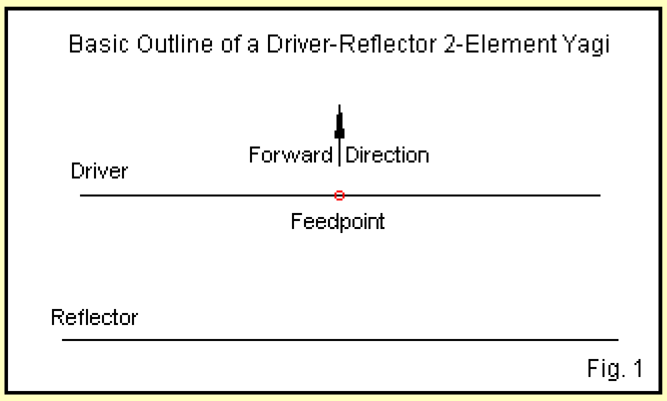
What Can We Expect from a 2-Element Beam?

Part 2
The Full-Size 2-Element Yagi

L. B. Cebik, W4RNL (SK)

In this episode, we shall develop some basic ideas about driver-reflector 2-element Yagis. The relatively broadband characteristics of the driver-reflector Yagi open it to relatively easy reproduction by the newcomer. As well, as we shall discover in the following 2 episodes, it is amenable to certain kinds of compacting. Therefore, we shall set aside the director in favor of the configuration shown in **Fig. 1**.



By working with a full-size 2-element Yagi, we simplify construction. Besides a mast and boom, all that we need are linear elements, usually made from aluminum tubing. As in the first episode, we shall use 3/8"-diameter elements. In practice, a builder would usually use elements with a tapered-diameter schedule. Typical element tubing ranges are 3/4-5/8-1/2-inch for very high wind loads or 5/8-1/2-3/8-inch for moderate wind loads.

The Full-Size 2-Element Yagi

Two-element Yagis have several variables around which the design revolves.

1. Spacing between elements;
2. Length of reflector; and
3. Length of driven element.

We can also handle these variables in a number of ways. for example, we can

1. Optimize gain at the design frequency;
2. Optimize front-to-back ratio at the design frequency;
3. Strive for resonance;
4. Strive for maximum operating bandwidth (perhaps as defined by a 2:1 SWR); and/or
5. Strive for a 50-ohm match.

The mix and match of design goals leads to an almost indefinitely large number of antenna designs, according to what compromises the designer reaches. A maximum gain design may yield a combination of elements leaving considerable reactance at the feedpoint. Altering the driven element toward resonance may yield an element combination, even when the reflector is re-maximized for gain, which is slightly off peak. Similar compromises apply to any other combination of ingredients in the design goals.

Designing for Maximum Font-to-Back Ratio

We shall look at several models in free space using different spacing values. We shall optimize the design for maximum front-to-back ratio and resonance for each spacing value. The degree of element lengthening needed for a gamma or Tee match, or the degree of shortening needed for a beta match, is too small to make a significant difference in performance. To see why designers lean toward the maximum front-to-back ratio frequency as the design center (or near-center), we shall later examine some beams designed for maximum gain at the design center frequency. We shall also look at some models over real ground using one or two spacing values and optimized for front-to-back ratio at antenna resonance to determine the operating bandwidth characteristics of the array.

In general, 2-element Yagis optimized for maximum front-to-back ratio have resonant feedpoint impedances in the mid-30-Ohm range with spacing values of about 1/8 wavelength and in the 50-ohm range with spacing values in the vicinity of 0.16 wavelength. These values represent a range of 4.1 to 5.4 feet at 29 MHz, which you can scale to any other frequency with an appropriate multiplier.

Let's take a more comprehensive look at this collection of antennas by specifying a sequence of spacing at 0.04 wavelength intervals from 0.08 wavelength through 0.24 wavelength (2.7' through 8.1'). The models will be in free space. The dimensions used for these models appear in **Table 1**.

Table 1. Dimensions of models used in evaluating performance vs. element spacing. All elements 3/8" aluminum.

Spacing		Driver Length		Reflector Length	
WL	Feet	WL	Feet	WL	Feet
0.08	2.71	0.472	16.01	0.502	17.02
0.12	4.07	0.466	15.82	0.503	17.06

0.16	**5.43**	**0.464**	**15.74**	**0.503**	**17.05**
0.20	**6.78**	**0.464**	**15.75**	**0.503**	**17.05**
0.24	**8.14**	**0.466**	**15.82**	**0.502**	**17.03**

Although there may not be very much difference between element lengths for each step, obtaining adequate performance over a desired bandwidth requires very careful building.

Table 2 provides data on the modeled performance of these beams using NEC (either -2 or -4). The gain values are for free space. To obtain an estimate of the gain at 1-wavelength above ground, add about 5.4 dB to the gain values in the tables. The driven element is resonant within j+/-1 Ohms in each case. Gain figures will be for 29 MHz, although that is the frequency of maximum front-to-back ratio. Maximum gain occurs somewhat lower in frequency.

Table 3. Modeled NEC (-2 or -4) performance of the 2-element Yagis in Table 1.
(Reference dipole gain in free space = 2.13 dBi)

Spacing	Gain (dBi)	Gain (dBdr)	F-B (dB)	Feed Z (R +/- jX)
0.08 wl	**6.32**	**4.19**	**11.37**	**17.27 + j0.06**
0.12	**6.25**	**4.12**	**11.20**	**32.04 - j0.00**
0.16	**6.12**	**3.99**	**10.84**	**46.87 + j0.03**
0.20	**5.88**	**3.75**	**10.35**	**61.07 - j0.13**
0.24	**5.56**	**3.43**	**9.71**	**73.01 - j0.34**

Let's make the same run with MININEC (**Table 3**). Typically, MININEC yields dimensions that are about 0.04' (1/2") shorter than NEC at 29 MHz, although some versions of MININEC have a correction factor to bring them into alignment as frequency increases. (The MININEC program Antenna Model has been so thoroughly corrected that its results correlate almost perfectly with NEC.)

Table 3. Modeled MININEC performance of the 2-element Yagis in Table 1.
(Reference dipole gain in free space = 2.12 dBi)

Spacing	Gain (dBi)	Gain (dBdr)	F-B (dB)	Feed Z (R +/- jX)
0.08 wl	**6.31**	**4.19**	**11.40**	**17.09 - j0.59**
0.12	**6.25**	**4.13**	**11.19**	**32.33 + j0.17**
0.16	**6.09**	**3.97**	**10.86**	**46.84 - j0.56**
0.20	**5.87**	**3.75**	**10.34**	**61.12 + j0.07**
0.24	**5.56**	**3.44**	**9.72**	**72.42 - j0.59**

The differences between the two modeling systems are not great enough to make a difference under any practical circumstance. If you create your own models using the dimensions in **Table 1**, you may find very small differences in the results that you obtain. Different implementations of both NEC and MININEC exhibit very small (and operationally insignificant) differences due to methods of compilation. As well, different CPUs may also show slight differences in results, even though using the same program. These differences would only matter if they reach the level of being operationally significant.

To understand why designers tend to select spacing values of 0.12 wavelength to 0.16 wavelength, we need one additional data table in hand: the SWR of the antennas across the band from 28 to 30 MHz (given here at 0.5 wavelength, using the SWR sweep facility of EZNEC). Each sweep in **Table 4** is centered on the resistive component of the feedpoint impedance at the design center frequency. Values greater than 1.0 occur at that frequency because of the remnant reactance.

Table 4. SWR values relative to the resonant impedance for the test models.

Spacing	SWR at 28	28.5	29	29.5	30 MHz
0.08 wl	**30.3**	**5.64**	**1.02**	**3.01**	**5.66**
0.12	**7.34**	**2.37**	**1.00**	**1.82**	**2.78**
0.16	**3.52**	**1.70**	**1.00**	**1.47**	**2.00**
0.20	**2.31**	**1.42**	**1.00**	**1.31**	**1.66**
0.24	**1.82**	**1.29**	**1.01**	**1.23**	**1.48**

Fig. 2 provides a graphic view of the same data so that you may better see the rates of change of SWR both above and below the design frequency.

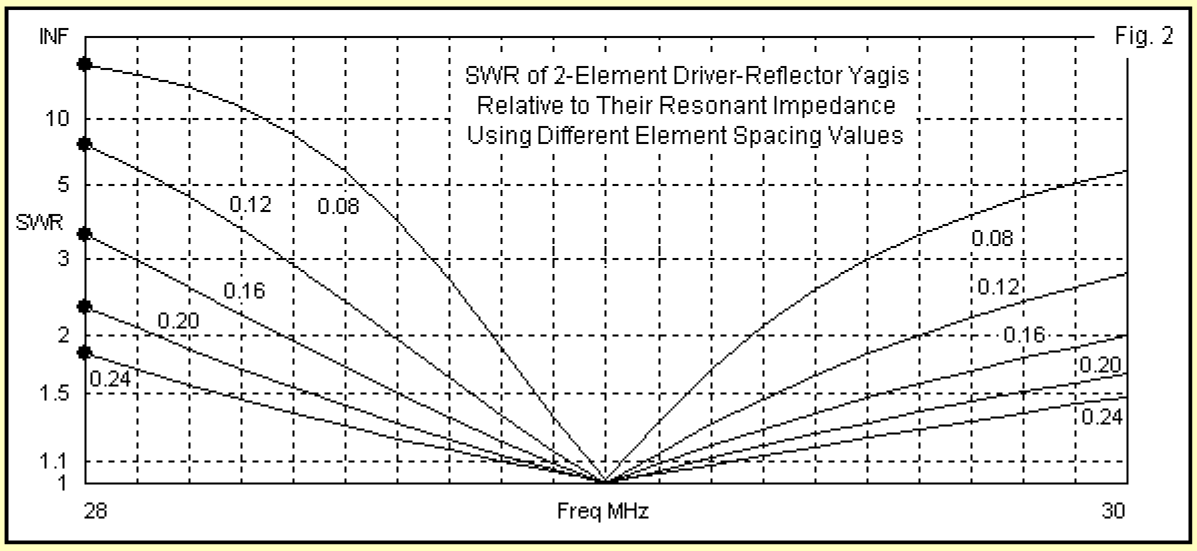


Fig. 2

Obviously, the widest spacing offers the greatest operating bandwidth, but at the cost of reduced gain and front-to-back ratio. Consequently, a design tends to compromise among the highest gain, the highest front-to-back ratio, adequate operating bandwidth, and feedpoint impedance. 0.16 wavelength spacing offers the opportunity for a direct match to 50-ohm coax feedlines with a fairly useful bandwidth for most of the HF ham bands. (Remember to reduce the bandwidth by dividing the 10-meter figure by the ratio of 29 MHz to the frequency of interest for lower HF bands.) Spacing values closer to 0.12 wavelength yield higher gains and front-to-back ratios, but over a narrower bandwidth.

There are two other design problems one must consider. First, the frequency of maximum gain is well below the frequency of maximum front-to-back ratio. The gain tapers gradually as the frequency increases within the operating bandwidth. Second, SWR increases rapidly below the design frequency and more slowly above it. When this factor is combined with the gain situation, one can design an illusion: an antenna with decent SWR but very little gain or front-to-back ratio in the upper half of its operating range.

To illustrate this situation, let's look at the models in more detail, examining their gain and front-to-back patterns across 10 meters. **Table 5** presents sampled data in 0.5-MHz increments.

Table 5. Performance of the 2-element Yagis from 28 to 30 MHz.

Frequency	**28**	**28.5**	**29**	**29.5**	**30 MHz**
0.08 wl spacing					
Gain (dBi)	**6.37**	**6.92**	**6.32**	**5.77**	**5.37**
Gain (dBdr)	**4.24**	**4.79**	**4.19**	**3.64**	**3.24**
F-B (dB)	**1.82**	**8.65**	**11.38**	**10.12**	**8.57**
0.12 wl spacing					
Gain (dBi)	**6.98**	**6.74**	**6.25**	**5.82**	**5.48**
Gain (dBdr)	**4.85**	**4.61**	**4.12**	**3.69**	**3.35**
F-B (dB)	**5.46**	**9.79**	**11.19**	**10.37**	**9.18**
0.16 wl spacing					
Gain (dBi)	**6.88**	**6.55**	**6.12**	**5.74**	**5.43**
Gain (dBdr)	**4.75**	**4.42**	**3.99**	**3.61**	**3.30**
F-B (dB)	**6.66**	**9.84**	**10.86**	**10.29**	**9.32**
0.20 wl spacing					
Gain (dBi)	**6.64**	**6.28**	**5.87**	**5.50**	**5.20**
Gain (dBdr)	**4.51**	**4.15**	**3.74**	**3.37**	**3.07**
F-B (dB)	**7.31**	**9.66**	**10.35**	**9.87**	**9.03**
0.24 wl spacing					
Gain (dBi)	**6.37**	**5.98**	**5.56**	**5.18**	**4.86**
Gain (dBdr)	**4.24**	**3.85**	**3.43**	**3.05**	**2.73**
F-B (dB)	**7.36**	**9.22**	**9.73**	**9.29**	**8.51**

Fig. 3 provides a graph of the gain curves for the three values of spacing (0.08, 0.16, and 0.24 wavelength). Had I used only the 3 middle values from the table, the gain curve lines would not be clear. The increment used in the sweeps is 0.1 MHz.

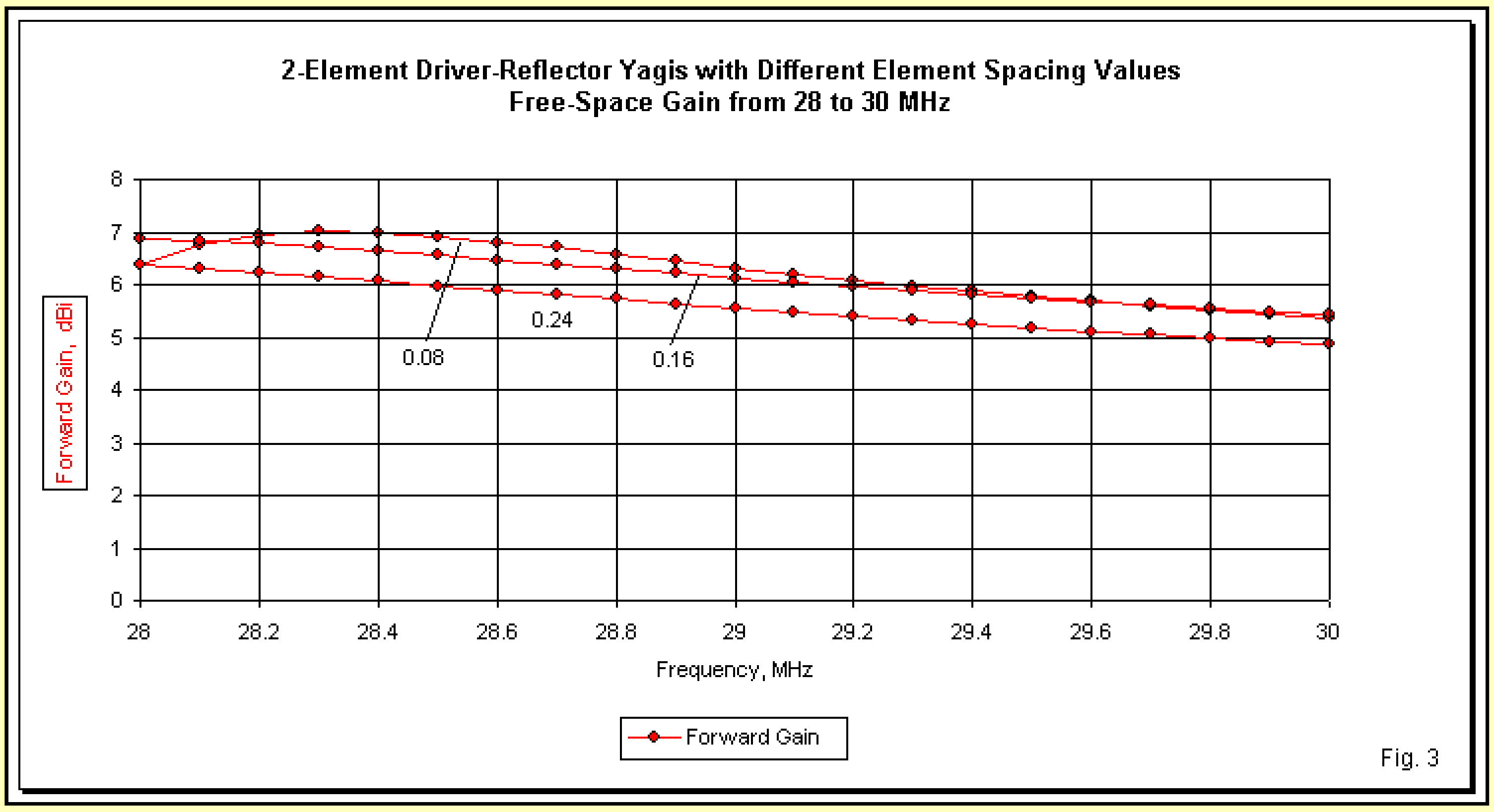


Fig. 3

The gain curves are generally parallel to each other. However, the display of the curve for the closest spacing shows what happens at some frequency below the design frequency. The gain rises slowly, but at a certain frequency, it begins to drop rapidly. The same phenomenon occurs with the curves for the wider spacing of elements, but the frequency at which the gain drops off falls below the limit of the sweep. The gain curve for the driver-reflector type of Yagi is unique. Any Yagi with at least one director will produce a curve with the opposite characteristic, that is, the gain will rise as frequency increases.

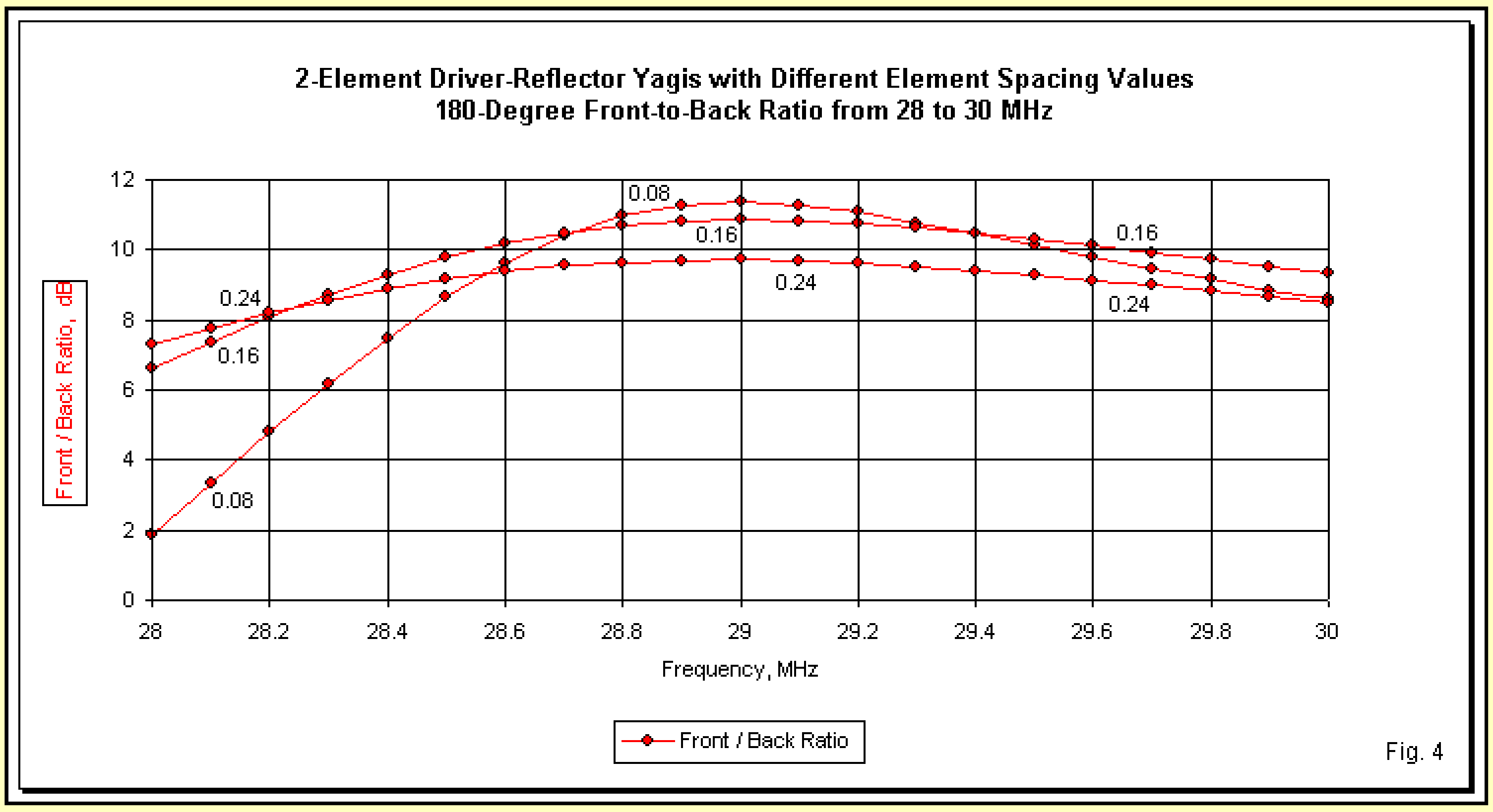


Fig. 4

Fig. 4 shows the 180-degree front-to-back ratios for the same three Yagi designs. At the design frequency, closer spacing yields a higher front-to-back ratio. However, closer spacing yields a smaller range over which the front-to-back ratio remains near its peak value. In contrast, wider spacing yields a lower value of peak front-to-back ratio, but the ratio remains near the peak value over a wider range of frequencies. Note that, like the SWR, the front-to-back ratio tends to decrease more rapidly below the design frequency than above it.

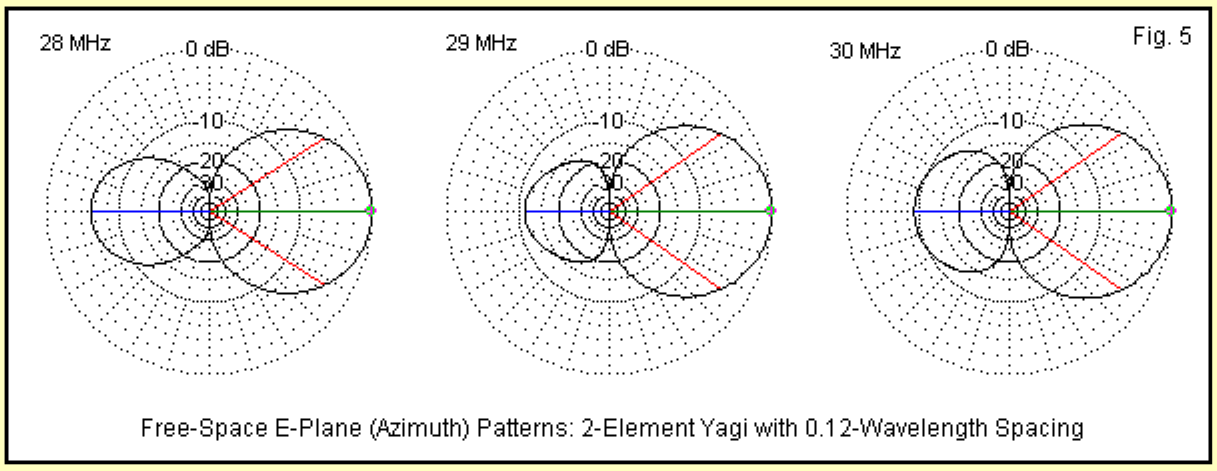


Fig. 5

Free-Space E-Plane (Azimuth) Patterns: 2-Element Yagi with 0.12-Wavelength Spacing

Fig. 5 shows three free-space patterns for the Yagi with 0.16-wavelength element spacing. It illustrates typical patterns at 28, 29, and 30 MHz. Note that the rear lobe changes its size or strength, but it remains "well behaved." That is, it does not develop large multiple lobes, but remains a single rearward lobe. The patterns also illustrate why we may use the 180-degree front-to-back ratio as a marker of performance with this series of beams. The 180-degree ratio and the worst-case ratio are identical. As we saw in the first episode, this feature does not hold true for every possible 2-element Yagi design.

From tables and graphs we can draw several conclusions applicable to 2-element Yagis on any band.

1. Reading across the tables, it is clear that the maximum gain frequency is within the sweep for the closest spaced beam, but at or beyond the lower frequency limit for the other models. The closer the spacing, the closer together are the frequencies of maximum gain and maximum front-to-back ratio.

2. The wider the spacing, the lower the overall values of gain for the entire sweep.

3. Gain falls off somewhat rapidly above the design center frequency. It rises even more rapidly below the design center frequency, although that curve is invisible in these tables.

4. If we compare SWR and gain data, it is clear that maximum gain occurs in a region of high SWR when the beam is designed for maximum front-to-back ratio.

5. Front-to-back ratio holds up best at spacing values between 0.12 and 0.20 wavelengths, inclusive.

It is therefore possible to design a beam with a wide operating (2:1 SWR) bandwidth using spacing values of 0.20 or 0.24 wavelength, but accrue little more than 3 dB gain over a dipole and a front-to-back ratio under 10 dB for most of that bandwidth. Equally, achieving more than 4 dB gain over a dipole and a front-to-back ratio greater than 10 dB for a large portion of the operating bandwidth is not feasible with a full size 2-element driver-reflector Yagi.

As a result of these limiting conditions, when a 2-element Yagi is designed for maximum front-to-back ratio, design compromises are necessary. When the bandwidth requirements are narrow, as on 17 and 12 meters, a spacing in the vicinity of 0.12 wavelength is often chosen for the best combination of gain and front-to-back ratio, along with a sufficiently high feedpoint impedance to assure efficiency. For wider bands, a spacing around 0.16 wavelength is favored, trading some gain and front-to-back ratio for operating bandwidth and an easy match to 50-Ohm coax.

Designing for Maximum Gain

The alternative design strategy we might use is to design our beam so that the array resonates at or close to the frequency of maximum gain. **Table 6** provides the dimensions for the new series of 2-element driver-reflector Yagis.

Table 6. Dimensions of maximum-gain models used in evaluating performance vs. element spacing. All elements 3/8" aluminum.

Spacing		Driver Length		Reflector Length	
WL	Feet	WL	Feet	WL	Feet
0.08	2.71	0.477	16.18	0.490	16.63
0.12	4.07	0.470	15.95	0.488	16.54

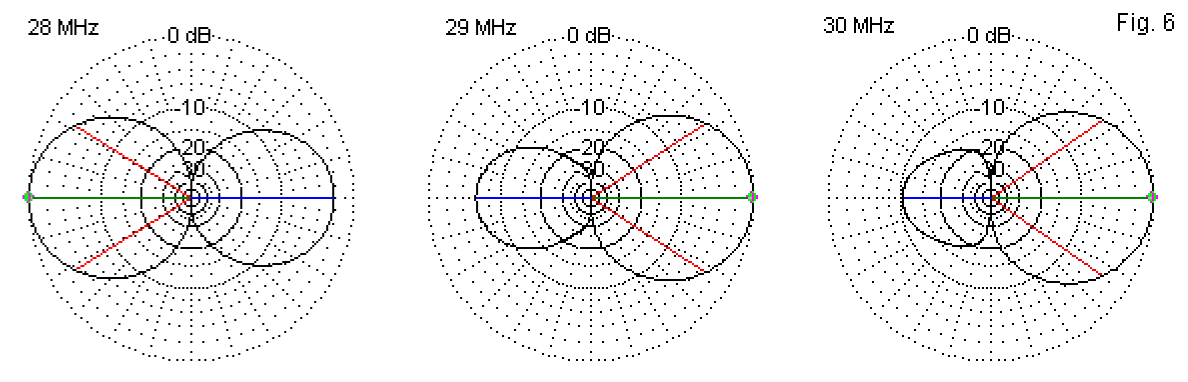
0.16	5.43	0.467	15.83	0.484	16.42
0.20	6.78	0.465	15.76	0.481	16.33
0.24	8.14	0.464	15.74	0.479	16.25

Compared to the Yagis designed for maximum front-to-back ratio at the design frequency, the maximum-gain versions have longer drivers and shorter reflectors, with the reflector length-differences being more radical. These difference yield a significant difference in performance at the design frequency (29.0 MHz), as shown in **Table 7**.

Table 7. Modeled free-space performance of 2-element driver-reflector Yagis designed for maximum gain at resonance.
NEC (-2 or -4) (Reference dipole gain in free space = 2.13 dBi)

Spacing	Gain (dBi)	Gain (dBdr)	F-B (dB)	Feed Z (R +/- jX)
0.08 wl	**7.02**	**4.89**	**6.16**	**9.54 + j0.20**
0.12	**6.99**	**4.86**	**6.38**	**19.59 - j0.23**
0.16	**6.88**	**4.75**	**5.95**	**30.83 + j0.29**
0.20	**6.69**	**4.56**	**5.85**	**43.47 + j0.11**
0.24	**6.43**	**4.30**	**5.65**	**55.92 - j0.24**

The gain figure for the 0.08 wavelength spaced Yagi optimized for gain approaches the absolute maximum gain obtainable from a 2-element parasitical array. However, this gain is obtained at a cost: a severe reduction in the front-to-back ratio and a very low feedpoint impedance. As spacing is increased, the maximum obtainable gain also decreases, along with the front-to-back ratio at that gain figure. Despite the severe reduction in the front-to-back ratio, which makes the beam almost a narrow-beamwidth dipole, the patterns remain well behaved with one exception. **Fig. 6** provides a sample pattern set at 28, 29, and 30 MHz to reveal the exception. The element spacing for the sample is 0.16-wavelength.



Free-Space E-Plane (Azimuth) Patterns: 2-Element Maximum Gain Yagi with 0.16-Wavelength Spacing

At 30 MHz, the pattern almost replicates the maximum front-to-back ratio version pattern at its design frequency. However, at the other end of the swept range, we find that the pattern has reversed itself, with the major lobe in the formerly rearward direction. The illustration has some importance in thinking about Yagis. Just because a parasitic element happens to be longer than the driver, it does not automatically become a reflector. Its function as a reflector or as a director depends upon the relative current magnitude and phase on the two elements, and those values change with each change in frequency for a fixed set of dimensions.

Maximum-gain 2-element Yagi designs have very limited SWR bandwidths, as demonstrated in **Table 8** and in **Fig. 7**.

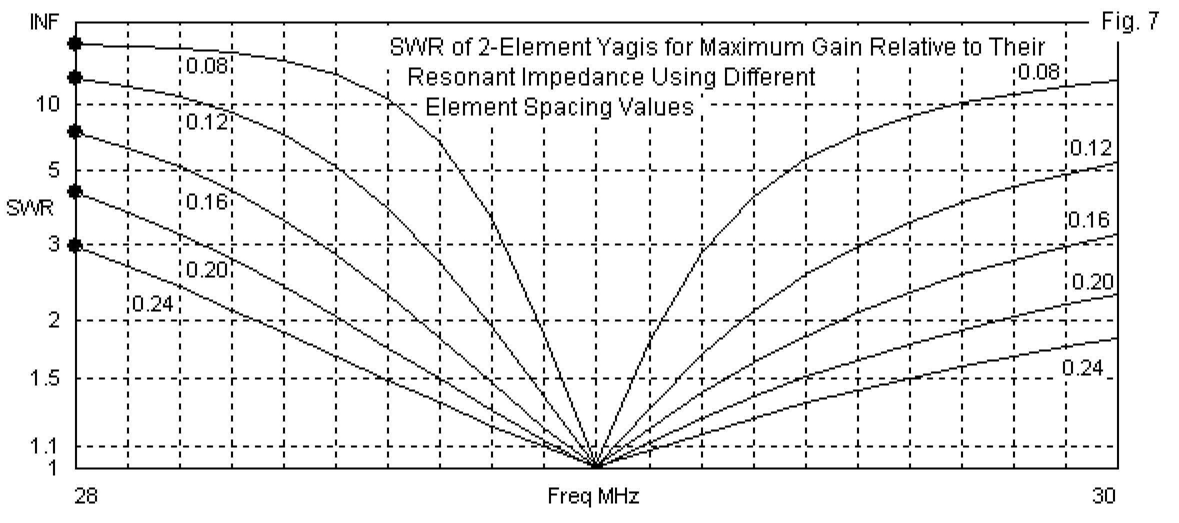


Table 8. SWR from 28 to 30 MHz relative to the resonant impedance of the Yagi.

Spacing	SWR at 28	28.5	29	29.5	30 MHz
0.08 wl	**39.8**	**16.1**	**1.02**	**7.03**	**14.43**
0.12	**15.1**	**5.22**	**1.01**	**3.00**	**5.37**
0.16	**7.09**	**2.84**	**1.01**	**2.07**	**3.21**
0.20	**4.24**	**2.03**	**1.00**	**1.65**	**2.28**
0.24	**2.97**	**1.67**	**1.01**	**1.43**	**1.83**

Only at a spacing of 0.24 wavelength do we obtain any significant operating bandwidth, and by that spacing, gain and front-to-back ratio have fallen severely. In fact, gain has decreased to the levels of more closely spaced maximum front-to-back designs.

As if these factors were insufficient reasons for designers to move the operating point of the array toward the maximum front-to-back region, an additional problem emerges if one examines the beam's properties across a frequency span. **Table 9** provides a rough indication of the difficulty.

Table 9. Operating characteristics from 28 to 30 MHz of Yagis designed for maximum gain.

Frequency	28	28.5	29	29.5	30 MHz
0.08 wl spacing					
Gain (dBi)	**7.14 R**	**6.08 R**	**7.02**	**6.60**	**6.04**
Gain (dBdr)	**5.01 R**	**3.95 R**	**4.89**	**4.47**	**3.91**
F-B (dB)	**10.44**	**0.86**	**6.16**	**10.54**	**10.57**

0.12 wl spacing					
Gain (dBi)	**6.92 R**	**6.23**	**6.99**	**6.67**	**6.21**
Gain (dBdr)	**4.79 R**	**4.10**	**4.86**	**4.54**	**4.08**
F-B (dB)	**4.49**	**1.31**	**6.38**	**9.97**	**10.87**
0.16 wl spacing					
Gain (dBi)	**6.30 R**	**6.37**	**6.88**	**6.63**	**6.23**
Gain (dBdr)	**4.17 R**	**4.24**	**4.75**	**4.50**	**4.10**
F-B (dB)	**2.21**	**1.96**	**5.95**	**9.09**	**10.51**
0.20 wl spacing					
Gain (dBi)	**5.52 R**	**6.37**	**6.69**	**6.45**	**6.06**
Gain (dBdr)	**3.39 R**	**4.24**	**4.56**	**4.32**	**3.93**
F-B (dB)	**0.50**	**2.65**	**5.85**	**8.50**	**9.91**
0.24 wl spacing					
Gain (dBi)	**5.41**	**6.26**	**6.43**	**6.17**	**5.78**
Gain (dBdr)	**3.29**	**4.13**	**4.30**	**4.04**	**3.65**
F-B (dB)	**0.63**	**3.07**	**5.65**	**7.87**	**9.17**

The entries labeled "R" indicate gain in the reverse direction from that of the remainder of the entries. The maximum gain point in the geometry of a 2-element Yagi occurs just above the frequency at which the parasitical element begins to function as a reflector. Below a certain critical frequency that varies with spacing, the parasitical element becomes a director, even though it is physically longer than the driven element. (It would be shorter if the driven element were lengthened to resonance.) **Fig. 8** shows the transition in graphical form using 3 of the sampled spacing values (0.08, 0.16, and 0.24 wavelength).

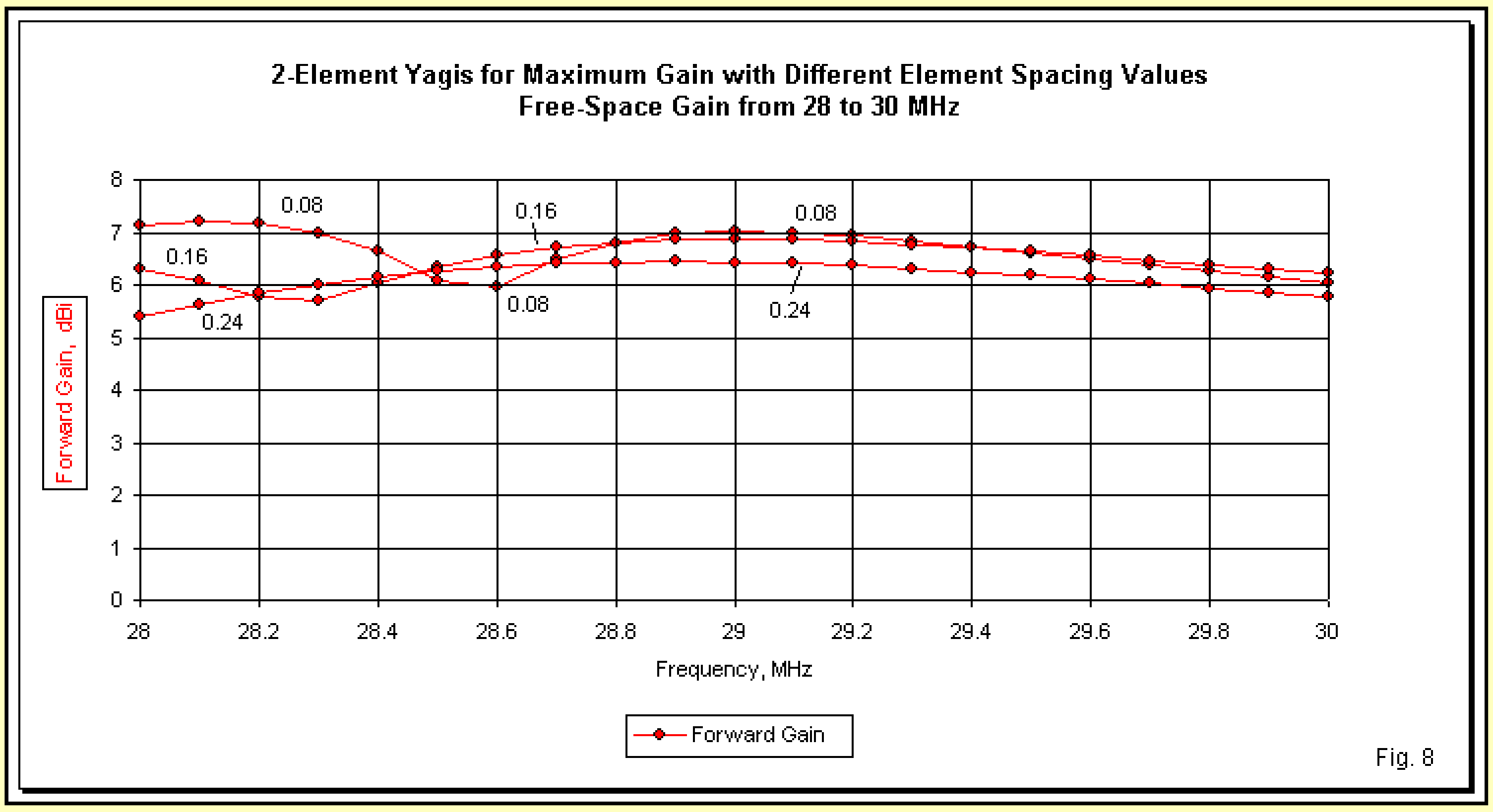


Fig. 8

The curve for a spacing of 0.24-wavelength does not undergo the reversal. However, the curves for the closer spacing values show a distinct minimum value, and below the frequency at which this occurs, the gain rises again, but in the reverse direction. Even though the graph uses 0.1-MHz increments, the minimum gain values do not approach zero. The actual transition occurs between sampled points and occurs over a very narrow frequency span. The frequency of transition, as a spread from the design frequency, is about 600 kHz for 0.16-wavelength spacing and only 400 kHz for 0.08-wavelength spacing. As spacing is increased, the frequency at which the beam flips directions grows more distant from the frequency of maximum gain. However, performance of the beam in the range between reversal and maximum gain is marginal at best.

The front-to-back curves, shown in **Fig. 9** for the same three samples, provide the same information relative to the frequencies at which the pattern reverses itself. The indicator is the minimum value of front-to-back ratio for each of the curves. From the rapidly declining value of front-to-back ratio, the 0.24-wavelength sample beam might reverse itself within 100-200 kHz below the limit of the sweep.

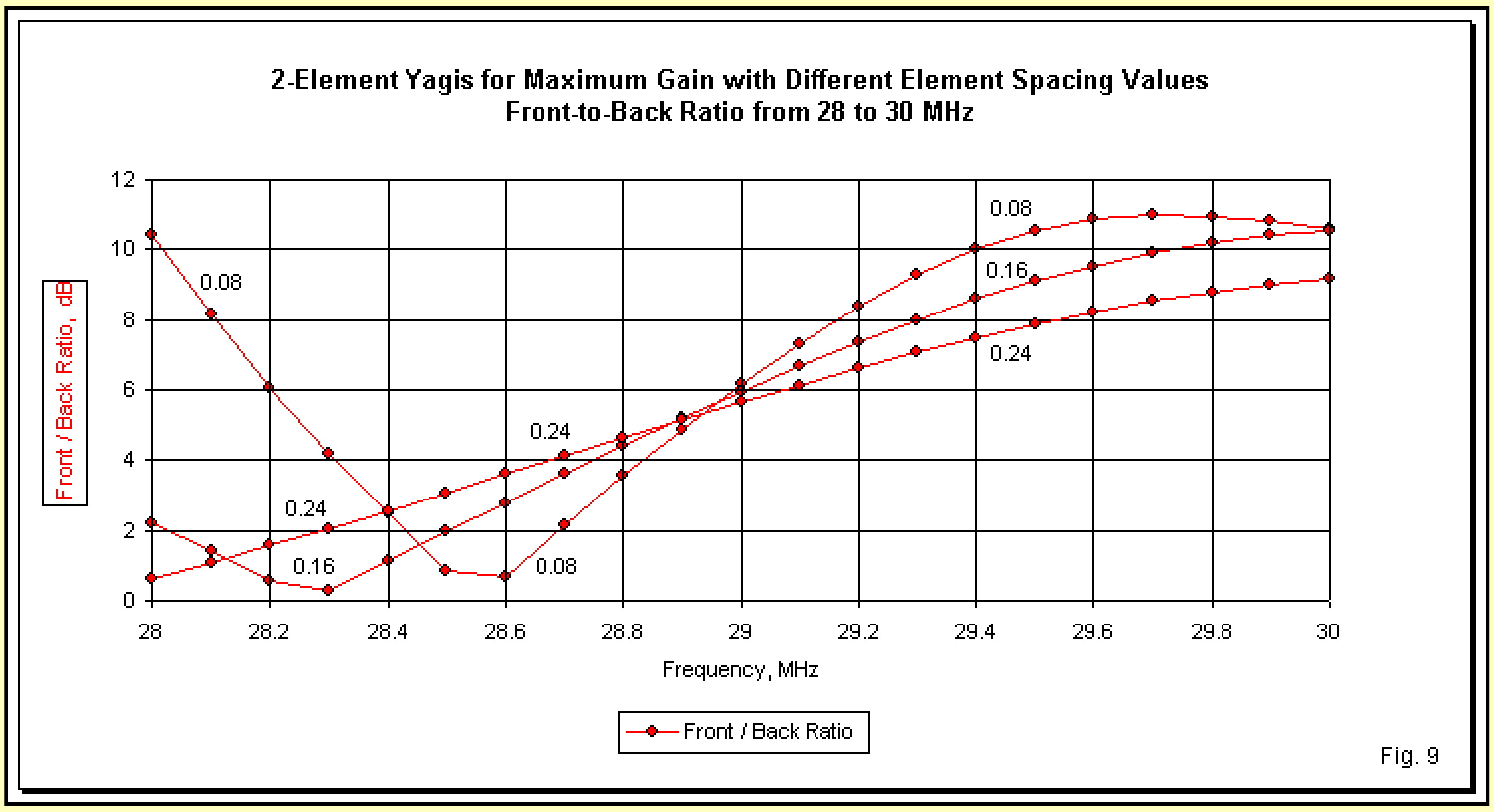


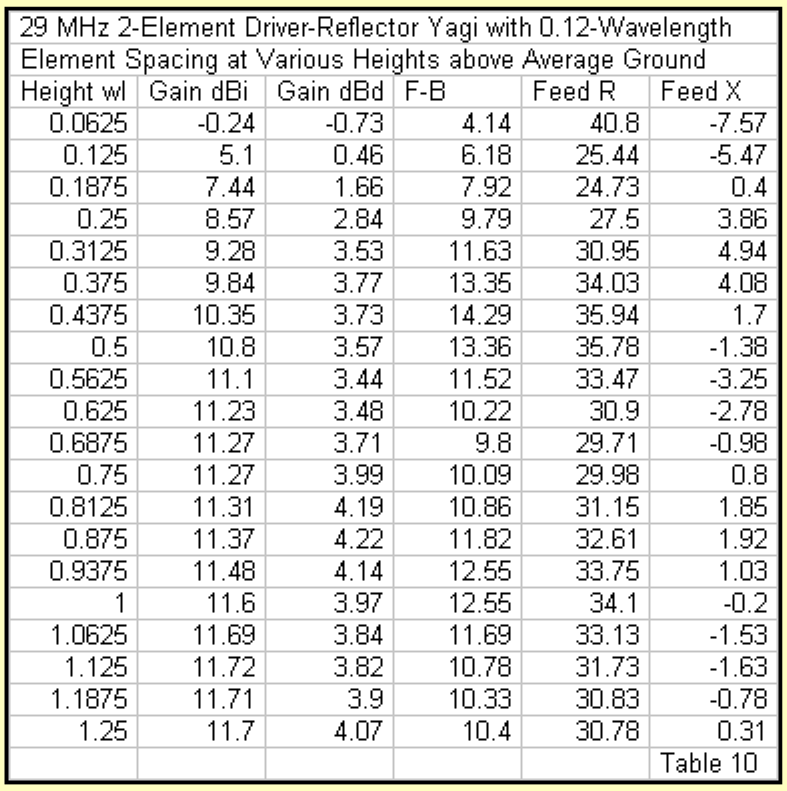
Fig. 9

We may note in passing, with an eye on the 0.08 wavelength spaced beam, that the driven-element-director configuration is capable of slightly higher gain than the driven-element-reflector arrangement.

The purpose of these latter tables and graphs is twofold. First, they demonstrate the maximum gain of which a full size 2-element driven-element-reflector Yagi is capable, and the conditions surrounding that achievement. Second, they also illustrate why designers tend to give up maximum gain in favor of maximum front-to-back ratio as the design focus: adequate gain, wider operating bandwidth, higher feedpoint impedances, and higher front-to-back ratios. We may reiterate that above the frequency of maximum front-to-back ratio, the feedpoint SWR (referenced to the impedance at the design center frequency) decreases more slowly than below the maximum F-B frequency, but both gain and F-B ratio decrease together. Hence, specifying the peak values of gain, front-to-back ratio, and operating bandwidth does not always give a fair indication of beam performance. That is why we need to view tables or graphs of performance over the entire operating passband. We may also note that in no case of normal directional operation does the driven-element-reflector reach 5 dBd(r).

Height above Ground

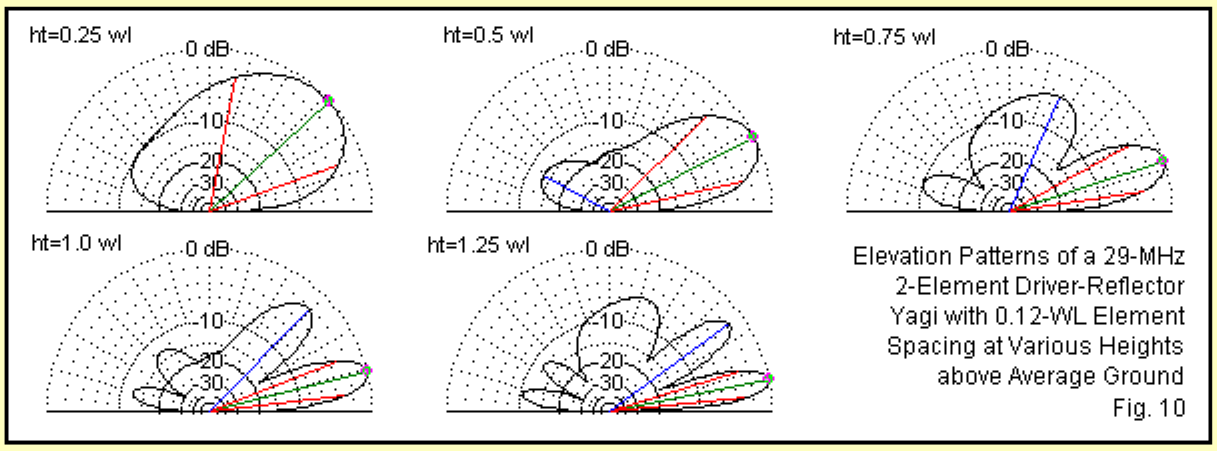
The characteristics of a given 2-element Yagi design are not constant with height above ground until the beam is well above 1 wavelength high. **Table 10** provides data on gain, elevation angle, front-to-back ratio and feedpoint impedance for one of the 2-element Yagis that we have explored in free space. To maximize gain while having a workable feedpoint impedance, I have selected the version with a spacing of 0.12-wavelength between the driver and reflector. However, with suitable changes in the exact numbers, any of the beams in the free-space collection would show similar trends as we vary the height above ground.



29 MHz 2-Element Driver-Reflector Yagi with 0.12-Wavelength Element Spacing at Various Heights above Average Ground

Height wl	Gain dBi	Gain dBd	F-B	Feed R	Feed X
0.0625	-0.24	-0.73	4.14	40.8	-7.57
0.125	5.1	0.46	6.18	25.44	-5.47
0.1875	7.44	1.66	7.92	24.73	0.4
0.25	8.57	2.84	9.79	27.5	3.86
0.3125	9.28	3.53	11.63	30.95	4.94
0.375	9.84	3.77	13.35	34.03	4.08
0.4375	10.35	3.73	14.29	35.94	1.7
0.5	10.8	3.57	13.36	35.78	-1.38
0.5625	11.1	3.44	11.52	33.47	-3.25
0.625	11.23	3.48	10.22	30.9	-2.78
0.6875	11.27	3.71	9.8	29.71	-0.98
0.75	11.27	3.99	10.09	29.98	0.8
0.8125	11.31	4.19	10.86	31.15	1.85
0.875	11.37	4.22	11.82	32.61	1.92
0.9375	11.48	4.14	12.55	33.75	1.03
1	11.6	3.97	12.55	34.1	-0.2
1.0625	11.69	3.84	11.69	33.13	-1.53
1.125	11.72	3.82	10.78	31.73	-1.63
1.1875	11.71	3.9	10.33	30.83	-0.78
1.25	11.7	4.07	10.4	30.78	0.31
					Table 10

To gather an appreciation of this data, you may wish to simultaneously view the data in episode 1 on the dipole at the same heights above average ground. Both the dipole and the Yagi use the same element material: 3/8" diameter aluminum. Therefore, we may make some fair comparisons between the two antennas.



Elevation Patterns of a 29-MHz 2-Element Driver-Reflector Yagi with 0.12-WL Element Spacing at Various Heights above Average Ground
Fig. 10

Fig. 10 shows elevation patterns for the Yagi at increments of 1/4-wavelength in height. These patterns correspond to the dipole elevation patterns in episode-1's Fig. 10. For every dipole elevation lobe and null, there is a corresponding lobe and null in the Yagi patterns. However, we find two major differences between the patterns. The first difference is obvious: the lobes to the rear of the Yagis forward direction are much weaker than the corresponding dipole lobes. We might easily overlook the second difference. Compare the emerging dipole and Yagi lobes at the highest elevation angles, especially at heights of 0.75 and 1.25 wavelength. The Yagi higher-angle lobes are always smaller than corresponding dipole lobes. In episode 1, we noted that beams obtain forward gain from several sources, one of which was a reduction in both the vertical and the horizontal beamwidth. The reduction in the strength of the Yagi upper-angle lobes is part of the reduction in the vertical beamwidth.

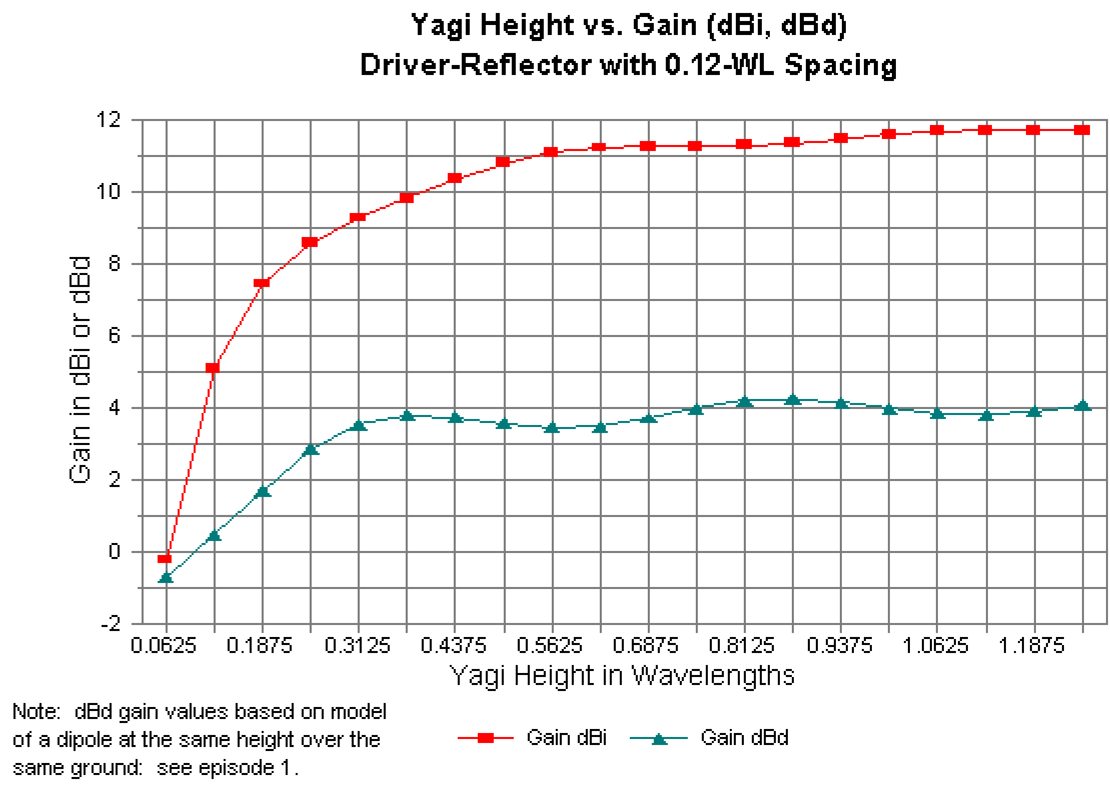


Fig. 11

As we observed in the behavior of the dipole, the gain of the 2-element Yagi does not increase smoothly as we increase its height above ground. However, the Yagi gain curve (in dBi), shown in **Fig. 11**, is much smoother than the dipole curve in episode 1. In fact, the only section of **Table 10** that shows a very tiny decline in gain is between heights of 1.125 wavelengths and 1.25 wavelengths. That decline is only 0.02 dB.

The curve designated dBd shows a different curvature than the one marked dBi. The dBd gain is based on the difference in gain in dBi between the Yagi and the dipole in episode 1. Since the gain of the dipole varies over a greater range than does the Yagi gain, the Yagi gain in dBd shows higher peaks and deeper nulls. Now suppose that you were selling a 2-element that is for all practical purposes identical to the Yagi sold by a competitor. If you check the gain of your antenna at a height of 7.8-wavelength, you may claim a gain of 4.22 dBd. If you check your competitor's beam at 5/8-wavelength, then its gain is only 4.48 dBd. By "judiciously" omitting the details of how you obtained the figures, you might even claim in your sales literature that your Yagi has more than a half-dB higher gain than your competitors. This small demonstration perhaps enlightens you as to why we shall focus upon dBi as the more useful unit of gain measurement.

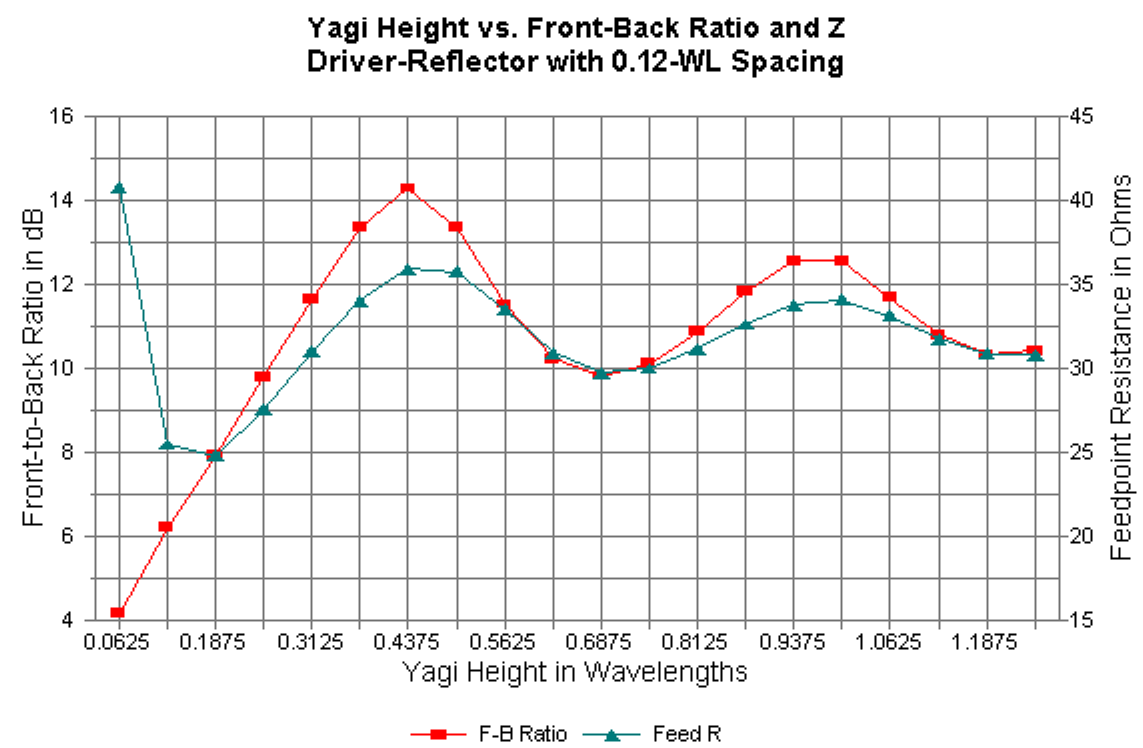


Fig. 12

The undulations in the front-to-back ratio with changing antenna height are much more pronounced than the small changes in forward gain. **Fig. 12** graphs the 180-degree front-to-back ratio of our sample Yagi. Using the right Y-axis, the graph also tracks the changes in the feedpoint resistance. The Yagi uses a single set of physical measurements, shown in **Table 1**. Hence, as **Table 10** makes clear, the reactance drifts slightly off resonance relative to the free-space value of the original design. However, the reactance drift is small and varies from being slightly capacitive to being slightly inductive, depending upon the exact height.

More significant than the reactance drift--especially for our understanding of 2-element Yagi behavior--is the fact that above a height of about 3/16-wavelength, the feedpoint resistance and the front-to-back ratio curves track each other very closely. In contrast, the gain curves--to the degree that one can detect peaks and nulls--are offset from these two curves. In a 2-element driver-reflector Yagi, the feedpoint impedance and the front-to-back ratio are very closely related. This and related height phenomena were reported upon extensively in "The Effects of Antenna Height on Other Antenna Properties: A Computer Study," *Communications Quarterly*, 2 (Fall, 1992), 57-79.

Needless to say, when fine shades of performance comparison are at stake, mere numbers for gain, front-to-back ratio, and operating bandwidth are normally meaningless without a complete specification of their derivation. Even summaries of typical cases of derivation can make comparison elusive, since they often leave ambiguous which derivation was used for a particular antenna. Until buyers of amateur radio antennas are provided with the same detailed information that can be demanded by military, government, and private corporations for contract fulfillment, *caveat emptor* must still rule the marketplace.

With this caution, we may complete our sampling of 2-element driver-reflector behavior--at least so far as full-size Yagis are concerned. However, modern-day urban and suburban amateurs are cramped for antenna space. They wonder if they can effectively shrink an antenna and still derive adequate performance from it. Since the 2-element Yagi seems the simplest beam to shrink, we should explore the possibilities.

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