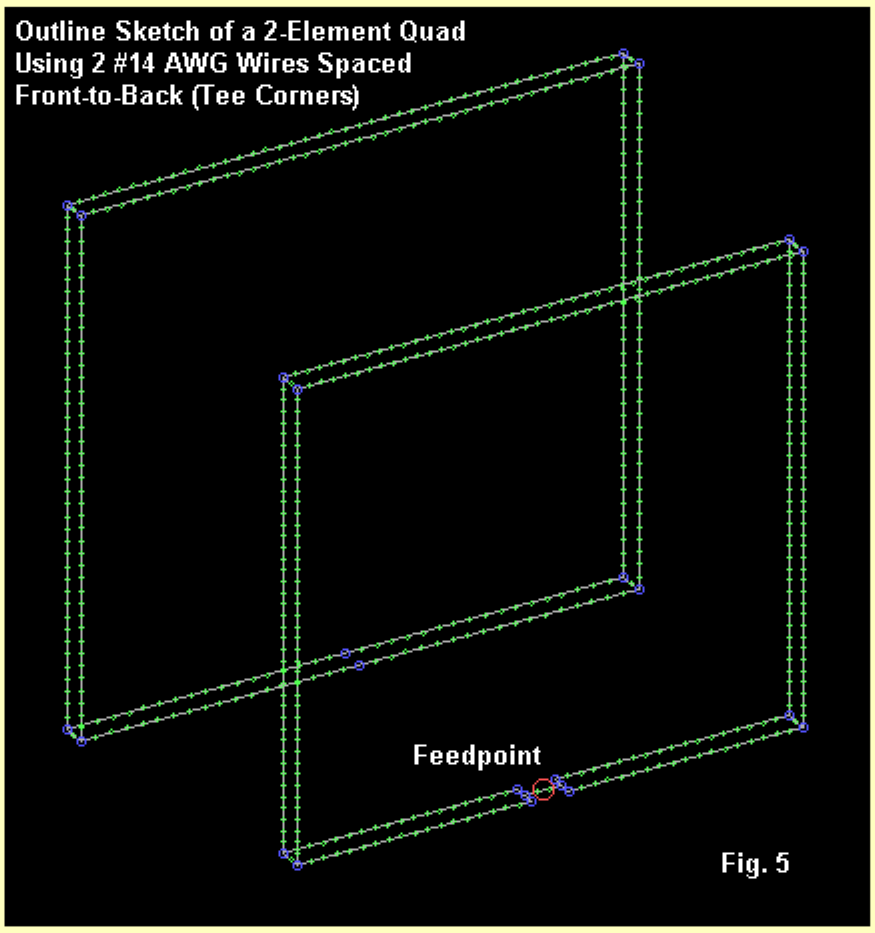
Outline Sketch of a 2-Element Quad
Using 2 #14 AWG Wires Spaced
Front-to-Back (Tee Corners)

Fig. 5

Since the SWR curve is relatively unimportant to the antenna's performance, we may by-pass that consideration and focus upon gain and front-to-back ratio, compared to the 0.5" antenna which the new version simulates.

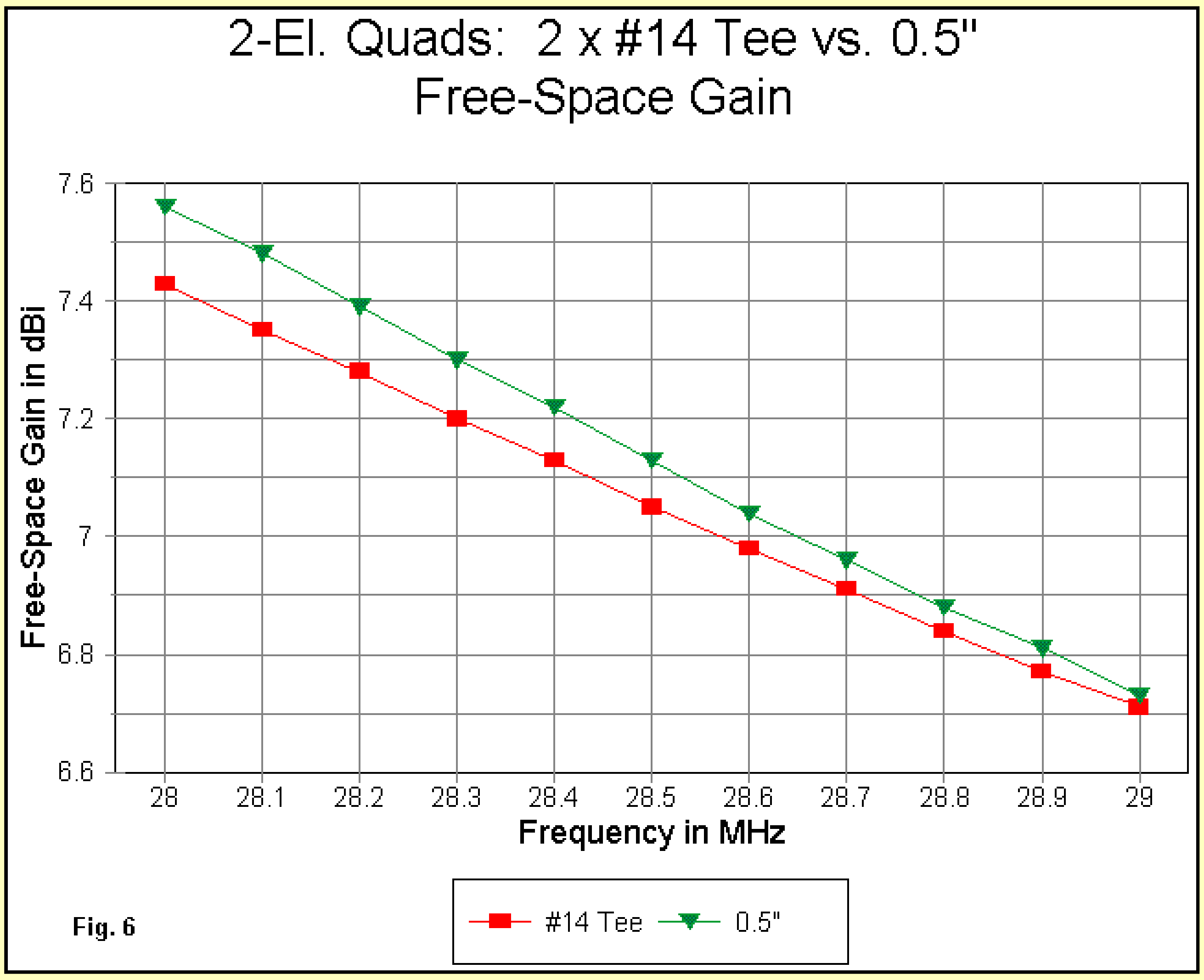
2-El. Quads: 2 x #14 Tee vs. 0.5"
Free-Space Gain

Fig. 6

Fig. 6 presents the gain curves across the first MHz of 10 meters for the 0.5" antenna and its counterpart. Of note is the NEC-4 deficit of about 0.1 dB average that we have previously noted. More important however is the shallower curve for the dual wire antenna. The lower rate of change in gain tends to indicate that the 5" spacing between wires is actually simulating a wire somewhat fatter than 0.5".

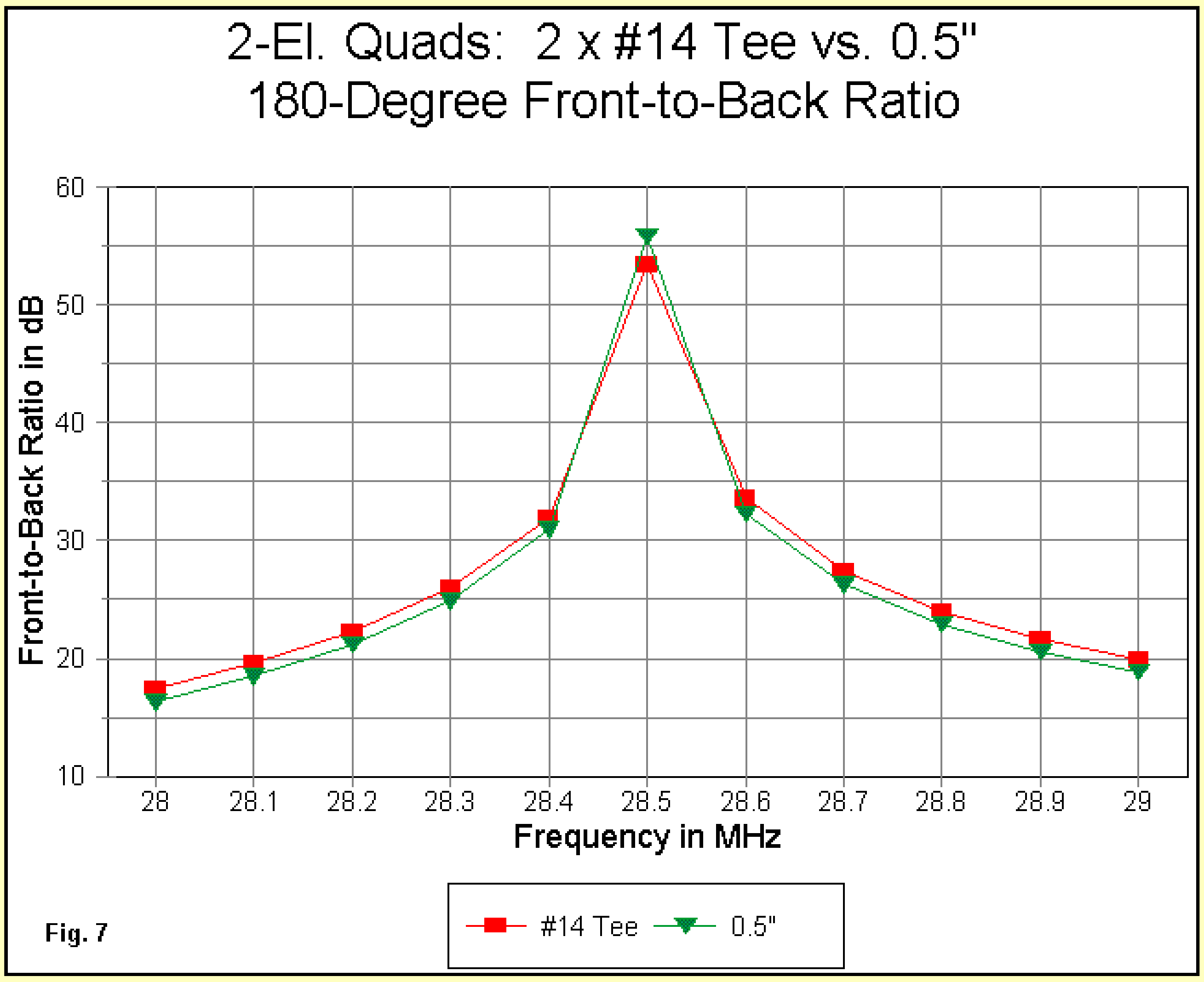

Fig. 7

The impression given by the gain curve in **Fig. 6** is confirmed in the front-to-back curve in **Fig. 7**. The dual-wire version of the antenna actually increases the passband for better than 20 dB front-to-back ratio from 28.1 to 29.0 MHz. This operating bandwidth is not a function of the very slightly lower peak front-to-back ratio at the design frequency. That difference only indicates that the 0.5" curve is better centered at 28.5 MHz.

With respect to gain and front-to-back ratio, then, there is little to choose between the dual thin-wire and the single fat wire models.

The Dual-Wire Planar Model

The model construction of the planar configuration of the dual-wire quad appears in **Fig. 8**. The construction of an actual planar antenna using the dual wire technique should parallel the model closely, especially with respect to the use of bridge wires and the feedpoint area of the driver.

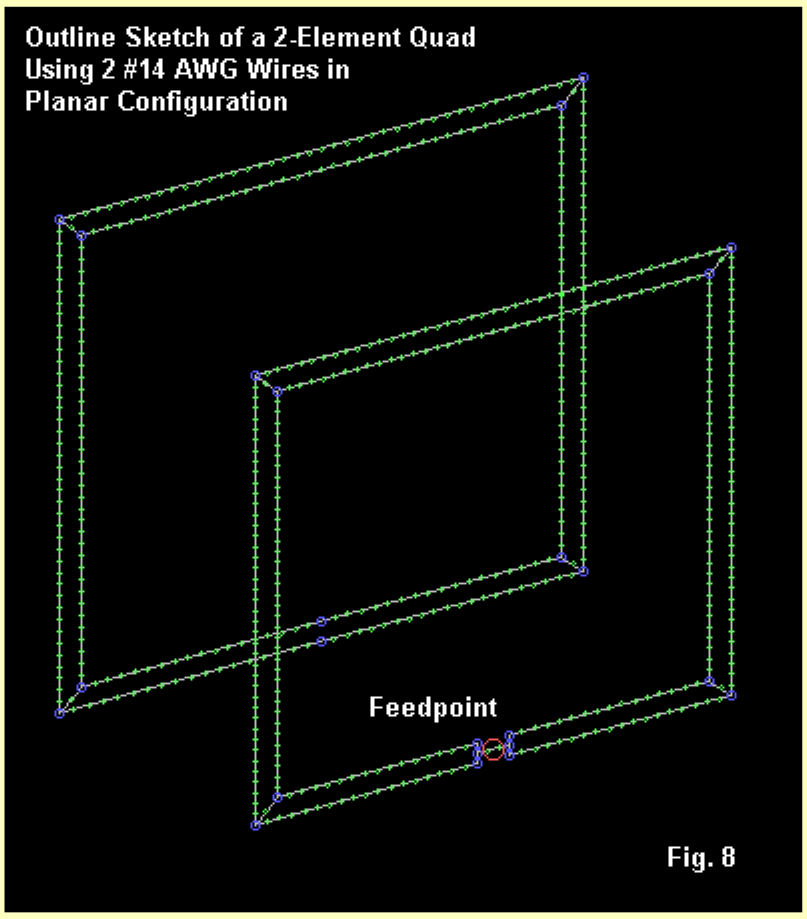

Fig. 8

Once more, we shall by-pass the SWR curves and focus our attention on gain and front-to-back performance bandwidths.

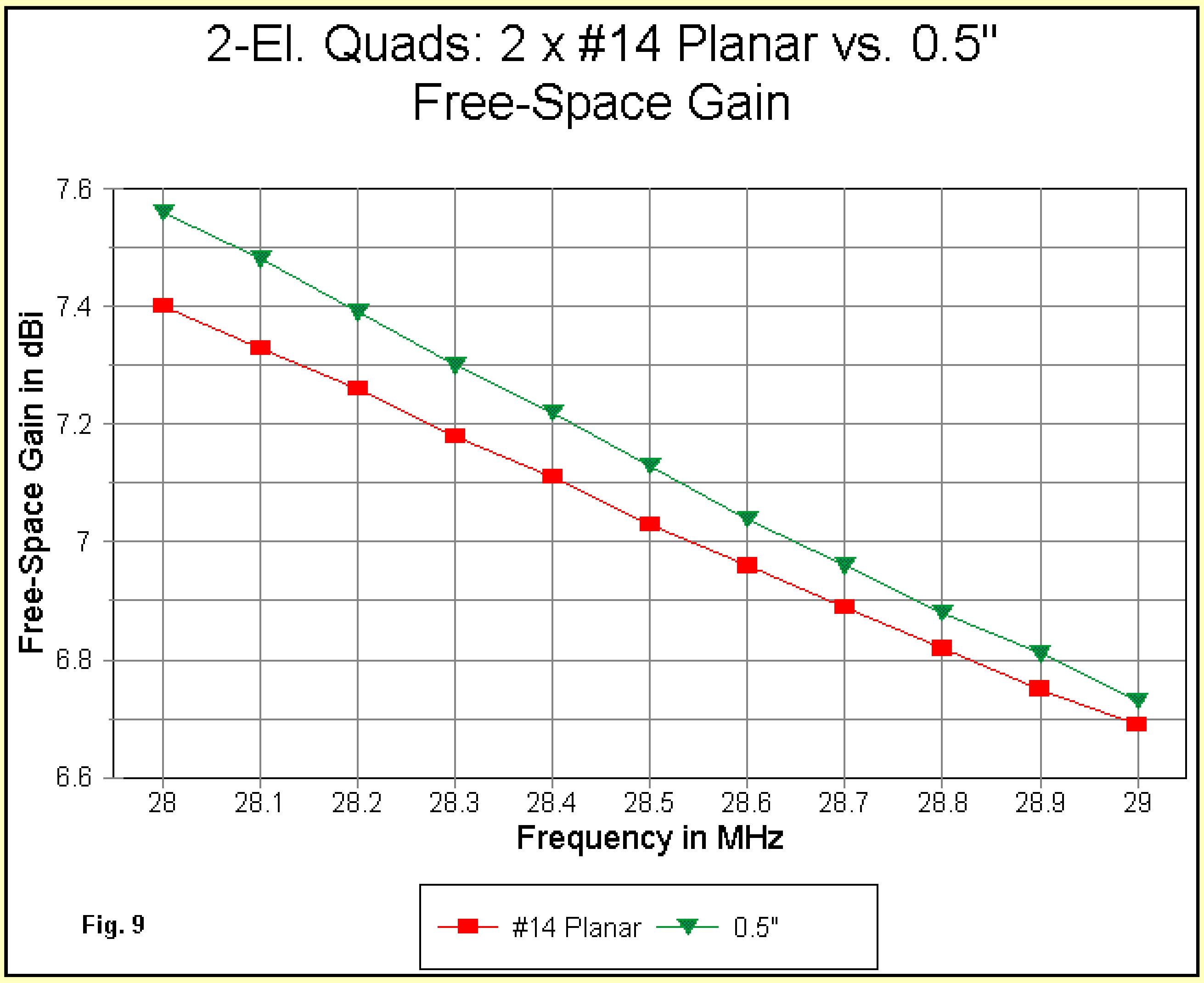

Fig. 9

Fig. 9 shows the gain curves of the planar model and the 0.5" standard. The planar model shows the same tendency toward a shallower rate of gain decrease across the band than the single 0.5" element model. Interestingly, the planar model begins 0.03 dB lower than the Tee model at 28 MHz, but ends up at the same gain value at 29 MHz.

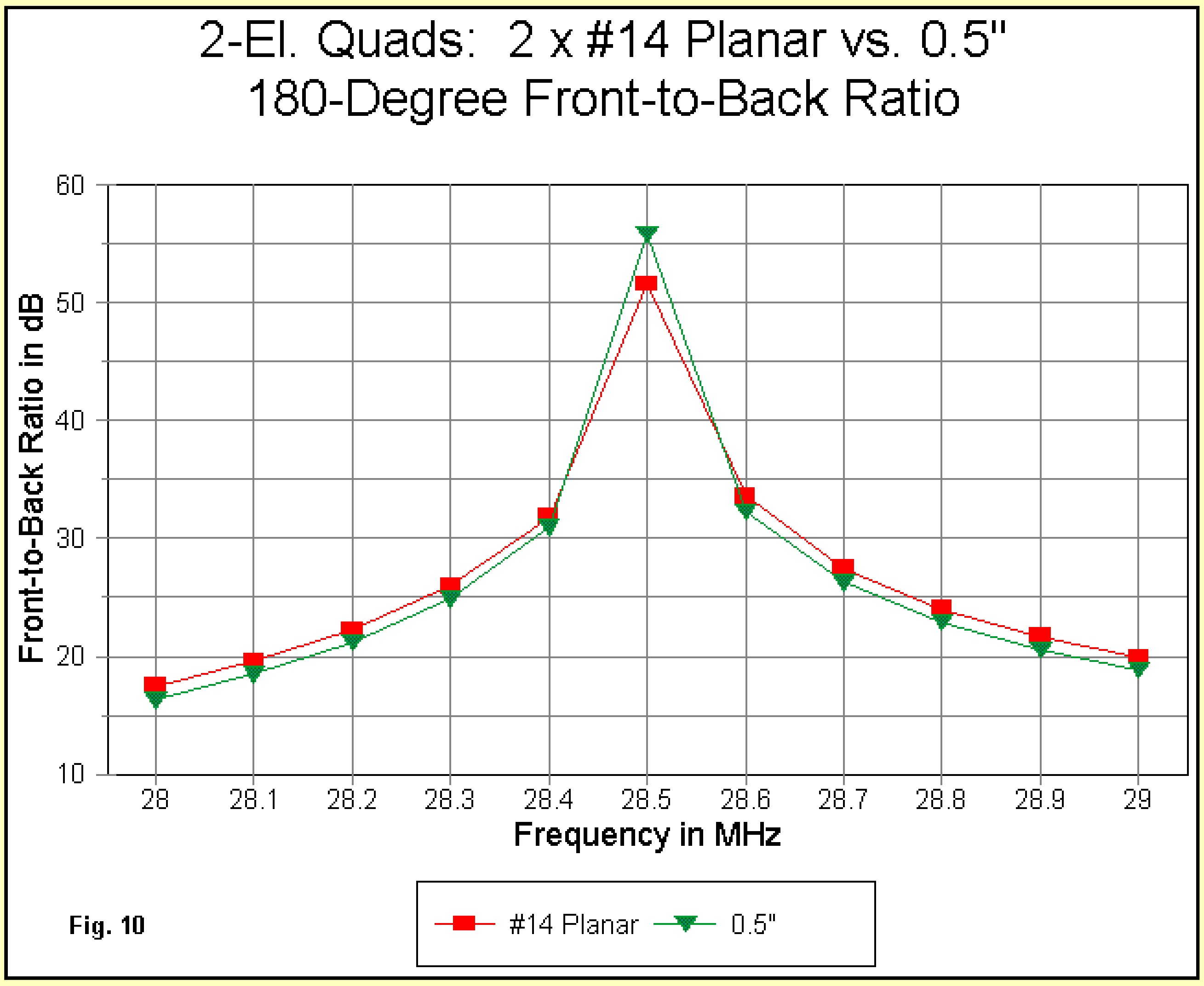

Fig. 10

The front-to-back curve in **Fig. 10** shows the same performance spread as the equivalent curve for the Tee--a 28.1 to 29 MHz passband for better than 20 dB front-to-back ratio. By now, it should be apparent why I have presented the Tee and planar curves separately: placed on the same graph, we could not see one through the other.

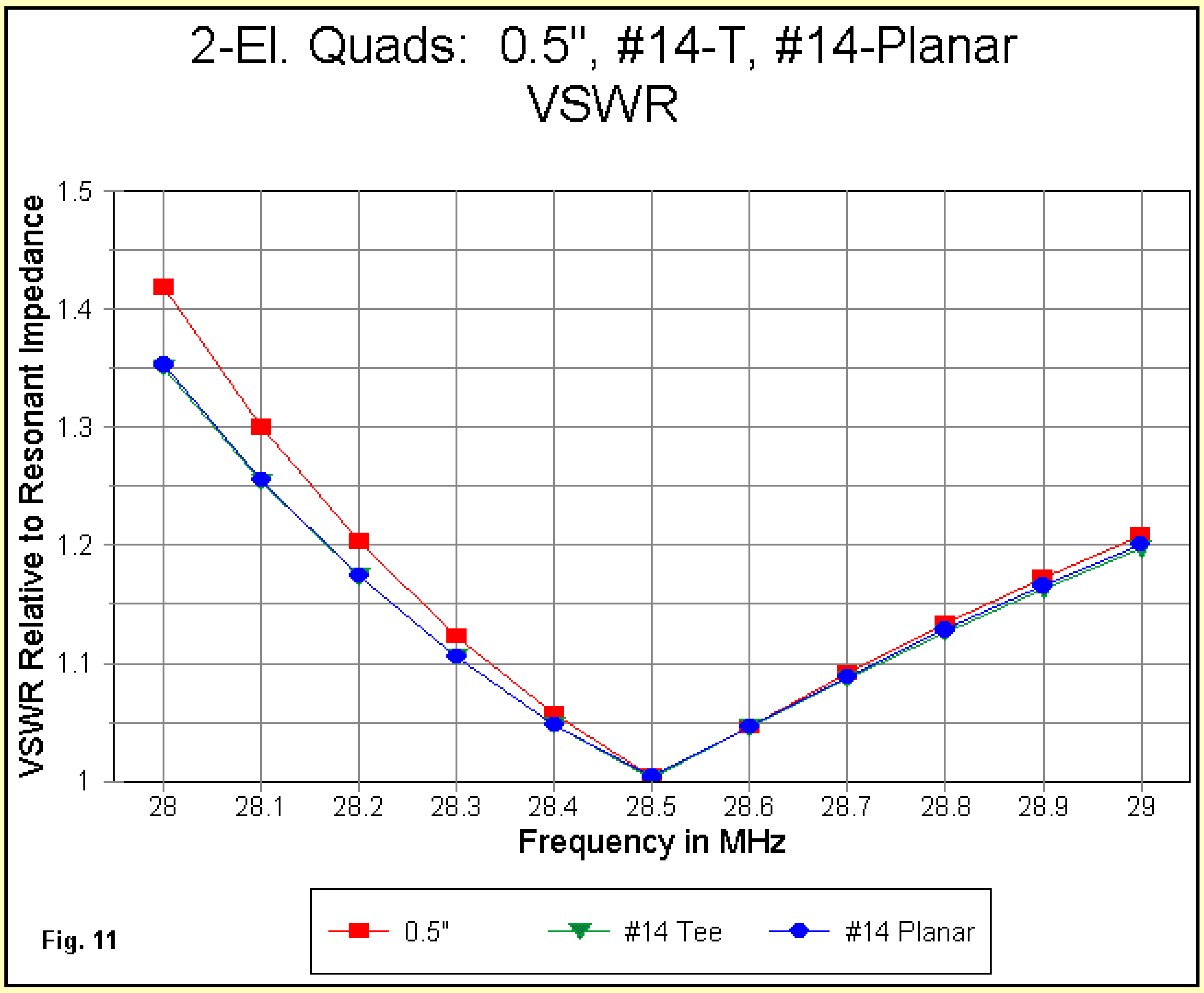

Fig. 11

To illustrate the point, **Fig. 11** presents the SWR curves for both dual-wire antennas, along with the curve for the 0.5" model. The Tee and planar curves overlie each other so closely that they are indistinguishable. In fact, for every operating parameter about which we might have concerns, the two versions of the dual-wire antenna are indistinguishable. Moreover, the curves also suggest one more time that the dual-wire antennas are of broader operating bandwidth in every important way than the 0.5" model for which they are a substitute.

Finding the exact spacing to be a precise substitute for the 0.5" element model would have been an exercise in unwarranted fussiness. 5" is a nice round number and convenient for modeling. #12 AWG wire (.0808" diameter) would have yielded a different dual-wire spacing for the same equivalence to a 0.5" single element. However, the more likely course of further experimentation should be to find the spacing (in easy-to-handle numbers) that yields a true minimum front-to-back ratio of 20 dB across the entire 1 MHz span of 10 meters.

The present exercise has been aimed at establishing the principles of dual-wire simulation of fat-wire elements in the optimized 2-element quad. I suspect that the wider bandwidth of performance with the 5" spacing suggests that a slightly wider element spacing might show further gains. However, that increase would be of the order of 0.001 wl for a total spacing of 0.165 wl at the design frequency. Such differences would likely be lost in the variables of actual antenna construction.

More significant to antenna construction are the physical consideration of choosing the planar or Tee models. Initially, the planar version seems more appealing, since it requires fewer parts. There is no need for fixing the Tee support to the main support arm. The absence of any significant difference between the Tee and planar model performance suggests that the planar model would perform equally well on either of the two main types of quad construction: the use of a spider hub and slanting support arms or the use of a boom with flat-plane support arm structures. The only possible deficit for the planar model is the need to have loops for each element that have different circumferences.

With proper construction, the dual-wire antennas--especially the planar model--can strengthen the overall assembly for each element by providing dual tensioning of the arms relative to each other. However, by using 2 wires for each element (relative to a narrow banded single #14 wire), we have increased the available wire for ice and snow loading. How the strengthening and the loading potentials balance, one cannot say in the abstract.

The dual-wire technique is not restricted to monoband 2-element quads. It is adaptable to 3-band and 5-band quads. I would suspect that single wire elements would satisfy the needs of the narrower bands--17 and 12 meters. However, the use of dual wire techniques might overcome the fall-off of performance on the wider bands--20, 15, and 10 meters. As well, the inherently wider SWR curve for the dual-wire configuration might overcome some of the interaction between bands that makes a shallow SWR curve difficult to obtain on some bands in some multi-band designs.

The key to a good multi-band 2-element quad employing dual-wire techniques for the wider bands lies in the balance of the support arm strength and the potential for winter loading. The wire weight would be about 60% greater than for single wire designs, with an equal increase in surface area. Hence, before tackling such a task, one would do well to assess the adequacy of the support structure.

In addition, the design of a multi-band 2-element quad using dual wire elements for some bands requires a total redesign of the elements relative to conventional values. Not only must the wire spacing be selected so that the coverage on each band meets design specifications, but as well, the driver and loop sizes must be refigured for the element spacing selected--along with the spacing between elements.

The design task is far from simple. However, it is feasible and may be one way to bring quad design from the 1960s into the new millennium. There is no good reason why quads should not enjoy the same high front-to-back ratios across the ham bands as the Yagis with which they compete.

An Additional Note on Dual-Wire Gain

The matter of the gain deficit that appeared in NEC-2 models of the dual-wire wider-band 2-element quads continued to disturb me. Even though the final deficit was small in NEC-4 models, I still wondered if there was a way of rebuilding the dual-wire models to eliminate any question of whether the deficit was real or a product of core limitations.

I rebuilt the planar model in the following way: I eliminated the driven element section for the feedpoint and ran both wires continuously from corner to corner. I then placed a source at the center of each lower driver wire to simulate a parallel feed of the two loops. The resulting model could use fewer segments, since the minimum segment size was now about 5" to keep the segment junctions parallel between the inner and outer loops of each element. Slight adjustments of driver and reflector brought the model to the optimal conditions of resonance and maximum front-to-back value. The Average Gain Test in NEC-2 registered 0.9996, a value considered to indicate a highly accurate model.

The resulting frequency sweep with the model on both NEC-2 and NEC-4 yielded an average gain differential of 0.025 dB between cores. At 28.5 MHz, the NEC-2 dual wire model gain is now within 0.06 dB of the 0.5" single wire model. There are no significant differences in the front-to-back and the SWR curves.

The following table summarizes the differences between the original and the alternative models at the design frequency. NEC-2 performance figures are shown.

Model	**Original Planar**	**Alternate Planar**	**0.5"**
Free-space gain	**6.92 dBi**	**7.07 dBi**	**7.13 dBi**
Max. front-to-back	**51.56 dB**	**49.44 dB**	**55.82 dB**
Feedpoint impedance	**141.8 + j0.5 Ohms**	**141.7 - j0.2**	**141.1 - j0.5 Ohms**
Driver Length	**1.003 wl**	**1.015 wl**	**1.020 wl**
Reflector Length	**1.107 wl**	**1.108 wl**	**1.103 wl**
Spacing	**0.164 wl**	**0.164 wl**	**0.164 wl**

The differential in reflector length is under 0.1% and makes no difference in operation. The driver length difference between the original and alternate models is about 1.2%, but falls within the range of field adjustments, since the builder may wish to alter the frequency of resonance within the passband. The feedpoint impedances are identical well-beyond any possibility of measuring a difference.

The disadvantage of using the alternate model is the requirement to calculate the parallel combination of series R+/-jX impedances for the two loops. However, the simplification of the model, the higher AGT rating, and the far better agreement with NEC-4 models all recommend the alternative. The alternative technique also holds some promise of allowing dual wire versions of long boom quad models, since the segmentation per loop is halved relative to the original planar model.

Of course, the alternative model tends to confirm my suspicion that there is no significant gain difference--even minusculely--between the dual-wire quads and the 0.5" single element quad.

Go to Quad List

Go to Main Index