

RECOMMENDATION ITU-R F.1336*

REFERENCE RADIATION PATTERNS OF OMNIDIRECTIONAL
AND OTHER ANTENNAS IN POINT-TO-MULTIPOINT
SYSTEMS FOR USE IN SHARING STUDIES

(Question ITU-R 202/9)

(1997)

The ITU Radiocommunication Assembly,

considering

- a) that, for coordination studies and for the assessment of mutual interference between point-to-multipoint (P-MP) radio-relay systems and between stations of such systems and stations of space radiocommunication services sharing the same frequency band, it may be necessary to use reference radiation patterns for radio-relay system antennas;
- b) that, for the above studies, radiation patterns based on the level exceeded by a small percentage of the side-lobe peaks may be appropriate;
- c) that the side-lobe patterns of antennas of different sizes are strongly influenced by the directivity of the antenna and by the ratio of the antenna diameter to the operating wavelength;
- d) that reference radiation patterns are required in situations where information concerning the actual radiation pattern is not available;
- e) that, at large angles, the likelihood of local ground reflections must be considered;
- f) that the use of antennas with the best available radiation patterns will lead to the most efficient use of the radio-frequency spectrum,

recommends

- 1 that, in the absence of particular information concerning the radiation pattern of the P-MP radio-relay system antenna involved (see Note 1), the reference radiation pattern as stated below should be used for:
 - 1.1 interference assessment between line-of-sight (LOS) P-MP radio-relay systems;
 - 1.2 coordination studies and interference assessment between LOS P-MP radio-relay stations and other services sharing the same frequency band;
- 2 that the following reference radiation patterns should be used for frequencies in the range 1-3 GHz (see Note 2):
 - 2.1 in cases involving a station that uses an antenna with an omnidirectional pattern in or near the horizontal plane, the following equations should be used for elevation angles that range from 0° to 90° (see Annex 1 and Note 3):

$$G(\theta) = \max\{G_1(\theta), G_2(\theta)\}$$

$$G_1(\theta) = G_0 - 12 (\theta/\phi_3)^2$$

$$G_2(\theta) = G_0 - 12 + 10 \log \left[\left(\max \{ \theta/\phi_3, 1 \} \right)^{-1.5} + k \right]$$

where:

$G(\theta)$: gain relative to an isotropic antenna (dBi)

G_0 : the maximum gain in or near the horizontal plane (dBi)

* This Recommendation should be brought to the attention of Radiocommunication Study Groups 7, 8, 10 and 11.

θ : elevation angle relative to the angle of maximum gain (degrees)

φ_3 : the 3 dB beamwidth in the vertical plane (degrees):

$$\varphi_3 = \frac{1}{\alpha^2 - 0.818}$$

with:

$$\alpha = \frac{10^{0.1 G_0} + 172.4}{191.0}$$

k : parameter which accounts for increased side-lobe levels above what would be expected for an ideal antenna;

2.1.1 in cases involving typical antennas the parameter k should be 1.5 (see Note 4);

2.1.2 in cases involving antennas with improved side-lobe performance, the parameter k should be 0;

2.2 in cases involving a low-cost, low-gain antenna with circular symmetry about the 3 dB beamwidth and with a gain less than about 20 dBi, the following equations should be used (see Annex 2 and Note 5):

$$G(\theta) = \begin{cases} G_0 - 12 (\theta / \varphi_3)^2 & \text{for } 0 \leq \theta < 1.078 \varphi_3 \\ G_0 - 14 & \text{for } 1.078 \varphi_3 \leq \theta < \varphi_1 \\ G_0 - 14 - 32 \log (\theta / \varphi_1) & \text{for } \varphi_1 \leq \theta < \varphi_2 \\ -8 & \text{for } \varphi_2 \leq \theta \leq 180^\circ \end{cases}$$

where:

$G(\theta)$: gain relative to an isotropic antenna (dBi)

G_0 : the main lobe antenna gain (dBi)

θ : off-axis angle (degrees)

φ_3 : the 3 dB beamwidth of the subscriber antenna (degrees)

$$= \sqrt{27\,000 \times 10^{-0.1 G_0}}$$

$\varphi_1 = 1.9 \varphi_3$ (degrees)

$\varphi_2 = \varphi_1 \times 10^{(G_0 - 6)/32}$ (degrees);

3 that further studies are required to improve the definition of antenna radiation pattern envelopes. This will ease frequency sharing with other services and improve spectrum utilization;

4 that the following Notes should be regarded as part of this Recommendation:

NOTE 1 – It is essential that every effort be made to utilize the actual antenna pattern in coordination studies and interference assessment.

NOTE 2 – Reference patterns should be developed for antennas used in frequency bands above 3 GHz. Reference radiation patterns should also be developed for other antennas which may be used in central stations of P-MP systems.

NOTE 3 – The reference radiation pattern given in *recommends* 2.1 primarily applies in situations where the maximum gain in the horizontal plane is between 8 dBi and 13 dBi. Further study is required to establish the full range over which the equations are valid.

NOTE 4 – The reference radiation pattern for omnidirectional and sectoral antennas given in § A.2.1.2.2.2.3 of Resolution 46 (WRC-95) of the World Radiocommunication Conference (Geneva, 1995) is:

$$G(\theta) = \begin{cases} G_0 - 12 (\theta / \varphi_3)^2 & \text{for } 0 \leq \theta < \varphi_3 \\ G_0 - 12 - 10 \log (\theta / \varphi_3) & \text{for } \varphi_3 \leq \theta \leq 90^\circ \end{cases}$$

The parameters are as defined in *recommends* 2.1.

Resolution 46 (WRC-95) and Annex 1 to Appendix S5 (WRC-95) indicate that this antenna pattern is provisional and that further study is underway in the ITU-R.

NOTE 5 – The reference radiation pattern given in *recommends* 2.2 primarily applies in situations where the maximum gain is less than or equal to 20 dBi and the use of Recommendation ITU-R F.699 produces inadequate results. Further study is required to establish the full range over which the equations are valid.

ANNEX 1

Reference radiation pattern for omnidirectional antennas as used in P-MP radio-relay systems

1 Introduction

An omnidirectional antenna is frequently used for transmitting and receiving signals at central stations of P-MP radio-relay systems. Studies involving sharing between these types of radio-relay systems and space service systems in the 2 GHz bands have used the reference radiation pattern described here.

2 Analysis

The reference radiation pattern is based on the following assumptions concerning the omnidirectional antenna:

- that the antenna is an n -element linear array radiating in the broadside mode;
- the elements of the array are assumed to be dipoles;
- the array elements are spaced $3\lambda/4$.

The 3 dB beamwidth, ϕ_3 , of the array in the elevation plane is related to the directivity D by:

$$D = 10 \log \left[191.0 \sqrt{0.818 + 1/\phi_3} - 172.4 \right] \quad \text{dBi} \quad (1)$$

Equation (1) may be solved for ϕ_3 when the directivity is known:

$$\phi_3 = \frac{1}{\alpha^2 - 0.818} \quad (2a)$$

with:

$$\alpha = \frac{10^{0.1D} + 172.4}{191.0} \quad (2b)$$

The relationship between the 3 dB beamwidth in the elevation plane and the directivity was derived on the assumption that the radiation pattern in the elevation plane was adequately approximated by:

$$f(\theta) = \cos^m \theta$$

where m is an arbitrary parameter used to relate the 3 dB beamwidth and the radiation pattern in the elevation plane. Using this approximation, the directivity was obtained by integrating the pattern over the elevation and azimuth planes.

The intensity of the far-field of a linear array is given by:

$$E_T(\theta) = E_e(\theta) \cdot AF(\theta) \quad (3)$$

where:

$E_T(\theta)$: total E -field at an angle of θ normal to the axis of the array

$E_e(\theta)$: E -field at an angle of θ normal to the axis of the array caused by a single array element

$AF(\theta)$: array factor at an angle θ normal to the axis of the array.

The normalized E -field of a dipole element is:

$$E_e(\theta) = \cos \theta \quad (4)$$

The array factor is:

$$AF_N = \frac{1}{N} \left[\frac{\sin(N\psi/2)}{\sin(\psi/2)} \right] \quad (5)$$

where:

N : number of elements in the array

$$\frac{\psi}{2} = \frac{1}{2} \left[2\pi \frac{d}{\lambda} \sin \theta \right]$$

d : spacing of the radiators

λ : wavelength.

The following procedure has been used to estimate the number of elements, N , in the array. It is assumed that the maximum gain of the array is identical to the directivity of the array.

- Given the maximum gain of the omnidirectional antenna in the elevation plane, compute the 3 dB beamwidth φ_3 using equations (2a) and (2b).
- Ignore the small reduction in off-axis gain caused by the dipole element, and note that the array factor AF_N evaluates to 0.707 (–3 dB) when $N\psi/2 = 1.3916$.
- N is then determined as the integer value, INT , of:

$$N = INT \left[\frac{2 \times 1.3916}{2\pi \frac{d}{\lambda} \sin\left(\frac{\varphi_3}{2}\right)} \right] \quad (6)$$

The normalized off-axis discrimination ΔD is given by:

$$\Delta D = 20 \log \left[|AF_N \times \cos \theta| \right] \quad \text{dB} \quad (7)$$

Equation (7) has been evaluated as a function of the off-axis angle (i.e., the elevation angle) for several values of maximum gain. For values in the range of 8 to 13 dBi, it has been found that the envelope of the radiation pattern in the elevation plane may be adequately approximated by the following equations:

$$G(\theta) = \max\{G_1(\theta), G_2(\theta)\}$$

$$G_1(\theta) = G_0 - 12 (\theta/\varphi_3)^2 \quad \text{dBi} \quad (8a)$$

$$G_2(\theta) = G_0 - 12 + 10 \log \left[\left(\max \{ \theta/\varphi_3, 1 \} \right)^{-1.5} + k \right] \quad \text{dBi} \quad (8b)$$

where k is a parameter which accounts for increased side-lobe levels above what would be expected for an ideal antenna.

Figures 1 to 4 compare the reference radiation envelopes with the theoretical antenna patterns generated from equation (8), for gains from 8 to 13 dBi, using a factor of $k = 0$. Figures 5 to 8 compare the reference radiation envelopes with actual measured antenna patterns using a factor of $k = 0$. In Figs. 7 and 8, it can be seen that the side lobes are about 15 dB or more below the level of the main lobe, allowing for a small percentage of side-lobe peaks which might exceed this value. However practical factors such as the use of electrical downtilt, pattern degradations at band-edges and production variations would further increase the side lobes to about 10 dB below the main lobe in actual field installations. The k factor, mentioned above, in equation (8), is intended to characterize this variation in side-lobe levels.

Figures 9 and 10 provide a comparison of a 10 and a 13 dBi gain antenna, at 2.4 GHz, with the reference radiation pattern envelope, using $k = 0.5$. A factor of $k = 0.5$ represents side-lobe levels about 15 dB below the main lobe peak. To account for further increases in side-lobe levels found in field installations, for typical antennas a factor of $k = 1.5$ should be used, representing side-lobe levels about 10 dB below the level of the main lobe. Finally, Figs. 11 and 12 illustrate the effect on elevation patterns of using various values of k .

FIGURE 1
Normalized radiation pattern of a linear array of dipole elements compared with the
approximate envelope of the radiation pattern
 $G_0 = 10 \text{ dBi}$, $k = 0$

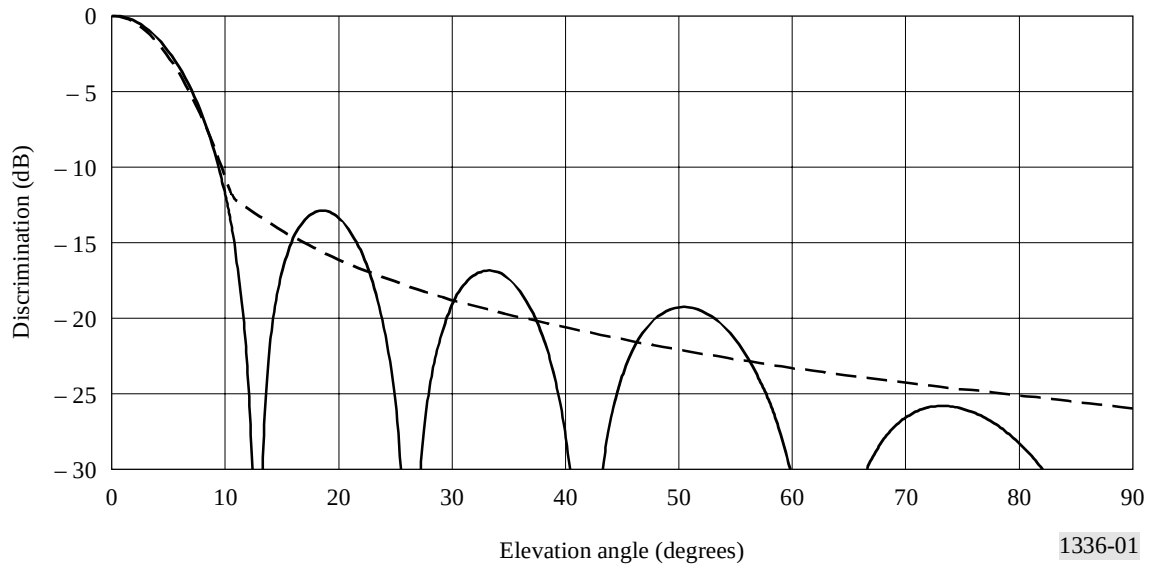


FIGURE 2
Normalized radiation pattern of a linear array of dipole elements compared with the
approximate envelope of the radiation pattern
 $G_0 = 11 \text{ dBi}$, $k = 0$

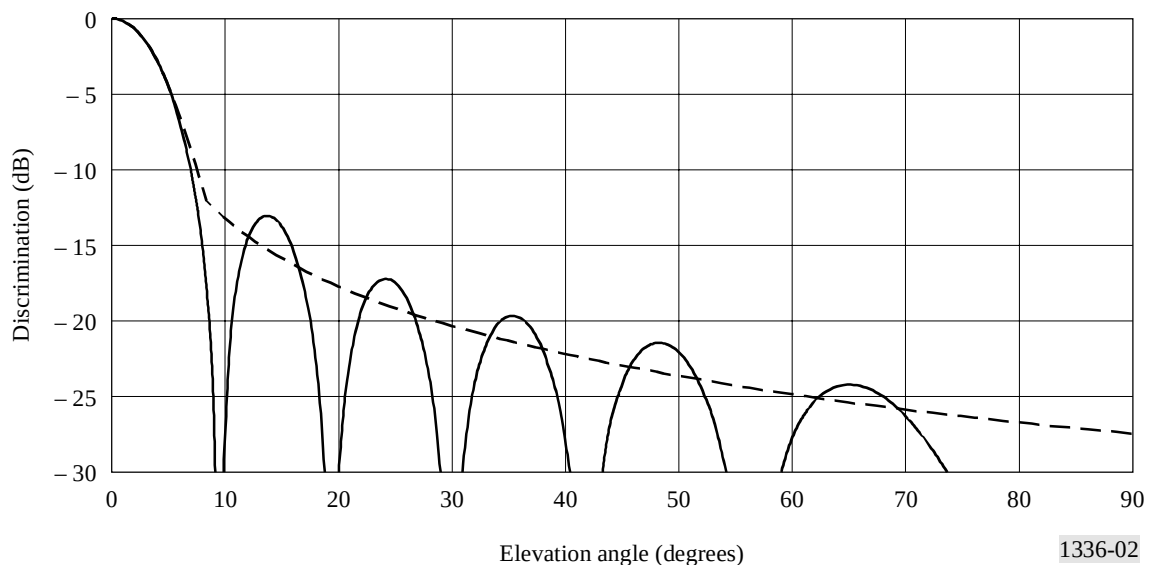


FIGURE 3

Normalized radiation pattern of a linear array of dipole elements compared with the approximate envelope of the radiation pattern

$$G_0 = 12 \text{ dBi}, k = 0$$

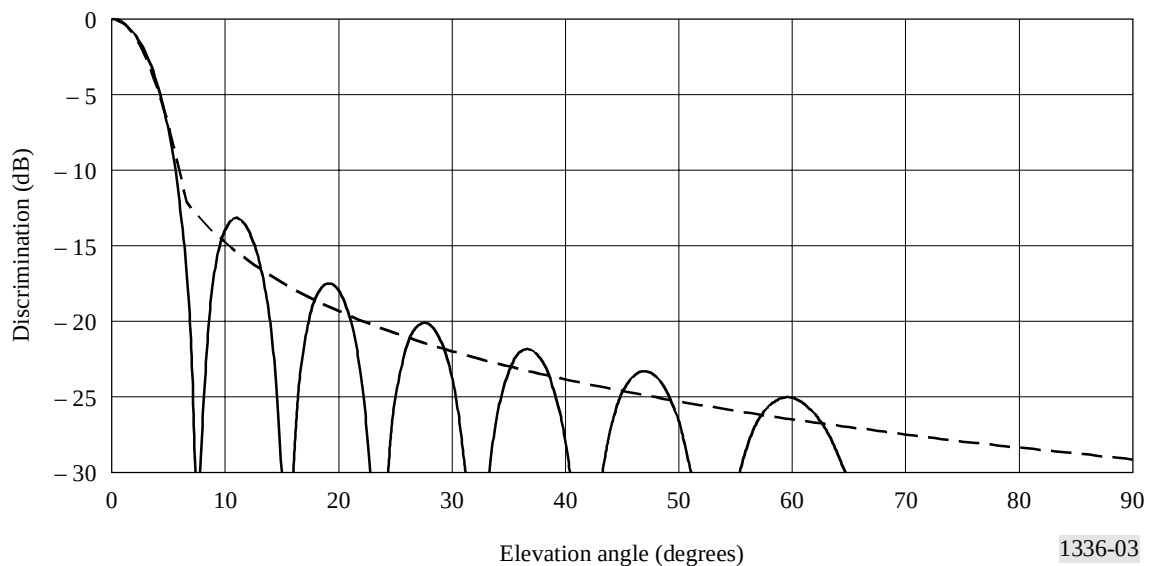


FIGURE 4

Normalized radiation pattern of a linear array of dipole elements compared with the approximate envelope of the radiation pattern

$$G_0 = 13 \text{ dBi}, k = 0$$

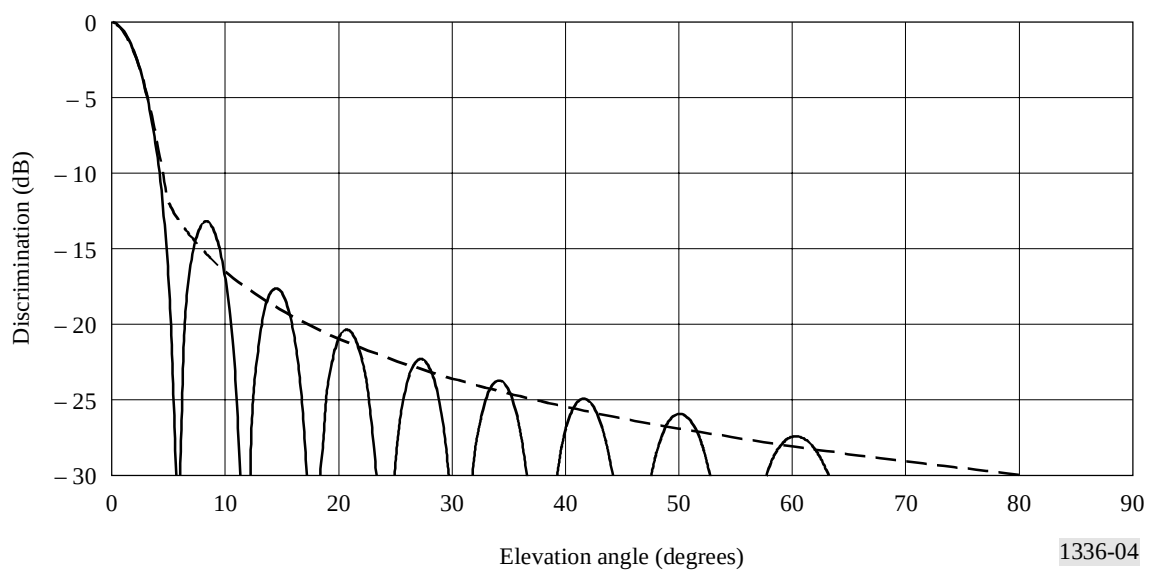
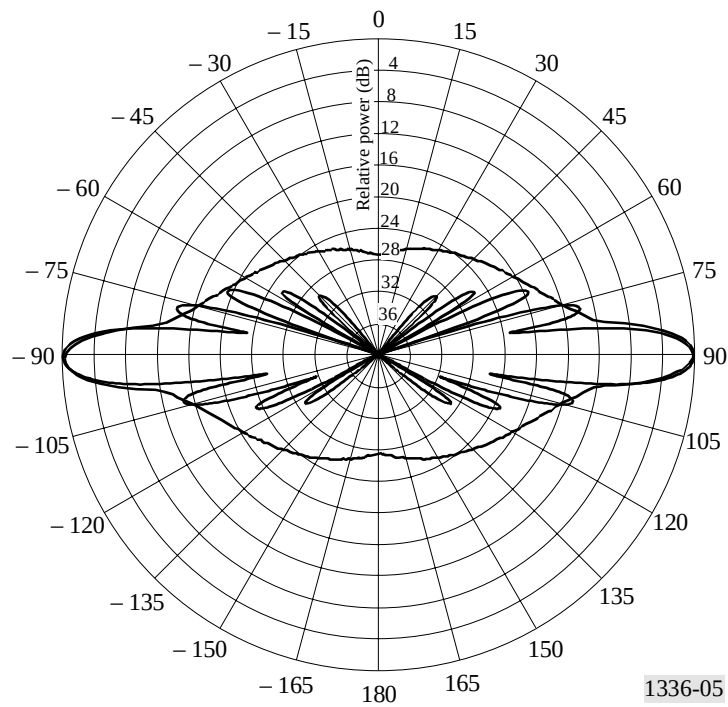


FIGURE 5

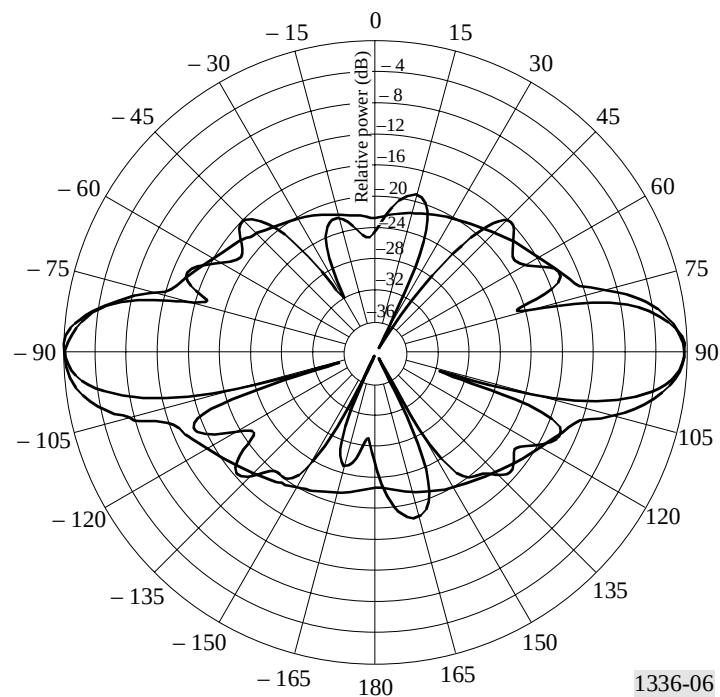
Comparison of measured and reference radiation pattern for an omnidirectional antenna with 11 dBi gain and operating in the band 928-944 MHz, $k = 0$



1336-05

FIGURE 6

Comparison of measured pattern and the reference radiation pattern envelope for an omnidirectional antenna with 8 dBi gain and operating in the band 1 850-1 990 MHz, $k = 0$



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FIGURE 7

Comparison of measured pattern and the reference radiation pattern envelope with $k = 0$ for an omnidirectional antenna with 10 dBi gain and operating in the 1.4 GHz band

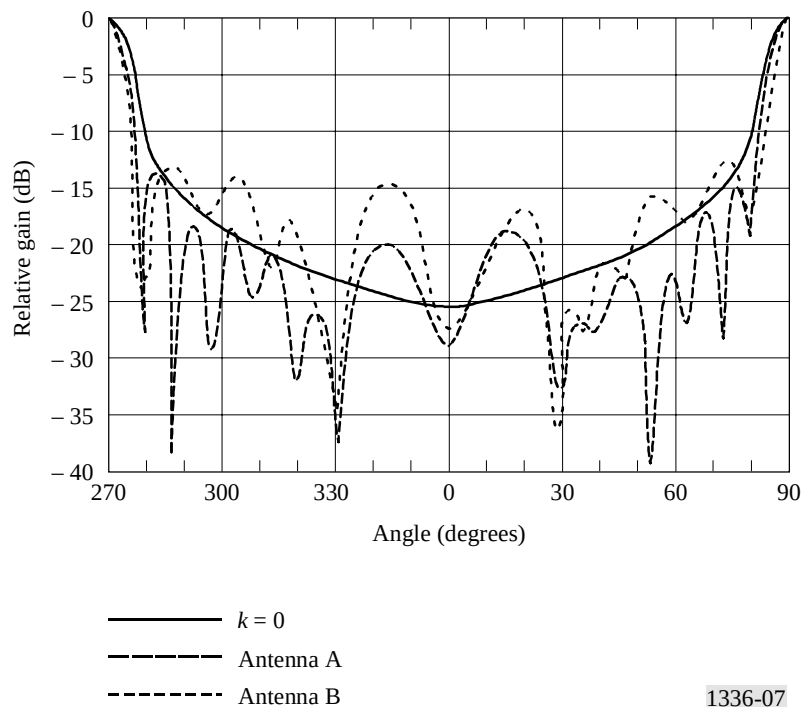


FIGURE 8

Comparison of measured pattern and the reference radiation pattern envelope with $k = 0$ for an omnidirectional antenna with 13 dBi gain and operating in the 1.4 GHz band

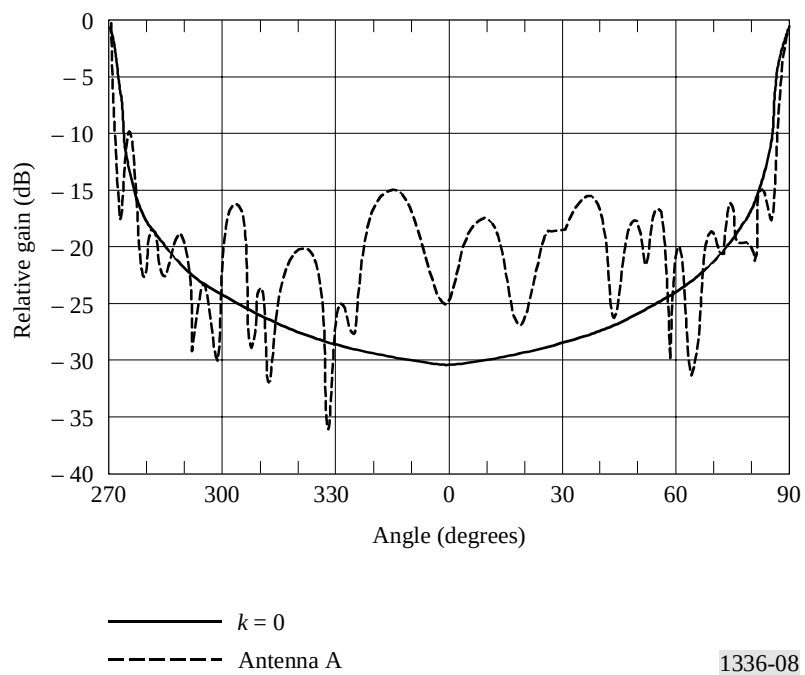


FIGURE 9

Comparison of measured pattern and the reference radiation pattern envelope with $k = 0.5$ for an omnidirectional antenna with 10 dBi gain and operating in the 2.4 GHz band

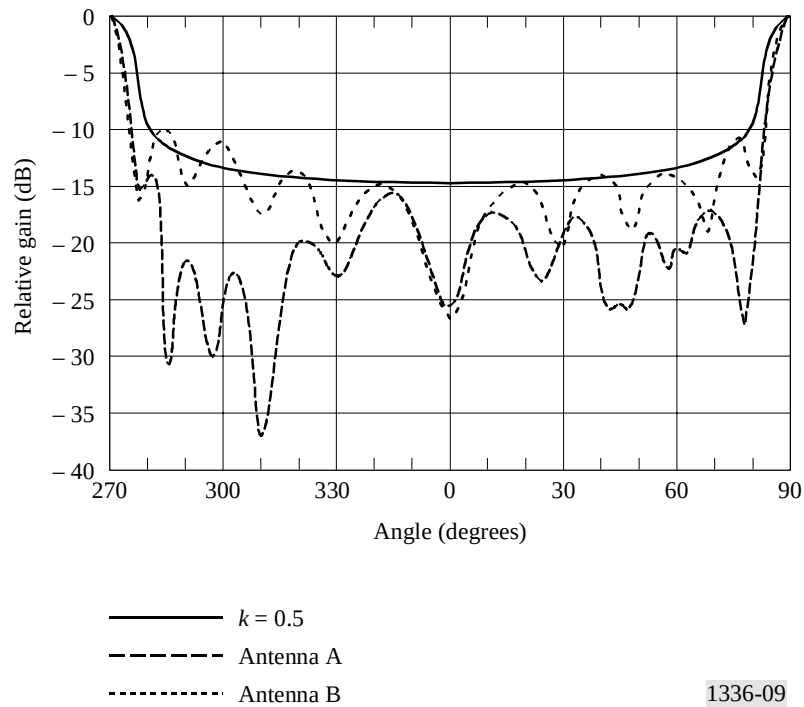


FIGURE 10

Comparison of measured pattern and the reference radiation pattern envelope with $k = 0.5$ for an omnidirectional antenna with 13 dBi gain and operating in the 2.4 GHz band

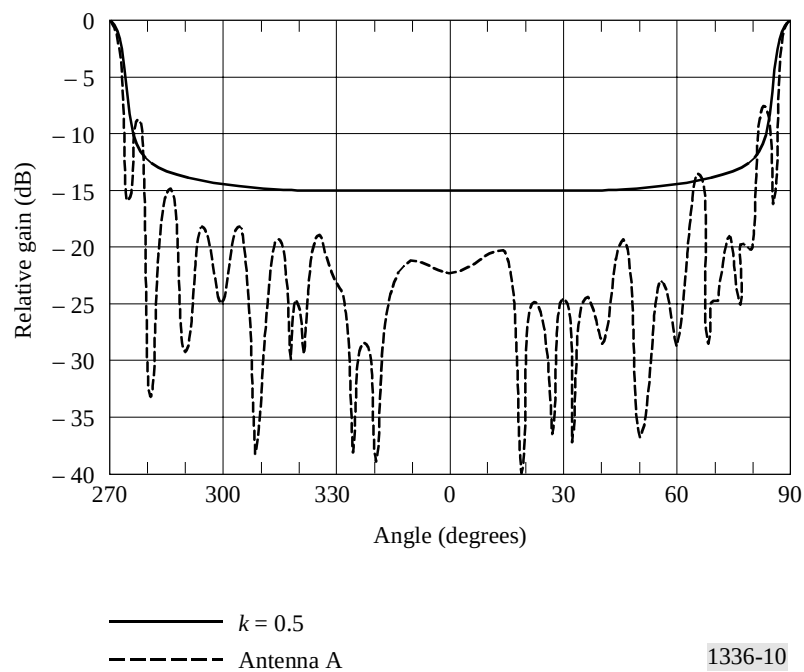
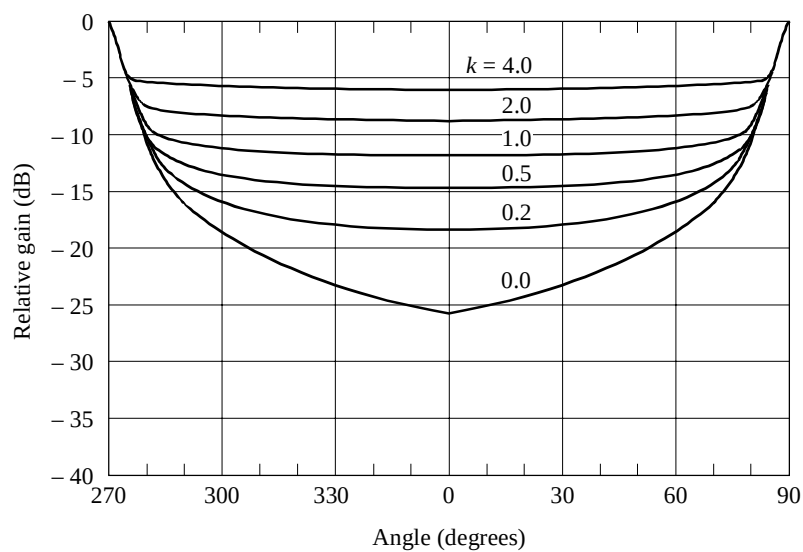


FIGURE 11

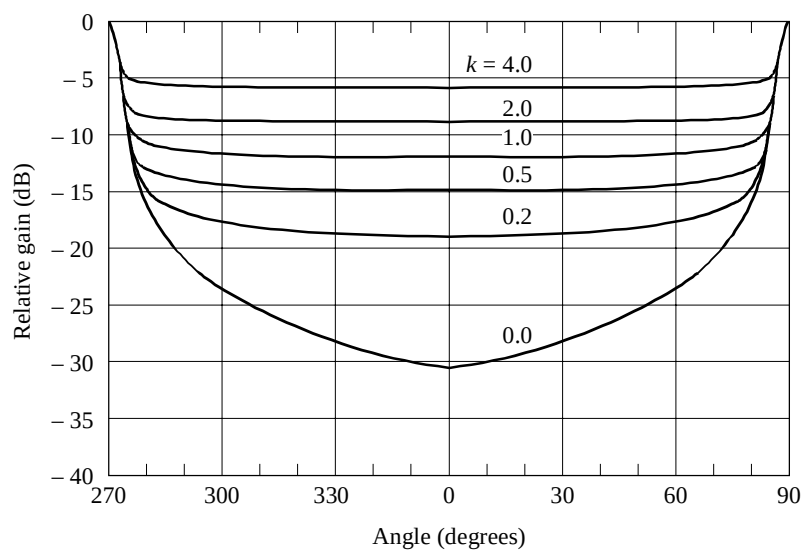
Reference radiation pattern envelopes for various values of k for an omnidirectional antenna with 10 dBi gain



1336-11

FIGURE 12

Reference radiation pattern envelopes for various values of k for an omnidirectional antenna with 13 dBi gain



1336-12

3 Summary, conclusions and further analyses

A reference radiation pattern has been presented for omnidirectional antennas exhibiting a gain between 8 and 13 dBi. The reference radiation pattern has been derived on the basis of theoretical considerations of the radiation pattern of a collinear array of dipoles. The proposed pattern has been shown to adequately represent the theoretical patterns and measured patterns over the range from 8 to 13 dBi. Further work is required to determine the range of gain over which the reference radiation pattern is appropriate especially with regard to antennas operating in frequency bands above 3 GHz.

ANNEX 2

Reference radiation pattern for low-gain circularly symmetric subscriber antennas as used in P-MP radio-relay systems

1 Introduction

An antenna with relatively low gain is frequently used for transmitting and receiving signals at the out-stations or in sectors of central stations of P-MP radio-relay systems. These antennas may exhibit a gain of the order of 20 dBi or less. It has been found that using the reference radiation pattern given in Recommendation ITU-R F.699 for these relatively low-gain antennas will result in an overestimate of the gain for relatively large off-axis angles. As a consequence, the amount of interference caused to other systems and the amount of interference received from other systems at relatively large off-axis angles will likely be substantially overestimated if the pattern of Recommendation ITU-R F.699 is used.

2 Analysis

The reference radiation pattern for a subscriber antenna is based on the following assumptions:

- that the directivity of the antenna is less than about 20 dBi;
- that the antenna pattern exhibits circularly symmetric about the main lobe;
- that the main lobe gain is equal to the directivity.

The proposed reference radiation pattern is given by:

$$G(\theta) = \begin{cases} G_0 - 12 (\theta / \varphi_3)^2 & \text{for } 0 \leq \theta < 1.078 \varphi_3 & (9) \\ G_0 - 14 & \text{for } 1.078 \varphi_3 \leq \theta < \varphi_1 & (10) \\ G_0 - 14 - 32 \log (\theta / \varphi_1) & \text{for } \varphi_1 \leq \theta < \varphi_2 & (11) \\ -8 & \text{for } \varphi_2 \leq \theta \leq 180^\circ & (12) \end{cases}$$

where:

$G(\theta)$: gain relative to an isotropic antenna (dBi)

G_0 : maximum on-axis gain (dBi)

G_1 : minimum off-axis gain (dBi)

θ : off-axis angle (degrees)

φ_3 : 3 dB beamwidth (degrees)

$$= \sqrt{27\,000 \times 10^{-0.1 G_0}}$$

$\varphi_1 = 1.9 \varphi_3$ (degrees)

$\varphi_2 = \varphi_1 \times 10^{(G_0 - 6)/32}$ (degrees).

3 Summary and conclusions

A reference radiation pattern has been presented for low-gain subscriber antennas exhibiting a gain of less than or equal to 20 dBi. The reference radiation pattern has been derived on the basis of limited data on the radiation patterns of flat plate array antennas considered for use in a local access point-to-multipoint system operating in the 2 GHz bands. The proposed pattern has been shown to more accurately represent the actual pattern than the pattern given in Recommendation ITU-R F.699. Further work is required to determine the range of gain over which the reference radiation pattern is appropriate and to compare the reference radiation pattern to measured patterns.
