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LB-879

RHOMBIC ANTENNAS FOR UHF TELEVISION

RADIO CORPORATION OF AMERICA

RCA LABORATORIES DIVISION

INDUSTRY SERVICE LABORATORY

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Rhombic Antennas for UHF Television

Approved

Stuart Wm Seeley

Introduction

The inherent broad band gain characteristics of the rhombic antenna, together with its mechanical simplicity are relatively favorable for its application as a receiving antenna for the u-h-f television band. The vertical beam width of a single horizontal rhombic antenna in free space generally is considerably wider than the horizontal beam width. To sharpen the vertical beam and also to obtain an impedance match to commonly used balanced transmission lines, vertically stacked rhombic pairs were investigated. To improve the broadband impedance characteristics double-wire rhombics were chosen in preference to single-wire structures.

The results given in this bulletin were measured under relatively favorable conditions and may not be realized in practice if the field is not homogeneous.

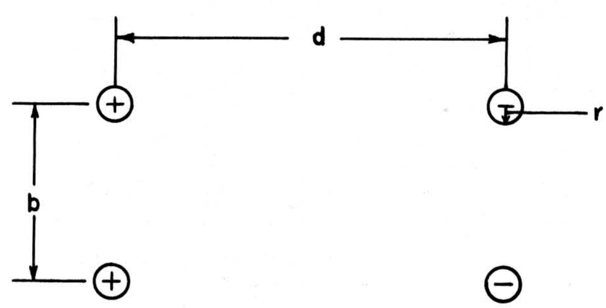
Design of the Rhombic Array Elements

The mid-point spacing of the double-wire sides was determined on the basis of a formula for the characteristic impedance of parallel-pair four-wire transmission lines, as given in Fig. 1. It was assumed that a design impedance of 400 ohms would be a good approximation. Accordingly, the entire rhombic was designed to resemble a tapered 400-ohm transmission line.

Bakelite spreaders and end plates mounted on wooden spars were used to support the wires. A typical structure may be seen in Figs. 2a and 2b. Number 14 (A.W.G.) hard-drawn copper wire was used in constructing the rhombus sides and number 10 hard-drawn copper wire was used in constructing the 400-ohm paralleling jumpers.

Rhombic Termination

Theoretically, a properly terminated rhombic antenna resembles a transmission line terminated in its characteristic impedance. If the rhombic is not properly terminated, reflections will cause a low front-to-back ratio. Front-to-back ratio measurements for various terminations were made on an early model of the rhombic array and it was found that an Allen-Bradley type EB 470-ohm ½-watt carbon resistor offered the best termination of the different values tried (Fig. 3).



$$Z_o = 138 \ \mathrm{Log}_{10} \left[\frac{d\sqrt{b^2+d^2}}{br} \right]$$

Fig. 1 – Transmission line impedance formula.

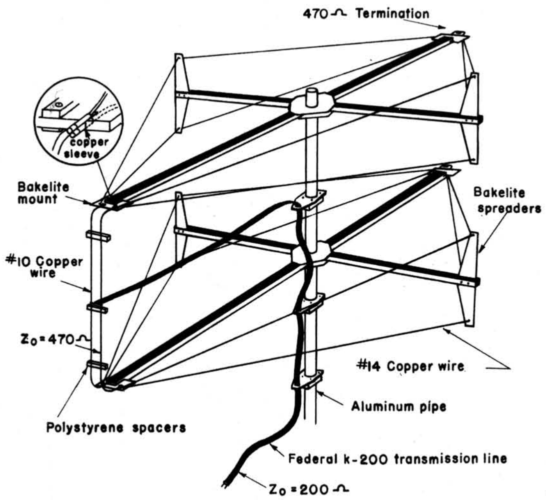


Fig. 2a - Perspective view of antenna.

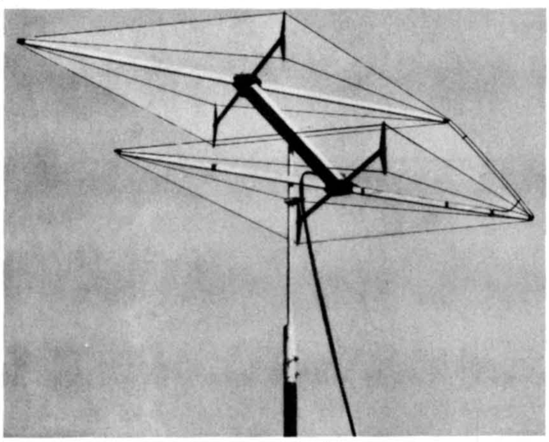


Fig. 2b - A photograph of antenna type D_2.

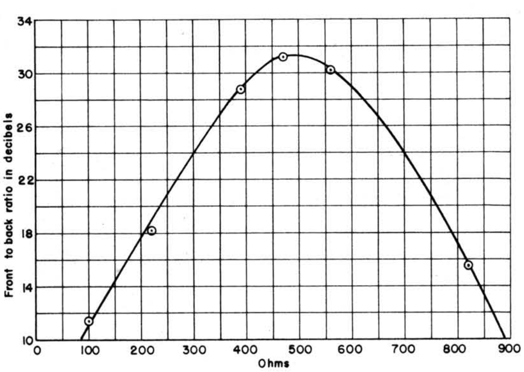
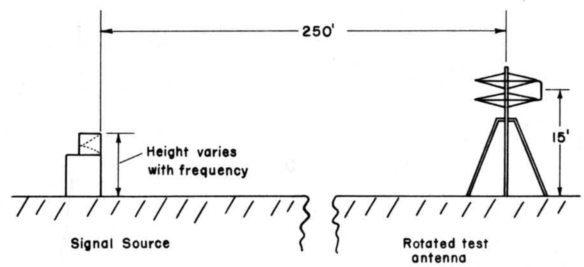


Fig. 3 - Effect of terminating resistance on front to back ratio.

Field Pattern Measurements

The antenna under test was placed on a rotating mount and a corner reflector antenna in a fixed position was used as the signal source. A spacing of 250 feet between the signal source and the antenna under test provided a negligibly distorted wave-front across the aperture of the receiving antenna. For each test frequency, the height of the signal source was adjusted so that the direct and ground reflected rays would add in phase and produce a first maximum at the center of the receiving antenna. Vertical patterns were obtained by placing the test antenna on its side and using a vertically polarized signal. A typical testing arrangement is shown in Fig.



'Fig. 4 - Typical antenna measuring arrangement.

Gain Measurements

All gain measurements were made by comparing the antenna under test with half-wave folded dipoles. A u-h-f receiver was used as a voltage indicator and the decibel gain was measured with a calibrated attenuator on a u-h-f signal generator. Construction details for the reference dipole are shown in Fig. 5.

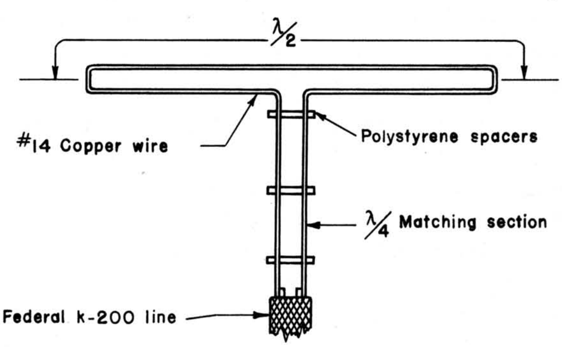


Fig. 5 - Reference antenna used in gain tests.

Descriptions and Characteristics of the Antennas

The antennas to be described have be designated as designs A, B, C, D_1 and D_2. A ief explanation of each antenna together with ield patterns, gain plots and effective area curves will be found on the following pages. All of the field patterns are plotted in terms of relative voltage.

An effective area plot (see Appendix) is included to demonstrate how the ability of the antenna to absorb energy from the passing electromagnetic wave varies with frequency. For all of the antennas to be described, Federal K-200 balanced transmission line was used for the lead-in. The attenuation in this line was asured to be 1.3 db per 100 feet at 534 Mc. 100 feet of lead-in was used with the A and B antenna designs while 25-foot lengths were used with the C, D_1 and D_2 arrays.

Antenna Design A

An outline of this antenna is illustrated in Fig. 6 while a perspective view showing construction details may be seen in Fig. 2a. The antenna dimensions were calculated for maximum signal across the load terminals to occur at the middle of the u-h-f television band. The azimuth field patterns (Figs. 7, 8 and 9) indicate the presence of fairly large side lobes throughout the entire band while the elevation field patterns (Figs. 10, 11 and 12) appear to be satisfactory.

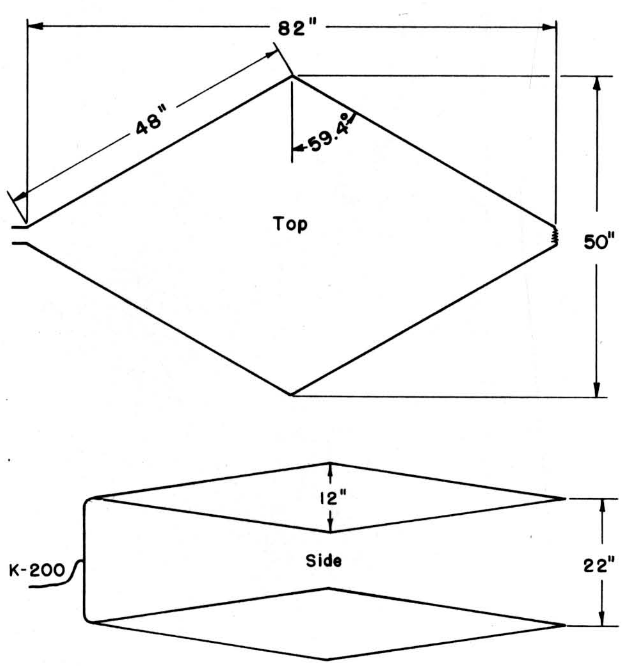


Fig. 6 - Rhombic antenna dimensions. (A design)

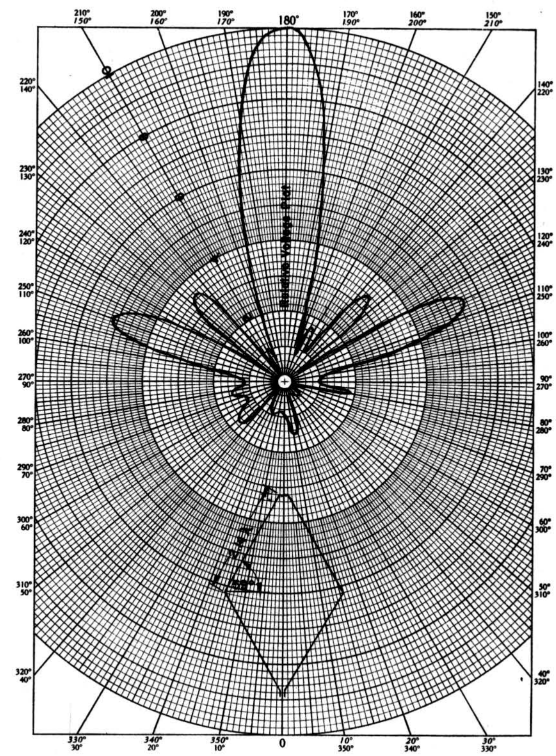


Fig. 7 - Azimuth field pattern - 530 Mc. (A design)

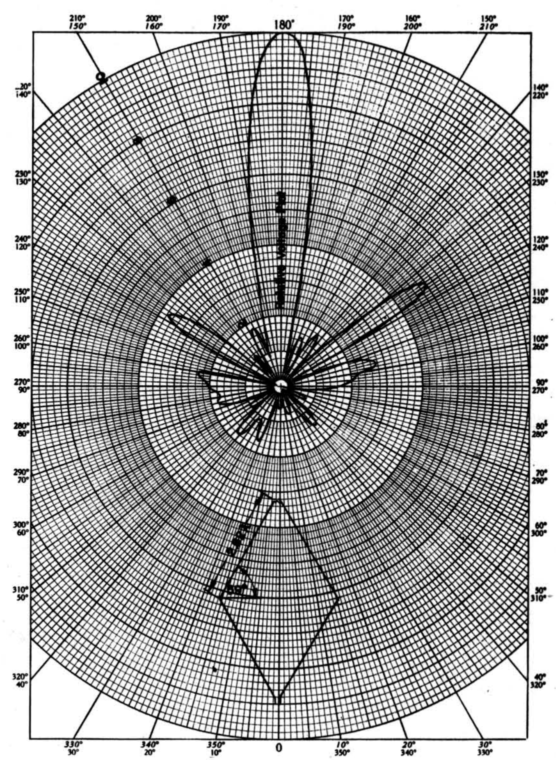


Fig. 8 - Azimuth field pattern - 700 Mc. (A design)

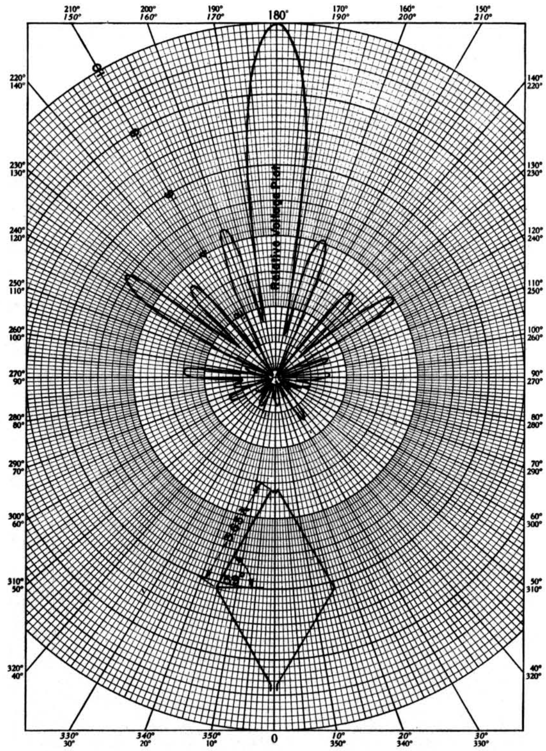


Fig. 9 – Azimuth field pattern – 900 Mc.
(A design)

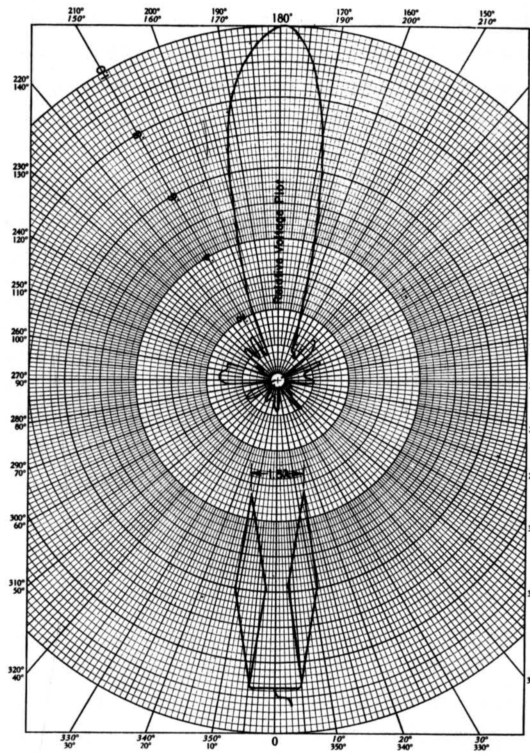


Fig. 11 – Elevation field pattern – 700 Mc.
(A design)

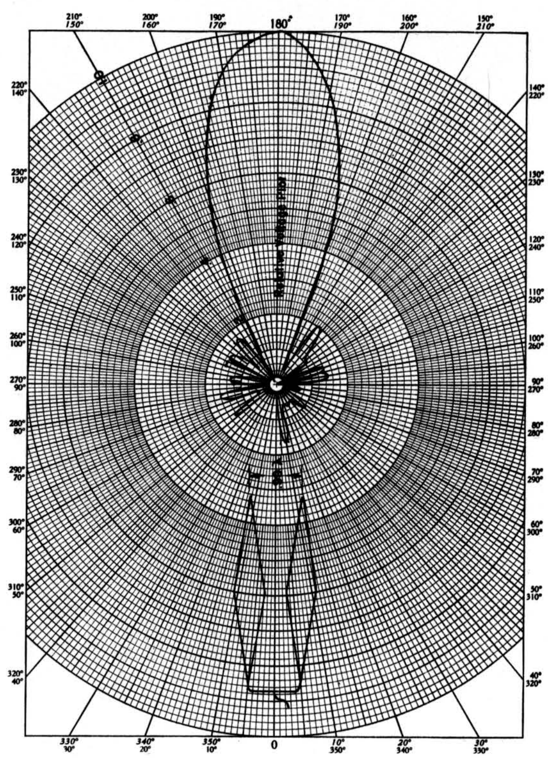


Fig. 10 – Elevation field pattern – 530 Mc.
(A design)

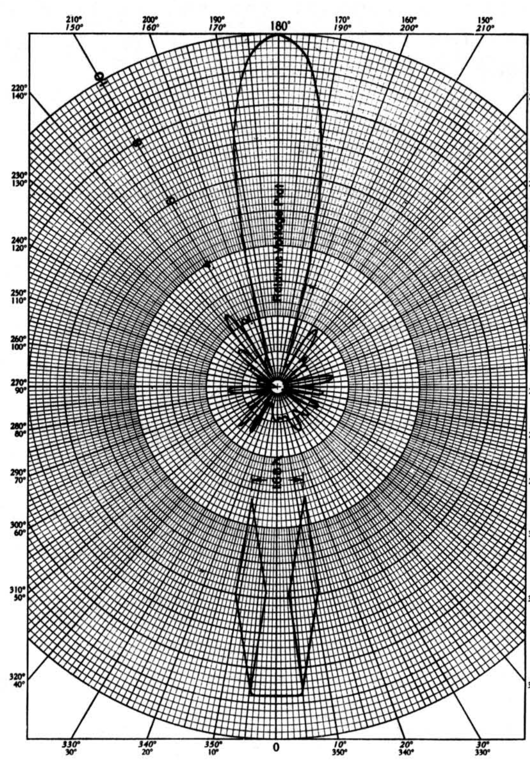


Fig. 12 – Elevation field pattern – 900 Mc.
(A design)

Although the gain curve (Fig. 13) appears to be fairly flat over the band, the effective area curve (Fig. 14) demonstrates how the received power decreases with frequency.

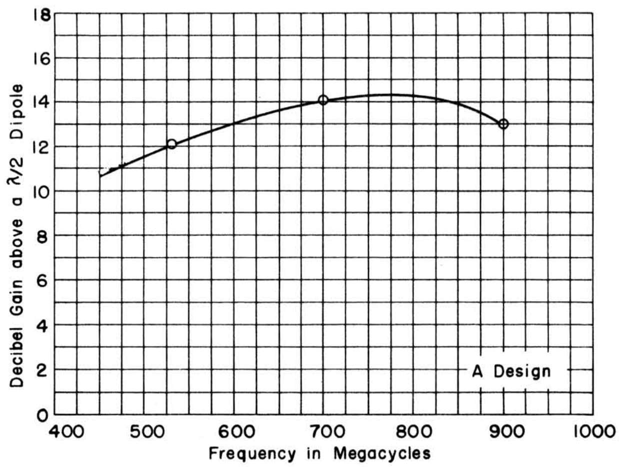


Fig. 13 – Gain curve for A design.

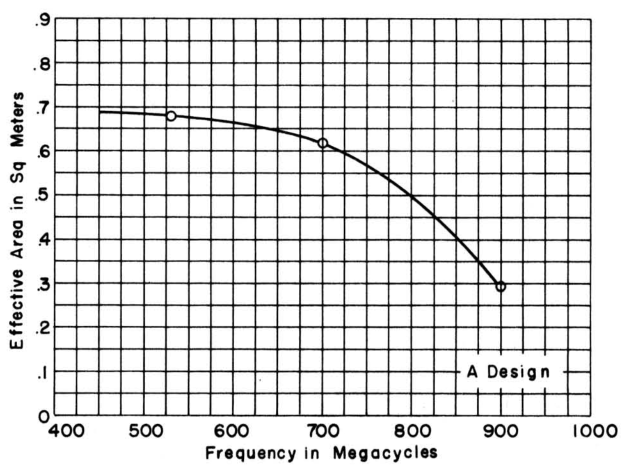


Fig. 14 – Effective area curve for A design.

Antenna Design B

This antenna is similar to the A design except for an increase in the fore-and-aft dimension. The new fore-and-aft dimension was calculated for maximum signal across the load terminals to occur near the upper end of the u-h-f television band. It was hoped that this modification of the A design would yield an increase in gain at the high end of the band without too great a drop in gain at the lower frequencies. Dimensions for the B antenna are shown in Fig. 15.

The azimuth field patterns (Figs. 16, 17 and 18) indicate the presence of large secondary lobes, the most prominent ones occurring near 700 Mc. The elevation field patterns (Figs. 19, 20 and 21) show that the main lobe becomes quite broad near the lower end of the band. Gain and effective area are low at the upper end of the band (Figs. 22 and 23).

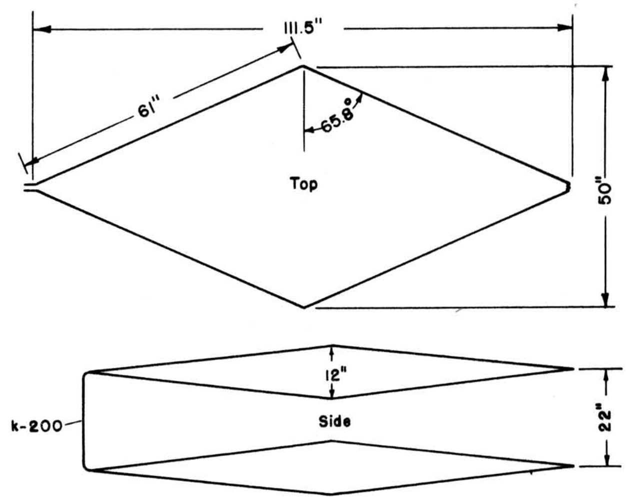


Fig. 15 – Rhombic antenna dimensions. (B design)

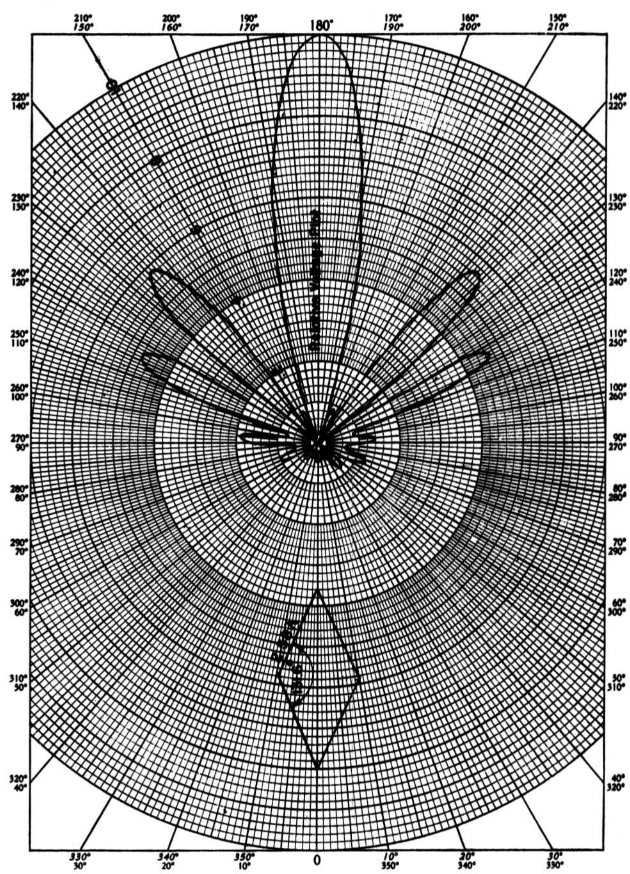


Fig. 16 – Azimuth field pattern – 500 Mc. (B design)

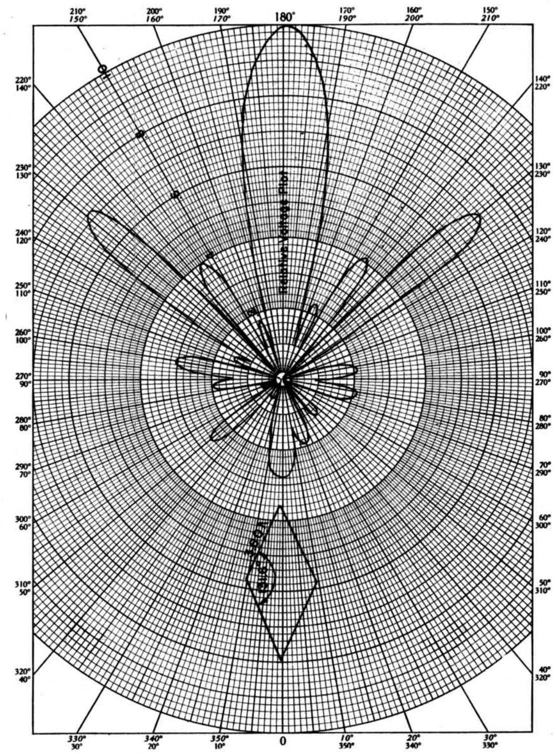


Fig. 17 - Azimuth field pattern - 700 Mc.
(B design)

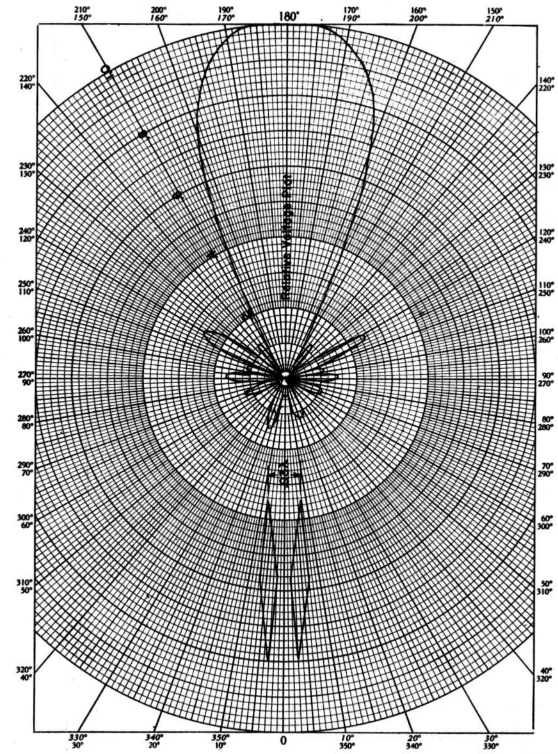


Fig. 19 - Elevation field pattern - 500 Mc.
(B design)

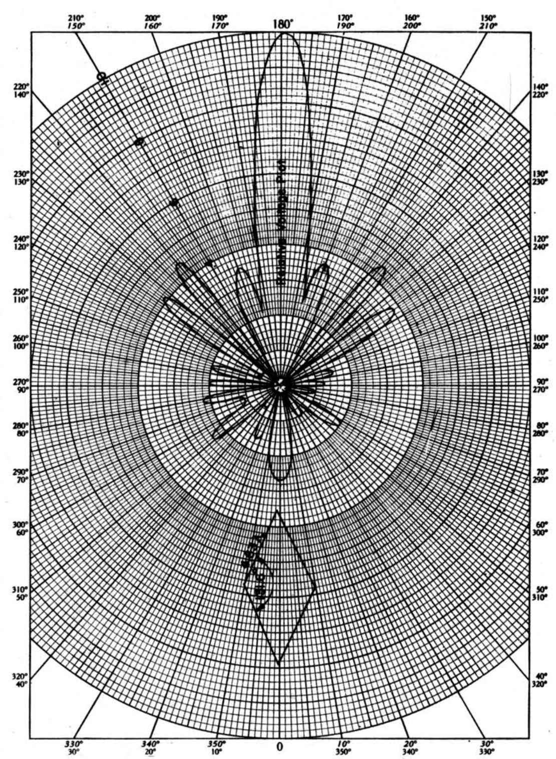


Fig. 18 - Azimuth field pattern - 900 Mc.
(B design)

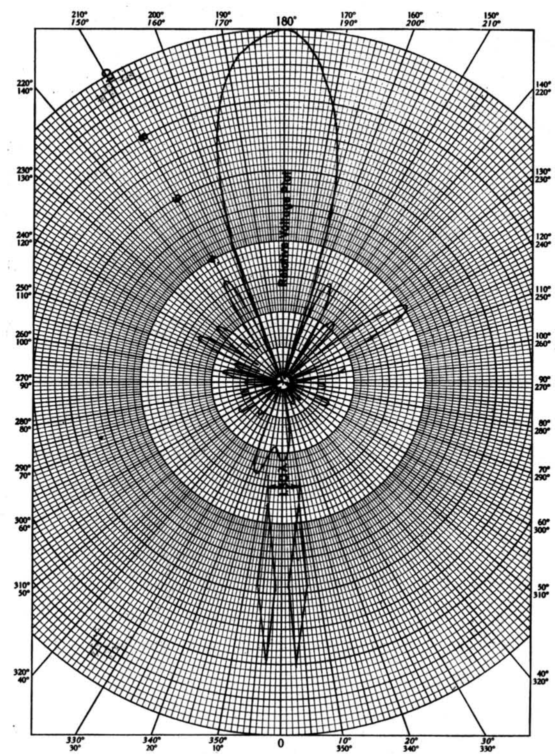


Fig. 20 - Elevation field pattern - 700 Mc.
(B design)

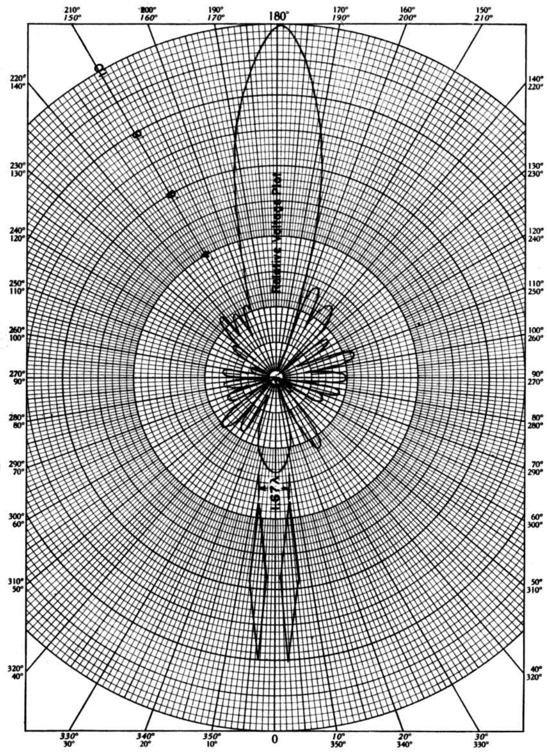


Fig. 21 - Elevation field pattern - 900 Mc. (B design)

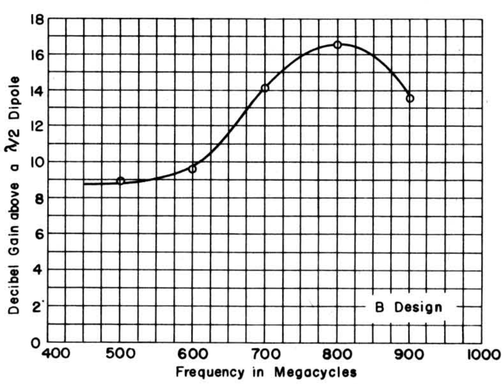


Fig. 22 - Gain curve for B design.

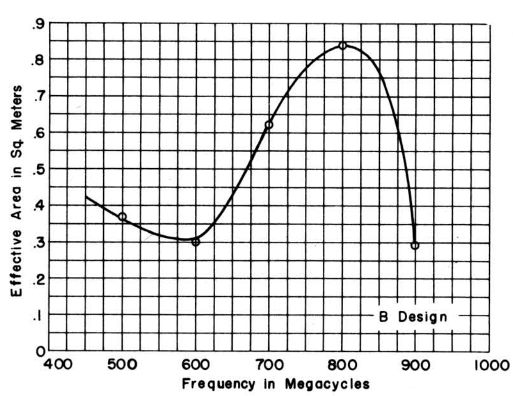


Fig. 23 - Effective area curve for B design.

Antenna Design C

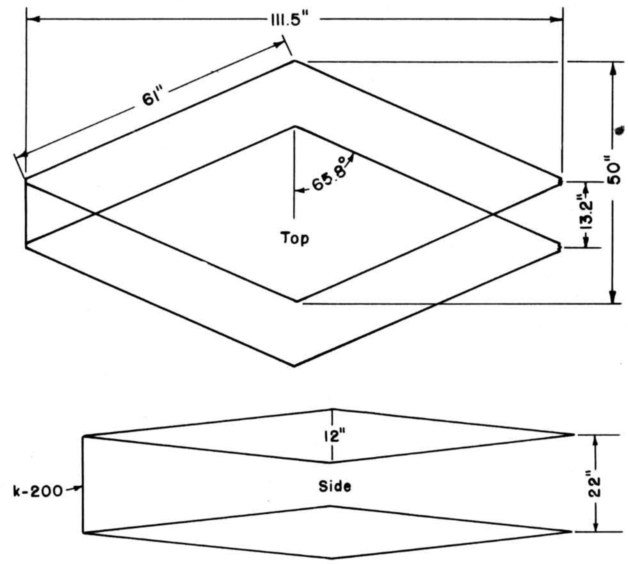


Fig. 24 - Rhombic antenna dimensions. (C design)

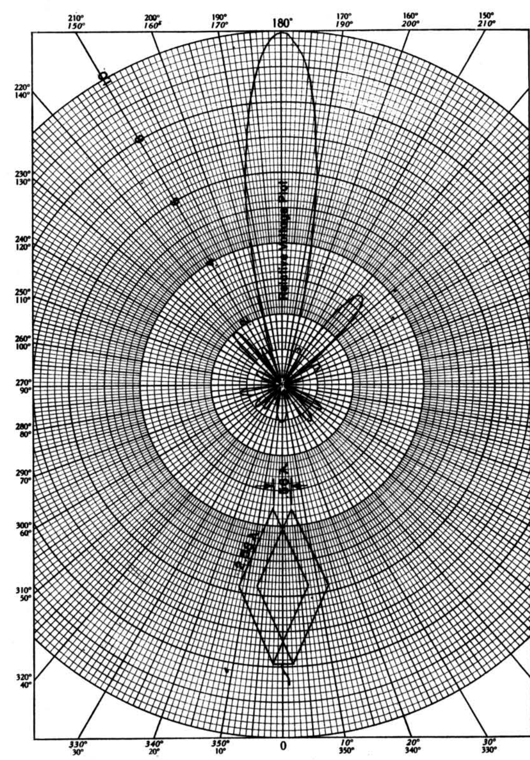


Fig. 25 - Azimuth field pattern - 500 Mc. (C design)

In an attempt to reduce the amplitudes of the secondary lobes in the horizontal radiation plane the rhombic elements in the B array were displaced laterally (Fig. 24). The lateral spacing was calculated to yield a null in the

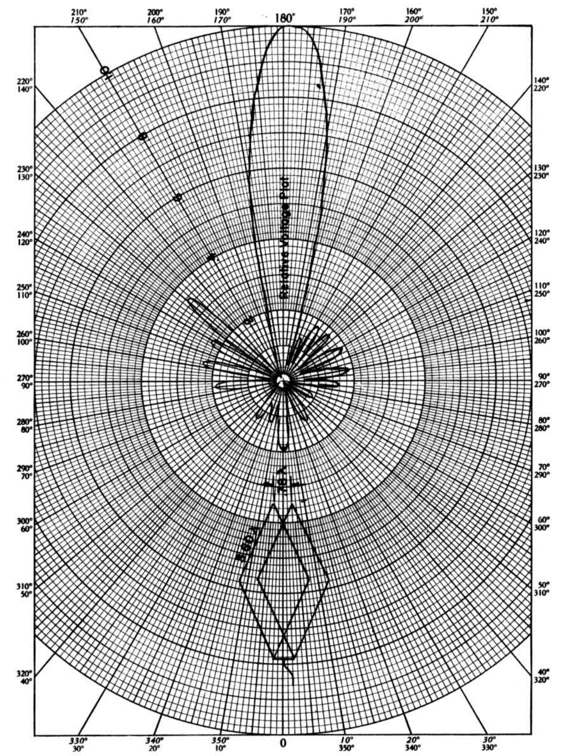


Fig. 26 - Azimuth field pattern - 700 Mc. (C design)

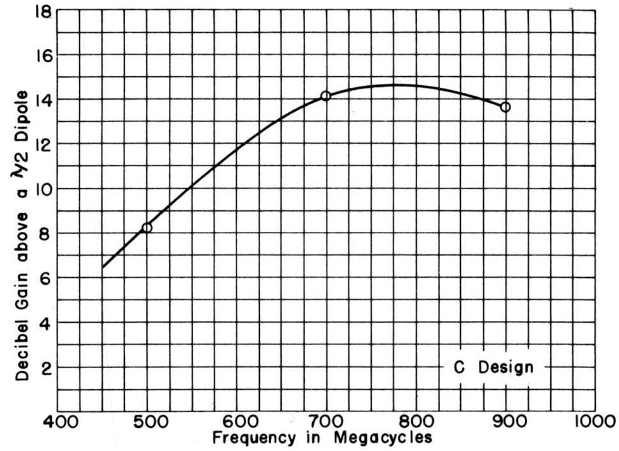


Fig. 28 - Gain curve for C design.

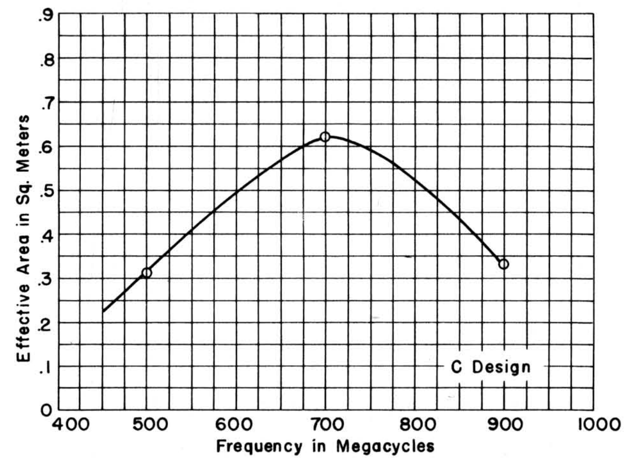


Fig. 29 - Effective area curve for C design.

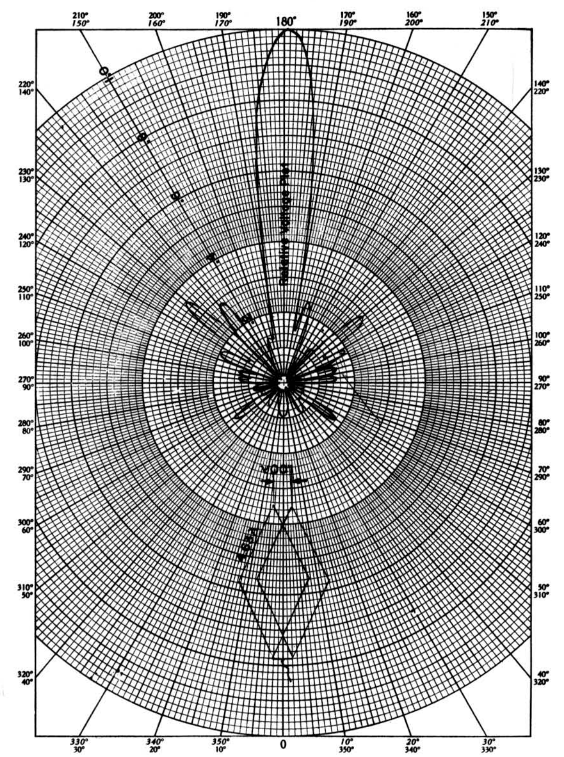


Fig. 27 - Azimuth field pattern - 900 Mc. (C design)

horizontal plane array factor near 40 degrees at 700 Mc in an attempt to reduce the amplitudes of the large secondary lobes present in the B design. Considerable improvement in the reduction of secondary lobe amplitudes, as evidenced in the azimuth field patterns (Figs. 25, 26 and 27), resulted from this modification. The gain and effective area curves are plotted in Figs. 28 and 29.

Antenna Design D_1

Although the C design was effective in reducing the amplitudes of the secondary lobes it was considered to be somewhat awkward mechanically. Consequently a D_1 design was constructed in which the rhombic elements were displaced longitudinally to attain a null in the horizontal plane array factor near 50 degrees at 700 Mc. In addition, the vertical spacing between the rhombic elements was increased to two feet. The transmission line tap point was as shown in the dimensional drawing (Fig. 30). The azimuth field patterns are shown in Figs. 31 through 35. The vertical field patterns (Figs. 36, 37 and 38) exhibit a large secondary lobe below the horizontal. The gain and effective area curves (Figs. 39 and 40) begin to fall near the upper end of the band.

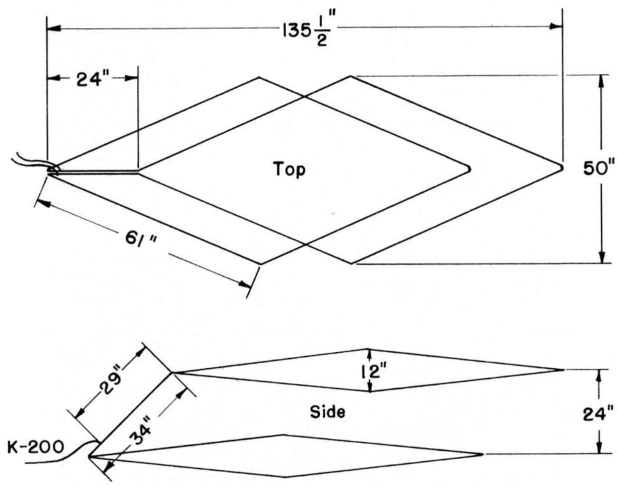


Fig. 30 - Rhombic antenna dimensions. (D_1 design)

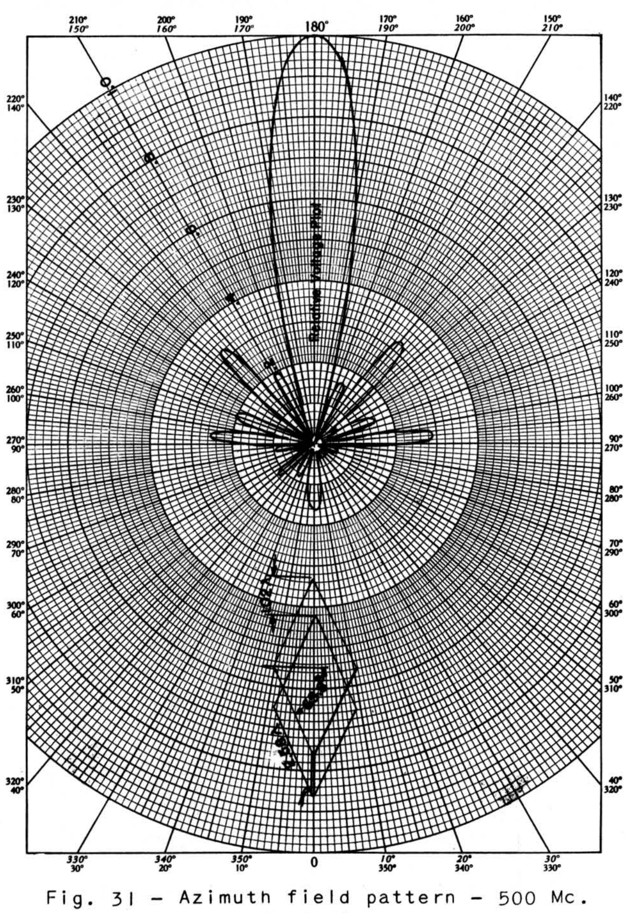


Fig. 31 - Azimuth field pattern - 500 Mc. (D_1 design)

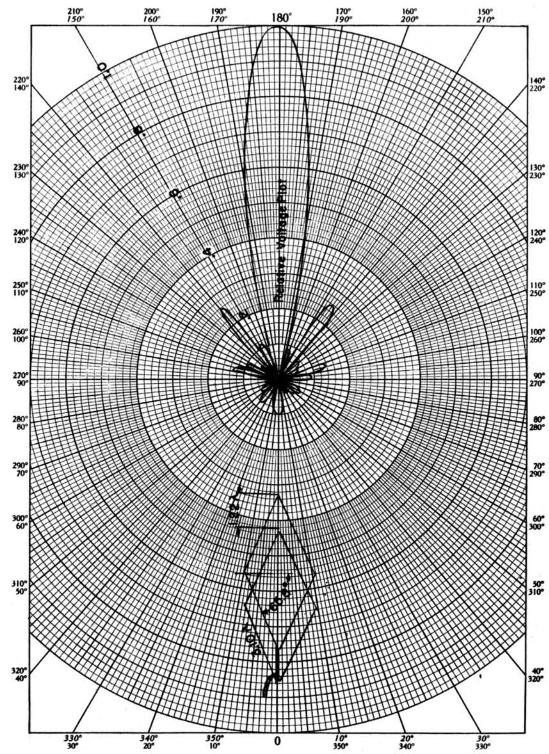


Fig. 32 - Azimuth field pattern - 600 Mc. (D_1 design)

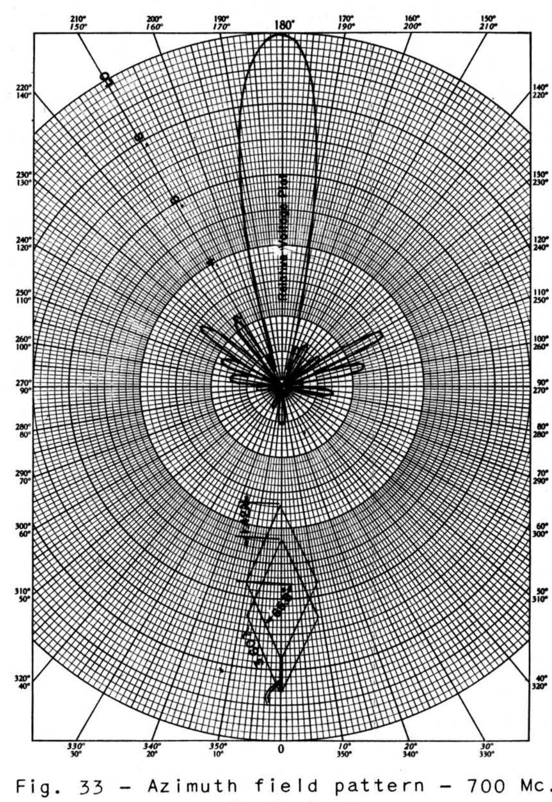


Fig. 33 - Azimuth field pattern - 700 Mc. (D_1 design)

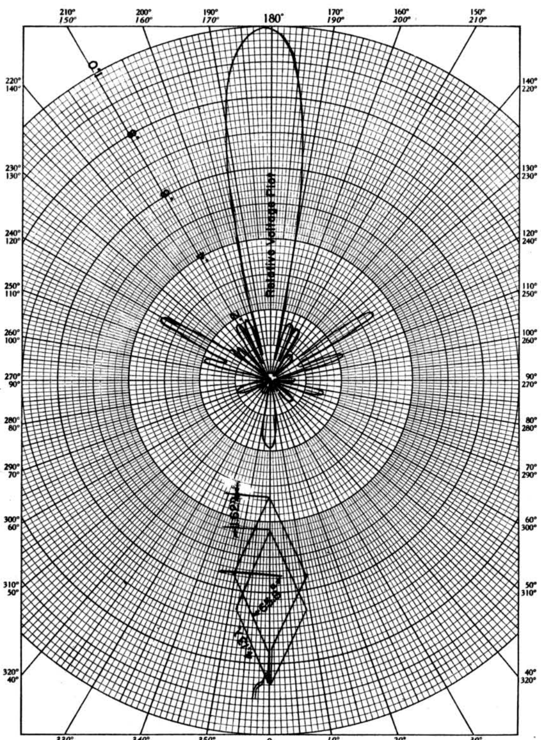


Fig. 34 - Azimuth field pattern - 800 Mc. (D_1 design)

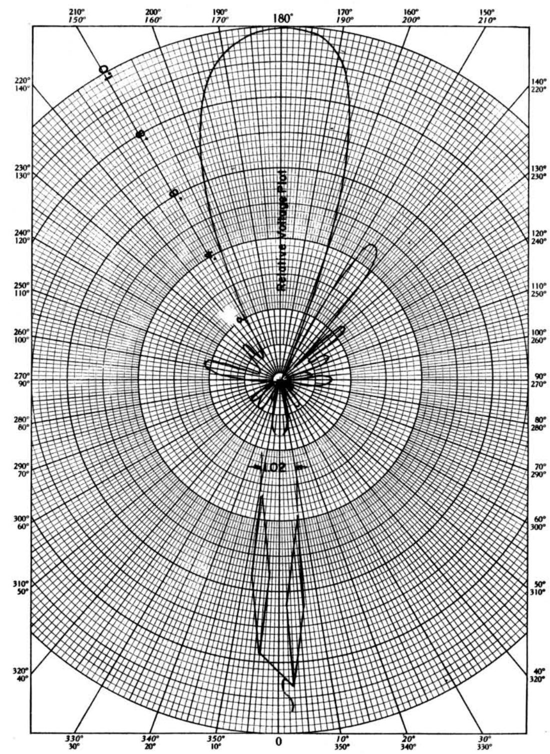


Fig. 36 - Vertical field pattern - 500 Mc. (D_1 design)

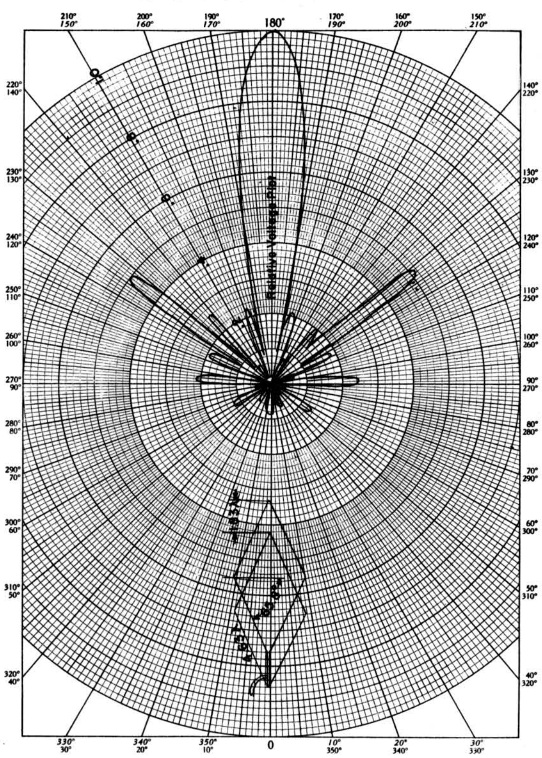


Fig. 35 - Azimuth field pattern - 900 Mc. (D_1 design)

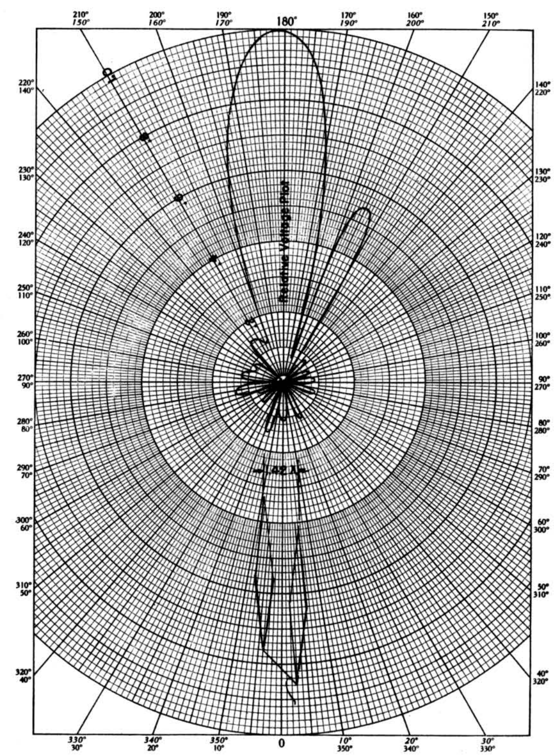


Fig. 37 - Vertical field pattern - 700 Mc. (D_1 design)

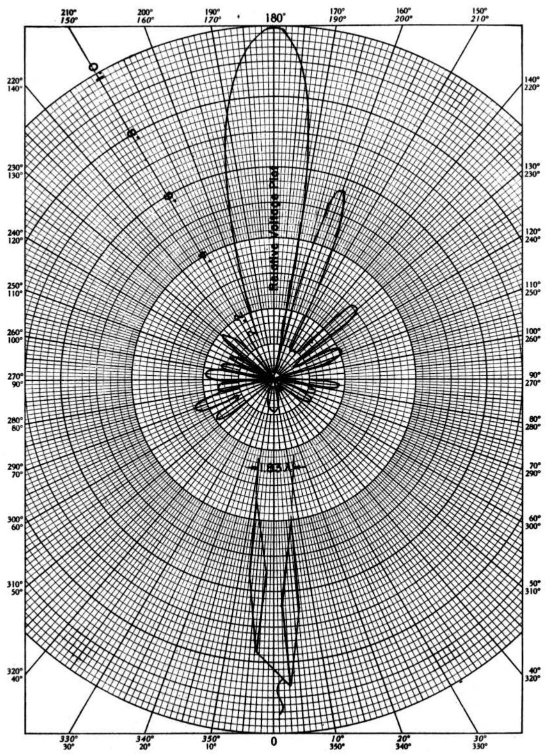


Fig. 38 - Vertical field pattern - 900 Mc. (D_1 design)

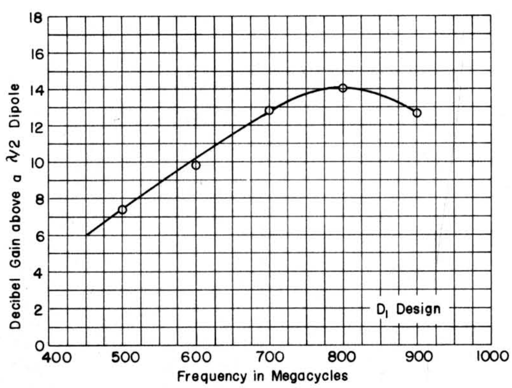


Fig. 39 - Gain curve for D_1 design.

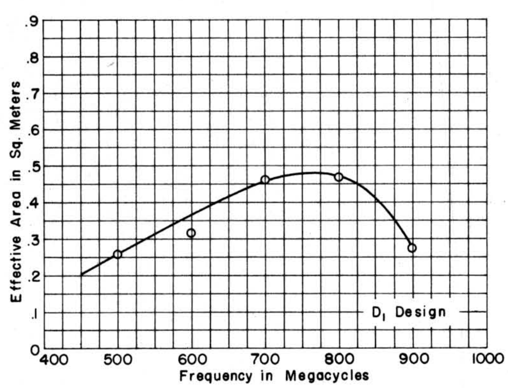


Fig. 40 - Effective area curve for D_1 design.

Antenna Design D_2

The transmission line tap point on the D_1 antenna was subsequently adjusted for optimum response at 900 Mc. It was found that considerable improvement resulted when the tap was displaced $1\frac{1}{4}$ inches from its original position. Field patterns and gain measurements were made with the tap in the displaced position (Fig. 41).

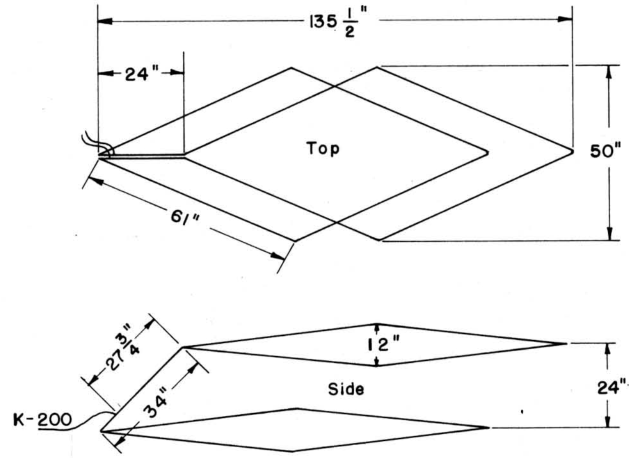


Fig. 41 - Rhombic antenna dimensions. (D_2 design)

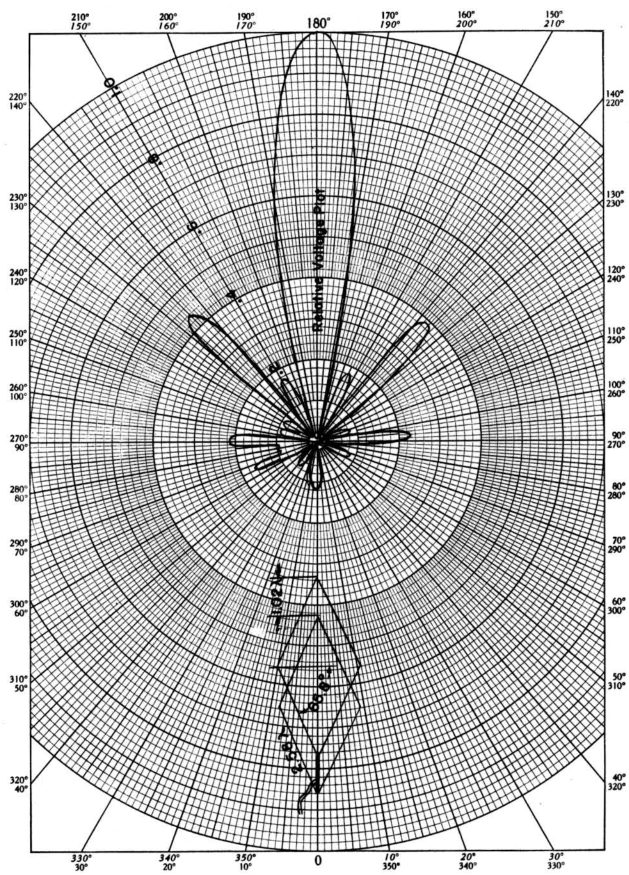


Fig. 42 - Azimuth field pattern - 500 Mc. (D_2 design)

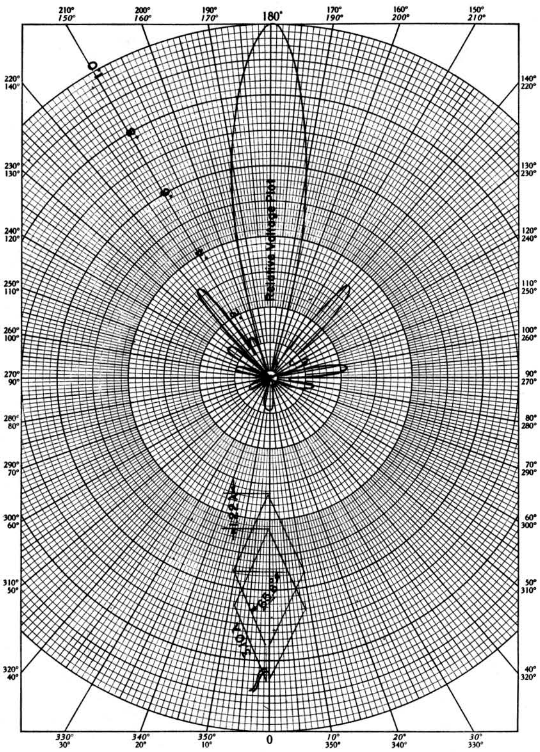


Fig. 43 - Azimuth field pattern - 600 Mc.
(D_2 design)

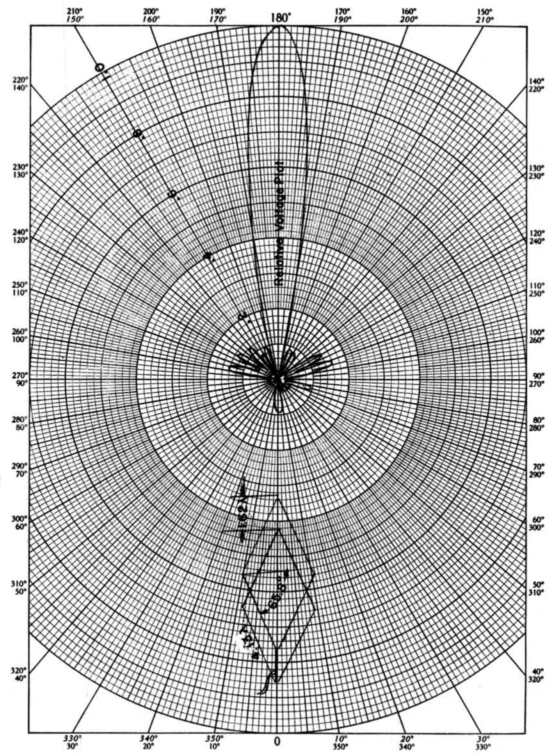


Fig. 45 - Azimuth field pattern - 800 Mc.
(D_2 design)

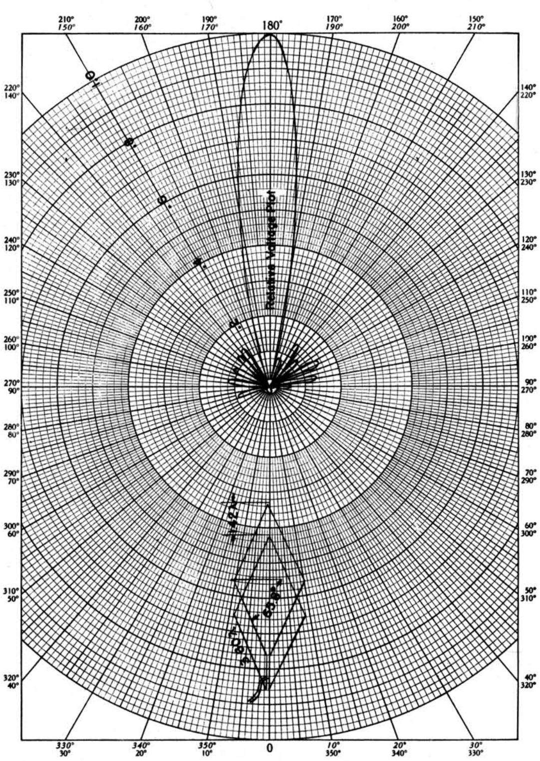


Fig. 44 - Azimuth field pattern - 700 Mc.
(D_2 design)

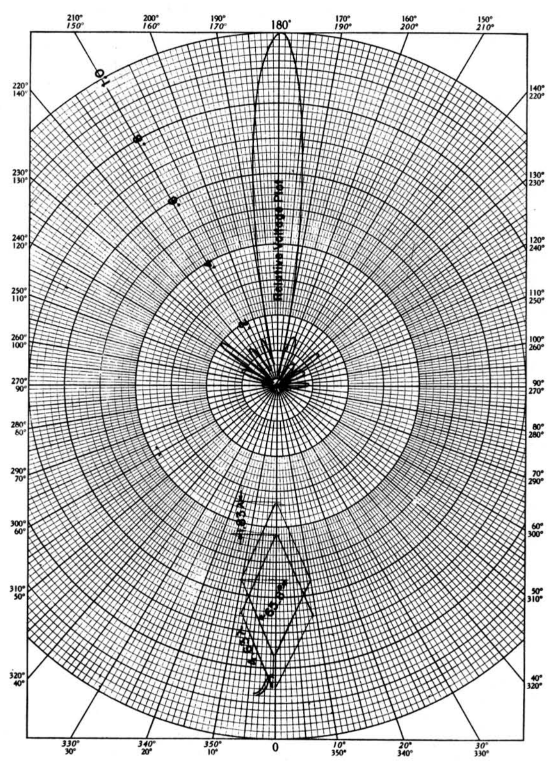


Fig. 46 - Azimuth field pattern - 900 Mc.
(D_2 design)

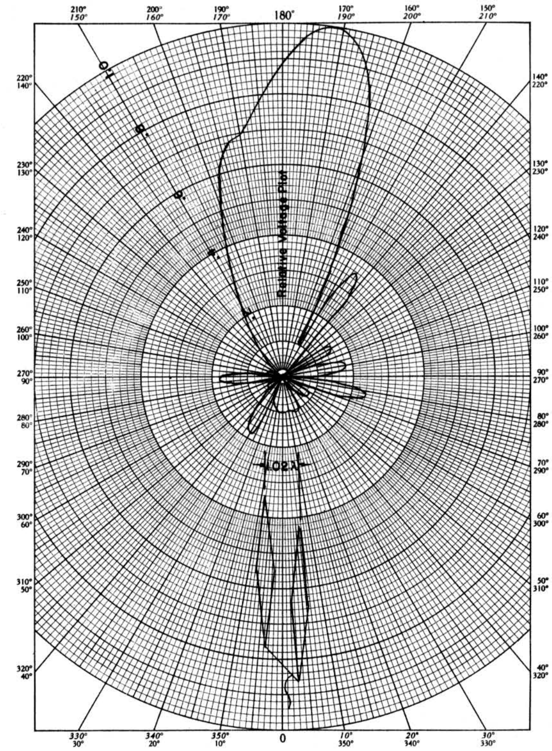


Fig. 47 - Vertical field pattern - 500 Mc.
(D_2 design)

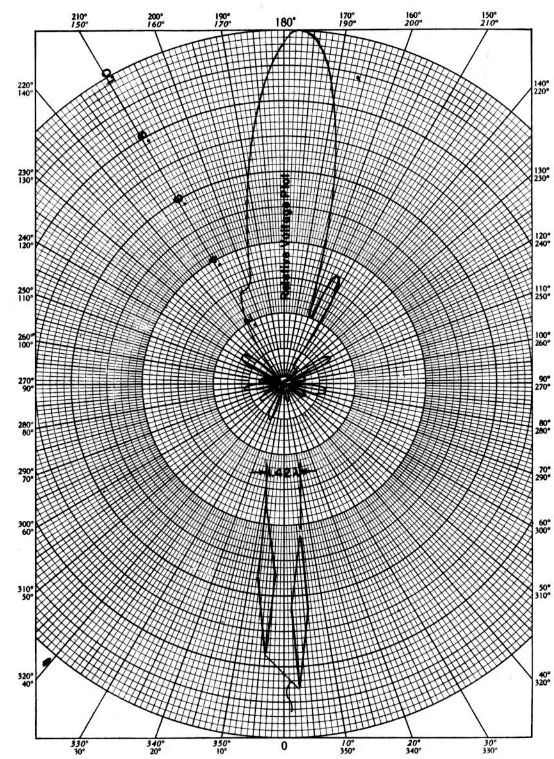


Fig. 48 - Vertical field pattern - 700 Mc.
(D_2 design)

The amplitudes of the secondary lobes in the azimuth field patterns (Figs. 42 through 46) remain negligibly small over a major portion of the band with a general increase occurring at the lower frequencies. The vertical field patterns (Figs. 47, 48 and 49) are somewhat distorted with the peak of the main lobe shifted below the horizontal. For comparison, the results of measurements made on a typical u-h-f grid-type corner reflector antenna have been included in the gain and effective area curves (Figs. 50 and 51). Dimensions for the corner reflector antenna are shown in Fig. 52.

Some characteristics of the design type D_2 antenna are summarized in Table I.

Table I

Characteristics of Type D_2 Rhombic Antenna

Frequency in Megacycles	Half-power Beam Width (degrees) Vertical	Horizontal	Gain Rel. to $\lambda/2$ Dipole	Eff. Area In Sq. Meters
500	28.4	15.5	9.6	0.43
600		16.1	11.6	0.47
700	19.0	13.0	13.0	0.48
800		13.2	14.7	0.55
900	13.8	11.0	17.0	0.73

Array elements—two double-wire rhombic antennas.

Termination of each half—Allen Bradley type EB 470-ohm ½-watt resistor.

Characteristic impedance of array—≈200 ohms.

Overall length—11 ft. 3½ in.

Width— 4 ft. 2 in.

Height— 3 ft. 0 in.

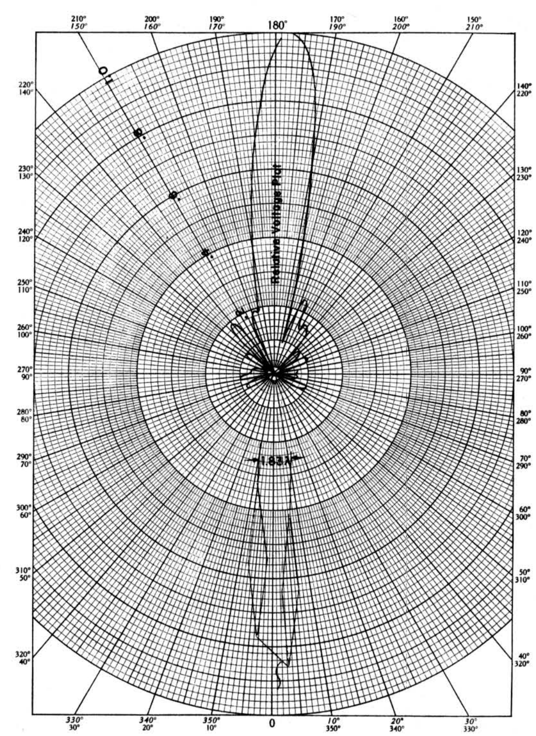


Fig. 49 - Vertical field pattern - 900 Mc.
(D_2 design)

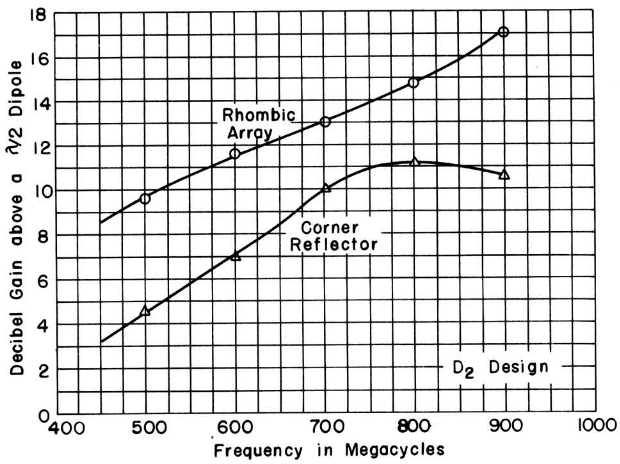


Fig. 50 – Gain curve for D_2 design.

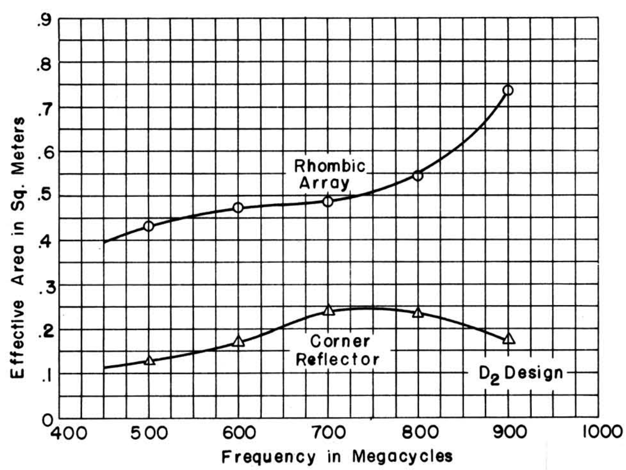


Fig. 51 – Effective area curve for D_2 design.

Conclusions

Of the five antennas tested, the D_2 design appears to give the most satisfactory performance over the entire u-h-f television band (in the region of 470 to 890 Mc). The sharpness of the horizontal beam together with the absence of large secondary lobes should aid considerably in reducing "ghosts" in regions of multipath signal reception. UHF propagation surveys have shown that, for a given radiated power, the signal energy available at a fixed receiving location decreases with frequency. The losses in the transmission line increase with frequency. Since the effective area curve is an indication of how the useful received power available at the load terminals of the antenna varies with frequency, the rising effective area vs frequency characteristic of the D_2 design would aid in compensating for propagation and transmission line losses.

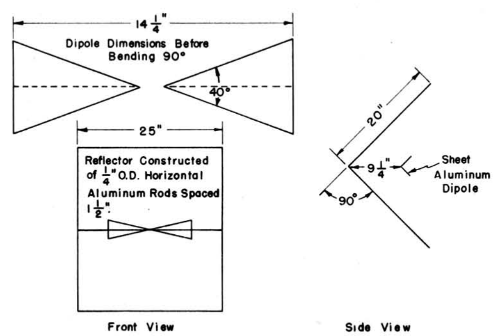


Fig. 52 – Corner reflector dimensions.

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Appendix

Effective Area of Antennas

When used for receiving, the received power (W) into a matched load is equal to the effective area (A) times the power density (P watts per square meter) of the incident wave.

$$W = AP \qquad (1)$$

Since the power density is equal to $E^2/120\pi$

$$W = AE^2/120\pi \qquad (2)$$

E = field strength in rms volts per meter.

The maximum power into the matched load impedance of a lossless half-wave dipole in free space is $E^2\lambda^2/4\pi^2R$ where R, the load impedance, is 73 ohms and λ is the wavelength in meters.

The effective area of a half-wave dipole with no heat loss is therefore:

$$A\lambda/2 \text{ dipole} = \frac{120\pi E^2\lambda^2}{4E^2\pi^2 73} = 0.1305\lambda^2 \qquad (3)$$

The effective area of an antenna with a power gain above a half-wave dipole is:

$$A = 0.1305\lambda^2 \text{ times power gain above a half-wave dipole.} \qquad (4)$$