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Recommendation ITU-R F.699-9

(02/2026)

F Series: Fixed service

Reference radiation patterns for fixed wireless system antennas for use in coordination studies and interference assessment in the frequency range from 100 MHz to 174.8 GHz

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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 F.699-9

Reference radiation patterns for fixed wireless system antennas for use in coordination studies and interference assessment in the frequency range from 100 MHz to 174.8 GHz

(Question ITU-R 110-3/5)

(1990-1992-1994-1995-1997-2000-2004-2006-2018-2026)

Scope

This Recommendation provides reference radiation patterns for, and information on, fixed wireless system antennas in the frequency range from 100 MHz to 174.8 GHz. This information may be used in coordination studies and interference assessments when particular information concerning the fixed wireless system (FWS) antenna is not available.

Keywords

Reference antenna radiation pattern, azimuth and elevation beamwidths, side-lobe peaks, cross polarization, frequency sharing

Abbreviations/Glossary

λ	wave length
φ	Off-axis angle (mainly in azimuth)
Θ	Off-axis angle (mainly in elevation)
D	Diameter
FSS	Fixed satellite service
FWS	Fixed wireless system
G	Antenna gain
H	Horizontal
P-P	Point to point
V	Vertical

Related ITU Recommendations

Recommendation ITU-R F.1245 – Mathematical model of average and related radiation patterns for point-to-point fixed wireless system antennas for use in interference assessment in the frequency range from 1 GHz to 86 GHz

Recommendation ITU-R F.1336 – Reference radiation patterns of omnidirectional, sectoral and other antennas for the fixed and mobile services for use in sharing studies in the frequency range from 400 MHz to about 70 GHz

The ITU Radiocommunication Assembly,

considering

a) that the reference radiation pattern of point-to-point fixed wireless system (FWS) antennas stated in Recommendation ITU-R F.1245 provides the antenna radiation pattern representing average side-lobe levels;

b) that if the average side-lobe radiation pattern is used in the assessment of the interference from a single source, the predicted interference will result in values that may be less than values that would be experienced in practice;

c) that, therefore, it is necessary to use the antenna radiation pattern of side-lobe peaks for FWS stations in the following cases:

– to predict the single-entry interference between a geostationary satellite and single FWS station, where the aggregation of interference from multiple sources is not considered;

– to predict the single-entry interference between FWS stations, where the aggregation of interference from multiple sources is not considered;

– to predict the single-entry interference between FWS stations and stations in space radiocommunication and other services sharing the same frequency band, where variable interference from a moving source or the aggregation of interference from multiple sources are not considered;

d) that, for the above studies, radiation patterns based on the level exceeded by a small percentage of the side-lobe peaks may be appropriate;

e) that the side-lobe patterns of antennas of different sizes are strongly influenced by the ratio of the antenna diameter to the operating wavelength;

f) that the antenna gain may be estimated by the ratio of the antenna diameter to the operating wavelength;

g) that in cases where only the maximum antenna gain is known, the ratio between the antenna diameter and the wavelength (D/λ) may be estimated for antennas with circular symmetry;

h) that reference radiation patterns are required for the case where information concerning the antenna diameter is not available;

i) that, at large angles, the likelihood of local ground reflections must be considered;

j) 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 FWS antenna involved (see Note 1), and taking into account *considering c)*, the reference radiation pattern as stated below should be considered for:

1.1 interference assessment between FWS;

1.2 coordination studies and interference assessment between FWS stations and stations in space radiocommunication and other services sharing the same frequency band;

2 that the following reference radiation pattern should be adopted for frequencies in the range 100 MHz to 174.8 GHz;

2.1 in cases where the ratio between the antenna diameter and the wavelength is greater than 100, the following equations should be used (see Notes 6 and 7):

2.1.1 for frequencies in the range 1 GHz to 70 GHz,

$$G(\varphi) = G_{max} - 2.5 \times 10^{-3} \left(\frac{D}{\lambda}\varphi\right)^2 \quad \text{for } 0° < \varphi < \varphi_m$$

$$G(\varphi) = G_1 \quad \text{for } \varphi_m \leq \varphi < \varphi_r$$

$$G(\varphi) = 32 - 25 \log \varphi \quad \text{for } \varphi_r \leq \varphi < 48°$$

$$G(\varphi) = -10 \quad \text{for } 48° \leq \varphi \leq 180°$$

2.1.2 for frequencies in the range 70 GHz to 86 GHz,

$$G(\varphi) = G_{max} - 2.5 \times 10^{-3} \left(\frac{D}{\lambda}\varphi\right)^2 \quad \text{for } 0° < \varphi < \varphi_m$$

$$G(\varphi) = G_1 \quad \text{for } \varphi_m \leq \varphi < \varphi_r$$

$$G(\varphi) = 32 - 25 \log \varphi \quad \text{for } \varphi_r \leq \varphi < 120°$$

$$G(\varphi) = -20 \quad \text{for } 120° \leq \varphi \leq 180°$$

where:

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

φ: off-axis angle (degrees)

D: antenna diameter
λ: wavelength
} expressed in the same units

G_1: gain of the first side-lobe = $2 + 15 \log \frac{D}{\lambda}$ (dBi)

$$\varphi_m = \frac{20\lambda}{D}\sqrt{G_{max} - G_1} \quad \text{degrees}$$

$$\varphi_r = 15.85 \left(\frac{D}{\lambda}\right)^{-0.6} \quad \text{degrees}$$

2.2 in cases where the ratio between the antenna diameter and the wavelength is less than or equal to 100, the following equations should be used (see Notes 6 and 7):

2.2.1 for frequencies in the range 1 GHz to 70 GHz

$$G(\varphi) = G_{max} - 2.5 \times 10^{-3} \left(\frac{D}{\lambda}\varphi\right)^2 \quad \text{for } 0° < \varphi < \varphi_m$$

$$G(\varphi) = G_1 \quad \text{for } \varphi_m \leq \varphi < 100\frac{\lambda}{D}$$

$$G(\varphi) = 52 - 10 \log \frac{D}{\lambda} - 25 \log \varphi \quad \text{for } 100\frac{\lambda}{D} \leq \varphi < 48°$$

$$G(\varphi) = 10 - 10 \log \frac{D}{\lambda} \quad \text{for } 48° \leq \varphi \leq 180°$$

2.2.2 for frequencies in the range 70 GHz to 86 GHz,

$$G(\varphi) = G_{max} - 2.5 \times 10^{-3} \left(\frac{D}{\lambda}\varphi\right)^2 \quad \text{for } 0° < \varphi < \varphi_m$$

$$G(\varphi) = G_1 \quad \text{for } \varphi_m \leq \varphi < 100\frac{\lambda}{D}$$

$$G(\varphi) = 52 - 10\log\frac{D}{\lambda} - 25\log\varphi \qquad \text{for } 100\frac{\lambda}{D} \leq \varphi < 120°$$

$$G(\varphi) = -10\log\frac{D}{\lambda} \qquad \text{for } 120° \leq \varphi \leq 180°$$

2.3 for frequencies in the range 100 MHz to less than 1 GHz, in cases where the ratio between the antenna diameter and the wavelength is greater than 0.63 (G_{max} is greater than 3.7 dBi), the following equations should be used:

$$G(\varphi) = G_{max} - 2.5\times10^{-3}\left(\frac{D}{\lambda}\varphi\right)^2 \qquad \text{for } 0° < \varphi < \varphi_m$$

$$G(\varphi) = G_1 \qquad \text{for } \varphi_m \leq \varphi < 100\frac{\lambda}{D}$$

$$G(\varphi) = 52 - 10\log\frac{D}{\lambda} - 25\log\varphi \qquad \text{for } 100\frac{\lambda}{D} \leq \varphi < \varphi_s$$

$$G(\varphi) = -2 - 5\log\frac{D}{\lambda} \qquad \text{for } \varphi_s \leq \varphi \leq 180°$$

where:

$$\varphi_s = 144.5\left(\frac{D}{\lambda}\right)^{-0.2}$$

2.4 that for frequencies between 86 and 174.8 GHz, the same equations given in *recommends* 2 for frequencies between 70 GHz and 86 GHz (see *recommends* 2.1.2 and 2.2.2) should be used (see Note 8);

3 that in cases where only the maximum antenna gain is known, D/λ (both D and λ expressed in the same unit) may be estimated from the following expression (see Note 5):

$$20\log\frac{D}{\lambda} \approx G_{max} - 7.7$$

where G_{max} is the main lobe antenna gain (dBi). Where only the ratio D/λ is known, the maximum antenna gain may be estimated from the following expression: $G_{max} \approx 20\log\frac{D}{\lambda} + 7.7$.

Therefore, G_{max} approximates 48 dBi for $D/\lambda = 100$;

4 that in cases where only the beamwidths of the antenna are known:

4.1 D/λ (expressed in the same unit) may be estimated approximately by the following expression:

$$D/\lambda \approx 70/\theta$$

where θ is the beamwidth (−3 dB) (degrees);

4.2 given θ, G_{max} may be estimated approximately by:

$$G_{max}\ (dBi) \approx 44.5 - 20\log\theta$$

5 that the ITU-R membership submit measured radiation patterns or specifications to allow new and improved reference radiation patterns for use in coordination studies and interference assessment to be developed and proposed (see Attachment 1 to Annex 1);

6 that Annex 1 should be referred to for additional information concerning reference radiation patterns for FWS antennas;

7 that for the detailed calculation of interference levels on interference paths, it is necessary to consider the cross-polar response of the victim and interfering system antennas;

7.1 that for the calculation in *recommends* 7, including the component of signal radiated on the intended polarity by the transmitting antenna and the co-polar response of the victim receive antenna to the component of signal radiated on the unintended polarity by the transmitting antenna, the following equation may be used:

$$G_t(\varphi_t) + G_r(\varphi_r) = 10 \cdot \log\left(10^{\frac{G_{tH}(\varphi_t) + G_{rV}(\varphi_r)}{10}} + 10^{\frac{G_{tV}(\varphi_t) + G_{rH}(\varphi_r)}{10}}\right) \quad \text{dBi}$$

where the following parameters refer to antenna gain (dBi):

$G_t(\varphi_t)$: transmit antenna effective gain in the direction of the victim antenna

$G_r(\varphi_r)$: receive antenna effective gain in the direction of the interfering antenna

$G_{tH}(\varphi_t)$: horizontally polarized gain component of the transmit antenna

$G_{rV}(\varphi_r)$: vertically polarized gain component of the receive antenna

$G_{tV}(\varphi_t)$: vertically polarized gain component of the transmit antenna

$G_{rH}(\varphi_r)$: horizontally polarized gain component of the receive antenna.

φ_t and φ_r: are the angles between the direction of main beam and direction towards victim and transmitting antenna respectively.

Further information and numerical examples on using the equation above is given in Annex 2.

8 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 – It should be noted that the radiation pattern of an actual antenna may be worse than the reference radiation pattern over a certain range of angles (see Note 3). Therefore, the reference radiation pattern in this Recommendation should not be interpreted as establishing the maximum limit for radiation patterns of existing or planned FWS antennas. Noting that for certification purpose, administrations may adopt standards, usually based on statistical measurements of real antennas, that may represent different values for the side-lobe radiation pattern levels.

NOTE 3 – The reference radiation pattern should be used with caution over the range of angles for which the particular feed system may give rise to relatively high levels of spill-over.

NOTE 4 – The reference pattern in *recommends* 2 is only applicable for one polarization (horizontal or vertical). Reference patterns for two polarizations (horizontal and vertical) are under study.

NOTE 5 – The reference radiation pattern included in this Recommendation is only for antennas which are rotationally symmetrical. It can be applied also to square/polygonal reflectors and flat panel antennas, provided that their equivalent D/λ ratio is derived from the maximum gain, using formula in *recommends* 3. The reference radiation pattern for antennas with asymmetrical apertures and for non-aperture FWS antennas in the frequency range from 100 MHz to 1 GHz requires further study. For such antennas, the above reference patterns may be considered to be provisionally valid. In this case, the D/λ value computed from G_{max} is an equivalent D/λ and not the actual D/λ.

NOTE 6 – Mathematical models of average radiation patterns for use in certain coordination studies and interference assessment are given in Recommendation ITU-R F.1245.

NOTE 7 – Reference radiation patterns of omnidirectional and sectoral antennas in point-to-multipoint systems are given in Recommendation ITU-R F.1336.

NOTE 8 – Further study is required to ensure that reference radiation patterns continue to develop to take account of advances in antenna design.

NOTE 9 – While generally applicable, the reference pattern in *recommends* 2 does not suitably model some practical fixed service antennas and it should be treated with caution over a range of angles from 5° to 70° (see also NOTES 2 and 3).

NOTE 10 – In Annex 1, for some Figures representing antennas above 70 GHz, the patterns for equations in *recommends* 2.1 and 2.2 referring to antennas below 70 GHz are provided only for information.

Annex 1

Reference radiation patterns for FWS antennas

TABLE OF CONTENTS

Page

1 Introduction

For the study of frequency sharing between FWS and the FSS or of the possibility of frequency reuse in a FWS network, it is often necessary to use a reference diagram, because the actual radiation pattern of the antennas is not always accurately known or gives too many details. The reference pattern should therefore represent the side-lobe peaks in a simplified fashion.

The reference radiation pattern to be selected may, however, vary according to the use for which it is intended.

In general, the reference radiation patterns in the main text of this Recommendation shall be used.

2 Uses of reference radiation patterns

The two main uses of reference radiation patterns are the following:

2.1 Preliminary studies within the coordination area

In the determination of the coordination area around an earth station, FWS station antennas are assumed to point directly at the earth station. However, in most cases there will be some angular discrimination. The use of a simple reference radiation diagram makes it possible to eliminate from further consideration FWS stations situated in the coordination area but not likely to produce interference.

This diagram, must, of necessity, be conservative to prevent the elimination of critical contributing sources of interference. The precise calculation of the interference level, of course, requires more accurate information on the antenna diagram.

2.2 Frequency reuse in a fixed wireless network

In a fixed wireless network, the same frequency may be used many times, either on sections sufficiently distant from each other or on sections starting from the same station and lying in different directions, or on the same section using cross-polarization.

In the last two cases, the performance of the antenna is of great importance, and a fairly precise reference radiation pattern must be used for the network project; this pattern may be less simple than that considered in § 2.1, administrations are encouraged to use high performance antenna types in high spectrum use areas.

3 Results of measurements on the antennas of fixed wireless links

Measurements with numerous antennas provide adequate confirmation of the reference radiation patterns in the main text of this Recommendation at least up to a value of D/λ of approximately 180. However, the following points must be borne in mind:

3.1 Some antennas of relatively old designs have less satisfactory performance characteristics than more recent models. The existence of such medium performance antennas should be taken into account for frequency sharing.

3.2 The above computation is based on the assumption that the antennas operate in free-space conditions. The performance characteristics of antennas installed in the field may, however, be slightly less satisfactory owing to reflection from neighbouring obstacles or from other antennas installed on the same mast.

Attachment 1
to Annex 1

Measured patterns for use in the further development of this Recommendation

1 Introduction

There is a continuing need to review and update the reference radiation patterns contained in this Recommendation. This Attachment contains comparisons of some practical antenna pattern envelopes and radiation patterns with the corresponding reference patterns derived from this Recommendation and Recommendation ITU-R F.1245.

It is noted that in some cases, a portion of the side lobes of the measured patterns exceed the reference pattern of this Recommendation. This observation is further described in Notes 2 and 3 to the *recommends* section, which points out that this Recommendation provides appropriate reference patterns to be used in studies, and not maximum limits for real antennas.

FIGURE 1

2 150 MHz point-to-point antenna of 1 m diameter (*D*/λ= 7.14; gain= 22.4 dBi)

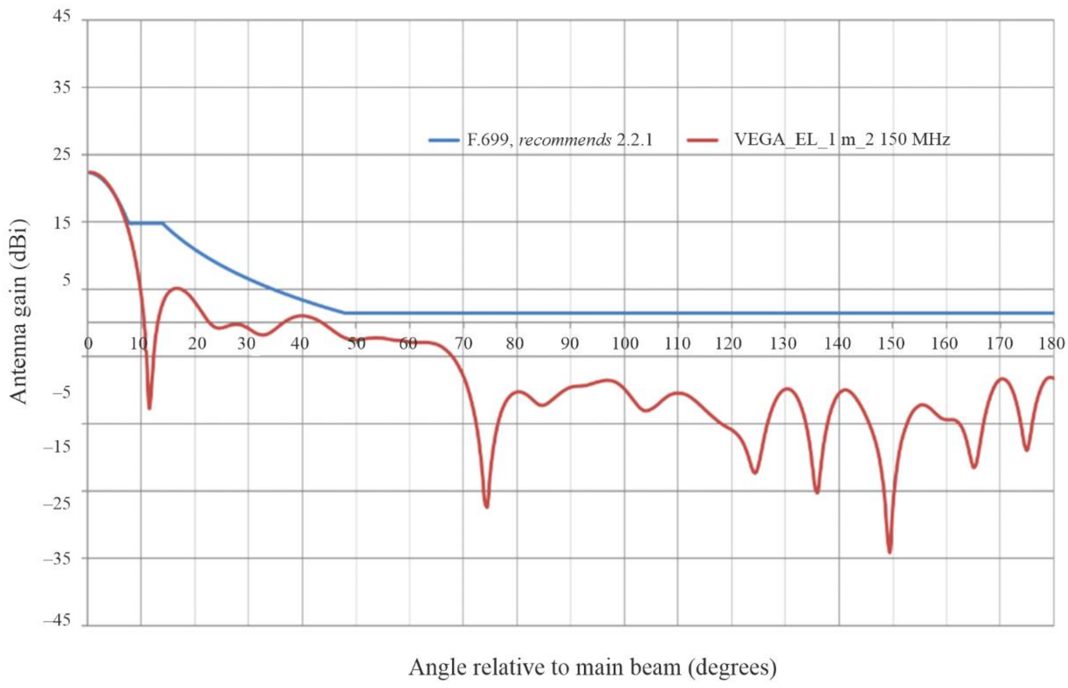

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FIGURE 2

10.7 GHz point-to-point antenna of 3 m diameter (*D*/λ = 114; gain = 49.8 dBi) (H: horizontal polarization, V: vertical polarization)

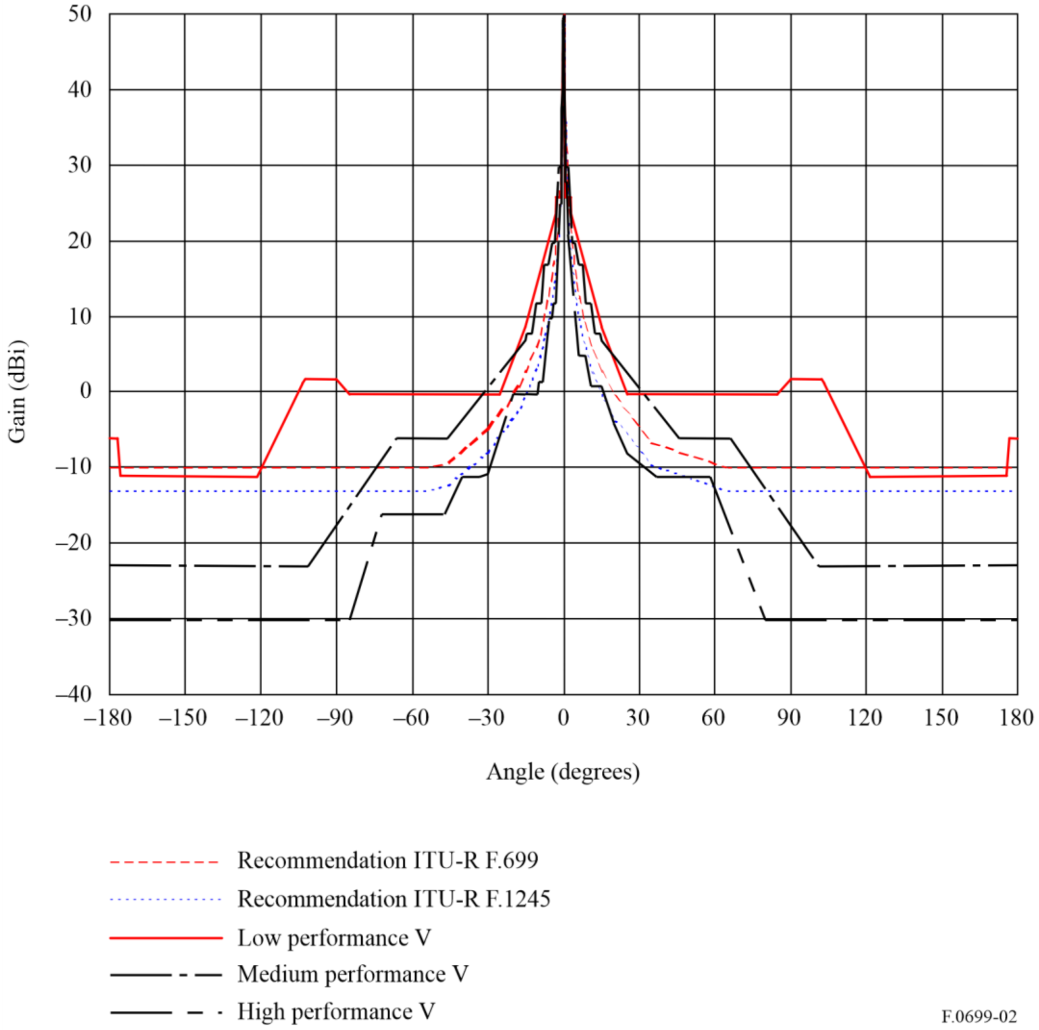


FIGURE 3

10.7 GHz point-to-point antennas of 1.8 m diameter (D/λ = 14.6; Patterns for a sample of production antennas with horizontal polarization)

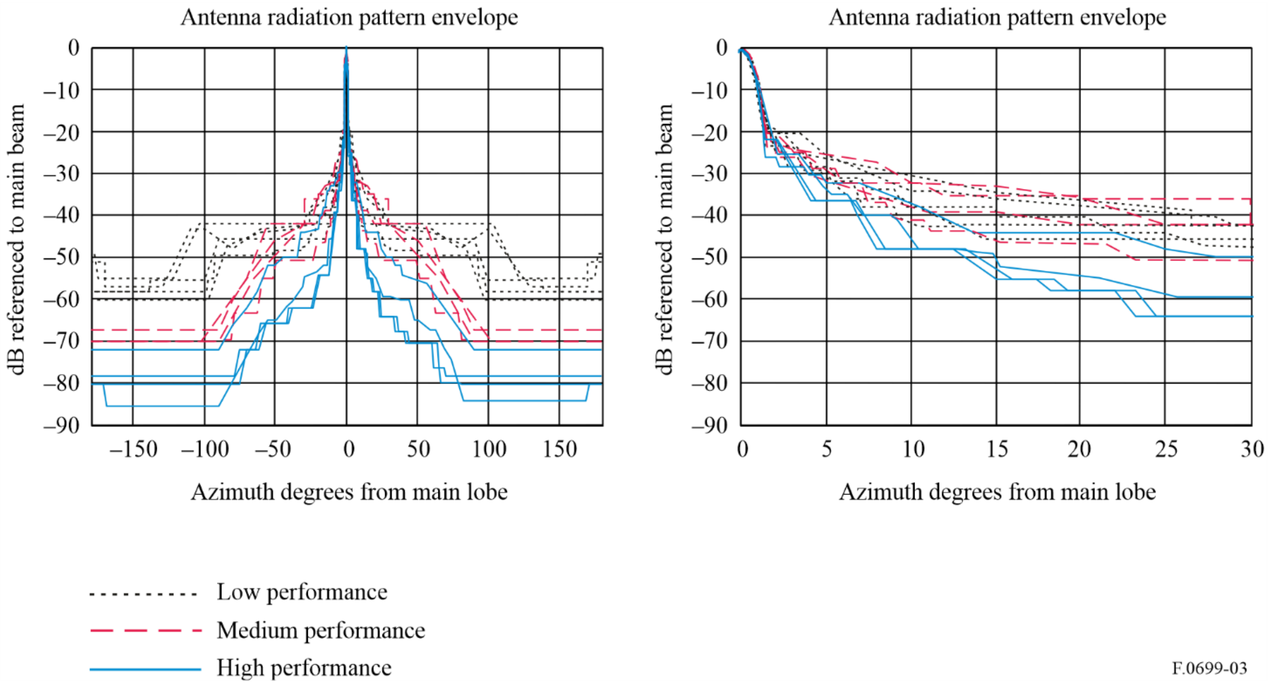


FIGURE 4

10.5 GHz point-to-point antenna of 1.2 m diameter (*D*/λ = 43; gain = 39.9 dBi) (H: horizontal polarization, V: vertical polarization)

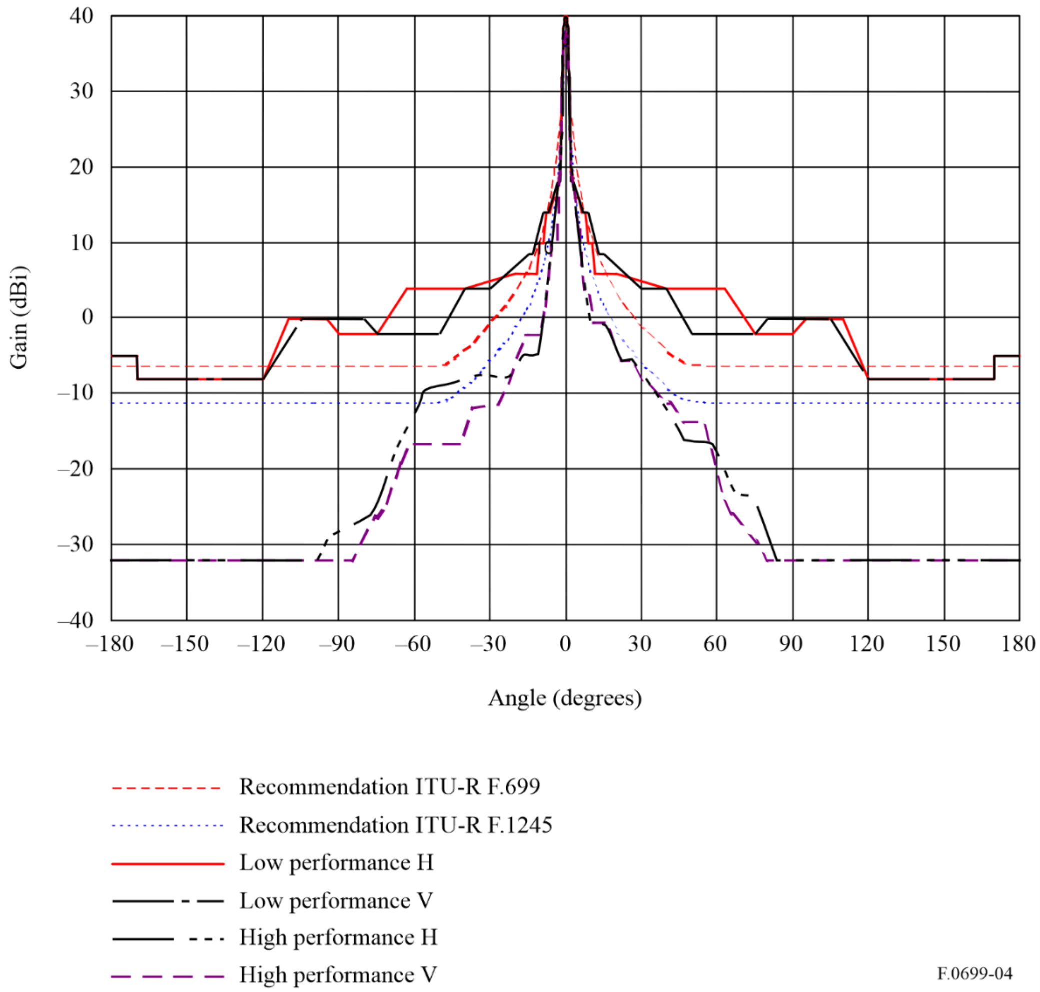


FIGURE 5

21 GHz lens horn point-to-point antenna of 50 cm diameter (*D*/λ = 37; gain = 40 dBi)

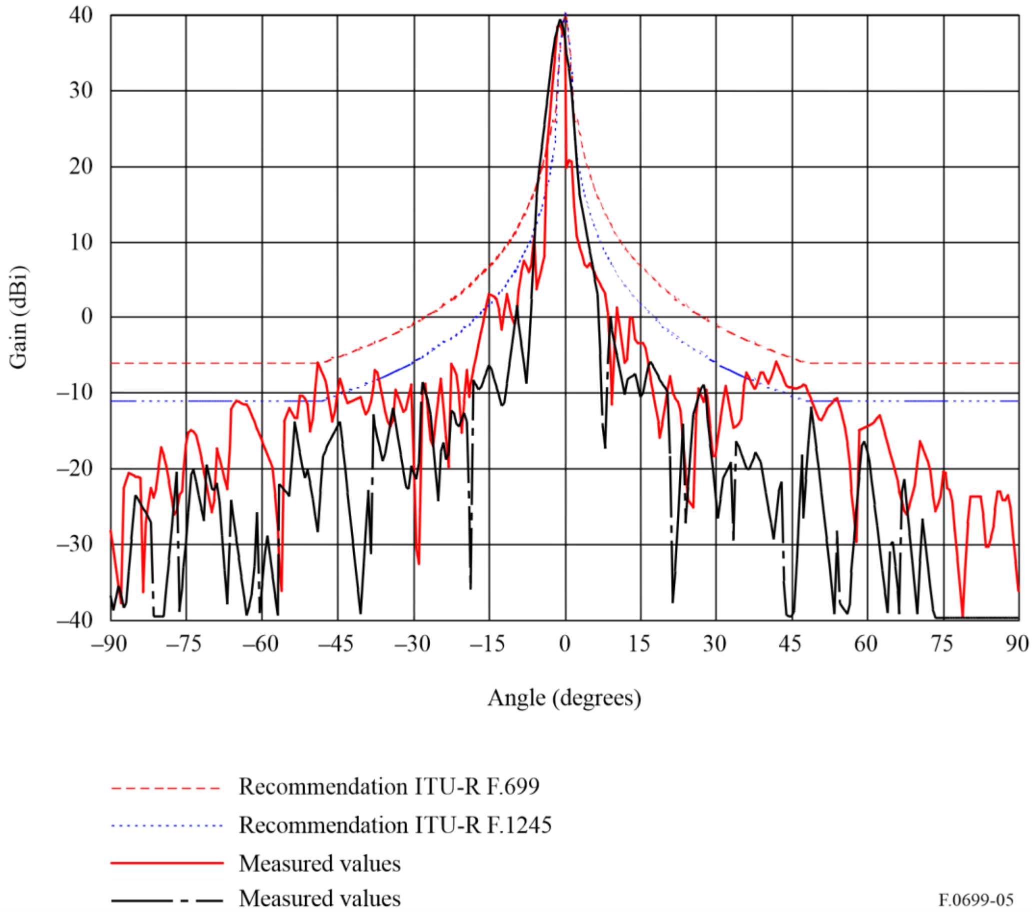


FIGURE 6

31 GHz point-to-point antenna of 0.3 m diameter (D/λ = 32; gain = 36.9 dBi) (H: horizontal polarization, V: vertical polarization)

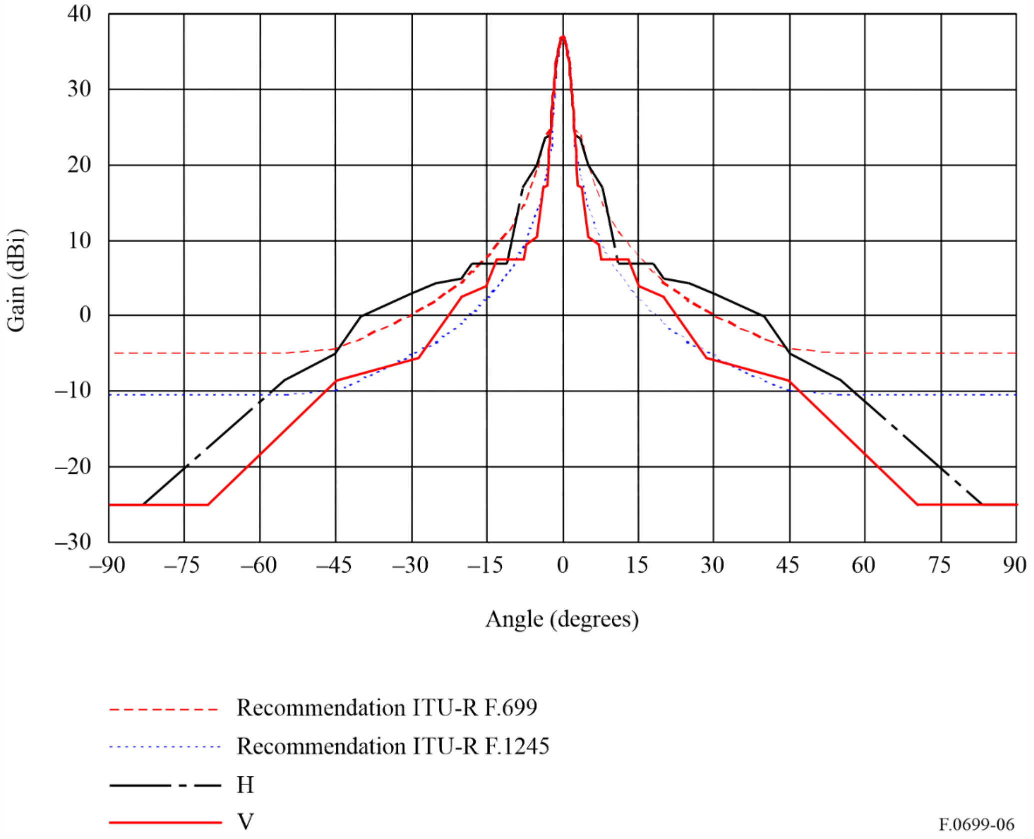
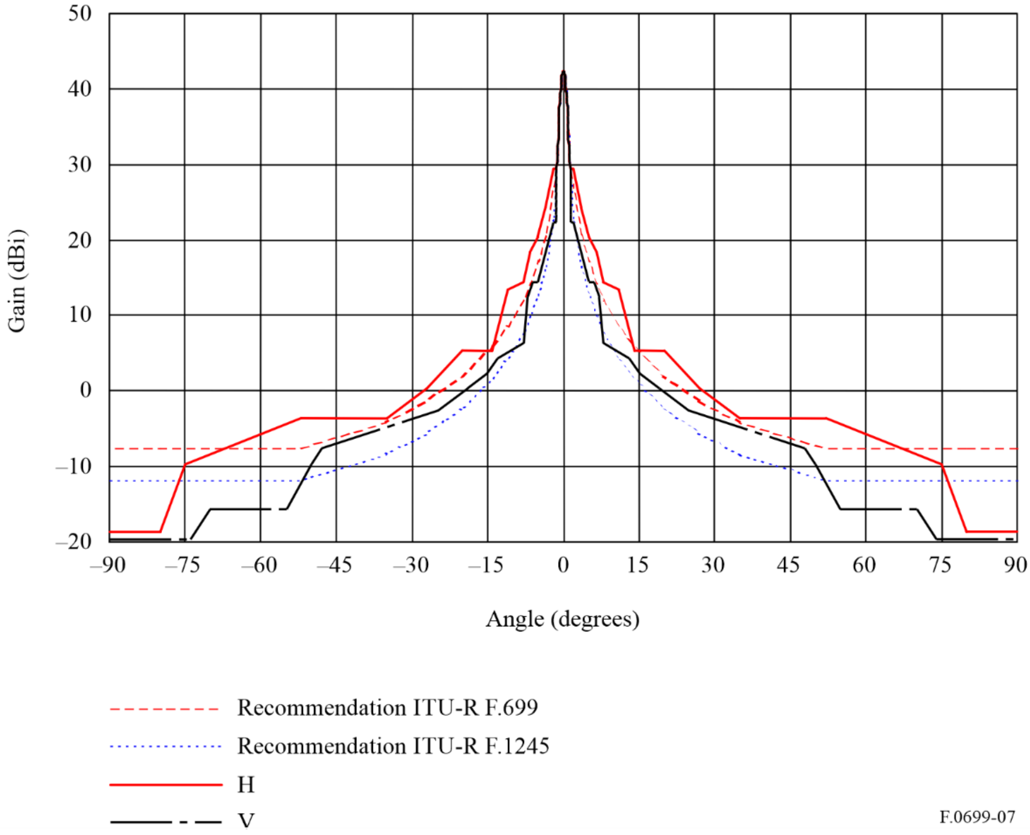


FIGURE 7

55 GHz point-to-point antenna of 0.3 m diameter (*D*/λ = 57; gain = 42.4 dBi) (H: horizontal polarization, V: vertical polarization)



The following Figures depict measured patterns of antennas operating above 70 GHz, compared to the equations in *recommends* 2.1.2 (for D/λ >100) and 2.2.2 (for D/λ ≤100) (see Note 10). Antenna patterns at and above 275 GHz are available in the Report ITU-R F.2416.

FIGURE 8

Example of 76 GHz point-to-point antenna of 1 foot diameter (D/λ = 96; gain = 44.4 dBi; θ_3 = 1.0°) compared to *recommends* 2.2.2 (see Note 10)

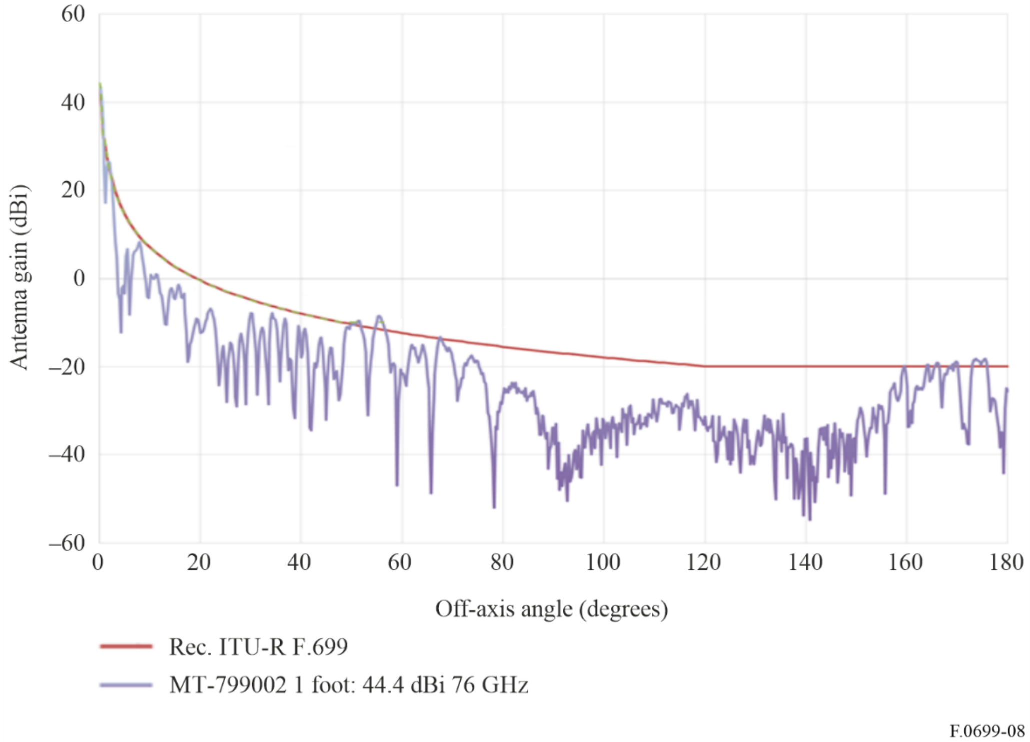


FIGURE 9

Example of 71 GHz point-to-point antenna of 65 cm diameter (D/λ = 154; gain = 49.2 dBi; θ_3 = 0.5°) compared to *recommends* 2.1.1 and 2.1.2 (see Note 10)

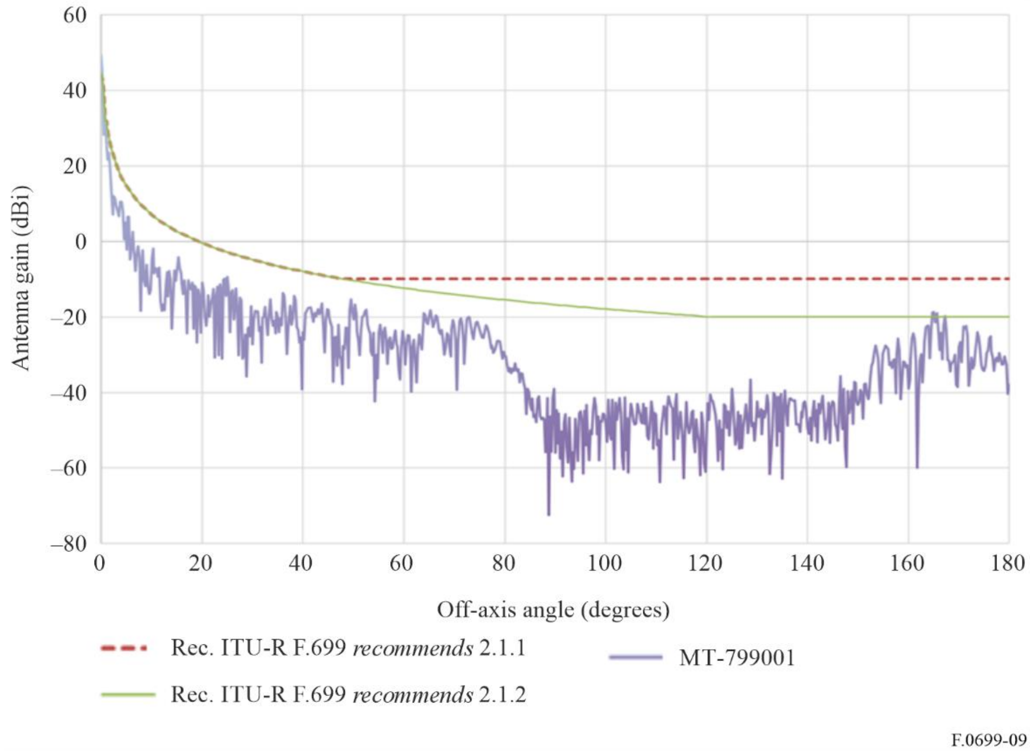


FIGURE 10

Example of 72 GHz point-to-point antenna of 2 foot diameter (*D*/λ = 144; gain = 50 dBi; θ_3 = 0.5°) compared to *recommends* 2.1.2 (see Note 10)

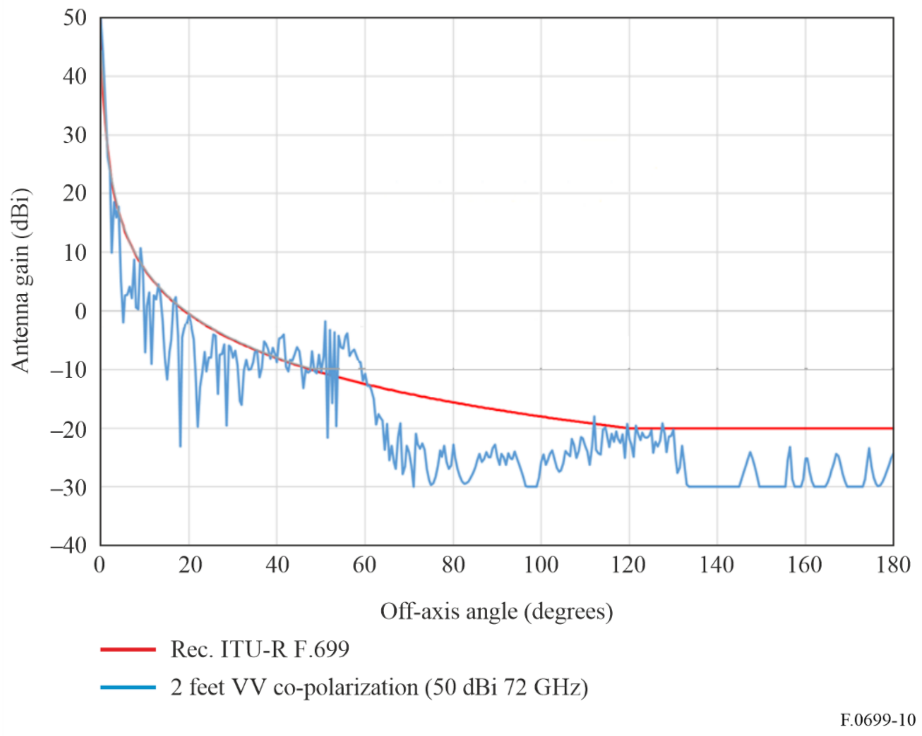


FIGURE 11

Example of 72 GHz point-to-point antenna of 1 foot diameter (*D*/λ = 72; gain = 44 dBi; θ_3 = 1°) compared to *recommends* 2.2.2 (see Note 10)

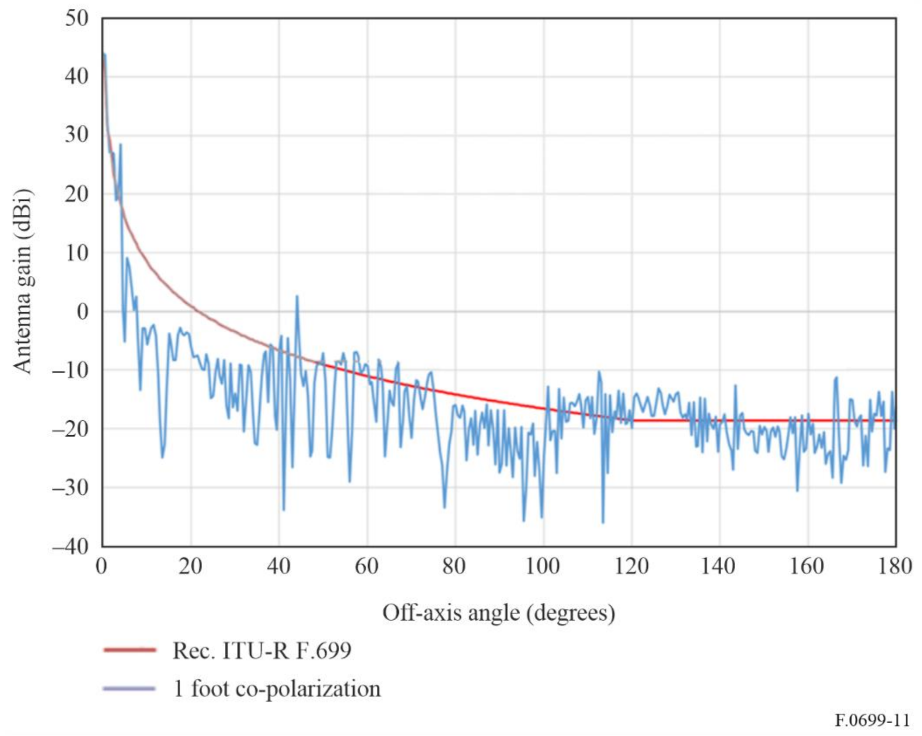


FIGURE 12

Example of 86 GHz square point-to-point antenna of 70 mm × 70 mm × 4 mm approximate dimensions (D/λ = 16.4; gain = 32 dBi) compared to *recommends* 2.1.1 and 2.1.2 (see Notes 5 and 10)

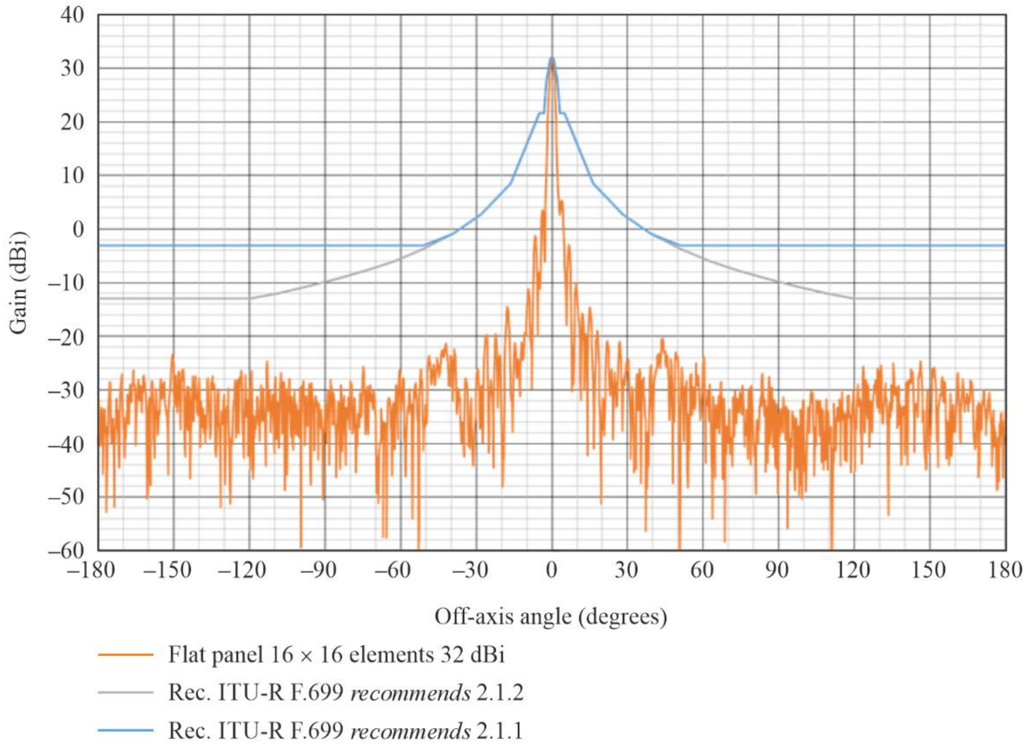


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FIGURE 13

Example of 83.5 GHz flat square point-to-point antenna (D/λ = 40.7; gain = 39.9 dBi), horizontal co-polar attenuation (not gain) pattern (in blue), compared to *recommends* 2.2.2 (in black) (see Notes 5 and 10)

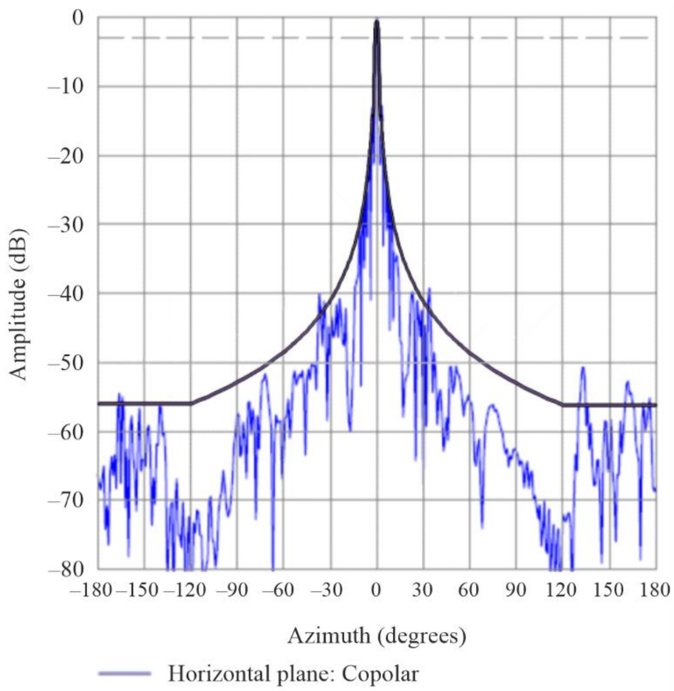

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FIGURE 14

Example of 86 GHz 2 foot point-to-point antenna with vertical polarization (*D*/λ=172) compared to *recommends* 2.1.2 (see Note 10)

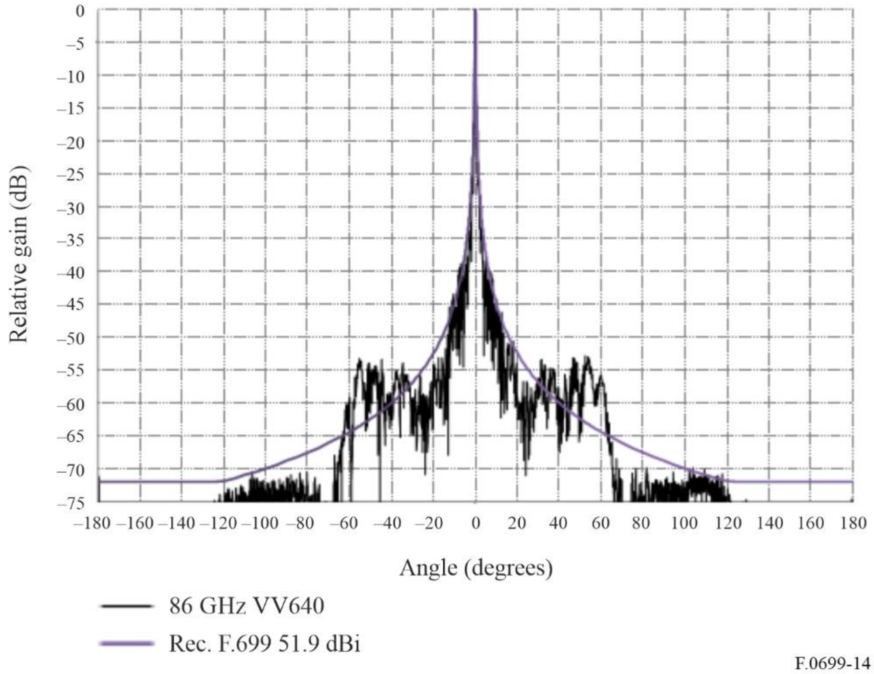

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FIGURE 15

Example of 96 GHz Cassegrain point-to-point antenna of 20 cm diameter (*D*/λ = 64; gain = 44 dBi) compared to *recommends* 2.2.2

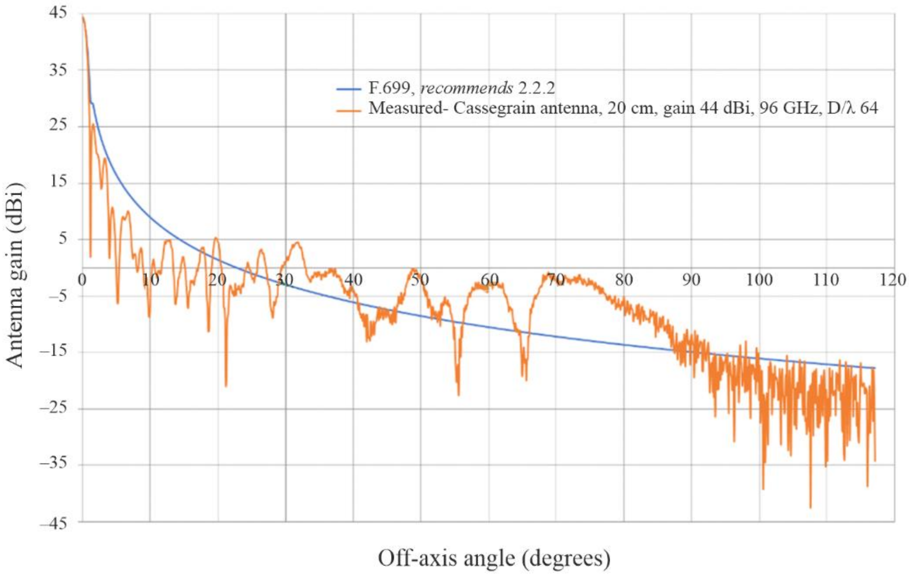

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FIGURE 16

Example of 152 GHz 16 × 16 slot array with H-plane (D/λ = 40.7; gain = 31 dBi) compared to *recommends* 2.2.2 (see Notes 5 and 10)

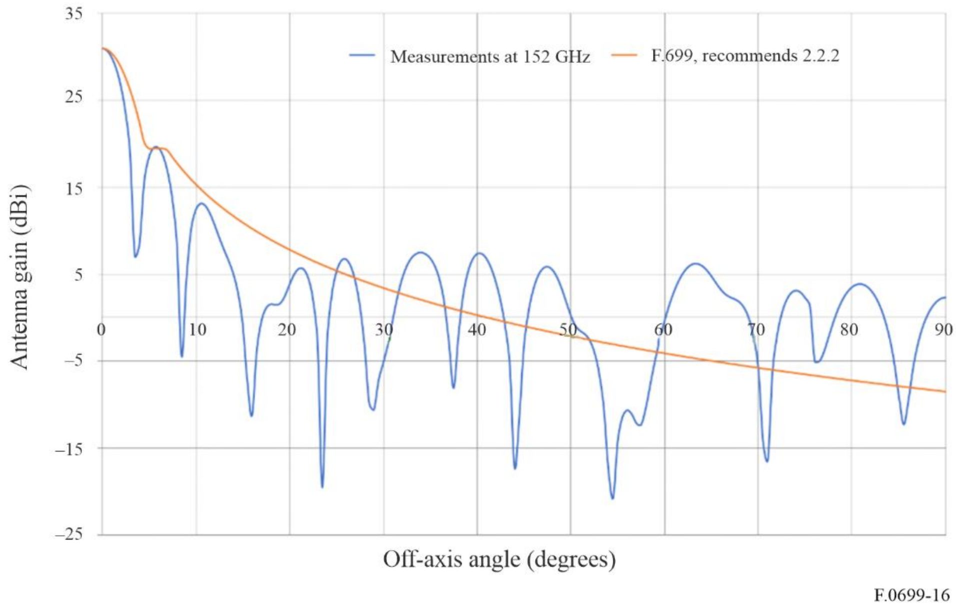
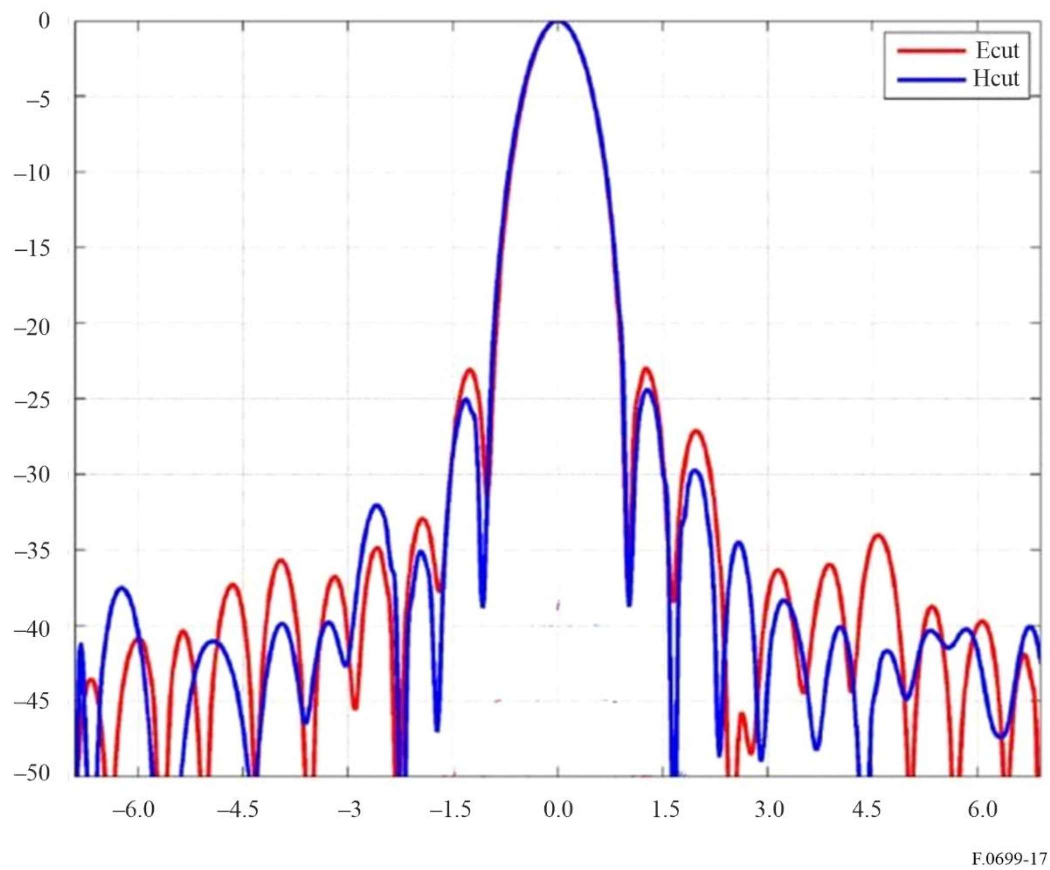


FIGURE 17

Example of 157 GHz Gaussian optics lens-horn antenna; diameter 150 mm, D/λ 78.5, Gain 44.9 dBi, 3 dB beamwidth 0.810. Relative V and H gains, dB versus angle in degrees



Annex 2

Information on the application of *recommends* 7

1 Introduction

Some Figures and numerical examples are given with the aim to support the designations used in the equation of *recommends* 7.1.

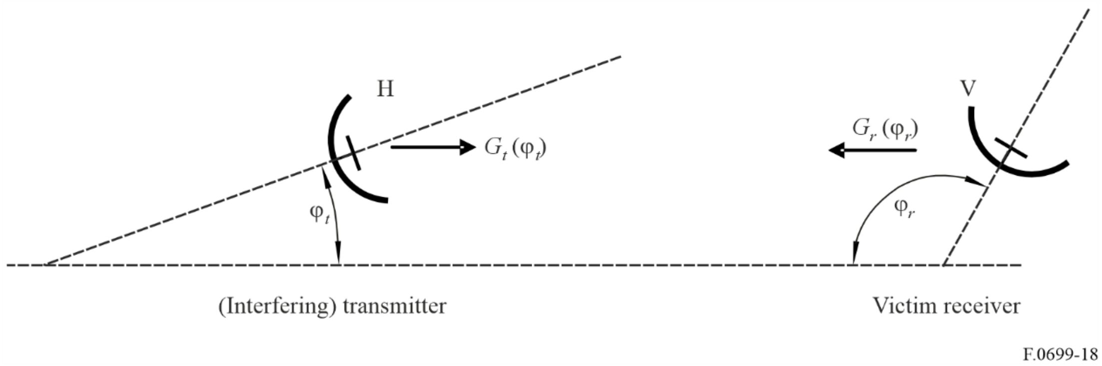
An alternative equation (see § 4) can be used if relative antenna gains data are given.

In the case of a mutual gain calculation between co-polar antennas the alternative equation shall be used (see § 5).

2 Situation

FIGURE 18

Generic example of mutual situation and orientation of transmitting antenna and victim receiving antenna



3 The numerical example

FIGURE 19

Example of transmitter antenna mask for co- and cross-polarization

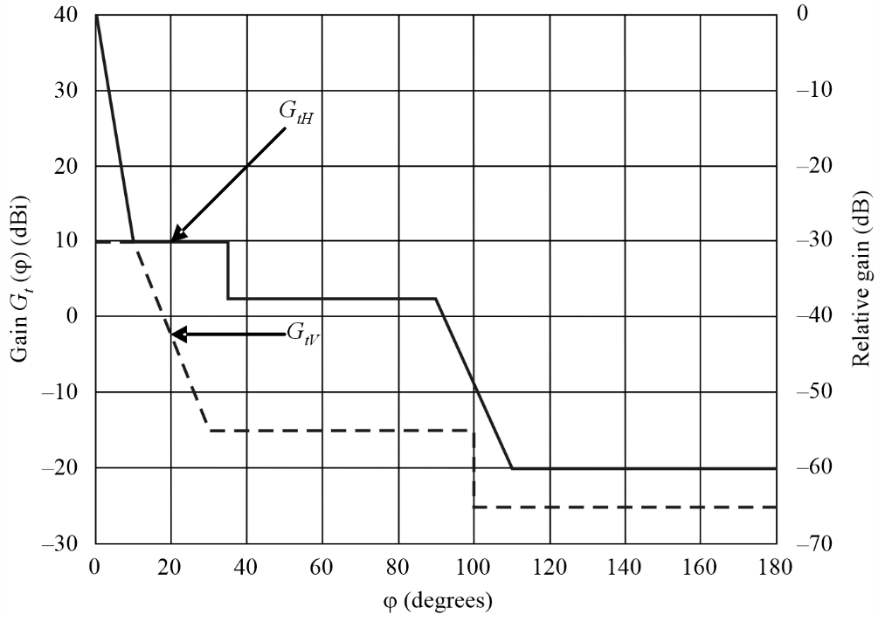


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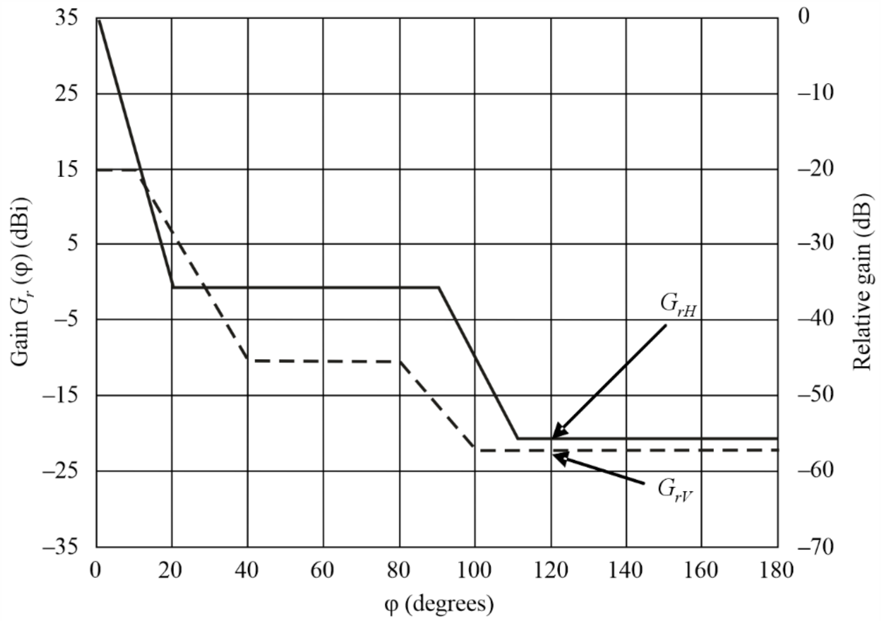
FIGURE 20

Example of receiver antenna mask for co- and cross-polarization



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The example for cross-polarized antennas is given below.

The following values can be obtained from Figs 18, 19 and 20:

$\varphi_t =$ 20°

$\varphi_r =$ 120°

$G_{tH}(\varphi_t) =$ 10 dBi

$G_{rV}(\varphi_r) =$ −21.6 dBi

$G_{tV}(\varphi_t) =$ −2 dBi

$G_{rH}(\varphi_r) =$ −20 dBi

Using these values in the equation gives us the following result: $G_t(20°) + G_r(120°) = -11.6$ dBi.

Due to the reciprocity theorem the result of a mutual gain calculation is the same if the transmitter and receiver antennas are exchanged.

4 Alternative equation for cross-polarized case

In the case that G_{tmax}, G_{rmax} and relative gain of sideband lobes are given (as shown in the right side scale in Figs 19 and 20), equation (2) is applicable:

$$G_t(\varphi_t) + G_r(\varphi_r) = G_{tmax} + G_{rmax} + 10 \cdot \log\left(10^{\frac{G_{tH}(\varphi_t)+G_{rV}(\varphi_r)}{10}} + 10^{\frac{G_{tV}(\varphi_t)+G_{rH}(\varphi_r)}{10}}\right) \quad \text{dBi} \qquad (1)$$

In equation (1) G_{tmax}, G_{rmax} and the result are given in dBi, but the side lobes' relative gain in dB.

5 Alternative equation for co-polarized case

If both antennas are co-polar the values should be changed accordingly and the equation will become:

$$G_t(\varphi_t) + G_r(\varphi_r) = 10 \cdot \log\left(10^{\frac{G_{tH}(\varphi_t)+G_{rH}(\varphi_r)}{10}} + 10^{\frac{G_{tV}(\varphi_t)+G_{rV}(\varphi_r)}{10}}\right) \quad \text{dBi} \qquad (2)$$

The numerical example gives, in the co-polar case, a common gain of −9.8 dBi with the same antennas as used above (Figs 19 and 20).