A Packaged Antenna for Short-Hop Microwave Radio Systems

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This paper describes a packaged antenna specially designed for mounting on a slender tapered aluminum mast and gives typical measured electrical characteristics. The antenna is used in a 1.5-mile experimental repeater installation operating at 11 GHz. The masts and foundations for the experimental system are described briefly.

The antenna package is an upright cylinder, a shape chosen to minimize mast twisting caused by wind, and to present a pleasing appearance in combination with a slender mast. The radiating elements consist of a waveguide aperture feed, a 30-inch parabolic reflector mounted with its axis vertical at the top of the package, and a 45-degree flat reflecting plate similar to an inverted periscope. The space below the 45-degree reflector houses all the repeater electronics. Because of the shielding effect of the cylindrical housing, this antenna like the horn-reflector antenna, has very low radiation in the far side and back lobe regions.

I. INTRODUCTION

When considering antenna designs suitable for short-hop microwave radio relay application, the more important factors are: low side and rear lobe radiation for suppressing radio interference, reasonably good aperture efficiency, and a structural design which permits inexpensive and simple fabrication.[1] In addition, the antenna should have symmetry permitting the use of orthogonal polarizations for increased channel capacity. Other considerations include a suitable enclosure for the antenna and electronic equipment and provisions for initial radio beam alignment. A supporting structure is required which is high enough to permit radio beam clearance over natural and man-made obstacles, is pleasing in appearance and low in wind loading, and has sufficient structural stiffness to prevent excessive radio beam tilting in heavy wind.

This paper describes such an antenna system which is used in a 1.5-mile experimental repeater installation in New Jersey operating at 11 GHz with transmitting and receiving terminals located on Crawford Hill and a repeater at Bell Laboratories property in Holmdel.[2]

II. THE ANTENNA AND ENCLOSURE

Electrically, the antenna consists of the basic components shown in Fig. 1: a small aperture feed, a paraboloidal reflector, and a 45-degree plane reflector. This arrangement permits the antenna package to have the shape of an upright cylinder which is desirable for minimum wind loading, ease of azimuthal positioning, and vertically stacking two or more antennas. In addition, the pivoted plane reflector provides a convenient means for initial beam elevation adjustment.

The paraboloidal reflector is a spun aluminum dish with a focal length of 14.5 inches and a diameter of 30 inches. The plane reflector is an elliptically shaped aluminum honey-comb-core sandwich, 0.5 inch thick, supported by two free pivots at either end of its minor

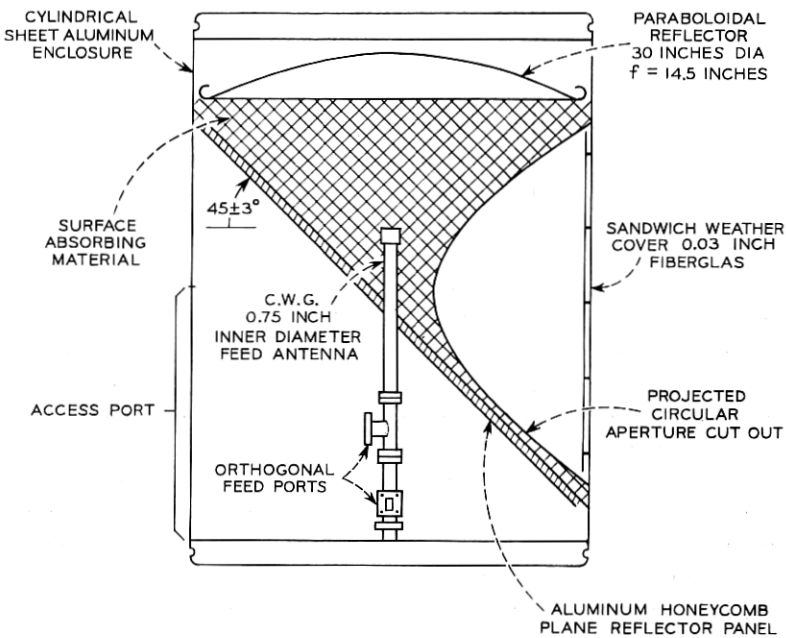

Fig. 1 — Short-hop system antenna package showing components essential to the electrical characteristics.

axis; a third support, a linkage for the elevation adjustment, is located at the upper end of the reflector. The space below the plane reflector is available for the repeater electronics.

The antenna feed is a circular dominant mode waveguide aperture, one inch in diameter, with a two-step transformer for matching to free space. The measured radiation pattern of the feed is almost circularly symmetric over the paraboloidal reflector and provides a field illumination taper of −11 dB at the edge of the paraboloid with respect to its center. Dual polarization is achieved by two orthogonal sidewall couplers.[3] Linear polarizations, vertical and horizontal with respect to the earth, are used for the experimental installation. Orthogonal circular polarizations could also have been used, and would have the advantage over linear polarizations that no cross-polarized coupling would result from the component of mast tilt orthogonal to the radio beam. The disadvantages of orthogonal circular polarizations are that a low loss, broadband 90° phase shifter is required and the reflections from the paraboloid appear as cross talk between the orthogonal input ports rather than as return loss in each port.

The antenna system and the repeater electronics are enclosed in a cylindrical housing 34 inches in diameter and 42 inches high (Fig. 2a). Fabrication is entirely of aluminum with stainless steel fasteners. The cylindrical shell is 0.050-inch sheet aluminum. The inside of the shell is covered with an electrically absorbent material (not shown in the photograph) which eliminates spurious side lobes caused by multiple internal reflection of spill-over radiation from the feed.

Since the large aperture severely weakens the cylindrical shell, a structural framework is provided as shown in Fig. 2b. The top and bottom sections of the structure each consist of two spun aluminum pans, $\frac{1}{16}$ inch thick, joined by radial ribs to form a stiff sandwich. The large perforations in the pans are for interconnecting cables and for ventilation; the external holes are covered with wire mesh. The uprights and bracing struts are square aluminum tubing. The antenna and housing, without electronics, weigh about 85 pounds.

A portion of the cylindrical shell at the rear of the housing can be removed to provide access to the feed assembly and the electronic packages as seen in the photograph. A weather cover (not shown) is provided for the aperture. It consists of a curved sandwich of two $\frac{1}{32}$-inch Fiberglas sheets, appropriately spaced to minimize reflections, and attached to the enclosure by an escutheon plate, self tapping screws, and a waterproof nonsetting cement.

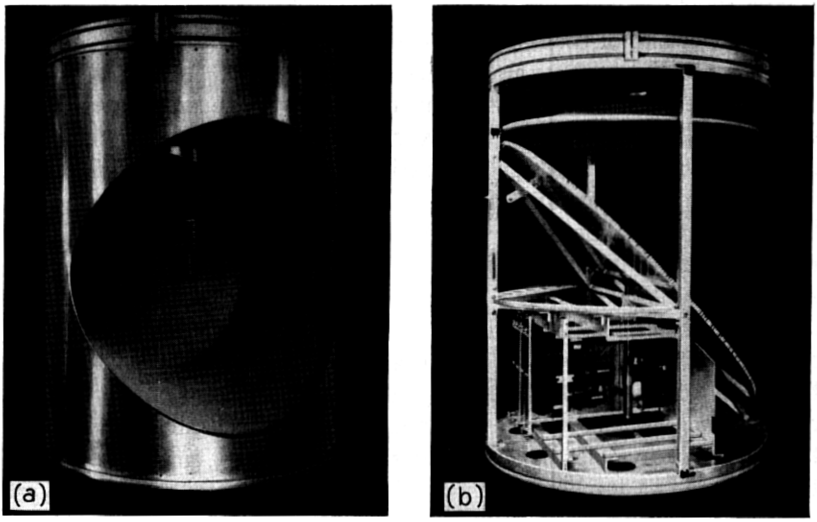

Fig. 2 — Two views of the antenna structure: (a) A front view without weather cover or inner absorbing liner. The embossed girth band and clamp are also shown at the top of the package. (b) A side view without outer skin showing the internal structure.

For installation in the field, the package is secured to a cast aluminum fixture at the top of the supporting mast, or to another package in the stacked configuration, by the girth band and clamp seen on the top of the canister in Fig. 2. This band is made from $\frac{1}{32}$-inch sheet aluminum and has embossed ridges which mate with circumferential grooves, $\frac{3}{16}$-inch deep, in the spun aluminum pans forming the top and bottom sections of the antenna enclosure. Thin Teflon spacers between the canisters reduce friction thus making it possible, after loosening the girth band clamp, to rotate the canister for azimuthal beam positioning, smoothly and accurately, while maintaining a secure hold.

An important attribute of the packaged antenna design is that the housing can be assembled and the antenna components physically aligned in the shop with sufficient precision, using square, level, and plumb bob, that electrical adjustments for bore sight and focal distance are not required. This was demonstrated with the two models assembled for the experimental system; the measured electrical bore sight agreed with the shop-established mechanical bore sight within 0.15 degrees. In making the shop alignments, the focal distance is adjusted by moving the paraboloidal reflector by means of slotted holes in mounting brackets attached to the rim; since the radio packages are semirigidly attached to the feed line ports, it is necessary to move the reflector rather than the feed. Screw adjustments are provided for centering the feed aperture on the axis of the paraboloid. A third shop adjustment consists of placing the plane reflector at 45 degrees to the axis of the paraboloid and zeroing the pointer on a calibrated elevation scale on the outside of the canister; a slotted screw, also accessible from the outside, drives a linkage which adjusts the plane reflector for setting the beam in elevation.

III. ANTENNA ELECTRICAL CHARACTERISTICS

3.1 *Radiation Patterns and Gain. Weather Covers*

The radiation characteristics of the antenna system and enclosure are extremely good, particularly without the weather cover. The aluminum cylindrical enclosure, with its electrically absorbent lining, provides excellent shielding which results in very low radiation in the far side lobe region, similar to the performance of the horn-reflector antenna.[4]

Typical measured radiation patterns of the antenna without a weather cover are shown in Figs. 3 through 7. These measurements were made in the principal planes at 11.2 GHz with linear polarizations. Patterns measured at the extremes of the 10.7 to 11.7 GHz band were similar. The line labeled "Isotropic Level" represents the relative power that a hypothetical non-directional antenna would receive. In the azimuthal plane, Figs. 3 and 4, the patterns for both polarizations demonstrate the shielding effect of the enclosure; the response falls abruptly at about ±70 degrees. Figure 5, an expanded version of Fig. 3, shows the main beam and near side lobes in greater detail and illustrates the symmetry of the radiation pattern. This symmetry further attests to the accurate mechanical shop alignment of the antenna components. In the elevation plane (Figs. 6 and 7) a small spill-over lobe is evident at about +90 degrees. This lobe is not of great concern in the pole-line application since in this case it is directed toward the earth.

Initially, the weather cover used was a single sheet of Fiberglas, $\frac{1}{32}$ inch thick. This material has a relatively high dielectric constant (about four). Because the weather cover is curved in the horizontal plane and the angle of incidence approaches grazing at the edges of the aperture, prominent side lobes appeared at about ±90° in azimuth. These lobes, caused by reflections at the cover, were 3 dB above the

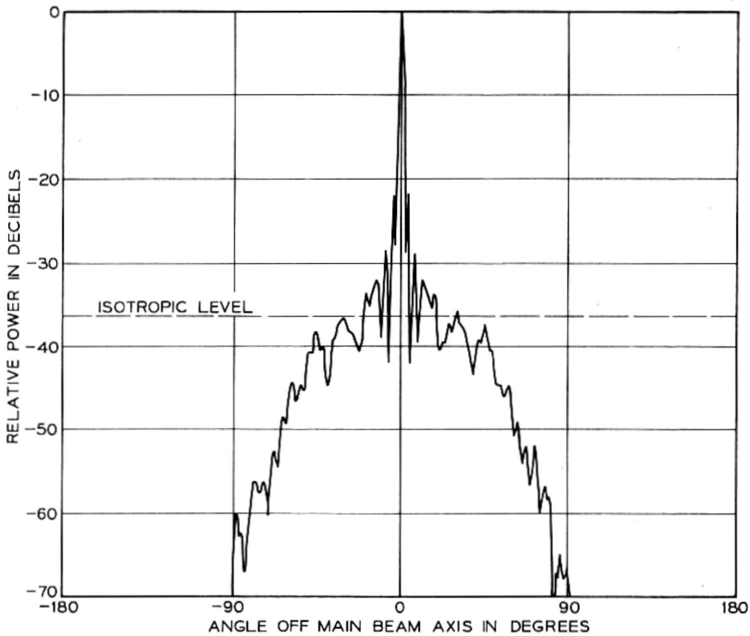

Fig. 3 — Far field radiation pattern in the horizontal plane with horizontal polarization at 11.2 GHz and without weather cover.

isotropic level for vertical polarization and 5 dB below the isotropic level for horizontal polarization.

To reduce these wide angle side lobes, a double-layer cover was designed and installed. Since the cover is curved only in one plane, it was readily constructed from flat sheets using appropriate spacers. The spacing required to cancel the reflections was computed; it varies from 0.15 inches at the center to 0.35 at the edges of the aperture.[5] Radiation patterns taken in the azimuthal plane with the double-layer cover in place are shown in Figs. 8 and 9 for vertical and horizontal polarizations. That the reflections were not cancelled completely may be seen by comparing the far side lobes in Figs. 8 and 9 with those in Figs. 3 and 4. The cancellation could probably be improved by careful adjustment of the spacing. A further advantage of the double-layer cover is that the loss resulting from reflection was reduced to 0.1 dB from 0.5 dB for the single layer cover.

The gain of the antenna was measured on a 1500-foot range using a

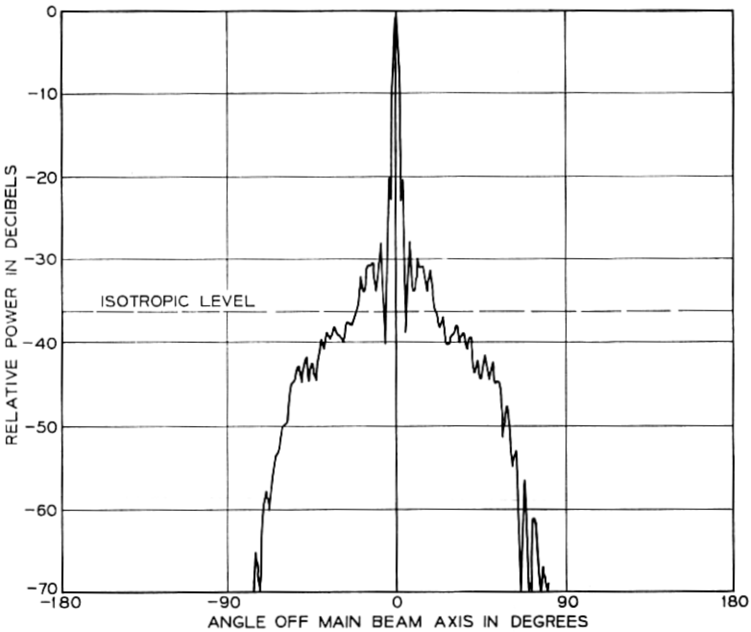

Fig. 4 — Far field radiation pattern in the horizontal plane with vertical polarization at 11.2 GHz and without weather cover.

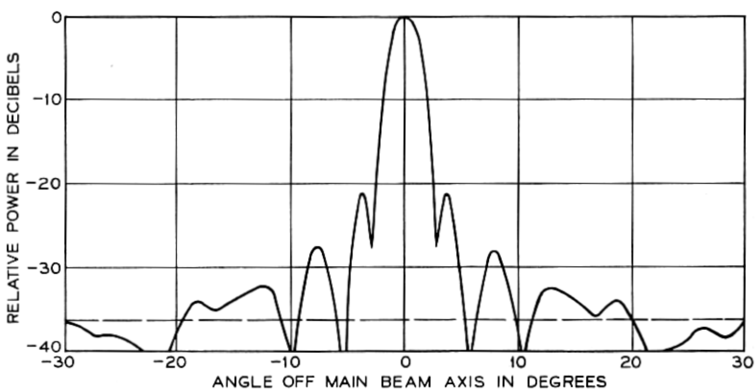

Fig. 5 — An expanded pattern of Fig. 3 centered on the main beam to show more detail and evidence of symmetry.

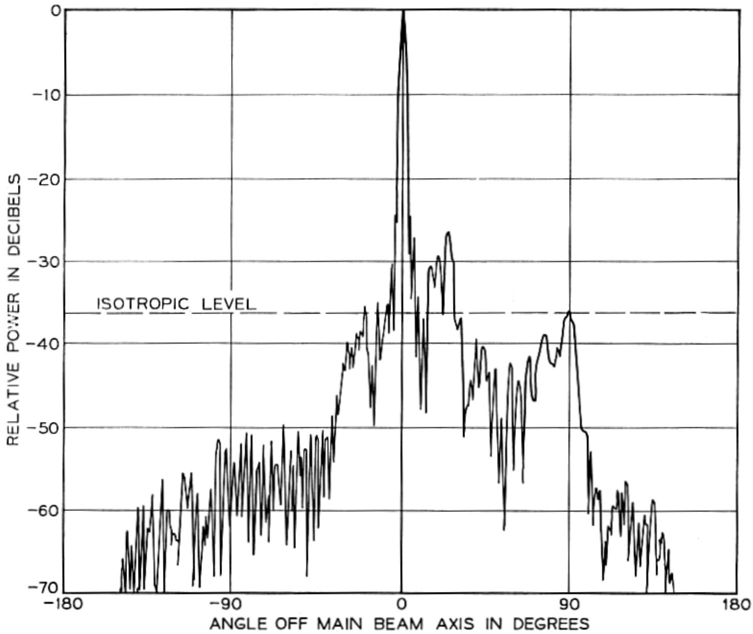

Fig. 6 — Far field radiation pattern in elevation with vertical polarization at 11.2 GHz and without weather cover. The high side lobe at +90 degrees elevation is directed toward the ground in normal applications.

standard gain horn as a reference. Two identical antenna packages, constructed for the experimental short-hop radio system, were measured. Table I summarizes the results of these measurements. The half-power beamwidth of the main lobe is 2.4 degrees at 11.2 GHz, and the gain is 36.6 dB corresponding to an aperture efficiency of about 57 percent.

3.2 *Cross Polarization. Cross Coupling. Return Loss*

Since the short-hop radio systems are expected to use both vertically and horizontally polarized radiations as a means of increasing channel capacity, the cross-polarized characteristics of the antenna are of importance. A parabolic antenna, using a feed such as a dipole or dominant mode circular waveguide, converts some energy from one polarization to its orthogonal counterpart. In theory, this cross-polarized energy appears in planes at 45 degrees to the principal planes, the principal planes being null planes of cross-polarized radiation. However, in practice it is difficult to maintain the principle planes as null planes and it is also difficult to measure cross-polarization in the 45 degree planes. Some measurements have been made which indicate that, with careful initial alignment of two antennas, it is possible to obtain −35 to −40 dB cross-polarization suppression on the axis. The principal difficulty in maintaining this cross-polarized level will be tilting of the antenna resulting from bending of the mast during high wind conditions. It can be shown that cross-polarized radiation from a parabolic reflector may, in principle, be eliminated by using a feed antenna whose E- and H-plane radiation patterns are identical over the area of the reflector. Such feeds with circularly symmetric radiation patterns can be achieved by the use of dual waveguide modes.[6,7]

Another parameter which may be of importance in some applications is the cross coupling between two antennas stacked on the same mast. This cross coupling was measured to be less than −80 dB for most orientations and polarization combinations. As expected, the worst case

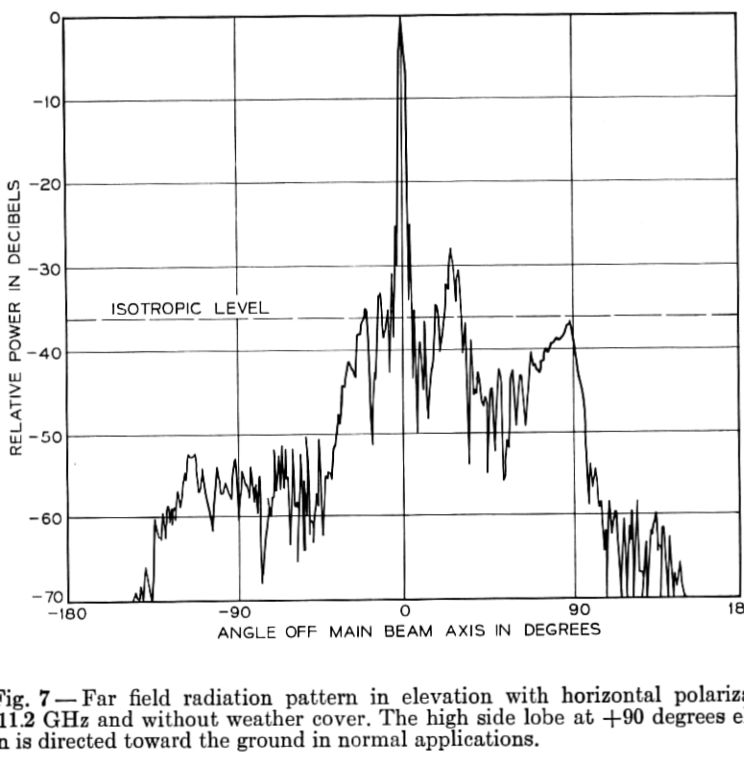

Fig. 7 — Far field radiation pattern in elevation with horizontal polarization at 11.2 GHz and without weather cover. The high side lobe at +90 degrees elevation is directed toward the ground in normal applications.

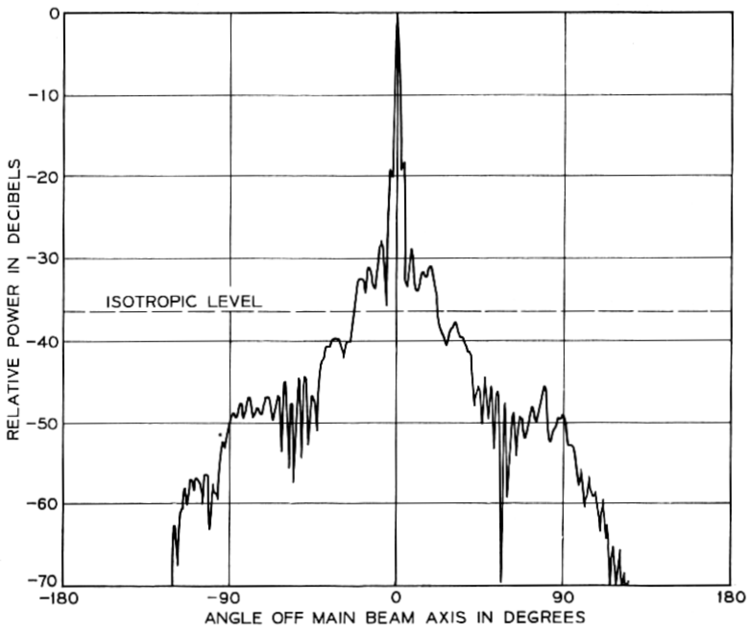

Fig. 8 — Far field radiation pattern in the horizontal plane with horizontal polarization and with the sandwich weather cover installed.

is for vertical polarizations with both beams pointing in the same general direction; for this case, the coupling increases to a maximum of −75 dB. Figures 10a, b, and c show the measured cross coupling as a function of the angle between the beam axes for the three combinations of polarization. The cross coupling between orthogonal feed ports on a single antenna is less than −40 dB.

The feed port return loss measured over the 10.7 to 11.7 GHz band is greater than 20 dB except for a few spot frequencies where it is about 18 dB. No special matching techniques are used to minimize reflections from the paraboloidal surface. The return loss, in almost equal parts, results from reflections at the aperture of the feed and at the surface of the parabolic reflector.

IV. SUPPORT MAST AND FOUNDATION

The choice of a mast to support the antenna packages for the experimental short-hop radio relay installation was based on a number of criteria, some of which were subjective. It was felt that the mast should be 60 feet high to simulate typical installations where trees might be present. It should be strong enough to withstand the most adverse weather conditions and stiff enough to maintain the radio beam alignment within adequate limits during winds of gale force. The mast should present a pleasing appearance in combination with the antenna packages and, preferably, should be of aluminum for low maintenance. Finally, for the experimental system, it should be readily available.

A mast fulfilling the above requirements was easily obtained since it was being manufactured for use as a lighting support. It is a tapered spun aluminum tube, 60 feet in length, fabricated in two 30-foot sections joined at the time of the installation by a field joint. The outside diameter of the mast is 16 inches at the base, tapering to 10 inches at the top. The lower section has a wall thickness of 0.625 inches; the wall thickness of the upper section is 0.50 inches. The mast alone weighs about 1700 pounds. The end slope of the composite mast with two antenna packages in place, as in a repeater configuration, is computed to be about 0.1 degree for a steady wind force of one pound per square

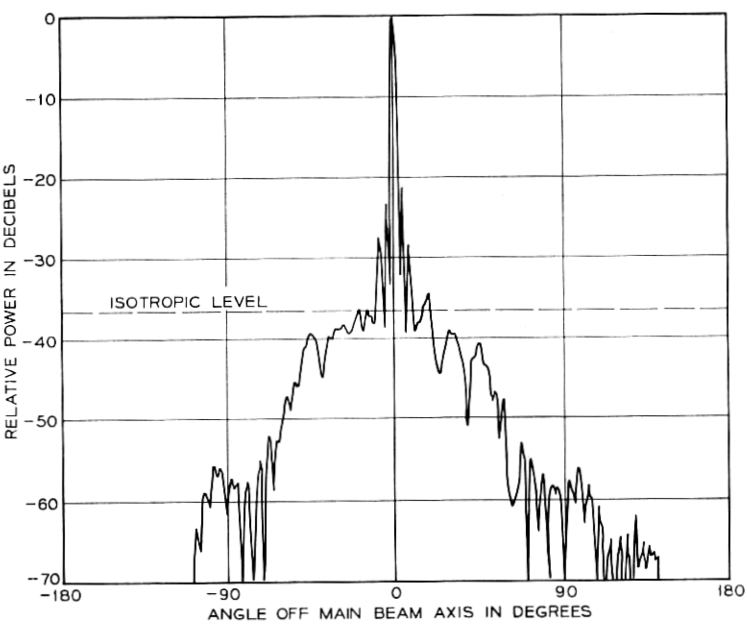

Fig. 9 — Far field radiation pattern in the horizontal plane with vertical polarization and with the sandwich weather cover installed.

TABLE I—SUMMARY OF ANTENNA MEASUREMENTS WITH SANDWICH WEATHER COVER INCLUDED

	Antenna 1				Antenna 2			
Measurement plane	Azimuth		Elevation		Azimuth		Elevation	
Polarization	Vertical	Horizontal	Vertical	Horizontal	Vertical	Horizontal	Vertical	Horizontal
−3 dB beam width in degrees	2.37	2.46	2.42	2.39	2.43	2.35	2.39	2.43
1st side-lobe level (dB)	−18.5	−20.5	−22.0	−23.5	−21.5	−22.0	−22.0	−20.0
Gain (average, vertical, and horizontal polarization)	36.7				36.6			

Area gain, $4\pi A/\lambda^2$, for a 30-inch circular aperture at 11.2 GHz is 39.02 dB.

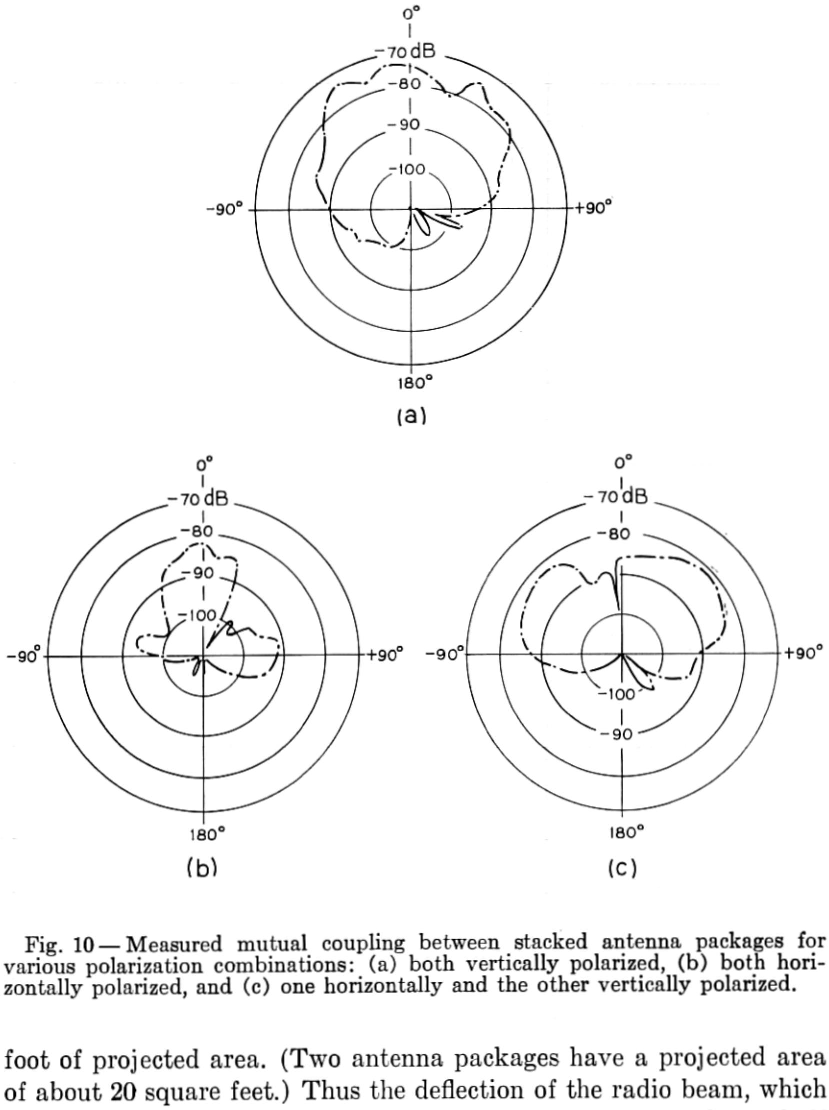

Fig. 10 — Measured mutual coupling between stacked antenna packages for various polarization combinations: (a) both vertically polarized, (b) both horizontally polarized, and (c) one horizontally and the other vertically polarized.

foot of projected area. (Two antenna packages have a projected area of about 20 square feet.) Thus the deflection of the radio beam, which is the same as the end slope of the mast, should be no more than a half beamwidth, 1.2 degrees, for steady winds up to about 65 miles per hour. The mast is expected to survive winds in excess of 200 miles per hour. A stiffer mast of the same weight could be obtained by increasing the diameter and decreasing the wall thickness.

The top of the mast is fitted with a cast aluminum spider flange to

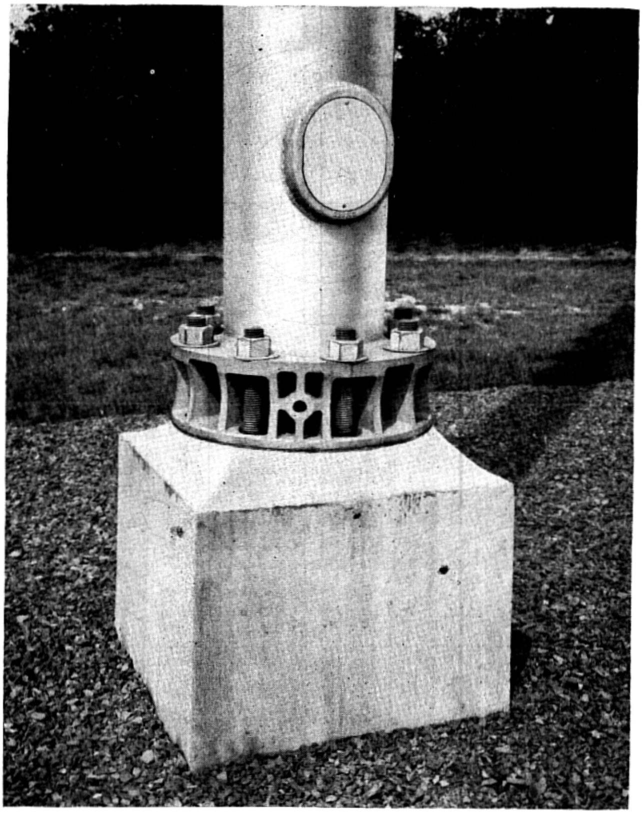

Fig. 11 — View of base flange and above ground portion of the foundation. The mounting bolts are 2 inches in diameter.

which the antenna package is fastened by means of the girth band and clamp described in Section II. The base of the mast is welded to a heavy cast aluminum flange for bolting to the foundation as shown in Fig. 11. The overturning moment is about 100,000 pound-feet for steady winds of 100 miles per hour. Figure 12 shows a complete repeater installation with support mast and two stacked antenna packages. Beneath the shallow conical top which overhangs the upper cannister is a screened opening which, with the large holes in the bases of the cannisters, provides a free flow of air for ventilation of the repeater packages. The rectangular box, about 8 feet above the base of the tower, houses a propane gas-fueled thermoelectric generator which provides electric power for the repeater.[2]

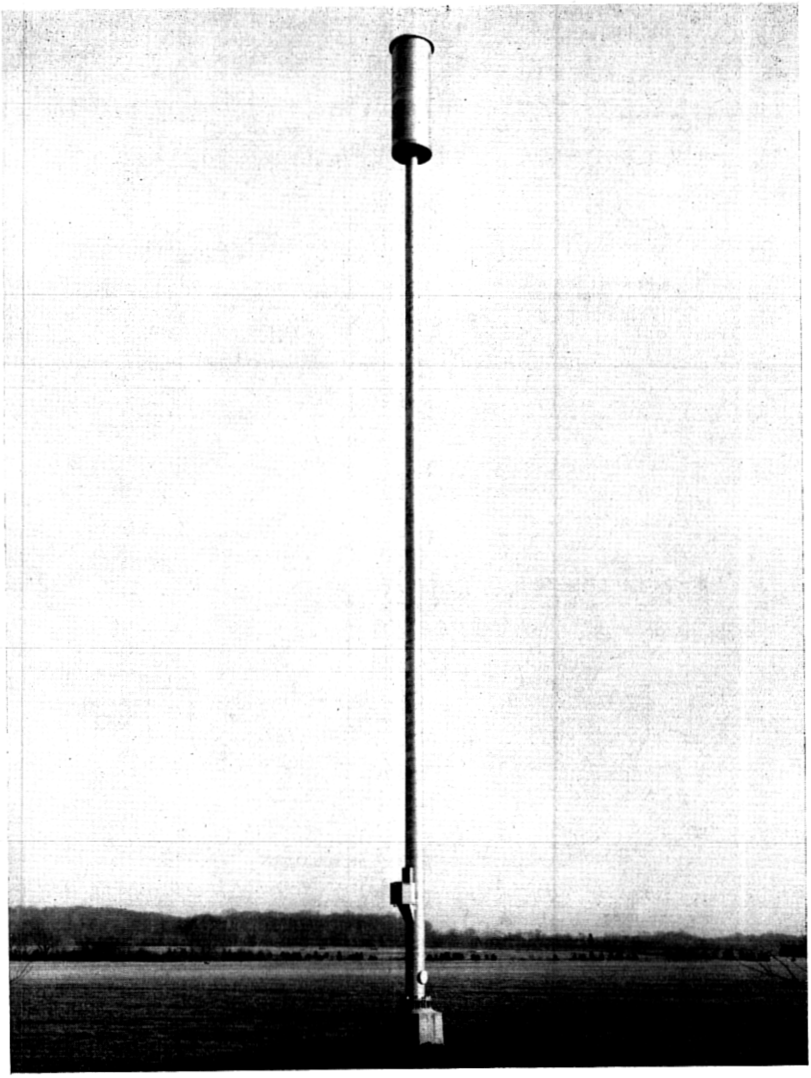

Fig. 12 — A simulated repeater installation showing two antenna packages stacked on the 60-foot aluminum mast. The mast is tapered from 16 inches in diameter at the base to 10 inches at the top. The antenna packages are 34 inches in diameter and each is 42 inches high.

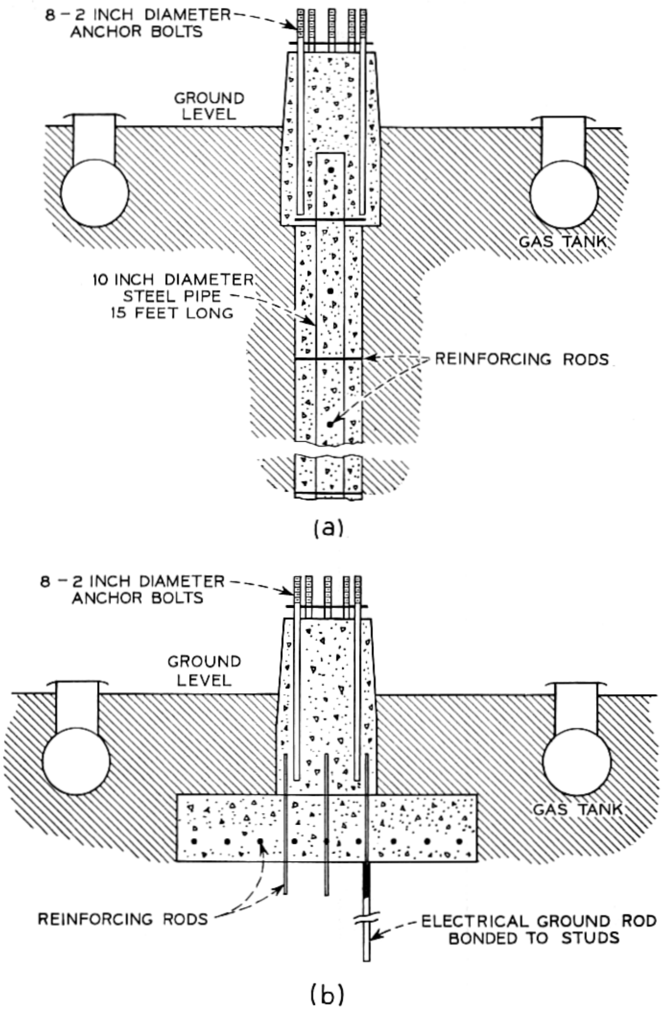

Fig. 13 — Schematic cross sections of the two foundations constructed for the experimental short-hop installation. The above ground pedestals are about 3 feet square and include an access duct for the gas line. The cylindrical gas tanks are also shown. (a) A reinforced concrete post-type foundation 18 inches in diameter and extending about 15 feet into the ground. (b) A reinforced concrete pad foundation 9 feet square and 2 feet thick.

For the experimental installation, two different foundations were constructed. For the repeater installation at Holmdel, where the bearing quality of the soil is only fair because of poor drainage, a reinforced concrete pad foundation, 9 feet square and 2 feet thick was constructed. At Crawford Hill, where the bearing strength of the soil is very good, a reinforced concrete post foundation was used. Schematic cross-sections in Figs. 13a and b show both of these installations. For the post-type foundation, a hole 15 feet deep was drilled with an 18-inch auger. A steel pipe, 10 inches in diameter, with reinforcing rods at right angles to the axis, was inserted and the pipe as well as the hole was filled with concrete. This type of foundation is preferred where possible because it is simple to install and requires a minimum of right-of-way area.

The reinforced concrete pedestals are 3 feet square and are identical for both foundations. Eight threaded rods, 2 inches in diameter, secure the base flange of the mast to the foundation. Adjustable nuts below and above the flange are used to plumb the mast while elongated holes in the flange permit a small adjustment of the mast (and antenna packages) in azimuth. Conduits, not shown in the drawings, are provided for gas lines from the gas storage tanks through the centers of the pedestals to the mast.

For the experimental installation, it was possible to determine the angles of elevation and the bearings of the sites by surveying techniques so that the masts, with antenna packages attached, were erected and aligned mechanically with good accuracy using theodolites and alignment marks on the antennas and mast flanges. This was shown later when it was found that the antenna beams were within 0.05 degree in elevation and 0.3 degree in azimuth of true bearing.

V. ACKNOWLEDGMENTS

The antenna packages and masts were assembled by the Crawford Hill shops under the direction of H. W. Anderson who also collaborated in the mechanical design. J. H. Hammond assisted in all the electrical measurements.

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