RECOMMENDATION ITU-R S.1714

Static methodology for calculating epfd↓ to facilitate coordination of very large antennas under Nos. 9.7A and 9.7B of the Radio Regulations

(2005)

The ITU Radiocommunication Assembly,

considering

a) that WRC-2000 adopted, in Article 22 of the Radio Regulations (RR) , equivalent power flux-density (epfd) limits to be met by non-GSO FSS systems in order to protect GSO FSS and GSO broadcasting-satellite service networks in parts of the frequency range 10.7-30 GHz;

b) that WRC-2000 agreed that additional protection above that provided by the epfd limits in *considering* a) is required for certain GSO FSS networks with specific receive earth stations having all of the following characteristics:

i) earth station antenna maximum isotropic gain greater than or equal to 64 dBi for the frequency band 10.7-12.75 GHz or 68 dBi for the frequency bands 17.8-18.6 GHz and 19.7-20.2 GHz;

ii) *G*/*T* of 44 dB/K or higher;

iii) emission bandwidth of 250 MHz or more for the frequency bands below 12.75 GHz or 800 MHz or more for the frequency bands above 17.8 GHz;

c) that, in order to provide this additional protection, WRC-2000 adopted RR Nos. 9.7A and 9.7B, establishing a procedure for effecting coordination between specific earth stations in a geostationary network in the FSS and systems in the FSS using satellites in non-GSO in certain frequency bands;

d) that the technical conditions for triggering coordination under RR Nos. 9.7A and 9.7B are defined in RR Appendix 5 and include the thresholds in *considering* b) and the following epfd↓ radiated by the non-GSO FSS satellite system into the earth station employing the very large antenna when this antenna is pointed towards the wanted GSO satellite:

i) in the frequency band 10.7-12.75 GHz:

a) –174.5 dB(W/(m^2 · 40 kHz)) for any percentage of time for non-GSO satellite systems with all satellites only operating at or below 2 500 km altitude; or

b) –202 dB(W/(m^2 · 40 kHz)) for any percentage of the time for non-GSO satellite systems with any satellites operating above 2 500 km altitude;

ii) in the frequency bands 17.8-18.6 GHz or 19.7-20.2 GHz:

a) –157 dB(W/(m^2 · MHz)) for any percentage of time for non-GSO satellite systems with all satellites only operating at or below 2 500 km altitude; or

b) –185 dB(W/(m^2 · MHz)) for any percentage of the time for non-GSO satellite systems with any satellites operating above 2 500 km altitude;

e) that the calculation of epfd↓ produced by a non-GSO satellite system as a function of time requires the use of a suitable simulation software tool;

f) that Recommendation ITU-R S.1503 provides a specification for a software simulation tool for calculating epfd↓ as a function of time, however it does not take into account the inclination of a GSO satellite;

g) that as a consequence of the high gain of the very large GSO earth station antennas and the nature of the epfd↓ equation, non-GSO satellites in the side lobes of the very large GSO earth station antennas do not significantly contribute to the epfd↓ value;

h) that WRC-03 adopted Resolution 85 (WRC-03) which allows, on a provisional basis until appropriate software is available, for coordination under RR Nos. 9.7A and 9.7B to be effected using only the characteristics of the GSO FSS network;

j) that there is limited guidance for conducting coordination under RR Nos. 9.7A and 9.7B,

recommends

1 that the methodology in Annex 1 to this Recommendation could be used by administrations effecting coordination under RR Nos. 9.7A and 9.7B to calculate the worst case static epfd↓ value from a non-GSO system at a specific GSO earth station antenna when this antenna is pointed towards the wanted GSO satellite;

2 that the results from *recommends* 1 should be compared to the epfd↓ protection criterion of the GSO network and the criterion referred to in *considering* d) to determine if there is potential for the non-GSO system to not meet this protection criterion;

3 that if the non-GSO system meets the GSO epfd↓ protection criterion and the criterion referred to in *considering* d) then coordination should be considered complete;

4 that if the non-GSO system does not meet the GSO epfd↓ protection criterion or the criterion referred to in *considering* d) then a more detailed analysis will be required.

Annex 1

1 Description of the methodology

In Circular Letter CR/176, the Radiocommunication Bureau requested that administrations responsible for non-GSO satellite systems in certain frequency bands subject to epfd limits submit supplementary information to the ITU within six months of 26 March 2002 pursuant to *resolves* 2 of Resolution 59 (WRC-2000). This supplementary information contains the details about the satellite network operations and the pfd masks that are required to calculate the epfd levels produced by the non-GSO systems. The methodology proposed in this Recommendation makes use of this supplementary information and does not require any other additional information regarding the non-GSO satellite systems.

In order to meet the epfd↓ limits, non-GSO satellite systems will need to employ some sort of mitigation technique. One of the most common techniques is GSO arc avoidance. GSO arc avoidance can be employed by means of establishing an exclusion zone in three different ways:

– The exclusion zone is defined from the GSO earth station to ±X° to the GSO arc and the non-GSO satellite can transmit to a non-GSO earth station located at least a predefined distance from the GSO earth station while inside the exclusion zone;

– The exclusion zone is as defined in Fig. 1 however, the non-GSO satellite cannot transmit while inside the exclusion zone;

– The exclusion zone is defined by latitude, and the non-GSO satellite cannot transmit when its sub-satellite latitude is between a certain $\pm X$ latitude range.

A diagram of each of these three types of GSO arc avoidance techniques is provided in Figs. 1 through 3.

FIGURE 1

Case 1 Exclusion zone

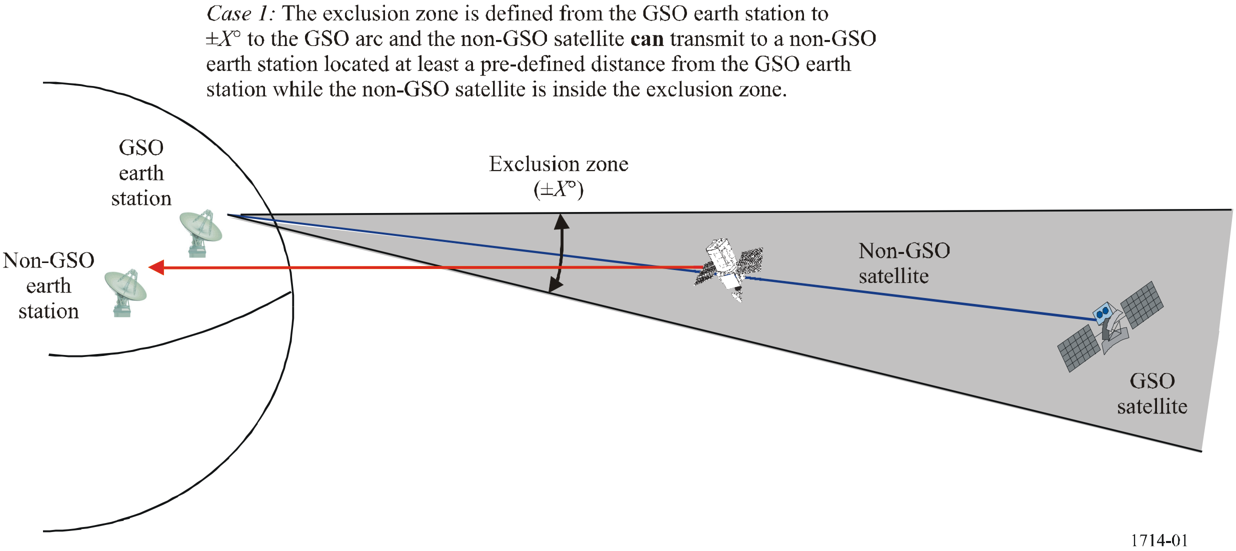


FIGURE 2

Case 2 Exclusion zone

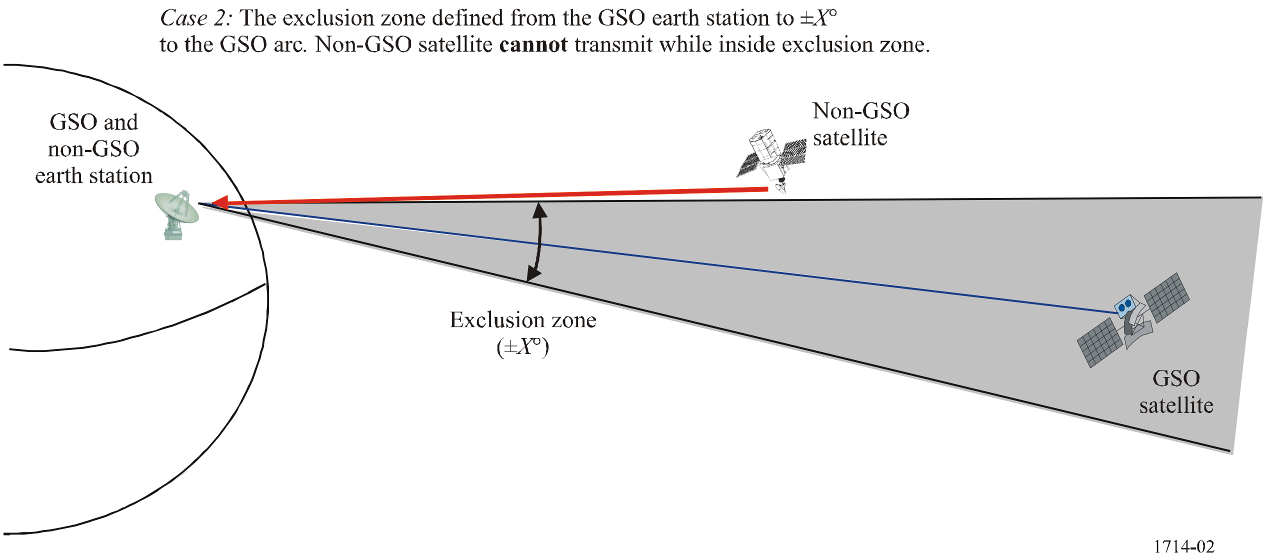
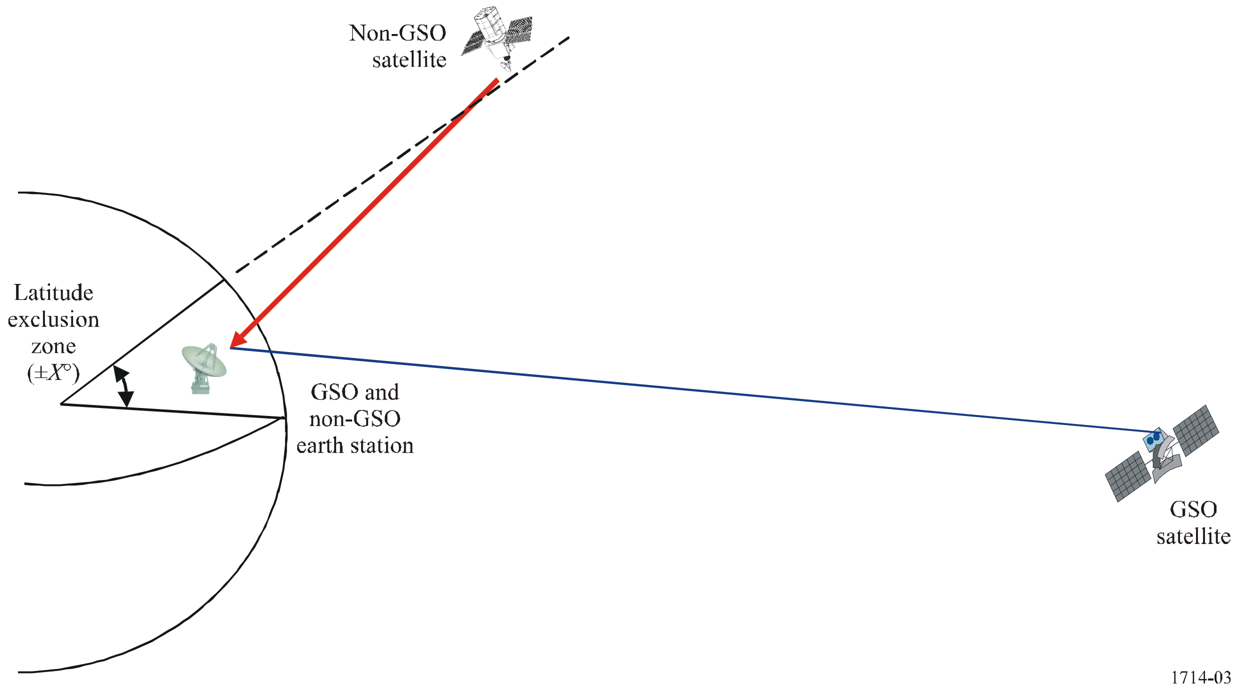


FIGURE 3

Case 3 Exclusion zone

Case 3: The non-GSO satellite cannot transmit when the sub-satellite latitudes is between a certain latitude range. For example, a medium earth orbit (MEO) would not transmit between + and – *X*° latitude. A high earth orbit (HEO) would not transmit below + *X*° latitude or above – *X*° latitude depending on the hemisphere of the apogee.



Cases 1 and 2 describe the forms of GSO arc avoidance that would most likely be used by a low earth orbit (LEO) constellation; whereas Case 3 would most likely be used with a HEO type constellation, while all three types of arc avoidance could be used with a MEO constellation. Because it is unlikely for a HEO to use the arc avoidance described in Cases 1 and 2, the calculations in these methodologies are limited to circular orbits. The methodology for Case 3 can be utilized for a HEO constellation as long as the radius to the HEO satellite when it crosses the cut on/off latitude is known. The epfd↓ thresholds in RR Appendix 5 used to determine the technical conditions for triggering coordination between non-GSO FSS systems and specific earth stations in a GSO FSS network are defined on the basis of altitude, with one trigger for non-GSO systems with all satellites operating at or below 2 500 km altitude and another trigger value for non-GSO FSS systems with any satellites operating above 2 500 km altitude. Table 1 shows the relationship between non-GSO orbit type, RR Appendix 5 coordination trigger, and the cases considered for mitigation techniques.

TABLE 1

Relationship between orbit type, RR Appendix 5 trigger, and mitigation technique

Orbit type	**Appendix 5 Coordination trigger (km)**	**Mitigation techniques**
LEO	≤ 2 500	Cases 1 and 2
MEO	> 2 500	Cases 1, 2 and 3
HEO	> 2 500	Case 3

2 Case 1

Case 1 depicts the scenario when an exclusion zone is defined from the GSO earth station to ±*X*° to the GSO arc. When the non-GSO is within this exclusion zone it can transmit but not in the direction of the GSO earth station. The distance away from the GSO earth station that the non-GSO can transmit to is determined by the non-GSO operations. The worst-case geometry for this case is depicted in Fig. 1 where the non-GSO is directly in line between the GSO satellite and the GSO earth station but the non-GSO is transmitting to an earth station away from the GSO earth station. This geometry produces a non-GSO side lobe into GSO main beam interference scenario. This mitigation technique would typically be used with a LEO constellation but would also work with a MEO constellation. The algorithm to calculate the epfd↓ value requires the following Steps:

Step 1: Inputs: Radius of the Earth, non-GSO radius, non-GSO inclination, GSO radius, GSO satellite longitude, GSO satellite inclination, GSO earth station latitude, GSO earth station longitude.

Step 2: Calculate the azimuth and elevation angles from the GSO earth station to the GSO satellite.

Step 3: Calculate the sub-satellite latitude and longitude of the non-GSO for the same azimuth and elevation as the GSO satellite.

Step 4: If the non-GSO pfd masks are presented in alpha vs. delta longitude form (see Recommendation ITU-R S.1503 for alpha and delta longitude definitions).

a) From the pfd masks choose the pfd for the latitude nearest the sub-satellite latitude of the non-GSO for Alpha = 0 or *X* = 0 and the longitude difference between the GSO and the non-GSO satellites.

b) Since this is an in-line event the G(theta)/G(max) portion of the epfd calculation is equal to 1 or 0 dB.

c) Because the GSO satellite has a very large bandwidth, there may be several sets of pfd masks with overlapping frequencies; all of these should be included.

d) Calculate the epfd as defined in RR No. 22.5C.

Step 5: If the non-GSO pfd masks are presented in azimuth vs. elevation form (see Recommendation ITU-R S.1503 for azimuth and elevation definitions).

a) Calculate the Earth centred fixed (ECF) coordinates of the GSO satellite, earth station and non-GSO satellite.

b) Translate and rotate vector between non-GSO satellite and GSO earth station from ECF coordinates to satellite centred coordinates.

c) Calculate azimuth and elevation from the non-GSO satellite to the GSO earth station.

d) From the pfd masks choose the pfd for the latitude nearest the sub-satellite latitude of the non-GSO satellite for the azimuth and elevation from the non-GSO satellite to the GSO earth station.

e) Since this is an in-line event the G(theta)/G(max) portion of the epfd calculation is equal to 1 (numerical) or 0 dB.

f) Because the GSO has a very large bandwidth, there may be several sets of pfd masks with overlapping frequencies; all of these should be included.

g) Calculate the epfd as defined in RR No. 22.5C.

An Excel worksheet with the appropriate equations and calculations preprogrammed has been developed. A picture of the Case 1 calculation page is shown in Table 2. The input values for the non-GSO satellite system are fictional and do not represent any particular system.

TABLE 2

Case 1 Excel spreadsheet calculations

Case 1: Exclusion zone defined from the GSO Earth station to ± *X*° to the GSO arc				
Non-GSO satellite CAN transmit inside exclusion zone but not toward GSO earth station				
Worst case: non-GSO satellite is inline with the GSO satellite and Alpha = 0 or *X* = 0				
Note: This algorithm is only valid for circular non				
Inputs				
	Radius of the Earth (km)	Re	6 378.15	
	Non-GSO radius (km)	Rn	7 878	
	Non-GSO satellite inclination (degrees)	i	55	
	GSO radius (km)	Rg	42 164	
	GSO satellite Longitude (degrees)	GSO Long.	–30	
	GSO satellite Inclination (degrees)	ig	5	
	Earth station latitude (degrees)	φ	38	
	Earth station longitude (degrees)	earth Long.	–77	
Calculations				
	GSO satellite latitude (degrees)	δg	5	
	Difference between earth station and GSO satellite longitude (degrees)	Δλg	47	GSO Long. – earth Long.
	Calculate gamma angle from earth station to GSO satellite (degrees)	γg	53.91141	acos[sin(φ) * sin(δg) + cos(φ) * cos(δg) * cos(Δλg)}
	Calculate slant range from earth station to GSO satellite (km)	dg	3 8751.35	sqrt(Re^2 + Rg^2 – 2*Re*Rg*cos(γg))
	Calculate elevation angle from earth station to GSO satellite (degrees)	el	28.44516	acos[(Rg/dg) * sin(γg)]
	Calculate azimuth angle from the earth station to GSO satellite (degrees)	az	115.6339	if (Δλg>0 and φ<0) or (Δλg<0 and φ<0) then asin [cos(δg) * sin (Δλg/sin(Δλg/sinγg)] else 180 – asin [cos(δg) * (Δλg)/sin(γg)]
	Calculate gamma angle from earth station to non-GSO satellite (degrees)	γn	16.16731	acos((Re/Rn) * cos(el)) – el
	Calculate sub-satellite latitude of non-GSO satellite at this Az and El (degrees)	δ	29.76146	If φ > 0 Then 90 – acos[cos(90-φ) * cos(γn) + sin(90-φ) * sin(γn) * cos(az)] else 90 – acos[cos(90+φ) * cos(γn) + sin(90-φ) * sin(γn) * cos(az+180)]
	Calculate long difference between non-GSO satellite and earth station (degrees)	Δλn	16.80892	if Δλg>0 then acos[(cos(γn) – sin(φ) * sin(δ)) / (cos(φ) * cos(δ))] else –1*acos[(cos(γn) – sin(φ) * sin(δ)) / (cos(φ) * cos(δ))]
	Calculate the sub-satellite longitude of the non-GSO satellite at this Az and El (degrees)	nGSO Long.	–60.1911	earth Long.+ Δλn

TABLE 2 (*continued*)

If satellite pfd masks are presented in Alpha vs Delta Longitude form				
	Calculate the Delta longitude between GSO and non-GSO satellites (degrees)	delta	30.19108	GSO Long – nGSO Long
Choose pfd from mask for latitude nearest to sub-satellite latitude of non-GSO satellite, because the GSO satellite VLA frequency bandwith is very large there may be several sets of masks with overlapping frequencies, all of these should be added in since this is an in-line event the G_r(theta)/G_r(max) portion of epfd calculation is equal to 1 (numerical) or 0 dB.				
	Freq 1: pfd of non-GSO satellite with Alpha = 0 or X = 0 and Delta	pfd1	–140	example
	Freq 2: pfd of non-GSO satellite with Alpha = 0 or X = 0 and Delta (input NA if not applicable)	pfd2	–131	example
		...		
	freq n: pfd of non-GSO satellite with Alpha = 0 or X = 0 and Delta (input NA if not applicable)	pfdn	–140	example
	Calculate worst-case epfd (dB(W/(m^2 · MHz)))	epfd	–130.025	10 log(10^(pfd1/10)+10^(pfd2/10)+...+10^(pfdn/10))
If satellite pfd masks are presented in azimuth vs elevation form				
Calculate the x, y, z components of the earth station in ECF				
	Earth station x value (km)	Xe	1 130.615	Re * cos(φ) * cos(earth Long.)
	Earth station y value (km)	Ye	–4 897.23	Re * cos(φ) * sin(earth Long.)
	Earth station z value (km)	Ze	3 926.781	Re * sin(φ)
Calculate the x, y, z components of the non-GSO satellite in ECF				
	Non-GSO x value (km)	Xn	3 399.674	Rn * cos(δ) * cos(nGSO Long.)
	Non-GSO y value (km)	Yn	–5 934.02	Rn * cos(δ) * sin(nGSO Long.)
	Non-GSO z value (km)	Zn	3 910.561	Rn * sin(δ)
Calculate vector between non-GSO satellite and earth station				
	Vector X (km)	X	–2 269.06	Xe – Xn
	Vector Y (km)	Y	1 036.788	Ye – Yn
	Vector Z (km)	Z	16.21997	Ze – Zn
Calculate longitude of ascending node				
	Difference between satellite longitude and ascending node (degrees)	del	23.6024	asin(tan(δ) / tan(i))
	Longitude of ascending node (degrees)	an	–83.7935	nGSO Long. – del

TABLE 2 (*end*)

Calculate argument of perigee plus true anomaly				
	Argument of perigee plus true anomaly (degrees)	arg	37.29943	asin(sin(δ) / sin(i))
Calculate some values for the transformation matrix of the earth station XYZ ECF coordinates to xyz sat (satellite centred) coordinates				
	Cosine of longitude of ascending node	cos_an	0.108113	cos(an)
	Sine of longitude of ascending node	sin_an	–0.99414	sin(an)
	Cosine of non-GSO satellite inclination	cos_inc	0.573576	cos(i)
	Sine of non-GSO satellite inclination	sin_inc	0.819152	sin(i)
	Cosine of argument of perigee plus true anomaly	cos_arg	0.79548	cos(arg)
	Sine of argument of perigee plus true anomaly	sin_arg	0.60598	sin(arg)
	Earth station *x* value from satellite point of view (km)	x sat	–194.273	X[-cos(an)*sin(arg)-sin(an)*cos(i)*cos(arg)]+ Y[cos(an)*cos(i)*cos(arg)-sin(an)*sin(arg)]+ Z[sin(i)*cos(arg)]
	Earth station *y* value from satellite point of view (km)	y sat	1 752.088	X[-cos(an)*cos(arg)+sin(an)*cos(i)*sin(arg)]- Y[sin(an)*cos(arg)+cos(an)*cos(i)*sin(arg)]- Z[sin(i)*sin(arg)]
	Earth station *z* value from satellite point of view (km)	z sat	1 765.294	X[sin(an)*sin(i)]+Y(-cos(an)*sin(i)]+Z[cos(i)]
	Azimuth to earth station from satellite point of view (degrees)	az	–6.32715	atan(x sat/y sat)
	Elevation to earth station from satellite point of view (degrees)	el	45.04008	atan(z sat/(sqrt(x sat^2+y sat^2)))
Choose pfd from mask for latitude nearest to sub-satellite latitude of non-GSO satellite, because the GSO satellite VLA frequency bandwith is very large there may be several sets of masks with overlapping frequencies, all of these should be added in since this is an in-line event the G_r(theta)/G_r(max) portion of epfd calculation is equal to 0				
	Freq 1: pfd of non-GSO satellite with azimuth and elevation to the earth station	pfd1	–140	example
	Freq 2: pfd of non-GSO satellite with azimuth and elevation to the earth station	pfd2	–131	example
		...		
	Freq *n*: pfd of non-GSO satellite with azimuth and elevation to the earth station	pfdn	–140	example
	Calculate worst-case epfd (dB(W/(m^2 · MHz)))	epfd	–130.025	10 log(10^(pfd1/10)+10^(pfd2/10)+...+10^(pfdn/10))

3 Case 2

Case 2 depicts the scenario when an exclusion zone is defined from the GSO earth station to ±*X*° to the GSO arc. When the non-GSO is within this exclusion zone it cannot transmit to any earth stations. The worst-case geometry for this case is depicted in Fig. 2 where the non-GSO is at the edge of the exclusion zone transmitting towards co-located GSO and non-GSO earth stations. This geometry produces a non-GSO main beam into GSO side lobe interference scenario. This mitigation technique would typically be used with a LEO constellation but would also work with a MEO constellation. The algorithm to calculate the epfd$_{\downarrow}$ value requires the following steps:

Step 1: Inputs: Radius of the Earth, non-GSO radius, non-GSO inclination, GSO radius, GSO satellite longitude, GSO satellite inclination, GSO earth station latitude, GSO earth station longitude.

Step 2: Calculate the azimuth and elevation angles from the GSO earth station to the GSO satellite.

Step 3: Because the non-GSO satellite exclusion zone is based on the 0° inclined GSO arc, calculate the azimuth and elevation angles from the GSO earth station to a GSO satellite at 0° inclination and at the longitude of the victim GSO satellite.

Step 4: Calculate the sub-satellite latitude and longitude of the non-GSO satellite at the same azimuth as the 0° inclined GSO satellite and *X*° (exclusion zone angle) plus elevation to the 0° inclined GSO satellite in order to find the location of the non-GSO satellite at the edge of the exclusion zone.

Step 5: Calculate the off axis receive angle (delta between the elevation to the non-GSO satellite and the inclined GSO satellite at maximum excursion) and the corresponding gain at the GSO earth station.

Step 6: If the non-GSO satellite pfd masks are presented in Alpha vs. Delta longitude form (see Recommendation ITU-R S.1503 for Alpha and Delta longitude definitions).

a) From the pfd masks choose the pfd for the latitude nearest the sub-satellite latitude of the non-GSO satellite for Alpha = Alpha$_{-0}$ or $X = X_0$ and the longitude difference between the GSO and the non-GSO satellites.

b) Because the GSO has a very large bandwidth, there may be several sets of pfd masks with overlapping frequencies; all of these should be included.

c) Calculate the epfd as defined in RR No. 22.5C.

Step 7: If the non-GSO satellite pfd masks are presented in azimuth vs. elevation form (see Recommendation ITU-R S.1503 for azimuth and elevation definitions).

a) Calculate the ECF coordinates of the GSO satellite, earth station and non-GSO satellite.

b) Translate and rotate vector between non-GSO satellite and GSO earth station from ECF coordinates to satellite centred coordinates.

c) Calculate azimuth and elevation from the non-GSO satellite to the GSO earth station.

d) From the pfd masks choose the pfd for the latitude nearest the sub-satellite latitude of the non-GSO satellite for the azimuth and elevation from the non-GSO satellite to the GSO earth station.

e) Because the GSO has a very large bandwidth, there may be several sets of pfd masks with overlapping frequencies; all of these should be included.

f) Calculate the epfd as defined in RR No. 22.5C.

An Excel worksheet with the appropriate equations and calculations preprogrammed has been developed. A picture of the Case 2 calculation page is shown in Table 3. The input values for the non-GSO satellite system are fictional and do not represent any particular system.

TABLE 3

Case 2 Excel spreadsheet calculations

Case 2: Exclusion zone is defined from the GSO earth station to +/– *X*° to the GSO arc				
Non-GSO satellite CANNOT transmit while in the exclusion zone				
Worst case: Non-GSO satellite is at edge of exclusion zone transmitting directly to the GSO earth station				
Alpha = a_0 or $X = X_0$				
Note: This algorithm only valid for circular non-GSO satellites				
Inputs				
	Radius of the Earth (km)	Re	6 378.15	
	Non-GSO radius (km)	Rn	7 878	
	Non-GSO satellite inclination (degrees)	i	55	
	Non-GSO exclusion zone angle (degrees)	β	10	
	GSO radius (km)	Rg	42 164	
	GSO satellite longitude (degrees)	GSO Long.	–30	
	GSO satellite inclination (degrees)	ig	5	
	Earth station latitude (degrees)	φ	38	
	Earth station longitude (degrees)	earth Long.	–77	
	Earth station antenna maximum gain (dB)	G(max)	70	
Calculations				
	GSO satellite latitude (degrees)	δg	5	
	Difference between earth station and GSO satellite longitude (degrees)	Δλg	47	GSO Long. - earth Long.
	Calculate gamma angle from earth station to GSO satellite (degrees)	γg	53.91141	acos[sin(φ) * sin(δg) + cos(φ) * cos(δg) * cos(Δλg)]
	Calculate slant range from earth station to GSO satellite (km)	dg	38 751.35	sqrt(Re^2+Rg^2-2*Re*Rg*cos(γg))
	Calculate elevation angle from earth station to GSO satellite (degrees)	el	28.44516	acos[(Rg/dg)*sin(γg)]
	Calculate azimuth angle from the earth station to GSO satellite (degrees)	az	115.6339	if (Δλg>0 and φ<0) or (Δλg<0 and φ<0) then asin[cos(δg)*sin(Δλg)/sin(γg)] else 180-asin[cos(δg)*sin(Δλg)/sin(γg)]
	Calculate gamma angle from earth station to 0º inclined GSO satellite (degrees)	γ0	57.49168	acos[cos(φ) * cos(Δλg)]
	Calculate slant range from earth station to 0º inclined GSO satellite (km)	d0	39107.9	sqrt(Re^2+Rg^2-2*Re*Rg*cos(γ0))

TABLE 3 (*continued*)

	Calculate elevation angle from earth station to 0º inclined GSO satellite (degrees)	el0	24.60297	acos[(Rg/d0)*sin(γ0)]
	Calculate elevation angle to non-GSO satellite at edge of exclusion zone (degrees)	ngso_el	34.60297	el0 + β
	Calculate off bore angle at GSO earth station	θ	6.157819	ngso_el – el
	Calculate the gain of the earth station at θ° off bore (dB)	G(θ)	9.264328	Recommendation ITU-R S.1428
	Calculate gamma angle from earth station to non-GSO satellite (degrees)	γn	13.60588	acos((Re/Rn)*cos(ngso_el))-ngso_el
	Calculate sub-satellite latitude of non-GSO satellite at this Az and new El (degrees)	δ	31.21079	If φ>0 then 90 – acos[cos(90-φ) * cos(γn) + sin(90-φ) * sin(γn) * cos(az)] else 90 – acos[cos(90+φ) * cos(γn) + sin(90-φ) * sin(γn) * cos(az+180)]
	Calculate long difference between non-GSO and earth station (degrees)	Δλn	14.35798	if Δλg>0 then acos[(cos(γn) – sin(φ) * sin(δ)) / (cos(φ) * cos(δ))] else –1*acos[(cos(γn) – sin(φ) * sin(δ)) / (cos(φ) * cos(δ))]
	Calculate the sub-satellite longitude of the non-GSO at this Az and El (degrees)	nGSO Long.	–62.64202	earth Long. + Δλn
If satellite pfd masks are presented in Alpha vs Delta longitude form				
	Calculate the Δ longitude between GSO and non-GSO (degrees)	delta	32.64202	GSO Long. – nGSO Long.
Choose pfd from mask for latitude nearest to sub-satellite latitude of non-GSO satellite, because the GSO satellite VLA frequency bandwith is very large there may be several sets of masks with overlapping frequencies, all of these should be added in.				
	Freq 1: pfd of non-GSO satellite with Alpha = a_0 or $X = X_0$ and Delta	pfd1	–140	example
	Freq 2: pfd of non-GSO satellite with Alpha = a_0 or $X = X_0$ and Delta (input NA if not applicable)	pfd2	–131	example
	...			
	Freq *n*: pfd of non-GSO satellite with Alpha = a_0 or $X = X_0$ and Delta (input NA if not applicable)	pfdn	–140	example
	Calculate worst-case epfd (dB(W/(m^2 · MHz)))	epfd	–190.7604	10 log(10^((pfd1+G(X)-G(Max))/10)+10^((pfd2+G(X) – G(Max))/10)+...+10^((pfdn+G(X)-G(Max))/10))
If satellite pfd masks are presented in azimuth vs elevation form				
Calculate the *x*, *y*, *z* components of the earth station in ECF				
	Earth station *x* value (km)	Xe	1 130.615	Re * cos(φ) * cos(earth Long.)
	Earth station *y* value (km)	Ye	–4 897.233	Re * cos(φ) * sin(earth Long.)
	Earth station *z* value (km)	Ze	3 926.781	Re * sin(φ)

TABLE 3 (*continued*)

Calculate the *x*, *y*, *z* components of the non-GSO satellite ECF				
	Non-GSO satellite *x* value (km)	Xn	3 096.342	Rn * cos(δ) * cos(nGSO Long.)
	Non-GSO satellite *y* value (km)	Yn	–5 984.187	Rn * cos(δ) * sin(nGSO Long.)
	Non-GSO satellite *z* value (km)	Zn	4 082.286	Rn * sin(δ)
Calculate vector between non-GSO satellite and earth station				
	Vector X (km)	X	–1 965.727	Xe – Xn
	Vector Y (km)	Y	1 086.953	Ye – Yn
	Vector Z (km)	Z	–155.5047	Ze – Zn
Calculate longitude of ascending node				
	Difference between satellite longitude and ascending node (degrees)	del	25.10263	asin(tan(δ) / tan(i))
	Longitude of ascending node (degrees)	an	–87.74465	nGSO Long. – del
Calculate argument of perigee plus true anomaly				
	Argument of perigee plus true anomaly (degrees)	argptrue	39.24153	asin(sin(δ) / sin(I))
Calculate some values for the transformation matrix of the earth station XYZ ECF coordinates to *xyz* sat (satellite centred) coordinates				
	Cosine of longitude of ascending node	cos_an	0.039353	cos(an)
	Sine of longitude of ascending node	sin_an	–0.999225	sin(an)
	Cosine of non-GSO satellite inclination	cos_inc	0.573576	cos(i)
	Sine of non-GSO satellite inclination	sin_inc	0.819152	sin(i)
	Cosine of argument of perigee plus true anomaly	cos_arg	0.774486	cos(arg)
	Sine of argument of perigee plus true anomaly	sin_arg	0.632591	sin(arg)
	Earth station *x* value from satellite point of view (km)	x sat	–216.2066	X[-cos(an)*sin(arg)-sin(an)*cos(i)*cos(arg)]+ Y[cos(an)*cos(i)*cos(arg)-sin(an)*sin(arg)]+ Z[sin(i)*cos(arg)]
	Earth station *y* value from satellite point of view (km)	y sat	1 678.841	X[-cos(an)*cos(arg)+sin(an)*cos(i)*sin(arg)]- Y[sin(an)*cos(arg)+cos(an)*cos(i)*sin(arg)]- Z[sin(i)*sin(arg)]
	Earth station *z* value from satellite point of view (km)	z sat	1 484.749	X[sin(an)*sin(i)]+Y(-cos(an)*sin(i)]+Z[cos(i)]
	Azimuth to earth station from satellite point of view (degrees)	az	–7.338344	atan(x sat/y sat)
	Elevation to earth station from satellite point of view (degrees)	el	41.25547	atan(z sat/(sqrt(x sat^2+y sat^2)))

TABLE 3 (*end*)

Choose pfd from mask for latitude nearest to sub-satellite latitude of non-GSO satellite, because the GSO satellite VLA frequency bandwith is very large there may be several sets of masks with overlapping frequencies, all of these should be added in.				
	Freq 1: pfd of non-GSO satellite with azimuth and elevation to the earth station	pfd1	–140	example
	Freq 2: pfd of non-GSO satellite with azimuth and elevation to the earth station	pfd2	–131	example
		...		
	Freq *n*: pfd of non-GSO satellite with azimuth and elevation to the earth station	pfdn	–140	example
	Calculate worst-case epfd (dB(W/(m^2 · MHz)))	epfd	–191.2207	10 log(10^((pfd1+G(X)–G(Max))/10)+10^((pfd2+ G(X)G(Max))/10)+...+10^((pfdn+G(X) G(Max))/10))

4 Case 3

Case 3 depicts the scenario when an exclusion zone is defined within ±X° latitude for the non-GSO sub-satellite latitude point. When the non-GSO satellite is within this exclusion zone it cannot transmit to any earth station. The worst-case geometry for this case is depicted in Fig. 3 where the non-GSO satellite is at the edge of the exclusion zone transmitting towards co-located GSO and non-GSO earth stations. This geometry produces a non-GSO satellite main beam into GSO satellite side-lobe interference scenario. This mitigation technique would typically be used with a MEO constellation but would also work with a HEO constellation. The algorithm to calculate the epfd$_\downarrow$ value requires the following steps:

Step 1: Inputs: Radius of the Earth, non-GSO radius, non-GSO satellite inclination, non-GSO satellite cut-off latitude, GSO satellite longitude, GSO satellite inclination, GSO radius, GSO earth station latitude, GSO earth station longitude, GSO earth station maximum antenna gain.

Step 2: Calculate the minimum off-axis angle from the GSO earth station to the non-GSO satellite (this function is performed in a macro that moves the non-GSO satellite in longitude along the cut-off latitude and computes the off-axis angle and then records the minimum).

Step 3: Calculate the sub-satellite latitude and longitude of the non-GSO at the minimum off-axis angle.

Step 4: Calculate the off axis receive angle and gain at the GSO earth station.

Step 5: If the non-GSO pfd masks are presented in Alpha vs. Delta longitude form (see Recommendation ITU-R S.1503 for Alpha and Delta longitude definitions).

a) From the pfd masks choose the pfd for the latitude nearest the sub-satellite latitude of the non-GSO satellite for Alpha = Alpha$_{_0}$ or $X = X_0$ and the longitude difference between the GSO satellite and the non-GSO satellite.

b) Because the GSO satellite has a very large bandwidth, there may be several sets of pfd masks with overlapping frequencies; all of these should be included.

c) Calculate the epfd as defined in RR No. 22.5C.

Step 6: If the non-GSO pfd masks are presented in azimuth vs. elevation form (see Recommendation ITU-R S.1503 for azimuth and elevation definitions).

a) Calculate the ECF coordinates of the GSO, earth station and non-GSO.

b) Translate and rotate vector between non-GSO satellite and GSO earth station from ECF coordinates to satellite centred coordinates.

c) Calculate azimuth and elevation from the non-GSO satellite to the GSO earth station.

d) From the pfd masks choose the pfd for the latitude nearest the sub-satellite latitude of the non-GSO satellite for the azimuth and elevation from the non-GSO satellite to the GSO earth station.

e) Because the GSO satellite has a very large bandwidth, there may be several sets of pfd masks with overlapping frequencies; all of these should be included.

f) Calculate the epfd as defined by RR No. 22.5C.

An Excel worksheet with the appropriate equations and calculations preprogrammed has been developed. A picture of the Case 3 calculation page is shown in Table 4. The input values for the non-GSO satellite system are fictional and do not represent any particular system.

TABLE 4

Case 3 Excel spreadsheet calculations

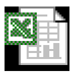
Case 3: Non-GSO satellite CANNOT transmit when above or below a certain latitude. A MEO would not transmit between + or – *X* latitude. A HEO would not transmit below +*X* latitude or above –*X* latitude depending on the hemisphere of the apogee				
Worst case: Non-GSO satellite is at the specified latitude transmitting directly to the GSO earth station				
Alpha = a_0 or $X = X_0$				
Note: For a HEO satellite the input for the non-GSO radius is the radius HEO at the latitude of cut-off/on				
Inputs				
	Radius of the earth (km)	Re	6 378.15	
	GSO radius (km)	Rg	42 164	
	Non-GSO satellite inclination (degrees)	i	55	
	Non-GSO radius (km)	Rn	23 958	
	Non-GSO satellite cut-off/on latitude (degrees)	β	–45	
	Is the cut-off latitude both positive and negative? (1 = Yes or 2 = No)		1	
	GSO satellite longitude (degrees)	GSO Long.	–30	
	GSO satellite inclination (degrees)	GSO_inc	5	
	Earth station latitude (degrees)	φ	38	
	Earth Station longitude (degrees)	earth Long.	–77	
	Earth station antenna maximum gain (dB)	G(max)	70	
Calculations				
	Calculate minimum off axis angle	β	44.09438	macro
	Non-GSO satellite longitude at minimum off axis angle	nGSO Long.	–32	macro
	Non-GSO satellite latitude at minimum off axis angle	nGSO Lat.	45	macro
	Calculate the gain of the earth station at θ° off bore	G(β)	–15.33	Recommendation ITU-R S.1428
If satellite pfd masks are presented in Alpha vs. Delta longitude form				
	Calculate the Delta longitude between GSO and non-GSO satellites (degrees)	delta	2	

TABLE 4 (*continued*)

Choose pfd from mask for latitude nearest to sub-satellite latitude of non-GSO satellite, because the GSO satellite VLA frequency bandwith is very large there may be several sets of masks with overlapping frequencies, all of these should be added in.				
	Freq 1: pfd of non-GSO satellite with Alpha = a_0 or $X = X_0$ and Delta	pfd1	–140	example
	Freq 2: pfd of non-GSO satellite with Alpha = a_0 or $X = X_0$ and Delta	pfd2	–131	example
	...			
	Freq *n*: pfd of non-GSO satellite with Alpha = a_0 or $X = X_0$ and Delta	pfdn	–140	example
	Calculate worst case epfd	epfd	–215.3562	10 log(10^((pfd1+G(X)–G(Max))/10)+10^((pfd2+G(X)–G(Max))/10)+...+10^((pfdn+G(X)-G(Max))/10))
If satellite pfd masks are presented in azimuth vs elevation form				
Calculate the *x*, *y*, *z* components of the earth station in ECF				
	Earth station *x* value (km)	Xe	1 130.62	Re * cos(φ) * cos(earth Long.)
	Earth station *y* value (km)	Ye	–4 897.23	Re * cos(φ) * sin(earth Long.)
	Earth station *z* value (km)	Ze	3 926.78	Re * sin(φ)
Calculate the *x*, *y*, *z* components of the non-GSO satellite ECF				
	Non-GSO satellite *x* value (km)	Xn	14 366.67	Rn * cos(δ) * cos(nGSO Long.)
	Non-GSO satellite *y* value (km)	Yn	–8 977.29	Rn * cos(δ) * sin(nGSO Long.)
	Non-GSO satellite *z* value (km)	Zn	16 940.86	Rn * sin(δ)
Calculate vector between non-GSO satellite and earth station				
	Vector X (km)	X	–13 236.05	Xe – Xn
	Vector Y (km)	Y	4 080.057	Ye – Yn
	Vector Z (km)	Z	–13 014.08	Ze – Zn
Calculate longitude of ascending node				
	Difference between satellite longitude and ascending node (degrees)	del	44.44366	asin(tan(δ) / tan(i))
	Longitude of ascending node (degrees)	an	–76.44	nGSO Long. – del
Calculate argument of perigee plus true anomaly				
	Argument of perigee plus true anomaly (degrees)	argptrue	59.67984	asin(sin(δ) / sin(I))

TABLE 4 (*end*)

Calculate some values for the transformation matrix of the earth station XYZ ECF coordinates to *xyz* sat (satellite centred) coordinates				
	Cosine of longitude of ascending node	cos_an	0.234401	cos(an)
	Sine of longitude of ascending node	sin_an	–0.97214	sin(an)
	Cosine of non-GSO satellite inclination	cos_inc	0.573576	cos(i)
	Sine of non-GSO satellite inclination	sin_inc	0.819152	sin(i)
	Cosine of argument of perigee plus true anomaly	cos_arg	0.504831	cos(arg)
	Sine of argument of perigee plus true anomaly	sin_arg	0.863218	sin(arg)
	Earth station *x* value from satellite point of view (km)	x sat	–2 728.648	X[-cos(an)*sin(arg)-sin(an)*cos(i)*cos(arg)]+ Y[cos(an)*cos(i)*cos(arg)-sin(an)*sin(arg)]+ Z[sin(i)*cos(arg)]
	Earth station *y* value from satellite point of view (km)	y sat	18 668.32	X[-cos(an)*cos(arg)+sin(an)*cos(i)*sin(arg)]– Y[sin(an)*cos(arg)+cos(an)*cos(i)*sin(arg)]– Z[sin(i)*sin(arg)]
	Earth station *z* value from satellite point of view (km)	z sat	2 292.286	X[sin(an)*sin(i)]+Y(-cos(an)*sin(i)]+Z[cos(i)]
	Azimuth to earth station from satellite point of view (degrees)	az	–8.31573	atan(x sat/y sat)
	Elevation to earth station from satellite point of view (degrees)	EL	6.927433	atan(z sat/(sqrt(x sat^2+y sat^2)))
Choose pfd from mask for latitude nearest to sub-satellite latitude of non-GSO satellite, because the GSO VLA frequency bandwith is very large there may be several sets of masks with overlapping frequencies, all of these should be added in.				
	Freq 1: pfd of non-GSO satellite with azimuth and elevation to the earth station	pfd1	–140	example
	Freq 2: pfd of non-GSO satellite with azimuth and elevation to the earth station	pfd2	–131	example
		...		
	Freq *n*: pfd of non-GSO satellite with azimuth and elevation to the earth station	pfdn	–140	example
	Calculate worst-case epfd (dB(W/(m^2 · MHz)))	epfd	–215.8165	10 log(10^((pfd1+G(X)-G(Max))/10)+10^((pfd2+G(X)-G(Max))/10)+...+10^((pfdn+G(X)-G(Max))/10))



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