Design of a 2-3-Element Full-Performance Yagi for Portable and Field Use with No-Tool Configuration Changing
Part 3: Improving 20- and 17-Meter Performance

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Introduction

Parts 1 and 2 described the electrical and mechanical design of a Yagi beam for field and other portable uses. It employed a 12' boom for high performance from 3 elements on 15, 12, and 10 meters and full 2-element performance on 17 and 20 meters. The maximum element length was 26.33' to optimize gain and front-to-back ratio on each band. The beam required no matching section, but connected directly to a 50-Ω coaxial cable with 1.6:1 SWR or better.

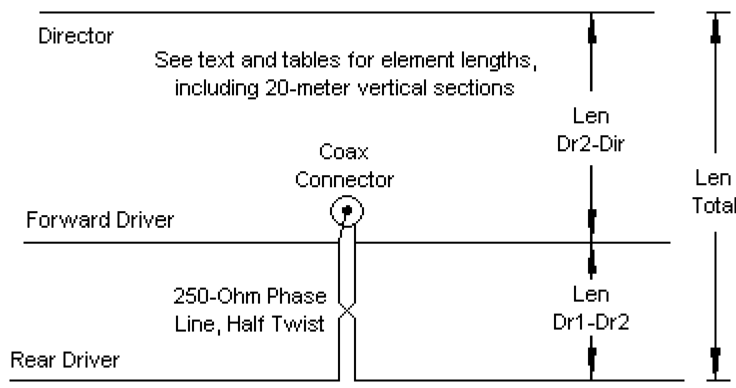
When using 3 elements, the beam provided a free-space forward gain value of between 6.7 and 7.2 dBi, with a front-to-back ratio of about 20 dB. In contrast, when using only 2 elements (on 17 and 20 meters), the gain dropped to about 6 dBi, with a front-to-back ratio barely over 10 dB. One residual question left by the discussion is whether it might be possible to increase the gain and front-to-back ratio on the lower bands to values more in keeping with those obtained on 15 through 10 meters. Of course, the maximum boom length must remain 12', and the feedpoint must not require a matching section or network to arrive at a 50-Ω impedance. As well, the individual elements must retain the structure assigned to them in the first two parts of these notes.

There is a means of designing arrays that will meet the requirements to a significant but incomplete degree. We may obtain gain values from 6.6 dBi for the 20-meter version (with its drooping element ends) to 6.8 dBi for 17 meters, with front-to-back ratios ranging from 17 to 19 dB. The cost is the addition of 3 new components to the storage and transportation package. However, each component is pre-constructed so that in the field, assembly and disassembly still require no tools. We may obtain the improved performance level by using 3 elements on 20 and on 17 meters in a design that I originally developed for very wide-band serve on 6 meters and on 10 meters. Monoband beams for those bands have appeared in the pages of *QST*.

The revised beam design employs an expansion of the 2-element driver-director form of Yagi. This configuration tends to need only a short boom to obtain the highest practical forward gain (perhaps 6.8 dBi) and a very useful front-to-back ratio (15 to 20 dB, depending upon the exact boom length). The design has two flaws in its original form. First, it exhibits a very low feedpoint impedance with boom lengths that yield superior performance levels. Second, we may obtain the performance only over a very narrow operating passband. The combination of limitations precludes the use of a 2-element driver-director Yagi for the portable and field beam.

We can increase both the feedpoint impedance value and the operating bandwidth of the array by adding a second driver element and phasing the driver pair correctly. With proper spacing between the drivers, a 250-Ω reversed phase line will yield a 50-Ω feedpoint impedance. The single director used in conjunction with the pair of drivers is sufficient to provide a wide operating bandwidth not only for the feedpoint impedance, but also for the other key operating characteristics. The total boom length required for the 3-element array is less than the boom length required by a conventional 50-Ω 2-element driver-reflector Yagi. **Fig. 1** shows the general scheme of the short-boom phased-driver Yagi.

Fig. 1

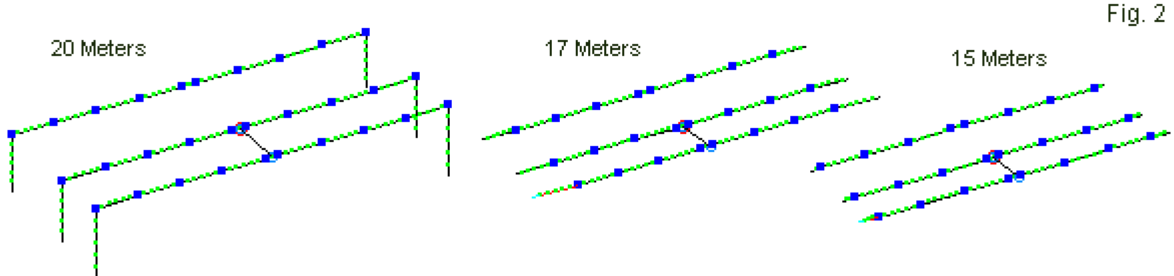


3-Element Wide-Band Short-Boom Yagi
General Outline

The array does require that we develop pre-constructed phase-line assemblies that can withstand transport in the antenna package. We shall suggest plug-in assemblies. As well, we shall have to construct the former reflector element (which is still a reflector on 15 through 10 meters) in such a way that we may convert it simply and without tools from a rear driver (also called driver 1) into a continuous parasitic element and back again. As well, the design must be able to handle not only linear elements, but also the 20-meter elements with drooping element ends, since the maximum element length remains 316".

Fig. 2 provides outlines of the configurations of the beam for 20 through 15 meters. I have designed the 15-meter version as a comparator for the 15-meter 3-element conventional Yagi shown in Part 1 of these notes. The sketches derive from antenna modeling software and are approximately to scale. Since the length of each element section is constant, except at the element ends, the diagrams permit a reasonable comparison of array sizes for the three bands shown.

Fig. 2

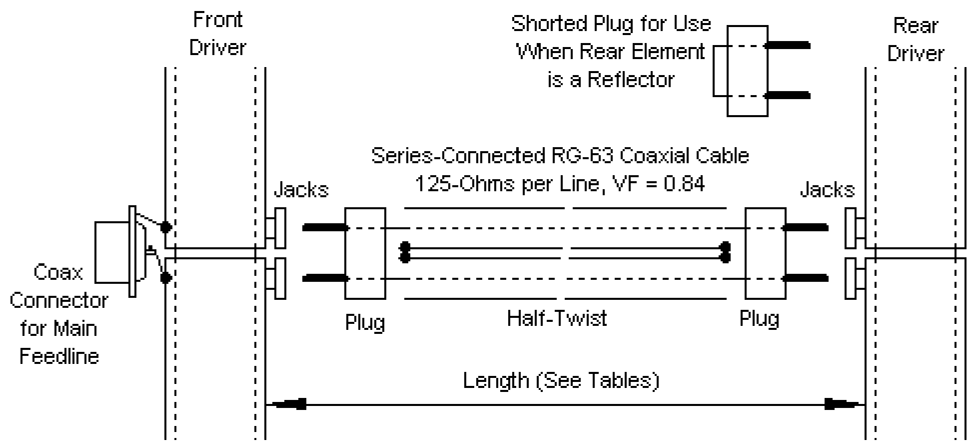


General Outlines of 3-Element Yagis with 2 Phased Driver Elements

Element Revision and Phase-Line structure

With the exception of the specific antenna components shown in the following discussion, all mechanical details of the revised array remain unchanged from the suggestions presented in Part 2. Element sections use hitch-pin clips to lock them in operating position according to the taper schedule shown in that part of these notes. The element-to-boom mounting plates use spring-action tool clips to hold the element in place and to secure the element to the boom.

Fig. 3



Required New Components and Element Modifications to Set Up Elements for Use in a Phased-Driver Yagi

Fig. 3 outlines the significant new components and the revision of the element structure. In the original beam, only the driven element required a split element, with the director and reflector using construction suited to continuous parasitic elements. Under the revision discussed here, the reflector element will also require split construction with a non-conductive centerpiece to set the element gap and to ensure a linear structure. In some configurations, we shall place a short circuit across the gap and use the element as a reflector. In the new beam configuration, we shall leave the gap and connect the “rear” end of a phasing line to each side of the gap.

The former driver element becomes the front or forward driver (driver 2) in the new beam configuration. This element retains the coax connector for the main feedline. In standard Yagi use, we need use only this connector. However, the element also requires a means to connect the forward or “front” end of the phase line to each side of the element gap.

Early prototypes of the phased-driver Yagi used bare-wire 250-Ω phase lines, that is, sections of 250-Ω parallel transmission line with a half-twist between the forward and the rearward ends. An equally usable phase line may employ side-by-side sections of RG-63 coaxial cable in a series connection. The series connection simply uses the center conductors to run from the forward to the rearward driver—with the obligatory half-twist. The coaxial cable braids are soldered together at each end of the phase line but make contact with nothing else. A few short lengths of heat-shrink tubing will hold the two coax lengths in physical proximity. The 125-Ω coaxial cable has a velocity factor of 0.84, but we may design to that value with success. The physical length of each phase-line assembly is simply the distance between the driver elements.

Fig. 3 shows plugs at each end of each phase line. We might use almost any 2-terminal plug for which we have jacks that are compatible with the two driver elements. For example, dual banana plugs are usable with suitable cautions. The jacks may run through the elements, with connections made on the opposite side of the element from the phase line. Other schemes are also possible. One key element is to provide the junction of the plug and the phase-line proper with a solid mechanical grip so that the user cannot inadvertently tear the line from the plug during assembly or disassembly. An additional molding that grips both the plug and the line may be advisable. The plug body is part of the total phase-line length.

The suggested construction of the phase lines has several advantages. First, we may construct phase lines for each band for which we use the new beam design. The lines will be flexible enough to withstand a U-turn for storage within the limits of the original specifications for the transport and storage package. Second, we may use the plug-and-jack system to simplify assembly. We may place the rear driver and then plug in the phase line for the desired operating band. We next plug the forward end of the line into the front driver. The front-driver placement is at the end of the phase line, with no further measurement or marking required. Third, we may restore the rear-most element to parasitic service simply by replacing the phase line plug with a shorted plug that becomes the final component added to the overall package.

Electrical Dimensions and Performance

Performance of the revised 3-element beam will vary from one band to the next. The required droop in the 20-meter elements provides about 0.2-dB less forward gain than purely linear elements. The following notes cover 20 through 15 meters to permit a thorough evaluation of the array. I do not recommend the configuration for 12 and 10 meters, because on those bands, the standard Yagi configurations shown in Part 1 yield superior performance without the need for phase lines.

For each band, the tables present the array dimensions and the modeled performance at the band edges and at mid-band. Each data collection also includes sweep graphs for the forward gain and the 180° front-to-back ratio and for the feedpoint resistance, reactance, and 50-Ω SWR values. The collection also has free-space E-plane patterns for the new beam design.

20 Meters

20-meter performance provides an average of 0.5-dB additional gain and a 7- to 8-dB improvement in the front-to-back ratio over the 2-element configuration shown in Part 1. The following table shows the dimensions and the performance data from the design models. The original 2-element performance values appear in italics.

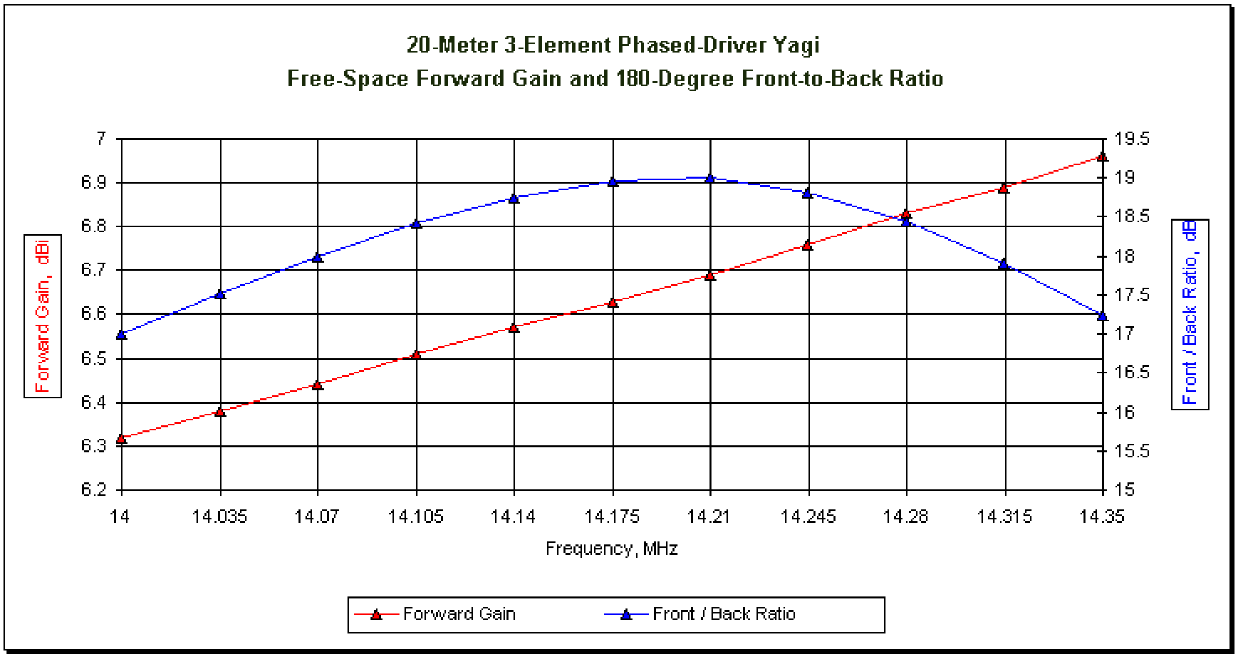
20-meter outer dimensions in inches

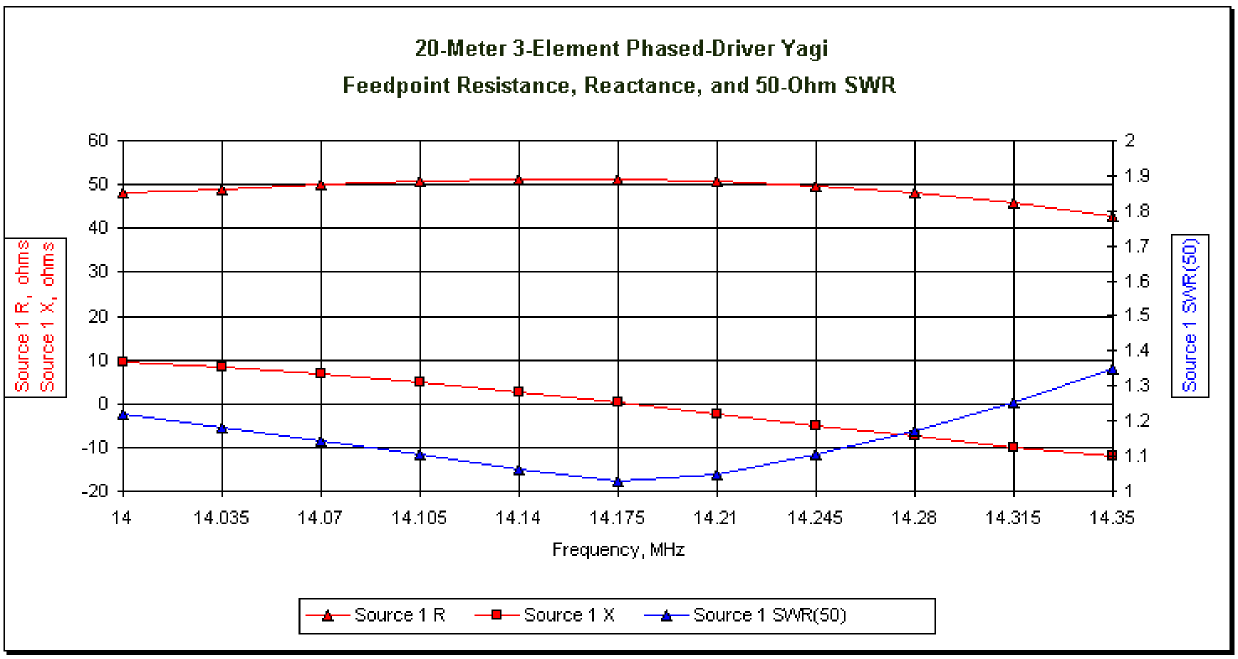
Element	Length	Space from Reflector	Vertical end length
Rear Driver	316	---	64
Front Driver	316	50 (= phase-line length)	55
Driver	316	129	49

Performance

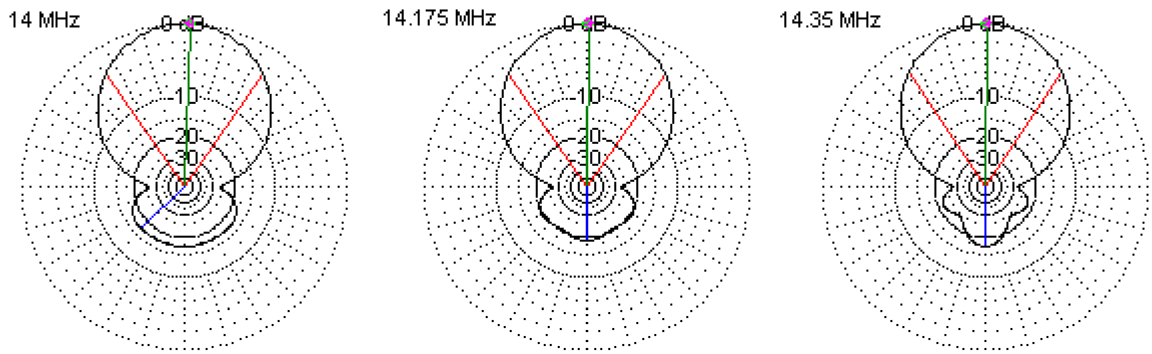
Category	14.0	14.175	14.35
Gain dBi	6.32	6.63	6.96
	6.45	*6.07*	*5.73*
180° front-to-back ratio dB	17.01	18.96	17.23
	10.09	*10.75*	*10.28*
Impedance (R +/- jX Ω)	48.0 + j9.6	51.3 + j0.3	42.8 - j11.9
50-Ω SWR	1.22	1.03	1.35

As both the numerical data and the sweep graph show, the use of a director provides a rising forward gain values as we increase the operating frequency within the passband. The gain varies by about 0.6-dB across the band, a small amount in view of the use of drooping element ends. The front-to-back ratio varies by less than 2 dB.





Despite the inherent wide-band properties of the original 2-element design, the use of phased drivers and a single reflector produces a shallower SWR curve. The feedpoint resistance changes by less than 9 Ω while the reactance swing is less than 20 Ω. The wide-band properties of the array tend to assure good performance in the field, where element placement errors up to a half-inch are possible under stressful assembly conditions. You may gauge the performance improvement by comparing the pattern shapes in the gallery with the corresponding set of patterns in Part 1 of these notes.



Free-Space 20-Meter E-Plane Patterns

17 Meters

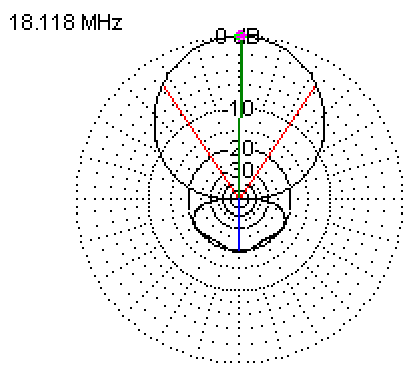
Since only the 17-meter rear driver requires a length longer than 316", the design model assumes the addition of a linear extension, as suggested in Part 2 of the earlier notes. The extension needs to be about 4" on each end of the rear driver only. The other two elements fall well within the side-to-side limits of the element construction specified in the initial designs. However, one may replace the linear extension with a short downward wire about 6-7" long, depending upon its diameter.

17-meter outer dimensions in inches

Element	Length	Space from Reflector	Vertical end length
Rear Driver	324	---	---*
Front Driver	310	39 (= phase-line length)	---
Driver	302	101	---

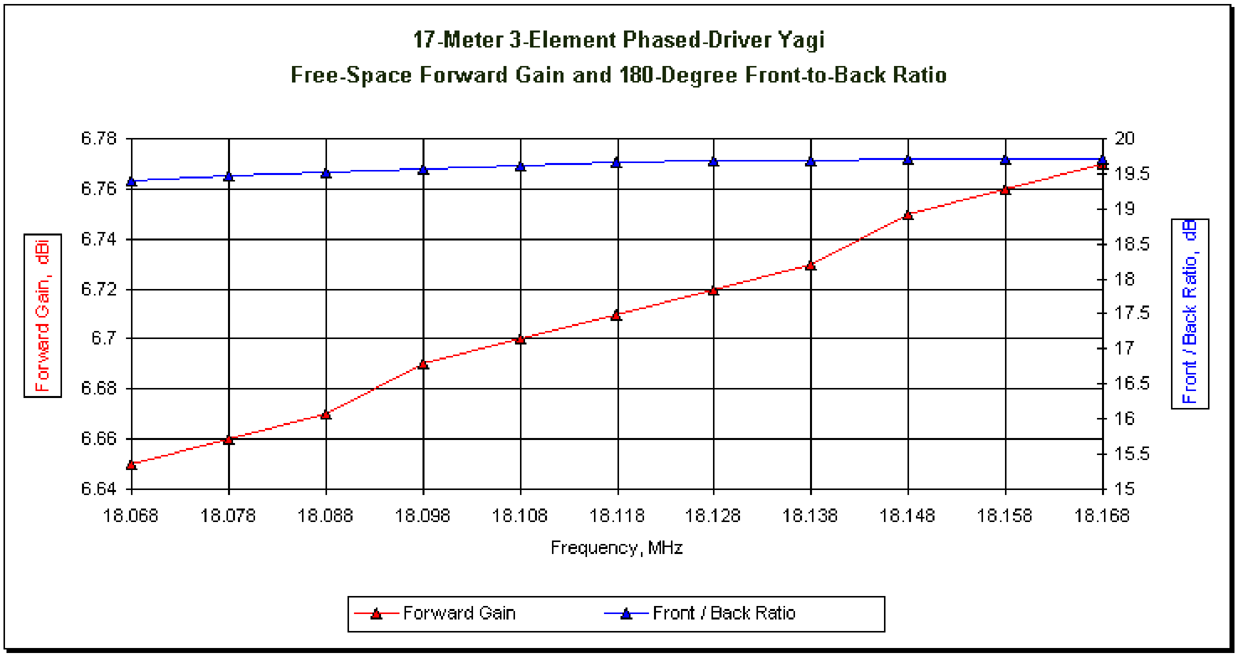
Performance

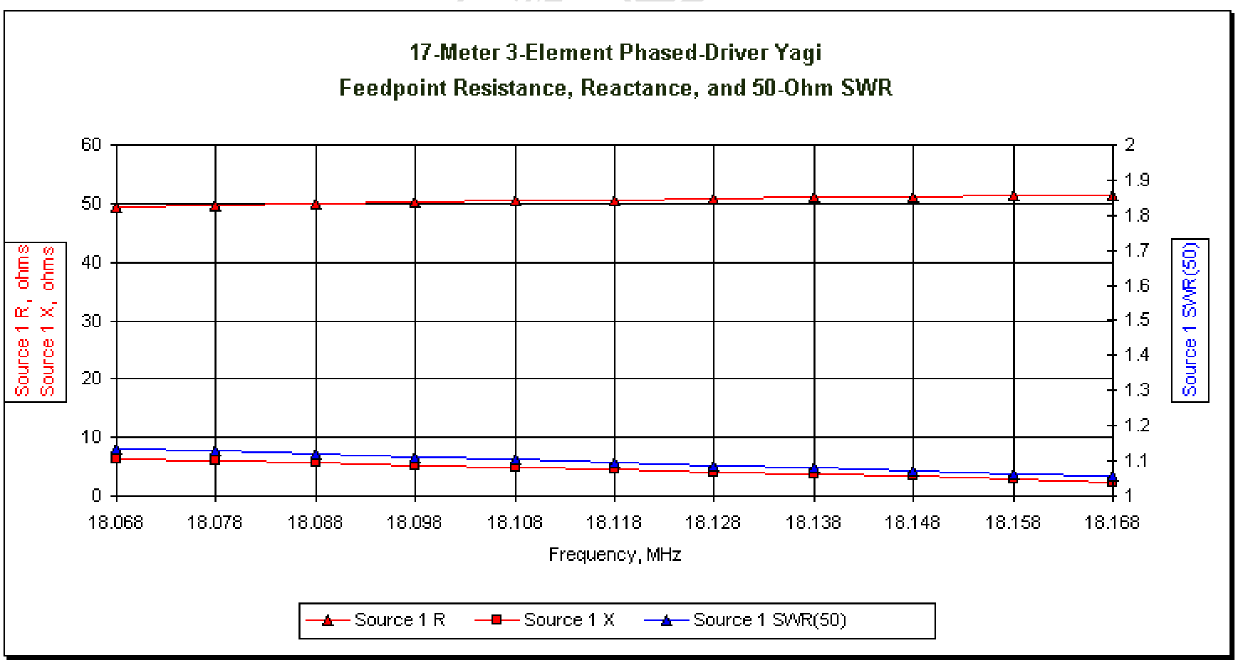
Category	18.068	18.118	18.168
Gain dBi	6.65	6.71	6.77
	6.08	*6.01*	*5.95*
180° front-to-back ratio dB	19.41	19.66	19.72
	9.82	*9.90*	*9.97*
Impedance (R +/- jX Ω)	49.5 + j6.3	50.6 + j4.5	51.4 + j2.4
50-Ω SWR	1.14	1.10	1.06



Free-Space 17-Meter E-Plane Pattern

Note that the overall boom length is only about 8.4', allowing the user to set up the beam using only 3 of the 4 suggested boom sections. Despite its short length, the new beam produces an additional 0.7-dB of forward gain and nearly 10-dB better front-to-back ratio values than the 2-element design. It does so with a clean pattern, and a single pattern captures the entire narrow band. As the sweep graph shows, the gain rises by about 0.1-dB across the band, with a virtually flat front-to-back ratio curve.





The curves for the feedpoint resistance, reactance, and 50-Ω SWR values are equally flat, as we would expect from a wide-band beam used on a very narrow amateur band.

15 Meters

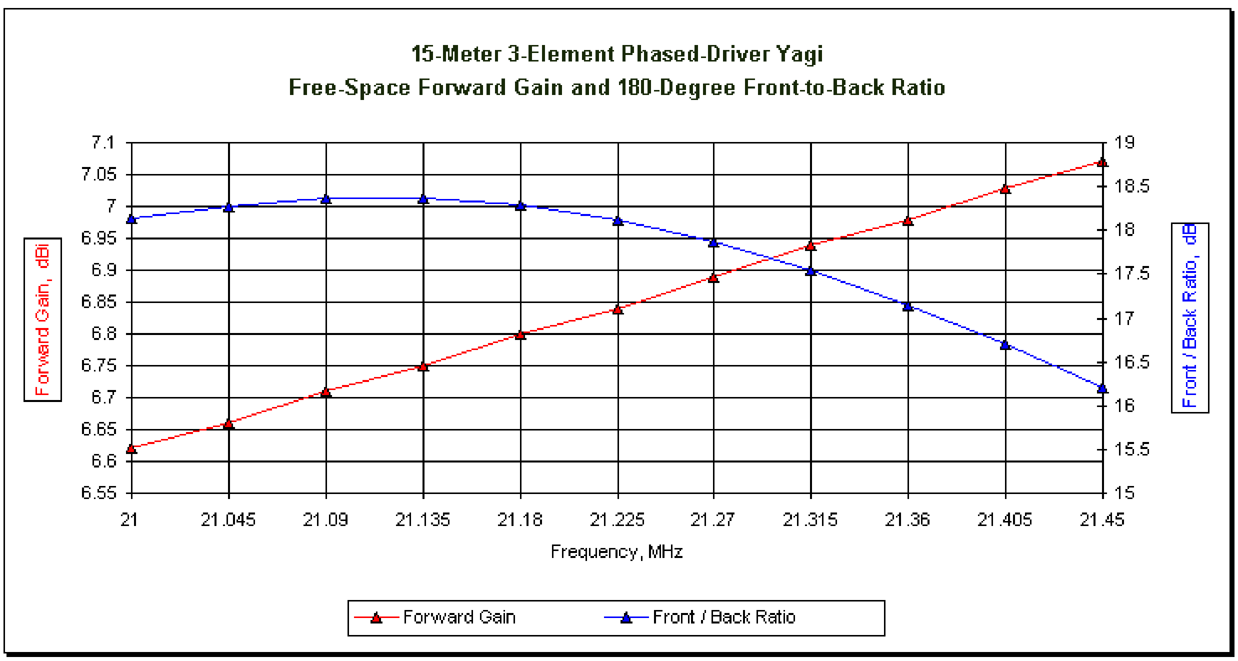
I am including an analysis of the modeled performance of the phased-driver Yagi on 15 meters to permit a comparison with the standard Yagi design shown in Part 1. The total required boom length is only about 7.2', allowing use of the new design on only 3 of the 4 boom sections. In some situations, the weight and wind load reduction might be significant. However, the new design does require its own 33.5" phase line.

15-meter outer dimensions in inches

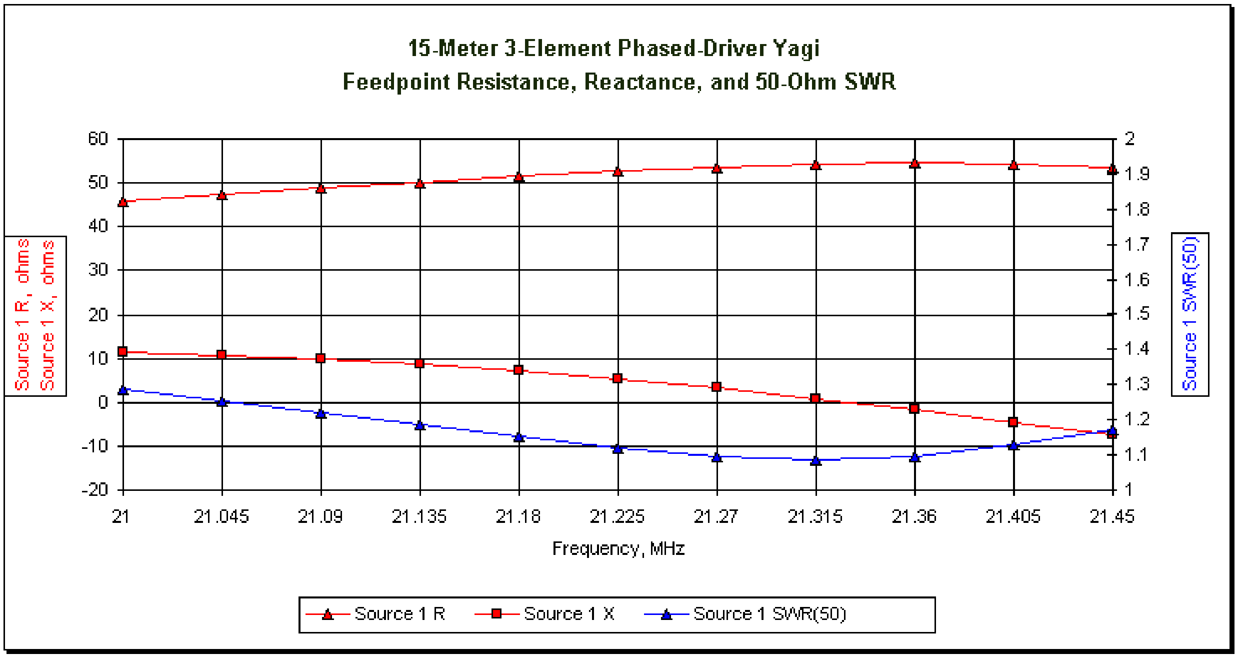
Element	Length	Space from Reflector
Rear Driver	272	---
Front Driver	262	33.5 (= phase-line length)
Director	257	86

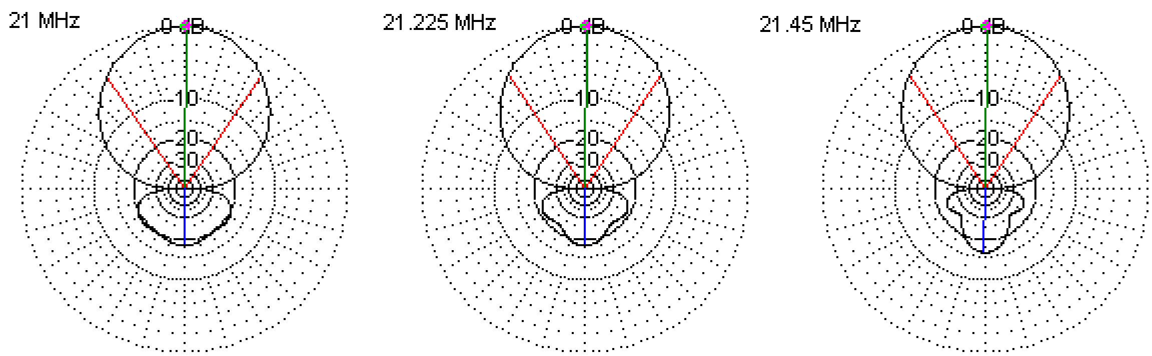
Performance

Category	21.0	21.225	21.45
Gain dBi	6.62	6.84	7.07
	6.91	*6.97*	*7.12*
180° front-to-back ratio dB	18.13	18.12	16.20
	17.90	*21.29*	*25.39*
Impedance (R +/- jX Ω)	45.8 + j11.4	52.7 + j5.3	53.6 – j7.5
50-Ω SWR	1.29	1.12	1.17



Although further design tweaking might yield a front-to-back curve better centered in the passband, the maximum value would not increase. The new design has a somewhat lower average front-to-back ratio across the band and nowhere reaches 20 dB. As well, the gain is not only slightly lower than the values produced by the standard design on the 12' boom, but as well, the gain value varies more widely across the passband. In contrast, the 50-Ω SWR curve for the new design is shallower, with a maximum value less than 1.3:1. The standard design in Part 1 shows values of 1.4:1 and 1.6:1 at the lower and upper band edges, respectively.





Free-Space 15-Meter E-Plane Patterns

Both types of beam show clean patterns at all frequencies within the 15-meter band. Therefore, the decision on which design to use reduces to the weight that a user might place on the individual factors and the degree to which one design has an advantage over the other.

Factor	Advantage
1. Gain and front-to-back ratio	standard design
2. 50-Ω SWR	phased-driver design
3. Mechanical simplicity	standard design
4. Boom length	phased-driver design

12 and 10 Meters

It is possible to carry the phased-driver design down to 12 and 10 meters. For example, a 10-meter version of the 3-element dual-driver Yagi would need a boom only 64" long, plus end allowance for the element-mounting system. Both the 10- and 12-meter versions would allow use on only 2 of the 4 recommended boom sections. The performance would closely resemble the performance of the 15-meter version of the array. However, the standard designs yield forward gain values of at least 7.3 dBi at each band center. The front-to-back values are above 20 dB on 10 meters and above 30 dB on 12 meters, although both beams show some rearward sidelobe development.

Because 12-meter and 10-meter elements are shorter, the overall load on the 12' boom is less. When we also consider the simplicity of the standard Yagi designs, adding further phase-line sections to the storage and transport package seems less inviting. Therefore, I have limited the recommended re-design work to replacing the 2-element driver-reflector beams for 20 and 17 meters with phased-driver 3-element arrays.

Conclusion

The substitution of any of the 3-element phased-driver Yagi designs for the initial 2- and 3-element standard Yagi designs will require a revision in hitch-pin hole placement on the smaller element sections to establish locking points that set the element length on various bands. In most cases, a builder would decide in advance of construction which versions of the Yagis to include in the package. Similarly to the initial mechanical design, the holes require markings to ease field assembly. The markings should not add to the element section diameter, since even small "bumps" on an element section may hinder the process of nesting the element sections for storage. See Part 2 for further details.

Except for 20 meters, which requires a boom length of 129" (10.75'), phased-driver Yagi designs allow the user to remove one or more 3' sections of the boom. For balance, the mounting point of these designs is just forward of the front driver element. The builder should decide in advance of construction what boom configuration is most useful for each band and therefore where markings should go on the boom for spring-clip attachment to the mast.

The preventive maintenance needs of the phased-driver Yagi configurations are essentially identical to those for the original designs. The user should inspect and assure the cleanliness of all components in the storage and transport package before each field use and immediately after each use. Element sections require cleaning to ensure smooth nesting during storage. The phased-driver Yagis present small additions to the maintenance routine. If bent to form a U for storage in the package, the user should assure that the phase lines do not crimp at the bend. The plugs and jacks require inspection and cleaning to ensure good electrical mating when used.

The phased-driver Yagis provide a means of increasing the forward gain and the front-to-back ratio on 20 and 17 meters roughly to equalize performance on those bands with the performance of the standard Yagis for 15 through 10 meters. They exact a penalty in terms of adding several components to the package, namely, the phase lines, the shorting plug, and the jacks added to the rearward two elements. The design requires a separate phase line assembly for each band using the phased-driver system. Each phase line assembly requires some special care, especially at the junctions between the RG-63 lines and the plugs, to give the assembly long life without damage. Nevertheless, the phase-line assemblies use standard components, with special construction treatment applied only at the plug-to-line junction.

In providing alternative array designs for the Yagi configurations, I have converted what appears to be a pre-set field and portable beam for 20-10 meters into a project that requires considerable design responsibility on the part of any builder. By using nearly the entire 12' field boom on each band, the original design minimized the number of decisions required by a builder. The use of the alternative Yagis for as many bands as the builder chooses also entails construction decisions regarding the number of boom sections to be used and the placement of elements on them for each band to assure balance on the field mast. The result will be a considerable increase in the number of markings required to guide and ease field assembly. Indeed, one may wish to add a plastic-sealed card to the storage and transport package for that purpose, possibly with color-coded markings. The marking material for the boom should not chemically interact with the 6063-T832 aluminum used for the boom and the elements. Because the markings will be subject to friction wear from the spring-action tool clips, they may need periodic renewal.

With either set of Yagi configurations, the field and portable beam for 20 through 10 meters offers the builder a durable directional array. Although each band change requires a change in the length of elements and in their placement on the boom, the resulting antenna provides full-size Yagi performance in a lightweight arrangement, with the additional advantage of easy assembly and disassembly, along with compact storage.

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