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Recommendation **ITU-R S.1503-2**
(12/2013)

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 22 of the Radio Regulations

S Series

Fixed-satellite service

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RECOMMENDATION ITU-R S.1503-2

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 22 of the Radio Regulations

(2000-2005-2013)

Scope

This Recommendation provides a functional description of the software for use by the Radiocommunication Bureau of ITU to conduct examination of non-GSO FSS system notifications for their compliance with the "validation" limits specified in the Radio Regulations.

Keywords

Epfd; non-GSO; methodology.

Abbreviations/Glossary

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

e.i.r.p. mask: equivalent isotropic radiated power mask used to define the emissions of the non-GSO earth station in the epfd(up) calculation or the emissions of the non-GSO satellite for the epfd(IS) calculation.

epfd: equivalent power flux-density, as defined in RR No. **22.5C.1**, of which there are three cases to consider:

> epfd(down): emissions from the non-GSO satellite system into a GSO satellite earth station;

> epfd(up): emissions from the non-GSO earth station into a GSO satellite;

> epfd(IS): inter-satellite emissions from the non-GSO satellite system into a GSO satellite system.

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

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

WCG: Worst Case Geometry, the location of the GSO earth station and GSO satellite that analysis suggests would cause the highest single entry epfd values for given inputs.

Related ITU-R Recommendations

Recommendation ITU-R BO.1443-2   Reference BSS earth station antenna patterns for use in interference assessment involving non-GSO satellites in frequency bands covered by RR Appendix 30

Recommendation ITU-R S.672-4   Satellite antenna radiation pattern for use as a design objective in the fixed-satellite service employing geostationary satellites

Recommendation ITU-R S.1428-1   Reference FSS earth-station radiation patterns for use in interference assessment involving non-GSO satellites in frequency bands between 10.7 GHz and 30 GHz

The ITU Radiocommunication Assembly,

considering

a) that WRC-2000 adopted, in Article **22**, single-entry limits applicable to non-geostationary satellite orbit (non-GSO) fixed-satellite service (FSS) systems in certain parts of the frequency range 10.7-30 GHz to protect geostationary satellite orbit (GSO) networks operating in the same frequency bands from unacceptable interference;

b) that these frequency bands are currently used or planned to be used extensively by geostationary-satellite systems (GSO systems);

c) that during the examination under Nos. **9.35** and **11.31**, the Bureau examines non-GSO FSS systems to ensure their compliance with the single-entry epfd limits given in Tables 22-1A, 22-1B, 22-1C, 22-1D, 22-1E, 22-2 and 22-3 of Article **22** of the Radio Regulations (RR);

d) that to perform the regulatory examination referred to in *considering* c), 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;

e) 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;

f) 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;

g) 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 should 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 Tables 22-1A, 22-1B, 22-1C, 22-1D, 22-1E, 22-2 and 22-3 of Article **22** of the RR.

Annex 1

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

TABLE OF CONTENTS

PART A

Fundamental constraints and basic assumptions

1 General

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 limits contained in Tables 22-1A, 22-1B, 22-1C, 22-1D, 22-1E, 22-2 and 22-3 of Article **22** of the RR.

The algorithm could also under certain conditions permit examination of whether coordination is required between non-GSO FSS systems and large earth stations under Articles **9.7A** and **9.7B** using the criteria in RR Appendix **5**.

The algorithm in this Recommendation was developed based upon a reference GSO satellite in equatorial orbit with zero inclination angle. The analysis to determine whether a non-GSO satellite system meets the epfd limits in Article **22** of the RR is made by calculating the epfd levels at this reference satellite or at an earth station pointing towards it. A GSO satellite system operating at other inclination angles could be predicted to receive higher epfd levels without the non-GSO satellite system being considered in breach of the Article **22** limits. Analysis under RR Nos. **9.7A** and **9.7B**, however, is to determine if coordination is required by comparing against the trigger level in Appendix **5** of the RR, and therefore in this case other methodologies, including those that assume non-zero GSO satellite inclination, could be acceptable alternatives.

1.2   Software block-diagram

The block-diagram of the software algorithm described in this Annex is shown in Fig. 1. It comprises initial data and calculation for the notifying administration and the BR. The 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 provided by the BR.

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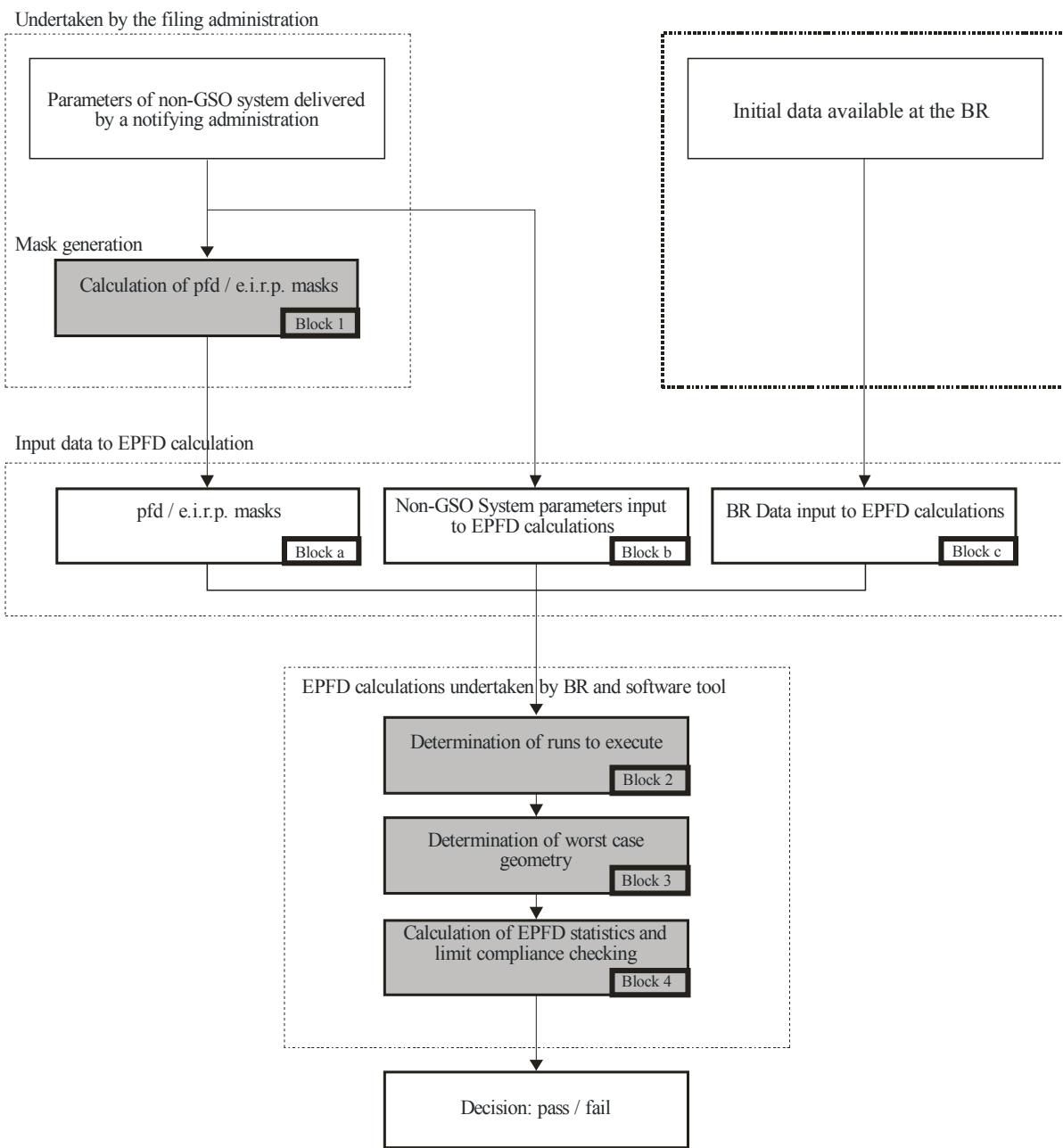
NOTE 1 – A pfd mask is a maximum pfd produced by a non-GSO space station and is defined in Part C.

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 or (azimuth, elevation) angles of the non-GSO space station.

The pfd / e.i.r.p. masks are calculated by the filing administration as identified in Block 1 and then supplied with the other non-GSO system parameters in Blocks a and b. The BR supplies additional parameters, in particular the epfd limits in Block c.

FIGURE 1

Stages in epfd Verification - Key Logic Blocks

Undertaken by the filing administration

Parameters of non-GSO system delivered
by a notifying administration

Initial data available at the BR

Mask generation

Calculation of pfd / e.i.r.p. masks

Block 1

Input data to EPFD calculation

pfd / e.i.r.p. masks

Block a

Non-GSO System parameters input
to EPFD calculations

Block b

BR Data input to EPFD calculations

Block c

EPFD calculations undertaken by BR and software tool

Determination of runs to execute

Block 2

Determination of worst case
geometry

Block 3

Calculation of EPFD statistics and
limit compliance checking

Block 4

Decision: pass / fail

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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 derivation 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 (such as possible beam pointing and transmit powers). The first stage would be finalized by the delivery of the pfd / e.i.r.p. mask to the BR.

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

–   Identification of the runs required for a non-GSO network taking into account the frequencies for which it has filed and the frequency ranges for which there are epfd limits in Article **22** (Block 2).

–   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).

–   Making a decision on interference compliance with appropriate epfd limits.

The estimations are based on the non-GSO system parameters (Blocks a and b) delivered by a notifying administration and the initial data (Block c) 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 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 2, 3 and 4.

Parts E, F   –   These parts define requirements on the software related to valuation of delivered software and to verification of the software output on validity.

2   Fundamental assumptions

2.1   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	$dB(W/(m^2 \cdot BW_{ref}))$
Average number of co-frequency non-GSO earth stations per unit area	$1/km^2$
epfd↓, epfd↑ or epfd$_{is}$	$dB(W/BW_{ref})$
Antenna gain	dBi
Geographical position on the Earth's surface	degrees

2.2   Constants

The functional description of the software for examination of non-GSO networks notification at the BR uses the constants shown in Table 2.

TABLE 2

Constants to be used by software

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	μ	3.986012×10^5	km^3/s^2
Speed of light	c	2.99792458×10^5	km/s
Angular rate of rotation of the Earth	ω_e	$4.1780745823 \times 10^{-3}$	degrees/s
Earth rotation period	T_e	86 164.09054	s
Factor of the Earth non-sphericity	J_2	0.001082636	–

2.3   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.6.3 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.6.3.

2.4   Constellation types

The algorithm in this Recommendation has been developed to be applicable to at least the non-GSO satellite systems shown in Table 3.

TABLE 3

Orbit type classification

Type	Orbit shape	Equatorial ?	Repeating ?
A	Circular	No	Yes
B	Circular	No	No
C	Circular	Yes	n/a
D	Elliptical	No	Yes
E	Elliptical	No	No

3   Modelling methodology

The approach described in this Annex involves time simulation in which interference levels are evaluated on a time step by time step basis. Section D.4 defines the method to calculate the size of time steps and the total number of time steps to be used. This section also identifies an optional dual time step approach to reduce run times without altering the resulting decision.

PART B

Input parameters

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*: Provide 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↑ levels and downlink equivalent pfd (epfd↓) levels (cumulative time distributions of epfd↑ or epfd↓).

– *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 § A.1.3.

Detailed parameters are needed by the BR in support of Function 2 and so this section focuses on the parameters needed to fulfil that requirement.

The parameters provided should be consistent, so that if the administrations modifies its network so that the pfd / e.i.r.p. changes then a new mask would need to be supplied to the BR.

1.2 Scope and overview

This section identifies inputs to the software in four main paragraphs:

– Paragraph 2 defines the inputs from the BR;

– Paragraph 3 defines the inputs from the non-GSO operator excluding the pfd / e.i.r.p masks;

– Paragraph 4 defines the pfd / e.i.r.p. masks.

An Attachment to Part B then maps the parameters to the SRS database tables.

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

2 BR supplied parameters to software

The BR supplies two types of data, firstly the type of run to execute:

RunType	One of {Article 22, 9.7A, 9.7B}
SystemID	ID of system to examine (either non-GSO or large earth station)

The second data is to provide the threshold epfd levels to use as the pass / fail criteria. These are accessed by the software when generating the runs and consists of a series of records as follows:

epfddirection	One of {Down, Up, IS}
VictimService	One of {FSS, BSS}
StartFrequencyMHz	Start of frequency range for which epfd threshold applies
EndFrequencyMHz	End of frequency range for which epfd threshold applies
VictimAntennaType	Reference code for antenna pattern to be used in calls to ITU supplied antenna gain pattern DLL
VictimAntennaDishSize	Dish size of victim antenna pattern to be used in calls to ITU supplied antenna gain pattern DLL
VictimAntennaBeamwidth	Beamwidth of victim antenna pattern to be used in calls to ITU supplied antenna gain pattern DLL
RefBandwidthHz	Reference bandwidth in Hz of epfd level
NumPoints	Number of points in epfd threshold mask
epfdthreshold[N]	epfd level in dBW/m^2/Reference bandwidth
epfdpercent[N]	Percentage of time associated with epfdthreshold

3 Non-GSO system inputs to software

These are split into constellation parameters and then a set of orbit parameters for each space station.

3.1 Non-GSO constellation parameters

N_{sat}	Number of non-GSO satellites
H_MIN	Minimum operating height (km)
DoesRepeat	Flag to identify that constellation repeats using station keeping to maintain track
AdminSuppliedPrecession	Flag to identify that the constellation orbit model precession field is supplied by the admin
W_{delta}	Station keeping range (degrees)
ORBIT_PRECESS	Administration supplied precession rate (degrees/second)
MIN_EXCLUDE	Exclusion zone angle (degrees)
N_{co}[latitude]	Maximum number of non-GSO satellites operating co-frequency at latitude lat
ES_TRACK	Maximum number of co-frequency tracked non-GSO satellites
ES_MINELEV	Minimum elevation angle of the non-GSO earth station when it is transmitting (degrees)
ES_MIN_GSO	Minimum angle to GSO arc (degrees)
ES_DENSITY	Average number of non-GSO earth stations (km^2)
ES_DISTANCE	Average distance between cell or beam footprint centre (km)
ES_LAT_MIN	Minimum limit of the latitude range of non-GSO ES (degrees)
ES_LAT_MAX	Maximum limit of the latitude range of non-GSO ES (degrees)

3.2 Non-GSO space station parameters

A[N]	Semi-major axis of orbit (km)
E[N]	Eccentricity of orbit
I[N]	Inclination of orbit (degrees)
O[N]	Longitude of ascending node of orbit (degrees)
W[N]	Argument of perigee (degrees)
V[N]	True anomaly (degrees)

4 pfd / e.i.r.p. masks

4.1 Non-GSO downlink pfd mask

FreqMin	Minimum of frequency range in MHz for this pfd mask
FreqMax	Maximum of frequency range in MHz for this pfd mask
RefBW	The power level in the pfd mask should be given with respect to the same reference bandwidth as the epfd thresholds in the tables in Article **22** relevant for the frequency ranges covered. If the tables in Article **22** give two reference bandwidths (e.g. 40 kHz and 1 MHz) then the smaller bandwidth should be used.
MaskType	One of {α, X, or (az,el)}
Option 1 pfd_mask (satellite, latitude, α (or X), ΔL)	The pfd mask is defined by: – the non-GSO satellite – the latitude of the non-GSO sub-satellite point – the separation angle α between this non-GSO space station and the GSO arc, as seen from any point on the surface of the Earth as defined in § D.6.4.4 – the difference ΔL in longitude between the non-GSO sub-satellite point and the point on the GSO arc where the α (or X) angle is minimized as defined in § D.6.4.4
Option 2 pfd_mask (satellite, latitude, Az, El)	The pfd mask is defined by: – the non-GSO satellite – the latitude of the non-GSO sub-satellite point – the azimuth angle, defined in § D.6.4.5 – the elevation angle, defined in § D.6.4.5

4.2 Non-GSO uplink e.i.r.p. mask

FreqMin	Minimum of frequency range in MHz for this pfd mask
FreqMax	Maximum of frequency range in MHz for this pfd mask
RefBW	The power level in the e.i.r.p. mask should be given with respect to the same reference bandwidth as the epfd thresholds in the tables in Article **22** relevant for the frequency ranges covered. If the tables in Article **22** give two reference bandwidths (e.g. 40 kHz and 1 MHz) then the smaller bandwidth should be used.
NumMasksLat	Number of e.i.r.p. masks to cover full latitude range

Latitude[Lat]	Latitude to use an ES_e.i.r.p. mask
ES_ID	Reference of non-GSO ES or –1 if using generic ES
ES_e.i.r.p. [θ][Lat]	Non-GSO earth station e.i.r.p. as a function of the off-axis angle and latitude

4.3   Non-GSO inter-satellite e.i.r.p mask

FreqMin	Minimum of frequency range in MHz for this e.i.r.p. mask
FreqMax	Maximum of frequency range in MHz for this e.i.r.p. mask
RefBW	The power level in the e.i.r.p. mask should be given with respect to the same reference bandwidth as the epfd thresholds in the tables in Article **22** relevant for the frequency ranges covered. If the tables in Article **22** give two reference bandwidths (e.g. 40 kHz and 1 MHz) then the smaller bandwidth should be used.
Latitude[Lat]	Latitude to use an SAT_e.i.r.p. mask
SAT_e.i.r.p.[θ][Lat]	Non-GSO satellite e.i.r.p. as a function of the off-axis angle and latitude

Attachment to Part B

This Attachment to Part B details the parameters that the epfd software uses from the SRS database

Table 4 lists the current RR Appendix **4** information for non-GSO satellite systems included in the BR space networks system (SNS) database. The relationship between the database tables is shown in Fig. 2. Mask information and link tables are not shown in Fig. 2 but are described in Table 4.

Format description

| Value	Description
X	Used to describe alphanumeric data. e.g. X(9) specifies a 9-character field containing alphanumeric data XXX is equivalent to X(3).
9	Used to describe digits
'.'	Shows the position of a decimal point
S	Implies a sign (sign leading separate) e.g. S999.99 implies a numeric field with a range of values from –999.99 to +999.99 99 implies a numeric field with a range of values from 0 to 99

FIGURE 2

Extract from SRS entity relationship

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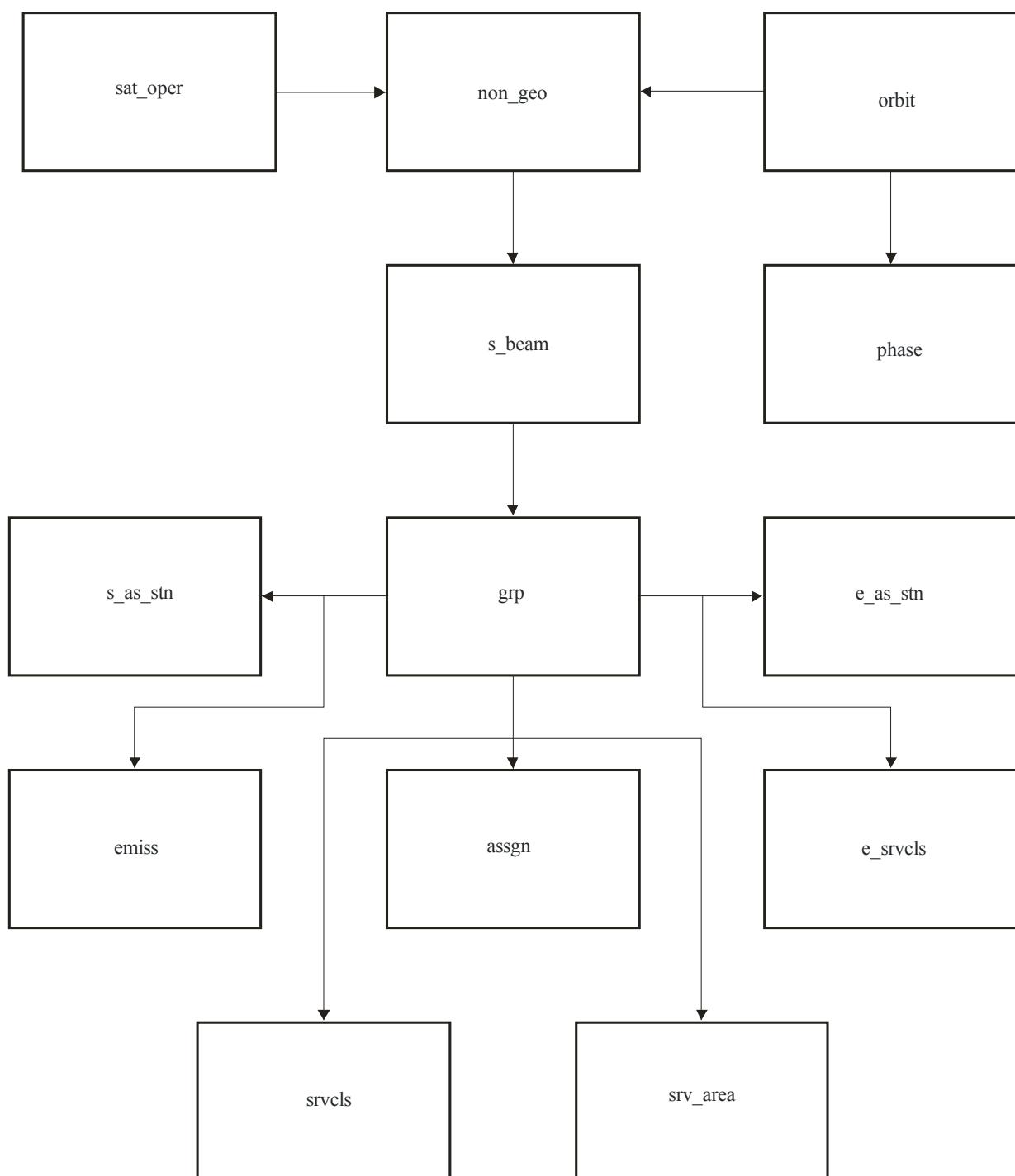
TABLE 4

Appendix 4 data for epfd analysis

Notice

Data Item	Data Type	Format	Description	Validation
ntc_id	Number	9(9)	Unique identifier of the notice	Primary Key
ntc_type	Text	X	Code indicating if the notice is of a geostationary satellite [G], Non-geostationary satellite [N], specific earth station [S] or typical earth station [T]	value != Null
d_rcv	Date/Time	9(8)	Date of receipt of the notice	
ntf_rsn	Text	X	Code indicating that the notice has been submitted under RR1488 [N], RR1060 [C], RR1107 [D], 9.1 [A], 9.6 [C], 9.7A [D], 9.17 [D], 11.2 [N], 11.12 [N], AP30/30A-Articles 2A, 4 & 5 [B], AP30B-Articles 6 & 7 [P], AP30B-Article 8 [N] or Res49 [U]	The software looks a value that is 'C' or 'N'
st_cur	Text	XX	Current processing status of the notice	The software looks for a value that is '50' in the Article **9.7A** check

Non-geo

Data Item	Data Type	Format	Description	Validation
ntc_id	Number	9(9)	Unique identifier of the notice	Primary Key
sat_name	Text	X(20)	Name of the satellite	
nbr_sat_td	Number	9(4)	Maximum number of co-frequency tracked non-geostationary satellites receiving simultaneously	value != Null && value > 0
avg_dist	Number	9(3).9	Average distance between co-frequency cells in kilometres	value != Null && value > 0
density	Number	9.9(6)	Average number of associated earth stations transmitting with overlapping frequencies per km^2 in a cell	value != Null && value > 0
f_x_zone	Text	X	Flag indicating the type of zone: if the exclusion zone angle is the angle alpha [Y] or the angle X [N]	value != Null && (value == 'Y' || 'N')
x_zone	Number	99.9	Width of the exclusion zone in degrees	value != Null && value > 0

orbit

Data Item	Data Type	Format	Description	Validation
ntc_id	Number	9(9)	Unique identifier of the notice	Foreign Key
orb_id	Number	99	Sequence number of the orbital plane	Primary Key
nbr_sat_pl	Number	99	Number of satellites per non-geostationary orbital plane	value != Null && value > 0
right_asc	Number	999.99	Angular separation in degrees between the ascending node and the vernal equinox	value != Null
inclin_ang	Number	999.9	Inclination angle of the satellite orbit with respect to the plane of the Equator	value != Null
apog	Number	9(5).99	The farthest altitude of the non-geostationary satellite above the surface of the Earth or other reference body – expressed in kilometres Distances > 99999 km are expressed as a product of the values of the fields "apog" and "apog_exp" (see below) e.g. 125 000 = 1.25×10^5	value != Null && value > 0
apog_exp	Number	99	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.	value != Null && value >= 0
perig	Number	9(5).99	The nearest altitude of the non-geostationary satellite above the surface of the Earth or other reference body – expressed in kilometres 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 = 1.25×10^5	value != Null && value > 0
perig_exp	Number	99	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.	value != Null && value >= 0
perig_arg	Number	999.9	Angular separation (degrees) between the ascending node and the perigee of an elliptical orbit. If RR No. **9.11A** applies	

orbit (continued)

Data Item	Data Type	Format	Description	Validation
op_ht	Number	99.99	Minimum operating height of the non-geostationary satellite above the surface of the Earth or other reference body – expressed in kilometres Distances > 99 km are expressed as a product of the values of the fields "op_ht" and "op_ht_exp" (see below) e.g. $250 = 2.5 \times 10^2$	value != Null && value > 0
op_ht_exp	Number	99	Exponent part of the operating height expressed in power of 10 To indicate the exponent; give 0 for 10^0, 1 for 10^1, 2 for 10^2, etc.	value != Null && value >= 0
f_stn_keep	Text	X	Flag indicating if the space station uses [Y] or does not use [N] station-keeping to maintain a repeating ground track	value != Null && (value == 'Y' || 'N')
rpt_prd_dd	Number	999	Day part of constellation repeat period (s)	
rpt_prd_hh	Number	99	Hour part of constellation repeat period (s)	
rpt_prd_mm	Number	99	Minute part of constellation repeat period (s)	
rpt_prd_ss	Number	99	Second part of constellation repeat period (s)	
f_precess	Text	X	Flag indicating if the space station should [Y] or should not [N] be modelled with specific precession rate of the ascending node of the orbit instead of the J2 term	value != Null && (value == 'Y' || 'N')
precession	Number	999.99	For a space station that is to be modelled with specific precession rate of the ascending node of the orbit instead of the J2 term, the precession rate in degrees/day measured counter-clockwise in the equatorial plane	If f_precess == 'Y' then value != Null && value > = 0
long_asc	Number	999.99	Longitude of the ascending node for the jth orbital plane measured counter-clockwise in the equatorial plane from the Greenwich meridian to the point where the satellite orbit makes its south-north crossing of the equatorial plane $(0° = j < 360°)$	value != Null && value > = 0
keep_rnge	Number	99.9	Longitudinal tolerance of the longitude of the ascending node	If f_stn_keep == 'Y' then value != Null && value > = 0

Phase

Data Item	Data Type	Format	Description	Validation
ntc_id	Number	9(9)	Unique identifier of the notice	Foreign Key
orb_id	Number	99	Sequence number of the orbital plane	Foreign Key
orb_sat_id	Number	99	Satellite sequence number in the orbital plane	value != Null && value >= 0
phase_ang	Number	999.9	Initial phase angle of the satellite in the orbital plane If RR No. **9.11A** applies	value != Null && value >= 0

Grp

Data Item	Data Type	Format	Description	Validation
ntc_id	Number	9(9)	Unique identifier of the notice	Foreign Key
grp_id	Number	9(9)	Unique identifier of the group	Primary Key
emi_rcp	Text	X	Code identifying a beam as either transmitting [E] or receiving [R]	value != Null && (value == 'E' || 'R')
beam_name	Text	X(8)	Designation of the satellite antenna beam	
elev_min	Number	S9(3).99	Minimum elevation angle at which any associated earth station can transmit to a non-geostationary satellite or minimum elevation angle at which the radio astronomy station conducts single-dish or VLBI observations	value != Null && value >= 0
freq_min	Number	9(6).9(6)	Minimum frequency in MHz (assigned frequency – half bandwidth) (of all frequencies for this group)	value != Null && value > 0
freq_max	Number	9(6).9(6)	Maximum frequency in MHz (assigned frequency + half bandwidth) (of all frequencies for this group)	value != Null && value > 0
d_rcv	Date/Time	9(8)	Date of receipt of the list of frequency assignments pertaining to the group	
noise_t	Number	9(6)	Receiving system noise temperature	Only validated for **9.7A/B** checks

srv_cls

Data Item	Data Type	Format	Description	Validation
grp_id	Number	9(9)	Unique identifier of the group	Foreign Key
seq_no	Number	9(4)	Sequence number	value != Null && value >= 0
stn_cls	Text	XX	Class of station	

Mask_info

Data Item	Data Type	Format	Description	Validation
ntc_id	Number	9(9)	Unique identifier of the group	Foreign Key
mask_id	Number	9(4)	Sequence number	Foreign Key
sat_name	Text	X(20)	Name of the station	
f_mask	Text	X	Code identifying a mask as either earth station e.i.r.p. [E] or space station e.i.r.p. [S] or space station pfd [P]	value != Null && (value == 'E' || 'S'|| 'P')
f_mask_type	Text	X(20)	Mask format	If f_mask == 'P' then (value != Null && (value == 'alpha_deltaLongitude' || 'X_deltaLongitude'|| 'azimuth_elevation')) If f_mask == 'S' then (value != Null && (value == 'Offaxis' || 'azimuth_elevation'))
freq_min	Number	9(6).9(6)	The lowest frequency for which the mask is valid (GHz)	value != Null && value > 0
freq_max	Number	9(6).9(6)	The highest frequency for which the mask is valid (GHz)	value != Null && value > 0

e_as_stn

Data Item	Data Type	Format	Description	Validation
grp_id	Number	9(9)	Unique identifier of the group	Foreign Key
seq_no	Number	9(4)	Sequence number	value != Null && value >= 0
stn_name	Text	X(20)	Name of the transmitting or receiving station	
stn_type	Text	X	Code indicating if the earth station is specific [S] or typical [T]	value != Null && (value == 'S' || 'T')
bmwdth	Number	999.99	Angular width of radiation main lobe expressed in degrees with two decimal positions	value != Null && value > 0

sat_oper

Data Item	Data Type	Format	Description	Validation
ntc_id	Number	9(9)	Unique identifier of the notice	Foreign Key
lat_fr	Number	S99.999	Lower limit of the latitude range	value != Null
lat_to	Number	S99.999	Upper limit of the latitude range	value != Null
nbr_op_sat	Number	9(4)	Maximum number of non-geostationary satellites transmitting with overlapping frequencies to a given location within the latitude range	value != Null

mask_lnk1

Data Item	Data Type	Format	Description	Validation
grp_id	Number	9(9)	Unique identifier of the group	Foreign Key
ntc_id	Number	9(9)	Unique identifier of the notice	Foreign Key
mask_id	Number	9(4)	Unique identifier of the mask	Foreign Key
orb_id	Number	99	Sequence number of the orbital plane	Foreign Key
sat_orb_id	Number	99	Satellite sequence number in the orbital plane	value != Null && value >= 0

mask_lnk2

Data Item	Data Type	Format	Description	Validation
grp_id	Number	9(9)	Unique identifier of the group	Foreign Key
seq_e_as	Number	9(4)	Sequence number of the associated earth station	Foreign Key
ntc_id	Number	9(9)	Unique identifier of the notice	Foreign Key
mask_id	Number	9(4)	Unique identifier of the mask	Foreign Key
orb_id	Number	99	Sequence number of the orbital plane	Foreign Key
sat_orb_id	Number	99	Satellite sequence number in the orbital plane	value != Null && value >= 0

Tables used in the Article 9.7A/9.7B calculations

e_stn

Data Item	Data Type	Format	Description	Validation
ntc_id	Number	9(9)	Unique identifier of the notice	Foreign Key
stn_name	Text	X(20)	Name of the earth station	value != Null
sat_name	Text	X(20)	Name of the associated space station	value != Null
lat_dec	Number	S9(2).9(4)	Latitude in degrees with four decimals	value != Null
long_dec	Number	S9(2).9(4)	Longitude in degrees with four decimals	value != Null
long_nom	Number	S999.99	Nominal longitude of the associated space station, give '–' for West, '+' for East	value != Null

e_ant

Data Item	Data Type	Format	Description	Validation
ntc_id	Number	9(9)	Unique identifier of the notice	Foreign key
emi_rcp	Text	X	Code identifying a beam as either transmitting [E] or receiving [R]	value != Null
bmwdth	Number	999.99	Beamwidth of the earth station antenna	
gain	Number	S99.9	Maximum isotropic gain of the earth station antenna	

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 α (or X) between this non-GSO space station and the GSO arc, as seen from any point on the surface of the Earth (at the satellite), as defined in § D.6.4.4;
–   the difference ΔL in longitude between the non-GSO sub-satellite point and the point on the GSO arc where the α (or X) angle is minimized, as defined in § D.6.4.4.

Option 2: As a function of:
–   the non-GSO satellite;
–   the latitude of the non-GSO sub-satellite point;
–   the azimuth angle, defined in § D.6.4.5;
–   the elevation angle, defined in § D.6.4.5.

Whatever parameters 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 α or X angle pfd masks implies that the same definition of GSO angle is used for exclusion angle in the calculation of epfd↓.

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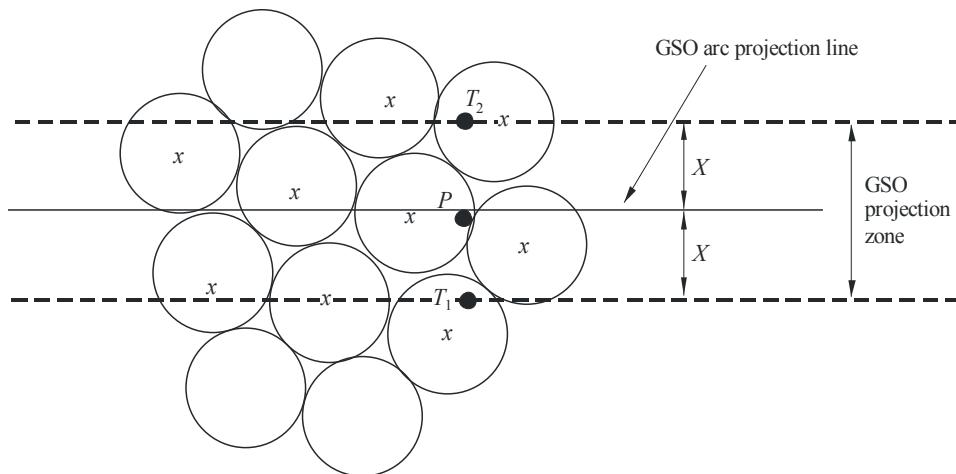
With regard to the use of a non-operating zone around the GSO arc, there are at least three different ways of modelling a non-GSO system based on a cell architecture:

– 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 α_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 α_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.

Figure 3 shows a satellite-based reference with beam switch off inside an X angle based exclusion zone.

FIGURE 3

Overhead beam view of satellite-based exclusion angle

x: beam turned off when edge within GSO projection zone

S.1503-03

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 beams in the co-frequency band.

Some non-GSO 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 epfd levels.

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.

The 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^2)) 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^2)) 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^2)) in the reference bandwidth

and

$$pfd\_co_i = P_i + G_i - 10\log_{10}(4\,\pi\,d^2)$$

where:

P_i: maximum power emitted by the beam i in the reference bandwidth (dB(W/BW$_{ref}$))

BW_{ref}: 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:

φ: spherical coordinate

v: $u = \sin\theta\cos\varphi$, $v = \sin\theta\sin\varphi$

B: $A = \theta\cos\varphi$, $B = \theta\sin\varphi$
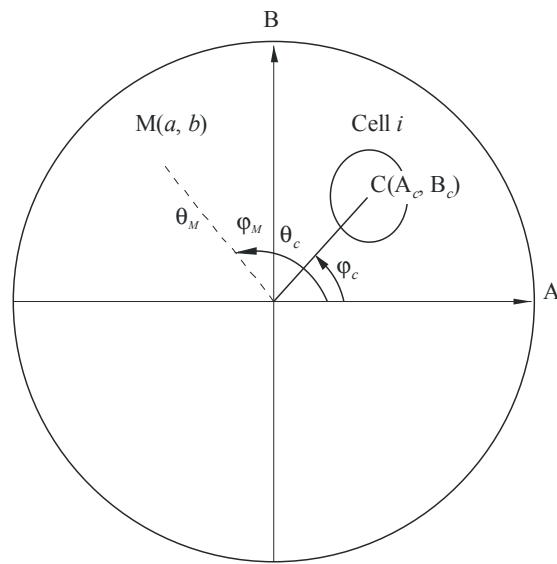
(Az, El): $\sin(El) = \sin\theta\sin\varphi$, $\tan(Az) = \tan\theta\cos\varphi$

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

FIGURE 4

Antenna plane (A, B)

S.1503-04
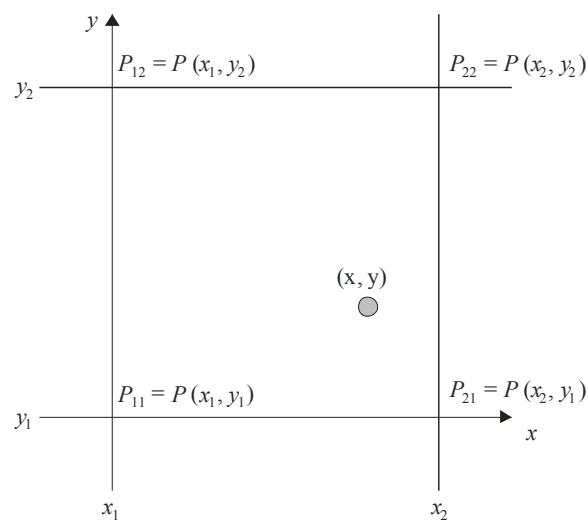
The coordinates of the point M at the Earth's surface are (a, b) in the antenna plane (A, B), corresponding to (θ_M, φ_M) in the polar reference.

The coordinates of the point C centre of the cell i, are (A_c, B_c) in the antenna plane (A, B), and (θ_c, φ_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, and the point M(a, b) may be located between four points of the grid (A, B).

In general, it is therefore necessary to undertake interpolation between data points. Consider a grid of values P for a range of x values = $\{x_1, x_2, …\}$ and y values = $\{y_1, y_2,…\}$ as in Fig. 5.

FIGURE 5

Interpolation between data points

S.1503-05

The value of parameter P at point (x, y) can be derived by identifying the bounding values and hence:

$$\lambda_x = \frac{x - x_1}{x_2 - x_1}$$

$$\lambda_y = \frac{y - y_1}{y_2 - y_1}$$

Then P can be interpolated using:

$$P = (1 - \lambda_x)(1 - \lambda_y)P_{11} + \lambda_x(1 - \lambda_y)P_{21} + (1 - \lambda_x)\lambda_y P_{12} + \lambda_x\lambda_y P_{22}$$

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 α, as an example. If the pfd mask is provided as a function of the X angle, the following calculation remains the same replacing α with X angle.

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

The angle α 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 ΔL.

At each point of the non-GSO satellite footprint, the pfd value depends on:
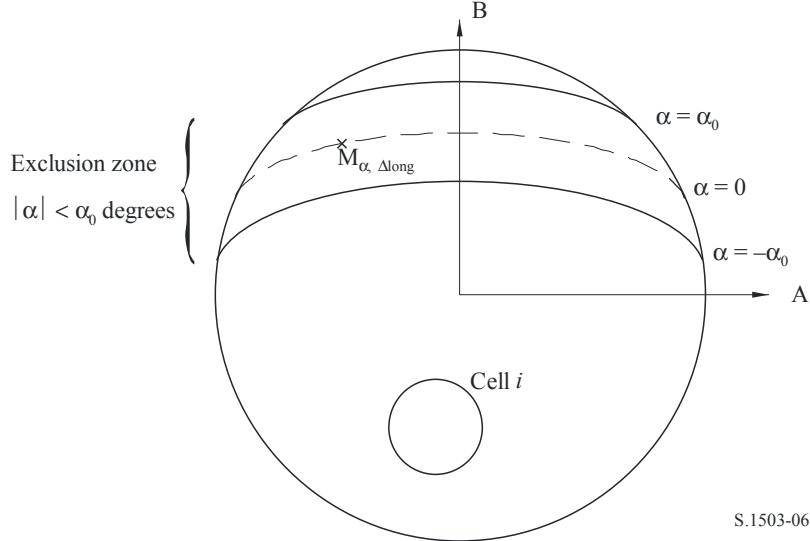
– the configuration of the spot beams which are illuminated by the satellite;
– the maximum number of co-frequency beams which can be illuminated simultaneously;
– the maximum number of co-frequency, co-polarization beams which can be illuminated simultaneously;
– the maximum power available at the satellite 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-α lines, i.e. the points on the surface of the Earth which share the same value of α (see Figs. 6 and 7).

FIGURE 6

**Field of view of a non-GSO space station (Option 1)**

S.1503-06
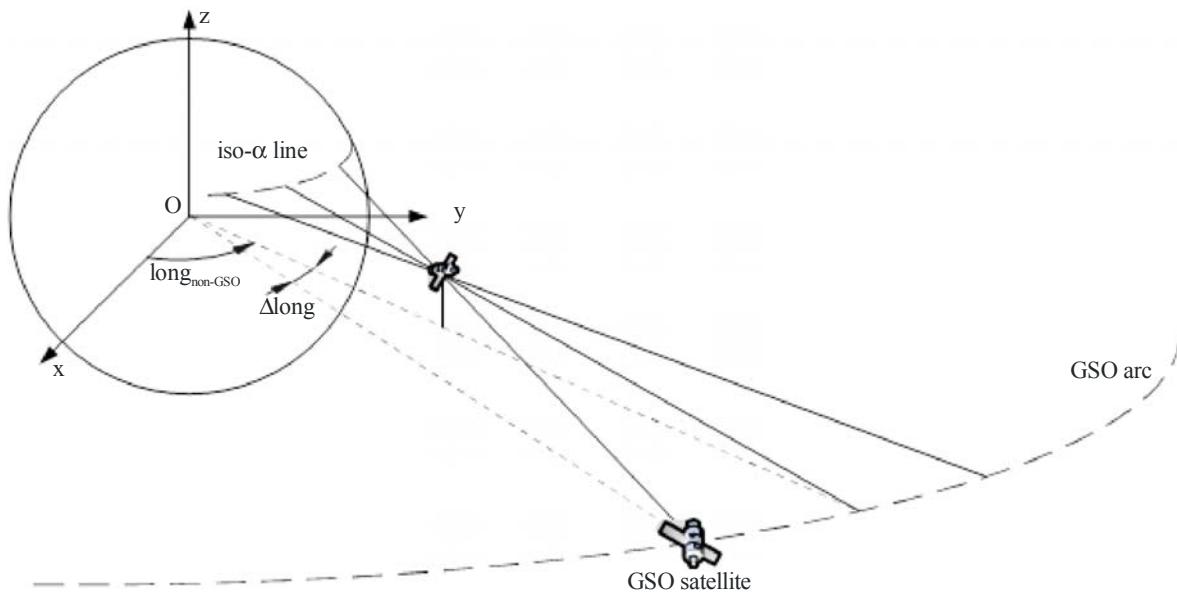
Step 3: Along the iso-α line, define intervals of ΔL: difference in longitude between the non-GSO sub-satellite point and the point on the GSO arc where the α (or X) angle is minimized.

Step 4: Per each interval of ΔL, the iso-α line can be defined by a set of n points $M_{\alpha,k}$ for $k = 1$, $2,...n$. To determine the maximum pfd corresponding to a given value of α, it is necessary to calculate the maximum pfd at each of the points $M_{\alpha,k}$ for $k = 1, 2,...n$. 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 7

View in 3D of the iso-α line

S.1503-07

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 α_0 of the GSO arc. In this particular case, any beam illuminating a cell which is crossed by an iso-α 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 α_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-α_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 α within an interval of ΔL is:

$$pfd(\alpha, \Delta L) = \max_{k = 1, 2, \ldots n}(pfd(\mathrm{M}_{\alpha,k}))$$

Step 7: The location of an iso-α 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
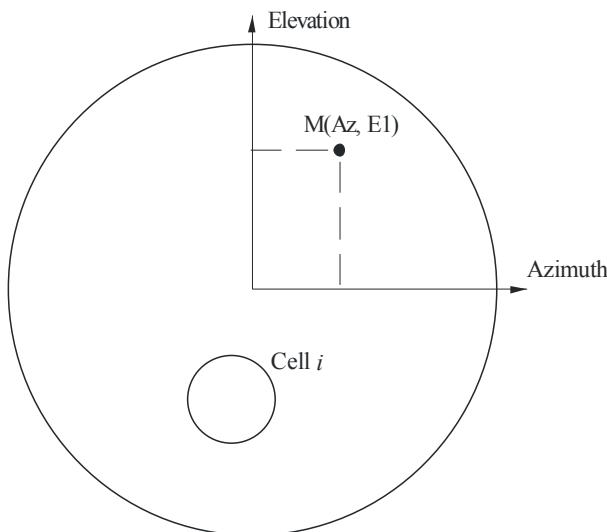
The pfd mask is defined in a grid in azimuth and elevation, per latitude of the non-GSO sub-satellite.

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 8

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

S.1503-08

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 α_0 of the GSO arc. In this particular case, any beam illuminating a cell which is crossed by an iso-α line corresponding to a value $|\alpha| \le \alpha_0$ 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 α_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-α_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. There can be different e.i.r.p. masks applicable at different latitudes.

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↑ (see § 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:

$$ES\_e.i.r.p(\theta) = G(\theta) + P$$

where:

ES_e.i.r.p.:   equivalent isotropic radiated power in the reference bandwidth (dB(W/BW$_{ref}$))

θ: separation angle between the non-GSO space station and the GSO space station at the non-GSO earth station (degrees)

$G(θ)$:   earth station directional antenna gain (dBi)

P: maximum power delivered to the antenna, in the reference bandwidth (dB(W/BW$_{raf}$))

BW$_{raf}$:   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.

This exercise would be repeated for all latitudes for which the ES_e.i.r.p. could be different.

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.

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:

$$NGSO\_SS\_e.i.r.p.(θ) = G(θ) + P$$

where:

NGSO_SS_e.i.r.p.:   equivalent isotropic radiated power in the reference bandwidth (dB(W/BW$_{ref}$))

θ: separation angle between the boresight of the non-GSO space station and the pointing direction of the GSO space station (degrees)

$G(θ)$:   space station antenna gain pattern (dBi) corresponding to the aggregation of all beams

P: maximum power, in the reference bandwidth (dB(W/BW$_{rif}$))

BW$_{rif}$:   reference bandwidth (kHz).

4   pfd and e.i.r.p. mask format

4.1   General structure of masks

One of the inputs to Recommendation ITU-R S.1503 are the pfd and e.i.r.p. masks, namely:

–   For epfd(down) runs, the pfd mask(s), containing tables of pfd(α, Δlong) or of pfd(azimuth, elevation) together with the latitude for which each table is valid.

–   For epfd(up) runs, the non-GSO earth station e.i.r.p. mask(s), each one contains tables of e.i.r.p. (θ) together with the latitude for which each table is valid.

–   For epfd(IS) runs, the non-GSO satellite e.i.r.p. masks, each one contains tables of e.i.r.p. (θ) together with the latitude for which each table is valid.

During the simulation, the software will calculate the relevant parameters, such as latitude and off-axis angle or α angle, and then use the mask to calculate a pfd or e.i.r.p. using the following approach:

1) The array of {Latitude, Table} is searched and the table which has the nearest latitude to the value calculated in the simulation is selected.

2) Using the selected table, the pfd or e.i.r.p. is then calculated by interpolation using:

a) pfd: calculated using bi-linear interpolation in either pfd(α, Δlong) or pfd(azimuth, elevation);

b) e.i.r.p.: calculated using linear interpolation in e.i.r.p. (θ).

Each table is independent i.e. at different latitudes it can use a different grid resolution and range. The mask does not need to cover the whole range: outside the supplied values the last valid value is assumed to be used.

However, it should be noted that for latitude and {azimuth, elevation, α, Δlong} regions where no actual pfd is produced, in order to avoid using nearest latitude table containing operational pfd values it is advisable to provide extremely low pfd values for these ranges to simulate no transmission scenario.

The pfd mask table is not assumed to be symmetric in {azimuth, elevation, α, Δlong} and should be given for the full range from positive to negative extremes. The e.i.r.p. masks are assumed to be symmetric around the boresight line via use of the off-axis angle as the parameter. In the case that the {azimuth, elevation, α, Δlong, off-axis angle} calculated in the simulation is outside the ranges given in the pfd or e.i.r.p. masks, then the last valid value should be used.
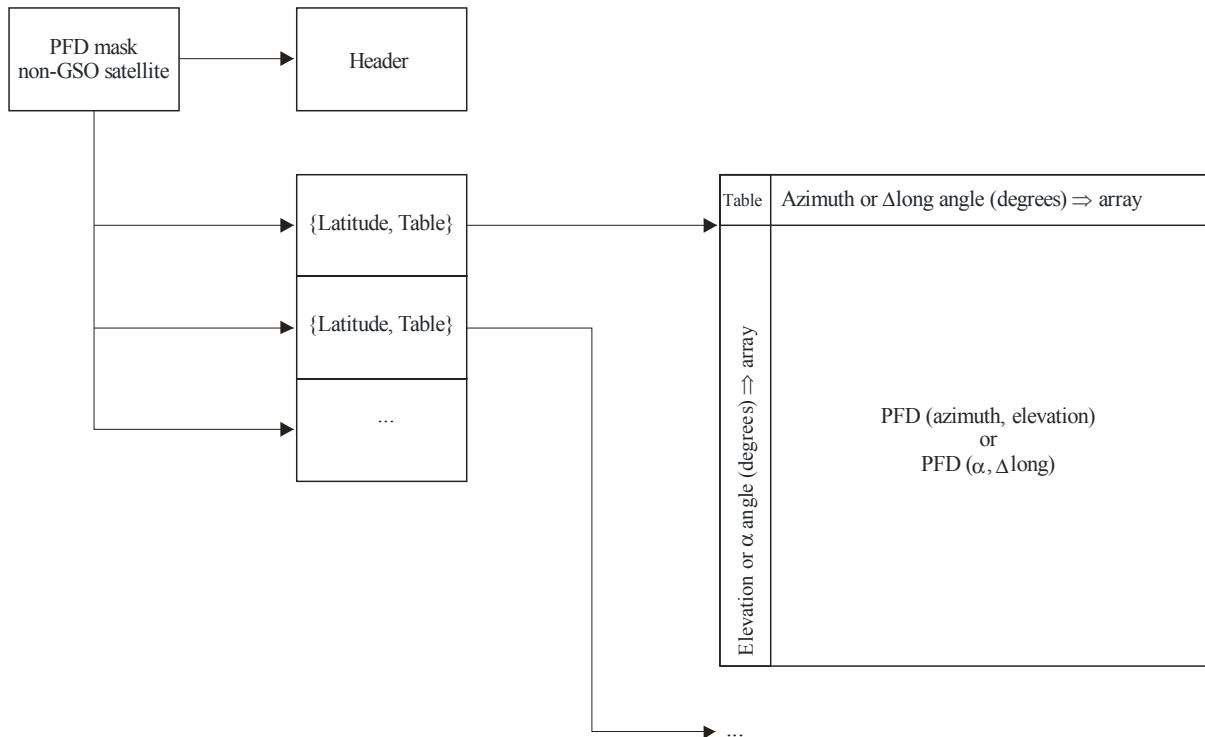
For the ES e.i.r.p. masks, there is the option to specify the position by (latitude, longitude) rather than density via a reference to a specific ES in the SRS. Note that it is not permitted to mix types: either all non-GSO ES are to be defined via specific ES or all via the density field.

Each mask has header information giving:

– Notice ID

– Satellite name

– Mask ID

– Lowest frequency mask is valid in MHz

– Highest frequency mask is valid in MHz

– Mask type

– Parameters of mask.
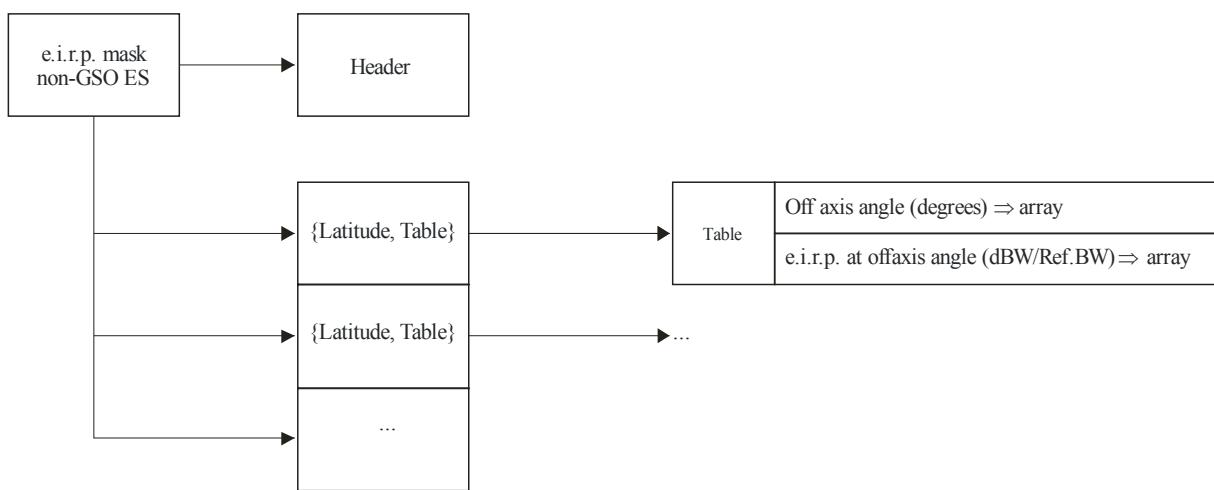
The masks relationships are shown in Figs. 9 to 11.

FIGURE 9

Structure of pfd mask data for epfd(down)
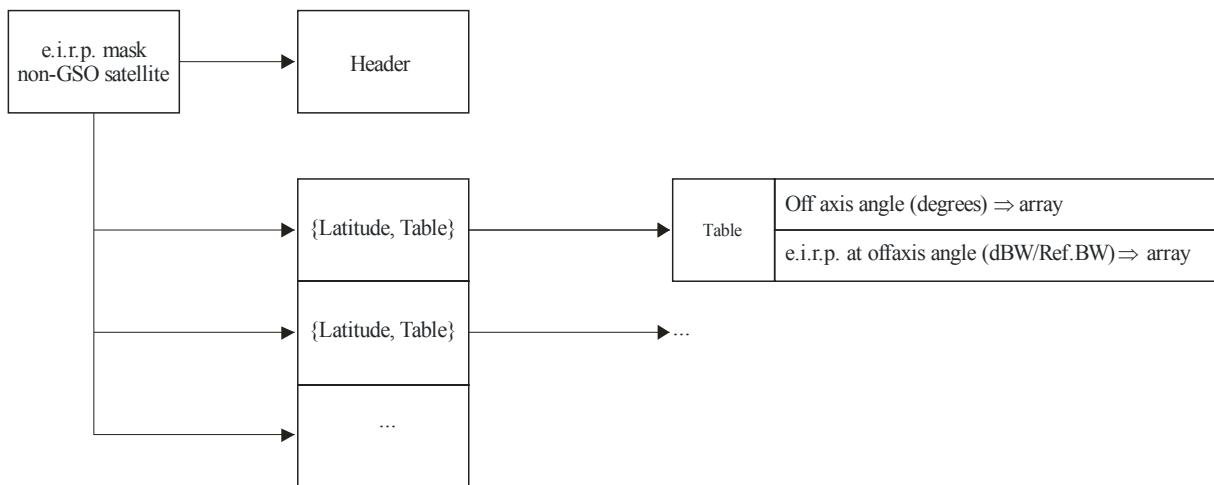
S.1503-09

FIGURE 10

Structure of pfd mask data for epfd(up)

S.1503-10

FIGURE 11
Structure of pfd mask data for epfd(IS)

S.1503-11

The pfd masks are to be provided to the ITU BR in XML format as:

– It is both machine readable and human readable

– Allows both format and type checking

– Is an international standard for exchange of data.

The XML format is plain text with opening and closing blocks, as in

<satellite_system>

</satellite_system>

Within each section there are then fields relevant to that block.

At the top level the satellite system is identified via its notice ID and name using:

<satellite_system ntc_id="NNNNNNN" sat_name="NAME">

[Header]

[Tables]

</satellite_system>

Within this structure there is the header followed by each of the tables.

The format for each mask is described in more detail in the sections below.

4.2   pfd mask for epfd(down)

The header format of the pfd mask is as follows:

<pfd_mask mask_id="N" low_freq_mhz="F1" high_freq_mhz="F2" type="Type" a_name="latitude" b_name="B" c_name="C">

where (see Table 5):

TABLE 5

pfd mask header format

Field	Type or range	Units	Example
mask_id	Integer	–	3
low_freq_mhz	Double precision	MHz	10 000
high_freq_mhz	Double precision	MHz	
type	{alpha_deltaLongitude, azimuth_elevation}	–	alpha_deltaLongitude
a_name	{latitude}	–	latitude
b_name	{alpha, azimuth}	–	alpha
c_name	{deltaLongitude, elevation}	–	deltaLongitude

For each of a, b, c there are then arrays of values, such as:

<by_a a="N">

</by_a>

The values within that open/close structure then all relate to a = N: a similar structure is used for b values.

The innermost group gives the actual pfd value, such as:

<pfd c="0">–140</pfd>

An example pfd mask would therefore be:

<satellite_system ntc_id="12345678" sat_name="MySatName">

<pfd_mask mask_id="3" low_freq_mhz="10000" high_freq_mhz="40000" type="alpha_deltaLongitude" a_name="latitude" b_name="alpha" c_name="deltaLongitude">

<by_a a="0">

   <by_b b="–180">

     <pfd c="–20">–150</pfd>

     <pfd c="0">–140</pfd>

     <pfd c="20">–150</pfd>

   </by_b>

   <by_b b="–8">

     <pfd c="–20">–165</pfd>

     <pfd c="0">–155</pfd>

     <pfd c="20">–165</pfd>

   </by_b>

   <by_b b="–4">

     <pfd c="–20">–170</pfd>

     <pfd c="0">–160</pfd>

```
            <pfd c="20">–170</pfd>
        </by_b>
        <by_b b="0">
            <pfd c="–20">–180</pfd>
            <pfd c="0">–170</pfd>
            <pfd c="20">–180</pfd>
        </by_b>
        <by_b b="4">
            <pfd c="–20">–170</pfd>
            <pfd c="0">–160</pfd>
            <pfd c="20">–170</pfd>
        </by_b>
        <by_b b="8">
            <pfd c="–20">–165</pfd>
            <pfd c="0">–155</pfd>
            <pfd c="20">–165</pfd>
        </by_b>
        <by_b b="180">
            <pfd c="–20">–150</pfd>
            <pfd c="0">–140</pfd>
            <pfd c="20">–150</pfd>
        </by_b>
    </by_a>
    </pfd_mask>
    </satellite_system>
```

4.3   e.i.r.p. mask for epfd(up)

The header format of the pfd mask is as follows:

> *<eirp_mask_es mask_id="N" low_freq_mhz="F1" high_freq_mhz="F2" min_elev="E"*
> *d_name="separation angle" ES_ID = "–1">*

where (see Table 6):

TABLE 6

Non-GSO ES e.i.r.p. mask header format

Field	Type or range	Units	Example
mask_id	Integer	–	1
low_freq_mhz	Double precision	MHz	10 000
high_freq_mhz	Double precision	MHz	
min_elev	Double precision	degrees	10
d_name	{separation angle}	–	Separation angle
ES_ID	Integer	–	12345678 −1 if non-specific

There are then arrays of e.i.r.p. values for given off-axis angles, such as:

<eirp d="0">30.0206</eirp>

An example pfd mask would therefore be:

<satellite_system ntc_id="12345678" sat_name="MySatName">

<eirp_mask_es mask_id="1" low_freq_mhz="10000" high_freq_mhz="40000" min_elev="0" d_name="separation angle", ES_ID=−1>

<eirp d="0">30.0206</eirp>

<eirp d="1">20.0206</eirp>

<eirp d="2">12.49485</eirp>

<eirp d="3">8.092568</eirp>

<eirp d="4">4.9691</eirp>

<eirp d="5">2.54634976</eirp>

<eirp d="10">−4.9794</eirp>

<eirp d="15">−9.381681</eirp>

<eirp d="20">−12.50515</eirp>

<eirp d="30">−16.90743</eirp>

<eirp d="50">−18.9471149</eirp>

<eirp d="180">−18.9471149</eirp>

</eirp_mask_es>

</satellite_system>

4.4 e.i.r.p. mask for epfd(IS)

The header format of the pfd mask is as follows:

<eirp_mask_ss mask_id="N" low_freq_mhz="F1" high_freq_mhz="F2" d_name="separation angle">

where (see Table 7):

TABLE 7

Non-GSO satellite e.i.r.p. mask header format

Field	Type or Range	Units	Example
mask_id	Integer	–	1
low_freq_mhz	Double precision	MHz	10 000
high_freq_mhz	Double precision	MHz	
d_name	{separation angle}	–	Separation angle

There are then arrays of e.i.r.p. values for given off-axis angles, such as:

<eirp d="0">30.0206</eirp>

An example pfd mask would therefore be:

<satellite_system ntc_id="12345678" sat_name="MySatName">

<eirp_mask_ss mask_id="2" low_freq_mhz="10000" high_freq_mhz="40000" d_name="separation angle">

<eirp d="0">30.0206</eirp>

<eirp d="1">20.0206</eirp>

<eirp d="2">12.49485</eirp>

<eirp d="3">8.092568</eirp>

<eirp d="4">4.9691</eirp>

<eirp d="5">2.54634976</eirp>

<eirp d="10">–4.9794</eirp>

<eirp d="15">–9.381681</eirp>

<eirp d="20">–12.50515</eirp>

<eirp d="30">–16.90743</eirp>

<eirp d="50">–18.9471149</eirp>

<eirp d="180">–18.9471149</eirp>

</eirp_mask_ss>

</satellite_system>

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 epfd limits.

There are three key tasks that the software must complete as identified in Fig. 1:

1)   determination of the runs to execute;

2)   for each run, determination of worst case geometry;

3)   for each run, calculation of epfd statistics and checking compliance with the limits.

1.2   Background

This section assumes that the following approaches are used:

epfd↓ calculation: Each non-GSO satellite has a pfd mask and the pfd for each satellite is used to calculate the aggregate epfd↓ at an earth station of a GSO system. This is repeated for a series of time steps until a distribution of epfd↓ is produced. This distribution can then be compared with the limits to give a go/no go decision.

epfd↑ 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 epfd↑ at the GSO can be calculated. This is repeated for a series of time steps until a distribution of epfd↑ is produced. This distribution can then be compared with the limits to give a go/no go decision.

epfd$_{is}$ calculation: From the e.i.r.p. and off-axis angle for each space station, the epfd$_{is}$ at the GSO space station can be calculated. This is repeated for a series of time steps a distribution of 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:   Determination of runs to execute

§ 3:   Determination of worst case geometry for each run

§ 4:   Calculation of time step size and number of time steps

§ 5:   Calculation of epfd statistics and limit compliance checking

§ 5.1:   Defines the epfd↓ algorithm

§ 5.2:   Defines the epfd↑ algorithm

§ 5.3:   Defines the epfd$_{is}$ algorithm

§ 6:   Defines the core geometry and algorithms used by both epfd calculations including gain patterns

§ 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   General assumptions and limitations

A general limitation on the generation of epfd statistics is:

   Bin size: $S_B = 0.1$ dB

To be consistent with the evaluation algorithm in § D.7.1.3 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, α and X, as described in § D.6.4.4 are based upon a number of test points, with specified separation between them:

   Separation between GSO test points: 1e-5 radians.

1.5   Database and interface

Wherever feasible, input data should be taken from the SRS or other databases, combined with BR resources such as DLLs to define epfd limits and calculate antenna gains.

2   Determination of runs to execute

2.1   Article 22 runs

For an Article **22** run a key task is to determine which runs to execute given a non-GSO filing and the epfd limits specified in the RR.

```
For all ES e.i.r.p. masks in non-GSO notice
{
    Get frequency range of ES e.i.r.p. mask (fmin, fmax)
    From LimitsAPI request all epfd(up) limits in range (fmin, fmax)
    For all epfd(up) limits returned
    {
        Set FrequencyRun = max(fmin(mask), fmin(limits)) + RefBW/2
        CreateRun:
            Direction = Up
            Frequency = FrequencyRun
            Sat_Beamwidth = From Limits API
            Sat_GainPattern = From Limits API
            epfd_Threshold = From Limits API
            Ref_BW = From Limits API
    }
}
For all PFD masks in non-GSO notice
{
    Get frequency range of pfd mask (fmin, fmax)
    From LimitsAPI request all FSS epfd(down) limits in range (fmin, fmax)
    For all epfd(down) limits returned
    {
        Set FrequencyRun = max(fmin(mask), fmin(limits)) + RefBW/2
        CreateRun:
            Direction = Down
```

```
                Service = FSS
                Frequency = FrequencyRun
                ES_DishSize = From Limits API
                ES_GainPattern = From Limits API
                epfd_Threshold = From Limits API
                Ref_BW = From Limits API
        }
    From LimitsAPI request all BSS epfd(down) limits in range (f_min, f_max)
    For all epfd(down) limits returned
    {
            Set FrequencyRun = max(f_min(mask), f_min(limits)) + RefBW/2
            CreateRun:
                Direction = Down
                Service = BSS
                Frequency = FrequencyRun
                ES_DishSize = From Limits API
                ES_GainPattern = From Limits API
                epfd_Threshold = From Limits API
                Ref_BW = From Limits API
        }
}
For all Satellite EIRP masks in non-GSO notice
{
    Get frequency range of satellite EIRP mask (f_min, f_max)
    From LimitsAPI request all epfd(is) limits in range (f_min, f_max)
    For all epfd(is) limits returned
    {
            Set FrequencyRun = max(f_min(mask), f_min(limits)) + RefBW/2
            CreateRun:
                Direction = Intersatellite
                Frequency = FrequencyRun
                Sat_Beamwidth = From Limits API
                Sat_GainPattern = From Limits API
                epfd_Threshold = From Limits API
                Ref_BW = From Limits API
        }
}
```

2.2 Article 9.7A

For Article **9.7A** runs the criteria and threshold is defined in Appendix **5** of the Radio Regulations and runs are generated as follows:

```
If the selected earth station meets the criteria in Appendix 5
{
    Get the frequency range of the selected ES(f_min, f_max)
    Get all non-GSO networks in the SRS that overlap that frequency range
    For each non-GSO network returned
    {
        For all pfd masks in non-GSO notice
        {
                Get frequency range of PFD mask Mask(f_min, f_max)
                If there is overlap ES(f_min, f_max) with Mask(f_min, f_max)
```

```
              {
                      Get RefBW from Appendix 5
                      Set FrequencyRun = max(ES_fmin, Mask_fmin) + RefBW/2
                      CreateRun:
                              Direction = Down
                              Frequency = FrequencyRun
                              ES_DishSize = From ES filing
                              ES_GainPattern = From ES filing
                              epfd_Threshold = From Appendix 5
                              Ref_BW = From Appendix 5
              }
          }
      }
}
```

2.3   Article 9.7B

For Article **9.7B** runs the criteria and threshold is defined in Appendix **5** of the Radio Regulations and runs are generated as follows:

```
For all pfd masks in non-GSO notice
{
      Get frequency range of pfd mask Mask(fmin, fmax)
      Get all ES in the SRS that overlap that frequency range
      For each ES returned
      {
          If the earth station meets the criteria in Appendix 5
          {
                  Get the frequency range of the ES(fmin, fmax)
                  Get RefBW from Appendix 5
                  Set FrequencyRun = max(ES_fmin, Mask_fmin) + RefBW/2
                  CreateRun:
                          Direction = Down
                          Frequency = FrequencyRun
                          ES_DishSize = From ES filing
                          ES_GainPattern = From ES filing
                          epfd_Threshold = From Appendix 5
                          Ref_BW = From Appendix 5
                  }
          }
      }
}
```

3   Worst case geometry

3.1   WCG epfd↓

3.1.1   Inputs

The inputs to the algorithm are as follows:

pfd_mask: the pfd mask to check

α :   the GSO arc avoidance angle of the non-GSO system

h :   the minimum operating height of the non-GSO system

ε :   the minimum elevation angle of the non-GSO system

i :   the inclination angle of the non-GSO system

ES :   the parameters of the ES including gain pattern.

3.1.2   Algorithm

This section describes the algorithm to determine the Worst Case Geometry (WCG) for the epfd(down) direction.

Note that there could be different pfd masks at different frequencies: this process is assumed to be repeated for each valid frequency range.

The WCG is based upon search in (θ, φ) as seen by the non-GSO satellite, with particular care taken for the region ($-\alpha_0$, $+\alpha_0$) including $\alpha = 0$. This search is repeated at a number of test non-GSO satellite latitudes. In addition, specific checks are made for the highest latitudes for which $\alpha = \{-\alpha_{0,0}, +\alpha_0\}$ to ensure compatibility with the methodology in Recommendation ITU-R S.1714.
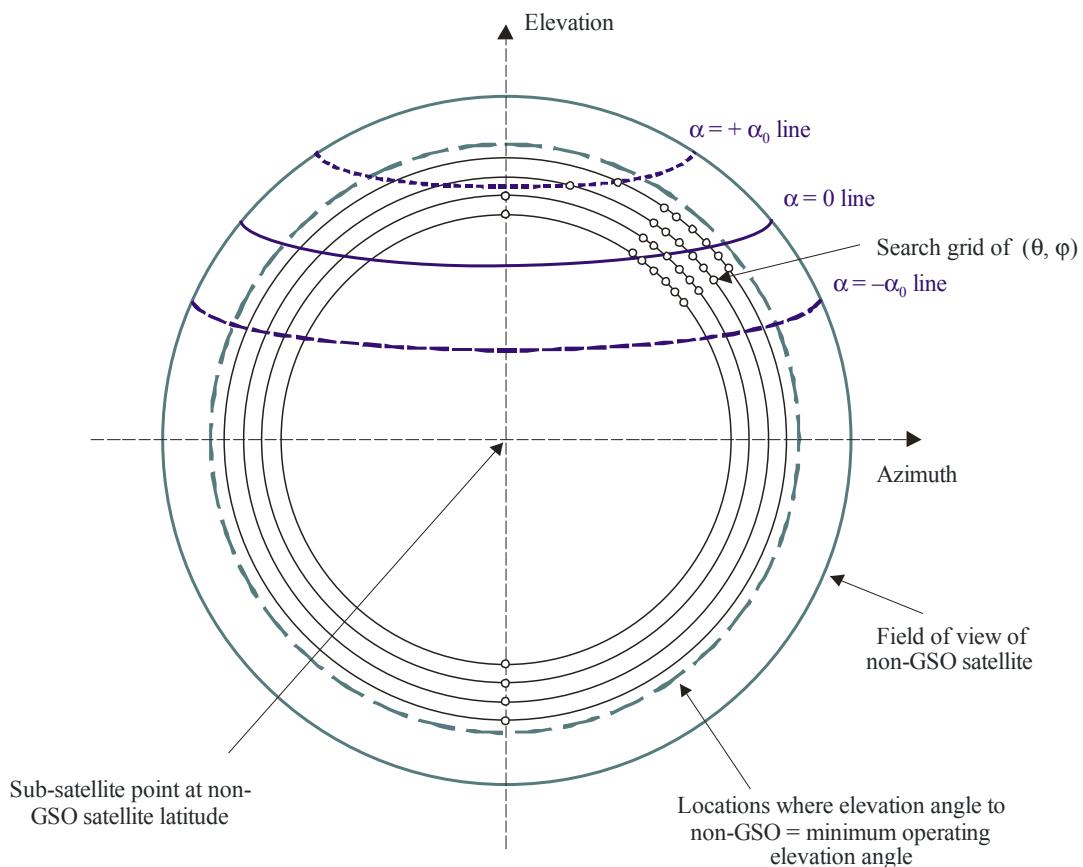
For each test point considered, the algorithm calculates the epfd using the pfd mask and receive antenna gain, and compares that to the threshold for the relevant latitude.

It is likely that multiple test points will result in the same difference between epfd level and threshold. To assess which should be used as the WCG, the angular velocity of the non-GSO satellite as seen by the ES is calculated, and the geometry selected is that:

–   Gives the highest difference between epfd level and threshold to the resolution of the resulting statistics (0.1 dB).

–   If multiple geometries meet point 1, select the one that would result in geometry that gives the lowest angular velocity of the satellite as seen by the ES.

The search algorithm is shown in Fig. 12.

FIGURE 12

Search (θ, φ) grid for WCG

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The algorithm is described in the following pseudo code:

```
WCGA_Down:
Set WorstEPFDBin = -9999
Set WorstAngularVelocity = +9999
For all satellites in the order listed in ITU DB
{
     Determine PFD mask to use for this satellite
     If this PFD mask has not been checked so far then
          Call GetWCGA_Down
     End if
Next satellite
```

```
GetWCGA_Down (PFD_Mask, α₀, ε₀, ES):
     StepSize = min(ES.Beamwidth, PFD_Mask_StepSize)/Nₕᵢₜₛ
If (i = 0)
{
     CheckWCG_Down (latitude = 0)
}
Else
{
     LatNumSteps = RoundUp(i / StepSize)
     For n = 0 to LatNumSteps inclusive
     {
```

```
                latitude = i * n / LatNumSteps
                CheckWCG_Down(latitude)
                If (n > 0)
                {
                    CheckWCG_Down(-latitude)
                }
        }
        CheckExtremeWCG(α = 0 & θ = +π/2}
        CheckExtremeWCG(α = 0 & θ = -π/2}
        If (α₀ > 0)
        {
            CheckExtremeWCG(α = −α₀ & θ = +π/2}
            CheckExtremeWCG(α = −α₀ & θ = -π/2}
            CheckExtremeWCG(α = +α₀ & θ = +π/2}
            CheckExtremeWCG(α = +α₀ & θ = -π/2}
        }
}


CheckWCG_Down(latitude):
    Locate non-GSO satellite at latitude
    Calculate φ₀ for elevation angle ε₀ and radius r
    CheckCase(latitude, θ = 0, φ = 0)
    PhiSteps = RoundUp(φ₀ / StepSize)
    For φ = PhiStepSize to φ₀ inclusive in PhiSteps steps
    {
                ThetaMin = −π/2
                ThetaMax = +3π/2
                If the PFD mask is symmetric in DeltaLong or Azimuth
                    ThetaMax = π/2
                NumThetaSteps = RoundUp(2πφ/PhiStepSize)
                ThetaStepSize = (ThetaMax-ThetaMin)/NumThetaSteps
            For ThetaStep = 0 to NumThetaSteps inclusive
            {
                    θ = ThetaMin + ThetaStep*ThetaStepSize
                CheckCase(latitude, θ, φ)
            }
            If can calculate θ that corresponds to α = 0
                CheckCase(latitude, θ, φ)
            If (α₀ > 0)
            {
                If can calculate θ that corresponds to α = −α₀
                CheckCase(latitude, θ, φ)
            If can calculate θ that corresponds to α = +α₀
                CheckCase(latitude, θ, φ)
    }
    If mask is not symmetric then repeat for other hemisphere
}
```

```
CheckCase(latitude, θ, φ):
    Convert (θ, φ) to (az, el)
    Create line from non-GSO satellite N in direction (az, el)
    Identify point P in which line intersects Earth
    At point P calculate (α, X, Δlong) angles wrt point N
    At point P calculate AngularVelocity using methodology below
    Calculate PFD from mask, latitude & (az, el, α, X, Δlong)
    Calculate G_rel(α)
    Calculate EPFDThreshold from latitude of point P
    Calculate EPFDMargin = PFD + G_rel(α) - EPFDThreshold
    Calculate EPFDbin = EPFDMargin/BinSize
    If WorstEPFDBin < EPFDBin
    {
        WorstEPFDBin = EPFDBin
        Worst AngularVelocity = AngularVelocity
        Store this (N, P)
    }
    Else if (WorstEPFDBin = EPFDBin &&
            WorstAngularVelocity > AngularVelocity)
    {
        WorstAngularVelocity = AngularVelocity
        Store this (N, P)
    }


CheckExtremeWCG(α,θ):
    Iterate in true anomaly until find latitude for (α, θ)
    Calculate φ_0 at latitude
    CheckCase(latitude, θ, φ_0)
```

The algorithm uses the geometry given in the sections below.

3.1.3 Geometry

3.1.3.1 Conversion between (az, el) and (θ, φ)

The following equations can be used:

$$\cos(\varphi) = \cos(az)\ \cos(el)$$

$$\sin(el) = \sin(\theta)\ \sin(\varphi)$$

3.1.3.2 Setting satellite at latitude

Key steps in this algorithm are the calculation of the position and velocity vectors of the non-GSO satellite and ES. The latitude can be used to derive the true anomaly, ν, using:

$$\sin(\omega + \nu) = \frac{\sin lat}{\sin i}$$

To derive the position and velocity vectors, the following equations could be used:

In the satellite plane:

$$\underline{r}_{sat} = r_{sat}(\cos \nu \ \underline{P} + \sin \nu \ \underline{Q})$$

$$\underline{v}_{sat} = \sqrt{\frac{\mu}{\rho}}(-\sin v \, \underline{P} + (e + \cos v) \, \underline{Q})$$

where:

        P, Q: unit vectors in the orbit plane with origin the centre of the Earth and P aligned with the orbit's major axis

        a, e, v: orbital elements.

Also:

$$r_{sat} = \frac{p}{1 + e \cos v}$$

$$p = a(1 - e^2)$$

The non-GSO's position and velocity vectors can then be converted from the PQW orbit plane based frame to Earth centred vectors using the standard rotation matrix via the (Ω, ω, i) orbital elements. It can be assumed that second order effects including the J_2 factor need not be considered.

The position vector equation can also be used to calculate a latitude from a true anomaly, v, and hence by iteration locate the satellite at the required latitude.

3.1.3.3 Calculation of maximum φ in satellite viewpoint
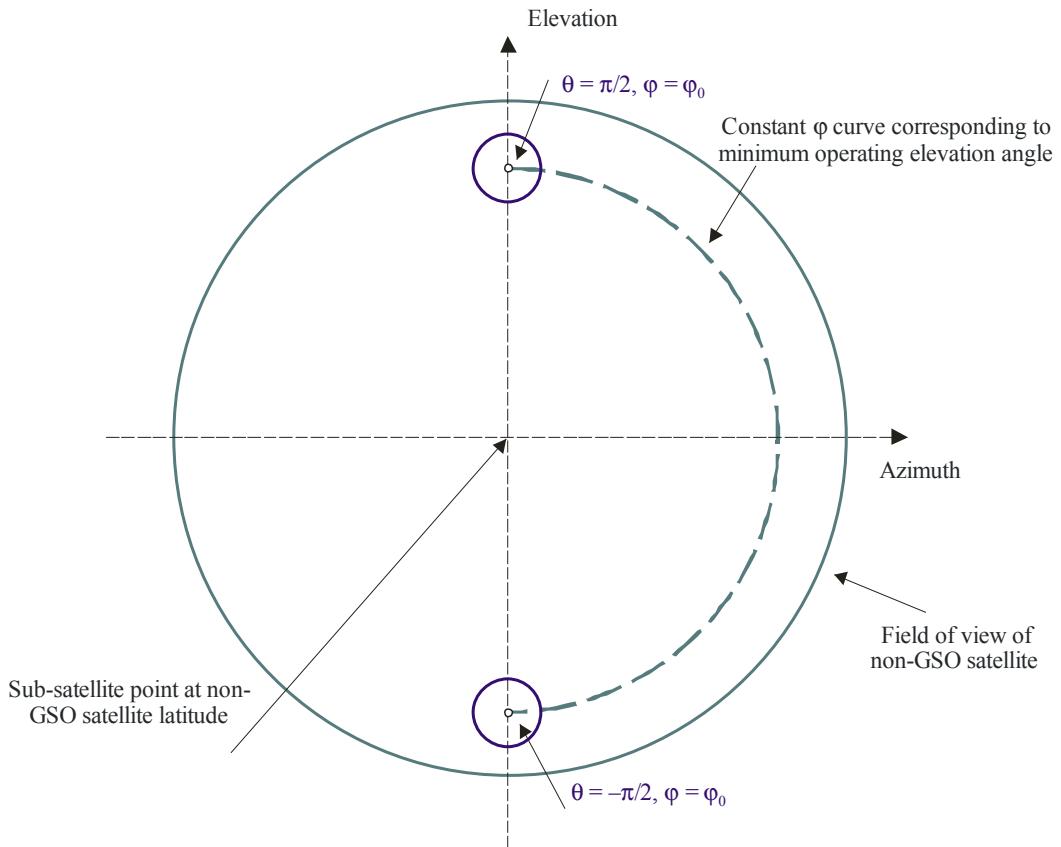
For a given latitude and hence satellite radius, the maximum angle at the satellite from sub-satellite point φ_0 can be derived from the elevation angle ε using:

$$\sin(\varphi_0) = \frac{R_e}{r_{sat}} \sin\left(\frac{\pi}{2} + \varepsilon\right)$$

3.1.3.4 Calculation of alpha for maximum φ in satellite viewpoint

For a given latitude and hence satellite radius, the maximum angle at the satellite from sub-satellite point φ_0 can be derived from the elevation angle ε using the equation above. There will then be two extrema points as shown in Fig. 13:

FIGURE 13

Extrema cases to derive α

S.1503-13

Then the alpha value at the extrema can be calculated as follows:

– Convert given (θ, φ) into (azimuth, elevation)

– Calculate line from non-GSO satellite in direction (azimuth, elevation)

– Calculate nearest intersection point P with Earth radius R_e

– At point P calculate α angle of non-GSO satellite.

3.1.3.5 Calculation of angular velocity

The inputs are as follows:

ES position vector:	$\underline{r}_{es}$
ES position vector:	$\underline{v}_{es}$
Non-GSO satellite position vector:	$\underline{r}_{sat}$
Non-GSO satellite position vector:	$\underline{v}_{sat}$

From these, it is possible to calculate the apparent velocity and vector from the ES to the satellite:

$$\underline{r} = \underline{r}_{sat} - \underline{r}_{es}$$

$$\underline{v} = \underline{v}_{sat} - \underline{v}_{es}$$

The angle between these two vectors can then be calculated:
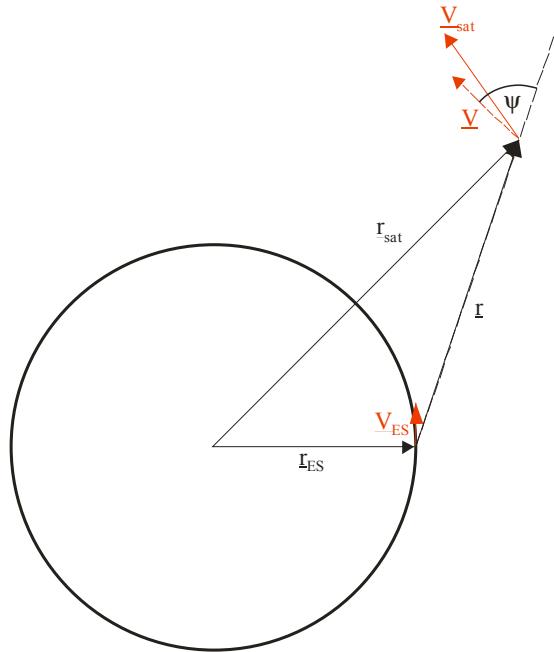
$$\cos \psi = \frac{r \cdot v}{rv}$$

The instantaneous angular velocity is then:

$$\theta = \frac{v}{r}\sin\psi$$

The various terms are shown in Fig. 14:

FIGURE 14

Vectors to calculate non-GSO satellite apparent angular velocity

S.1503-14

Note that a low angular velocity will result in higher likelihoods of interference and hence for a given epfd value the WCG that gives the least apparent angular velocity would be the one to use.

The ES's velocity vector can be derived from its position vector (x, y, z) as follows:
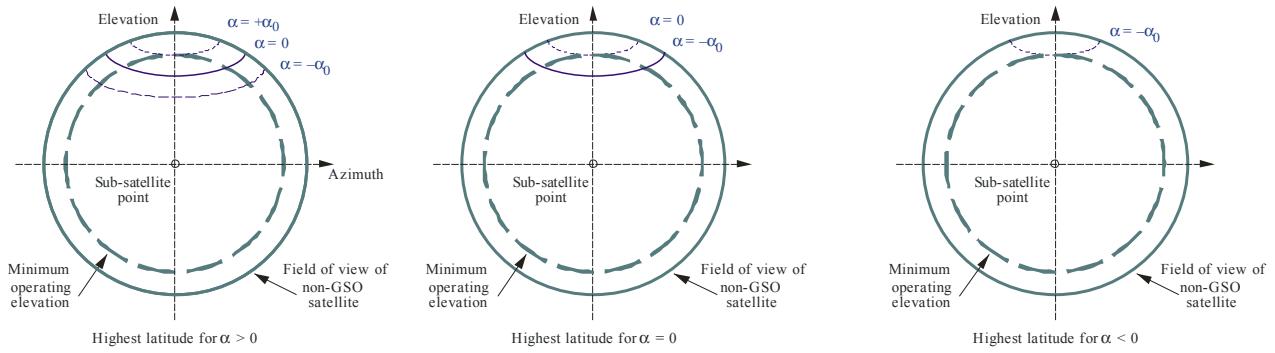
$$\underline{v}_{es} = w_e \begin{pmatrix} -y \\ x \\ 0 \end{pmatrix}$$

Where w_e is the Earth's angular velocity in radians per second.

3.1.3.6   Find latitude from (α, h, ε)

This section describes how to go from α, h, ε to non-GSO latitude assuming the satellite is at the highest latitude for which the relevant α line intersects the point where the elevation angle is ε and $\theta = \pi/2$ as shown in Fig. 15.

FIGURE 15

Calculation of highest latitude for a given value of α
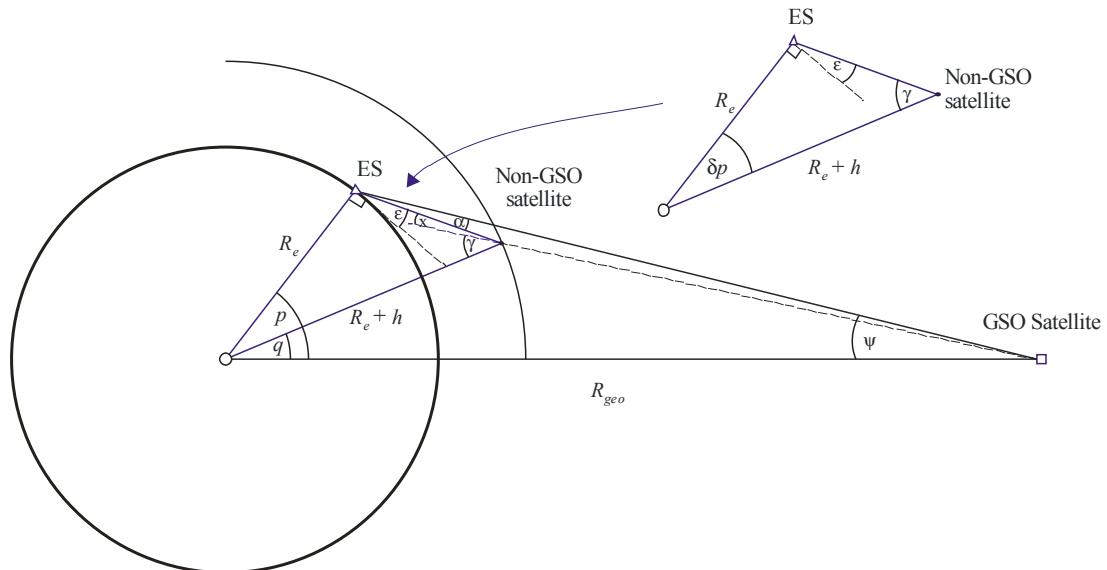
The method depends upon whether α is positive or negative as in the following two sub-sections:

3.1.3.7   Find latitude from (α, h, ε) with $\alpha \geq 0$

The geometry for this case is shown in Fig. 16:

FIGURE 16

Highest latitude for $\alpha \geq 0$

Hence the angles can be derived as follows:

$$\psi = \arcsin\left(\frac{R_e}{R_{Geo}} \sin\left(\frac{\pi}{2} + \varepsilon + \alpha \right) \right)$$

$$p = \frac{\pi}{2} - \psi - \varepsilon - \alpha$$

$$\gamma = \arcsin\left(\frac{R_e}{R_e + h}\sin\left(\frac{\pi}{2} + \varepsilon\right)\right)$$

$$\delta p = \frac{\pi}{2} - \gamma - \varepsilon$$

$$q = p - \delta p$$

Note that this approach is only valid for $\varepsilon + \alpha < \pi/2$. In cases where $\varepsilon + \alpha \geq \pi/2$, then an error flag should be raised: if necessary use $p = q = 0$.

3.1.3.8 Find latitude from (α, h, ε) with $\alpha < 0$

The geometry for this case is shown in Fig. 17:

FIGURE 17

Highest latitude for $\alpha < 0$

S.1503-17

Hence the angles can be derived as follows:
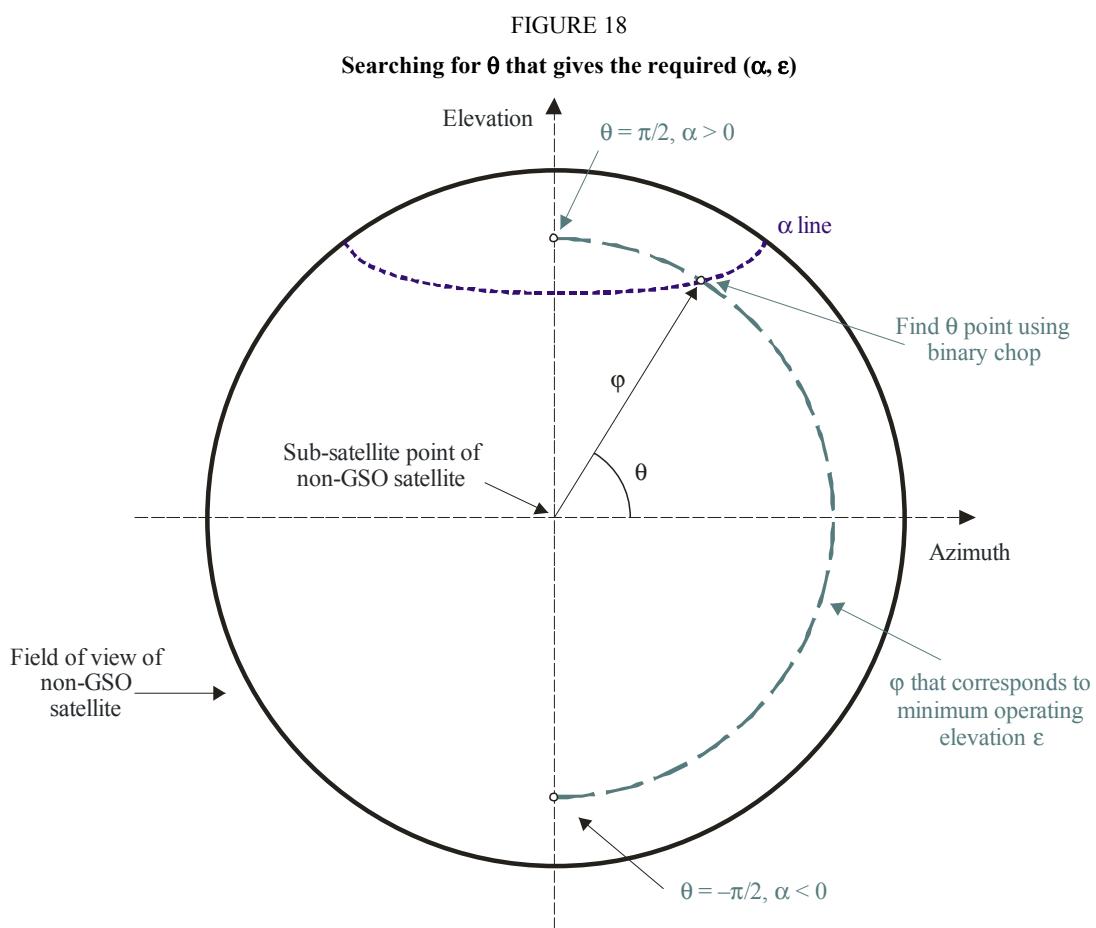
$$\psi = \arcsin\left(\frac{R_e}{R_{Geo}}\sin\left(\frac{\pi}{2} + \varepsilon\right)\right)$$

$$p = \frac{\pi}{2} - \psi - \varepsilon$$

$$\gamma = \arcsin\left(\frac{R_e}{R_e + h}\sin\left(\frac{\pi}{2} + \varepsilon + \alpha\right)\right)$$

$$\delta p = \frac{\pi}{2} - \gamma - \varepsilon - \alpha$$

$$q = p - \delta p$$

Note that this approach is only valid for $\varepsilon + \alpha < \pi/2$. In cases where $\varepsilon + \alpha \geq \pi/2$, then an error flag should be raised: if necessary use $p = q$.

3.1.3.9 Find (θ, φ) from (latitude, α, h, ε)

In this case, the non-GSO satellite is assumed to be at a given latitude (which could be the orbit inclination) and from α, h, ε it is possible to work out the θ angle.

The satellite's field of view is shown in Fig. 18:

FIGURE 18

Searching for θ that gives the required (α, ε)

S.1503-18

The first stage is to calculate φ_0 as follows:

$$\sin(\varphi_0) = \frac{R_e}{R_e + h} \sin\left(\frac{\pi}{2} + \varepsilon\right)$$

From this, the result can be derived using a binary chop algorithm as follows:

```
FindThetaPhiFromAlpha(lat, α, h, ε):
    Configure Non-GSO satellite at latitude = lat
    Phi0 = GetPhiZero(h, ε) using equation above
    Theta0 = −π/2
    Theta1 = +π/2
    Alpha0 = GetAlpha(Theta0, Phi0)
```

```
    Alpha1 = GetAlpha(Theta1, Phi0)
    If Alpha0 < α then
    {
        Return fail with (Theta0, Phi0) as nearest angles
    }
    Else if Alpha1 > α
    {
        Return fail with (Theta1, Phi0) as nearest angles
    }
    While (Theta1 – Theta0 < 1e-6)
    {
        Theta2 = (Theta1 + Theta0)/2
        Alpha2 = GetAlpha(Theta2, Phi0)
        If (Alpha2 > α)
        {
            Theta1 = Theta2
            Alpha1 = Alpha2
        }
        Else
        {
            Theta0 = Theta2
            Alpha0 = Alpha2
        }
    }
    Return (Theta1, Phi0) and ok

GetAlpha(θ, φ):
    Convert (θ, φ) to (az, el)
    Create line in direction (az, el) from non-GSO satellite
    Identify point P where line intersects Earth
    At point P calculate α
    Return α
```

3.2 WCG epfd↑

3.2.1 Inputs

The inputs to the algorithm are as follows:

ES_eirp : the non-GSO ES e.i.r.p. mask to check

θ_{adB} : the GSO satellite's beam half power beamwidth

ε : the minimum elevation angle of the GSO system

$a, i, e, \Omega, \omega, \nu$: the inclination orbit parameters of the non-GSO system.

3.2.2 Algorithm

The WCGA for the epfd(up) case is as follows

```
WCGA_UP:
    Calculate φ0
    From φ0 calculate LatBS
    If single EIRP mask for all ES and ES from density
```

```
         If orbit (e = 0, i > 0)
             WCG(lat, Δlong) = {Lat_BS, 0}
         If orbit (e = 0, i = 0)
             WCG(lat, Δlong) = {0, Lat_BS}
         If orbit (e > 0) and apogee in northern hemisphere
             WCG(lat, Δlong) = {Lat_BS, 0}
         If orbit (e > 0) and apogee in southern hemisphere
             WCG(lat, Δlong) = {−Lat_BS, 0}
    Else
         If ES from density
             If (i = 0)
                 Call WCGA_UP_Equatorial_all
             Else
                 Call WCGA_UP_General
             Endif
         Else
             If non-GSO satellite repeats
                 Call WCGA_UP_SpecifcES_Repeating
             Else
                 Call WCGA_UP_SpecifcES_NonRepeating
             Endif
         Endif
    Endif
Endif
```

The various cases, their functions and geometries are described in the following sections.

3.2.3   Geometry

3.2.3.1   General

In general, the worst single entry epfd is when the ES is in the main beam of the GSO satellite and is pointing as closely as possible directly at it. The nearest the ES can point towards the GSO defined by the exclusion zone size, hence the worst single entry epfd is:
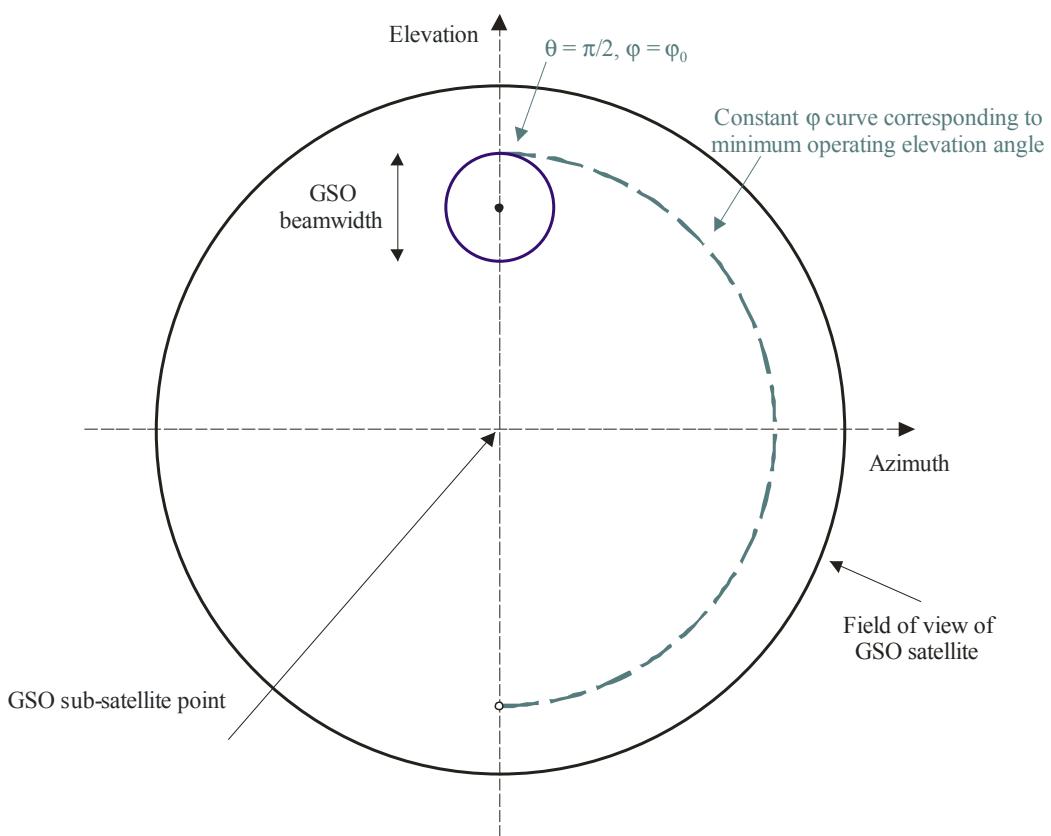
$$EPFD = EIRP(\alpha_0) - 10\log_{10}(4\pi D^2)$$

Where D is the distance from the ES to the GSO satellite.

This gives the worst single entry interference: the aggregate epfd will also depend upon the area covered by the GSO beam, which will depend upon the incident angle.

The GSO system's geometry relating to the WCGA(up) is shown in Fig. 19:

FIGURE 19

GSO system geometry for WCGA(up)
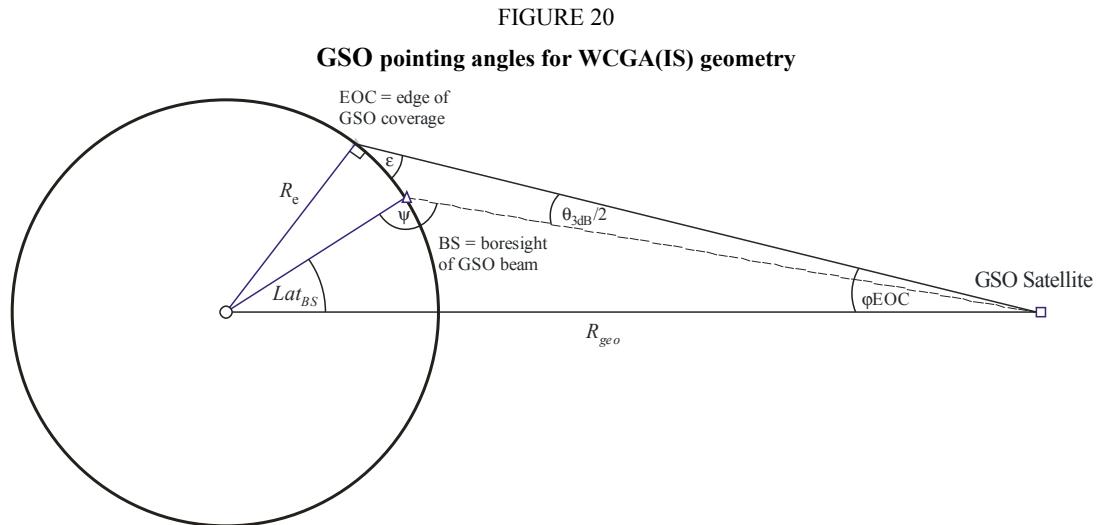
S.1503-19

Note that for non-GSO systems in circular orbit with global coverage:

– The area of the surface of the Earth covered by the beam (and hence of the non-GSO satellite constellation's orbital shell) is furthest away from the sub-satellite point, hence with constant density of ESs there will be more of them at higher latitudes.

– The probability of a non-GSO satellite being in a defined latitude range increases with latitude.

– The GSO system will have a minimum elevation angle for operating reasons.

From these constraints, the latitude of the GSO beam's boresight can be calculated from an assumed minimum elevation angle and beamwidth taken from the epfd limits in Article **22** of the RR.

FIGURE 20

GSO pointing angles for WCGA(IS) geometry

S.1503-20

Here the latitude of the ES can be derived as follows:

$$\sin\varphi_{EOC} = \frac{R_e}{R_{geo}} \sin\left(\frac{\pi}{2} + \varepsilon\right)$$

$$\varphi_{BS} = \varphi_{EOC} - \frac{\theta_{adB}}{2}$$

Then, noting that $\psi > \pi/2$:

$$\sin(\pi - \psi) = \frac{R_{geo}}{R_e} \sin(\varphi_{BS})$$

Hence:

$$Lat_{BS} = \pi - \varphi_{BS} - \psi$$

These equations can be used to derive the values in Table 8:

TABLE 8

WCG(up) geometry for constrained scenarios
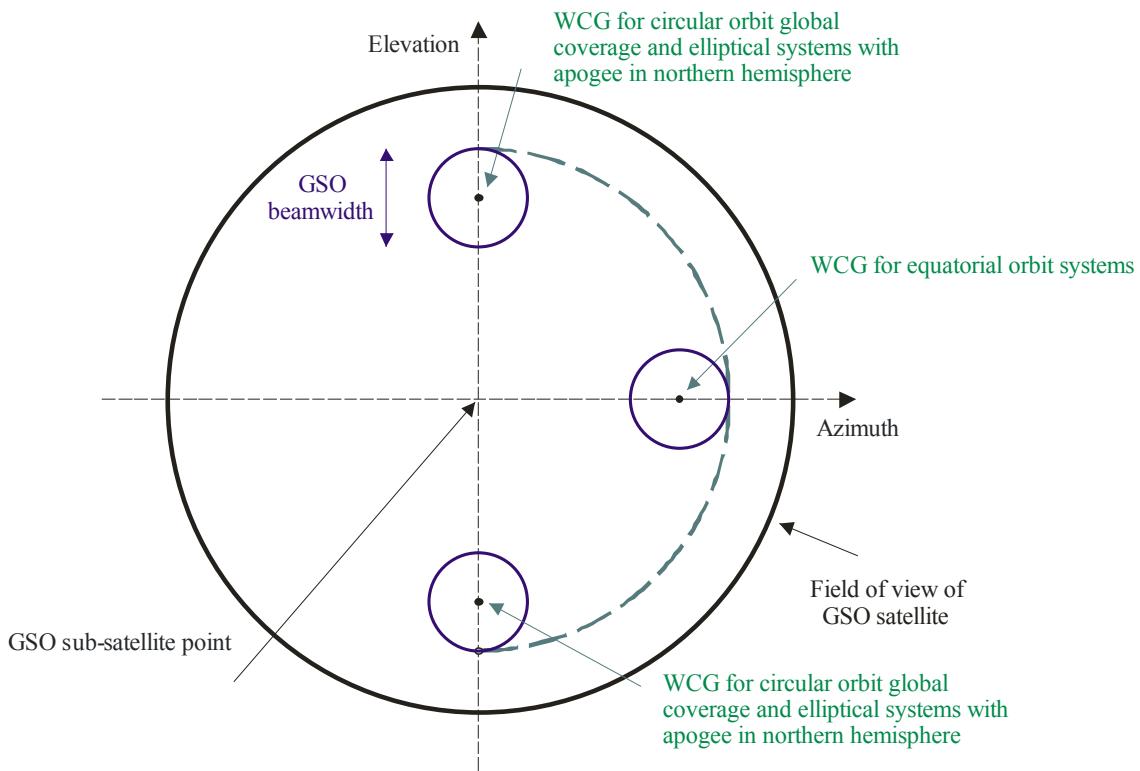
Frequency band	**Ku**	**Ka**
Beamwidth (degrees)	4	1.55
Minimum elevation angle (degrees)	10	20
Latitude	42.5	50.9

This approach is appropriate for:

–   Global coverage non-GSO systems in circular orbit with single e.i.r.p. mask.

–   Gobal coverage non-GSO systems in elliptical orbit with apogee in the northern hemisphere with single e.i.r.p. mask.

Simple changes are required to derive the WCG locations for equatorial systems and non-GSO systems with elliptical orbits with apogee in the southern hemisphere when a single e.i.r.p. mask is used, as shown in Fig. 21:

FIGURE 21

WCG(up) locations for selected constellation types

S.1503-21

Analysis of the WCG(up) suggests that there are three special cases to consider:

1)   Equatorial orbit systems when the e.i.r.p. varies by latitude

2)   Cases where the ESs are at specified locations rather than evenly distributed

3)   General case when the ES e.i.r.p. varies by latitude

These are discussed in the following sections.
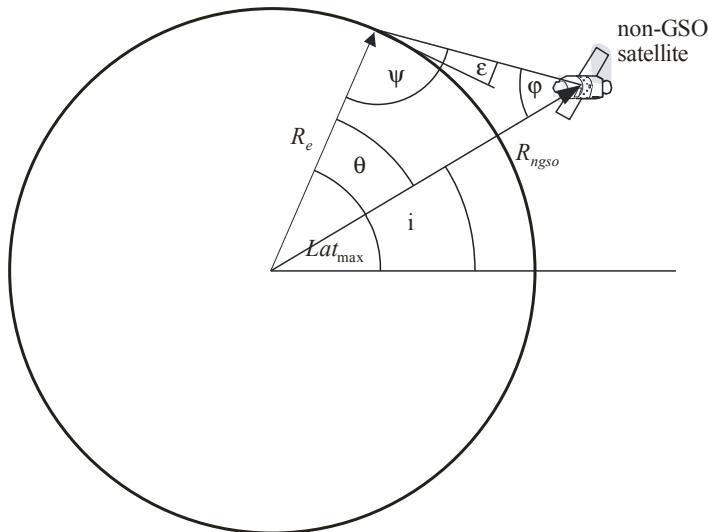
Note that the epfd(up) limits in Article **22** are 100% of time to be met, 0% of time permitted to be exceeded and hence the time factor is not important.

3.2.3.2   Range in latitude

When calculating the WCG(up) and also the epfd(up), it is necessary to identify where the ES could be located. While most systems in types A and B have global coverage, non-GSO networks of type C will be limited in the latitude range.

The latitude range can be derived from the satellite's height, its inclination angle and the minimum operating elevation angle for the ES, as in Fig. 22:

FIGURE 22

Calculation of maximum latitude for ESs

S.1503-22

For elliptical systems, there will be two values, one for the apogee and another for the perigee, and so the inputs would be:

Semi-major axis of orbit (km): a

Eccentricity of orbit: e

Minimum elevation angle (radians): ε

Inclination angle (radians): i

From these parameters, the following calculations can be undertaken:

$$r_a = a(1 + e)$$

$$\psi = \frac{\pi}{2} + \varepsilon$$

$$\varphi_a = \sin^{-1}\left(\frac{R_e}{r_a} \sin \psi\right)$$

$$\theta_a = \pi - (\psi + \varphi_a)$$

Then:

$$Lat_{max} = i + \theta_a$$

Similarly, using:

$$r_p = a(1 - e)$$

Using the same equations but replacing suffix (a) with (p), the following can be derived:

$$Lat_{min} = -i - \theta_p$$

This assumes that for elliptical systems, the apogee is in the northern hemisphere, i.e. that one of the following is true:

$e = 0$

$\omega = 270°$

where:

ω: argument of perigee.

In the case that:

$$e > 0$$
$$\omega = 90°$$

Then the following adjustments should be made:

$$Lat_{max}' = -Lat_{min}$$
$$Lat_{min}' = -Lat_{max}$$

In the case that the orbit inclination is zero and eccentricity zero (i.e. for an equatorial circular orbit) then these equations reduce to:

$$Lat_{max} = \theta$$
$$Lat_{min} = -\theta$$
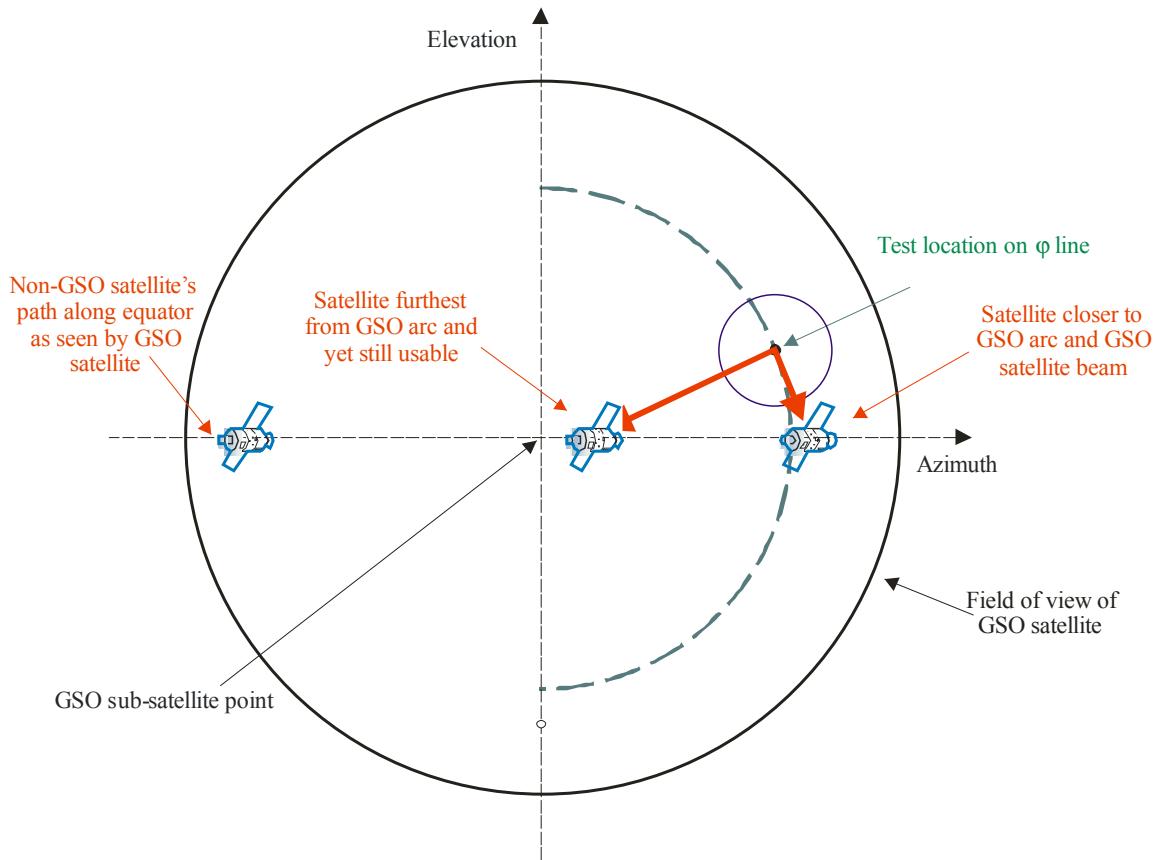
3.2.3.3 Equatorial orbits with multiple e.i.r.p. masks

3.2.3.3.1 Introduction

The scenario for non-GSO systems with equatorial orbits and e.i.r.p. masks that vary by latitude is shown in Fig. 23:

FIGURE 23

Geometry for WCG(up) for non-GSO constellation in equatorial orbit

S.1503-23

The geometry means that any non-GSO ES on the equator will always be in-line with some point on the GSO arc and hence would have to use extremely low power or be forced to be inactive by the α

exclusion zone angle. As the non-GSO ES latitude increases, the angle to the GSO arc also increases, permitting higher e.i.r.p.s.

The epfd at the GSO satellite will be:

$$EPFD = EIRP(\theta) - 10\log_{10}(4\pi D^2)$$

where θ is the off-axis angle at the non-GSO ES towards the GSO satellite.

The approach to take depends upon whether all the e.i.r.p. masks are monotonically decreasing with the off-axis angle. If they are, then it is possible just to consider the case at each edge of the mask: otherwise it becomes necessary to search in latitude.

3.2.3.3.2 e.i.r.p. masks monotonically decreasing

If each of the e.i.r.p. masks are monotonically decreasing with the off-axis angle, then it is solely necessary to check the start and end of the range of latitudes for which the mask is valid.
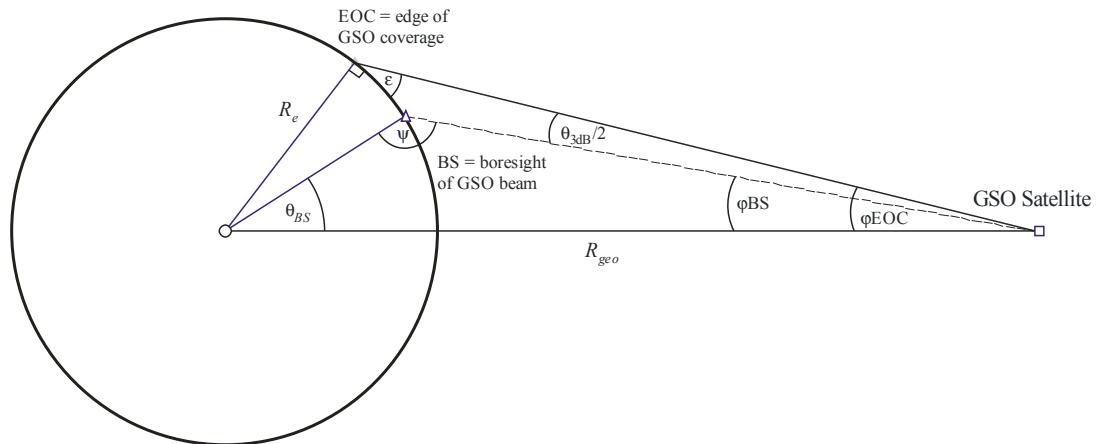
From the equations in the section on the general case:

$$\sin(\pi - \psi_{BS}) = \frac{R_{geo}}{R_e}\sin(\varphi_{BS})$$

$$\theta_{BS} = \pi - \varphi_{BS} - \psi_{BS}$$

where the angles are as shown in Fig. 24.

FIGURE 24

Angles to GSO beam boresight

S.1503-24

Then from the latitude of the non-GSO ES, it is possible to work out the delta longitude between it and the GSO satellite using:

$$\cos\theta_{BS} = \cos lat_{ES}\cos\Delta long_{ES}$$

So that:

$$\cos\Delta long_{ES} = \frac{\cos\theta_{BS}}{\cos lat_{ES}}$$

Hence the position vectors of each can be derived as:

$$\underline{r}_{ES} = R_e\begin{pmatrix}\cos lat_{ES}\cos\Delta long_{ES}\\\cos lat_{ES}\sin\Delta long_{ES}\\\sin lat_{ES}\end{pmatrix}$$

$$\underline{r}_{GSO} = R_{GSO} \begin{pmatrix} 1 \\ 0 \\ 0 \end{pmatrix}$$

It is possible to calculate the azimuth of the non-GSO ES as seen by the GSO satellite using:

$$D^2 = R_e^2 + R_{geo}^2 + 2R_e R_{geo} \cos \Delta long_{ES}$$

$$\sin Azimuth = \frac{R_e}{D} \sin \Delta long_{ES}$$

From this, noting that the non-GSO satellite is by definition on the equator with zero latitude, the delta longitude between the GSO satellite and the point on the non-GSO orbit that minimizes the off-axis angle at the non-GSO ES can be derived using:

$$\sin(\pi - \psi_{NGSO}) = \frac{R_{geo}}{R_{NGSO}} \sin(Azimuth)$$

$$\Delta long_{NGSO} = \pi - Azimuth - \psi_{NGSO}$$

With angle notation the same as for the GSO boresight calculation above.

Hence:

$$\underline{r}_{NGSO} = R_e \begin{pmatrix} \cos \Delta long_{NGSO} \\ \sin \Delta long_{NGSO} \\ 0 \end{pmatrix}$$

From the non-GSO ES there are then two vectors:

$$\underline{r}_1 = \underline{r}_{GSO} - \underline{r}_{ES}$$

$$\underline{r}_2 = \underline{r}_{NGSO} - \underline{r}_{ES}$$

It is then possible to calculate the off-axis angle at the non-GSO ES as the angle between these two vectors and the distance to the GSO the size of vector $\underline{r}_1$.

The angle to use in the epfd calculation is the maximum of this and the exclusion zone size:

$$x = max(\alpha_0, Angle(\underline{r}_1, \underline{r}_2))$$

Hence the epfd is:

$$EPFD = EIRP(x) - 10\log_{10}(4\pi r_1^2)$$

The WCG is the location of the ES with the highest single entry epfd.

Hence:

```
WCGA_UP_Equatorial_Masks:
    For all EIRP masks
        Call WCGA_Up_Equatorial(max(−Lat_Max, Mask start latitude))
        Call WCGA_Up_Equatorial(min(+Lat_Max, Mask end latitude))
    Next mask
```

3.2.3.3.3   e.i.r.p. masks not monotonically decreasing

If the non-GSO e.i.r.p. mask is not monotonically decreasing, then it becomes necessary to check additional latitudes. The latitude range is determined by the range of visibility in latitude of the non-GSO satellite constellation, calculated using the equations above.

The algorithm requires a step size, which should be the minimum of 1° and the smallest step size in the e.i.r.p. masks.

It is assumed that the e.i.r.p. mask is symmetric in latitude.

There is then an outer loop:

```
WCGA_UP_Equatorial_all:
    LatStepSize = min(1, StepSizeinEIRPMask)
    Calculate LatMax from non-GSO orbit parameters
    For latitude = 0 to LatMax
        Get EIRP mask for this latitude
        WCGA_Up_Equatorial(latitude)
    Next latitude
```

The WCGA_Up_Equatorial(latitude) is the same as for the case above with monotonically increasing e.i.r.p. masks, namely:

```
WCGA_Up_Equatorial(latitude):
    Calculate the GSO satellite's φBS
    For this latitude, calculate the Δlongitude
    Calculate the ES and GSO satellite vectors
    Calculate the longitude of the non-GSO satellite
    Calculate the non-GSO satellite vector
    Calculate offaxis angle at ES
    Calculate EPFD
    If this is the highest EPFD so far then store it
```

3.2.3.4   Specific ES locations
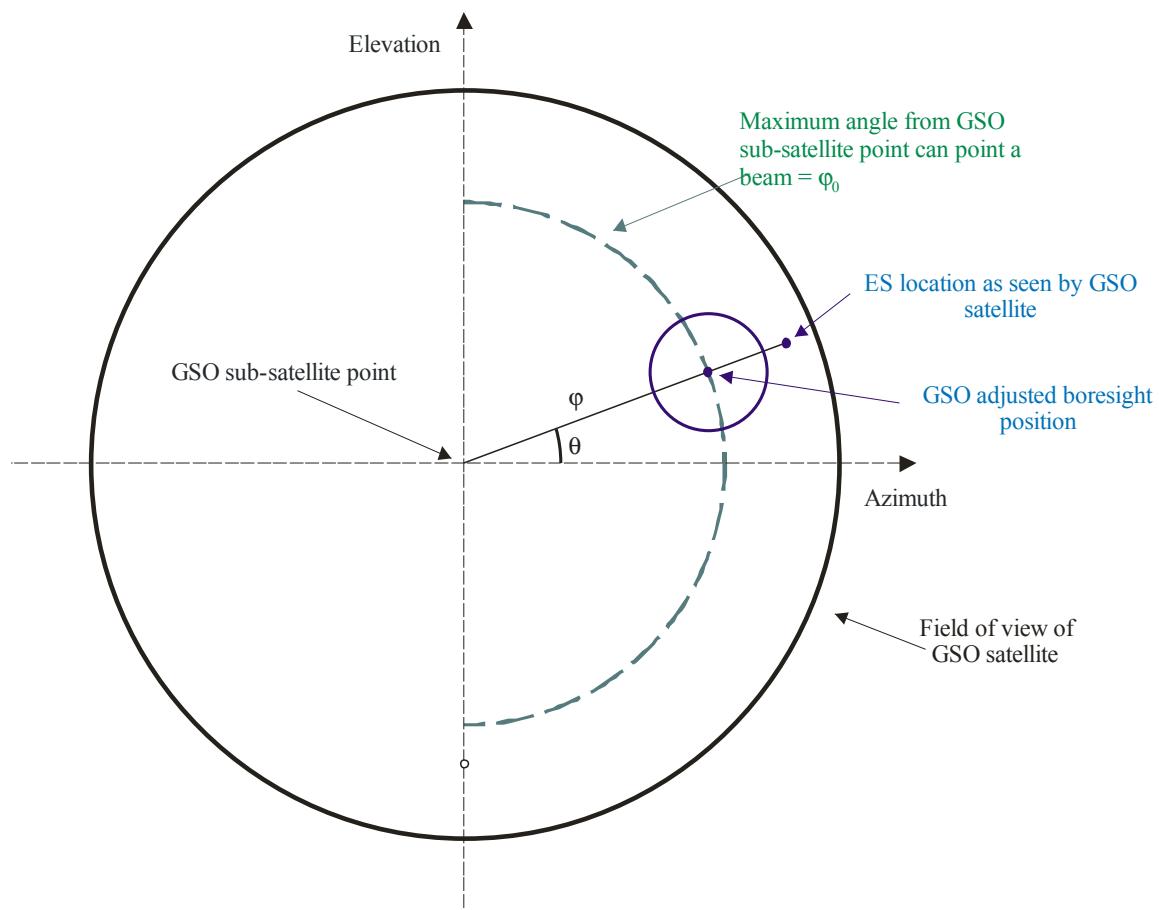
Some non-GSO networks are proposing to only use a specific set of ES locations and will not have a general wide spread deployed assumed in the existing WCGA(up). The algorithm to use will depend upon whether the constellation repeats or not: if the constellation repeats then the geometric permutations will be significantly reduced.

3.2.3.4.1 Specific ES repeating orbit

If there are specific ES locations and the non-GSO satellite network using a repeating track orbit then there will be a highly limited number of geometries that are feasible. It is therefore possible to fly the satellite for the repeat period and then, for each ES, for each non-GSO satellite, calculate the α. If $\alpha \leq \alpha_0$, or the elevation angle is below the minimum, then the ES would not transmit, otherwise the epfd towards that location can be derived.

In some cases, the ES would appear to be very close to the rim of the Earth as seen by the GSO satellite. However as noted elsewhere, it is assumed that there are restrictions in the pointing of the GSO satellite beam. It is therefore necessary to adjust the boresight so that it is as close as possible to the non-GSO ES using the geometry in Fig. 25.

FIGURE 25

WCG(up) adjustment of GSO beam boresight

S.1503-25

The inputs are the non-GSO ES location (latitude, longitude) and the longitude on the GSO arc corresponding to the α towards the non-GSO satellite.

Then:

Calculate the two position vectors given in the equations above

Calculate the (azimuth, elevation) of the ES as seen by the GSO

Calculate the (θ, φ) of the ES as seen by the GSO

Derive the adjusted point (θ, φ_0) of the boresight

Calculate $\Delta\varphi = \varphi - \varphi_0$

Calculate the (azimuth, elevation) of the boresight

Create a line from the GSO satellite in this direction

Calculate the intersection point = BS location

Hence the algorithm is:

```
WCGA_UP_SpecifcES_Repeating:
    Set WorstEPFD = -999
    For each ES

        Get the EIRP mask for this ES
        Get the beamwidth for this EIRP mask
        Use the beamwidth to calculate the time step = t_step
        Get t_repeat = the repeat period of the constellation
        For t = 0 to t_repeat with step size t_step
            Update the position vector of this ES
            For all non-GSO satellites
                Update the position vector of this satellite
                If this satellite is visible to the ES
                    Calculate α for this satellite, ES
                    Calculate elevation angle ε for this satellite
                    If α > α₀ and ε > ε₀ then
                        Calculate d = distance ES to α point on GSO arc
                        Calculate GSO boresight position and Δφ
                        Calculate EPFD = EIRP(α) + Grel(Δφ)
                                            -10log₁₀(4πd²)
                        If EPFD > WorstEPFD then
                            WorstEPFD = EPFD
                            Store this GSO(long, boresight) geometry
                        Endif
                    Endif
                Endif
            Next satellite
        Next time step
    Next ES
```
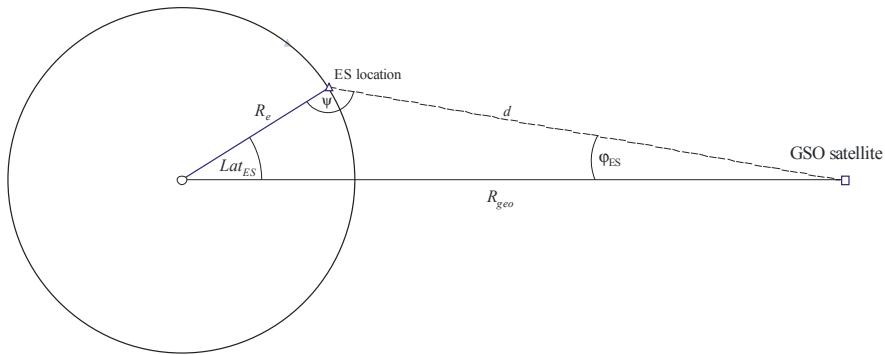
3.2.3.4.2 Specific ES non-repeating orbit

If there are specific ES and the non-GSO constellation drifts, it will eventually be in every possible configuration, and eventually there will be the case where the non-GSO satellite and ES have the same longitude and the non-GSO satellite is just at the edge of the exclusion zone, as in Fig. 26:

FIGURE 26

Distance from non-GSO ES to GSO satellite

S.1503-26

The distance can be calculated using:

$$d^2 = R_e^2 + R_{geo}^2 - 2R_e R_{geo} \cos lat_{ES}$$

The ES could be located above the maximum boresight location for the GSO satellite. This can be checked by calculating φ using:

$$\sin \varphi_{ES} = \frac{R_e}{d} \sin lat_{ES}$$

If $\varphi_{ES} > \varphi_0$ then $\Delta\varphi = \varphi_{ES} - \varphi_0$ else $\Delta\varphi = 0$.

At this point:

$$EPFD = EIRP(\alpha_0) + G_{rel}(\Delta\varphi) - 10\log_{10}(4\pi d^2)$$

It is therefore possible to iterate over all non-GSO ES and for each latitude and e.i.r.p. mask derive a single entry epfd. The ES which has the highest single entry epfd can then be selected.

The GSO satellite is then at the same longitude as the ES and with boresight at the minimum of the ES latitude and value calculated from the elevation angle and beamwidth.

3.2.3.5 General case

This case is for when the e.i.r.p. mask varies by latitude and the non-GSO satellite system provides global coverage to ES given via a density rather than specific locations.
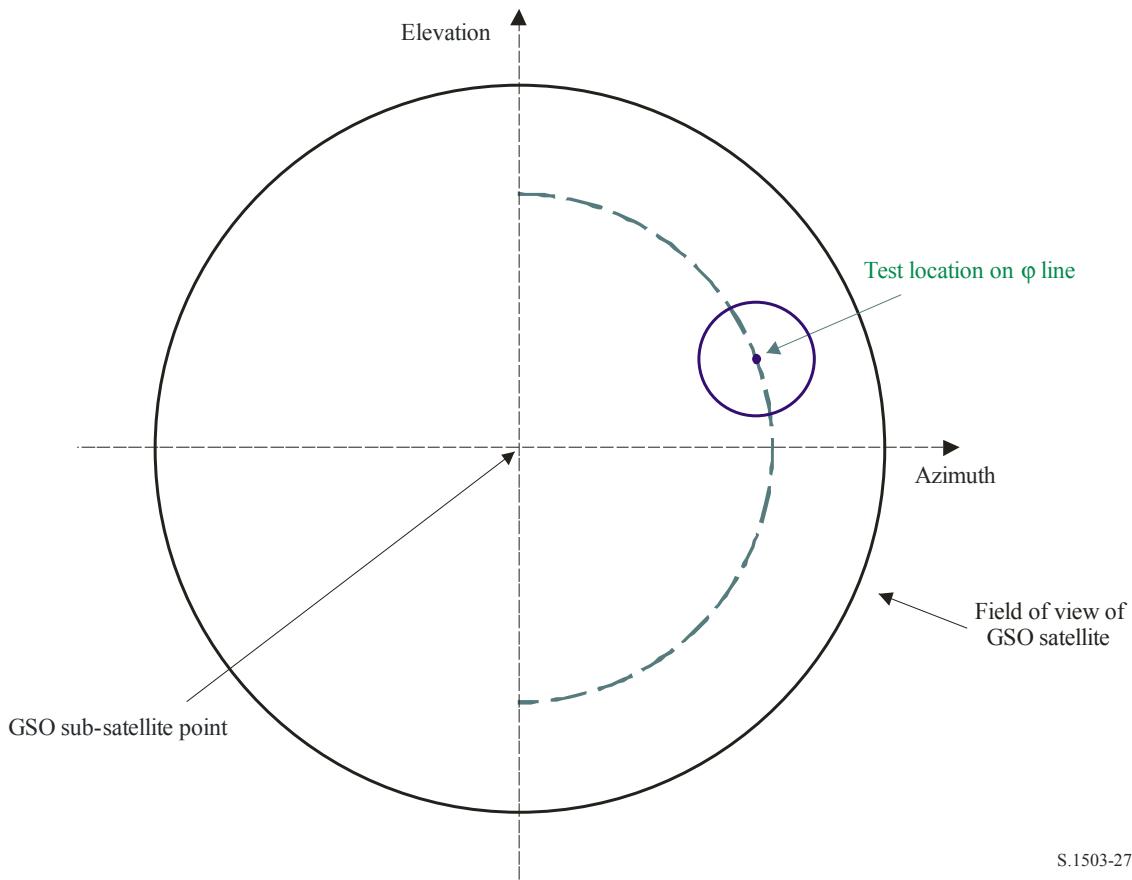
In this case the non-GSO satellite will cover all locations in the sky as seen by the non-GSO ES and so the epfd will be:

$$EPFD = EIRP(\alpha_0) + 10\log_{10}(4\pi d^2)$$

Note that to get epfd values in the same units as given in the RR, the distance should be in metres rather than km.

This epfd will decrease as the path loss increases towards the edge of coverage. However the aggregation effect of increasing area as the beam points away from the sub-satellite point is more significant. Hence the worst case will be at the limit identified previously:

FIGURE 27
WCGA(up) GSO beam location

S.1503-27

Therefore the WCGA in the case where the e.i.r.p. mask varies by latitude is to look at the e.i.r.p. masks to determine which has the highest e.i.r.p.(α_0). When there is a range of latitudes with the same value, the highest should be taken.

Then from the θ_{BS} and latitude, the difference in longitude can be calculated using:

$$\cos \theta_{BS} = \cos lat_{BS} \cos \Delta long_{BS}$$

The GSO longitude should be selected such that the first satellite of the non-GSO constellation goes through the centre of this beam during its first orbit. The first step is the two test position vectors:

$$\underline{r_{ES}} = R_e \begin{pmatrix} \cos lat_{ES} \cos \Delta long_{ES} \\ \cos lat_{ES} \sin \Delta long_{ES} \\ \sin lat_{ES} \end{pmatrix}$$

$$\underline{r_{GSO}} = R_{GSO} \begin{pmatrix} 1 \\ 0 \\ 0 \end{pmatrix}$$

It is then possible to create a line:

$$\underline{r} = \underline{p} + \lambda \underline{q}$$

where:

$$\underline{p} = \underline{r_{GSO}}$$

$$\underline{q} = \underline{r_{ES}} - \underline{r_{GSO}}$$

The non-GSO satellite should be somewhere along that line during its first orbit in the simulation.

For circular orbits the radius is constant and so the point at which the non-GSO satellite crosses this line can be calculated by finding the first positive solution of the following quadratic equation in λ:

$$\lambda^2 q^2 + 2\lambda \underline{p} \cdot \underline{q} + \left(p^2 - r_{ngso}^2\right) = 0$$

From the position vector of the non-GSO satellite its (latitude, Δlongitude) can be calculated.

Note that the calculations above were based upon a reference GSO satellite with longitude zero and hence this is not the actual longitude but rather difference in longitude required between the GSO satellite and the non-GSO satellite when it reaches the required latitude.

The moment that that satellite reaches this latitude can be derived from:

$$\sin(\omega + v) = \frac{\sin lat}{\sin i}$$

From v, the actual longitude of the non-GSO satellite can be calculated when it reaches the required longitude, and the actual longitude of the GSO satellite derived as:

$$long_{GSO} = long_{NGSO} - \Delta longitude$$

For elliptical systems, this could require iteration in v. One approach is as follows:

```
SetSatelliteElliptical:
    Set LatIn1 = 0.00001
    Set LatIn2 = LatBS
    LatOut1 = CalcLatOut(LatIn1)
    LatOut2 = CalcLatOut(LatIn2)
    While (abs(LatIn1 - LatIn2) > 1e-6)
        LatIn3 = (LatIn1 + LatIn2)/2
        LatOut3 = CalcLatOut(LatIn3)
        if (dLatIn3 > dLatOut3)
        {
            dLatIn2 = dLatIn3
            dLatOut2 = dLatOut3
        }
        else
        {
            dLatIn1 = dLatIn3
            dLatOut1 = dLatOut3
        }
    Wend
CalcLatOut(LatIn):
    From LatIn calculate non-GSO (w + v) and hence v
    Hence calculate r_ngso = p/(1 + e*cos(nu))
    Solve line for point P where r = r_non
    Calculate latitude of point P
    Return latitude calculated
```

Hence:

```
    WCGA_UP_General:
    Set WorstEIRP = -999
    Set MaxLat = 0
    Calculate φ₀
    For each EIRP mask
        Calculate ThisEIRP = max(EIRP(θ > α₀), EIRP(α₀))
        If ThisEIRP > WorstEIRP
```

```
                Set MaxLat = the largest absolute latitude for this mask
                WorstEIRP = ThisEIRP
            Endif
        Next mask
        From MaxLat and φ₀ calculate the Δlongitude
        Calculate when first non-GSO satellite would be inline
        Hence set WCG
```

3.3   WCG epfd$_{IS}$

3.3.1   Inputs

The inputs to the algorithm are as follows:

SS_eirp :   the satellite e.i.r.p. mask to check

θ_{adB} :   the GSO satellite's beam half power beamwidth

ε :   the minimum elevation angle of the GSO system

$a, i, e, \Omega, \omega, \nu$:   the inclination orbit parameters of the non-GSO system.

3.3.2   Algorithm

```
WCGA_IS:
    From the EPFD limits get the gain pattern to use
    From the EPFD limits get the GSO beamwidth θₐdB
    From  θₐdB calculate φ₁, φ₂
    Using the gain pattern calculate Grel(φi) for i = 1,2
    From φ₁ calculate LatBS
            If for all satellites i = 0 then
            {
                Worst Case Geometry:
                    BS.Latitude = 0
                    BS.Longitude = LatBS
                    GSO.Longitude = 0
            }
    Else
    {
                Set WorstEPFDBin = -9999
                Set WorstAngularVelocity = +9999
            For all satellites in the order listed in ITU DB
                {
                Determine EIRP mask to use for this satellite
                If this EIRP mask has not been checked so far then
                Call GetWCGA_IS(EIRP_mask, i)
            End if
        Next satellite
            Rotate GSO, BS in longitude to ensure inline event
        }

GetWCGA_IS(EIRP_Mask, i):
    LatStep = i / RoundUp(i)
    For lat=-i to +i in LatStep steps
    {
```
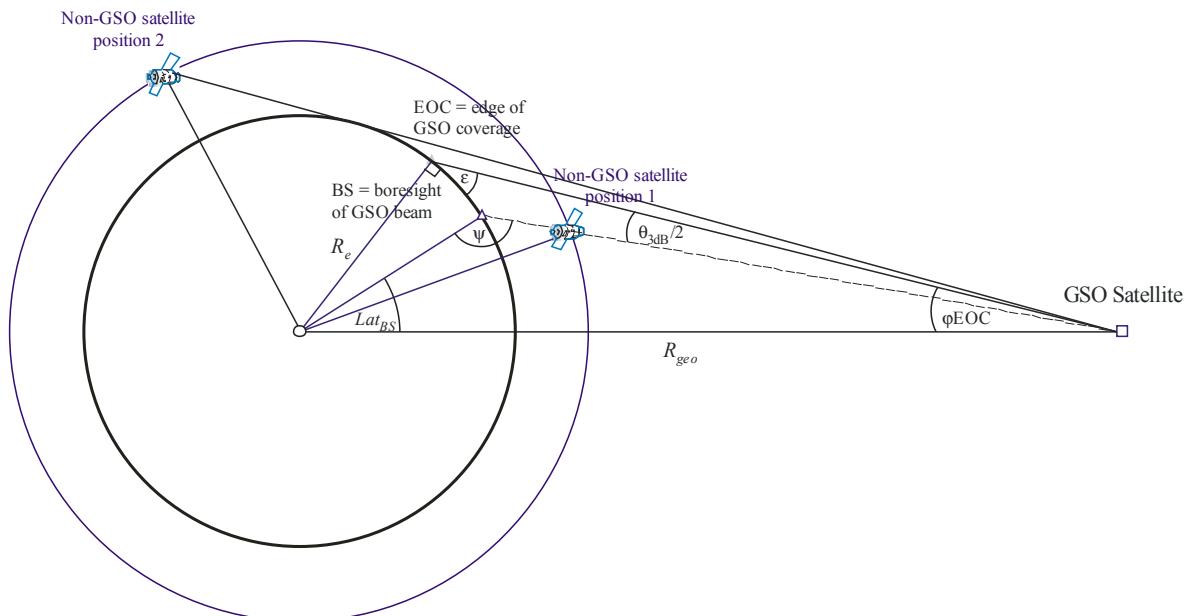
```
        Set satellite at latitude to calculate r, v
        If satellite is above minimum operating height
        {
                From r, φᵢ calculate ψᵢ
                From φᵢ, ψᵢ calculate Dᵢ, θᵢ
                Try to calculate Δlongᵢ
                In the cases that the geometries are feasible
                {
                        From the GSO gain pattern calculate G_rel(φᵢ)
                        From the EIRP mask calculate EIRP(ψᵢ)
                        Calculate EPFDᵢ

                        Calculate r_gso, v_gso
                        Calculate θ of non-GSO satellite as seen by GSO
                        If EPFDᵢ is higher than WorstEPFD
                        {
                                Store this geometry
                                WorstAngularVelocity = θ
                                WorstEPFD = EPFDᵢ
                        }
                        Else if EPFDᵢ is the same bin as WorstEPFD
                        {
                                If θ is lower than WorstAngularVelocity
                                {
                                        Store this geometry
                                        WorstAngularVelocity = θ
                                }
                        }
                }
        }
}
```

3.3.3 Geometry

There are two potentially significant geometries, which is when the non-GSO satellite just becomes visible as seen by the GSO satellite and when it traverses the GSO satellite beam, as shown below:

FIGURE 28

**Two WCG(IS) non-GSO satellite locations**
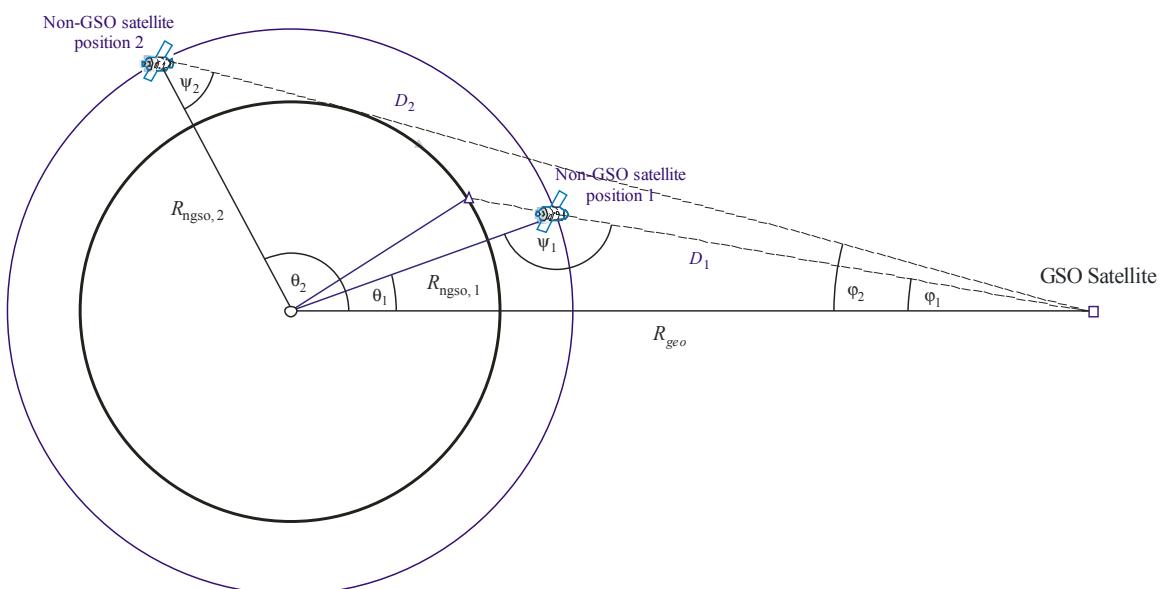
S.1503-28

In some cases, the same WCG location will handle both geometries – e.g. for an equatorial satellite system a beam at the extreme in azimuth will be aligned for both geometries.

From the radius of the non-GSO satellite at each of the positions, it is possible to calculate the off-axis angle at the satellite and hence e.i.r.p.(θ) together with the distance:

FIGURE 29

Two WCG(IS) calculation of satellite off-axis angle

S.1503-29

where:

$$\varphi_1 = \varphi_{BS} \text{ (from above)}$$

$$\sin\varphi_2 = \frac{R_e}{R_{gso}}$$

Hence:

$$\sin\psi_i = \frac{R_{geo}}{R_{ngso,i}}\sin\varphi_i$$

Where $i = \{1, 2\}$ noting that $\psi_1 > \frac{\pi}{2}$ and that $\psi_2 < \frac{\pi}{2}$

Then:

$$\theta_i = \pi - \varphi_i - \psi_i$$

$$D_i = R_{ngso,i}\frac{\sin\theta_i}{\sin\varphi_i}$$

Hence given a non-GSO satellite with radius distance $R_{ngso,i}$ at the two specified geometries, the two single entry epfd levels can be calculated as:

$$EPFD_i = EIRP(\psi_i) + G_{rel,i} - 10\log_{10}(4\pi D_i^2)$$

Note that $G_{rel,1} = 0$ and $G_{rel,2} = G_{rel}(\varphi_2 - \varphi_1)$.

By setting the non-GSO satellite at a specified latitude, it is therefore possible to derive the single entry epfd from the radius vector and the two geometries identified above.

In some cases, there will be no in-line geometry – for example for elliptical systems at apogee the line from the non-GSO satellite to the GSO arc will at no point intersect the Earth. This can be checked by calculating the difference in longitude between the non-GSO satellite and the point on the GSO arc from the geometry above and the non-GSO satellite's latitude using:

$$\cos\Delta long_i = \frac{\cos\theta_i}{\cos lat_i}$$

If there is no solution to this equation, then there is no position that meets the required geometry. Other positions could be excluded if the non-GSO satellite was below the minimum operating height.

Given multiple locations with the same single entry epfd, then the one to use would be the one with the lowest angular velocity, using the same method as for WCGA(down), noting that the velocity vector of the GSO satellite can be derived in the same way as for earth stations, i.e.

$$\underline{v}_{gso} = w_e \begin{pmatrix} -y \\ x \\ 0 \end{pmatrix}$$

The position of the GSO satellite would be chosen such that one of the non-GSO satellites with the e.i.r.p. mask identified traverses the critical geometry during its first orbit, using the same methodology as for the WCGA(up).

Additional geometry for the WCG for epfd(IS) is described in §§ C.3.1.3 and C.3.2.3 above.

4 Calculation of time step size and number of time steps

4.1 Simulation time increment and accuracy

The simulation time increment is one of the most important parameters for the 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, downlink and intersatellite cases are shown below.

4.2 Description of the procedure for the 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 the 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, the method for determining a simulation time increment Δt_{ref} is based on ensuring the required number N_{hit} of pfd↓ estimations during the time interval Δt when a non-GSO satellite passes through the main beam of a GSO earth station antenna:

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

The time required for a non-GSO satellite passing through the main beam of a GSO earth station antenna depends on mutual location of the earth and space stations of the GSO network as well as on orbital parameters of the non-GSO network. The value of Δt 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 Δt is determined by equations (2) and (3) (see Fig. 30):

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

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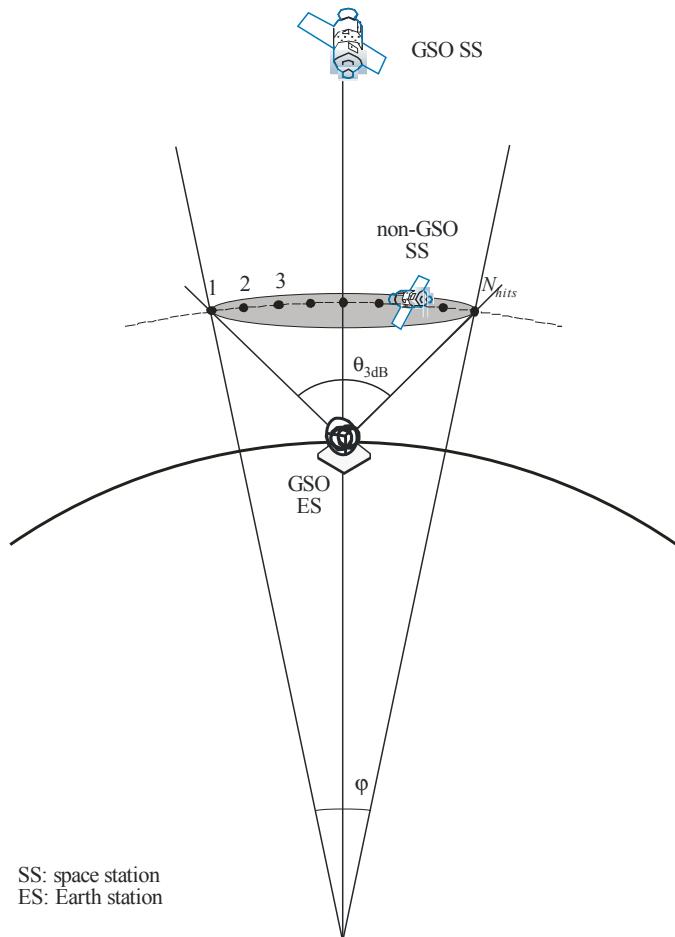
$$\varphi = \frac{1}{2}\theta_{3dB} - \arcsin\left[\frac{R_e}{R_e+h}\sin\left(\frac{1}{2}\theta_{3dB}\right)\right]$$

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

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

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

ω_e: Earth rotation angular velocity at the equator (degrees/s)

i: orbit inclination (degrees)

θ_{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.

FIGURE 30

Calculation of epfd(down) time step size

SS: space station
ES: Earth station

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

N_{hit} should be set to 16 as derived in § D.4.5. 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.
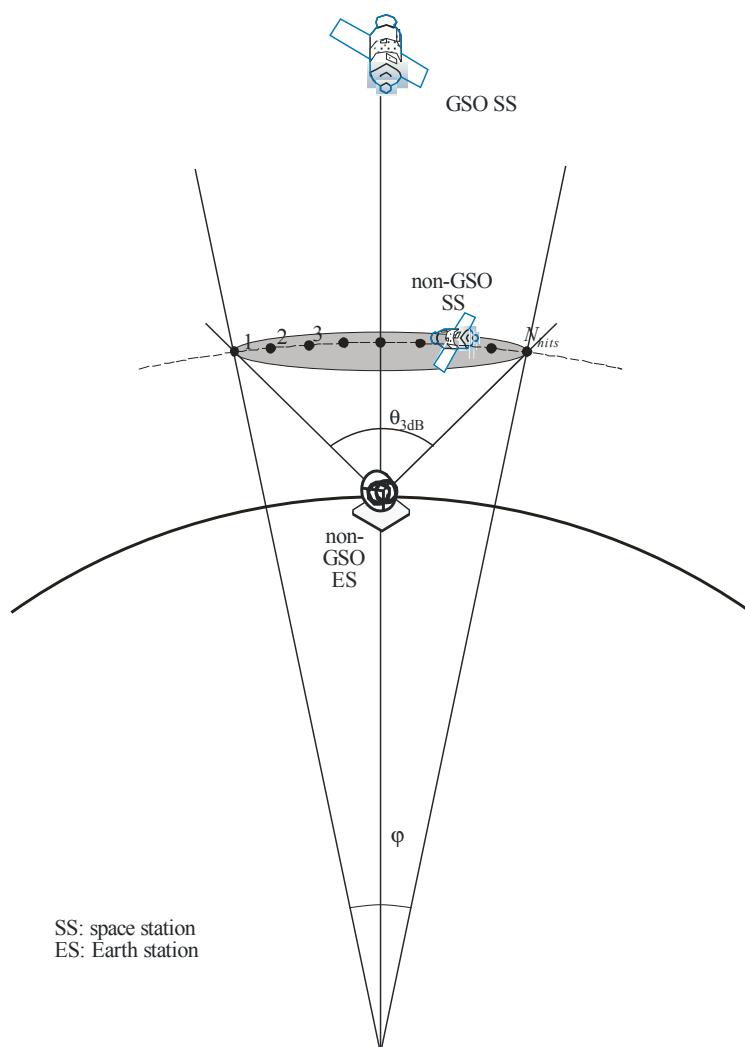
TABLE 9

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	φ_{3dB}	degrees
Number of epfd↓ calculations required during the time a non-GSO satellite is passing through the main beam of a GSO earth station antenna	N_{hit}	–

4.3   Description of the procedure for the 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 is in the main beam of a non-GSO earth station antenna). The required number N_{hit} of epfd↑ 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. 31) 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.

FIGURE 31

Calculation of epfd(up) time step size

S.1503-31

TABLE 10

Input data

Parameter	Designation	Units
Orbit inclination	i	degrees
Orbit altitude	h	km
Non-GSO earth station antenna 3 dB beamwidth	φ_{3dB}	degrees
Number of epfd↑ calculations required during the time a GSO satellite is passing through the main beam of a non-GSO earth station antenna	N_{hit}	–

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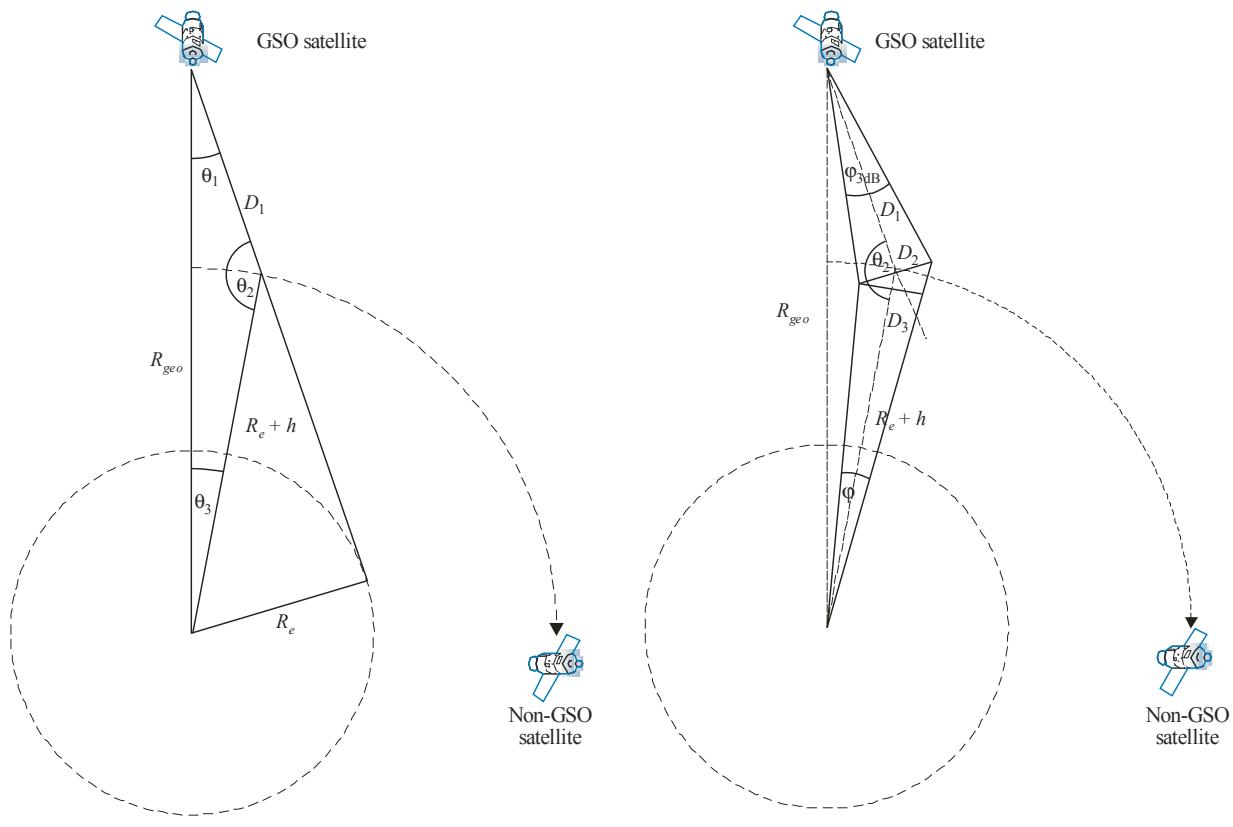
The time step size for epfd$_{is}$ calculations is derived by considering that there should be at least N_{hit} time steps during which the non-GSO satellite is within the main beam of the GSO satellite. Given that the shortest time step is when the beam at the GSO is pointed as far as possible away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

R_e: radius of the Earth

h: height of non-GSO orbit

R_{geo}: radius of geostationary orbit

θ_{3dB}: half power beamwidth of GSO beam.

For eccentric orbit systems, calculate the height when the non-GSO satellite crosses the equator, i.e. when $\nu = -\omega$.

Then the time step can be calculated using the following algorithm (see Fig. 32).

FIGURE 32

Geometric parameters involved in the equations

S.1503-32

Calculate:

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

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

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

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

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

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

Then calculate the value:

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

which can be used in equation (2) to calculate the step size to use.
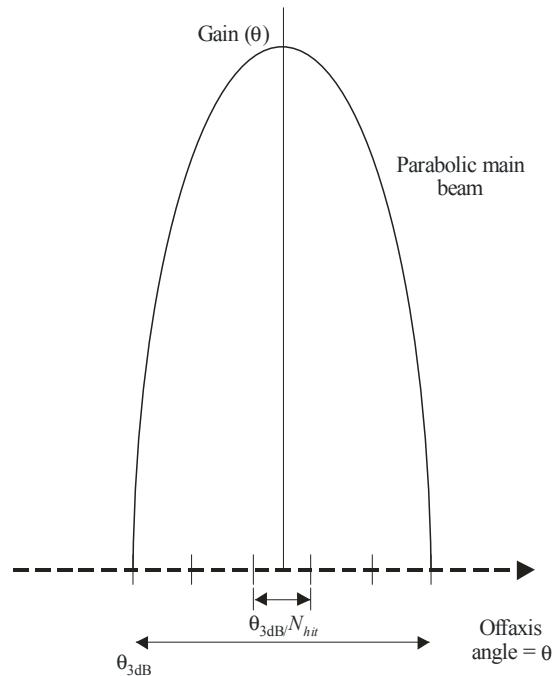
4.5 Derivation of N_{hit}

The time step size is selected to ensure there is sufficient resolution of the epfd within the victim's main beam. The necessary resolution is driven by the bin size of 0.1 dB and from this the number of steps within the main beam can be derived.

N_{hit} should be selected so that the highest epfd will be detected in the simulation and identified to be within the right bin. This implies a resolution in the calculations of (0.1 dB)/2 = 0.05 dB.

The greatest error would occur when two time steps are located equally spaced on either side of the main beam, as in Fig. 33:

FIGURE 33

Calculation of N_{hits}

S.1503-33

The spacing between samples will be:

$$\Delta\theta = \frac{\theta_{3dB}}{N_{hit}}$$

The gain pattern within the main beam can be assumed to be parabolic and hence following:

$$G_{rel} = 12\left(\frac{\theta}{\theta_{3dB}}\right)^2$$

The slope on this curve is:

$$\frac{dG_{rel}}{d\theta} = \frac{24}{\theta_{3dB}^2}\theta$$

Hence we can derive N_{hit} required for a difference in gain of 0.05 dB as follows:

$$\Delta G_{rel} = 0.05 = 24 \cdot \frac{\theta}{\theta_{3dB}} \cdot \frac{\Delta\theta}{\theta_{3dB}} = 24 \cdot \frac{\theta}{\theta_{3dB}} \cdot \frac{1}{N_{hit}}$$

So:

$$N_{hit} = 480 \cdot \frac{\theta}{\theta_{3dB}}$$

Therefore for the time step nearest the main beam when:

$$\theta = \frac{1}{2}\frac{\theta_{3dB}}{N_{hit}}$$

Then:

$$N_{hit} = RoundUp\left[\sqrt{240}\right] = 16$$

This approach can also be used for cross-track sampling, and hence $N_{track} = N_{hit} = 16$.

4.6   Total simulation run time

This section describes the calculation of number of time steps for the epfd↓ and epfd↑ algorithms specified in § D.5. 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 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.

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 with orbit inclination non-zero. For equatorial orbit constellations in which all satellites have the same altitude, then it is sufficient to run for a single repeat period. This can be calculated as follows:

$$T_{run} = \frac{2\pi}{w_s - w_e}$$

$$N_{steps} = RoundDown \frac{T_{run}}{T_{step}}$$

Where w_s and w_e are the rotation angular velocities of the satellite and Earth as given in § D.2.

Table 11 shows the input parameters used in all other constellation types.

TABLE 11

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:

$N_{min} =$ $N_S \times 100/(100 - (\text{maximum } \% \text{ in the Tables of Article } \mathbf{22} \text{ of the RR less than } 100\%))$

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

$$N_{min} = 1\,000\,000$$
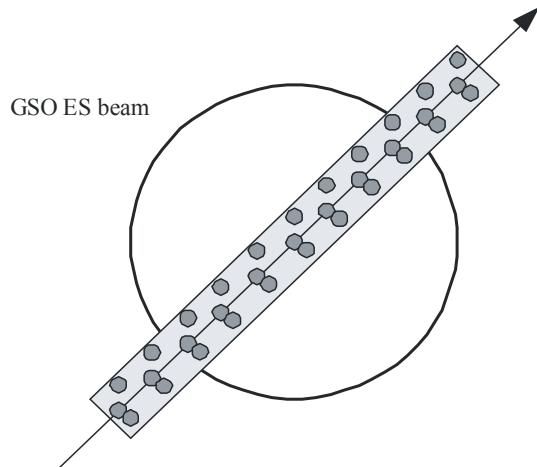
4.6.1 Repeating orbits

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 described in § D.6.3.

With this parameter, a simulated orbit would be repeated but in reality there would be a slight drift due to longitudinal station keeping errors. It is expected that station keeping changes within the orbit plane would make no difference and so are not included.

The result should be as shown in Fig. 34:

Track of repeating orbit non-GSO satellite through GSO ES beam

S.1503-34

In Fig. 34, 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 12

Input data

Parameter	Designation	Units
Constellation repeat period	Prepeat	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, = 16, as specified in § D.4.5.

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:

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

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:

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

4.6.2 Non-repeating orbits
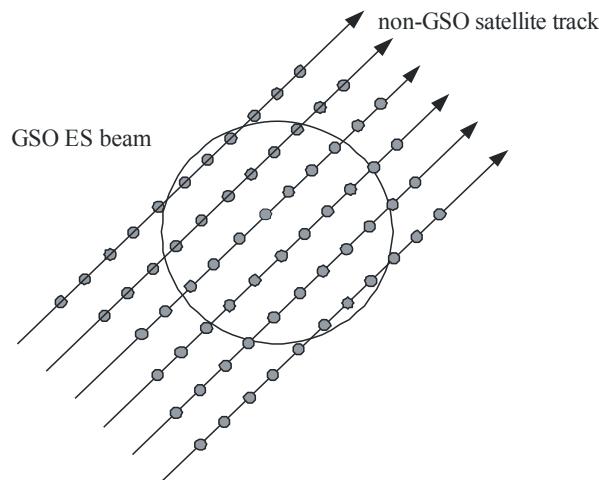
In this case the longitudinal spacing between successive ascending node passes must be examined so that there are sufficient tracks within the main beam. The time step size and number of time steps can be used to determine how far a particular orbit will have processed within the run. The same numbers 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 as shown in Fig. 35.

FIGURE 35

Track of non-repeating orbit non-GSO satellite through GSO ES beam

S.1503-35

In Fig. 35, 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 13

Input data

Parameter	Designation	Units
Orbit inclination	i	degrees
Orbit semi-major axis	a	km
GSO earth station antenna 3 dB beamwidth[(1)]	φ_{3dB}	degrees
Required number of tracks of a non-GSO satellite passing through the main beam of a GSO earth station antenna	N_{tracks}	–

[(1)] In the case of calculating run length for epfd↓. In the case of epfd$_{is}$ and epfd↑:

epfd↑: calculate φ 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 φ 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: Using the equations in § D.6.3.2, calculate the $\overline{n}, \Omega_r, \omega_r$

Step 2: Convert the $\overline{n}, \Omega_r, \omega_r$ into degrees per minute

Step 3: Calculate the nodal period of the orbit in minutes using:

$$P_n = \frac{360}{w_r + \overline{n}}$$

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):

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

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):

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

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° that this corresponds to, rounding up to nearest integer below:

$$N_{360} = \text{int}\left(\frac{S_{total}}{360}\right)$$

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

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

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

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

or:

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

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:

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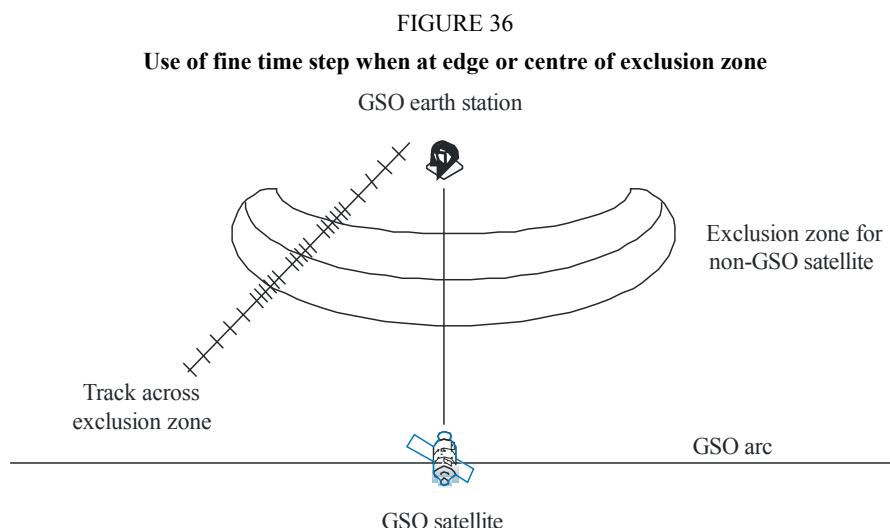
4.7   Dual time step option

4.7.1   Dual time step option epfd(down)

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 α or $X = 0$

–   exclusion angle α or $X =$ edge of exclusion zone.

Figure 36 shows where to use the finer time step:

FIGURE 36

Use of fine time step when at edge or centre of exclusion zone

S.1503-36

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:

$$\varphi_{coarse} = 1.5°$$

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 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 φ_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° or φ_1:

$$\varphi_{FSR\_1} = \max\ (3.5°, \varphi_1)$$

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:

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

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 (φ_{3dB}). This ratio is defined as:
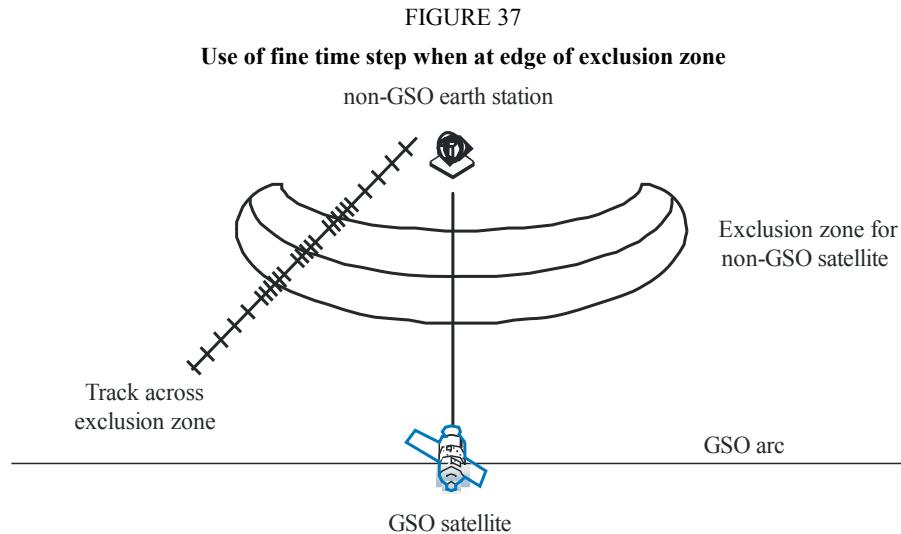
$$N_{coarse} = Floor\ ((N_{hits} * \varphi_{coarse}) / \varphi_{3dB})$$

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°.

4.7.2   Dual time step option epfd(up)

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 when within the exclusion zone.

Figure 37 shows where to use the finer time step:

FIGURE 37

Use of fine time step when at edge of exclusion zone

S.1503-37

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:

$$\varphi_{coarse} = 1.5°$$

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 (φ_{3dB}). This ratio is defined as:

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

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°.
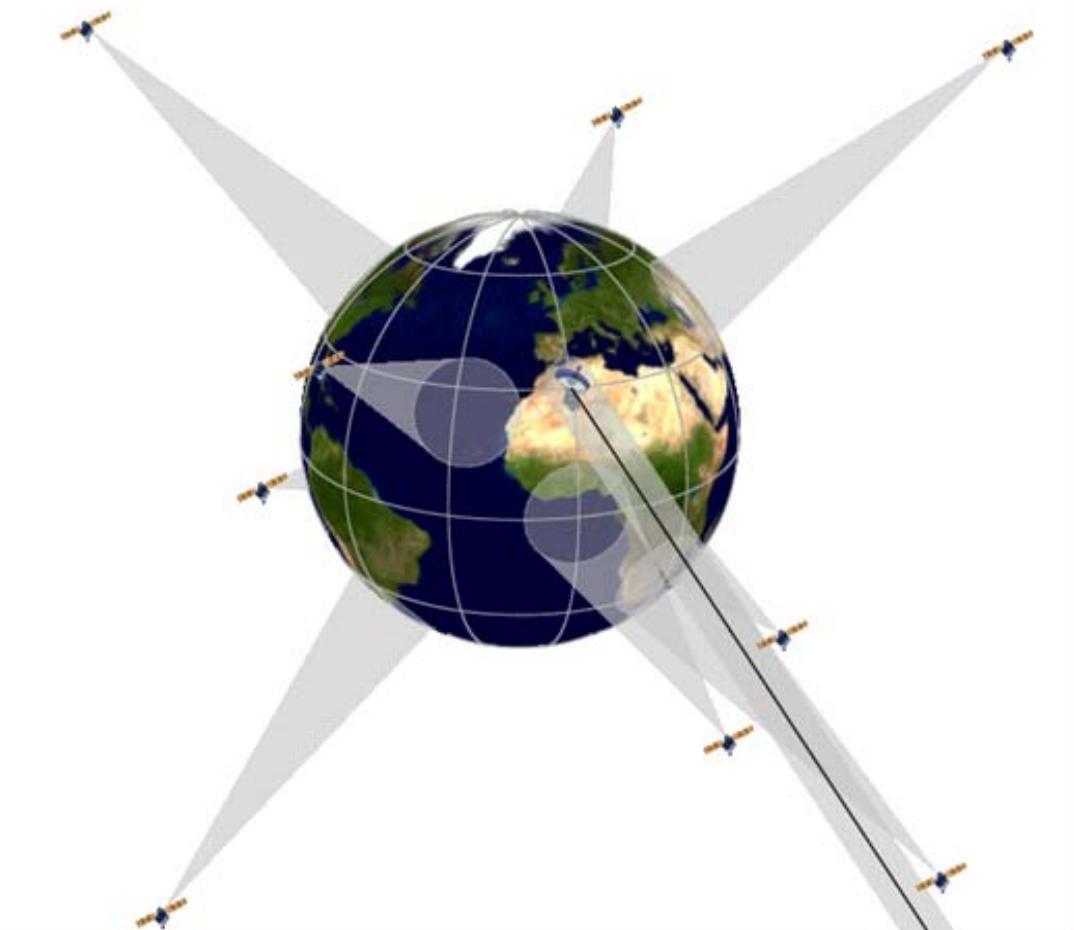
5   epfd calculation description

5.1   epfd↓ software description

This section describes the algorithm to calculate the epfd↓ 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↓ at an earth station of a GSO system is calculated. This is repeated for a series of time steps until a distribution of epfd↓ is produced. This distribution can then be compared with the limits to give a go/no go decision.

Figure 38 shows the geometry with constellation of non-GSO satellites and test GSO satellite transmitting to a GSO earth station.

FIGURE 38

Example of epfd(down) scenario

S.1503-38

5.1.1 Configuration parameters

These run definition parameters are:

Parameter name	Parameter value	Parameter units and ranges
Frequency	F_DOWN	GHz
GSO satellite longitude	GSO_LONG	degrees
GSO earth station latitude	GSO_ES_LAT	degrees
GSO earth station longitude	GSO_ES_LONG	degrees
GSO earth station dish size	GSO_ES_D_ANT	m
GSO earth station gain pattern	GSO_ES_PATTERN	One of those in § D.6.5
Reference bandwidth	REFBW	kHz
Number of epfd↓ points	Nepfd_DOWN	–
Array of Nepfd_DOWN epfd↓ values	epfd_DOWN[I]	$dB(W/(m^2 \cdot BW_{ref}))$
Array of Nepfd_DOWN percentages	PC[I]	%

5.1.2   Non-GSO system parameters

The following parameters, as specified in § B.3.1 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}	–
Transmit centre frequency[1]	F_DOWN$_{sat}$	GHz
Exclusion zone parameter	Alpha or X	–
Exclusion zone angle	MIN_EXCLUDE	degrees
Maximum number of satellites operating at f_{sat} by latitude	N_{co}[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

For each satellite the following parameters specified in § B.3.2 – Parameters provided by administration of the non-GSO system, would be used, where the definitions of the parameters are specified in § D.6.3.1 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

5.1.3   Run time step parameters

The following run parameters should be calculated using the algorithm in § D.4:

Parameter description	Parameter name	Parameter units
Time step	TSTEP	s
Number of time steps	NSTEPS	–

5.1.4 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.

To calculate epfd↓ 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 § D.5.1.2.

Step 2: Read in GSO parameters as specified in § D.5.1.1.

Step 3: If required, calculate the maximum epfd GSO location using the algorithm in § D.3.1.

Step 4: Initialize statistics by zeroing all bins of epfd↓ values.

Step 5: If required calculate number of time steps and time step size using algorithm in § D.4 and hence calculate end time.

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

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

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 any of the α or X angles for the last time step were within φ_{FSR_1} of zero or φ_{FSR_2} of the exclusion zone angle (φ_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 § D.6.1.

Step 8: Update position vectors of all GSO satellites based on coordinate system in § D.6.2.

Step 9: Update position and velocity vectors of all non-GSO satellites based on coordinate system, orbit prediction model and station keeping algorithm in § D.6.3.

Step 10: Set epfd↓ = 0.

Step 11: Select all non-GSO satellites visible to the GSO earth station using the algorithm in § D.6.4.1.

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, α or X, Δlong) or (lat, azimuth, elevation) as required, using the definition of angles in § D.6.4.4 or § D.6.4.5.

Step 14: Using the pfd mask for the selected non-GSO satellite, calculate pfd(lat, α or X, Δlong) or pfd(lat, azimuth, elevation) at the GSO earth station using the non-GSO satellite pfd mask as specified in § D.5.1.5.

Step 15: Calculate the off-axis angle φ at GSO earth station between line to the GSO satellite and the non-GSO satellite.

Step 16: Calculate $G_{RX}(\varphi)$ = Receive gain (dB) at GSO earth station using relevant gain pattern specified in algorithms in § D.6.5.

Step 17:   Calculate epfd$\downarrow_i$ for this non-GSO satellite using:

Step 18:   epfd$\downarrow_i$ = pfd(α) + G_{RX}(φ) − 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 defined 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 § D.7.1.2.

Step 24:   Compare epfd$\downarrow$ statistics with limits using the algorithm in § D.7.1.

Step 25:   Output results in format specified in § D.7.3.

5.1.5   pfd mask calculation

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

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 (α, 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. If the angles are outside the pfd mask, the software calculates pfd from the highest angle in the mask (i.e. at the mask edge).

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.

5.1.6   Outputs

The result of the algorithm is two arrays in format:

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

where PC_CALC[I] is the percentage of time epfd_DOWN_CALC[I] is exceeded.

5.2   epfd↑ software description

This section describes the algorithm to calculate epfd↑ from non-GSO earth stations into a GSO uplink. The locations of the ES can be defined in one of two ways:
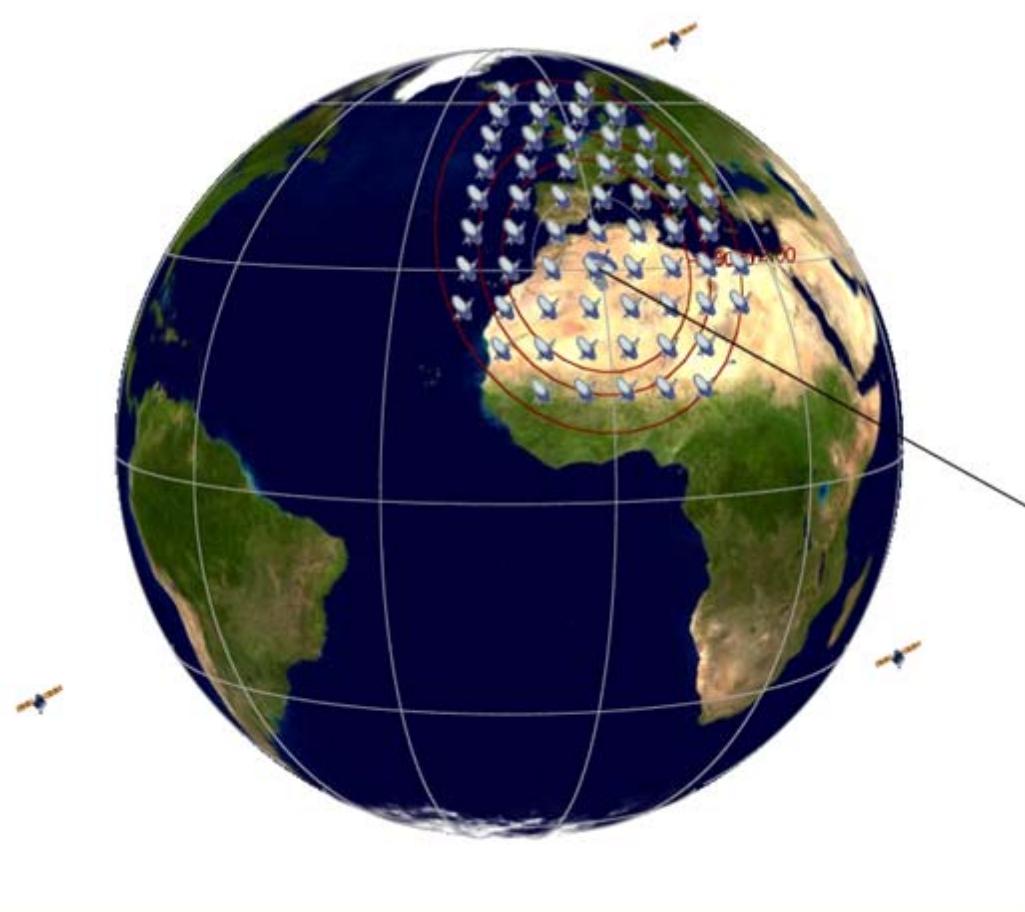
1)   It is assumed that the Earth is populated with a uniform distribution of non-GSO earth stations. In this case the ES_ID in the e.i.r.p. mask should be set to −1.

2)   The locations of specific ES are used via a field in the ES e.i.r.p. mask. In this case the density field is not used.

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 epfd↑ 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 epfd↑ is produced. This distribution can then be compared with the limits to give a go/no go decision.

Figure 39 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 39

Example of epfd(up) scenario

S.1503-39

5.2.1   Configuration parameters

This sub-section specifies the parameters required for all epfd↑ 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 generated by in § D.2.1

Parameter name	Parameter value	Parameter units and ranges
Frequency	FREQ	GHz
GSO gain pattern	FEND_UP	One of those in § D.6.5
GSO peak gain	GSO_SAT_PEAKGAIN	dBi
GSO half power beamwidth	GSO_SAT_BEAMWIDTH	degrees
Reference bandwidth	RAFBW	kHz
Number of epfd↑ points	Nepfd_UP	–
Array of Nepfd_UP epfd↑ values	epfd_UP[I]	$dB(W/(m^2 \cdot BW_{ref}))$
Array of Nepfd_UP percentages	PC_UP[I]	%

5.2.2   Determination of maximum epfd configuration

The maximum epfd location of the GSO satellite and beam centre is defined in § D.3.2.

5.2.3   Calculation of run steps

The time step and number of time steps are calculated using the algorithm in § D.4 which also describes the optional dual time step option.

5.2.4   Inputs

5.2.4.1   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.

5.2.4.2   Non-GSO system parameters

The following parameters, as specified in § B.3.1 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 § B.3.2, would be used, where the definitions of the parameters are specified in § D.6.3.1 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 § B.4.2 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 by latitude	ES_EIRP[lat]	$dB(W/BW_{ref})$
Minimum elevation angle	ES_MINELEV	degrees
Minimum angle to GSO arc	ES_MIN_GSO	degrees
Average number of non-GSO ES per km^2	ES_DENSITY	km^2
Average distance between cell or beam footprint centres	ES_DISTANCE	km

5.2.4.3 GSO system parameters

The GSO system can be either calculated or use worst-case parameters using the algorithm in § D.3.2 or entered values. The required parameters as specified 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 § D.6.5

These parameters are defined in §§ D.6.1 and D.6.2.

5.2.4.4 Run parameters

The following run parameters should be calculated using the algorithm in § D.4:

Parameter description	Parameter name	Parameter units
Time step	TSTEP	s
Number of time steps	NSTEPS	–

5.2.5   Production of non-GSO earth station distribution

In the case that the non-GSO ES locations are defined by a distribution, 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:
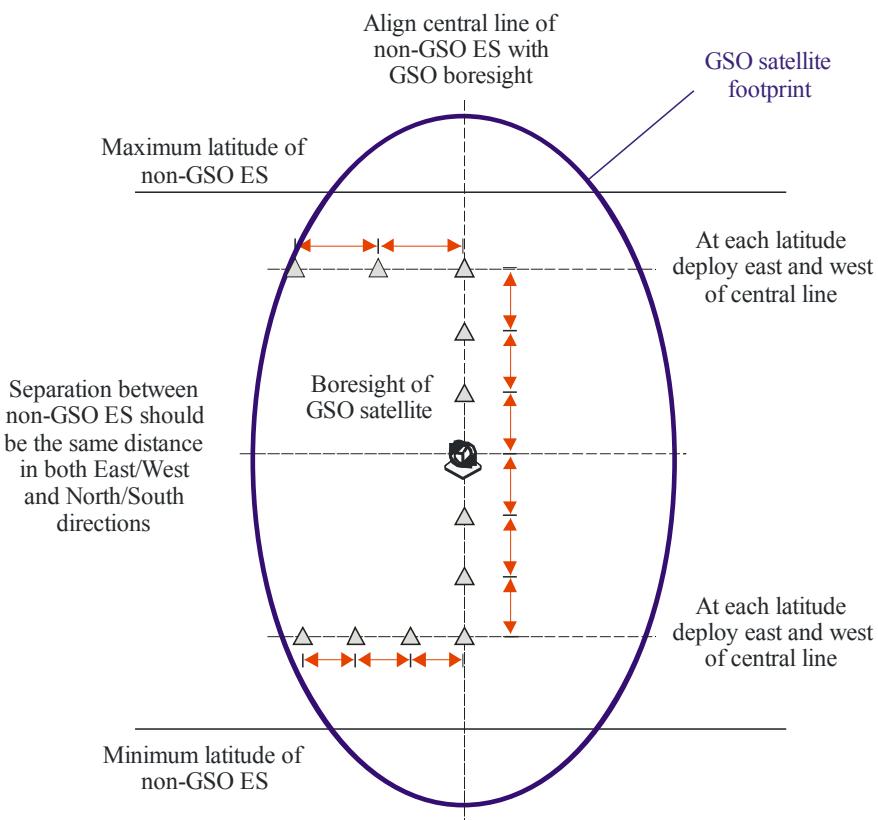
$$\text{REP\_e.i.r.p.} = \text{ES\_e.i.r.p.} + 10\log_{10}(\text{NUM\_ES})$$

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_e.i.r.p.

The deployment method should be symmetric around the (latitude, longitude) of the GSO satellite's boresight, as shown in Fig. 40.

FIGURE 40

Deployment method for non-GSO earth stations

No non-GSO ESs should be deployed below the minimum latitude or above the maximum latitude, where these two extreme values are derived using the methodology above.

The separation in latitude in radians between non-GSO ES can be calculated from the distance using:

$$\Delta lat = \frac{d}{R_e}$$

The separation in longitude in radians between non-GSO ES can be calculated using:

$$\Delta long = \frac{d}{R_e \cos lat}$$

5.2.6 Algorithms and calculation procedures

To calculate epfd↑ 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 § D.5.2.4.2.

Step 2:   Read in GSO parameters as specified in § D.5.2.4.3.

Step 3:   If required calculate maximum epfd GSO location using the algorithm in § D.3.2.

Step 4:   If required calculate locations of non-GSO earth stations using the algorithm in § D.5.2.5.

Step 5:   Initialize statistics by zeroing all bins of epfd↑ values.

Step 6:   If required calculate number of time steps and time step size using the algorithm in § D.4 and hence calculate end time.

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

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

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 $T_{step} = T_{fine}$.

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

   Sub-step 7.3:   Otherwise if any of the α angles for the last time step were within φ_{coarse} of the exclusion zone angle then set the $T_{step} = T_{fine}$; otherwise, use $T_{step} = T_{coarse}$.

Step 8:   Update position vectors of all earth stations using algorithm in § D.6.1.

Step 9:   Update position and velocity vectors of all non-GSO satellites using algorithm in § D.6.3.2.

Step 10:   Update position vectors of GSO satellite using algorithm in § D.6.2.

Step 11:   Set epfd↑ = 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 § D.6.4.1.

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 satellite 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 ES_EIRP[lat] (dB(W/BW$_{raf}$)) of non-GSO earth station at its given latitude in direction of GSO satellite using non-GSO earth station e.i.r.p. mask in § C.3.

$$REP\_EIRP = ES\_EIRP[lat] + 10\log_{10} (NUM\_ES)$$

Step 19:   Calculate G_{RX} = receive relative gain (dB) at GSO satellite using relevant gain pattern specified in the algorithms in § D.6.5.

Step 20:   Calculate D = distance (km) between the non-GSO earth station and the GSO satellite using the algorithm in § D.6.4.1.

Step 21:   Calculate the spreading factor $L_{FS} = 10\log(4\pi D^2) + 60$.

Step 22:   Calculate epfd↑$_i$ for this non-GSO satellite:

$$epfd\uparrow_i = REP\_EIRP - L_{FS} + G_{RX} - G_{max}$$

Step 23:   Increment epfd↑ by epfd↑$_i$.

Step 24:   Increment epfd↑ statistics by this epfd↑.

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

Sub-step 24.1:   Increment epfd↑ statistics by the epfd↑ for this time step by T_{step}/T_{fine} entries.

Step 25:   Generate the epfd↑ CDF from the epfd↑ pdf using the algorithm in § D.7.1.2.

Step 26:   Compare epfd↑ statistics with limits using the algorithm in § D.7.1.

Step 27:   Output results in format specified in § D.7.2.

5.2.7   Outputs

The result of the algorithm is two arrays of size NEPFD↑ in format:

Array of Nepfd_UP epfd$_\uparrow$ values	epfd_UP_CALC[I]	dB(W/(m^2 · BW$_{ref}$))
Array of Nepfd_UP percentages	PC_CALC[I]	%

where PC_CALC[I] is the percentage of time epfd_UP_CALC[I] is exceeded.

5.3   epfd$_{is}$ software description

This section describes the algorithm to calculate epfd$_{is}$ from non-GSO space stations into a GSO uplink. From the e.i.r.p. and off-axis angle for each space station, the 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 epfd$_{is}$ is produced. This distribution can then be compared with the limits to give a go/no go decision.

5.3.1   Configuration parameters

This sub-section specifies the parameters required for all epfd$_{is}$ 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 derived in § D.2.1.

Parameter name	Parameter value	Parameter units and ranges
Frequency band start	FREQ	GHz
GSO gain pattern	FEND_IS	One of those in § D.5.5
GSO peak gain	GSO_SAT_PEAKGAIN	dBi
GSO half power beamwidth	GSO_SAT_BEAMWIDTH	degrees
Reference bandwidth	RIFBW	kHz
Number of $epfd_{is}$ points	Nepfd_IS	–
Array of Nepfd_IS $epfd_{is}$ values	epfd_IS[I]	$dB(W/(m^2 \cdot BW_{rif}))$
Array of Nepfd_IS percentages	PC_IS[I]	%

5.3.2 Determination of maximum epfd configuration

The maximum epfd location of GSO satellite and beam centre is defined in § D.3.3

5.3.3 Calculation of run steps

A single time step and number of time steps are calculated using the algorithm in § D.4.

5.3.4 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.

5.3.4.1 Non-GSO system parameters

The following parameters, as specified in § 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 § B.2.1 would be used, where the definitions of the parameters are specified in § D.6.3.1 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 space stations, the following parameters, as specified in § B.4.3 would be used:

Parameter description	Parameter name	Parameter units
e.i.r.p. per space station by latitude	non-GSO_SS_EIRP	dB(W/BW$_{rif}$)
Minimum transmit frequency[1]	IS_F	GHz

[1] The filing administration can supply a set of space station e.i.r.p. masks and associated frequency range for which the mask is valid.

5.3.4.2   GSO system parameters

The GSO system can either use worst-case parameters using the algorithm in § D.5.2 or entered values. The required parameters 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 § D.5.5

These parameters are defined in §§ D.6.1 and D.6.2.

5.3.4.3   Run parameters

The following run parameters should be calculated using the algorithm in § D.4:

Parameter description	Parameter name	Parameter units
Time step	TSTEP	s
Number of time steps	NSTEPS	–

5.3.5   Algorithms and calculation procedures

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

To calculate epfd$_{is}$ 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 § D.5.3.4.2.

Step 2: Read in GSO parameters as specified in § D.5.3.4.3.

Step 3: If required calculate worst-case GSO location using algorithm in § D.3.3.

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

Step 5: If required calculate number of time steps and time step size using algorithm in § D.4 and hence calculate end time.

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

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

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 $T_{step} = T_{fine}$.

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 any of the α angles for the last time step were within φ$_{coarse}$ of the exclusion zone angle then set the $T_{step} = T_{fine}$; otherwise, use $T_{step} = T_{coarse}$.

Step 7: Update position and velocity vectors of all non-GSO satellites using algorithm in § D.6.3.

Step 8: Update position vectors of GSO satellite using algorithm in § D.6.2.

Step 9: Set epfd$_{is}$ = 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 § D.6.4.1.

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$_{rif}$)) of non-GSO space station in direction of GSO satellite using the e.i.r.p. mask in § C.3 for the non-GSO space station's latitude.

Step 14: Calculate G_{RX} = receive relative gain (dB) at GSO satellite using relevant gain pattern specified in algorithms in § D.6.5.

Step 15: Calculate D = distance (km) between the non-GSO space station and the GSO satellite using the algorithm in § D.6.4.1.

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

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

$$epfd_{isi} = e.i.r.p. - L_{FS} + G_{RX} - G_{max}$$

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

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

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

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

Step 20: Generate the epfd$_{is}$ CDF from the epfd$_{is}$ pdf using the algorithm in § D.7.1.2.

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

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

5.3.6   Outputs

The result of the algorithm is two arrays in format:

Array of Nepfd_IS epfd$_{is}$ values	epfd_IS_CALC[I]	dB(W/(m^2 · BW$_{rif}$))
Array of Nepfd_IS percentages	PC_CALC[I]	%

where PC_CALC[I] is percentage of time epfd_IS_CALC[I] is exceeded.
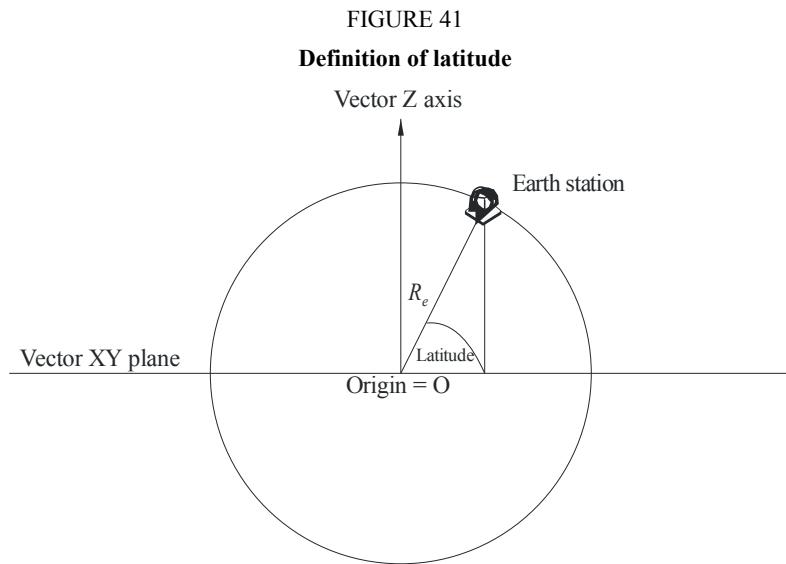
6   Geometry and algorithms

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.

6.1   Earth coordinates system

Figure 41 shows the reference coordinate system for earth stations.

FIGURE 41

Definition of latitude

S.1503-41
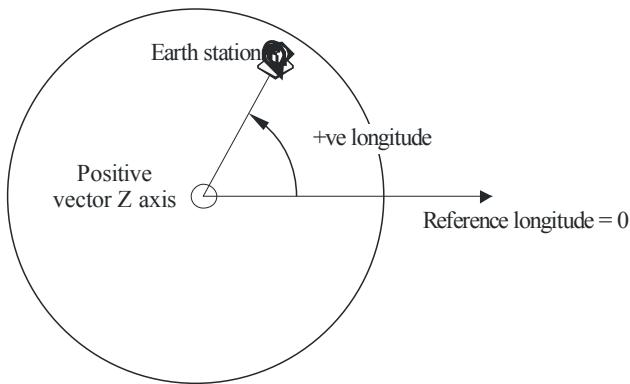
The Earth is defined as a sphere with radius as specified in § A.2.2 = R_e. The Earth rotates around an axis, the Z axis, at a rate defined in § A.2.2 = Ω_e. Perpendicular to the Z axis, crossing the Earth at the Equator, is the XY plane.

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 Fig. 42.

FIGURE 42

Definition of longitude

S.1503-42

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 than 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:

$$\text{Long} = \arccos\left(\frac{x}{\sqrt{x^2+y^2}}\right) \qquad \text{if } y \geq 0 \tag{5}$$

$$\text{Long} = -\arccos\left(\frac{x}{\sqrt{x^2+y^2}}\right) \qquad \text{if } y < 0 \tag{6}$$

$$\text{Lat} = \arctan\left(\frac{z}{\sqrt{x^2+y^2}}\right) \tag{7}$$

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

$$x = R_e \cos(\text{lat}) \cos(\text{long}) \tag{8}$$

$$y = R_e \cos(\text{lat}) \sin(\text{long}) \tag{9}$$

$$z = R_e \sin(\text{lat}) \tag{10}$$

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:

$$\begin{bmatrix} x \\ y \\ z \end{bmatrix} = \begin{bmatrix} R_e \cos(\text{lat}) \cos(\text{lon} + \Omega_e t) \\ R_e \cos(\text{lat}) \sin(\text{lon} + \Omega_e t) \\ R_e \sin(\text{lat}) \end{bmatrix} \tag{11}$$
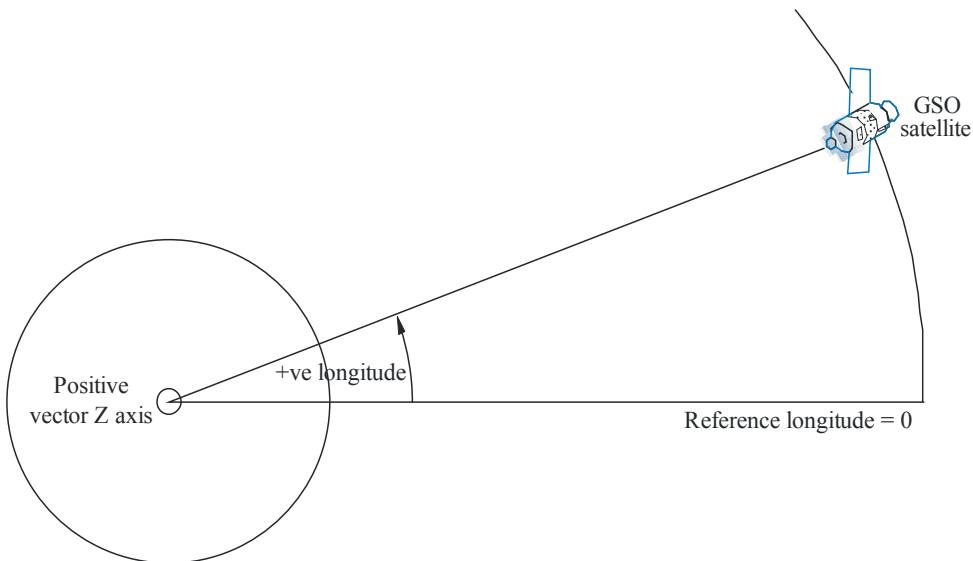
where:

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

Ω_e: angular rate of rotation of the Earth.

6.2 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 § A.2.2. Individual geostationary satellites have location on this circle defined by a longitude as shown in Fig. 43.

FIGURE 43

**Definition of GSO satellite longitude**

S.1503-43
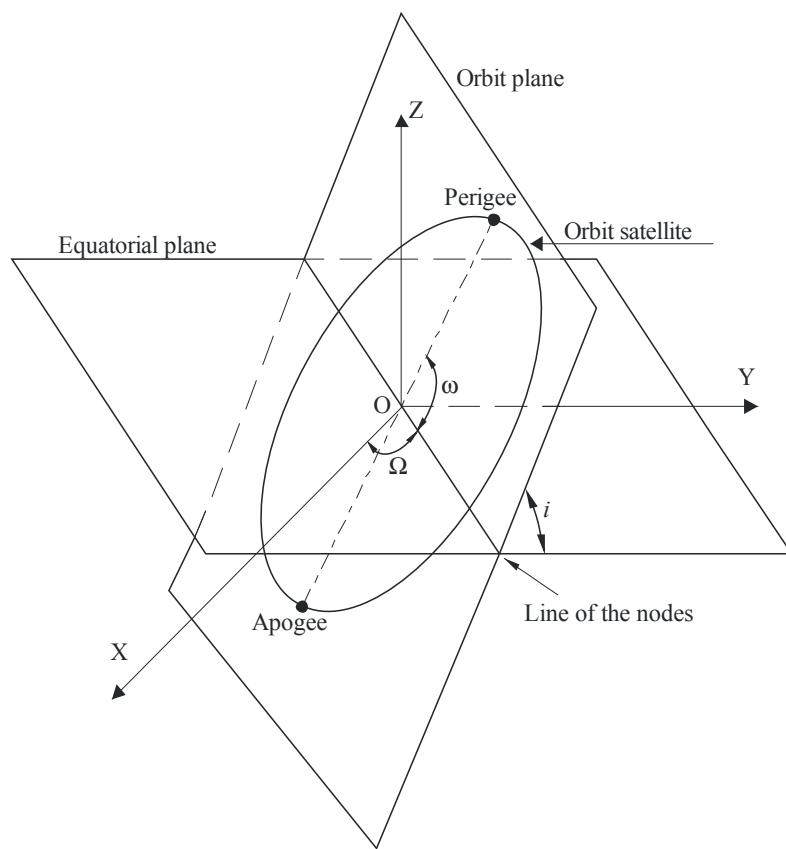
Geostationary satellites are assumed to have constant longitude in time. The conversion to and from vectors can use the same algorithms as in the section above by setting the latitude to zero.

6.3 Non-GSO satellite coordinate system

6.3.1 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. 44.

FIGURE 44

Orbit plane angles
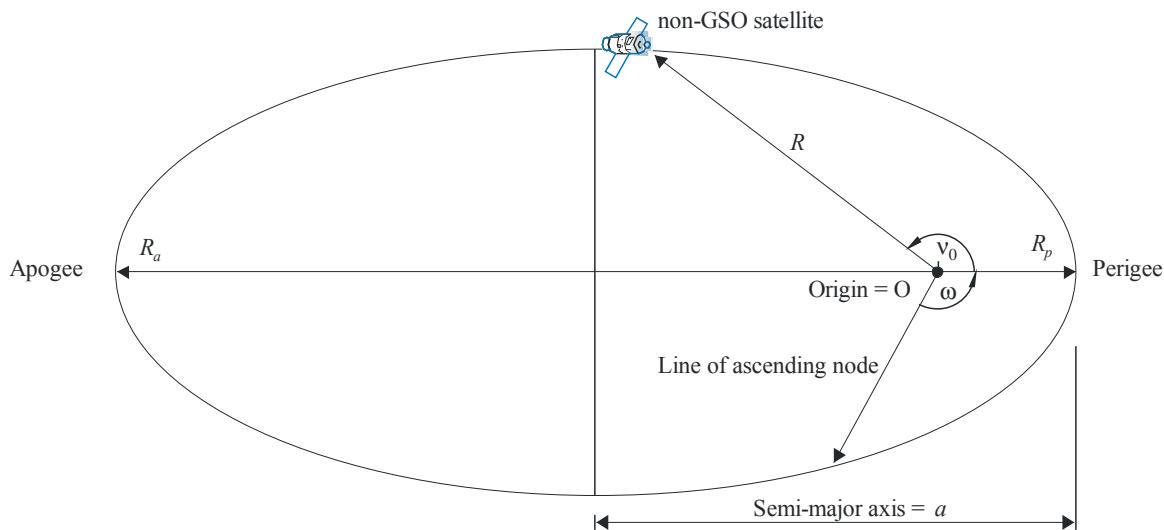
S.1503-44

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

Ω: 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. 45.

FIGURE 45

Definition of non-GSO satellite in-plane angles

S.1503-45

The shape of the orbit is defined by:

$$a = (R_a + R_p)/2 \qquad (12)$$

$$e = (R_a - R_p) / (R_a + R_p) \qquad (13)$$

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:

ω: 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, ω can be set to zero and v_0 assumed to be the same as the argument of latitude defined as:

$$\mu_0 = \omega + v_0 \qquad (14)$$

Other useful terms are:

$$p = a(1 - e^2) \qquad (15)$$

$$M = E - e \sin E \qquad (16)$$

$$\tan \frac{v}{2} = \sqrt{\frac{1+e}{1-e}} \tan \frac{E}{2} \qquad (17)$$

$$R = \frac{p}{1 + e \cos(v)} \qquad (18)$$

$$T = 2\pi \sqrt{a^3/\mu} \qquad (19)$$

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 ν.

These can be used by the algorithm to predict the future position of the non-GSO satellite as described in § D.5.

6.3.2 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 three additional precession factors for the ascending node and argument of perigee as described below.

Line of nodes

$$\bar{n} = n_0 \left(1 + \frac{3}{2} \frac{J_2 R_e^2}{p^2} \left(1 - \frac{3}{2} \sin^2(i)\right)(1 - e^2)^{1/2}\right) \tag{20}$$

where:

$J_2 = 0.001082636$

$n_0 = \sqrt{\dfrac{\mu}{a^3}}$

Orbit precession in ascending node longitude.

The rate of ascending node longitude secular drift is defined as:

$$\Omega_r = -\frac{3}{2} \frac{J_2 R_e^2}{p^2} \bar{n} \cos(i) \tag{21}$$

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

Perigee argument precession.

Perigee argument secular shift rate is defined as:

$$\omega_r = \frac{3}{2} \frac{J_2 R_e^2}{p^2} \bar{n} \left(2 - \frac{5}{2} \sin^2(i)\right) \tag{22}$$

Perigee argument precession rate at $i = 0$ and $i = 180$ is maximum. For $i_1 = 63°26'06''$ or $i_2 = 116°33'54''$ 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.

Use of precession terms

Perigee argument is defined as:

$$\omega = \omega_0 + \omega_r t \tag{23}$$

where:

ω_0: perigee argument at an initial moment

ω_r: perigee argument precession rate.

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

$$\Omega = \Omega_0 + \Omega_r t \tag{24}$$

where:

   Ω_0:   ascending node longitude at an initial moment

   Ω_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:

$$\begin{bmatrix} x \\ y \\ z \end{bmatrix} = \begin{bmatrix} R(\cos(\nu + \omega)\cos(\Omega) - \sin(\nu + \omega)\sin(\Omega)\cos(i)) \\ R(\cos(\nu + \omega)\sin(\Omega) + \sin(\nu + \omega)\cos(\Omega)\cos(i)) \\ R\sin(\nu + \omega)\sin(i) \end{bmatrix} \tag{25}$$

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; the numerical methods of solving the below expressions were used for its definition. The expression is:

$$M = M_0 + \bar{n}t \tag{26}$$

6.3.3   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 affect this, then the main parameter to vary is the longitude of the ascending node.

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

This is implemented by rotating the station's position and velocity vectors around the Z axis by the required angle as specified in § D.6.3.4.

6.3.4   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:

a)   where administrations supply a detailed value of the orbit precession rate with respect to a point Earth mass to ensure a repeat ground track;

b)   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:

$$\begin{bmatrix} x' \\ y' \\ z' \end{bmatrix} = \begin{pmatrix} \cos\theta & -\sin\theta & 0 \\ \sin\theta & \cos\theta & 0 \\ 0 & 0 & 1 \end{pmatrix} \begin{bmatrix} x \\ y \\ z \end{bmatrix} \tag{27}$$
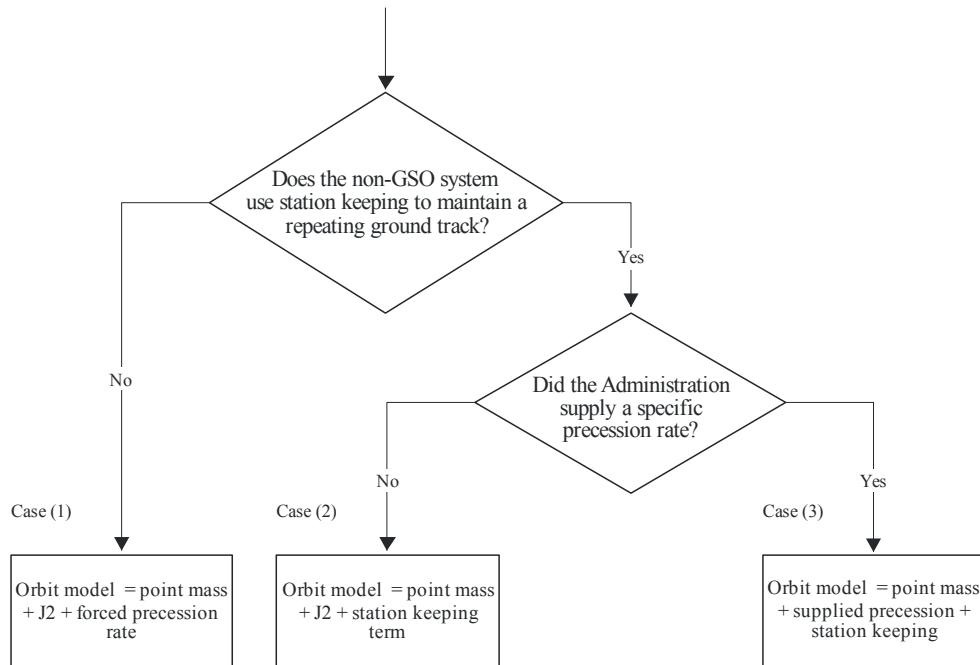
to rotate by angle θ.

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

6.3.5 Combining the orbit models

The various options for the orbit model can be combined in three ways as shown Fig. 46:

FIGURE 46

Flowchart of orbit model options

S.1503-46

Note that the equatorial orbit $i = 0$ constellation is a special case in that there is no station keeping but the ground track of each satellite repeats just after one orbit.

It should therefore be treated as Case (1) but with forced precession set to zero as described in § D.4.

6.3.6 Mapping orbit parameters from SRS data

The following orbit parameters are given in the SRS / IFIC database:

Table *orbit*:

– Apogee height (km) = h_a

– Perigee height (km) = h_p

– Inclination angle (degrees) = INC

– Right ascension (degrees) = RA

– Longitude of ascending node (degrees) = LAN

– Argument of perigee (degrees) = AP.

Table *phase*:

– Phase angle (degrees) = PA.

For most of these fields it is possible to map nearly directly to the orbit parameters required, such as:

$$a = R_e + \frac{h_a + h_p}{2}$$

$$e = \frac{h_a - h_p}{2a}$$

$$i = INC$$

$$\Omega = LAN$$

$$\omega = AP$$
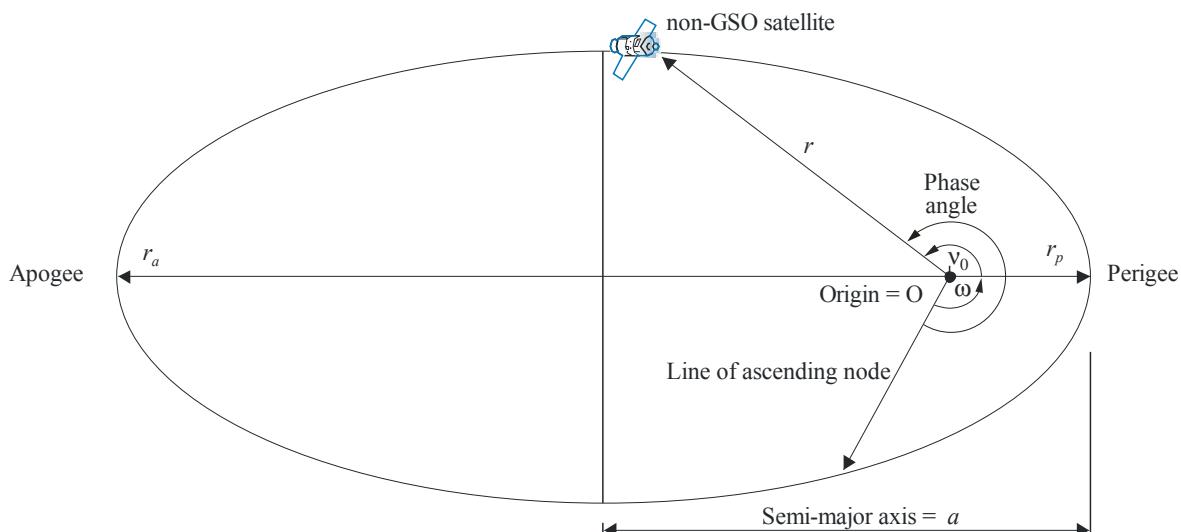
Note that this algorithm uses the ascending node definition based upon longitude rather than right ascension to ensure the orbit is correctly referenced to earth station longitude.

The last field to define is the true anomaly, ν, which can be derived from the phase angle. The phase angle is defined in RR Appendix 4 as:

A.4.b.5.b: *the initial phase angle (ω_i) of the i-th satellite in its orbital plane at reference time t = 0, measured from the point of the ascending node (0° ≤ ω_i < 360°)*

The phase angle is shown in Fig. 47:

FIGURE 47

Definition of phase angle

S.1503-47

The true anomaly can therefore be derived from the phase angle as follows:

$$\nu_0 = PA - \omega$$

6.4 Geometry

6.4.1 Distance between two stations

Given two station's position vectors in the form (x, y, z), the distance D between them can be calculated using:

$$D = \sqrt{(x_1 - x_2)^2 + (y_1 - y_2)^2 + (z_1 - z_2)^2}$$

6.4.2 Distance to Earth horizon

The distance to the horizon D_h for a station with Earth centred position vector of magnitude R can be calculated as follows:

$$D_h = \sqrt{R^2 - R_e^2}$$
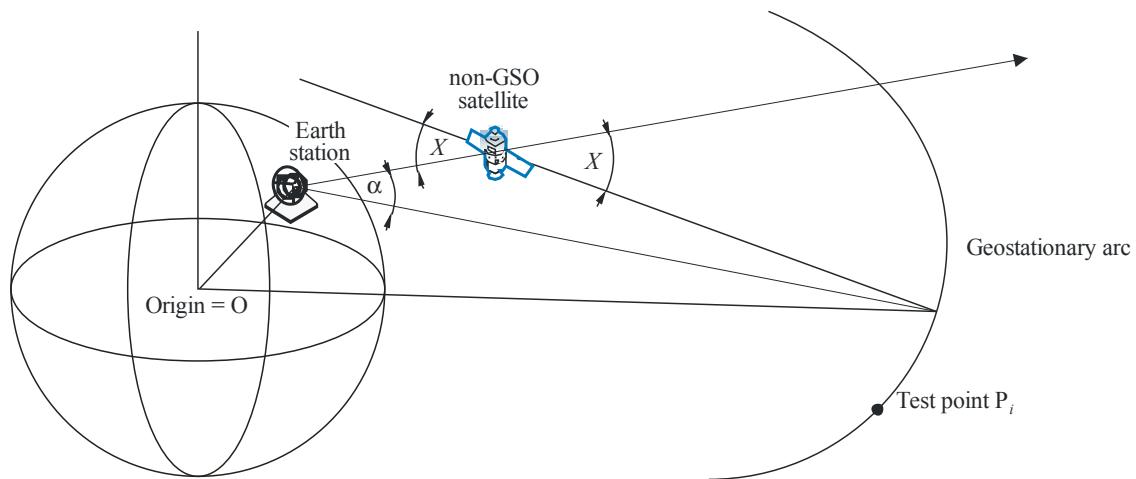
6.4.3 Satellite visibility check

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 § D.6.1.

6.4.4 Angle to GSO arc and ΔLongitude

Figure 48 shows the definition of the α angle and X angle.

FIGURE 48

Definition of α and X angles

S.1503-48

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 α_i between that line and a line from the earth station to the non-GSO satellite.

The α angle is the minimum of all the test points for which the line does not intersect the Earth, 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 for which the line does not intersect the Earth, i.e.

$$X = \min \ (X_i)$$

The sign of α and X is determined by whether the line from the earth station to the non-GSO satellite intersects the XY plane at a distance less than or greater than the GSO radius as follows:

Given:

      Earth station position vector: $\underline{R}_{ES}$

Non-GSO satellite position vector: $\underline{R}_{NS}$

Construct line:

$$\underline{R} = \underline{R}_{ES} + \lambda \underline{R}_{EN}$$

where:

$$\underline{R}_{EN} = \underline{R}_{NS} - \underline{R}_{ES}$$

This line crosses the XY plane when:

$$R(z) = 0$$

i.e. when

$$\lambda_{z=0} = \frac{-R_{ES}(z)}{R_{EN}(z)}$$

Hence:

$$\underline{R}_{z=0} = \underline{R}_{ES} + \lambda_{z=0} \underline{R}_{EN}$$

The sign of α, X is then determined by:
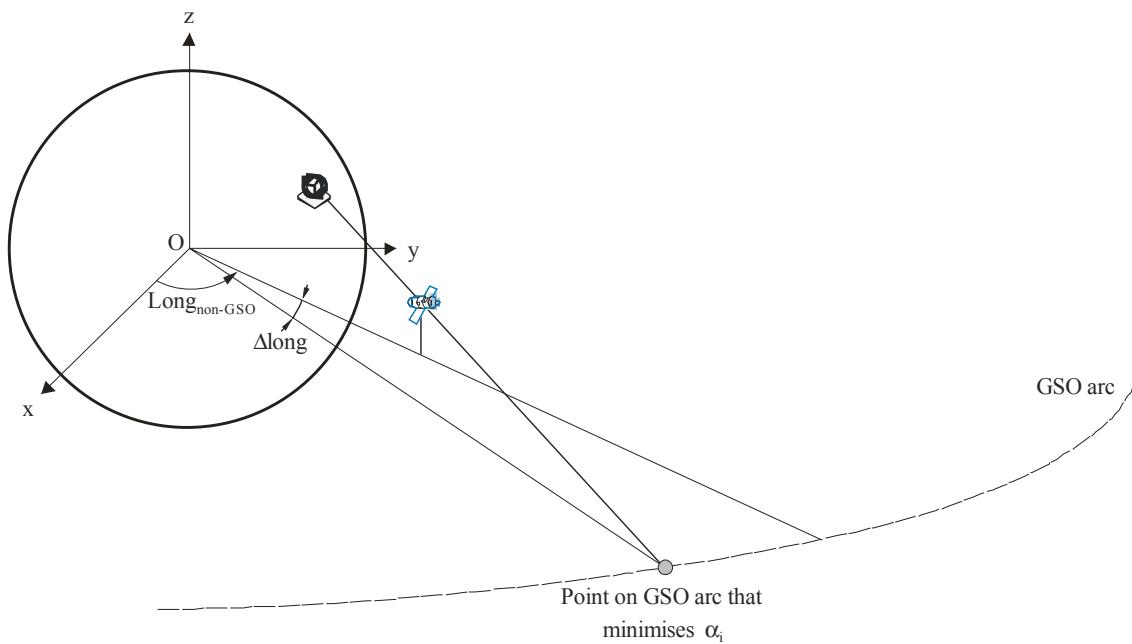
If $R_{z=0} > R_{geo}$ then α is positive

If $R_{z=0} = R_{geo}$ then α is zero

If $R_{z=0} < R_{geo}$ then α is negative.

From the test point identified to give the α or X angle, the Δlongitude can be calculated between the non-GSO sub-satellite point and the point on the GSO arc where the α (or X) angle is minimized, as shown in Fig. 49:

FIGURE 49

Definition of Δlongitude

Point on GSO arc that
minimises α_i

S.1503-49

Hence:
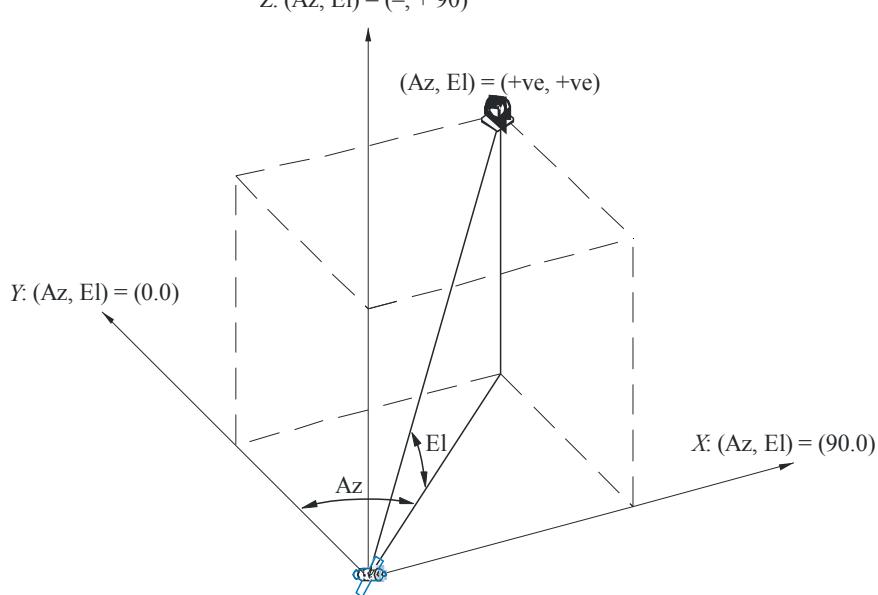
ΔLong = LongAlpha − LongNGSO

The α or X iteration should use test points that meet the requirements in § D.1.4.

6.4.5 Satellite azimuth and elevation

Figure 50 shows the definition of the azimuth and elevation angles used for the non-GSO satellite:

FIGURE 50

Definition of azimuth and elevation

S.1503-50

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.

6.5 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.

6.5.1 GSO earth station gain patterns

6.5.1.1 FSS earth station gain pattern

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

6.5.1.2 BSS earth station gain pattern

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

6.5.2 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 **22** based upon Recommendation ITU-R S.672.

In the 11-14 GHz bands, a peak gain of 32.4 dBi, a beamwidth of 4° and a first side-lobe level of 20 dB should be assumed; in the 20-30 GHz bands, a peak gain of 40.7 dBi, a beamwidth of 1.55° and a first side-lobe level of 10 dB should be assumed.

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 § D.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:

$$\text{CDF}_i = 100 \, (1 - \text{SUM} \, (\text{PDF}_{min}: \text{PDF}_i))$$

where:

PDF_x: PDF table entry for a pfd value of X dB, normalized so that the total sum for all PDF_x 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 § D.7.1.4 shall be output.

7.3.2   Summary table

The summary table shall show the following data (see Table 14):

TABLE 14

Summary table

Specification point		Result	Simulation point
pfd value	Probability		Probability
J_1 dB(W/(m^2 · BW$_{ref}$))	P_1	Pass/fail	P_y
:	:	:	:
J_i dB(W/(m^2 · BW$_{ref}$))	P_i	Pass/fail	P_y

where:

J_i and P_i: pfd 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(↓/↑) 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↓ 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 ±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 § 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 § 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

Software implementing this Recommendation

1   Operating system

The software shall run on Microsoft platforms under the Windows XP or higher operating system.

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 DVD, in the Weekly Circular and its Special Sections. They are also used to provide input data to software packages performing RR Appendix 8 and pfd examinations. Graphical Interface for Batch Calculations (GIBC) is used to carry out examination using these different modules. 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 epfd 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.

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.

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