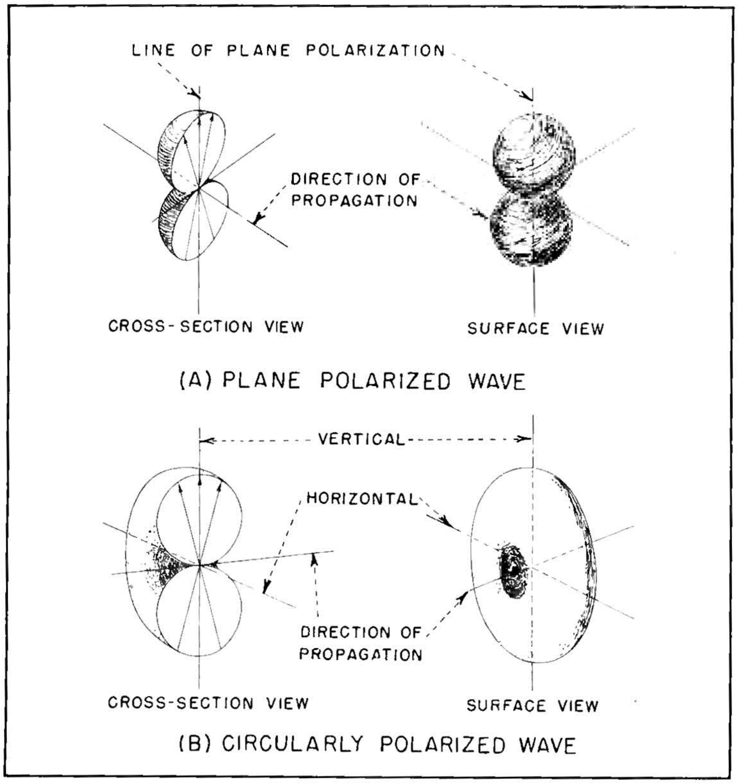
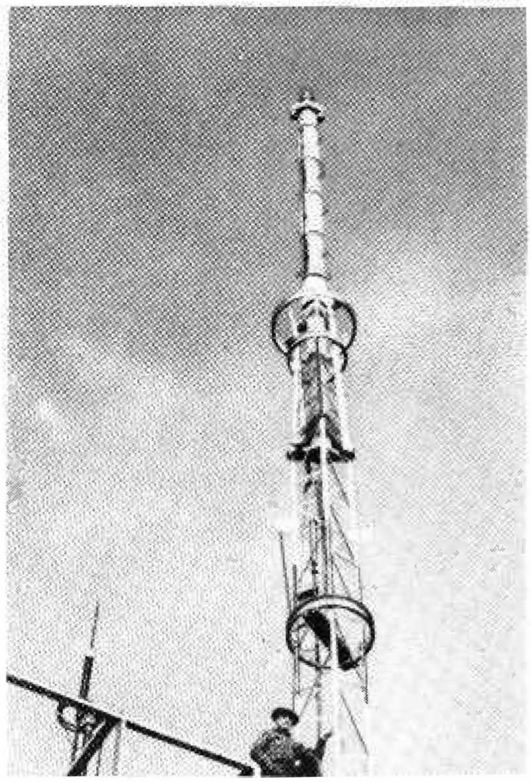


FIG. 1—Reception patterns of half-wave dipole in plane and circularly polarized fields



Circularly polarized antenna in use by radio station WHKX

Circular Polarization in F-M Broadcasting

Experimental field intensity measurements substantiate theoretical advantages to be gained over plane polarization. The high-gain omnidirectional broadcast transmitting antenna described allows most convenient location of home receivers

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More than two years ago the United Broadcasting Company initiated an experimental program to investigate the use of circular polarization for f-m.

The early experimental work was carried on with a prototype circular-polarization antenna consisting of a vertical half-wave dipole and a horizontal loop, mounted on the same vertical axis. A report covering this work was furnished to the Federal Communications Commission in October 1946.[1, 2] Within 30 days the Commission had amended the Standards of Good Engineering Practice to permit the addition of a vertical component having the same magnitude as the horizontal component and thus making it possible to supply the service area with a diversely polarized signal from a circularly polarized f-m broadcasting antenna by radiating twice the power of either component operating alone.[3]

During the past year field measurements have been made on W8XUB and WHKX in Cleveland to determine quantitatively the im-

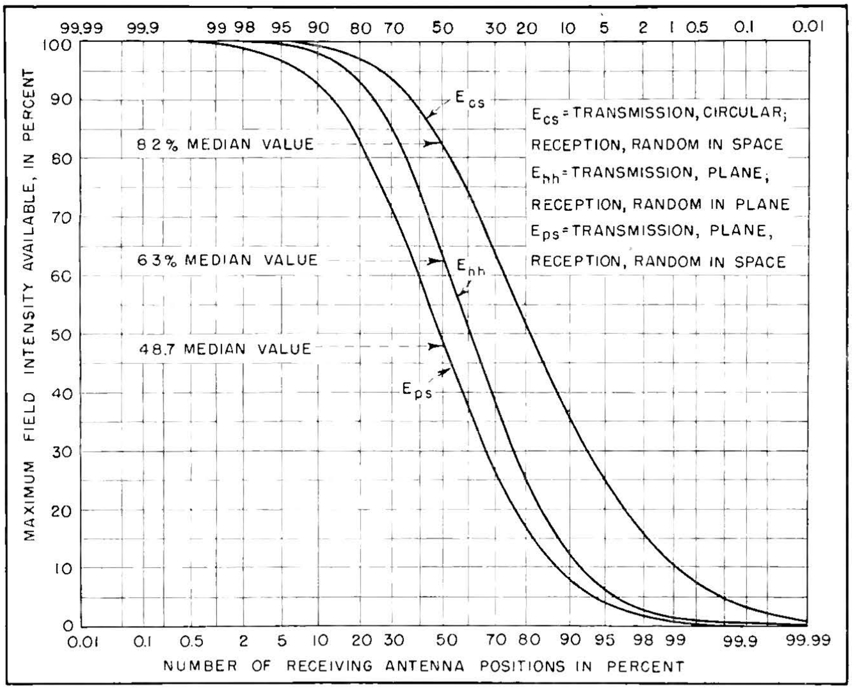


FIG. 2—Distribution of field intensity with receiving antennas in random placements

provement of circular polarization over plane polarization, and a research program has been carried on by the Ohio State University Research Foundation in Columbus to develop a high-gain circularly polarized broadcasting antenna.

Theoretical Advantages

One of the principal advantages of circular polarization over plane polarization is that space is more completely filled with a diversely polarized signal. Figure 1 shows that in a plane-polarized field a simple receiving antenna can be placed in only one position for maximum signal pickup and in a whole plane of positions for zero signal pickup, while in a circularly polarized field a simple receiving antenna can be placed in a whole plane of positions for maximum signal pickup and in only one position for zero signal pickup.

It should be emphasized that although the radiated power can be doubled in going from plane to circular polarization the more important consideration is that the polarization changes from a single line or linear dimension to a surface or two-dimension phenomenon. The radiated power from many f-m stations using plane or horizontal polarization is limited to an equivalent 20-kw, 500-foot antenna in accordance with FCC allocation standards. All of these stations have the privilege of improving their service to the public by employing circular polarization and radiating up to an equivalent 40-kw, 500 foot antenna.

If reception patterns are investigated on a theoretical statistical basis by placing a half-wave receiving antenna at random the curves of Fig. 2 result. For a circularly polarized field with receiving antennas placed at random in space the median value is 82 percent. In a plane-polarized field with receiving antennas placed at random in the plane of polarization the median value is 63 percent. If the receiving antennas are placed at random in space when the field is plane polarized the median value is 48.7 percent.

If ratios between the curves of Fig. 2 are expressed in decibels of improvement the two theoretical curves of Fig. 3 result. The median improvement of circular polarization over plane polarization for antennas placed at random in space is 4.6 decibels, while the improvement of circular polarization over plane polarization when the receiving antennas are placed in the plane of polarization is 2.3 decibels. It should be observed that the improvement to 50 percent of the sets will be much more than this value, as indicated by the sharp upward

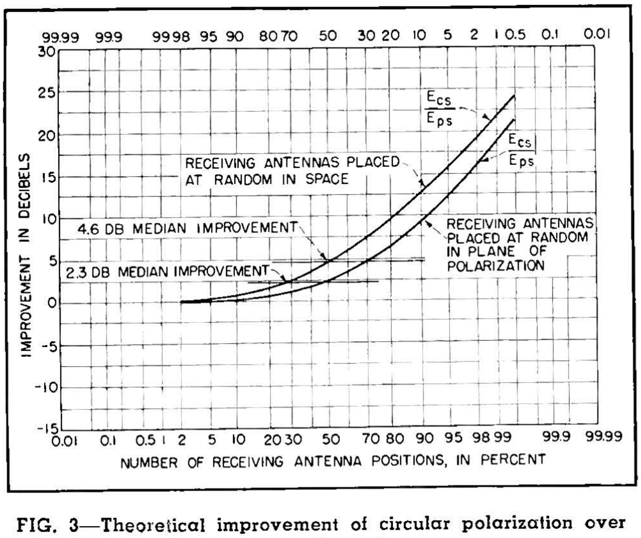


FIG. 3—Theoretical improvement of circular polarization over plane polarization

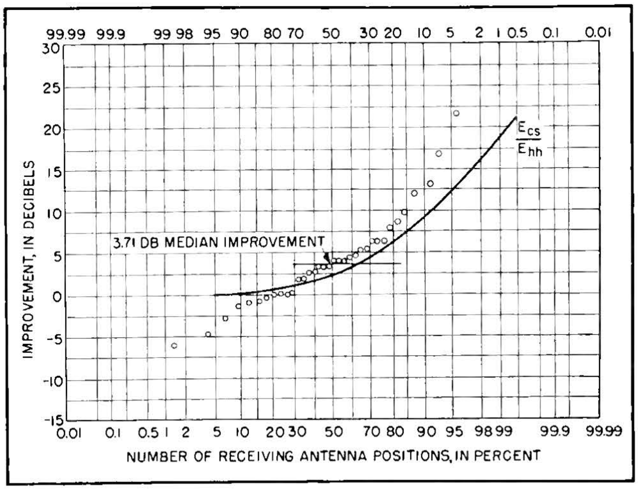


FIG. 4—Improvement of circular over horizontal polarization when receiving antennas are horizontal

curvature toward the right end of these curves.

Field Measurements

To determine quantitatively the improvement of circular polarization over plane polarization as it affects the average home receiver it was assumed that the f-m receiving antenna built into the home receiver must be served. Therefore, 372 carefully controlled field-intensity measurements were made in 36 typical homes throughout the service area of W8XUB.

Measurements in the home were made with a half-wave dipole placed six inches in front and with the center of the dipole level with the top of the home receiver. In other words, an effort was made to reflect into the results the effect of the position of the home receiver as selected by the housewife.

With the test half-wave dipole horizontal, the transmitting antenna was caused to radiate, first horizontal polarization and then circular polarization of equal maximum field intensities. The ratio of these measurements made in 36 homes shows in Fig. 4 that the median improvement is 3.71 decibels. The theoretical curve was also drawn in this figure for comparison purposes. It will be noted that the field measurements data is in fair agreement with the theoretical curve. It is believed that cancellations and reinforcements due to reflections from metalic plumbing and wiring in and around the home cause the measured points to fall below the theoretical curve toward the left end and rise above the theoretical curve toward the right end.

If the receiving antenna is placed at random in space it should be possible to check the theoretical curve of Fig. 3. To accomplish this, measurements of circular polarization transmission with vertical receiving antennas were compared to both vertical and horizontal-polarized transmission with the same vertical receiving antennas. Then a similar set of ratio measurements were made with horizontal receiving antennas. Figure 5 presents 72 such ratio measurements with a median improvement of 4.87 decibels. This is in good agreement with the theoretical median improvement of 4.6 decibels. Again cancellations and reinforcements are believed to be the reason for the statistical data to fall below the theoretical curve at the left and rise above the theoretical curve at the right.

Another case of interest is the improvement that can be expected when the receiving antennas are vertical. A practical application is whip antennas on automobiles and power-cord antennas such as are commonly used on table-model receivers. The 21 statistical measurements for this condition are presented in Fig. 6, which shows a median improvement of 9.25 decibels. The improvement for three points was too great to plot; however, their effect is reflected by shifting the other points to the left.

Summarizing the results indicated by the above field measurements, it is more profitable for a broadcaster to divide the available power between the horizontal and vertical components and employ circular polarization even for serving only horizontal receiving antennas placed in the home. However, such division of total power is not necessary under the Standards of Good Engineering Practice for f-m broadcast stations. Under these standards the broadcaster can expect to more than double the power (3.71 db) in horizontal receiving antennas and increase the power more than eight times (9.25 db) in vertical receiving antennas within the service area.

Antenna Development

The program at the Ohio State Research Foundation embodied basic research on two methods of producing circular polarization. The first employed excitation of a single element geometrically shaped, such as spiral slots or helical antennas, to produce the desired polarization. The second group consisted of horizontal and vertical radiating elements, each fed with the proper proportion of energy to produce equal-magnitude fields and with the proper time-phase difference to produce circular polarization.[4]

In developing the antenna the

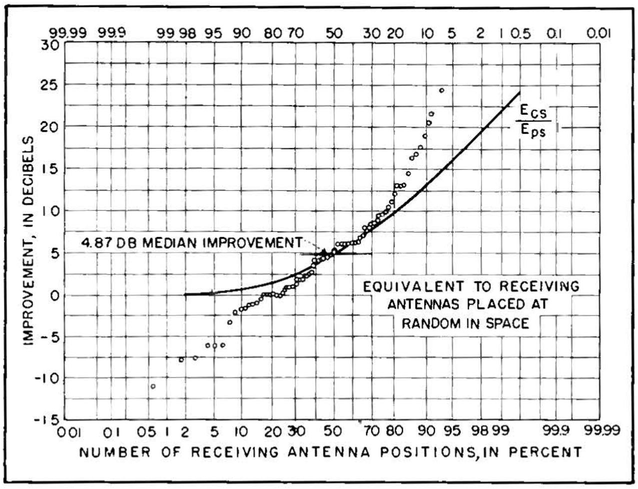


FIG. 5—Improvement of circular over plane polarization with randomly placed receiving antennas

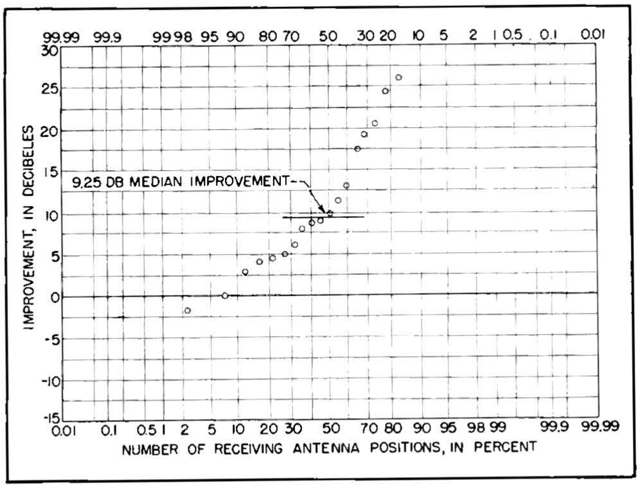


FIG. 6—Improvement of circular polarization over horizontal with vertical receiving antennas

problem was attacked theoretically and experimentally by means of model technique.[5] The theoretical work was devoted to slots in cylinders[6] since it appeared early in the development that this type of antenna would probably be used as the radiating element to produce the horizontal polarized component of the circularly polarized antenna.

To produce circular polarization in the horizontal plane it should be remembered that both the horizontal and vertical radiating elements must have a uniform pattern in magnitude and phase. It has been shown[6] that two diametrically opposed axial or longitudinal slots in a cylinder will satisfy the requirement for the horizontal component, as the magnitude was essentially uniform and the phase shift was less than three degrees through the f-m broadcast band for cylinders whose diameters were 16 inches. By making the cylinder a half-wavelength long and feeding the slots at the center, the desired horizontal component can be produced. The vertical component can be obtained by feeding the half-wavelength cylinders as full-wavelength vertical dipoles. The 90-degree time-phase requirement was satisfied by using a phase control as shown in Fig. 7, which also shows the basic elements and how they were developed and combined to produce the circularly polarized experimental antenna as used by station WHKX, and illustrated on the cover of ELECTRONICS for April 1948.

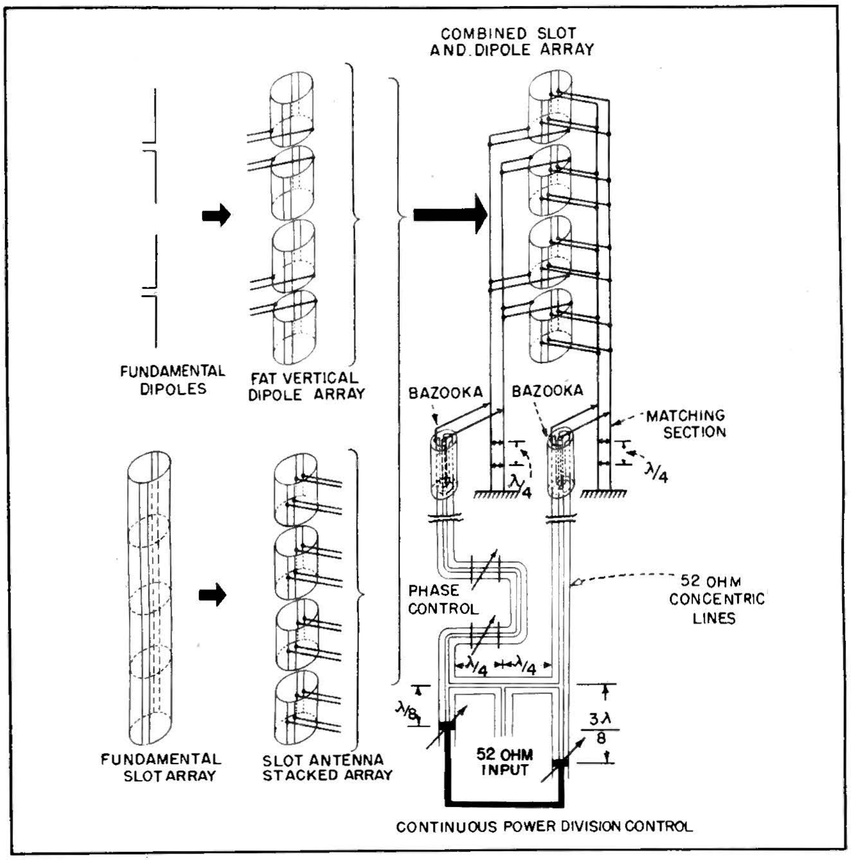
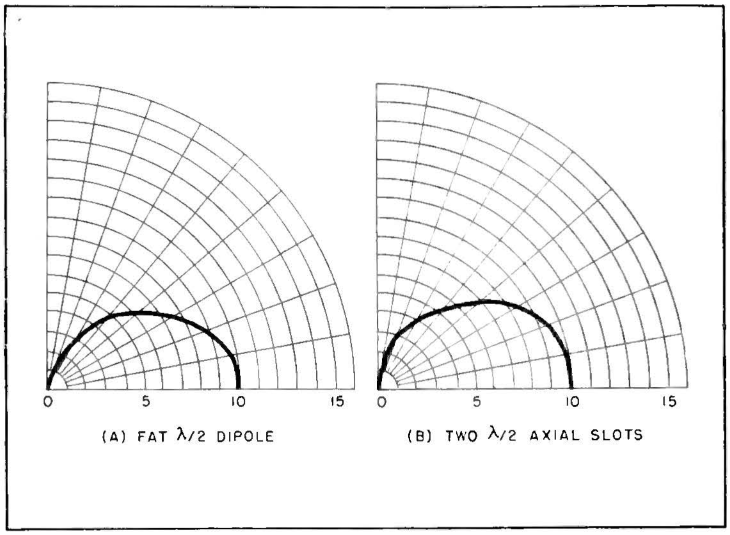


FIG. 7—Development of the circular-polarized antenna from dipoles and a slot array

Experimental data on the slots showed them to have vertical patterns which were similar to the vertical fat dipole and indicated that the units or full-wavelengths bays could be stacked suitably for high gain. Vertical patterns at 100 mc for both elements are shown for half-wave cylinders 16 inches in diameter, in Fig. 8. The horizontal-plane patterns for the two elements are quite uniform, as shown in Fig. 9. With this basic information a model for a circularly polarized antenna was constructed and tested. Pattern tests proved the antenna to be circularly polarized in the horizontal plane and that the units could be stacked for high



(A) FAT λ/2 DIPOLE

(B) TWO λ/2 AXIAL SLOTS

FIG. 8—Vertical field patterns for both vertical and horizontal-polarized elements at 100 mc, using 16-in. diameter cylinder

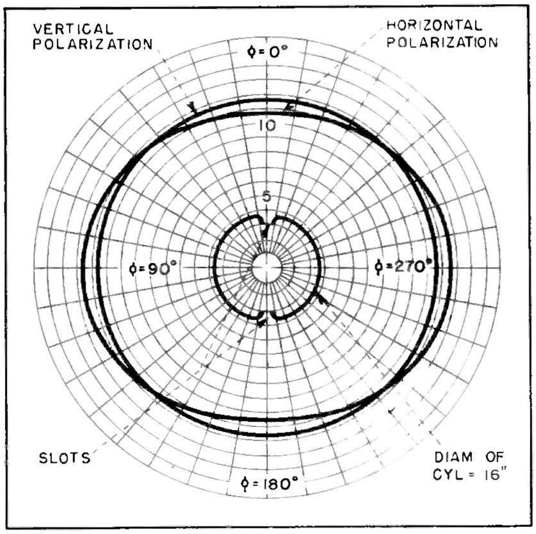


FIG. 9—Vertical and horizontal-polarization components of horizontal-plane pattern at 100 mc

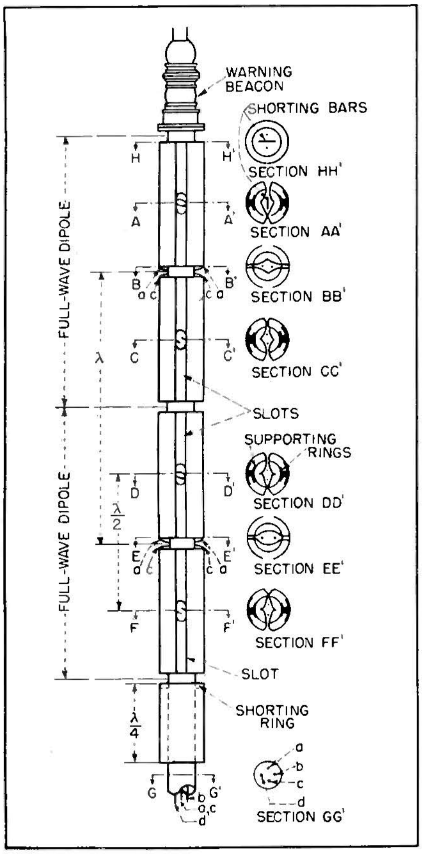


FIG. 10—Construction and feed details

gain. As a result of these studies the full-scale antenna was fabricated and installed for experimental operation.

The Antenna

One unit, or bay, of the antenna consists of two half-wavelength cylindrical sections with two diametrically opposed axial (longitudinal) slots cut in each section as shown in Fig. 10. For the vertical radiating element, the two cylindrical sections are fed at the center of a vertical full-wavelength fat dipole. Since the units are one wavelength long, the feeding problem is simple when the units are stacked in a vertical collinear array, to obtain a high-gain vertical pattern. The horizontally polarized component is obtained by feeding the axial slots, cut in each section of the cylinder, in phase with equal amplitudes of current so the circular pattern in the horizontal plane is obtained.

Feeding the antenna can be accomplished with a multiwire balanced transmission line as shown in Fig. 7 and 10, or a coaxial-line feed system can be employed throughout. The full-scale model employs a balanced four-wire line. The copper-clad steel conductors are stretched from the top to the bottom of the supporting mast and on the inside of it. One pair of conductors is used to feed the vertical radiating elements and the other pair the horizontal radiating elements. The correct phase relationship for the two slots in each cylinder is obtained by properly crossing the connectors from the transmission lines to the slots as shown in Fig. 10. Since the feed points from one cylinder to the next cylinder are a half wavelength apart, altering the crossed connectors keeps the units in phase so they can be stacked. The feed points for the dipoles are one wavelength apart and can thus be fed in phase to produce a simple collinear array of stacked elements.

Each section of the galvanized-iron cylinder shell is fastened to a standard 10-inch steel mast with metal castings to support the shell to the mast. This is possible because the support point is at zero potential, being an odd quarter-wavelength away from the vertical-polarization feed points and equidistant between the horizontal feed points. This keeps the entire antenna free of insulators. A quarter-wavelength skirt is placed at the bottom of the antenna to minimize currents on the supporting structure. Bazookas are used to transform from balanced to unbalanced transmission lines as shown in Fig. 7.

With independent phase and power control it is easy to adjust for true circular polarization. The condition of polarization is determined at WHKX by a half-wave sampling dipole mounted level with the center of the circular-polarization antenna on a wooden pole at a distance of about 100 feet. This dipole can be rotated by a rope control to any position in a plane at right angles to the direction of propagation. The r-f meter at the center of the dipole can be observed by using a telescope mounted in the transmitter building.

The gain of the antenna is a function of the number of units or bays and may be determined by the conventional method used in computing the gain of collinear arrays.

Commercial Antennas

For commercial antennas it may be more desirable to use a concentric transmission line harness-type of feed throughout. By first resonating and then controlling the resistance magnitude at the various antenna-element feed points the standing waves on the feeder lines can be reduced to a minimum. The commercial broadcast antennas can be fabricated in this fashion. All openings in the cylinders will be covered with plastic to minimize effects from weather conditions. It will then be practical to bulk heat the antenna structure if icing is expected to be severe enough to require it. A ladder can be mounted on the cylinders without affecting the radiation pattern, thus making it easy to service the flasher beacon at the top of the antenna.

Acknowledgments

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