Reflections on Reflectors

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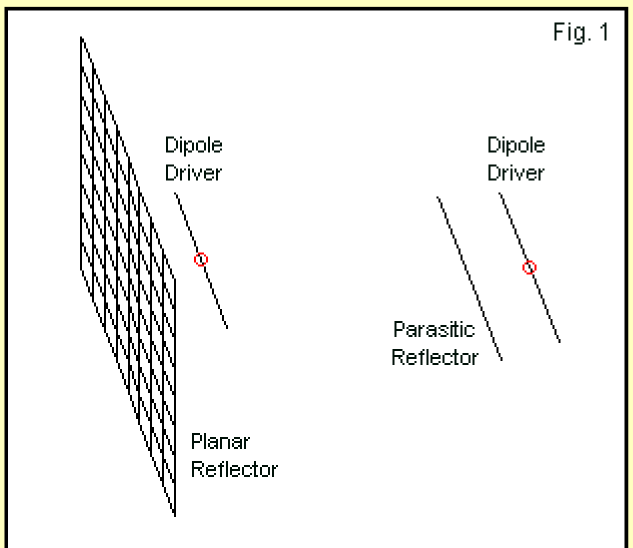
Some reflectors reflect-and others do not. Consider the two different beams in **Figure 1**. One uses a planar reflector, while the other uses a parasitic reflector. The planar reflector actually reflects. In important ways, the parasitic reflector does not-at least not in the way we usually imagine the situation with parasitic beams.



The Options: A Planar or a Parasitic Reflector

The most common mental picture that we generate when first encountering the conventional names of Yagi elements is something like a lighthouse beacon. Each light has a reflector to determine the beam direction and a lens to direct and focus the light signal from the structure. So we link the lighthouse's Fresnel lens to the parasitic director or directors of a beam and we associate the beam's reflector with the lighthouse's reflector. Indeed, some lighthouses do not use reflectors, and so, too, we can actually construct parasitic beams without a reflector element. The mental picture is simple, straightforward, coincident with the beam-element names-and mostly wrong.

Some beam types do reflect energy in the conventional lighthouse or flashlight sense. These beams differ in some important respects from parasitic beams, of which the Yagi-Uda array is the most common form. Since I have received numerous questions about the differences between-and the potential interchangeability of-the two types of reflectors, it seems useful to look briefly at these two options for creating directional antennas.

Reflectors that Reflect

Let's begin with reflectors that reflect: the planar (or curtain or sheet) reflector, the corner reflector, and the parabola. Each type has special needs and many variations, and we shall confine our discussion to the planar reflector as perhaps the simplest form of reflector screen. Planar reflectors are very old and often went under the name "billboard" reflectors in the 1920s. **Figure 2** shows the basic principles of the planar reflector's operation, largely derived from optical principles applied to RF energy. The basic unit for understanding the sketch is the ray. If we think of a dipole element, shown on end in the sketch, as emitting rays in all directions, we can trace the patterns that emerge. Some rays are completely reflected forward, where they add to or subtract from the rays from the dipole itself in standard interference patterns. Some rays to the side have no reflected rays for such combinations and hence form partially shadowed areas. Behind the reflector sheet is an area where almost no rays go, creating a full shadow. However, at the reflector edges, we encounter diffraction, with some energy scattered in virtually all directions. Hence, a planar reflector with finite dimensions cannot create an infinite front-to-back ratio.

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

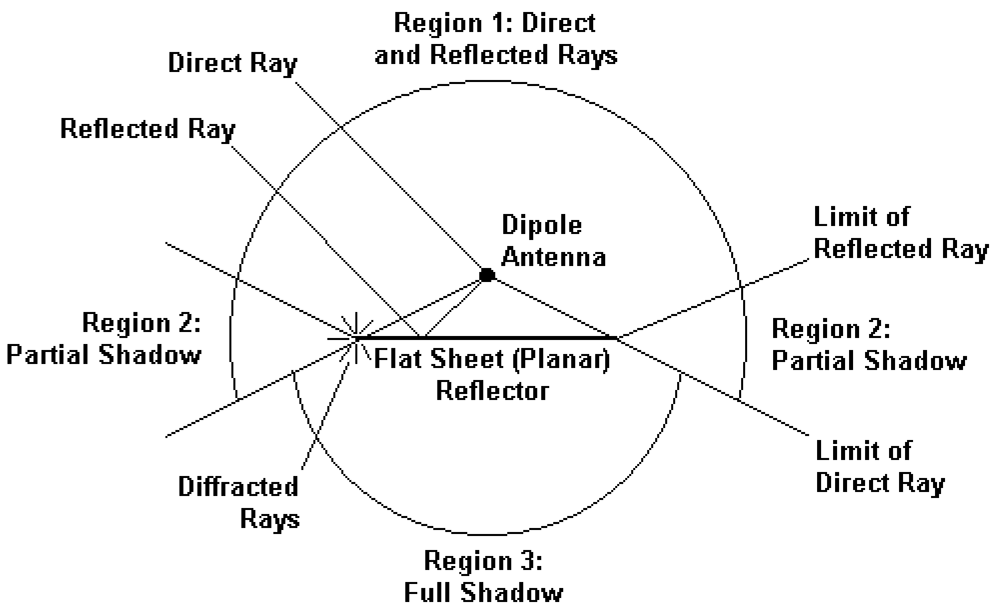


Fig. 2

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

Ahead of them, we can place arrays of phase-fed driver elements, both simple and complex. For example, a common UHF beam uses a planar reflector with a double-diamond element. However, for clarity, we shall use a simple dipole as the driver. As shown in **Figure 3**, we place the dipole ahead of the reflector plane, and the forward radiation consists of the direct rays from the dipole and the reflected rays from the sheet. The reflector size and the placement of the dipole are not arbitrary. The sketch shows most of the critical dimensions for making such a beam.

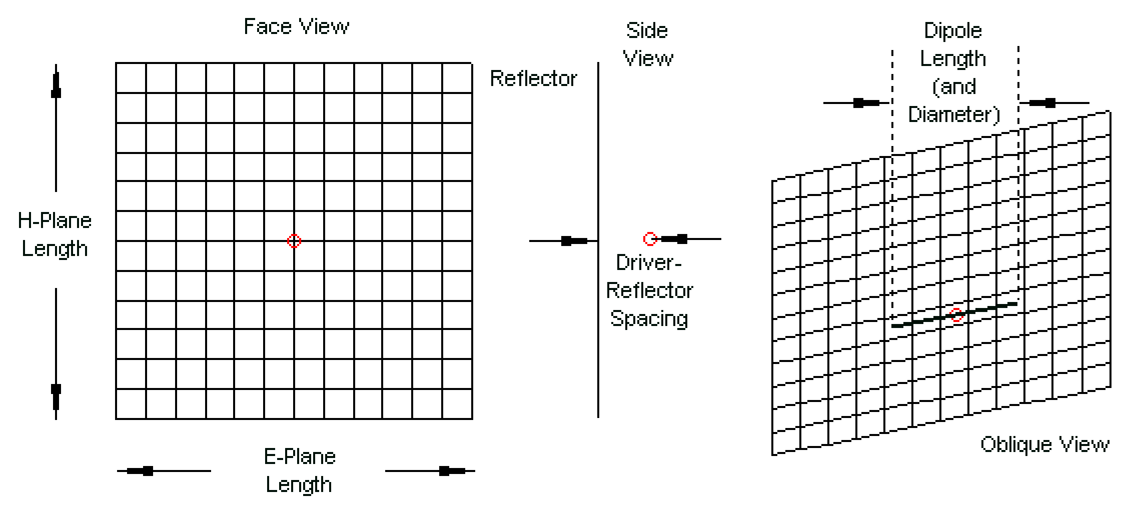


Fig. 3

Planar Reflector and Dipole Driver: Critical Dimensions

Let's begin by assuming that we wish to set the dipole's feedpoint impedance at 50 Ohms. We shall remove this limiting assumption later. However, it will serve us to illustrate one or two points about planar reflectors. First, as shown in the top portion of **Table 1**, the size of the reflector does make a difference in planar beam performance. If our main concern is the front-to-back ratio, then the size of the screen may grow indefinitely, especially off the ends of the dipole, to increase the ratio. If our concern is gain, then there is an optimal reflector size for maximum gain. As a rule of thumb, the reflector should extend from 0.4-wavelength to 0.6-wavelength beyond the limits of the driving element or array. The larger the driver assembly that we use, the larger that the screen must be to achieve maximum gain from the total assembly. As a side note, in the range of reflector sizes shown, using a constant dipole length and spacing from the reflector, the feedpoint impedance does not change significantly as we change the size of the planar reflector.

Table 1. Planar reflector-and-dipole performance as functions of reflector size and element spacing at 435 MHz with 4-mm-diameter dipole

Reflector size: constant 0.175-λ dipole spacing, constant dipole length of 0.442-λ

	Gain dBi	F-B Ratio dB	Feedpoint Z R +/- jX Ω	SWR 50 420 MHz	SWR 50 450 MHz
Small (0.8-λ by 0.8-λ)					
	8.37	16.00	49.7 + j2.0	1.76	1.71
Medium (1.2-λ by 1.2-λ)					
	9.31	18.34	50.1 – j0.3	1.80	1.65
Large (1.6-λ by 1.6-λ)					
	8.64	22.96	49.5 + j0.2	1.81	1.67

Dipole-to-reflector spacing: reflector constant 1.2-λ by 1.2-λ

Spacing λ	Gain dBi	F-B Ratio dB	Feedpoint Z R +/- jX Ω	Dipole Length λ
0.185	9.25	18.17	54.3 – j0.5	0.442
0.175	9.31	18.34	50.1 – j0.3	0.442
0.165	9.37	18.51	45.8 – j0.5	0.442
0.155	9.42	18.67	41.8 + j0.2	0.4428
0.145	9.46	18.81	37.5 + j0.1	0.4434
0.135	9.50	18.94	33.3 – j0.6	0.444

For the simple dipole driver, the 1.2-wavelength-by-1.2-wavelength reflector provides maximum gain. A double-diamond or a bobtail curtain drive might provide up to 2 dB additional gain. As well curtain arrays exist that set vertical and horizontal bays of drivers before very large screens for additional gain. We may increase the front-to-back ratio by increasing the E-plane dimension, that is, the dimension of the reflector parallel to the driving element. If the screen is about 2-wavelength in this direction, the 180ï¿½ front-to-back ratio will approach 30 dB. However, the worst-case front-to-back ratio will tend to remain relatively constant in the 22-24-dB range despite high 180ï¿½ values. Only the rear lobe in line with the axis of the beam undergoes radical reduction.

A second factor is the spacing of the dipole from the reflector plane. As shown by the sample modeled data in Table 1, we can achieve higher gain values and higher front-to-back ratios by moving the dipole closer to the screen. The closer spacing results in more complete illumination of the reflector by the dipole source. As the dipole approaches the reflector, its resonant length slowly changes. As well, the resonant impedance decreases. Whether the performance improvements are worth the inconvenience of requiring more complex matching methods for the amateur's standard 50-Ohm cable is a user decision. Different driver assemblies have different optimal spacing values for a direct 50-Ohm match to the feedline, and as driver assemblies grow more complex, the best match spacing may not be close to the best performance spacing.

Table 2. 435-MHz performance of a planar reflector-and-dipole and of 2- and 3-element Yagis

	Gain dBi	F-B Ratio dB	Feedpoint Z R +/- jX Ω	2:1 SWR Limits F(low) MHz	F(high) MHz
Medium reflector with a 4-mm dipole spaced 0.175-λ away					
	9.31	18.34	50.1 – j0.3	<420	>450
2-element driver-reflector Yagi with 0.125-λ element spacing and 4-mm-diameter elements					
	6.27	11.26	32.8 + j0.4	425	448
3-element Yagi with 0.348-λ boom and 4-mm-diameter elements					
	8.27	24.65	25.3 – j0.4	428	443
Rod planar-reflector simulator (1.2-λ by 1.2-λ via 13 0.036-λ diameter rods spaced 0.1-λ)					
	9.28	18.48	49.2 – j1.0	<420	>450

Note: medium and rod planar reflectors use a 4-mm-diameter dipole spaced 0.175-λ.

When deciding between a planar reflector array and a parasitic beam, we must measure our communications needs against the likely performance of the potential antennas. **Table 2** lists some of the key modeled performance characteristics in free-space of the medium-size reflector with a dipole driver and of two types of Yagis: a 2-element driver-reflector array with the element spacing close to the value that yields the best front to back ratio and a 3-element relatively long boom (0.345-wavelength) Yagi. The 2-element Yagi often serves as a seeming analog to the planar reflector array, but its performance does not approach either the gain or the front-to-back ratio of the true reflector antenna. The 3-

element Yagi in the list beats the planar reflector in the front-to-back category, but not in gain. Of course, we can always add an almost indefinitely large number of directors to the Yagi to improve its gain and to narrow its beamwidth in both the E-plane and the H-plane. See **Figure 4** for free-space patterns in both planes for all three antennas.

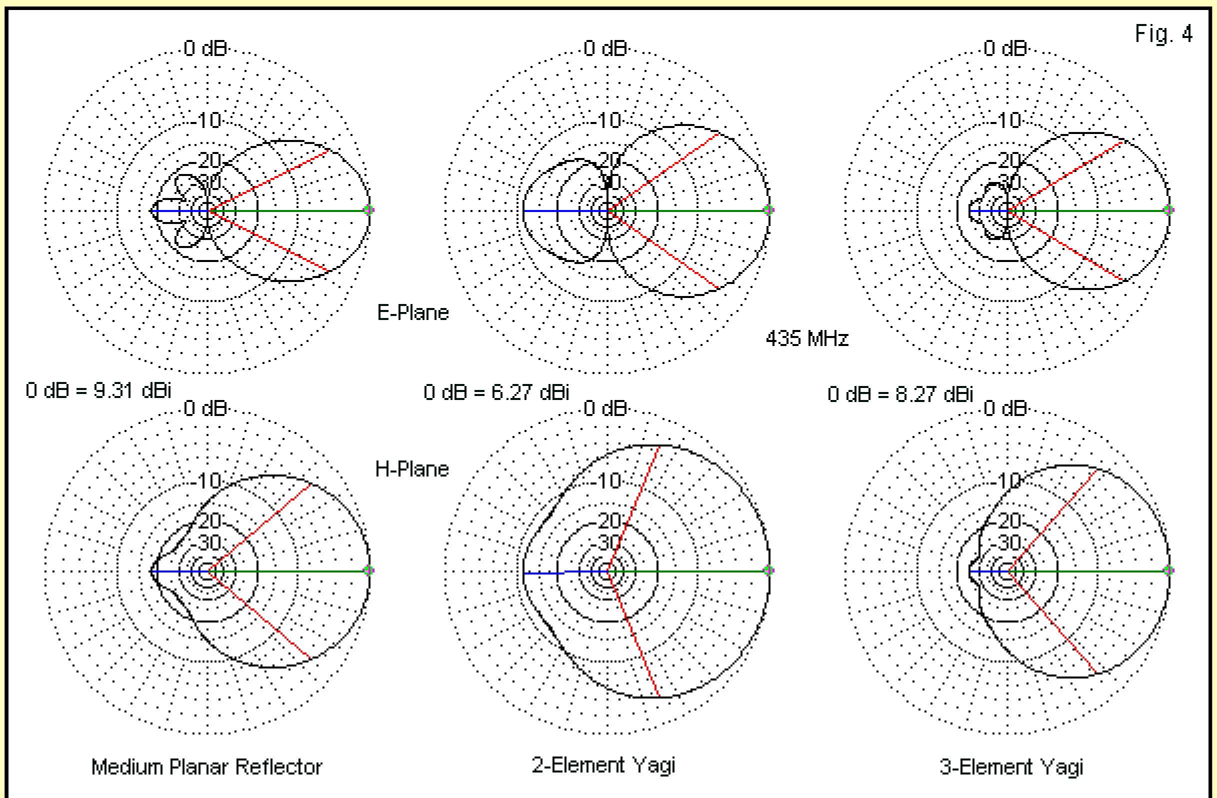


Fig. 4

Comparative E-Plane and H-Plane Free-Space Patterns
Planar Reflector Plus 2- and 3-Element Yagis

The ultimate decision on whether to use a Yagi or a planar reflector does not normally rest on small differentials in gain and the front-to-back ratio. The Yagi, exemplified by the 3-element version in these notes, has by nature a fairly narrow operating bandwidth in which the performance values remain stable. We sometimes talk of broadband vs. narrow band Yagis, but such discussions are relative to Yagis alone. Compared to the planar reflector array, all Yagis are narrow band antennas. **Figure 5** provides data on the modeled gain and front-to-back performance of the 3-element Yagi and the simple planar reflector array. The planar array values are very nearly flat from 420 to 450 MHz. The degree of increasing gain is comparable to the increase that we associate with the dipole alone as it grows longer as a function of a wavelength. In contrast, the Yagi gain shows a continuous rise with frequency. Just above the band edge, it will peak and then the Yagi will reverse its direction. The Yagi front-to-back ratio peaks at mid-band and declines toward the band edges.

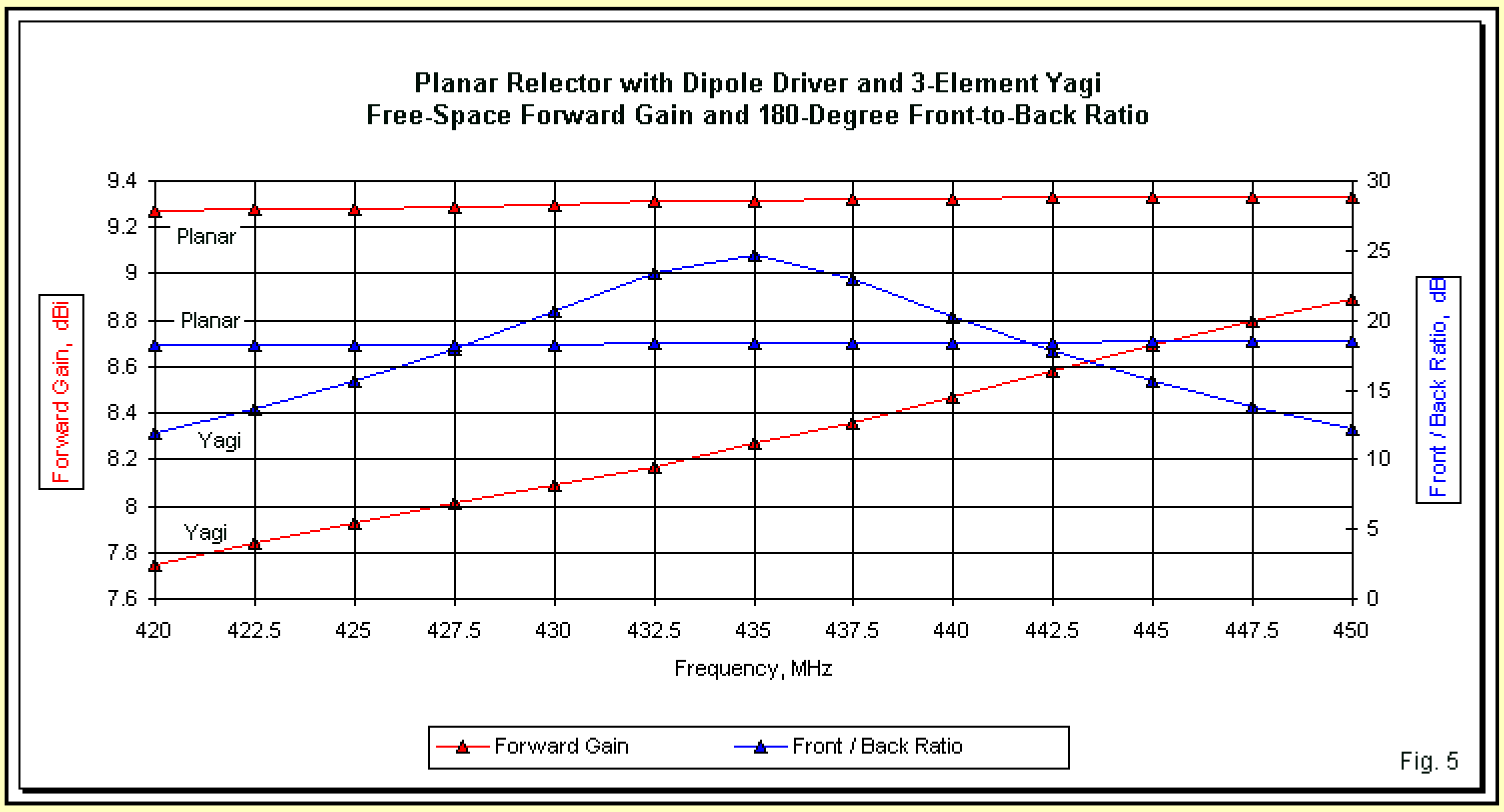


Fig. 5

Paralleling the performance curves are the SWR curves. **Figure 6** shows three curves, each referenced to the self-resonant impedance of each antenna. The broadest curve belongs to a simple dipole, in this case, using a 4-mm-diameter element like all other elements in these notes. The planar array curve comes next and shows that the antenna provides impedance service almost as wide as the gain and front-to-back curves. In contrast, the 3-element Yagi provides less than a 2:1 SWR only over about half of the 70-cm band.

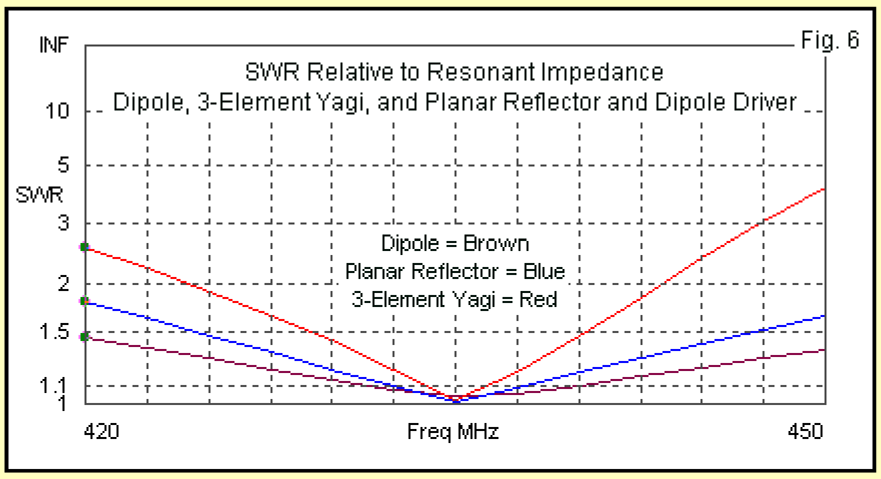


Fig. 6

Table 2 has a special final entry. We may simulate a solid planar reflector by using a series of rods in the plane of the driver. Obtaining the performance of a solid or screen reflector has several requirements. As shown in **Figure 7**, the total area of the rod reflector, much used in the past for television antennas, must equal the area of the screen reflector. In addition, the simulated solidity of the screen depends upon using a number of rods and an individual rod diameter that together fill in the screen. The fewer the rods that we use, the fatter we must make each rod. The present example uses 13 rods, each 0.036-wavelength (25-mm at 435 MHz). In most applications, the performance of a rod reflector is the same as an equal-size screen. However, in other optically based reflector forms, such as corner reflectors, the rod reflector will show hybrid characteristics, partially parasitic and partially optical.

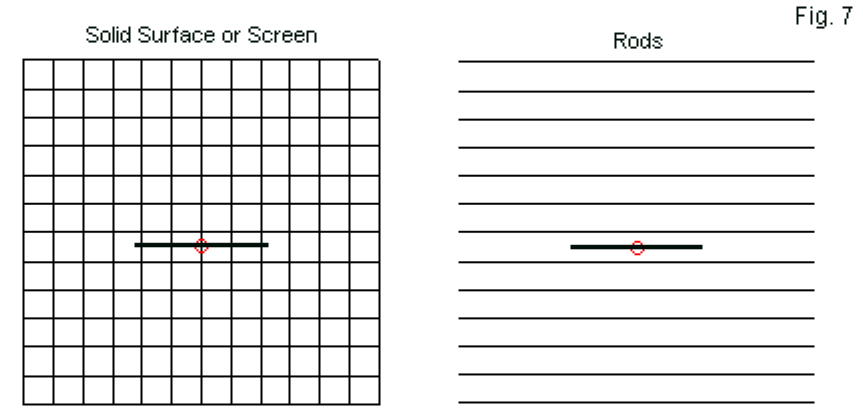


Fig. 7

Dipole Driver with Solid Surface or Screen Planar Reflector
and with Multiple-Rod Substitute

Parasitic "Reflectors"

Applied to a parasitic array, the term reflector is simply a conventionalized term used to locate the appropriate element. The fact that it is normally-but not always-longer than the driver element leads to misimpressions about how it works. In fact, parasitic arrays are special forms of phased element sets in which we let the geometry of the elements determine the correct relative current magnitudes and phase angles of the elements for directional operation. For arrays based on half-wavelength elements, we normally measure the current magnitude and phase angle at the element center, where the current reaches its peak value.

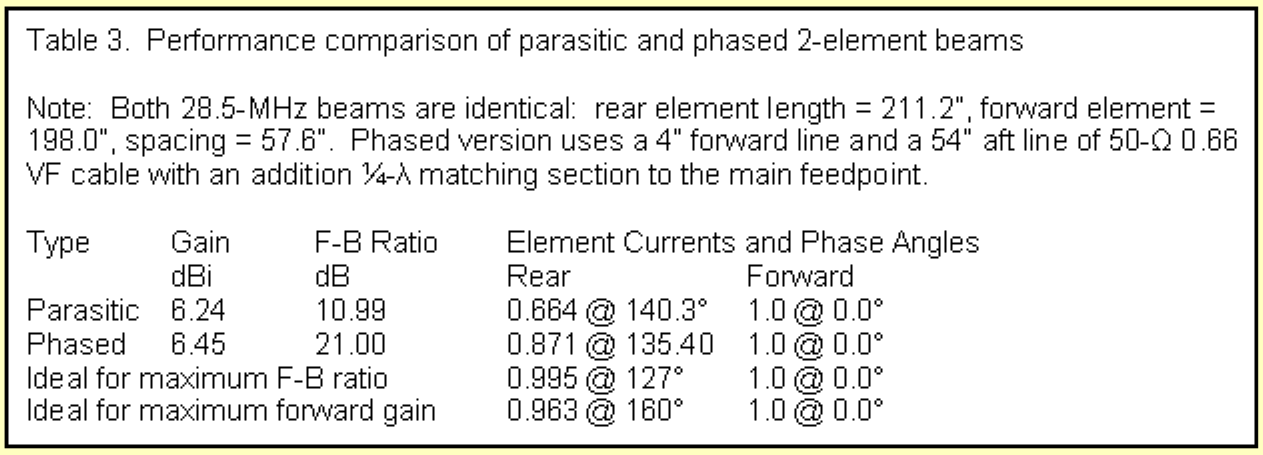


Table 3. Performance comparison of parasitic and phased 2-element beams

Note: Both 28.5-MHz beams are identical: rear element length = 211.2", forward element = 198.0", spacing = 57.6". Phased version uses a 4" forward line and a 54" aft line of 50-Ω 0.66 VF cable with an addition ¼-λ matching section to the main feedpoint.

Type	Gain dBi	F-B Ratio dB	Element Currents and Phase Angles Rear	 Forward
Parasitic	6.24	10.99	0.664 @ 140.3°	1.0 @ 0.0°
Phased	6.45	21.00	0.871 @ 135.40	1.0 @ 0.0°
Ideal for maximum F-B ratio			0.995 @ 127°	1.0 @ 0.0°
Ideal for maximum forward gain			0.963 @ 160°	1.0 @ 0.0°

When we have only two elements of equal or nearly equal length, we can find relative current magnitude and phase angle combinations that yield a maximum front-to-back ratio and other combinations that yield maximum gain. The values for each combination vary with the spacing and the exact length of the elements involved. Let's turn to a 10-meter portable beam that I built a number of years ago. **Table 3** shows the dimensions of the array, and the two lower angles provide the ideal figures for either a very high 180ï¿½ front-to-back ratio or for maximum gain (with a front-to-back ratio in the 7-8-dB range).

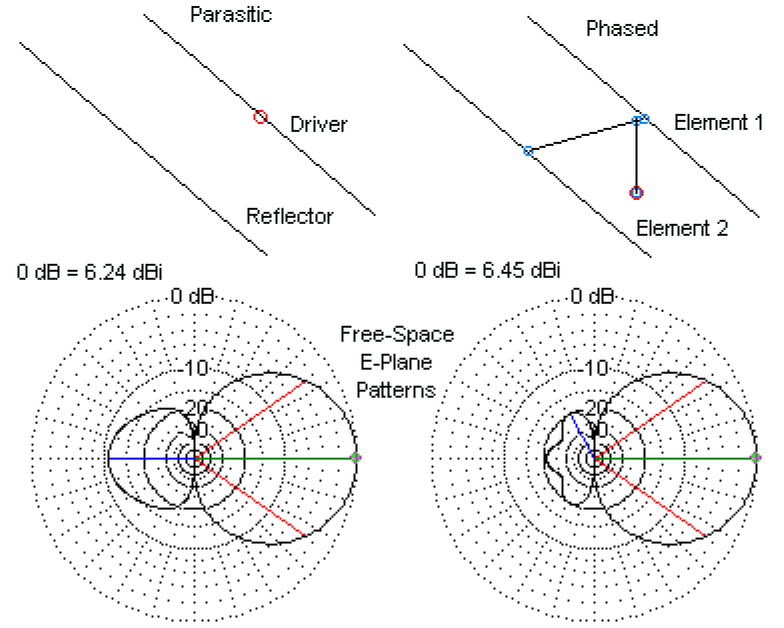


Fig. 8

Identical Element Pairs
Parasitically and Phase Fed

Figure 8 provides outlines of two forms for the same element set. The first form employs the beam as a standard driver-reflector Yagi. As the tabular values show, confirmed generally by the free-space E-plane pattern, the beam has modest performance, but is typical of the genre. The second form of the beam adds a harness of transmission lines that improve the current magnitude and phase angle relationships between the forward and the rear elements relative to the beam direction. (It is somewhat of a mistake to label phased array elements as a driver and a reflector.) The gain increases slightly, but the most noticeable operational improvement is the front-to-back ratio. As the E-plane pattern shows, the entire rearward radiation has decreased very significantly.

The exercise simply points to two significant facts about parasitic reflectors. First, we use a reflector size and spacing to obtain as best we can within physical geometry limits a current magnitude and phase angle combination to enhance the directivity of a beam. Second, relative to the driver, the reflector phase angle will normally be positive. As we add directors to a Yagi array, the role of the reflector changes. Although we may adjust its position and length to enhance performance slightly, it serves largely to set the driver's impedance. How much of a role the reflector element plays in obtaining a desired level of gain or front-to-back ratio depends upon the particular Yagi design.

As we increase the number of elements in a parasitic beam, the simple relationships in the current and phase angle among the elements tend to shift. The reflector remains at a positive phase angle relative to the driver in almost all cases, while the first director ahead of the driver will have a negative phase angle relative to the driver. (For exercises in this regard, we normally set the driver current magnitude at 1.0 and a phase angle of 0.0ï¿½. The normalized set-up eases the process of comparing values among beam designs.) As soon as we use even one director, the idealized 2-element relationships become void relative to specific values.

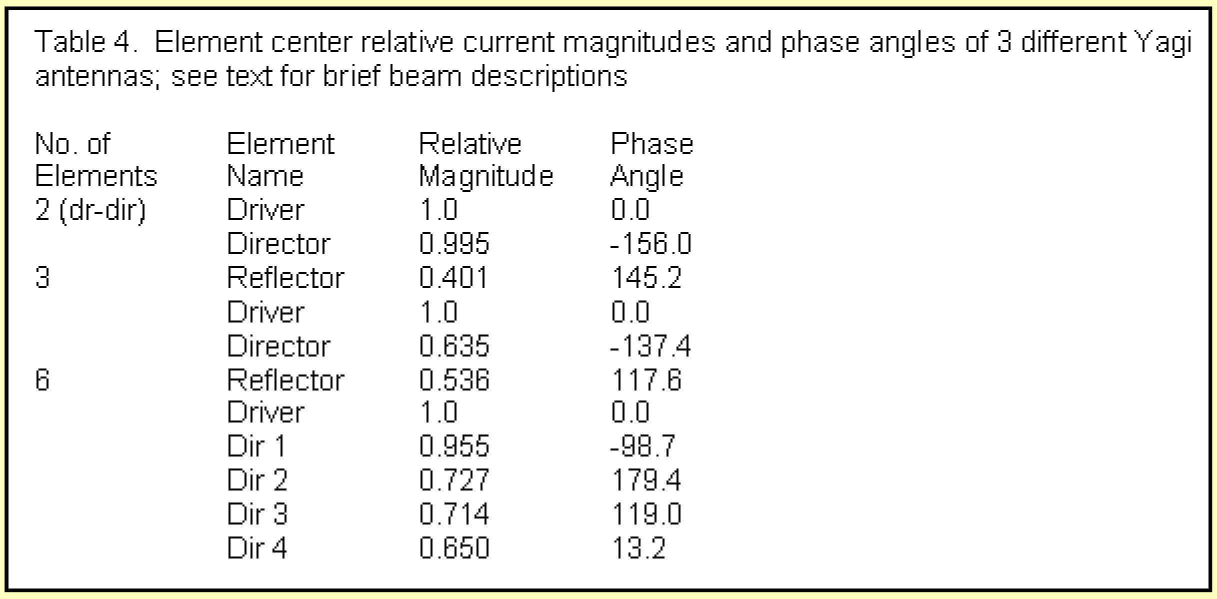
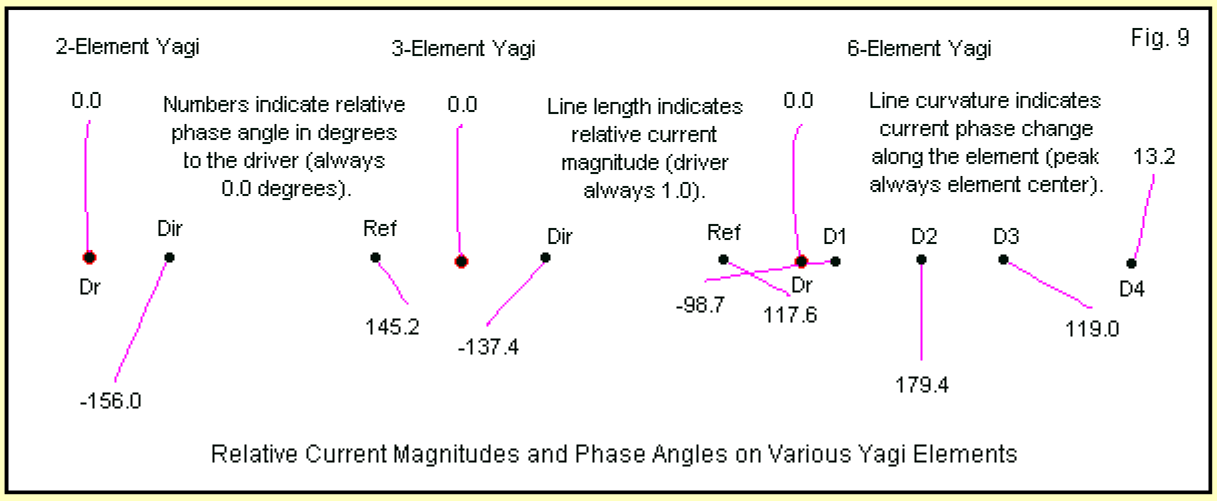


Table 4. Element center relative current magnitudes and phase angles of 3 different Yagi antennas; see text for brief beam descriptions

No. of Elements	Element Name	Relative Magnitude	Phase Angle
2 (dr-dir)	Driver	1.0	0.0
	Director	0.995	-156.0
3	Reflector	0.401	145.2
	Driver	1.0	0.0
	Director	0.635	-137.4
6	Reflector	0.536	117.6
	Driver	1.0	0.0
	Dir 1	0.955	-98.7
	Dir 2	0.727	179.4
	Dir 3	0.714	119.0
	Dir 4	0.650	13.2

Table 4 provides the element-center current magnitude and phase angle values for 3 Yagi beams: a 2-element driver-director array, a 3-element antenna, and a 6-element OWA (optimized wide-band antenna) design. **Figure 9** shows the current magnitudes and phase angles in graphical form. The length of each line is proportional to the relative current magnitude, while the angle is proportional to the phase angle relative to the vertical line for the driver current. Some of the lines have perceptible curves, indicating the change in the current phase angle along the element from the center peak to the element end that intersects with the edge dot representing the element. In this set of examples, a counterclockwise direction indicates a negative phase angle, while a clockwise direction indicates a positive phase angle. (If you model antennas and replicate this exercise using parasitic beams of your choice, be certain that all elements-and sections of elements in stepped-diameter element designs-use the same orientation. Universally reversing the element direct will reverse the clockwise-counterclockwise orientation of the graphs, while randomly changing element and element section directions will yield a largely unreadable graph.)



Relative Current Magnitudes and Phase Angles on Various Yagi Elements

The 2-element Yagi shows a relative director current that is nearly identical to the value of the driver, with a relative phase angle of -156ï¿½. At the design frequency (435 MHz), the two elements have nearly ideal conditions for achieving a high front-to-back ratio. Maximum front-to-back values would require a relative current magnitude of about 1.025 with a phase angle of -154ï¿½ at the element spacing shown (0.08-wavelength). (Note that with two elements, the required ideal current magnitudes and phase angles will be the same relative to the forward and rearward elements. However, in a parasitic design, which element we feed makes a considerable difference in our ability to find a geometry that will produce desirable results. The present design produces excellent performance, but only over a very narrow bandwidth.)

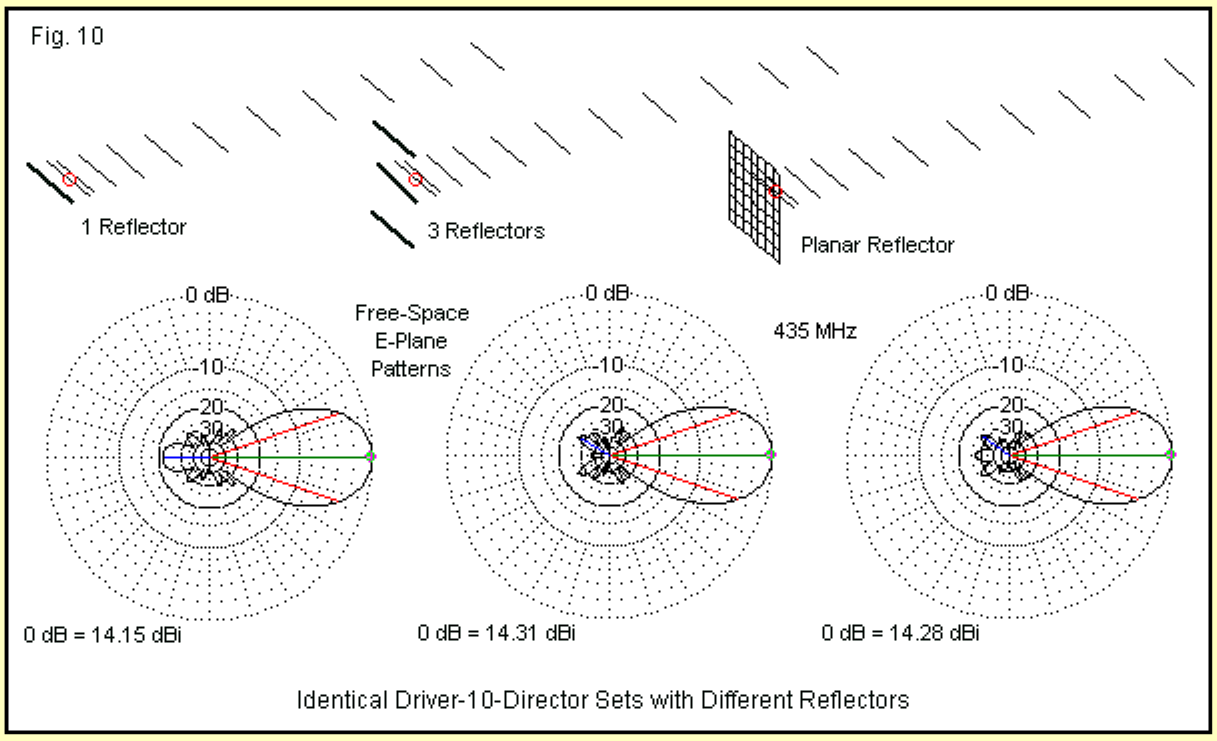
The current magnitudes and phases angles associated with the 3-element Yagi coincide roughly with at least the phase-angle rules of thumb. The reflector phase angle is positive, while the director phase angle is negative. However, the exact values are functions of the element lengths and their spacing from the driver. There are numerous configurations for 3-element Yagis, each suited to a specific performance task. In each case, the exact values will be different from those shown for the same beam. The 6-element Yagi illustrates how complex the pattern of current magnitude and phase-angle values may become as we add directors and configure them for desired performance levels. The sample beam has a wide bandwidth (relative to Yagis as a whole) in part controlled by the close spacing of the driver and the first director. Above the design frequency, the first director's current magnitude will actually exceed the magnitude on the driver and form a secondary driver to control performance at the higher end of the operating spectrum. Hence, the current magnitude and phase-angle values on the array element will shift with the operating frequency.

In fact, we normally design parasitic beams by reference to the performance they yield, letting the current magnitudes and phase angles be whatever they must be to obtain that performance. Antenna modeling software abets this process, since the performance values generally appear with polar plots of anticipated radiation patterns. Hence, many beam designers never look at the current values on the elements. This process helps us forget that parasitic reflectors do not reflect in the optical sense. Rather, they remain part of the phasing system for a directional set of elements.

The Interchangeability of Planar and Parasitic Reflectors

The idea of replacing a parasitic reflector with a planar reflector is natural, but filled with questions. The key question is whether we gain anything in the process. Long-boom Yagi enthusiasts have pondered this question since (at least) DJ9BV's use of a reflector plane consisting of 4 reflector elements. The spacing between the reflectors was too wide to form a true planar reflector, but the builder claimed additional performance relative to a single reflector.

Fig. 10



Identical Driver-10-Director Sets with Different Reflectors

The feasibility of replacing a single parasitic reflector with a planar reflector depends in large part on the radiation directed toward it. Therefore, the key test is whether the set of elements from the driver forward and with no reflector element has a large rearward lobe or set of lobes. In such cases, a planar reflector or some other system of reflectors may improve performance over a single parasitic reflector. **Figure 10** outlines a series of arrays that use a driver with 10 identical directors. The sketches show a single parasitic reflector, a system of three reflectors, and a planar reflector. **Table 5** shows the results of the experiment.

Table 5. Free-space performance comparison among identical 435-MHz element sets (driver plus 10 directors, all 4-mm in diameter) with different reflector assemblies

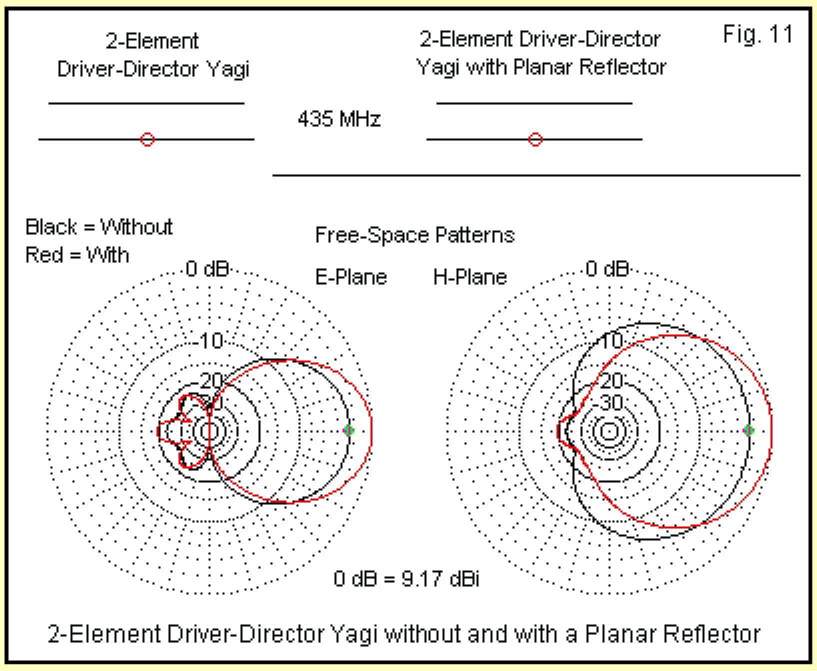
Reflector Type	Gain dBi	F-B Ratio dB	Feedpoint Z R +/- jX Ω
None	12.99	13.08	48.1 – j7.5
1 element	14.15	21.45	57.5 + j9.8
3 elements	14.31	37.10	60.4 + j8.7
Screen	14.28	33.25	59.2 + j12.8

Note: single reflector element is 348 mm long; additional 2 reflectors are 350 mm long and spaced 15 mm behind the center reflector and 210 mm above and below the main element axis. The screen required for the performance shown is 500 mm by 500 mm and in the normal single-reflector position.

A single reflector element provides good performance from the array. The free-space gain is over 14 dBi, and the front-to-back ratio is greater than 20 dB. The second step adds two further reflectors, each about 2 mm longer than the original and space 15 mm behind the central reflector element. The vertical distance between these reflectors is 420 mm. The augmented parasitic system increases the gain by less than 0.2 dB. The 180ï¿½ front-to-back ratio gives us an illusion of a high improvement in the rearward direction, but the pattern in Figure 10 shows that there are quartering rear sidelobes that are down by only about 5 dB relative to the single-reflector version.

The final step in the progression replaces the system of reflector elements with a planar reflector. To obtain the performance of the 3-reflector model, the screen required 500-mm by 500-mm dimensions. Whether either "improved" reflector system is worth the construction effort may depend as much on mechanical factors as on performance benefits. The 3-reflector system is complex, requiring a boom extension and a vertical support for the elements. The planar reflector might consist of light screen material, but it would require bracing to maintain its shape. Both augmented reflector system would add to the wind forces on the antenna. Hence, the decision to use an augmented reflector system must weigh performance against potential mechanical disadvantages.

Fig. 11



2-Element Driver-Director Yagi without and with a Planar Reflector

A planar reflector may give the illusion of improving the performance of a small Yagi. Consider the 2-element driver-director array that we used to show current magnitudes and phase angles on the elements. Since it has no reflector, perhaps adding a planar reflector might improve performance. **Figure 11** shows the outline and free-space patterns of the two arrays. The pattern with the higher gain belongs to the version with the planar reflector. In this case, the presence of the reflector appears to improve performance-at least with respect to gain-by almost 2 dB. The key pattern modification is the reduced beamwidth of the planar version.

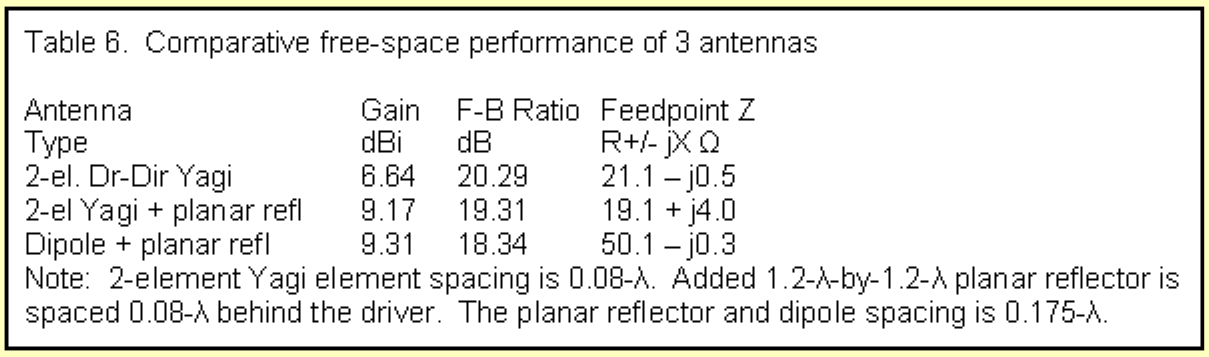


Table 6. Comparative free-space performance of 3 antennas

Antenna Type	Gain dBi	F-B Ratio dB	Feedpoint Z R+/- jX Ω
2-el. Dr-Dir Yagi	6.64	20.29	21.1 – j0.5
2-el Yagi + planar refl	9.17	19.31	19.1 + j4.0
Dipole + planar refl	9.31	18.34	50.1 – j0.3

Note: 2-element Yagi element spacing is 0.08-λ. Added 1.2-λ-by-1.2-λ planar reflector is spaced 0.08-λ behind the driver. The planar reflector and dipole spacing is 0.175-λ.

However, consult **Table 6**. The first two entries confirm the impression that we gleaned from the patterns. The final entry shows what is actually happening. With only a dipole, a planar array has virtually the same performance as the reflector with 2 elements ahead of it. The director adds nothing to the planar array performance, but does reduce the feedpoint impedance. For the best performance, we might keep the planar reflector and do away with the parasitic director.

Planar and other optically based reflectors depend upon the illumination provided by the source. Planar arrays are most effective with either single drivers or collections of phase-fed drivers properly spaced ahead of them. Corner arrays tend to require single dipole drivers or end-to-end arrays of drivers, since the illumination of a corner reflector with a 60 degree to 90 degree angle is quite complex. In contrast, parabolic reflectors operate best when the total driving source energy points toward and illuminates the entire the parabolic surface. Ray-tracing graphs and equations best describe the function of each type of reflector.

In contrast, parasitic reflectors require positions and lengths that determine the optimal current magnitude and phase angle for directional beam operation. However, the exact values depend upon the complex interaction of all of the antenna elements. Although we can certainly design Yagi and other parasitic beams without reference to element current magnitudes and phase angles, reference to these parameters may help us understand why a Yagi is not a flashlight.

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