International Telecommunication Union

ITU-R

Radiocommunication Sector of ITU

Recommendation ITU-R S.1714-1

(01/2022)

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

S Series

Fixed-satellite service

International Telecommunication Union

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Note: *This ITU-R Recommendation was approved in English under the procedure detailed in Resolution ITU-R 1.*

Electronic Publication
Geneva, 2022

RECOMMENDATION ITU-R S.1714-1

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

(2005-2022)

Scope

This Recommendation provides a methodology for calculating the worst-case static epfd↓ value from a non-GSO (non-geostationary-satellite orbit) system at any GSO earth station the geographic coordinates of which are known (specific GSO earth station) and the antenna of which is pointed towards the wanted GSO space station..

Keywords

epfd, non-GSO, methodology, **9.7A**, **9.7B**, static

Abbreviations/Glossary

Alpha angle (Alpha): the minimum angle at the GSO earth station between the line to the non-GSO satellite and the lines to the GSO arc.

epfd↓: equivalent power flux-density, as defined in RR No. **22.5C.1**, emissions from the non-GSO satellite system into a GSO satellite earth station.

pfd mask: power flux-density mask used to define the emissions of the non-GSO satellite in the epfd↓ calculation.

X angle (*X*): the minimum angle at the non-GSO satellite between the line from the GSO earth station and the lines to the GSO arc.

Related ITU Recommendations, Reports

Recommendation ITU-R S.1503-3	Functional description to be used in developing software tools for determining conformity of non-geostationary-satellite orbit fixed-satellite service systems or networks with limits contained in Article **22** of the Radio Regulations

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 (fixed-satellite service) 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;

i) 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 the relevant provisions of the Radio Regulations could be considered as complied with;

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 should be conducted.

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 ±*X* latitude range.

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

FIGURE 1

Case 1 – Exclusion zone

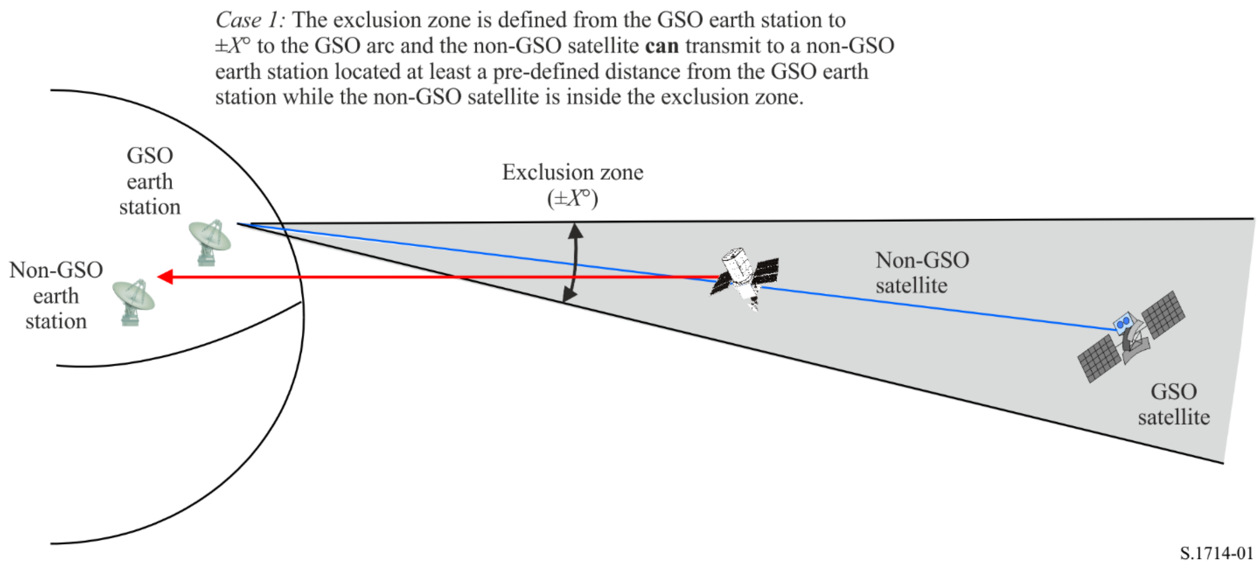


FIGURE 2

Case 2 – Exclusion zone

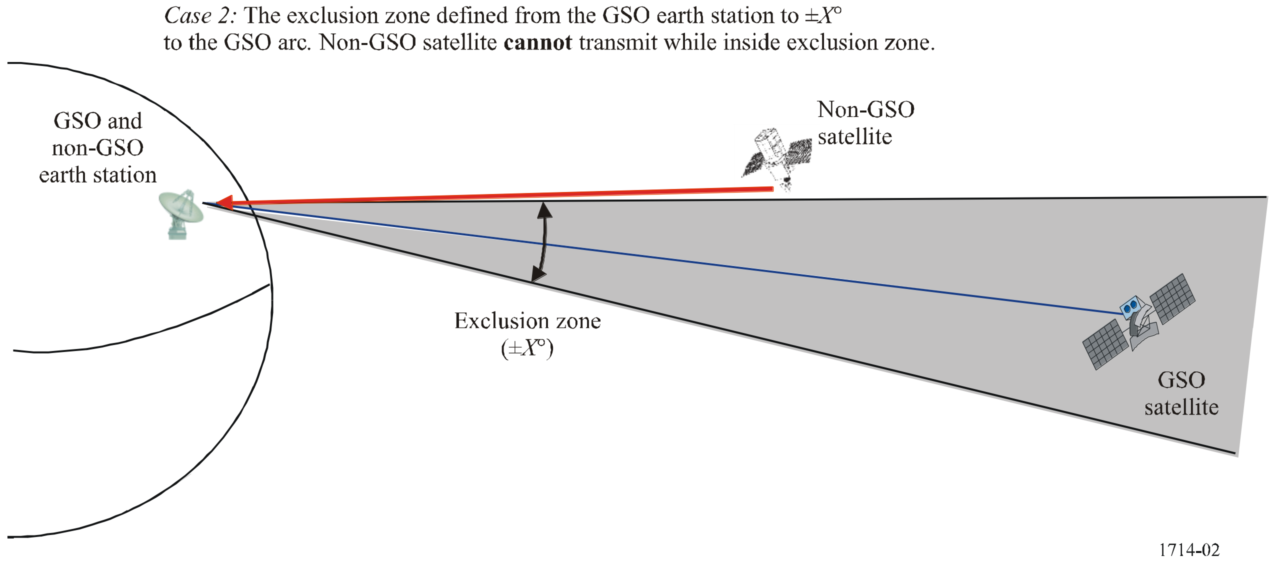
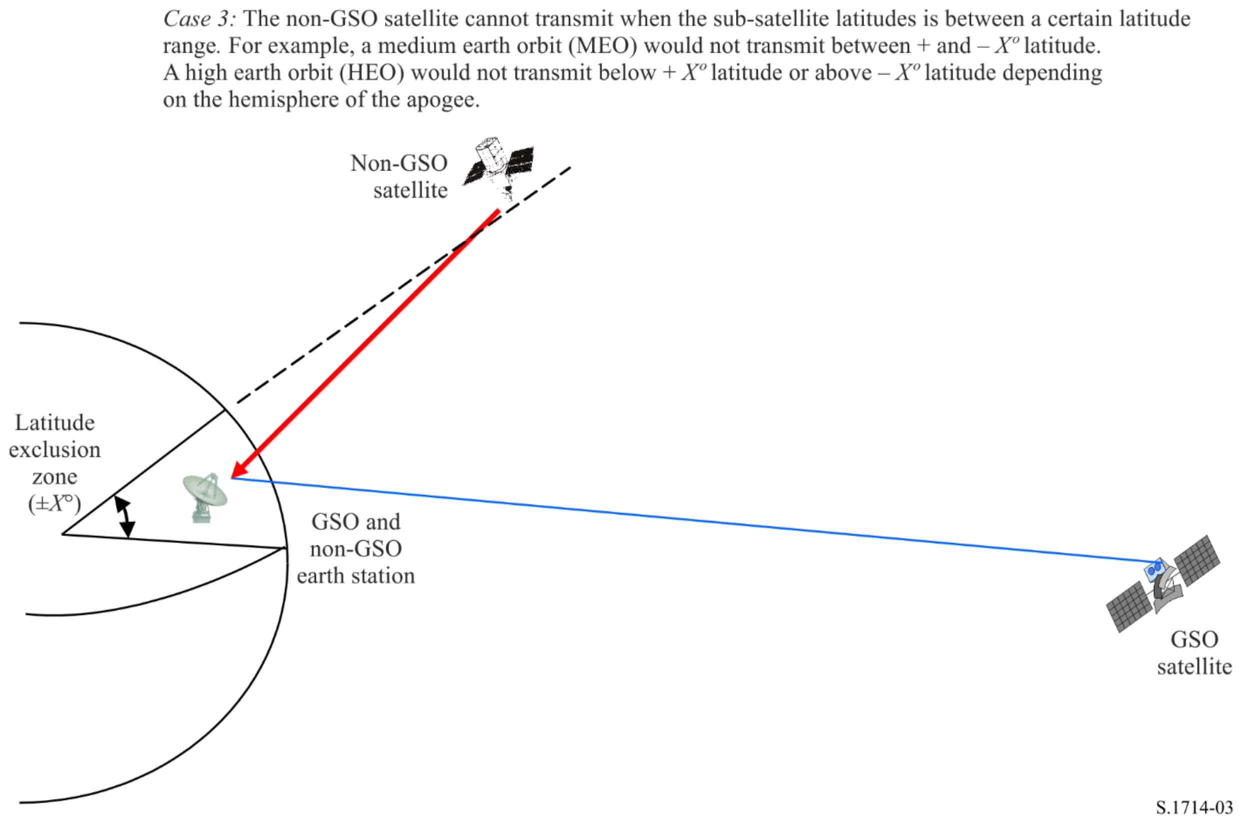


FIGURE 3

Case 3 – Exclusion zone



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 orbit radius, non-GSO inclination, GSO orbit 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) Calculate Alpha as the angle at the GSO earth station between the line to the non-GSO satellite and the line to the GSO arc.

b) From the pfd masks choose the pfd for the latitude nearest the sub-satellite latitude of the non-GSO, Alpha, and the longitude difference between the GSO and the non-GSO satellites.

c) Since this is an in-line event the $G(\theta)/G_{max}$ portion of the epfd calculation is equal to 1 or 0 dB.

d) 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.

e) 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 pre-programmed 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 – Rev1 Excel spreadsheet calculations

Case 1 Rev1: 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 in line with the GSO satellite at maximum inclination and GSO earth station				
Note: This algorithm is only valid for circular non-GSO satellites				
Inputs				
	Radius of the Earth (km)	R_e	6 378.15	
	Non-GSO radius (km)	R_n	7 878	
	Non-GSO satellite inclination (degrees)	i	55	
	GSO radius (km)	R_g	42 164	
	GSO satellite longitude (degrees)	GSO_{long}	–30	
	GSO satellite inclination (degrees)	i_g	5	
	Earth station latitude (degrees)	φ	38	
	Earth station longitude (degrees)	$earth_{long}$	–77	
	Mask Ref BW (kHz)		40	Determined from Mask file (40 or 1 000)
	Band (Ku or Ka)		Ka	
Calculations				
	GSO satellite latitude (degrees)	δ_g	5	
	Difference between earth station and GSO satellite longitude (degrees)	$\Delta\lambda_g$	47	$GSO_{long} - earth_{long}$
	Calculate gamma angle from earth station to GSO satellite (degrees)	γ_g	53.91141	$\text{acos}[\sin(\varphi) \times \sin(\delta_g) + \cos(\varphi) \times \cos(\delta_g) \times \cos(\Delta\lambda_g)]$
	Calculate slant range from earth station to GSO satellite (km)	d_g	3 8751.35	$\sqrt{R_e^2 + R_g^2 - 2 \times R_e \times R_g \times \cos(\gamma_g)}$
	Calculate elevation angle from earth station to GSO satellite (degrees)	El	28.44516	$\text{acos}\left[\left(\frac{R_g}{d_g}\right) \times \sin(\gamma_g)\right]$
	Calculate azimuth angle from the earth station to GSO satellite (degrees)	Az	115.6339	If ($\Delta\lambda_g > 0$ and $\varphi < 0$) or ($\Delta\lambda_g < 0$ and $\varphi < 0$) then $\text{asin}\left[\cos(\delta_g) \times \sin\left(\frac{\Delta\lambda_g}{\sin\left(\frac{\Delta\lambda_g}{\sin \gamma_g}\right)}\right)\right]$ else $180 - \text{asin}\left[\cos(\delta_g) \times \frac{\sin(\Delta\lambda_g)}{\sin(\gamma_g)}\right]$
	Calculate gamma angle from earth station to non-GSO satellite (degrees)	γ_n	16.16731	$\text{acos}\left(\left(\frac{R_e}{R_n}\right) \times \cos(El)\right) - El$
	Calculate sub-satellite latitude of non-GSO satellite at this *Az* and *El* (degrees)	δ	29.76146	If $\varphi > 0$ then $90 - \text{acos}[\cos(90 - \varphi) \times \cos(\gamma_n) + \sin(90 - \varphi) \times \sin(\gamma_n) \times \cos(Az)]$ else $90 - \text{acos}[\cos(90 + \varphi) \times \cos(\gamma_n) + \sin(90 - \varphi) \times \sin(\gamma_n) \times \cos(Az + 180)]$
	Calculate long difference between non-GSO satellite and earth station (degrees)	$\Delta\lambda_n$	16.80892	If $\Delta\lambda_g > 0$ then $\text{acos}\left[\frac{\cos(\gamma_n) - \sin(\varphi) \times \sin(\delta)}{\cos(\varphi) \times \cos(\delta)}\right]$ else $-1 \times \text{acos}\left[\frac{\cos(\gamma_n) - \sin(\varphi) \times \sin(\delta)}{\cos(\varphi) \times \cos(\delta)}\right]$
	Calculate the sub-satellite longitude of the non-GSO satellite at this *Az* and *El* (degrees)	$nGSO_{long}$	–60.1911	$earth_{long} + \Delta\lambda_n$

TABLE 2 (*continued*)

If satellite pfd masks are presented in Alpha vs Delta longitude form				
Determine the resulting Alpha as measured from the geostationary orbital arc when the non-GSO is in conjunction with the inclined GSO at maximum inclination				
	GSO arc latitude (degrees)		0	
Calculate the *x*, *y*, *z* components of the VLA latitude in ECF				
	VLA *x* value (km)		1 130.615 4	$R_e \times \cos(\varphi) \times \cos(earth_{long})$
	VLA *y* value (km)		−4 897.233	$R_e \times \cos(\varphi) \times \sin(earth_{long})$
	VLA *z* value (km)		3 926.781 2	$R_e \times \sin(\varphi)$
Calculate the *x*, *y*, *z* components of the GSO arc in ECF				
	GSO arc *x* value (km)		36 515.095	$R_g \times \cos(GSO_{lat}) \times \cos(GSO_{long})$
	GSO arc *y* value (km)		−21 082	$R_g \times \cos(GSO_{lat}) \times \sin(GSO_{long})$
	GSO arc *z* value (km)		0	$R_g \times \sin(\varphi)$
Calculate the *x*, *y*, *z* components of the non-GSO satellite at the latitude at which in-line conjunction with inclined GSO at maximum inclination occurs in ECF				
	Non-GSO *x* value (km)		3 399.673 8	$R_n \times \cos(\delta) \times \cos(nGSO_{long})$
	Non-GSO *y* value (km)		−5 934.022	$R_n \times \cos(\delta) \times \sin(nGSO_{long})$
	Non-GSO *z* value (km)		3 910.561 3	$R_n \times \sin(\delta)$
Calculate vectors needed to calculate Alpha as seen from GSO at maximum inclination				
	VLA to GSO arc vector (km)		39 107.898	$\sqrt{(GSO_{arc\,x} - VLA_x)^2 + (GSO_{arc\,y} - VLA_y)^2 + (GSO_{arc\,z} - VLA_{zx})^2}$
	VLA to non-GSO vector (km)		2 494.758 2	$\sqrt{(nGSO_x - VLA_x)^2 + (nGSO_y - VLA_y)^2 + (nGSO_z - VLA_{zx})^2}$
	GSO arc to non-GSO vector (km)		36 624.921	$\sqrt{(nGSO_x - GSO_{arc\,x})^2 + (nGSO_y - GSO_{arc\,y})^2 + (nGSO_z - GSO_{arc\,zx})^2}$
	Alpha		5 390 246	$\text{acos}\left[\frac{((VLA\ to\ GSO_{arc\,vector})^2 + (VLA\ to\ nGSO_{vector})^2 - (GSO_{arc}\ to\ nGSO_{vector})^2)}{(2 \times VLA\ to\ GSO_{arc\,vector} \times VLA\ to\ nGSO_{vector})}\right]$
	Calculate the Delta longitude between GSO and non-GSO satellites (degrees)	*delta*	30.19108	$GSO_{long} - nGSO_{long}$

TABLE 2 (*continued*)

Choose pfd from the pfd mask having a sub-satellite latitude, Alpha and Delta nearest to those calculated above. Because the GSO satellite VLA frequency bandwidth is very large there may be several sets of masks with overlapping frequencies, and 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	pfd_1	–140	example
	Freq 2: pfd of non-GSO satellite (input NA if not applicable)	pfd_2	–131	example
		...		
	Freq *n*: pfd of non-GSO satellite (input NA if not applicable)	pfd_n	−140	example
	Calculate worst-case epfd (dB(W/(m² · 40 kHz)))	*epfd*	−130.025	$10\log\left(10^{\left(\frac{pfd_1}{10}\right)}+10^{\left(\frac{pfd_2}{10}\right)}+\cdots+10^{\left(\frac{pfd_n}{10}\right)}\right)$
	Calculate worst-case epfd (dB(W/(m² · MHz)))	*epfd*	−116.045	$10\log\left(10^{\left(\frac{pfd_1}{10}\right)}+10^{\left(\frac{pfd_2}{10}\right)}+\cdots+10^{\left(\frac{pfd_n}{10}\right)}\right)$
	Epfd trigger level (dB(W/(m² · 40 kHz)))	*epfd*	−171.0	From ITU RR Appendix **5**
	Epfd trigger level (dB(W/(m² · MHz)))	*epfd*	−157.0	From ITU RR Appendix **5**
	Epfd trigger violated		YES	
If satellite pfd masks are presented in azimuth vs elevation form				
Calculate the *x*, *y*, *z* and *r* components of the earth station in ECF				
	Earth station *x* value (km)	X_e	1 130.615	$R_e \times \cos(\varphi) \times \cos\left(earth_{long}\right)$
	Earth station *y* value (km)	Y_e	–4 897.23	$R_e \times \cos(\varphi) \times \sin\left(earth_{long}\right)$
	Earth station *z* value (km)	Z_e	3 926.781	$R_e \times \sin(\varphi)$
	Earth station *r* value (km)	R_{es}	6 378.15	$\sqrt{X_e^2 + Y_e^2 + Z_e^2}$
Calculate the *x*, *y*, *z* components of the non-GSO satellite in ECF				
	Non-GSO *x* value (km)	X_n	3 399.674	$R_n \times \cos(\delta) \times \cos\left(nGSO_{long}\right)$
	Non-GSO *y* value (km)	Y_n	–5 934.02	$R_n \times \cos(\delta) \times \sin\left(nGSO_{long}\right)$
	Non-GSO *z* value (km)	Z_n	3 910.561	$R_n \times \sin(\delta)$
	Non-GSO radius (km)	R_n	7 878.00	$\sqrt{X_n^2 + Y_n^2 + Z_n^2}$
Calculate vector between non-GSO satellite and earth station				
	Vector *X* (km)	*X*	–2 269.06	$X_e – X_n$
	Vector *Y* (km)	*Y*	1 036.788	$Y_e – Y_n$
	Vector *Z* (km)	*Z*	16.219 97	$Z_e – Z_n$

TABLE 2 (*continued*)

	Vector *r* (km)	*r*	2 494.76	$\sqrt{X^2+Y^2+Z^2}$
North vector				
	North *X*	N_x	0	North vector *x* component
	North *Y*	N_y	0	North vector *y* component
	North *Z*	N_z	1	North vector *z* component
	North magnitude	N_{mag}	1	North vector magnitude
Calculate the satellite *X* component of the satellite frame by cross product of negative of the vector from satellite to center of Earth and North vector				
	X frame – *x* component	X'_x	5 934.021 63	$-Y_n \times N_z + N_y \times Z_n$
	X frame – *y* component	X'_y	3 399.673	$-Z_n \times N_x + N_z \times X_n$
	X frame – *z* component	X'_z	0	$-X_n \times N_y + N_x \times Y_n$
	X magnitude	X'_{mag}	6 838.89	$\sqrt{X'^2_x + X'^2_y + X'^2_z}$
Calculate the *Z* component of the satellite frame by cross product of negative of the vector from satellite to center of Earth and the *X* component of the satellite frame				
	Z frame – *x* component cosine of longitude of ascending node	Z'_x	−13 294 632.6	$-Y_n \times X'_z + X'_y \times Z_n$
	Z frame – *y* component sine of longitude of ascending node	Z'_y	23 205 355.1	$-Z_n \times X'_x + X'_z \times X_n$
	Z frame – *z* component cosine of non-GSO satellite inclination	Z'_z	46 770 394.5	$-X_n \times X'_y + X'_x \times Y_n$
	Z magnitude sine of non-GSO satellite inclination	Z'_{mag}	53 876 762.8	$\sqrt{Z'^2_x + Z'^2_y + Z'^2_z}$
Calculate the magnitude of the vector from satellite to earth station in the direction of the satellite axis by taking dot products				
	Magnitude in the *X* direction	X_{delta}	−1 453.437 9	$X \times \frac{X'_x}{X'_{mag}} + Y \times \frac{X'_y}{X'_{mag}} + Z \times \frac{X'_z}{X'_{mag}}$
	Magnitude in the *Y* direction	Y_{delta}	1 752.088 4	$-X \times \frac{X_n}{r} - Y \times \frac{Y_n}{r} - Z \times \frac{Z_n}{r}$
	Magnitude in the *Z* direction	Z_{delta}	1 020.550 3	$X \times \frac{Z'_x}{Z'_{mag}} + Y \times \frac{Z'_y}{Z'_{mag}} + Z \times \frac{Z'_z}{Z'_{mag}}$
Calculate the azimuth and elevation to the earth station from the satellite point of view				
	Azimuth to earth station from satellite point of view (degrees)	*Az*	−39.677	$\text{atan}\left(\frac{Y_{delta}}{X_{delta}}\right)$
	Elevation to earth station from satellite point of view (degrees)	*El*	24.146	$\text{asin}\left(\frac{Z_{delta}}{r}\right)$

TABLE 2 (*end*)

Choose pfd from the pfd mask for having a sub-satellite latitude, azimuth, and elevation, latitude nearest to sub-satellite latitude of non-GSO satellite, those calculated above. Because the GSO satellite VLA frequency bandwidth is very large there may be several sets of masks with overlapping frequencies, and 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	pfd_1	–140	example
	Freq 2: pfd of non-GSO satellite with azimuth and elevation to the earth station	pfd_2	–131	example
		...		
	Freq n: pfd of non-GSO satellite with azimuth and elevation to the earth station	pfd_n	–140	example
	Calculate worst-case epfd (dB(W/(m² · 40 kHz)))	*epfd*	−130.025	$10\log\left(10^{\left(\frac{pfd_1}{10}\right)}+10^{\left(\frac{pfd_2}{10}\right)}+\cdots+10^{\left(\frac{pfd_n}{10}\right)}\right)$
	Calculate worst-case epfd (dB(W/(m² · MHz)))	*epfd*	−116.045	$10\log\left(10^{\left(\frac{pfd_1}{10}\right)}+10^{\left(\frac{pfd_2}{10}\right)}+\cdots+10^{\left(\frac{pfd_n}{10}\right)}\right)$
	Epfd trigger level (dB(W/(m² · 40 kHz)))	*epfd*	−171.0	
	Epfd trigger level (dB(W/(m² · MHz)))	*epfd*	−157.0	
	Epfd trigger violated		YES	

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□ value requires the following steps:

Step 1: Inputs: Radius of the Earth, non-GSO orbit radius, non-GSO inclination, GSO orbit 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: Calculate the resulting Alpha angle ($Alpha_{Conjunction}$) as measured from the geostationary orbital arc when the non-GSO is in conjunction with the inclined GSO at maximum inclination

a) If $Alpha_{Conjunction}$ is greater than *X*° (exclusion zone angle) then the conjunction can occur while the inclined GSO is outside of the exclusion zone angle and Case 1 should be used.

b) If $Alpha_{Conjunction}$ is less than or equal to *X*° (exclusion zone angle) then the conjunction occurs while the inclined GSO is within the exclusion zone angle and Case 2 should be used.

Step 7: 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$_{-0}$ 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 8: 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 pre-programmed 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				
Note 1: This algorithm only valid for circular non-GSO satellites				
Note 2: If Alpha angle at conjunction is greater than non-GSO exclusion zone angle, Case 1 should be used				
Inputs				
	Radius of the Earth (km)	R_e	6 378.15	
	Non-GSO radius (km)	R_n	7 878	
	Non-GSO satellite inclination (degrees)	i	55	
	Non-GSO exclusion zone angle (degrees)	β	10	
	GSO radius (km)	R_g	42 164	
	GSO satellite longitude (degrees)	GSO_{long}	–30	
	GSO satellite inclination (degrees)	i_g	5	
	Earth station latitude (degrees)	φ	38	
	Earth station longitude (degrees)	$earth_{long}$	–77	
	Earth station antenna maximum gain (dB)	G_{max}	70	
	Mask Ref BW (kHz)		40	Determined from mask file (40 or 1 000)
	Band (Ku or Ka)		Ka	
Calculations				
	GSO satellite latitude (degrees)	δ_g	5	
	Difference between earth station and GSO satellite longitude (degrees)	$\Delta\lambda_g$	47	$GSO_{long} - earth_{long}$
	Calculate gamma angle from earth station to GSO satellite (degrees)	γ_g	53.91141	$\text{acos}\left[\sin(\varphi) \times \sin(\delta_g) + \cos(\varphi) \times \cos(\delta_g) \times \cos(\Delta\lambda_g)\right]$
	Calculate slant range from earth station to GSO satellite (km)	d_g	38 751.35	$\sqrt{R_e^2 + R_g^2 - 2 \times R_e \times R_g \times \cos(\gamma_g)}$
	Calculate elevation angle from earth station to GSO satellite (degrees)	El	28.44516	$\text{acos}\left[\left(\frac{R_g}{d_g}\right) \times \sin(\gamma_g)\right]$
	Calculate azimuth angle from the earth station to GSO satellite (degrees)	Az	115.6339	If ($\Delta\lambda_g > 0$ and $\varphi < 0$) or ($\Delta\lambda_g < 0$ and $\varphi < 0$) then $\text{asin}\left[\frac{\cos(\delta_g) \times \sin(\Delta\lambda_g)}{\sin(\gamma_g)}\right]$ else $180 - \text{asin}\left[\frac{\cos(\delta_g) \times \sin(\Delta\lambda_g)}{\sin(\gamma_g)}\right]$
	Calculate gamma angle from earth station to 0° inclined GSO satellite (degrees)	γ_0	57.49168	$\text{acos}\left[\cos(\varphi) \times \cos(\Delta\lambda_g)\right]$
	Calculate slant range from earth station to 0° inclined GSO satellite (km)	d_0	39 107.9	$\sqrt{R_e^2 + R_g^2 - 2 \times R_e \times R_g \times \cos(\gamma_0)}$

TABLE 3 (*continued*)

	Calculate elevation angle from earth station to 0º inclined GSO satellite (degrees)	El_0	24.60297	$\text{acos}\left[\left(\frac{R_g}{d_0}\right) \times \sin(\gamma_0)\right]$
	Calculate elevation angle to non-GSO satellite at edge of exclusion zone (degrees)	$nGSO_{El}$	34.60297	$El_0 + \beta$
	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)	$G(\theta)$	9.264328	Recommendation ITU-R S.1428 (macro)
	Calculate gamma angle from earth station to non-GSO satellite (degrees)	γ_n	13.60588	$\text{acos}\left(\left(\frac{R_e}{R_n}\right) \times \cos(nGSO_{El})\right) - nGSO_{El}$
	Calculate sub-satellite latitude of non-GSO satellite at this *Az* and new *El* (degrees)	δ	31.21079	If $\varphi > 0$ then $90 - \text{acos}[\cos(90 - \varphi) \times \cos(\gamma_n) + \sin(90 - \varphi) \times \sin(\gamma_n) \times \cos(Az)]$ else $90 - \text{acos}[\cos(90 + \varphi) \times \cos(\gamma_n) + \sin(90 - \varphi) \times \sin(\gamma_n) \times \cos(Az + 180)]$
	Calculate long difference between non-GSO and earth station (degrees)	$\Delta\lambda_n$	14.35798	If $\Delta\lambda_g > 0$ then $\text{acos}\left[\frac{(\cos(\gamma_n) - \sin(\varphi) \times \sin(\delta))}{(\cos(\varphi) \times \cos(\delta))}\right]$ else $-1 \times \text{acos}\left[\frac{(\cos(\gamma_n) - \sin(\varphi) \times \sin(\delta))}{(\cos(\varphi) \times \cos(\delta))}\right]$
	Calculate the sub-satellite longitude of the non-GSO at this *Az* and *El* (degrees)	$nGSO_{long}$	–62.64202	$earth_{long} + \Delta\lambda_n$
	Calculate Gamma angle from earth station to non-GSO in conjunction (degrees)	γ_{nc}	16.16731	$\text{acos}\left(\left(\frac{R_e}{R_n}\right) \times \cos(El)\right) - El$
	Calculate sub-satellite latitude of non-GSO at conjunction *Az* and *El* (degrees)	δ_c	29.76146	If $\varphi > 0$ then $90 - \text{acos}[\cos(90 - \varphi) \times \cos(\gamma_n) + \sin(90 - \varphi) \times \sin(\gamma_n) \times \cos(Az)]$ else $90 - \text{acos}[\cos(90 + \varphi) \times \cos(\gamma_n) + \sin(90 - \varphi) \times \sin(\gamma_n) \times \cos(Az + 180)]$
	Calculate long difference between non-GSO in conjunction and earth station (degrees)	$\Delta\lambda_{nc}$	16.80892	If $\Delta\lambda_g > 0$ then $\text{acos}\left[\frac{\cos(\gamma_n) - \sin(\varphi) \times \sin(\delta)}{\cos(\varphi) \times \cos(\delta)}\right]$ else $-1 \times \text{acos}\left[\frac{\cos(\gamma_n) - \sin(\varphi) \times \sin(\delta)}{\cos(\varphi) \times \cos(\delta)}\right]$
	Calculate the sub-satellite longitude of the non-GSO at conjunction *Az* and *El* (degrees)	$nGSO_{long\ c}$	−60.1911	$earth_{long} + \Delta\lambda_n$
Determine the resulting Alpha as measured from the geostationary orbital arc when the non-GSO is in conjunction with the inclined GSO at maximum inclination				
	GSO arc latitude (degrees)	GSO_{lat}	0	
Calculate the *x*, *y*, *z* components of the VLA latitude in ECF				
	VLA *x* value (km)	VLA_x	1 130.615	$R_e \times \cos(\varphi) \times \cos(earth_{long})$
	VLA *y* value (km)	VLA_y	−4 897.23	$R_e \times \cos(\varphi) \times \sin(earth_{long})$
	VLA *z* value (km)	VLA_z	3 926.781	$R_e \times \sin(\varphi)$
Calculate the *x*, *y*, *z* components of the GSO arc in ECF				
	GSO arc *x* value (km)	$GSO_{arc\ x}$	36 515.1	$R_g \times \cos(GSO_{lat}) \times \cos(GSO_{long})$

TABLE 3 (*continued*)

	GSO arc *y* value (km)	$GSO_{arc\ y}$	−21 082	$R_g \times \cos(GSO_{lat}) \times \sin(GSO_{long})$
	GSO arc *z* value (km)	$GSO_{arc\ z}$	0	$R_g \times \sin(\varphi)$
Calculate the *x*, *y*, *z* components of the non-GSO satellite at the latitude at which in-line conjunction with inclined GSO at maximum inclination occurs in ECF				
	Non-GSO *x* value (km)	$nGSO_x$	3 399.674	$R_n \times \cos(\delta) \times \cos(nGSO_{long})$
	Non-GSO *y* value (km)	$nGSO_y$	−5 934.02	$R_n \times \cos(\delta) \times \sin(nGSO_{long})$
	Non-GSO *z* value (km)	$nGSO_z$	3 910.561	$R_n \times \sin(\delta)$
Calculate vectors needed to calculate Alpha as seen from GSO at maximum inclination				
	VLA to GSO arc vector (km)	$VLA\text{-}GSO_{arc}$	39 107.9	$\sqrt{(GSO_{arc\ x} - VLA_x)^2 + (GSO_{arc\ y} - VLA_y)^2 + (GSO_{arc\ z} - VLA_{zx})^2}$
	VLA to non-GSO vector (km)	$VLA\text{-}nGSO$	2 494.758	$\sqrt{(nGSO_x - VLA_x)^2 + (nGSO_y - VLA_y)^2 + (nGSO_z - VLA_{zx})^2}$
	GSO arc to non-GSO vector (km)	$GSO_{arc}\text{-}nGSO$	36 624.92	$\sqrt{(nGSO_x - GSO_{arc\ x})^2 + (nGSO_y - GSO_{arc\ y})^2 + (nGSO_z - GSO_{arc\ zx})^2}$
	Alpha at conjunction	$Alpha_{conj}$	5.390 246	$\text{acos}\left[\frac{(VLA\ to\ GSO_{arc} vector)^2 + (VLA\ to\ nGSO\ vector)^2 - (GSO_{arc}\ to\ nGSO\ Vector)^2}{2 \times VLA\ to\ GSO_{arc} Vector\ \times VLA\ to\ nGSO\ Vector}\right]$
If Alpha at conjunction > β, use Case 1, else continue with Case 2			CASE 2	
If satellite pfd masks are presented in Alpha vs Delta longitude form				
	Calculate the Delta longitude between GSO and non-GSO (degrees)	*delta*	32.64202	$GSO_{long} - nGSO_{long}$
Choose pfd from the pfd mask having an Alpha = a_0, and a sub-satellite latitude and Delta nearest to those calculated above. Because the GSO satellite VLA frequency bandwidth 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	pfd_1	–140	example
	Freq 2: pfd of non-GSO satellite	pfd_2	–131	example
	...			
	Freq *n*: pfd of non-GSO satellite	pfd_n	–140	example
	Calculate worst-case epfd (dB(W/(m² · 40 kHz)))	*epfd*	−190.760	$10\log\left(10^{\frac{pfd_1+G(X)-G_{max}}{10}} + 10^{\frac{pfd_2+G(X)-G_{max}}{10}} + \cdots + 10^{\frac{pfd_n+G(X)-G_{max}}{10}}\right)$
	Calculate worst-case epfd (dB(W/(m² · MHz)))	*epfd*	–176.781	$10\log\left(10^{\frac{pfd_1+G(X)-G_{max}}{10}} + 10^{\frac{pfd_2+G(X)-G_{max}}{10}} + \cdots + 10^{\frac{pfd_n+G(X)-G_{max}}{10}}\right)$
	Epfd trigger level (dB(W/(m² · 40 kHz)))	*epfd*	−171.0	From ITU RR Appendix **5**
	Epfd trigger level (dB(W/(m² · MHz)))	*epfd*	−157.0	From ITU RR Appendix **5**
	Epfd trigger violated		NO	

TABLE 3 (*continued*)

If satellite pfd masks are presented in azimuth vs elevation form				
Calculate the *x*, *y*, *z*, and *r* components of the earth station in ECF				
	Earth station *x* value (km)	X_e	1 130.615	$R_e \times \cos(\varphi) \times \cos(earth_{long})$
	Earth station *y* value (km)	Y_e	–4 897.233	$R_e \times \cos(\varphi) \times \sin(earth_{long})$
	Earth station *z* value (km)	Z_e	3 926.781	$R_e \times \sin(\varphi)$
	Earth station *r* value (km)	R_{es}	6 378.15	$\sqrt{X_e^2 + Y_e^2 + Z_e^2}$
Calculate the *x*, *y*, *z*, and *r* components of the non-GSO satellite ECF				
	Non-GSO satellite *x* value (km)	X_n	3 096.342	$R_n \times \cos(\delta) \times \cos(nGSO_{long})$
	Non-GSO satellite *y* value (km)	Y_n	–5 984.187	$R_n \times \cos(\delta) \times \sin(nGSO_{long})$
	Non-GSO satellite *z* value (km)	Z_n	4 082.286	$R_n \times \sin(\delta)$
	Non-GSO *r* value (km)	R_n	7 878.00	$\sqrt{X_n^2 + Y_n^2 + Z_n^2}$
Calculate vector between non-GSO satellite and earth station				
	Vector *X* (km)	X	–1 965.727	$X_e - X_n$
	Vector *Y* (km)	Y	1 086.953	$Y_e - Y_n$
	Vector *Z* (km)	Z	–155.504 7	$Z_e - Z_n$
	Vector *r* (km)	r	2 251.61	$\sqrt{X^2 + Y^2 + Z^2}$
North vector				
	North *X*	N_x	0	North vector *x* component
	North *Y*	N_y	0	North vector *y* component
	North *Z*	N_z	1	North vector *z* component
	North magnitude	N_{mag}	1	North vector magnitude
Calculate the satellite *X* component of the satellite frame by cross product of negative of the vector from satellite to center of Earth and North vector				
	X frame – *x* component	X'_x	5984.1867	$-Y_n \times N_z + N_y \times Z_n$
	X frame – *y* component	X'_y	3096.3422	$-Z_n \times N_x + N_z \times X_n$
	X frame – *z* component	X'_z	0	$-X_n \times N_y + N_x \times Y_n$
	X magnitude	X'_{mag}	6737.79	$\sqrt{X'^2_x + X'^2_y + X'^2_z}$
Calculate the *Z* component of the satellite frame by cross product of negative of the vector from satellite to center of Earth and the *X* component of the satellite frame				
	Z frame – *x* component	Z'_x	–12640154.2	$-Y_n \times X'_z + X'_y \times Z_n$
	Z frame – *y* component	Z'_y	24429161.1	$-Z_n \times X'_x + X'_z \times X_n$

TABLE 3 (*end*)

	Z frame – *z* component	Z'_z	45397825.7	$-X_n \times X'_y + X'_x \times Y_n$
	Z magnitude	Z'_{mag}	53080316.4	$\sqrt{Z'^2_x + Z'^2_y + Z'^2_z}$
Calculate the magnitude of the vector from satellite to earth station in the direction of the satellite axis by taking dot products				
	Magnitude in the *X* direction	X_{delta}	–1246.357	$X \times \frac{X'_x}{X'_{mag}} + Y \times \frac{X'_y}{X'_{mag}} + Z \times \frac{X'_z}{X'_{mag}}$
	Magnitude in the *Y* direction	Y_{delta}	1678.8409	$-X \times \frac{X_n}{r} - Y \times \frac{Y_n}{r} - Z \times \frac{Z_n}{r}$
	Magnitude in the *Z* direction	Z_{delta}	835.35433	$X \times \frac{Z'_x}{Z'_{mag}} + Y \times \frac{Z'_y}{Z'_{mag}} + Z \times \frac{Z'_z}{Z'_{mag}}$
Calculate the azimuth and elevation to the earth station from the satellite point of view				
	Azimuth to earth station from satellite point of view (degrees)	*Az*	–36.5898	$atan\left(\frac{x_{sat}}{y_{sat}}\right)$
	Elevation to earth station from satellite point of view (degrees)	*El*	21.7775	$atan\left(\frac{z_{sat}}{\sqrt{x^2_{sat} + y^2_{sat}}}\right)$
Choose pfd from the pfd mask for having the latitude nearest to sub-satellite latitude, *Az* and *El* nearest to those calculated above of non-GSO satellite. Because the GSO satellite VLA frequency bandwidth 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	pfd_1	–140	example
	Freq 2: pfd of non-GSO satellite with azimuth and elevation to the earth station	pfd_2	–131	example
		...		
	Freq *n*: pfd of non-GSO satellite with azimuth and elevation to the earth station	pfd_n	–140	example
	Calculate worst-case epfd (dB(W/(m^2 · 40 kHz)))	$epfd_{40kHz}$	–190.760	$10\log\left(10^{\frac{pfd_1+G(X)-G_{max}}{10}} + 10^{\frac{pfd_2+G(X)-G_{max}}{10}} + \cdots + 10^{\frac{pfd_n+G(X)-G_{max}}{10}}\right)$
	Calculate worst-case epfd (dB(W/(m^2 · MHz)))	*epfd*	–176.781	$10\log\left(10^{\frac{pfd_1+G(X)-G_{max}}{10}} + 10^{\frac{pfd_2+G(X)-G_{max}}{10}} + \cdots + 10^{\frac{pfd_n+G(X)-G_{max}}{10}}\right)$
	Epfd trigger level (dB(W/(m^2 · 40 kHz)))	*epfd*	–171.0	From ITU RR Appendix **5**
	Epfd trigger level (dB(W/(m^2 · MHz)))	*epfd*	–157.0	From ITU RR Appendix **5**
	Epfd trigger violated		NO	

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. If the GSO inclination is greater than the non-GSO cut-off latitude, a conjunction can occur, and Case 1 should be used. In this situation, for HEO non-GSO orbits, use the radius of the HEO satellite at the latitude of conjunction for the non-GSO radius in Case 1. The algorithm to calculate the epfd↓ value requires the following steps:

Step 1: Inputs: Radius of the Earth, non-GSO orbit radius, non-GSO satellite inclination, non-GSO satellite cut-off latitude, GSO satellite longitude, GSO satellite inclination, GSO orbit 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} 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 pre-programmed 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				
Note 1: For a HEO satellite the input for the non-GSO radius is the radius HEO at the latitude of cut-off/on				
Note 2: If the GSO inclination is greater than the non-GSO cut-off latitude, a conjunction can occur, and Case 1 should be used. In this situation, for HEO a satellite the input for the non-GSO radius is the radius HEO at the latitude of conjunction				
Inputs				
	Radius of the earth (km)	R_e	6 378.15	
	GSO radius (km)	R_g	42 164	
	Non-GSO satellite inclination (degrees)	i	55	
	Non-GSO radius (km)	R_n	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	
	Mask Ref BW (kHz)		40	Determined from mask file (40 or 1 000)
	Band (Ku or Ka)		Ka	
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)	–12	Recommendation ITU-R S.1428 (macro)
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 the pfd mask having an Alpha = a_0, and a sub-satellite latitude and Delta nearest to those calculated above. Because the GSO satellite VLA frequency bandwidth 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	pfd_1	–140	example
	Freq 2: pfd of non-GSO satellite	pfd_2	–131	example
	...			
	Freq *n*: pfd of non-GSO satellite	pfd_n	–140	example
	Calculate worst-case epfd (dB(W/(m² · 40 kHz)))	$epfd_{40kHz}$	−212.025	$10\log(10^{\frac{pfd_1+G(X)-G_{max}}{10}}+10^{\frac{pfd_2+G(X)-G_{max}}{10}}+\cdots+10^{\frac{pfd_n+G(X)-G_{max}}{10}}$
	Calculate worst-case epfd (dB(W/(m² · MHz)))	*epfd*	–198.045	$10\log(10^{\frac{pfd_1+G(X)-G_{max}}{10}}+10^{\frac{pfd_2+G(X)-G_{max}}{10}}+\cdots+10^{\frac{pfd_n+G(X)-G_{max}}{10}}$
	Epfd trigger level (dB(W/(m² · 40 kHz)))	*epfd*	−199.0	From ITU RR Appendix **5**
	Epfd trigger level (dB(W/(m² · MHz)))	*epfd*	−185.0	From ITU RR Appendix **5**
	Epfd trigger violated?		NO	
If satellite pfd masks are presented in azimuth vs elevation form				
Calculate the *x*, *y*, *z*, and *r* components of the earth station in ECF				
	Earth station *x* value (km)	X_e	1 130.62	$R_e \times \cos(\varphi) \times \cos(earth_{long})$
	Earth station *y* value (km)	Y_e	–4 897.23	$R_e \times \cos(\varphi) \times \sin(earth_{long})$
	Earth station *z* value (km)	Z_e	3 926.78	$R_e \times \sin(\varphi)$
	Earth station *r* value (km)	R_{es}	6 378.15	$\sqrt{X_e^2+Y_e^2+Z_e^2}$
Calculate the *x*, *y*, *z*, and radius components of the non-GSO satellite ECF				
	Non-GSO satellite *x* value (km)	X_n	14 366.67	$R_n \times \cos(\delta) \times \cos(nGSO_{long})$
	Non-GSO satellite *y* value (km)	Y_n	–8 977.29	$R_n \times \cos(\delta) \times \sin(nGSO_{long})$
	Non-GSO satellite *z* value (km)	Z_n	16 940.86	$R_n \times \sin(\delta)$
	Non-GSO radius (km)	R_n	23 958	$\sqrt{X_n^2+Y_n^2+Z_n^2}$
Calculate vector between non-GSO satellite and earth station				
	Vector *X* (km)	*X*	–13 236.05	$X_e - X_n$
	Vector *Y* (km)	*Y*	4 080.057	$Y_e - Y_n$
	Vector *Z* (km)	*Z*	–13 014.08	$Z_e - Z_n$

TABLE 4 (*continued*)

	Vector *r* (km)	r	19 005.428	$\sqrt{X^2 + Y^2 + Z^2}$
North vector				
	North *X*	N_x	0	North vector *x* component
	North *Y*	N_y	0	North vector *y* component
	North *Z*	N_z	1	North vector *z* component
	North magnitude	N_{mag}	1	North vector magnitude
Calculate the satellite *X* component of the satellite frame by cross product of negative of the vector from satellite to center of Earth and North vector				
	X frame – *x* component	X'_x	8977.2903	$-Y_n \times N_z + N_y \times Z_n$
	X frame – *y* component	X'_y	14 366.667	$-Z_n \times N_x + N_z \times X_n$
	X frame – *z* component	X'_z	–0	$-X_n \times N_y + N_x \times Y_n$
	X magnitude	X'_{mag}	16 940.86	$\sqrt{X'^2_x + X'^2_y + X'^2_z}$
Calculate the *Z* component of the satellite frame by cross product of negative of the vector from satellite to center of Earth and the *X* component of the satellite frame				
	Z frame – *x* component	Z'_x	–243383767.2	$-Y_n \times X'_z + X'_y \times Z_n$
	Z frame – *y* component	Z'_y	152083056.9	$-Z_n \times X'_x + X'_z \times X_n$
	Z frame – *z* component	Z'_z	286992882	$-X_n \times X'_y + X'_x \times Y_n$
	Z magnitude	Z'_{mag}	405869226.0	$\sqrt{Z'^2_x + Z'^2_y + Z'^2_z}$
Calculate the magnitude of the vector from satellite to earth station in the direction of the satellite axis by taking dot products				
	Magnitude in the *X* direction	X_{delta}	–3553.954595	$X \times \frac{X'_x}{X'_{mag}} + Y \times \frac{X'_y}{X'_{mag}} + Z \times \frac{X'_z}{X'_{mag}}$
	Magnitude in the *Y* direction	Y_{delta}	18668.32096	$-X \times \frac{X_n}{r} - Y \times \frac{Y_n}{r} - Z \times \frac{Z_n}{r}$
	Magnitude in the *Z* direction	Z_{delta}	263.6282482	$X \times \frac{Z'_x}{Z'_{mag}} + Y \times \frac{Z'_y}{Z'_{mag}} + Z \times \frac{Z'_z}{Z'_{mag}}$
Calculate the azimuth and elevation to the earth station from the satellite point of view				
	Azimuth to earth station from satellite point of view (degrees)	Az	–10.77862297	$\text{atan}\left(\frac{Y_\delta}{X_\delta}\right)$
	Elevation to earth station from satellite point of view (degrees)	El	0.794787166	$\text{asin}\left(\frac{Z_\delta}{r}\right)$

TABLE 4 (*end*)

Choose pfd from the pfd mask for having the latitude nearest to sub-satellite latitude, *Az*, and *El* nearest to those calculated above of non-GSO satellite. Because the GSO satellite VLA frequency bandwidth 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	pfd_1	–140	example
	Freq 2: pfd of non-GSO satellite with azimuth and elevation to the earth station	pfd_2	–131	example
		...		
	Freq *n*: pfd of non-GSO satellite with azimuth and elevation to the earth station	pfd_n	–140	example
	Calculate worst-case epfd (dB(W/(m^2 · 40 kHz)))	$epfd_{40kHz}$	–212.025	$10\log\left(10^{\left(\frac{pfd_1+G(X)-G_{max}}{10}\right)}+10^{\left(\frac{pfd_2+G(X)-G_{max}}{10}\right)}+\cdots+10^{\left(\frac{pfd_n+G(X)-G_{max}}{10}\right)}\right)$
	Calculate worst-case epfd (dB(W/(m^2 · MHz)))	*epfd*	–198.045	$10\log\left(10^{\left(\frac{pfd_1+G(X)-G_{max}}{10}\right)}+10^{\left(\frac{pfd_2+G(X)-G_{max}}{10}\right)}+\cdots+10^{\left(\frac{pfd_n+G(X)-G_{max}}{10}\right)}\right)$
	Epfd trigger level (dB(W/(m^2 · 40 kHz)))	*epfd*	–199.0	From ITU RR Appendix **5**
	Epfd trigger level (dB(W/(m^2 · MHz)))	*epfd*	–185.0	From ITU RR Appendix **5**
	Epfd trigger violated?		NO	

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