A Diamond Jubilee

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Diamonds are (or can be) a ham's best friend. In the VHF and UHF ranges, they offer a many-faceted potential for antennas that are sturdy, potentially compact, and broad banded, with high performance for their size. Once we learn a few of their secrets, they also prove to be relatively easy to field adjust. Moreover, we can design them for a direct 50-Ω feed to ease fussing with matching networks. Finally, they will prove to be equally effective in vertical and horizontal service. They do not replace the long-boom Yagi, but they do have a definite place in the repertoire of amateur antennas.

In the following notes, we shall look at a few diamond basics, beginning with circles and advancing to strings of 4 diamonds. We shall examine questions such as what shape they should be, how many we should use, and what diameter elements are usable. We shall also see how height affects their performance. Of course, the simple diamond—whether a solitaire or a bracelet—is a bi-directional antenna. We shall examine the use of both parasitic and planar reflectors to arrive at a directional beam with some interesting properties that may prove useful.

In the past, I have had occasion to look at diamonds from various perspectives. Unfortunately, the test frequencies for those efforts have been scattered across the spectrum. Therefore, many readers have had some difficulty in drawing the material together into a cohesive whole. As a partial remedy, these notes will use a standard frequency of 299.7925 MHz, where 1 m = 1 λ, so that any design is scaleable to any desired frequency. In the NEC-4 models, I shall use lossless wire. In the VHF/UHF range, the normal element diameter is an appreciable percentage of a wavelength and the differences in performance between lossless wire and real copper and aluminum is well under 1%.

Our celebration of diamonds has one shadow. Over the years, I have received requests to create some algorithms that might simplify the design of diamond antennas. There are both physical and modeling limitations that prevent me from optimizing diamonds to this level. We shall examine a few of the constraints along the way. However, with the data provided here, the more rabid experimenter may find an entry into the field of diamonds a bit friendlier than before.

Diamond Basics

The diamond is a variant of the resonant 1-λ closed-loop antenna element. Although not used until such loops had been well established, the most basic form for such loops is the circle. In the realm of symmetrical loops, the circle has the highest gain—about 0.3 dB higher than comparable squared loops—and the highest feedpoint impedance—about 140 Ω at resonance. We may devolve the circle down to a much more common square form, as shown in **Fig. 1**. At HF, as well as higher, the square has proven to be the most practical loop shape. Most quad beams use this shape. We may use the square with two wires parallel to the ground or with the entire form shifted 45° to form what I shall call the diamond quad. To maintain either polarization, we shift the feedpoint as we tilt the square loop. Hence, we feed at the bottom (or the top) for horizontal polarization and on the side for vertical polarization. Whether we feed the loop at the center of a side or at a corner, the resonant impedance is close to 125 Ω.

In fact, the 1-λ loop element is actually two ½-λ dipoles fed in phase and curved or bent to join at the low-current, high-voltage ends. The effective distance between the high-current regions of the two dipoles is about ¼-λ. Hence, the typical square quad loop gives us about 3.3 dBi free-space gain compared the to 2.15-dBi figure used for ideal dipoles. We can increase gain very slightly by feeding each dipole in phase. Perhaps it is also useful to remember that a closed loop radiates broadside to the plane of the loop. This holds true for loop lengths between about 0.75-λ to about 1.5-λ. Smaller and larger loop sizes revert to a dominant edge radiation pattern.

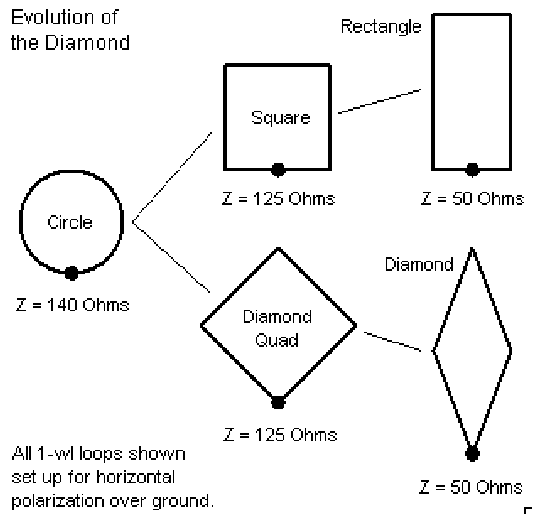


Fig. 1

Antenna builders have long known that we can stretch the square into a rectangle with 2 desirable results. First, we reduce the feedpoint impedance down to (and past) 50 Ω. Second, up to a certain stretching limit, we increase the loop's gain. Since the loop consists of 2 dipoles in phase, the closer they come to being ½-λ apart, the higher the gain that we achieve. Of course, we hit a limit, when the feedpoint wire and its opposing counterpart are too short to radiate effectively with the desired polarization. The exact point varies with the wire diameter and composition, as shown by such rectangle enthusiasts as Dan Handelsman, N2DT. By limiting ourselves to a 50-Ω feedpoint, we shall not hit the limit, but we shall increase the antenna's free-space bi-directional gain to the 4-dBi region.

What applies to the rectangle also applies to the diamond. By stretching the diamond quad loop into a true diamond, we increase the gain and lower the feedpoint impedance to a manageable value, such as 50 Ω. My selection of 50 Ω as a standard feedpoint impedance for this exercise is not based on any theory. In selecting it, we may deny ourselves a bit of performance that is theoretically possible. But, my experience suggests that many antenna builders set aside designs with odd impedances (except for Yagis that use a gamma match). The diamond deserves a better fate than such instant divorce.

1. The Single Diamond Element

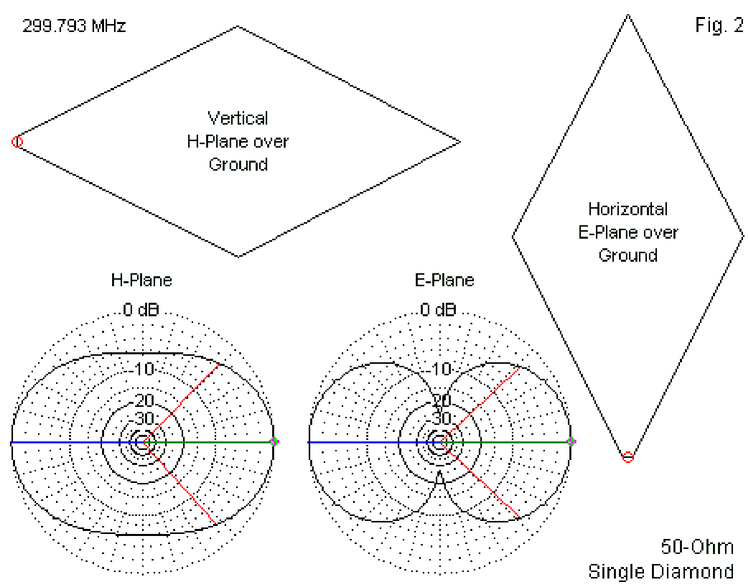


Fig. 2

Now let's see what a diamond can do for us—just one at first, as in **Fig. 2**. The patterns show the free-space E-plane and H-plane patterns, which correspond in shape to the azimuth patterns we would obtain in horizontal and vertical service over ground. Of course, the diamond is horizontally polarized when it is bottom fed and more vertical in physical structure, and vice versa. The following lines summarize the NEC model reports.

1. Single diamond in free-space at 299.7925 MHz

El Dia.	Length	Width	Side	Circum.	L/W Ratio	Gain	Impedance	AGT
λ	λ	λ	λ	λ		dBi	R+/-jX Ω	
0.001	0.475	0.26	0.271	1.083	1.827:1	4.14	50.4 – j0.4	1.003
0.005	0.5	0.262	0.282	1.129	1.908:1	4.22	50.6 + j0.2	1.035

Fig. 3 provides a guide to the measurement numbers, where L, the length, is always the longer dimension and W, width, is the shorter.

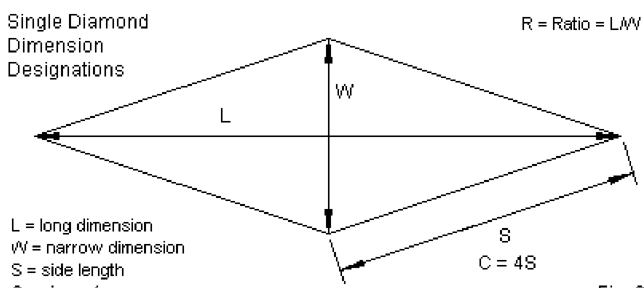


Fig. 3

We may explore the patterns and data with some profit. For example, the H-plane pattern shows us one reason why the elongated diamond (and its kindred rectangle) shows high gain. A simple vertical dipole would yield a circular H-plane pattern, while a standard squared loop would show a small amount of flattening to form an egg-shaped oval. The diamond shows a racetrack oval, indicating a relative high front-to-sidelobe radio (about 6 dB). The "missing" energy now resides in the main lobes.

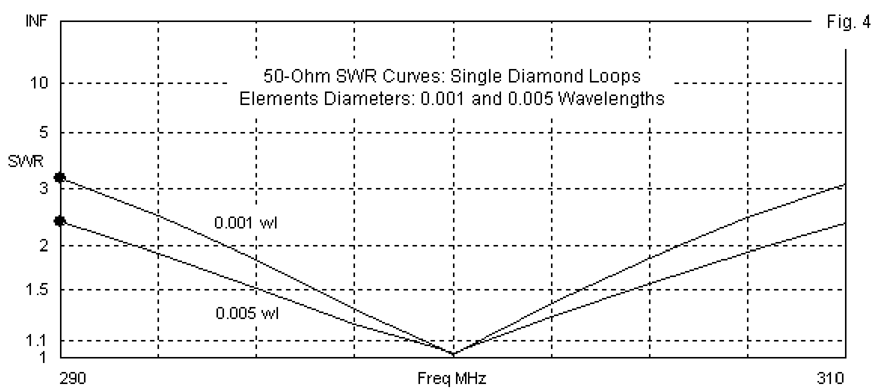
Like any closed loop (and some nearly closed loops), increasing the element diameter does not shorten the required overall element length, but actually lengthens the resonant circumference. As well, the ratio of length to width also increases as we increase the element diameter. The modeled numbers are subject to several restrictions. For example, due to the very sharp angles at the long ends, especially with fatter elements, the AGT scores draft away from the ideal value of 1.000. The results grow less reliable the further from ideal that the AGT value drifts. In addition, the numbers apply to bare wire. Insulated wire will have an antenna velocity factor ranging from about 0.95 to 0.98, depending on the composition of the insulation and its thickness. Hence, insulated diamond will have slightly smaller circumferences and may even require a revision in the length-to-width ratio.

In addition, the sample wires represent cases for thin and thick elements at 300 MHz. If we were to exactly scale the diamonds for the ham bands from 6 m through 23 cm, what counts as thick and thin in typical construction would lose its correlation to the baseline models. 0.001-λ corresponds roughly to AWG #12 wire at 2 meters and AWG #16 of 220. 0.005-λ is a little over 1/8" at 432 MHz and AWG #14 at 33 cm. Few of the other diameters shown in **Table 1** correspond directly to commonly used element sizes at the listed frequencies.

The bottom line is that the numbers provide basic guidance and some trends in terms of growing or shrinking element sizes to obtain a 50-Ω diamond. The structure of diamonds for a desired feedpoint impedance will remain—at least for now—an experimenter's province. The squarer the diamond, the higher the impedance and the lower the gain, and vice versa. The fatter the element diameter, the larger the circumference and the higher the length-to-width ratio for a given impedance.

Single Diamonds										Table 1
Thin-Wire Versions										
Fq MHz	Dia mm	L mm	W mm	S mm	C mm	Dia in	L in	W in	S in	C in
52	5.765	2738.48	1498.96	1560.95	6243.80	0.227	107.81	59.01	61.45	245.82
146	2.053	975.35	533.88	555.95	2223.80	0.081	38.40	21.02	21.89	87.55
223.5	1.341	637.14	348.75	363.17	1452.68	0.053	25.08	13.73	14.30	57.19
435	0.689	327.36	179.19	186.60	746.40	0.027	12.89	7.05	7.35	29.39
915	0.328	155.63	85.19	88.71	354.84	0.013	6.13	3.35	3.49	13.97
1270	0.236	112.13	61.37	63.91	255.64	0.009	4.41	2.42	2.52	10.06
Thick-Wire Versions										
Fq MHz	Dia mm	L mm	W mm	S mm	C mm	Dia in	L in	W in	S in	C in
52	28.826	2882.62	1510.49	1627.2	6508.80	1.135	113.49	59.47	64.06	256.25
146	10.267	1026.69	537.98	579.55	2318.20	0.404	40.42	21.18	22.82	91.27
223.5	6.707	670.68	351.43	378.59	1514.36	0.264	26.40	13.84	14.91	59.62
435	3.446	344.59	180.56	194.52	778.08	0.136	13.57	7.11	7.66	30.63
915	1.638	163.82	85.84	92.47	369.88	0.064	6.45	3.38	3.64	14.56
1270	1.180	118.03	61.85	66.63	266.52	0.046	4.65	2.44	2.62	10.49
Notes:	All versions use bare lossless wire and have 50-Ohm feedpoint impedances.									
	Dia = element diameter; mm = millimeters; in = inches. See Fig. 2 for an explanation of other designations.									

The single quad loop has a limited SWR bandwidth that varies with the element diameter. With a 0.001-λ element, the bandwidth is about 4.0% relative to a 2:1 50-Ω SWR value. Increasing the diameter to 0.005-λ widens the span to about 5.3%. **Fig. 4** shows the modeled SWR curves for our baseline antennas. Each version of the baseline antenna would serve well on 220, but the wider 70-cm band has a bandwidth of 6.9%, requiring a fatter diamond element for full coverage.



Like any resonant single element antenna, the diamond shows a rising gain curve as we operate the antenna over a selected passband. As shown in the frequency sweep curves of **Fig. 5**, the total change in gain is relatively small over the 6.7% passband, about 0.26 dB. Although imperceptible in the graph, the fatter element has a slightly lower (0.02 dB) total change in gain across the span.

As a 50-Ω bi-directional antenna, the single diamond is a reasonable performer, especially as an attic VHF antenna. Construction is straightforward, and a simple PVC frame is adequate for VHF applications. For local communications, a modest hand-turned TV mast may be all of the outdoor support needed. Horizontally, some turning may be needed due to the deep nulls in the E-plane pattern. However, in vertical service, orienting the main lobes toward the weakest desired station or repeater may allow full area coverage without having to re-orient the antenna.

At 6 meters, a single diamond may be all that limited real estate will support, since the long dimension is nearly 9'. However, at 2-meters and higher, we may realistically dream of multiple diamonds. And then we may convert our dreams into physical reality.

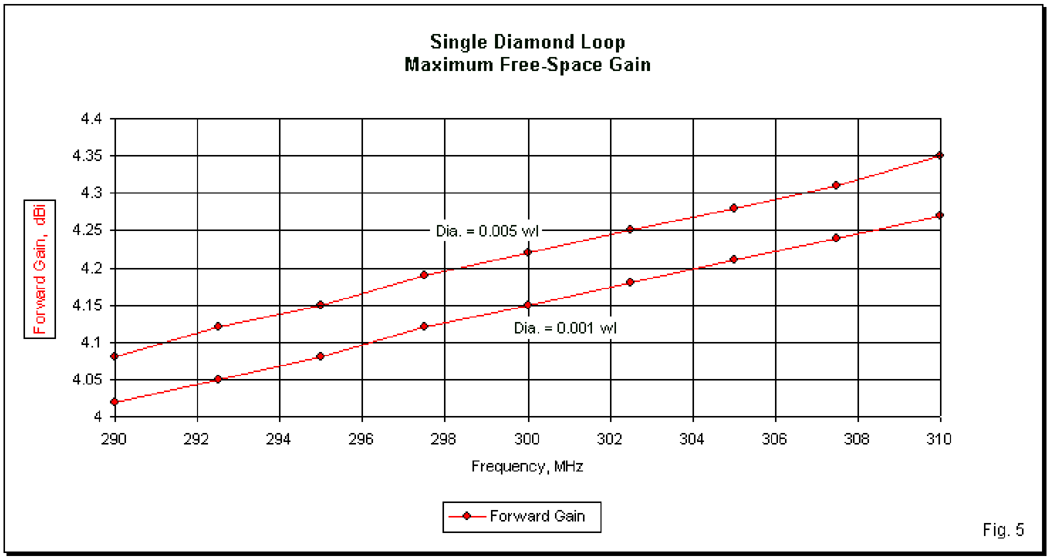


Fig. 5

2. *The Double-Diamond Element*

Above 6 meters, the double diamond becomes a popular alternative for a bi-directional closed-loop antenna element—also useful in beams. The element, as shown in the outline section of **Fig. 6**, consists of two diamonds fed *across* the center junction, separating the top diamond wires from the bottom pair. The E-plane pattern maintains its free-space figure-8, but the H-plane pattern shows a further reduction in the beamwidth, suggesting more gain in the main lobes. The rough equivalent of a double or dual diamond is 3 vertical dipoles fed in phase, but less with less than ½-λ spacing between elements. The H-plane pattern corresponds to the azimuth pattern when the antenna is vertically polarized over ground, while the E-plane pattern corresponds to the azimuth pattern when we use the antenna horizontally polarized, meaning that the diamonds are at right angles to the view shown in **Fig. 5**.

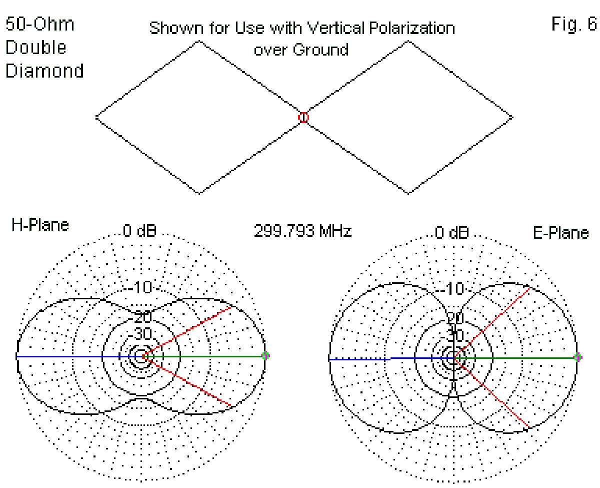


Fig. 6

2. Double diamond in free-space at 299.7925 MHz

El Dia.	Length	Width	Side	Circum.	L/W Ratio	Gain	Impedance	AGT
λ	λ	λ	λ	λ		dBi	R+/-jX Ω	
0.001	0.870	0.318	0.269	2.154	1.370:1	5.93	49.8 + j0.0	0.995
0.005	0.91	0.330	0.281	2.241	1.379:1	6.23	50.2 - j0.1	1.008

The length shown in the data lines indicates the total length from one tip to the other. The length of one diamond in the pair is, of course, half that value. The circumference is 8 times the length of a side. A new construction variable enters with the double diamond: the length of the segment containing the feedpoint is variable and will change the reported impedance. As well, actual construction of the feedpoint region is highly variable, ranging from a plate and connector to a simple soldered coaxial-cable junction. Hence, the dimensions shown will not directly scale to a practical design for shop construction without considerable testing and field adjustment.

Immediately noticeable is the fact that the gain of a double diamond over a single diamond is not 3 dB. The amount is closer to about 2 dB. One contributing factor is the length-to-width ratio, calculated on the basis of a single diamond from the pair. To obtain a 50-Ω impedance, the ratio is considerably lower than we find in a 50-Ω single diamond. Therefore, the spacing between virtual dipoles in the set is smaller, resulting in less gain than for a double diamond with a higher ratio (and, as a consequence, a much lower feedpoint impedance). Apart from that limitation, the double diamond follows the same general trends as a single diamond. As the element diameter increases, the circumference becomes larger, as does the length-to-width ratio.

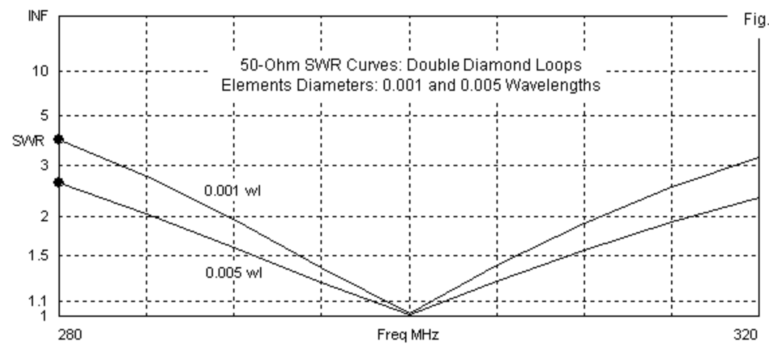


Fig. 7

As shown in **Fig. 7**, larger element diameters result in wider SWR bandwidths. Note that the sweep used to obtain the curves runs from 280 to 320 MHz, correctly suggesting that the lower length-to-width ratio of the double diamond results in a wider SWR passband for both element diameters. The 0.001-λ element has a modeled 2:1 SWR bandwidth of about 7.2%, while the fatter 0.005-λ elements has a bandwidth of over 10%. These values are about double the values for the single 50-Ω diamond.

The double diamond is nearly twice the length of a single diamond, but no harder to build on a PVC or other frame. However, we may obtain similar performance with a shorter overall length if we simply alter the geometry a bit.

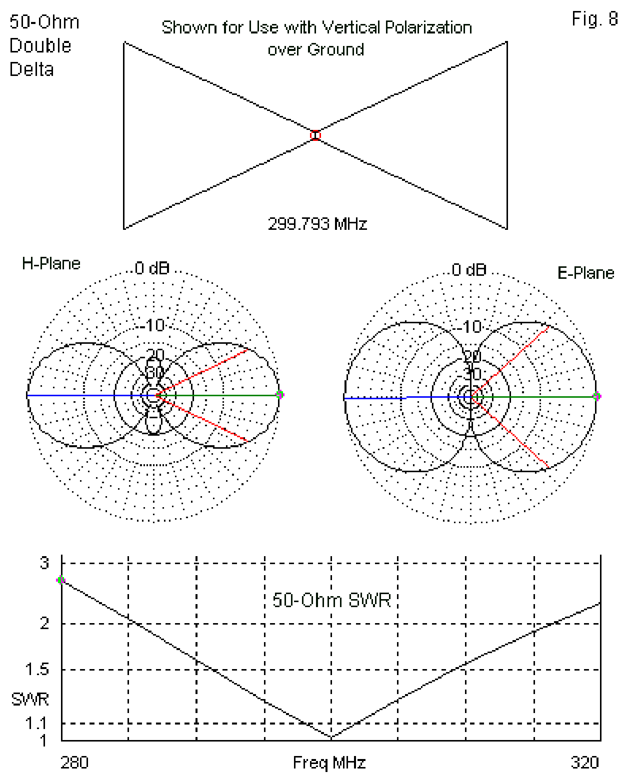
3. The Double-Delta Element

The double delta element cuts off the pointed outer ends of the double diamond. The result is not a bow-tie, because each loop remains about 1-λ in circumference. We also retain the feedpoint across the center junction, as shown in **Fig. 8**. Of course, to obtain a 50-Ω feedpoint impedance, we must adjust the remaining dimensions, as shown in the data lines for the version using a 0.005-λ element diameter.

3. Double delta in free-space at 299.7925 MHz

El Dia.	Length	Width	Side	End	Circum.	L/W Ratio	Gain	Impedance	AGT
λ	λ	λ	λ	λ	λ		dBi	R+/-jX Ω	
0.005	0.717	0.350	0.397	350	2.287	1.024:1	6.16	50.6 - j0.1	0.947

The length-to-width ratio is for one of the two triangles as measured from one end wire to the feedpoint.



The performance of the double delta is very similar to that of the double diamond with a small exception in the H-plane. The wholly vertical end wires change the pattern shape from a peanut to a pair of eggs with a center propeller. Operationally, we could not notice the difference. As well, the SWR bandwidth is the same (10%) as for the 0.005-λ diameter double diamond. Whether used vertically or horizontally, the performance will be the same for both the double diamond and the double delta, but the delta version will save about 20% of the length requirement.

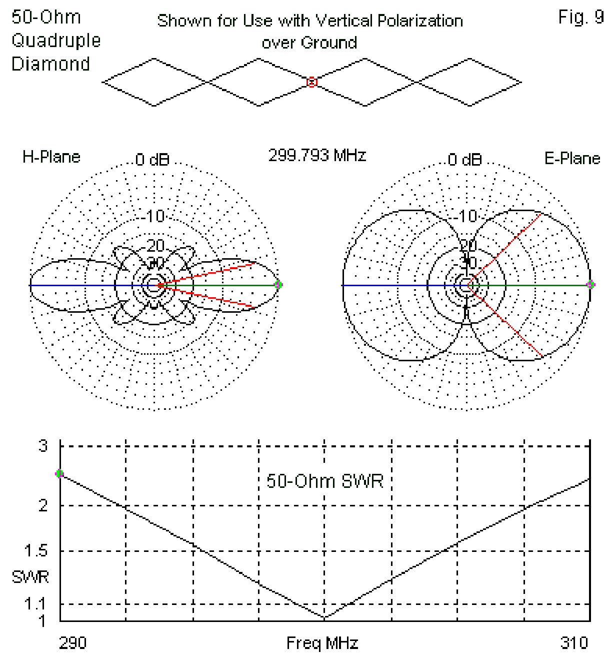
4. A Quadruple Diamond Element

Because multiple loops work when we feed them where they meet, we do not find any triple diamonds. Theoretically, a triple is possible if we feed it at one end. However, the more conventional approach is to increase the number of loops in pairs. Therefore, we jump from the double diamond to the quadruple diamond. We shall let the quadruple be the largest antenna element in out jubilee, although I have heard of arrays using up to 8 diamonds in a string.

Like a double diamond, we feed the quadruple at the center by separating the top and the bottom wires at the junction. However, as suggested in the outline sketch in **Fig. 9**, the junctions on each side of the feedpoint are significant, basically because we do not create a junction. Instead, the wires that form each pair of diamonds on either side of the central feedpoint bypass each other with a small gap. Like the feedpoint separation distance, the mid-leg gap size has a bearing on the feedpoint impedance and therefore an influence on the other dimensions of the total 4-part element. The following data lines show the dimensions used in the sample model.

4. Quadruple diamond in free-space at 299.7925 MHz

El Dia.	Length	Width	Side	Circum.	L/W Ratio	Gain	Impedance	AGT
λ	λ	λ	λ	λ		dBi	R+/-jX Ω	
0.005	2.036	0.233	0.280	4.478	2.185:1	9.14	49.3 - j0.0	0.937



The length-to-width ratio rests on the length of one of the four diamonds. Note that the ratio is very high, higher even than the ratio for a dingle diamond. The high ratio separates the high-current regions of the antenna to a more optimum distance to effect a higher gain, about 3.2 dB higher than the gain of a double diamond and 5.2 dB higher than the gain of a single diamond. All of these gain numbers result from setting a 50-Ω impedance as a constant for the exercise. Had we designed each element for maximum gain without regard for the feedpoint impedance, the gain ratios would have differed.

The H-plane pattern shows a very narrow beamwidth with very evident sidelobes. We cannot eliminate the sidelobes without seriously reducing the element's gain. In most cases, the sidelobe strength is small enough (at –15-dB relative to the main lobes) to be unobjectionable. The sidelobes would only be evident if we use the element in vertically polarized service over ground. The E-plane pattern, which would become the horizontally polarized azimuth pattern over ground, remains essentially unchanged in its beamwidth and shape, although it is stronger than the corresponding azimuth patterns of the smaller elements.

Since the length-to-width ratio is high, we might expect a relatively small 2:1 50-Ω SWR passband. As the SWR portion of **Fig. 9** reveals, the modeled SWR bandwidth is about 4.3% for a design using a 0.005-λ element diameter.

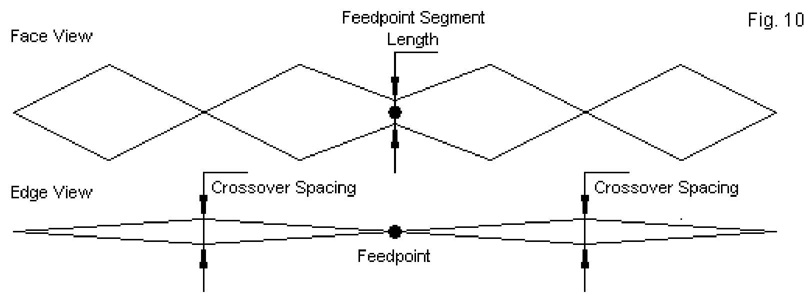
The quadruple diamond is impractical in the VHF range. However, it has found considerable use in arrays designed for UHF, especially from about 800 MHz and up.

Limitations, Errors, and Anticipations

Before we enter the realm of converting these bi-directional diamond elements into directional beams, we likely should pause in order to summarize a few points and to add some cautionary notes. Foremost on our list of limitations is our inability to develop a reliable set of algorithms to automate the design process for diamond elements. There are a variety of reasons for this limitation, some of which lie wholly within the modeling enterprise, and others that involve the translation of a model into a physical antenna.

The data entries for each modeled diamond element have included an Average Gain Test (AGT) value, which is a measure of model reliability within NEC. Wire size and very acute angles combine to limit how close a given model may come to the ideal value of 1.000. In many cases, the variability of the

AGT score will disqualify a series of test models from serving as the basis for a reliable regression exercise.



Variables That Affect Both Model and Physical Antenna Performance

In addition, as we add more diamonds to the element, we increase the number of gaps that influence both the feedpoint impedance and the final set of dimensions. The two views of the quadruple diamond that appear in **Fig. 10** reveal the feedpoint distance and the gap that we leave to separate the crossing wires in the assembly. Each change in the gap size will alter the dimensions slightly. A series of test models designed to create a design algorithm would have to use a fixed gap space as measured in terms of a wavelength. However, a physical antenna would normally use the smallest reliable gap possible. Therefore, any standard model would leave gaps that are too small or too large at most frequencies for which we design the elements.

When we actually model some directional beams, we shall discover that the required element sizes will change. Moreover, we shall add a further variable to the dimensional list. In fact, for some of the arrays that we shall encounter, no one single set of dimensions will emerge as the proper design dimensions, even if we retain our 50-Ω feedpoint constant. As a consequence, these notes and models can only serve as baseline guidance, capable of showing trends, but not suitable for physical replication.

The Significance of Correct Construction

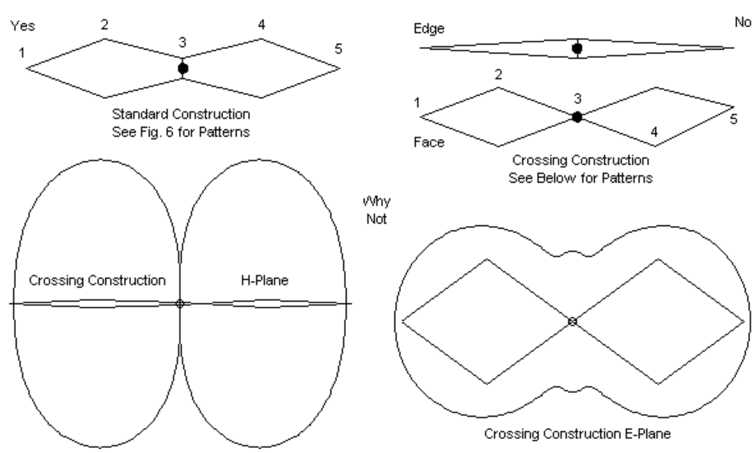


Fig. 11

Those who wish to replicate some of the diamond models must also use caution not to commit a very common error. **Fig. 11**, in the upper left, shows the correct order of junctions for wires that compose a double diamond. All of the numbered wires are on the same side of the feedpoint, and a similar set would emerge on the other side. The erroneous way to model (and build) a double diamond appears in the upper right. We can set the feedpoint segment between wires and then run the wires from point 2 on one side across the feedpoint position at point 3 and then down to point 4. This method of modeling (and construction) sets the two diamonds into opposition, so that the resulting patterns have the appearance shown at the bottom of the figure. These are very weak patterns, about 4 dB lower in maximum gain than the desired double diamond patterns.

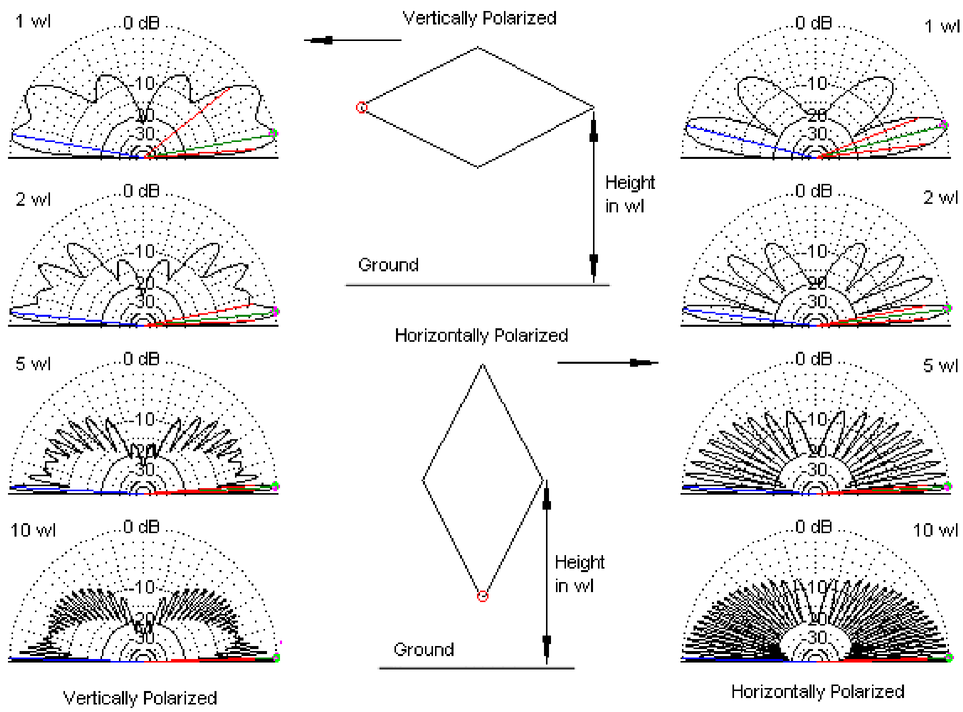
We should also attend to the expectations that we may have for antenna performance as we use the antenna over ground. First, the antenna has an appearance that is contradictory to its actual performance. To operate a diamond element—however many the diamonds within it—for vertical polarization, we must extend the long dimension parallel to the ground. To operate it for horizontal polarization requires that the long dimension be up and down. When used horizontally, the E-plane pattern becomes the azimuth pattern, and its beamwidth remains almost constant from one to 4 diamonds in the string. However, when vertically polarized, the H-plane pattern becomes the azimuth pattern, and its beamwidth narrows as we add more diamonds to the strong.

I am always amazed by how little amateurs appreciate the differences in the operation of an antenna as we shift from a horizontal mode to a vertical mode. Even several wavelengths above ground, not only do we find difference beamwidth values, but as well, we see a significant variation in the maximum gain and the elevation angle of maximum field strength (the take-off or TO angle). **Table 2** provides some modeled values of gain and the TO angle of a single diamond that uses a 0.005-λ diameter element. For vertical polarization, we stretch the long axis of the antenna from left to right (or vice versa), and the height marks the line from one acute angle to the other. For horizontal polarization, we set the long axis vertically, with the height marking a line between the points of the two shallower angles.

Single Diamond Gain and TO Angle above Average Ground						Table 2
Subject antenna is a single diamond with a 0.005-wl diameter elements.						
Test frequency: 299.7925 MHz						
Vertical Polarization				Horizontal Polarization		
Ht wl	Gain dBi	TO angle		Ht wl	Gain dBi	TO angle
Free Sp.	4.22			Free Sp.	4.22	
1	5.19	10.0		1	9.33	13.5
2	7.07	6.0		2	9.85	6.9
3	7.96	4.2		3	9.99	4.6
4	8.46	3.3		4	10.06	3.5
5	8.78	2.7		5	10.10	2.8
6	9.00	2.3		6	10.12	2.4
7	9.16	1.9		7	10.14	2.0
8	9.29	1.7		8	10.15	1.8
9	9.38	1.5		9	10.16	1.6
10	9.47	1.4		10	10.17	1.4
20	9.84	0.7		20	10.20	0.7

Due to the greater ground losses for vertically polarized radiation, the gain for any height is lower than for horizontally polarized radiation. However, so too is the TO angle. The angular difference is small, but clearly notable. The gain differential will also show up in signal strength in point-to-point communications, which underlies the use of horizontal polarization for non-repeater, non-mobile long-distance SSB and digital communications at VHF. The gain values shown apply to average soil and will change if we change soil types within the local area of the antenna. The differential will increase with decreasing soil quality, since poor soil will affect vertically polarized radiation to a greater degree than horizontally polarized radiation up to a certain height above ground.

Not only do we find a difference in the gain and TO angle as we change polarization, we also discover that the pattern of elevation lobes also changes. **Fig. 12** provides some sample elevation patterns for the single diamond at various heights above ground. The patterns for horizontal polarization form an orderly group, and for short-boom or (as in this case) “no-boom” one-element antennas, the elevation angle of each lobe answers to a relatively simple equation. When the antenna is vertically polarized, the lobe structure grows far more complex, with some lobes seeming to fold into adjacent lobes. The pattern is not clear at relatively low heights. However, it becomes much clearer in the sample pattern for a 10-λ height. The null in the pattern for vertical patterns at 15° or so is due to the pseudo-Brewster angle effect. The null angle changes with soil quality, especially relative permittivity.



Diamond Elevation Patterns vs. Height and Orientation (Polarization)

Fig. 12

Two-Element Diamond Parasitic Beams

One temptation facing every diamond builder grows out of the relationship between the diamond and its squarer quad cousins. We can easily construct a 2-element quad beam, using either the square form or the diamond quad form. Therefore, it appears to be equally easy to create a parasitic diamond beam. We simply need a driver and a reflector both of which have the same general shapes but different sizes.

However, we stipulated at the beginning of these notes that we shall insist on obtaining a 50-Ω feedpoint impedance without needing any sort of matching system. That requirement complicates the design process, and the level of performance that we can obtain does not live up to our expectations. (I note this fact because we shall see a second method of creating diamond-based beams in which we can easily obtain the desired impedance.) Nevertheless, we can create parasitic diamond beams. We shall examine two examples, one using single diamond elements, another using double diamond elements.

1. The Single Diamond 2-Element Parasitic Beam

The single diamond beam is perhaps the easier to design, but its performance—especially the front-to-back ratio is not outstanding, although the properties are usable as a utility beam. The following data lines may explain why. The data includes dimensions for the loop structure of each element, followed by information appropriate to beam evaluation. I have omitted the side length and the total circumference of the loops from the dimension entries, since those are easily calculated. The most notable aspect of the dimension data is the fact the designing a parasitic 2-element diamond beam requires no change to the length values. All dimensional differences occur with respect to the diamond width values. (This facet of diamond beam design will also hold true of double diamond parasitic beams.)

The performance data adds values for the 180° front-to-back ratio and for the beamwidth in both the E-plane and the H-plane. (The beamwidth values are of passing interest in this context, but will acquire some significance in the following sections of these notes.)

5. Single diamond 2-element beam in free-space at 299.7925 MHz

Dimensions:	El Dia.	Element	Length	Width	Element	Length	Width	Spacing
	λ		λ	λ		λ	λ	λ
	0.005	Driver	0.508	0.208	Reflector	0.508	0.238	0.21
Performance:	Gain	F-B Ratio	EplBW	HplBW	Impedance			
	dBi	dB	degrees	degrees	R+/-jX Ω			
	8.09	11.17	76.4	77.0	49.6 – j3.9			

The outline sketch in **Fig. 13** shows the antenna set up for horizontal polarization, if the antenna were not if free space. Note that the H-plane pattern does not show a distinct null 90° away from the heading of the forward lobe. Rather, the pattern folds past that line and would take on a cardioidal shape if the front-to-back ratio were very high.

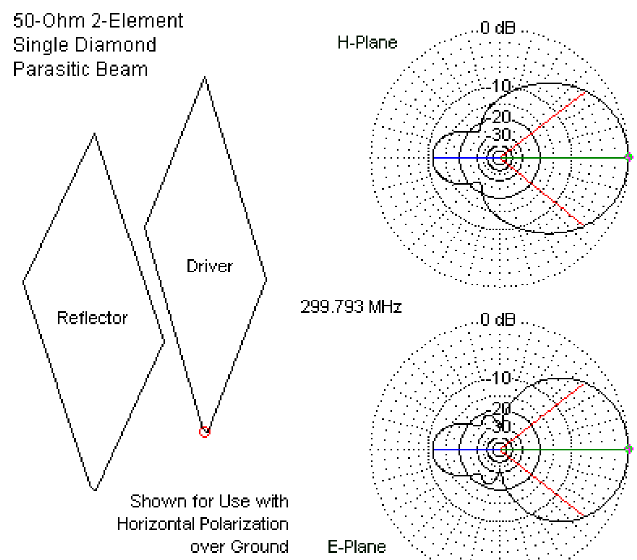


Fig. 13

One of the drawbacks of parasitic quad design, whatever the shape of the elements, is the fact that all such designs show relatively narrow-band characteristics in almost all performance categories. **Fig. 14** sweeps from 290 to 310 MHz (a 6.7% bandwidth) and traces the single diamond beam's forward gain, front-to-back ratio, and 50-Ω SWR. In that span, which is less than the width of the 70-cm band), the gain shows a peak value within the swept region, a function of careful design. However, the total gain change across the passband is 1.4 dB, a fairly high change for a beam with such fat elements.

As is the case with virtually all 1-λ loop (or quad) beams, the front-to-back ratio undergoes a more massive change within the same passband. The values range from 2 to 22 dB. The 180° front-to-back ratio exceeds 10 dB for only about half the operating passband and exceeds 15 dB for less than 40% of the passband. The 50-Ω SWR curve is equally problematical, although in a different way. The SWR values remain low from the design frequency to well beyond the upper end of the sweep range. However, the 50-Ω SWR value exceeds 2:1 at just about the same frequency at which the beam achieves maximum gain.

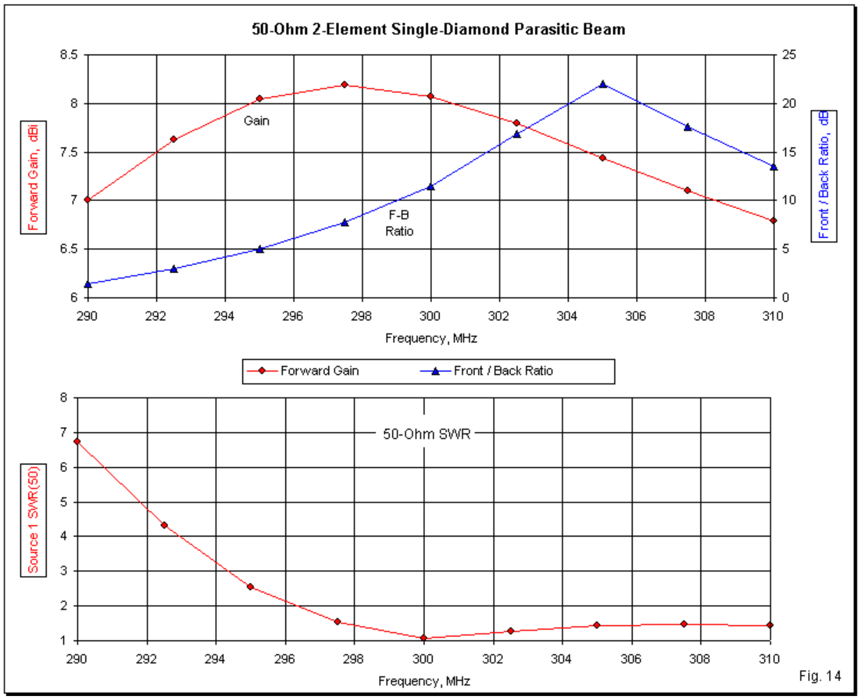


Fig. 14

2. The Double Diamond 2-Element Parasitic Beam

If we turn to the double diamond element as the basis for our parasitic beam, we obtain improved performance, but still shy of expectations. **Fig. 15** shows the outline of the beam, oriented for vertical polarization over ground, although the model remains in free space. The H-plane pattern shows the narrower beamwidth that emerges from having virtual vertical dipoles fed in phase but at less than the spacing needed for maximum gain.

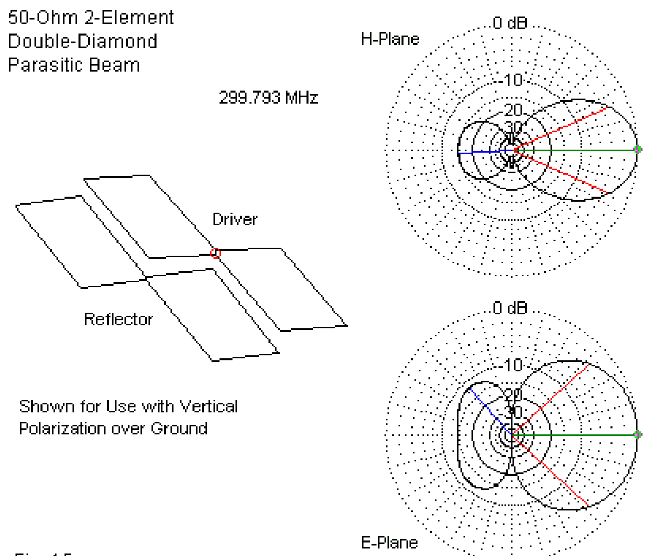


Fig. 15

The data entries provide length and width values applicable to the entire element structures. Once more, all size adjustments occur with respect to the values for diamond width, since reductions in the driver length result in serious reductions in forward gain. As with the single diamond design, the required element spacing is relatively wide (greater than 0.2 λ) for 2-element quads.

6. Double diamond 2-element beam in free-space at 299.7925 MHz

Dimensions:	El Dia.	Element	Length	Width	Element	Length	Width	Spacing
	λ		λ	λ		λ	λ	λ
	0.005	Driver	1.028	0.230	Reflector	1.028	0.256	0.22
Performance:	Gain	F-B Ratio	EplBW	HplBW	Impedance			
	dBi	dB	degrees	degrees	R+/-jX Ω			
	9.24	14.71	84.8	48.6	53.9 + j1.3			

Fig. 16 provides a frequency sweep for the double diamond 2-element beam. The smaller length-to-width ratio of the diamonds within the elements provides a wider operating bandwidth, so this sweep covers 40 MHz. The SWR bandwidth is particularly notable, providing an 11% bandwidth. However, the gain and the front-to-back ratio remain relatively narrow-band phenomena. Across the swept range, the gain varies by 2 dB. The front-to-back ratio exceeds 10 dB for only about half of the passband.

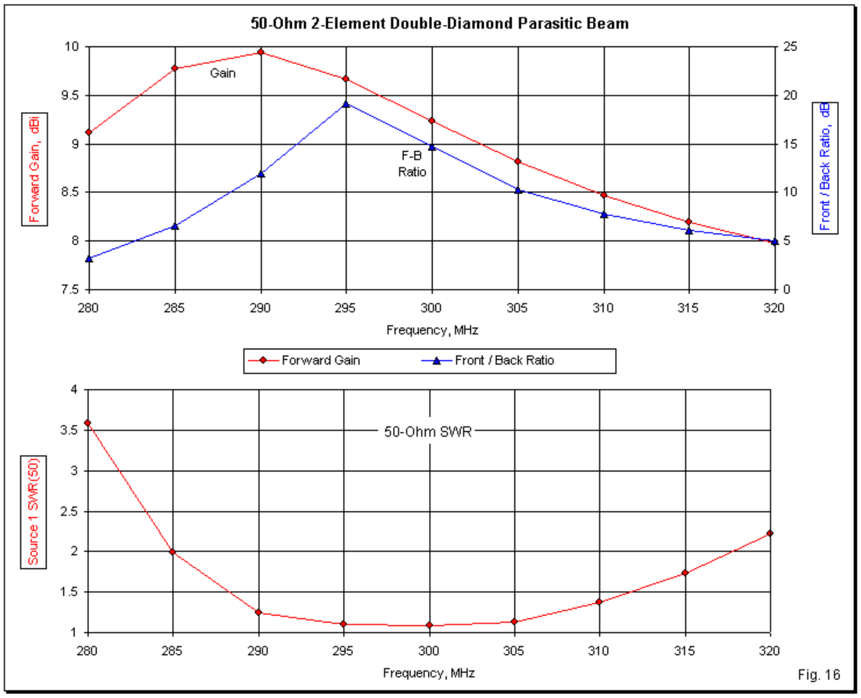


Fig. 16

In virtually all phases of quad beam design, SWR has been less of a challenge than broadening the bandwidth of the forward gain and the front-to-back ratio. Closed loops do not respond to many of the techniques used with linear elements. The development of broadband designs does not have a single goal, such as allowing full-band coverage of wider amateur bands. A second goal of broad banding that is equally important to those who build their own antennas has to do with the ease of replicating a design in the limited confines of a home workshop or of converting a design model into a physical reality. The shop tolerances for a broadband design are considerably larger while still permitting a successful product.

Parasitic beams, especially 2-element designs, are inherently narrow-band assemblies. The dimensions of both the driver and the reflector are critical to arriving at acceptable performance, and both dimensions are frequency sensitive. If we wish to expand and level the performance curves, we must turn to alternative techniques.

Planar Reflector Diamond Beams

When adequately designed, planar reflectors provide a very useful means of achieving the performance improvements that we wish from diamond drivers. To understand their operation, we must set aside most of what we think we know about parasitic reflectors, since the operating principles for the two types of reflectors are so different. A parasitic reflector is an element that receives its energy from the fed element (the driver) and is sized and spaced to produce currents having a desirable relative current magnitude and phase angle so as to yield a directional radiation pattern. A Yagi director operates in the same manner, but with different required values of relative current magnitude and phase angle. Parasitic reflectors do not reflect in the flashlight sense.

In contrast, a planar reflector belongs to a family of reflectors based on principles derived ultimately from optics. Other members of the family include corners, troughs, and parabolas. **Fig. 17** shows the basic parameters of a planar reflector.

Limitations of a Planar Reflector Having a Finite H-Plane Dimension

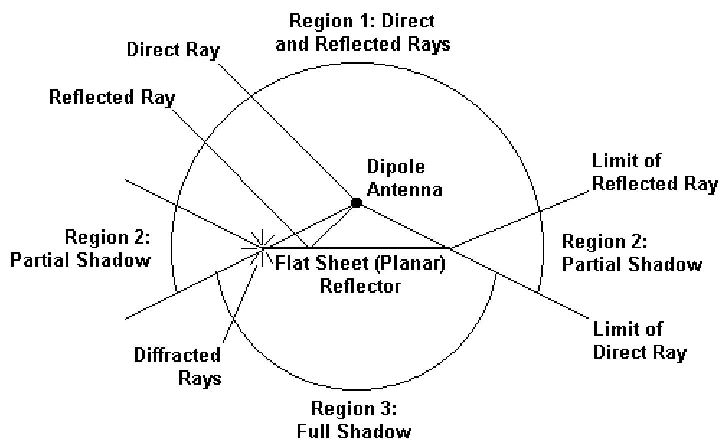


Fig. 17 Adapted from Kraus, Antennas, 2nd Ed., p. 548

The flat sheet that forms an ideal planar reflector has 3 regions. The forward region is subject to both direct and reflected rays from the driver element. Hence, any optically based reflector does not benefit from trying to combine parasitic and optical techniques, such as adding a director to the driver. Indeed, such attempts simply increase the difficulty of obtaining a desired performance level. The region of partial shadow, of course, depends upon the size of the planar reflector. (Parabolic reflectors tend to reduce this region to an absolute minimum, but the level of success is dependent upon reflector size, as it is for the planar reflector.) Theoretically, the region of full shadow should produce an infinitely large front-to-back ratio. However, the diffraction of rays at the reflector edge reduces that ratio to a good but finite value.

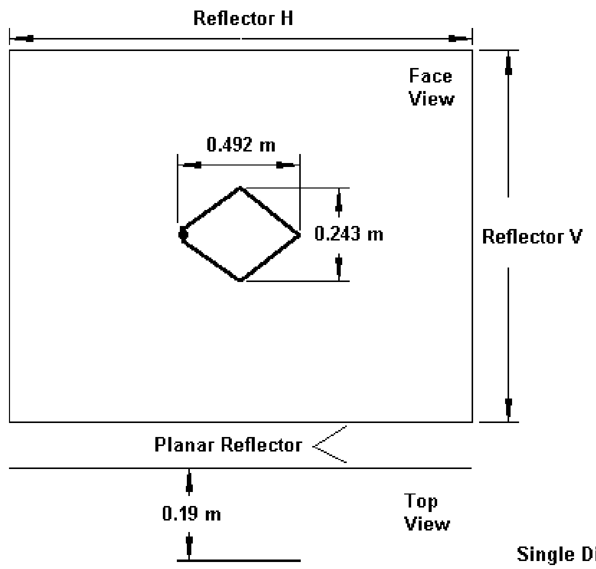
Planar reflectors have two properties that deserve special note. In the extensive exploration of these arrays in *Planar and Corner Reflectors*, I discovered that the optimal size planar reflector is relatively constant for any type of driver. The reflector surface should extend between 0.4 λ and 0.5 λ beyond the limits of the driver element in both horizontal and vertical directions. We shall briefly look at what happens when we try to get away with a typical amateur skimpy planar reflector. Second, the exact dimensions of a planar reflector are far less critical than the dimensions of a parasitic reflector. Therefore, the planar reflector array is inherently a broadband device.

As we explore several examples of diamond-based planar arrays, we shall uncover one more fact, a fact that further dashes any hope of developing a simplified set of design algorithms for such arrays. No single set of driver dimensions will satisfy our desire to produce highly competent arrays with a 50-Ω feedpoint impedance. With any reflector based on optical principles, the distance between the driver element and the planar surface also plays a role in setting the feedpoint impedance. We may spend endless hours searching for the combination of driver dimensions and driver-reflector spacing that produce both a 50-Ω impedance and maximum gain. To illustrate the principles of planar reflector design, I have not gone that far. The sample beams—within the limits of a somewhat variable AGT score—only yield good examples, but not necessarily the best.

1. A Single Diamond Driver with a Planar Reflector

The most rudimentary diamond-planar beam consists of a single diamond driver and a planar reflector, set up as shown in **Fig. 18**. For this set of examples, I have used an element diameter of 0.004 λ in order to make use of research done in connection with the reflector book. As noted, the dimensions shown are not the only set that will produce a 50-Ω array, but they are a good set.

Fig. 18



Single Diamond Driver and Planar Reflector Outlines

7. Single diamond driver and planar reflector in free space at 299.7925 MHz

Dimensions:	El Dia.	Element	Length	Width	Reflector	H	V	Spacing
	λ		λ	λ		λ	λ	λ
	0.004	Driver	0.492	0.243	Small	0.6	0.4	0.19
					Optimal	1.4	0.8	0.19

Performance:	Gain	F-B Ratio	EplBW	HplBW	Impedance
	dBi	dB	degrees	degrees	R+/-jX Ω
Small Ref.	8.51	6.40	69.4	69.0	35.6 + j3.2
Optimal Ref.	9.54	17.71	64.8	65.2	49.2 – j0.1

The data entries compare two reflector sizes, a small version that just exceeds the driver dimensions and an optimal size designed for the best combination of gain and front-to-back ratio at the design feedpoint impedance. Because I do not recommend the use of the small reflector, I did not waste time in optimizing all dimensions to perfect its feedpoint impedance.

Fig. 19 compares the forward gain of the two reflector designs from 290 to 310 MHz. The relatively constant differential between the values at any frequency in the passband is evident. However, also note that the gain value does not change by more than 0.1 dB across the pass band for either version. **Fig. 20** present comparable data for the 180° front-to-back ratio. For either reflector design, the value changes by only about 1 dB across a 20 MHz passband. The characteristics that we could not find in a parasitic design—that is, wide-band gain and front-to-back curves—are inherent in planar reflector designs. When we use an optimal reflector size, we also obtain higher numerical values in both categories.

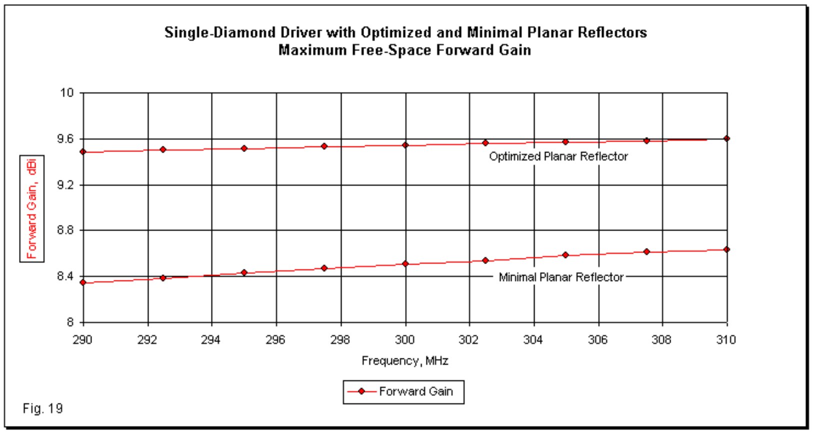


Fig. 19

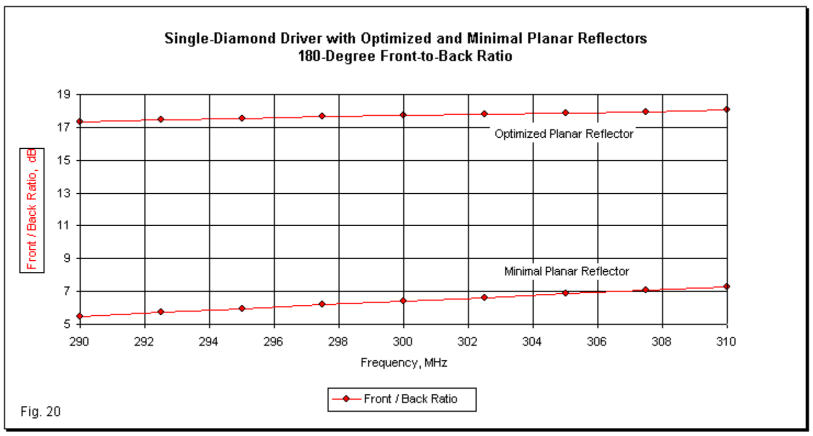


Fig. 20

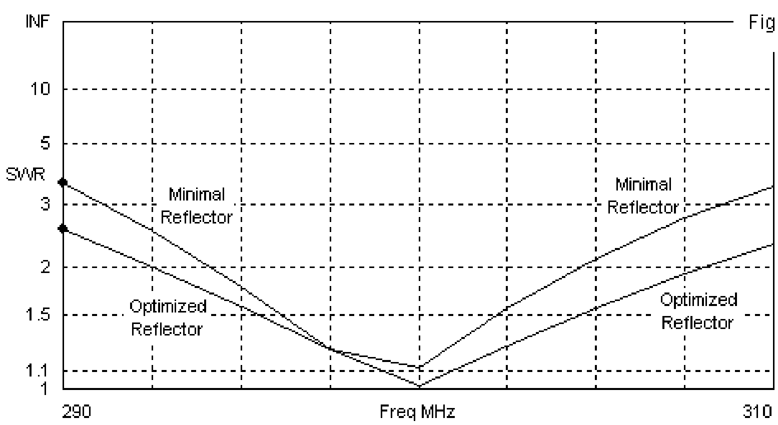
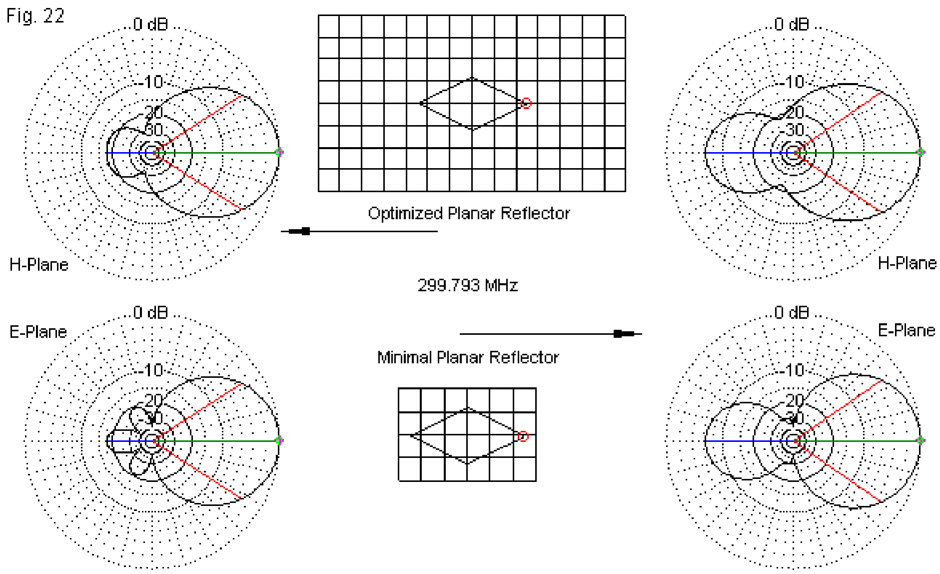


Fig. 21

If the single diamond with an optimal planar reflector has any limitation, it lies in the area of the 2:1 SWR bandwidth. As shown on **Fig. 21**, the bandwidth is only about 5%. Part of the reason lies in the use of a high length-to-width ratio for the single diamond driver: about 2.02:1. Diamonds with smaller ratios tend to have wider SWR bandwidths, although only extensive modeling would indicate whether the wider diamonds would have beneficial or harmful effects on other performance numbers.

Fig. 22 shows the E-plane and H-plane patterns for both the small and the optimal reflector. The obvious aspect of the patterns is the improved rearward radiation performance of the larger reflector. However, let's also note that the E-plane and the H-plane beamwidths do not change significantly relative to reflector size. We should also note the shape, especially of the E-plane rearward lobe structure. This structure indicates that the reflector size that we have selected is at least close to being optimal.



Free-Space E-Plane and H-Plane Patterns: Single-Diamond with Planar Reflectors
Minimal and Optimized Reflectors Shown

We may also note from the outlines of the two models the use of wire-grid techniques to model the planar reflector. I have modeled the same arrays using more closely spaced grid elements with the same results. Physical planar reflectors may use a solid surface, perforated aluminum, aluminum screening on a frame, or other cross-wire materials as long as the opening are not greater than about 0.05-λ. They all will look like solid surfaces to the driver, so that you may use other factors, such as weight and wind resistance, to reach a final decision on the best material for your antenna.

2. A Double Diamond Driver with a Planar Reflector

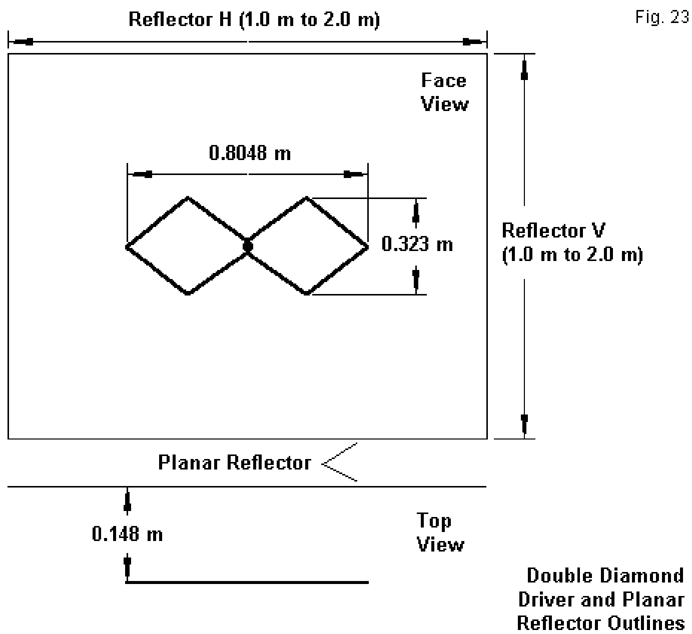
Assuming that a diamond-based antenna is suitable for an application, the single diamond driver and planar reflector are perhaps best used at 6 meters, where they would serve well as a vertically polarized rotatable array for repeater use or as a directional antenna at a repeater installation. Planar reflectors can be mounted directly to a tower face or a support mast for fixed directional service. (Yagis normally require some spacing between the mast and the reflector element to prevent detuning.)

For higher frequencies, the double diamond driver with a planar reflector provides superior service. We may replicate our minimal vs. optimal reflector exercise with the antenna shown in the data lines and sketched in **Fig. 23**.

8. Double diamond driver and planar reflector in free space at 299.7925 MHz

Dimensions:	El Dia.	Element	Length	Width	Reflector	H	V	Spacing
	λ		λ	λ		λ	λ	λ
	0.004	Driver	0.805	0.323	Small	1.0	0.5	0.148
					Optimal	1.6	1.2	0.148

Performance:	Gain	F-B Ratio	EplBW	HplBW	Impedance
	dBi	dB	degrees	degrees	R+/-jX Ω
Small Ref.	10.17	12.26	68.2	48.4	43.4 + j3.4
Optimal Ref.	11.13	21.20	54.6	51.1	49.6 – j0.6



The double-driver diamond has run through a wide selection of reflector sizes, ranging from 1.0 λ to 2.0 λ in both the vertical and horizontal dimensions (as these labels apply in **Fig. 23**). The results with respect to forward gain appear in **Fig. 24**. Regardless of the horizontal dimension, a vertical (or E-plane) height of 1.2 λ proves to show the highest gain. At that vertical dimension, the gain peaks at a horizontal (or H-plane) dimension of between 1.6 λ and 1.8 λ.

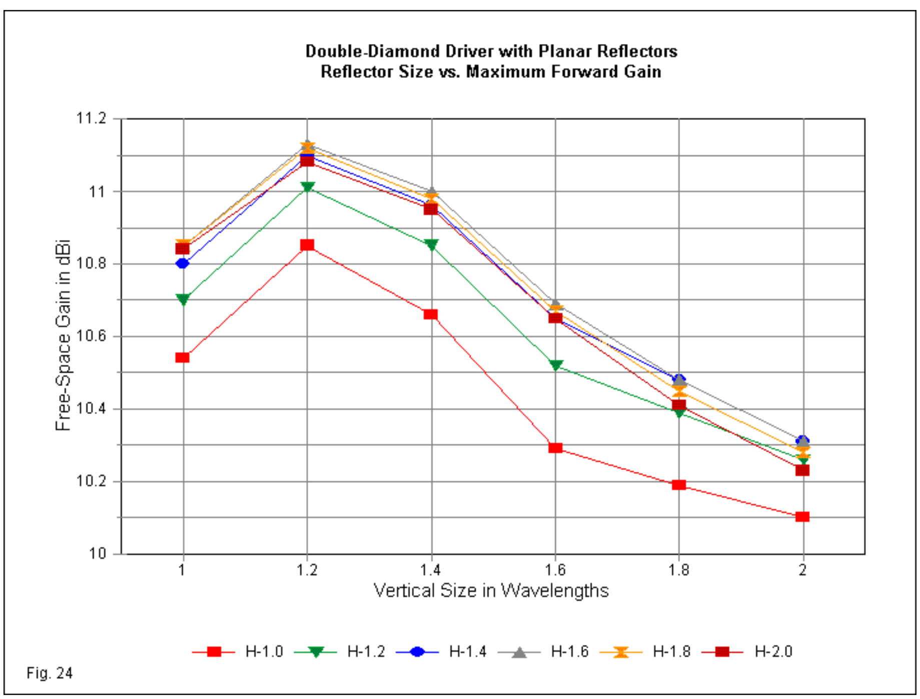


Fig. 25 shows the same range of reflector sizes modeled to check the 180° front-to-back ratio. For horizontal dimensions less than 1.3 λ, the front-to-back ratio peaks within the vertical size range. However, for horizontally longer reflector planes, the front-to-back ratio has not peaked by a 2.0-λ vertical dimension. This result follows from the basic nature of a planar reflector, if we consider the growing size

of the full shadow zone as we increase the size of the reflector. Since the double diamond driver shows a minimum front-to-back ratio of 20 dB with the smallest reflector tested (1.0 λ by 1.0 λ), reflector size generally relates to maximum gain.

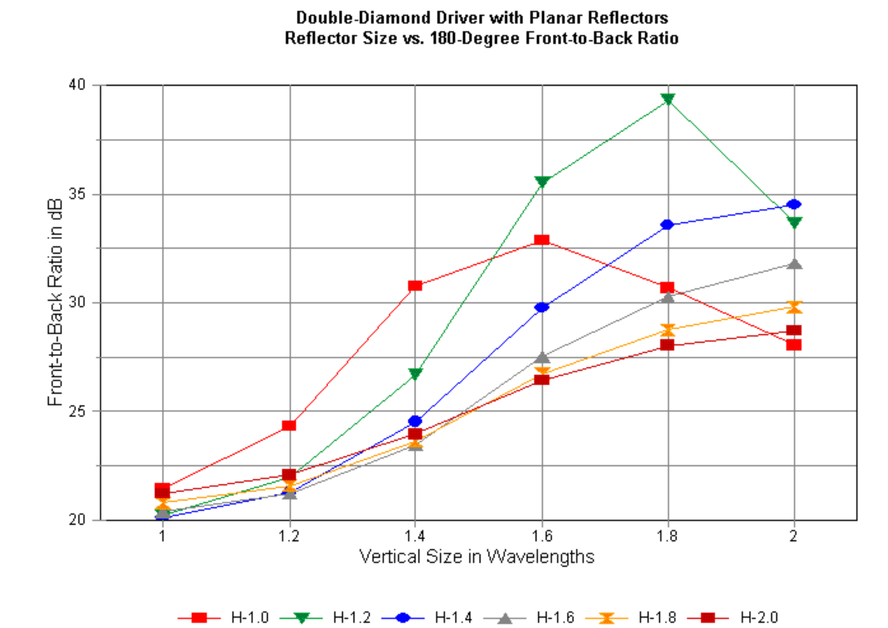
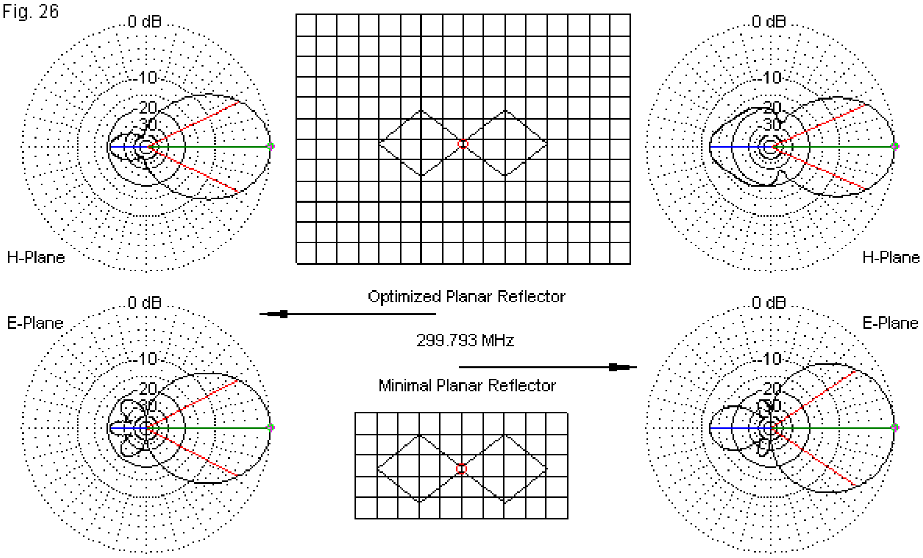


Fig. 25

The minimum (or typical amateur) reflector is smaller yet than the smallest reflector in the tests that produced the graphs. It is barely larger than the driver outline. However, the double diamond driver has a length-to-width ratio of about 1.25:1, suggesting that it will have a fairly wide bandwidth for its operating parameters. This shows up most clearly in the fact that the feedpoint impedance of the minimal reflector version of the array is less distant from the target impedance than we found to be the case for the single diamond driver.

Fig. 26


Free-Space E-Plane and H-Plane Patterns: Double-Diamond with Planar Reflectors
Minimal and Optimized Reflectors Shown

Fig. 26 compares the E-plane and the H-plane patterns for the minimal and the optimal reflectors using the double diamond driver. Although the patterns for the minimal reflector are deficient relative to what they might be, they show a clear relationship to the patterns for the optimal reflector size.

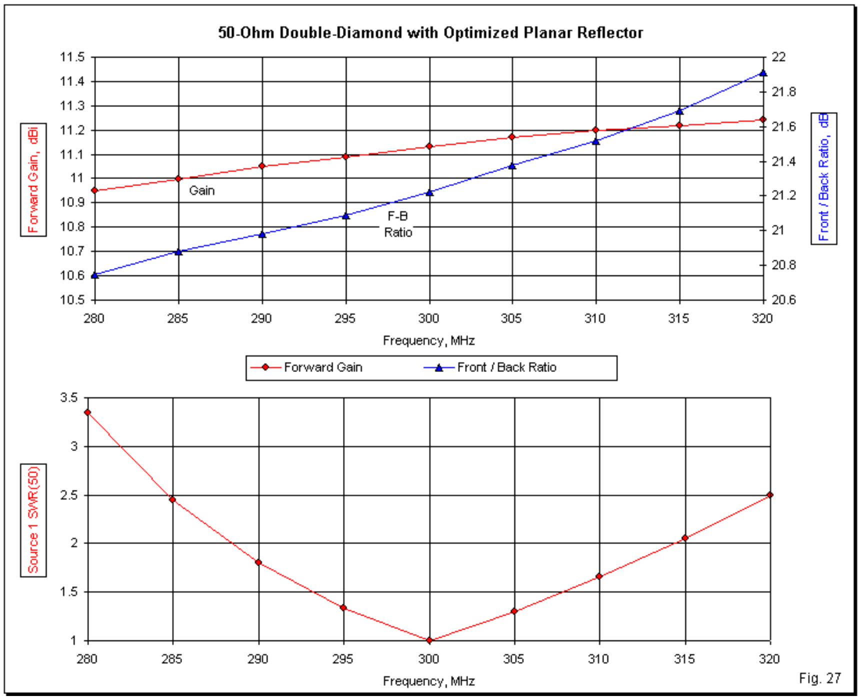


Fig. 27

In **Fig. 27**, we find frequency sweep data from 280 to 320 MHz (double the sweep range that we used for the single diamond driver) using the optimized reflector. Across that passband, the gain changes by only about ¼-dB, while the front-to-back ratio changes by 1.3 dB. Unlike the parasitic 2-element double-diamond beam, the planar reflector yields very broadband operation so that the SWR becomes the limiting factor. The 2:1 50-Ω SWR bandwidth is about 9%, which is adequate for virtually any amateur band and for replication in most home shops. Indeed, the double diamond driver with a planar reflector is a good example of the benefits of the planar reflector when the driver geometry is complex. We obtain both better and more broadband performance than we can obtain from nearly any 2-element parasitic arrangement.

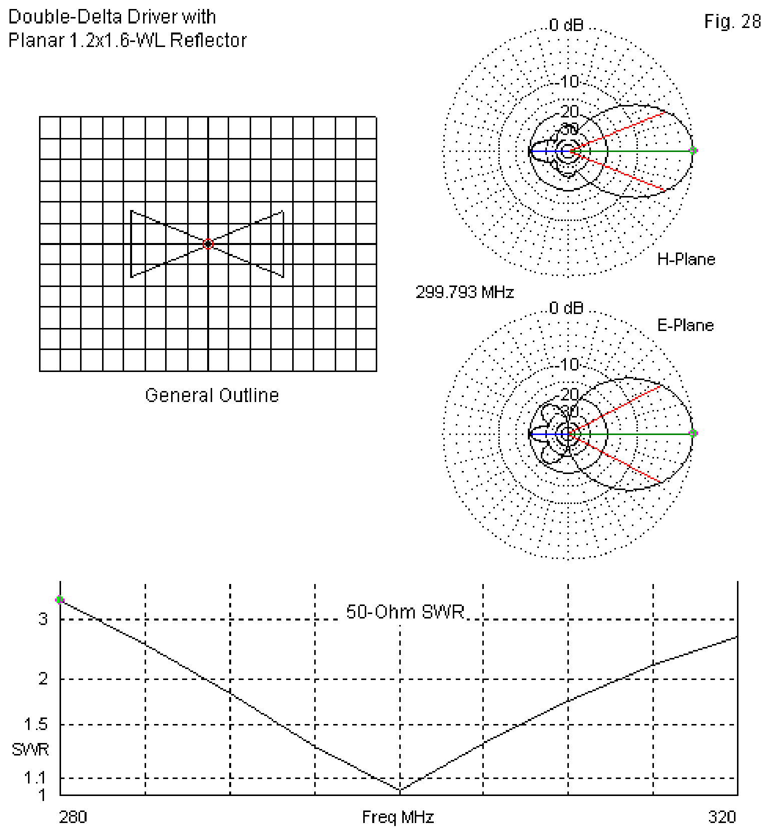
3. A Double Delta Driver with a Planar Reflector

When we examined driver elements alone, we briefly paused to look at the double delta shape as an alternative to the double diamond. We can pause once more to look at the double delta driver with the same planar reflector that we used with the optimal double diamond array. In this case, the test is only a starting point to a fuller analysis, since I have not run the driver through a full range of reflector sizes. Nevertheless, the data entries show very comparable performance, even though the required spacing for the double delta driver is greater than for the double diamond.

9. Double delta driver and planar reflector in free space at 299.7925 MHz

Dimensions:	El Dia.	Element	Length	Width	Reflector	H	V	Spacing
	λ		λ	λ		λ	λ	λ
	0.005	Driver	0.717	0.306	Optimal	1.6	1.2	0.165

Performance:	Gain	F-B Ratio	EplBW	HplBW	Impedance
	dBi	dB	degrees	degrees	R+/-jX Ω
	10.61	20.83	55.1	44.8	50.6 + j0.3



Because the high-current regions on the delta end wires are closer to the feedpoint than is the case with the double diamond, the H-plane pattern in **Fig. 28** shows small sidelobes (more than 25-dB down from the main forward lobe). In all other respects, the double delta driver is comparable to the double diamond. For most applications, the slight gain and SWR bandwidth advantages of the double diamond would be marginal.

4. A Quadruple Diamond Driver with a Planar Reflector

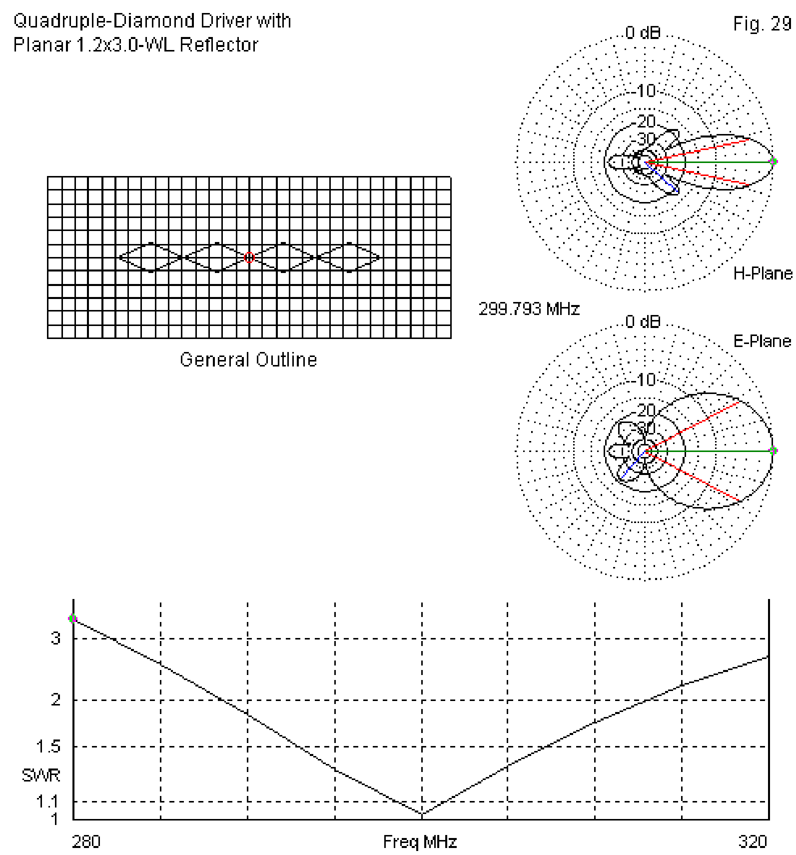
Although the use of a quadruple diamond driver may lie beyond the scope of most home workshops, we should examine what happens when we add a planar reflector to the complex driver. The data entries show the essential information, while **Fig. 29** provides some graphical clarifications. Make no mistake: the quadruple diamond array with an optimized planar reflector is a large antenna. It chief physical merit is that most of its size lies in the planar reflector that we can mount directly to the supporting structure.

10. Quadruple diamond driver and planar reflector in free space at 299.7925 MHz

Dimensions:	El Dia.	Element	Length	Width	Reflector	H	V	Spacing
	λ		λ	λ		λ	λ	λ
	0.005	Driver	1.968	0.220	Optimal	3.0	1.2	0.147

Performance:	Gain	F-B Ratio	EplBW	HplBW	Impedance
	dBi	dB	degrees	degrees	R+/-jX Ω
	13.04	21.64	55.4	24.9	50.6 + j0.3

The quadruple diamond element shows forward sidelobes in the H-plane. As the patterns in **Fig. 29** plainly reveal, we do not lose these sidelobes when we add the reflector, although the rearward ones are barely distinguishable. Note that the E-plane pattern has retained both its shape and its beamwidth throughout the entire sequence of planar reflector arrays that we have viewed.



Like its smaller kin, the quadruple diamond driver with a planar reflector is a broadband antenna. The 2:1 50-Ω SWR bandwidth is over 8%. It is likely that a horizontally polarized version of the antenna—in which the E-plane pattern becomes the azimuth pattern—will represent an easier mounting task with a greater potential for durability in the winds. The view of the antenna shown in **Fig. 29** is for vertical polarization over ground, and in this orientation the narrow beamwidth H-plane pattern becomes the azimuth pattern. The very long (3-λ) reflector size may be more suited to fixed mounting using at least 2 supports. The narrow beamwidth may prove useful for applications such as data transfer under these conditions.

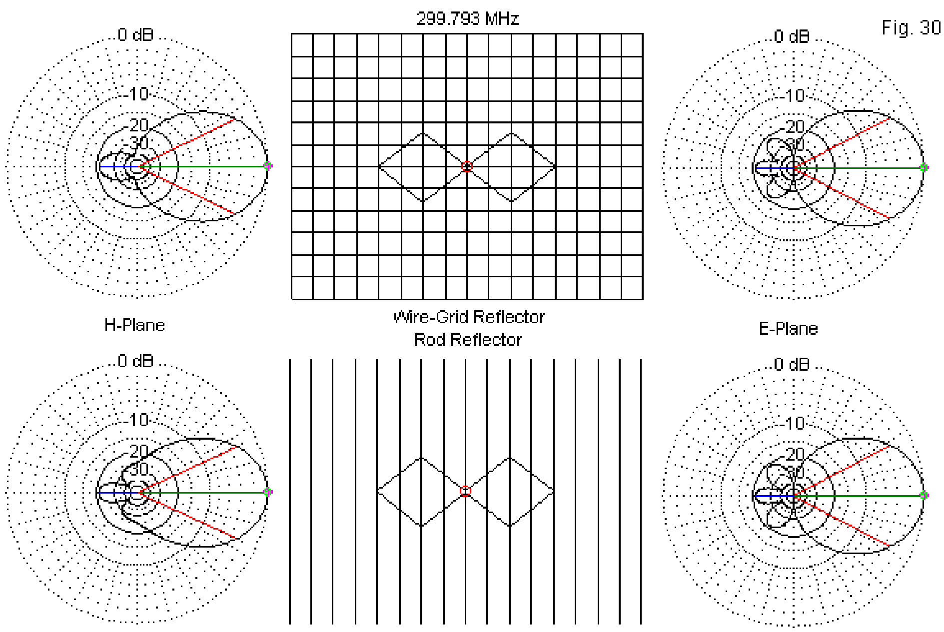
If a diamond is a ham's best friend, then the planar reflector is the diamond driver's best friend. With adequate size, the reflector is capable of providing very good gain and broadband operation. In horizontally polarized service, the diamond driver with a planar reflector also provides a relatively constant beamwidth, regardless of the number of diamonds in the driver. In vertically polarized applications, the beamwidth narrows as we add more diamonds to the driver, since each added diamond represents a new phased dipole in the chain.

If you survey the sample arrays in this small collection of planar beams, you will discover that in every case, the driver diamonds required re-sizing relative to a similar diamond element used as an independent bi-directional antenna. As I noted at the beginning of this section of the notes, the trends that you find will not have mathematical precision. Modeling limitations constitute one reason for the difficulty. However, the fact that the spacing between the reflector and the driver adds a new variable to the other dimensional variables means that there may be no single set of dimensions that will achieve the goals of a 50-Ω high-performance diamond driver and planar reflector array. In addition, builders tend to choose different construction techniques according to the frequency of operation. 6-meter arrays may use anything from wire to copper tubing for the driver element. Wire drivers require supporting frames. Upper UHF drivers tend to use materials that yield a self-supporting diamond driver, with insulated supports at the ends. The arena can provide the inveterate antenna experimenter with many months of happy experimentation (with a few frustrating hours thrown in for good measure).

Rod-Based Planar Reflectors

The earliest experiments with planar reflectors did not use solid planes or even screen approximations of them. Rather, they used a series of wires or rods spaced at regular intervals. Today, commercial short-wave broadcasting phased dipole arrays use a similar system of wires to form a planar reflector for large arrays. When planar (and corner) reflectors entered the world of television antennas, most manufacturers used the same technique to create planar reflectors. The chief reason for using rods rather than a screen is mechanical. Round rods or wires slip the wind more easily than even an open mesh of wires, such as the wire-grid structures that we have used to simulate a solid reflective surface.

Initial industry tests suggested that if we set the rods in the same polarization as the driver, the resulting surface will act just like a wire-grid or a solid surface. My modeling studies suggest that the calculations are somewhat light. To obtain optimal reflective properties from a rod-based surface requires that we use somewhat fatter and more closely spaced elements. All of my models use rods that are 0.01-λ in diameter (30 mm or about 1.2" at 300 MHz) with a 0.1-λ spacing center-to-center between rods (0.1 m or about 4" at 300 MHz). Under these conditions, we obtain results that are remarkably similar to those we obtain from the wire-grid models.



E-Plane and H-Plane Patterns for a Double-Diamond Driver with Wire-Grid and Rod Planar Reflectors with the Same Outer Dimensions

Fig. 30 compares the outline and the free-space patterns of a double diamond driver using both wire-grid and rod-based reflectors with identical outside dimensions. The E-plane patterns on the right are so close to being identical that they leave nothing upon which to comment. The H-plane patterns are operationally indistinguishable, although we do find some unsuppressed low-level radiation with the rod reflector at right angles to the heading of the main forward lobe.

As the following data entries for both antennas show, the reflector dimensions are 1.2 λ vertically (relative to the sketch in **Fig. 30**) and 1.6 λ horizontally. To fill the reflector space in the model, we need 17 reflector rods using the specified element diameter and spacing. In general, if a builder chooses to use thinner rods, he should space them proportionally closer together. (Old television antennas make very bad models for adequate construction, since virtually all such antennas used the least possible material in order to minimize the cost of manufacture.)

11. Double diamond driver and planar reflector in free space at 299.7925 MHz

Dimensions:	El Dia.	Element	Length	Width	Reflector	H	V	Spacing
	λ		λ	λ		λ	λ	λ
	0.004	Driver	0.805	0.323	Wire-Grid	1.6	1.2	0.148
					Rod-Based	1.6	1.2	0.147

Performance:	Gain	F-B Ratio	EplBW	HplBW	Impedance
	dBi	dB	degrees	degrees	R+/-jX Ω
Wire-Grid.	11.13	21.20	54.6	51.1	49.6 – j0.6
Rod-Based	11.02	20.87	54.8	50.0	50.4 + j1.2

As the data suggest, we find nothing to choose between the two ways of forming a planar reflector that we could detect in operation or even in the most sensitive range measurements. Likewise, both types of reflectors provide essentially the same operating bandwidth, as shown in the comparative 50-Ω SWR curves in **Fig. 31**. When it comes to planar reflectors, both techniques are entirely effective.

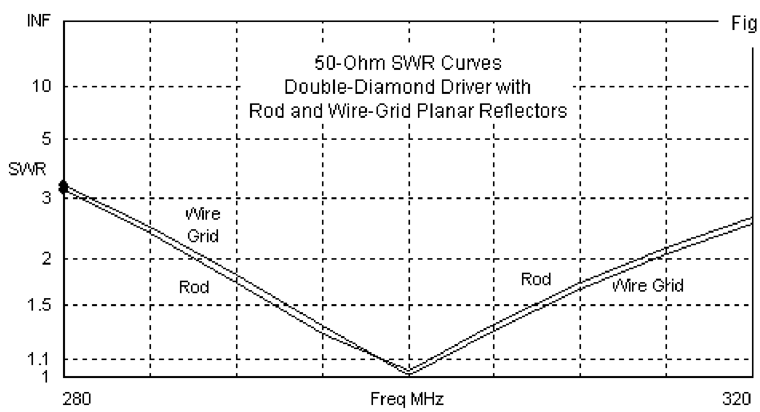


Fig. 31

We must enter a special caution at this point. The rod-based reflector is not just like a wire-grid or solid counterpart. The current levels in any portion of a planar reflector are very low, but a wire-grid or solid reflector will show slightly higher values near the center, with decreasing values as we progress toward the edges. The current magnitude pattern is almost symmetrical as we increase the distance from the very center of the reflector. Every junction of wires provides multiple paths for current distribution within the wire-grid structure.

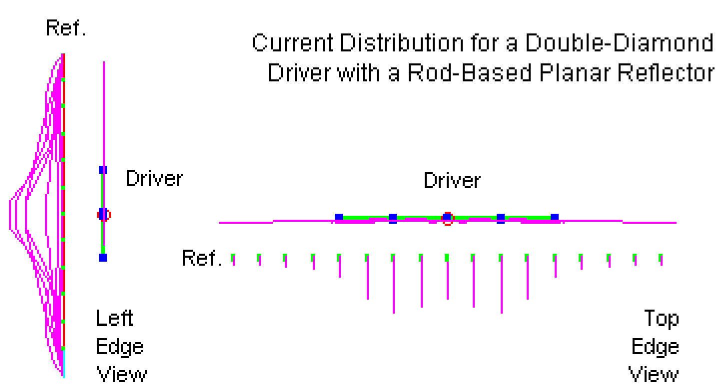


Fig. 32

Fig. 32 presents the current distribution along the wires of a rod-based reflector. The view on the right shows higher current levels at a distance from the center point. The end and the center dots represent regions of high driver current. The high-current rods receive virtually double the radiated energy, since they receive equal amounts from adjacent high-current regions of the driver. (We may note in passing that the rods immediately opposite the end dots of the driver show about half the current level as the rod opposite the center dot, attesting to the binomial current distribution in the phased driver assembly.)

A second feature of the rod-based reflector appears on the left. We expect the peak current level near the vertical center of the graphic. However, notice that we find small current peaks further out along some of the rods. The vertical size of the reflector is 1.2 λ, the size that yields maximum array gain. This length of rod is somewhat under a resonant 3/2-λ length for the rod. (That length would be closer to 1.4 λ, given the rod's large diameter.) Since planar reflectors achieve maximum gain with reflector vertical dimensions that are well under rod resonance, the small aberrations of current distribution relative to a wire-grid or solid surface create no problems. Hence, the rod-based planar reflector is as capable as a solid or wire-grid version.

I note these facts because reflectors using optically based principles have other applications, for example, in corner reflectors. In some of these applications, the optimal reflector dimension along the length of a rod will be considerably longer than we use in a simple single-surface planar reflector. As we survey reflector sizes for such applications, we often find that wire-grid models show peak gain with different reflector sizes than for counterpart rod-based reflectors. Indeed, rod-based reflectors may show a significant spike in performance as the rods pass through a length of about 1.4 λ, while the wire-grid version shows only a normal progression of gain values. Unlike the wire-grid reflector, the rod-based reflector does show hybrid properties that combine the optical reflection with parasitic element phasing.

We can draw two conclusions from this brief note—more adequately covered in *Planar and Corner Reflectors*. First, we cannot presume that, just because planar reflectors show no ill effects from parasitic action on rods, all similar applications will be equally free of them. (I should also note in passing that in corner reflectors, experiments in England have shown that we may actually tune the reflector rods to enhance corner reflector gain.) Second, for virtually all applications using single bays of diamond drivers, a vertical reflector size of 1.2 λ provides us with a practical limit to rod length in order to avoid the potential for unanticipated parasitic effects.

Thinking Bigger

As we increase the frequency of operation for any kind of diamond array with a planar reflector, we begin to think about stacking them to obtain additional gain. In Europe, use of multiple double diamonds in a single phased array is common from 23 cm upward. Some of the craftsmanship that I have seen is incredible, but it is not as clear that careful design analysis has gone into the shaping of the diamonds to arrive at nearly optimal performance. Therefore, let's spend a short time looking at the advantages and pitfalls inherent in stacking diamonds with planar reflectors.

We may begin by setting two double diamonds side-by-side, as shown in the outline portion of **Fig. 33**. The design shown uses a center-line-to-center-line spacing of 0.5 λ. The distance is a compromise. Closer spacing between the double diamonds yields less gain, but a cleaner pattern, that is, a pattern without E-plane sidelobes. These sidelobes begin to appear with a spacing of about 0.25 λ and grow stronger as we increase the spacing (and the gain). The sidelobes are larger if we try to use the pair of double diamonds as a bi-directional array without a reflector. With the reflector, the sidelobes are about 17 dB below the strength of the main forward lobe. I arbitrarily used this value as a limit, although other applications might well call for close spacing between the double diamonds for a cleaner pattern in the E-plane.

The reflector size cannot be smaller than shown without reducing both the gain and the front-to-back ratio. As the reflector vertical size shrinks, the front-to-back ratio decreases faster than the forward gain.

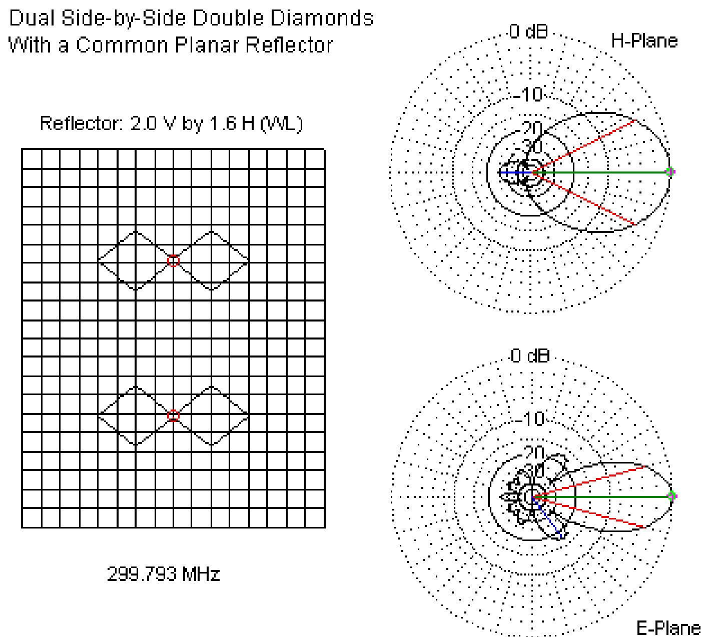


Fig. 33

The following data entries compare a single double diamond and the pair of side-by-side diamonds, both with relatively optimal reflectors.

12. Double diamond driver and planar reflector in free space at 299.7925 MHz

Dimensions:	El Dia.	Element	Length	Width	Reflector	H	V	Spacing
	λ		λ	λ		λ	λ	λ
	0.004	Driver	0.805	0.323	Single	1.6	1.2	0.148
					Pair	1.6	2.0	0.148

Performance:	Gain	F-B Ratio	EplBW	HplBW	Impedance
	dBi	dB	degrees	degrees	R+/-jX Ω
Single	11.13	21.20	54.6	51.1	49.6 – j0.6
Pair	13.42	22.44	31.3	50.7	49.3 – j4.5

Within the limits of having a "clean" pattern in both planes, the stacking gain does not reach the theoretical 3-dB level. Instead, we gain about 2.3 dB. In exchange, we give up 23° of E-plane beamwidth. Only the specifications associated with a particular application can determine if the exchange is fair.

We may also stack double diamonds end-to-end for additional gain. In **Fig. 34**, we can see the long stack and one of the conditions of obtaining the cleanest possible pattern. When we stack diamonds end-to-end, the required spacing is nearly zero, or the H-plane pattern sidelobes grow much larger than the set shown in the pattern sample. However, at near-zero spacing, the performance closely resembles what we obtain from a quadruple diamond with a planar reflector. Compare the patterns with those in **Fig. 29**. The chief difference is that the quadruple diamond produces deeper nulls between the main lobe and the sidelobes. Both arrays use the same reflector that is vertically 1.2 λ and horizontally 3.0 λ with respect to the views shown for each array. (The vertical dimension represents the E-plane, while the horizontal dimension represents the H-plane for both arrays.)

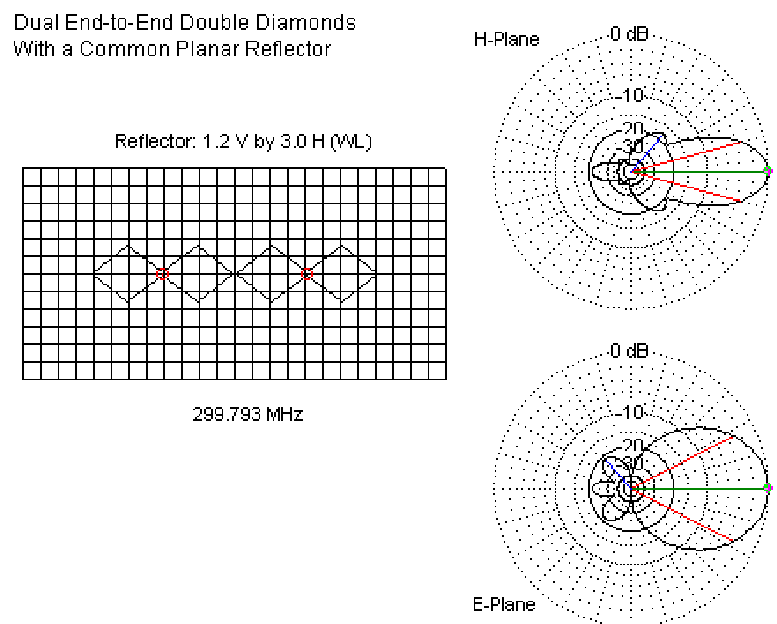


Fig. 34

13. Quadruple diamond driver and a pair of double diamond drivers, both with identical planar reflectors in free space at 299.7925 MHz

Dimensions:	El Dia.	Element	Length	Width	Reflector	H	V	Spacing
	λ		λ	λ		λ	λ	λ
Quadruple	0.005	Driver	1.968	0.220	Optimal	3.0	1.2	0.147
Double	0.004	Driver	0.805	0.323	Optimal	3.0	1.2	0.148

Performance:	Gain	F-B Ratio	EplBW	HplBW	Impedance
	dBi	dB	degrees	degrees	R+/-jX Ω
Quadruple	13.04	21.64	55.4	24.9	50.6 + j0.3
Double	13.42	21.72	54.8	29.6	56.8 + j0.9

For both of our stacked double diamond arrays, I have not corrected for driver interactions. The data entries show the level of interaction between driver assemblies with the spacing used between them.

If we wish to create a quad of double diamonds, we might as well use a pair of quadruple diamonds instead—arranged side-by-side with a centerline spacing of about 0.5 λ. The performance will be equivalent to a quad of double diamonds, but the phasing arrangements will be simpler and therefore have fewer losses in the GHz range. The following data entries show that we acquire another 2.2-dB gain (depending on with which entry we compare the numbers). The general outline and the free-space patterns appear in **Fig. 35**.

14. Quadruple diamond drivers side-by-side and planar reflector in free space at 299.7925 MHz

Dimensions:	El Dia.	Element	Length	Width	Reflector	H	V	Spacing
	λ		λ	λ		λ	λ	λ
	0.005	Driver	1.968	0.220	Optimal	3.0	1.8	0.147

Performance:	Gain	F-B Ratio	EplBW	HplBW	Impedance
	dBi	dB	degrees	degrees	R+/-jX Ω
	15.63	27.18	33.5	25.0	52.5 – j5.5

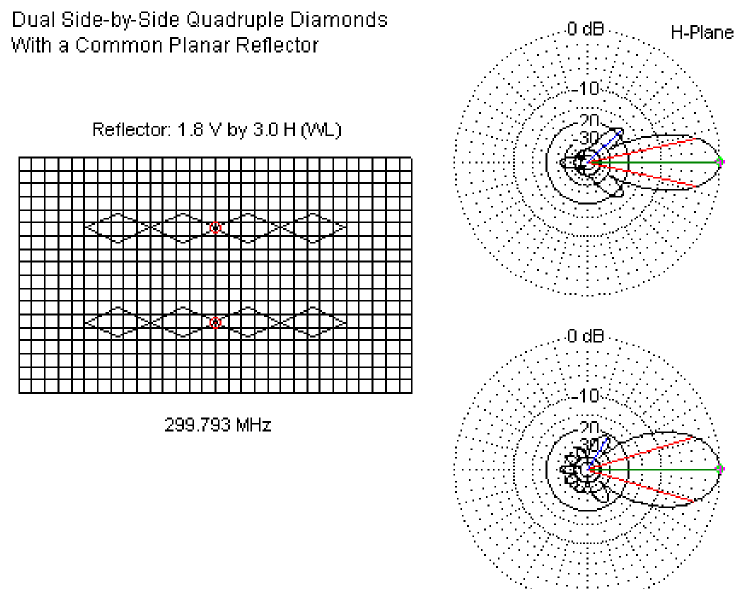


Fig. 35

The patterns show that we now have sidelobes in both planes. The strength of the lobes will vary slightly with the size of the reflector, which in this sample is only close to optimal. Nevertheless, when we create a quadruple, either by using two pair of double diamonds or one pair of quadruple diamonds, we obtain a reasonably symmetrical beamwidth for the main lobe.

Even in large collections of arrays using diamond-based drivers, the driver shape and the spacing of the driver from the reflector plane combine to yield the target feedpoint impedance and the performance level. Perfecting a design requires close attention to these interactions long in advance of bending driver element material in the shop. Of course, using multiple complex drivers with large planar reflectors is impractical in the VHF region. However, for 23 cm and upward, PC board reflectors become very practical for fairly large arrays. I have only held all models at the same 300-MHz frequency for ease of direct performance comparisons.

Conclusion

We have come a long distance from our first step in developing a single 50-Ω resonant diamond loop. We have followed the shifting length-to-width ratios for each diamond as we increased single-element performance by looking at double and quadruple diamond antennas. We observed that the fatter we made the element, the larger the loop circumference grew and the higher the length-to-width ratio became if we wished to retain a 50-Ω feedpoint impedance. As well, we saw that as the length-to-width ratio increased, the operating bandwidth decreased.

We also paused to explore the possibilities for parasitic 2-element diamond beams. Perhaps the chief limiting factor for such beams is the narrow bandwidth for virtually all operating parameters, including gain, front-to-back ratio, and SWR. Therefore, we turned to planar reflector as a means to provide broadband operation, and—with adequate size—this optically based reflector type yielded smooth performance over an extended frequency range. However, we also saw that we cannot succumb to the amateur temptation to use the smallest possible reflector. Instead, the planar reflector needs to extend at least 0.4-λ beyond the driver limits in every direction. We may replace a solid or screen reflector with adequately sized rods to form a planar reflector with virtually equal performance potential.

The planar reflector has one significant limit of its own. Adding parasitic elements to the driver adds virtually nothing to array performance and often disrupts feedpoint impedance values to make an adequate array almost impossible to achieve. This limitation follows from the fact that the planar reflector uses principles that are not compatible with the manner in which parasitic arrays achieve their gain. Consequently, the planar reflector (and all of its kindred reflector shapes) requires us to use a solitary driver element. Unlike corner reflectors, that demand dipole drivers or collinear arrangements of them, the planar reflector can accept drivers with complex forms, such as side-by-side phased dipoles, half-squares, bobtail curtains, and quad loops. Of course, the planar reflector also gracefully accepts single and multiple diamond drivers.

The diamond driver with a planar reflector is not a Yagi and does not pretend to replace a Yagi except where it is the better choice of an antenna to perform a given communications task. Still, the following question is virtually inevitable: how do Yagis and diamond arrays stack up against each other? To provide a provisional answer we may return to the double diamond with the 1.2-λ by 1.6-λ wire-grid reflector as the same planar array. The free-space forward gain at the design frequency is about 11.3 dBi, about the same that we might obtain from a 7-element Yagi. For comparative purposes, I have selected from my collection of Yagi designs an optimized wide-band antenna (OWA) model that has close to the widest operating bandwidth of any Yagi in the class. In volume, the Yagi is smaller, having a 1-λ boom and an element spread of just over 0.5-λ at the widest point. **Fig. 36** provides the general outline.

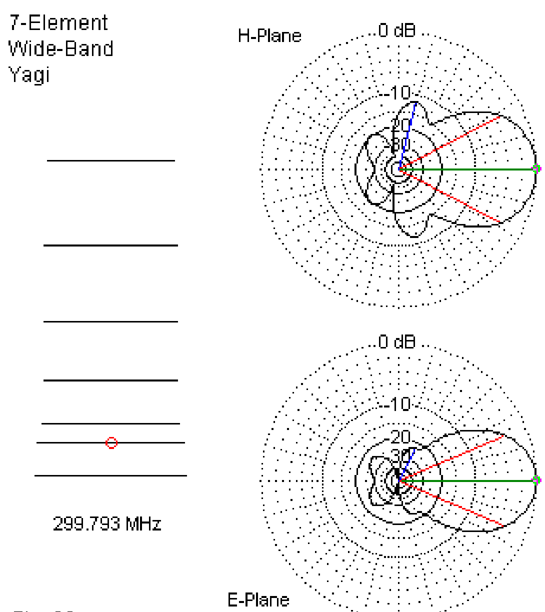


Fig. 36

The figure also contains H-plane and E-plane patterns for the Yagi. You may compare these patterns to those on the left side of **Fig. 26**, the double diamond with the optimized reflector. Many Yagi users are only familiar with the E-plane pattern, which is very clean in this case, as a function of the OWA design. However, like any Yagi, the H-plane pattern—which we would experience if we used this antenna for vertically polarized service—has a wider beamwidth and very strong sidelobes. Compare the H-plane pattern to the clean pattern for the double diamond array.

The Yagi has a peak gain of just over 11.5 dBi, compared to the 11.3-dBi figure for the double diamond array. However, the planar reflector array sustains that gain from at least 280 through 320 MHz, the limits of the frequency sweep that I performed on the array. A similar sweep for the Yagi shows a relatively smooth gain curve only between 285 and 305 MHz, as shown in the overlapping patterns in **Fig. 37**. Although the Yagi numbers are excellent for a parasitic beam, the gain passband is only about half the value attained by the double diamond array.

We obtain a more extreme situation for the 180-degree front-to-back ratio. The double diamond array varies the front-to-back ratio by only about 1 dB across the swept frequency range, with all values above

20 dB. In contrast, the Yagi curve exceeds 15 dB for about half the passband. These curves also appear in **Fig. 37**. Indeed, above about 310 MHz, the Yagi is useless as an antenna.

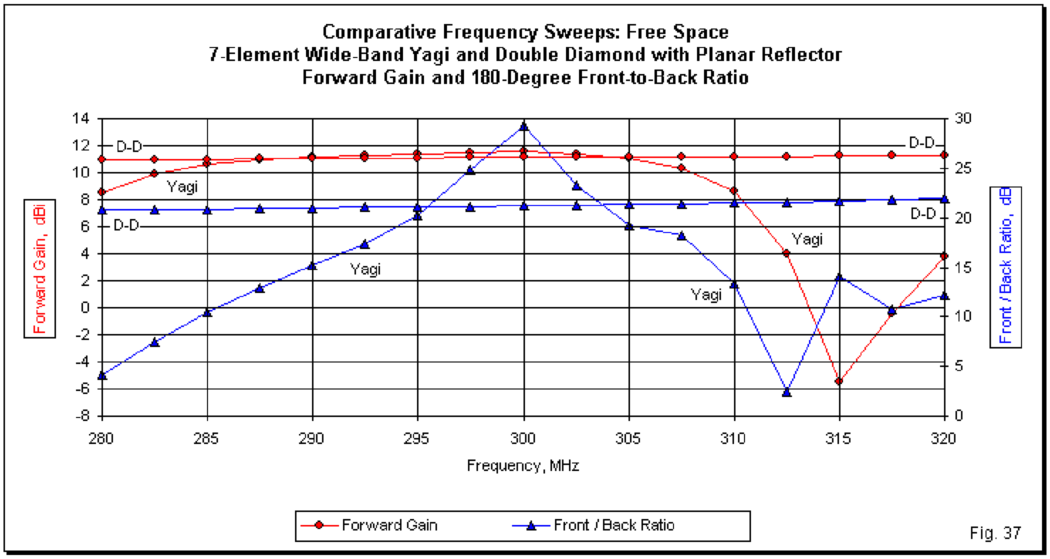


Fig. 37

The comparative 50-Ohm SWR curves in **Fig. 38** tell a similar story. However, the Yagi curve cuts off at an even lower frequency (about 306 MHz) for an effective SWR bandwidth of about 6.3%. Although this figure is very good for Yagis, it is over 25% narrower than the 2:1 50-Ω SWR passband for the double diamond array.

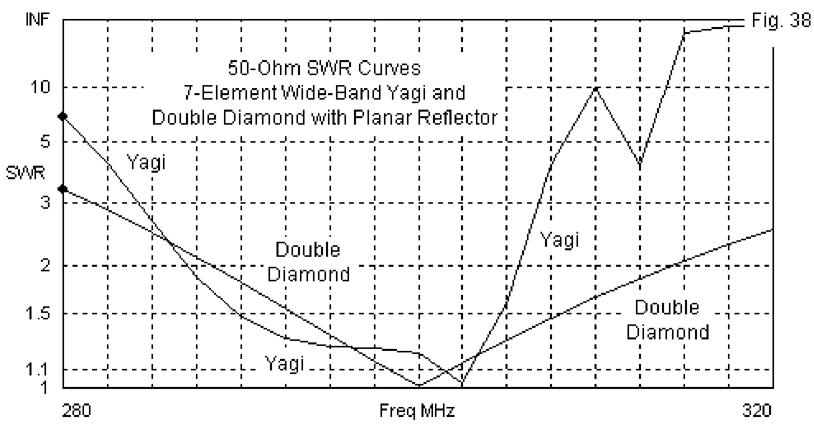


Fig. 38

What the double diamond array cannot offer is the potential for additional gain by adding more directors.

The diamond arrays that we have examined, then, have broadband characteristics, mid-range gain values, very clean patterns, and a flat face on the world. They are very useful where attaching the reflector directly to a mast or tower fits the installation requirements. As well, the double-diamond version of the planar reflector array is equally competent in vertical or horizontal service. One virtue of the diamonds that we have examined is that we can obtain most of the materials from a hardware center rather than having to visit a jewelry store.