

2-Element Yagis: How Short Can We Go?

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After developing extensive data and model antennas for linear loading, I ran across an article on a 10-meter 2-element Yagi that used 8' elements on a 4' boom with center-loading and a beta hairpin match.¹ That led me to wonder how short we might make a Yagi, given that shortening elements permits an increase in front-to-back ratio at the expense of some gain. The results are interesting and worth passing on.

Beginning with center-loaded dipole performance, I modeled 0.75" aluminum elements ranging from full size (16.54') down to the point where gain in dBi fell below zero (6'). **Table 1** summarizes the data, while **Figure 1** displays it in graphical form. The dipoles were initially modeled using infinite Q (0.0 Ohms resistance) and then rechecked at Qs of 500 down to 100. The infinite-Q reading provides a measure of the natural drop in basic gain as the antenna element becomes shorter. The finite Qs provide a measure of the losses incurred by center-loading the element to resonance with an inductor (or even a linear-loading element). Note the shape of the curve as the Q decreases linearly.

Modeled Performance of Shortened 10-Meter Dipoles

Antenna Length (ft)	Load X_L (Ohms)	Feed Z (Ohms)	Gain in dBi					
			---	500	400	300	200	100
16.54 (full size)	0	70.9	2.12					
14'	131	43.0	2.02	1.98	1.97	1.96	1.94	1.83
12'	247	28.4	1.93	1.86	1.84	1.81	1.75	1.57
10'	366	18.1	1.87	1.70	1.66	1.59	1.46	1.07
8'	510	10.7	1.83	1.43	1.34	1.19	0.90	0.14
6'	697	5.7	1.79	0.83	0.62	0.29	-0.29	-1.70

Table 1. A comparison of the modeled performance characteristics of shortened center-loaded dipoles on 10-meters.

Although conventional, registering comparisons in terms of one gain figure as a percentage of another may not be greatly informative in making comparisons. Negative gains relative to an isotropic source are possible and do represent radiation by the antenna. The real question is whether the gain of any configuration is adequate to the job to which the antenna is assigned or whether something better may be available. The graph may give a better sense of the manner in which an antenna with decreasing length and center-load-Q may likely disappoint the builder if a full-size dipole is the standard of comparison.

Gain vs. Q of Center-Loaded Dipoles Element = 0.75" Aluminum

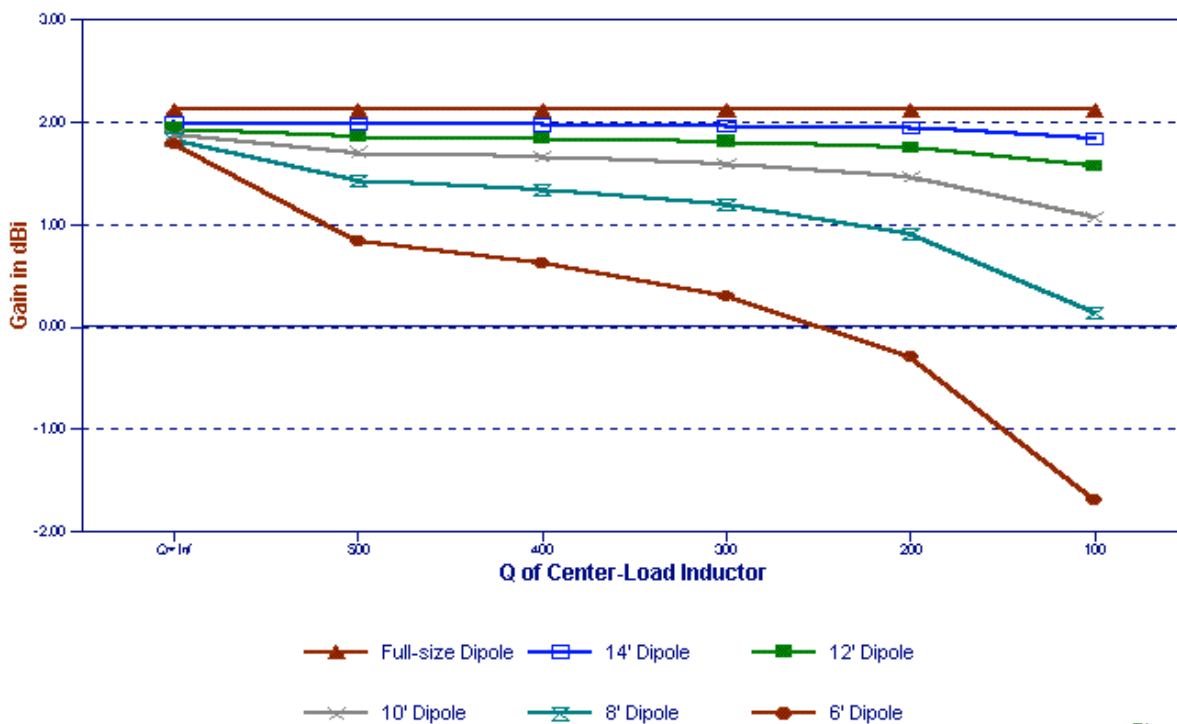


Fig. 1

Applying the dipole data selectively to full-size and shortened center-loaded 2-element Yagis produced the data in **Table 2**. The full-size Yagi used the 4' boom specified for the 8' model and is only a slight variation on the standard used throughout these tests. Models with 8' elements and with 12' elements were run at Qs from infinity to 100 to gauge the performance possibilities of half- and three-quarter-size antennas. With both shortened antennas, the front-to-back ratio is superior to a full-size 2-element Yagi at a cost in gain and SWR bandwidth. However, the 12' model shows a decrease in front-to-back ratio as the Q decreases, while the 8' model increases the front-to-back ratio with Q decreases down to 200.

Figures 2, 3, and 4 provide frequency-swept azimuth patterns in free space for the full-size, the 12' and the 8' models respectively. The full-size model, as expected, shows a consistent rear pattern throughout the 28 to 29 MHz range. In contrast, the rear pattern of the 12' model shows the narrow bandwidth of the maximum front-to-back ratio point, with usable front-to-rear ratios from 28.25 to 29 MHz, as compared to the full-size model. The rear pattern of the 8' model deteriorates much more quickly as the frequency departs from the 28.5 MHz design center. At 28.0 MHz, the antenna is essentially a lossy dipole.

Modeled Performance of Shortened 2-Element Yagis

Antenna and Load Q	Gain (dBi)	Front-to-Back Ratio (dB)	Feedpoint Impedance (Ohms)
Full-size Yagi ¹	6.63	11.27	29.9
12' Elements			
---	6.24	21.22	16.7
500	6.01	19.98	17.2
400	5.95	19.70	17.3
300	5.86	19.25	17.6
200	5.68	18.43	18.0
100	5.17	16.38	19.3
8' Elements			
---	5.76	13.69	11.0
500	4.88	16.93	12.1
400	4.68	17.92	12.4
300	4.36	19.80	12.8
200	3.78	24.96	13.7
100	2.34	21.83	16.2

Note 1: All antennas modeled with 0.75" aluminum elements and a 4' boom. Full size antenna: DE = 16.08'; Refl = 17.49'. All driven elements resonated, although in practice, the matching system may require a different length or load.

Table 2. A comparison of modeled performance characteristics of center-loaded shortened 2-element Yagis.

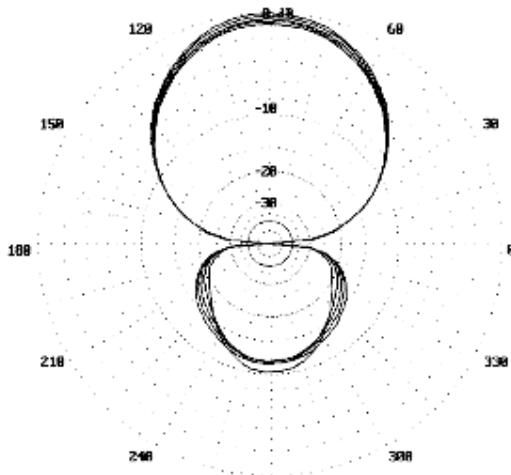


Fig. 2

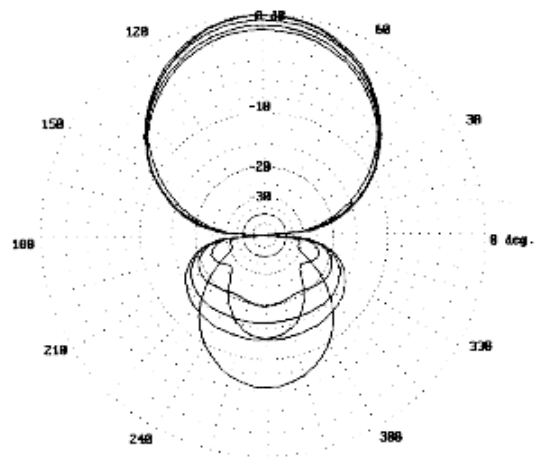


Fig. 3

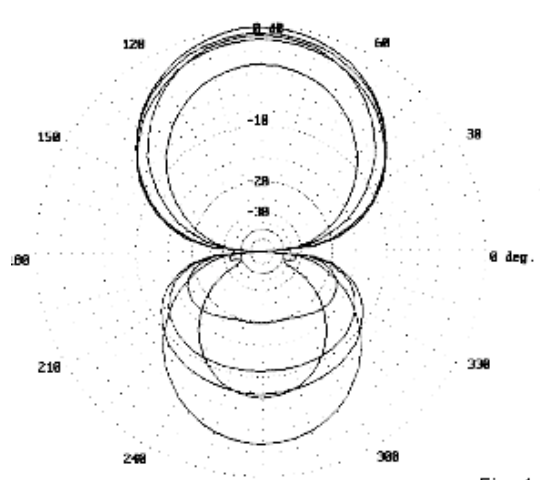


Fig. 4

SWR Bandwidth for Full and Short Yagis Design Center Frequency = 28.5 MHz

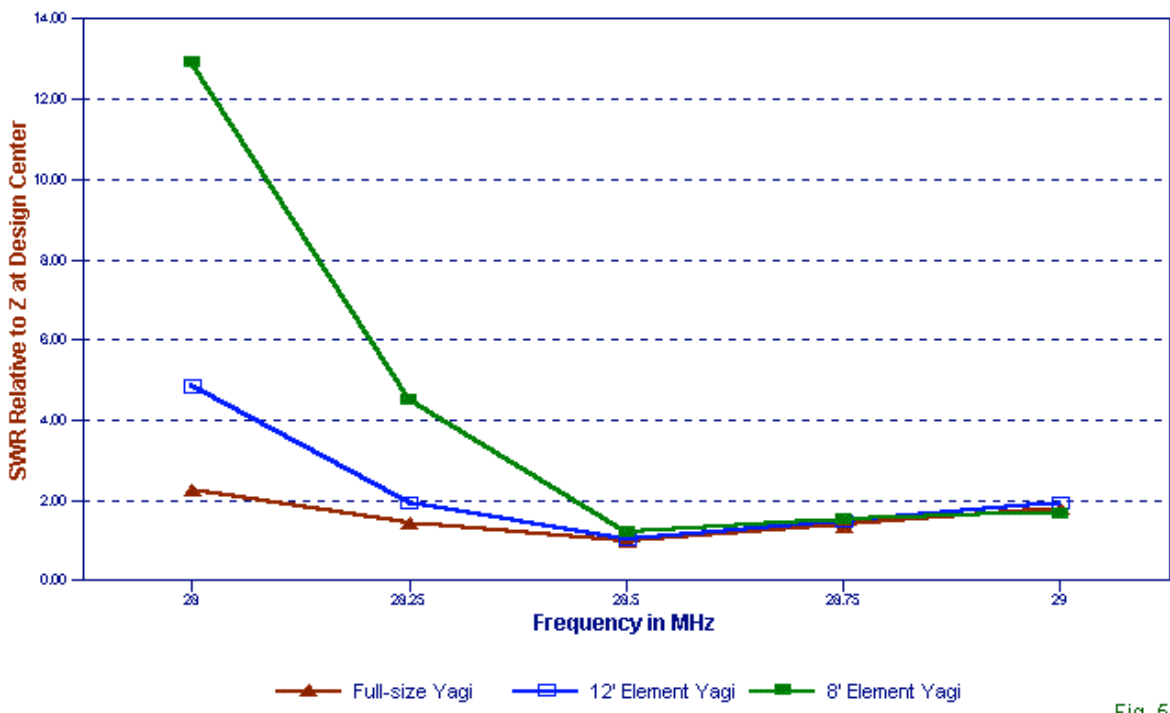


Fig. 5

That the patterns of the shortened Yagis degrade more quickly below design center is also reflected in the SWR bandwidth curves shown in **Figure 5**. Even the full size Yagi shows a steeper SWR curve below design center than above. The 12' model is well off match at 28 MHz, while the 8' model reaches a similar departure from match only 250 kHz below design center. The curves suggest that the antennas are best designed for a lower center-frequency, since the

SWR increases slowly above that frequency. However sound that conclusion may be with respect to the full-size Yagi, it tells only part of the story with respect to the shortened models one must also account for the degrading front-to-back ratio as the frequency departs upward from center.

Do the numbers condemn the shortest model? Not necessarily. Whether a particular antenna is right to build depends upon a collection of factors that perhaps only the user can balance. A full-size 2-element Yagi exhibits good gain within its class, about 2 S-units of front-to-back ratio, and a broad bandwidth, all at the expense of a larger physical structure. The 12' model shows a decreased bandwidth with respect to front-to-back ratio and SWR, but it maintains reasonably good gain and up to 3 S-units of front-to-back ratio with a size only three-fourths that of the full-size Yagi. The 8' model holds the appeal of a truly portable Yagi with some gain and 3 S-units of front-to-back ratio at its design center frequency. However, its gain is significantly reduced and its bandwidth is quite narrow. Moreover, with a feedpoint resistance in the neighborhood of 12 Ohms, the ratio of loss resistance to radiation resistance is much increased. Nevertheless, a small antenna with some gain over a dipole and a good front-to-back ratio over a narrow bandwidth can have many uses.

Both shortened antennas were modeled for patterns and SWR bandwidth curves at a center-load Q of 300, that obtainable on the 12' model with a linear-loading element. It is dubious whether such a Q could be sustained for either the 12' or the 8' model with inductive loading. Connection losses, weathering losses, and other factors are likely to reduce the Q of even the most elegant loading coil assemblies to levels below 100 unless the antenna is often cleaned or is operated within a protected environment. Unfortunately, as **Table 2**'s data would suggest, these further reductions in gain might make the antenna less attractive as it weathers. However, for portable use--where assembly and disassembly provide reminders to clean all connections--the antenna may have its niche in the array of antennas in amateur use.

Like almost every other final evaluation question we have encountered, the inquiry, "How short can we go?" has no single reply. User needs, competing designs, parts availability, and building skills all contribute to the final answer for each ham.

Notes

1. Glenn Blackwell, K4HJJ, "A Half-size Two Element Beam with a Full Size Punch," *10-10 International News*, 33 (Spring, 1995), 6.