ITU World Radiocommunication Seminar

Equivalent power-flux density limits examination

2-6 December 2024, Geneva, Switzerland

Equivalent power-flux density limits examination

Part I - Overview

Non-GSO regulations

- ✓**Coordination – ensures protection of existing services on equitable access basis**
  - ✓Coordination between non-GSO and GSO in limited frequency bands (No. 9.12A)
  - ✓Coordination between non-GSO in limited frequency bands (9.12)
  - ✓List is given in Rule of Procedure under No. 9.11A
  - ✓9.21 is also applicable if established in the footnote(s)
- ✓**Hard Limits:**
  - ✓Article 21 PFD limits to protect terrestrial services
  - ✓Article 22 EPFD limits to protect GSO from non-GSO
- ✓**Ultimate protection of GSO**
  - ✓ No. **22.2**. Non-geostationary-satellite systems shall not cause unacceptable interference to and shall not claim protection from geostationary-satellite networks in the fixed-satellite service and the broadcasting-satellite service
  - ✓ Resolution **76**. Protection of GSO FSS and BSS networks from the maximum aggregate equivalent power flux density produced by multiple non geostationary FSS systems in frequency bands where EPFD limits have been adopted

Rationale behind the limits

Traditionally efforts were made to maximize use of the orbit/spectrum resource on the arc of GSO satellites

This work has permitted co-frequency, co-coverage service to earth stations as small as about 1 meter in diameter from satellites as close as 2 degrees apart on the GSO arc

The next logical extension is to implement such sharing between satellites on the GSO arc and non-GSO satellites operating a close to the GSO arc

The work of the ITU-R has focused on developing an optimum set of sharing rules that will ensure the adequate protection of existing services, while facilitating to the greatest extent possible the introduction of non-GSO FSS systems

The establishment of power limits is a benefit to non-GSO FSS operators, because it provides the bounds within which non-GSO FSS systems may operate without individual negotiations with every GSO network

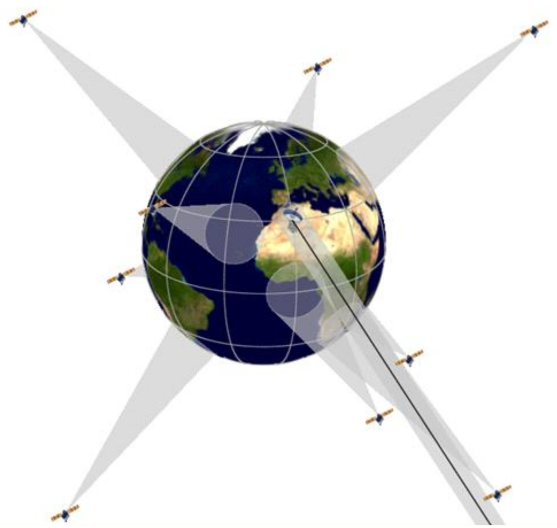
These power limits were established in the form of Equivalent Power Flux Density (EPFD) limits

What is EPFD

Equivalent power-flux density (EPFD) takes into account the aggregate of the emissions from all non-GSO satellites in the direction of any GSO earth station, taking into account the GSO antenna directivity

EPFD considers pointing of a victim receiving antenna with respect to any source of interference

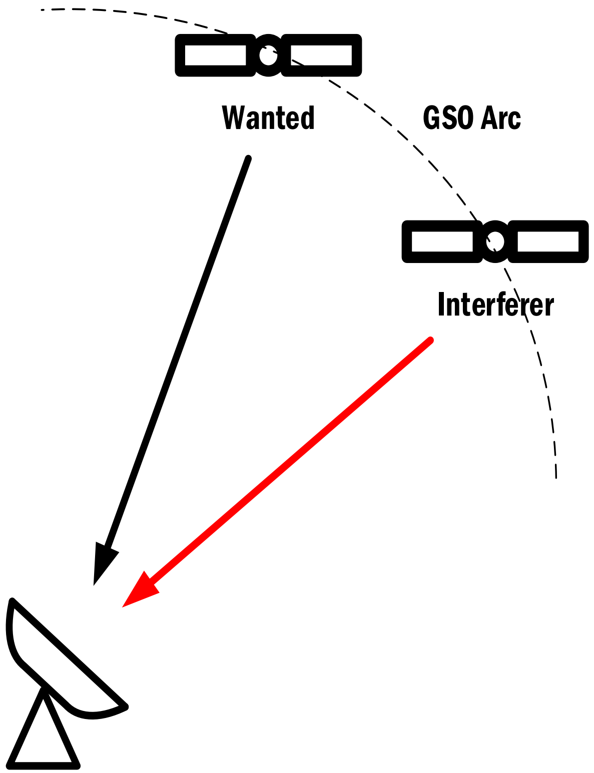
Complex calculation methodology considers an interference varying in time and space



S.1503-38

Why use EPFD an interference metric?

GSO to GSO



Wanted/interferer geometry is fixed

Criteria ΔT/T, C/I

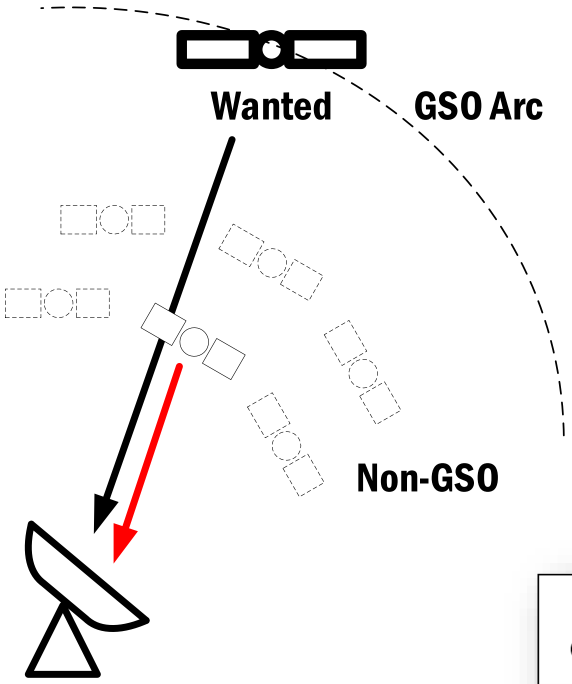
Interfering signal path loss

≈

Wanted signal path loss

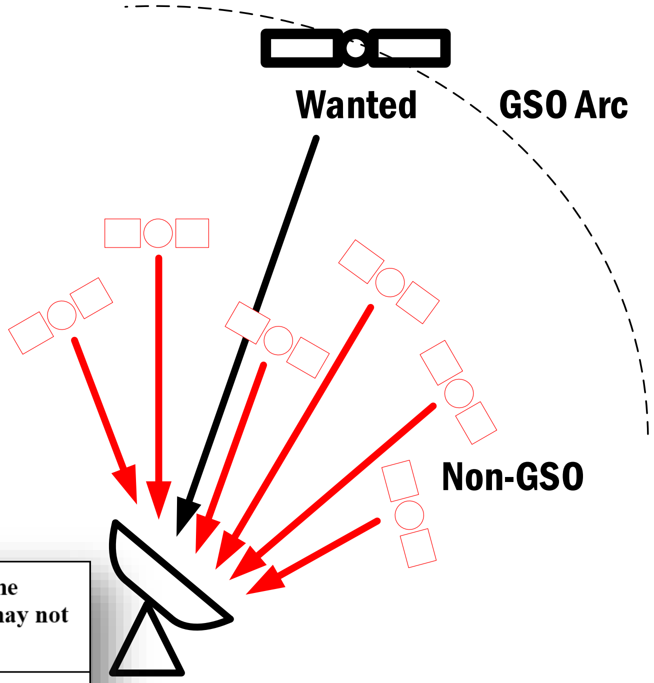
Why use EPFD an interference metric?

Non-GSO to GSO



Constantly changing wanted vs interferer geometry

epfd↓ (dB(W/m²))	Percentage of time during which epfd↓ may not be exceeded
−175.4	0
−174	90
−170.8	99
−165.3	99.73
−160.4	99.991
−160	99.997
−160	100



Aggregate effect of interference from several sources

Regulatory Framework

Article **22 – Hard Limits to protect GSO from Non-GSO**

Hard EPFD limits enable non-GSO FSS systems to share frequencies with and protect GSO systems without requiring individual coordinations with all the systems worldwide

FSS non-GSO satellite systems shall comply with the EPFD limits contained in Tables **22-1A**, **22-1B, 22-1C, 22-1D, 22-1E, 22-2 and 22-3** of RR Article **22**

- ✓ Article 22 contains reference parameters of GSO stations to be protected

Frequency band (GHz)	epfd↓ (dB(W/m²))	Percentage of time during which epfd↓ may not be exceeded	Reference bandwidth (kHz)	Reference antenna diameter and reference radiation pattern[7]
10.7-11.7 in all Regions; 11.7-12.2 in Region 2; 12.2-12.5 in Region 3 and 12.5-12.75 in Regions 1 and 3	−175.4 −174 −170.8 −165.3 −160.4 −160 −160	0 90 99 99.73 99.991 99.997 100	40	60 cm Recommendation ITU-R S.1428-1

EPFDdown limits

EPFDdown is the most constraining parameter in the non-GSO/GSO sharing issues since non-GSO satellites are generally much closer to GSO earth stations than the GSO satellites

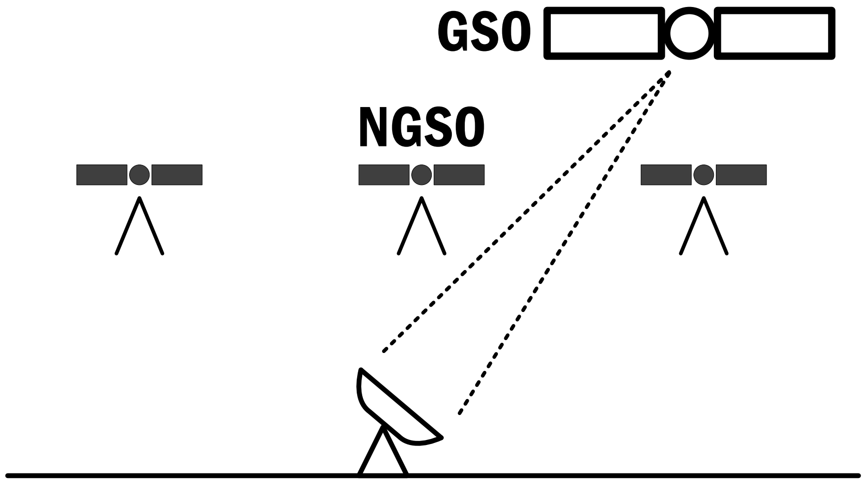
Due to the movement of non-GSO satellites the interference level caused by a non-GSO system is a function of the percentage of time considered

- Higher levels of interference may occur for very short durations, that is, for small percentages of time (referred to as the "short term"),
- Lower levels occur more generally, for larger percentages of time (referred to as the "long term")

EPFDdown limits are derived as a curve associating an EPFD level for each percentage of time:

- That better models the statistical nature of NGSO interference
- The shape of the curve is a very important factor in avoiding undue burdens to either type of system

EPFD on downlink - *EPFDdown*

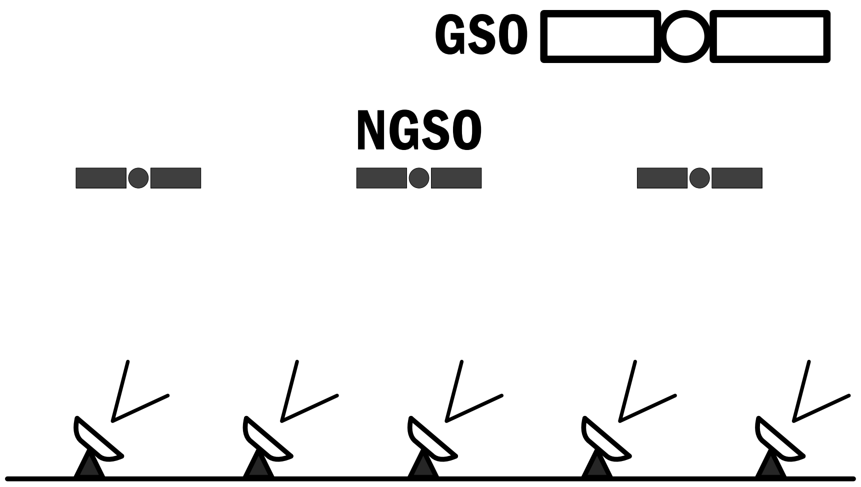


EPFDup limits

EPFDup takes into account the angular discrimination of the satellite antenna, leading to a more accurate assessment of the received interference

It was agreed a curve is not needed for the *EPFDup* limit, and instead a single limit, specifying an *EPFDup* level never to be exceeded (for any percentage of time) would suffice

EPFD on uplink - *EPFDup*



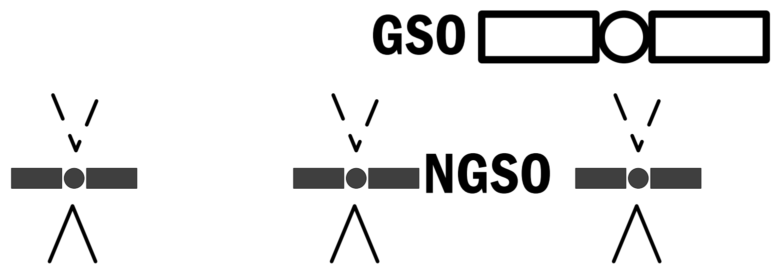
EPFDis limits

Inter-satellite interference in the bands in which non-GSO satellites operate downlinks and GSO satellites operate uplinks.

- 10.7-11.7 GHz and 12.5-12.75 GHz in Region 1
- 12.7- 12.75 GHz in Region 2
- 17.8-18.4 GHz

A reference bandwidth of 40 kHz should be used for the Ku-Band EPFD limits, and reference bandwidths of 40 kHz and 1 MHz should be used for the Ka-band EPFD limits.

EPFD on inter-satellite path - *EPFDis*



Overview of Recommendation ITU-R S.1503

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

Establishes computational methodology to calculate and verify single-entry EPFD limits in Article 22

The calculation algorithm assumes worst case

Uses the non-GSO parameters defined in its filing

The input parameters represent an envelop of transmission characteristics within which the non-GSO system shall operate

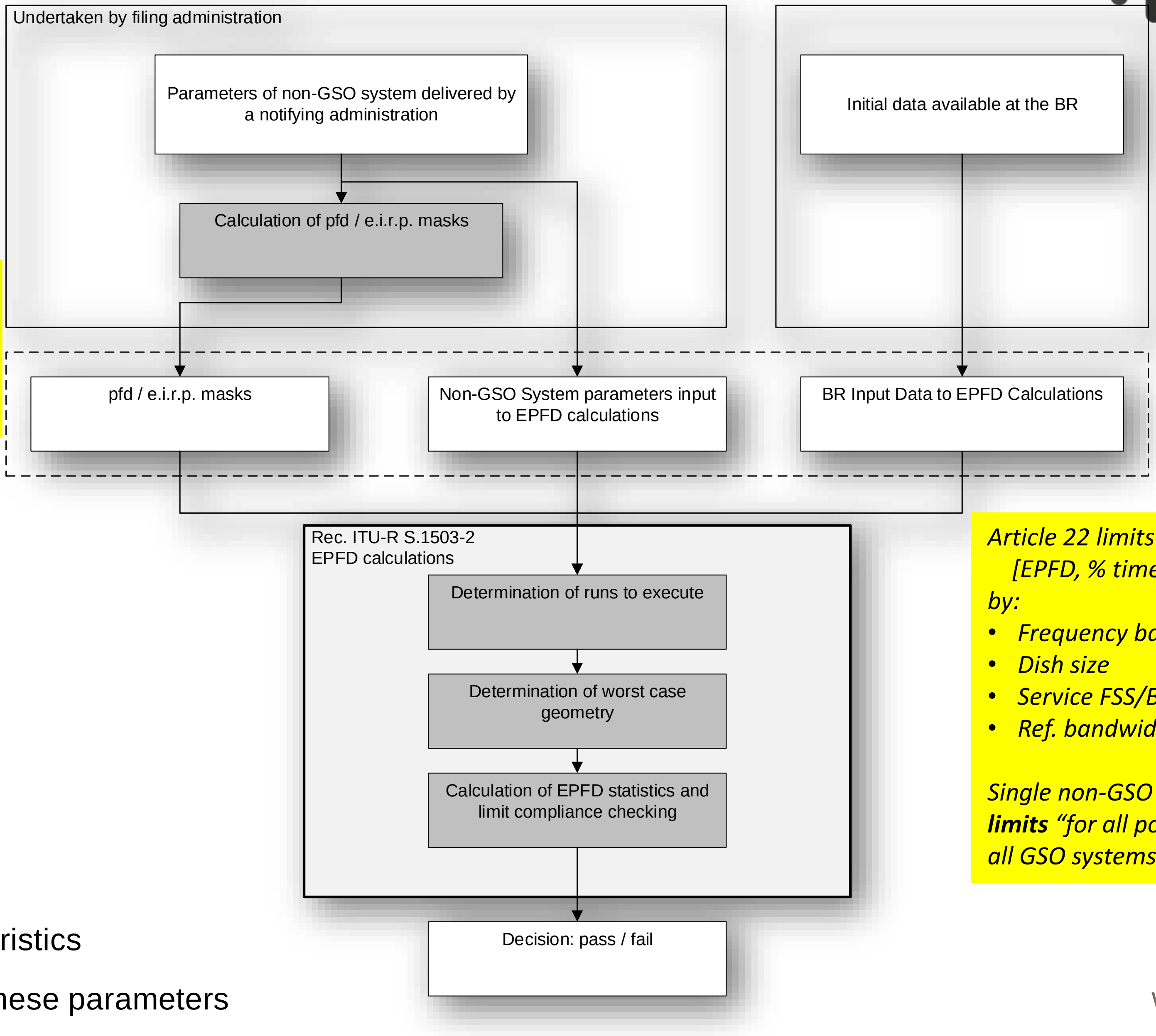
The calculation algorithm ensures the results are statistically significant so can be compared against the Article 22 limits

Get familiar with ITU-R Recommendation S. 1503

- PART A – Assumptions
- PART B – Input parameters
- PART C – Generation of pfd/e.i.r.p. masks
- PART D – General description of software algorithms

ITU WRS GENEVA 2024

Ap4 "for space stations operating in a frequency band subject to Nos. 22.5C, 22.5D or 22.5F..."



Article 22 limits:
[EPFD, % time]
by:

- *Frequency band*
- *Dish size*
- *Service FSS/BSS*
- *Ref. bandwidth*

*Single non-GSO system **verification limits** "for all pointing directions" for all GSO systems*

Objectives:

Protection for GSO systems

Flexibility for non-GSO systems

Approach:

Measurable non-GSO system characteristics

Computation of EPFD CDF based on these parameters

Three main concepts

Alpha angle. Calculation of the alpha angle to establish geometry between non-GSO stations and GSO arc (GSO victim links)

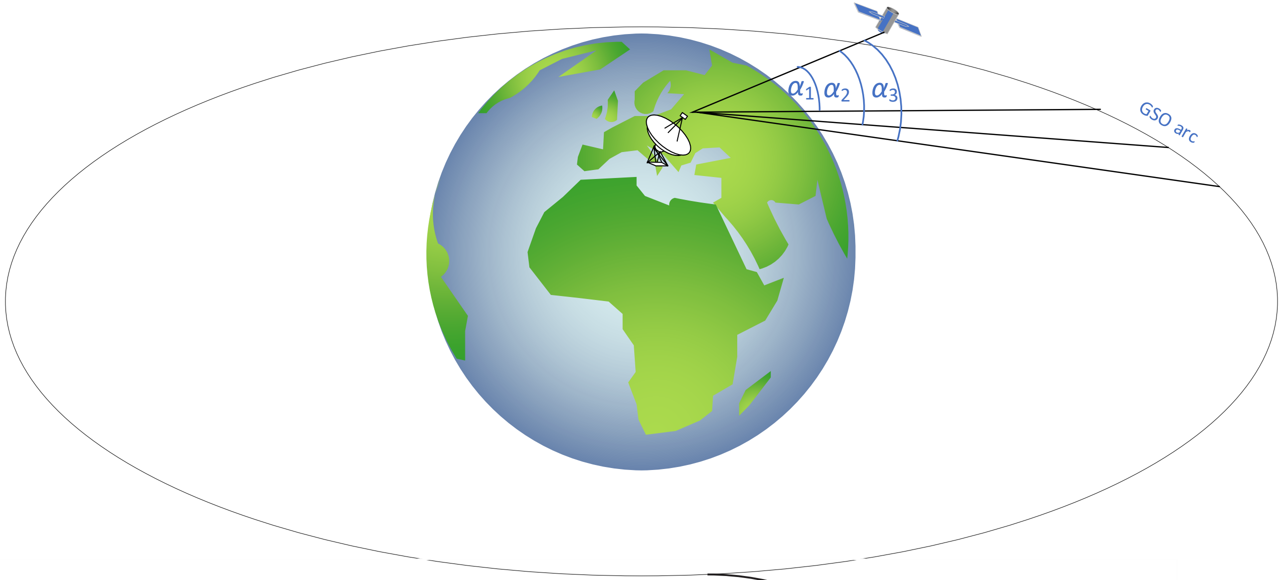
Mask concept. The use of the “mask” to define transmission envelope

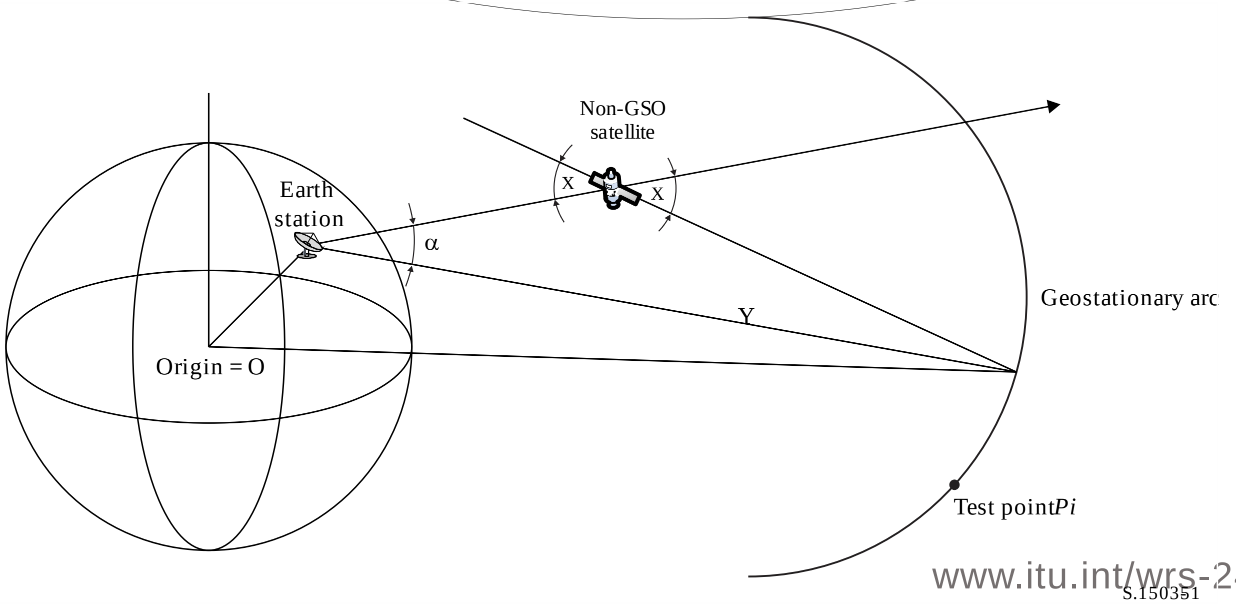
Worst-case geometry – to avoid calculations everywhere within GSO footprint and provide worst-case location of GSO earth station and GSO satellite which may receive highest level of interference

Alpha angle

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.

Used to describe position of non-GSO satellite versus GSO arc



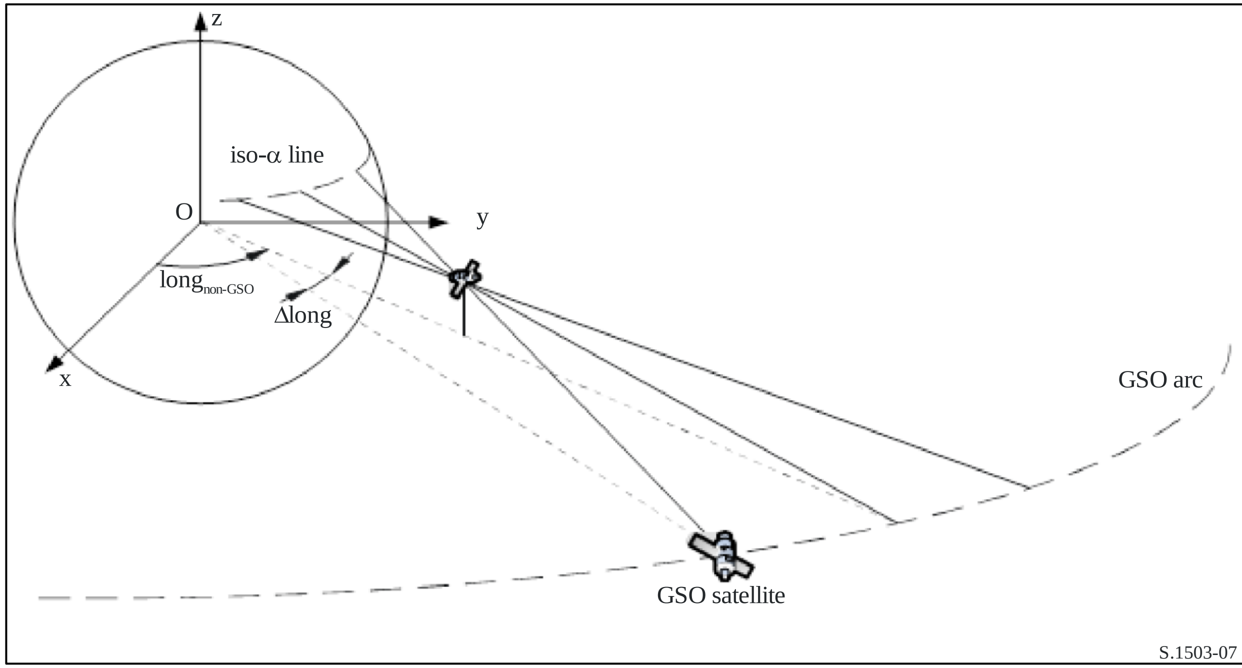


Alpha angle

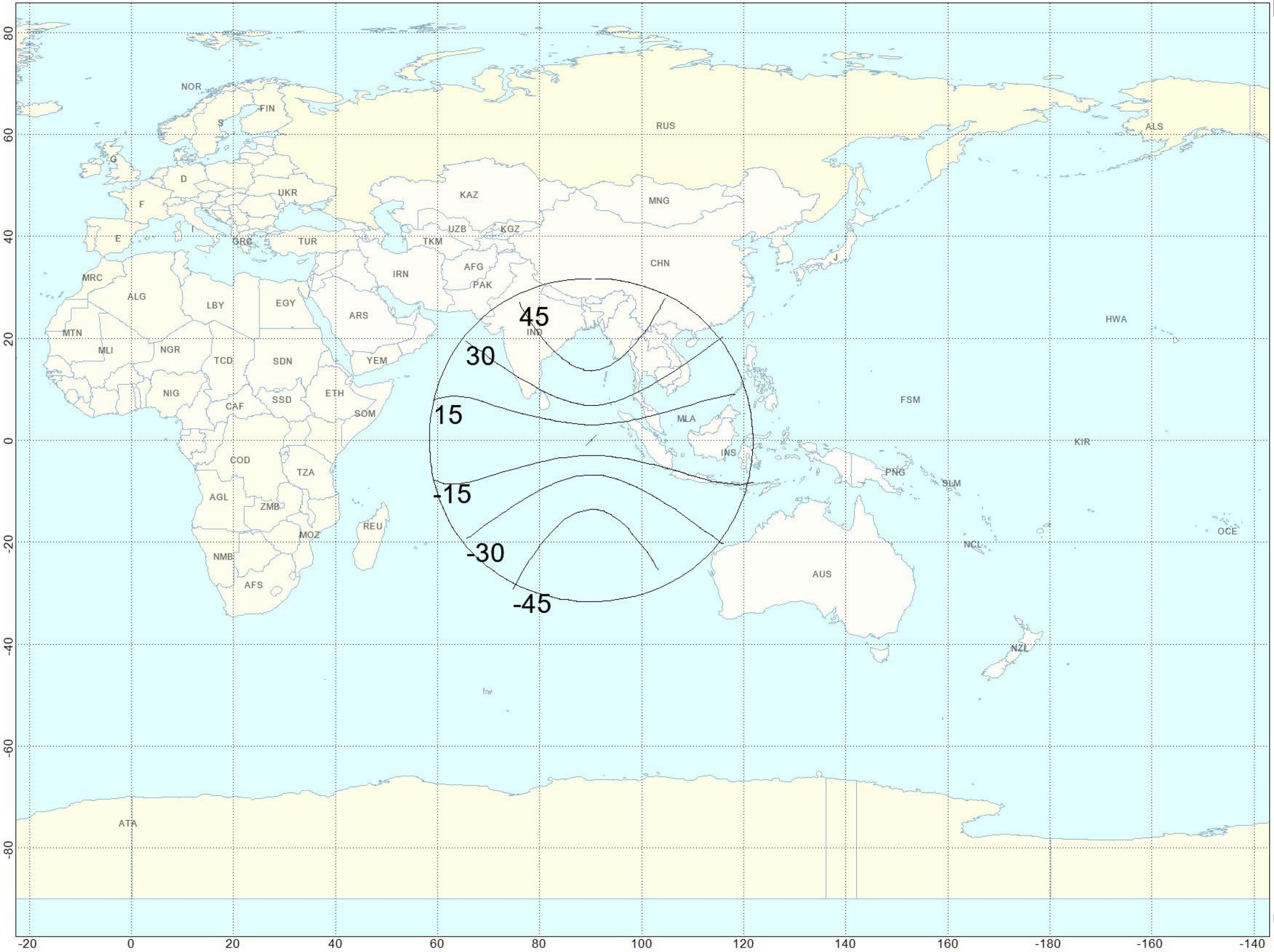
Alpha angle is positive when vector to non-GSO satellite is oriented toward North and negative when it is oriented towards South

It can be associated with the difference ΔL in longitude between the non-GSO sub-satellite point and the point on the GSO arc where the α angle is minimized

Consider alpha angle at any point is minimum off-axis angle of GSO earth station antenna towards non-GSO satellite



Alpha angle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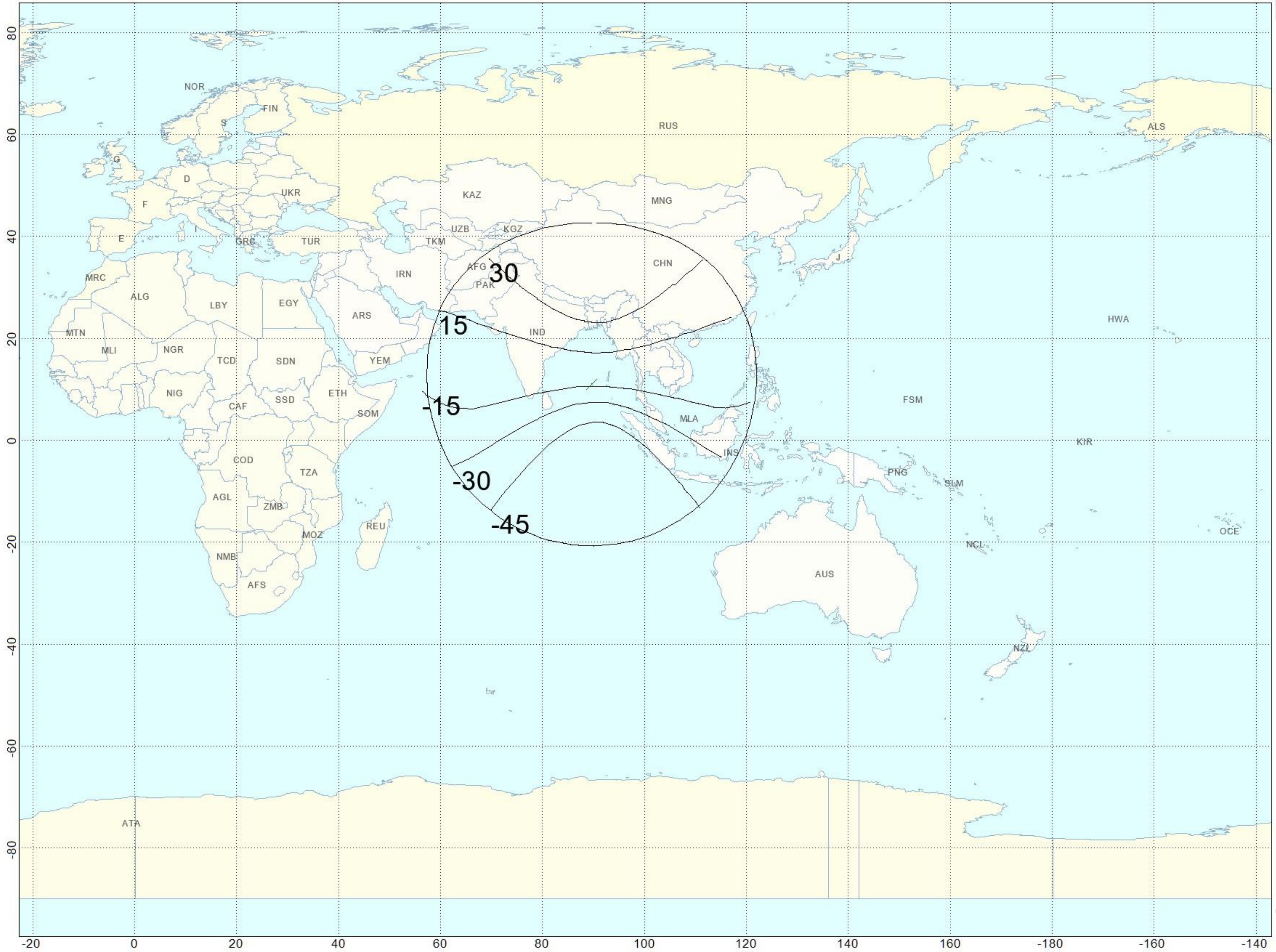

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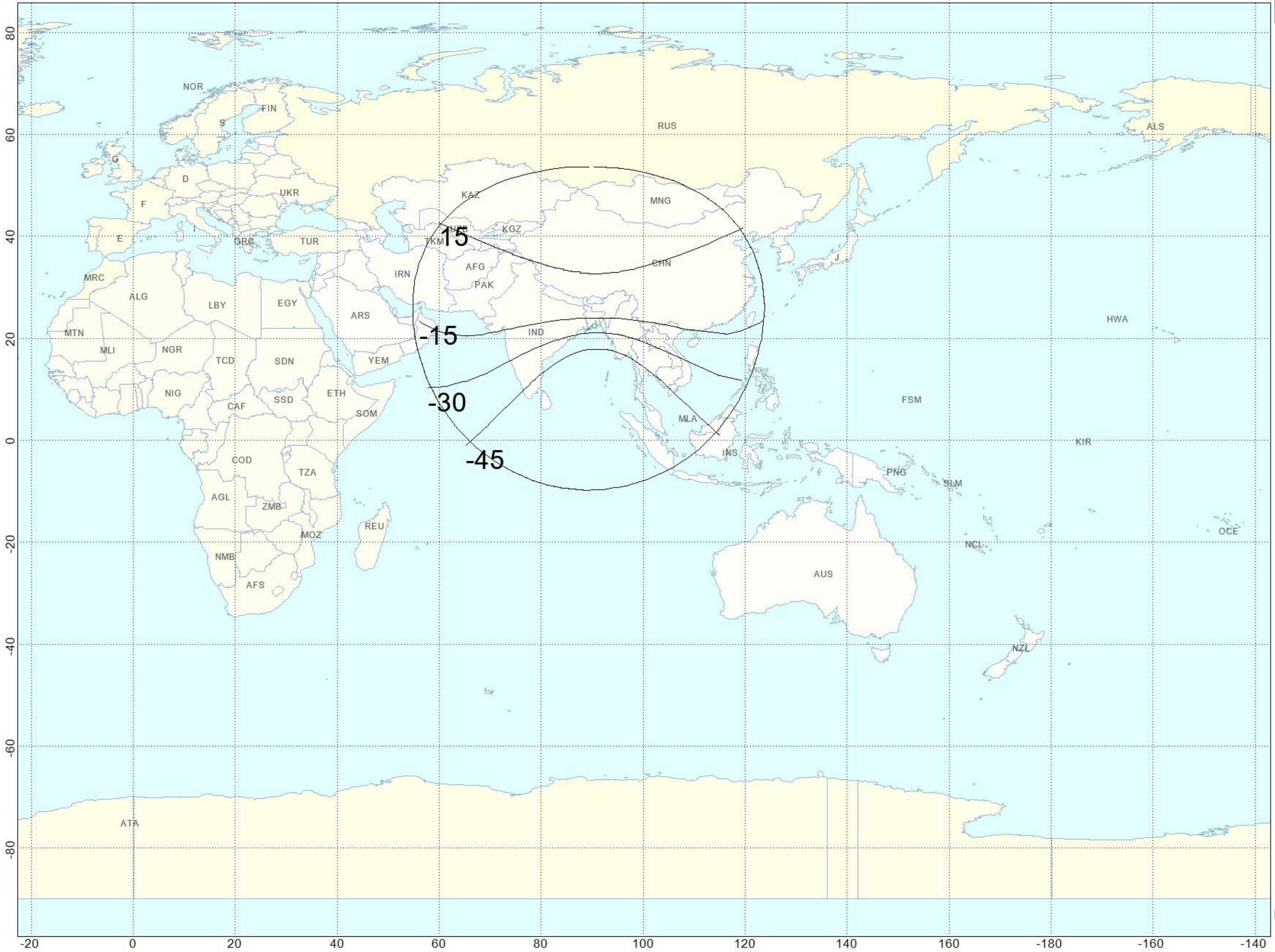
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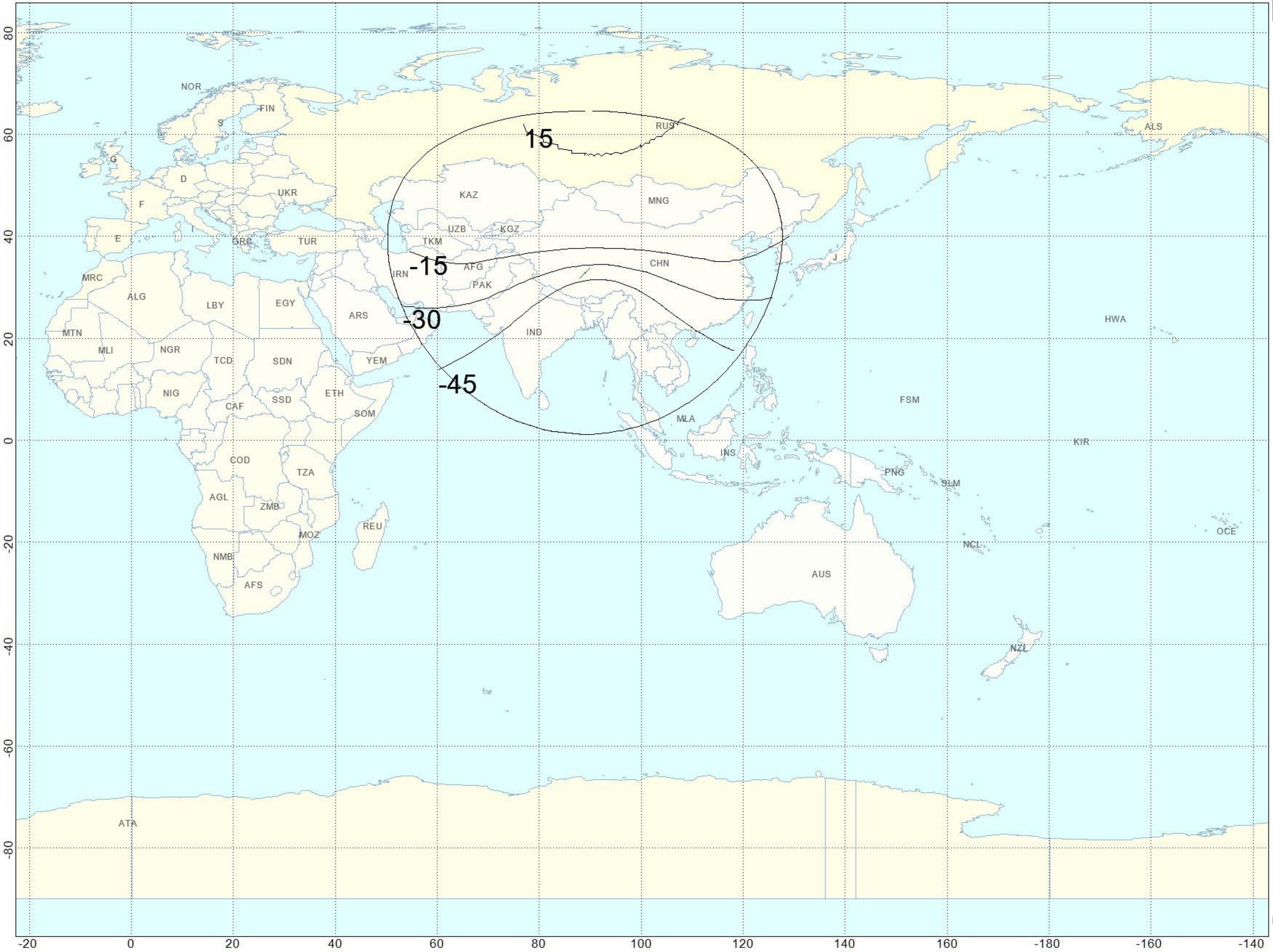
Alpha angle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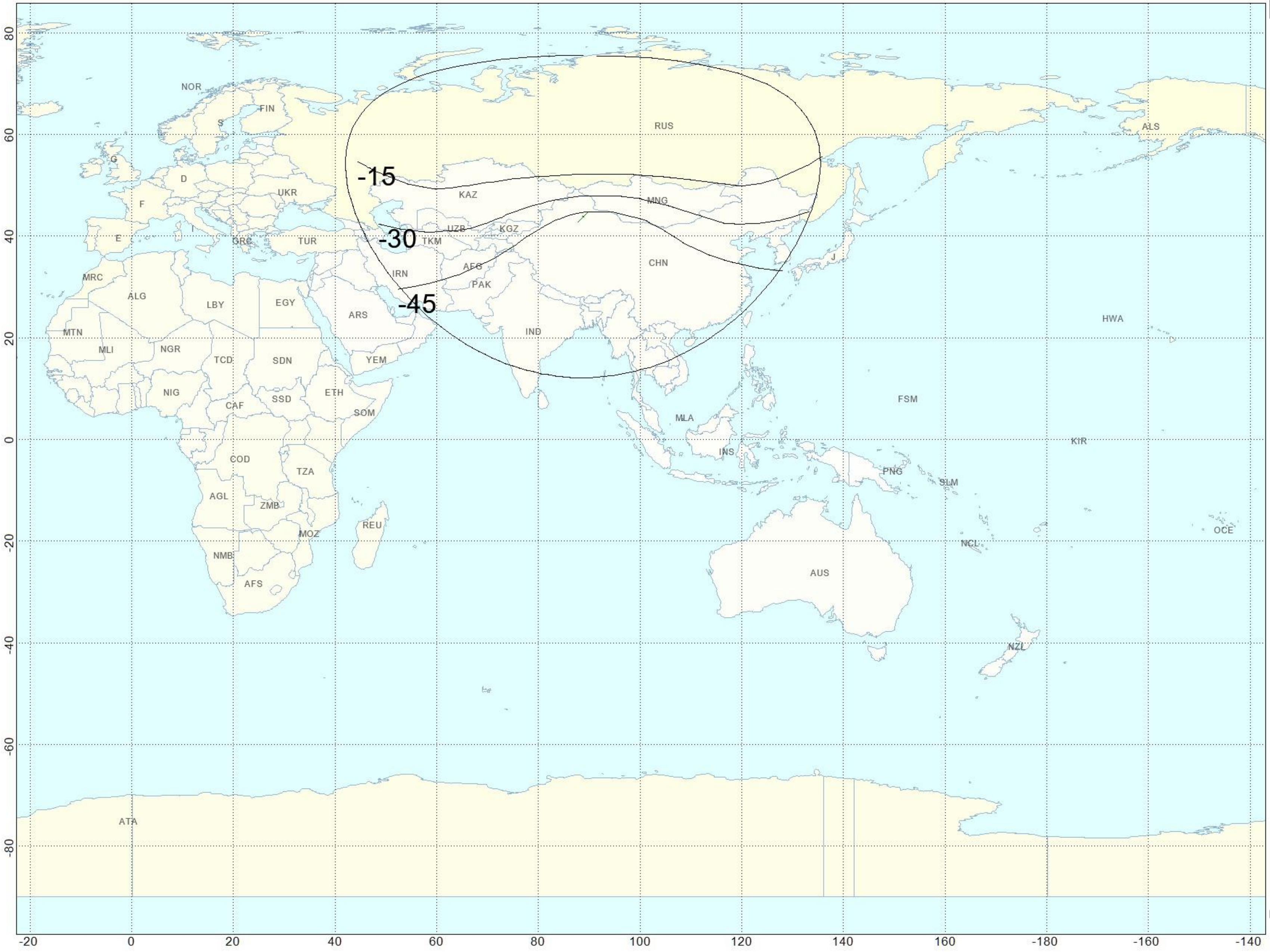
Alpha angle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Alpha angle – exclusion zone

Defined at notice level to describe exclusion zone towards GSO arc

Two parameters

- Type of exclusion zone ***f_x_zone***
  Earth-station based angle – alpha angle and
  Satellite-based angle – X angle
- Exclusion zone angle ***x_zone*** α_0 :
  - Is not a width, the width will be: $[-\alpha_0; \alpha_0]$

The use of Alpha angle

Type of calculation	Restrict transmission inside exclusion zone	Should be modelled and included inside the mask	Used to vary simulation timestep
EPFDdown	**No !**	**Yes**	**Yes**
EPFDup	**Yes**	**No**	**Yes**
EPFDis	**No**	**Yes**	**Yes**

Concept of the “mask”

To compute *EPFDdown*, the methodology employs «**PFD masks**» provided by the notifying administration. These PFD masks represent the maximum PFD each NGSO satellite could produce when operating at maximum power in the worst-case beam configuration. Methodology assumes that at each time step all the NGSO satellites contributing to interference operate at this maximum level. Runs of simulations of the NGSO constellation are used to compute the EPFDdown statistics at a GSO earth station located at a worst-case point on the Earth.

To compute *EPFDup*, the methodology employs «**EIRP masks**» again provided by the notifying administration. The EIRP masks represent the maximum EIRP each NGSO earth station could produce, as a function of the off-axis angle from the transmitting antenna main beam. Using the EIRP masks to represent the emissions of the earth stations and the density of NGSO earth stations, the methodology established simulation of the NGSO constellation to compute the EPFDup statistics generated by the system.

To compute *EPFDis*, the methodology employs «**inter-satellite EIRP masks**» based on the same concepts as the other masks.

Concept of the “mask”

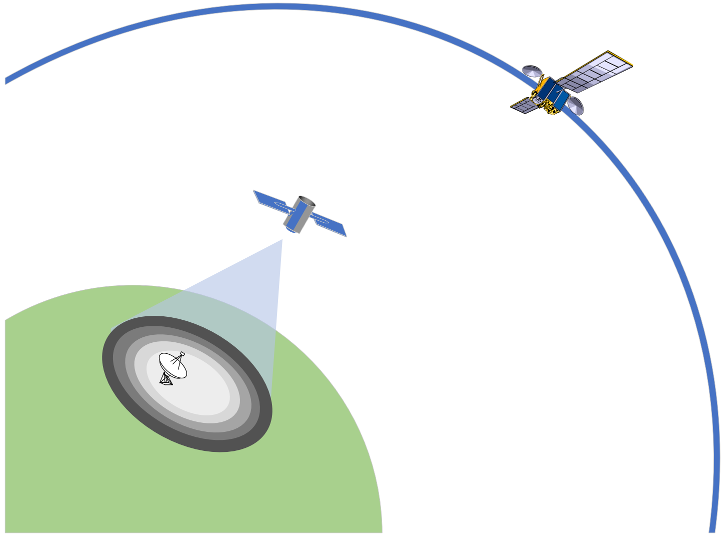
Defines non-GSO station transmission “footprint”

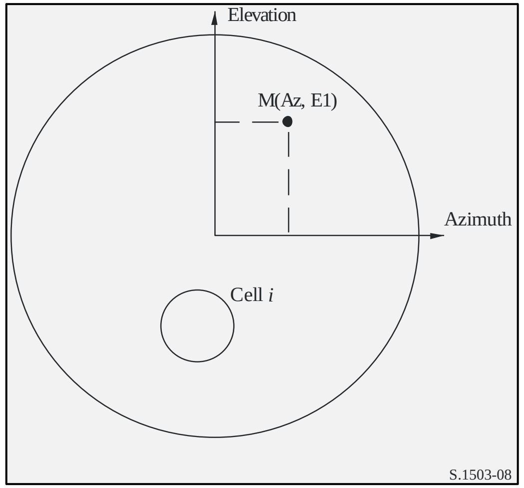
- For transmitting non-GSO earth station in form of eirp and off-axis eirp mask
- For transmitting non-GSO satellite in form of pfd-mask given either in:
  - azimuth-elevation satellite-based coordinate system or
  - relative to GSO arc (alphaAngl)
- For transmitting non-GSO satellite in bi-directional frequency bands in form of eirp and off-axis eirp mask

Masks are presented in XML-format and embedded in MS Access .MDB container

- https://www.itu.int/ITU-R/go/space-mask-XMLfile/en

Not included in BR IFIC SRS database





PFD Mask used in *EPFDdown*

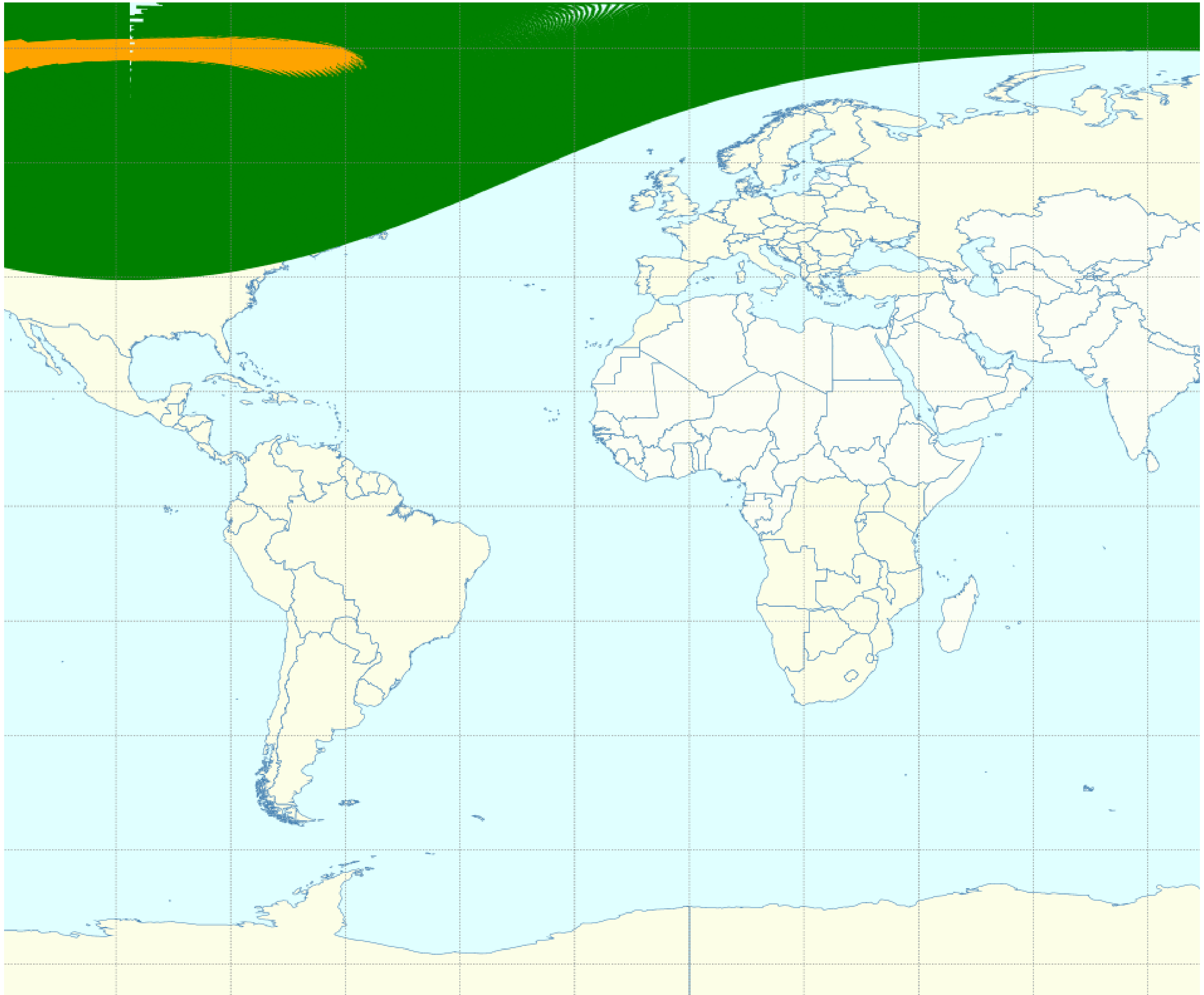
Its definition is based on consideration:

- Mitigation techniques used towards GSO receiving stations (beam switching)
- Multi-beam use
- Variation of transmission per sub-satellite latitude
- Minimum elevation angle to provide service
- Beam antenna pattern

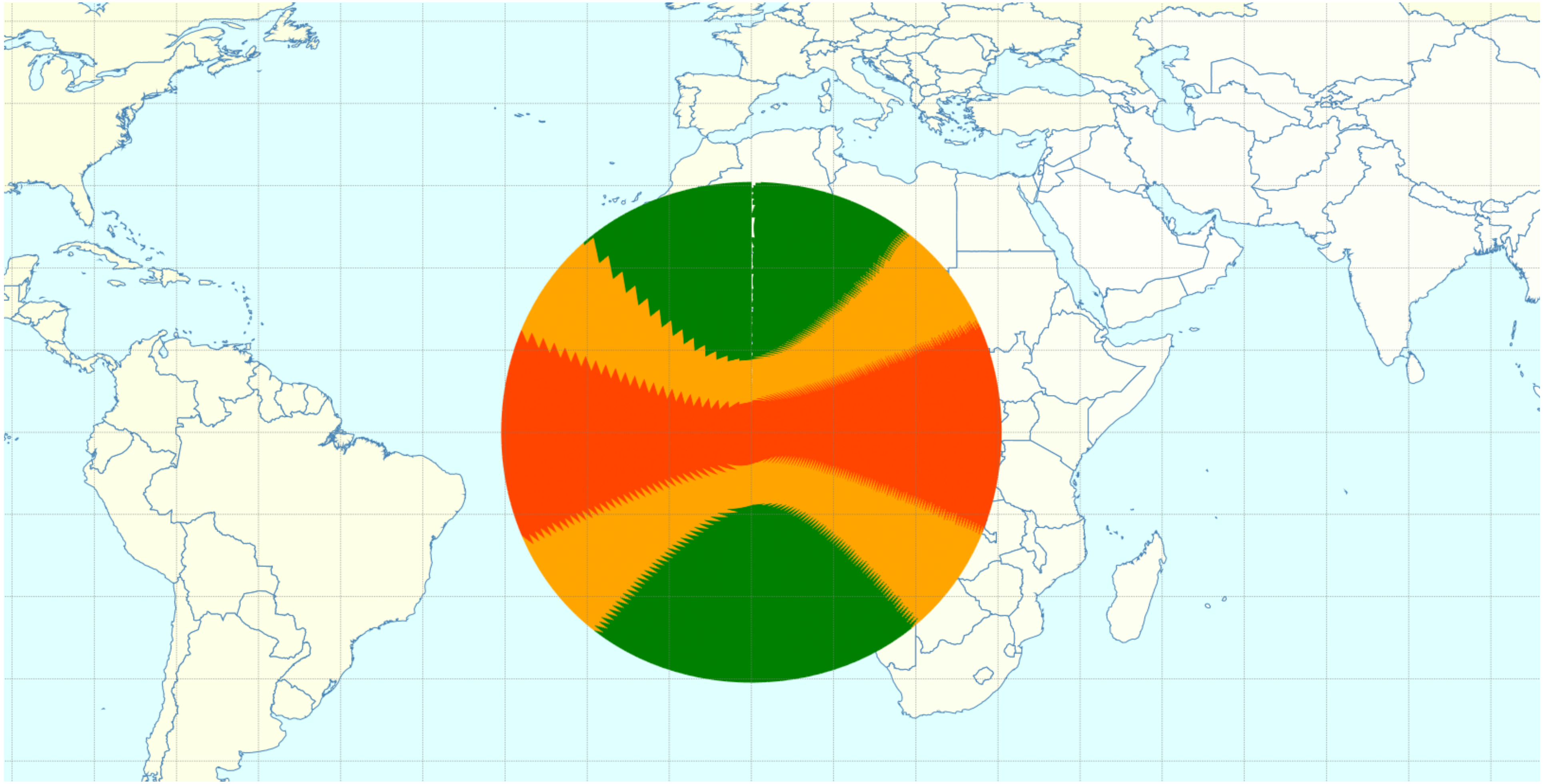
Provided for each frequency band subject to EPFD

Can have several different PFD-masks assigned to specific orbital planes or even satellites

Exclusion zone is defined in the mask



Red zone (low transmission level) is 20 degrees



PFD Masks formats

PFD Mask can take a form of:

PFD as a function of

– azimuth and elevation angles from a non-GSO space station towards a point on the Earth

or

PFD as a function of

– the separation angle α between a non-GSO space station and the GSO arc, as seen from any point on the surface of the Earth

– the difference Δ L in longitude between the non-GSO sub-satellite point and the point on the GSO arc where the α angle is minimized

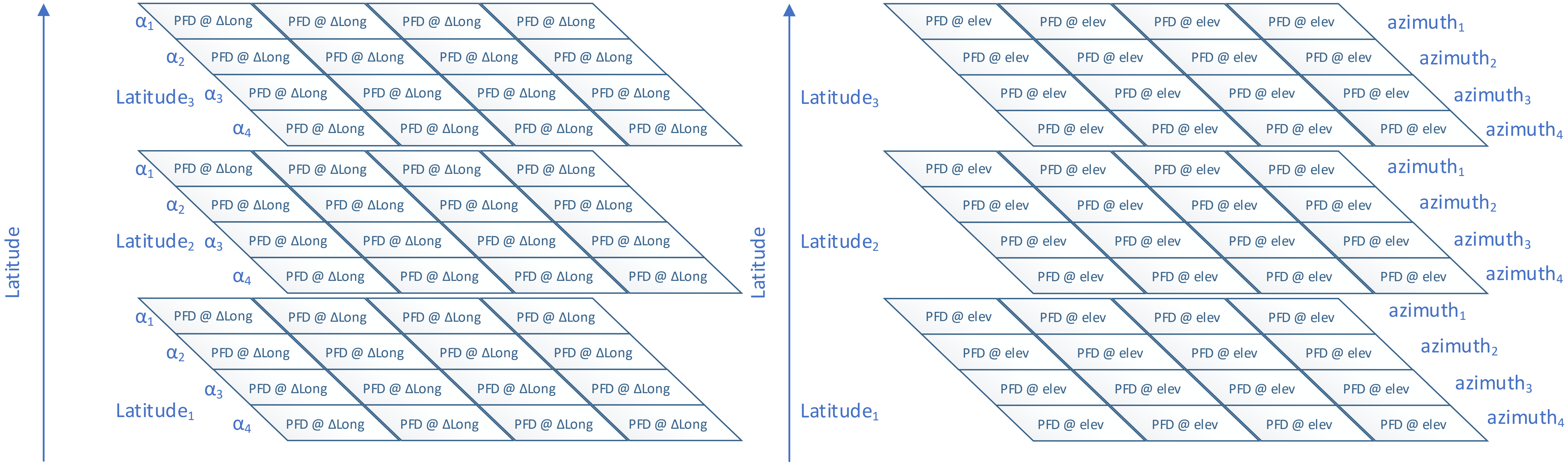
(α, ΔL) PFD Mask is used together with exclusion zone angle α supplied separately from the mask

Highest level of hierarchy is a latitude

Each latitude table may have its own dimensions (range of azimuth/elevations or alpha/deltaLongitudes

Recommendation ITU-R S.1503

PFD Masks formats



PFD Masks formats


```
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<pfd_mask a_name="latitude" b_name="azimuth" c_name="elevation" high_freq_mhz="20200" low_freq_mhz="19700" refbw_khz="40" mask_id="1" type="azimuth_elevation">
<by_a a = "0">
        <by_b       b="-59.8">
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                <pfd        c="-1.3">-141.22</pfd>
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                <pfd        c="1.7">-141.3</pfd>
                <pfd        c="2">-141.33</pfd>
        </by_b>
        ....
```

Defining mask

Choosing the format:

- α–deltaLongitude is less latitude dependent than AzEl
- AzEl is better for representation and understanding

Make sure that mask covers all ranges of latitudes, azimuth/elevation, alpha/deltaLongitude

It is a dangerous approach to provide data only for specific latitude and geometry where WCG is occurring – EPFD should be met everywhere

Exception, If same values are applicable to all latitudes of SSP provide only latitude=0 tables

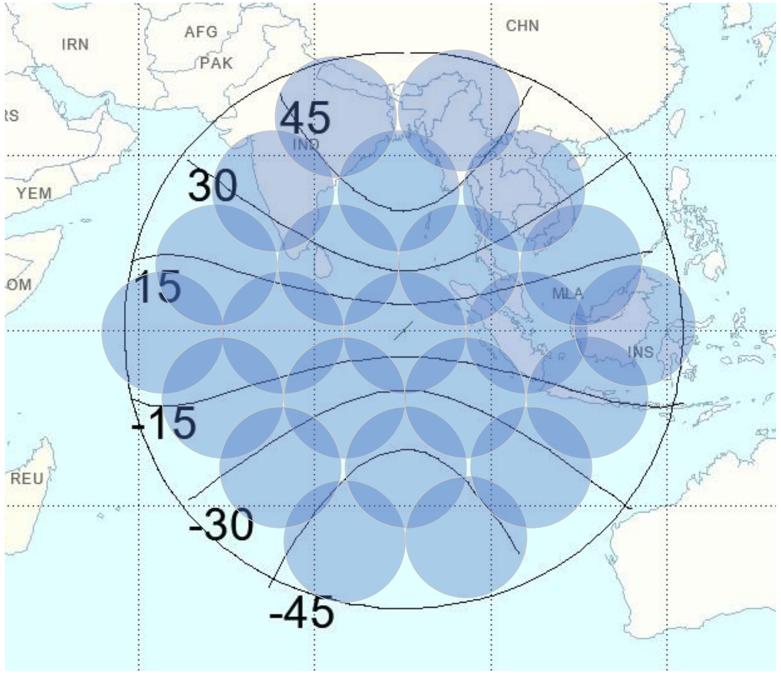
If appropriate mask is given but EPFD is still exceeded, consider increasing sampling of latitude, azimuth/elevation

For latitude, azimuth/elevation identified in EPFD software in a calculation step, which can not be found in the mask, the software would use closest tables in the mask

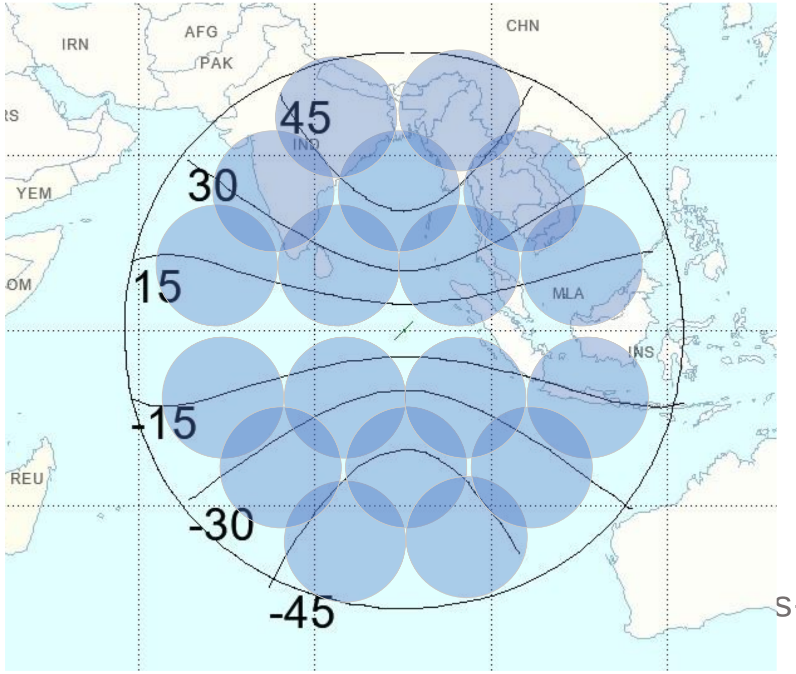
Defining mask - approaches

Approach 1 - Defining mask using operational system characteristics

- Most adequate approach
- Is normally based on submitted characteristics of transmitting emissions
- Mask will resemble real use of spectrum by the system
- Its definition is based on the understanding how any GSO will be protected
- Described in section ***C2.4***



Switching off beams inside GSO exclusion zone



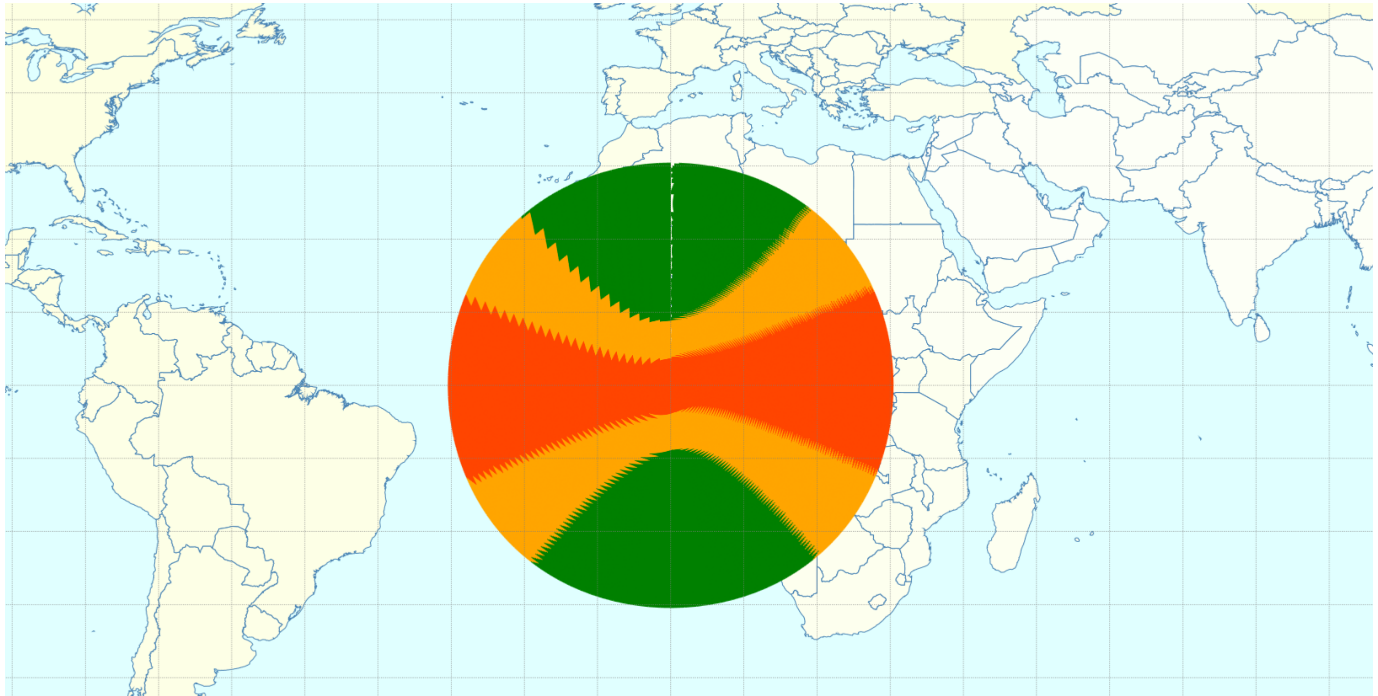
Defining mask - approaches

Approach 2 – Define maximum envelope which meets EPFD limit (reversing the limit)

May not reflect real use and filed transmitting characteristics

Understanding is missing how GSO will be protected in practice

Even though the mask is not required for the coordination, during the coordination question may be raised whether such mask is implementable

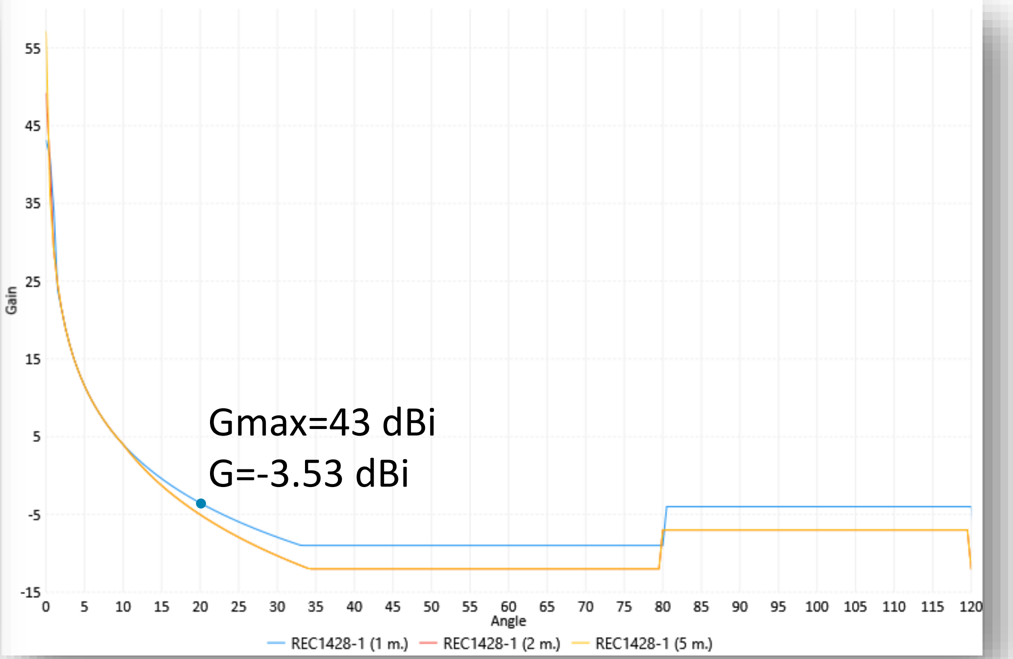


Defining mask – example maximum PFD calculation

TABLE 22-1B (WRC-03)

Limits to the epfd↓ radiated by non-geostationary-satellite systems in the fixed-satellite service in certain frequency bands[3, 6, 8]

Frequency band (GHz)	epfd↓ (dB(W/m²))	Percentage of time during which epfd↓ may not be exceeded	Reference bandwidth (kHz)	Reference antenna diameter and reference radiation pattern[7]
17.8-18.6	−175.4 −175.4 −172.5 −167 −164 −164	0 90 99 99.714 99.971 100	40	1 m Recommendation ITU-R S.1428-1
	−161.4 −161.4 −158.5 −153 −150 −150	0 90 99 99.714 99.971 100	1 000	
	−178.4 −178.4 −171.4 −170.5 −166 −164 −164	0 99.4 99.9 99.913 99.971 99.977 100	40	2 m Recommendation ITU-R S.1428-1
	−164.4 −164.4 −157.4 −156.5 −152 −150 −150	0 99.4 99.9 99.913 99.971 99.977 100	1 000	
	−185.4 −185.4 −180 −180 −172 −164 −164	0 99.8 99.8 99.943 99.943 99.998 100	40	5 m Recommendation ITU-R S.1428-1
	−171.4 −171.4 −166 −166 −158 −150 −150	0 99.8 99.8 99.943 99.943 99.998 100	1 000	



$$PFD = EPFD_{limit} - G_{max} + G_r - 10\log(N_{co}) = -164 - 43 - 3.53 - 10\log(1) = -117.5\,\frac{\mathrm{dB}}{\mathrm{W}\,m^2}\,(40\ \mathrm{kHz})$$

Other parameters used in *EPFDdown*

α – GSO exclusion zone angle (arc avoidance angle)

f_x_zone, **x_zone**

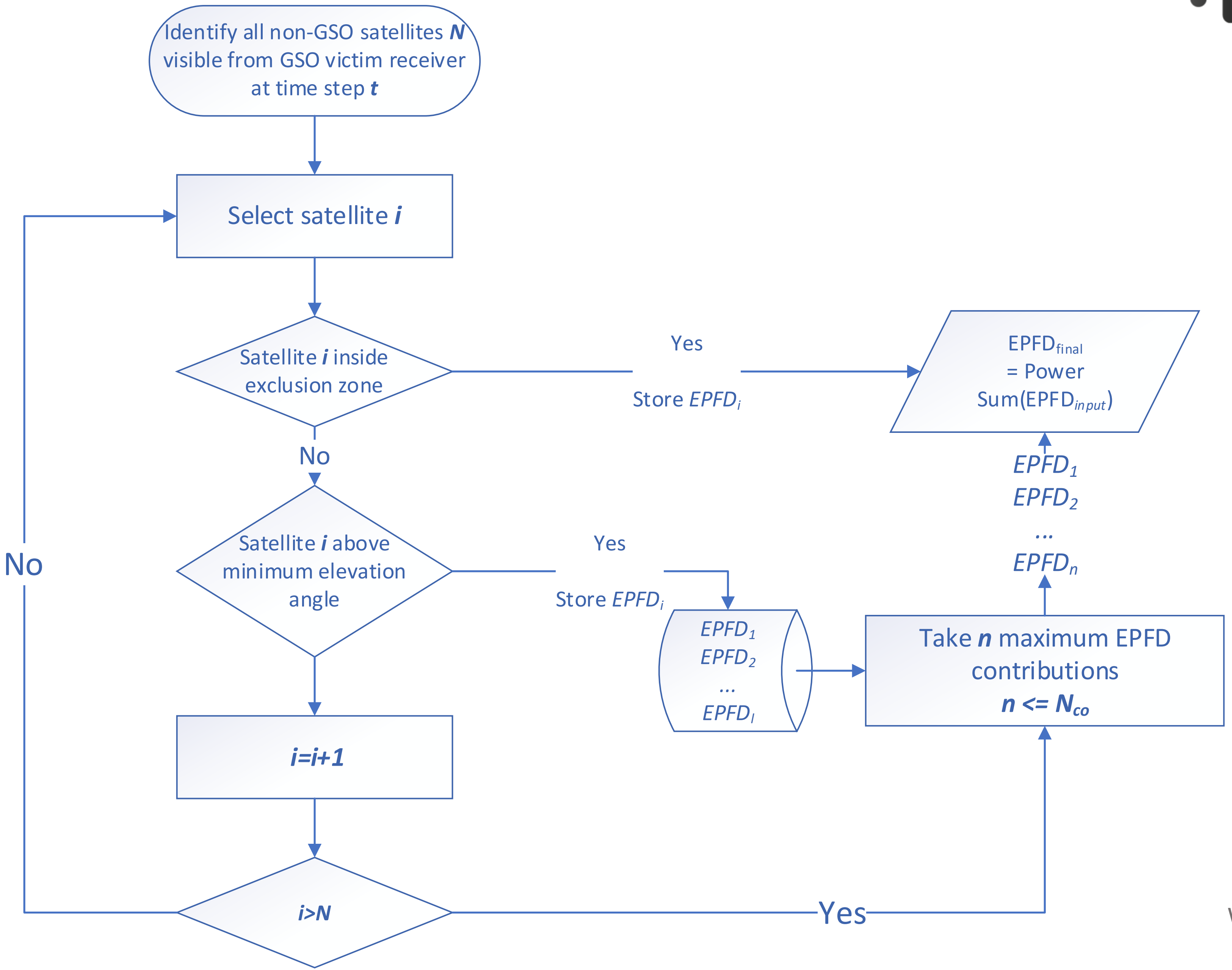
ε - minimum elevation angle – minimum elevation angle from non-GSO earth station at which transmission occurs from any non-GSO space station

elev_min

N_{co} - maximum number of co-frequency satellites providing simultaneous co-located service

sat_oper table

These parameters will control the number of contributions in $\boldsymbol{EPFD_{final}}$


Identify all non-GSO satellites ***N*** visible from GSO victim receiver at time step ***t***
Select satellite ***i***
Satellite ***i*** inside exclusion zone
Yes
Store $EPFD_i$
$EPFD_{final}$ = Power Sum($EPFD_{input}$)
No
Satellite ***i*** above minimum elevation angle
Yes
Store $EPFD_i$
$EPFD_1$
$EPFD_2$
...
$EPFD_l$
Take ***n*** maximum EPFD contributions
$n <= N_{co}$
$EPFD_1$
$EPFD_2$
...
$EPFD_n$
No
$i=i+1$
$i>N$
Yes

EIRP Mask used in *EPFDup*

the mask pattern defined in terms of the power in the reference bandwidth for a series of off-axis angles with respect to a specified reference point" (A.14.b.6)

EIRP mask defines maximum radiated power by any non-GSO earth station

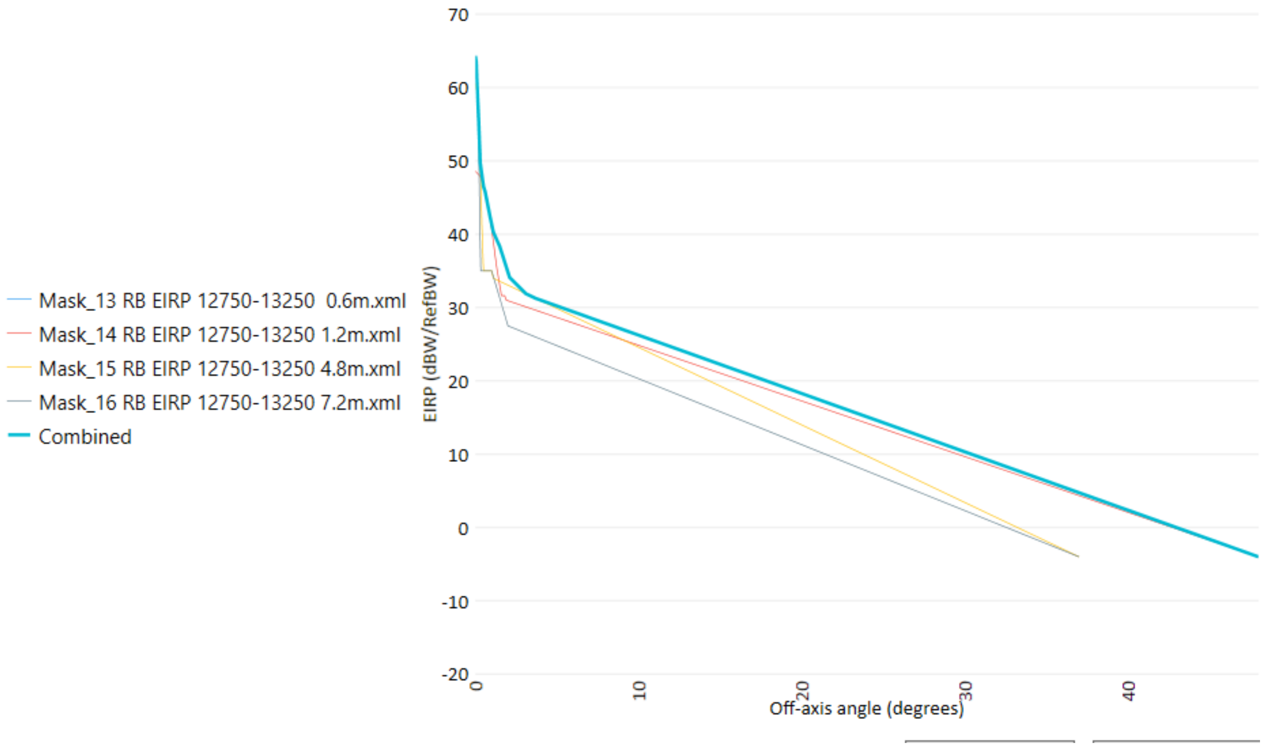
If single ES is considered, the EIRP mask is representing EIRP + antenna gain pattern:

$$EIRP = P_{tx} + G(\varphi)$$

Different earth stations with different antennas to be operated in the same band?

Need to be presented by single EIRP mask.

This single mask should be presented as a combination (envelope) of all EIRP/gain functions from all earth stations:



EPFDup

Important parameters used to represent population of earth stations:

For Uplink,

The average distance on the Earth's surface between co-frequency beams (*d*) from the non-GSO system (km) and density of co-frequency non-GSO ES *(Density)*

Used to derive the number of earth stations operating within GSO footprint defined at -15 dB level. Number of ES within co-frequency beam:

$$NUM\_ES = d * d * Density$$

EIRP of representative ES:

$$REP\_e.i.r.p. = ES\_e.i.r.p. + 10\log10\ (NUM\_ES)$$

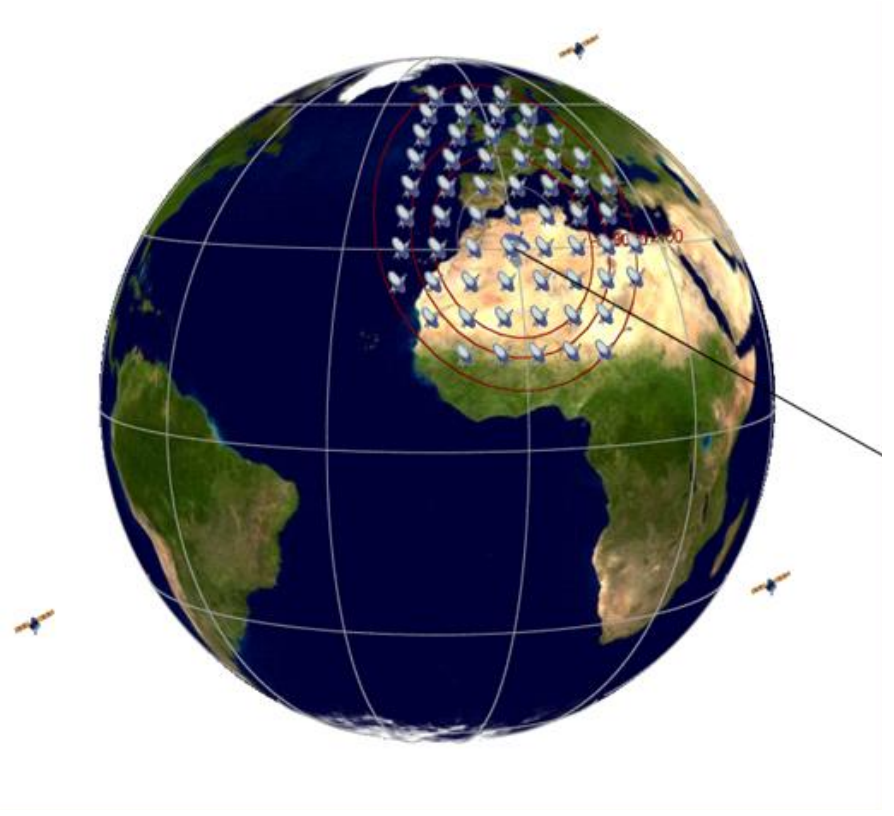
Defined in fields **avg_dist** and **density**

EPFDup

Representative ES are then populated within GSO beam footprint with separation in longitude and latitude:

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

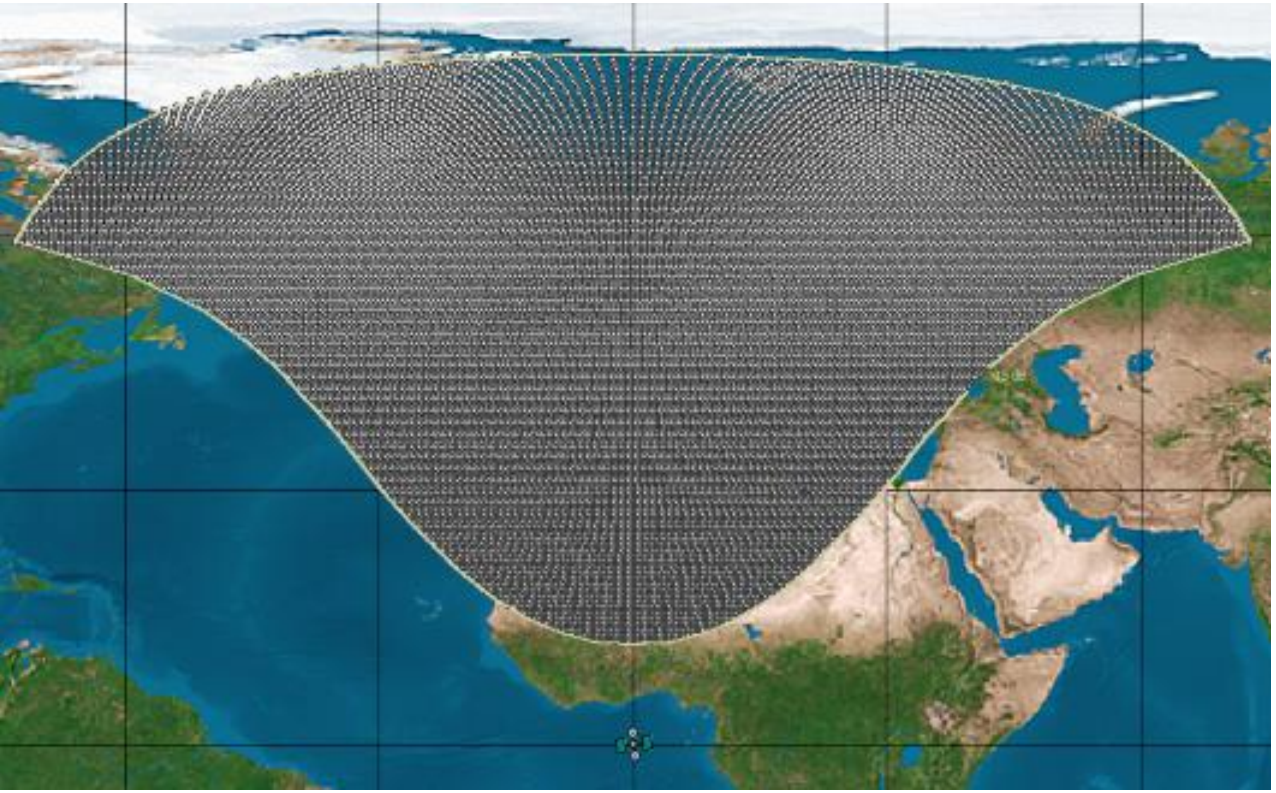
$$\Delta long = \frac{d}{R_e \cos lat}$$



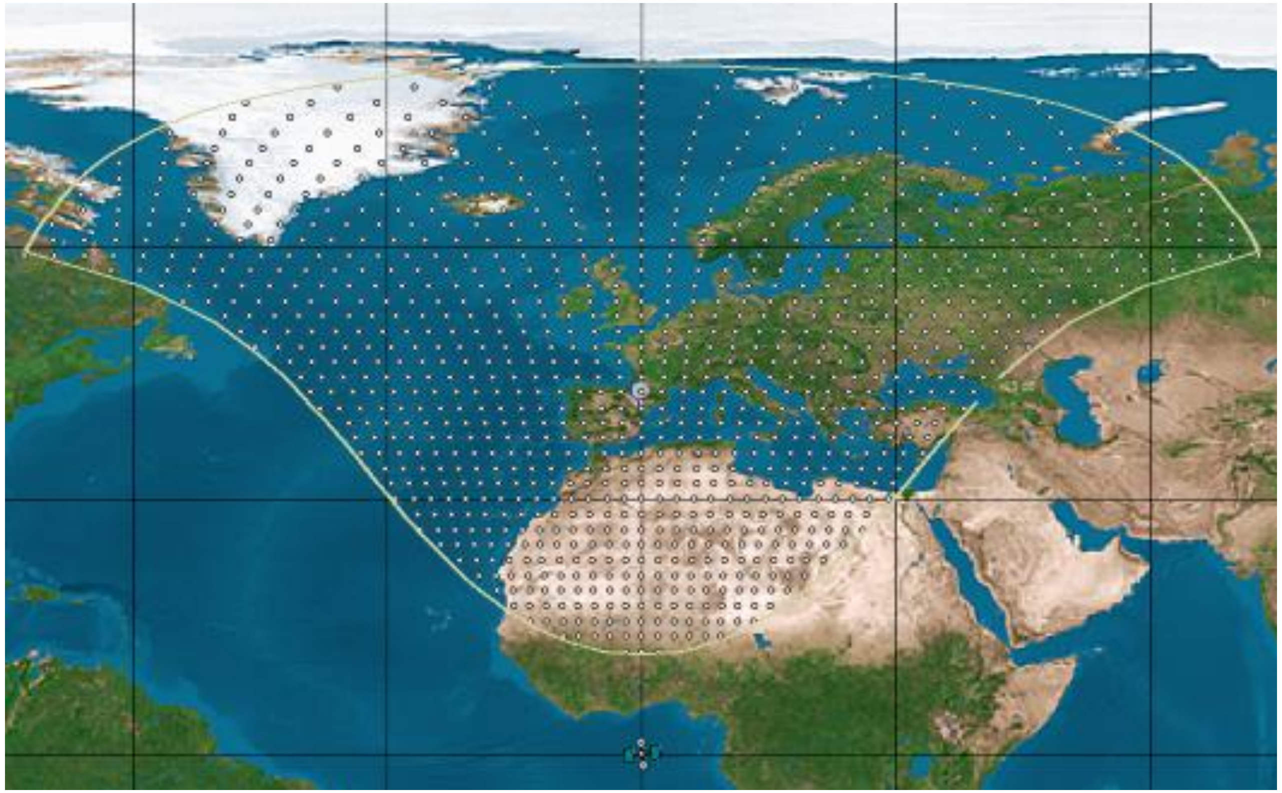
S.1503-39

EPFDup

avg_dist=40 km



avg_dist=200 km



Other parameters used in *EPFDup*

α – GSO exclusion zone angle (arc avoidance angle)

f_x_zone, **x_zone**

ε - minimum elevation angle – minimum elevation angle from non-GSO earth station at which transmission occurs from any non-GSO space station

elev_min

N_{co} - maximum number of co-frequency tracked earth stations

nbr_sat_td

These parameters will control the number of contributions in $\boldsymbol{EPFD_{final}}$

EIRP Mask format


```
<?xml version="1.0" encoding="utf-8"?>
<satellite_system ntc_id="104" sat_name="NSKY">
  <eirp_mask_es mask_id="2" low_freq_mhz="27600" high_freq_mhz="28500" refbw_khz="40" min_elev="5" a_name="latitude" d_name="separation angle" ES_ID="-1">
    <by_a a="45">
      <eirp d="6">-4.73</eirp>
      <eirp d="8">-7.85</eirp>
      <eirp d="10">-10.27</eirp>
      <eirp d="12">-12.25</eirp>
      <eirp d="14">-13.93</eirp>
      <eirp d="16">-15.38</eirp>
      <eirp d="18">-16.66</eirp>
      <eirp d="20">-17.81</eirp>
      <eirp d="25">-20.22</eirp>
      <eirp d="30">-22.21</eirp>
      <eirp d="35">-23.88</eirp>
      <eirp d="40">-24.27</eirp>
      <eirp d="45">-24.27</eirp>
      <eirp d="50">-24.27</eirp>
      <eirp d="60">-24.27</eirp>
      <eirp d="70">-24.27</eirp>
      <eirp d="80">-24.27</eirp>
      <eirp d="90">-24.27</eirp>
      <eirp d="100">-24.27</eirp>
      …
```

EIRP Mask used in *EPFDis*

the mask pattern defined in terms of the power in the reference bandwidth for a series of off axis angles with respect to a specified reference point (A.14.a.4)

EIRP mask defines maximum radiated power by any non-GSO earth station towards GSO arc

The reference point is nadir (sub-satellite point)


```
<?xml version="1.0" encoding="utf-8"?>
<satellite_system ntc_id=“104" sat_name=“NSKY">
  <eirp_mask_ss mask_id=“1" low_freq_mhz="17800" high_freq_mhz="18400" a_name="latitude" d_name="separation angle">
    <by_a a="0">
      <eirp d="40">-35.0</eirp>
      <eirp d="45">-37.5</eirp>
      <eirp d="50">-37.5</eirp>
      <eirp d="55">-37.5</eirp>
      <eirp d="60">-37.5</eirp>
      <eirp d="65">-37.5</eirp>
      <eirp d="70">-37.5</eirp>
      <eirp d="75">-37.5</eirp>
      <eirp d="80">-37.5</eirp>
```

Worst Case Geometry

The purpose of “Worst Case Geometry” (WCG) algorithm is to identify victim GSO-link geometry which may receive the highest single entry EPFD value

Following parameters are identified:

- GSO Earth Station Longitude and Latitude
- GSO Space Station Longitude

The criteria for the geometry to be selected as the worst-case:

- It produces highest EPFD-level (i.e. short-term)
- Angular speed and elevation angle are also considered

No identification is based on long-term:

- Long-term interference is depending upon the constellation geometry and operating characteristics => it is difficult to define an algorithm that identifies other points on the EPFD CDF without doing a full simulation
- The long-term EPFD is more driven by aggregation effects than the short-term, hence again is hard to calculate without doing a full simulation
- The long-term EPFD is assessed not in isolation (i.e. what is the highest EPFD) but compared to a threshold in Article 22 that varies by percentage of time, so again is hard to assess what is worst without a full simulation

Orbital elements

1. Inclination of orbit
2. Apogee/perigee, eccentricity
3. Right ascension of ascending node and/or longitude of ascending node
4. Phase angle of the satellite within its orbital plane (mean anomaly)
5. Argument of perigee

New capturing model as of 1st January 2025

Background

- A single system may require several different sets of parameters to describe the system operation. For example:

Mode of operation	Spectrum requirements	Elevation angle	Nco	Earth station population density
Telecommand, telemetry and control links	Low	Low	Low	Extremely low
User links	Medium	High	Low/Medium	High
Gateway links	High	High	High	Low

- Such parameters like exclusion zone angle, Nco, Earth Station density are defined at notice level (means only one value for each parameter can be recorded in the notice)
- Thus, it is not possible to capture all modes of operation in a single notice database
- Existing solution was to provide one database (for examination only) for each mode of operation.

New capturing model as of 1st January 2025

New SNS v10 Structure

- Additional tables are added ***epfd_param*** and ***epfd_freq***
- ***epfd_param*** will contain all parameters required to define a mode of operation described as **Scenario**
- There could be several scenarios within one single submission. These scenarios are captured in **SpaceCap**
- Same rule is applicable as before - no frequency overlap between scenarios

Scenario	Mode of operation	Frequency bands
Scenario 1 “TT&C”	Telecommand, telemetry and control links	↑ 12.5-12.75 GHz
Scenario 2 “User”	User links	↓ 10.7-11. 7 GHz ↑ 13.75-14.5 GHz
Scenario 3 “Gateway”	Gateway links	↓ 17.8-18.6 GHz ↓ 19.7-20.2 GHz ↑ 27.5-28.6 GHz ↑ 29.5-30 GHz

New capturing model as of 1st January 2025

Advantages

- Parameters for all modes of operation are captured immediately in **SpaceCap** and validated for their completeness at the time of initial submission
- The notice is self-contained and related information is easily extracted from the notice
- No need for several examination database (pending development of new EPFD Validation Software which can read new tables)
- No need for the Bureau to interpret paper notes, separate databases and files to start examination

Follow additional guidelines to be posted at www.itu.int/epfdsupport

Additional slides

How EPFD limits were derived?

GSO protection criteria

Collecting the data for GSO representative links and factors to be considered in link budget

Defining aggregate EPFD limits

Defining single-entry EPFD limits

GSO protection criteria used – Short-term criteria

Recommendation ITU-R S.1323, the aggregate interference from all non-GSO FSS systems sharing frequencies with a GSO link should not

> 3.1 be responsible for at most 10% of the time allowance for the BER (or C/N value) specified in the short-term performance objectives of the desired network and corresponding to the shortest percentage of time (lowest C/N value);

Example:

If a GSO link has a required availability of 99.5%, its corresponding unavailability is

100 - 99.5% = 0.5%, or about 263 minutes per year.

This means that the non-GSO systems are allowed to create 263 * 0.1 = 26.3 minutes of unavailability on this link per year.

If the GSO operator specifies an availability of 99.999%, the non-GSO system can cause only 0.52 minute of unavailability per year.

GSO protection criteria used – Short-term criteria

Loss of synchronization:

High interference level could cause loss of synchronization of the link which can in result increase significantly unavailability time.

Based on measurements for sync-loss thresholds for systems with data rates less than 34 Mbits/sec, the ITU-R agreed that the following sync-loss thresholds need to be considered when determining EPFD levels that should not be exceeded:

Modulation and coding	C/(N+I) (dB)
QPSK rate 7/8	6.0
QPSK rate 3/4	5.3
QPSK rate 1/2	3.5
8-PSK	8.1
16-QAM	11.0

GSO protection criteria used – Long-term criteria

Recommendation ITU-R S.1323:

that this allowance corresponding to long-term interference, when used in addition to recommends 3, 4, 5 and 6, should be expressed by requiring that the aggregate interference should not exceed 6% of the total system noise power for more than 10% of the time

Defining aggregate EPFD limits

The studies within ITU-R have agreed to use methodology D to meet ITU-R S 1323 Recommendation objectives (10% criterion and sync loss criterion) using CR/92 and CR/116 database as verification criteria. This methodology is also conservative.

This methodology compares the performance of a GSO link with and without the non-GSO environment created by a set of limits. Then, it computes whether the relative degradation increase is higher than 10%

- this method tends to reduce the number of fading sources that affect the GSO link performance to one which is the rain fade
- the CR/92 and CR/116 database which methodology encompass very sensitive GSO links have been used to derive the EPFD limits.

Input: GSO FSS link parameters

1-1-1 : Ku band transparent (Annex 2 format)	
Carrier Number	2
ADMINISTRATION	**XYZ**
JTG4-9-11 Document Number	
GEOSTATIONARY NETWORK	**XYZ SCPC**
PERFORMANCE OBJECTIVES	
Threshold #1 (N/A for not applicable): C/(N+I) (dB)	10
% of the year C/(N+I) should be exceeded	95
Threshold #1 (N/A for not applicable): C/(N+I) (dB)	7.2
% of the year C/(N+I) should be exceeded	99.95
Threshold #1 (N/A for not applicable): C/(N+I) (dB)	2.5
% of the year C/(N+I) should be exceeded	99.99
WAVEFORM DESCRIPTION	
Access type (TDMA, CDMA, FDMA,...)	FDMA
Modulation type (e.g. FM, QPSK, BPSK)	FM
Noise bandwidth per carrier (kHz)	30
TRANSMIT EARTH STATION CHARACTERISTICS	
Altitude (km)	0
Latitude (+: North, -: South) from Equator (degrees)	-33.9
Elevation angle (degrees)	50
Temperature at ground level (¡ãC)	25
Relative humidity (%)	80
Rain model (ITU/Crane)	ITU
Rain zone (as per rain model)	P
Rain fall rate exceeded for 0.01% of an average year (mm/h) if available	N/A
On-axis Earth station transmit e.i.r.p. (dBW)	53.5
Antenna pointing loss towards the geostationary satellite (dB)	0.5
Inter modulation earth stations C/I (dB)	28
Power control range (>0, 0 dB if none) (dB)	10
Power control accuracy (applicable only if up link power control used) (dB)	2
Polarisation isolation (C/I of wanted to unwanted polarisation) (dB)	28
RECEIVE EARTH STATION CHARACTERISTICS	
Altitude (km)	0
Latitude (+: North, -: South) from Equator (degrees)	-37.8
Temperature at ground level (¡ãC)	43.1
Relative humidity (%)	20
Elevation angle (degrees)	60
Rain zone (as per rain model)	L
Rain fall rate exceeded for 0.01% of an average year (mm/h) if available	42
Earth station receive noise temperature (K)	250
On-axis antenna gain (dBi)	53.4
Antenna diameter(m)	4.6
Antenna pointing loss (dB)	1
Polarisation isolation (C/I of wanted to unwanted polarisation) (dB)	30

SPACE STATION RECEIVE CHARACTERISTICS	
Transponder bandwidth (MHz)	54
Receive frequency (GHz)	14.25
Receive polarisation (H: horizontal, V: Vertical, C: Circular)	H
Automatic level control range (0 if none) (dB)	10
Peak receive antenna gain (dBi)	32.1
Receive satellite antenna gain in the direction of transmit earth station (dBi)	30.1
Satellite receive temperature (K)	900
Receive cross-polarisation isolation (C/I ratio, 100 if not applicable) (dB)	30
Receive frequency re-use isolation (C/I ratio, 100 if not applicable) (dB)	30
Transponder total input back-off (dB)	8
SPACE STATION TRANSMIT CHARACTERISTICS	
Transmit frequency (GHz)	12.502
Transmit polarisation (H: horizontal, V: Vertical, C: Circular)	V
Transponder total output back-off (dB)	4
Satellite e.i.r.p. in the direction of the receive earth station (dBW)	24.7
Transmit cross-polarisation isolation (C/I ratio, 100 if not applicable) (dB)	30
Transmit frequency re-use isolation (C/I ratio, 100 if not applicable) (dB)	30
Transparent/remodulating transponder	Transparent
Satellite adjacent transponder isolation (dB)	28
Transponder inter modulation C/I(dB)	20
INTERFERENCE FROM OTHER GSO NETWORKS AND TERRESTRIAL SERVICES	
Up link clear-sky C/I due to other geostationary networks (dB)	22
Up link clear-sky C/I due to sharing with fixed service (dB) (100 dB if no sharing)	100
Down link clear-sky C/I due to other geostationary networks (dB)	31.9
Down link clear-sky C/I due to sharing with fixed services (dB) (100 dB if no sharing)	100

Input: EPFD mask

		Not to exceed value (dBW/m2/4kHz)	Percentage of time (% of an average year)	
	apfd : mask	-1000	100	
	1			
	4			
	epfd : mask	-178.5	0	<- constraint n°1
number of lines ->	**8**	-176.5	33	<- constraint n°2
reference bandwidth (kHz) ->	**4**	-174.5	66	<- constraint n°3
comment (if desired) ->	**My comment**	-171.5	97	
		-171.5	97	
		-171	98.5	
		-170.1	99.5	
		-170	100	<- constraint n°i

Result

Carrier Name / Number	2		
epfd mask used	My comment		
Sampling step	0.05		
Required performances	**#1**	**#2**	**#3**
total link C/(N+I) (dB)	10	7.2	2.5
availability (%)	95	99.95	99.99
Calculated performances	**#1**	**#2**	**#3**
C/(N+I) (dB)	10	7.2	2.5
availability without ngso's (%)	99.92862	99.95084	99.97102
availability with ngso's (%)	99.92781	99.95058	99.971
	0.07138	0.04916	0.02898
	0.07219	0.04942	0.029
Increase (%)	**1.134771645**	**0.528885273**	**0.069013112**

Defining single-entry limit

The process is to convert aggregate-limit mask into single-entry mask limit applicable to a single non-GSO FSS

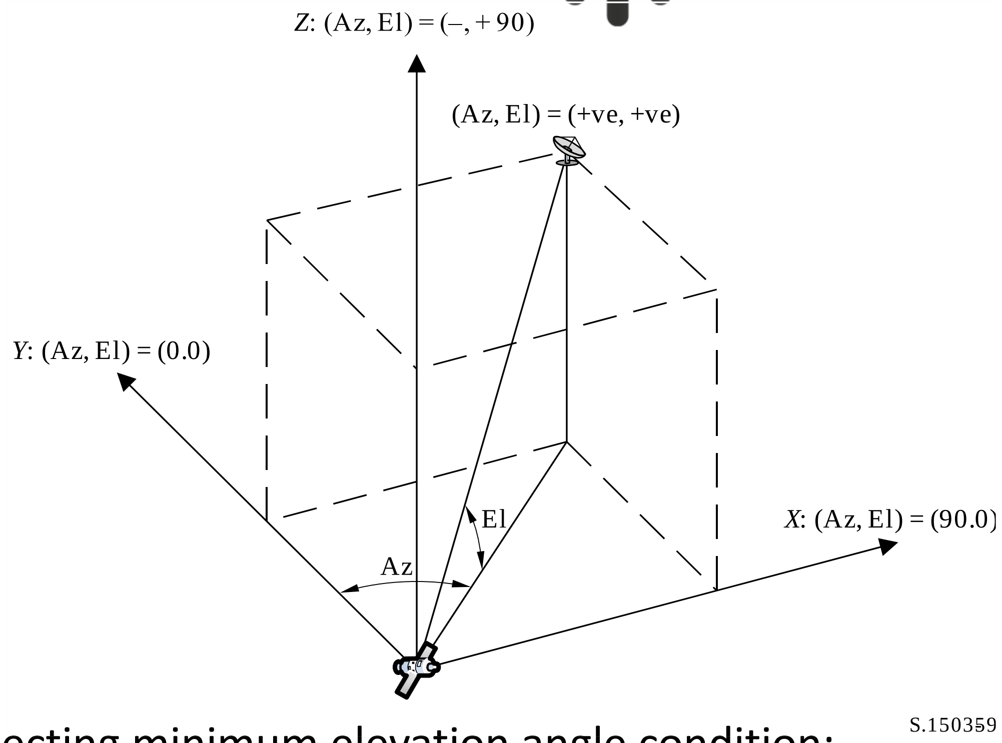
Key parameter is maximum effective number of non-GSO FSS systems able to share the same frequency band, ***Neffective***=3.5

Conversion principles:

- Short term: apportion in time
- Long term: apportion in power

Resolution **76** is adopted to ensure that aggregate EPFD limits are met

Generation of the mask – coordinate system



Example of the simple approach

- Define input requirements:
  - Minimum elevation angle to provide service
  - Required width of exclusion zone
  - Additional attenuation contours
- Orbit simulation or static calculation
- For each latitude of sub-satellite point
  - Place non-GSO satellite at given latitude ***L***
  - Init pfd-table $\boldsymbol{PFD_L}$ for latitude ***L***
  - For each pointing of antenna inside non-GSO footprint respecting minimum elevation angle condition:
    - Identify whether antenna is pointed inside exclusion zone, if yes, continue with another antenna pointing
    - Calculate pfd beam footprint given current antenna pointing for each grid-point inside non-GSO footprint
    - Add pfd-values from beam footprint to $\boldsymbol{PFD_L}$ if pfd-value is larger than the one already in $\boldsymbol{PFD_L}$
  - Record $\boldsymbol{PFD_L}$ table in alpha/deltaLongitude or azimuth/Elevation coordinate system (see next slide).

- Generate the mask using pfd-tables for different latitudes ($\boldsymbol{PFD_1}$, $\boldsymbol{PFD_2}$, $\boldsymbol{PFD_3}$ etc.)

Generation of Azimuth Elevation mask

Inputs:

- Position of the non-GSO satellite described by its sub-satellite coordinates $\boldsymbol{Lon_{SSP}}, \boldsymbol{Lat_{SSP}}$ and orbit height $\boldsymbol{h}$
- PFD-mask is longitude independent so assume $\boldsymbol{Lon_{SSP}}$=0
- GSO exclusion zone (angle and required attenuation)

Steps:

For each target point within non-GSO footprint (*Lon, Lat*) calculate Azimuth and Elevation to target point:

To compute spacecraft viewing angles given the sub-satellite point at Lon_{SSP}, Lat_{SSP} and target point at *Lon, Lat*, and $\Delta L = |Lon_{SSP} - Lon|$:

Angular distance to target point from subsatellite point (great-circle distance) $\cos\lambda = \sin Lat_{SSP}\ \sin Lat + \cos Lat_{SSP} \cos Lat\ \cos \Delta L \quad (\lambda < 180\ deg)$

Azimuth relative to north (of target from subsatellite point) $\cos Az_{earth} = \frac{\sin Lat - \cos\lambda \sin Lat_{SSP}}{\sin\lambda \cos Lat_{SSP}}$

Distance from satellite to earth-based target: $D^2 = R_e^2 + (R_e + h)^2 - 2.R_e(R_e + h)cos\lambda$

Generation of Azimuth Elevation mask - steps

Continued:

Angle at satellite between line to sub-satellite point and line to target:

$$sin\rho = \frac{R_e}{D} sin\lambda$$

Then the (θ, ϕ) coordinates of target at the satellite can be calculated:

$$\theta = \frac{\pi}{2} - Az_{earth}$$

$$\phi = \rho$$

Where (see section D. 3.1.3.1 of Recommendation ITU-R S.1503-2):

θ - angle between azimuth axis and line to target

ϕ - angle at the satellite from sub-satellite point to target

The (azimuth, elevation) of target at the satellite can then be calculated from these (θ, ϕ) using:

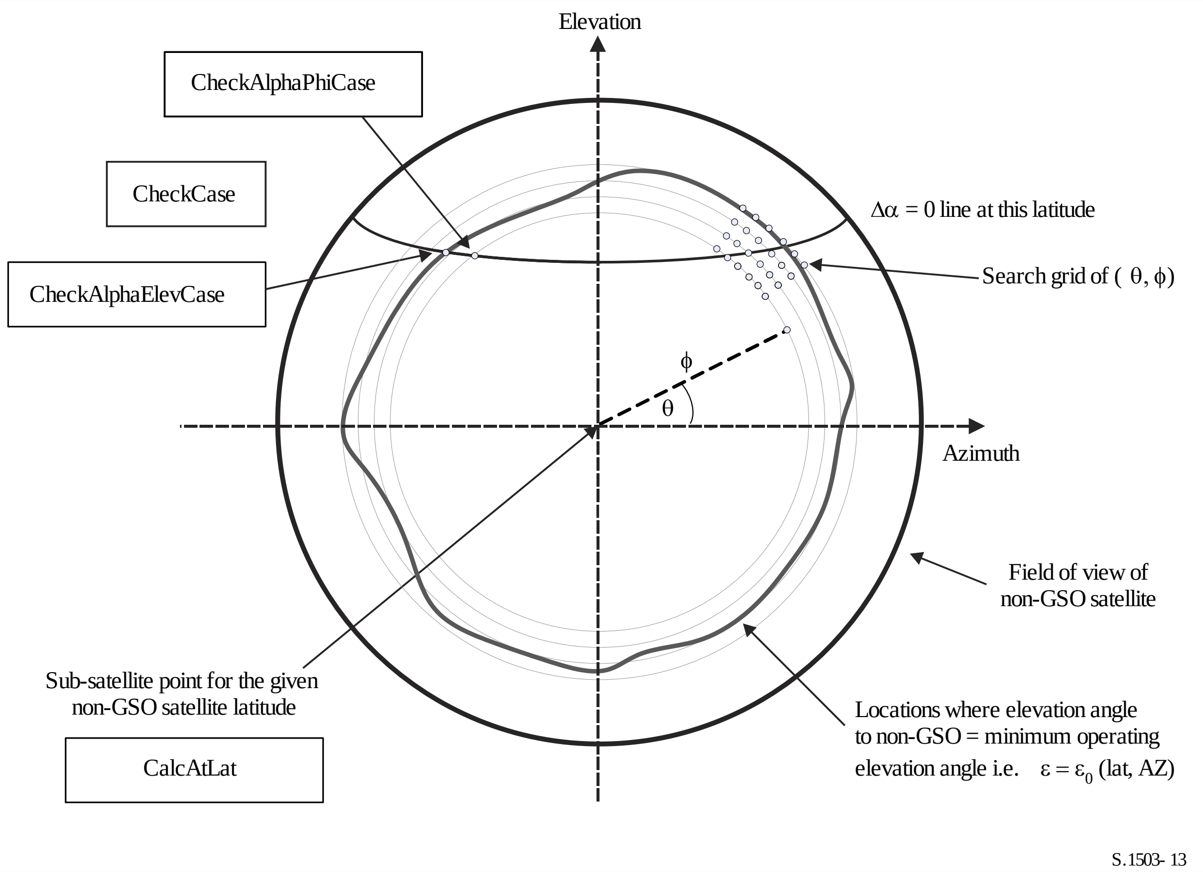
$$El_{sat} = \arcsin(\sin\phi \sin\theta)$$

$$Az_{sat} = \arccos\frac{cos\phi}{cosEl_{sat}}$$

Worst Case Geometry – Downlink

The purpose is to identify highest EPFD => which is characterized by the highest product of PFD in the mask and GSO earth station antenna gain

If there are several points with the highest EPFD => select the point having lowest angular velocity and elevation angle



Worst Case Geometry – Uplink

The purpose is to identify highest EPFD => which is characterized by the highest product of PFD in the mask and GSO earth station antenna gain

no need to consider the likelihood of particular geometries, only the maximum epfd(up) value

$$epfd(up) \cong e.i.r.p.(\varphi, lat) + 10log_{10}(NUM\_ES) + 10log_{10}\left(N_{co,es}(lat)\right) + \sum_{i=1}^{i=N_{ES}} G_{rel,rx} - L_S$$