

## RECOMMENDATION ITU-R S.1503

**FUNCTIONAL DESCRIPTION TO BE USED IN DEVELOPING SOFTWARE TOOLS FOR  
DETERMINING CONFORMITY OF NON-GEOSTATIONARY-SATELLITE ORBIT  
FIXED-SATELLITE SYSTEM NETWORKS WITH LIMITS CONTAINED IN  
ARTICLE S22 OF THE RADIO REGULATIONS**

(Resolutions 130 (WRC-97) and 538 (WRC-97))

(2000)

The ITU Radiocommunication Assembly,

*considering*

- a) that for the use of non-geostationary systems in the fixed-satellite service (non-GSO FSS systems) in certain frequency bands including bands covered by Appendices S30, S30A and S30B, WRC-97 adopted provisional power limits and included these limits in Table S22-1 of Article S22 of the Radio Regulations (RR) and Annex 1 to Resolution 130 (WRC-97) and Annex to Resolution 538 (WRC-97);
- b) that these frequency bands are currently used or planned to be used extensively by geostationary-satellite systems (GSO systems);
- c) that to perform the regulatory examination of such non-GSO FSS systems, the Radiocommunication Bureau (BR) requires a software tool that permits the calculation of the power levels produced by such systems, on the basis of the specific characteristics of each non-GSO FSS system submitted to the Bureau for coordination or notification, as appropriate;
- d) that GSO FSS and GSO broadcasting-satellite service (BSS) systems have individual characteristics and that interference assessments will be required for multiple combinations of antenna characteristics, interference levels and probabilities;
- e) that designers of satellite networks (non-GSO FSS, GSO FSS and GSO BSS) require knowledge of the basis on which the BR will make such checks;
- f) that such tools may be already developed or under development and may be offered to the BR,

*recommends*

- 1** that the functional description specified in Annex 1 be used to develop software tools calculating the power levels produced by non-GSO FSS systems and the compliance of these levels with the limits contained in Table S22-1 of Article S22 of the RR;
- 2** that Annex 1, Part H be considered as a basis by the BR for the evaluation of candidate software supplied by administrations.

NOTE 1— Radiocommunication Study Group 4 will take the lead-role, in consultation with Radiocommunication Study Group 11, in the future maintenance of this Recommendation, in particular to modify it as required to be able to determine compliance with further requirements called by ITU-R.

## ANNEX 1

## CONTENTS

	<i>Page</i>
Part A – Fundamental constraints and basic assumptions.....	2
Part B – Parameters of non-GSO system .....	14
Part C – Generation of pfd/e.i.r.p. masks .....	29
Part C' – Maximum epfd location of GSO network.....	39
Part D – Software for the examination of non-GSO filings .....	45
Part E – Testing of the reliability of the software outputs.....	85
Part F – Operational environment for the software .....	86
Part G – Software development and maintenance .....	87
Part H – Procedures for the evaluation of a candidate software.....	87

## Functional description of software for use by the BR in checking compliance of non-GSO FSS systems with epfd limits

### PART A

#### Fundamental constraints and basic assumptions

## 1 General

### 1.1 Software composition

#### 1.1.1 Purpose

The software algorithm described in this Annex is designed for its application by the BR to conduct examination of the non-GSO FSS system notifications for their compliance with the validation limits specified by the RR.

#### 1.1.2 Software block-diagram

The block-diagram of the software algorithm described in this Annex is shown in Fig. 1. It consists of two sections: that of initial data and that of calculation. The initial data section contains the whole set of parameters relevant to the notified non-GSO system, a set of reference GSO system parameters as well as epfd limits.

The calculation section is designed for estimations required to examine notified non-GSO systems compliance with the epfd limits. The calculation section is based on a concept of a downlink power flux-density (pfd) mask (see Note 1), an uplink effective isotropic radiated power (e.i.r.p.) mask (see Note 2) and inter-satellite e.i.r.p. mask (see Note 3).

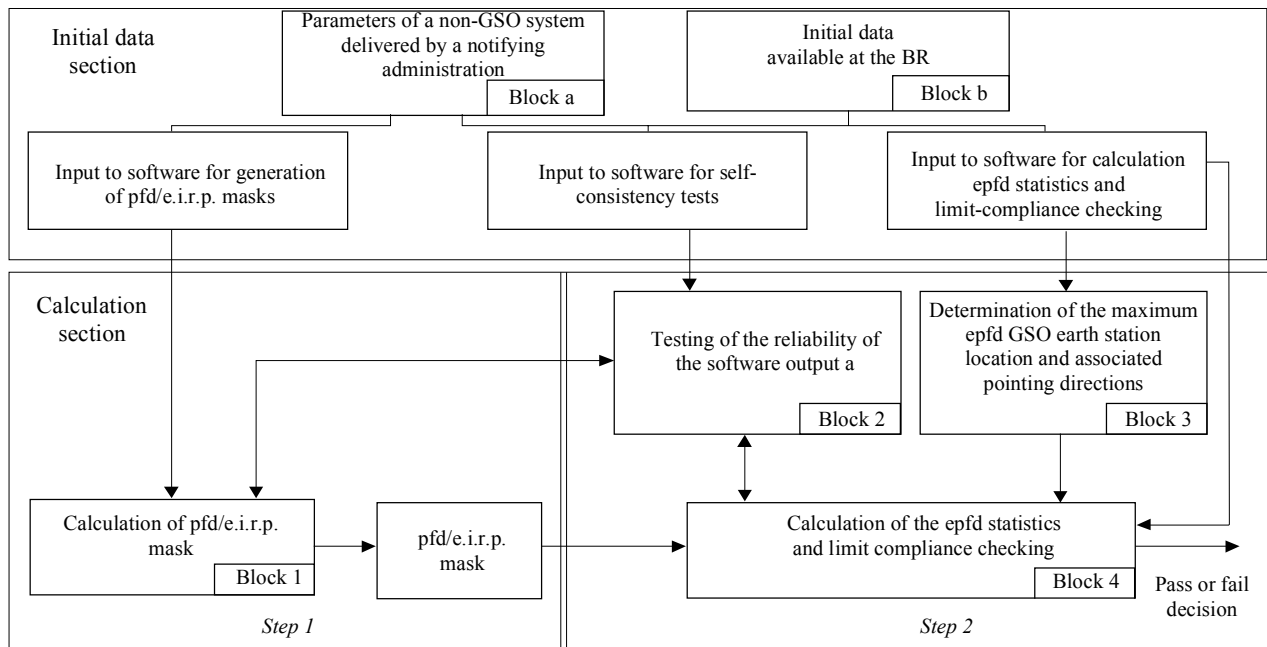
NOTE 1 – A pfd mask is a maximum pfd produced by a non-GSO space station and is defined in Part C.

NOTE 2 – An e.i.r.p. mask is a maximum e.i.r.p. radiated by a non-GSO earth station and is a function of an off-axis angle for the transmitting antenna main beam.

NOTE 3 – An inter-satellite e.i.r.p. mask is a maximum e.i.r.p. radiated by a non-GSO space station and is a function of an off-axis angle for the boresight of the non-GSO space station.

A pfd/e.i.r.p. mask is calculated in Block 1 based on the notified non-GSO system parameters delivered from the initial data section. Block 4 tests the aggregate interference produced by non-GSO network stations for meeting epfd limits. The verification in Block 4 is effected on the basis of the non-GSO system constellation characteristics from the initial data section, a pfd/e.i.r.p. mask from Block 1 and output data from Block 3. The output data are verified for validity in Block 2.

FIGURE 1



1503-01

### 1.1.3 Allocation of responsibilities between Administrations and the BR for software employment

Taking into account significant complexity regarding specific features of different non-GSO system configurations in the software it would seem appropriate to impose some burden of responsibility relevant to testing for epfd limits on administrations notifying appropriate non-GSO systems. Therefore the examination procedure for meeting epfd limits would consist of two stages. The first stage would include the software development (Block 1) and conducting all the calculations by the administrations notifying non-GSO systems. The stage would also include estimation of a mask for pfd/e.i.r.p. produced by interfering non-GSO network stations. The mask would account for all the features of specific non-GSO systems arrangements. The first stage would be finalized with delivering the pfd/e.i.r.p. mask in analytical or documented formats to the BR. Moreover the notifying administration would provide the BR with the software used in Block 1 for the pfd/e.i.r.p. mask estimation, the complete software description and parameters from Block a, as well as any additional information that is useful to regenerate the pfd/e.i.r.p. mask. The information mentioned shall also be available for other administrations.

The second stage calculations would be effected at the BR. The second stage would feature the following operations:

- Definition of the maximum epfd geometry of a GSO space station and an earth station of that network (Block 3). It would ensure verification of sharing feasibility for a notified non-GSO network with any GSO network in the FSS and BSS.
- epfd statistics estimation (Block 4).
- Software results verification for validity (Block 2).
- Making a decision on interference compliance with epfd limits (Block 4).

The estimations are based on the non-GSO system parameters (Block a) delivered by a notifying administration and the initial data (Block b) available at the BR.

Any administration may use software that uses the algorithms defined in this Annex together with data on the non-GSO networks to estimate statistics for interference into its own GSO networks and check for compliance with epfd limits. It would assist in solving probable disputes between the BR and administrations concerned.

The elements of the software block-diagram discussed are presented hereinafter in detail. The Parts are as follows:

- Part A – Basic limitations and main system requirements for the software as a whole are presented.
- Part B – Non-GSO networks parameters and initial data for Blocks a and b are discussed.
- Part C – Definitions and estimation algorithms for pfd/e.i.r.p. masks relative to non-GSO network earth and space stations are presented. Specifics of those masks applying in simulation is also discussed (Block 1).
- Part C' – This part deals with procedures to define the maximum epfd location of GSO network stations.
- Part D – The part deals with general requirements on the software related to examination of non-GSO networks notifications, algorithms to estimate epfd statistics, and the format for output data presentation. Part D covers issues of Blocks 3 and 4.
- Parts E, H – These parts define requirements on the software related to valuation of delivered software and to verification of the software output on validity (Block 2).
- Parts F, G – The software documentation and follow up, operational environment and interface requirements and other matters are described.

## 1.2 Units of measurement

To provide for adequate simulation results and to avoid errors a common measurement units system is used in Table 1 for the software description. The list of measurement units for the basic physical parameters is shown in Table 1.

TABLE 1

**The system of measurement units for basic physical parameters used  
for the software performance description**

Parameter	Units
Distance	km
Angle	degrees
Time	s
Linear rotation velocity	km/s
Angular rotation velocity	degrees/s
Frequency	GHz
Frequency bandwidth	kHz
Power	dBW
Power spectral density	dB(W/Hz)
pfd	dB(W/(m <sup>2</sup> · BW <sub>ref</sub> ))
Average number of co-frequency non-GSO earth stations per unit area	1/km <sup>2</sup>
epfd <sub>d</sub> , epfd <sub>↑</sub> or epfd <sub>is</sub>	dB(W/BW <sub>ref</sub> )
Antenna gain	dBi
Geographical position on the Earth's surface	degrees

### 1.3 Constants

The functional description of the software for examination of non-GSO networks notification at the BR uses the following constants (constants related to the Earth).

TABLE 2  
Constants related to the Earth

Parameter	Notation	Numerical value	Units
Radius of the Earth	$R_e$	6 378.145	km
Radius of geostationary orbit	$R_{geo}$	42 164.2	km
Gravitational constant	$\mu$	$3.986012 \times 10^5$	km <sup>3</sup> /s <sup>2</sup>
Speed of light	$c$	$2.99792458 \times 10^5$	km/s
Angular rate of rotation of the Earth	$\omega_e$	$4.1780745823 \times 10^{-3}$	degrees/s
Earth rotation period	$T_e$	86 164.09054	s
Factor of the Earth non-sphericity	$J_\alpha$	$2.634 \times 10^{10}$	km <sup>5</sup> /s

### 1.4 The Earth model

The force of the Earth attraction is the main factor to define a satellite orbital motion. Additional factors include:

- orbit variations due to the Earth's oblateness and its mass distribution irregularities;
- solar and lunar attraction;
- medium drag for satellite;
- solar radiation pressure, etc.

The function description of software in this Annex accounts orbit perturbations only due to the Earth oblateness. It is motivated by the fact that effect of other perturbing factors is significantly less. The Earth's oblateness causes secular and periodic perturbations of ascending node longitude and orbit perigee argument. Part D describes expressions to account the Earth's oblateness effect.

The orbits of some repeating ground tracks can be very sensitive to the exact orbit model used. Administrations could also provide the BR with their own independently determined average precession rates that could be used by the software instead of the values calculated using the equation in Part D.

## 2 System requirements

Two approaches are described in this Annex: analytical method and time simulation: time simulation in which interference levels are evaluated at each time step and the analytical method in which interference levels are evaluated at increments of the position (longitude and latitude) of a non-GSO network reference satellite. Paragraph 2.1 and 2.2 of Part A refer to the choice of time steps and the total number of time steps to be used in the time simulation approach. Paragraph 2.3 of Part A refers to the choice of the longitude and latitude increments to be used in the analytical method approach.

### 2.1 Simulation time increment and accuracy

The simulation time increment is one of the most important parameters for determination of a distribution function of interference from non-GSO networks on the basis of the simulation model. Its specified value should guarantee absence of cases when high-level short-term interference exceeding an acceptable level is missed and is not considered.

Otherwise results of simulation analysis will be inaccurate and sometimes erroneous. The decrease of a simulation time increment allows to increase accuracy of obtained results but at the same time results in increase of total number of simulation time increments and amount of required calculations.

The description of calculation algorithms for simulation time increment in uplink and downlink is shown below.

### 2.1.1 Description of the procedure for determination of minimum downlink simulation time increment

The value of simulation time increment should guarantee acquisition and description of the most short-term interference scenarios with required accuracy. The high-level short-term interference is caused by emission of a non-GSO space station which is in-line situation (a non-GSO satellite passes through the main beam of a GSO earth station antenna). Therefore, one method for determining a simulation time increment  $\Delta t_{ref}$  could be based on ensuring the required number  $N_{hit}$  of pfd<sub>↓</sub> estimations during the time interval  $\Delta t$  when a non-GSO satellite passes through the main beam of a GSO earth station antenna:

$$\Delta t_{ref} = \frac{\Delta t}{N_{hit}} \quad (1)$$

The time required for of a non-GSO satellite passing through the main beam of a GSO earth station antenna depends on mutual location of earth and space stations of the GSO network as well as on orbital parameters of the non-GSO network. Determination of the exact value  $\Delta t$  in general is hampered. The value of  $\Delta t$  should be computed at the location where the time for a non-GSO satellite to pass through the GSO main beam is smallest. Since this occurs when a GSO earth station is located directly under a GSO space station, pass time  $\Delta t$  could be determined by equations (2) and (3) (see Fig. 2):

$$\Delta t = \frac{2\varphi}{\omega} \quad (2)$$

where:

$$\varphi = \frac{1}{2} \varphi_{3dB} - \arcsin \left[ \frac{R_e}{R_e + h} \sin \left( \frac{1}{2} \varphi_{3dB} \right) \right] \quad (3)$$

$$\omega = \sqrt{(\omega_s \cos(i) - \omega_e)^2 + (\omega_s \sin(i))^2} \quad (3)$$

$$\omega_s = \frac{0.071}{[(R_e + h)/R_e]^{1.5}}$$

$\omega_s$ : non-GSO satellite angular velocity of rotation around the Earth at the minimum operational altitude, (degrees/s); for multiple orbits, the greatest such  $\omega_s$  should be selected

$\omega_e$ : Earth rotation angular velocity at the equator (degrees/s)

$i$ : orbit inclination (degrees)

$\varphi_{3dB}$ : GSO earth station antenna 3 dB beamwidth (degrees)

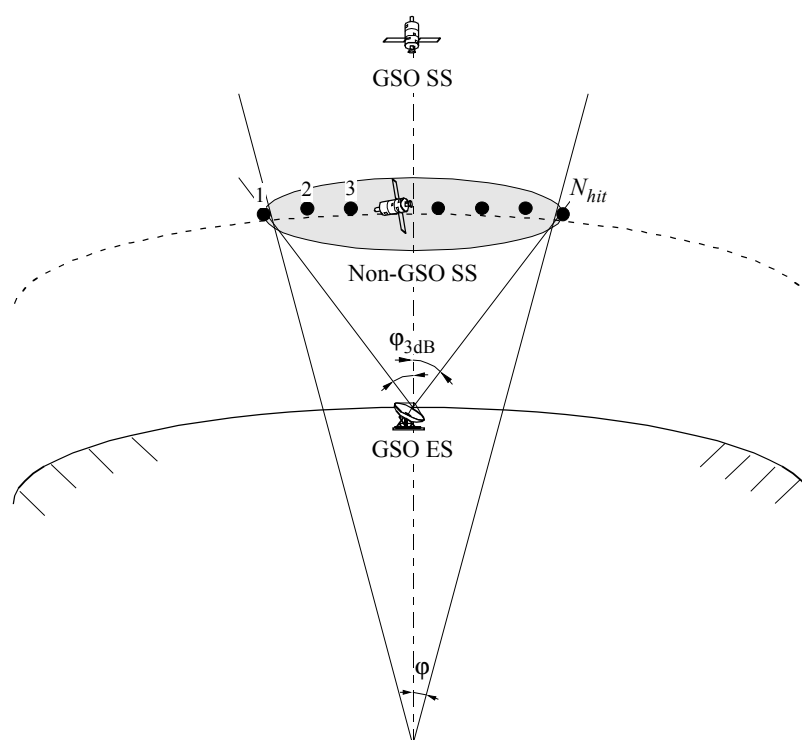
$R_e$ : Earth radius (km)

$h$ : orbit altitude (km) (see Note 1).

NOTE 1 – In the case that the constellation has multiple values of  $h$  for different sub-constellations or planes, the lowest value should be used. In the case of elliptical orbits the minimum operating height should be used.

The  $N_{hit}$  value defines simulation accuracy. The higher the  $N_{hit}$  value the higher the accuracy of the final results.

FIGURE 2



SS: satellite station  
ES: earth station

1503-02

Selection of  $N_{hit}$  value could be based on Recommendation ITU-R S.1325 which recommends the  $N_{hit}$  value of 5 and greater. In a case when a non-GSO network satellite constellation consists of satellites with different orbital parameters it is necessary to determine a simulation time increment for each type of the orbits concerned and to define a minimum one.

TABLE 3

**Input data**

Parameter	Designation	Units
Orbit inclination	$i$	degrees
Orbit altitude or for elliptical orbits the minimum operating height	$h$	km
GSO earth station antenna 3 dB beamwidth	$\phi_{3dB}$	degrees
Number of $epfd_{\downarrow}$ calculations required during the time a non-GSO satellite is passing through the main beam of a GSO earth station antenna	$N_{hit}$	—

**2.1.2 Algorithm of determination of downlink simulation time increment**

Calculation algorithm:

*Step 1:* Input the data listed in Table 3.

*Step 2:* For satellites with different altitude and inclination – calculate the simulation time increments by equations (1) and (2).

*Step 3:* Select a simulation time increment.

### 2.1.3 Description of the procedure for determination of minimum uplink simulation time increment

High-level short-term uplink interference would be caused by emissions from a non-GSO earth station during an in-line event (when a GSO SS would be in the main beam of a non-GSO earth station antenna). The required number  $N_{hit}$  of  $epfd_{\uparrow}$  measurements should be effected within the period of the GSO satellite staying in the main beam of the non-GSO earth station antenna to ensure acquisition and definition of the in-line event. If the non-GSO earth station were directly below the GSO satellite (see Fig. 3) then the value of the minimum simulation time increment could be calculated using equations (1) and (2). In that case a width of the non-GSO earth station antenna main beam should be taken instead of that of the GSO earth station antenna main beam.

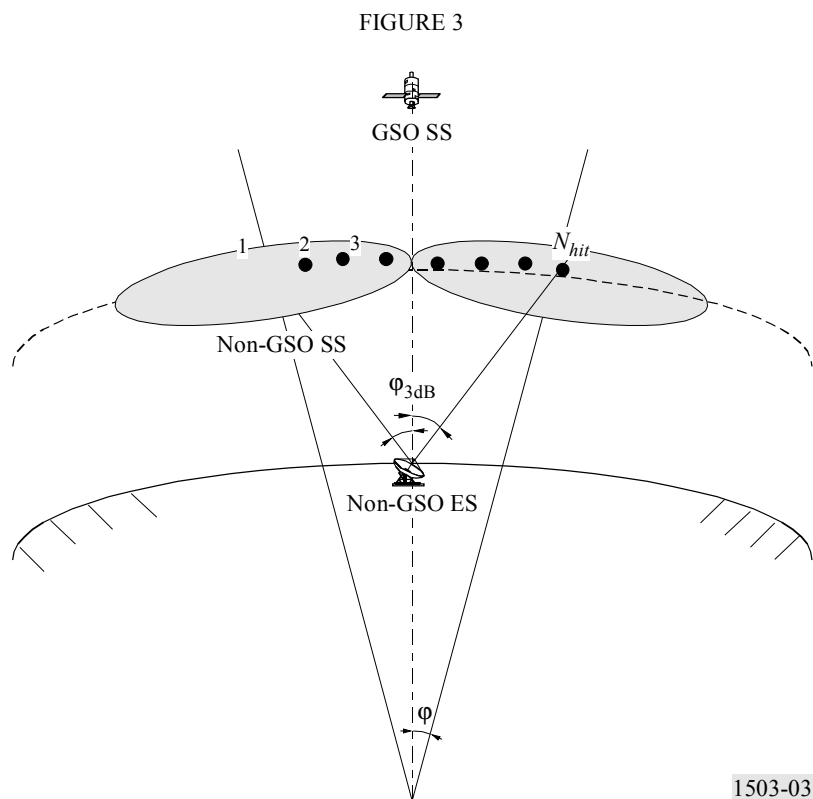


TABLE 4

#### Input data

Parameter	Designation	Units
Orbit inclination	$i$	degrees
Orbit altitude	$h$	km
Non-GSO earth station antenna 3 dB beamwidth	$\varphi_{3dB}$	degrees
Number of $epfd_{\uparrow}$ calculations required during the time a GSO satellite is passing through the main beam of a non-GSO earth station antenna	$N_{hit}$	—



### 2.1.4 Algorithm of determining the uplink simulation time increment

Calculation algorithm:

*Step 1:* Input the data listed in Table 4.

*Step 2:* For satellites with different altitude and inclination - calculate the simulation time increments by equations (1) and (2).

*Step 3:* Select a simulation time increment.

### 2.1.5 Description of the procedure for determination of minimum inter-satellite simulation time increment

The time step size for  $\text{epfd}_{\text{is}}$  calculations is derived by considering that there should be at least  $N_{\text{hit}}$  time steps during which the non-GSO satellite is within the main beam of the GSO satellite. Given that the shortest time step is when the beam at the GSO is pointed as far as possible away from the sub-satellite point, and given the following:

$R_e$ : radius of the Earth

$h$ : height of non-GSO orbit

$R_{\text{geo}}$ : radius of geostationary orbit

$\varphi_{3\text{dB}}$ : half power beamwidth of GSO beam.

Then the time step can be calculated using the following algorithm (see Fig. 4):

Calculate:

$$\theta_1 = \arcsin\left(\frac{R_e}{R_{\text{geo}}}\right)$$

$$\theta_2 = 180 - \arcsin\left(\sin(\theta_1) \frac{R_{\text{geo}}}{R_e + h}\right)$$

$$\theta_3 = 180 - (\theta_1 + \theta_2)$$

$$D_1 = (R_e + h) \frac{\sin \theta_3}{\sin \theta_1}$$

$$D_2 = 2D_1 \sin\left(\frac{\varphi_{3\text{dB}}}{2}\right)$$

$$D_3 = D_2 \cos(180 - \theta_2)$$

Then calculate the value:

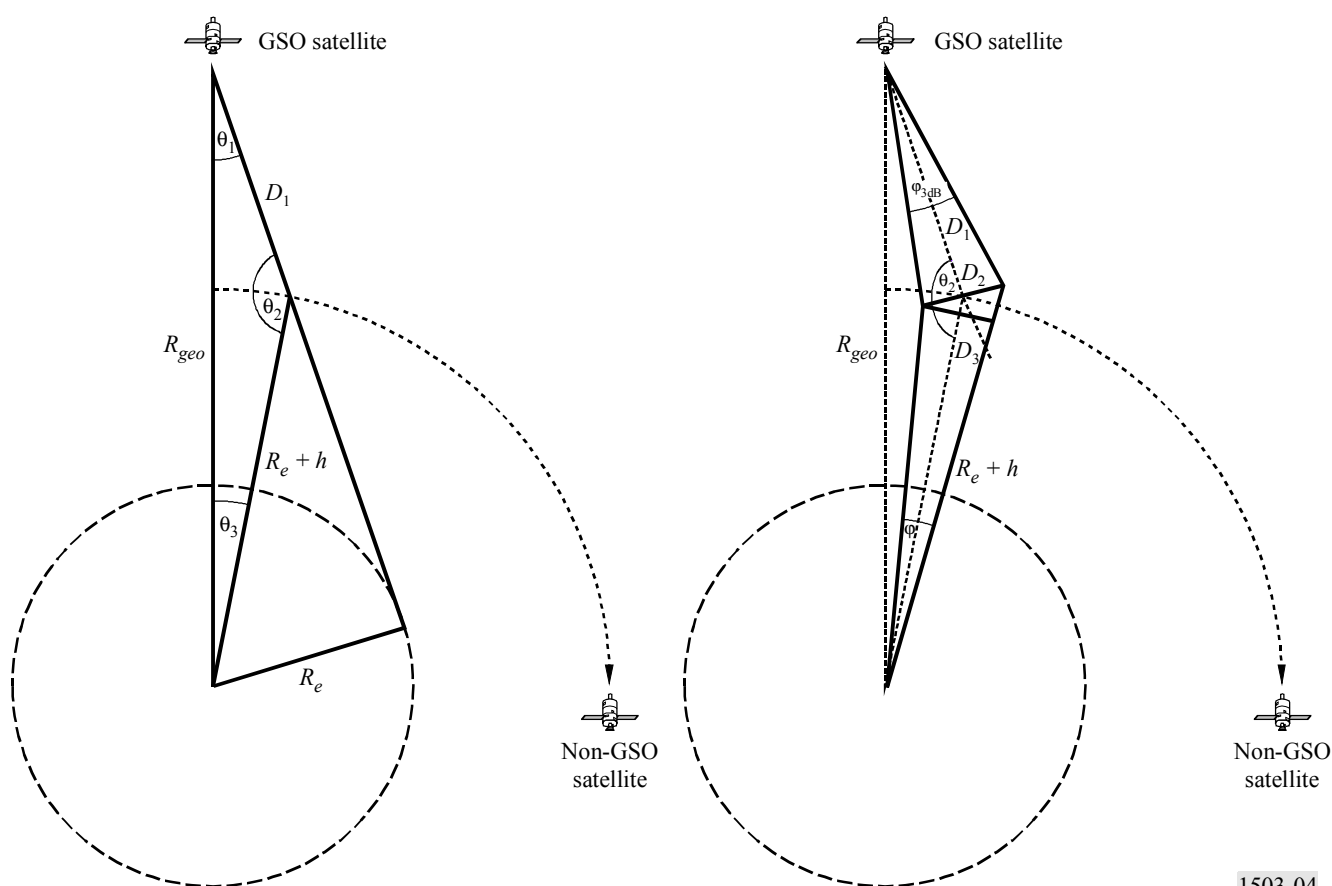
$$\varphi = 2 \arctan\left[\frac{D_3/2}{(R_e + h) - (D_2/2) \sin(180 - \theta_2)}\right] \quad (4)$$

which can be used in equation (2) to calculate the step size to use.

## 2.2 Total simulation run time

This section describes the calculation of number of time steps for the  $\text{epfd}_{\downarrow}$  and  $\text{epfd}_{\uparrow}$  algorithms specified in Part D. The basic approach first considers constellations with repeating and non-repeating ground track separately, where systems that use repeating ground tracks use station keeping to ensure that the satellites follow a single Earth trace. For example, in the case of a 6 h orbit, there will be minor launch errors and perturbations that would make the orbit drift unless station keeping was used operationally to ensure the track repeats. Administrations therefore must indicate to the BR whether station keeping is used to maintain a single track.

FIGURE 4  
Geometric parameters involved in the equations



1503-04

Some constellations have different values for inclination, height, or eccentricity between the planes. In this case, it is assumed that, to maintain coverage, the constellation would be designed so that the separation between planes does not change significantly. For the case of repeating ground tracks, this means that there will be a single repeat period for the constellation. This is the time for all satellites within the constellation to return to the same position relative to the Earth and each, within the constraints of station keeping. For the case of non-repeating ground tracks, there will be a single period for all the orbit planes to process around the equator.

This approach is to be used for constellations with both circular and elliptical orbits.

Table 5 shows the input parameters used in all constellation types.

TABLE 5

**Input data**

Parameter	Designation	Units
Constellation repeats yes/no	Type	–
Minimum samples taken to get statistical significance	$N_S = 10$	–

In both cases the time step can be calculated using the method described above. The number of time steps should be at least:

$$N_{min} = N_S \times 100 / (100 - (\text{maximum \% in the Tables of Article S22 of the RR less than 100\%}))$$

So for example for the 99.999% case the number of steps would be:

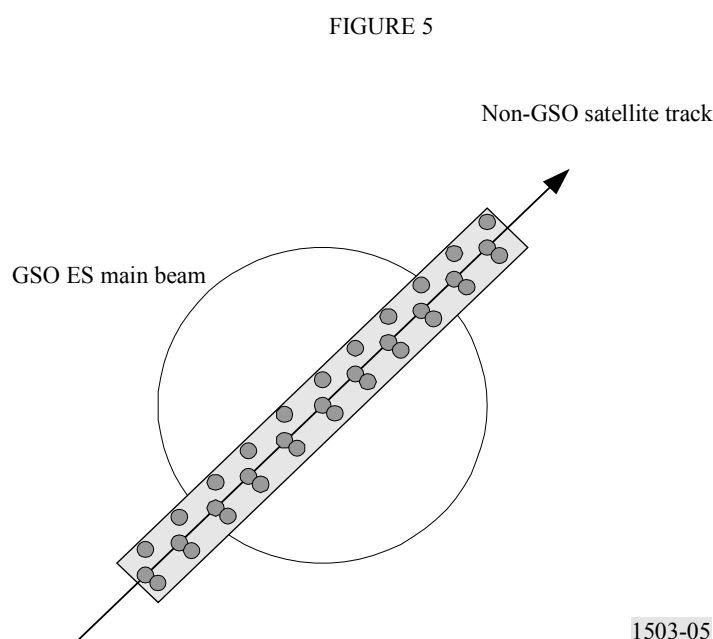
$$N_{min} = 1\,000\,000$$

### 2.2.1 Repeating orbits

For those orbits specified as being repeating, the orbit predictor has to be accurate to ensure repeatability. Thus, there is an option for administrations to specify the exact longitude precession rate with respect to a point mass orbit predictor that ensures the orbit would repeat. The definition and use of this parameter is in Part D.

With this parameter, a simulated orbit would be repeated but in reality there would be a slight drift due to longitudinal station keeping errors. This effect is modelled by mechanisms such as random sampling or linear drift in orbit as discussed in Part D.

It is expected that station keeping changes within the orbit plane would make no difference and so are not included. The result should be like Fig. 5:



In Fig. 5 it can be seen that the result would be a series of samples within the main beam of the GSO earth station that is sufficiently fine to resolve the main beam, includes station keeping drift and produces sufficient samples to generate the required statistics.

TABLE 6

#### Input data

Parameter	Designation	Units
Constellation repeat period	$P_{repeat}$	s

Given the following parameters:

$N_{min}$ : minimum number of time steps required for statistical significance

$P_{repeat}$ : time period that the constellation repeats (s)

$T_{step}$ : time step (s)

$N_{tracks}$ : number of tracks through the main beam, = 5, as specified by Recommendation ITU-R S.1325.

For this case the time step should not exactly divide the constellation repeat period. If:

$$N_{repsteps} = P_{repeat}/T_{step}$$

is an integer, then calculate a revised time step equal to:

$$T'_{step} = T_{step} (1 + N_{repsteps}) / N_{repsteps}$$

Calculate the time period required to get the minimum number of time steps for statistical significance:

$$T_{sig} = N_{min} \cdot T_{step}$$

This corresponds to the following number of constellation repeats:

$$N_{rep} = \text{round}(T_{sig}/P_{repeat}) \text{ to nearest integer above.}$$

The number of repeats of the constellation is the largest of  $N_{rep}$  or  $N_{tracks}$  i.e.

$$N_{run} = \max(N_{rep}, N_{tracks})$$

Then the total run time is:

$$T_{run} = N_{run} \cdot P_{repeat}$$

So the number of time steps is then:

$$N_{steps} = \text{round}(T_{run}/T_{step}) \text{ to nearest integer below.}$$

### 2.2.2 Non-repeating orbits

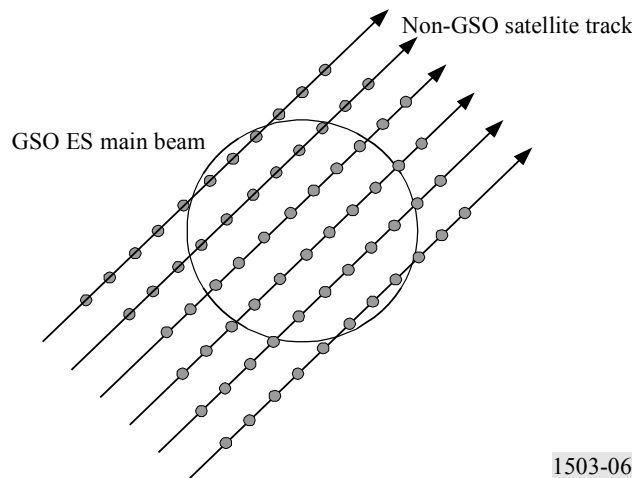
In this case the longitudinal spacing between successive ascending node passes must be examined so that there are sufficient tracks within the main beam. The time step size and number of time steps can be used to determine how far a particular orbit will have processed within the run. The same numbers can be used to determine how many time steps are required for the orbit to drift around the equator. The orbit period can then be used to work out the difference between tracks.

The constant that specifies the required number of points within the main beam can be used to specify the number of tracks though the main beam required (i.e.  $N_{track} = N_{hits}$ ). If the gap between tracks is too large or too fine (resulting in either insufficient samples or excessive run times respectively) then artificial precession can be used.

It is expected that station keeping drift should cancel out in the long term and so would not be required for these calculations.

The result should be like Fig. 6:

FIGURE 6



1503-06

In Fig. 6 it can be seen that the result would be a series of tracks within the main beam of the GSO earth station that is sufficiently fine to resolve the main beam and produces sufficient samples to generate the required statistics.

TABLE 7

## Input data

Parameter	Designation	Units
Orbit inclination	$i$	degrees
Orbit semi-major axis	$a$	km
GSO earth station antenna 3 dB beamwidth <sup>(1)</sup>	$\Phi_{3dB}$	degrees
Required number of tracks of a non-GSO satellite passing through the main beam of a GSO earth station antenna	$N_{tracks}$	—

<sup>(1)</sup> In the case of calculating run length for  $epfd_{\downarrow}$ . In the case of  $epfd_{is}$  and  $epfd_{\uparrow}$ :

$epfd_{\uparrow}$ : calculate  $\phi$  using the beamwidth of the non-GSO earth station as specified in its e.i.r.p. mask using the calculation in equation (3)

$epfd_{is}$ : calculate  $\phi$  using the beamwidth of the GSO satellite in the calculation in equation (4).

Two parameters are required:

$S_{pass}$ : longitudinal spacing between successive ascending passes through the equatorial plane

$S_{req}$ : required resolution of passes through the equatorial plane based upon GSO earth station beam size.

These are calculated using the following steps:

*Step 1:* Calculate nodal regression rate of the non-GSO orbit,  $\Omega_r$ , using the following equation:

$$\Omega_r = -6.91951 \times 10^{-3} \times (R_e/a)^{3.5} \cos(i) \quad \text{degrees/min}$$

where:

$i$ : orbital inclination (degrees).

*Step 2:* Calculate the satellite's Keplerian period,  $P_k$ , assuming a circular orbit and no orbital perturbations:

$$P_k = 84.48905 (a/R_e)^{1.5} \quad \text{min}$$

Convert this to seconds to get:

$$T_{period} = P_k \cdot 60$$

*Step 3:* Calculate the satellite's nodal period,  $P_n$ , accounting for the Earth's oblateness:

$$P_n = P_k \{1 - [0.75 \cdot J_2 (6 - 5 (\sin i)^2) \cdot (R_e/a)^2]\} \quad \text{min}$$

where  $J_2$  is the first order Earth oblateness term = 0.001082636 (dimensionless).

*Step 4:* Calculate the longitudinal spacing between successive ascending passes through the equatorial plane,  $S$ , given the Earth's rotation rate ( $\Omega_e = 0.250684$  degrees/min):

$$S_{pass} = (\Omega_e - \Omega_r) P_n \quad \text{degrees}$$

The equations above apply to circular orbits. For elliptical orbit systems where the calculations above would be significantly different, the value of  $S_{pass}$  should be supplied by the administration.

*Step 5:* From the GSO earth station beamwidth and height  $S_{req}$  can be calculated using equation (3):

$$S_{req} = \frac{2\phi}{N_{tracks}}$$

*Step 6:* Calculate the number of orbits to fully populate around the equator, taking into account that each plane has ascending and descending nodes:

$$N_{orbits} = \frac{180}{S_{req}}$$

*Step 7:* Round  $N_{orbits}$  to next highest integer.

*Step 8:* Calculate total angle orbit has rotated round during this time:

$$S_{total} = N_{orbits} \cdot S_{pass}$$

*Step 9:* Calculate the number of multiples of  $360^\circ$  that this corresponds to, rounding up to nearest integer above:

$$N_{360} = 1 + S_{total} \bmod 360$$

*Step 10:* Calculate the separation between planes that this corresponds to:

$$S_{actual} = \frac{360N_{360}}{N_{orbits}}$$

*Step 11:* To ensure that the orbit drifts with the required precession rate the following additional artificial precession should be included:

$$S_{artificial} = S_{actual} - S_{pass} \quad \text{degrees/orbit}$$

or:

$$D_{artificial} = \frac{S_{artificial}}{T_{period}} \quad \text{degrees/s}$$

*Step 12:* Part D gives more information on how this parameter is used. The total run time is then the time to process around the equator, namely:

$$T_{run} = T_{period} \cdot N_{orbits}$$

*Step 13:* The total number of time steps is then:

$$N_{steps} = \text{Round}(T_{run} / T_{step}) \text{ to nearest integer below.}$$

### 2.3 Longitude and latitude increments for use in the analytical method approach

In the analytical method approach (see Part D, § 6), the position (longitude and latitude) of a non-GSO network reference satellite is varied in some specified increments, covering the range of all possible values of longitude and latitude. These longitude and latitude increments play a role similar to that of the time step in the time simulation approach and have to be chosen to guarantee precise results. The choice of these parameters should be done according to the guidelines in Part D, § 6.3 and 6.4.

## PART B

### Parameters of non-GSO system

## 1 Introduction

### 1.1 Background

Certain parameters for a non-GSO network and other data must be specified in order to accomplish the requisite software functions:

- *Function 1:* Calculate the pfd masks for the non-GSO satellites (downlink) and the e.i.r.p. mask for the earth stations transmitting to those satellites (uplink).
- *Function 2:* Apply the e.i.r.p. mask in the calculation of uplink epfd<sub>↑</sub> levels and downlink equivalent pfd (epfd<sub>↓</sub>) levels (cumulative time distributions of epfd<sub>↑</sub> or epfd<sub>↓</sub>).
- *Function 3:* Determine whether the pfd/e.i.r.p. mask levels are consistent with basic transmission parameters of the non-GSO network, only in the case of dispute.

The roles of the administration of the non-GSO network and the BR are discussed in Part A, § 2.1. The first of the above functions (Function 1) is performed by the administration of the non-GSO network, and parameters used for that function are provided to the BR to corroborate the pfd masks in support of its role in performing Function 3. Detailed parameters are needed by the BR in support of Function 2.

## 1.2 Scope and overview

This section identifies inputs to the software in four main paragraphs. Paragraph 2 of Part B defines all of the inputs to facilitate design of the BR databases. Paragraphs 3 to 5 of Part B describe the inputs in terms of their use within the three software functional elements: Function 1 – Generation of pfd masks (§ 3 of Part B); Function 2 – Comparison of epfd levels with limit values (§ 4 of Part B); and Function 3 – Checking of submitted parameters for self-consistency (§ 5 of Part B).

Note that in the following tables, square brackets in variable names indicate an index for that variable and not tentative text.

## 1.3 Cross references to relevant Parts

The following Table indicates the relevant Parts of this Annex where input and database parameters generally are applied. More detailed cross-references for specific parameters are provided in § 2 of Part B.

Software function	Relevant Parts of this Annex where parameter inputs are applied
Function 1 – Generation of pfd /e.i.r.p. masks	§ 1-4, Part C
Function 2 – Calculation of cumulative time distributions of $epfd_{\uparrow}$ and $epfd_{\downarrow}$	§ 1-6, Part D
Function 3 – Tests	Part E

## 2 Common BR database parameters

### 2.1 Parameters provided by administration of the non-GSO system

Annex 1 to Part B details the existing and future RR Appendix S4 parameters of any non-GSO FSS constellation to be provided by administrations to the BR for coordination request or notification processing.

### 2.2 BR supplied inputs and database parameters

$S_B$ § 2.5, 3.4.5 and 4.1.4.5, Part D	Bin size for quantizing epfd statistics (0.1 dB)
REGION1_UP § 4.1.1, Part D	Applicability of Region 1 (yes or no)
REGION1_DOWN § 3.1, Part D	Applicability of Region 1 (yes or no)
REGION2_UP § 4.1.1, Part D	Applicability of Region 2 (yes or no)
REGION2_DOWN § 3.1, Part D	Applicability of Region 2 (yes or no)
REGION3_UP § 4.1.1, Part D	Applicability of Region 3 (yes or no)
REGION3_DOWN § 3.1, Part D	Applicability of Region 3 (yes or no)

REFBW § 3.1, Part D	Reference bandwidth for epfd calculations (kHz)
NEPFD_DOWN § 3.1, Part D	Number of epfd <sub>↓</sub> points
EPFD_DOWN_RR[I] § 3.1, Part D	Array of NEPFD_DOWN values (dB(W/m <sup>2</sup> )) in reference bandwidth, from Article S22 of the RR
DOWN_PC_RR[I] § 3.1, Part D	Array of NEPFD_DOWN percentages (%) from Article S22 of the RR

RAFBW § 4.1.1, Part D	Reference bandwidth for epfd <sub>↑</sub> calculations (kHz)
NEPFD_UP § 4.1.1, Part D	Number of epfd <sub>↑</sub> points
EPFD_UP_RR[I] § 4.1.1, Part D	Array of NEPFD_UP values (dB(W/m <sup>2</sup> )) in the reference bandwidth, from Article S22 of the RR
UP_PC_RR[I] § 4.1.1, Part D	Array of NEPFD_UP percentages, from Article S22 of the RR

F_DOWN <sub>sat</sub> § 3.4.2, Part D	Downlink transmit centre frequency (GHz)
Nfreq § 3.4.2, Part D	Number of frequency/regions
GSO_SEPARATION § 2.5, Part D	Separation between GSO satellite test points (1°)
GSO_LONG § 3.4.3 and 4.1.4.3, Part D	GSO satellite longitude(s) (degrees)
GSO_ES_LAT § 3.4.3, Part D	GSO earth station latitude (degrees)
GSO_ES_LONG § 3.4.3, Part D	GSO earth station longitude (degrees)
GSO_ES_PATTERN § 3.4.3, Part D	Reference gain pattern of the GSO earth station, from among those specified in Part D, § 5.5
GSO_ES_D_ANT § 3.1 and 3.4.3, Part D	Earth station antenna diameter

BS_LAT § 4.1.2 and 4.1.4.3, Part D	GSO boresight latitude
BS_LONG § 4.1.2 and 4.1.4.3, Part D	GSO boresight longitude
ES_F § 4.1.4.2, Part D	Uplink frequency (GHz)
GSO_SAT_PATTERN § 4.1.1 and 4.1.4.2, Part D	GSO satellite reference antenna gain pattern and related parameters, selected from among those in Part D, § 5.5.2
GSO_SAT_PEAKGAIN § 4.1.1, Part D	GSO satellite peak gain
GSO_SAT_BEAMWIDTH § 4.1.1, Part D	GSO satellite half power beamwidth



RIFBW § 4.2.1, Part D	Reference bandwidth for $\text{epfd}_{\text{is}}$ calculations (kHz)
NEPFD_IS § 4.2.1, Part D	Number of $\text{epfd}_{\text{is}}$ points
EPFD_IS[I] § 4.2.1, Part D	Array of NEPFD_IS values ( $\text{dB(W/m}^2\text{)}$ ) in the reference bandwidth
IS_PC[I] § 4.2.1, Part D	Array of NEPFD_IS percentages

IS_F § 4.2.4.2, Part D	Frequency for $\text{epfd}_{\text{is}}$ calculation (GHz)
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For the analytical method only:

PHISTEPCG § 3.4.4, Part D	Longitude step for the coarse grid (degrees)
THETASTEPCG § 3.4.4, Part D	Latitude step for the coarse grid (degrees)
PHISTEPFG § 3.4.4, Part D	Longitude step for the fine grid (degrees)
THETASTEFG § 3.4.4, Part D	Latitude step for the fine grid (degrees)

### 3 Non-GSO system inputs to software

All data, algorithms, test points, and methodologies used for generation of the pfd masks shall be provided to the BR to verify the submitted pfd masks for archival purposes in the case of dispute.

#### 3.1 Non-GSO orbit parameters

$N_{\text{sat}}$ § 3.4.2 and 4.1.4.2, Part D	Number of non-GSO satellites
$N_{\text{co}}[\text{latitude}]$ § 3.4.2, Part D	Maximum number of non-GSO satellites operating co-frequency at latitude lat
A[N] § 3.4.2 and 4.1.4.2, Part D	Semi-major axis of orbit (km)
E[N] § 3.4.2 and 4.1.4.2, Part D	Eccentricity of orbit
I[N] § 3.4.2 and 4.1.4.2, Part D	Inclination of orbit (degrees)
O[N] § 3.4.2 and 4.1.4.2, Part D	Longitude of ascending node of orbit (degrees)
W[N] § 3.4.2 and 4.1.4.2, Part D	Argument of perigee (degrees)
V[N] § 3.4.2 and 4.1.4.2, Part D	True anomaly (degrees)
$W_{\text{delta}}$ § 3.4.2 and 4.1.4.2, Part D	Station keeping range for ascending node
H_MIN § 3.4.2, Part D	Minimum operating height (km)
ORBIT_PRECESS § 3.4.4, 4.1.4.4 and 4.2.4.4, Part D	Precession rate

## 3.2 Non-GSO RF parameter inputs

### 3.2.1 Earth stations

non_GSO_ES_PATTERN § 3.3, Part C	Non-GSO earth station antenna pattern
$P$ § 3.4, Part C	Maximum power at the input to the non-GSO earth station antenna, in the reference bandwidth (dBW)
FSTART_UP § 4.1.1, Part D	Uplink frequency band start (GHz)
FEND_UP § 4.1.1, Part D	Uplink frequency band end (GHz)
REGION1_UP § 4.1.1, Part D	Applicable in Region 1
REGION2_UP § 4.1.1, Part D	Applicable in Region 2
REGION3_UP § 4.1.1, Part D	Applicable in Region 3
ES_TRACK § 4.1.4.2, Part D	Maximum number of co-frequency tracked non-GSO satellites
ES_EIRP § 4.1.4.2, Part D	e.i.r.p. per non-GSO earth station (dBW) in the reference bandwidth RABW
ES_MINELEV § 4.1.4.2, Part D	Minimum elevation angle of the non-GSO earth station when it is transmitting (degrees)
ES_MIN_GSO § 4.1.4.2, Part D	Minimum angle to GSO arc (degrees)
ES_DENSITY § 4.1.4.2, Part D	Average number of non-GSO earth stations co-frequency with GSO link (km <sup>2</sup> )
ES_DISTANCE § 4.1.4.2, Part D	Average distance between cell or beam footprint centres stations co-frequency with GSO link (km)

### 3.2.2 Satellites

FSTART_DOWN § 3.1, Part D	Downlink frequency band start (GHz)
FEND_DOWN § 3.1, Part D	Downlink frequency band end (GHz)
REGION1_DOWN § 3.1, Part D	Applicable in Region 1
REGION2_DOWN § 3.1, Part D	Applicable in Region 2
REGION3_DOWN § 3.1, Part D	Applicable in Region 3
$P_i$ § 2.3.1, Part C	Maximum power emitting by the non-GSO satellite antenna beam $i$ (dBW) in the reference bandwidth
$G$ § 2.3.1, Part C	Non-GSO satellite antenna gain (dBi)
$G_{cross}$ § 2.3.1, Part C	Cross-polarization non-GSO satellite antenna gain (dBi)
$N_{co}$ § 2.3.1, Part C	Maximum number of co-frequency, co-polarization beams
$N_{cross}$ § 2.3.1, Part C	Maximum number of co-frequency cross polarization beams
ANTENNA_POINTING § 2.4.1 and 2.4.2, Part C	Description of antenna pointing method of the non-GSO satellites (e.g. steerable/fixed cells on the Earth, fixed relative to satellite's direction of motion, fixed relative to lines of longitude)

### 3.2.3 $\text{epfd}_{\text{is}}$ calculations

FSTART_IS § 4.2.1, Part D	Frequency band start where $\text{epfd}_{\text{is}}$ applied (GHz)
FEND_IS § 4.2.1, Part D	Frequency band end where $\text{epfd}_{\text{is}}$ applied (GHz)
REGION1_IS § 4.2.1, Part D	Applicable in Region 1
REGION2_IS § 4.2.1, Part D	Applicable in Region 2
REGION3_IS § 4.2.1, Part D	Applicable in Region 3
non_GSO_SS_EIRP § 4.2.4.2, Part D	e.i.r.p. per non-GSO space station (dBW) in the reference bandwidth RIFBW

### 3.3 Detailed data on mitigation technique(s) employed

Description of mitigation technique used, including all aspects affecting calculation of pfd masks.

### 3.4 pfd spatial reference system

#### 3.4.1 Uplink direction of transmission

Mitigation technique § 2.2, Part C	Description of non-GSO cell-wide observance of exclusion zone or cell-centre observance of exclusion zone (text defining mitigation techniques used for uplink and downlink directions of transmission), or others
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#### 3.4.2 Downlink direction of transmission

Mitigation technique § 2.2, Part C	Description of non-GSO cell-wide observance of exclusion zone or cell-centre observance of exclusion zone (text defining mitigation techniques used for uplink and downlink directions of transmission), or other
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## 4 Inputs to software for calculating $\text{epfd}_{\uparrow}$ and $\text{epfd}_{\downarrow}$ and limit-compliance checking

### 4.1 Non-GSO orbit parameter inputs

See Part B, § 3.1.

## 4.2 Non-GSO downlink pfd mask

MIN_EXCLUDE § 3.4.2, Part D	Exclusion zone angle
Option 1 pfd_mask (satellite, latitude, $\alpha$ (or $X$ ), $\Delta L$ ) § 2, Part C	<p>The pfd mask is defined by:</p> <ul style="list-style-type: none"> <li>– the non-GSO satellite</li> <li>– the latitude of the non-GSO sub-satellite point</li> <li>– the separation angle <math>\alpha</math> between this non-GSO space station and the GSO arc, as seen from any point on the surface of the Earth. The <math>\alpha</math> angle is therefore the minimum topocentric angle measured from this particular earth station between the interfering non-GSO space station and any space station in the GSO arc (or the separation angle <math>X</math>, which is the angle between a line projected from the GSO arc through the non-GSO space station to the ground and a line from the non-GSO space station to the edge of the non-GSO beam)</li> <li>– the difference <math>\Delta L</math> in longitude between the non-GSO sub-satellite point and the point on the GSO arc where the <math>\alpha</math> (or <math>X</math>) angle is minimized</li> </ul>
Option 2 pfd_mask (satellite, latitude, Az, El) § 2, Part C	<p>The pfd mask is defined by:</p> <ul style="list-style-type: none"> <li>– the non-GSO satellite</li> <li>– the latitude of the non-GSO sub-satellite point</li> <li>– the azimuth angle, defined in Part D, § 5.4.3</li> <li>– the elevation angle, defined in Part D, § 5.4.3</li> </ul>

## 4.3 Non-GSO uplink pfd mask

Mitigation technique § 2.2, Part C	Description of non-GSO cell-wide observance of non-operating zone or cell-centre observance of non-operating zone (text defining mitigation techniques used for uplink and downlink directions of transmission), or others
ES_EIRP[0] § 3.1, Part C	Non-GSO earth station e.i.r.p. as a function of the off-axis angle
ES_TRACK § 4.1.4.2, Part D	Maximum number of co-frequency tracked non-GSO satellites
ES_MINELEV § 4.1.4.2, Part D	Minimum elevation angle of the non-GSO earth station when it is transmitting (degrees)
ES_MIN_GSO § 4.1.4.2, Part D	Minimum angle to GSO arc (degrees)
ES_DENSITY § 4.1.4.2, Part D	Average number of non-GSO earth stations (km <sup>2</sup> )
ES_DISTANCE § 4.1.4.2, Part D	Average distance between cell or beam footprint centre (km)

## 4.4 pfd compliance test points

### 4.4.1 Points identified by notifying administration

Points should be provided by the administration as the most sensitive (maximum epfd) points that would cause the greatest interference to GSO networks. In addition, the methodology used to determine those points should be provided. This includes locations of GSO satellites, GSO satellite antenna boresight, and GSO earth stations.

#### **4.4.2 Points determined by BR in pre-processing**

Points should be determined by the BR and an indication of the methodology used to determine the points should be provided.

## **5 Inputs to software for self-consistency tests**

Data from Part B, § 3 and Annex 1 to Part B.

### ANNEX 1

#### TO PART B

This Annex 1 to Part B presents the actual format of the RR Appendix S4 database, which should be updated to include the parameters needed.

Table 8 lists the current RR Appendix S4 information for non-GSO satellite systems currently included in the BR space networks system database and the associated database for graphical data (Graphical Interference Management System, GIMS). The relationship between the database tables is shown in Fig. 7. New alphanumerical or graphical data elements used for processing pfd calculations involving non-GSO satellite networks would certainly be required and should be identified, defined as to their format and location in the data structure of the BR databases and added to this Table. The list of such additional elements should eventually serve as a basis for administrations' contributions on additional or modified information to be added to RR Appendix S4 at the forthcoming WRC. Once RR Appendix S4 has been updated, the BR will proceed with including them on the notice forms and in the database.

FIGURE 7

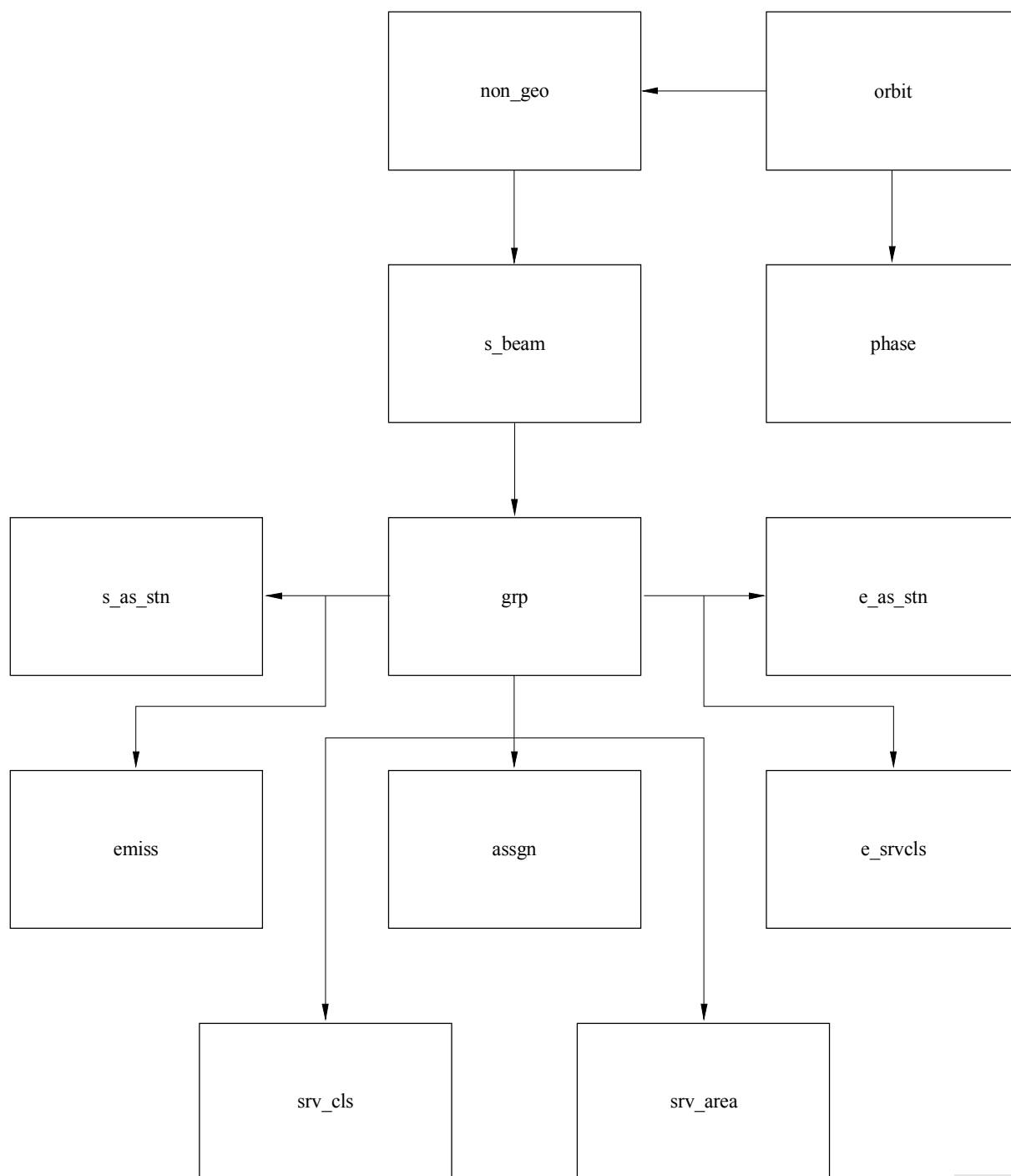


TABLE 8

## ApS4/II notified data for non-GSO system

Table Name	Data Item	Items in RR Appendix S4	Format	S4/II	Description	Comment
<b>assgn</b>				x	Assigned frequency	
	freq_sym	C.2.a	X	x	Symbol indicating kilohertz [K], megahertz [M] or gigahertz [G]	
	freq_assgn	C.2.a	9(5).9(5)	x	Assigned frequency	
<b>e_as_stn</b>				x	<b>Associated earth station</b>	
	stn_name	C.10.b.1	X(20)	x	Name of the transmitting or receiving station	
	ctry		XXX	x	Symbol of the country or geographical area in which the station is located	
	stn_type	C.10	X	x	Code indicating if the earth station is specific [S] or typical [T]	
	long_deg	C.10.b.2	999	x	Degree part of longitude coordinate of the station expressed in degrees, minutes and seconds	
	long_ew	C.10.b.2	X	x	Longitude direction indicator: East [E] or West [W]	
	long_min	C.10.b.2	99	x	Minute part of longitude coordinate of the station expressed in degrees, minutes and seconds	
	long_sec	C.10.b.2	99	x	Second part of longitude coordinate of the station expressed in degrees, minutes and seconds	
	lat_deg	C.10.b.2	99	x	Degree part of latitude coordinate of the station expressed in degrees, minutes and seconds	
	lat_ns	C.10.b.2	X	x	Latitude direction indicator: North [N] or South [S]	
	lat_min	C.10.b.2	99	x	Minute part of latitude coordinate of the station expressed in degrees, minutes and seconds	
	lat_sec	C.10.b.2	99	x	Second part of latitude coordinate of the station expressed in degrees, minutes and seconds	
	noise_t	C.10.c.5	9(6)	x	Total receiving system noise temperature, expressed in kelvins referred to the output of the receiving antenna	
	gain	C.10.c.2	S99.9	x	Maximum isotropic gain of the antenna expressed in dB with one decimal position	
	bmwidth	C.10.c.3	999.99	x	Angular width of radiation main lobe expressed in degrees with two decimal positions	

TABLE 8 (continued)

Table Name	Data Item	Items in RR Appendix S4	Format	S4/II	Description	Comment
<b>e_as_stn</b>				x	<b>Associated earth station</b> ( <i>cont.</i> )	
	ant_type	C.10.c.4a	X(12)	x	Antenna radiation pattern indicated by a reference to the appropriate ITU-R Recommendation	
	diag_e	C.10.c.4b	99	x	Number of the attachment for the radiation pattern diagram	
	coefa		99.9	x	For non-standard antennas	
	coefb		99.9	x	For non-standard antennas	
	coefc		99.9	x	For non-standard antennas	
	coefd		99.9	x	For non-standard antennas	
	phil		99.9	x	For non-standard antennas	
<b>e_srvcls</b>				x	<b>Nature of service and class of station for an associated earth station</b>	
	stn_cls	C.10.c.1a	XX	x	Class of station code	
	nat_srv	C.10.c.1b	XX	x	Nature of service code	
<b>emiss</b>				x	<b>Emission</b>	
	design_emi	C.7.a	X(9)	x	Designation of emission	
	pwr_tot_pk	C.8.a.1/C.8.b.1	S99.9	x	Power delivered to the antenna [dBW]	
	pwr_ds_max	C.8.a.2/C.8.b.2	S99.9	x	Maximum power density [dBW/Hz]	
	pwr_min_pk	C.8.c.1	S99.9	x	Minimum peak power delivered to the antenna [dBW]	
	pwr_ds_min	C.8.c.2	S99.9	x	Minimum power density [dBW/Hz]	
	c_to_n	C.8.e	S99.9	x	C/N (total, clear sky) objective	



TABLE 8 (continued)

Table Name	Data Item	Items in RR Appendix S4	Format	S4/II	Description	Comment
<b>grp</b>				x	<b>Common data for a group of assigned frequencies</b>	
	emi_rcp		X	x	Code identifying a beam as either transmitting [E] or receiving [R]	
	beam_name	B.1	X(4)	x	Designation of the satellite antenna beam	
	bdwidth	C.3.a	9(8)	x	Assigned frequency band expressed (kHz)	
	d_inuse	A.2.a	9(8)	x	Date of bringing into use	Date in yyyyymmdd format
	f_emi_type	C.8.a/C.8.b	X	x	Flag indicating that for the set of emissions associated to a list of frequency assignments the maximum peak power and maximum power density values provided are of type C.8.b	
	emi_rsn	C.8.c	99	x	Number of the attachment indicating the reason for minimum peak power and minimum power density (C.8.c) information being absent	
	noise_t	C.5.a	9(6)	x	Receiving system noise temperature	
	polar_type	C.6	XX	x	Symbol indicating the type and the direction of polarization, where applicable (in case of circular or elliptical polarization)	
	polar_ang	C.6	999.99	x	In case of linear polarization the value of the angle (degrees) measured anticlockwise in a plane normal to the beam axis from the equatorial plane to the electric vector of the wave	
	diag_area	C.11.a	99	x	Number of the attachment for the service area diagram	
	diag_spect	C.9.c	99	x	Number of the attachment for the spectrum mask diagram	
	pwr_max	C.8.g/C.8.d	S99.9	x	Maximum total peak envelope power (dBW) or maximum aggregate power (dBW) supplied to the input of the antenna	
	attch_mux	C.9.c	99	x	Number of the attachment for the type of modulation and multiple access	
	area_no	C.11.a	99	x	Sequence number associating a particular service area diagram with the group	
	area_name		X(20)	x	Name of the service area	

TABLE 8 (continued)

Table Name	Data Item	Items in RR Appendix S4	Format	S4/II	Description	Comment
<b>non_geo</b>				x	<b>Non-geostationary space station</b>	
	sat_name	A.1	X(20)	x	Name of the satellite	
	inclin_ang	A.4.b.1	999.9	x	Inclination angle of the satellite orbit with respect to the plane of the Equator	
	prd_ddd	A.4.b.2	999	x	Day part of the time elapsing between two consecutive passages of a non-geostationary satellite through a point in its orbit	
	prd_hh	A.4.b.2	99	x	Hour part of the time elapsing between two consecutive passages of a non-geostationary satellite through a point in its orbit	
	prd_mm	A.4.b.2	99	x	Minute part of the time elapsing between two consecutive passages of a non-geostationary satellite through a point in its orbit	
	apog	A.4.b.3a	9(5).99	x	The farthest altitude of the non-geostationary satellite above the surface of the Earth or other reference body (km)	Distances > 99 999 km are expressed as a product of the values of the fields “apogee” and “apog_exp” (see below) e.g.: 125 000 = $1.25 \times 10^5$
	apog_exp	A.4.b.3a	99	x	Exponent part of the apogee expressed in power of 10	To indicate the exponent; give 0 for $10^0$ , 1 for $10^1$ , 2 for $10^2$ , etc.
	perig	A.4.b.3b	9(5).99	x	The nearest altitude of the non-geostationary satellite above the surface of the Earth or other reference body (km)	Distances > 99 999 km are expressed as a product of the values of the fields “perigee” and “perig_exp” (see below) e.g.: 125 000 = $1.25 \times 10^5$
	perig_exp	A.4.b.3b	99	x	Exponent part of the perigee expressed in power of 10	To indicate the exponent; give 0 for $10^0$ , 1 for $10^1$ , 2 for $10^2$ , etc.
	ref_body		X	x	Code for the reference body about which the satellite orbits	
	nbr_sat	A.4.b.4	9(4)	x	Number of non-geostationary satellites used in an identical non-geostationary orbit	
	nbr_plane	A.4.b.5	99	x	Number of non-geostationary orbital planes	

TABLE 8 (continued)

Table Name	Data Item	Items in RR Appendix S4	Format	S4/II	Description	Comment
<b>orbit</b>				x	<b>Orbital plane of a non-geostationary satellite</b>	
	nbr_sat_pl	A.4.b.5	99	x	Number of satellites per non-geostationary orbital plane	
	right_asc	A.4.b.5	999.99	x	Angular separation in degrees between the ascending node and the vernal equinox	
	inclin_ang	A.4.b.5	999.9	x	Inclination angle of the satellite orbit with respect to the plane of the Equator	
	semi_major	A.4.b.5	9(5)	x	Semi major axis of the satellite orbit (kilometres)	
	eccentr	A.4.b.5	9.99	x	Eccentricity of the satellite orbit	
	perig_arg	A.4.b.5	999.9	x	Angular separation (degrees) between the ascending node and the perigee of an elliptical orbit	
<b>phase</b>				x	<b>Initial phase angle of a non-geostationary satellite in an orbital plane</b>	
	phase_ang	A.4.b.5	999.9	x	Initial phase angle of the satellite in the orbital plane	
<b>s_as_stn</b>				x	<b>Associated space station</b>	
	<i>sat_name</i>	C.10.a	X(20)	x	Name of the associated space station	
	<i>beam_name</i>		X(4)	x	Designation of the associated satellite antenna beam	
	stn_type	C.10	X	x	Type of the associated space station: geostationary [G] or non-geostationary [N]	
	long_nom		S999.99	x	Nominal longitude of the associated space station, give “–” for West “+” for East	In degrees from –179.99 to + 180.00

TABLE 8 (end)

Table Name	Data Item	Items in RR Appendix S4	Format	S4/II	Description	Comment
<b>s_beam</b>				x	<b>Satellite antenna beam</b>	
	<i>emi_rcp</i>		X	x	Code identifying a beam as either transmitting [E] or receiving [R]	
	<i>beam_name</i>	B.1	X(4)	x	Designation of the satellite antenna beam	
	ang_alpha	B.4.b	999.9	x	Satellite beam orientation	
	ang_beta	B.4.b	99.9	x	Satellite beam orientation	
	ant_type	B.4.a/B.4.b	X(12)	x	Antenna radiation pattern indicated by a reference to the appropriate ITU-R Recommendation	
	diag_e	B.4.a/B.4.b	99	x	Number of the attachment for the radiation pattern diagram	
	diag_elev	B.4.b	99	x	Number of the attachment for the gain versus elevation angle diagram	
	gain	B.4.a	S99.9	x	Maximum isotropic gain of the antenna (dB) with one decimal position; copolar gain for plans	
	loss_attn	B.4.b	99	x	Number of the attachment for spreading loss data	
	pwr_max_4k	B.4.b	S99.9	x	Maximum e.i.r.p. at 4 kHz	
	pwr_avg_4k	B.4.b	S99.9	x	Average e.i.r.p. at 4 kHz	
	pwr_max_1m	B.4.b	S99.9	x	Maximum e.i.r.p. at 1 MHz	
	pwr_avg_1m	B.4.b	S99.9	x	Average e.i.r.p. at 1 MHz	
	coefa		99.9	x	For non-standard antennas	
	coefb		99.9	x	For non-standard antennas	
<b>srv_area</b>				x	<b>Service area</b>	
	<i>ctry</i>	C.11.a	XXX	x	Symbol of the country or geographical area	
<b>srv_cls</b>				x	<b>Nature of service and class of station for the group of frequency assignments</b>	
	stn_cls	C.4.a	XX	x	Class of station	
	nat_srv	C.4.b	XX	x	Nature of service	

## PART C

## Generation of pfd/e.i.r.p. masks

**1 Definition**

The purpose of generating pfd masks is to define an envelope of the power radiated by the non-GSO space stations and the non-GSO earth stations so that the results of calculations encompass what would be radiated regardless of what resource allocation and switching strategy are used at different periods of a non-GSO system life.

The concept of satellite-based reference angle could be used to calculate the pfd mask.

**2 Generation of satellite pfd masks****2.1 General presentation**

The satellite pfd mask is defined by the maximum pfd generated by any space station in the interfering non-GSO system as seen from any point at the surface of the Earth. A four dimensional pfd mask is recommended for use by the BR verification software and is defined following one of the two options:

*Option 1:* As a function of:

- the non-GSO satellite;
- the latitude of the non-GSO sub-satellite point;
- the separation angle  $\alpha$  between this non-GSO space station and the GSO arc, as seen from any point on the surface of the Earth. The  $\alpha$  angle is therefore the minimum topocentric angle measured from this particular earth station between the interfering non-GSO space station and any space station in the GSO arc (or the separation angle  $X$ , which is the angle between a line projected from the GSO arc through the non-GSO space station to the ground and a line from the non-GSO space station to the edge of the non-GSO beam);
- the difference  $\Delta L$  in longitude between the non-GSO sub-satellite point and the point on the GSO arc where the  $\alpha$  (or  $X$ ) angle is minimized.

*Option 2:* As a function of:

- the non-GSO satellite;
- the latitude of the non-GSO sub-satellite point;
- the azimuth angle, defined in Part D, § 5.4.3;
- the elevation angle, defined in Part D, § 5.4.3.

Whatever parameters (e.g.  $\alpha$  angle,  $X$  angle,...) are used to generate the pfd mask, the resulting pfd mask should be converted to one of the format options above.

Because the non-GSO space station can generate simultaneously a given maximum number of beams, it should be taken into account in order to better fit the system design and not be too constraining for non-GSO systems.

The mitigation techniques used by the non-GSO system, such as the GSO arc avoidance, are implemented in the calculation of the pfd mask. The GSO arc avoidance defines a non-operating zone on the ground in the field of view of a non-GSO space station. The location of this non-operating zone on the ground will move as a function of the latitude of the non-GSO sub-satellite point. To get a more accurate model of a non-GSO system, the latitude of the non-GSO sub-satellite point is taken as a parameter to the pfd mask calculation.

Use of  $\alpha$  or  $X$  angle pfd masks implies that the same definition of GSO angle is used for exclusion angle in the calculation of  $\text{epfd}_{\downarrow}$ .

## 2.2 Mitigation techniques description

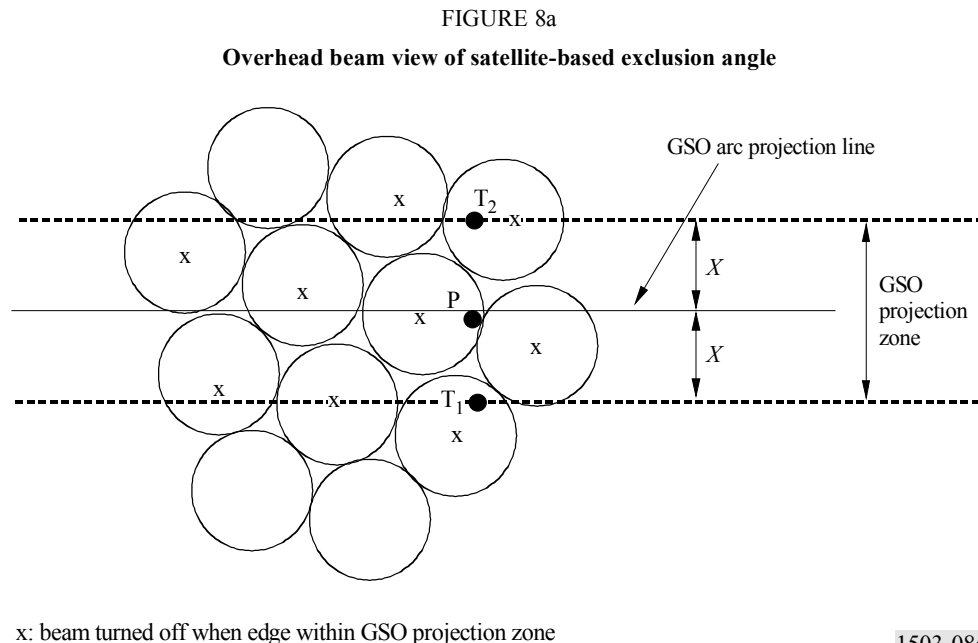
The mitigation technique implemented within the non-GSO system should be accurately explained in this section in order to be fully modelled in the calculation of the  $\text{epfd}_{\uparrow}$ .

With regard to the use of a non-operating zone around the GSO arc, there are at least three different ways of modelling a non-GSO system based on a cell architecture:

- Cell-wide observance of a non-operating zone: a beam of a non-GSO space station is switched off if the separation angle between this non-GSO space station and the GSO arc, at any point of the non-GSO cell is less than  $\alpha_0$  (GSO arc avoidance angle).
- Cell-centre observance of a non-operating zone: a beam of a non-GSO space station is switched off when the centre of the cell sees this non-GSO space station at less than  $\alpha_0$  from the GSO arc.
- A satellite based reference: a beam of a non-GSO space station turns off when a satellite-based reference angle,  $X$ , is less than  $X_0$ . The reference angle,  $X$ , is the angle between a line projected from the GSO arc through the non-GSO space station to the ground and a line from the non-GSO space station to the edge of the non-GSO beam.

Other mitigation techniques may be used by a non-GSO system which are not listed here. Information on these techniques will be provided by the non-GSO administration for the description and verification of the pfd mask.

Figs. 8a and 8b define the  $\alpha$  angle and the  $X$  angle:



1503-08a

## 2.3 pfd calculation

### 2.3.1 pfd calculation

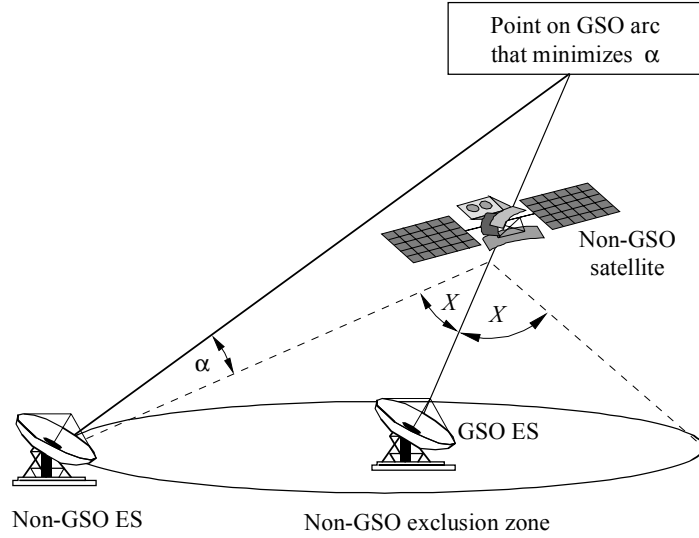
The pfd radiated by a non-GSO space station at any point on the Earth's surface is the sum of the pfd produced by all illuminating beam in the co-frequency band.

Some non-SFO systems have tracking antennas which point to cells fixed on the Earth's surface and do not move with the spacecraft. However, since the pfd mask is generated with respect to the non-GSO location, assumptions must be made in the development of the pfd mask. Making the simplifying assumption that the cells move with the spacecraft can lead to inaccurate geographic distributions of  $\text{epfd}$  levels.

It was noted that as non-GSO systems use mitigation techniques, there will be no main beam-to-main beam alignment. Therefore de-polarization effects mean that both co-polarization and cross-polarization contributions must be included as sources of interference.

FIGURE 8b

**Relationship between geometries for satellite-based exclusion angle,  $X$ , and ground-based angle,  $\alpha$ , in case of interference from non-GSO into GSO networks**



1503-08b

This implementation of the pfd mask explicitly accounts for both co-polarization and cross-polarization from non-GSO satellites into GSO earth stations for like types of polarization (circular-to-circular or linear-to-linear). Isolation between systems of different types of polarization (circular-to-linear) is not directly covered. A study has shown that the average total interference power over all axial ratios and polarization ellipse orientations is a very small net increase in the received interference power in the BSS antenna of 0.048 dB. The bounds of any cross-polarization contributions, that are very unlikely to be reached, are from -30 dB to +3 dB.

Then:

$$pfd = 10 \log \left( \sum_i^{N_{co}} 10^{pfd_{co_i}/10} + \sum_j^{N_{cross}} 10^{pfd_{cross_j}/10} \right)$$

where:

- $pfd$ : pfd radiated by a non-GSO space station (dB(W/m<sup>2</sup>) in the reference bandwidth
- $i$ : index of the beams illuminated in the polarization considered
- $N_{co}$ : maximum number of beams which can be illuminated simultaneously in the polarization considered
- $pfd_{co_i}$ : pfd produced at the point considered at the Earth's surface by one beam in the polarization considered dB((W/m<sup>2</sup>)) in the reference bandwidth
- $j$ : index of the beams illuminated in the opposite polarization to the polarization considered
- $N_{cross}$ : maximum number of beams which can be illuminated simultaneously in the opposite polarization to the polarization considered
- $pfd_{cross_j}$ : pfd produced at the point considered at the Earth's surface by one beam in the opposite polarization to the polarization considered (dB(W/m<sup>2</sup>)) in the reference bandwidth

and

$$pfd_{co_i} = P_i + G_i - 10 \log_{10} (4 \pi d^2)$$

where:

- $P_i$ : maximum power emitting by the beam  $i$  in the reference bandwidth (dB(W/BW<sub>ref</sub>))
- BW<sub>ref</sub>: reference bandwidth (kHz)

- $G_i$ : gain generated by the beam  $i$  in the polarization considered at the point considered at the Earth's surface (dBi)
- $d$ : distance between the non-GSO space station and the point considered at the Earth's surface (if the non-GSO satellite antenna gain is in isoflux,  $d$  is the altitude of the non-GSO space station) (m)

and

$$pfd\_cross_j = P_j + G\_cross_j - 10 \log_{10} (4 \pi d^2)$$

where:

- $G\_cross_j$ : cross-polarization gain generated by the beam  $j$  illuminated in the opposite polarization to the polarization considered, at the point considered at the Earth's surface (dBi)

It is expected that the parameters used to generate the pfd/e.i.r.p. mask correspond to the performance of the non-GSO satellite over its anticipated lifetime.

### 2.3.2 Satellite antenna gain at the point considered at the Earth's surface

The objective of this section is to determine the gain in the direction of a point M at the Earth's surface when the satellite antenna points towards a cell  $i$ . The antenna coordinate can be defined by four ways of the coordinate system:

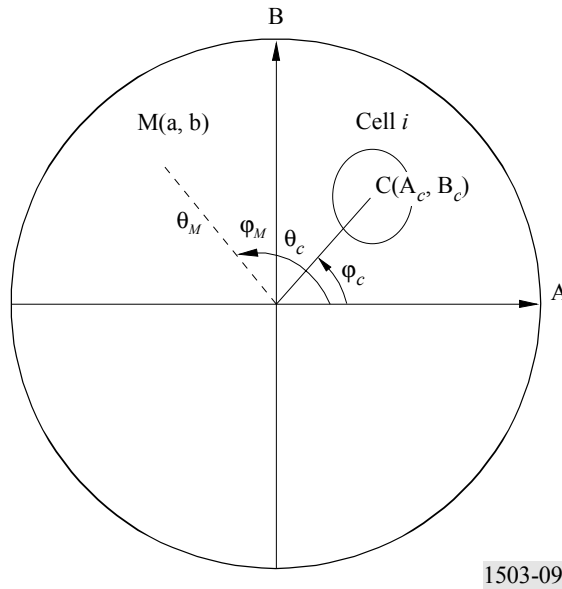
- $\varphi$ : spherical coordinate
- $v$ :  $u = \sin \theta \cos \varphi$ ,  $v = \sin \theta \sin \varphi$
- $B$ :  $A = \theta \cos \varphi$ ,  $B = \theta \sin \varphi$
- $(Az, El)$ :  $\sin(El) = \sin \theta \sin \varphi$ ,  $\tan(Az) = \tan \theta \cos \varphi$

As an example, the following calculations are performed in the antenna reference (A, B).

The sampling of the non-GSO antenna pattern should be adapted so that interpolation does not lead to gain level significantly different from real values.

Figure 9 presents the geometry in the antenna plane (A, B).

FIGURE 9  
Antenna plane (A, B)

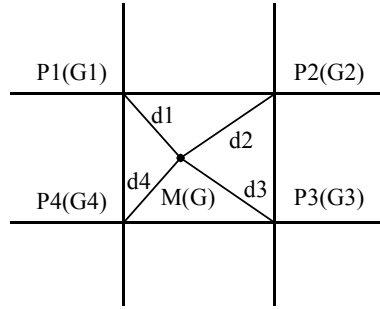


The coordinates of the point M at the Earth's surface are (a, b) in the antenna plane (A, B), corresponding to  $(\theta_M, \varphi_M)$  in the polar reference.

The coordinates of the point C centre of the cell  $i$ , are  $(A_c, B_c)$  in the antenna plane (A, B), and  $(\theta_c, \varphi_c)$  in the spherical reference.



For satellite antenna gain patterns with functional descriptions (i.e. equations), the gain into the point M may be computed directly from the coordinates  $C(A_c, B_c)$  and  $M(a, b)$ . For other patterns, the satellite antenna gains are provided in a grid of (A, B) points. The point  $M(a, b)$  may be located between four points of the grid (A, B). Thus, it is necessary to evaluate the gain at the point M knowing the gain for the four points: P1(G1), P2(G2), P3(G3) and P4(G4).



1503-09bis

The four gains are weighted by the distances between  $P_i$  and M before being added up.

If  $(a_j, b_j)$  are the (A, B) coordinates of point  $P_j$ , and  $d_j$  ( $j = 1, \dots, 4$ ) the distance of point  $P_j$  to the point M then:

$$d_j = \sqrt{(a - a_j)^2 + (b - b_j)^2}$$

If  $d_j = 0$ , then  $G_i(M) = G_i(P_j)$

else:

$$m_j = \frac{\frac{1}{d_j}}{\sum_{k=1}^4 \frac{1}{d_k}}$$

and

$$G_i(M) = 10 \log_{10} \left( \left( \sum_{j=1}^4 m_j \sqrt{10^{\frac{G_i(P_j)}{10}}} \right)^2 \right)$$

The  $G_i(M)$  is then the gain of the non-GSO satellite antenna illuminating beam  $i$  in the direction of the point M.

The sampling of the non-GSO satellite antenna pattern should be adapted so that interpolation does not lead to significant approximation.

The same criteria should be used when sampling the pfd mask.

## 2.4 Methodology

The pfd mask is defined by the maximum pfd generated by any space station in the interfering non-GSO system and as a function of the parameters defined either in option 1 or option 2. For the generation of the pfd mask, the cells in the non-GSO satellite footprint are located according to the beam pointing utilized by the non-GSO system. For satellites with steerable antennas, the satellite can point to the same area of the Earth throughout its track through the sky.

These cells are fixed relative to the Earth's surface. For satellites that have antenna-pointing angles fixed relative to the satellite, the cell pattern is the same relative to the satellite but is moving relative to the Earth.

### 2.4.1 Option 1

Option 1 has been described for a pfd mask defined as a function of the separation angle  $\alpha$ , as an example. If the pfd mask is provided as a function of the  $X$  angle, the following calculation remains the same replacing  $\alpha$  with  $X$  angle.

The pfd mask is defined as a function of the separation angle  $\alpha$  between this non-GSO space station and the GSO arc, as seen from any point on the surface of the Earth, and the difference  $\Delta L$  in longitude between the non-GSO sub-satellite point and the GSO satellite

The angle  $\alpha$  is therefore the minimum topocentric angle measured from this particular earth station between the interfering non-GSO space station and any point in the GSO arc.

The objective of the mask is to define the maximum possible level of the pfd radiated by the non-GSO space station as a function of the separation angle between the non-GSO space station and the GSO arc at any point on the ground, per interval of  $\Delta L$ .

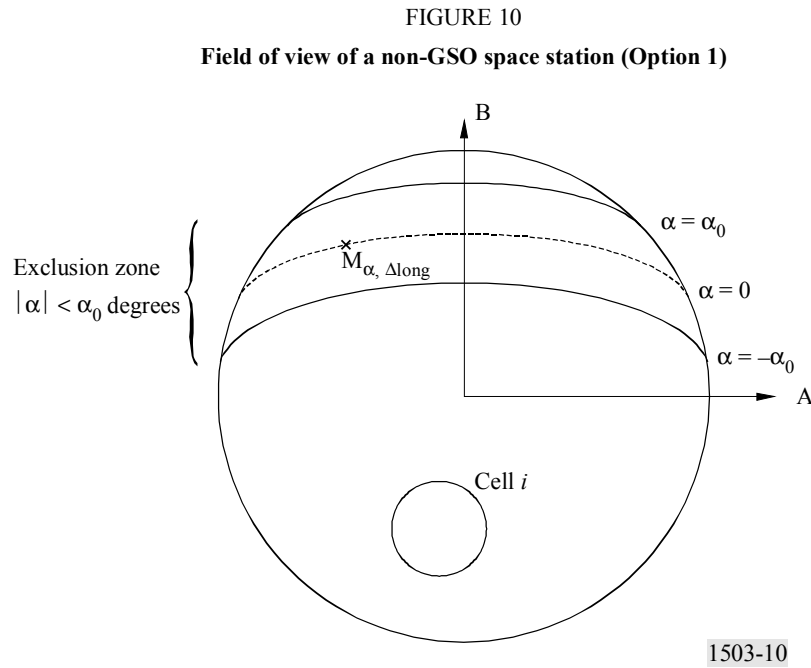
At each point of the non-GSO satellite footprint, the pfd value depends on:

- the configuration of the spot beams which are illuminated by the satellite;
- the maximum number of co-frequency beams which can be illuminated simultaneously;
- the maximum number of co-frequency, co-polarization beams which can be illuminated simultaneously;
- the maximum power available at the satellite repeater.

The proposed methodology for the generation of the pfd mask is explained in the following steps:

*Step 1:* At any given time, in the field of view of a non-GSO space station,  $N_{total}$  is the maximum number of cells that can be seen with the minimum service elevation angle.

*Step 2:* In the field of view of the non-GSO space station, it is possible to draw iso- $\alpha$  lines, i.e. the points on the surface of the Earth which share the same value of  $\alpha$  (see Figs. 10 and 11).



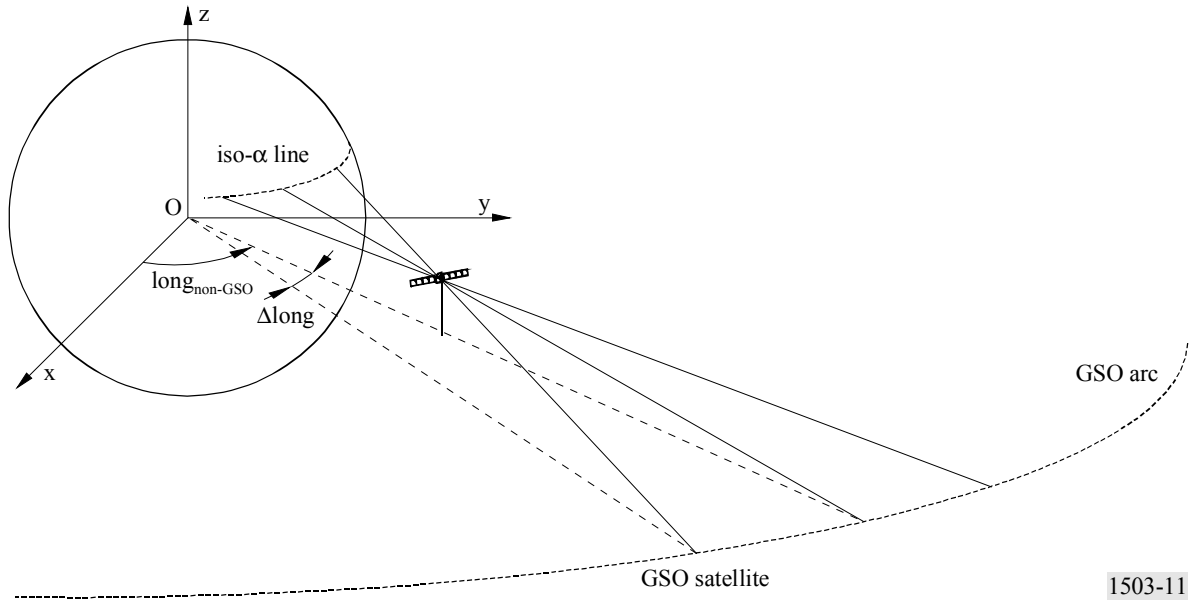
*Step 3:* Along the iso- $\alpha$  line, define intervals of  $\Delta L$ : difference in longitude between the non-GSO sub-satellite point and the point on the GSO arc where the  $\alpha$  (or  $X$ ) angle is minimized.

*Step 4:* Per each interval of  $\Delta L$ , the iso- $\alpha$  line can be defined by a set of  $n$  points  $M_{\alpha,k}$  for  $k = 1, 2, \dots, n$ . To determine the maximum pfd corresponding to a given value of  $\alpha$ , it is necessary to calculate the maximum pfd at each of the points  $M_{\alpha,k}$  for  $k = 1, 2, \dots, n$ . The maximum pfd at a given  $M_{\alpha,k}$  is determined by first finding the pfd contributed by each cell  $i$  toward  $M_{\alpha,k}$  taking into account the dependency of the sidelobe patterns on the beam tilt angle. The maximum pfd contributions toward  $M_{\alpha,k}$  are then summed, with the number of contributions constrained by the physical limitations of the space station:

- Out of the  $N_{total}$  cells that can be seen within the coverage area of the space station under a minimum elevation angle for communication, only  $N_{co}$  can be illuminated at the same frequency bandwidth, in one sense of polarization, and  $N_{cross}$  in the other sense of polarization. This characterizes the limitation of the antenna system on the non-GSO space station. To calculate the mask in one polarization, the cells which can be illuminated in the polarization concerned are identified, and the cross-polarization level is considered for other cells.

- Out of these  $N_{co}$  and  $N_{cross}$  cells, only a given number can be powered simultaneously. This characterizes the limitation of the repeater system of the non-GSO space station.
- If applicable, the limitations in terms of frequency reuse pattern and polarization reuse pattern also need to be clarified.
- If applicable the power allocated to one cell may vary taking into account the elevation angle relative to this cell, for example.

FIGURE 11  
View in 3D of the iso- $\alpha$  line



*Step 5:* The generation of the pfd mask also needs to take into account accurately the mitigation technique implemented within the non-GSO system.

With regard to the use of a non-operating zone around the GSO arc, there are three different ways of modelling a non-GSO system based on a cell architecture:

- cell-wide observance of a non-operating zone: a beam is switched off when one point on the Earth sees a non-GSO satellite within  $\alpha_0$  of the GSO arc. In this particular case, any beam illuminating a cell which is crossed by an iso- $\alpha$  line corresponding to a value  $|\alpha| \leq \alpha_0$  is switched off;
- cell-centre observance of a non-operating zone: a beam is switched off when the centre of the cell sees a non-GSO satellite within  $\alpha_0$  of the GSO arc. In this case, any beam illuminating a cell with its centre inside the non-operating zone bounded by the two iso- $\alpha_0$  lines is switched off;
- if a satellite based reference is chosen: a beam of a non-GSO space station turns off when the angle,  $X$ , is less than  $X_0$ . The reference angle  $X$  is the angle between a line projected from the GSO arc through the non-GSO space station to the ground and a line from the non-GSO space station to the edge of the non-GSO beam.

*Step 6:* The maximum pfd value corresponding to a given value  $\alpha$  within an interval of  $\Delta L$  is:

$$\text{pfd}(\alpha, \Delta L) = \max_{k=1, 2, \dots, n}(\text{pfd}(M_{\alpha, k}))$$

*Step 7:* The location of an iso- $\alpha$  line, hence the value of the maximum pfd along this line depends on the latitude of the non-GSO sub-satellite point. Therefore, a set of pfd masks will need to be provided, each corresponding to a given latitude of the sub-satellite point.

*Step 8:* A set of pfd masks may be needed (one per non-GSO satellite).

### 2.4.2 Option 2

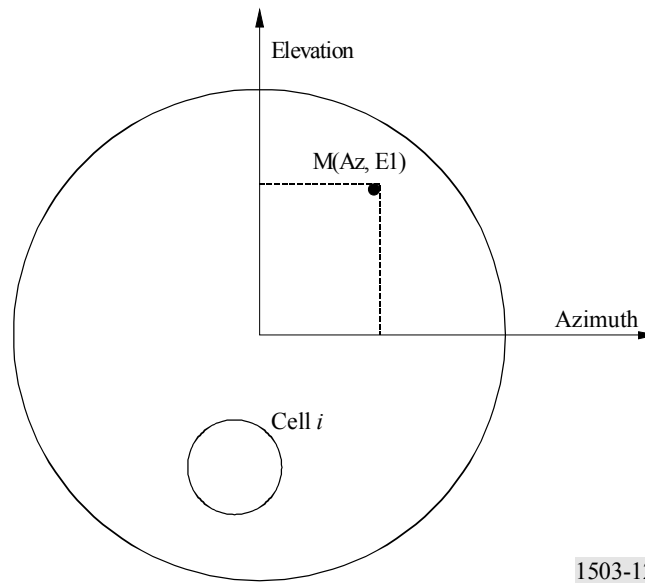
The pfd mask is defined in a grid in azimuth and elevation, per latitude of the non-GSO sub-satellite.

The objective of the mask is to define the maximum possible level of the pfd radiated by the non-GSO space station in this azimuth elevation grid.

At each point of the non-GSO satellite footprint, the pfd value depends on:

- the configuration of the spot beams which are illuminated by the satellite;
- the maximum number of co-frequency beams which can be illuminated simultaneously;
- the maximum number of co-frequency, co-polarization beams which can be illuminated simultaneously;
- the maximum power available at the satellite repeater.

FIGURE 12  
Field of view of a non-GSO space station (Option 2)



1503-12

The proposed methodology for the generation of the pfd mask is explained in the following steps:

*Step 1:* At any given time, in the field of view of a non-GSO space station,  $N_{total}$  is the maximum number of cells that can be seen with the minimum service elevation angle.

*Step 2:* For each point  $M(Az, El)$ , determine the maximum pfd. The maximum pfd at a given  $M_{\alpha,k}$  is determined by first finding the pfd contributed by each cell  $i$  toward  $M(Az, El)$  taking into account the dependency of the sidelobe patterns on the beam tilt angle. The maximum pfd contributions toward  $M_{\alpha,k}$  are then summed, with the number of contributions constrained by the physical limitations of the space station:

- Out of the  $N_{total}$  cells that can be seen within the coverage area of the space station under a minimum elevation angle for communication, only  $N_{co}$  cells can be illuminated at the same frequency bandwidth, in one sense of polarization, and  $N_{cross}$  cells in the other sense of polarization. This characterizes the limitation of the antenna system on the non-GSO space station. To calculate the mask in one polarization, the cells which can be illuminated in the polarization concerned are identified, and the cross-polarization level is considered for other cells.
- Out of these  $N_{co}$  and  $N_{cross}$  cells, only a given number can be powered simultaneously. This characterizes the limitation of the repeater system of the non-GSO space station.
- If applicable, the limitations in terms of frequency reuse pattern and polarization reuse pattern also need to be clarified.
- If applicable the power allocated to one cell may vary taking into account the elevation angle relative to this cell, for example.

*Step 3:* The generation of the pfd mask also needs to take into account accurately the mitigation technique implemented within the non-GSO system.

With regard to the use of a non-operating zone around the GSO arc, there are three different ways of modelling a non-GSO system based on a cell architecture:

- cell-wide observance of a non-operating zone: a beam is switched off when one point on the Earth sees a non-GSO satellite within  $\alpha_0$  of the GSO arc. In this particular case, any beam illuminating a cell which is crossed by an iso- $\alpha$  line corresponding to a value  $|\alpha| \leq \alpha_0$  is switched off;
- cell-centre observance of a non-operating zone: a beam is switched off when the centre of the cell sees a non-GSO satellite within  $\alpha_0$  of the GSO arc. In this case, any beam illuminating a cell with its centre inside the non-operating zone bounded by the two iso- $\alpha_0$  lines is switched off;
- if a satellite based reference is chosen: a beam of a non-GSO space station turns off when the angle,  $X$ , is less than  $X_0$ . The reference angle  $X$  is the angle between a line projected from the GSO arc through the non-GSO space station to the ground and a line from the non-GSO space station to the edge of the non-GSO beam.

*Step 4:* A set of pfd masks may need to be provided as a function of the latitude of the sub-satellite point.

*Step 5:* A set of pfd masks may be needed (one per non-GSO satellite).

### 3 Generation of e.i.r.p. masks

#### 3.1 Generation of earth station e.i.r.p. masks

##### 3.1.1 General presentation

The earth station e.i.r.p. mask is defined by the maximum e.i.r.p. as a function of the off-axis angle generated by an earth station.

The non-GSO earth station is located in a non-GSO cell which is served by a maximum number of non-GSO space stations.

The density of non-GSO earth stations which can operate co-frequency simultaneously is also used as an input to the calculation.

##### 3.1.2 Mitigation techniques description

The mitigation technique implemented within the non-GSO system should be accurately explained in this section in order to be fully modelled in the calculation of the epfd $\uparrow$  (see Part C, § 2.2).

##### 3.1.3 Earth station antenna pattern

The earth station antenna pattern used needs to be identified to calculate the earth station e.i.r.p. mask.

##### 3.1.4 Methodology

*Step 1:* The earth station e.i.r.p. mask is defined by the maximum e.i.r.p. radiated in the reference bandwidth by the earth station as a function of the off-axis angle, and is given by:

$$ES\_EIRP(\theta) = G(\theta) + P$$

where:

- ES\_EIRP: equivalent isotropic radiated power in the reference bandwidth (dB(W/BW<sub>ref</sub>))
- $\theta$ : separation angle between the non-GSO space station and the GSO space station at the non-GSO earth station (degrees)
- $G(\theta)$ : earth station directional antenna gain (dBi)
- $P$ : maximum power delivered to the antenna, in the reference bandwidth (dB(W/BW<sub>raf</sub>))
- BW<sub>raf</sub>: reference bandwidth (kHz).

*Step 2:* Assuming that the non-GSO cells are uniformly distributed on the Earth's surface, the simultaneous co-frequency transmit non-GSO earth stations are evenly distributed over the cell. Therefore the interferer can be located at the centre of the cell to perform the simulation.

### 3.2 Generation of space station e.i.r.p. masks

The space station e.i.r.p. mask is defined by the maximum e.i.r.p. generated by a non-GSO space station as a function of the off-axis angle between the boresight of the non-GSO space station considered and the direction of the GSO space station.

#### 3.2.1 Methodology

The space station e.i.r.p. mask is defined by the maximum e.i.r.p. radiated in the reference bandwidth by the space station as a function of the off-axis angle, and is given by:

$$\text{NGSO\_SS\_EIRP}(\theta) = G(\theta) + P$$

where:

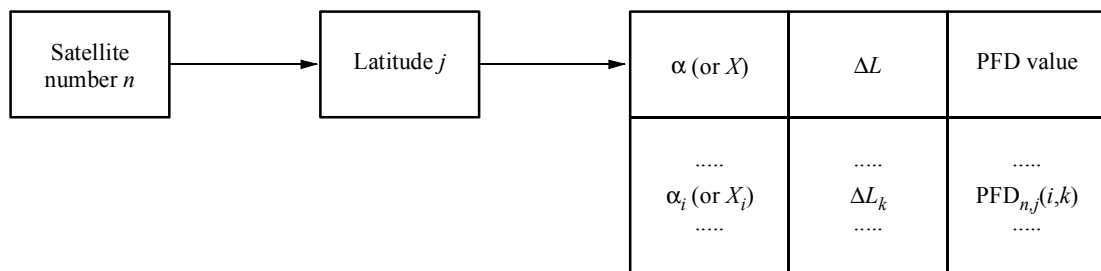
- NGSO\_SS\_EIRP: equivalent isotropic radiated power in the reference bandwidth (dB(W/BW<sub>ref</sub>))
- $\theta$ : separation angle between the boresight of the non-GSO space station and the pointing direction of the GSO space station (degrees)
- $G(\theta)$ : space station antenna gain pattern (dBi) corresponding to the aggregation of all beams
- $P$ : maximum power, in the reference bandwidth (dB(W/BW<sub>ref</sub>))
- BW<sub>ref</sub>: reference bandwidth (kHz).

## 4 Format of the pfd mask

This structure allows an administration to supply the data with fewer degrees of freedom if desired (dimension of the pfd mask less than 4). The file format would define which approach is used.

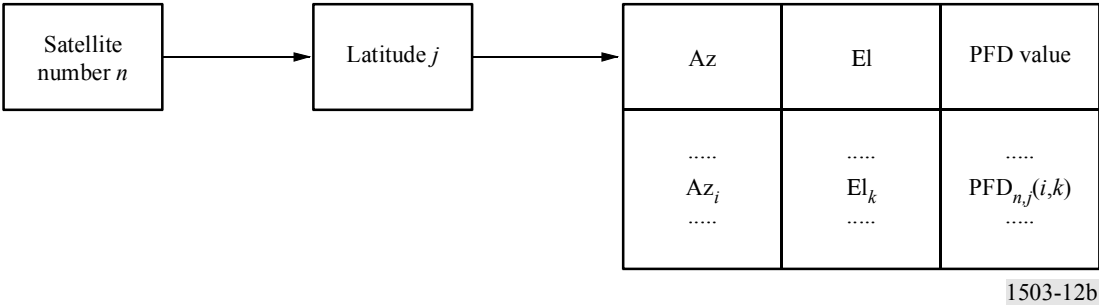
### 4.1 Option 1

The four dimensional pfd mask database format should be the following one:



4.2 Option 2

The four dimensional pfd mask database format should be the following one:



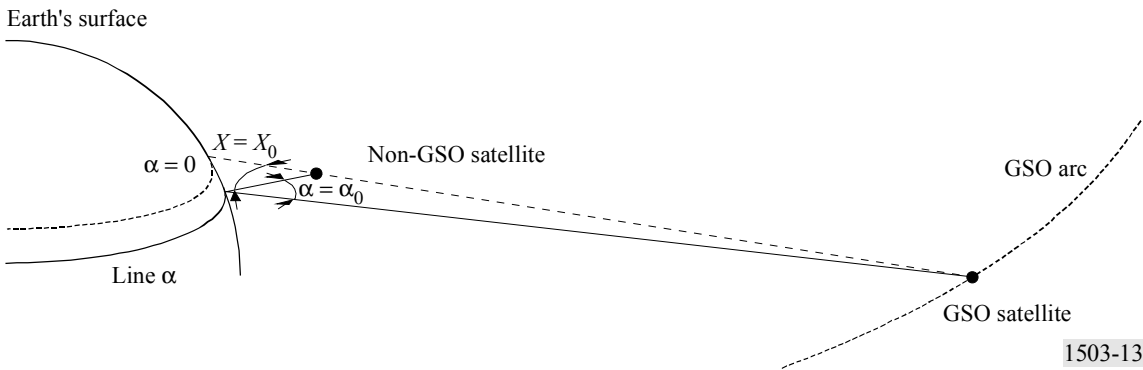
PART C'

Maximum epfd location of GSO network

1 Maximum epfd location of the GSO earth station pointing towards the GSO satellite, for epfd<sub>d</sub> calculation

The solution proposed to define a maximum epfd location of the GSO earth station is based on a pfd mask referenced by latitude of the non-GSO space station, angle to GSO arc  $\alpha$  (or satellite angle  $X$ ) (see Fig. 13), and the difference between the longitude of the GSO satellite and the longitude of the non-GSO sub-satellite point  $\Delta\text{long}$ .

FIGURE 13  
Representation of the maximum epfd situation

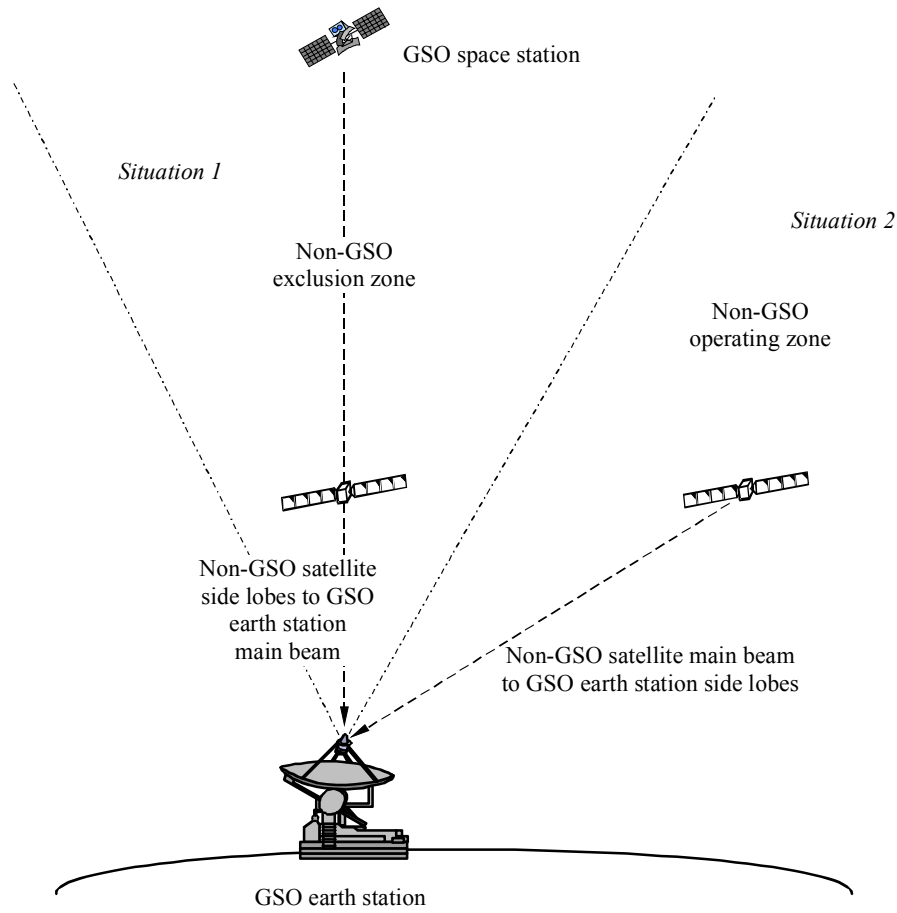


To take into account the different values that the RR Article S22 limits may have for different latitudes, throughout this section maximum epfd should be understood as maximum (epfd-limit).

The highest peaks of downlink interference may occur either:

- Situation 1: When a non-GSO satellite side lobes passes through the main beam of a GSO earth station, or
- Situation 2: When a non-GSO satellite main beam passes through the side lobes of the GSO earth station.

FIGURE 14  
Representation of the two situations of maximum epfd geometry



1503-14

The maximum  $\text{epfd}_{\downarrow}$  occurs in situation 1 only when non-GSO satellites are switched on in the exclusion zone. The maximum  $\text{epfd}_{\downarrow}$  in situation 2 can occur either when non-GSO satellites are switched on or off in the exclusion zone.

For non-GSO satellites that are on in the exclusion zone, whether the maximum  $\text{epfd}_{\downarrow}$  occurs in situation 1 or situation 2, depends on which of the following level is the highest for the non-GSO system studied:

- $\text{pfd}(\alpha = 0 \text{ (or } X = 0), \Delta L)$
- $\text{pfd}(\alpha = \alpha_0 \text{ (or } X = X_0), \Delta L) \cdot G(\theta)/G_{\max}$

where:

$\theta$ : off-axis angle at the GSO earth station

$\alpha_0$ : angle between the GSO arc and the non-GSO satellite at the edge of the exclusion angle.

### 1.1 Non-GSO system with satellites switched on in the exclusion zone

The worst, in the sense of deepest, non-GSO interference is driven by the maximum single satellite interference.

*Situation 1:* Maximum  $\text{epfd}_{\downarrow}$  is for an in-line situation.

The in-line case for single satellite interference is when a non-GSO satellite is in the main beam of the GSO earth station, i.e. when  $\alpha = 0$  (or  $X = 0$ ). However it could in principle be up to half a time step out.



The downlink pfd mask can be examined to determine the latitude of the sub-satellite point, and the difference in longitude  $\Delta\text{long}$  at which the maximum pfd occurs for  $\alpha = 0$  (or  $X = 0$ ).

The intersection of the  $\alpha = 0$  (or  $X = 0$ ) line with the Earth is a set of maximum epfd<sub>↓</sub> locations.

*Situation 2:* Maximum epfd<sub>↓</sub> is for a non-GSO satellite main beam passing through the side lobes of the GSO earth station antenna

The methodology used to achieve the maximum epfd<sub>↓</sub> situation will be the same as for non-GSO satellite switching off in the exclusion zone.

## 1.2 Non-GSO system with satellites switched off in the exclusion zone

The maximum epfd<sub>↓</sub> for single satellite interference is when a non-GSO satellite is closest to the exclusion zone of the GSO earth station, i.e. when  $\alpha = \pm\alpha_0$  (or  $X = \pm X_0$ ).

The downlink pfd mask can be examined to determine the latitude of the sub-satellite point, and the difference in longitude  $\Delta\text{long}$  at which the maximum pfd occurs for  $\alpha = \pm\alpha_0$  (or  $X = \pm X_0$ ).

Therefore this criteria determines the latitude of the non-GSO satellite contributing maximum epfd<sub>↓</sub>, Lat(non-GSO), and the difference between the longitude of the non-GSO sub-satellite point and the longitude of the GSO satellite when it occurs.

The locations of the GSO earth stations are then determined by the points on the Earth for which the angle between the non-GSO satellite and the GSO satellite equals  $\alpha_0$  ( $X_0$ ).

## 1.3 Algorithm for the research of maximum epfd<sub>↓</sub> locations

In the following paragraph all  $\alpha$  angles can be replaced by an  $X$  angle.

*Step 1:* If non-GSO satellites are switched off in the exclusion zone, then go to Step 2 else go to Step 4.

*Step 2:* Determine the non-GSO satellite latitude (non-GSO lat) and  $\Delta\text{long}$  (the difference between the non-GSO space station longitude and the GSO space station longitude) for which

$$\frac{PFD(\alpha = \alpha_0, \Delta\text{long})}{G_{\text{max}}} \frac{G(\theta)}{G_{\text{max}}} \text{ is maximum}$$

*Step 3:* Store  $\Delta\text{long}$ , non-GSO lat. Go to Step 6.

*Step 4:* If  $\max_{\Delta\text{long}} \frac{PFD(\alpha = \alpha_0, \Delta\text{long})}{G_{\text{max}}} - pfd(\alpha = 0, \Delta\text{long}) > 0$

then the maximum epfd<sub>↓</sub> occurs at  $\alpha = \alpha_0$ , else the maximum epfd<sub>↓</sub> occurs at  $\alpha = 0$ .

*Sub-step 4.1:* Determine the non-GSO latitude (non-GSO lat) and  $\Delta\text{long}$  (the difference between the non-GSO space station longitude and the GSO space station longitude) for which:

$$\frac{PFD(\alpha = \alpha_0, \Delta\text{long})}{G_{\text{max}}} \frac{G(\theta)}{G_{\text{max}}} \text{ is maximum (if maximum epfd}_{\downarrow} \text{ occurs at } \alpha = \alpha_0)$$

$$\frac{PFD(\alpha = \alpha_0, \Delta\text{long})}{G_{\text{max}}} \text{ is maximum (if maximum epfd}_{\downarrow} \text{ occurs at } \alpha = 0).$$

*Step 5:* Store non-GSO lat,  $\Delta\text{long}$ .

*Step 6:* Select the first non-GSO satellite which is at the latitude: non-GSO lat.

*Step 7:* Store the non-GSO satellite longitude.

*Step 8:* Calculate the GSO satellite longitude.

*Step 9:* If non-GSO satellites are switched off in the exclusion zone or if the non-GSO satellites operate in the exclusion zone and have a maximum epfd<sub>↓</sub> at  $\alpha \neq 0$ , then calculate the latitude and the longitude of the GSO earth station at the point on the Earth for which the angle between the non-GSO satellite and the GSO satellite equals to  $\alpha_0$  (see geometry calculations in the Annex to Part C').

*Step 10:* If the non-GSO satellites operate in the exclusion zone and have a maximum  $\text{epfd}_{\downarrow}$  at  $\alpha = 0$ , then calculate the latitude and the longitude of the GSO earth station at the intersection of the  $\alpha = 0$  line to the Earth (see geometry calculations in the Annex to Part C').

*Step 11:* Store GSO network location.

## 2 Determination of GSO network location for maximum $\text{epfd}_{\uparrow}$

The  $\text{epfd}_{\uparrow}$  produced by the emissions of all the earth stations of a non-GSO system operating in the FSS, is evaluated at any point of the geostationary arc.

For duration purposes it is not possible to calculate  $\text{epfd}_{\uparrow}$  statistics for all possible space station locations and pointing directions. Thus it is necessary to define a method to determine the location where the maximum  $\text{epfd}_{\uparrow}$  occurs.

The  $\text{epfd}_{\uparrow}$  is dependent on the density of the non-GSO earth station which are visible from the GSO space station with regard to its antenna aperture.

The difference in free space losses from the GSO space station between a non-GSO earth station at the GSO sub-satellite point and a non-GSO earth station at  $10^\circ$  elevation is about 1.2 dB, which is second order compared to the density of non-GSO earth stations.

In the mean time, the further from the sub-satellite point the GSO satellite is pointing, the larger the beam size illuminated on the ground. In the case where the GSO satellite antenna discrimination is taken into account, the pointing direction of the maximum  $\text{epfd}_{\uparrow}$  corresponds to a case where there is a high density of non-GSO earth stations within the GSO coverage area and a maximum number of contributors in the far side lobes.

Therefore, the maximum  $\text{epfd}_{\uparrow}$  will occur for a GSO space station pointing far from the sub-satellite point.

Then, the GSO space station located at a longitude of  $50^\circ$  E and pointing towards a direction at  $42.5^\circ$  N corresponds to one of the maximum  $\text{epfd}_{\uparrow}$  locations. This calculation has been achieved by assuming that the edge of the coverage area is at an elevation of  $10^\circ$ , and that a GSO antenna aperture of  $4^\circ$  in the 14/11 GHz band is used.

In the 30/20 GHz band, the GSO space station is located at a longitude of  $50^\circ$  E and pointing towards a direction at  $50.9^\circ$  N, which corresponds to a minimum elevation angle of  $20^\circ$  and a GSO antenna aperture of  $1.55^\circ$ .

## 3 Determination of GSO network location for maximum $\text{epfd}_{\text{is}}$

The location of the GSO space station and its pointing direction remains the same as for the computation of the  $\text{epfd}_{\uparrow}$  (see Part C, § 2).

### ANNEX 1

#### TO PART C'

## 1 In-line geometry

Let the system be considered in the geocentric reference.

Let:

$R_e$ : earth radius

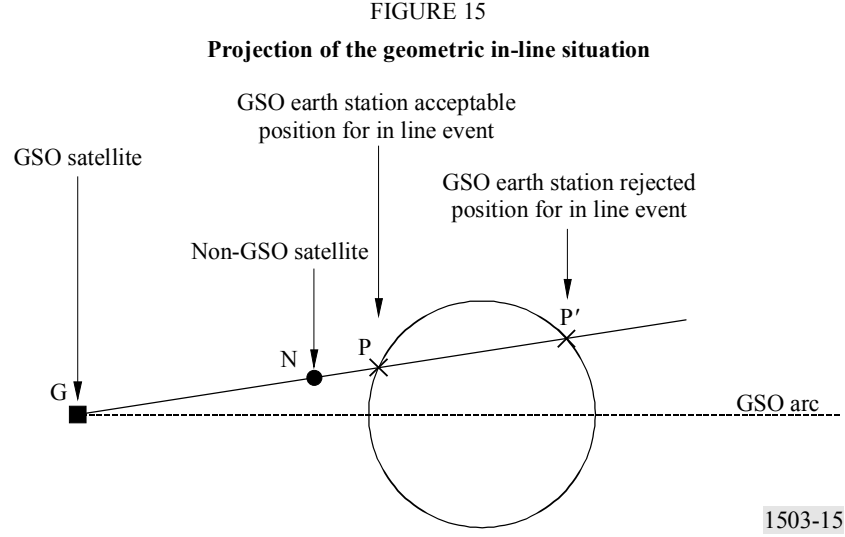
$P(x, y, z)$ : GSO earth station coordinates in this reference

$S(x_S, y_S, z_S)$ : GSO satellite coordinates in this reference

$N(x_N, y_N, z_N)$ : non-GSO satellite coordinates in this reference.

## 2 Downlink in-line geometry

This section describes calculation of the position of the GSO earth station for the in-line maximum  $\text{epfd}_{\downarrow}$  algorithm described in Part C, § 1. The calculation uses the non-GSO satellite position and the GSO satellite position for the maximum  $\text{epfd}_{\downarrow}$ , using the geometry below:



The GSO earth station is at the interception of:

the sphere of equation (5):

$$x^2 + y^2 + z^2 = R_e^2 \quad (5)$$

and the line passing by the GSO satellite and non-GSO satellite:

$$\vec{GP} = k \cdot \vec{GN} \quad \text{with } k \in \Re$$

that is to say:

$$\begin{cases} x - x_G = k (x_N - x_G) \\ y - y_G = k (y_N - y_G) \\ z - z_G = k (z_N - z_G) \end{cases} \quad (6)$$

Equations (5) and (6) lead to:

$$(x_G + k (x_N - x_G))^2 + (y_G + k (y_N - y_G))^2 + (z_G + k (z_N - z_G))^2 = R_e^2$$

then:

$$\begin{aligned} & k^2((x_N - x_G)^2 + (y_N - y_G)^2 + (z_N - z_G)^2) + 2k(x_G(x_N - x_G) + y_G(y_N - y_G) + z_G(z_N - z_G)) \\ & + x_G^2 + y_G^2 + z_G^2 = R_e^2 \end{aligned} \quad (7)$$

The resolution of (7) gives two solutions:  $k_1$  and  $k_2$  determined as follows:

If:

$$\Delta = 4(x_G(x_N - x_G) + y_G(y_N - y_G) + z_G(z_N - z_G))^2 - 4((x_N - x_G)^2 + (y_N - y_G)^2 + (z_N - z_G)^2)((x_G^2 + y_G^2 + z_G^2) - R_e^2)$$

then:

$$k1 = \frac{-2(x_G(x_N - x_G) + y_G(y_N - y_G) + z_G(z_N - z_G)) - \sqrt{\Delta}}{2((x_N - x_G)^2 + (y_N - y_G)^2 + (z_N - z_G)^2)}$$

and

$$k2 = \frac{-2(x_G(x_N - x_G) + y_G(y_N - y_G) + z_G(z_N - z_G)) + \sqrt{\Delta}}{2((x_N - x_G)^2 + (y_N - y_G)^2 + (z_N - z_G)^2)}$$

The GSO earth station position can either be:

$$\begin{bmatrix} x = k1(x_N - x_G) + x_G \\ y = k1(y_N - y_G) + y_G \\ z = k1(z_N - z_G) + z_G \end{bmatrix} \quad \text{or} \quad \begin{bmatrix} x = k2(x_N - x_G) + x_G \\ y = k2(y_N - y_G) + y_G \\ z = k2(z_N - z_G) + z_G \end{bmatrix}$$

The correct GSO earth station position is the one for which:

$$\left\| \vec{PG} \right\| \text{ is minimum and will be recorded only if } \left\| \vec{NG} \right\| < \left\| \vec{PG} \right\|$$

That is to say:

$$(x_N - x)^2 + (y_N - y)^2 + (z_N - z)^2 \text{ has to be minimum and point P is recorded only if:}$$

$$(x_G - x_N)^2 + (y_G - y_N)^2 + (z_G - z_N)^2 < (x_G - x)^2 + (y_G - y)^2 + (z_G - z)^2$$

### 3 Maximum epfd<sub>↓</sub> geometry for non-inline situation

#### 3.1 Using $\alpha$ angle

In this case, the maximum epfd<sub>↓</sub> occurs for a GSO earth station placed at a point on the Earth for which the angle between the non-GSO satellite and the GSO satellite equals  $\alpha_0$ .

The system of equations that has to be satisfied to determine the GSO earth station location is then:

$$\cos \alpha_0 = \frac{\vec{GN} \cdot \vec{GS}}{\|\vec{GN}\| \cdot \|\vec{GS}\|} \quad (8)$$

and

$$\sin \alpha_0 = \frac{\|\vec{GN} \times \vec{GS}\|}{\|\vec{GN}\| \cdot \|\vec{GS}\|} \quad (9)$$

The unknown parameters of this set of equations are  $(x, y, z)$ , the coordinates of the GSO earth station in the geocentric reference. As  $(x, y, z)$  only depends on the latitude and longitude of the GSO earth station, the unknown parameters can be reduced to two by applying the changes of reference:

$$x = R_e \cos(\text{lat}) \cos(\text{long})$$

$$y = R_e \cos(\text{lat}) \sin(\text{long})$$

$$z = R_e \sin(\text{lat})$$

The set of equations (8) and (9) has two unknown parameters and therefore a single solution.

### 3.2 Using an $X$ angle

In this case, the maximum  $\text{epfd}_{\downarrow}$  occurs for a GSO earth station placed at a point on the Earth for which the angle at the non-GSO satellite between the GSO earth station and the line projection from the GSO satellite through the non-GSO satellite to the surface of the Earth is equal to  $X_0$ .

If  $P_{in-line}$  is the line projection from the GSO satellite through the non-GSO satellite to the surface of the Earth, then the system of equations that has to be satisfied to determine the GSO earth station location is then:

$$\cos X_0 = \frac{\overrightarrow{NG} \cdot \overrightarrow{NP_{in-line}}}{\|\overrightarrow{NG}\| \cdot \|\overrightarrow{NP_{in-line}}\|} \quad (10)$$

and

$$\sin X_0 = \frac{\overrightarrow{NG} \cdot \overrightarrow{NP_{in-line}}}{\|\overrightarrow{NG}\| \cdot \|\overrightarrow{NP_{in-line}}\|} \quad (11)$$

The set of equations (10) and (11) has two unknown parameters and therefore a single solution.

## PART D

### Software for the examination of non-GSO filings

## 1 Introduction

### 1.1 Scope

The scope of this section is to specify part of a software requirements document (SRD) for a computer program that can be used by the BR to calculate whether a specific non-GSO system proposed by an administration meets  $\text{epfd}$  limits. This section defines two approaches: time simulation, in which interference levels are evaluated at each time step and the analytical method where interference levels are evaluated at increments of the position (latitude and longitude) of a reference satellite (see Part D, § 6).

### 1.2 Background

This section assumes that the following approaches are used:

*$\text{epfd}_{\downarrow}$  calculation:* Each non-GSO satellite has a pfd mask and the pfd for each satellite is used to calculate the aggregate  $\text{epfd}_{\downarrow}$  at an earth station of a GSO system. This is repeated for a series of time steps (or reference satellite positions, in the analytical method) until a distribution of  $\text{epfd}_{\downarrow}$  is produced. This distribution can then be compared with the limits to give a go/no go decision.

*$\text{epfd}_{\uparrow}$  calculation:* The Earth is populated with a distribution of non-GSO earth stations. Each earth station points towards a non-GSO satellite using pointing rules for that constellation, and transmits with a defined e.i.r.p.. From the e.i.r.p. and off-axis gain pattern for each earth station, the  $\text{epfd}_{\uparrow}$  at the GSO can be calculated. This is repeated for a series of time steps (or reference satellite positions, in the analytical method) until a distribution of  $\text{epfd}_{\uparrow}$  is produced. This distribution can then be compared with the limits to give a go/no go decision.

*$\text{epfd}_{is}$  calculation:* From the e.i.r.p. and off-axis angle for each space station, the  $\text{epfd}_{is}$  at the GSO space station can be calculated. This is repeated for a series of time steps (or reference satellite positions, in the analytical method) until a distribution of  $\text{epfd}_{is}$  is produced. This distribution can then be compared with the limits to give a go/no go decision.

The SRD provides detailed algorithms that would allow it to be implemented in software by any interested parties without reference to any specific development methodology.

### 1.3 Overview

This section is structured into the following paragraphs:

- § 2: General requirements of the algorithm, such as constants and environment
- § 3: Defines the  $\text{epfd}_{\downarrow}$  algorithm
- § 4.1: Defines the  $\text{epfd}_{\uparrow}$  algorithm
- § 4.2: Defines the  $\text{epfd}_{\text{is}}$  algorithm
- § 5: Defines the core geometry and algorithms used by both  $\text{epfd}$  calculations including gain patterns
- § 6: Specifies details of the analytic method
- § 7: Specifies the output formats and process to obtain a go/no-go decision

Note that where square brackets are included as part of a parameter name, this indicates an index into an array, not tentative text.

### 1.4 Cross references

This section is part of an overall document, and the following Parts give additional information.

#### **Part A: Fundamental constraints and basic assumptions**

This Part relates to the two basic approaches in the SRD, in particular the calculation of time step for the time simulation approach and the choice of the reference satellite longitude and latitude increments in the analytical method approach.

#### **Part B: Parameters of non-GSO systems**

This Part gives the complete list of required parameters, from which a sub-set of parameters is used as inputs to the  $\text{epfd}$  software sections.

#### **Part C: pfd mask definition**

This Part gives further information about the definition and format of the pfd mask used for  $\text{epfd}_{\downarrow}$  calculations.

#### **Part C': Maximum $\text{epfd}$ geometry**

This Part gives information about how to calculate the locations of the GSO earth station and satellite that gives the maximum  $\text{epfd}$ .

#### **Part F: Operational environment for the software**

This Part gives further information about platform requirements and the operating system under which the software is expected to run.

#### **Part H: Procedures for the evaluation of the candidate software**

This Part gives further information about the user interface requirements.

## 2 General requirements

### 2.1 Software environment

The software should match the environment defined in Part F.

### 2.2 Implementation requirements

The criteria used to evaluate candidate software are defined in Part H.

### 2.3 Program interfaces

It is preferable that the program shall read data electronically, but it should also be possible to enter data from the keyboard. Output should be either electronic format or printed via printer configured for the PC.

### 2.4 Algorithm constants

The algorithms should use the following constants as specified in Part A – Fundamental constraints and basic assumptions for the simulation:

- radius of the Earth
- radius of the geostationary orbit
- gravitational constant
- $J_\alpha$  parameter
- speed of light
- angular rate of rotation of the Earth.

### 2.5 General assumptions and limitations

It is assumed that pfd masks are used to define the transmit radio characteristics of the non-GSO satellites. The Earth is assumed to be a sphere with orbit prediction algorithm based upon single point mass plus  $J_2$  factor.

A general limitation on the generation of epfd statistics, as described in Part B, § 2.2 is:

Bin size:  $S_B = 0.1$  dB

To be consistent with evaluation algorithm in Part D, § 7.13 epfd values calculation for each time step should be rounded to the lower values with a maximum precision of 0.1 dB.

The calculation of angle to GSO arc,  $\alpha$  and  $X$ , as described in Part D, § 5.4.2 are based upon a number of test points, with specified separation between them.

Separation between GSO test points: GSO\_SEPARATION.

### 2.6 Frequency selection

Separate frequency values will generally be required for assessment of epfd levels into each service (FSS and BSS) in each of the frequency bands within a service. Let  $F_{\text{(down/up/is)}}$  denote the list containing the set of frequency values to be tested. The following procedure shall be employed to determine the set of values in  $F_{\text{(down/up/is)}}$ .

*Step 0:* Empty the  $F_{\text{(down/up/is)}}$  list

*Step 1:* For each service (FSS and BSS), repeat Step 2

*Step 2:* For each set of limits, repeat Step 3

*Step 3:* For each antenna diameter, repeat Steps 4 and 5

*Step 4:* Find the lowest frequency which is shared by GSO and non-GSO

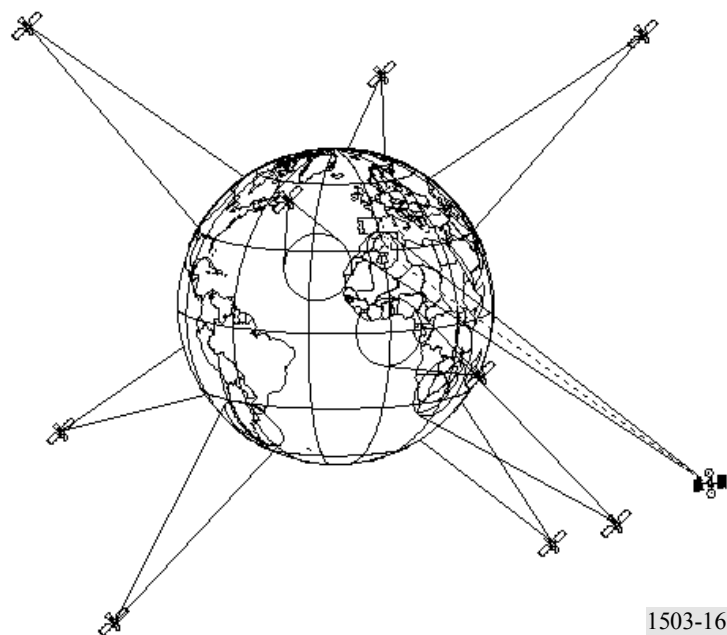
*Step 5:* Add that frequency to the list of values in  $F_{\text{(down/up/is)}}$ , to be tested.

## 3 epfd<sub>↓</sub> software description

This section describes the algorithm to calculate the epfd<sub>↓</sub> from a non-GSO constellation into a GSO downlink. It is assumed that each non-GSO satellite has a pfd mask. From the pfd for each satellite the aggregate epfd<sub>↓</sub> at an earth station of a GSO system is calculated. This is repeated for a series of time steps (or reference satellite positions, in the analytical method) until a distribution of epfd<sub>↓</sub> is produced. This distribution can then be compared with the limits to give a go/no go decision.

Figure 16 shows the geometry with constellation of non-GSO satellites and test GSO satellite transmitting to a GSO earth station.

FIGURE 16



### 3.1 Configuration parameters

This sub-section specifies the parameters required for all  $epfd_{\downarrow}$  calculations defined in the RR. This would be a data-set of  $N$  sets of limits that can be shared between runs. The Table could be queried so that the required values can be used depending upon non-GSO system frequency.

These constants as described in Part B, § 2.2 are:

Parameter name	Parameter value	Parameter units and ranges
Frequency band start	FSTART_DOWN	GHz
Frequency band end	FEND_DOWN	GHz
Applicable Region 1	REGION1_DOWN	Yes or No
Applicable Region 2	REGION2_DOWN	Yes or No
Applicable Region 3	REGION3_DOWN	Yes or No
Dish size	GSO_ES_D_ANT	m
Gain pattern	GSO_ES_PATTERN	One of those in Part D, § 5.5
Reference bandwidth	REFBW	kHz
Number of $epfd_{\downarrow}$ points	NEPFD_DOWN	–
Array of NEPFD_DOWN $epfd_{\downarrow}$ values	EPFD_DOWN[I]	$\text{dB}(\text{W}/(\text{m}^2 \cdot \text{BW}_{\text{ref}}))$
Array of NEPFD_DOWN percentages	PC[I]	%

From the EPFD\_DOWN[I] arrays the number of bins and bin ranges can be calculated using:

*Step 1:* Calculate EPFD\_DOWN\_MIN = minimum value in EPFD\_DOWN[I] array.

*Step 2:* Calculate EPFD\_DOWN\_MAX = maximum value in EPFD\_DOWN[I] array.

*Step 3:* Calculate EPFD\_DOWN\_START by rounding EPFD\_DOWN\_MIN to nearest 10 dB below.



Step 4: Calculate EPFD\_DOWN\_END by rounding EPFD\_DOWN\_MAX to nearest 10 dB above.

Step 5: Number of bins = (EPFD\_DOWN\_END – EPFD\_DOWN\_START)/ $S_B$ .

This will give a set of bins that are of size  $S_B$  (bin size specified in Part D, § 2.5) and are below and above the epfd<sub>↓</sub> limits required.

### 3.2 Determination of maximum epfd configuration

The algorithms to determine the location of the GSO earth station and satellite that corresponding to the maximum epfd configuration are given in Part C'.

### 3.3 Calculation of run steps

#### 3.3.1 Time simulation approach

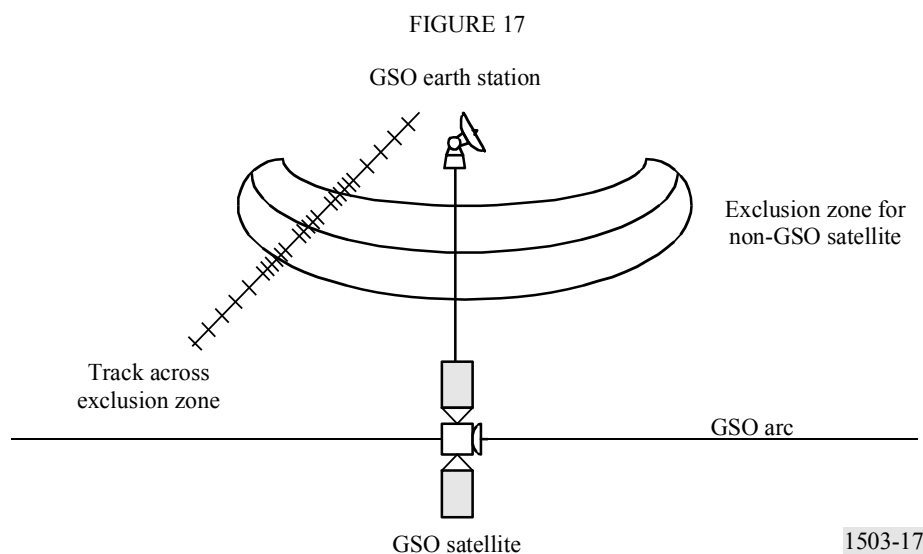
The fine time step is calculated using the algorithm in Part A, together with the calculation of the number of time steps.

##### Dual time step option

In order to improve simulation performance an option to the algorithm is to implement two time steps. A coarse time step would be used except when any non-GSO satellite is near one of the two conditions:

- exclusion angle  $\alpha$  or  $X = 0$
- exclusion angle  $\alpha$  or  $X =$  edge of exclusion zone.

Figure 17 shows where to use the finer time step:



The algorithm in Part D, § 3.5.1 shows the optional steps for dual time steps as sub-steps, i.e. 5.1, 5.2, 6.1, 6.2, 6.3 and 22.1.

A coarse step size is used for non-critical regions far from the GSO earth station main beam axis and exclusion zone boundaries. This step size is defined as a topocentric angle:

$$\varphi_{coarse} = 1.5^\circ$$

This coarse step size is used for all antenna beamwidths and all non-GSO systems.

There are two possible fine step regions because of the two possible maximum epfd locations of a non-GSO:

- a) When a non-GSO satellite is near the main beam, the fine step region (FSR) is defined as a fixed topocentric angle from the axis of the GSO earth station beam ( $X$  or  $\alpha = 0$ ).
  - If  $D/\lambda > 100$ , set the edge of the first sidelobe region to  $\varphi_r$  of the GSO earth station pattern:

$$\varphi_1 = \varphi_r = 15.85(D/\lambda)^{-0.6}$$

- If  $D/\lambda < 100$ , set the edge of the first sidelobe region to that defined in the GSO earth station pattern:

$$\varphi_1 = 95 \lambda/D$$

The off-bore angle for the fine step region is defined as the greater of  $3.5^\circ$  or  $\varphi_1$ :

$$\Phi_{FSR\_1} = \max(3.5^\circ, \varphi_1)$$

- b) When a non-GSO satellite is near the exclusion zone, the fine step region measured from the boundary of the exclusion zone ( $X = X_0$  or  $\alpha = \alpha_0$ ) is defined as:

$$\Phi_{FSR\_2} = \Phi_{coarse}$$

The size of the coarse step needs to be an integer multiple of fine steps for statistical purposes. Since the coarse step size is constant, the ratio of coarse steps to fine steps is dependent only upon the beamwidth of the GSO earth station ( $\varphi_{3dB}$ ). This ratio is defined as:

$$N_{coarse} = \text{Floor}((N_{hits} * \varphi_{coarse}) / \varphi_{3dB})$$

where floor is a function that truncates the decimal part of the ratio and outputs the integer part of the ratio. This produces a conservative ratio of fine steps to coarse steps to ensure that a coarse step is never larger than the target topocentric size of  $1.5^\circ$ .

### 3.3.2 Analytical approach

The longitude and latitude steps for the position of the reference satellite are chosen according to the procedure in Part D, § 6.3.

## 3.4 Inputs and file formats

### 3.4.1 Input parameters

The term input is a generic term that can include input files or input provided by the user through some graphic interface or prompting by the software. This section contains a description of the input parameters that are necessary to perform the epfd analysis. The following subsections contain tables of the required inputs for the non-GSO system parameters, GSO system parameters, run parameters, statistical parameters, and file formats.

### 3.4.2 Non-GSO system parameters

The following parameters, as specified in Part B, § 2.1 would be used.

Parameter description	Parameter name	Parameter units
Satellite pfd mask	See Part C for definition and format	
Number of non-GSO satellites	$N_{sat}$	–
Number of frequency/regions <sup>(1)</sup>	$N_{freq}$	–
Region <sup>(1)</sup>	One of 1, 2 or 3	–
Transmit centre frequency <sup>(1)</sup>	F_DOWN <sub>sat</sub>	GHz
Exclusion zone parameter	Alpha or $X$	–
Exclusion zone angle	MIN_EXCLUDE	degrees
Maximum number of satellites operating at $f_{sat}$ by latitude	$N_{col}[\text{Latitude}]$	–
Orbit has repeating ground track maintained by station keeping	Yes or No	–
Administration is supplying specific node precession rate	Yes or No	–
Station keeping range for ascending node as half total range	$W_{delta}$	degrees
Minimum operating height	H_MIN	km

<sup>(1)</sup> The filing administration can supply a set of (satellite frequency, applicable region). The ITU database of limits can be searched to extract those applicable for each set.

For each satellite the following parameters specified in Part B, § 2.1 – Parameters provided by administration of the non-GSO system, would be used, where the definitions of the parameters are specified in Part D, § 5.3.1 at the time of the start of the simulation.

Note that in the Table below, the indices [N] are present to indicate that there would be a different value for each satellite, and the  $N$ -th value corresponds to the  $N$ -th satellite. For the pfd mask it indicates that the pfd data is structured in such a way that the pfd[N] entry is a reference that points to a particular sub-set. For example each satellite in the constellation could reference the same pfd(lat, az, el), pfd(lat, X, Δlong), or pfd(lat, α, Δlong) table.

Parameter description	Parameter name	Parameter units
pfd mask to use	pfd[N]	–
Semi-major axis	A[N]	km
Eccentricity	E[N]	–
Inclination	I[N]	degrees
Longitude of ascending node	O[N]	degrees
Argument of perigee	W[N]	degrees
True anomaly	V[N]	degrees

Because of the use of a pfd mask, the number of antennas on the satellite and the non-GSO RF link parameters are not necessary for epfd<sub>↓</sub> calculation. However each satellite could have an individual pfd mask, and so for each satellite there would be a reference into the pfd mask database. Each satellite must have an independent set of six orbital parameters for orbit definition and subsequent propagation.

### 3.4.3 GSO system parameters

The GSO system parameters can be taken from either the algorithm in Part D, § 3.2 or entered values. In that case the following parameters specified in Part B, § 2.1 are used:

Parameter description	Parameter name	Parameter units
GSO satellite longitude	GSO_LONG	degrees
GSO earth station latitude	GSO_ES_LAT	degrees
GSO earth station longitude	GSO_ES_LONG	degrees
Reference earth station gain pattern	GSO_ES_PATTERN	One of those in Part D, § 5.5
Earth station antenna diameter	GSO_ES_D_ANT	m

The latitude and longitude of the GSO satellite and earth station are defined in Part D, § 5.2 and 5.1.

### 3.4.4 Run parameters

The run parameters can be either calculated using the algorithm in Part D, § 3.3 or entered values. For the time simulation approach the required parameters are:

Parameter description	Parameter name	Parameter units
Time step	TSTEP	s
Number of time steps	NSTEPS	–
Precession mechanism	J2 or Admin Supplied or Artificial	–
Precession rate	ORBIT_PRECESS	degrees/s

For the analytical method approach, the required parameters are related to increments in the reference satellite position:

Parameter description	Parameter name	Parameter units
Longitude step for the coarse grid	PHISTEPCG	degrees
Latitude step for the coarse grid	THETASTEPCG	degrees
Longitude step for the fine grid	PHISTEPFG	degrees
Latitude step for the fine grid	THETASTEFG	degrees

### 3.4.5 Other parameters

The run would also use the  $\text{epfd}_{\downarrow}$  limits database from Part D, § 3.1 to get three defining parameters for the  $\text{epfd}_{\downarrow}$  statistics:

Parameter description	Parameter name	Parameter units
Starting value for $\text{epfd}_{\downarrow}$ bins	EPFD_DOWN_START	$\text{dB}(\text{W}/\text{m}^2 \cdot \text{BW}_{\text{ref}})$
Bin size (Part D, § 2.5)	$S_B$	$\text{dB}(\text{W}/\text{m}^2 \cdot \text{BW}_{\text{ref}})$
Number of $\text{epfd}_{\downarrow}$ bins	N_BINS	—

### 3.4.6 File formats

File formats should be in ASCII (text) format to allow visual inspection and modification of the input parameters to the routines. It would also be acceptable to have the input parameters in a binary database format if a graphical interface is provided to view and modify input parameters before running the simulation.

## 3.5 Algorithms and calculation procedures

The operating non-GSO satellites are those outside the exclusion zone, above their minimum operating elevation angle and transmitting towards (i.e. height above or equal to MIN\_OPERATING\_HEIGHT) the GSO earth station. The maximum number of operating non-GSO satellites is the maximum number of non-GSO satellites allowed to transmit co-frequency towards the same area on the ground.

### 3.5.1 Time simulation approach

To calculate  $\text{epfd}_{\downarrow}$  values from one non-GSO system into one GSO system earth station the following algorithm should be used. The algorithm can be used on multiple GSO systems in parallel if required.

*Step 1:* Read in parameters for non-GSO system as specified in Part D, § 3.4.2.

*Step 2:* Read in GSO parameters as specified in Part D, § 3.4.3.

*Step 3:* If required, calculate the maximum  $\text{epfd}$  GSO location using the algorithm in Part D, § 3.2.

*Step 4:* Initialize statistics by zeroing all bins of  $\text{epfd}_{\downarrow}$  values.

*Step 5:* If required calculate number of time steps and time step size using algorithm in Part D, § 3.3 and hence calculate end time.

If a dual time step algorithm is included then use Sub-step 5.1, otherwise  $N_{\text{coarse}} = 1$  all the time.

*Sub-step 5.1:* Calculate coarse step size  $T_{\text{coarse}} = T_{\text{fine}} * N_{\text{coarse}}$ .

- Step 6:* If a dual time step algorithm is included then repeat Sub-step 6.1 to Step 22 until end time is reached, otherwise repeat Steps 7 to 22 until end time is reached.
- Sub-step 6.1:* If it is the first time step then set  $T_{step} = T_{fine}$ .
- Sub-step 6.2:* Otherwise if there are less than  $N_{coarse}$  steps remaining then set  $T_{step} = T_{fine}$ .
- Sub-step 6.3:* Otherwise if the any of the  $\alpha$  or  $X$  angles for the last time step were within  $\Phi_{FSR\_1}$  of zero or  $\Phi_{FSR\_2}$  of the exclusion zone angle ( $\phi_0$  or  $X_0$ ) then set  $T_{step} = T_{fine}$  otherwise set  $T_{step} = T_{coarse}$ .
- Step 7:* Update position vectors of all earth stations based on coordinate system in Part D, § 5.1.
- Step 8:* Update position vectors of all GSO satellites based on coordinate system in Part D, § 5.2.
- Step 9:* Update position and velocity vectors of all non-GSO satellites based on coordinate system, orbit prediction model and station keeping algorithm in Part D, § 5.3.
- Step 10:* Set  $epfd_{\downarrow} = 0$ .
- Step 11:* Select all non-GSO satellites visible to the GSO earth station using the algorithm in Part D, § 5.4.1.
- Step 12:* Repeat Steps 13 to 18 for each visible non-GSO satellite.
- Step 13:* Calculate the parameters required by the pfd mask, either (lat,  $\alpha$  or  $X$ ,  $\Delta$ long) or (lat, azimuth, elevation) as required, using the definition of angles in Part D, § 5.1.
- Step 14:* Using the pfd mask for the selected non-GSO satellite, calculate pfd(lat,  $\alpha$  or  $X$ ,  $\Delta$ long) or pfd(lat, azimuth, elevation) at the GSO earth station using the non-GSO satellite pfd mask as specified in Part D, § 3.6.
- Step 15:* Calculate off axis angle  $\phi$  at GSO earth station between line to the GSO satellite and the non-GSO satellite.
- Step 16:* Calculate  $G_{RX}(\phi)$  = Receive gain (dB) at GSO earth station using relevant gain pattern specified in algorithms in Part D, § 5.5.
- Step 17:* Calculate  $epfd_{\downarrow i}$  for this non-GSO satellite using:
- Step 18:*  $epfd_{\downarrow i} = pfd(\alpha) + G_{RX}(\phi) - G_{max}$  where  $G_{max}$  is the peak gain of the GSO earth station antenna.
- Step 19:* Sort the  $epfd_{\downarrow}$  contributions of the non-GSO satellites.
- Step 20:* Repeat Step 21 for the  $N_{co}[lat]$  largest  $epfd_{\downarrow}$  contributions on this list plus those satellites within the exclusion zone, where  $N_{co}[lat]$  is the maximum number of operating non-GSO satellites at the latitude of GSO\_ES considered corresponding to the maximum number of satellites allowed to transmit at the same frequency towards the same area on the ground, fulfilling the GSO exclusion zone and minimum elevation angle requirements as defining by for the non-GSO system.
- Step 21:* Increment  $epfd_{\downarrow}$  by the  $epfd_{\downarrow i}$  value.
- Step 22:* Increment  $epfd_{\downarrow}$  statistics by  $epfd_{\downarrow}$  for this time step by  $(T_{step}/T_{fine})$  entries.
- Step 23:* Generate the  $epfd_{\downarrow}$  CDF from the  $epfd_{\downarrow}$  PDF using the algorithm in Part D, § 7.1.2.
- Step 24:* Compare  $epfd_{\downarrow}$  statistics with limits using algorithm in Part D, § 7.1.
- Step 25:* Output results in format specified in Part D, § 7.3.

### 3.5.2 Analytical method approach

To calculate  $epfd_{\downarrow}$  values from one non-GSO system into one GSO system earth station the following algorithm should be used. The algorithm can be used on multiple GSO systems in parallel if required.

- Step 1:* Read in parameters for non-GSO system as specified in Part D, § 3.4.2.
- Step 2:* Read in GSO parameters as specified in Part D, § 3.4.3.

- Step 3:* If required, calculate maximum EPFD GSO location using algorithm in Part D, § 3.2.
- Step 4:* Initialize statistics by zeroing all bins of  $\text{epfd}_{\downarrow}$  values.
- Step 5:* Make a partition of the non-GSO reference satellite  $\phi$ - $\theta$  plane.
- Step 6:* Repeat Steps 7 to 23 for each element (cell) of the  $\phi$ - $\theta$  plane partition.
- Step 7:* Calculate the probability PROB of finding the non-GSO reference satellite inside the cell according to the expression in Part D, § 6.1.
- Step 8:* Place the non-GSO reference satellite at the centre of the cell.
- Step 9:* Determine the location of all other satellites in the constellation (there are two possible constellation configurations) according to the expressions in Part D, § 6.2.
- Step 10:* Repeat Steps 11 to 23 for each of the two configurations.
- Step 11:* Set  $\text{epfd}_{\downarrow} = 0$ .
- Step 12:* Select all non-GSO satellites visible to the GSO earth station using the algorithm in Part D, § 5.4.1.
- Step 13:* Repeat Steps 14 to 19 for each visible non-GSO satellite.
- Step 14:* Calculate the parameters required by the pfd mask, either (lat,  $\alpha$  or  $X$ ,  $\Delta$ long) or (lat, azimuth, elevation) as required, using the definition of angles in Part D, § 5.1.
- Step 15:* Using the pfd mask for the selected non-GSO satellite, calculate  $\text{pfd}(\text{lat}, \alpha \text{ or } X, \Delta \text{long})$  or  $\text{pfd}(\text{lat}, \text{azimuth}, \text{elevation})$  at the GSO earth station using the non-GSO satellite pfd mask as specified in Part D, § 3.6.
- Step 16:* Calculate off axis angle  $\phi$  at GSO earth station between the line to the GSO satellite and the non-GSO satellite.
- Step 17:* Calculate  $G_{RX}(\phi)$  = Receive gain in dB at GSO earth station using relevant gain pattern specified in algorithms in Part D, § 5.5.
- Step 18:* Calculate  $\text{epfd}_i$  for this non-GSO satellite using:
- Step 19:*  $\text{epfd}_i = \text{pfd}(\alpha) + G_{RX}(\phi) - G_{\max}$  where  $G_{\max}$  is the peak gain of the GSO earth station antenna.
- Step 20:* Sort the  $\text{epfd}_i$  contributions of the non-GSO satellites.
- Step 21:* Repeat Step 22 for the  $N_{\text{co}}[\text{lat}]$  largest  $\text{epfd}_i$  contributions on this list plus those satellites within the exclusion zone, where  $N_{\text{co}}[\text{lat}]$  is the maximum operating non-GSO satellites at the latitude of GSO\_ES considered corresponding to the maximum number of satellites allowed to transmit at the same frequency towards the same area on the ground, fulfilling the GSO exclusion zone and minimum elevation angle requirements as defining by for the non-GSO system.
- Step 22:* Increment  $\text{epfd}_{\downarrow}$  by the  $\text{epfd}_i$  value.
- Step 23:* Locate in the  $\text{epfd}_{\downarrow}$  histogram the bin corresponding to the value of  $\text{epfd}_{\downarrow}$  and add  $\text{PROB}/2$  to it.
- Step 24:* Generate the  $\text{epfd}_{\downarrow}$  CDF from the  $\text{epfd}_{\downarrow}$  PDF using the algorithm in Part D, § 7.1.2.
- Step 25:* Compare  $\text{epfd}_{\downarrow}$  statistics with limits using algorithm in Part D, § 7.1.
- Step 26:* Output results in format specified in Part D, § 7.3.

### 3.6 pfd mask calculation

The pfd mask is defined as a table of pfd values for various angles and latitudes.

It can be assumed that  $\alpha$  or  $X$  angles increase from zero as the definition of  $\alpha$  or  $X$  in Part D, § 5.4.2 results in  $\alpha$  or  $X$  that are greater than or equal to zero.

Note that the latitude range should be:

Minimum:  $-I$

Maximum:  $+I$

where  $I$  is the inclination of the non-GSO satellite's orbit.

In general the (azimuth, elevation), or ( $\alpha$ , or  $X$ ) angles calculated at each time step will be between two values in the arrays. In this case linear interpolation between pfd values should be used.

The mask that is closer in latitude to that of the reference satellite should be used. Part C gives more information about the format and sampling of the pfd mask.

### 3.7 Outputs

The result of the algorithm is two arrays of size NEPFD\_DOWN (as specified in Part D, § 3.1) in format:

Array of NEPFD_DOWN $\text{epfd}_{\downarrow}$ values	EPFD_DOWN_CALC[I]	$\text{dB}(\text{W}/(\text{m}^2 \cdot \text{BW}_{\text{ref}}))$
Array of NEPFD_DOWN percentages	PC_CALC[I]	%

where PC\_CALC[I] is percentage of time EPFD\_DOWN\_CALC[I] is exceeded.

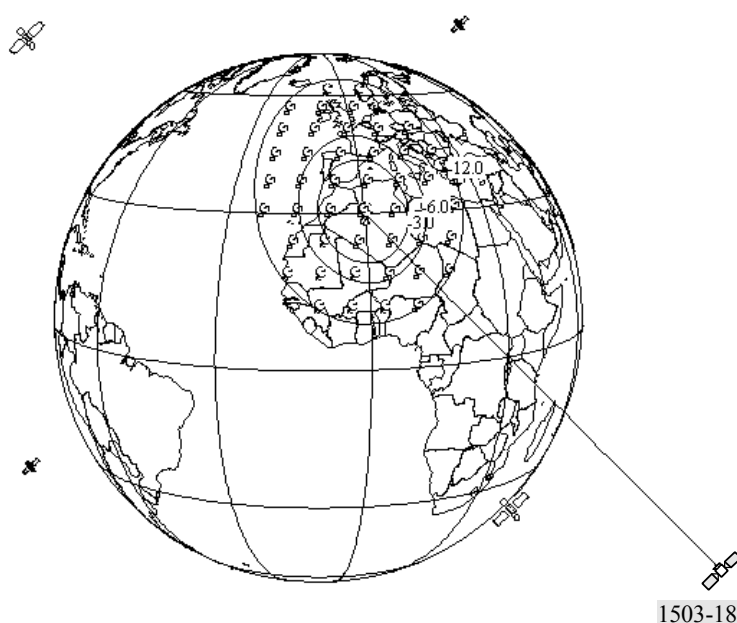
## 4 Software description

### 4.1 $\text{epfd}_{\uparrow}$ software description

This section describes the algorithm to calculate  $\text{epfd}_{\uparrow}$  from non-GSO earth stations into a GSO uplink. It is assumed that the Earth is populated with a uniform distribution of non-GSO earth stations. Each earth station points towards a non-GSO satellite using pointing rules for that constellation, and transmits with a defined e.i.r.p.. From the e.i.r.p. and off-axis gain pattern for each earth station, the  $\text{epfd}_{\uparrow}$  at the GSO can be calculated. This is repeated for a series of time steps (or reference satellite positions, in the analytical method) until a distribution of  $\text{epfd}_{\uparrow}$  is produced. This distribution can then be compared with the limits to give a go/no go decision.

Figure 18 shows the geometry with population of non-GSO earth stations transmitting to a constellation of non-GSO satellites, together with a test GSO satellite receiving from a GSO earth station.

FIGURE 18



#### 4.1.1 Configuration parameters

This sub-section specifies the parameters required for all  $\text{epfd}_{\uparrow}$  calculations defined in the RR. This would be a data-set of  $N$  sets of limits that can be shared between runs. The Table could be queried so that the required values can be used depending upon non-GSO system frequency.

For each set of limits the following would be defined as specified in Part B, § 2.2.

Parameter name	Parameter value	Parameter units and ranges
Frequency band start	FSTART_UP	GHz
Frequency band end	FEND_UP	GHz
Applicable Region 1	REGION1_UP	Yes or No
Applicable Region 2	REGION2_UP	Yes or No
Applicable Region 3	REGION3_UP	Yes or No
GSO gain pattern	GSO_SAT_PATTERN	One of those in Part D, § 5.5
GSO peak gain	GSO_SAT_PEAKGAIN	dBi
GSO half power beamwidth	GSO_SAT_BEAMWIDTH	degrees
Reference bandwidth	RAFBW	kHz
Number of $\text{epfd}_{\uparrow}$ points	NEPFD_UP	–
Array of NEPFD_UP $\text{epfd}_{\uparrow}$ values	EPFD_UP[I]	$\text{dB}(\text{W}/(\text{m}^2 \cdot \text{BW}_{\text{ref}}))$
Array of NEPFD_UP percentages	PC_UP[I]	%

From the EPFD\_UP[I] arrays the number of bins and bin ranges can be calculated using:

*Step 1:* Calculate EPFD\_UP\_MIN = minimum value in EPFD\_UP[I] array.

*Step 2:* Calculate EPFD\_UP\_MAX = maximum value in EPFD\_UP[I] array.

*Step 3:* Calculate EPFD\_UP\_START by rounding EPFD\_UP\_MIN to nearest 10 dB below.

*Step 4:* Calculate EPFD\_UP\_END by rounding EPFD\_UP\_MAX to nearest 10 dB above.

*Step 5:* Number of bins =  $(\text{EPFD\_UP\_END} - \text{EPFD\_UP\_START})/S_B$ .

This will give a set of bins that are of size  $S_B$  (bin size specified in Part D, § 2.5) and are below and above the  $\text{epfd}_{\uparrow}$  limits required.

#### 4.1.2 Determination of maximum epfd configuration

The maximum  $\text{epfd}$  location of the GSO satellite and beam centre is defined in Part C'.

#### 4.1.3 Calculation of run steps

##### 4.1.3.1 Time simulation approach

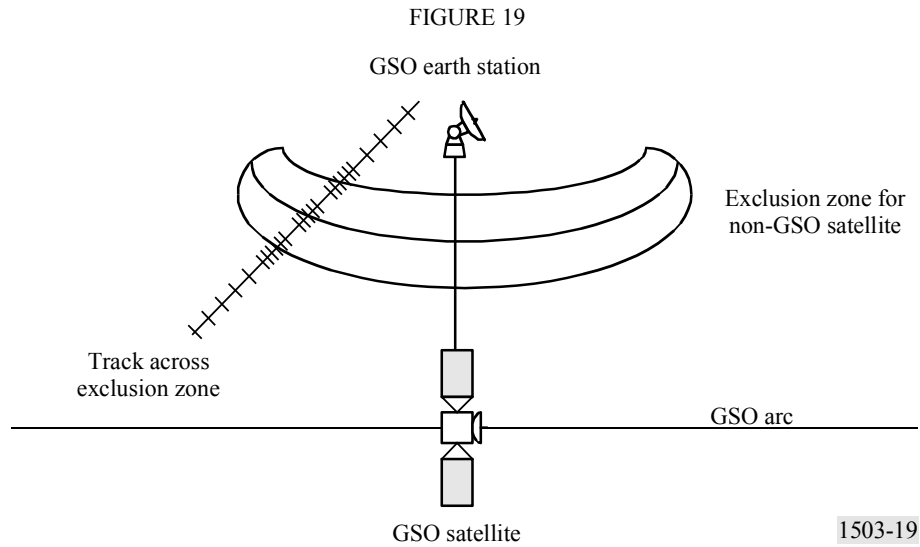
A single time step and number of time steps are calculated using the algorithm in Part A.

##### Dual time step option

In order to improve simulation performance an option to the algorithm is to implement two time steps. A coarse time step would be used except when any non-GSO satellite is near the edge of the exclusion zone. Note that there is no need to check for the central line representing  $\alpha = 0$  as non-GSO earth station does not transmit to the non-GSO satellite within the exclusion zone.



Figure 19 shows where to use the finer time step:



The algorithm in Part D, § 4.6.1 shows the optional steps for dual time steps as sub-steps, i.e. 6.1, 6.2, 7.1, 7.2, 7.3 and 24.1.

A coarse step size is used for non-critical regions far from the GSO earth station main beam axis and exclusion zone boundaries. This step size is defined as a topocentric angle:

$$\phi_{coarse} = 1.5^\circ$$

This coarse step size is used for all antenna beamwidths and non-GSO systems.

The size of the coarse step needs to be an integer multiple of fine steps for statistical purposes. Since the coarse step size is constant, the ratio of coarse steps to fine steps is dependent only upon the beamwidth of the non-GSO earth station ( $\phi_{3dB}$ ). This ratio is defined as:

$$N_{coarse} = \text{Floor}((N_{hits} * \phi_{coarse}) / \phi_{3dB})$$

where floor is a function that truncates the decimal part of the ratio and outputs the integer part of the ratio. This produces a conservative ratio of fine steps to coarse steps to ensure that a coarse step is never larger than the target topocentric size of  $1.5^\circ$ .

#### 4.1.3.2 Analytical approach

The longitude and latitude steps for the position of the reference satellite are chosen according to the procedure in Part D, § 6.3.

#### 4.1.4 Inputs and file formats

##### 4.1.4.1 Input parameters

This section defines the input parameters for a particular non-GSO system scenario. In this case, input is a generic term that could include files or user input. Information is required for:

- non-GSO system;
- GSO system;
- run configuration.

#### 4.1.4.2 Non-GSO system parameters

The following parameters, as specified in Part B, § 2.1 would be used:

Parameter description	Parameter name	Parameter units
Number of non-GSO satellites	$N_{sat}$	–
Orbit has repeating ground track maintained by station keeping	Yes or No	–
Administration is supplying specific node precession rate	Yes or No	–
Station keeping range for ascending node as half total range	$W_{\text{delta}}$	degrees

For each satellite the following parameters specified in Part B, § 2.1, would be used, where the definitions of the parameters are specified in Part D, § 5.3.1 at the time of the start of the simulation.

Note that in the Table below, the indices [N] are present to indicate that there would be a different value for each satellite, and the  $N$ -th value corresponds to the  $N$ -th satellite.

Parameter description	Parameter name	Parameter units
Semi-major axis	A[N]	km
Eccentricity	E[N]	–
Inclination	I[N]	degrees
Longitude of ascending node	O[N]	degrees
Argument of perigee	W[N]	degrees
True anomaly	V[N]	degrees

Each satellite must have an independent set of six orbital parameters for orbit definition and subsequent propagation.

To define the characteristics of non-GSO earth stations, the following parameters, as specified in Part B, § 2.1 would be used:

Parameter description	Parameter name	Parameter units
Maximum number of co-frequency tracked non-GSO satellites	ES_TRACK	–
Earth station e.i.r.p. mask	ES_EIRP	dB(W/BW <sub>ref</sub> )
Number of frequency/regions <sup>(1)</sup>	$N_{freq}$	-
Region <sup>(1)</sup>	One of 1, 2 or 3	-
Central transmit frequency <sup>(1)</sup>	ES_F	GHz
Minimum elevation angle	ES_MINELEV	degrees
Minimum angle to GSO arc	ES_MIN_GSO	degrees
Average number of non-GSO ES per km <sup>2</sup>	ES_DENSITY	/km <sup>2</sup>
Average distance between cell or beam foot-print centres	ES_DISTANCE	km

<sup>(1)</sup> The filing administration can supply a set of (earth station frequency, applicable region). The ITU database of limits can be searched to extract those applicable for each set.

#### 4.1.4.3 GSO system parameters

The GSO system can be either calculated or use worst-case parameters using the algorithm in Part D, § 4.1.2 or entered values. The required parameters as specified in Part B, § 2.1 are:

Parameter description	Parameter name	Parameter units
GSO satellite longitude	GSO_SAT_LONG	degrees
GSO boresight latitude	BS_LAT	degrees
GSO boresight longitude	BS_LONG	degrees
GSO reference gain pattern	GSO_SAT_PATTERN	One of those in Part D, § 5.5

These parameters are defined in Part D, § 5.1 and 5.2.

#### 4.1.4.4 Run parameters

The run parameters can be either calculated the using algorithm in Part D, § 4.1.3 or entered values. For the time simulation approach, the required parameters are:

Parameter description	Parameter name	Parameter units
Time step	TSTEP	s
Number of time steps	NSTEPS	—
Precession mechanism	J2 or Admin Supplied or Artificial	—
Precession rate	ORBIT_PRECESS	degrees/s

For the analytical method approach, the required parameters are related to increments in the reference satellite position:

Parameter description	Parameter name	Parameter units
Longitude step for the coarse grid	PHISTEPCG	degrees
Latitude step for the coarse grid	THETASTEPCG	degrees
Longitude step for the fine grid	PHISTEPFG	degrees
Latitude step for the fine grid	THETASTEFG	degrees

#### 4.1.4.5 Other parameters

The run would also use the  $\text{epfd}_{\downarrow}$  limits database from Part D, § 4.1.1 to get three defining parameters for the  $\text{epfd}_{\downarrow}$  statistics:

Parameter description	Parameter name	Parameter units
Starting value for $\text{epfd}_{\uparrow}$ bins	EPFD_UP_START	$\text{dB}(\text{W}/(\text{m}^2 \cdot \text{BW}_{\text{ref}}))$
Bin size (Part D, § 2.5)	$S_B$	$\text{dB}(\text{W}/(\text{m}^2 \cdot \text{BW}_{\text{ref}}))$
Number of $\text{epfd}_{\uparrow}$ bins	N_BINS	—

#### 4.1.4.6 File formats

File formats should be in ASCII (text) format to allow visual inspection and modification of the input parameters to the routines. It would also be acceptable to have the input parameters in a binary database format if a graphical interface is provided to view and modify input parameters before running the simulation.

#### 4.1.5 Production of non-GSO earth station distribution

To produce the distribution of non-GSO earth stations, the following method should be used:

*Step 1:* Calculate the number of actual operating non-GSO earth stations that the representative earth station will represent using:

$$\text{NUM\_ES} = \text{ES\_DISTANCE} * \text{ES\_DISTANCE} * \text{ES\_DENSITY}$$

*Step 2:* Calculate e.i.r.p. to use for each representative non-GSO earth station using:

$$\text{REP\_EIRP} = \text{ES\_EIRP} + 10\log_{10}(\text{NUM\_ES})$$

*Step 3:* Define the GSO service area as the region enclosed by the contour representing a relative gain of 15 dB.

*Step 4:* For every distance ES\_DISTANCE in latitude and distance ES\_DISTANCE in longitude within the service area defined in Step 3, locate a representative non-GSO earth station with radiating with REP\_EIRP.

#### 4.1.6 Algorithms and calculation procedures

##### 4.1.6.1 Time simulation approach

To calculate  $\text{epfd}_{\uparrow}$  values from one non-GSO system into one GSO system satellite the following algorithm should be used. The algorithm can be used on multiple GSO systems in parallel if required:

*Step 1:* Read in parameters for non-GSO system as specified in Part D, § 4.1.4.2.

*Step 2:* Read in GSO parameters as specified in Part D, § 4.1.4.3.

*Step 3:* If required calculate maximum  $\text{epfd}$  GSO location using the algorithm in Part D, § 4.1.2.

*Step 4:* If required calculate locations of non-GSO earth stations using the algorithm in Part D, § 4.1.5.

*Step 5:* Initialize statistics by zeroing all bins of  $\text{epfd}_{\uparrow}$  values.

*Step 6:* If required calculate number of time steps and time step size using the algorithm in Part D, § 4.1.3 and hence calculate end time.

If a dual time step algorithm is included then use Sub-step 6.1, otherwise  $N_{\text{coarse}} = 1$  all the time.

*Sub-step 6.1:* Calculate coarse step size  $T_{\text{coarse}} = T_{\text{fine}} * N_{\text{coarse}}$ .

*Step 7:* Repeat Steps 8 to 24 for all time steps.

If a dual time step algorithm is included then repeat Sub-step 7.1 to Step 22 until end time is reached.

*Sub-step 7.1:* If it is the first time step then set  $T_{\text{step}} = T_{\text{fine}}$ .

*Sub-step 7.2:* Otherwise if there are less than  $N_{\text{coarse}}$  steps remaining then set  $T_{\text{step}} = T_{\text{fine}}$ .

*Sub-step 7.3:* Otherwise if any of the  $\alpha$  angles for the last time step were within  $\phi_{\text{coarse}}$  of the exclusion zone angle then set the  $T_{\text{step}} = T_{\text{fine}}$  otherwise use  $T_{\text{step}} = T_{\text{coarse}}$ .

*Step 8:* Update position vectors of all earth stations using algorithm in Part D, § 5.1.

*Step 9:* Update position and velocity vectors of all non-GSO satellites using algorithm in Part D, § 5.2.

*Step 10:* Update position vectors of GSO satellite using algorithm in Part D, § 5.3.

- Step 11:* Set  $\text{epfd}_{\uparrow} = 0$ .
- Step 12:* Repeat Steps 13 to 23 for all non-GSO earth stations.
- Step 13:* Determine if this non-GSO earth station is visible to the GSO satellite using the algorithm in Part D, § 5.4.2.
- Step 14:* If the non-GSO earth station is visible to the GSO satellite then do Steps 15 to 23.
- Step 15:* Repeat Steps 16 to 23 for the maximum number of non-GSO satellites that can be tracked.
- Step 16:* Select the  $i$ -th satellite away from the GSO arc that is above minimum elevation angle and not inside the GSO exclusion zone.
- Step 17:* If the algorithm has selected a satellite then do Steps 18 to 23.
- Step 18:* Calculate  $\text{ES\_EIRP}$  (dB(W/BW<sub>raf</sub>)) of non-GSO earth station in direction of GSO satellite using non-GSO earth station e.i.r.p. mask in Part C, § 3.

$$\text{REP\_EIRP} = \text{ES\_EIRP} + 10\log_{10}(\text{NUM\_ES})$$

- Step 19:* Calculate  $G_{RX}$  = receive relative gain (dB) at GSO satellite using relevant gain pattern specified in the algorithms in Part D, § 5.5.
- Step 20:* Calculate  $D$  = distance (km) between the non-GSO earth station and the GSO satellite using the algorithm in Part D, § 5.4.1.
- Step 21:* Calculate the spreading factor  $L_{FS} = 10 \log(4\pi D^2) + 60$ .
- Step 22:* Calculate  $\text{epfd}_{\uparrow i}$  for this non-GSO satellite:

$$\text{epfd}_{\uparrow i} = \text{REP\_EIRP} - L_{FS} + G_{RX} - G_{max}$$

- Step 23:* Increment  $\text{epfd}_{\uparrow}$  by  $\text{epfd}_{\uparrow i}$ .
- Step 24:* Increment  $\text{epfd}_{\uparrow}$  statistics by this  $\text{epfd}_{\uparrow}$ .

If a dual time step algorithm is included then the step below should be used:

*Sub-step 24.1:* Increment  $\text{epfd}_{\uparrow}$  statistics by the  $\text{epfd}_{\uparrow}$  for this time step by  $T_{step}/T_{fine}$  entries.

- Step 25:* Generate the  $\text{epfd}_{\uparrow}$  CDF from the  $\text{epfd}_{\uparrow}$  PDF using the algorithm in Part D, § 7.1.2.
- Step 26:* Compare  $\text{epfd}_{\uparrow}$  statistics with limits using algorithm in Part D, § 7.1.
- Step 27:* Output results in format specified in Part D, § 7.2.

#### 4.1.6.2 Analytical method approach

To calculate  $\text{epfd}_{\uparrow}$  values from one non-GSO system into one GSO system satellite the following algorithm should be used. The algorithm can be used on multiple GSO systems in parallel if required:

- Step 1:* Read in parameters for non-GSO system as specified in Part D, § 4.1.4.2.
- Step 2:* Read in GSO parameters as specified in Part D, § 4.1.4.3.
- Step 3:* If required calculate maximum  $\text{epfd}$  GSO location using algorithm in Part D, § 4.1.2, or other suitable method.
- Step 4:* If required calculate locations of non-GSO earth stations using algorithm in Part D, § 4.1.5.
- Step 5:* Initialize statistics by zeroing all bins of  $\text{epfd}_{\uparrow}$  values.
- Step 6:* Make a partition of the non-GSO reference satellite  $\phi$ - $\theta$  plane.
- Step 7:* Repeat Steps 8 to 25 for each element (cell) of the  $\phi$ - $\theta$  plane partition.
- Step 8:* Calculate the probability PROB of finding the non-GSO reference satellite inside the cell according to the expression in Part D, § 6.1.
- Step 9:* Place the non-GSO reference satellite at the centre of the cell.
- Step 10:* Determine the location of all other satellites in the constellation (there are two possible constellation configurations) according to the expressions in Part D, § 6.2.

*Step 11:* Repeat Steps 12 to 25 for each of the two configurations.

*Step 12:* Set  $\text{epfd}_{\uparrow} = 0$ .

*Step 13:* Repeat Steps 14 to 24 for all non-GSO earth stations.

*Step 14:* Calculate if this non-GSO earth station is visible to the GSO satellite using the algorithm in Part D, § 5.4.2.

*Step 15:* If the non-GSO earth station is visible to the GSO satellite then do Steps 16 to 24.

*Step 16:* Repeat Steps 17 to 24 for the maximum number of non-GSO satellites that can be tracked.

*Step 17:* Select the  $i$ -th satellite away from the GSO arc that is above minimum elevation angle and not inside the GSO exclusion zone.

*Step 18:* If the algorithm has selected a satellite then do Steps 19 to 24.

*Step 19:* Calculate  $\text{ES\_EIRP}$  (dB(W/BW<sub>ref</sub>)) of non-GSO earth station in direction of GSO satellite using non-GSO earth station e.i.r.p. mask in Part C, § 3.

$$\text{REP\_EIRP} = \text{ES\_EIRP} + 10\log_{10}(\text{NUM\_ES})$$

*Step 20:* Calculate  $G_{RX}$  = receive relative gain (dB) at GSO satellite using relevant gain pattern specified in the algorithms in Part D, § 5.5.

*Step 21:* Calculate  $D$  = distance (km) between the non-GSO earth station and the GSO satellite using the algorithm in Part D, § 5.4.1.

*Step 22:* Calculate the spreading factor  $L_{FS} = 10 \log(4\pi D^2) + 60$ .

*Step 23:* Calculate  $\text{epfd}_{\uparrow i}$  for this non-GSO satellite using the  $\text{REP\_EIRP}$  value calculated in Part D, § 4.1.5:

$$\text{epfd}_{\uparrow i} = \text{REP\_EIRP} - L_{FS} + G_{RX} - G_{\max}$$

*Step 24:* Increment  $\text{epfd}_{\uparrow}$  by  $\text{epfd}_{\uparrow i}$ .

*Step 25:* Locate in the  $\text{epfd}_{\uparrow}$  histogram the bin corresponding to the value of  $\text{epfd}_{\uparrow}$  and add  $\text{PROB}/2$  to it.

*Step 26:* Generate the  $\text{epfd}_{\uparrow}$  CDF from the  $\text{epfd}_{\uparrow}$  PDF using the algorithm in Part D, § 7.1.2.

*Step 27:* Compare  $\text{epfd}_{\uparrow}$  statistics with limits using the algorithm in Part D, § 7.1.

*Step 28:* Output results in format specified in Part D, § 7.2.

#### 4.1.7 Outputs

The result of the algorithm is two arrays of size  $\text{NEPFD}_{\uparrow}$  (as specified in Part D, § 4.1.1) in format:

Array of $\text{NEPFD\_UP EPFD}_{\uparrow}$ values	$\text{EPFD\_UP\_CALC}[I]$	dB(W/(m <sup>2</sup> · BW <sub>ref</sub> ))
Array of $\text{NEPFD\_UP}$ percentages	$\text{PC\_CALC}[I]$	%

where  $\text{PC\_CALC}[I]$  is percentage of time  $\text{EPFD\_UP\_CALC}[I]$  is exceeded.

## 4.2 $\text{epfd}_{\text{is}}$ software description

This section describes the algorithm to calculate  $\text{epfd}_{\text{is}}$  from non-GSO space stations into a GSO uplink. From the e.i.r.p. and off-axis angle for each space station, the  $\text{epfd}_{\text{is}}$  at the GSO space station can be calculated. This is repeated for a series of time steps (or reference satellite positions, in the analytical method) until a distribution of  $\text{epfd}_{\text{is}}$  is produced. This distribution can then be compared with the limits to give a go/no go decision.

### 4.2.1 Configuration parameters

This sub-section specifies the parameters required for all  $\text{epfd}_{\text{is}}$  calculations. This would be a data-set of  $N$  sets of limits that can be shared between runs. The Table could be queried so that the required values can be used depending upon non-GSO system frequency.

For each set of limits the following would be defined as specified in Part B, § 2.2.

Parameter name	Parameter value	Parameter units and ranges
Frequency band start	FSTART_IS	GHz
Frequency band end	FEND_IS	GHz
Applicable Region 1	REGION1_IS	Yes or No
Applicable Region 2	REGION2_IS	Yes or No
Applicable Region 3	REGION3_IS	Yes or No
GSO gain pattern	GSO_SAT_PATTERN	One of those in Part D, § 5.5
GSO peak gain	GSO_SAT_PEAKGAIN	dBi
GSO half power beamwidth	GSO_SAT_BEAMWIDTH	degrees
Reference bandwidth	RIFBW	kHz
Number of $\text{epfd}_{\text{is}}$ points	NEPFD_IS	–
Array of NEPFD_IS $\text{epfd}_{\text{is}}$ values	EPFD_IS[I]	$\text{dB}(\text{W}/(\text{m}^2 \cdot \text{BW}_{\text{ref}}))$
Array of NEPFD_IS percentages	PC_IS[I]	%

From the EPFD\_IS[I] arrays the number of bins and bin ranges can be calculated using:

*Step 1:* Calculate EPFD\_IS\_MIN = minimum value in EPFD\_IS[I] array.

*Step 2:* Calculate EPFD\_IS\_MAX = maximum value in EPFD\_IS[I] array.

*Step 3:* Calculate EPFD\_IS\_START by rounding EPFD\_IS\_MIN to nearest 10 dB below.

*Step 4:* Calculate EPFD\_IS\_END by rounding EPFD\_IS\_MAX to nearest 10 dB above.

*Step 5:* Number of bins =  $(\text{EPFD\_IS\_END} - \text{EPFD\_IS\_START})/S_B$ .

This will give a set of bins that are of size  $S_B$  (bin size specified in Part D, § 2.5) and are below and above the  $\text{epfd}_{\text{is}}$  limits required.

#### 4.2.2 Determination of maximum epfd configuration

The maximum epfd location of GSO satellite and beam centre is defined in Part C'.

#### 4.2.3 Calculation of run steps

##### 4.2.3.1 Time simulation approach

A single time step and number of time steps are calculated using the algorithm in Part A.

##### 4.2.3.2 Analytical approach

The longitude and latitude steps for the position of the reference satellite are chosen according to the procedure in Part D, § 6.3.

#### 4.2.4 Inputs and file formats

##### 4.2.4.1 Input parameters

This sub-section defines the input parameters for a particular non-GSO system scenario. In this case, input is a generic term that could include files or user input. Information is required for:

- non-GSO system;
- GSO system;
- run configuration.

#### 4.2.4.2 Non-GSO system parameters

The following parameters, as specified in Part B, § 2.1 would be used:

Parameter description	Parameter name	Parameter units
Number of non-GSO satellites	$N_{sat}$	–
Orbit has repeating ground track maintained by station keeping	Yes or No	–
Administration is supplying specific node precession rate	Yes or No	–
Station keeping range for ascending node as half total range	$W_{delta}$	degrees

For each satellite the following parameters specified in Part B, § 2.1 would be used, where the definitions of the parameters are specified in Part B, § 5.3.1 at the time of the start of the simulation.

Note that in the Table below, the indices [N] are present to indicate that there would be a different value for each satellite, and the  $N$ -th value corresponds to the  $N$ -th satellite.

Parameter description	Parameter name	Parameter units
Semi-major axis	A[N]	km
Eccentricity	E[N]	–
Inclination	I[N]	degrees
Longitude of ascending node	O[N]	degrees
Argument of perigee	W[N]	degrees
True anomaly	V[N]	degrees

Each satellite must have an independent set of six orbital parameters for orbit definition and subsequent propagation.

To define the characteristics of non-GSO earth stations, the following parameters, as specified in Part B, § 2.1 would be used:

Parameter description	Parameter name	Parameter units
e.i.r.p. per space station	non-GSO_SS_EIRP	dB(W/BW <sub>ref</sub> )
Number of frequency/regions <sup>(1)</sup>	$N_{freq}$	–
Region <sup>(1)</sup>	One of 1, 2 or 3	–
Minimum transmit frequency <sup>(1)</sup>	IS_F	GHz

<sup>(1)</sup> The filing administration can supply a set of (earth station frequency, applicable region). The ITU database of limits can be searched to extract those applicable for each set.

#### 4.2.4.3 GSO system parameters

The GSO system can be either calculated or use worst-case parameters using the algorithm in Part D, § 5.2 or entered values. The required parameters as specified in Part B, § 2.1 are:

Parameter description	Parameter name	Parameter units
GSO satellite longitude	GSO_SAT_LONG	degrees
GSO boresight latitude	BS_LAT	degrees
GSO boresight longitude	BS_LONG	degrees
GSO reference gain pattern	GSO_SAT_PATTERN	One of those in Part D, § 5.5



These parameters are defined in Part D, § 5.1 and 5.2.

#### 4.2.4.4 Run parameters

The run parameters can be either calculated using the algorithm in Part D, § 4.1.3 or entered values. For the time simulation approach, the required parameters are:

Parameter description	Parameter name	Parameter units
Time step	TSTEP	s
Number of time steps	NSTEPS	–
Precession mechanism	J2 or Admin Supplied or Artificial	–
Precession rate	ORBIT_PRECESS	degrees/s

For the analytical method approach, the required parameters are related to increments in the reference satellite position:

Parameter description	Parameter name	Parameter units
Longitude step for the coarse grid	PHISTEPCG	degrees
Latitude step for the coarse grid	THETASTEPCG	degrees
Longitude step for the fine grid	PHISTEPFG	degrees
Latitude step for the fine grid	THETASTEFG	degrees

#### 4.2.4.5 Other parameters

The run would also use the  $\text{epfd}_{\text{is}}$  limits database from Part D, § 4.1.1 to get three defining parameters for the  $\text{epfd}_{\text{is}}$  statistics:

Parameter description	Parameter name	Parameter units
Starting value for $\text{epfd}_{\text{is}}$ bins	EPFD_IS_START	$\text{dB}(\text{W}/(\text{m}^2 \cdot \text{BW}_{\text{ref}}))$
Bin size (Part D, § 2.5)	$S_B$	$\text{dB}(\text{W}/(\text{m}^2 \cdot \text{BW}_{\text{ref}}))$
Number of $\text{epfd}_{\text{is}}$ bins	N_BINS	–

#### 4.2.4.6 File formats

File formats should be in ASCII (text) format to allow visual inspection and modification of the input parameters to the routines. It would also be acceptable to have the input parameters in a binary database format if a graphical interface is provided to view and modify input parameters before running the simulation.

#### 4.2.5 Algorithms and calculation procedures

In the calculation of the dual time step for the  $\text{epfd}_{\text{is}}$  computation,  $N_{\text{coarse}} = 1$ .

#### 4.2.5.1 Time simulation approach

To calculate  $\text{epfd}_{\text{is}}$  values from one non-GSO system into one GSO system satellite the following algorithm should be used. The algorithm can be used on multiple GSO systems in parallel if required:

*Step 1:* Read in parameters for non-GSO system as specified in Part D, § 4.1.4.2.

*Step 2:* Read in GSO parameters as specified in Part D, § 4.1.4.3.

*Step 3:* If required calculate worst-case GSO location using algorithm in Part D, § 4.1.2.

*Step 4:* Initialize statistics by zeroing all bins of  $\text{epfd}_{\text{is}}$  values.

*Step 5:* If required calculate number of time steps and time step size using algorithm in Part D, § 4.1.3 and hence calculate end time.

If a dual time step algorithm is included then use Sub-step 5.1, otherwise  $N_{\text{coarse}} = 1$  all the time.

*Sub-step 5.1:* Calculate coarse step size  $T_{\text{coarse}} = T_{\text{fine}} * N_{\text{coarse}}$ .

*Step 6:* Repeat Steps 7 to 19 for all time steps.

If a dual time step algorithm is included then repeat Sub-step 6.1 to Step 17 until end time is reached.

*Sub-step 6.1:* If it is the first time step then set  $T_{\text{step}} = T_{\text{fine}}$ .

*Sub-step 6.2:* Otherwise if there are less than  $N_{\text{coarse}}$  steps remaining then set  $T_{\text{step}} = T_{\text{fine}}$ .

*Sub-step 6.3:* Otherwise if the any of the  $\alpha$  angles for the last time step were within  $\phi_{\text{coarse}}$  of the exclusion zone angle then set the  $T_{\text{step}} = T_{\text{fine}}$  otherwise use  $T_{\text{step}} = T_{\text{coarse}}$ .

*Step 7:* Update position and velocity vectors of all non-GSO satellites using algorithm in Part D, § 5.2.

*Step 8:* Update position vectors of GSO satellite using algorithm in Part D, § 5.3.

*Step 9:* Set  $\text{epfd}_{\text{is}} = 0$ .

*Step 10:* Repeat Steps 10 to 18 for all non-GSO space stations.

*Step 11:* Determine if this non-GSO space station is visible to the GSO satellite using the algorithm in Part D, § 5.4.2.

*Step 12:* If the non-GSO space station is visible to the GSO satellite then do Steps 13 to 18.

*Step 13:* Calculate e.i.r.p. (dB(W/BW<sub>ref</sub>)) of non-GSO space station in direction of GSO satellite using the e.i.r.p. mask in Part C, § 3.

*Step 14:* Calculate  $G_{RX}$  = receive relative gain (dB) at GSO satellite using relevant gain pattern specified in algorithms in Part D, § 5.5.

*Step 15:* Calculate  $D$  = distance (km) between the non-GSO space station and the GSO satellite using the algorithm in Part D, § 5.4.1.

*Step 16:* Calculate the spreading factor  $L_{FS} = 10 \log(4\pi D^2) + 60$ .

*Step 17:* Calculate  $\text{epfd}_{\text{isi}}$  for this non-GSO satellite:

$$\text{epfd}_{\text{isi}} = \text{e.i.r.p.} - L_{FS} + G_{RX} - G_{\text{max}}$$

*Step 18:* Increment  $\text{epfd}_{\text{is}}$  by  $\text{epfd}_{\text{isi}}$ .

*Sub-step 19:* Increment  $\text{epfd}_{\text{is}}$  statistics by this  $\text{epfd}_{\text{is}}$ .

If a dual time step algorithm is included then the step below should be used:

*Sub-step 19.1:* Increment  $\text{epfd}_{\text{is}}$  statistics by the  $\text{epfd}_{\text{is}}$  for this time step by  $T_{\text{step}}/T_{\text{fine}}$  entries.

*Step 20:* Generate the  $\text{epfd}_{\text{is}}$  CDF from the  $\text{epfd}_{\text{is}}$  PDF using the algorithm in Part D, § 7.1.2.

*Step 21:* Compare  $\text{epfd}_{\text{is}}$  statistics with limits using algorithm in Part D, § 7.1.

*Step 22:* Output results in format specified in Part D, § 7.2.

### 4.2.5.2 Analytical method approach

To calculate  $\text{epfd}_{\text{is}}$  values from one non-GSO system into one GSO system satellite the following algorithm should be used. The algorithm can be used on multiple GSO systems in parallel if required:

- Step 1:* Read in parameters for non-GSO system as specified in Part D, § 4.1.4.2.
- Step 2:* Read in GSO parameters as specified in Part D, § 4.1.4.3.
- Step 3:* If required calculate worst-case GSO location using algorithm in Part D, § 4.1.2.
- Step 4:* Initialize statistics by zeroing all bins of  $\text{epfd}_{\text{is}}$  values.
- Step 5:* Make a partition of the non-GSO reference satellite  $\phi$ - $\theta$  plane.
- Step 6:* Repeat Steps 7 to 19 for each element (cell) of the  $\phi$ - $\theta$  plane partition.
- Step 7:* Calculate the probability PROB of finding the non-GSO reference satellite inside the cell according to the expression in Part D, § 6.1.
- Step 8:* Place the non-GSO reference satellite at the centre of the cell.
- Sub-step 8.1:* Determine the location of all other satellites in the constellation (there are two possible constellation configurations) according to the expressions in Part D, § 6.2.
- Sub-step 8.2:* Repeat Steps 9 to 19 for each of the two configurations.
- Step 9:* Set  $\text{epfd}_{\text{is}} = 0$ .
- Step 10:* Repeat Steps 10 to 18 for all non-GSO space stations.
- Step 11:* Determine if this non-GSO space station is visible to the GSO satellite using the algorithm in Part D, § 5.4.2.
- Step 12:* If the non-GSO space station is visible to the GSO satellite then do Steps 13 to 18.
- Step 13:* Calculate e.i.r.p. ( $\text{dB}(\text{W}/\text{BW}_{\text{rif}})$ ) of non-GSO space station in direction of GSO satellite using the e.i.r.p. mask in Part C, § 3.
- Step 14:* Calculate  $G_{\text{RX}}$  = receive relative gain (dB) at GSO satellite using relevant gain pattern specified in algorithms in Part D, § 5.5.
- Step 15:* Calculate  $D$  = distance (km) between the non-GSO space station and the GSO satellite using the algorithm in Part D, § 5.4.1.
- Step 16:* Calculate the spreading factor  $L_{\text{FS}} = 10 \log(4\pi D^2) + 60$ .
- Step 17:* Calculate  $\text{epfd}_{\text{isi}}$  for this non-GSO satellite:
- $$\text{epfd}_{\text{isi}} = \text{e.i.r.p.} - L_{\text{FS}} + G_{\text{RX}} - G_{\text{max}}$$
- Step 18:* Increment  $\text{epfd}_{\text{is}}$  by  $\text{epfd}_{\text{isi}}$ .
- Step 19:* Locate in the  $\text{epfd}_{\text{is}}$  histogram the bin corresponding to the value of  $\text{epfd}_{\text{is}}$  and add  $\text{PROB}/2$  to it.
- Step 20:* Generate the  $\text{epfd}_{\text{is}}$  CDF from the  $\text{epfd}_{\text{is}}$  PDF using the algorithm in Part D, § 7.1.2.
- Step 21:* Compare  $\text{epfd}_{\text{is}}$  statistics with limits using algorithm in Part D, § 7.1.
- Step 22:* Output results in format specified in Part D, § 7.2.

### 4.2.6 Outputs

The result of the algorithm is two arrays of size  $\text{NEPFD}_{\text{is}}$  (as specified in Part D, § 4.1) in format:

Array of $\text{NEPFD}_{\text{IS}}$ EPFD <sub>is</sub> values	EPFD_IS_CALC[I]	$\text{dB}(\text{W}/(\text{m}^2 \cdot \text{BW}_{\text{rif}}))$
Array of $\text{NEPFD}_{\text{IS}}$ percentages	PC_CALC[I]	%

where PC\_CALC[I] is percentage of time EPFD\_IS\_CALC[I] is exceeded.

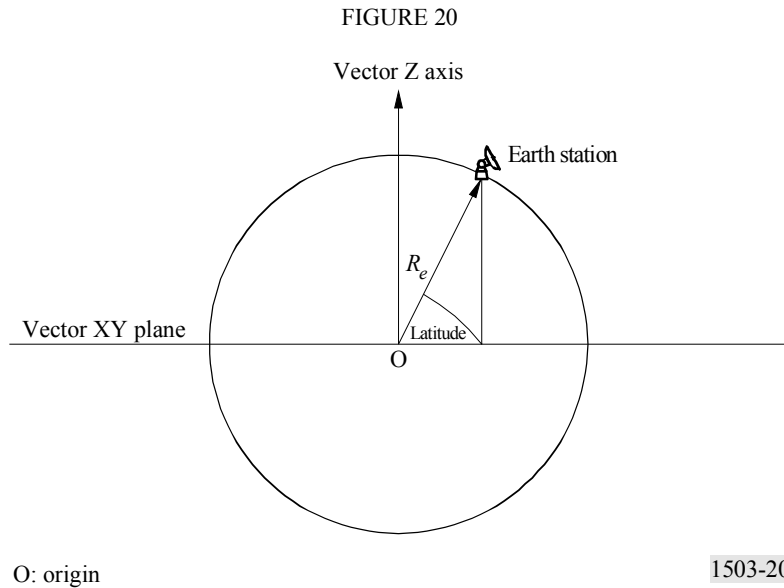
## 5 Geometry and algorithms

This section describes the geometry that defines the core algorithms used in the software. One aspect is the conversion into a generic cartesian vector based coordinate system. The precise orientation of the  $X$  vector is not specified in this Recommendation to allow alternative implementations by developers. The axis chosen should not impact the results as satellite and Earth coordinates are defined relative to the Earth.

To aid developers examples coordinate systems are used to show how to convert to and from generic vectors.

### 5.1 Earth coordinates system

Figure 20 shows the reference coordinate system for earth stations.

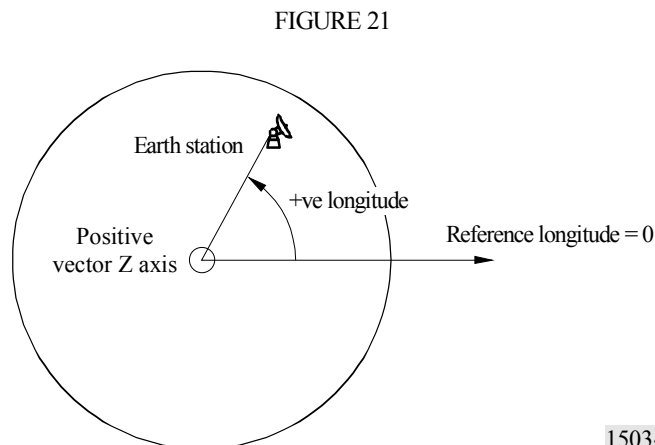


The Earth is defined as a sphere with radius as specified in Part D, § 2.5 =  $R_e$ . The Earth rotates around an axis, the  $Z$  axis, at a rate defined in Part D, § 2.5 =  $\Omega_e$ . Perpendicular to the  $Z$  axis, crossing the Earth at the Equator, is the  $XY$  plane.

Earth stations are located on this sphere based upon two angles:

**Latitude:** angle between line from centre of Earth to earth station and  $XY$  plane

**Longitude:** angle as shown in Figure 21.



Earth stations are assumed to have constant position in time.

The orientation within the XY plane of the X and Y axes is not specified in this Recommendation as all locations are referenced to the Earth rather one particular inertial frame. This allows different implementations to use different reference points if required without impacting on the results.

One possible implementation is what is described as the geocentric inertial system. For this example case, conversion from geographic coordinates is achieved using:

$$\text{Long} = \arccos\left(\frac{x}{\sqrt{x^2 + y^2}}\right) \quad \text{if } x \geq 0 \quad (11)$$

$$\text{Long} = -\arccos\left(\frac{x}{\sqrt{x^2 + y^2}}\right) \quad \text{if } x < 0 \quad (12)$$

$$\text{Lat} = \arctan\left(\frac{z}{\sqrt{x^2 + y^2}}\right) \quad (13)$$

If this example coordinate system is used, then the conversion from geographic coordinates into geocentric inertial system coordinates is:

$$x = R_e \cos(\text{lat}) \cos(\text{long}) \quad (14)$$

$$y = R_e \cos(\text{lat}) \sin(\text{long}) \quad (15)$$

$$z = R_e \sin(\text{lat}) \quad (16)$$

where:

$(x, y, z)$ : coordinates in the geocentric inertial system

long: geographic longitude

lat: geographic latitude.

In this example geocentric inertial reference system the equation for motion of a mass point on the Earth's surface would be as:

$$\begin{bmatrix} x \\ y \\ z \end{bmatrix} = \begin{bmatrix} R_e \cos(\text{lat}) \cos(\text{lon} + \Omega_e t) \\ R_e \cos(\text{lat}) \sin(\text{lon} + \Omega_e t) \\ R_e \sin(\text{lat}) \end{bmatrix} \quad (17)$$

where:

lat: geographic latitude of the mass point on the Earth's surface

lon: geographic longitude of the mass point on the Earth's surface

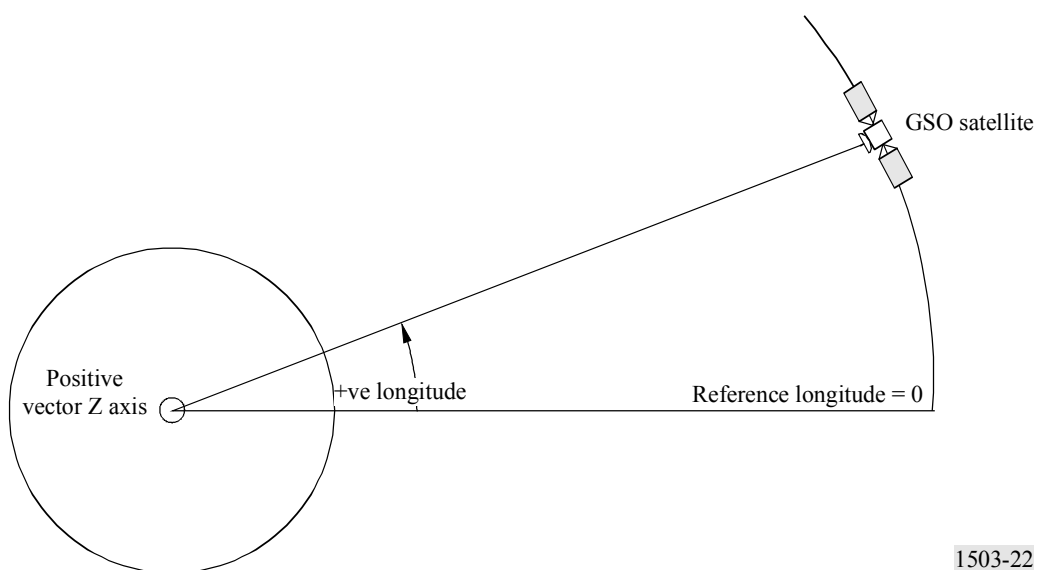
$t$ : time

$\Omega_e$ : angular rate of rotation of the Earth.

## 5.2 GSO satellite coordinate system

The geostationary arc is a circle in the XY plane at a distance of  $R_{geo}$  from the Earth's centre where  $R_{geo}$  is specified in Part A, § 1.3. Individual geostationary satellites have location on this circle defined by a longitude as shown in Fig. 22.

FIGURE 22



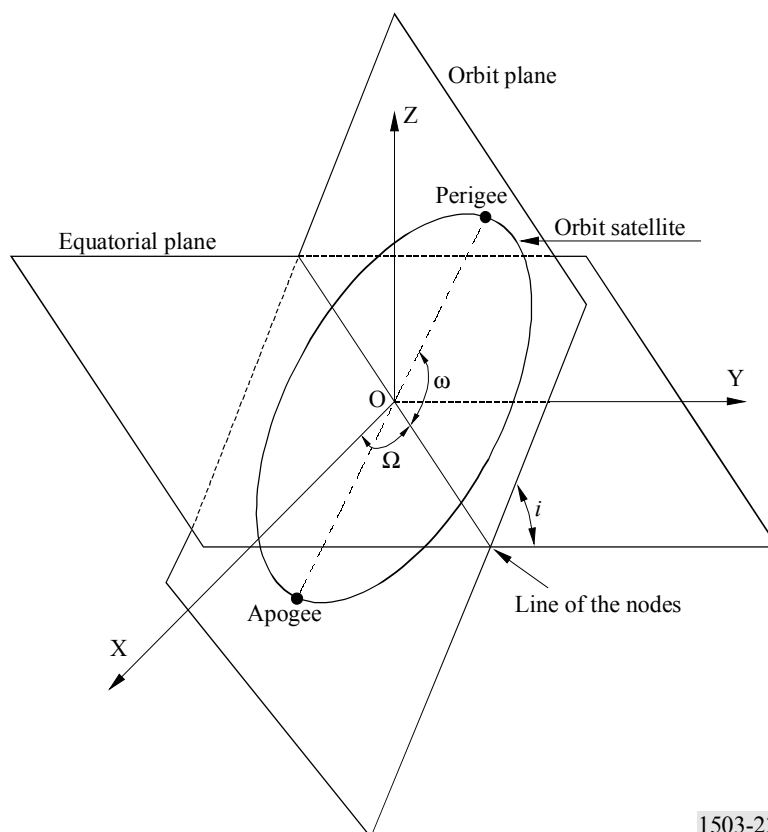
Geostationary satellites are assumed to have constant longitude in time. The conversion to and from vectors can use the same algorithms as in the section above by setting the latitude to zero.

### 5.3 Non-GSO satellite coordinate system

#### 5.3.1 Non-GSO satellite orbit parameters

This section defines the parameters that specify an orbit for non-GSO satellites. Non-GSO satellites move in a plane as shown in Fig. 23.

FIGURE 23

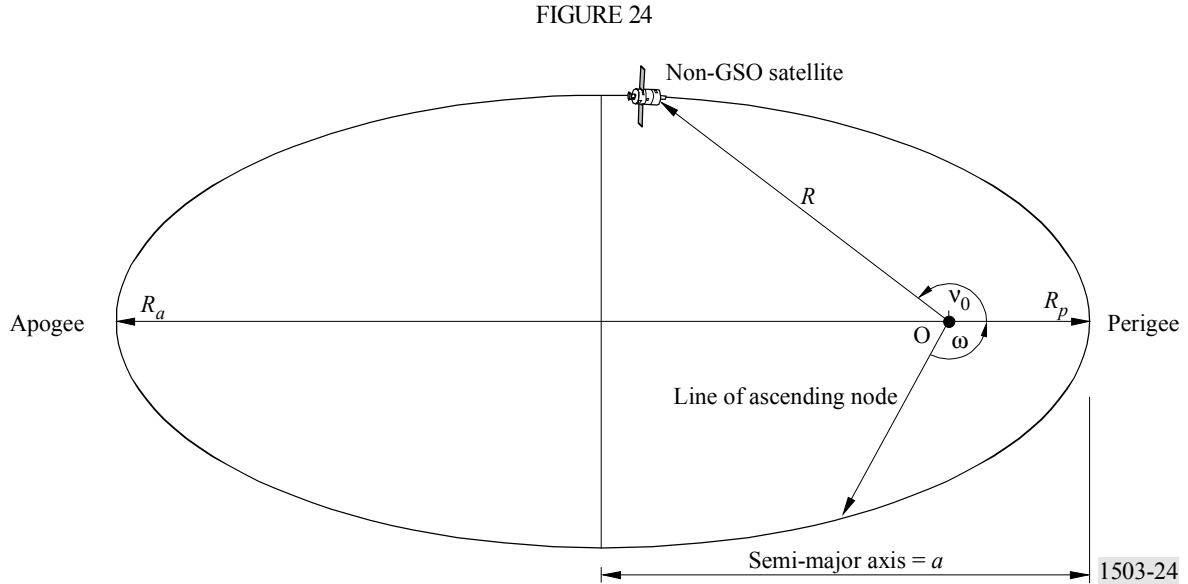


The plane of the orbit is referenced to the Earth by two angles:

$\Omega$ : longitude of ascending node: This defines where the ascending orbit plane intersects the equatorial plane. As the orbit is fixed in inertial space while the Earth rotates, a time reference for which this angle is valid must be given. In this case it is the start of the simulation.

$i$ : inclination angle: This is defined as the angle between the plane of the orbit and the equatorial plane.

The orbit and position of the non-GSO satellite within the orbit is then defined by further parameters as shown in Fig. 24.



The shape of the orbit is defined by:

$$a = (R_a + R_p)/2 \quad (18)$$

$$e = (R_a - R_p) / (R_a + R_p) \quad (19)$$

where:

$a$ : semi-major axis

$e$ : eccentricity

$R_a$ : distance from the centre of the Earth to the satellite at apogee

$R_p$ : distance from the centre of the Earth to the satellite at perigee.

The position of the perigee within the orbit plane is defined by:

$\omega$ : argument of perigee, angle between the line of the nodes and perigee.

The position of a non-GSO satellite within the plane at a particular time is defined by:

$v_0$ : angle between perigee and specified point on orbit.

For circular orbits,  $\omega$ , can be set to zero and  $v_0$  assumed to be the same as the argument of latitude defined as:

$$\mu_0 = \omega + v_0 \quad (20)$$

Other useful terms are:

$$p = a(1 - e^2) \quad (21)$$

$$M = E - e \sin E \quad (22)$$

$$\tan \frac{v}{2} = \sqrt{\frac{1+e}{1-e}} \tan \frac{E}{2} \quad (23)$$

$$R = \frac{p}{1 + e \cos(v)} \quad (24)$$

$$T = 2\pi\sqrt{a^3/\mu} \quad (25)$$

where:

$p$ : focal parameter

$E$ : eccentric anomaly

$M$ : mean anomaly

$T$ : period of orbit

$R$ : distance from centre of Earth to satellite when satellite is at position  $v$ .

These can be used by the algorithm to predict the future position of the non-GSO satellite as described in § 5.3.2.

### 5.3.2 Non-GSO satellite orbit predictor

Given the orbital elements in the section above, standard orbit mechanics can be used to predict the position of the satellite at future times. In addition there are two additional precession factors for the ascending node and argument of perigee as described below.

*Orbit pecession in acending node longitude.* The rate of ascending node longitude secular drift is defined as:

$$\Omega_r = -\frac{J_\alpha \cos(i)}{p^2 \sqrt{a^3 \mu}} \quad (26)$$

It follows from the above that polar orbits have zero precession rate and equatorial ones have a maximum precession rate. With direct satellite motion ( $i < 90^\circ$ ) the ascending node shifts to the west (to  $\Omega$  decreasing) and with reverse satellite motion ( $i > 90^\circ$ ) it shifts to the east (to  $\Omega$  increasing).

*Perigee argument precession.* Perigee argument secular shift rate is defined as:

$$\omega_r = \frac{J_\alpha (5 \cos^2(i) - 1)}{2p^2 \sqrt{a^3 \mu}} \quad (27)$$

Perigee argument precession rate at  $i = 0$  and  $i = 180$  is maximum. For  $i_1 = 63^\circ 26' 06''$  or  $i_2 = 116^\circ 33' 54''$  the precession rate is zero. If  $i < i_1$  or  $i > i_2$ , then the perigee precession is along a satellite motion direction, and if  $i_1 < i < i_2$ , then it is in the opposite direction.

Other precessions, such as periodic perigee argument precession rate are not taken into account since their effect is negligible.

#### *Use of precession terms*

The Earth's oblateness causes orbit plane shift along the ascending node longitude and perigee argument shift. Since three orbital parameters ( $i, p, e$ ) are constant during satellite motion two parameters ( $\Omega$  and  $\omega$ ) would vary with time.



Perigee argument is defined as:

$$\omega = \omega_0 + \omega_r t \quad (28)$$

where:

$\omega_0$ : perigee argument at an initial moment

$\omega_r$ : perigee argument precession rate.

A current value of an ascending node longitude is defined as:

$$\Omega = \Omega_0 + \Omega_r t \quad (29)$$

where:

$\Omega_0$ : ascending node longitude at an initial moment

$\Omega_r$ : ascending node longitude precession rate.

The conversion to generic cartesian based vector would depend upon the direction of the  $X$  vector. For an example coordinate system and for circular orbits, the satellite motion expression in the geocentric inertial reference system could be defined as:

$$\begin{bmatrix} x \\ y \\ z \end{bmatrix} = \begin{bmatrix} R(\cos(v + \omega)\cos(\Omega) - \sin(v + \omega)\sin(\Omega)\cos(i)) \\ R(\cos(v + \omega)\sin(\Omega) + \sin(v + \omega)\cos(\Omega)\cos(i)) \\ R\sin(v + \omega)\sin(i) \end{bmatrix} \quad (30)$$

A satellite motion in an elliptical orbit is non-uniform therefore the Kepler expression and a concept of a mean anomaly would be used in the model to define the real anomaly as a function of time. Since an explicit dependence of the true anomaly on time is unavailable so the numerical methods of solving the below expressions were used for its definition. The expression is:

$$M = \sqrt{\frac{\mu}{a^3}} (t - t_0) \quad (31)$$

As use of the  $E$  and  $M$  are not recommended for all types of orbits, transformations can be done such as using the universal variable  $x$  defined by:

$$\frac{dx}{dt} = \frac{\sqrt{\mu}}{r} \quad (32)$$

### 5.3.3 Non-GSO satellite orbit station keeping

An important aspect to station keeping is to simulate multiple passes of the non-GSO satellite through an earth station's main beam with slightly different crossing directions. As changing the position within the plane does not effect this then the main parameter to vary is the longitude of the ascending node.

The approach proposed is to give range  $\pm W_{\text{delta}}$  in longitude of ascending node. At the start of the simulation all stations in the constellation have this parameter offset by  $-W_{\text{delta}}$ . During the simulation this field would increase to 0 (at the run's mid point) and then increase to  $\pm W_{\text{delta}}$ .

This is implemented by rotating the station's position and velocity vectors around the  $Z$  axis by the required angle as specified in Part D, § 5.3.4

### 5.3.4 Forced orbit precession

The standard orbit prediction algorithm is based upon point Earth mass plus correcting factors for  $J_2$  perturbations. There are two cases where this requires to be over-ridden:

- where administrations supply a detailed value of the orbit precession rate with respect to a point Earth mass to ensure a repeat ground track;
- for non-repeat orbits where an artificial precession rate is used to ensure the required spacing between equatorial passes.

This is achieved by rotating the non-GSO satellite position and velocity vectors around the Z axis by the required angle, using rotation matrix:

$$\begin{bmatrix} x' \\ y' \\ z' \end{bmatrix} = \begin{pmatrix} \cos\theta & -\sin\theta & 0 \\ \sin\theta & \cos\theta & 0 \\ 0 & 0 & 1 \end{pmatrix} \begin{bmatrix} x \\ y \\ z \end{bmatrix} \quad (33)$$

to rotate by angle  $\theta$ .

NOTE 1 – The software should check the orbit precession rate supplied under item a) for self-consistency with the other input parameters.

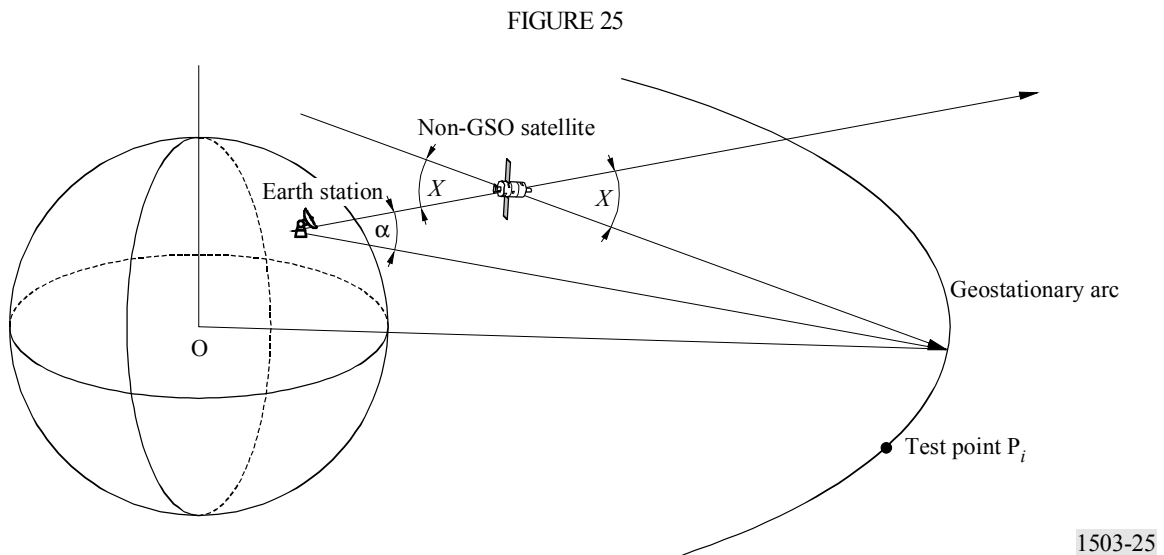
## 5.4 Geometry

### 5.4.1 Satellite visibility check

Two stations, whether earth stations or satellites, are visible if the direct distance between them is less than the sum of the distance to the horizon for each station, using the spherical Earth model described in § 5.1.

### 5.4.2 Angle to GSO arc

Figure 25 shows the definition of the  $\alpha$  angle and  $X$  angle.



The Figure shows a test earth station and non-GSO satellite.

For each test point  $P_i$  on the GSO arc there is a line from the earth station that intersects that point. There is then an angle  $\alpha_i$  between that line and a line from the earth station to the non-GSO satellite.

The  $\alpha$  angle is the minimum of all the test points, i.e.

$$\alpha = \min (\alpha_i)$$

Similarly for each test point  $P_i$  on the GSO arc there is a line from the non-GSO satellite that intersects that point. There is then an angle  $X_i$  between that line and a line from the earth station to the non-GSO satellite.

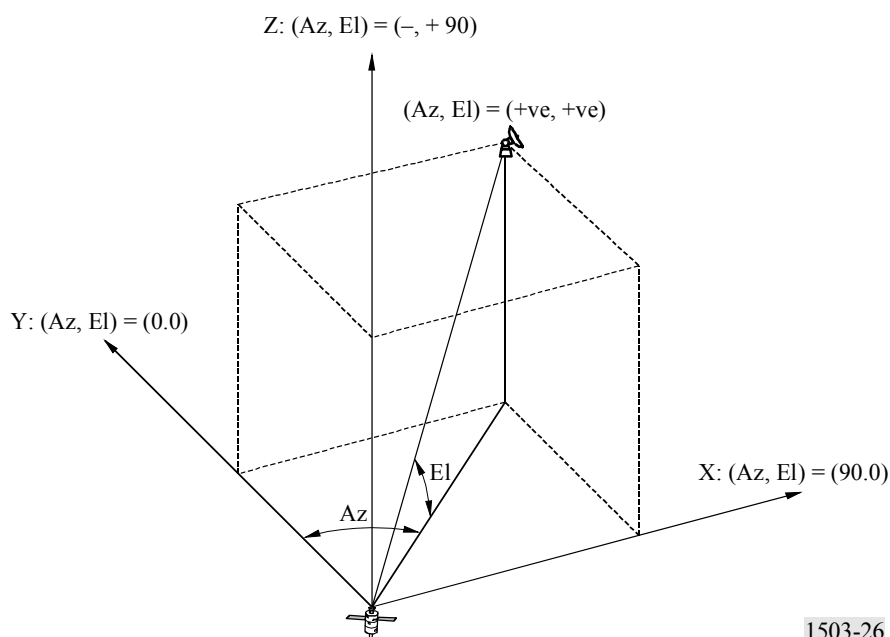
The  $X$  angle is the minimum of all the test points, i.e.

$$X = \min (X_i)$$

### 5.4.3 Satellite azimuth and elevation

Figure 26 shows the definition of the azimuth and elevation angles used for the non-GSO satellite:

FIGURE 26



It should be noted that direction of the cartesian  $X$ ,  $Y$ ,  $Z$  vectors in this diagram are:

- $X$ : +ve in the East direction from the non-GSO satellite
- $Y$ : towards the centre of the Earth from the non-GSO satellite
- $Z$ : +ve towards the North direction from the non-GSO satellite.

## 5.5 Gain patterns

This section defines the gain patterns used in the algorithms for earth stations and satellites. Note that all formula include the peak gain, so where relative gain is required the peak gain should be subtracted.

### 5.5.1 GSO earth station gain patterns

#### 5.5.1.1 FSS earth station gain pattern

The FSS earth station gain pattern to use is specified in Recommendation ITU-R S.1428.

#### 5.5.1.2 BSS earth station gain pattern

The BSS earth station gain pattern to use is specified in Recommendation ITU-R BO.1443.

### 5.5.2 GSO satellite gain pattern

The values of peak gain and half power beamwidth and the antenna reference radiation pattern to use are specified in RR Article S22.

### 5.5.3 Non-GSO earth station gain pattern

These data would be supplied as part of non-GSO filing, either in the form of tabulated values or as references to standard patterns defined in ITU-R Recommendations.

## 6 The analytical method approach

The analytical method can be used to evaluate the statistical behaviour of interference (e.g. epfd) in environments containing non-GSO networks. In the following paragraphs the analytical method is applied to evaluate the statistical behaviour of the epfd levels produced by a non-GSO network into receivers (earth station or satellites) of GSO networks.

## Methodology

Let us consider an interference environment involving one non-GSO interfering network and one (or more) GSO victim networks. The approach being considered in this method to assess interference in such an environment takes into account the fact that, once the position of one particular satellite (here referred to as the reference satellite) in the non-GSO interfering constellation is known, the epfd levels affecting the receivers in GSO satellite networks (considering that all systems parameters are given) can be uniquely determined. It further assumes that the positions of this reference satellite is characterized by a random vector. Based on these assumptions, epfd levels can be seen as random variables that are deterministic functions of the random position  $\mathbf{x} = (\varphi, \theta)^T$  (longitude  $\varphi$  and latitude  $\theta$ ) of the non-GSO reference satellite, and therefore their probability density functions can be determined from the probability density function  $p_x(\Phi, \Theta)$  of the position (longitude and latitude) of the reference satellite.

For a satellite placed in elliptical orbit around the Earth, when the argument of the perigee equals  $\pm\pi/2$ , this probability density function (see Note 1) is given by:

$$p_x(\Phi, \Theta) = \begin{cases} \frac{k(1+e)}{2\pi^2} \frac{\cos\Theta}{\sqrt{\sin^2 \delta - \sin^2 \Theta}} \left[ \frac{2 \sin \delta}{(1+k^2)\sin \delta - (1-k^2)g(\Theta)} \right]^2 & \text{for } \begin{matrix} -\delta < \Theta \leq \delta \\ -\pi < \Phi \leq \pi \end{matrix} \\ 0 & \text{otherwise} \end{cases} \quad (34)$$

where:

$\delta$ : angle between the orbital plane and the equatorial plane.

$$k = \sqrt{\frac{1+e}{1-e}} \quad (35)$$

$e$ : denoting the orbit eccentricity, and

$$g(\Theta) = \cos \omega \sqrt{\sin^2 \delta - \sin^2 \Theta} + \sin \omega \sin \Theta \quad (36)$$

where  $\omega$  is the argument of the perigee.

Using equation (34), it is possible, for example, to obtain the probability of having a satellite inside any given region in the sky. In the particular case of circular orbits ( $e = 0 \rightarrow k = 1$ ), equation (34) is reduced to:

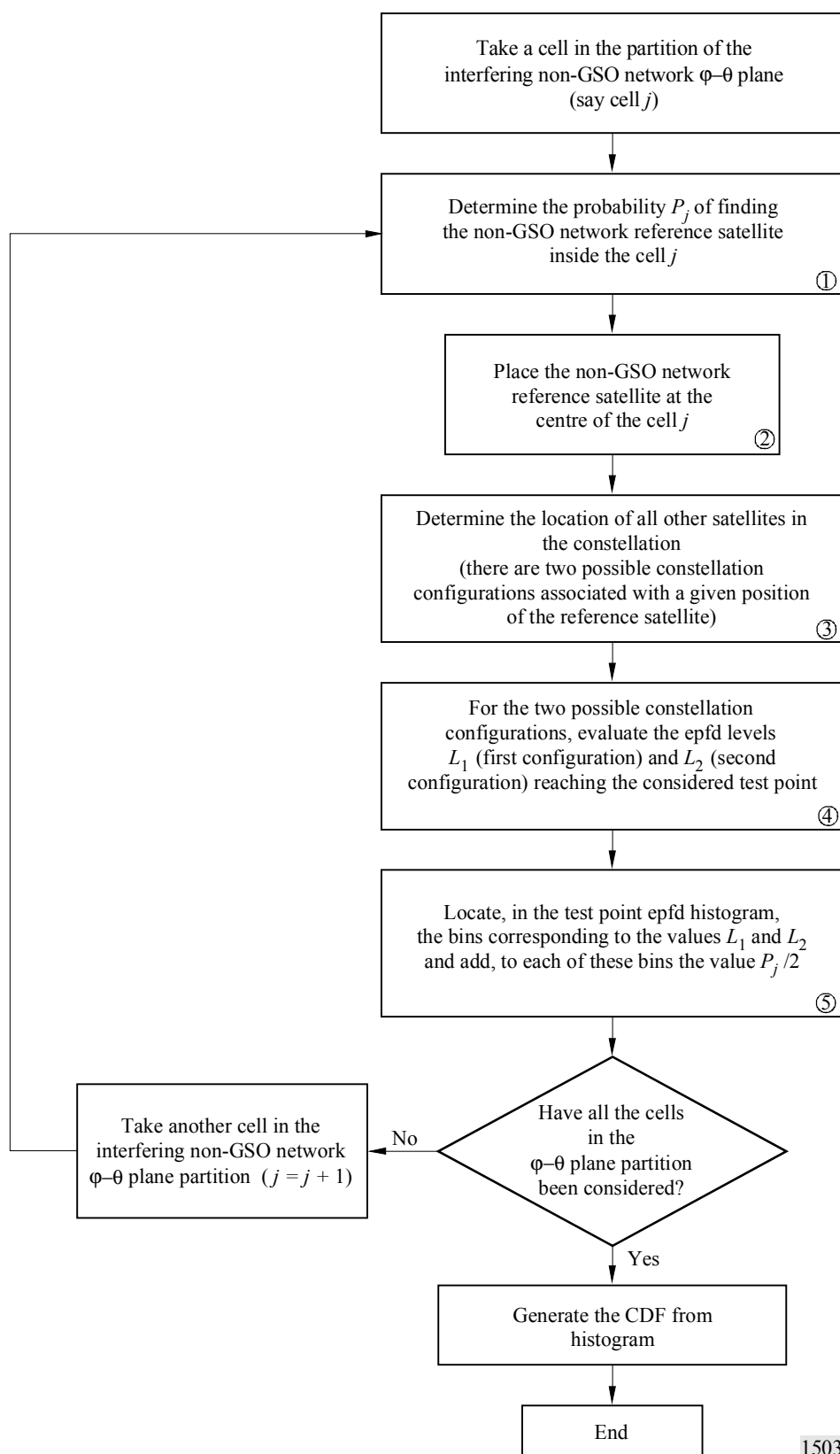
$$p_x(\Phi, \Theta) = \begin{cases} \frac{1}{2\pi^2} \frac{\cos \Theta}{\sqrt{\sin^2 \delta - \sin^2 \Theta}} & \text{for } \begin{matrix} -\delta < \Theta \leq \delta \\ -\pi < \Phi \leq \pi \end{matrix} \\ 0 & \text{otherwise} \end{cases} \quad (37)$$

NOTE 1 – A general expression for this probability density function, valid for any elliptical orbit satellite, has been developed and is under consideration by Radiocommunication Working Party 4A.

## Procedure to obtain the epfd CDFs

For simplicity, let us assume that only a single non-GSO network is involved in the interference environment. The longitude and latitude of the reference satellite of this non-GSO satellite network takes values on a  $\varphi$ - $\theta$  plane ( $-\pi < \varphi \leq \pi$ ,  $\delta \leq \theta \leq \delta$ ). In a first step, this plane is finely partitioned into small rectangular cells. For each of these partition cells, it is assumed that the reference satellite is located at its centre and, for this condition, the position of all other satellites in the constellation are determined. Once the position of all satellites are known, the epfd level(s) into the desired test point (or points) is evaluated. To generate the probability distribution of a quantized version of these quantities, the obtained value is quantized to the nearest quantization level and the probability of finding the reference satellite inside the considered cell, obtained using the probability density function in equation (34), is added to current value of probability associated to the corresponding quantization level. This procedure is then repeated for all partition cells and the so obtained histogram is integrated to generate the desired CDF. The flowchart in Fig. 27 illustrates the procedure described above. It reflects the algorithm and calculation procedures presented in Part D, § 3.5.2 and 4.1.6.2.

FIGURE 27  
Flow chart of the analytical method



Concerning the procedure described in the previous paragraphs, the following additional comments are pertinent:

a) Although the partition of the  $\varphi$ - $\theta$  plane into rectangular cells need not to be a grid-type of partition, the used of grid-type partitions is convenient for implementation purposes. However, to avoid a prohibitive amount of required computer time when applying the proposed analytical method to complex situations involving a large number of earth stations and satellites, the following points should be taken into account:

- The  $\varphi$ - $\theta$  plane quantization grid should be sufficiently fine to detect fast variations of the epfd levels that occur near to in-line interference situations. However, a fine quantization of the whole  $\varphi$ - $\theta$  plane could result in an excessively large computer time. So, the numerical implementation of the analytical method could, as an option, be split in two parts. The first part performs the calculations in the regions of the  $\varphi$ - $\theta$  plane for which the epfd level may have large variations (close to in-line interference), and where a fine quantization of the region is required. The second part of the numerical procedure performs the calculations in the regions of the  $\varphi$ - $\theta$  plane for which the epfd level has smooth variations, allowing for a coarser quantization. Finding the  $\varphi$ - $\theta$  plane regions associated with potential quasi in-line interference (RPII) corresponds to defining regions such that when the reference satellite is inside one of these regions in-line interference events involving one or more of the satellites in the constellation may occur. The important point here is to guarantee that when the reference satellite is not inside any of these regions, in-line interference does not occur and a coarser quantization grid can be used. The regions of potential in-line interference (RPII) are usually defined as rectangular regions around points of potential in-line interference (PPII). These PPII can be found using the methodology described in Part D, § 6.3.
- Once the potential occurrence of quasi in-line interference is detected (the reference satellite is inside one of the potential in-line interference regions), it is important to identify which satellites and earth stations are involved in it. This way epfd computations could be made considering that only a few interference entries (those associated with the in-line interference event) have to be re-computed when the reference satellite changes its location inside the considered potential in-line interference region. This measure could save a substantial amount of computer time when a large number of interference entries are present.

b) Given the position of the reference satellite, finding the position of all other satellites in the constellation (block 3 in the diagram in Fig. 27) is a problem that has two possible solutions. This is due to the fact that two different orbital planes, having the same inclination, can contain the reference satellite. Both solutions have to be taken into account in the proposed procedure. In the case of circular orbits, finding these solutions do not constitute a complex task, since the altitude of the satellites is previously known. For satellites in elliptical orbits, this is a more complex procedure, since the satellite altitudes change with time (see Part D, § 6.2).

### 6.1 Probability of the reference satellite being inside a rectangular cell

The probability of finding the reference satellite inside a rectangular cell (say, cell  $j$ ) in the  $\varphi$ - $\theta$  plane, defined by  $\varphi \in [\varphi_m, \varphi_M]$ ,  $\theta \in [\theta_m, \theta_M]$ , can be obtained by using the probability density function in expression (34) and is given by:

$$P_j = \frac{\varphi_M - \varphi_m}{2\pi} \begin{cases} [f(c_M) + f(\pi - c_m) - f(\pi - c_M) - f(c_m)] & \text{for } \theta_m \geq 0, \theta_M > 0 \\ [1 + f(c_M) + f(-\pi - c_m) - f(\pi - c_M) - f(c_m)] & \text{for } \theta_m < 0, \theta_M \geq 0 \\ [f(c_M) + f(-\pi - c_m) - f(-\pi - c_M) - f(c_m)] & \text{for } \theta_m < 0, \theta_M < 0 \end{cases} \quad (38)$$

with:

$$f(x) = \begin{cases} 0 & \text{for } -\infty < x \leq -\pi \\ \frac{1}{2} - \frac{k e}{2\pi} \frac{\tan(x/2)}{\tan^2(x/2) + k^2} + \frac{1}{\pi} \arctan\left(\frac{\tan(x/2)}{k}\right) & \text{for } -\pi < x \leq \pi \\ 1 & \text{for } \pi < x < \infty \end{cases} \quad (39)$$

and where:

$$c_m = \arcsin\left(\frac{\sin \theta_m}{\sin \delta}\right) - \omega \quad (40)$$

and

$$c_M = \arcsin\left(\frac{\sin \theta_M}{\sin \delta}\right) - \omega \quad (41)$$

In the case of circular orbits,  $\omega = 0$  in equations (40) and (41) and, since  $e = 0 \rightarrow k = 1$ , equation (39) is reduced to:

$$f(x) = \begin{cases} 0 & \text{for } -\infty < x \leq -\pi \\ \frac{1}{2} \left( 1 + \frac{x}{\pi} \right) & \text{for } -\pi < x \leq \pi \\ 1 & \text{for } \pi < x < \infty \end{cases} \quad (42)$$

## 6.2 Finding the position of all satellites in the constellation

In this section, the following notations and definitions are used.

$\mathbf{u}$	Unitary vector in the direction of the reference satellite
$\delta$	Orbit inclination angle
$\beta$	Satellite separation angle within the orbital plane (in terms of mean anomaly)
$\psi$	Angle between the intersections of adjacent orbit planes and the equatorial plane
$\lambda$	Satellite phasing between planes
$r$	Orbit radius (circular orbit)
$a$	Major semi-axis of the elliptical orbit
$e$	Orbit eccentricity
$\omega$	Argument of the perigee
$\mathbf{k}_z$	Unitary vector in the z-axis direction
$\gamma_\ell$	True anomaly of the reference satellite in constellation configuration $\ell$ , measured from the line of nodes
$\mathbf{v}_\ell$	True anomaly of the reference satellite in constellation configuration $\ell$
$E_\ell$	Eccentric anomaly of the reference satellite in constellation configuration $\ell$
$M_\ell$	Mean anomaly of the reference satellite in constellation configuration $\ell$
$(M_i^j)_\ell$	Mean anomaly of the $i$ -th satellite in the $j$ -th orbital plane, corresponding to constellation configuration $\ell$
$(E_i^j)_\ell$	Eccentric anomaly of the $i$ -th satellite in the $j$ -th orbital plane, corresponding to constellation configuration $\ell$
$J_n(\cdot)$	Bessel Function of first class and order $n$
$(\mathbf{v}_i^j)_\ell$	True anomaly of the $i$ -th satellite in the $j$ -th orbital plane, corresponding to constellation configuration $\ell$
$(\mathbf{u}_i^j)_\ell$	Unitary vector in the direction of the $i$ -th satellite in the $j$ -th orbital plane, corresponding to constellation configuration $\ell$
$(\mathbf{p}_i^j)_\ell$	Vector of the position of the $i$ -th satellite in the $j$ -th orbital plane, corresponding to constellation configuration $\ell$
$(r_i^j)_\ell$	Distance, from the centre of the Earth, of the $i$ -th satellite in the $j$ -th orbital plane, corresponding to constellation configuration $\ell$

Consider a geocentric, geostationary system of rectangular coordinates in which the x and y axis belong to the equatorial plane and the z-axis points to the north. Let  $\mathbf{u}$  denote the unitary vector pointing to the reference satellite location and  $(\mathbf{p}_i^j)_\ell$  be the vector characterizing the position of the  $i$ -th satellite in the  $j$ -th orbital plane, corresponding to constellation configuration  $\ell$ ,  $\ell=1, 2$ . The following steps are to be used in determining the locations  $(\mathbf{p}_i^j)_\ell$  ( $i=0, \dots, N_{\text{satelliteplane}} - 1, j=0, \dots, N_{\text{planes}} - 1, \ell=1, 2$ ) of all satellites in the two constellation configurations.

*Step 1:* Let  $\mathbf{u} = (u_x, u_y, u_z)^T$  and calculate, for  $\ell=1, 2$ , the unitary vectors  $\mathbf{n}_\ell$  defined by:

$$\mathbf{n}_\ell = \begin{pmatrix} (-u_z \cos \delta - a_\ell u_y)/u_x \\ a_\ell \\ \cos \delta \end{pmatrix} \quad (43)$$

with

$$a_\ell = \frac{-u_y u_z \cos \delta + (-1)^\ell u_x \sqrt{(u_x^2 + u_y^2) \sin^2 \delta - u_z^2 \cos^2 \delta}}{u_x^2 + u_y^2}$$

*Step 2:* Let  $\mathbf{k}_z$  be the unitary vector in the z-axis direction and calculate the following quantities for  $\ell=1, 2$ :

$$\mathbf{w}_\ell = \mathbf{k}_z \times \mathbf{n}_\ell \quad (\times \text{ denotes the cross product})$$

$$\gamma_\ell = \arccos \left( \frac{\mathbf{u}^T \mathbf{w}_\ell}{|\mathbf{w}_\ell|} \right) \text{sgn}(u_z) \quad (T \text{ denotes transpose and } \text{sgn}() \text{ denotes the signum function})$$

$$\mathbf{v}_\ell = (\gamma_\ell - \omega)_{\text{MOD } 2\pi}$$

$$E_\ell = 2 \arctan \left( \frac{\tan(\mathbf{v}_\ell / 2)}{k} \right) \quad \text{where } k = \sqrt{\frac{1+e}{1-e}}$$

$$M_\ell = E_\ell - e \sin E_\ell$$

$$(M_i^j)_\ell = M_\ell + i \beta + j \lambda \quad (44)$$

$$(E_i^j)_\ell = (M_i^j)_\ell + 2 \sum_{n=1}^{\infty} \frac{1}{n} J_n(ne) \sin(n(M_i^j)_\ell)$$

$$(\mathbf{v}_i^j)_\ell = 2 \arctan \left( k \tan \frac{(E_i^j)_\ell}{2} \right)$$

$$(\alpha_i^j)_\ell = (\mathbf{v}_i^j)_\ell - \mathbf{v}_\ell \quad (45)$$

Note that the quantity  $\beta$  in equation (44) is usually given by:

$$\beta = \frac{2\pi}{N_{\text{satelliteplane}}}$$



Step 3: Determine the location vectors of the satellites in the two constellation configurations by:

$$(\mathbf{p}_i^j)_\ell = (r_i^j)_\ell (\mathbf{u}_i^j)_\ell$$

where:

$$(r_i^j)_\ell = \frac{a(1-e^2)}{1-e \cos((\mathbf{v}_i^j)_\ell)}$$

and

$$(\mathbf{u}_i^j)_\ell = \cos((\alpha_i^j)_\ell) \mathbf{M}_j \mathbf{u} + \sin((\alpha_i^j)_\ell) \mathbf{M}_j \mathbf{b}_\ell$$

with:

$$\mathbf{b}_\ell = \mathbf{u} \times \mathbf{n}_\ell$$

and

$$\mathbf{M}_j = \begin{pmatrix} \cos j\psi & -\sin j\psi & 0 \\ \sin j\psi & \cos j\psi & 0 \\ 0 & 0 & 1 \end{pmatrix}$$

The angle  $\psi$  is usually given by:

$$\psi = \frac{2\pi}{N_{planes}}$$

In the particular case of circular orbits, since the true anomaly, the eccentric anomaly and the mean anomaly are all the same, and since  $a = r$  and  $e = 0 \rightarrow k = 1$ , Steps 2 and 3 simplify to:

Step 2:

$$(\alpha_i^j)_\ell = i\beta + j\lambda$$

Step 3:

$$(\mathbf{p}_i^j)_\ell = r (\mathbf{u}_i^j)_\ell$$

where:

$$(\mathbf{u}_i^j)_\ell = \cos((\alpha_i^j)_\ell) \mathbf{M}_j \mathbf{u} + \sin((\alpha_i^j)_\ell) \mathbf{M}_j \mathbf{b}_\ell$$

with:

$$\mathbf{b}_\ell = \mathbf{u} \times \mathbf{n}_\ell$$

and

$$\mathbf{M}_j = \begin{pmatrix} \cos j\psi & -\sin j\psi & 0 \\ \sin j\psi & \cos j\psi & 0 \\ 0 & 0 & 1 \end{pmatrix}$$

### 6.3 Choosing the longitude and latitude increments for the fine and coarse grids

The  $\varphi$ – $\theta$  plane quantization grid should be sufficiently fine to detect fast variations of the epfd levels that occur near to in-line interference situations. However, a fine quantization of the whole  $\varphi$ – $\theta$  plane could result in an excessively large computer time. So, the numerical implementation of the analytical method can, as an option, be split in two parts. The first part performs the calculations in the regions of the  $\varphi$ – $\theta$  plane in which the epfd level may have large variations (close to in-line interference), and where a fine quantization of the region is required. These regions are referred here as RPII. The second part of the numerical procedure performs the calculations in the regions of the  $\varphi$ – $\theta$  plane in which the epfd level has smooth variations, allowing for a coarser quantization. It is suggested that the longitude and latitude increments  $\Delta\varphi_f$  and  $\Delta\theta_f$  for the fine grid be chosen such that:

$$\Delta\varphi_f \leq \frac{\varphi}{10} \quad \text{and} \quad \Delta\theta_f \leq \frac{\varphi}{10}$$

where  $\varphi$  is the geocentric angle defined by equation (3) for  $\text{epfd}_{\uparrow/\downarrow}$  calculations and by equation (4) for  $\text{epfd}_{\text{is}}$  calculations. The longitude and latitude increments  $\Delta\varphi_c$  and  $\Delta\theta_c$  for the coarse grid should be chosen as:

$$\Delta\varphi_c = 1.5\varphi \quad \text{and} \quad \Delta\theta_c = 1.5\varphi$$

with  $\varphi$  given by equation (3) for  $\text{epfd}_{\uparrow/\downarrow}$  calculations and by equation (4) for  $\text{epfd}_{\text{is}}$  calculations.

Finding the  $\varphi$ – $\theta$  plane regions associated with potential quasi in-line interference (RPII) corresponds to defining regions such that when the reference satellite is inside one of these regions in-line interference events involving one or more of the satellites in the constellation may occur. The important point here is to guarantee that when the reference satellite is not inside any of these regions, in-line interference does not occur and a coarser quantization grid can be used. The RPII are defined as a regions (usually rectangular) around PPII. These PPII can be determined using the methodology described in Part D, § 6.4. It is suggested that the RPII be defined by a  $\Delta \times \Delta$  degree square region around the PPIIs, where:

$$\Delta = 5\varphi$$

with  $\varphi$  given by equation (3) for  $\text{epfd}_{\uparrow/\downarrow}$  calculations and by equation (4) for  $\text{epfd}_{\text{is}}$  calculations.

Although the above-mentioned values for the longitude and latitude increments as well as the size of the RPII were shown to be adequate in several exercises, they may have to be adjusted. Very large earth station (with very narrow beams) would require a decrease in the latitude and longitude increment size, but would allow for a smaller RPII. On the other hand, earth stations with a broad beam would allow for larger values of the longitude and latitude increments, but would require a larger RPII.

### 6.4 Finding the PPII

In the case that the optional fine grid is used then the following points are to be noted:

#### 6.4.1 Uplink interference ( $\text{epfd}_{\uparrow}$ )

For each GSO interfered-with satellite (test point), the following steps should be used in determining the PPII in the case of  $\text{epfd}_{\uparrow}$  calculations:

- Step 1:* For each interfering non-GSO network earth station, identify the position of the interfering network satellite that is in line with the considered earth station and the GSO interfered-with satellite.
- Step 2:* Place the reference satellite at this position and determine the position of all other satellites in the constellation for the two possible configurations, according to Part D, § 6.2.
- Step 3:* These  $N_{\text{non-GSO earth stations}} \times N_{\text{non-GSO satellites}} \times 2$  satellite positions form the set of PPIIs.

It should be noted that the switch-off algorithm should ensure that the non-GSO earth station does not transmit towards non-GSO satellites that are in the exclusion zone, and so the use of the fine grid for the uplink may not be necessary.

### 6.4.2 Downlink interference (epfd<sub>↓</sub>)

For each GSO network interfered-with earth station (test point), the following steps should be used in determining the PPII in the case of epfd<sub>↓</sub> calculations:

- Step 1:* Identify the position of the interfering network satellite that is in line with the considered interfered with GSO network earth station (test point) and the GSO satellite serving it.
- Step 2:* Place the reference satellite at this position and determine the position of all other satellites in the constellation for the two possible configurations, according to Part D, § 6.2.
- Step 3:* These  $N_{non-GSOsatellites} \times 2$  satellite positions form the set of PPIIs

### 6.4.3 Inter-satellite interference (epfd<sub>is</sub>)

For each GSO interfered-with satellite (test point), the following steps should be used in determining the PPII in the case of epfd<sub>is</sub> calculations:

- Step 1:* Let  $N_{GSOsatellitebeams}$  denote the number of co-frequency beams in the interfered-with GSO satellites being considered. For each of these beams, identify the position of the interfering non-GSO satellite that is on the beam axis.
- Step 2:* Place the reference satellite at this position and determine the position of all other satellites in the constellation for the two possible configurations, according to Part D, § 6.2.
- Step 3:* These  $N_{GSOsatellitebeams} \times N_{non-GSOsatellites} \times 2$  satellite positions form the set of PPIIs.

## 6.5 Additional use of fine grids

Fast variations of epfd can also occur when satellites approach the boundary curve that characterize the exclusion angle zone in the  $\theta$ - $\phi$  plane. In the vicinity of this boundary curve (exclusion zone vicinity regions(EZVR)), fine grids could be also used to better detect these fast variations. The following steps should be used to determine these EZVR:

- Step 1:* Determine, in the coarse grid, which cells contain the exclusion zone boundary curve. Let us say that the number of cells satisfying this condition is  $N_{EZ}$ .
- Step 2:* For each of these  $N_{EZ}$  cells, place the reference satellite at its centre and determine the position of all other satellites in the constellation for the two possible configurations, according to Part D, § 6.2, and identify the coarse grid cells containing them.
- Step 3:* These  $N_{EZ} \times N_{non-GSOsatellites} \times 2$  coarse grid cells will constitute the set of coarse grid cells inside which a finer grid is to be used.

## 7 Structure and format of results

### 7.1 Go/No-go decision

#### 7.1.1 Overall description of the decision process

When time simulation is used, the simulation produces a probability distribution function (PDF) of the pfd. The PDF records, for each pfd level, the number of simulation time-steps at which that pfd level occurred divided by the sum of all bins. The PDF shall be converted into a cumulative distribution function (CDF) which records for each pfd level the number of simulation time-steps at which that pfd level was exceeded normalized by the total number of simulation time steps.

When the analytical method is used, a PDF of the pfd is directly determined. This PDF records the probability of occurrence of each pfd level. These probability values correspond to the percentage of time that the pfd level would occur in an infinite time observation interval. This PDF can also be converted into a CDF.

#### 7.1.2 Production of the CDF

The process detailed in Part D, § 3.5 generated a PDF of the pfd values. This PDF shall be converted into a CDF which records for each pfd level an estimate of the percentage of time during which that pfd level is exceeded.

For each pfd value, the CDF shall be calculated by:

$$CDF_i = 100 (1 - \text{SUM} (\text{PDF}_{min}; \text{PDF}_i))$$

where:

PDF<sub>x</sub>: PDF table entry for a pfd value of  $X$  dB, normalized so that the total sum for all PDF<sub>x</sub> is 1.

### 7.1.3 Comparison procedure

The next stage is the comparison of the pfd limit values in the RR with those in the probability table.

*Step 1:* Perform Steps 2 through 4 for each specification limit  $i$ .

*Step 2:* Read the pfd value/probability pair ( $J_i$  and  $P_i$ ) from the database.

*Step 3:* If the pfd value  $J_i$  has a higher precision than  $S_B$  (currently 0.1 dB) round  $J_i$  to a lower value with a maximum precision of 0.1 dB.

*Step 4:* From the CDF find  $P_t$ , the probability that pfd value  $J_i$  was exceeded as obtained by the software.

*Step 5:* If  $P_i < P_t$  then record Pass: the CDF complies with this specification point. Else record Fail: the CDF does not comply with this specification point.

The final stage is the comparison of the maximum pfd value recorded during the software run with the limit specified for 100% time (if any).

From the CDF, find the maximum pfd value recorded during the software run,  $J_{max}$ . Compare it with the pfd limit specified for 100% time,  $J_{100}$ . If  $J_{max} < J_{100}$  then record Pass: the CDF complies with this specification point. If  $J_{max} \geq J_{100}$  then record Fail: the CDF does not comply with this specification point.

### 7.1.4 Decision process

If a Pass result was recorded for all of the specification limits, then the non-GSO network complies with the specification. If any Fail results were recorded, then the non-GSO network does not comply with the specification.

## 7.2 Background information to decision

The background information required is:

- pfd data generated in the software run (including antenna diameter) and reference antenna pattern;
- table of specification limits for various antenna diameters and reference antenna pattern.

## 7.3 Format for output

The output format shall be:

- statement of the result of the test;
- summary table;
- CDF table (for information only).

### 7.3.1 Statement of the result of the compliance test

The overall conclusion of the evaluation (Pass or Fail) as defined in Part D, § 7.1.4 shall be output.

### 7.3.2 Summary table

The summary Table shall show the following data:

Specification point		Result	Simulation point
pdf value	Probability		Probability
$J_1 \text{ dB(W/(m}^2 \cdot \text{BW}_{\text{ref}}))$	$P_1$	Pass/fail	$P_y$
:	:	:	:
$J_i \text{ dB(W/(m}^2 \cdot \text{BW}_{\text{ref}}))$	$P_i$	Pass/fail	$P_y$

where:

$J_i$  and  $P_i$ : pdf value/probability specification values from the database

Pass/fail: test result

$P_y$ : probability value from the probability table.

### 7.3.3 Probability table

The output shall include for information the calculated CDF which was used in the decision-making process.

## PART E

### Testing of the reliability of the software outputs

## 1 Evaluation of the computation accuracy of the candidate software

These tests could be performed by the software developer, and the results supplied to the BR along with the candidate software.

Software functions to be evaluated:

*Orbit projection* – Using a set of simplified parameters which result in a defined repeat period, run the software for the required simulation interval and check the actual (satellite vectors) against the predicted values.

*Offset angles* – Using appropriate sets of earth station and satellite locations, check the actual beam offset angle values against the predicted values. The sets of test data should cover the most complex trigonometrical cases: for example sites around longitude zero and longitude 180°.

*Time step and simulation duration* – Using appropriate sets of non-GSO network parameters, check the time step and simulation duration values generated by the software against the predicted values. This checking could be done, for example, through a comparison with results obtained with the analytical method.

*CDF generation* – Using sets of test input files with known CDF results, verify the CDF generation software.

*Go/no-go decision process* – Using sets of CDF test input files, verify the accuracy of the go/no-go decision process.

Should multiple implementations be available then sensitivity analysis could be used to evaluate them and their output can be compared to ensure consistency.

## **2 Evaluation of the epfd( $\downarrow/\uparrow$ ) statistics obtained by the BR**

These are tests which will be performed automatically by the software as part of each run, to confirm that the run did find the worst-case interference events.

epfd value for 100% time - the epfd $\downarrow$  value for 100% time obtained during the run should be compared with a value calculated from analysis of the non-GSO constellation. The obtained value should be within  $\pm 0.X$  dB of the expected value.

In cases in which the time simulation method is used, a software based on the analytical method described in Part D, § 6 can, if applicable, be used, as an option, to verify the reliability of the obtained statistical results.

## **3 Verification of the pfd masks**

The pfd masks are inputs to the BR validation tool to be provided by the notifying administration to the BR together with the software used for its calculation, the complete software description and parameters. The information required to generate the pfd mask could be made available to interested administrations to be used in case of dispute.

## **4 Re-testing of the BR software after any modifications or upgrades**

A set of tests should be defined for use on any occasions when the BR software or its operating environment has been modified or upgraded. Such tests could include:

- a) some or all of the tests defined in Part E, § 1 for the initial evaluation of the computational accuracy of the candidate software;
- b) repetition of a representative set of evaluations of actual non-GSO filings, and comparison of the results obtained by the original and modified software systems.

# **PART F**

## **Operational environment for the software**

### **1 Operating system**

The software shall run on 32 bit Window platforms under the Microsoft Windows NT version 4.0 (or later) and Microsoft Windows 95/98 or higher versions.

### **2 Interfaces to existing software and databases**

The BR captures all incoming notices related to space services into one central database for alphanumeric data (SNS) and into another database for graphical data (GIMS) such as antenna diagrams and service areas. These databases are used for the publication of the data on CD-ROM, in the Weekly Circular and its Special Sections. They are also used to provide input data to software packages performing RR Appendix 29 and pfd examinations. This guarantees that the data published are also the data used in these examinations. The BR considers this important for both the notifying administration and for administrations the services of which may be affected by the new station. For its regulatory and technical examination of satellite networks, the BR has only used so far on a regular basis software developed for GSO networks. However, when software for pfd calculations that works on non-GSO networks becomes available the same principle should apply. This is not only for the convenience of the BR, but to ensure consistency and transparency towards administrations.

## PART G

**Software development and maintenance****1 Software product development approach****1.1 Methodology**

The methodology used in the software product development approach should be described in the software documentation.

**1.2 Validation**

Validate conformity of the software results with the equations described or referenced in this text.

**2 Software user interface**

Software should comply with the BR interface requirements as in Part F, § 2.

**3 Software documentation and maintenance****3.1 Software requirements specification**

The software documentation should refer to the relevant sections of this Recommendation.

**3.2 Requirements implementation**

The purpose of this Recommendation is to state how the requirements of this Recommendation are to be implemented in the software.

**3.3 User manual**

The purpose of the user manual is to tell the user how to run different tests to obtain certain results. Given the complexity of these tests, they need to be given in detail.

**3.4 Maintenance and upgrade**

The fact that part of the software and not only the data depend on the characteristics of the system puts unusually high demands on the maintainability of the software.

## PART H

**Procedures for the evaluation of a candidate software**

The following steps should be followed for the evaluation of a candidate software:

*Step 1:* Evaluate the operational environment of the software. This evaluation should consider: whether the software runs on 32 bit Window platforms (Windows 95/98, Windows NT version 4.0, Windows 2000, or higher versions). The software should be able to run without any problem after the end of the year 1999. This evaluation should also consider memory and hard disk requirements, input and output files storage requirements, software portability, etc. Relevant parts of Part F of this Recommendation should be used as the guidelines.

*Step 2:* Evaluate software compliance: evaluate compliance with the constraints and basic assumptions (units, constants, earth model). Evaluate if the software uses the definitions, formats and units of non-GSO orbit and systems parameters, test points and inputs for self consistency tests. Relevant parts of Parts A and B of this Recommendation should be used as the guidelines.

*Step 3:* Evaluate calculations run time under usual and large volume loads (such as number of satellites), the ability to consider more than one constellation and evaluate calculation run time at different step sizes (e.g. minimum simulation uplink/downlink time increment for the simulation method or minimum longitude and latitude increments for the analytical method). Relevant parts of Parts A and E of this Recommendation should be used as the guidelines.

*Step 4:* Evaluate whether the software is user-friendly: ease-of-use (intuitive), availability of online help, indicator for run progress in terms of percentage completed, and availability of software technical support.

*Step 5:* Evaluate error handling and software recovery: determine clarity of error messages and whether errors can be detected and corrected. Determine if software can return to operational status after failure and adequacy of backup data.

*Step 6:* Evaluate software flexibility: software ability to provide results at intermediate calculation stages (users should be able to pause or cancel a run and save the results to a file at any stage during simulations), user ability to enter data from keyboard and/or input files and graphic interfaces, user ability to use different parameters and models: system parameters, reference antenna patterns, etc.

*Step 7:* Evaluate documentation and clarity and completeness of user manual(s): availability of clear and complete set of user manuals, flow-charts, examples in manuals, explanation of how requirements are implemented, the purpose of each segment of the software with references to the related part of this Recommendation. Part G, § 3.3 of this Recommendation should be used as the guideline.

*Step 8:* Evaluate consistency with the overall approaches used by the BR: use of ITU terminology and definitions, adherence to the BR input (BR supplied input and database parameters) and output file requirements, interface with the BR databases (alphanumeric or graphical), requirements for interface with existing BR software, etc. Relevant parts of Part F, § 3.4, 3.7, 4.1.4, 4.2.4, 4.2.6 and 4.1.7 of Part D should be used as the guidelines.

*Step 9:* Evaluate if the software meets requirements and that results conform to the equations described or referred to in this Recommendation) for: the generation of space station pfd masks, the generation of earth station e.i.r.p. masks, calculations of pfd, mitigation techniques considerations, earth station and satellite antenna gain considerations, worst locations of GSO network that give maximum epfd. Parts C and C' of this Recommendation should be used as the guidelines.

*Step 10:* Evaluate if the software performs the specified functions and that results conform to the equations described or referred to in this Recommendation for: the examination of non-GSO filings, calculation of cumulative epfd distributions, the geometries used in epfd calculations including gain patterns, comparison of epfd levels with the RR (Article S22) limits, pass/fail (go/no-go) decision, etc. Part D of this Recommendation should be used as the guideline.

*Step 11:* Evaluate availability of DLL files and/or COM for possibility of use with other applications.

*Step 12:* Evaluate upgrade and maintenance of software: Evaluate possibility and ease of trouble shooting, maintenance and upgrade by the user, and the definition of a set of tests to be conducted when the BR software or its operating environment are modified or upgraded. This should also include regression evaluation i.e., whether unchanged blocks of the software are not affected by modifications to other blocks. Part E, § 4 and Part G, § 3.4 should be used as the guidelines.

*Step 13:* Evaluate software applicability to all cases of interest: The software should be able to handle all types of non-GSO systems, including systems with long repeating tracks and constellations with slow precession rates.



*Step 14:* Evaluate reliability, sensitivity and accuracy: evaluate how the results reflect the expected system behaviour, reliability of the results (orbit projection, offset angles, CDF generation, go/no-go decision, maximum epfd value, epfd value for 100% time, etc.), calculation accuracy versus step size and sensitivity to input constants. Part E and Part D, § 6 should be used as the guidelines.

Software can be evaluated from functional testing considerations or structural testing considerations. Both test evaluations are essential and used here.

In functional testing, the software is regarded as a black box. It is subjected to an input and its output is verified for conformance with the specifications. In this case, the user concern is in what the software should do and not in the implementation details (i.e., how it is done). In structural testing, the details are considered. If the source code is made available, then the software programming language, programming style, comments within program, control methods and coding details are of concern. Table 10 may be used as a guidance for the evaluation of a candidate software. For each evaluation step, use a score of 1 to 10 where 10 represents excellence or complete satisfaction and 1 represents complete dissatisfaction or no availability.

TABLE 10

Software evaluation table

Consideration	Description	Score (1 to 10)
Operational environment(s)	Step 1	
Possibility of use with other applications	Step 11	
Friendliness of software	Step 4	
Flexibility and user interaction	Step 6	
Consistency with BR approaches	Step 8	
Error handling and software recovery	Step 5	
Upgrade and maintenance	Step 12	
Documentation/user manuals	Step 7	
Compliance (constraints and basic assumptions)	Step 2	
Execution time and stress testing	Step 3	
Design requirements (Parts C and C')	Step 9	
Design requirements and decisions (Part D)	Step 10	
Applicability to all cases of interest	Step 13	
Reliability, sensitivity and accuracy	Step 14	
Total score		