Source: Documents 4A/78 (Annex 22) and 4A/TEMP/40(Rev.2)

Working Party 4A

DRAFT REVISION TOOF RECOMMENDATION ITU-R S.731

Reference earth-station cross-polarized radiation pattern for use in frequency coordination and interference assessment in the frequency range from 2 to about 30 GHz

(1992)

The ITU Radiocommunication Assembly,

considering

a)   that, for coordination studies and for the assessment of mutual interference between radiocommunication-satellite systems and between earth stations of such systems and stations of other services sharing the same frequency band, it may be useful to use a cross-polarized radiation pattern for the earth-station antenna;

b)   that, for the determination of coordination distance and for the assessment of interference between earth and terrestrial stations, a cross-polarized radiation pattern based on the level exceeded by a small percentage of the side-lobe peaks may be appropriate;

c)   that, a reference earth-station co-polarized radiation pattern for use in frequency coordination and interference assessment is contained in Recommendation ITU-R S.465;

d)   that some measurements have been made of the cross-polarized off-axis gain performance of earth stations and radiation patterns have been developed which are quantitively similar;

e)   that a single cross-polarized off-axis reference pattern can be used which includes those contained in Annex 1;

f)   that the use of antennas with the best achievable radiation patterns will lead to the most efficient use of the radio-frequency spectrum and the geostationary-satellite orbit,

recognizing

1   that further measured information on cross-polarization performance is desirable;

2   that the measured off-axis gain performance of earth-station antennas contains the cross-polarization emission from the source antenna;

3   that the cross-polarized radiation patterns are measured in the main beam of the source antenna,

recommends

1   that, in the absence of particular information concerning the cross-polarized radiation pattern of the antenna for the earth station involved, a single reference radiation pattern may be used for:

1.1   frequency coordination studies and interference assessment between earth stations in the fixed-satellite services and stations of other services sharing the same frequency band;

1.2   coordination studies and interference assessment between networks in the fixed-satellite service;

2   that the following cross-polarized radiation pattern may be used on an interim basis for angles between the directions considered and the axis of the main beam, for frequencies in the range 2-30 GHz:

$$G_x(\varphi) = 23 - 20 \log \varphi \qquad \text{dBi} \qquad \text{for } \varphi_r \quad \leq \varphi \leq 7°$$
$$G_x(\varphi) = 20.2 - 16.7 \log \varphi \qquad \text{dBi} \qquad \text{for } 7° \quad < \varphi \leq 26.3°$$
$$G_x(\varphi) = 32 - 25 \log \varphi \qquad \text{dBi} \qquad \text{for } 26.3° < \varphi \leq 48°$$
$$G_x(\varphi) = -10 \qquad \text{dBi} \qquad \text{for } 48° \quad < \varphi \leq 180°$$

φ_r is equal to 1° or 100 λ/D, whichever is greater;

3   that the following Notes should be regarded as a part of this Recommendation.

NOTE 1 – The reference cross-polarized radiation pattern should be assumed to be rotationally symmetrical.

NOTE 2 – The reference cross-polarized pattern should be used <u>for cases involving</u><s>between two networks which employ only</s> opposite polarizations.

NOTE 3 – Other cross-polarized radiation patterns of earth stations may be used by mutual agreement between the administrations concerned.

NOTE 4 – 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 and for antennas with D/λ less than 50.

NOTE 5 – This cross-polarized radiation pattern complements the co-polarized pattern of Recommendation ITU-R S.465.

NOTE 6 – Annex 1 contains several cross-polarized off-axis radiation patterns corresponding to the envelopes of the peaks of the measured gain characteristics of various antennas, in support of <s>§</s> <u>*recommends*</u> 2.

ANNEX 1

Modelling of earth-station antenna cross-polar characteristics

This Annex presents background information used to develop cross-polarized patterns obtained ~~from pattern~~for theoretical and measured patterns. Pattern measurements ~~of~~were obtained for different ~~diameter antennas~~antenna diameters (1.2 m, 1.8 m, 2.4 m, 3.5 m at 12.625 GHz, and 3.7 m at ~~12.625~~10.7 GHz). For each antenna ~~type~~diameter, ~~a~~the relative measured and ~~an~~ envelope ~~pattern~~patterns are described. Equations are then derived which describe the relative cross-polarized envelopes for antennas ~~of~~with $D/\lambda \geq 100$ and $D/\lambda < 100$. A single function is developed which can be used to describe the off-axis cross-polarized pattern for all antennas.

Calculated co-polarized and cross-polarized patterns for single offset feed antennas are shown in Figs. 1 and 2 along with the respective envelope functions. The effects of feed supports for axisymmetric arrangements are shown in Fig. 3.

FIGURE 1

**1.8 m single offset antenna co- and cross-polar pattern
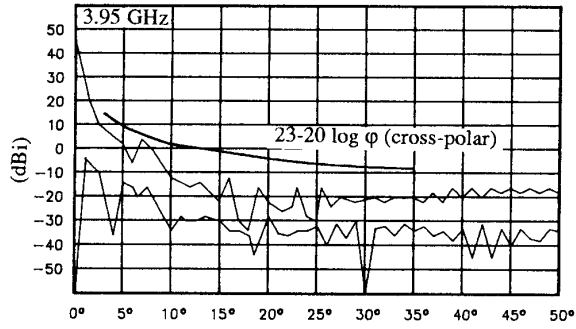calculated at 3.95 GHz – azimuth plane**
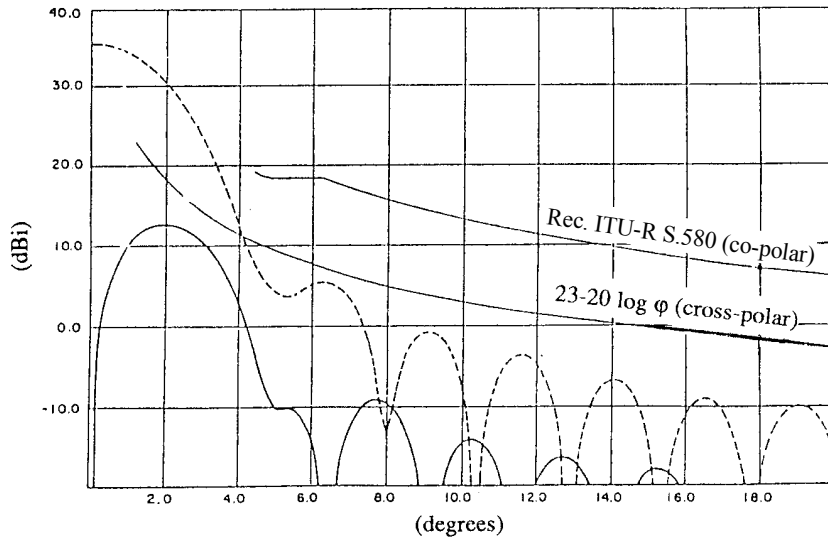
FIGURE 2

**1.8 m single offset antenna co- and cross-polar pattern
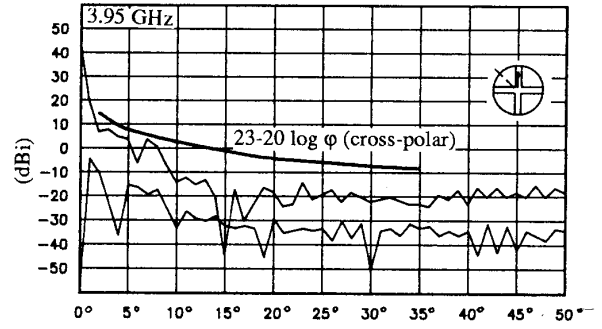calculated at 6.175 GHz – azimuth plane**
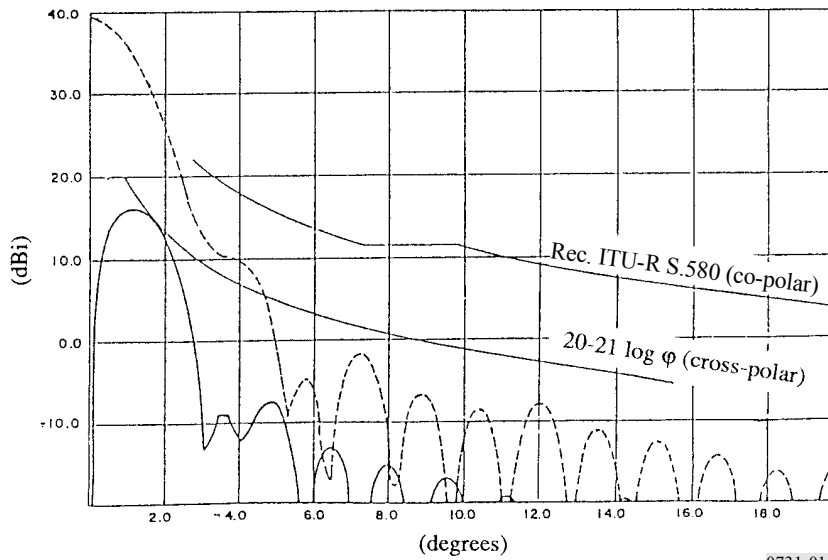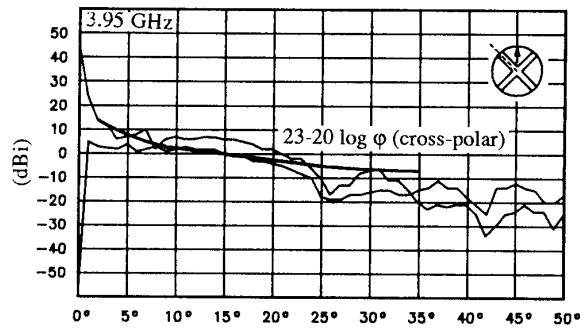

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FIGURE 3

**Theoretical analysis of strut effects on a 6 m double reflector
axisymmetric linearly polarized antenna,
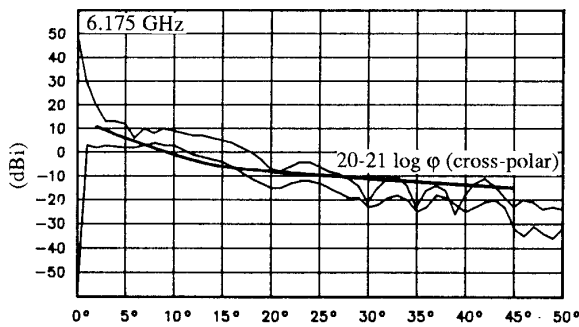at 3.95 GHz (a)-c)) and 6.175 GHz (d)-e))**
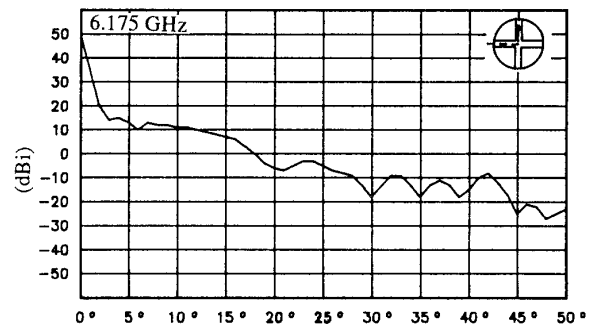
a) Co- and cross-polar 45° plane patterns, without struts

b) Same as a) including struts in vertical and horizontal planes

c) Same as a) including struts in 45° and 135° planes

d) Same as c) at the transmit band

e) Co- and cross-polar horizontal plane patterns, including struts in vertical and horizontal planes — transmit band

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In order to estimate the worst-case polarization discrimination (factor of polarization isolation), <u>the relative</u> co-polarized $G_{//}(\varphi)$ and cross-polarized $G_+(\varphi)$ envelopes have been obtained ~~for the antennas given above~~.

a) ~~In co-polarization, for the main lobe area where φ < φ₁ (φ₁ = 1° for large stations, φ₁ = 100 λ/D degrees for small antennas) the envelope pattern is extrapolated by a quadratic lobe defined between G_{//}(φ₁) for φ = φ₁ and 0 dB for φ = 0°.~~

b) ~~No constraints are placed on the cross-polarization, other than the co-polarized design objective pattern as defined by the ITU-R. The cross-polarization level is such as G₊(φ) < G_{//}(φ'₁) (with φ'₁ = 2 φ₁) for 0° < φ < φ₁. The two co- and cross-polarized envelopes are overlapping as they reach the isotropic level (φ ≥ φ_{ISO}).~~

a) The relative co-polarized envelope used in this Annex is assumed as follows:

For systems with $D/\lambda \le 100$,

$$G_{//}(\varphi) \quad = 52 - 10 \log (D/\lambda) - 25 \log \varphi - G_0 \qquad \text{dBi} \qquad \text{for } (100 \, \lambda/D)° \le \varphi \le 48°$$

$$= 10 - 10 \log (D/\lambda) - G_0 \qquad \text{dBi} \qquad \text{for } 48° \qquad < \varphi \le 180°$$

For systems with $D/\lambda > 100$,

$$G_{//}(\varphi) \quad = 32 - 25 \log \varphi - G_0 \qquad \text{dBi} \qquad \text{for } 1° \qquad \le \varphi \le 48°$$

$$= -10 - G_0 \qquad \text{dBi} \qquad \text{for } 48° \qquad < \varphi \le 180°$$

b) The cross-polarization level is such that $G_+(\varphi) = G_{//}(\varphi_1')$ (with $\varphi_1' = 2.2\varphi_1$ for small antennas, and $\varphi_1' = 1.8\varphi_1$ for large antennas) for $0° < \varphi < \varphi_1$.

Finally, <u>the relative</u> cross-polarized <u>envelopes</u>~~patterns~~ could have the following envelopes:

1 Small antennas ($D < 100\lambda$)

$G_0 =$ maximum co-polarized gain of antenna (dBi)

$G(\varphi) =$ $52 - 10 \log (D/\lambda) - 25 \log \varphi - G_0$ (dBi)

$\varphi_1 =$ $100 \, \lambda/D$ (degrees)

$\varphi_{1'} =$ $2.2 \, \varphi_1$ (degrees)

$\varphi_2 =$ $25.1°$

$\varphi_{ISO} = 10^{\dfrac{52 - 10 \log (D/\lambda)}{25}}$ (degrees)

for $0 < \varphi \le \varphi_1$,

$$G_+(\varphi) = G(\varphi_1') \tag{1}$$

for $\varphi_1 < \varphi \le \varphi_2$,

$$G_+(\varphi) = G(\varphi) - \left(G(\varphi_1) - G(\varphi_1') \right) \frac{\varphi_{ISO} - \varphi}{\varphi_{ISO} - \varphi_1} \tag{2}$$

if $\varphi > \varphi_{ISO}$,

$$G_+(\varphi) = 52 - 10 \log (D/\lambda) - 25 \log \varphi - G_0 \tag{3}$$

for $\varphi_2 < \varphi \leq 180°$,

$$G_+(\varphi) = 10 - 10 \log (D/\lambda) - G_0 \tag{4}$$

The patterns shown in Figs. 4 and 6 are calculated for stations with antenna diameters of 1.20 m and 1.80 m operating at a centre frequency of 12.625 GHz. The patterns measured for these types of antennas are shown in Figs. 5, 7 and 8. In each case one example of the measured co- and cross-polarized pattern is given, but the envelopes shown are averages from measurements on several antennas of the same type.

~~**1   Small antennas ($D < 100\lambda$)**~~

~~G_0:   gain of antenna main lobe~~

~~$\varphi_1 = 100 \lambda/D$ (degrees)~~

~~$G(\varphi) = 52 - 10 \log (D/\lambda) - 25 \log \varphi - G_0$~~

~~$\varphi'_1 = 2.2 \varphi_1$~~

~~$\varphi_2 = 25.1°$~~

~~$\varphi_{ISO} = 10^{(52 - 10 \log (D/\lambda)/25)}$ (degrees)~~

~~for $0 < \varphi < \varphi_1$~~

~~$G_+(\varphi) = G(\varphi'_1)$ (1)~~

~~for $\varphi_1 < \varphi < \varphi_2$~~

~~$G_+(\varphi) = G(\varphi) - [G(\varphi_1) - G(\varphi'_1)] \cdot (\varphi_{ISO} - \varphi)(\varphi_{ISO} - \varphi_1)$ (2)~~

~~(if $\varphi > \varphi_{ISO}$, $G_+(\varphi) = G_+(\varphi)$)~~

~~for $\varphi_2 < \varphi < 180°$~~

~~$G_+(\varphi) = 10 - 10 \log (D/\lambda) - G_0$ (3)~~

~~The envelopes shown in Figs. 4 and 5 are obtained for stations of the following diameters: 1.20 m and 1.80 m at 12.625 GHz. In each case one example of the measured co- and cross-polarized pattern is given, but the envelopes shown are averages from measurements on several antennas of the same type.~~

~~The patterns measured for these types of antennas are shown in Figs. 4a, 5a and 5b.~~

FIGURE 4

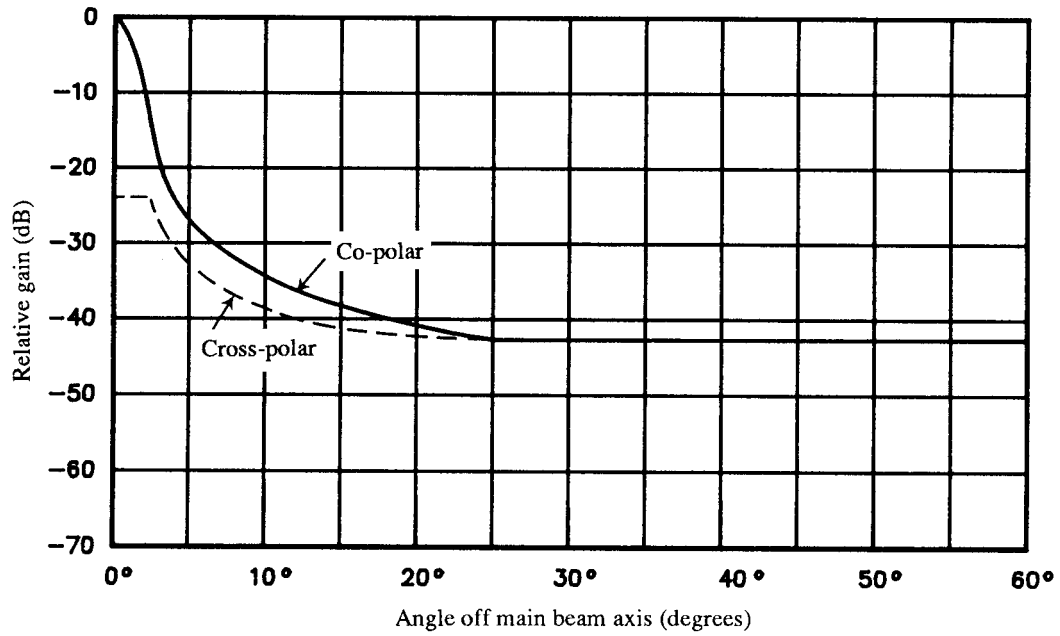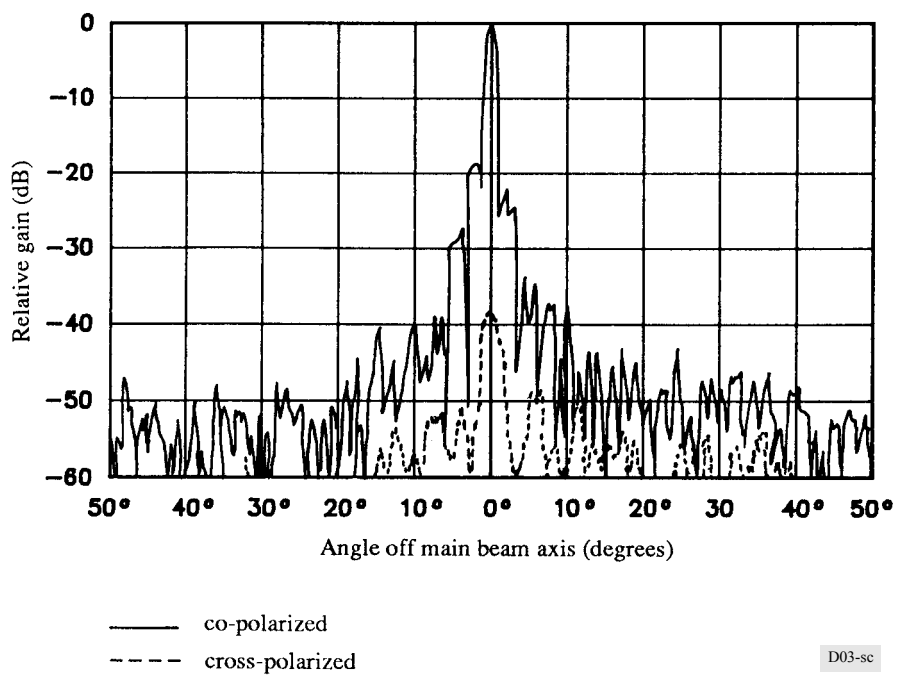**1.2 m antenna, f = 12.625 GHz, co- and cross-polarized templates**

FIGURE 4a

1.2 m antenna, co- and cross-polarized measured patterns

—————— co-polarized

– – – – cross-polarized

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FIGURE 5

1.80 m antenna, f = 12.625 GHz, co- and cross-polarized templates

Angle off main beam axis (degrees)
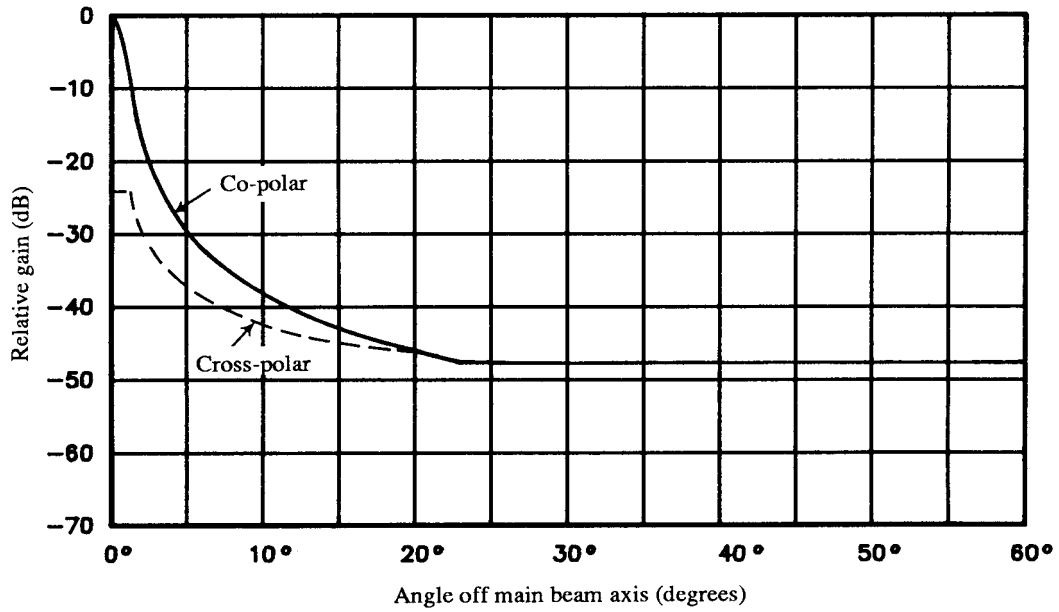
FIGURE 5a

1.80 m antenna, co-polarized measured pattern

Angle off main beam axis (degrees)
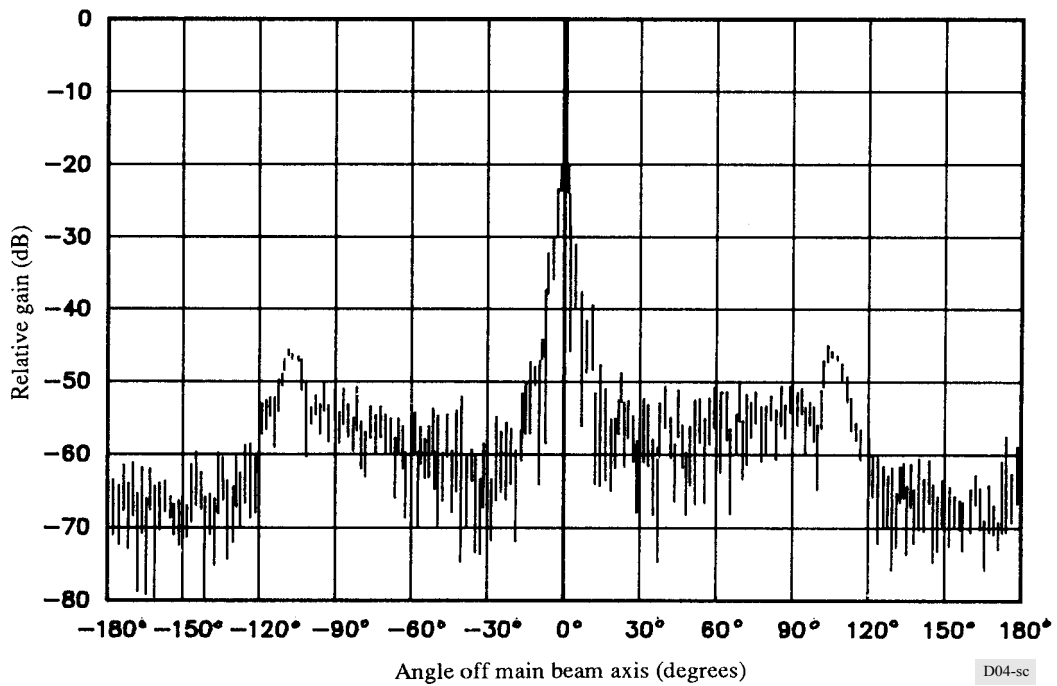
FIGURE 5b

1.80 m antenna, cross-polarized measured pattern
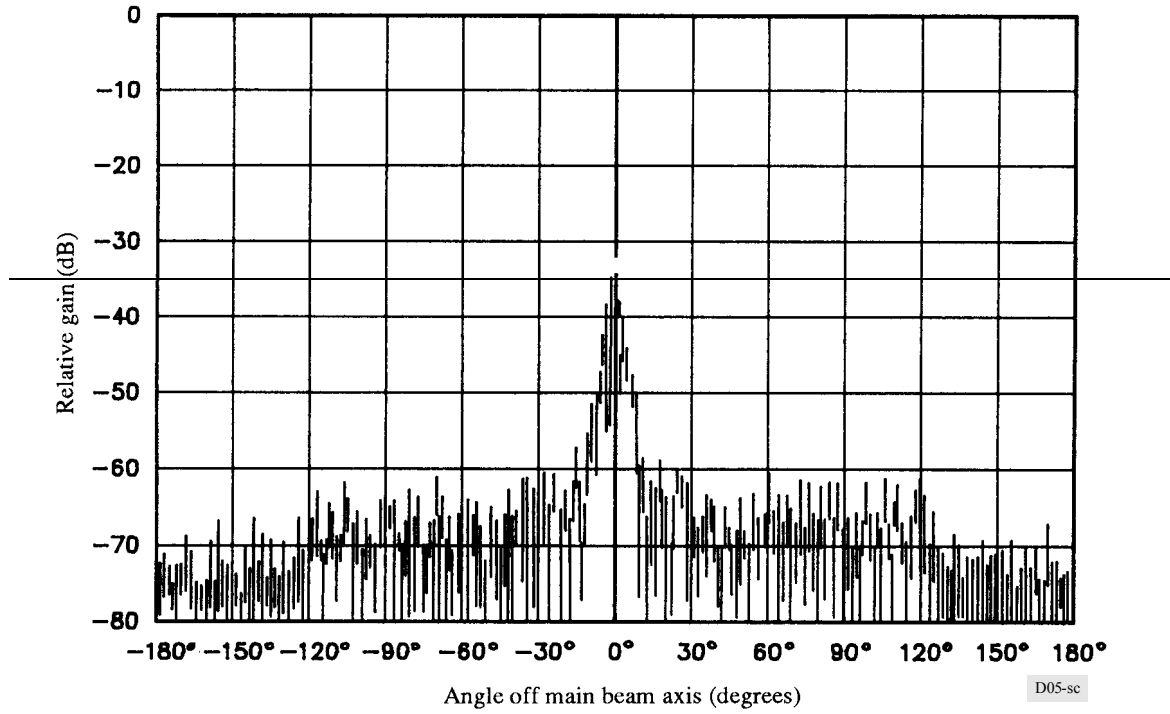
FIGURE 4

1.2 m antenna, *f* = 12.625 GHz, relative co- and cross-polar calculated patterns
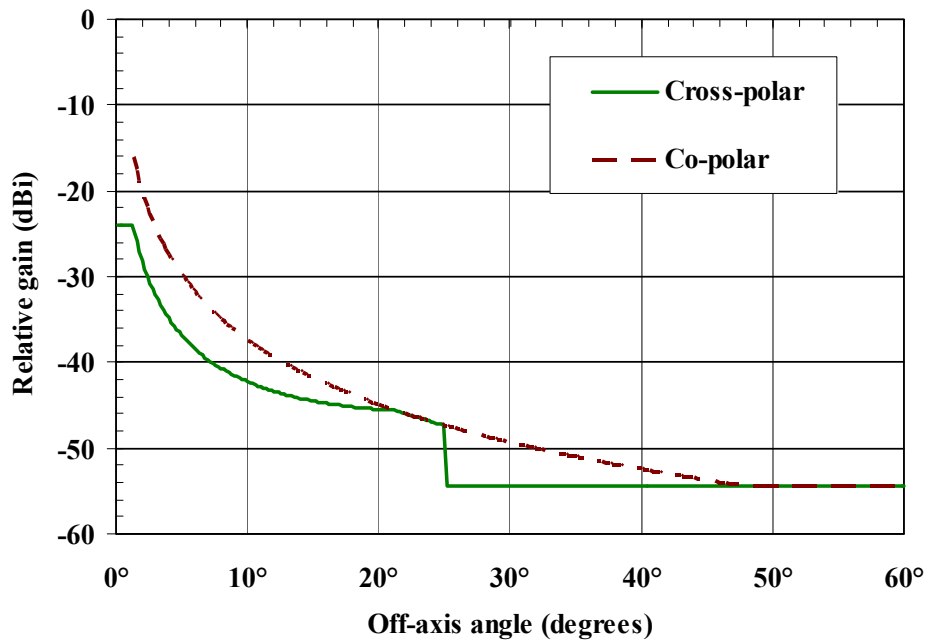
FIGURE 5

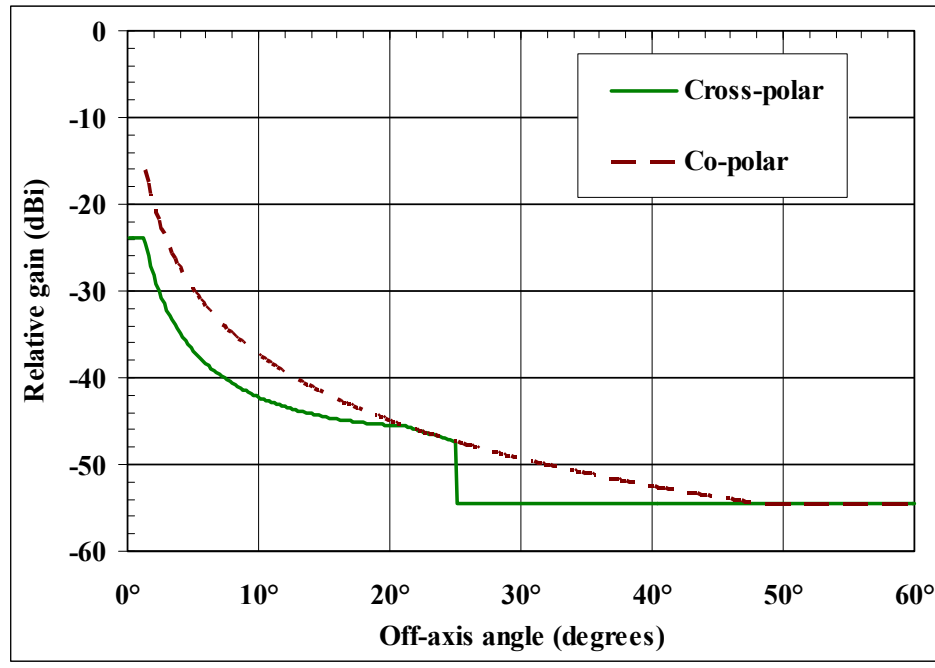**1.2 m antenna, f = 12.625 GHz, relative co- and cross-polar measured patterns**
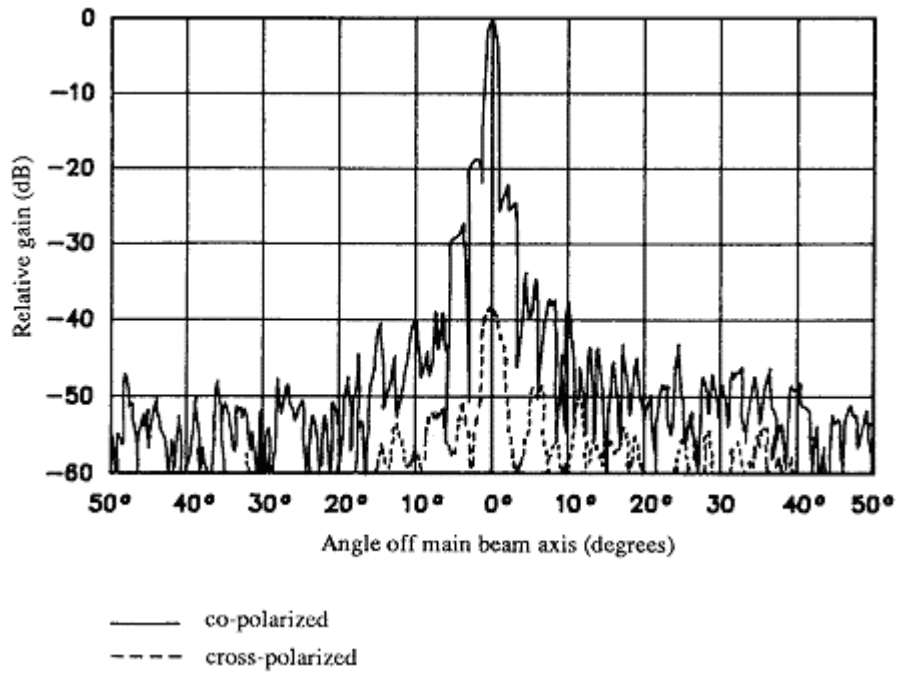
FIGURE 6

1.8 m antenna, f = 12.625 GHz, relative co- and cross-polar calculated patterns

FIGURE 7

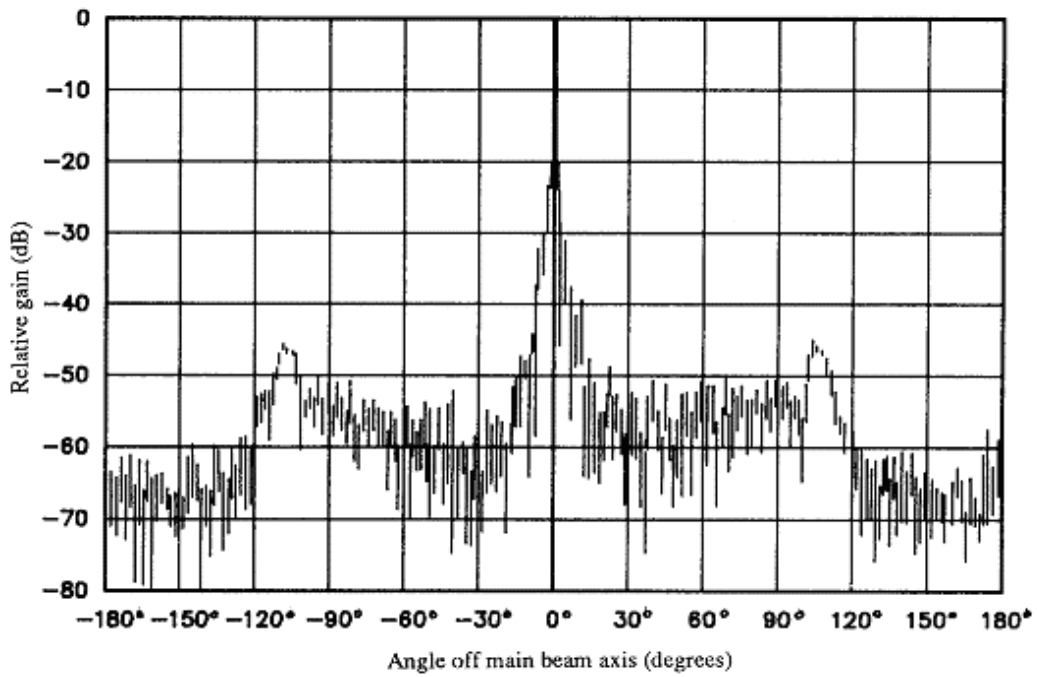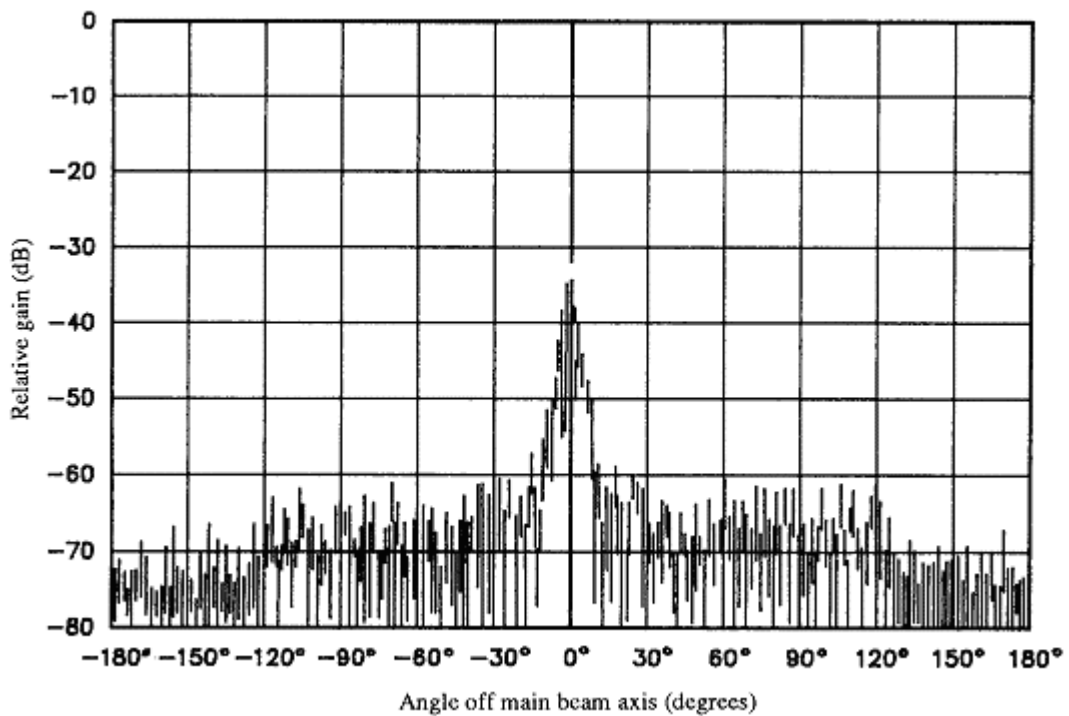**1.8 m antenna, *f* = 12.625 GHz, relative co-polar measured pattern**

FIGURE 8

1.8 m antenna, *f* = 12.625 GHz, relative cross-polar measured pattern

2 Large antennas ($D \geq 100\lambda$)

~~G_0 :~~ $\underline{G_0}$ = maximum co-polarized gain of antenna ~~main lobe~~(dBi)

~~$\varphi_1 = 1°$~~

~~$G(\varphi) = 29 - 25 \log \varphi - G_0$ (dBi)~~

~~$\varphi'_1 = 1.8 \varphi_1$~~

~~$\varphi_2 = 20°$~~

~~$\varphi_3 = 26.3°$~~

~~$\varphi_4 =$~~

$\varphi_1 = 1°$

$\varphi_1' = 1.8 \varphi_1$ (degrees)

$\varphi_2 = 20°$

$\varphi_3 = 33.1°°$

~~$\varphi_{ISO} = 10^{(29/25)}$ (degrees)~~

~~for $0 < \varphi < \varphi_1$~~

~~$G_+(\varphi) = G(\varphi'_1)$~~ (4)

~~for $\varphi_1 < \varphi < \varphi_2$~~

~~$G_+(\varphi) = G(\varphi) - [G(\varphi_1) - G(\varphi'_1)] \cdot (\varphi_{ISO} - \varphi)/(\varphi_{ISO} - \varphi_1)$~~ (5)

~~for $\varphi_2 < \varphi < \varphi_3$~~

~~$G_+(\varphi) = -3.5 - G_0$~~

~~$G_+(\varphi) = G_1(\varphi) - [G(\varphi_1) - G(\varphi'_1)] \cdot (\varphi_{ISO} - \varphi)/(\varphi_{ISO} - \varphi_1)$~~ (6)

~~(if $\varphi > \varphi_{ISO}$, $G_+(\varphi) = G_\#(\varphi)$)~~

~~for $\varphi_3 < \varphi < \varphi_4$~~

~~$G_+(\varphi) = 32 - 25 \log \varphi - G_0$~~ (7)

~~for $\varphi_4 < \varphi < 180°$~~

~~$G_+(\varphi) = -10 - G_0$~~ (8)

$$\varphi_{ISO} = 10^{\frac{29}{25}} \cong = 14.45°$$

for $0 < \varphi \leq \varphi_1$,

$$G_+(\varphi) = G(\varphi'_1) \tag{5}$$

for $\varphi_1 < \varphi \leq \varphi_2$,

$$G_+(\varphi) = G(\varphi) - \left(G(\varphi_1) - G(\varphi'_1)\right)\frac{\varphi_{ISO} - \varphi}{\varphi_{ISO} - \varphi_1} \tag{6}$$

for $\varphi_2 < \varphi \leq \varphi_3$,

$$G_+(\varphi) = 32 - 25 \log \varphi - G_0 \tag{7}$$

for $\varphi_3 < \varphi \leq 180^\circ$,

$$G+(\varphi) = -10 - G_0 \tag{8}$$

~~The envelopes~~The patterns shown in ~~Figs. 6, 7 and 8~~the Figures below are ~~obtained~~calculated for stations ~~of~~with the following antenna diameters and frequencies: 2.40 m~~,~~ and 3.50 m at 12.625 GHz, and 3.70 m at ~~12.625~~10.70 GHz. The patterns measured for these types of antennas are shown in Figs. 10, 11, 13, 14, 16 and 17. In each case, one example of the co- and cross-polarized measurements is shown, but the envelopes given were derived from the average of several antennas of the same type. ~~The patterns measured for these types of antennas are shown in Figs. 6a, 7a, 8a, 6b, 7b and 8b.~~

The functions given above for $D < 100\lambda$ and $D \geq 100\lambda$ can be expressed in terms of absolute gain. The functions given for $D < 100\lambda$ can be normalized to a $(32 - 25 \log \varphi)$ co-polar function by letting $(52 - 10 \log \varphi)$ equal 32. Evaluation of these functions as absolute gain for various values of D/λ is as follows:

$$G_x(\varphi) = 22.70 + 0.29\,\varphi - 25 \log \varphi \qquad \text{dBi} \qquad \text{for } D/\lambda = 25 \tag{9}$$

$$= 22.69 + 0.37\,\varphi - 25 \log \varphi \qquad \text{dBi} \qquad \text{for } D/\lambda = 50 \tag{10}$$

$$= 22.87 + 0.42\,\varphi - 25 \log \varphi \qquad \text{dBi} \qquad \text{for } D/\lambda = 75 \tag{11}$$

$$= 22.15 + 0.47\,\varphi - 25 \log \varphi \qquad \text{dBi} \qquad \text{for } D/\lambda = 100 \tag{12}$$

The angles at which these gain functions are equal to a co-polar envelope gain of $(32 - 25 \log \varphi)$ are 31.7°, 25.2°, 21.4° and 20.8° respectively. Additional functions which have been developed are:

$$G_x(\varphi) = 20 - 21 \log \varphi \qquad \text{dBi} \tag{13}$$

$$G_x(\varphi) = 23.6 - 20 \log \varphi \qquad \text{dBi} \tag{14}$$

$$G_x(\varphi) = 22 - 25 \log \varphi \qquad \text{dBi} \tag{15}$$

Equation (15) is based on a requirement that the cross-polar gain be 10 dB less than the co-polar gain out to 7°.

These functions are plotted in Fig. ~~9~~18. From this Figure, a single function which adequately covers all the above functions is:

$$G_\lambda(\varphi) = 23 - 20 \log \varphi \qquad \text{dBi} \qquad \text{for } \varphi_r \leq \varphi \leq 7^\circ$$

$$= 20.2 - 16.7 \log \varphi \qquad \text{dBi} \qquad \text{for } 7^\circ < \varphi \leq 26.3^\circ$$

$$= 32 - 25 \log \varphi \qquad \text{dBi} \qquad \text{for } 26.3^\circ < \varphi \leq 48^\circ$$

$$= -10 \qquad \text{dBi} \qquad \text{for } 48^\circ < \varphi \leq 180^\circ$$

φ_r is equal to 1° or 100 λ/D, whichever is greater.

FIGURE 6

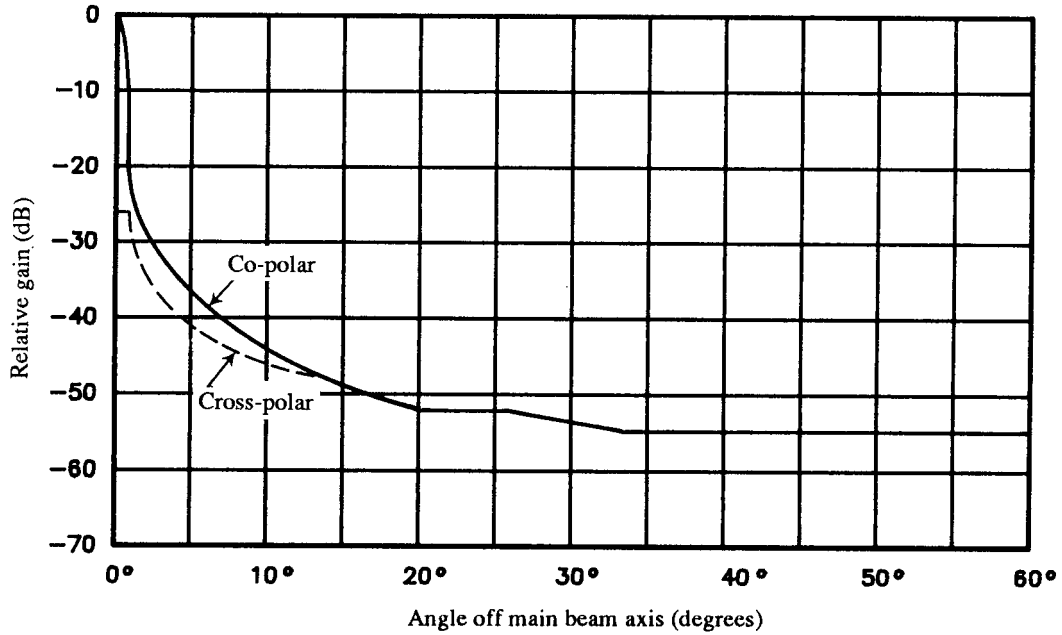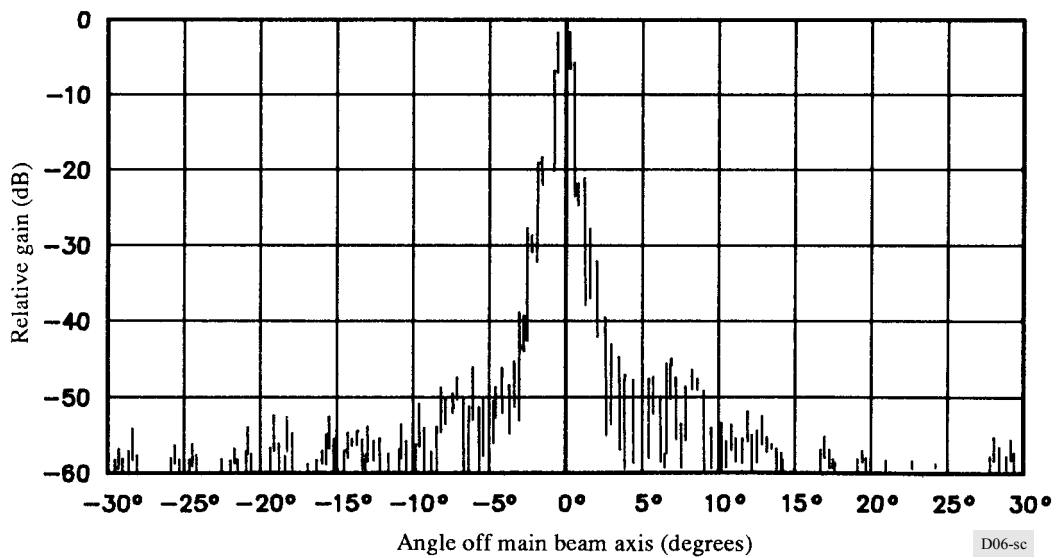2.40 m, antenna, f = 12.625 GHz, co- and cross-polarized templates

Angle off main beam axis (degrees)

.FIGURE 6a

2.40 m antenna, co-polarized measured pattern

Angle off main beam axis (degrees)

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FIGURE 6b

2.40 m antenna, cross-polarized measured pattern

Angle off main beam axis (degrees)
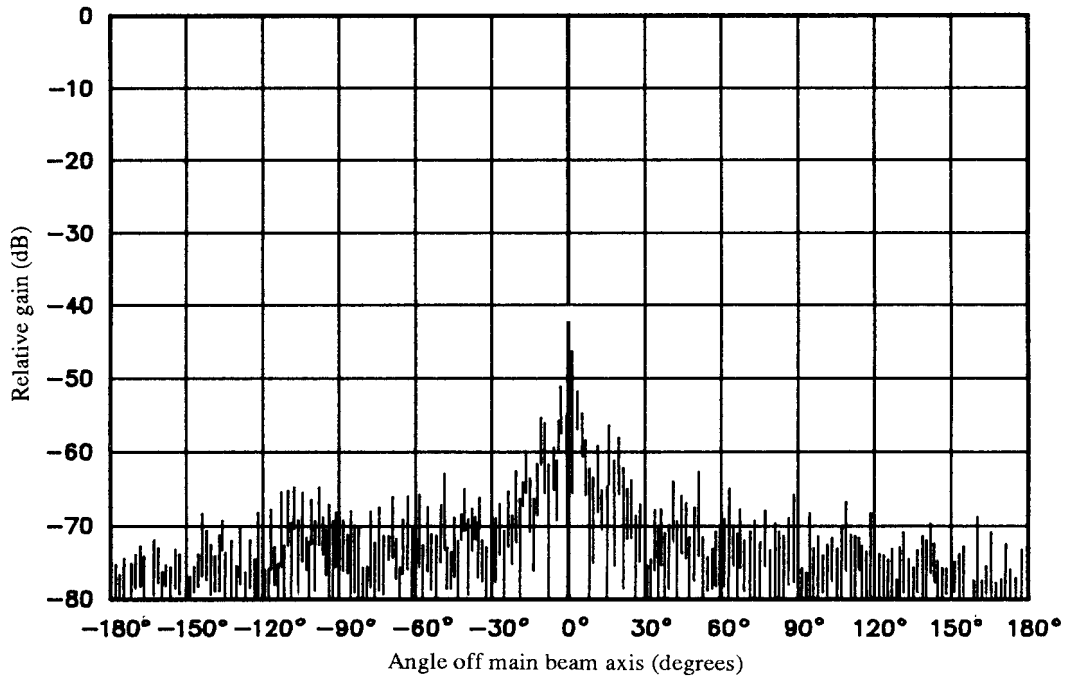
FIGURE 7

3.50 m antenna, f = 12.625 GHz, co- and cross-polarized templates

Angle off main beam axis (degrees)

D07-sc
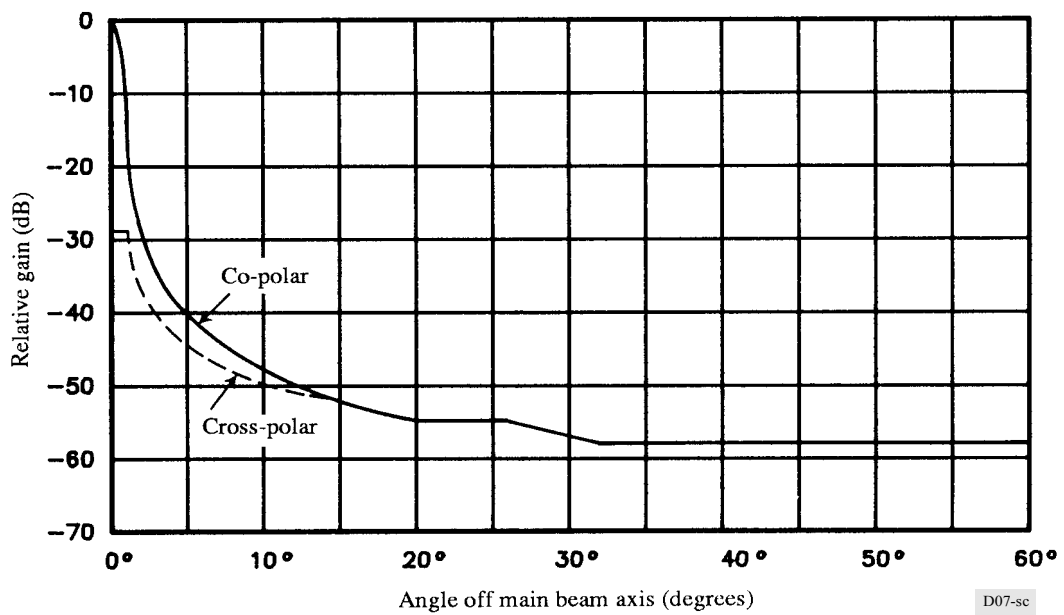
FIGURE 7a

3.50 m antenna, co-polarized measured pattern

Angle off main beam axis (degrees)
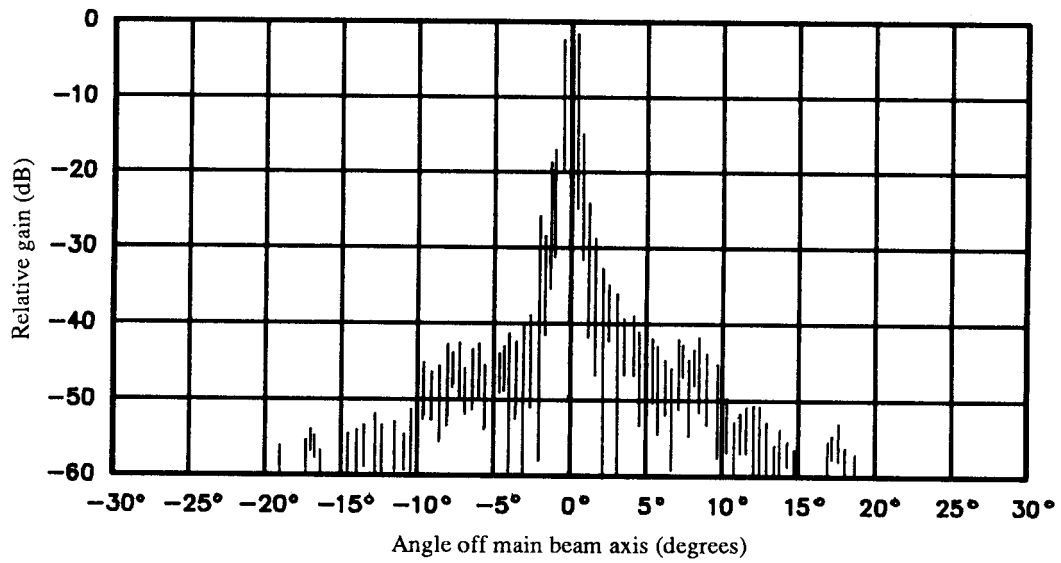
FIGURE 7b

3.50 m antenna, cross-polarized measured pattern

Angle off main beam axis (degrees)
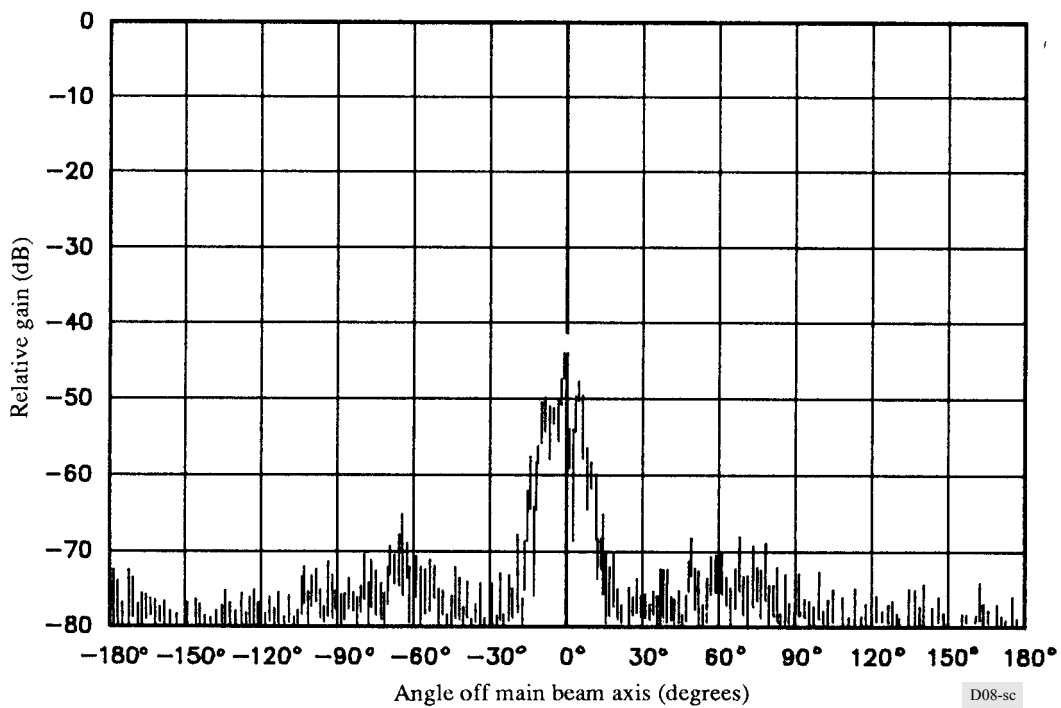
FIGURE 8

3.70 m antenna, $f = 10.7$ GHz, co- and cross-polarized templates

Co-polar

Cross-polar

Relative gain (dB)

Angle off main beam axis (degrees)
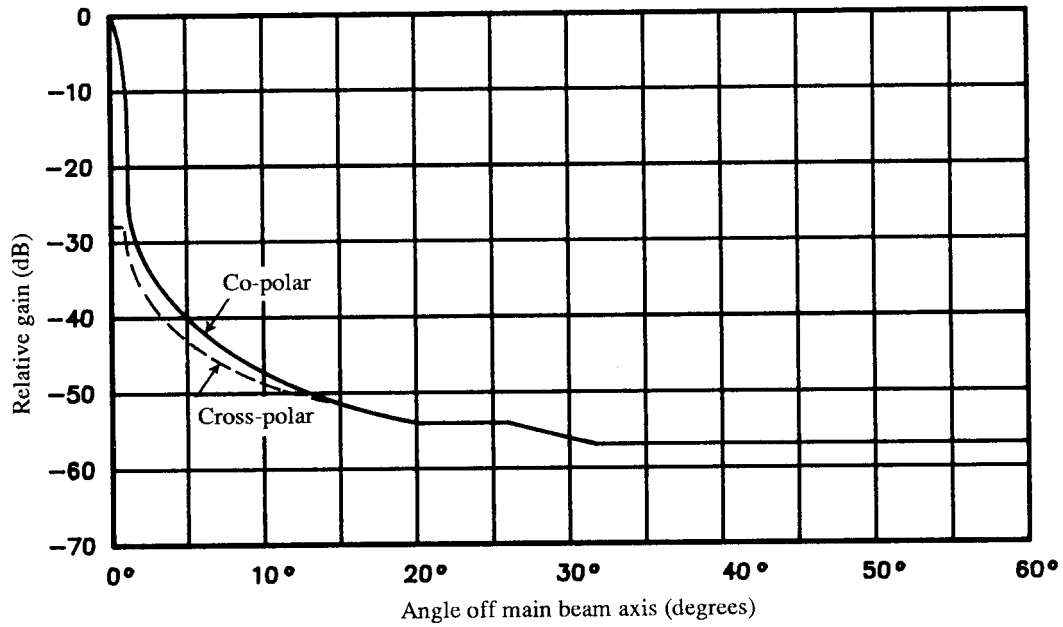
FIGURE 8a

3.70 m antenna, co-polar measured pattern

Relative gain (dB)

Angle off main beam axis (degrees)
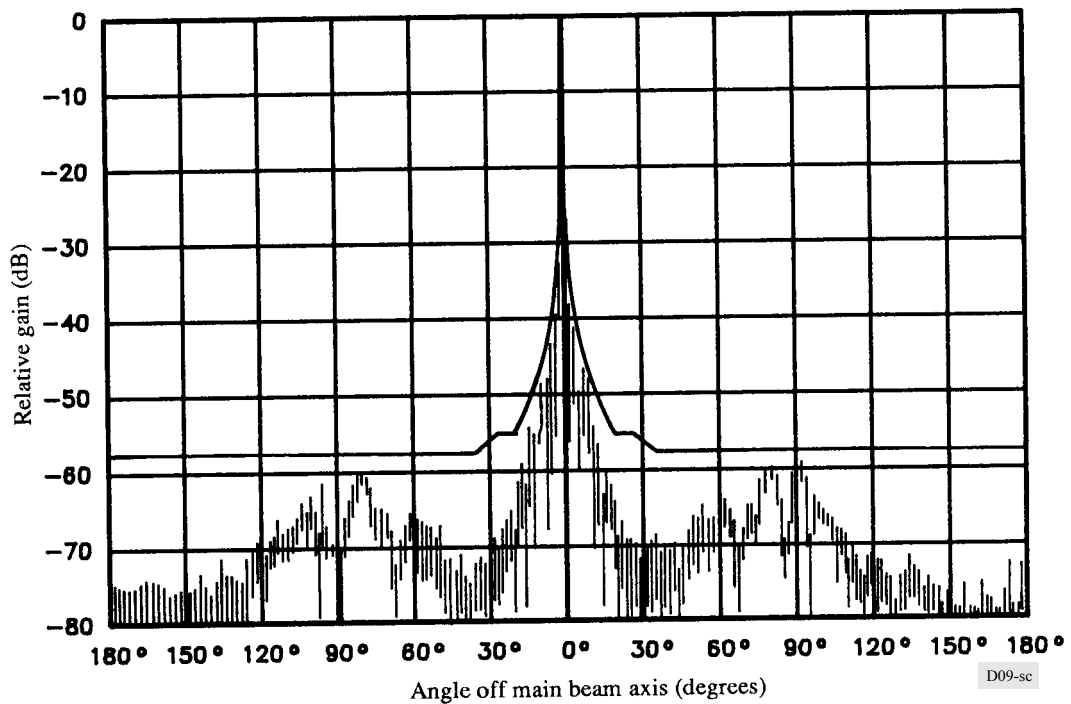
D09-sc

FIGURE 8b

3.70 m antenna, co-polar measured pattern

Angle off main beam axis (degrees)

D10-sc
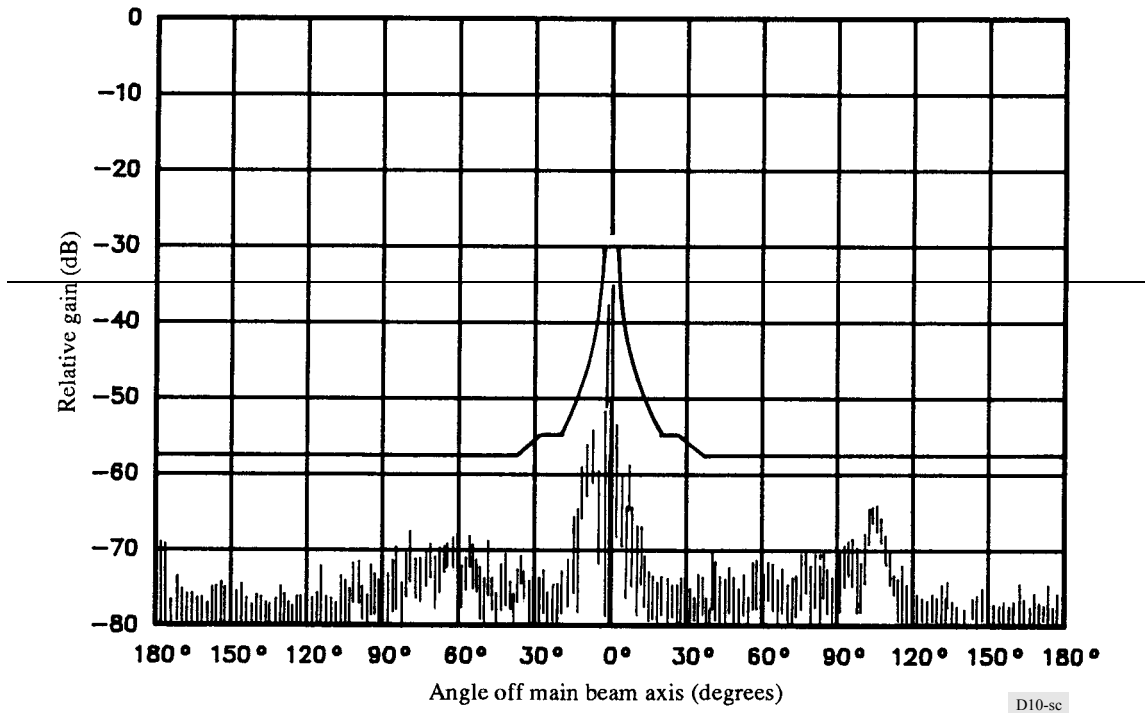
FIGURE 9

Cross-polarized side-lobe envelope gain functions
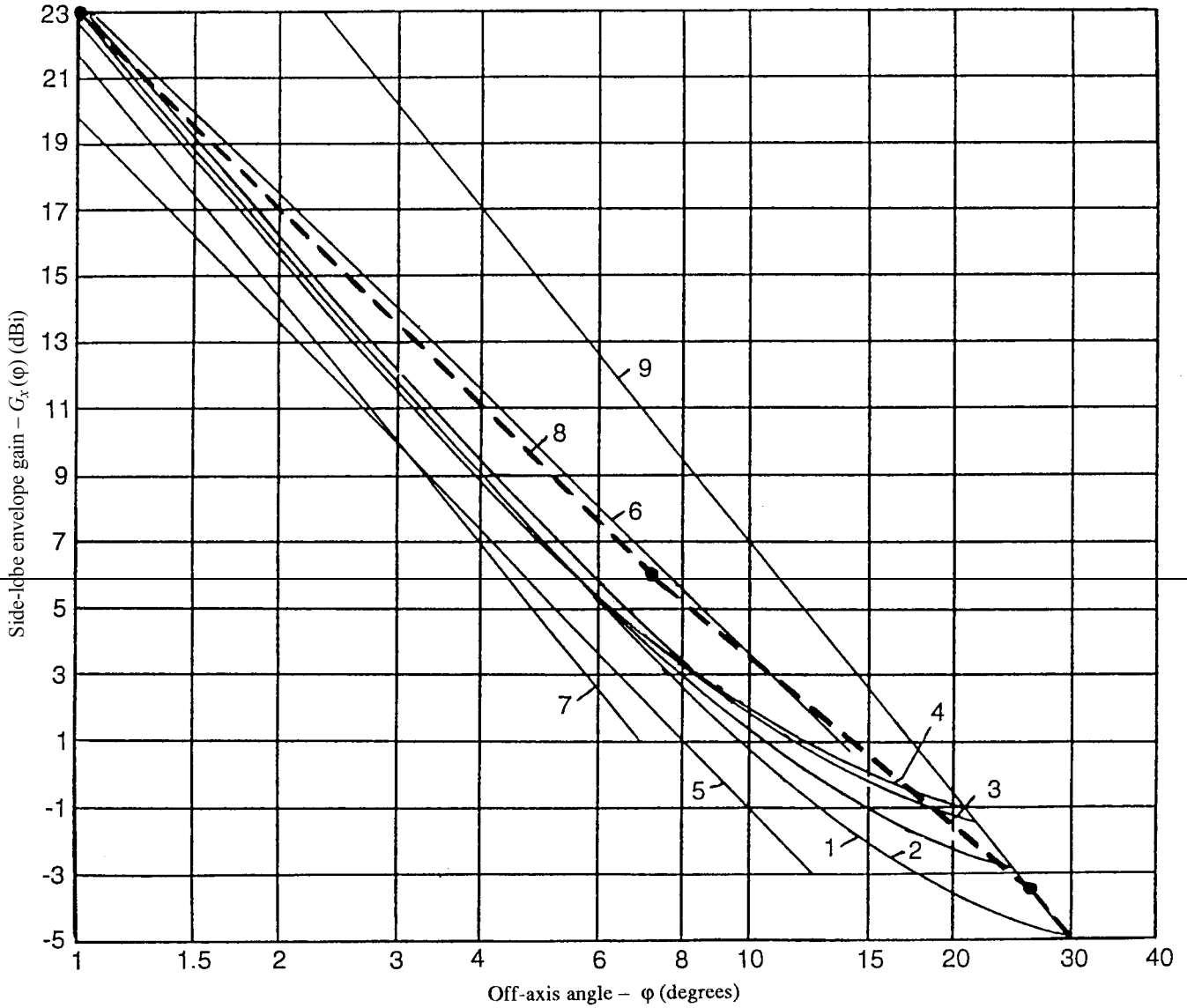
1	$G_x(\varphi)$	$= 22.7 + 0.29\,\varphi - 25\log\varphi$	dBi	for $D/\lambda = 25$	
2		$= 22.69 + 0.37\,\varphi - 25\log\varphi$	dBi	for $D/\lambda = 50$	
3		$= 22.87 + 0.42\,\varphi - 25\log\varphi$	dBi	for $D/\lambda = 75$	
4		$= 22.15 + 0.47\,\varphi - 25\log\varphi$	dBi	for $D/\lambda = 100$	
5		$= 20 - 21\log\varphi$	dBi		
6		$= 23.6 - 20\log\varphi$	dBi		
7		$= 22 - 25\log\varphi$	dBi		
8	$G_x(\varphi)$	$= 23 - 20\log\varphi$	dBi	for $\varphi_r \le \varphi \le 7°$	
		$= 20.2 - 16.7\log\varphi$	dBi	for $7° < \varphi \le 26.3°$	
		$= 32 - 25\log\varphi$	dBi	for $26.3° < \varphi \le 48°$	
9	$G_x(\varphi)$	$= 32 - 25\log\varphi$	dBi		

D11-sc

FIGURE 9

2.4 m antenna, *f* = 12.625 GHz, relative co- and cross-polar calculated patterns
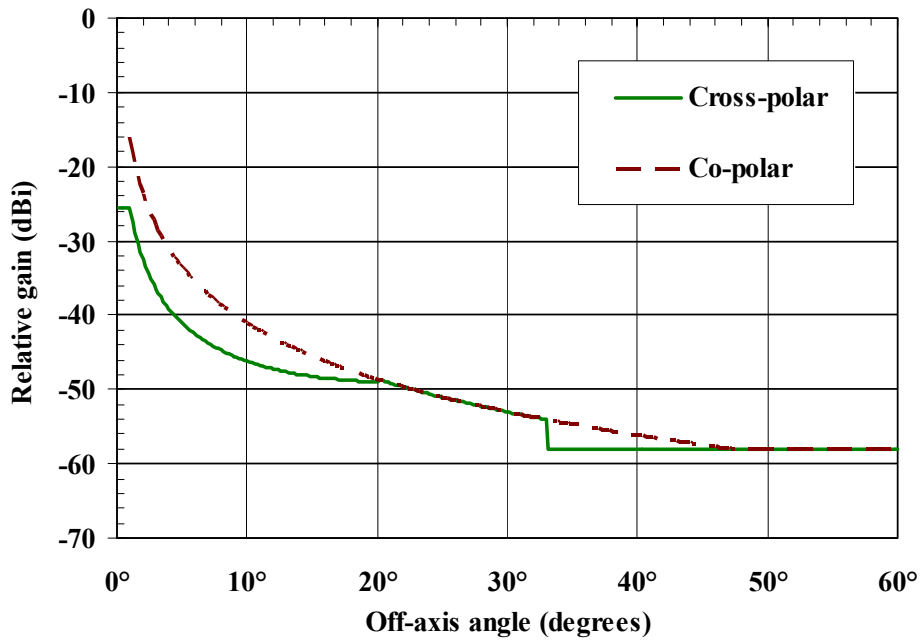

FIGURE 10

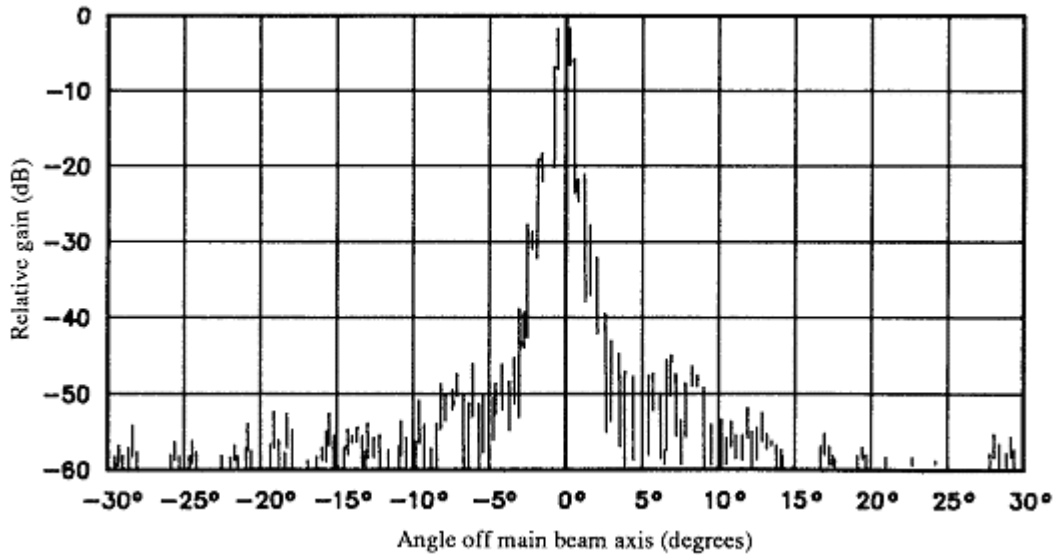**2.4 m antenna, *f* = 12.625 GHz, relative co-polar measured pattern**

FIGURE 11

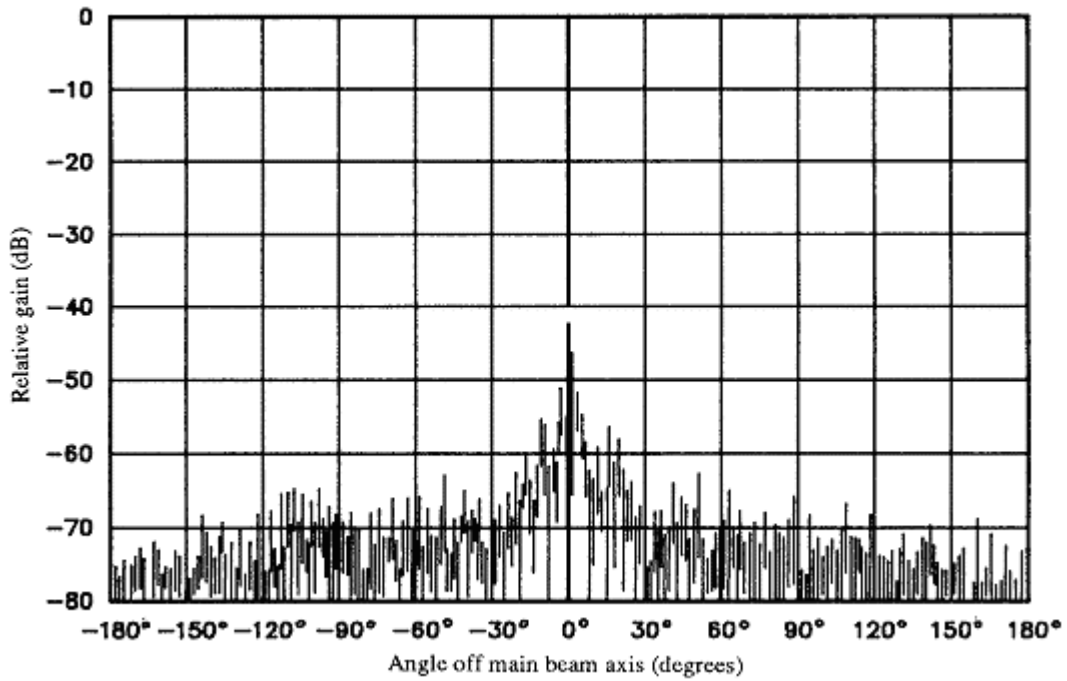**2.4 m antenna, *f* = 12.625 GHz, relative cross-polar measured pattern**

FIGURE 12

3.5 m antenna, *f* = 12.625 GHz, relative co- and cross-polar calculated patterns
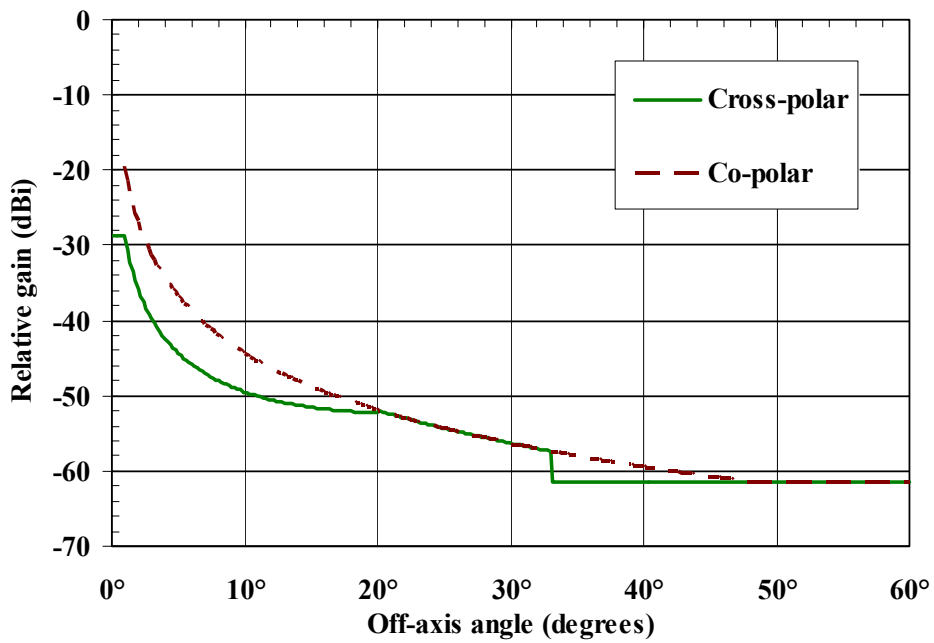
FIGURE 13

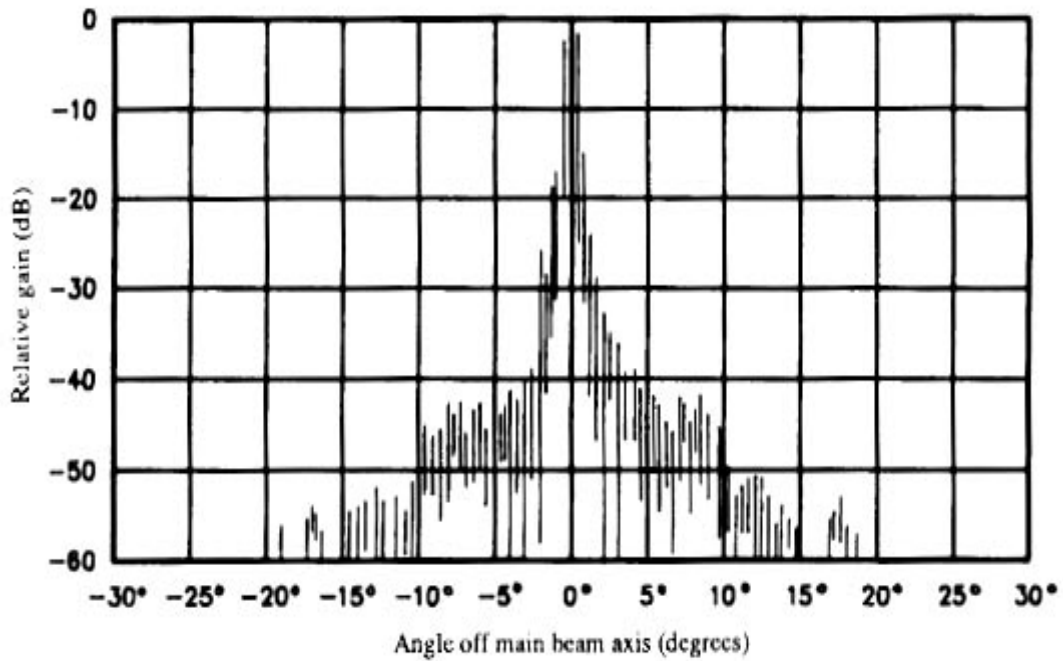**3.5 m antenna, f = 12.625 GHz, relative co-polar measured pattern**

FIGURE 14

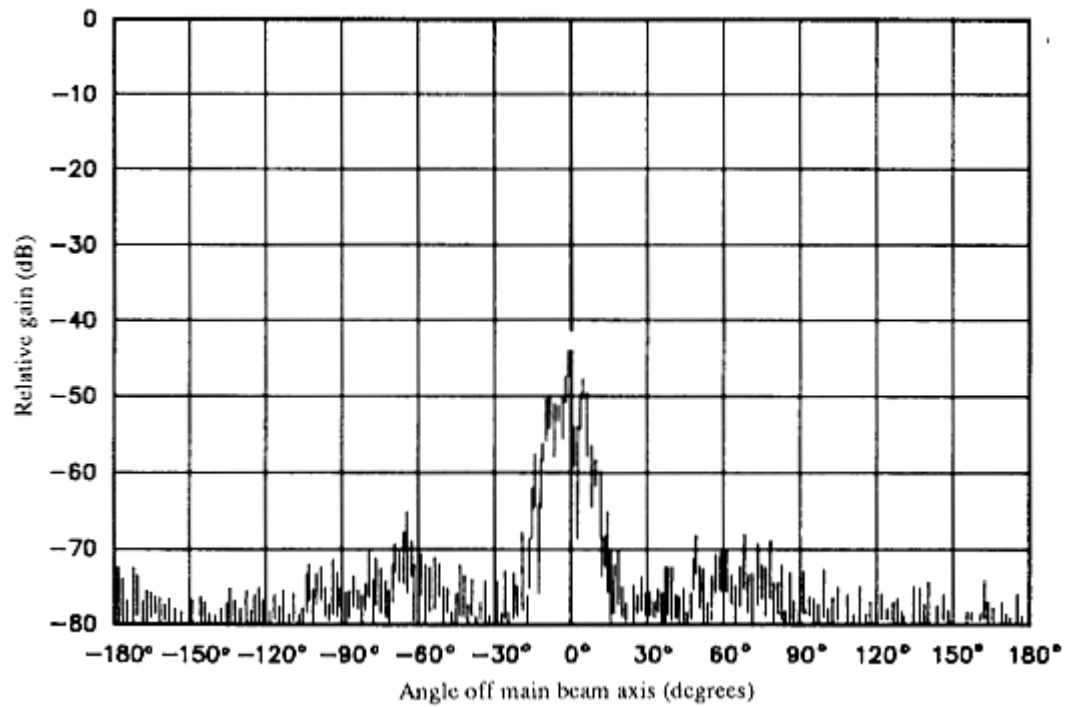**3.5 m antenna, f = 12.625 GHz, relative cross-polar measured pattern**

FIGURE 15

3.7 m antenna, *f* = 10.7 GHz, relative co- and cross-polar calculated patterns
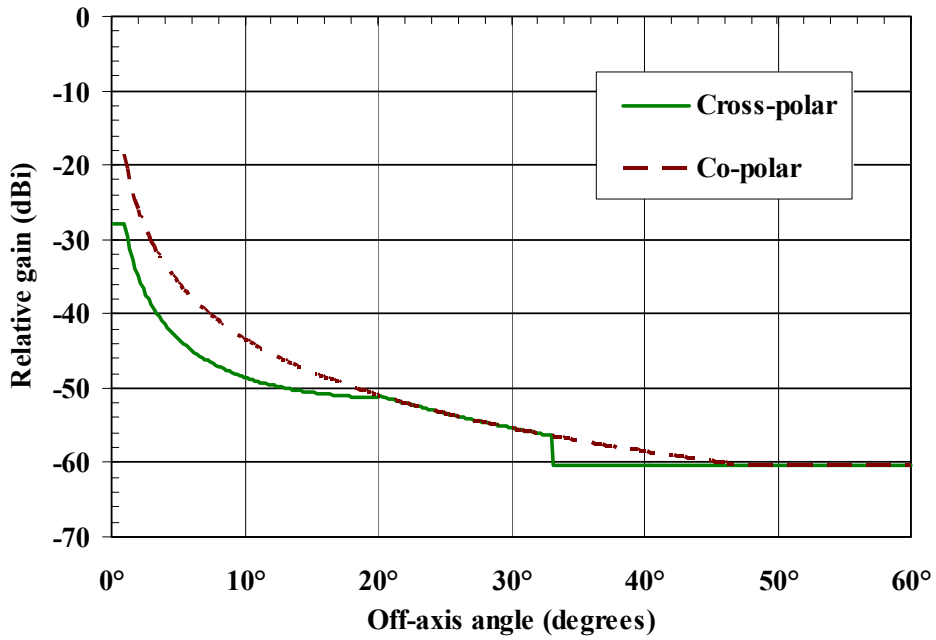

FIGURE 16

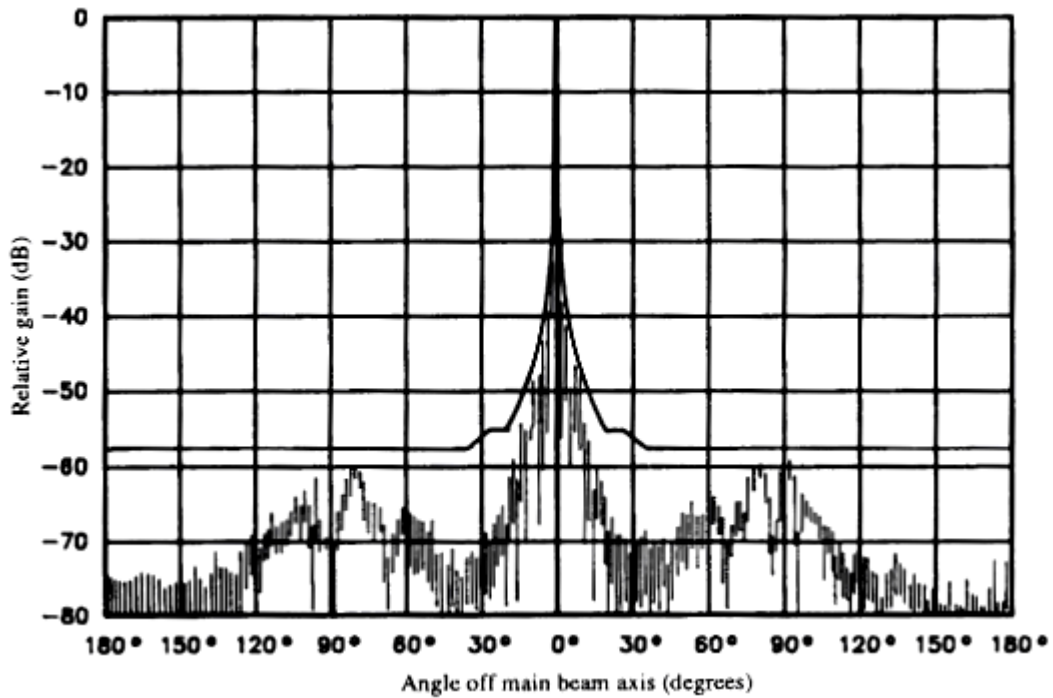**3.7 m antenna, *f* = 10.7 GHz, relative co-polar measured pattern**

FIGURE 17

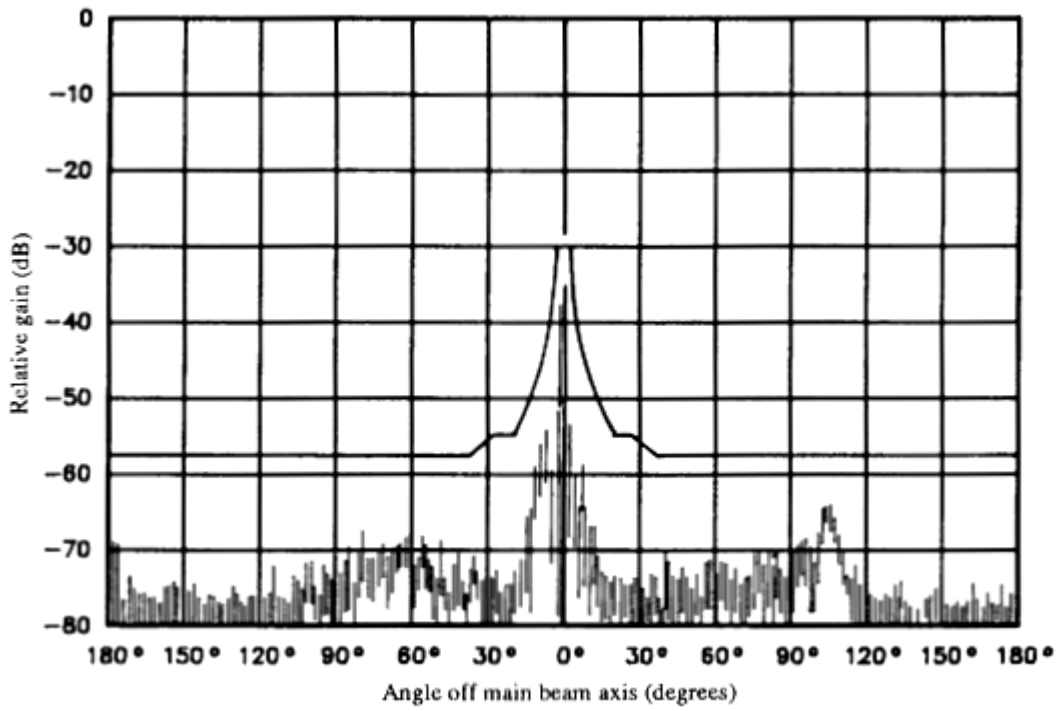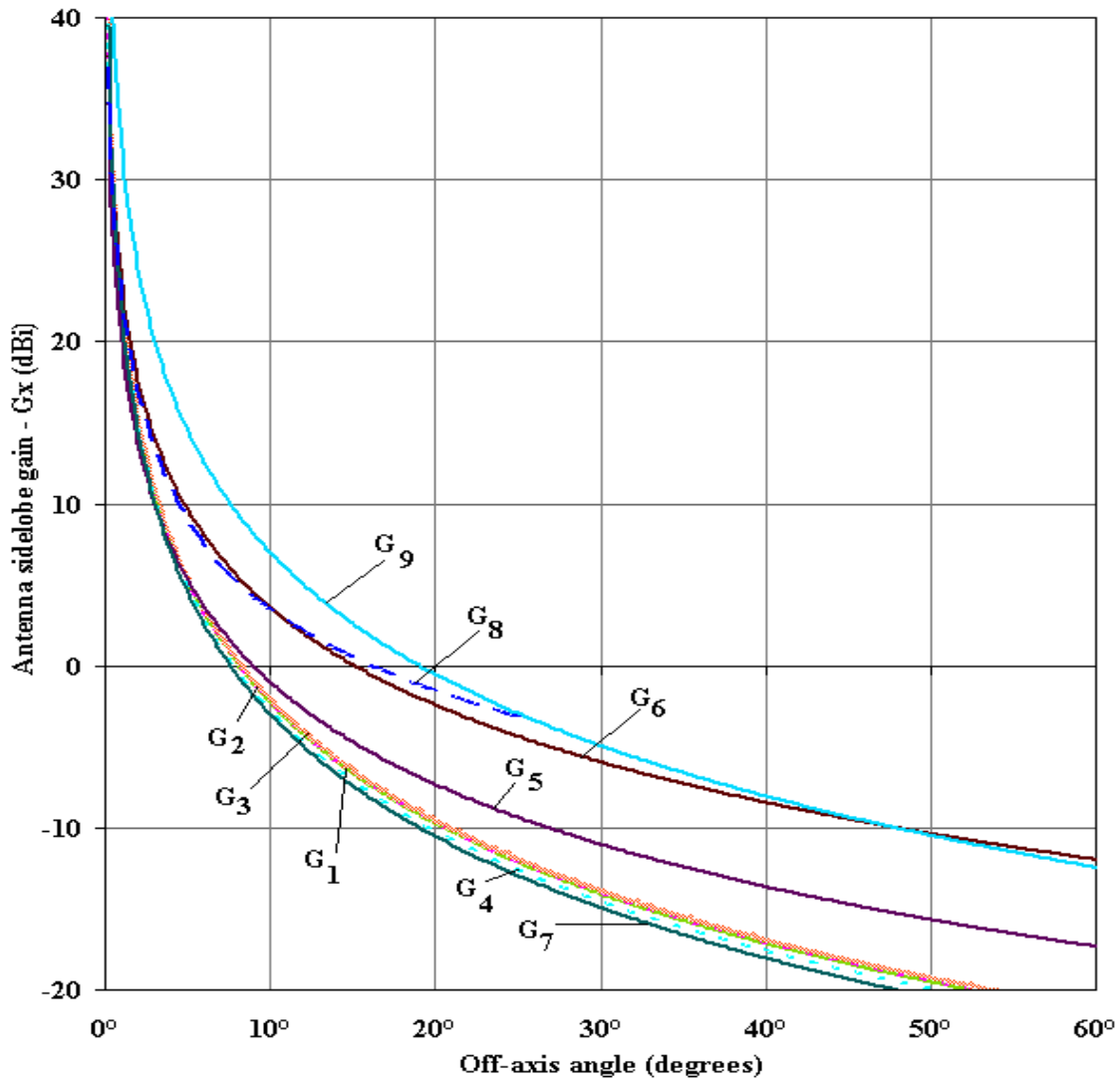**3.7 m antenna, *f* = 10.7 GHz, relative cross-polar measured pattern**

FIGURE 18

Absolute cross-polar side-lobe antenna gain pattern

$$G_1(\varphi) \quad = \quad 22.70 + 0.29\varphi - 25 \log \varphi \qquad \text{(for } D/\lambda = 25)$$

$$G_2(\varphi) \quad = \quad 22.69 + 0.37\varphi - 25 \log \varphi \qquad \text{(for } D/\lambda = 50)$$

$$G_3(\varphi) \quad = \quad 22.87 + 0.42\varphi - 25 \log \varphi \qquad \text{(for } D/\lambda = 75)$$

$$G_4(\varphi) \quad = \quad 22.15 + 0.47\varphi - 25 \log \varphi \qquad \text{(for } D/\lambda = 100)$$

$$G_5(\varphi) \quad = \quad 20.0 - 21 \log \varphi$$

$$G_6(\varphi) \quad = \quad 23.6 - 20 \log \varphi$$

$$G_7(\varphi) \quad = \quad 22.0 - 25 \log \varphi$$

$$G_8(\varphi) \quad = \quad 23.0 - 20 \log \varphi \qquad\qquad \text{for } \varphi_r \quad \leq \varphi \leq 7°$$

$$ \quad = \quad 20.2 - 16.7 \log \varphi \qquad \text{for } 7° \quad < \varphi \leq 26.3°$$

$$ \quad = \quad 32.0 - 25 \log \varphi \qquad \text{for } 26.3° < \varphi \leq 48°$$

$$G_9(\varphi) \quad = \quad 32 - 25 \log \varphi$$

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