International Telecommunication Union

ITU-R

Radiocommunication Sector of ITU

Recommendation ITU-R BT.1195-1

(01/2013)

Transmitting antenna characteristics at VHF and UHF

BT Series

Broadcasting service (television)

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Note: *This ITU-R Recommendation was approved in English under the procedure detailed in Resolution ITU-R 1.*

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RECOMMENDATION ITU-R BT.1195-1

Transmitting antenna characteristics at VHF and UHF

(Question ITU-R 30/6)

(1995-2013)

The ITU Radiocommunication Assembly,

considering

a) that, by Resolution 76-1, the ex-CCIR has decided that the results of the studies carried out by Radiocommunication Study Group 10 and the related antenna diagrams should be contained in ITU-R Recommendations separately published;

b) that comprehensive information on the characteristics of transmitting and receiving antenna systems at VHF and UHF is required for frequency planning;

c) that computer-based procedures are required to give, in a standardized form, the gain and directivity patterns of transmitting and receiving antenna systems;

d) that it is essential to verify both the antenna system element radiation pattern and the overall antenna system radiation pattern by measurements;

e) that standardized measurement methods are required to verify the radiation patterns mentioned in *considering* d);

f) that differences are to be expected between theoretical and measured performance due to practical aspects of VHF and UHF antennas,

recommends

1 that the formulae contained in Part 1 of Annex 1 and the associated computer programs described in Part 3 of Annex 1 should be used to evaluate VHF and UHF antenna systems performances for planning purposes;

2 that the measurement methods contained in Part 2 of Annex 1 should be used to verify the practical performances of the antenna system elements and of the overall antenna system.

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Annex 1

PART 1

VHF and UHF transmitting antenna pattern calculation

Table of Contents

		Page
1	Introduction	4
1.1	Reference frames	4
2	Geometrical representation of antenna radiation patterns	5
3	Radiation patterns and gain calculation	6
4	Radiating elements	7
4.1	Point sources	7
4.2	Arrays of point sources	9
4.2.1	Pattern multiplication	9
4.2.2	Vectorial pattern addition	9
4.3	VHF and UHF elementary radiators	10
5	Polarization	11
5.1	Elliptical polarization	11
5.2	Horizontal and vertical polarization	12
5.3	Slant polarization	12
5.4	Circular polarization	12
6	Antenna arrays	13
6.1	Broadside arrays	13
6.1.1	Linear antenna arrays with parasitic elements	16
6.2	The amplitude and phase radiation patterns	18
6.3	Calculation of the radiation pattern of antenna arrays	20
6.4	VHF and UHF antenna arrays	21
6.4.1	Panel type antennas	21
6.4.2	Yagi antennas	24
6.4.3	Other types of antenna array	24
7	Antenna systems	24

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Page

7.1 The antenna system pattern 25

7.1.1 Null filling 25

7.1.2 Beam tilting 28

7.2 Antenna system radiation patterns 29

7.3 Examples of antenna system pattern 32

7.3.1 Dipole antenna systems 32

7.3.2 Yagi antenna systems 33

7.3.3 Panel antenna systems 34

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PART 1

to Annex 1

VHF and UHF transmitting antenna pattern calculation

1 Introduction

This Part briefly summarizes the basic theoretical principles of VHF and UHF antennas and the general characteristics of antenna systems realized by a number of individual radiators.

Some examples of antenna systems are also given in order to show their performance and orientate the user in selecting the configuration that best suits the requirements.

In particular § 6.4 and § 7.2 give the analytical procedure to calculate the overall radiation pattern of an antenna system. The aim of this section is to provide a recommended unified approach to evaluate the performance of an antenna system in ideal conditions.

However, it is to be borne in mind that deviations from the patterns calculated according to the above procedure can be encountered in practical situations as described in Part 2.

1.1 Reference frames

In the Radio Regulations, the horizontal angle of the "beam" of an antenna (the "beam tilt") is specified in degrees relative to the horizontal; a downward tilt being a negative angle. Beam azimuth is specified in degrees measured clockwise from true north. For regulatory purposes, it is essential that a common frame of reference, such as that enshrined in these definitions, is used to ensure that the effect of the beam of one antenna is properly considered in relation to the intended service area of another. This Recommendation, however is concerned with the properties of the antenna itself and the mathematical formulae are more tractable and less cumbersome if:

– a reference frame related to the antenna itself is used; and

– all angles are in radians rather than degrees.

Throughout the Recommendation both polar and Cartesian coordinates are used as appropriate. Polar coordinates use:

r – distance from the origin, θ – elevation angle, and φ – azimuth angle

Cartesian co-ordinates use:

x – arbitrary horizontal axis, y – arbitrary horizontal axis (orthogonal to x), and z – vertical axis

The "x" axis is frequently the axis of the main beam of the antenna. Where these coordinate systems are "overlaid", the common reference (r, $\theta = 0$, $\varphi = 0$) is taken to be the x-axis.

It is important to note that when considering the service area of the antenna and its potential effects on the service area of others, the beam direction must be referenced back to true north.

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2 Geometrical representation of antenna radiation patterns

An antenna can consist of a single element or an array of radiating elements. The spatial radiation distribution, or pattern, of an antenna can be represented by a three-dimensional locus of points, with each point having a value of cymomotive force (c.m.f.)*, based on a sphere centred at the electrical centre of the antenna and of radius which is large compared to the physical and electrical dimensions of the antenna.

The c.m.f. at a point on the sphere is indicated in dB below the maximum c.m.f., which is labelled 0 dB.

The three-dimensional radiation pattern is based on the reference coordinate system of Fig. 1.

The following parameters are defined:

θ : elevation angle from the horizontal ($-\pi/2 < \theta < \pi/2$) negative angles represent downward beam tilt;

φ : azimuthal angle from an x-axis ($0 < \varphi < 2\pi$);

r : distance between the origin and the observation point;

Q : observation point.

The x, y and z axes are a set of orthogonal Cartesian coordinates over which the polar coordinates are sometimes laid to aid the mathematical representation of certain of the properties of the antenna. While the ‘z’ axis is always vertical, the ‘x’ and ‘y’ axes are chosen to best represent the antenna and its characteristics.

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* Definition of cymomotive force and specific cymomotive force (see Recommendation ITU-R BS.561).

The cymomotive force at a given point in space is the product of the electric field strength at that point produced by the antenna and the distance from that point to the antenna. This distance must be large enough for the reactive components of the field to be negligible.

The c.m.f (V) is numerically equal to the electric field strength (mV/m) at a distance of 1 km.

The specific cymomotive force at a point in space is the c.m.f. at that point when the power radiated by the antenna is 1 kW.

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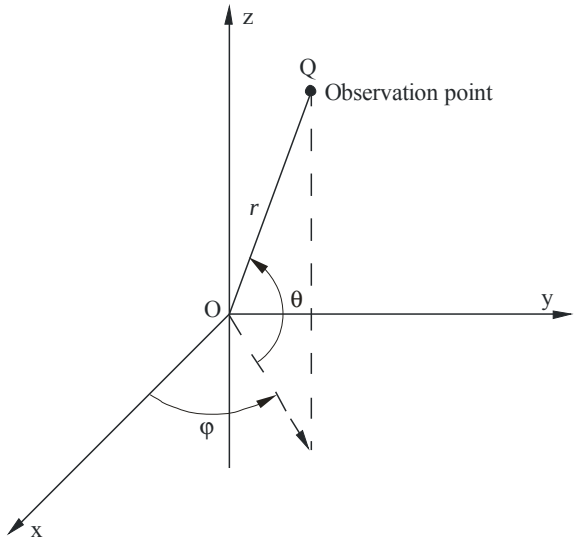
FIGURE 1

The reference coordinate system



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3 Radiation patterns and gain calculation

In the reference coordinate system of Fig. 1, the magnitude of the electrical field contributed by an antenna is given by the following expression:

$$|E(\theta, \varphi)| = k\,|f(\theta, \varphi)| \tag{1}$$

where:

$|E(\theta, \varphi)|$: magnitude of the electrical field;

$|f(\theta, \varphi)|$: radiation pattern function;

k: normalizing factor to set $|E(\theta, \varphi)|_{max} = 1$, i.e. 0 dB.

Expressing the total electrical field in terms of its components in a spherical coordinate system, gives:

$$|E(\theta, \varphi)| = \left[|E_\theta(\theta, \varphi)|^2 + |E_\varphi(\theta, \varphi)|^2 \right]^{1/2} \tag{2}$$

The directivity, D, of a radiating source is defined as the ratio of its maximum radiation intensity (or power flux-density) to the radiation intensity of an isotropic source radiating the same total power. It can be expressed by:

$$D = \frac{4\pi\,|E(\theta, \varphi)|^2_{max}}{\int_0^{2\pi}\int_{-\pi/2}^{\pi/2} |E(\theta, \varphi)|^2 \cos\theta\, d\theta\, d\varphi} \tag{3}$$

When equation (1) is applied, D can be expressed in terms of the normalized radiation pattern function of the source, $|f(\theta, \varphi)|$:

$$D = \frac{4\pi |f(\theta, \varphi)|^2_{max}}{\int_0^{2\pi}\int_{-\pi/2}^{\pi/2} |f(\theta, \varphi)|^2 \cos\theta\, d\theta\, d\varphi} \tag{4}$$

The above definition of directivity is a function only of the shape of the source radiation pattern.

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To take into account the antenna efficiency, it is necessary to define its gain G, expressed as a ratio of its maximum radiation intensity to the maximum radiation intensity of a reference antenna with the same input power.

When a lossless isotropic antenna is taken as the recommended reference antenna, the gain, G_i, is expressed by:

$$G_i = 10 \log_{10} D \qquad \text{dB} \tag{5}$$

Another expression used in practice is the gain relative to a half-wave dipole, G_d, that is:

$$G_d = G_i - 2.15 \qquad \text{dB} \tag{6}$$

4 Radiating elements

4.1 Point sources

When the radiation from an antenna is in the far field condition (Fraunhofer zone), i.e. when the distance from the antenna is such that its electromagnetic fields can be taken as being orthogonal to the direction of propagation, the antenna can be considered as a point source.

At VHF and UHF, this distance is usually so small that, particularly in the service area, any radiating element can be considered as a point source, regardless of its size and complexity.

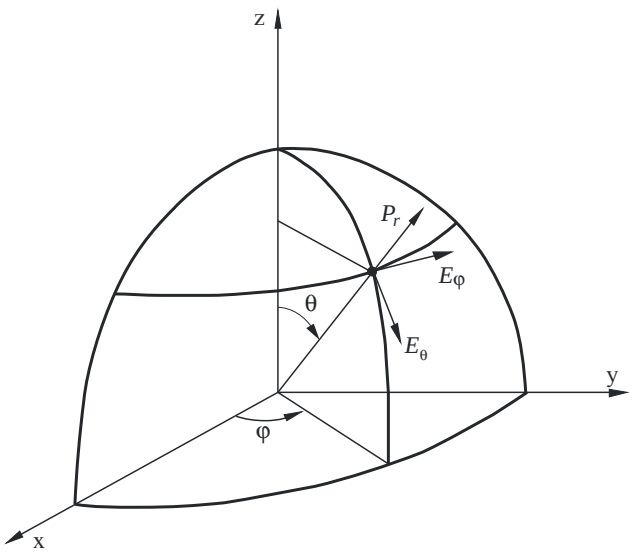
Furthermore, the radiation pattern of these point sources, used as an approximation of typical VHF and UHF radiating elements, is usually directional.

In far field conditions the power flux from a point source is always radial.

The Poynting vector results therefore only from two transverse electrical field components E_θ and E_φ as shown in Fig. 2.

FIGURE 2

Relation of the Poynting vector and the electrical far field components



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When the spherical wave front is at a sufficiently large distance that it can be considered as a plane, the average Poynting vector (radial component only) P_r is given by:

$$P_r = \frac{E_2}{2Z_0} \tag{7}$$

where:

$$E^2 = E_\theta^2 + E_\varphi^2 \tag{8}$$

and:

Z_0: intrinsic impedance of free space

E: total electrical field intensity.

Considering the variation of the total electrical field strength at a constant radius, the resulting pattern will be a function of θ and φ. Normalizing the pattern values with respect to its maximum value (assumed in the direction of maximum radiation) the resulting pattern is called a relative amplitude radiation pattern.

The electrical field strength E generated at a distance r by an isotropic source radiating a power P_{is} is given by (see also Recommendation ITU-R P.525):

$$E = \left[30\, P_{is} / r^2\right]^{1/2} \qquad \text{V/m} \tag{9}$$

where:

P_{is}: isotropic power (W)

r: distance (m)

The above relation is also known as the free-space propagation condition.

Referring the isotropic radiated power P_{is} to the half-wave dipole radiated power P, i.e., $P_{is} = 1.64\, P$, the expression of the electrical field strength becomes:

$$E = 7.014 \sqrt{P} / r \qquad \text{V/m} \tag{10}$$

Expressing E in mV/m and r in m:

$$E = 7.014 \times 10^3 \sqrt{P} / r \qquad \text{V/m} \tag{11}$$

or, expressing E in dB(μV/m)

$$E = 20 \log_{10}\left(\sqrt{P} / r\right) + 136.9 \qquad \text{dB(μV/m)} \tag{12}$$

Considering a non-isotropic point source, the electrical field strength E_{ni} radiated in the different directions will be affected by the radiation pattern, so that

$$E_{ni} = \mathrm{f}(\theta, \varphi) \cdot E_{is} \tag{13}$$

where:

E_{ni}: electrical field strength generated at the observation point Q (r, θ, φ) by a non-isotropic point source radiating power P

f(θ, φ): relative amplitude radiation pattern function of the non-isotropic point source

E_{is}: electrical field strength generated at the observation point Q by an isotropic point source radiating the same power P

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4.2 Arrays of point sources

When considering arrays of point sources such as those normally encountered at VHF and UHF where complex antenna systems are often required, the following two cases are of immediate interest:

a) arrays of non-isotropic, similar point sources;

b) arrays of non-isotropic and dissimilar point sources.

Case a) refers to arrays whose elements have equal relative amplitude radiation patterns (same shape) oriented in the same direction. This is normally the case of an array of vertically stacked panel antennas (see § 6.4.1) beaming toward the same direction.

Case b) is the most general case where no correlation exists between the relative amplitude radiation patterns of the array sources which may arbitrarily be oriented.

4.2.1 Pattern multiplication

For arrays of non-isotropic but similar point sources (case a) of § 4.2), the principle of pattern multiplication applies. According to this principle, the relative amplitudes of the radiation pattern of an array of non-isotropic but similar point sources is the product of the amplitude pattern of the individual source and that of an array of isotropic point sources, while the total phase pattern results from the sum of the phase patterns of the individual source and that of the array of isotropic point sources.

This can be expressed by:

$$E(\theta, \varphi) = f(\theta, \varphi) \cdot F(\theta, \varphi) \qquad \angle \left(f_p(\theta, \varphi) + F_p(\theta, \varphi) \right) \tag{14}$$

where, according to the coordinate system shown in Fig. 1:

E: vector of the electrical field strength

$f(\theta, \varphi)$: relative amplitude radiation pattern function of the individual source

$f_p(\theta, \varphi)$: phase radiation pattern function of the individual source

$F(\theta, \varphi)$: relative amplitude radiation pattern function of the array of isotropic sources (also called array factor)

$F_p(\theta, \varphi)$: phase radiation pattern function of the array of isotropic sources.

4.2.2 Vectorial pattern addition

When the more general case of an array of dissimilar non-isotropic point sources is considered (i.e. non-isotropic sources having different radiation pattern and/or different orientation of the maximum radiation direction, case b) of § 4.2), the principle of pattern multiplication can no longer be applied.

This is a typical situation for VHF and UHF antenna systems, where the radiating elements (panels, Yagi, etc.) are considered as point sources with similar or dissimilar radiation patterns oriented in different directions.

In this case, the resulting radiation pattern $\boldsymbol{E}(\theta, \varphi)$ is calculated by a vectorial addition of the radiation (amplitude and phase) of each individual point source at any specified angle, as follows:

$$\boldsymbol{E}(\theta, \varphi) = \sum_{i=1}^{n} E_i(\theta, \varphi) \tag{15}$$

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where:

$E_i(\theta, \varphi)$: radiated electrical field of the i-th source

$\boldsymbol{E}(\theta, \varphi)$: resulting field strength.

4.3 VHF and UHF elementary radiators

Although elementary radiators are seldom individually used in VHF and UHF broadcasting, a brief survey will be given of the most common elementary radiators which are used to form the majority of the VHF and UHF antenna systems.

The basic radiators are: the dipole, the loop, the slot and the helix.

The dipole is the most common elementary radiator at VHF and UHF.

In the coordinate system of Fig. 3, the field components E_θ and E_φ produced by a dipole of length ℓ with sinusoidal current distribution are:

$$E_\theta = -60\,\mathrm{j}\,I_0 \frac{\mathrm{e}^{-\mathrm{j}\,r\,\beta}}{r} \cdot \frac{\cos(\beta\ell \sin\varphi \cos\theta)/2 - \cos\beta\ell/2}{1 - \sin^2\varphi \cos^2\theta} \cdot \sin\varphi \sin\theta$$

$$E_\varphi = 60\,\mathrm{j}\,I_0 \frac{\mathrm{e}^{-\mathrm{j}\,r\,\beta}}{r} \cdot \frac{\cos(\beta\ell \sin\varphi \cos\theta)/2 - \cos\beta\ell/2}{1 - \sin^2\varphi \cos^2\theta} \cdot \cos\varphi \qquad (16)$$

where:

I_0: feed current

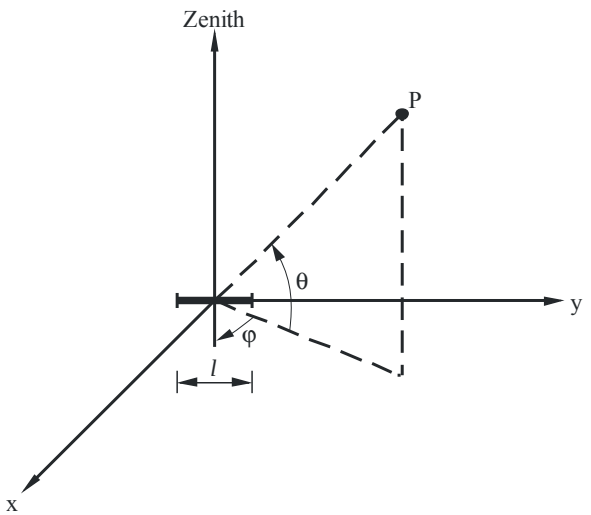
$\beta =$ $2\,\pi/\lambda$

r: distance of the point Q of calculation.

The above expression simplifies for $l = 0.5\,\lambda$ (see also CCIR Antenna Diagrams, edition 1984).

FIGURE 3

Elementary dipole in the reference coordinate system



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In this case, the dipole offers a 72 Ω resistive impedance at its resonant frequency and can be considered equivalent to a series resonant circuit.

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Increasing the diameter of the conductor that forms the arms of the dipole has the effect of increasing the capacity and decreasing the inductance in the equivalent series resonant circuit. Since the Q of the circuit is consequently lowered, the dipole can operate over a wide frequency range.

5 Polarization

Traditionally horizontal polarization has been used for FM broadcasting and horizontal or vertical polarization for TV broadcasting.

In recent years, the wide-spread use of FM receivers with built-in antennas and FM car radios has brought about the use of other forms of polarization e.g. circular and slant.

This technique is now also being introduced for TV transmission, especially at UHF, where circular polarization seems to offer better performance in reducing "ghost" images in urban areas.

Report ITU-R BS.464 gives the necessary information for the selection of the most suitable polarization to be used for any new FM service, according to the individual circumstances.

A brief summary of the various forms of polarization is given below to allow for a better evaluation of their differences.

5.1 Elliptical polarization

The different forms of wave polarization may be considered as special cases of the more general case of elliptical polarization.

Referring to Fig. 4, an elliptically polarized wave may be represented by two mutually perpendicular linear waves, propagating along the z-axis and having the respective electrical fields expressed by:

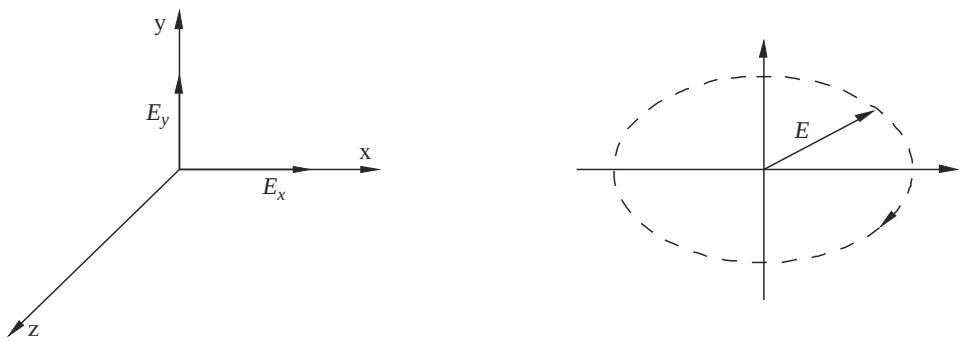
$$E_x = E_1 \sin \omega t$$

$$E_y = E_2 \sin (\omega t + \varphi) \qquad (17)$$

where φ is the phase difference between the two waves. When the elliptically polarized wave travels along the z-axis, the resulting E vector describes an ellipse whose semi-axes are given by E_1 and E_2.

FIGURE 4

Elliptical polarization



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5.2 Horizontal and vertical polarization

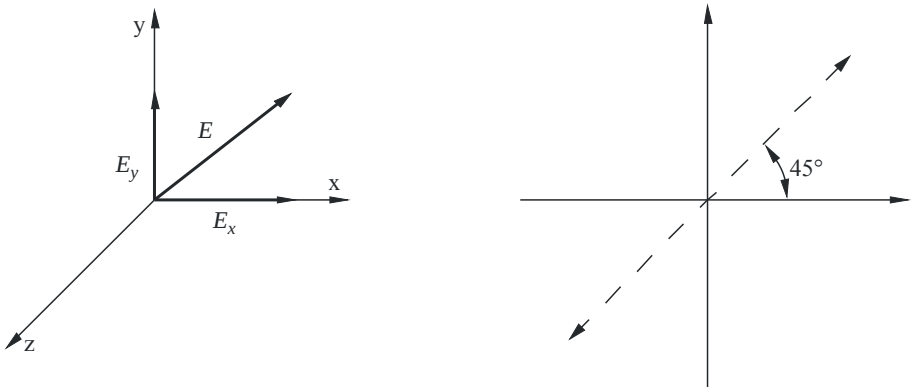
These two cases occur when in equation (17) either $E_y = 0$ (horizontal polarization) or $E_x = 0$ (vertical polarization).

5.3 Slant polarization

A 45° slant polarization occurs when in equation (17) $E_1 = E_2$ and $\varphi = 0$.

FIGURE 5

Slant polarization



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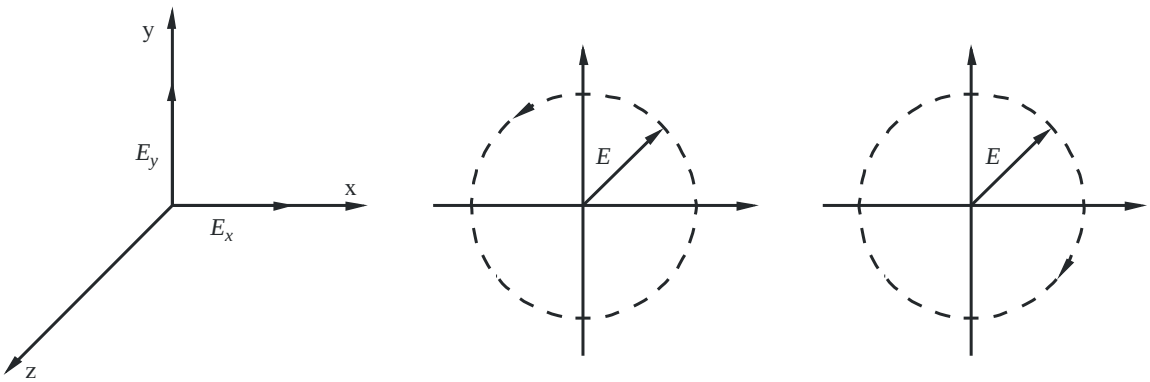
5.4 Circular polarization

Circular polarization occurs when in equation (17), $E_y = E \sin \omega t$ and $E_x = \pm E \cos \omega t$. When the sign is positive, the rotation of the wave is clockwise in the positive z-axis direction (right-hand circular polarization).

When the sign is negative, left-hand circular polarization occurs:

FIGURE 6

Circular polarization



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Circular or slant polarizations can be produced by using two linearly polarized antennas respectively radiating vertical and horizontal polarization in the appropriate phase relationship as given above.

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6 Antenna arrays

As mentioned in § 4.3, at VHF and UHF elementary radiators are very seldom used individually and are usually assembled in arrays to achieve:

– higher gain;

– unidirectional pattern.

The most frequently used arrays are linear arrays of elementary radiators. These arrays assembled by the manufacturer, are available to the design engineer in a variety of forms e.g. dipole, Yagi, panel antennas, etc. They are then used to form more complex antenna systems (i.e. arrays of arrays).

In most of the cases these arrays have unidirectional patterns obtained by the use of a reflector which according to the specific case, may be a reflecting metallic surface or a suitable parasitic or active element.

The following sections give some of the fundamental properties of specific linear arrays, which are of immediate use to the designer of antenna systems, e.g. broadside and collinear arrays and linear arrays with parasitic elements.

6.1 Broadside arrays

Broadside arrays are easily realized by feeding the elements of a linear array with currents having the same amplitude and phase. The resulting pattern has its maximum (or maxima if no reflector is provided) oriented toward the perpendicular to the line of the array (or to the plane containing the radiating sources).

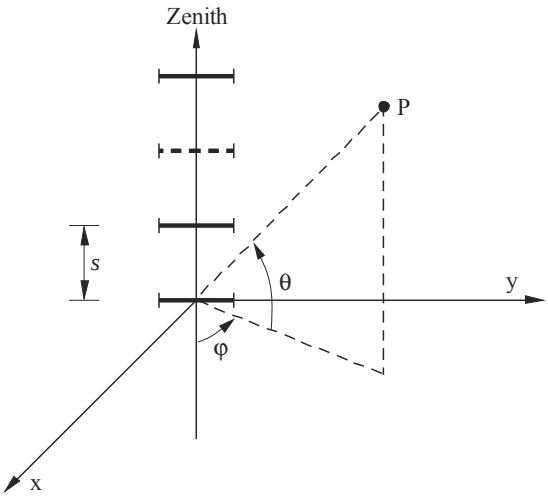
At VHF and UHF, there are two types of broadside arrays which are of immediate interest to the designer: the horizontal dipole vertical array and the vertical dipole omnidirectional collinear array.

Horizontal dipole vertical arrays

Horizontal dipole vertical arrays have a repetitive structure (see Fig. 7) consisting of a vertical stack of equally spaced horizontal dipoles (usually 0.5 λ) fed with currents having the same amplitude and phase.

FIGURE 7

Horizontal dipole vertical array



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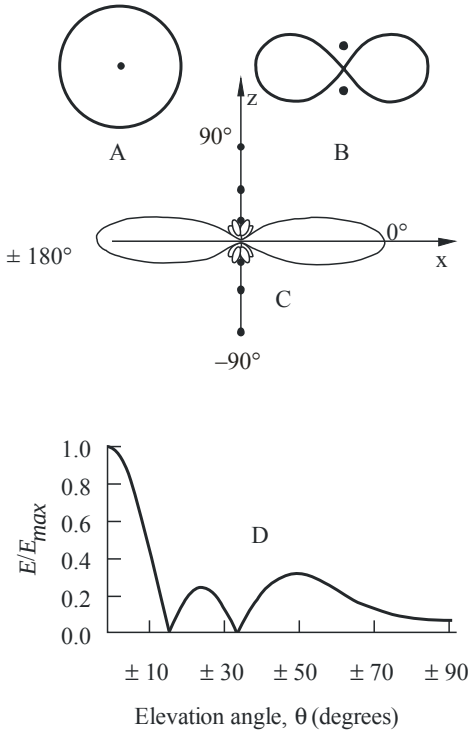
Typical patterns of this type of array (in the x-z plane) are shown in Fig. 8.

FIGURE 8

Effect of stacking several point sources having equal currents and phase



A: vertical pattern of single source
B: two sources
C: six sources
D: vertical pattern of C in cartesian coordinates

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It is important to note that the gain of the array is a function of the number of elements and their spacing (and hence of the length of the array).

This relationship is shown in Fig. 9, where it can be seen that depending on the value of *n*, the optimum spacing lies in the range 0.65-0.95 λ. It should be stressed that this optimum spacing is frequency dependent, and that when an antenna system is designed for wide-band (or for adjacent channels) operation, a safety margin should be taken to avoid the steep reduction of gain which occurs at spacing values exceeding the optimum. Usual spacing values for this type of array for individual panel antennas with *n* up to 4 elements, are of the order of 0.5 λ.

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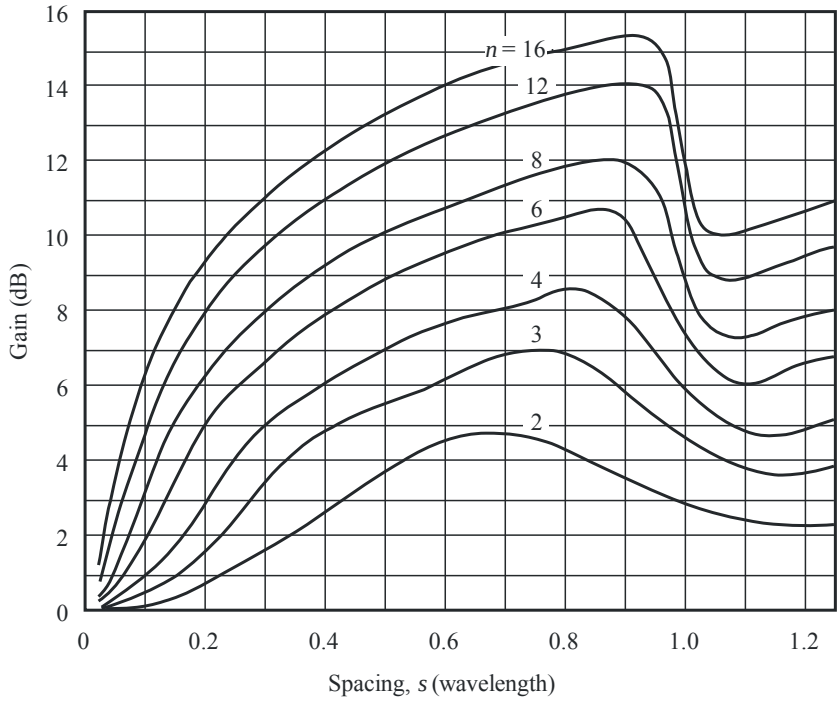
FIGURE 9

Gains of horizontal dipole vertical array (without reflector) as a function of the number *n* of elements and their spacing *s*. The gain is referred to that of a single element



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However, when assembling an array of individual radiators (dipoles), the designer can select values closer to the optimum.

Omnidirectional collinear arrays

Omnidirectional collinear arrays consist of a vertical stack of equally spaced vertical dipoles fed with currents having the same amplitude and phase (see Fig. 10).

This configuration offers an omnidirectional azimuth pattern and a directive vertical pattern. The overall gain is a function of the number of the elements *n* and their spacing *s*, as shown in Fig. 11.

This type of radiating structure is widely used at VHF, especially for omnidirectional antenna systems in FM broadcasting (see also § 7.3.1). It is usually designed by assembling the individual sources (very often folded dipoles), and care should be taken to select the optimum spacing. An adequate margin should be allowed in the case of multichannel operation.

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FIGURE 10

Omnidirectional collinear array

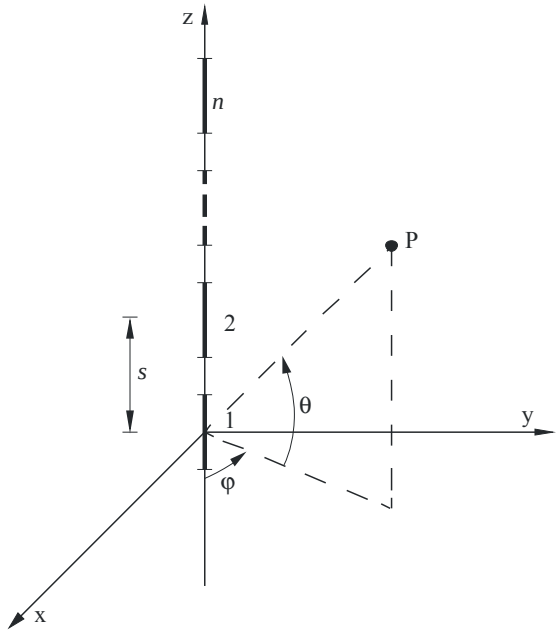

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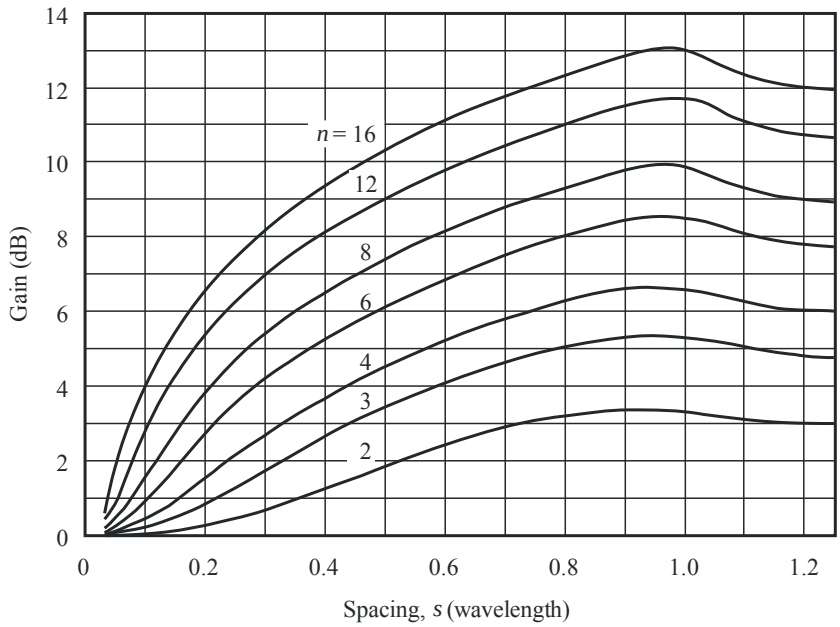
FIGURE 11

Gain of a vertical collinear array as a function of the number *n* of elements and their spacing *s*. The gain is referred to that of a single element



BT.1195-11

6.1.1 Linear antenna arrays with parasitic elements

In linear antenna arrays with parasitic elements, the electromagnetic field radiated by the driven element induces currents that flow in the parasitic elements.

At VHF and UHF the most important application of an array with parasitic elements is that represented by the Yagi antenna, schematically shown in Fig. 12.

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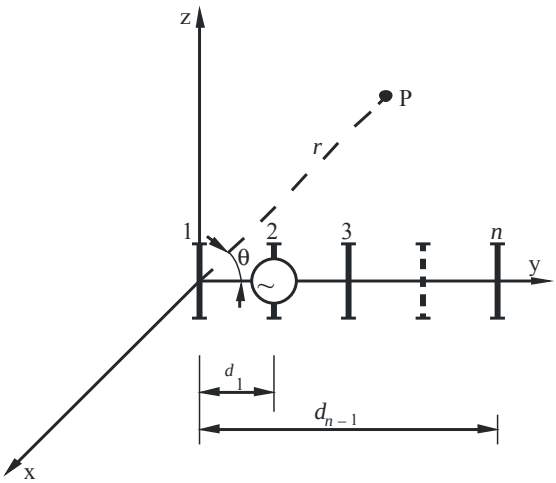
The Yagi antenna consists of a driven element, a reflector and one or more directors. The overall gain increases with the number of directors that are used.

FIGURE 12

Yagi antenna



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NOTE 1 – A quantitative calculation of the pattern can be performed by considering that the *i*-th element pattern function of the vertically polarized Yagi antenna shown in Fig. 12 in the z-y vertical plane is:

$$f_i = \frac{\cos(\beta\, h_i \cos\theta) - \cos(\beta\, h_i)}{\sin\theta} \tag{18}$$

where:

θ : elevation angle

h_i : half-length of the i-element

$\beta =$ $2\,\pi/\lambda$

Since the patterns for each element of a Yagi antenna are different, the principle of pattern multiplication (see § 4.2.1) cannot be used, and it is necessary to carry out a vectorial addition (see also § 4.2.2).

The pattern will be given by:

$$E(\theta, \varphi) = \sum_{i=1}^{n} I_i \cdot f_i(\theta) \cdot e^{j\beta d_{i-1}\cos\theta} \tag{19}$$

where:

n : total number of dipoles

I_i : current in the *i*-element

d_{i-1} : distance of the *i*-element from the reflector ($d_0 = 0$).

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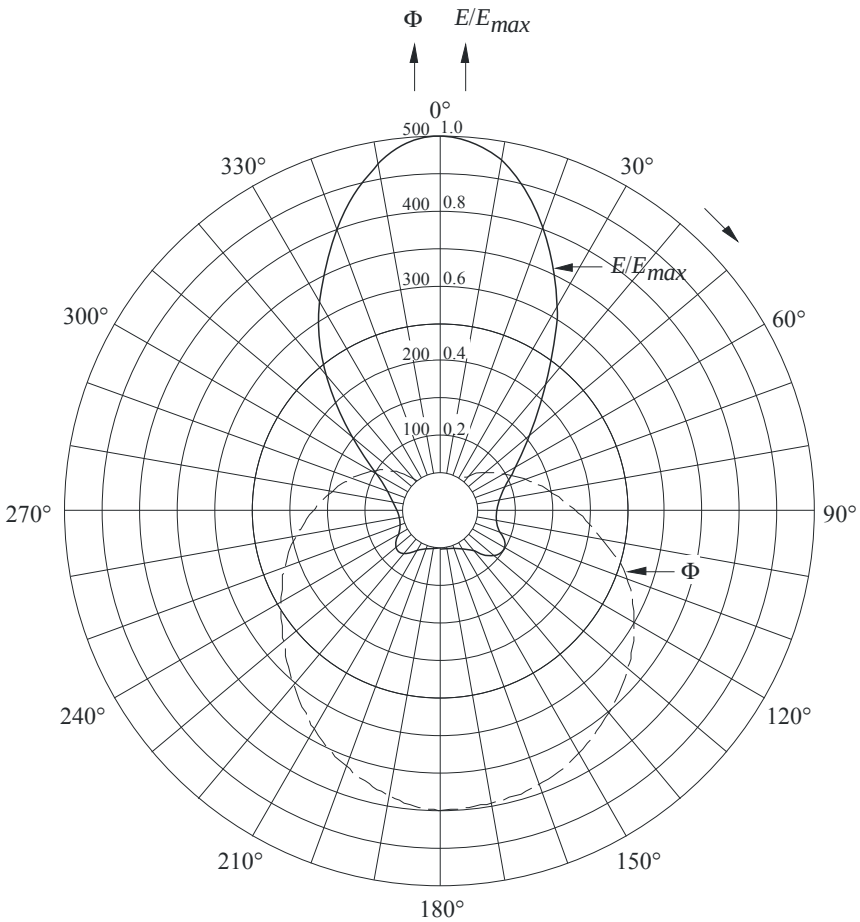
6.2 The amplitude and phase radiation patterns

When a single point source is considered, the spatial distribution of the received signal is completely identified by the relative amplitude radiation pattern, i.e. no additional useful information is provided by the associated phase pattern.

In the case of non-isotropic sources of finite size used in an array, the resulting radiation pattern has to be determined by using both the relative amplitude radiation pattern and the associated phase pattern (see Fig. 13).

FIGURE 13

Radiation pattern (amplitude and phase) of an UHF array



E/E_{max} : relative amplitude radiation pattern
Φ: phase pattern (degrees)

BT.1195-13

As mentioned, both the amplitude and phase radiation pattern in the direction of maximum radiation are needed to evaluate the overall antenna pattern. These patterns are normally provided by the manufacturer or measured by the user according to the procedures indicated in Part 2 and should both be used as indicated in § 7.2, to calculate the antenna system pattern.

However, in some cases where an existing system using individual antennas without sufficient technical specifications is to be redesigned or in general when only the relative amplitude pattern is known, the following less accurate approach may be followed.

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In this case, the reference point of the radiation i.e., the origin of the relative amplitude radiation pattern, may be suitably transposed to a point called the "phase centre" or the "electrical centre" where the phase pattern shows the least variation over the widest angular sector, i.e., to the actual geometrical centre of the radiated wavefront.

Within this angular sector, the array can be considered as a non-isotropic point source, located at the phase centre, whose radiation pattern can be again completely determined by using only the amplitude radiation pattern.

In arrays using dipoles and reflectors, the phase centre usually lies in the zone between the dipole input terminals and the reflecting screen, and typically lies near the dipole terminals.

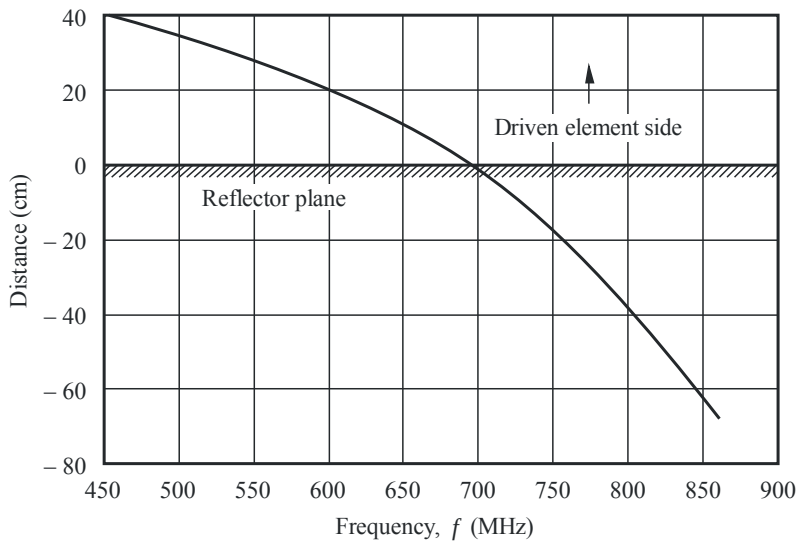
In the case of a panel array (see § 6.4.1) the exact location of the phase centre, based on measurements, is generally specified by the manufacturer.

Since at VHF and UHF the majority of the individual antennas can operate over relatively large bandwidths (see § 6.4.1), the manufacturer performs the measurements and locates the phase centre for different frequencies in the operating band. From these measurements, a curve is derived which shows the variation of the geometrical position of the phase centre versus frequency (see Fig. 14).

From Fig. 14 it can also be seen the limitations of the phase centre approach when calculating the radiation pattern at directions where large variations in the geometrical position of the phase centre are predicted. This inaccuracy is particularly important at those points where the effects of the combined radiation of more antennas is to be calculated and may considerably alter the resulting radiation pattern where minima and sidelobes are considered.

FIGURE 14

Location of the phase centre of a wideband UHF panel antenna



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The manufacturer often provides also a family of curves giving the phase patterns obtained at various frequencies. These curves are useful for evaluating the validity of the assumption that a phase centre can be used as the location of the point source in the band concerned (see Fig. 15).

NOTE 1 – In those situations where the phase centre location is not known e.g. old antenna system being re-designed to operate on frequencies different from that of the original design, insufficiently specified radiators, etc., a rule of thumb, often used in the design of antenna systems, consists in placing the phase centre at the feeding terminals of the radiating dipoles. This assumption gives a more conservative result for the overall pattern. It can also be applied to other type of radiating elements e.g. Yagi antennas.

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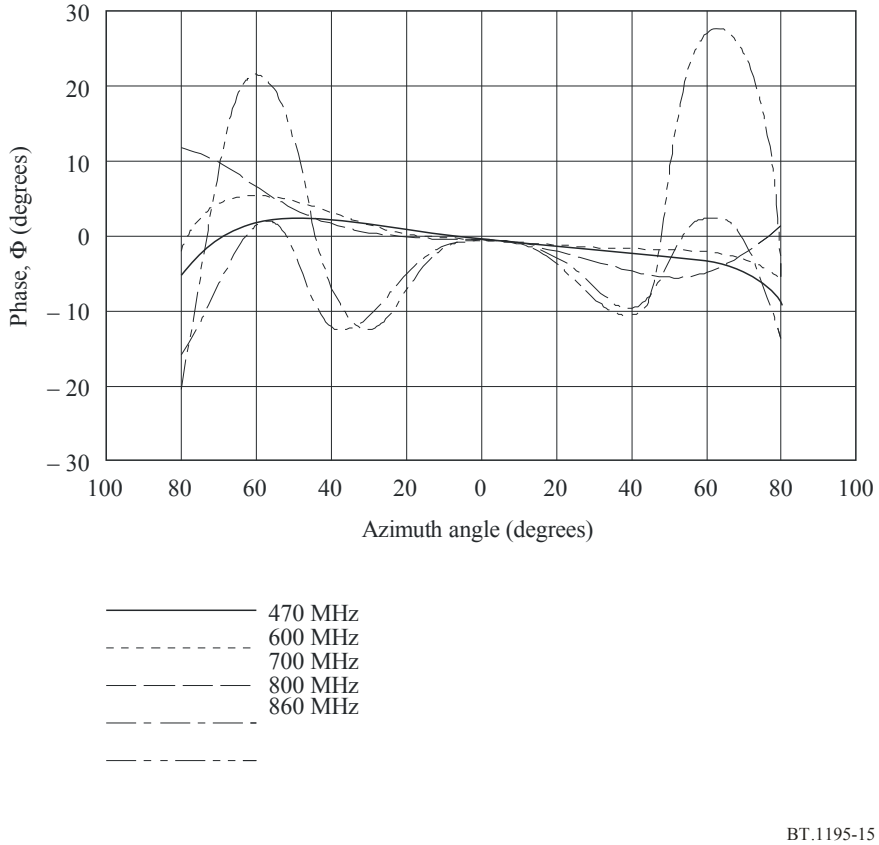
FIGURE 15

Phase patterns of a wideband UHF panel antenna at various operating frequencies



6.3 Calculation of the radiation pattern of antenna arrays

When designing antenna systems with radiators supplied by a manufacturer (simple dipoles, panel or Yagi antennas, etc.), the radiation patterns provided by the manufacturer are usually the vertical and the horizontal section of the 3-dimensional amplitude and/or phase pattern which contains the direction of maximum radiation. Letting $f_A(\theta, \varphi)$ be the amplitude pattern function of the radiator, the horizontal and vertical radiation patterns can be respectively expressed by:

$$f_{AH}(\varphi)\big|_{\theta = \theta_{max}} \quad \text{and} \quad f_{AV}(\theta)\big|_{\varphi = \varphi_{max}} \tag{20}$$

where θ_{max} and φ_{max} are respectively the elevation angle and the azimuth angle at which the maximum radiation occurs.

For practical purposes the angles θ_{max} and φ_{max} are normally set to zero in the manufacturer's data sheet. The actual values of the amplitude radiation pattern for angles $\theta \neq \theta_{max}$ and $\varphi \neq \varphi_{max}$ can be found by the relationship:

$$f_A(\theta, \varphi) = f_{AH}(\varphi)\big|_{\theta = \theta_{max}} \cdot f_{AV}(\theta)\big|_{\varphi = \varphi_{max}} \tag{21}$$

In the same way the phase pattern function $f_P(\theta, \varphi)$ can be expressed by:

$$f_P(\theta, \varphi) = f_{PH}(\varphi)\big|_{\theta = \theta_{max}} + f_{PV}(\theta)\big|_{\varphi = \varphi_{max}} \tag{22}$$

where $f_{PH}(\varphi)\big|_{\theta = \theta_{max}}$ and $f_{PV}(\theta)\big|_{\varphi = \varphi_{max}}$ are respectively the horizontal and vertical phase pattern function of the radiator.

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This expression is based on the assumption verified in practice, that any other vertical or horizontal section of the pattern will have a shape similar to the vertical or horizontal section, containing the direction of maximum radiation.

6.4 VHF and UHF antenna arrays

6.4.1 Panel type antennas

At VHF and particularly at UHF, the dimensions of the elementary radiators are small enough to allow the design of complete antenna systems using elements furnished as a complete product by the manufacturer.

These elements, called panels, are fabricated by the manufacturer by assembling elementary radiators into more complex arrays. The design engineer can then use these panels as "building bricks" for the construction of the final antenna system.

This technique is widely used for modern VHF and UHF antenna system design since it allows for a better control and optimization of the antenna system pattern and hence of spectrum efficiency and economy in the design of the overall system.

A panel may consist of a single simple half-wave dipole mounted at a pre-determined distance from an integral reflecting plane, or for more complicated arrays of 4 (or more) narrow or broad-band, linearly or circularly polarized elementary radiators.

The manufacturer optimizes the panel as regards to:

– gain,
– radiation pattern,
– return loss,
– impedance,
– operating frequency band.

The parameters used in the optimization are:

– physical structure of elementary radiators,
– mutual spacing of elementary radiators,
– distance of the radiators from the reflector (and in some cases the shape of the reflector),
– feeder system.

A very important design characteristic of modern panel antennas is the capability of broadband operation. The same antenna system can often be required to radiate simultaneously more than one programme. This is typically the case for transmitting stations, which are part of a broadcasting network that has to provide two or three programme services to a given area, usually on channels widely spaced in frequency.

This constraint may not be so stringent for FM sound broadcasting in Band II where the required bandwidth is only about ±10% of the centre frequency, but it considerably affects the design of panels required to fully cover both Bands IV and V (470-960 MHz).

In this case a careful design of the elementary radiator is needed in order to lower the Q of its equivalent circuit. This reduction is usually achieved by using radiating elements with large surface or cross-section area.

A typical design of VHF panels is shown in Fig. 16. It consists of two vertically stacked, centre-fed, full wavelength dipoles. The corresponding vertical and horizontal radiation patterns are shown in Fig. 17.

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