RECOMMENDATION ITU-R BO.1834*

Coordination between geostationary-satellite orbit fixed-satellite service networks and broadcasting-satellite service networks in the band 17.3-17.8 GHz and among the broadcasting-satellite service and associated feeder-link networks serving Region 2 in the bands 17.3-17.8 GHz and 24.75-25.25 GHz

(2007)

Scope

This Recommendation addresses the issue of inter-service coordination between BSS networks serving Region 2 and FSS networks serving Regions 1 and/or 3 in all or part of the frequency band 17.3-17.8 GHz. This issue arises as a consequence of the introduction of the primary BSS allocation in Region 2 as of 1 April 2007, and the existing primary space-to-Earth FSS allocation in Region 1 (17.3-17.8 GHz) and Region 3 (17.7-17.8 GHz). It also addresses the issue of intra-service coordination among BSS and associated feeder-link networks in all or part of the frequency bands 17.3-17.8 GHz and 24.75-25.25 GHz. Representative FSS and BSS network characteristics are considered in order to perform a technical analysis of the coordination requirements.

The ITU Radiocommunication Assembly,

considering

a) that, per No. 5.517 of the Radio Regulations (RR), as of 1 April 2007, the broadcasting-satellite service (BSS) allocation in Region 2 in the band 17.3-17.8 GHz is in effect;

b) that there is a requirement for identifying the need for coordination between fixed-satellite service (FSS) networks serving Regions 1 and/or 3, and BSS networks serving Region 2;

c) that simple methods for identifying the need to coordinate between FSS and BSS networks and among BSS and associated feeder-link networks would accelerate the coordination process;

d) that typical network characteristics of BSS and FSS networks can be assumed for the establishment of a coordination arc to be applied between such networks;

e) that, when a coordination arc applies for the determination of coordination requirements, administrations can request, under the provisions of No. 9.41 of the RR, to be included in the coordination process for networks outside the established coordination arc defined in Appendix 5 of the RR;

f) that, in the cases referred to in *considering* e), administrations requesting to be included in the coordination process may need some information in order to help them in conducting this coordination,

* The Syrian Arab Republic is of the view that this Recommendation does not provide additional information with regard to the decisions adopted by WRC-2000 and WRC-03.

recognizing

a) that, per No. 5.517 of the RR, the fixed-satellite service (space-to-Earth) in Region 2 in the band 17.7-17.8 GHz shall not claim protection from and shall not cause harmful interference to the broadcasting-satellite service in this band,

recommends

1 that administrations, when conducting coordination under the provisions of No. 9.7 of the RR, between assignments pertaining to GSO BSS and associated feeder-link networks serving Region 2 in the frequency bands 17.3-17.8 GHz and 24.75-25.25 GHz, should take into consideration the material provided in Annex 1 in order to facilitate this coordination;

2 that administrations, when conducting coordination under the provisions of No. 9.7 of the RR, between assignments pertaining to a GSO FSS network serving Region 2 in the frequency band 17.3-17.8 GHz and assignments pertaining to a GSO BSS network serving Region 1 and/or 3 in the same frequency band, should take into consideration the material provided in Annex 2 in order to facilitate this coordination.

Annex 1

Coordination among GSO BSS and associated feeder-link networks serving Region 2 in the 17.3-17.8 GHz and 24.75-25.25 GHz unplanned frequency bands

1.1 Introduction

WRC-03 adopted a provisional value of ±16° as the coordination arc applicable for the BSS in bands above 17.3 GHz. Resolution 901 (WRC-03) invites ITU-R to "conduct studies on the applicability of the coordination arc concept for space radiocommunication services not yet covered by these Regulations".

This Annex provides the results of a study to determine the applicability of the provisional coordination arc value for triggering coordination for the 25/17 GHz BSS frequency band in Region 2. Based on information supplied by Canada in accordance with Appendix 4 of the RR, the analysis was performed for two Canadian BSS networks using the unplanned bands 24.75-25.25 GHz (feeder link) and 17.3-17.8 GHz (downlink). Both the traditional BSS system and multimedia forward link were examined. The coordination filings for the CAN-BSS network are divided into two different groups embracing two system designs, and eleven orbital positions. The first group, called CAN-BSS-A for the purpose of this study, covers five orbital positions ranging from 78° W to 103° W. The second group, CAN-BSS-B, covers the remaining six orbital positions from 82° W to 118.7° W.

Appendix 8 of the RR contains a method for calculating the need for coordination between two geostationary satellites sharing the same frequency band. It is based on the increase of the equivalent satellite noise temperature due to interference. Given that coordination is required for any $\Delta T/T$ greater or equal to 6%, this method can be reengineered to find the required orbital spacing between satellites.

1.2 Assumptions and results

1.2.1 Assumptions

In order to perform the analysis, a certain number of assumptions were made.

1. A homogeneous satellite model was used for the interfering satellite, based on the design of the wanted satellite for each group.
2. Since the coordination filings are identical for each of the two groups, a single central satellite longitude was chosen to represent each group.
3. The wanted and interfering earth stations were assumed to be in the same location as this represents the worst-case scenario. In both the traditional broadcast and multimedia cases, the downlink beams are designed to uniformly cover the entire service area (in this case North and/or South America depending on the network). The traditional broadcast configuration uses one regional beam to illuminate the service area whereas the multimedia configuration uses many smaller steerable spot beams to illuminate the service area.
4. As Recommendation ITU-R S.465 does not define the main lobe, the antenna pattern in Annex 3 of Appendix 8 of the RR was used to define the antenna gain for those off-axis angles outside the range of Recommendation ITU-R S.465-5. This is consistent with the software implementation of earth station antenna patterns for use in coordination, as developed by BR.
5. The signal polarity was assumed to be the same between beams.

1.2.2 Results of analysis for traditional BSS configurations

Table 1 illustrates both the maximum and average (mean) values for the orbital separation required for coordination under the $\Delta T/T$ method, for both the North American and South American beams. The CAN-BSS-A group uses a 25 MHz transponder bandwidth, while CAN-BSS-B group uses a 27 MHz bandwidth.

The coordination arc is defined as the nominal orbital position of the satellite plus and minus the required orbital separation based on the $\Delta T/T$ method.

TABLE 1

Required orbital separation for Canadian networks using a traditional broadcast configuration

Broadcasting-satellite service – North American beams:			
CAN-BSS-A		**CAN-BSS-B**	
MAX	**MEAN**	**MAX**	**MEAN**
9.08°	6.94°	6.13°	5.72°

Broadcasting-satellite service – South American beams:			
CAN-BSS-A		**CAN-BSS-B**	
MAX	**MEAN**	**MAX**	**MEAN**
8.88°	7.11°	6.03°	5.44°

1.2.3 Results of analysis for multimedia broadcast configuration (forward-link only)

Table 2 illustrates both the maximum and average (mean) values for the orbital separation required for coordination under the $\Delta T/T$ method. Unlike the traditional broadcast configurations above, which have different beams for North and South America, the service area for the multimedia configuration covers the visible Earth.

TABLE 2

Required orbital separation for Canadian networks using a multimedia broadcast configuration

Multimedia-satellite service – Forward link:			
CAN-BSS-A		**CAN-BSS-B**	
MAX	**MEAN**	**MAX**	**MEAN**
17.95°	16.11°	16.47°	15.74°

Comparing Tables 1 and 2, it is observed that the coordination arc values of multimedia broadcast configuration are significantly larger than that of the traditional broadcast configuration. The major difference between the traditional broadcast and multimedia configurations are that while the traditional mode uses one regional shaped beam, the multimedia mode uses several smaller spot beams. Due in part to the higher gain of the spot beams, the e.i.r.p. for the multimedia configuration is higher compared to the traditional broadcast configuration. There is also an increase in the intersystem interference as multiple beams are required to cover the intended service area. Frequency reuse plans as well as channel and traffic planning can and are used to help mitigate this interference. The methodology of Appendix 8 of the RR assumes that both the wanted and interfering earth stations operate at the exact same frequency. This represents the absolute worst-case scenario does not take into account any mitigation techniques. This accounts for the increase in orbital separation required to reach a $\Delta T/T$ equal to 6%.

1.3 Conclusion

The coordination arc values calculated for the CAN-BSS networks using the traditional BSS design, which uses one shaped beam to cover the entire service area, range from ±5° to ±9°. This is well within the proposed value of ±16°.

Without taking into account any interference mitigation techniques, the multimedia broadcast design, utilizing spot beams and higher gain antennas, requires larger coordination arc values, which range from ±16° to ±18°. This is slightly above the proposed coordination arc value contained in Appendix 5 of the RR.

Consequently, the results presented in this Annex show that a coordination arc of ±16 degrees is appropriate for intraservice, intraregional coordination for Region 2 BSS and associated feeder-link systems in the bands 17.3-17.8 GHz and 24.75-25.25 GHz.

Annex 2

Coordination between GSO FSS (space-to-Earth) networks and Region 2 GSO BSS networks in the band 17.3-17.8 GHz

2.1 Introduction

Following the decision of WRC-03 to introduce a preliminary value of ±16° for the coordination arc associated with BSS networks in frequency bands above 17.3 GHz, ITU-R reviewed the appropriateness of such a value for the specific case of the interregional coordination between FSS (space-to-Earth) with respect to BSS in Region 2 in the frequency band 17.3-17.8 GHz. This band is allocated, *inter alia,* to the broadcasting-satellite service in Region 2 and to the fixed-satellite service in the space-to-Earth direction in Region 1. No. 5.516B of the RR applies with regard to the FSS downlink allocation in the frequency band 17.3-17.7 GHz. No. 5.517 of the Radio Regulations applies with regard to the FSS downlink allocation in Region 2 in the frequency band 17.7-17.8 GHz.

This Annex records the studies performed within ITU-R on the specific case described above and provides the results derived from these studies.

This Annex only addresses the interservice coordination between BSS in Region 2 and FSS (space-to-Earth) in Region 1. The results given in this Annex essentially rely on the fact that there exists a natural geographical isolation between land masses of the two Regions. Therefore they can not be extended to the intraservice BSS coordination in Region 2. They can, however, easily be extended to FSS (space-to-Earth) in Region 3 with respect to BSS in Region 2, since there exists a similar geographical isolation between these two Regions.

2.2 Methodology

The methodology to study the appropriate possible coordination arc value was derived from the method described in Appendix 8 of the Radio Regulations as prescribed by Appendix 5 of the RR for requests for coordination under No. 9.7 of the RR.

The purpose of this analysis is:

1. To assess the e.i.r.p. which could be radiated over Region 2 by an FSS network without triggering a coordination with a BSS network depending of the orbital separation between the two networks.
2. To compare the values found in the studies described above with technical parameters of BSS and FSS systems intended to be deployed in the band 17.3-17.8 GHz.

2.2.1 Derivation of maximum e.i.r.p. radiated without triggering a coordination

From the receiving system noise temperature and the interference criterion, an interference density was computed. The e.i.r.p. density towards a Region was then computed from this interference density taking into account only free space loss:

$$e.i.r.p.(density) = 10\log\left(\frac{T_{ES}\dfrac{\Delta t}{t}kl_d}{g_{ES}(\theta_t)}\right)$$

where:

e.i.r.p. (density): e.i.r.p. density radiated by a satellite towards a Region (dBW/Hz)

T_{ES}: receiving earth station system noise temperature at antenna output (K)

$\Delta t/t$: interference criterion

k: Boltzmann's constant $(1.38\times10^{-23}\ J/K)$

l_d: downlink free space loss

$g_{ES}(\theta_t)$: receiving earth station antenna gain towards the interfering satellite

θ_t: topocentric angle between wanted and interfering satellites.

The free-space loss was computed assuming a distance of 38 650 km and a frequency of 17.3 GHz. It was further assumed that the topocentric angle is 10% larger than the geocentric angle. No polarization advantage was taken into account.

2.3 Technical parameters of BSS and FSS systems

2.3.1 BSS systems

2.3.1.1 Interference criterion

The criterion is derived from the section of Appendix 5 of the RR dealing with No. 9.7 of the RR under which BSS networks in the band 17.3-17.8 GHz in Region 2 are coordinated:

$$\frac{\Delta T}{T} = 6\%$$

2.3.1.2 Receiving earth station characteristics

The following characteristics of BSS systems intended to be deployed in the band 17.3-17.8 GHz are extracted from Appendix 1 to this Annex:

– antenna diameter: 30 cm[1], 45 cm, 60 cm, 90 cm, 120 cm and 140 cm[2];

– antenna radiation pattern: five antenna patterns were considered, namely Annex III of Appendix 8 of the RR, Recommendation ITU-R S.465-5 (complemented by Appendix 8 of the RR for the main beam), Recommendation ITU-R S.580-6 (complemented by Appendix 8 of the RR for the main beam), Recommendation ITU-R BO.1213-1 and the pattern given in Appendix 1 to this Annex;

– receiving system noise temperature at the output of BSS earth station antenna: two values for the earth station noise temperature were considered, namely 140 K and 170 K. For the purpose of this Annex, the more sensitive value was used, i.e. 140 K.

---

[1] Appendix 1 to this Annex does not mention the possible use of 30 cm antennas. It is however felt that this may occur in the future. Therefore, this analysis was conducted by including such an antenna diameter. The results are presented as two separate cases (Tables 4 and 5) depending on the inclusion of the 30 cm antennas or not.

[2] Community reception may use larger antennas. However, due to the narrower width of their main beam, it is generally easier to protect this kind of application except for very closely spaced networks (i.e. signals from both networks are received in the antenna main beam.)

2.3.1.3 BSS systems parameters

This section presents BSS parameters (mainly maximum satellite e.i.r.p. and geographic separation) of systems intended to be deployed in the band 17.3-17.8 GHz. Thus a comparison can be drawn between these parameters and the ones found in § 2.4 which will not trigger any coordination between BSS and FSS networks.

2.3.1.3.1 Maximum satellite e.i.r.p. density

Appendix 1 to this Annex indicates that, for one system, the maximum satellite e.i.r.p. will be 57.2 dBW/25 MHz (i.e. –16.8 dBW/Hz if an evenly spread power distribution is assumed) and, for the second one, the maximum satellite e.i.r.p. ranges from 64.2 dBW to 68.5 dBW (the associated channel bandwidths range from 25 MHz to 500 MHz). For this second network, it is not clear whether the higher e.i.r.p. relates to the larger channel: in such a case, the e.i.r.p. densities vary from –9.8 dBW/Hz to −18.5 dBW/Hz if an evenly spread power distribution is assumed.

2.3.1.3.2 Geographical discrimination

Some examples of Region 2 BSS satellite footprints (or envelopes) from information submitted under Appendix 4 of the RR (extracted from the SRS database) were examined. From these examples, it was found that, in most cases, the geographical isolation between Region 2 and Region 1 ranges from a little more than 10 dB to as much as 35 dB, except for certain high-latitude areas. For the purpose of this Annex, a parametric assessment was therefore made by using values of 10 dB, 15 dB and 20 dB as geographical isolation.

2.3.2 FSS systems

Characteristics of some FSS systems planned to be deployed in the band 17.7-20.2 GHz are extracted from Recommendation ITU-R S.1328, Annex 3, as shown in Table 1 below.[3] A comparison can then be drawn between these parameters and the ones found in § 2.4 which will not trigger any coordination between BSS and FSS networks.

2.3.2.1 Maximum satellite e.i.r.p.

TABLE 3

Examples of FSS systems characteristics

System name	Transponder bandwidth (MHz)	Maximum satellite e.i.r.p. (dBW)	Typical e.i.r.p. density (dBW/Hz)
A	120	61	–23.6
A'	250	61	–26.6
B	120	59	–21.3
J	120	61	–25.9
K	120	61	–20.8
L	120	60	–20.8
M	120	60.2	–20.9
N	24	54	–22.0

[3] Ref. Data of Rec. ITU-R S.1328 (accessible on the ITU-R website via http://www.itu.int/ITU-R/index.asp?category=information&link=mailing-list&group=rsg4&lang=en

TABLE 3 (*end*)

System name	Transponder bandwidth (MHz)	Maximum satellite e.i.r.p. (dBW)	Typical e.i.r.p. density (dBW/Hz)
S	**120**	**58**	**–22.6**
T	54	61	–16.3
U	36	51-55	–18.0
V	125	60-62	–19.1
W		22.6	–25.5
X		62.8	–23.1/–16.0
Y			–63/–38
Z	25-120	70	–4.1

2.3.2.2 Geographical discrimination

For the time being, no precise information is available with regards to the satellite antenna performance of FSS systems intended to be deployed in the band 17.3-17.7 GHz. Therefore, as for BSS systems, the analysis was performed for geographical isolation values of 10 dB, 15 dB and 20 dB.

2.4 Results

Section 2.3.2.1 presented some typical e.i.r.p. densities which will be radiated by FSS networks over Region 2. The Tables 4 and 5 summarize the minimum orbital separation required to transmit a certain e.i.r.p. density without triggering coordination depending on BSS antenna patterns. Table 4 gives the results by taking into account antennas as small as 30 cm. Table 5 gives the results without considering 30 cm antennas.

TABLE 4

Orbital separation required for not triggering coordination with BSS networks (30 cm antenna included)

		Geographical isolation								
		10 dB	10 dB	10 dB	15 dB	15 dB	15 dB	20 dB	20 dB	20 dB
		FSS satellite e.i.r.p. over Region 1								
		–5 dBW/Hz	–10 dBW/Hz	–15 dBW/Hz	–5 dBW/Hz	–10 dBW/Hz	–15 dBW/Hz	–5 dBW/Hz	–10 dBW/Hz	–15 dBW/Hz
BSS antenna patterns	Appendix 8 of the RR	22.8	14.4	9.1	14.4	9.1	5.7	9.1	5.7	2.9
	Recommendation ITU-R S.465-5	11.3	7.1	5.2	7.1	5.2	5.2	5.2	5.2	2.9
	Recommendation ITU-R S.580-6	8.6	5.4	5.2	5.4	5.2	5.2	5.2	5.2	2.9
	Recommendation ITU-R BO.1213-1	8.6	5.4	4.4	5.4	4.4	3.7	4.4	3.7	2.9
	Appendix 2 to this Annex	11.3	5.4	4.4	5.4	4.4	3.7	4.4	3.7	2.9

TABLE 5

Orbital separation required for not triggering coordination with BSS networks (30 cm antenna excluded)

		Geographical isolation								
		10 dB	10 dB	10 dB	15 dB	15 dB	15 dB	20 dB	20 dB	20 dB
		FSS satellite e.i.r.p. over Region 1								
		–5 dBW/Hz	–10 dBW/Hz	–15 dBW/Hz	–5 dBW/Hz	–10 dBW/Hz	–15 dBW/Hz	–5 dBW/Hz	–10 dBW/Hz	–15 dBW/Hz
BSS antenna patterns	Appendix 8 of the RR	19.4	12.2	7.7	12.2	7.7	4.8	7.7	4.8	2.7
	Recommendation ITU-R S.465-5	11.3	7.1	4.5	7.1	4.5	3.4	4.5	3.4	2.6
	Recommendation ITU-R S.580-6	8.6	5.4	3.4	5.4	3.4	3.4	3.4	3.4	2.6
	Recommendation ITU-R BO.1213-1	8.6	5.4	3.4	5.4	3.4	2.8	3.4	2.8	2.3
	Appendix 2 to this Annex	11.3	5.4	3.4	5.4	3.4	2.8	3.4	2.8	2.3

2.5 Conclusion

The analyses presented in this section show that a coordination arc of ±16° between Region 1 FSS (space-to-Earth) and Region 2 BSS in the band 17.3-17.7 GHz is overly conservative, and that a coordination arc of ±8° would generally suffice to trigger coordination of FSS networks serving Region 1 with BSS networks serving Region 2.

The results can be extended to the whole band 17.3-17.8 GHz for the FSS (space-to-Earth) in the three Regions with respect to BSS in Region 2, taking into account footnote No. 5.517 of the RR and the geographical isolation between Regions 2 and 3.

Consequently, a coordination arc of ±8° for the FSS (space-to-Earth) in the three Regions with respect to BSS in Region 2 in the band 17.3-17.8 GHz is appropriate.

Appendix 1
to Annex 2

Examples of system parameters of unplanned BSS systems and associated feeder links in frequency bands 17.3-17.8 GHz and 24.75-25.25 GHz

The following Table contains an example summary of the Canadian coordination information submitted to BR (CAN-BSS-95). The system plans to provide TV broadcasting and interactive multimedia services. Furthermore, coordination information submitted by another Region 2 country for providing broadcasting-satellite services is included in the third column, titled “Other”, of the Table.

System characteristics

		CAN-BSS-95	Other
Orbit		GEO	GEO
Position		95.0º W	101.0º W
Frequency	Uplink	24.75-25.25 GHz	24.75-25.25 GHz
	Downlink	17.3-17.8 GHz	17.3-17.8 GHz
Broadcast			
Coverage		North America	North America
Assigned channel bandwidth		25 MHz	25 MHz-500 MHz
Uplink			
Satellite receive antenna gain		35 dBi	49.4 dBi
ES (earth station) transmit antenna size		5.6 m, 3.5 m	5 m-13 m
ES transmit antenna gain (max)		61.1 dBi, 57.0 dBi	60.5 dBi-68.8 dBi
Receiving satellite system noise temperature		730 K	810 K

	CAN-BSS-95	Other
ES transmit antenna pattern	AP4 A, B, C, D, φ parameters: 29, 25, 32, 25, 7º	Rec. ITU-R S.465
Polarization	Circular left	Circular left
Maximum power supplied to the input of ES transmitting antenna	22.2 dBW	21.2 dBW-29.5 dBW
Downlink		
Satellite transmit antenna gain	35 dBi	49.4 dBi
ES receive antenna size	0.45 m-1.4 m	0.45 m-1.2 m
ES receive antenna gain	36.1 dBi-46.0 dBi	36.5 dBi-45.0 dBi
Polarization	Circular right	Circular right
ES receive noise temperature	170 K	140 K
ES receive antenna pattern	(see Appendix 2 to this Annex)	Rec. ITU-R S.465
Maximum power supplied to the input of satellite transmitting antenna	22.2 dBW	14.8 dBW-19.1 dBW
E_b/N_0	6.5 dB	No information
C/N threshold	6.6 dB	No information
Required C/N (clear-sky)	9.0 dB	Uplink 17.4 dB, Downlink 6-17.6 dB
Multimedia (CAN-BSS-95 only)		
Forward link		
Coverage	Visible Earth	
Channel bandwidth	25 MHz	
Uplink		
Satellite receive antenna gain	44.5 dBi	
ES transmit antenna size	5.6 m, 3.5 m	
ES transmit antenna gain (max)	61.1 dBi, 57.0 dBi	
Receiving satellite system noise temperature	730 K	
ES transmit antenna pattern	AP4 A, B, C, D, φ parameters: 29, 25, 32, 25, 7º	
Polarization	Circular left	
Maximum power supplied to the input of ES transmitting antenna	18.0 dBW	
Downlink		
Satellite transmit antenna gain	44.5 dBi	
ES receive antenna size	0.45 m-1.4 m	
ES receive antenna gain	36.1 dBi-46.0 dBi	
Polarization	Circular right	
ES receive noise temperature	170 K	
ES receive antenna pattern	(see Appendix 2 to this Annex)	
Maximum power supplied to the input of satellite transmitting antenna	21.0 dBW	

	CAN-BSS-95	Other
E_b/N_0	6.5 dB	
C/N threshold	6.6 dB	
Required C/N (clear-sky)	11.0 dB	
Return link		
Coverage	Visible Earth	
Channel bandwidth	55 MHz, 113 MHz	
Uplink		
Satellite receive antenna gain	44.5 dBi	
ES transmit antenna size	0.45 m-1.4 m	
ES transmit antenna gain (max)	39.2 dBi-49.1 dBi	
Receiving satellite system noise temperature	730 K	
E.S. transmit antenna pattern	Rec. ITU-R S.465	
Uplink polarization	Circular left, Circular right	
Maximum power supplied to the input of ES transmitting antenna	36.4 dBW, 39.7 MHz	
Downlink		
Satellite transmit antenna gain	44.5 dBi	
ES receive antenna size	5.6 m, 3.5 m	
ES receive antenna gain	58.0 dBi, 54 dBi	
Downlink polarization	Circular right, Circular left	
ES receive noise temperature	185 K	
ES receive antenna pattern	AP4 A, B, C, D, φ parameters: 29, 25, 32, 25, 7º	
Maximum power supplied to the input of satellite transmitting antenna	21.2 dBW	
E_b/N_0	6.5 dB	
C/N threshold	6.6 dB	
Required C/N (clear-sky)	10.0 dB	

Appendix 2 to Annex 2

Reference receiving antenna co-polar pattern

Antenna pattern:

$$G_{co}(\varphi) = G_{max} - 2.5 \times 10^{-3} \left(\frac{D}{\lambda} \varphi \right)^2 \quad \text{for} \quad 0 \leq \varphi < \varphi_m \text{ where } \varphi_m = \frac{\lambda}{D} \sqrt{\frac{G_{max} - G_1}{0.0025}}$$

$$G_{co}(\varphi) = G_1 = 29 - 25 \log \varphi_r \quad \text{for} \quad \varphi_m \leq \varphi < \varphi_r \text{ where } \varphi_r = 95 \frac{\lambda}{D}$$

$$G_{co}(\varphi) = 29 - 25 \log \varphi \quad \text{for} \quad \varphi_r \leq \varphi < 7^\circ$$

$$G_{co}(\varphi) = 7.9 \text{ dBi} \quad \text{for} \quad 7^\circ \leq \varphi < 9.2^\circ$$

$$G_{co}(\varphi) = 32 - 25 \log \varphi \quad \text{for} \quad 9.2^\circ \leq \varphi < 48^\circ$$

$$G_{co}(\varphi) = -10 \text{ dBi} \quad \text{for} \quad 48^\circ \leq \varphi < 180^\circ$$

where:

- G_{co}: co-polar gain (dBi)
- G_{max}: maximum isotropic gain of the antenna (dBi)
- φ: off-axis angle (degrees)
- D: antenna diameter (m)
- λ: wavelength (m).

NOTE 1 – Excerpt from Annex 11 of Document 6S/349 (Report of the fifth meeting of ITU-R Working Party 6S, Geneva, 17-26 March, 2003).