A Modern Giant Yagi

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[Note: This article represents an initial announcement, in the manner of a news report, although with equal time for anecdote and tutorial. The authors intend to publish further details in the near future.]

A giant HF Yagi antenna has been designed, constructed, and demonstrated, by radio amateurs W6TSW, W6VPH and K6BLG. In a significant application of the EM method-of-moments MININEC wire code [1], thirteen widely-spaced elements have been disposed on six towers, in a fixed-azimuth application. Overall antenna dimensions are 10 by 100 meters, by 25 meters above the ground: a structure roughly 0.5 × 5.0 × 1.0 wavelengths in the WARC-allocated "20-meter" amateur band. The elements are arranged for a considered balance among forward gain, sidelobe level, impedance level, and bandwidth, and structural wind survival and construction economies, with an EM emphasis on forward gain. Recently-available MININEC-based multiple-optimization software [2] has very conveniently and efficiently automated several of the EM-related design steps, requiring brute-force iterations. In fact, without such (PC-implemented) method-of-moments analysis and weighted, multi-parameter optimization, such a project would not likely be initiated. The wire and optimization codes have clearly enabled such a large undertaking to be approached with high confidence, with assurance that multiple objectives will be sensibly realized, and with trivial (or none at all) final adjustment. Still, indispensable human judgment, experience, and strategy remain necessary ingredients, despite over 15,000 machine-aided EM design iterations, in this instance.

The 100 meter (divided-boom) antenna, seen in Figure 1 [and on the cover] operates at a center frequency of 14.150 MHz (λ = 21.15m). The design provides a comfortably-high feed-point resistance (30Ω), with an impedance bandwidth (VSWR=1.5) somewhat more than 2 percent. In free space, the predicted directivity is +15.8 dBi[1]. The predicted directivity is fully +21.5 dBi, at a favorably-low elevation angle, when arrayed over low conductivity (in fact, good dielectric) ground. The actual power gain is 0.1 dB less at the feed point, due to calculated element dissipations, and 0.5 dB less again, due to the loss in the 55 meters of cable between the feed point and the transmitter/receiver. Each element is built with heavy-wall aluminum tubing, starting in the center with 32mm diameter, stepped twice, and ending with 19mm diameter at the tips. Each of the six, 75mm-diameter boom segments measures 9m.

To assure EM field purity in the six-tower environment, the topmost tower guys are dielectric. A conductor-free zone of a half-wavelength (minimum) radius is thus provided, for the intended horizontal polarization.

The antenna operates from a Southern California location, at a boresight of 15 degrees East of true North, on a great-circle heading to cover selected portions of Europe and Asia. The azimuth beamwidth is slightly less than plus and minus 15 degrees to the -3dB points. Following first turn on in February, 1991, it very quickly became evident that the performance in both transmission and reception equaled or exceeded all expectations. One measure of performance is based on many transmission and reception comparisons with an adjacent, well-constructed and widely-spaced five-element rotary Yagi, having a similarly-high feed-point resistance and overall efficiency. Another measure is the close compliance with the predicted impedance bandwidth, a vital and convenient observable.

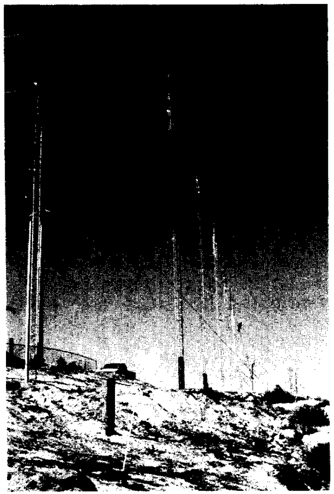

Photo 1. The 100-meter-long, 25-meter-high, divided-boom Yagi antenna. The width is about 10 meters, and it operates at 14.150 MHz.

A simple view of EM propagation on a well-designed, long Yagi is that of a travelling wave, partly bound to an (artificial) dielectric. The phase velocity on-axis follows from the above-unity index of refraction, and is therefore necessarily less than the speed of light. The phase velocity depends on the length, spacing, and diameter of the guiding element(s). A part of the power, carried off the center line, propagates at (or close to) the speed of light. Although many find it less than satisfying intuitively, a resultant EM field, distributed over an aperture at the end discontinuity farthest from the reflector, may then be viewed as responsible for essentially all radiation. More satisfying, perhaps, is to imagine the action of a somewhat distributed convex lens on the phase front. In a related view, a transmission-line low-pass filter is formed, whose

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[1] The authors thank B. Beezley for the full NEC final analytical calibration, which was within 0.1 dB of the MININEC results.

cutoff frequency occurs when the guiding element lengths become inductive, above $\lambda/2$. No propagation is supported in the stop band above. Higher passbands (and stop bands) exist, and are virtually never used. The vital importance of the propagating region immediately below the first cutoff, where the element lengths are just short of $\lambda/2$ and therefore barely capacitive, is that maximum Yagi gain is realized there.

Yagi antennas designed with an emphasis on forward-gain performance are noticeably subject to certain ordered errors, indeed, even at the half-percent level and less. This "touchiness" depends on how close the designer dares to approach the first stop band, while seeking to extract near-maximum gain. One example of an important ordered error involves the twice-stepped (or "tapered" diameter) element construction we use. Tapered-element resonance (or precise intended displacement therefrom) is difficult to predict at the half-percent accuracy level, even for benign (small-step) tapers, as used here. Despite some gain sacrifice, we designed-in a "scale safety factor" of 0.5 percent, to minimize (hopefully eliminate) the possibility of any director entering the stop band, and thereby becoming a reflector, due to a very small "resonance" modeling error. This was done simply by designing for an upper band-edge 0.5 percent higher than needed. Thus, an element or elements which might become too long in terms of the elevated frequency, would (presumably) continue to operate properly at the somewhat-lower (working) band edge, although with the above-mentioned gain sacrifice. The possibility of a director element inadvertently becoming a reflector would ruin travelling-wave action, and a small gain trade off for safety seems wise. In this project, we were highly motivated to avoid any critical scale-type error, especially to eliminate the prospect of post-construction climbing, disassembling, and slightly resizing 13 large elements 25 meters above the ground. Early in the planning, one of the authors (the one who does all the climbing) actually became quite demanding in this regard. On the other hand, element spacing errors of comparably small magnitude have a weak influence on the travelling-wave velocity on this otherwise highly-tuned structure, and spacing-related tolerances are not an issue for this design.

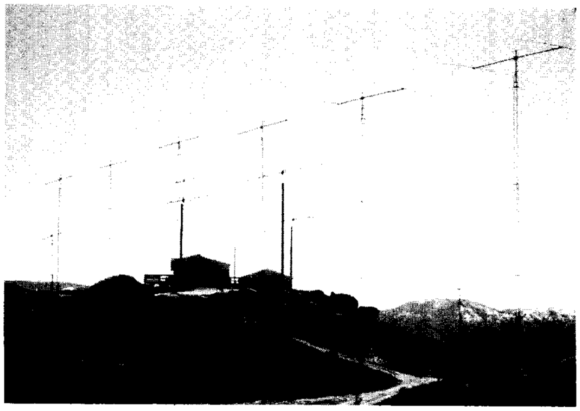
Photo 2. A different view of the 100-meter Yagi antenna.

For those wishing to gain excellent insight and feeling for Yagi antenna factors, truly classic references 3 through 6 are highly recommended. The (western) seminal reference is noted in 7.

To summarize, the combination of modern analytical and optimization tools, implemented on essentially any PC, together with practical experience and some sensible strategy, has indeed designed, predicted performance, and reliably produced an ambitious and significant result. Prior to the recent introduction and considered application of wire and optimization codes, such immediate success, realized without incident, was not always the case.

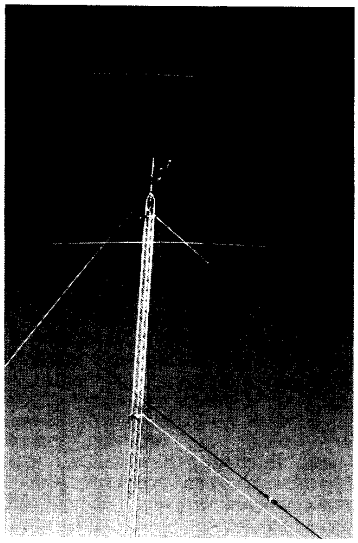
Photo 3. One of the authors making adjustments.

The excellent performance predictability, high directivity and efficiency, robustness to wind, and considered use of materials evident in this approach clearly allows low implementation risk and cost for other HF applications.

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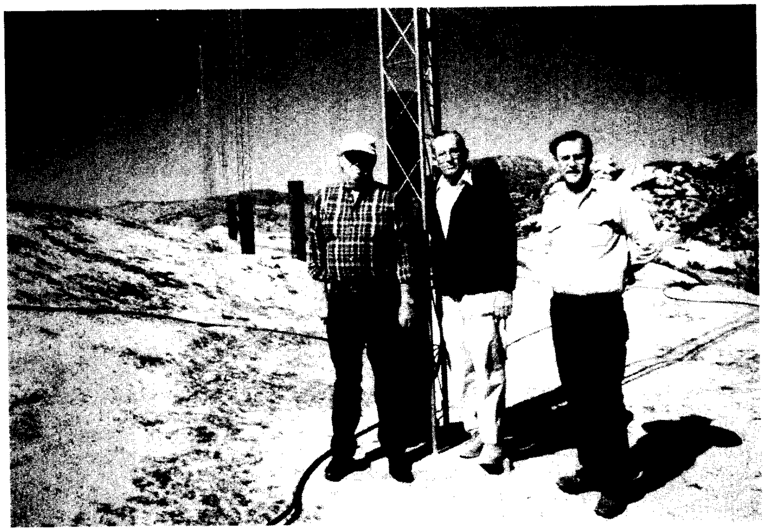
Introducing Feature Article Authors



The authors developed mixed emotions when confronted with their trilogy: The biographical data shows that their ages total 178 (years), of which 136 were spent as licensed radio amateurs. The authors uniformly and quickly point out none feels nearly so historic as the numbers suggest, and the surprisingly large radio time fraction – 76% and, naturally, increasing – merely supports the assertion that amateur radio is a very enjoyable and multifaceted hobby. Although none of the authors was born with a brass key in place of the proverbial silver spoon, morse code keys were acquired early, and all were licensed as young teens.

The senior author pioneered one of the very early three-element wide-spaced Yagi-Uda beams in the United States (1937), barely a decade following the famous Japanese invention, and has been an avid DXer since. The second author has a number of activities to his credit, including extensive travel in connection with setting up amateur satellite stations in the Caribbean region and Central America. When first licensed, the second author remained the youngest radio amateur in his state for several years, and is now quite well known worldwide as a top DXer. The junior author (somebody gets to enjoy being the youngest) is not nearly as proficient with high-speed morse as the more experienced pair and, consequently, suffers their united and constant goading. In retaliation, the junior author is known to "hog" the PC, paying more attention to arithmetic and design, and less to operating.

All authors are, or have been, involved in various electronic and/or microwave professional occupations and businesses. Currently, two of the authors are involved with the NASA Deep Space Network receivers and microwave antennas, while the third gets to enjoy using the new, 13-element antenna every day.