

RECOMMENDATION ITU-R BS.1386-1*

LF and MF transmitting antennas characteristics and diagrams**

(Question ITU-R 201/10)

(1998-2001)

The ITU Radiocommunication Assembly,

considering

- a) that Recommendations ITU-R BS.705 and ITU-R BS.1195 are defining respectively HF and VHF, UHF broadcasting antenna diagrams together with other relevant information;
- b) that the diagrams published in this Recommendation should be easy to be understood and used by the planning and designing engineers, while retaining all necessary useful information;
- c) the experience gained with the previous editions of Recommendations on antennas;
- d) that the characteristics of the LF and MF antennas as contained in Annex 1 to this Recommendation have a wide application,

recommends

1 that the formulae as illustrated by sample diagrams and contained in Annex 1 to this Recommendation together with the corresponding computer programs should be used to evaluate the performance of LF and MF transmitting antennas; particularly for planning purposes.

NOTE 1 – Part 1 of Annex 1 gives comprehensive and detailed information on the theoretical characteristics of LF and MF transmitting antennas.

Computer programs have been developed from the theory to calculate the radiation patterns and gain for the various included antenna types.

The real performance of antennas encountered in practice will deviate to a certain extent from its analytically calculated characteristics. To this purpose Part 2 gives advice about this deviation on the basis of the results of a comprehensive set of measurements carried out by various administrations with modern techniques.

* Radiocommunication Study Group 6 made editorial amendments to this Recommendation in 2002 in accordance with Resolution ITU-R 44.

** Chapter 2 of Part 2 of Annex 1 should be brought to the attention of the International Electrotechnical Commission (IEC).

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PART 1 – LF AND MF TRANSMITTING ANTENNA CHARACTERISTICS AND DIAGRAMS

1 Introduction

Efficient spectrum utilization at LF and MF demands for both omnidirectional and directional antennas whose characteristics and performance should be known as accurately as possible. Therefore, a unified approach to evaluate the antenna gain and radiation pattern should be made available to the engineer both for national planning and for international coordination. In the past the former CCIR responded to such a requirement by preparing Manuals of Antenna Diagrams (ed. 1963, 1978 and 1984), which included graphical representations of the radiation patterns of some of the most commonly used antenna types at MF and HF. For the sake of simplicity, the patterns were calculated assuming a sinusoidal current distribution and using computer facilities as

available at that time. Today modern antenna theories and powerful computing means allow the planning engineer to determine the antenna characteristics with far better accuracy and perform the relevant calculation on low cost computers.

The application of digital techniques to sound broadcasting at LF and MF is envisaged in the near future and relevant studies are already being carried out by the ITU-R. The advantages of such techniques combined with the propagation characteristics at LF and MF in comparison to broadcasting at VHF (such as larger coverage areas and more stable reception in mobile conditions, etc.) will make the new services not only more spectrum efficient but also more attractive from the economical point of view. However, the introduction of digital techniques to broadcasting at LF and MF, will put an emphasis on the use of advanced planning tools, such as the calculation of the antenna patterns, to be made available to future planning Conferences as well as to assess more precisely the performance of existing transmitting systems. This Recommendation has been developed to respond timely to such requirements providing, as in the case of the companion Recommendations ITU-R BS.705 and ITU-R BS.1195, that the associated computer program to be used to perform the relevant calculations.

2 Radiation patterns and gain calculation

2.1 General considerations

An LF-MF antenna system may consist of a single element or an array of radiating elements. Radiation patterns of an antenna system can be represented by a three-dimensional locus of points. The three-dimensional radiation pattern is based on the reference coordinate system of Fig. 1, where the following parameters can be defined:

- θ : elevation angle from the horizontal ($0^\circ \leq \theta \leq 90^\circ$)
- φ : azimuth angle with respect to the North direction, assumed to coincide with the y-axis ($0^\circ \leq \varphi \leq 360^\circ$)
- r : distance between the origin and distant observation point where the far field is calculated.

2.2 Radiation patterns

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

$$|E(\theta, \varphi)| = K |f(\theta, \varphi)| \quad (1)$$

where:

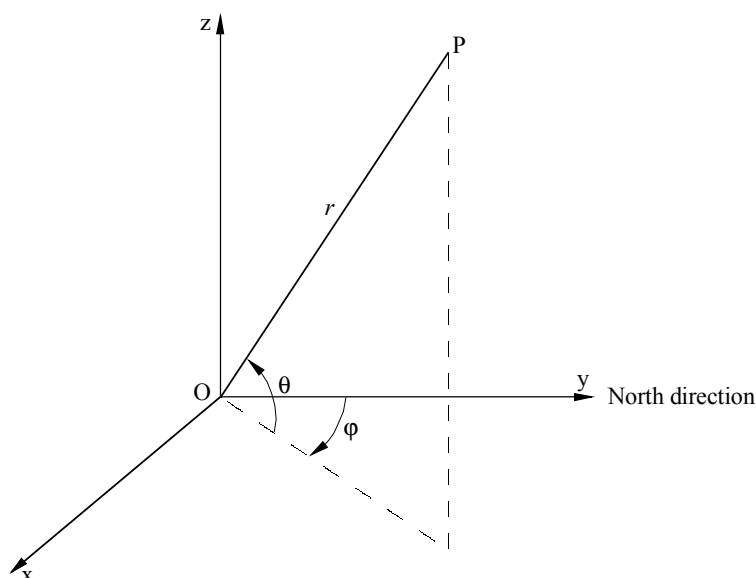
- $|E(\theta, \varphi)|$: magnitude of the electrical field
- $|f(\theta, \varphi)|$: radiation pattern function
- K : normalizing factor to set $|E(\theta, \varphi)|_{\max} = 1$, i.e. 0 dB.

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

$$|E(\theta, \varphi)|^2 = |E_\theta(\theta, \varphi)|^2 + |E_\varphi(\theta, \varphi)|^2 \quad (2)$$

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FIGURE 1
Reference coordinate system



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2.2.1 Graphical representation

A set of particular sections of the radiation pattern at specific elevation angles (azimuthal patterns) and at specific azimuthal angles (vertical patterns) is used to describe the full radiation pattern. The most important sections are the azimuthal patterns at the elevation angle at which the maximum cymomotive force (c.m.f.) occurs and the vertical pattern at the azimuthal angle at which the maximum c.m.f. occurs. These are referred to as the horizontal radiation pattern (HRP) and the vertical radiation pattern (VRP) respectively.

2.2.2 Tabular representation

A tabular representation of the full antenna pattern may be found to be a useful application when antenna data is integrated into a planning system. A resolution which is considered suitable for such a purpose consists of pattern values evaluated at each 2° for elevation angles and each 5° for azimuthal angles.

2.3 Directivity and gain

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:

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

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

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

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

The antenna efficiency is defined as a ratio of radiated power, P_{rad} , to the power at the input of antenna P_{input} :

$$\eta = \frac{P_{\text{rad}}}{P_{\text{input}}} \quad (5)$$

The antenna gain, G , is 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:

$$G_i = 10 \log_{10} D \quad \text{dB} \quad (6)$$

Other expressions used are the gain relative to a half-isotropic antenna, G_{hi} , that is:

$$G_{hi} = G_i - 3.01 \quad \text{dB} \quad (7)$$

and the gain, G_v , relative to a short vertical monopole:

$$G_v = G_i - 4.77 \quad \text{dB} \quad (8)$$

2.4 Effect of the ground

Using the assumptions given in § 2.1, and also the assumption that the antenna is located in the coordinate system of Fig. 1, where the x-y plane represents a flat homogeneous ground, the far field produced at the observation point $P(r, \theta, \phi)$, including the ground reflected part, can be derived as follows.

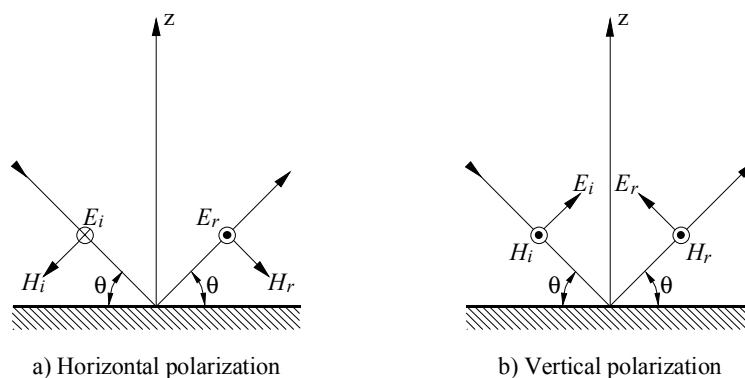
If the incident radiation on the ground is assumed to have a plane wavefront, the following two different cases can be considered.

- a) horizontal polarization;
- b) vertical polarization.

In the case of *horizontal polarization*, the incident (direct) electric vector is parallel to the reflecting x-y plane (and hence perpendicular to the plane of incidence, i.e. the plane containing the direction of propagation and the perpendicular to the reflecting surface, as shown in Fig. 2a)).

In the case of *vertical polarization*, the incident electric vector is parallel to the plane of incidence while the associated incident magnetic vector is parallel to the reflecting surface, as shown in Fig. 2b)).

FIGURE 2
Wave reflection on imperfect ground



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2.4.1 Wave reflection on imperfect ground

The total far-field components above ground in Fig. 2 can then be expressed as follows:

a) *Horizontal polarization*

$$E_h = E_i(r_1) + E_r(r_2) = E_i(r_1) + R_h E_i(r_2) \quad (9)$$

where:

E_h : total horizontal component

r_1 : direct distance between the antenna and the observation point

r_2 : distance from the image of the antenna to the observation point

E_i : direct electric field

E_r : reflected electric field

R_h : complex reflection coefficient for horizontally polarized waves defined as:

$$R_h = \frac{\sin \theta - \left[(\epsilon - \cos^2 \theta) - j \frac{18\,000 \cdot \sigma}{f_{\text{MHz}}} \right]^{1/2}}{\sin \theta + \left[(\epsilon - \cos^2 \theta) - j \frac{18\,000 \cdot \sigma}{f_{\text{MHz}}} \right]^{1/2}} \quad (10)$$

and

θ : grazing angle

ϵ : relative permittivity (or dielectric constant) of the ground

σ : conductivity of the ground (S/m)

f_{MHz} : operating frequency (MHz).

b) *Vertical polarization*

$$\begin{aligned} E'_h &= E_i(r_1) - R_v E_i(r_2) \\ E_v &= E_i(r_1) + R_v E_i(r_2) \end{aligned} \quad (11)$$

where:

E'_h : total horizontal component

E_v : total vertical component

R_v : complex reflection coefficient for vertically polarized waves defined as:

$$R_v = \frac{\left[\epsilon - j \frac{18\,000 \cdot \sigma}{f_{\text{MHz}}} \right] \sin \theta - \left[(\epsilon - \cos^2 \theta) - j \frac{18\,000 \cdot \sigma}{f_{\text{MHz}}} \right]^{1/2}}{\left[\epsilon - j \frac{18\,000 \cdot \sigma}{f_{\text{MHz}}} \right] \sin \theta + \left[(\epsilon - \cos^2 \theta) - j \frac{18\,000 \cdot \sigma}{f_{\text{MHz}}} \right]^{1/2}} \quad (12)$$

2.5 Antenna designation

In consideration of the variety of LF-MF antenna systems, a suitable antenna designation based only on the electrical length might not be feasible. Therefore, such a designation will have to be implemented on a case-by-case basis.

3 LF-MF antenna systems

3.1 General considerations

LF and MF antennas have in general few radiating elements. The height and the spacing of these elements are not restricted to $\lambda/2$. The radiation pattern of these antennas is a function of:

- radiating element cross-section;
- frequency of operation;
- earth system and ground characteristics;
- number of elements and their spacing;
- height of elements above the ground;
- orientation;
- feeding arrangement;
- characteristics of environment.

3.2 Radiating element cross-section

Various radiating structures are in common use, such as self-supporting towers, guyed masts and wire elements. Therefore, the cross-section and, as a consequence, the current in the radiating element vary considerably, affecting its radiation pattern and gain. In the case of radiating towers or masts, triangular or square cross-section are in common use, whilst wire structures are characterized by circular cross-sections. To simplify the calculation of LF-MF antenna patterns and gain for

planning purposes, each element of the antenna system is assumed to have the same cross-section. In addition the calculation procedure developed according to the theory included in Annex 1, automatically transforms any triangular or square section into an equivalent circular cross-section.

Input parameters to the calculation procedure

- Type of cross-section (T, S, C)
Triangular (T), square (S) or circular (C)
- Cross-section dimension (m)
The section side or, in the case of circular section, its diameter is to be specified.

3.3 Frequency of operation

The operating frequency of a given antenna system has an impact on the resulting radiation pattern. In some cases a given structure is used to operate on more than one channel or may be used to radiate on a channel different from the design frequency. In this case the pattern has to be evaluated at the actual operating frequency to get consistent results.

Input parameters to the calculation procedure

- Frequency (kHz)
(A default value of 1 000 kHz is included).

3.4 Earth system and ground characteristics

As mentioned in § 2.4, antenna systems at LF-MF are normally placed on an imperfect ground whose characteristics in terms of reflection coefficients, are specified by the dielectric constant and conductivity of the ground. However, efficient antenna systems at LF-MF require an earth system. An ideal earth system would consist of a perfectly conducting circular surface surrounding the base of the antenna.

In practice an earth system is realized by a network of radial conductors of suitable length and diameter that can only be an approximation of an ideal perfectly conducting surface.

The length of radials varies from 0.25λ to 0.50λ and the number of radials varies from 60 to 120, whilst their diameter is of the order of a few mm. A typical earth system configuration consists of a circular mesh of 120 wires 0.25λ long having a diameter of 2.7-3 mm. As usual it is necessary to optimize systems both from the technical and economical point of view.

In the case of directional vertical antennas (see § 3.2.2) each radiating element is normally provided with an individual earth system suitably connected to the others.

To simplify the calculation of LF-MF antenna patterns and gain for planning purposes, the earth system is assumed to be represented by a circular wire network centred on the base of the radiating element. In the case of arrays of radiating elements it is also assumed that the earth system parameters of each of the radiating elements are the same.

Input parameters to the calculation procedure

The following input parameters are needed to evaluate the radiation pattern on imperfect ground:

- Dielectric constant
(A default value of $\epsilon = 4$, is included)
- Ground conductivity (S/m)
(A default value of $S_0 = 0.01$ S/m is included)

The following additional input parameters are needed when an earth system is present:

- Earth system radius (m)
(A default value of 0.25λ at the default calculation frequency is included)
- Number of wires of the earth system
(A default value of 120 wires is included)
- Earth system wire diameter (mm)
(A default value of 2.7 mm is included).

3.5 Omnidirectional antenna types

3.5.1 Vertical monopoles

A basic radiator at LF-MF is the vertical monopole consisting of a vertical radiating element erected on an earth system. The vertical monopole can be realized by a self-supporting structure or by a guyed mast and can be fed in various ways i.e. by suitably selecting the feeding point height on its vertical structure. The base-fed vertical monopole is one of the most common feeding arrangements.

The radiating element cross-section may vary considerably according to various design approaches. Self-radiating towers show triangular or square sections with side lengths of the order of 5-10 m and recent realization of cage radiators have even larger cross sections.

The vertical monopole height normally ranges from 0.1λ to 0.625λ according to various operational requirements (see Part 2).

The base-feed impedance depends both on height and section of antenna. Increasing the section will lower the reactance and increase the bandwidth.

The vertical monopole provides an omnidirectional pattern on the azimuthal plane. However the associated vertical pattern is always significantly affected by the ground constants as well as by other physical parameters, e.g. the electrical antenna height, etc.

The presence of an earth system does not significantly affect the geometrical shape of the pattern, but it significantly affects the efficiency.

3.5.2 Types of vertical monopoles

Vertical monopoles with electrical heights in the range 0.15λ to 0.3λ can be easily realized at LF-MF by base-fed radiators (masts or towers) with insulated bases. Also grounded-base

constructions with a bottom-fed wire cage (folded monopole or shunt feed) can be used. In many cases relatively short radiators are top loaded to increase the electrical length.

– *Short monopoles*

For economical reasons short monopoles (i.e. with electrical heights considerably less than $\lambda/4$) are normally used at lower frequencies. It should be noted that the use of this kind of antenna for high power transmitters may cause high voltages.

– *Quarter-wavelength monopoles*

This type of radiator, having an electrical height of approximately $\lambda/4$, is well-suited when ground wave service is needed out to a relatively short distance only and sky wave service should begin as close as possible to the transmitting site.

– *Anti-fading antennas*

At LF and MF, fading of the received broadcast signal occurs when the ground-wave field strength has an intensity of the same order of magnitude of the sky-wave field strength. The resulting signal amplitude at the receiver will vary according to their relative phase difference which is affected by the propagation conditions.

Fading can be reduced by controlling the amount of sky-wave power radiated in the desired service area. This control can be achieved by selecting vertical monopoles with electrical heights in the range from 0.5λ to 0.6λ . In this case the vertical radiation pattern shows minimum and minor side lobes in the angular sector from 50° to 90° where radiation will be directed to the ionosphere.

3.6 Directional antennas

Directional antenna systems are widely used to:

- limit radiation toward the service area of other stations to reduce interference;
- concentrate radiation toward the desired coverage area;
- achieve higher gain.

At LF-MF the most common directional antenna systems consist of arrays of vertical radiators in two basic arrangements:

- arrays of vertical active elements;
- arrays of vertical passive elements (in combination with one or more active element).

Arrays of passive elements in combination with more than one active element are less frequently encountered in practical applications.

3.6.1 Arrays of active vertical elements

Arrays of vertical active elements are realized by a number of suitably spaced vertical radiators. The desired horizontal pattern directivity depends upon: spacing between the radiators, feeding current amplitude and phase of each element and feed location of each element.

By controlling these parameters it is possible to obtain a wide variety of patterns, even in the simple case of a two-element array. However, higher gains and directivities (and front-to-back ratios) are

achieved with arrays with more than two elements at the price of a more complex and expensive realization.

The vertical pattern of an array of vertical radiators will depend on the height of the elements, the ground system, the terrain characteristics, etc.

The radiating elements composing the array can be fed in various ways as previously mentioned, the most common and economical approach being the base-fed configuration.

It is to be noted that the arrays of vertical active elements offer a definitely better control of the resulting directional patterns in comparison to the arrays of vertical passive elements due to the possibility of a more accurate control of the current in each element. However this advantage is achieved at the price of a more complex and expensive feeding arrangement.

Finally it is to be mentioned that whilst the most common approach is to arrange the vertical radiator bases along a line in the horizontal plane, other configurations are common.

An array of four elements having their respective bases located at the corners of a square on the horizontal plane can provide a steerable main lobe of radiation by suitable control of the feeding arrangement. An approximately omnidirectional pattern can also be achieved.

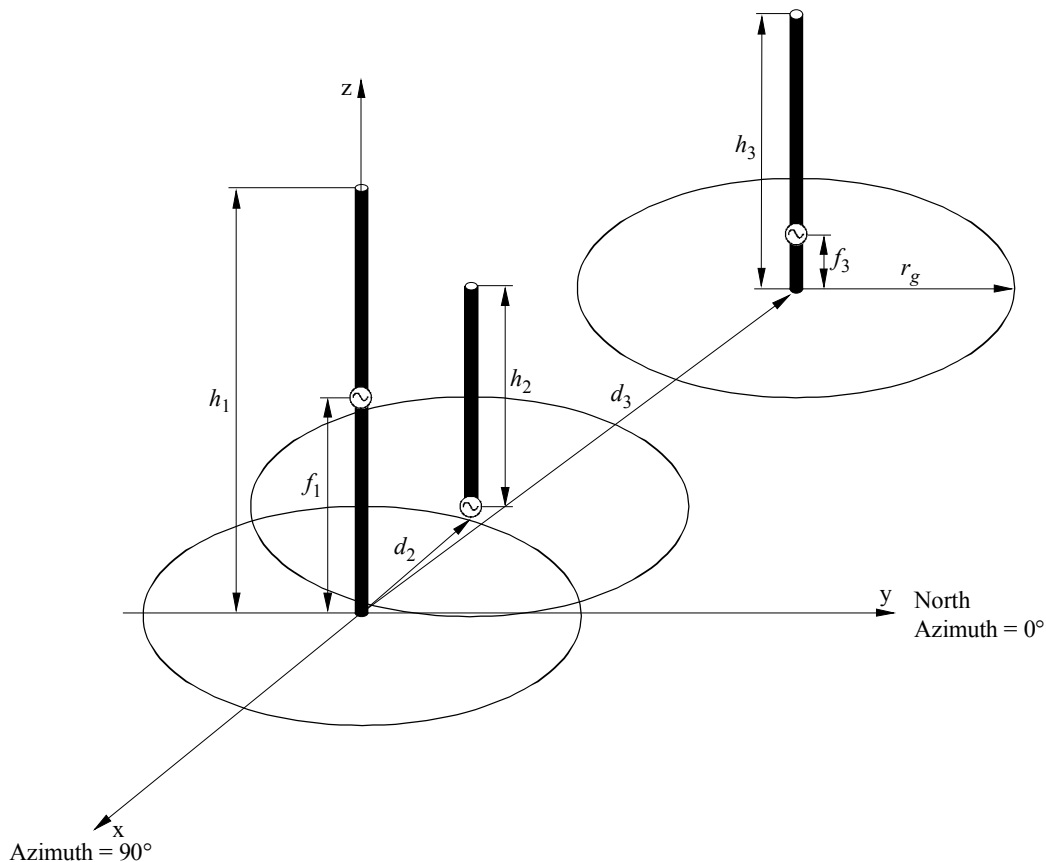
A few examples of patterns of these antenna systems, calculated applying a sinusoidal current distribution, have been included in previous ITU publications [see Manual of Antenna Diagrams, 1978]. However, the calculation procedure described in this Recommendation allows for the evaluation of the radiation pattern of arrays of vertical elements having whatever relative position in the horizontal plane and heights as shown in Fig. 3. It is also possible to take into account radiating elements not base-fed, by specifying the feeding point height.

Input parameters to the calculation procedure

With reference to Fig. 3, the following input parameters are needed by the calculation procedure:

- Height of each radiating element (m)
- Distance (m) of each element
(From element No. 1 considered as the origin of the coordinate system)
- Azimuth angle (degrees) of the line from element No. 1 to each other element
(Referred to the North direction coinciding with the y-axis)
- Feeding point height of each element (m)
- Feeding voltage amplitude (%)
(Expressed as a percentage for each element)
- Feeding voltage phase (degrees)
(Referred to the phase of the voltage applied to element No. 1, assumed to be 0°).

FIGURE 3
Arrays of active vertical elements



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3.6.2 Arrays of passive vertical elements

These represent the most economical approach to achieve directional azimuth patterns at the cost of a more cumbersome adjusting procedure.

They are in general realized by an active (base-fed or centre-fed) element with one or more passive element(s) suitably spaced on the horizontal plane. The desired horizontal directivity depends upon the placement of the radiators and the passive reactance placed at the feed point of each passive radiator.

By controlling these parameters it is possible to obtain a wide variety of azimuthal patterns, even in the simple case of a two-element array. However, higher gains and directivities (and front-to-back ratios) are achieved with arrays with more than one passive element at the price of a more expensive realization. It is to be noted that the overall gain of the array does not increase linearly with the number of radiators, so that arrays with many radiators may not represent an economical solution to specific high gain requirements.

The active element can be fed in various ways as previously mentioned, the most common and economical approach being the base-feeding arrangement.

It is to be noted that arrays of vertical passive elements need an efficient control of the current amplitude and phase of the passive elements to achieve the desired azimuth pattern. Once the placement of the elements has been fixed, the only way to realize such control is by inserting a