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Directional VHF Antennas

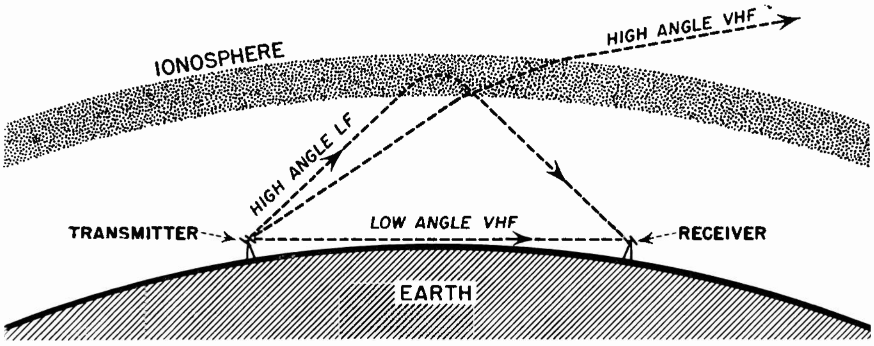
Part 2, Practical Designs

By the Engineering Department, Aerovox Corporation

THE AEROVOX RESEARCH WORKER for July, 1949 contained a discussion of the fundamental properties of the half-wave dipole antenna and defined three basic configurations in which multiple dipoles are used to obtain desirable directional effects in transmitting or receiving radio signals. These arrangements included; collinear dipoles, broadside dipoles, and end-fire dipoles of both the driven and the parasitically excited types. Approximate figures for the power gains of these systems of dipole antennas, as compared with the field radiated by a single dipole, were also given. This issue will describe several typical examples of practical antenna designs which make use of these types of directivity and which are applicable in the VHF region for FM, amateur radio, citizens radio (although not in the VHF band) and other point-to-point communication circuits. The method used for estimating the approximate power gain of a complex antenna array which uses more than one of the basic dipole combinations will also be illustrated. The following issue will detail the design and construction of a high-gain, all-channel television antenna.

Since radio waves in the VHF range (30 to 300 Mc.) are not normally reflected by the ionosphere, most antenna systems used at these frequencies are designed to radiate energy at low vertical angles. As shown by Fig. 1, VHF waves radiated at angles much above the horizontal penetrate into space, and are wasted. Therefore, a low angle of radiation is an important prerequisite for VHF antennas.

Power gains as great as 100 times (20 db.) can be conveniently achieved at the shorter wavelengths. Thus, a 10 watt transmitter used in conjunction with such an antenna would produce the same field strength in the favored direction as a 1000 watt transmitter coupled to a single half-wave dipole. These gains are produced by arranging various combinations of dipoles so that the radiation from all are additive in the desired direction, and cancel in the other directions in the manner discussed in Part 1. High antenna gain is thus usually achieved at the expense of angular coverage, i. e., the width of the radiation pattern decreases with increased gain.

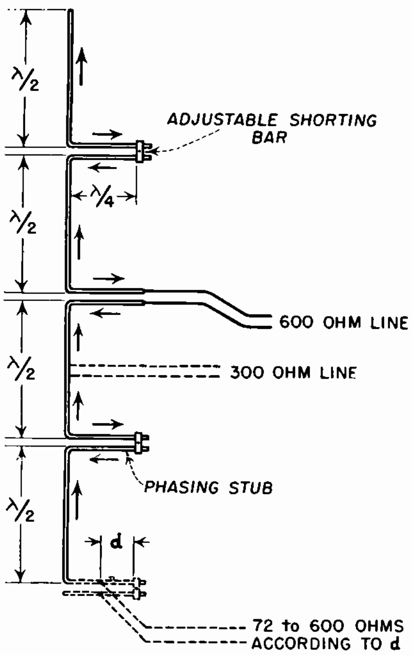


SHOWING IMPORTANCE OF LOW ANGLE RADIATION FOR VHF PROPAGATION
FIG. 1

A Vertical Collinear Array

There are applications, however, where an *omnidirectional* radiation pattern is required, and yet signal gain over a simple half-wave dipole would be desirable. Services such as police and taxi-cab mobile radio require fixed transmitting antenna systems for dispatching which are capable of radiating equally well in all compass directions. Power gains up to at least 6 db. (four times) can be obtained by the use of vertically stacked, vertical half-wave elements. The resulting collinear array maintains the 360 degree horizontal coverage of a single vertical dipole, but concentrates more of the radiated power at the more useful low angles of radiation. The vertical directivity becomes sharper as more dipole elements are added on the same axis, but the increasing height of the array limits the number used in practice, especially at the lower frequencies.

In the practical design of such an array, it is necessary to provide phase-



VERTICAL COLLINEAR ARRAY
FIG.2

reversing sections between each pair of collinear dipoles so that all elements radiate in-phase. This is usually accomplished with a phasing stub consisting of a shorted quarter-wave section of transmission line inserted between each pair of collinear radiators. Fig. 2 illustrates this arrangement. The entire collinear array may be thought of as a straight wire antenna several wavelengths long, in which the alternate half-wavelengths are folded up to prevent radiation from them. It is necessary to suppress the radiation from these alternate half-wave sections of the wire since the currents in them, and hence the radiated fields, are 180 degrees out-of-phase with those of the half-wave adjacent sections, so that cancellation of the desired radiation in the plane perpendicular to the axis of the array would occur.

Provision is usually made for adjustment of the length of the phasing stubs with frequency. The dotted lines in Fig. 2 show several alternate methods of feeding a collinear array. In most cases, a feed point near the center is desirable to provide symmetry of currents in the elements.

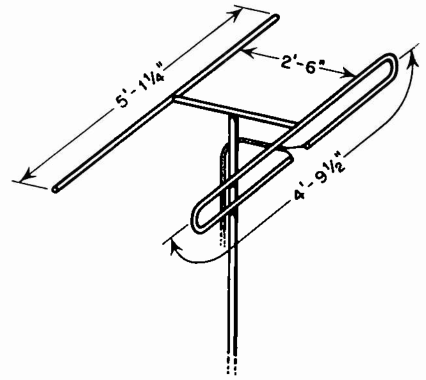
As mentioned in Part 1, the gain in decibels of a collinear array is approximately equal to the number of radiating dipoles used, if less than about eight. Because of the frequency sensitivity of the many tuned elements of this type of antenna, it may be used only over a relatively small frequency range.

A Simple FM Antenna

A two element array which has been used to some extent for FM reception is shown in Fig. 3. The folded dipole driven element provides an effective match to standard 300 ohm twin-lead, and has a frequency characteristic which is sufficiently broad to permit coverage of the 88 to 108 megacycle FH band presently used. A single parasitic reflector is used to provide about 4 db. gain. The reflector is wide-spaced to prevent lowering the dipole radiation resistance and decreasing the bandwidth.

The folded dipole and reflector should be constructed of copper or aluminum tubing about three-eighths inch in diameter. A metal boom may be used to support and space the elements at the points shown in the figure since the r.f. voltage at these points is zero. The length of the folded dipole in feet is determined from the practical formula; 468 divided by the operating frequency in megacycles. In this case, the FM mid-band frequency of 98 megacycles is used and the length of the dipole is measured to the centers of the shorting-bars, as shown in the figure.

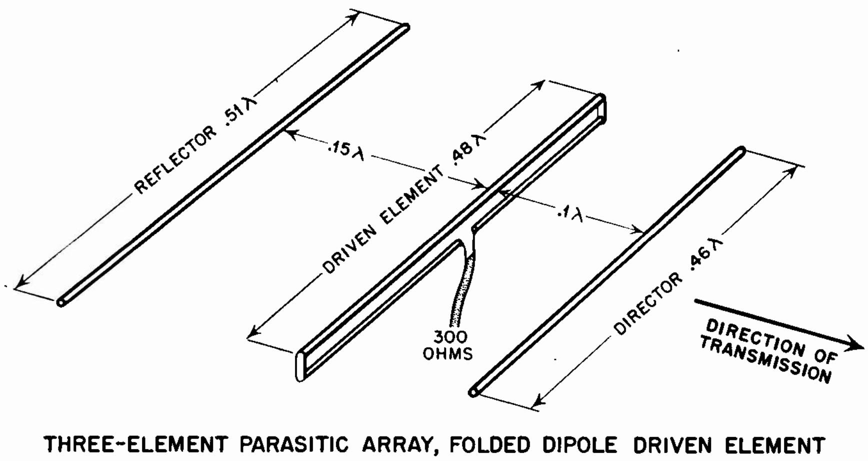
In some instances, especially for indoor use, folded dipole elements are constructed of 300 ohm twin-lead. This construction lends mechanical simplicity, but does not result in a folded dipole of optimum bandwidth characteristics. This is because the folded dipole derives its broad-band frequency characteristics from the fact that the feeding point impedance is determined by two distinct resonances in the folded structure; one is the resonance of the arms acting as a simple dipole antenna in which the feeding impedance becomes inductive as the frequency increases beyond resonance, and the other is the resonance of the arms acting as folded quarter-wave transmission line sections in which the input impedance becomes capacitative as the frequency is raised. These two reactances of oppositely-varying sign tend to cancel over a wide range of frequency and result in the feeding point impedance being more nearly a pure resistance for a properly constructed folded dipole. If a dielectric other than air is used between the conductors, however, the propagation constant of the folded transmission line sections is altered, with the result that they are no longer resonant at the same center frequency as the overall antenna considered as a dipole. Therefore, the advantageous cancellation of reactances does not occur and the broad-band performance of the folded dipole is impaired.



A SIMPLE F-M ANTENNA
FIG.3

A Three Element Parasitic Array

In amateur practice, and other point-to-point communication where unidirectional radiation characteristics are necessary to reduce interference, close-spaced beam antennas of the type shown in Fig. 4 have proven capable of excellent performance. This typical array consists of a folded dipole driven element and parasitically excited director and reflector



THREE-ELEMENT PARASITIC ARRAY, FOLDED DIPOLE DRIVEN ELEMENT
FIG.4

elements, spaced .1 and .15 wavelengths from the driven element respectively.

A polar diagram of the radiation pattern of this configuration, taken in the plane of the elements, is shown in Fig. 5. The corresponding pattern for a dipole antenna, radiating an equal amount of power, is shown in dotted lines for comparison. Since radius is proportional to power in this diagram, the power gain in db. of the array over the comparison dipole "standard" is given by the formula;

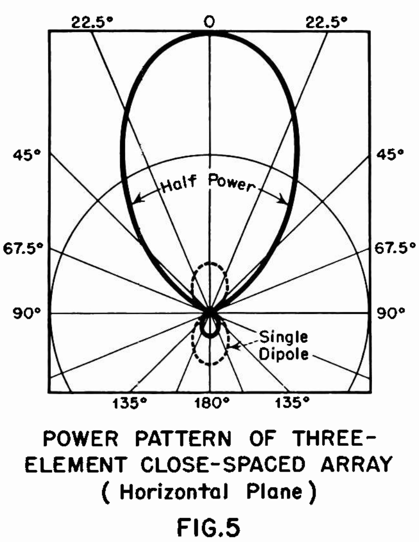
$$\text{(4)} \quad \text{POWER GAIN (db)} = 10 \log_{10} \frac{P_1}{P_2}$$

Where; P_1 is the maximum radius of the array pattern.

P_2 is the maximum radius of the dipole pattern.

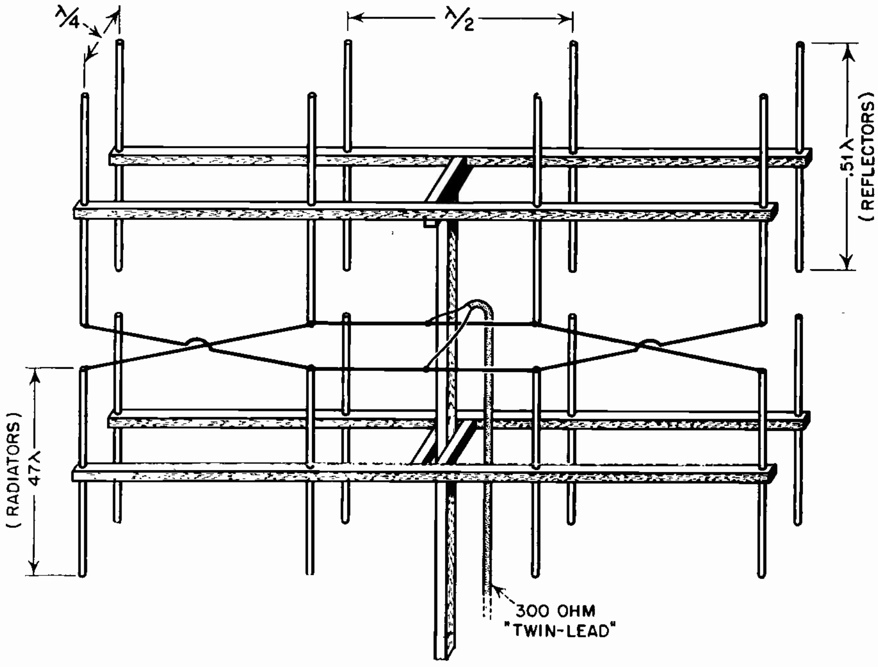
In this particular case, the ratio P1/P2 is about 5.4 and the gain is therefore found to be 7.3 db. The width of the radiation pattern, which is usually measured at the half-power points, is approximately 70 degrees.

When close-spaced parasitic elements are added to a dipole radiator, the normal radiation resistance, which approaches 73 ohms for a thin dipole in free space, is greatly reduced and may be as low as 8 ohms for the three element antenna shown. For this reason it is not practical to feed the array at the center of the driven element unless means are employed to transform this low center impedance to a higher value which can be matched to available transmission lines. A convenient method of accomplishing this impedance transformation is again by the use of the folded dipole, but since the impedance step-up ratio of a folded dipole having two conductors of equal size is only 4-to-1, a more elaborate system must be resorted to. Assuming a radiation resistance of 8 ohms for the array, the 9-to-1 impedance step-up of a three-conductor folded dipole could be used to match the antenna to 72 ohm transmission line or a folded dipole having unequal conductor sizes may be used. A conductor size ratio of 4-to-1, spaced about six times the radius of the small conductor, will give the high impedance step-up necessary to match the popular 300 ohm twin-lead.



POWER PATTERN OF THREE-ELEMENT CLOSE-SPACED ARRAY (Horizontal Plane)

FIG.5



16-ELEMENT VHF ARRAY

FIG.6

As a natural consequence of the use of close-spaced, parasitic elements, the frequency response of such an array is considerably less than that of the radiator used alone. This reduction of the operating bandwidth results from the reduction of the radiation resistance, which is inversely proportional to the antenna Q as is shown by Eq. 3 in Part 1. Directive antennas with greater element spacings are somewhat less frequency selective.

A Complex "Billboard" Array

An excellent example of a high-gain VHF antenna which uses collinear, broadside, and end-fire parasitic dipole combinations is shown in Fig. 6. It consists of two half-wave spaced broadside arrays of 4 elements each, stacked collinearly and backed up by 8 wide-spaced reflector elements, for a total of 16 elements. Each of the 8 driven elements is fed in-phase by a high-impedance, transposed-line, phasing section. Note that the driven elements are end-fed for a high input impedance. With the dimensions shown, the input impedance at the center of the phasing section is a reasonable match to 300 ohm transmission line.

Power gain exceeding 13 db. (20 times) can be obtained without critical adjustment of element lengths or spacing. The manner in which the gain of such an array of dipoles may be estimated from the figures given in Part 1 is as follows; four broadside dipoles give a gain of about 7 db. which is bidirectional and the addition to another set of dipoles collinear with them adds 2 db., which makes 9 db. for the eight driven elements. The use of parasitic reflectors behind each radiator contributes an additional 4 db., for a total of about 13 db. A plane reflector made of metal or small-mesh metal screen may be used in place of the dipole reflectors for slightly greater gain. The radiation is now essentially unidirectional and the pattern is rather narrow in either plane.

The mounting illustrated is for vertical polarization. The array may be used for horizontally polarized waves by rotating it 90 degrees in the same plane. The physical size of such complex VHF antennas become prohibitive at frequencies much below 100 megacycles, but their effectiveness has warranted their widespread use in commercial communication circuits, for radar sets operating at the lower frequencies, and for amateur radio applications in the VHF bands.

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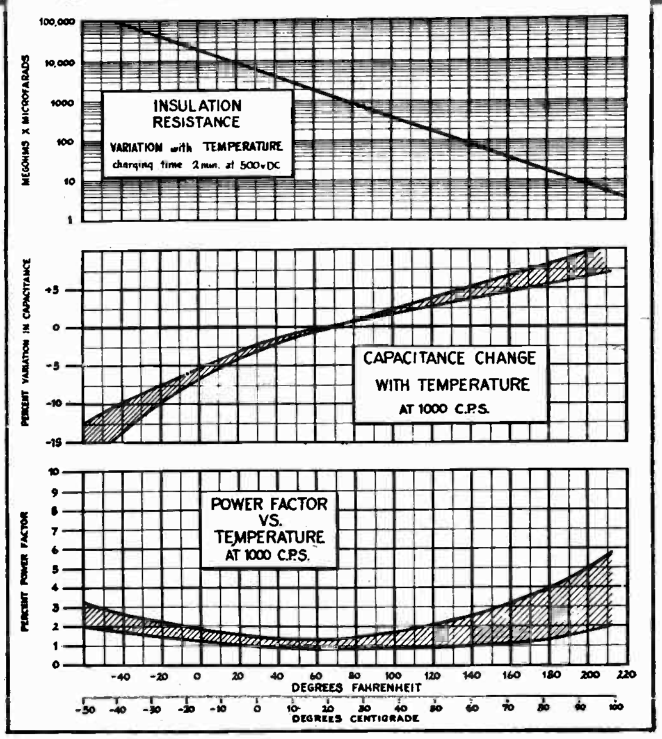

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