The Extended-Element Beam

Using only three elements, this beam has the gain of a 6-element Yagi array. Extending the elements is the key to such success.

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It is well known that the optimum length of a dipole antenna for maximum gain is approximately 5/4 wavelength. Such an antenna is commonly called an "extended double Zepp."[1] The radiation pattern is as shown in Fig. 1, and the gain is 3.1 dB over a half-wave dipole (3.1 dBd). It does not seem to have been recognized that extended-double-Zepp elements can be utilized in parasitic arrays. Such use results in a compact, high gain antenna, with characteristics generally similar to ordinary Yagi antennas, but with 3-dB greater gain and narrower beamwidth for the same number of elements. This has been verified both analytically and experimentally for 3-element arrays, shown schematically in Fig. 2.

An extensive experimental investigation was conducted on a 3-element beam designed to operate at 280 MHz (Fig. 3). The model was designed to permit exploring a range of element spacings and element tuning. Element tuning was accomplished by incorporating variable capacitors in parallel with the fixed inductors shown in Fig. 2. Element length is not at all critical; all elements were made 51.3 inches, or 1.22 wavelengths, long. The driven element was fed through a coiled coaxial type of balun, ensuring balanced feed. The radiation pattern of the driven element alone was observed to be virtually identical with what was expected theoretically (Fig. 1). E- and H-plane patterns and impedance measurements were made on the model for director and reflector spacings of 0.15 and 0.2 λ respectively, 0.175 and 0.225 λ, and 0.2 and 0.25 λ. The antenna was tuned for two conditions at each spacing — maximum gain and maximum front-to-back ratio. The results generally correspond to those expected for ordinary parasitic arrays.

Effect of Element Spacing

The wider spacings gave reduced gain and front-to-back ratio and increased bandwidth compared to the 0.15- and 0.2-λ director and reflector spacing. Table 1 gives a comparison of these characteristics for the three spacings. Closer spacings were not explored owing to the increasingly narrow bandwidths encountered, although the maximum front-to-back ratio would presumably be improved. Reduced bandwidth is the price paid for the extended-element beam advantages of compactness and mechanical convenience when compared to two ordinary Yagi antennas arrayed side-by-side and spaced at 1 λ. An extended-element beam performs very similarly to such an array in all respects except bandwidth.

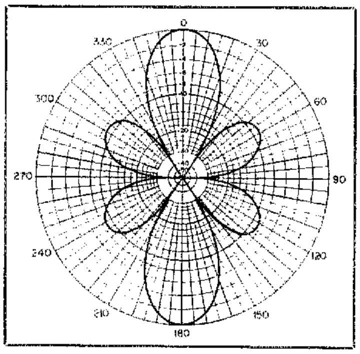

Fig. 1 — Free-space directive diagram for the extended double Zepp. This array has a gain of 3.1 dB over a dipole. (In this plot, the radiator lies along the 90°-270° line.)

Performance

Fig. 4 summarizes the front-to-back ratio, gain and VSWR observations for 0.15- and 0.2-λ director and reflector spacing. Increased gain with increasing frequency is a familiar characteristic of all Yagi antennas. The bandwidth over which the front-to-back ratio is high is less for the extended-element beam than with ordinary Yagi antennas, judging from Lawson's epic work.[2] If the maximum gain of an ordinary

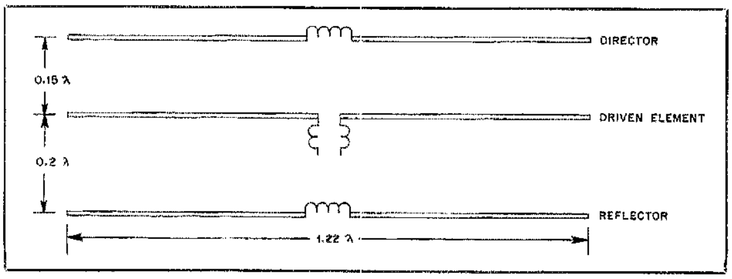

Fig. 2 — Extended-element beam, with suggested dimensions.

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[1] Notes appear on p. 37.

*c/o Electrospace Systems, Inc., Richardson, TX 75083-1359.

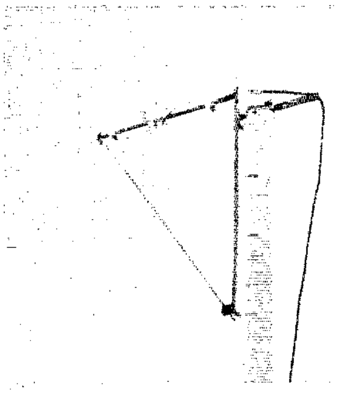


Fig. 3 — Extended-element beam model, designed to operate at 280 MHz.

3-element Yagi is 7 dBd, then we'd expect the maximum gain of an extended-element beam to be 10 dBd. This is very nearly what was observed. A gain penalty of about 0.7 dB is incurred when choosing tune-up for maximum front-to-back ratio rather than maximum gain, but often this will be the preferred choice, especially if bandwidth is a consideration.

Fig. 5 shows measured radiation patterns for the maximum gain and maximum front-to-back conditions. Lack of symmetry in the back lobe is believed to be caused by imprecision in model construction.

Tune-up Procedure

Considerable experimentation was carried out to determine the optimum tune-up procedure. Whether tuning for maximum gain or maximum front-to-back ratio, it was found that the director should be tuned first, with the reflector removed or open circuited. The director is tuned for maximum signal off the front or minimum signal toward the rear, as desired. Then, the reflector is tuned for maximum effect. The process converges very rapidly, such that it is not absolutely necessary to retune the director after tuning the reflector. However, this was sometimes found to improve the results. A convenient method that has been used successfully for tuning an antenna for maximum front-to-back ratio is to lash the antenna onto the side of a tower, with the reflector closest to the ground and at least λ/2 above ground. Then transmit from a dipole near ground at the base of the tower. The antenna under test is connected to a receiver, and the director and reflector tuned sequentially for minimum S-meter reading.

The suitability of the extended-element beam to this tuning approach is one of its advantages over ordinary Yagi antennas; the usual practice is to adjust element lengths to achieve the desired performance. A single ordinary Yagi requires six elements for 10-dBd gain. Optimizing such an antenna experimentally is clearly much more difficult than optimizing a 3-element extended-element array.

The driven element may be tuned and matched by conventional means quite in-

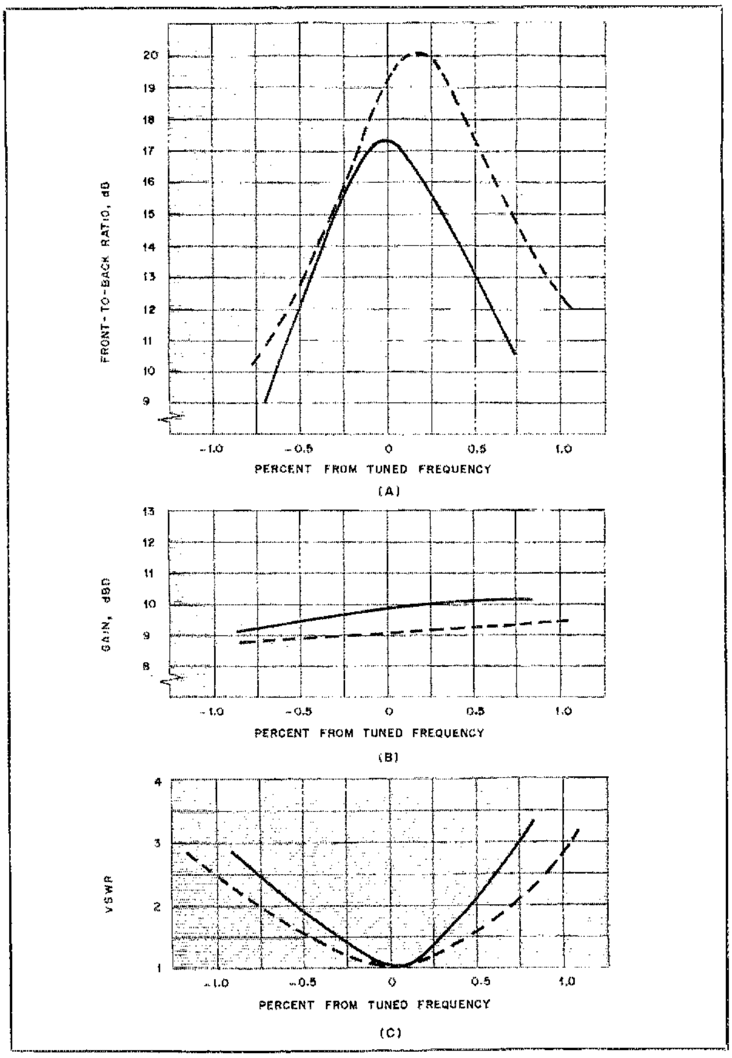


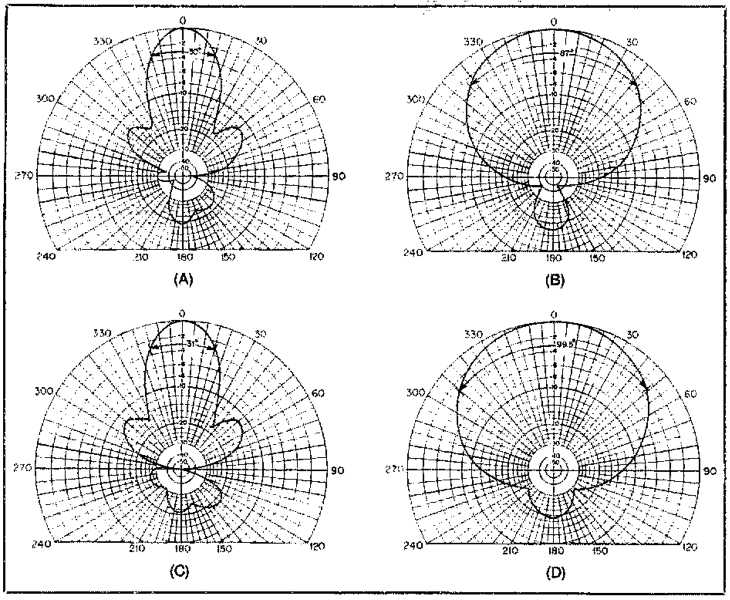
Fig. 4 — Performance of the extended-element beam with dimensions shown in Fig. 2. At A is the front-to-back ratio; at B, the gain over a dipole; and at C, the VSWR. In each plot, the solid line shows the performance with the beam tuned for maximum gain, and the broken line when tuned for maximum front-to-back ratio.

Table 1

Measured Performance of 3-Element Antennas

Dir. and Refl. Spacing (λ)	*Tuning Condition*	*Gain* (dBd)*	*F/B* (dB)*	*Input R* (Ohms)*	*Bandwidth for 2:1 VSWR (%)*
0.15 and 0.20	max. gain	9.8	17.3	25	1.0
0.15 and 0.20	max. F/B	9.1	19.2	34	1.5
0.175 and 0.225	max. gain	9.5	14.9	34	1.3
0.175 and 0.225	max. F/B	9.0	15.9	39	1.8
0.20 and 0.25	max. gain	9.5	9.3	31	1.1
0.20 and 0.25	max. F/B	8.2	13.8	51	2.1

*At tuned frequency (280 MHz)



(A) (B) (C) (D)

Fig. 5 — Measured patterns of the extended-element beam of Figs. 2 and 3. E-plane patterns are shown at the left, and H-plane patterns at the right. The patterns at A and B were obtained with the beam tuned for maximum gain, while those at C and D were for the beam tuned for maximum front-to-back ratio.

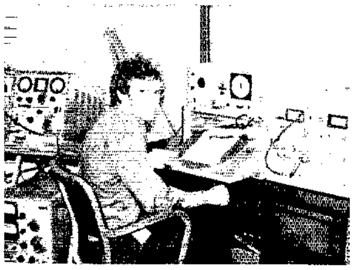


Fig. 6 — Pattern recording equipment, with author Schroeder.

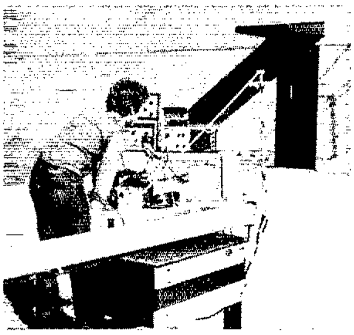


Fig. 7 — Impedance measurement in progress.

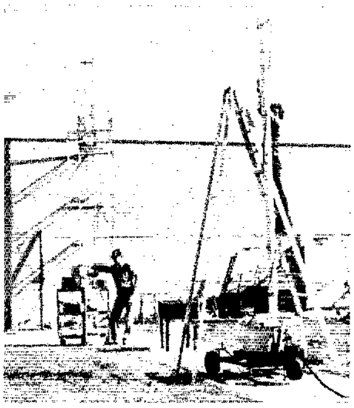


Fig. 8 — Antenna model being tuned on the pattern range.

dependent of the tuning of the director and reflector. The patterns of the antenna are not a function of the driven-element tuning.

The values of the inductors needed to tune the antenna must be determined experimentally. As a start, it is suggested that the reactance for the director be about 400 ohms, and that for the reflector about 600 ohms. A range of adjustment of approximately ±50% from these values is recommended. Probably the easiest mechanical arrangement for variable inductors is a length of transmission line made of rod or tubing, with a movable shorting strap.

Method of Measurements

All model measurements were made on the Electrospace Systems, Inc., antenna pattern range (Figs. 6-8). The range was set up carefully to minimize ground reflections. Impedances were measured with a Hewlett-Packard network analyzer (Fig. 7). Frequency settings were quite critical, and a frequency counter was used for all measurements.

Gains were calculated from the radiation patterns using the familiar expression

$$\text{Gain} = 10 \log \frac{41{,}253}{\theta_E \theta_H} - 2.14 \text{ dBd}$$

where

θ_E is the E-plane 3 dB beamwidth, and

θ_H is the H-plane 3 dB beamwidth.

(Gain and directivity are assumed to be synonymous here.) A gain-correction factor was developed to account for sidelobes. As a check, gains were measured experimentally by rotating the parasitic elements 90° to the driven element and observing the decrease in signal at the receiver. It was concluded that the gains calculated from measured patterns are probably accurate to within 0.2 dB.

Care was taken to ensure that the presence of the tuning person's body did not affect the tuning of the antenna (Fig. 8). Even so, the tuning for maximum front-to-back ratio was critical, and it is entirely possible that higher ratios than we observed can be achieved. Some scatter in the data (Table 1) suggests that tuning was not always optimized.

Future Work

A modest attempt to evaluate a 4-element array was made; it seems logical that such an array would work. However, no significant improvement in gain over a 3-element array was observed. More investigation of such arrays is needed.

Extended-element beams of three elements each for 10 and 15 meters, mounted on the same boom, are under construction as of this writing. This project may be the subject of a future article.

Acknowledgment

Thanks go to Toney Magnino, W5MVK, who provided considerable assistance in the experimental work, most particularly in the construction of the antenna model.

Notes

[1] G. Hall, ed., *The ARRL Antenna Book* (14th Ed.). Newington: ARRL, 1982, page 6-8.

[2] J. Lawson, "Yagi Antenna Design," *Ham Radio*, May 1980, p. 22.