FM CIRCULAR ANTENNA . . .

Development of a new horizontally polarized circular transmitting antenna having many advantages in frequency-modulation services

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EXPERIENCE over a period of years in the development of ultrahigh-frequency antenna equipment has shown that general simplicity in design is the key to commercial success. The circular antenna to be described is a result of a study directed toward the application of this principle to horizontally polarized television transmitting antennas having circular radiation patterns.

The first transmitting antenna system used for television at the General Electric Helderberg station was the cubical antenna shown in **Fig. 1**. This consisted of two horizontal sets of four half-wave elements forming a square, spaced vertically a distance of one-half wavelength, so as to give the general configuration of a cube. Each set of radiators, which we may consider equivalent to a single bay in the usual sense, had four insulated elements and four connecting terminals.

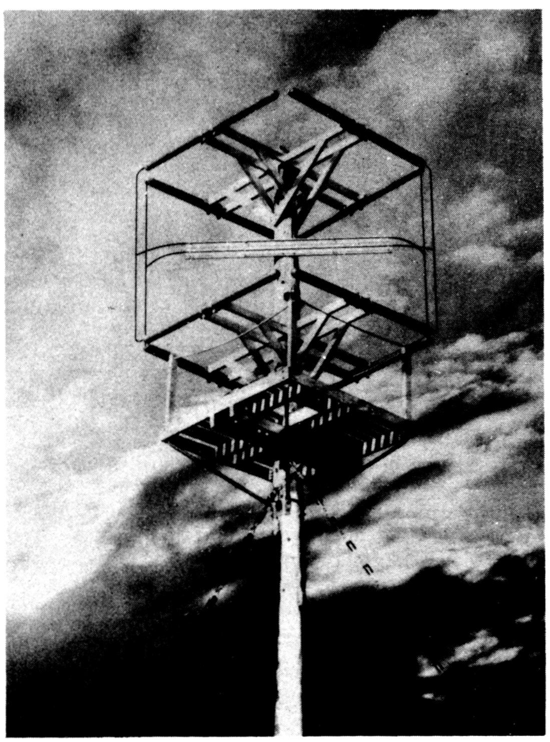

Fig. 1. The cubical television antenna

Development

It was soon found that each bay could be effectively replaced by a structure having only half the number of elements and half the number of terminals, in the form of a 90-deg V, as shown in **Fig. 2**. The polar pattern could be improved considerably by changing the angular separation of the elements to less than 90 deg. But this structure still required complete insulation of the elements and because of its size involved an elaborate mounting arrangement.

An improvement in the physical configuration of the antenna was achieved in the overlapping square of **Fig. 3**, where each element length was reduced to a quarter wavelength to secure a circular radiation pattern. A consideration of the natural capacity between the adjacent overlapping conductor surfaces made this antenna effectively equivalent to a loop antenna[1] with end capacity as shown in **Fig. 4**.

This led rapidly to a conception of the final complete antenna, the circuit of which is shown diagrammatically in **Fig. 5**, while the physical interpretation is given in **Fig. 6**. The multiple-current-path principle of impedance transformation[2] was utilized to boost the terminal impedance to a satisfactory value. The elements

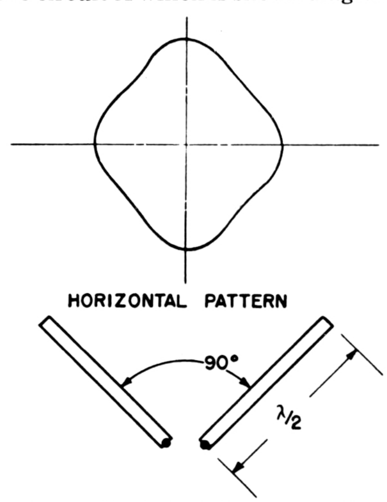

Fig. 2. The 90-deg "V" antenna and its horizontal radiation pattern

(1) "Ultrahigh-frequency Loop Antennas," by A. Alford and A. G. Kandoian, *AIEE Transactions Supplement*, vol. 59, p. 843, 1940.
(2) "Simple Television Antennas," by P. S. Carter, *RCA Review*, vol. 4, p. 168, Oct. 1939.

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A and *B* are each effectively a quarter wavelength long, being shortened from a physical quarter wavelength by the end capacity *C*. Obviously adjustment of the size of this end capacity serves to provide adjustment to resonance at any frequency over the frequency range of the antenna, without change in the main physical structure.

The adjustable capacitor is constructed of a heavy mycalex plate with conducting plates on each side similar in arrangement to the leaves of an automobile spring; this reduces its susceptibility to capacity change due to a collection of snow and ice. The radiating elements are constructed of standard steel pipe formed to circles of 33 in. diameter. The relative conductor diameters of the primary system *A* and secondary system *B* are determined by the degree of impedance boost desired. It was found that a wide range of

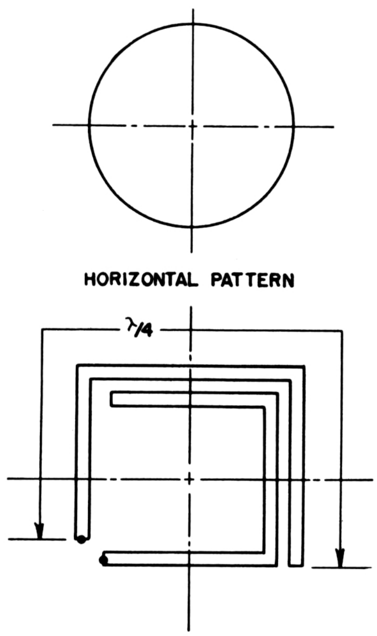

Fig. 3. The overlapping square antenna and its horizontal radiation pattern

impedance change is readily possible. Mounting is made at the ground-potential point *D* without insulation; this protects the transmission-line equipment from lightning.

The antenna may be considered a direct composition of three well-known antennas as indicated in **Fig. 7.** Here a folded dipole[2] is first provided with a concentrated end capacity.[3] Next, the element surfaces are bent to form a circular section to produce a loop antenna.[1] Provision of an adjustable capacity completes the arrangement

Attention to the patterns of current distribution serves to indicate how an approach to constant current around the loop circumference is obtained, with the resultant approach to uniform horizontal radiation as indicated in **Fig. 5.**

[3]"Control of Radiating Properties of Antennas," by C. A. Nickle' W. W. Brown, and R. B. Dome, *Proceedings of the IRE*, vol. 22, p. 1362, Dec. 1934.

The satisfactory development of this antenna was made possible only by proper facilities to make reliable electrical measurements. For measuring impedance of the antenna proper, and of transmission-line elements associated with it for matching

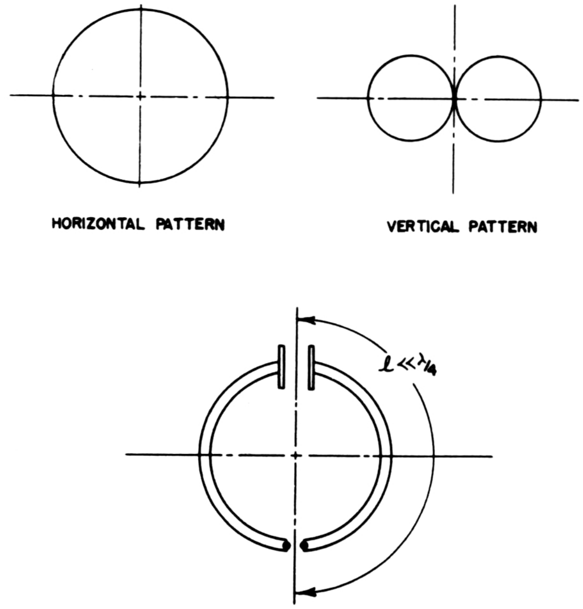

Fig. 4. Horizontal and vertical radiation patterns of simple loop antenna

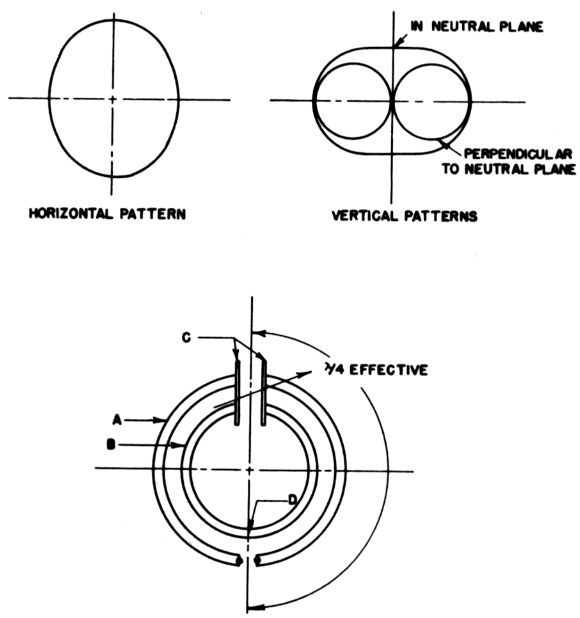

Fig. 5. Diagram of circular antenna and its accompanying radiation patterns. *A* and *B* antenna elements, *C* end capacity, *D* ground-potential point

purposes, use was made of a vector-impedance measuring means[4] for which was built the special unit shown in **Fig. 8.** It provides means for the accurate measurement with practically no limitations on the magnitudes

[4]"Measurements at Radio Frequency," by H. R. Meahl, M. W. Scheldorf, P. C. Michel, and T.M. Dickinson, *AIEE Transactions*, vol. 59, p. 654, Dec. 1940.

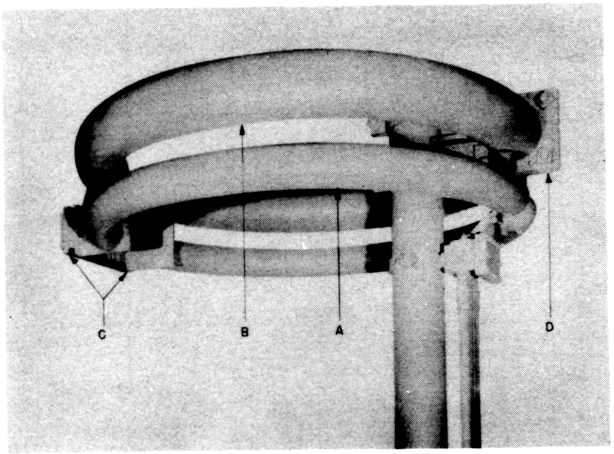

Fig. 6. The FM circular transmitting antenna. Elements *A* and *B* are each effectively a quarter wavelength long, being shortened from a physical quarter wavelength by end capacity *C*. Mounting is made at ground-potential point *D* without insulation

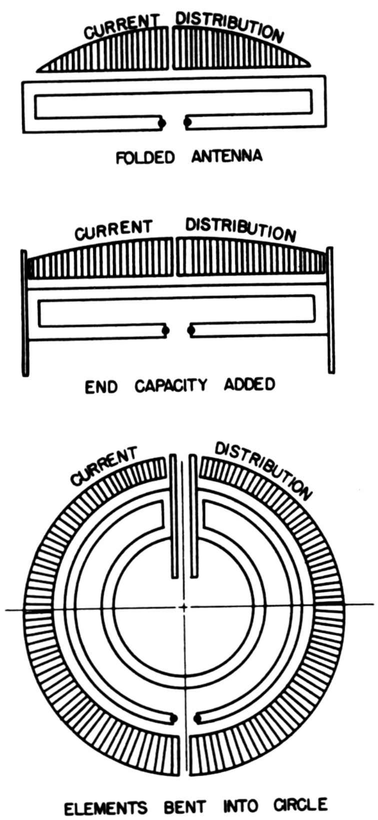

Fig. 7. Showing the composition of the circular antenna

of the vector components. Field-intensity measurements on a practical two-bay installation were made with a high-frequency field-intensity meter and a photoelectric recorder.

Performance Characteristics

A commercial design was completed for the FM band 42 to 50 megacycles. **Fig. 9** shows the impedance characteristic, when this antenna is mounted on a four-inch steel pole, with the capacitor set to resonance at 46.3 megacycles. The slopes of both the resistance and reactance curves prevent the use of this antenna for television purposes but it is quite satisfactory for FM. The variation of the resonant resistance over the FM range is given in **Fig. 10.** When the pole diameter is increased beyond four inches the resonant resistance decreases due to

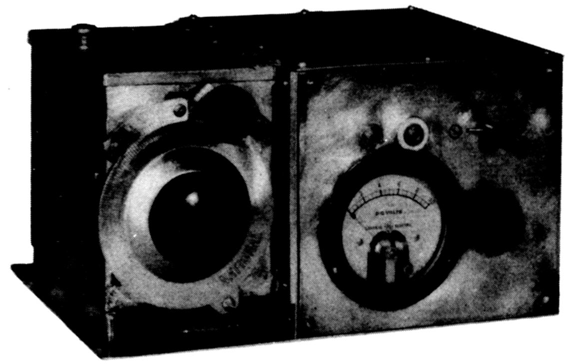

Fig. 8. The portable vector-impedance measuring unit

currents, induced in the pole surface, of a phase opposite to that in the radiating circles.

The calculated radiation patterns for this antenna, shown in **Fig. 5**, are a close approach to that which is secured from a small loop with constant current throughout its length. The deviation of the patterns from the simple shapes secured with a small loop, as indicated in **Fig. 4**, is due to the nonuniformity of current along the shortened quarter-wavelength elements. These patterns permit the calculation of the gain of the single antenna and arrangements of more than one vertical bay.

It was gratifying to realize a loss of only one decibel for the single antenna compared with the vertical dipole. It was found in the case of more than one unit that the optimum gain is obtained near a spacing of

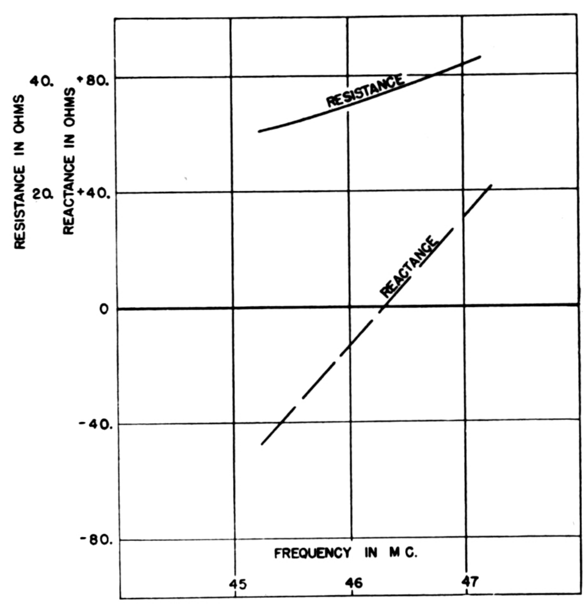

Fig. 9. Impedance of FM circular antenna, for a given capacitor setting, when mounted on a 4-in. steel pole. (Includes leads and transmission-line insulators)

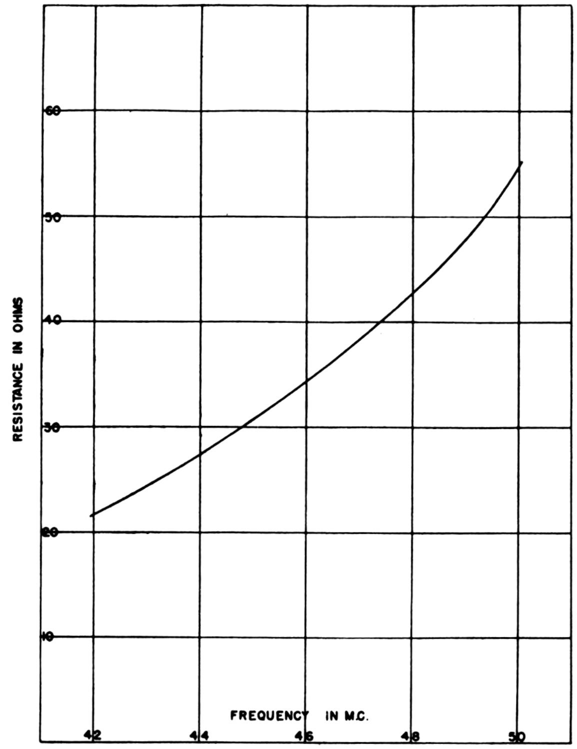

Fig. 10. Resonant resistance of circular antenna over the FM range when mounted on a 4-in. steel pole. (Includes leads and transmission-line insulators)

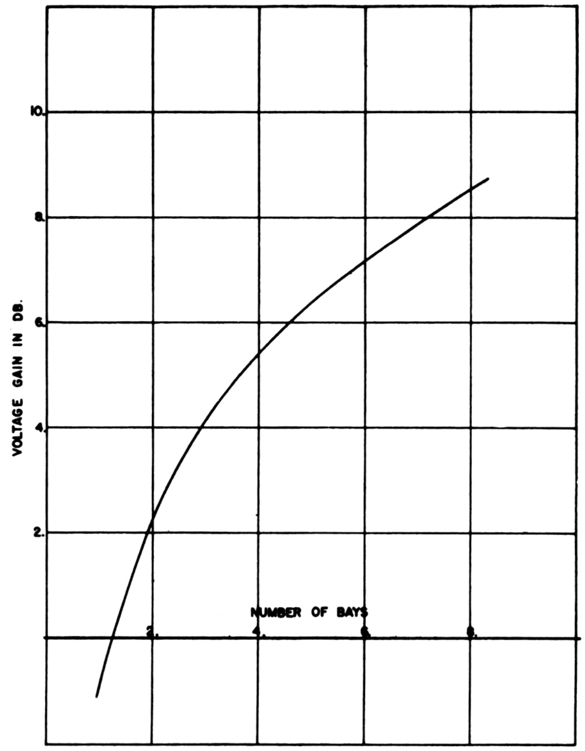

Fig. 11. Gain of FM circular antenna, compared with vertical half-wave dipole, for different numbers of bays spaced a wavelength apart

one wavelength. Since this spacing is also desirable from a standpoint of phasing, it is used for all combinations.

The gain characteristic is shown in **Fig. 11.** The improvement due to the large spacing, over antenna systems which require a closer spacing for the highest gain, is obvious. This agrees with the generally accepted condition that the gain of an antenna system is determined by the total "aperture," provided the spacing is near to the value which gives optimum gain.

Because the radiation is relatively low in a vertical direction, low mutual impedances were predicted. Rough calculations showed that these mutuals should be under ten per cent. To verify this, the impedance of a two-bay system with a 360-deg (or a wavelength) effective vertical spacing between the bays was measured with currents in phase and likewise 180 deg out of phase. The resulting impedance values at the input end of connecting transmission lines were $13.0 - j\,0.5$ and $13.6 - j\,4.0$ respectively. The small difference indicates the degree of mutual impedance present. This is of great importance when considering the adjustment of multi-bay systems. For all practical purposes, matching systems designed for a single bay will be usable for the multi-bay purpose. For the same reason, the adjustment of the elements to resonance becomes a simple matter in the case of multi-bay systems.

Matching

In order to match the antenna impedance to existing concentric transmission lines it is necessary to provide a means of adjusting the surge impedance of the matching elements over a considerable range. This is accomplished by varying the number of insulators and, in combination with this, the size of the inner conductor. After the manner of surge impedance

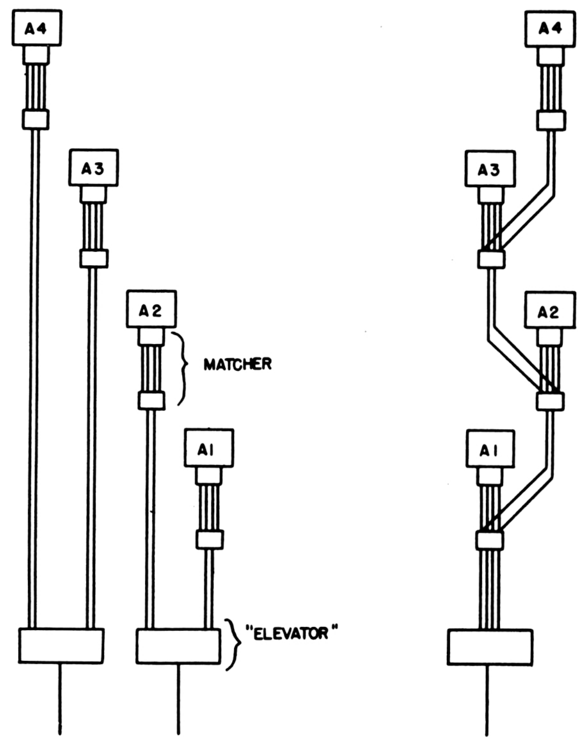

Fig. 12. Transmission-line arrangements for 4-bay antenna—low-power arrangement is at the *right*, high-power arrangement at *left*

and velocity of propagation variation have been determined, it is relatively simple to design a matching unit for the necessary condition. Fortunately, we have determined that, independent of insulator shape, the surge impedance and the velocity of propagation both vary as the inverse of the square root of the average dielectric constant, so that the performance of the matching unit may be accurately predetermined.

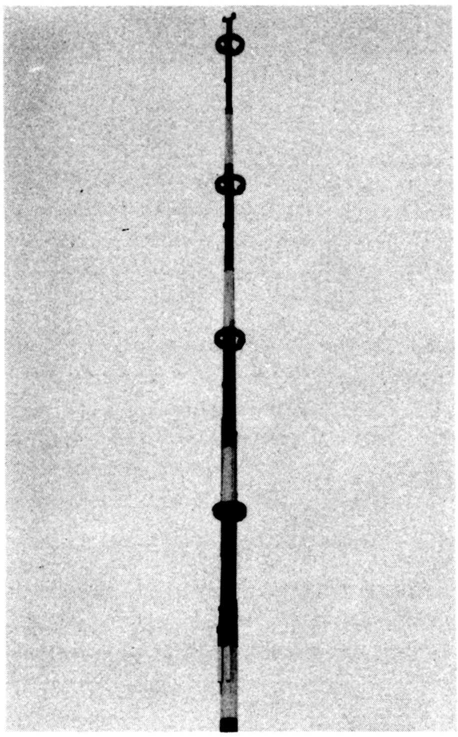

Fig. 13. Model of 4-bay FM circular antenna with transmission lines arranged for high-power application

The matching units are so constructed that the inner conductors and insulators may readily be removed after installation for changes in the exact number of insulators used, for cases where the standing waves must be reduced to exceptionally low values.

In order that the matching units may be mounted to the pole in a simple and sturdy manner, regardless of the pole diameter, the antenna elements are mounted so that the distance from the pole surface to the connecting terminals remains constant. This fortunately also makes the antenna mounting the simplest, an arrangement having been obtained where the major change necessary with pole-diameter change, is the diameter of the clamp that is fastened around the pole.

For low-power installations where it is possible to tolerate a considerable standing wave in the interconnecting transmission-line parts, the system is connected as shown at the right in **Fig. 12**, illustrating four vertical bays. When high power is used, where it is necessary to operate the lines at a low standing-wave condition, the lines must be connected as shown at the left in **Fig. 12**.

A four-bay antenna-system model connected for high-power use is shown in **Fig. 13.** The element mounted beneath each bay is used to match the antenna to two transmission lines in a balanced circuit. The elements near the base are the familiar phase-inverting elements, or elevators, which make it possible to connect a balanced load to a single-ended concentric transmission line. The term elevator is employed because the addition of the outer shield elevates the potential of the outer conductor of the transmission line above ground. For a two-bay installation only one of these elevator elements is used, connected in identical manner to its associated two antenna elements. For one bay alone it is possible to construct the matching unit and elevator in one compact unit.

Field Measurements

Field-intensity measurements were made on a two-bay installation and compared with a dipole mounted on the same pole at a height halfway between them. These results are given in **Fig. 14** where two sets of points are plotted, one in terms of the dipole directed North-South and another in terms of the dipole directed East-West. The circular average indicates a gain in voltage of 1.25 or +1.9 decibel.

An unusual experience with the field-intensity measurements may be of interest. There has been some question among engineers as to the advisability of making field measurements at these high frequencies near telephone lines and power lines. All

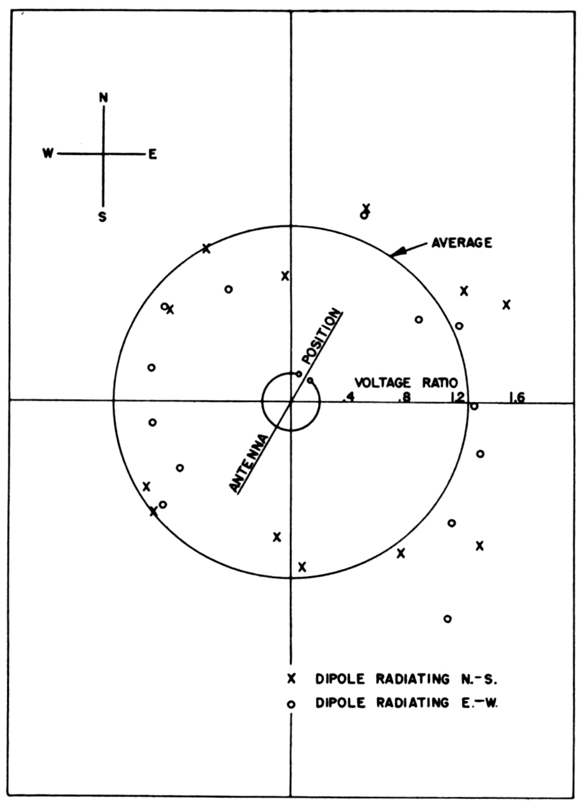

Fig. 14. Field measurements on a 2-bay FM circular antenna at 46.7 megacycles. (Compared with a dipole)

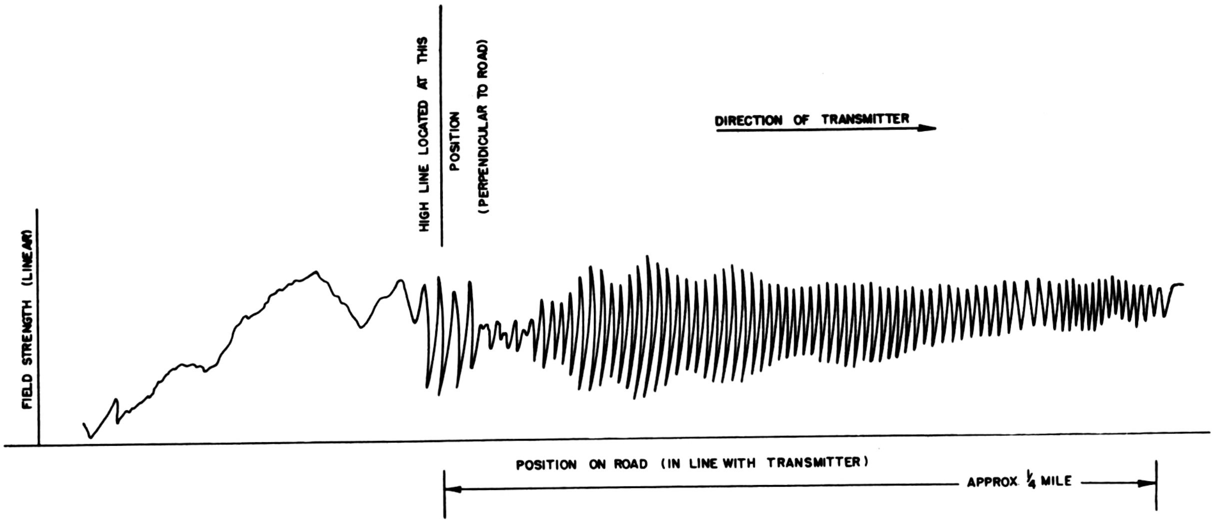

Fig. 15. Record of field strength near an 8-wire power line

our measurements were made avoiding them as a general precautionary measure. At one point in our work considerable reflection was noted at a quarter of a mile from a power line. A little investigation gave the result shown in **Fig. 15.** This is a record of field intensity near an eight-wire power transmission line, 18 miles from the transmitter, running perpendicular to the line of propagation, over a straight, level road running in the line of propagation. The degree of reflection that is secured is the point of principal interest. It results in a high standing-wave pattern of short period on the transmitter side and of long period on the opposite side where, at a remote point, there is practically complete cancellation of the signal that would exist without the presence of the high line. The record is shown for the interest of others who may have noted irregularities in similar instances.

Applications

The original single unit used for determination of the basic characteristics is in operation at the Muzak Radio Broadcast Station, Inc., call letters W47NY.

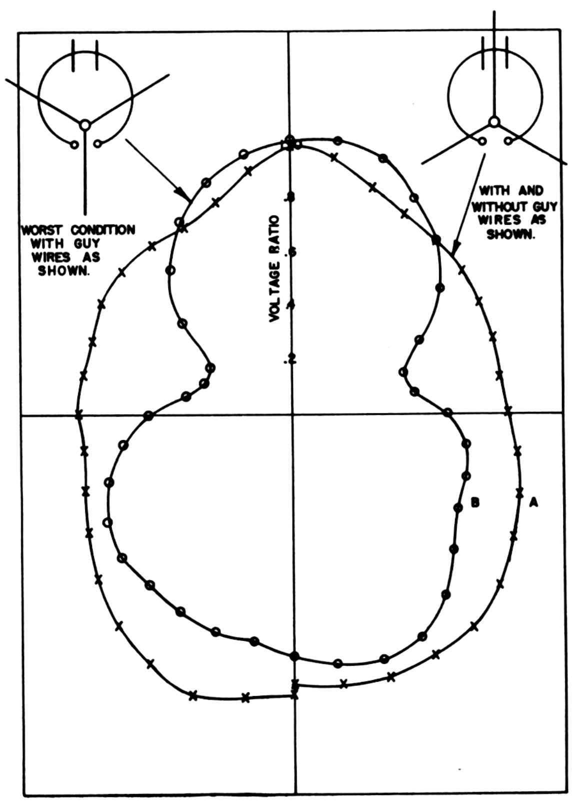

Fig. 16. Showing the effect of guy wires mounted to pole over the scale model circular antenna. (Measured horizontal patterns)

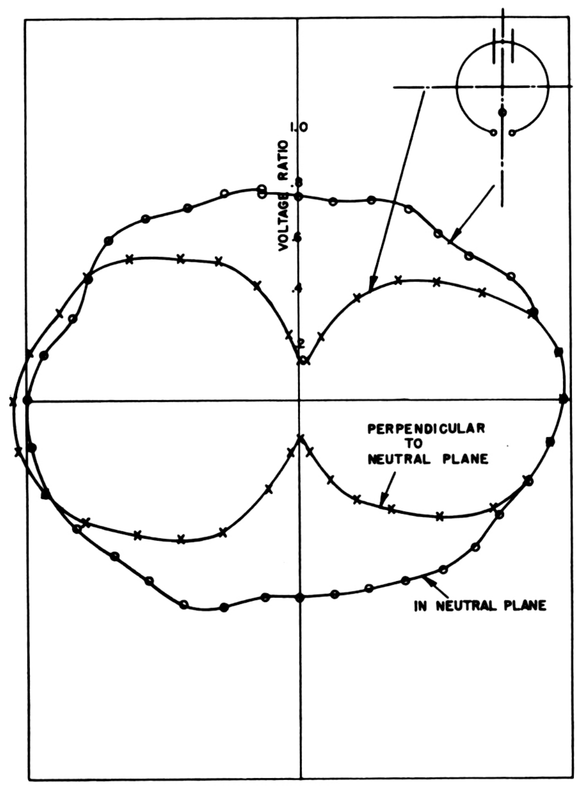

Fig. 17. Measured vertical patterns of the scale-model circular antenna without guy wires

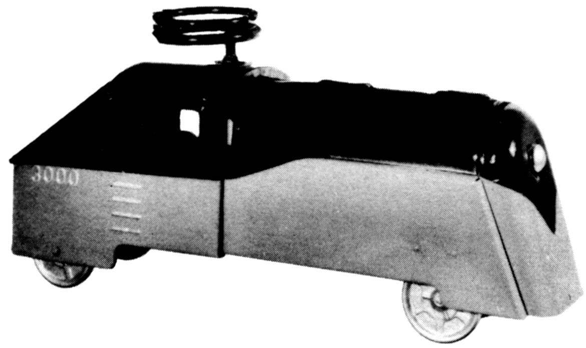

Fig. 18. Scale model of circular antenna mounted over a toy locomotive

Commercially designed units, as shown in **Fig. 6**, have been built for:

W73PH	William Penn Broadcast Company	Philadelphia	2-bay
W59C	WGN, Inc.	Chicago	2-bay
W67NY	Columbia Broadcasting System	New York City	2-bay
W57PH	Westinghouse Radio Stations, Inc.	Philadelphia	1-bay
W75NY	Metropolitan Television, Inc.	New York City	1-bay

The use of self-supporting tubular poles for these antennas introduces a serious structural problem when the number of bays exceeds four, because it is necessary to hold the pole diameter to a minimum in order that the transmission lines may pass between the surfaces of the pole and the lowest antenna element with sufficient clearance. To determine the possibility of using metal guy wires in order to reduce the pole diameters, radiation tests on a scale model have been made, operating at a frequency of 335 megacycles. A simple three-wire system was used, with metal throughout, fastened solidly to the vertical metal pole at an angle of 30 deg from the vertical. The antenna element was mounted under the guys and the spacing varied. In addition, for the closest spacing condition of a quarter wavelength, the guy-wire lengths were varied. The results are shown in **Fig. 16**. Curve *A* in **Fig. 16** shows the horizontal pattern of the scale model with no guy wires. The graph may also be used to show the patterns secured for all conditions of spacing and for all guy-wire lengths at the close spacing, provided the relative guy-wire arrangement is used as indicated in the associated diagram, where one of the wires passed through the neutral plane on the capacitor side of the antenna. However, when one of the guy wires passes through the neutral plane at the terminal side, there is considerable effect on the horizontal pattern. Curve *B* in **Fig. 16** shows the poorest curve, secured when the vertical spacing is only a quarter wavelength and when the guy-wire length is one-and-one-quarter wavelengths. It is obvious that guying will be no problem at all, when properly applied.

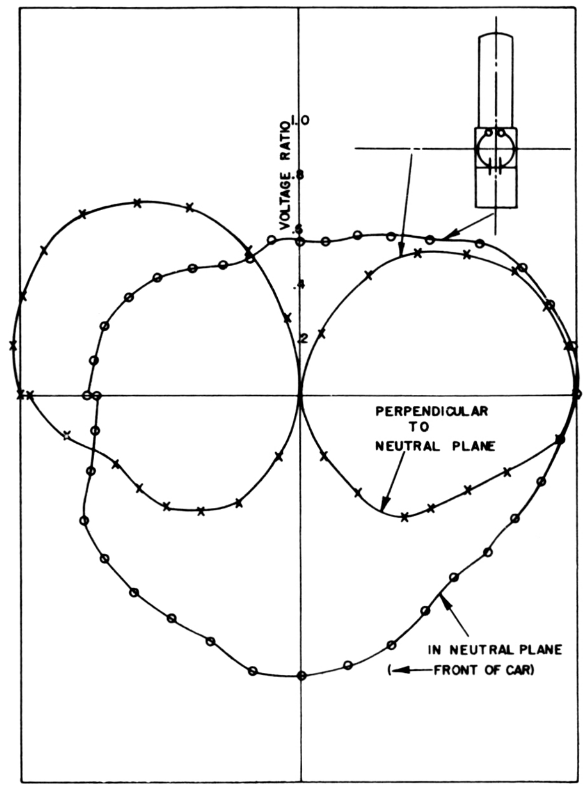

Fig. 20. Measured vertical patterns of scale-model circular antenna mounted over the locomotive model (Fig. 18)

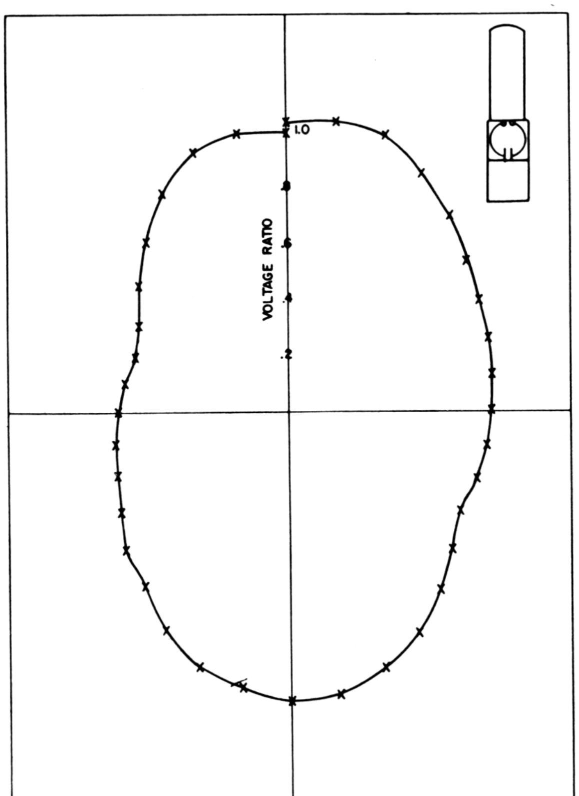

Fig. 19. The measured horizontal pattern of the scale-model circular antenna mounted over the locomotive model (Fig. 18)

Curve *A* in **Fig. 16** should be compared with that of **Fig. 5**, giving the calculated horizontal pattern.

In order to verify the calculated vertical patterns, measurements were made on the scale model with no guy wires as indicated in **Fig. 17**. The agreement is very satisfactory.

Because of its low vertical radiation, because of its low impedance, and because of its general physical configuration, this antenna has been seriously considered for operation in connection with metal-covered vehicles, such as police-radio cars, etc. Performance curves with the scale-model antenna mounted over a toy locomotive constructed of metal, as shown in **Fig. 18**, are indicated in **Figs. 19** and **20**. The principal change is a concentration of energy toward the mass of metal of the model locomotive.

These curves should be compared with similar curves on a vertical whip antenna mounted on top the toy locomotive (which gives the best curve known for an automobile-type antenna), as given in **Figs. 21** and **22**. In this case the energy is concentrated backward toward the largest mass of metal. A calculation of gain from the patterns as shown for both antennas reveals that the average gain for the circular unit is −1.20 decibels and for the vertical unit is −1.34 decibels compared with a free-space vertical antenna. The direction of lowest signals gives −4.6 decibels and −4.4 decibels, respectively. The physical advantage of the circular antenna is obvious.

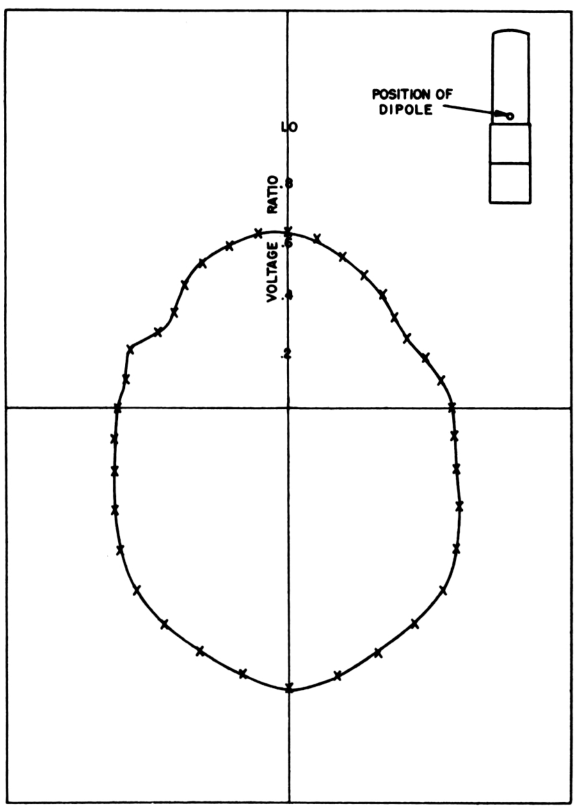

Fig. 21. Measured horizontal pattern of scale-model vertical "whip" antenna mounted on toy locomotive

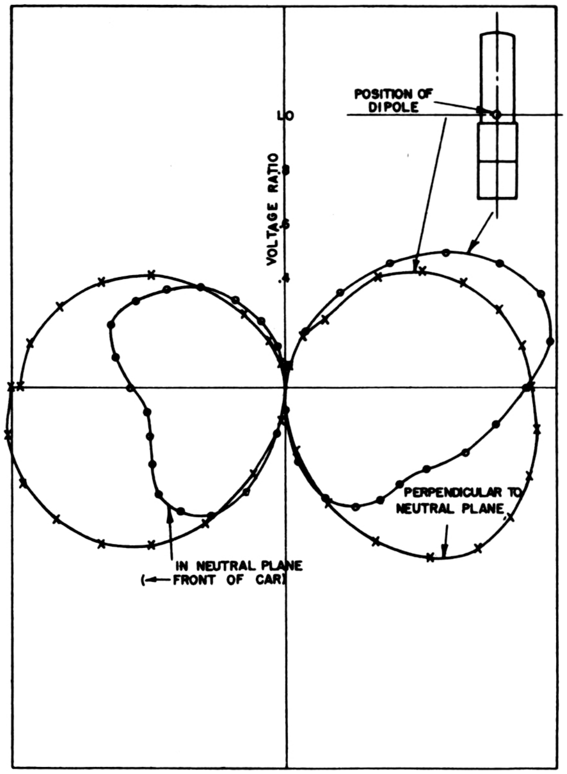

Fig. 22. Measured vertical patterns of scale-model "whip" antenna mounted on locomotive model

Features

This new antenna has the following features:

(1). A simple horizontally polarized antenna with only two terminals, yet essentially uniform in its horizontal radiating properties.

(2). Low mutual between vertical bays, which greatly improves adjustments of multi-bay installations.

(3). Ability to cover a wide frequency range, by simple means, with one physical structure.

(4). A system that is easily mounted to a pole of any diameter and grounded to that pole to provide lightning protection.

(5). A system that may be applied to metallically covered cars to an advantage.

(6). Improvement in gain per bay over existing units in the field.

(7). A design which permits sleet-melting readily if desired.

(8). A design which is pleasing in appearance.

Acknowledgment

The writer is indebted to H. P. Thomas for information on the cubical antenna, to L. M. Leeds who collaborated with the author on the circular antenna, to W. F. Goetter for contributing the means for transmission-line surge-impedance control, and to Dr. P. C. Michel for his contributions in the special measuring equipment used in the impedance measurements.

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