

High-Gain, Very Low Side-Lobe Antenna With Capability for Beam Slewing^{1,2}

Alvin C. Wilson

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A corner-reflector antenna having reflecting surfaces ten wavelengths wide and two wavelengths long was constructed, adjusted, and tested. The driven element was a collinear array of ten half-wave dipoles. Dolph-Chebyshev current distribution designed for side-lobe suppressions to -45 decibels was computed. The currents in the dipoles were adjusted as nearly as possible to this distribution. The phase of the dipole currents was graded so as to slew the main beam 10° off the forward direction. The radiation patterns were measured and found to be quite close to the computed.

Check of pattern stability with time and with changes in temperature and weather conditions showed it to be quite stable. Measurements of radiation pattern at frequencies departing from design frequency showed the operating bandwidth (determined by the preservation of the pattern) to be adequate for the applications likely to be considered for such antennas.

The half-power beam widths of the main lobe were 9.8° in the E -plane and 32° in the H -plane. On the basis of the measured beamwidths, the gain was calculated to be approximately 21.2 decibels relative to an isotropic radiator. The gain was experimentally measured to be 21.2 decibels.

1. Introduction

Operation of VHF ionospheric scatter communication services at frequencies below the F_2 MUF requires, especially for high speed binary data transmission, special means to avoid long range interference, including self-interference from backscatter [1].³ The use of narrow beam antennas designed to suppress the radiation outside the main lobe by at least 40 db has been indicated as one measure for reducing such interference. In special operating situations, severe requirements occasionally arise for suppression of radiation outside the main lobe as a means of avoiding interference to neighboring radio services. Under some circumstances, there would be an advantage in having an antenna in which the main beam could be slewed to either side or taking advantage of meteor reflections.

The performance of corner-reflector antennas became of interest to the National Bureau of Standards because they appeared to be well suited to communication via ionospheric scatter. Previous measurements have shown that this antenna can be designed to have a high gain with very low secondary lobe-levels [2, 3]. A collinear array of dipoles may be used in a corner-reflector antenna to obtain higher gain and more desirable directive characteristics than are obtainable by the use of a single dipole in a corner reflector.

A method of determining the optimum current distribution in a collinear array of isotropic radiators has been described by C. L. Dolph [4]. The resultant

current distribution across the array is based on the properties of Chebyshev polynomials. When a Dolph-Chebyshev current distribution is used, the main beamwidth will be as narrow as possible for a predetermined side-lobe level; or, if the main beamwidth is specified, the side-lobe level will be a minimum.

When a collinear array of dipoles is used in a corner reflector, the resultant pattern is more directive than the array pattern for the collinear dipoles alone, and further reduction in levels of side lobes is achieved.

Computations were made to obtain the Dolph-Chebyshev current distributions to limit the side lobes 40 db below the main beam level and the resultant half-power beamwidth for collinear arrays of 6, 8, 10, 12, 14, and 16 half-wave dipoles spaced 0.5 and 0.8 wavelengths apart. Table 1 shows the relative current distribution and resultant main beam half-power beamwidth.

TABLE 1. Computed dipole current distribution and resultant half-power beamwidth of main lobe for Dolph-Chebyshev current distribution to limit all side lobes 40 db below main beam level

Number of dipoles in collinear array	Half-power beamwidth in degrees		Current distribution, decibels of attenuation relative to center elements										
	0.5λ spacing between dipole centers	0.8λ spacing between dipole centers	Dipole right and left from array center										
			1	2	3	4	5	6	7	8			
6	23.6	15.0	0	4.2	14.0	-----	-----	-----	-----	-----	-----	-----	-----
8	18.0	11.4	0	2.4	7.6	16.7	-----	-----	-----	-----	-----	-----	-----
10	14.5	9.2	0	1.5	4.7	10.0	18.1	-----	-----	-----	-----	-----	-----
12	12.1	7.6	0	1.05	3.2	6.7	11.8	18.6	-----	-----	-----	-----	-----
14	10.3	6.4	0	0.76	2.3	4.8	8.3	13.1	18.9	-----	-----	-----	-----
16	9.0	5.6	0	.58	1.8	3.6	6.2	9.6	14.2	18.9	-----	-----	-----

¹ Contribution from Central Radio Propagation Laboratory, National Bureau of Standards, Boulder, Colo.

² The work reported herein was carried out on behalf of the U.S. Air Force, under support extended by U.S. Air Force Ground Electronics Engineering and Installation Agency, Rome, N.Y.

³ Figures in brackets indicate the literature references at the end of this paper.

In order to slew the main beam of a collinear array away from the forward direction, a change in the phase of current in the dipoles may be calculated for the desired amount of slewing.

The phase advance Φ_p of the current in a dipole p required to produce a slew angle β_0 off the broadside direction is given in degrees by

$$\Phi_p = -360 \frac{dp}{\lambda} \sin \beta_0$$

where dp is the distance of the dipole from the center of the array, taken as zero reference for phase. The negative sign signifies that the phase is retarded when the slew angle is in the direction of positive p .

Computations were made to obtain the radiation patterns for a collinear array of 16 half-wavelength dipoles, spaced a half-wavelength apart with the main beam slewed 0° , 10° , and 20° off from the forward direction. It was noted that, even with the beam slewed as much as 20° , the side lobes were still nearly 40 db down from the main beam level. Figure 1 presents these computed patterns.

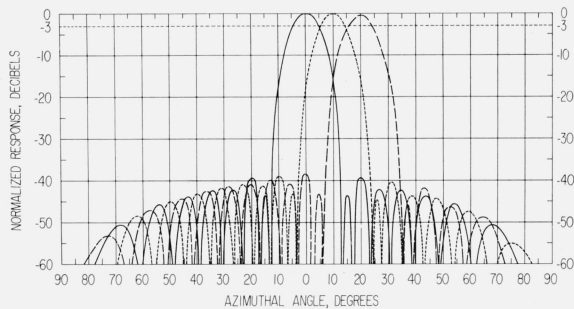


FIGURE 1. Computed radiation patterns in the E-plane of a collinear array of 16 half-wavelength dipoles spaced half-wavelength apart with a Dolph-Chebyshev current distribution computed to limit the side lobes below 40 db.

— Maximized in forward direction.
 - - - - Beam maximum 10° off forward direction.
 - · - · - Beam maximum 20° off forward direction.

The radiation patterns for a collinear array of 10 half-wavelength dipoles spaced 0.8λ apart in a corner reflector was computed. The aperture angle of the corner reflector was assumed to be 90° for purposes of computation, and the dipole position, distance to apex, 0.3 wavelength. Using a dipole current distribution to limit the side lobes 40 db below the main beam level, a main beamwidth at the half-power points of 9.2° was obtained. When the beam of this corner-reflector antenna is slewed by grading the phase of the dipole currents, the side lobes will not all be 40 db below the main beam level. With the beam slewed 10° , a high side lobe occurs at an azimuth of 68° in the direction opposite from slew; its level is 37 db below the main beam level. With the beam slewed 20° , the corresponding side lobe occurs at 56° with the response 17 db down from the main beam level. The high side lobes are actually secondary main lobes due to the dipole spacing being greater than a half-wavelength. Figure 2 shows the computed patterns for 0° , 10° , and 20° slew.

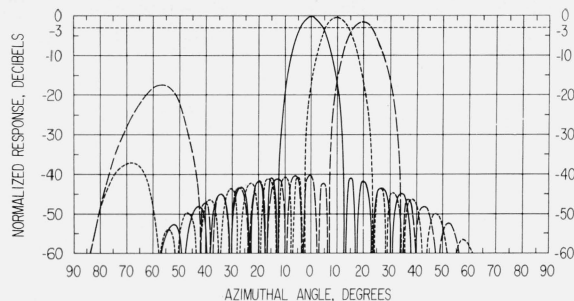


FIGURE 2. Computed radiation patterns of a 90° corner-reflector antenna using a collinear array of 10 half-wavelength dipoles as the driven element.

Dipoles spaced 0.8λ apart and 0.3λ from the apex. The dipole currents follow a Dolph-Chebyshev distribution computed to limit the side lobes below 40 db.

— Maximized in forward direction.
 - - - - Beam maximum 10° off forward direction.
 - · - · - Beam maximum 20° off forward direction.

A corner-reflector type of antenna with a Dolph-Chebyshev dipole current distribution was constructed, adjusted, and tested by the Boulder Laboratories of the National Bureau of Standards. The adjustments and tests were performed in two phases. The work performed in phase I consisted of the adjustments and measurements necessary to obtain side-lobe suppressions below -40 db. The work performed in phase II consisted of the adjustments and measurements necessary to slew the main beam 10° in addition to side-lobe suppressions below -40 db. Gain measurements were made for the antenna in both test phases.

The terminology employed here conforms to common usage. The width of the reflecting surfaces, W , is the dimension parallel to the apex line. The length, L , is measured along the direction normal to the apex line. The aperture angle, θ , is that formed by the two reflecting surfaces. The dipole position, S , is the distance of the driven element from the apex. The dipole spacing is measured between the dipole centers.

2. Experimental Procedure

On the basis of gains and radiation patterns obtained with corner-reflector structures having various combinations of lengths and widths of reflecting surfaces [2, 3] and on the basis of the computed radiation patterns for collinear arrays, a corner-reflector structure with reflecting surfaces 2 wavelengths long and 10 wavelengths wide and an aperture angle of 72° was constructed, adjusted, and tested with a Dolph-Chebyshev dipole current distribution to limit the side-lobe level.

The driven element was a collinear array of 10 half-wave dipoles spaced 0.8 wavelength center-to-center from each other and 0.45 wavelength from the apex of the corner-reflector structure.

The currents in the dipoles were initially adjusted to conform to the values determined for a Dolph-Chebyshev current distribution to limit the side lobes to -40 db. It was found, however, that small departures in current values, unavoidable in experi-

mental practice, would make the radiation pattern exceed this level by several decibels. The current distribution was then recomputed for -45 -db level and the currents readjusted accordingly. These dipole currents, progressing right and left from array center, were 0 , -1.7 , -5.3 , -11.1 , and -20.4 db, respectively.

A main beam slew of 10° off from the forward direction was chosen for these measurements. For a slew angle of 10° and for 0.8λ dipole spacing, the progressive phase difference between adjacent dipoles comes to be equal to 50° . The phase of the dipoles to the right from center were progressively advanced 50° while those to the left were progressively retarded 50° .

Measurements of gain and radiation pattern were carried out using the antenna as a receiving antenna and observing precautions against antenna tilt and other sources of error as described in NBS Circular No. 598 [5].

3. Results

Figure 3 presents the radiation patterns of the antenna in the E - and H -planes for the tests performed in phase I. The E -plane patterns can be seen to have a half-power beamwidth of 9° and a -40 -db beamwidth of 28° . Except for one point,

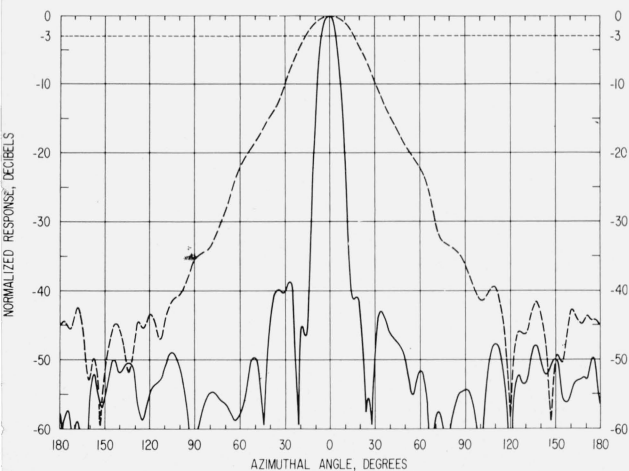


FIGURE 3. Radiation patterns in the E - and H -planes of a corner-reflector antenna using a collinear array of 10 half-wavelength dipoles as the driven element with a Dolph-Chebyshev current distribution to limit the side lobes.

Width of reflecting surfaces, $W/\lambda=10$.
 Length of reflecting surfaces, $L/\lambda=2$.
 Aperture angle, $\theta=72^\circ$.
 Dipole position, $S/\lambda=0.45$.
 Dipole spacing, 0.8λ .
 — E -plane.
 - - - H -plane.

the secondary lobe level is everywhere below -40 db. At an azimuth angle of -26.5° , the level of one secondary lobe reached -39 db. The departures of experimental adjustments from theoretical could be maintained sufficiently small to remain within the -40 -db level.

The radiation pattern of this antenna in the H -plane agrees very closely, as it should, with that

obtained using the same corner-reflector structure and a single half-wave dipole as the driven element (fig. 11 of ref. [3]). It should be noted that the radiation intensity in the 180° direction for the patterns in the two planes is not identical. This is explained by the fact that in making the measurement of the H -plane, due to the large width of the structure, one end of the corner reflector had to be suspended relatively close to the ground. The increase in the back radiation for the H -plane pattern is attributed to the resulting unbalance. Radiation levels of the order of -50 db are equivalent in intensity to 0.001 percent of those in the forward direction, and a small degree of unbalance is readily detectable at these levels.

Figure 4 presents the radiation pattern of the antenna in the E -plane after the adjustments described in phase II were completed. The main lobe is slewed 10° , as desired. The main beamwidth at the half-power points is approximately 9.8° .

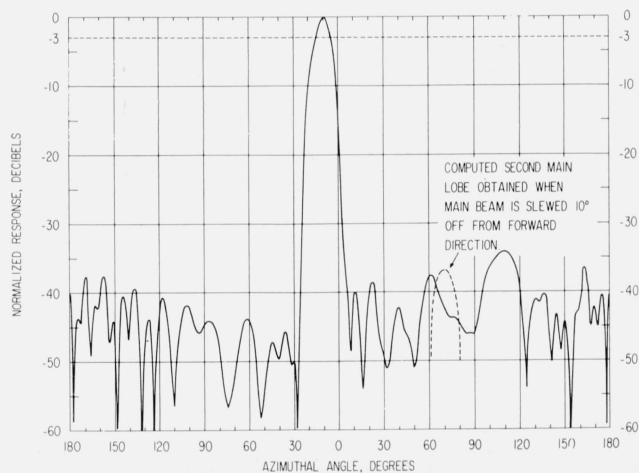


FIGURE 4. Radiation pattern in the E -plane of the corner-reflector antenna with the main beam slewed 10° off the forward direction.

Width of reflecting surfaces, $W/\lambda=10$.
 Length of reflecting surfaces, $L/\lambda=2$.
 Aperture angle, $\theta=72^\circ$.
 Dipole position, $S/\lambda=0.45$.
 Dipole spacing 0.8λ .

The effect of the dipole factor and the use of the corner reflector aids in suppression of the side lobes, but not sufficiently to keep all of the side lobes below -45 db. A relatively high side lobe occurs at an approximate azimuth of 60° in the opposite direction from slew with a response 37 db down from maximum. This side lobe is actually another main lobe due to the dipole spacing used. It is believed that this lobe causes the high side lobe which appears in the back direction at an azimuth of approximately 110° due to the limited width of the corner-reflector structure. The computed second main lobe obtained from slewing the main beam 10° from the forward direction is shown as the dashed line in figure 4. This lobe was computed for a corner-reflector aperture angle of 90° instead of 72° and for a -40 -db side-lobe level instead of -45 -db level. Other high side lobes which occur near 180° are

probably a function of the corner-reflector structure. No further attempt was made to reduce these back-radiation lobes since they were already below the secondary lobe level at 110° . Except for a small side lobe at the base of the main lobe, all lobes in the vicinity of the main beam are below -40 db and even approach -45 db.

Measurements were carried out to determine the degree of cross polarization. Figure 5 presents these results. The curve shown as the solid line is a normal E -plane radiation pattern. The curve shown

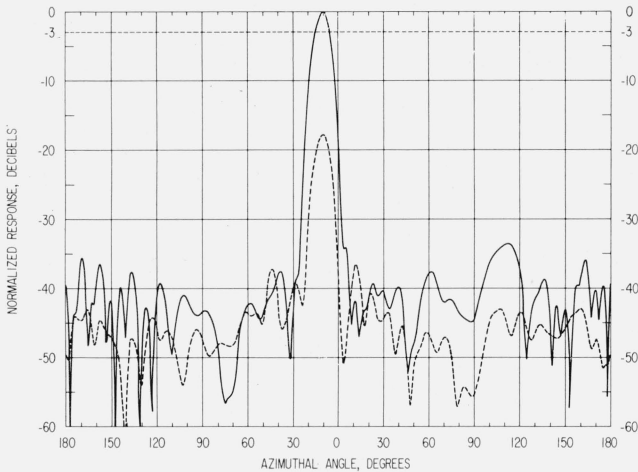


FIGURE 5. Radiation pattern in the E -plane and the cross polarization pattern in the same plane with the main beam steered 10° off the forward direction.

— Normal E -plane pattern.
 - - - - - Cross polarization pattern.

as the dashed line shows the cross polarization in the same plane. The main lobe of the cross polarization pattern is seen to be approximately 18 db below that of the normal pattern.

Measurements were made of the frequency sensitivity of the radiation pattern by taking patterns at 0.2-Mc/s intervals above and below the design frequency of 400 Mc/s. Figure 6 presents these patterns. As the frequency deviation became greater, the level of the side lobes near the base of the main beam increased. There was no measurable change in the back radiation or in the degree of beam slew.

Of considerable importance is the problem of electrical stability of the system with time. While the experimental measurements described were not designed with stability as the prime objective, measurements have been made on the antenna with adjustments left unchanged with time. Figure 7 shows radiation patterns recorded on three different days with adjustments not disturbed. The slight day-to-day changes appeared to be caused by weather conditions and temperature differences.

On the basis of the half-power beamwidths obtained for the H -plane from the radiation patterns of phase I and the E -plane from radiation patterns of phase II, the gain of the antenna over an isotropic radiator may be computed from the following [6]:

$$\text{Gain (db)} = 10 \log_{10} \frac{41,253}{W_E W_H}$$

$$\text{gain (db)} = 10 \log_{10} \frac{41,253}{9.8 \times 32}$$

$$\text{gain (db)} = 21.2.$$

This method of estimating the gain is most accurate when the main beam is narrow and the side lobes are minimum as is the case for this antenna. The gain was experimentally measured relative to a half-wave dipole. These measurements indicate a gain of 21.2 db over an isotropic radiator. This gain measurement was an average of three experimental measurements with maximum deviation ± 0.5 db.

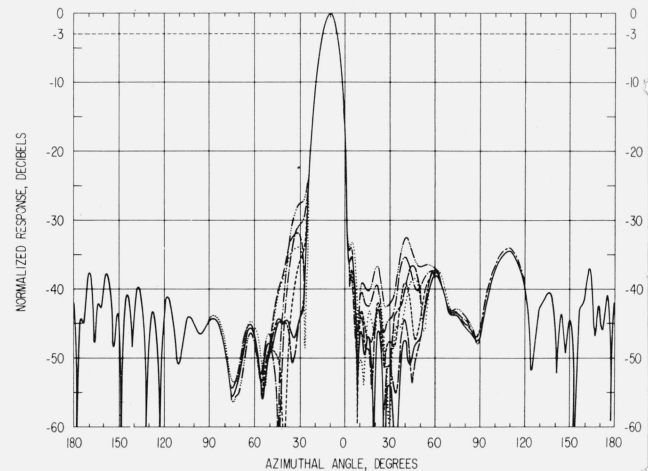


FIGURE 6. Effect of frequency changes on the radiation pattern.

— 400.60 Mc/s.
 400.40 Mc/s.
 - - - - - 400.20 Mc/s.
 — 400.00 Mc/s.
 - - - - - 399.80 Mc/s.
 399.60 Mc/s.
 - - - - - 399.40 Mc/s.

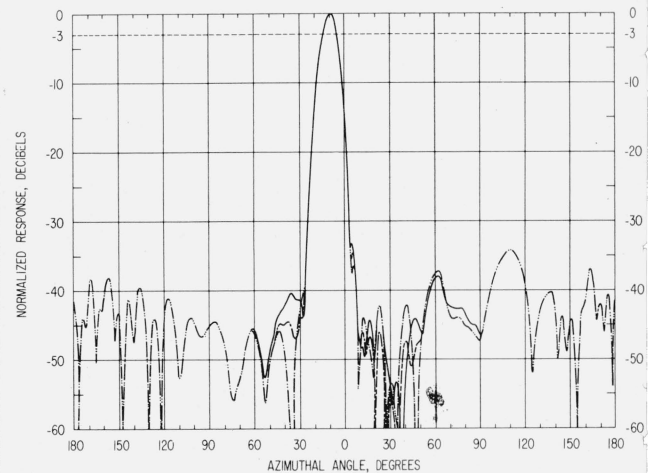


FIGURE 7. Stability of radiation pattern with time.

— Radiation pattern taken December 16, 1958.
 - - - - - Radiation pattern taken December 17, 1958.
 Radiation pattern taken December 18, 1958.

4. Conclusions

The experimental work described shows that it is possible to approach in practice the results obtained theoretically for side-lobe suppression and beam slewing by using an array of collinear dipoles in a corner-reflector antenna. Compensation can be made for deviations of actual dipole currents from the theoretical currents by using a current distribution for -45 db to obtain in practice -40-db side-lobe suppression.

The corner-reflector antenna using a collinear array of dipoles as the driven element has been found to be a suitable antenna type for applications requiring a high gain, low secondary radiation levels, and a capability for beam slewing.

Beam slewing of more than 10° is practical, depending upon the tolerance for a secondary lobe at a large angle from the main lobe. To reduce this difficulty, the dipole spacing may be reduced. At 0.5λ dipole spacing, the secondary lobe is effectively eliminated, but mutual coupling between dipoles increases the problems of adjustment of current distribution and phase.

Full-scale operational antennas of this type are practical to construct and maintain. The desired

degrees of beam slew can be obtained by the use of properly adjusted plug-in current distribution networks. For purposes of initial adjustment and subsequent monitoring, a current sampling loop should be built into each dipole.

The measurements were carried out with the assistance of W. L. Martin.

5. References

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