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TECHNICAL REPORT

# Satellite Earth Stations and Systems (SES); Technical Report on antenna performance characterization for GSO mobile applications

Reference
DTR/SES-00361

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*ETSI*

650 Route des Lucioles
F-06921 Sophia Antipolis Cedex - FRANCE

Tel.: +33 4 92 94 42 00 Fax: +33 4 93 65 47 16

Siret N° 348 623 562 00017 - NAF 742 C
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# Foreword

This Technical Report (TR) has been produced by ETSI Technical Committee Satellite Earth Stations and Systems (SES).

# Modal verbs terminology

In the present document "**shall**", "**shall not**", "**should**", "**should not**", "**may**", "**need not**", "**will**", "**will not**", "**can**" and "**cannot**" are to be interpreted as described in clause 3.2 of the ETSI Drafting Rules (Verbal forms for the expression of provisions).

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# 1 Scope

The present document provides a characterization of antenna performances for earth stations on mobile platforms. It identifies the technologies and antenna types used in such systems, which may not have the same performance characteristics considered when developing the existing ETSI standards for VSATs.

Antennas used on mobile platforms are typically smaller and have radiation patterns that may have variable symmetry and/or variable geographic skew angles toward the satellite. These types of antennas are typically used in low profile antennas or other special applications. Their radiating patterns may show non-conformances with regard to the ETSI off-axis EIRP density mask.

The present document proposes a method to cope with this non-conformances issue, called the "non-conformance-area" (NCA) method. The method relies on a geometrical mathematical object, called a NCA, defined as follows:

- A "non-conformance-area" (NCA) is an area of preferably simple geometric shape defined on the antenna radiating pattern that identifies the set of directions where the ETSI mask is exceeded, associated with an indicative level of severity in the perspective of a further interference analysis.

As far as 3D geometry in space is concerned, the NCA method is an extension of the ETSI TR 102 375 [i.6] report that "provides guidelines for determining the parts of the satellite earth station antenna radiation patterns concerned by the geostationary satellite orbit protection".

The rationale underlying the NCA method is:

1) As long as there is no victim system in the directions of a NCA, there is no possible harmful interference occurrence for that directions.

2) When a victim system happens to be in the directions of a NCA, a possible interference event occurs in the scope of a non-conformance to the ETSI mask. This event is called a "hit".

3) A coarse level of severity is associated by analysis to each "hit".

4) Statistics are performed about the occurences of "hits" during operations, providing with a comprehensive assessment of the hit occurences issue.

The NCA method may support a rationale as suggested by FCC 47 CFR 25.138 (b) [i.1] as stated hereafter:

- "*(b) Each applicant for earth station license(s) that proposes levels in excess of those defined in paragraph (a) of this section shall submit link budget analyses of the operations proposed along with a detailed written explanation of how each uplink and each transmitted satellite carrier density figure is derived. Applicants shall also submit a narrative summary which must indicate whether there are margin shortfalls in any of the current baseline services as a result of the addition of the applicant's higher power service, and if so, how the applicant intends to resolve those margin short falls. Applicants shall certify that all potentially affected parties (i.e. those GSO FSS satellite networks that are 2, 4, and 6° apart) acknowledge and do not object to the use of the applicant's higher power densities.*"

The NCA method may also support a rationale as suggested by FCC 47 CFR 25.227 (b)(2) [i.2].

# 2 References

## 2.1 Normative references

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The following referenced documents are not necessary for the application of the present document but they assist the user with regard to a particular subject area.

Ka band

[i.1] FCC 47 CFR 25.138: "Blanket Licensing provision of GSO FSS Earth Station in the 19.3-18.8 GHz (space-to-Earth), 19.7-20.2 GHz (space-to-Earth), 28.35-28.6 (Earth-to-Space) 28.35-28.6 GHz (Earth-to-Space), and 29.25-30.0 GHz (Earth-to-Space) bands".

Ku band

[i.2] FCC ESAAS 47 CFR 25.227: "Blanket licensing provisions for Earth Stations Aboard Aircraft (ESAAs) receiving in the 10.95-11.2 GHz (space-to-Earth), 11.45-11.7 GHz (space-to-Earth), and 11.7-12.2 GHz (space-to-Earth) frequency bands and transmitting in the 14.0-14.5 GHz (Earth-to-space) frequency band, operating with Geostationary Satellites in the Fixed-Satellite Service".

ITU

[i.3] Recommendation ITU-R S.524-9: "Maximum persissible levels of off-axis e.i.r.p density from earth station in geostationary-satellite orbit networks operating in the fixed-satellite service transmitting in the 6 Hz, 13 GHz, 14 GHz, and 30 GHz frequency bands".

[i.4] ITU Radio Regulations.

NOTE: Available at https://www.itu.int/pub/R-REG-RR.

ARINC

[i.5] ARINC 791 Mark 1 Aviation Ku-band and Ka-band satellite communication system Part 1 and Part 2.

ETSI

[i.6] ETSI TR 102 375: "Satellite Earth Stations and Systems (SES); Guidelines for determining the parts of satellite earth station antenna radiation patterns concerned by the geostationary satellite orbit protection".

[i.7] ETSI EN 302 186: "Satellite Earth Stations and Systems (SES); Harmonised Standard for satellite mobile Aircraft Earth Stations (AESs) operating in the 11/12/14 GHz frequency bands covering the essential requirements of article 3.2 of the Directive 2014/53/EU".

[i.8] ETSI EN 303 978: "Satellite Earth Stations and Systems (SES); Harmonised Standard for Earth Stations on Mobile Platforms (ESOMP) transmitting towards satellites in geostationary orbit, operating in the 27,5 GHz to 30,0 GHz frequency bands covering the essential requirements of article 3.2 of the Directive 2014/53/EU".

### ECC Report

[i.9] ECC Report 184: "The Use of Earth Stations on Mobile Platforms Operating with GSO Satellite Networks in the Frequency Ranges 17.3-20.2 GHz and 27.5-30.0 GHz".

NOTE: Available at http://www.erodocdb.dk/docs/doc98/official/pdf/ECCRep184.pdf.

# 3 Abbreviations

For the purposes of the present document, the following abbreviations apply:

| | |
|---|---|
| 1D | 1 Direction (phased array) or 1 Dimension (graph) |
| 2D | 2 Directions (phased array) or 2 Dimensions (graph) |
| 3D | 3 Dimensions (graph) |
| AES | Aircraft Earth Station |
| ARINC | Aeronautical Radio INCorporated. |
| CFR | Code of Federal Regulations |
| ECC | Electronic Communications Committee |
| EIPR | Effective Isotropic Radiated Power |
| EIRP | Equivalent Isotropically Radiated Power |
| EN | European Standard |
| ESAAS | Earth Stations Aboard Aircraft |
| Escan | Electric scan |
| ESOMP | Earth Stations on Mobile Platforms |
| ESV | Earth Stations on Vessels |
| ES-VA | Electric Steered Variable Aperture |
| ETSI | European Telecommunications Standards Institut |
| FCC | Federal Communications Commissions |
| FSS | Fixed-Satellite Service |
| GSO | Geostationnary Satellite Orbit |
| HS-VA | Hybrid Steered Variable Aperture |
| IMU | Inertial Measurment Unit |
| IPR | Intellectual Property Right |
| ITU | International Telecommuncation Union |
| ITU-R | International Telecommunications Union - Radiocommunications sector |
| LEO | Low Earth Orbit |
| LMES | Land Mobile satellite Earth Stations |
| LOS | Line Of Sight |
| MEO | Medium-Earth Orbit |
| MS-FA | Mechanically Steered Fixed Aperture |
| MS-VA | Mechanically Steered Variable Aperture |
| NCA | Non Conformance Area (method) |
| NGSO | Non-Geostationnary Satellite Orbit |
| PFD | Power Flux Density |
| RMS | Root Mean Square |
| VMES | Vehicle-Mounted Earth Stations |

# 4 General concepts

Fore the purpose of the present document, the satcom antenna technologies for Mobile Platforms are partitioned as follows:

1) The radiating panel generates a fixed beam, typically in the boresigth direction of its radiating surface. It is mechanically aimed toward the satellite. For the purpose of the present document, this antenna type is called **MS-FA for Mechanically Steered - Fixed Aperture**.

2) The radiating panel has an electric beam steering capacity either 1D or 2D (for 1 and 2 Directions) from its boresight. In case of a partial electric beam steering (a complementary mechanical beam steering is implemented), the antenna type is called **HS-VA for Hybrid Steered - Variable Aperture**.

3) The radiating panel has an electric beam steering capacity either 1D or 2D (for 1 and 2 Directions). In case of full electric beam steering (no complementary mechanical beam steering is required), the antenna is called **ES-VA for Electric Steered -Variable Aperture**.

For ease of understanding, each antenna type is matched to a particular antenna technology:

1) Mechanically Steered Fixed Aperture (MS-FA): a rectangular radiating panel mounted on a mechanical Elevation over Azimuth positioner. The antenna is housed under a "low profile" radome mounted flat on the platform body (for instance the fuselage of an aircraft).

2) Hybrid Steered Variable Aperture (HS-VA): a MS-FA antenna where the antenna radiating panel performs an electric cross-elevation axis. The overall physical shape is kept unchanged with regard to MS-FA type. The antenna is housed the under a "low profile" radome the same way.

3) Electric Steered Variable Aperture: a thin radiating panel mounted flat on the platform's body (for instance the aircraft fuselage), and performing a 2D electric beam-steering from its boresight. It is sometimes referred to as a conformal antenna.

The rationale linking the antenna types to the antenna technologies is:

1) Only asymmetrical (e.g. "low profile") antennas are considered in the scope of this study. Hence, the cross-elevation axis, if any, is bound to be electric. A mechanical cross-elevation axis rotation has its range limited by the radiating panel bumping into the radome and into its floor.

2) If the elevation axis is mechanical, the antenna type is either MS-FA or HS-VA depending on the existence of one cross-elevation axis or not.

3) If the elevation axis is electric, the antenna type is either MS-FA (if the radiating panel surface is typically inclined from the platform horizontal around 45°) or ES-VA (if the radiating panel is mounted flat/horizontal on the platform body).

Several other technologies such as multipanel antennas, 3 axis mechanical antennas, etc., are eligible that can take place between the classic Elevation over Azimuth (e.g. MS-FA) and the full 2D phased array conformal antenna (e.g. ES-VA). But the objective of this technical report is not to compare antenna technologies or to discuss about their feasability. The objective of this technical report is to work out a method (the NCA method) to address non-conformances with regard to the ETSI off-axis EIRP density mask on a generic basis. The three antenna types above have been retained to illustrate this method.

One should note that the three antenna types above can also be related to the typical maps shown on Figure 1 (satcom on-axis EIRP density maps):

1) The MS-FA antenna on-axis EIRP density is restricted by its poor directivity when operated on the equator (the so called "equator effect" according to the Arinc 791 standard [i.5]). Furthermore, the antenna cannot be operated at the satellite nadir because of the positioner azimuth gimbal lock (the black spot at the satellite nadir).

2) The HS-VA antenna on-axis EIRP density is lower at the far East/West to the target GSO satellite nadir because of the electronic cross-elevation axis scan range being limited.

3) The ES-VA antenna performances decrease when the target GSO satellite elevation is low because of the 2D phased array limited scan range.

NOTE: The Earth as viewed by a GSO satellite. The target satellite nadir is at the center . The colored black/red/white mask provides an indication of the terminal maximum allowable on-axis EIRP density (The clearer the higher the EIRP density).

**Figure 1: EIRP density maps depending on the Earth terminal location**

The key point is the EIRP density to be reduced in given situations, down to switching off the transmission, to prevent harmful interferences to adjacent systems.

The objective of the following chapter is to provide further analysis and clarification about this issue. The analysis will be threefold for each antenna type:

1) Define the antenna.

2) Describe the motivation for the special shape/characteristics.

3) Describe the specific non conformant issues with regard to spatially symmetric antenna (as the circular parabolic reflector) related ETSI standards.

# 5 Antenna Technologies for Mobile Platforms

## 5.1 Mechanically Steered, Fixed Aperture

### 5.1.1 Define the antenna

A MS-FA antenna is shown on Figure 2. The radiating panel (yellow) is typically of rectangular shape and is mounted on an Elevation over Azimuth mechanical gimbal. The antenna beam follows the radiating panel boresight direction.

- The Z rotational axis is the electromechanical Azimuth axis. Its movement is n × 360° with an unlimited number of turns.

- The Y rotational axis represents the electromechanical Elevation axis. Its movement ranges typically 0° to 90° from the horizontal.

- The XY plane follows the radiating panel rectangular surface. In the scope of this study, the radiating panel is smaller in the X direction (Height) than in the Y direction (Width) because the antenna is low profile.

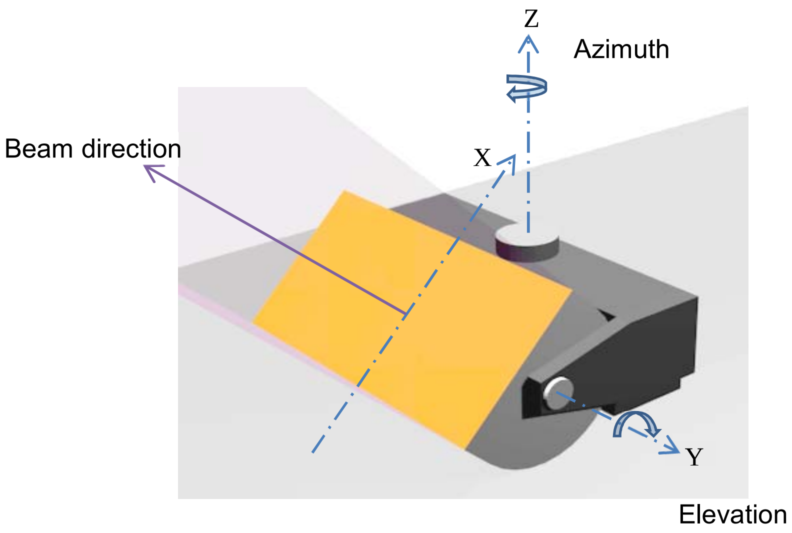


**Figure 2: MS-FA antenna overview**

### 5.1.2 Define the motivation of the special shape/characteristic

The motivation for a MS-FA antenna is its capability to be housed under a low profile radome while being able to target low elevation satellites. The rectangular shape of the radiating panel maximizes the ratio between the radiating panel surface and the antenna sweep volume, and thus minimizes the height of the radome.

There are many implementations for the radiating panel : elliptic parabolic, multiparabolic, lenses arrays, waveguides arrays, patches, horn boxes, etc. The requirements are stringent on the radiating diagram: dual polarization switched or driven, dual band or wideband, environmental conditions, low cost, etc.

The Elevation over Azimuth gimbal is classic. The key point is the aiming accuracy - down to ±0,2° is required by the FCC - to be achieved on a mobile platform. The requirements are stringent on motor torques, frictions forces, axis alignment, axis coders accuracy, IMU, conscan tracking … A well-known weakness is the inability to track a satellite located in the vicinity of the azimuth axis direction (the so called "azimuth gimbal lock" effect), the gimbal behaving as a spinning top around its Azimuth axis (https://en.wikipedia.org/wiki/Gimbal lock). The aiming accuracy is impaired when the antenna is aimed at high elevations satellites.

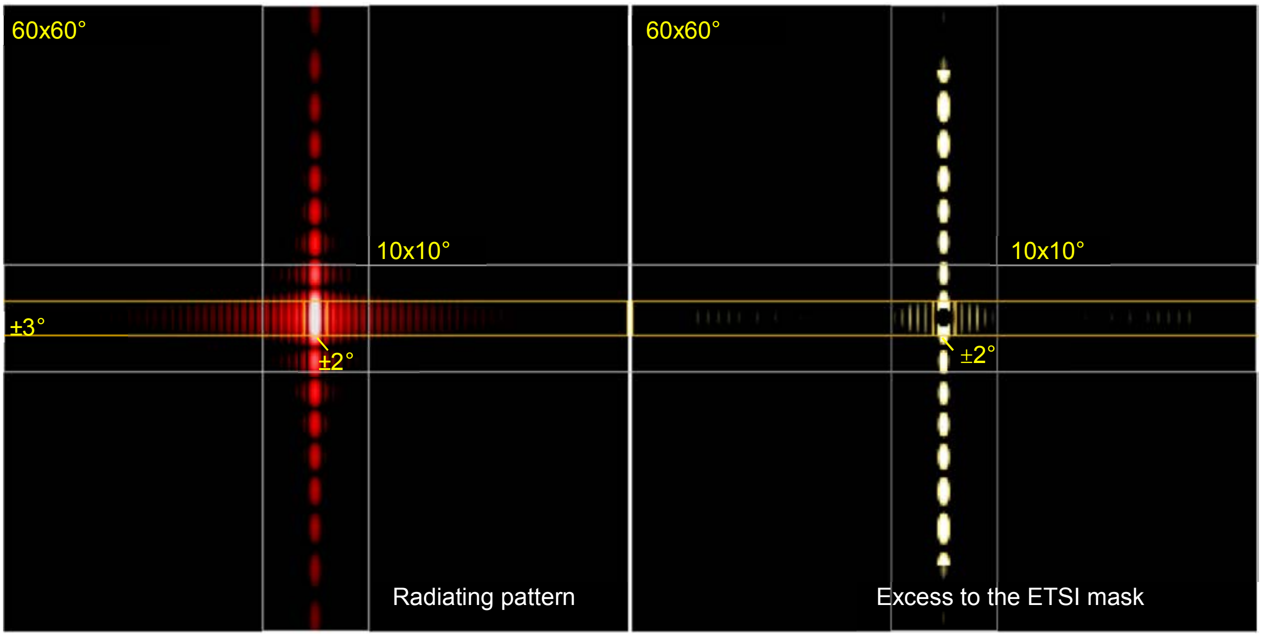
### 5.1.3 Describe the specific non conformant issues

A 40 × 10 cm Ka band rectangular radiating panel is considered for the analysis.

The analysis is performed for an average 25 dBW/40 kHz on axis EIRP density at 30 GHz.

Figure 3 provides a simulated radiating pattern (left) and compares it to the ETSI mask (right) (areas in excess in white), assuming the satcom located on the same longitude as the satellite. Figure 4 provides a 3D view of the radiating pattern. The horizontal and vertical cuts of the radiating pattern are provided on Figure 5 and Figure 6.

The radiating pattern is cross-shaped. The ETSI mask is strongly exceeded in the up/down direction.



NOTE: The ±3° limits along the vertical axis indicates the GSO arc assuming the satcom is located on the satellite meridian, with its azimuth axis vertical. The ±2° limits along the horizontal axis indicates the frontier with the adjacent GSO satellites. The 3 dB relaxation on the ETSI mask is taken into account where applies. Assumptions: 40 × 10 cm panel, uniform aperture, 25 dBW/40 kHz on axis EIRP, 30 GHz, no radome.

**Figure 3: MS-FA radiating pattern 2D view**

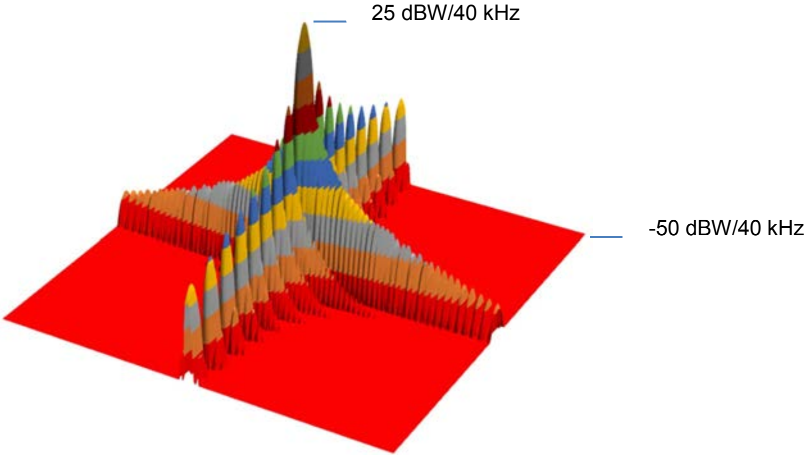
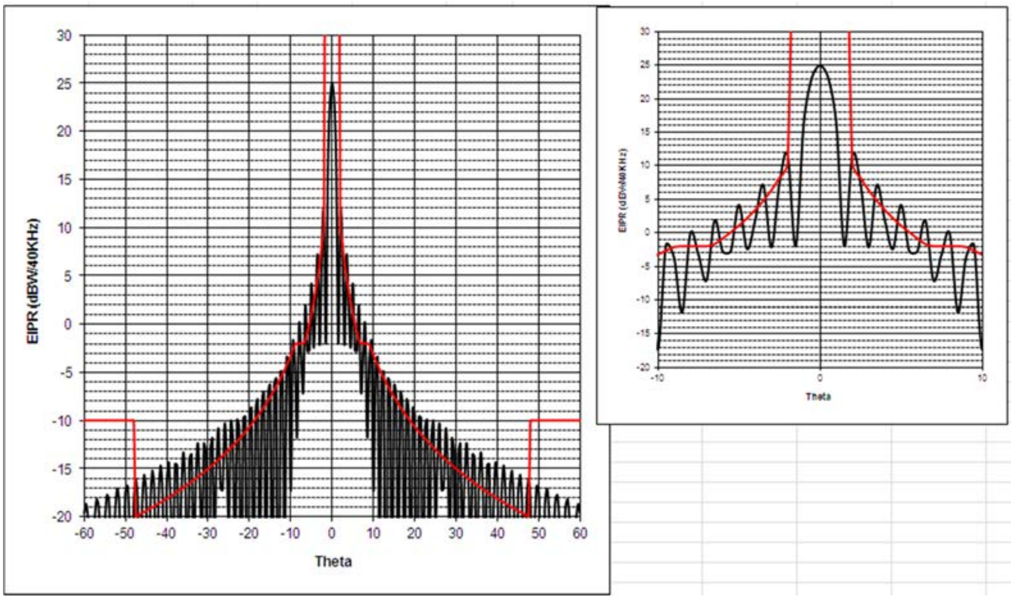
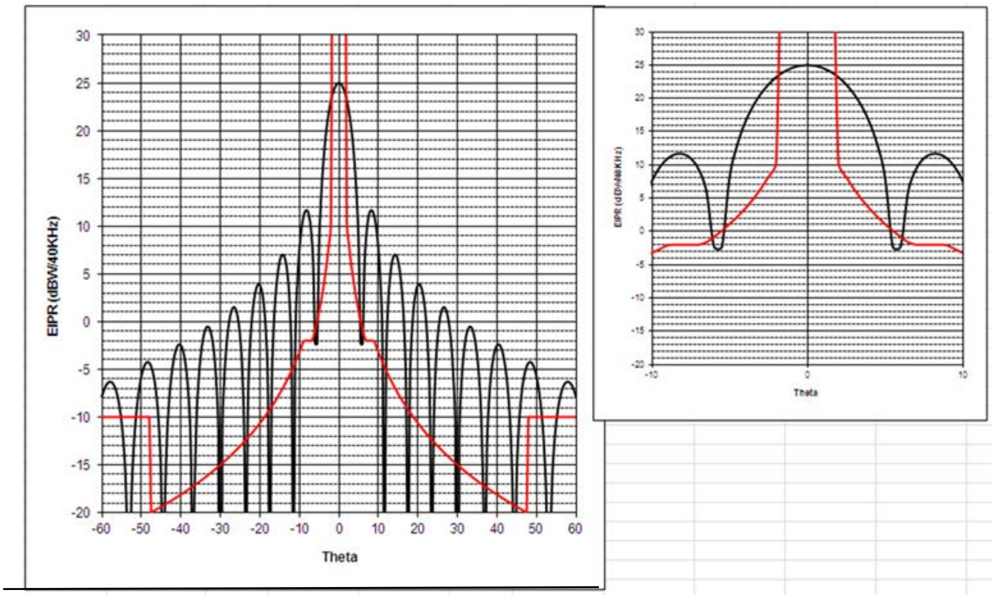


**Figure 4: MS-FA radiating pattern 3D view**



NOTE: ETSI mask (in red): no relaxation. ±0,2° margin included for the aiming accuracy. Assumptions: 40 × 10 cm panel, uniform aperture, 25 dBW/40 kHz on axis EIRP density, 30 GHz, no radome.

**Figure 5: MS-FA radiating pattern horizontal cut (e.g. following radiating panel broadside)**



NOTE: ETSI mask (in red) with no relaxation. ±0,2° margin taken for the aiming accuracy. Assumptions: 40 × 10 cm panel, uniform aperture, 25 dBW/40 kHz on axis EIRP density, 30 GHz, no radome.

**Figure 6: MS-FA radiating pattern vertical cut (following radiating panel narrow side)**

Figure 7 and Figure 8 provide a theoretical radiating pattern of a 12' (30 cm) dish antenna to compare with. The dish antenna looks cleaner than its rectangular counterpart, reflecting the ETSI mask favouring round shaped symmetric antennas. But neither antenna rectangular or circular is permitted to operate at a 25 dBW/40 kHz EIRP density according to the ETSI rules. Moreover the Figure 5 shows that the rectangular aperture complies better to the ETSI mask as far as the GSO arc is considered.

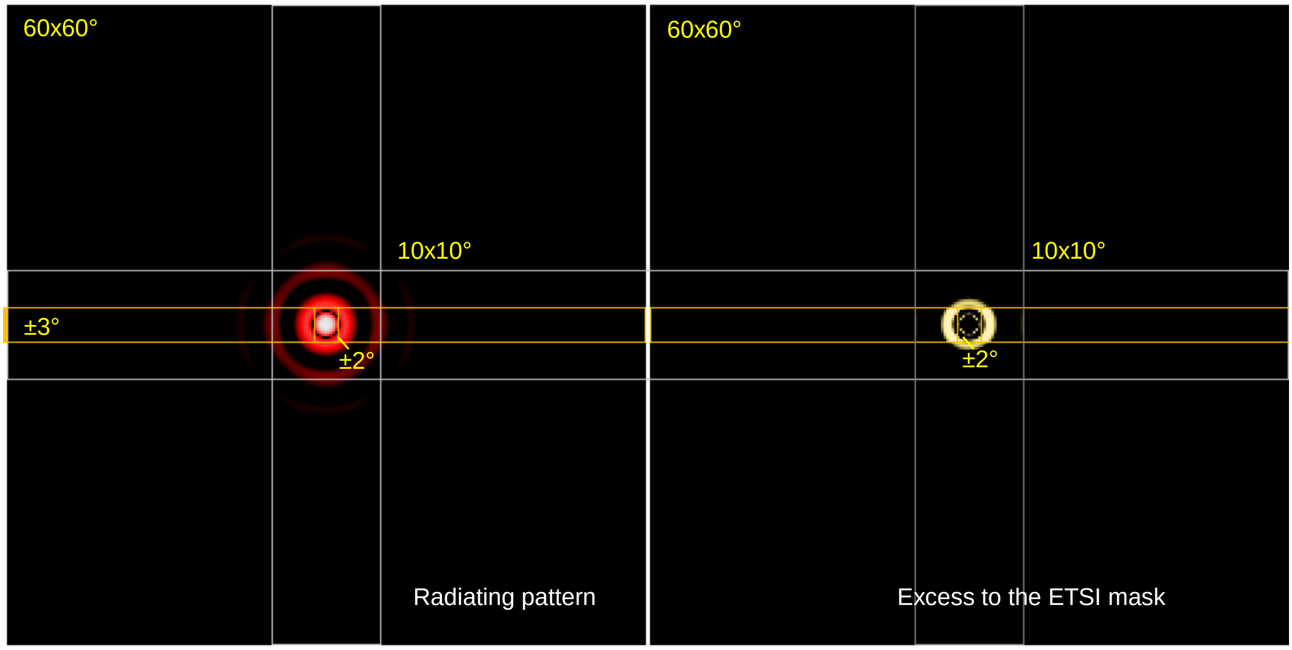


Figure 7: Radiating pattern circular dish 30 cm

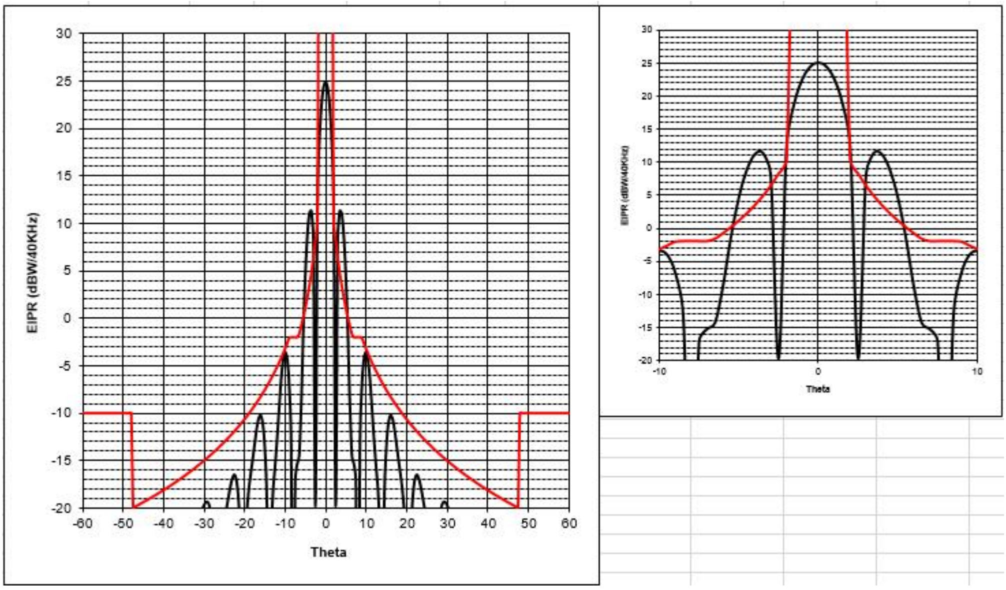


Figure 8: Radiating pattern circular dish 12' (30 cm)

A commonplace issue for a MS-FA antenna is the radiating panel showing a rotation around its main beam direction (while aimed to the satellite), the so called "skew angle" as shown on Figure 9 and Figure 10.

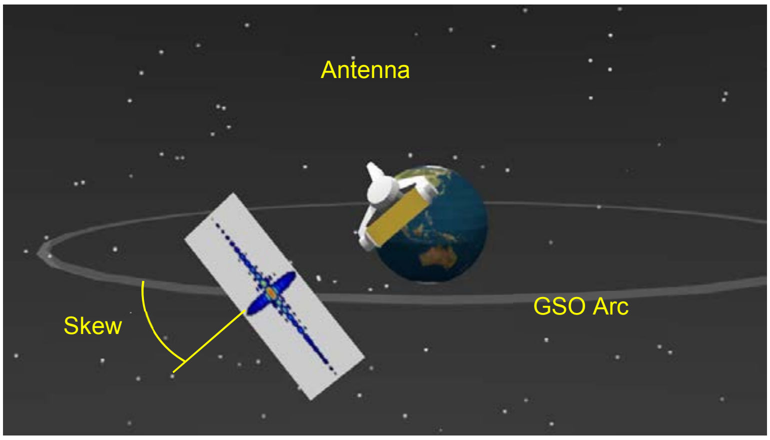


Figure 9: Antenna skew

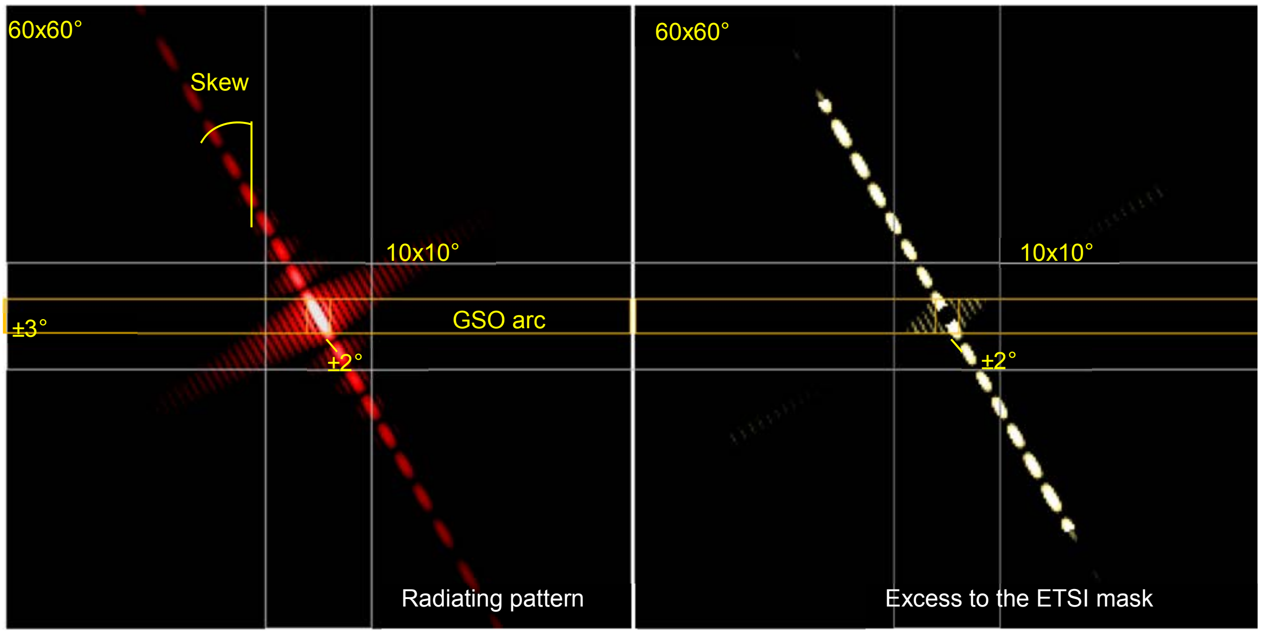


Figure 10: MS-FA radiating pattern and antenna skew

The skew angle depends on the satcom location on the Earth and its platform attitude roll, pitch, yaw. Calculating the skew angle requires a suite of Euler rotations, from space to Earth, from Earth to the platform, from the platform to the antenna radiating panel.

There is anyway a simple equation in the case the antenna Azimuth axis is locally vertical and the satellite is a GSO satellite:

$$\tan(\text{skew}) = -\operatorname{cotan}(\text{latitude}).\sin(\text{delta-longitude})$$

where "delta-longitude" and "latitude" are the satcom longitude and latitude, "delta-longitude" being the longitude relative to GSO satellite longitude.

Figure 11 provides an illustration of this skew angle that is named later "natural skew". The skew angle is equal to zero when the satcom is located on the satellite longitude.

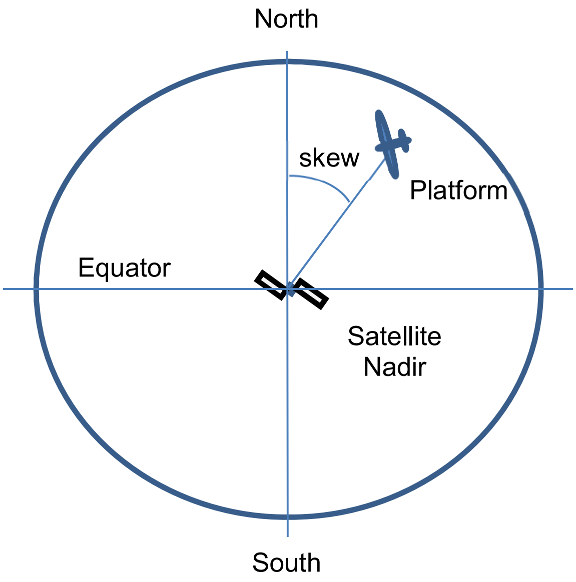


Figure 11: Earth as viewed from the satellite- natural skew

Beyond a given value of skew, typically 45°, the main beam of the antenna infringes into the adjacent GSO satellites vicinity. The on-axis EIRP density is reduced accordingly to meet the ETSI off-axis EIRP mask on the GSO arc.

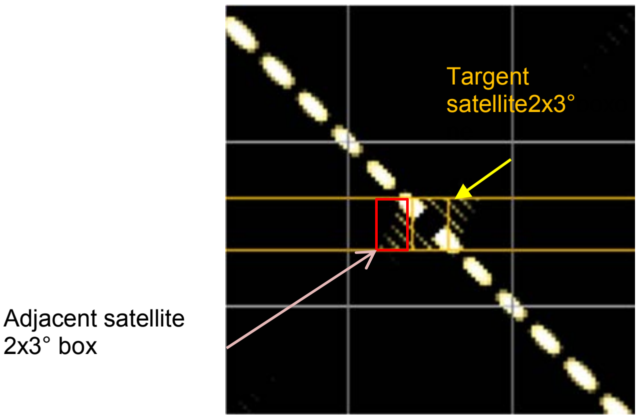
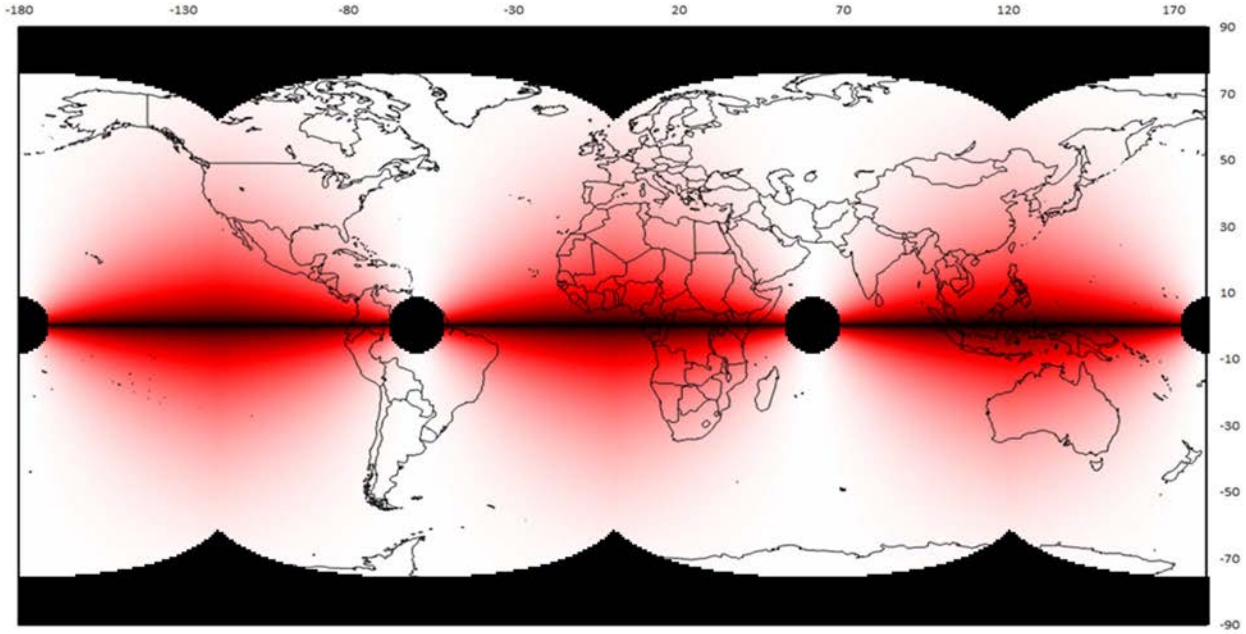


Figure 12: The radiating pattern
(shown as it excess to the ETSI mask) infringing into the adjacent GSO satellite area

High skew angles explain the east-west restriction on the MS-FA EIRP density map shown on the Figure 13 The so called "equator effect" according to the Arinc 791 [i.5] standard is quite visible.

The restriction at the satellite nadir (the black spot) reflects the azimuth axe lock effect of the antenna gimbal.



NOTE: 3 GSO satellites 120° spaced starting from 63,3°East. The colored black/red/white mask provides an indication of the terminal permitted EIRP density (The clearer the higher the EIRP density).

**Figure 13: MS-FA antenna EIRP density map on the Earth terminal location**

The above properties can be taken for granted as a general fact for MS-FA antennas. Real cases are more complex. Neither the target GSO satellite nor the adjacent GSO satellites are perfectly centred on its 2 × 3° box. A mobile platform is not purely horizontal. The radiating pattern can suffer from several impairments: grating lobes, spurious sidelobes, radome transmission and reflections, platform's body masks. The interferences to the NGSO satellites topic should also be addressed.

In this end, this is a case by case analysis. This is the purpose of the NCA method to address this issue.

## 5.2 Hybrid Steering, Variable Aperture

### 5.2.1 Define the antenna

A "1 D Phased Array" radiating panel of rectangular shape (yellow) is mounted on an electromechanical two-axis gimbal Elevation over Azimuth type (in dark grey):

- The Z rotational axis is the electromechanical Azimuth axis. Its movement is n × 360° with an unlimited number of turns.
- The Y rotational axis represents the electromechanical Elevation axis. Its movement ranges typically from 0° to 90° from the horizontal.
- The X rotational axis represents the Cross-Elevation axis which is the electric axis of the 1 D Phased Array radiating panel. It is located at the centre of the radiating panel and runs parallel to its narrow side. The cross elevation rotation angle, so called escan angle, ranges typically ±45° from the normal to the radiating panel.

Figure 14 shows the antenna in two values for the Elevation (Y) and Cross-Elevation (X, escan) angles.

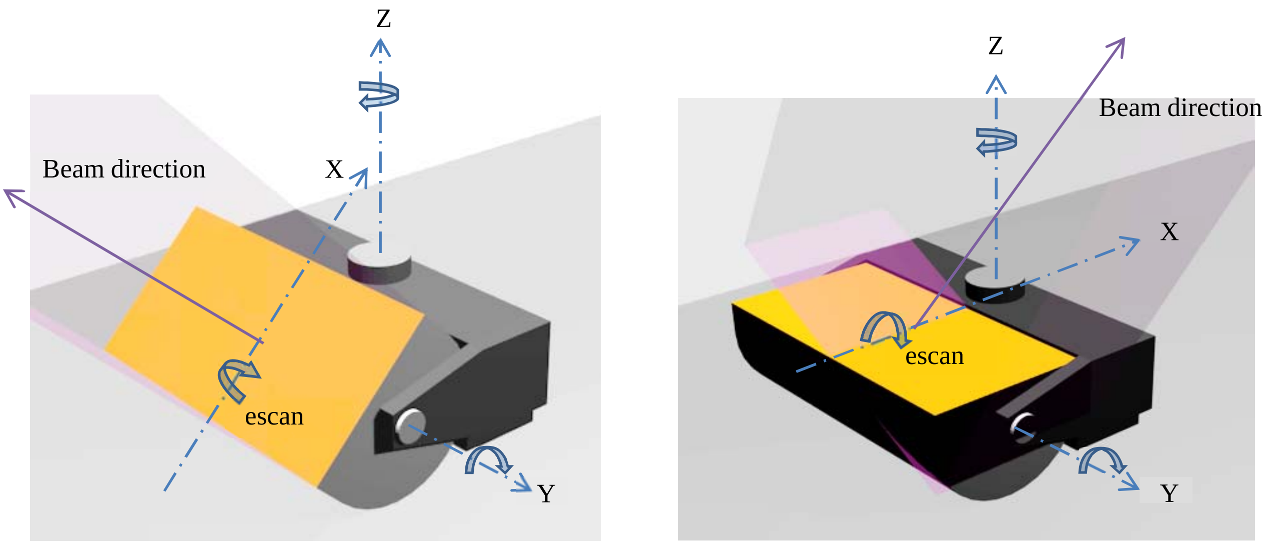


**Figure 14: The HS-VA "1D Phased Array" satcom antenna**

### 5.2.2 Define the motivation of the special shape/characteristic

The 1D HS-VA antenna has three advantages:

- It can be housed under a low profile radome while aiming a low elevation direction the same as for the MS-FA antenna.
- The positionner is 3-axis.
- The high directivity of the radiating panel along its broadside is carried out electrically and is therefore less sensitive to mechanical stress (backlash, friction, inertia), that favours a precise antenna aiming.

The specific advantages of a 3-axis positioner are:

- No azimuth gimbal axe lock. Operation at the satellite nadir is possible.
- Capability to adjust the "skew" with the cross elevation axis (angle escan). This permits to master the radio interference to the adjacent satellites, including the NGSO satellite ones.

The skew adjustment capability depends on the local elevation of the satellite. There is a simple formulae when the Azimuth axis is vertical:

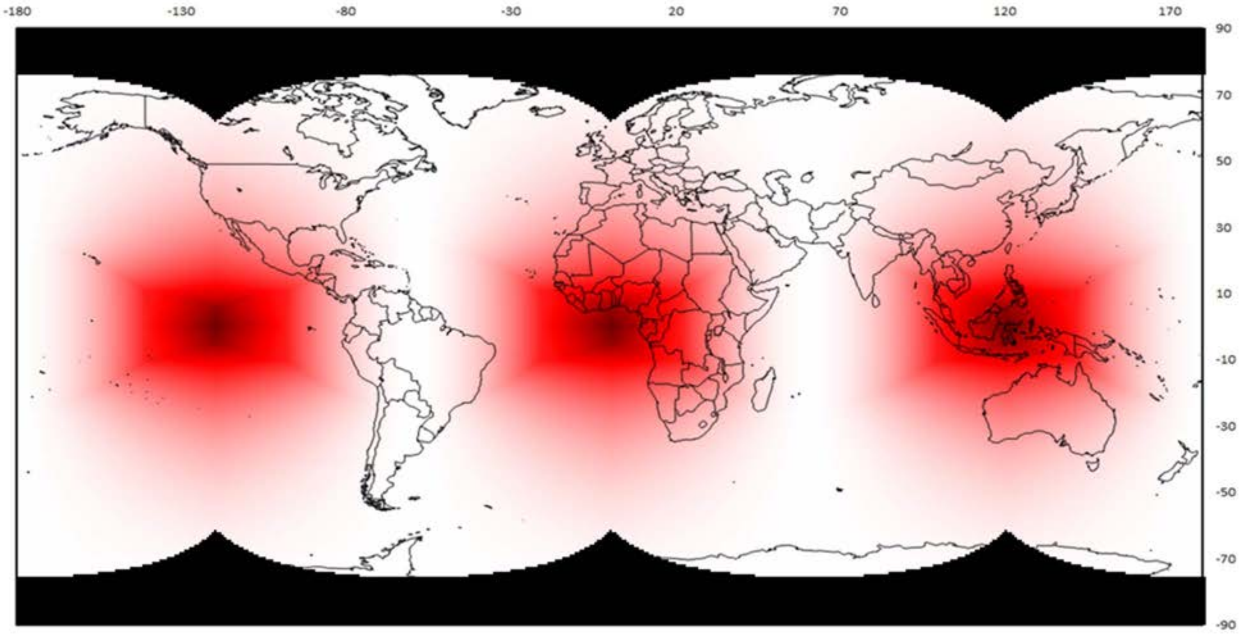
$$\sin(\text{skew}) = \tan(\text{escan}) \tan(\text{elevation})$$

("skew" starting from the "natural skew" at escan = 0° position)

For escan ranging from -45 ° to 45 °, and assuming the azimuth angle is vertical:

- If the satellite shows a more than 45° elevation, all the values of skew are possible.
- For a low elevation satellite, the skew can be adjusted by up to plus or minus the satellite local elevation.

With regard to the MS-FA antenna, the HS-VA antenna is no more impaired by the skew limitation and the gimbal axe lock as long as the escan angle does not meet its (say ±45°) maximum that occurs the satcom is located at the far east/west of the satellite nadir, as shown on the Figure 15.



NOTE: 3 GSO satellites 120° spaced starting from 63,3° East. The colored black/red/white mask provides an indication of the terminal permitted EIRP density (The clearer the higher the EIRP density).

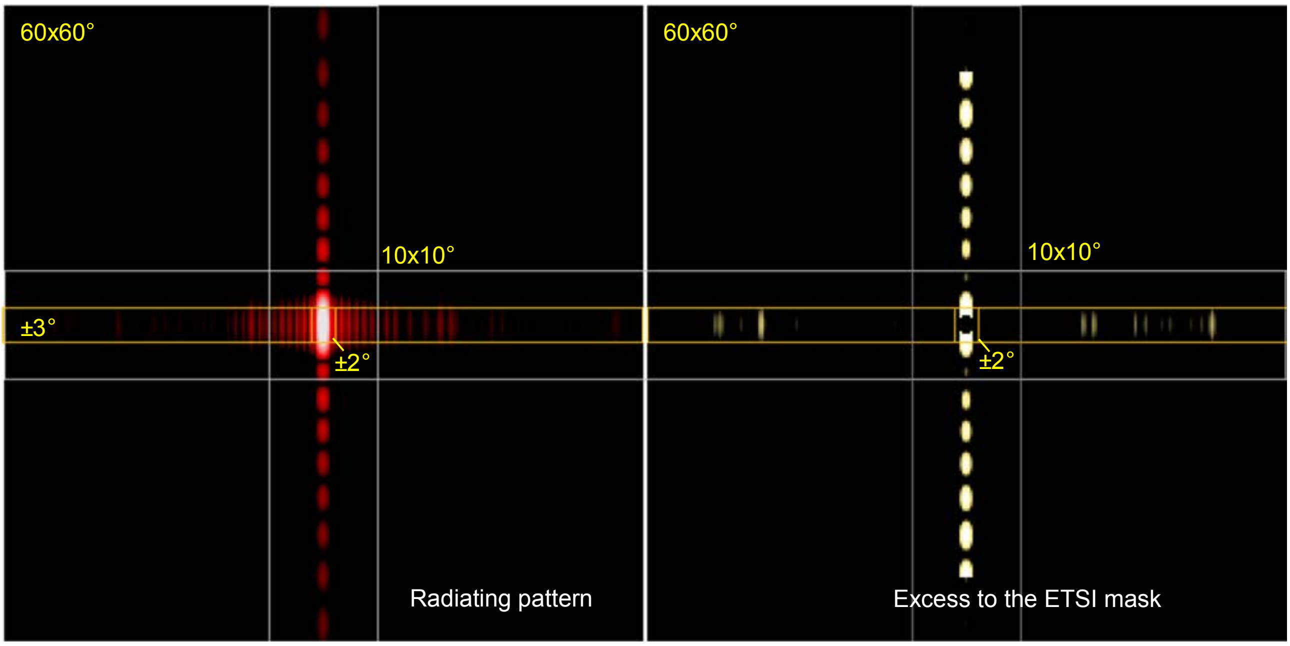
**Figure 15: HS-VA antenna EIRP density map on the Earth terminal location**

### 5.2.3 Describe the specific non conformant issue

A 40 × 10 cm Ka band rectangular radiating panel is considered for the analysis.

The analysis is performed for an average 25 dBW/40 kHz on axis EIRP density at 30 GHz.

Figure 16 provides a simulated radiating pattern (left) and compares it to the ETSI mask (right, excess areas in white). The Cross-Elevation escan is set to 0°. The radiating pattern is similar to a MS-VA antenna. This is quite visible on Figure 17. The horizontal and vertical cuts are provided on Figure 18 and Figure 19.



NOTE: The ±3° limits along the vertical axis indicates the GSO arc area assuming the satcom is located on the satellite meridian with its azimuth axis vertical. The ±2° limits along the horizontal axis indicates the frontier to the adjacent GSO satellites. The 3 dB relaxation on the ETSI mask is taken into account where applies. Assumptions: 40 × 10 cm panel, 25 dBW/40 kHz on axis EIRP, 30 GHz, no radome, escan = 0°.

Figure 16: HS-VA radiating pattern escan = 0° 2D view

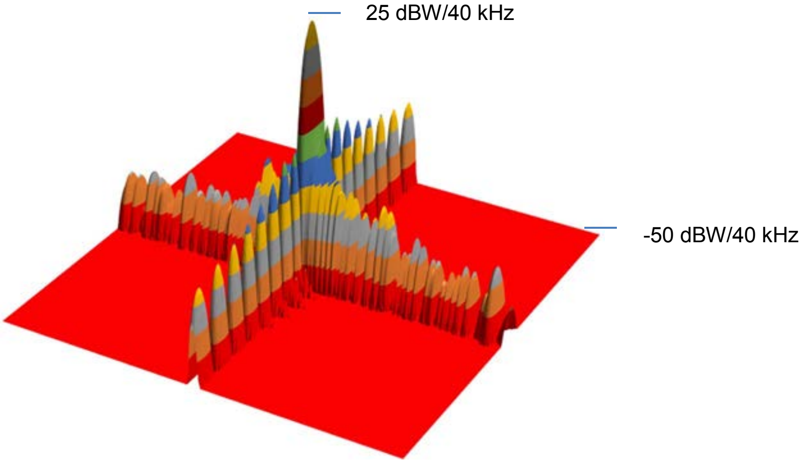
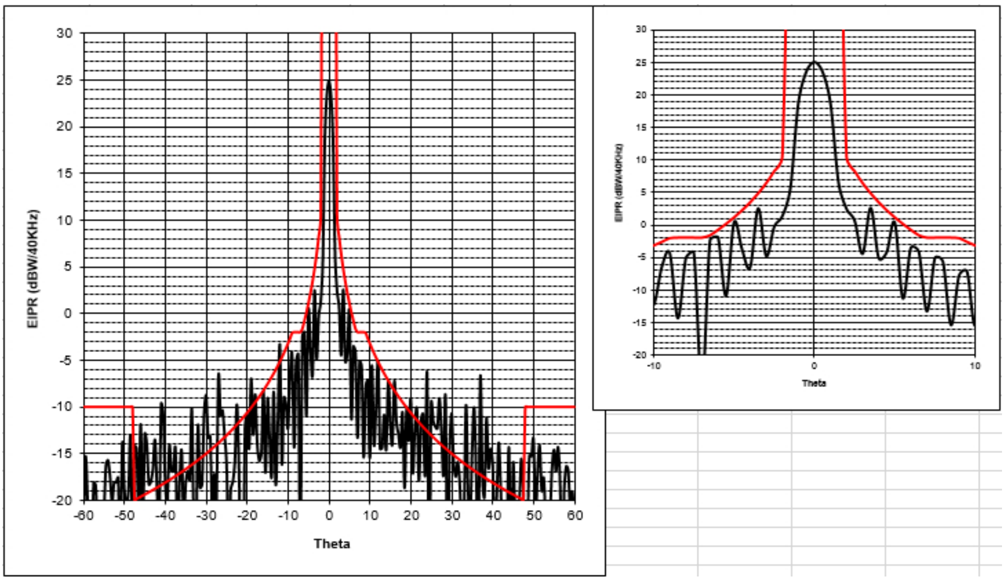
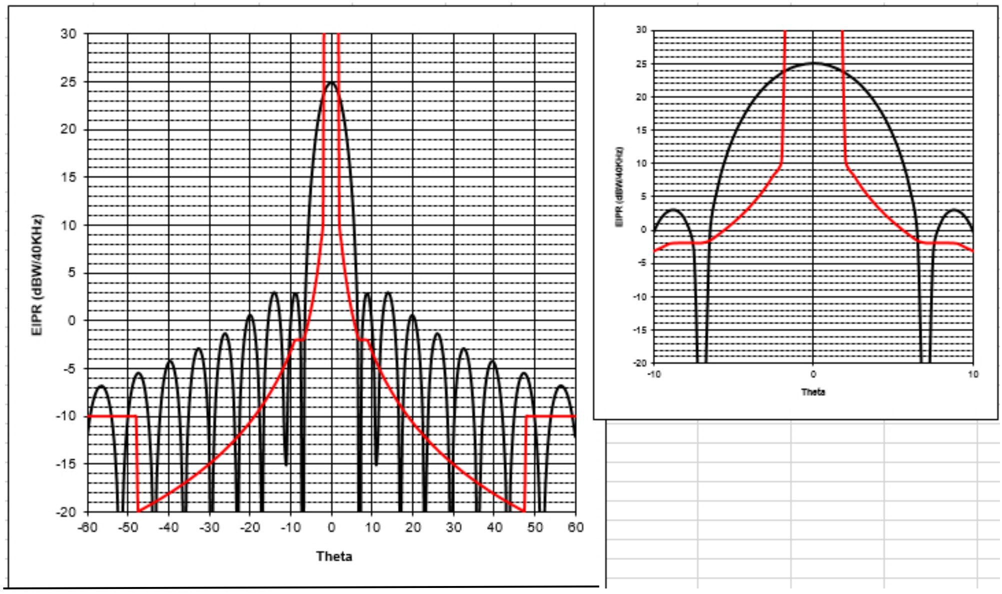


Figure 17: HS-VA radiating pattern escan = 0° 3D view



NOTE: ETSI mask (in red): no relaxation and ±0,2° margin taken for the aiming accuracy. A 6 dB Hamming taper is applied on the aperture law. 3° and 0.5 dB RMS phase/amplitude RMS accuracy for radiating elements.

**Figure 18: HS-VA radiating pattern escan = 0° horizontal cut (e.g. following broadside)**



NOTE: ETSI mask (in red): no relaxation and ±0,2° margin taken for the aiming accuracy. A 6 dB Hamming taper is applied on the aperture law. 3° and 0,5 dB RMS phase/amplitude RMS accuracy for radiating elements.

**Figure 19: HS-VA radiating pattern escan = 0° vertical cut (e.g. following narrow side)**

Figure 20 and Figure 21 show the radiating pattern of the HS-VA antenna for escan = 30° and escan = 45°. The main beam inflates in the direction of the escan angle. The vertical sidelobes pattern follows an elliptical path. The antenna gain decreases following a cos (escan) law.

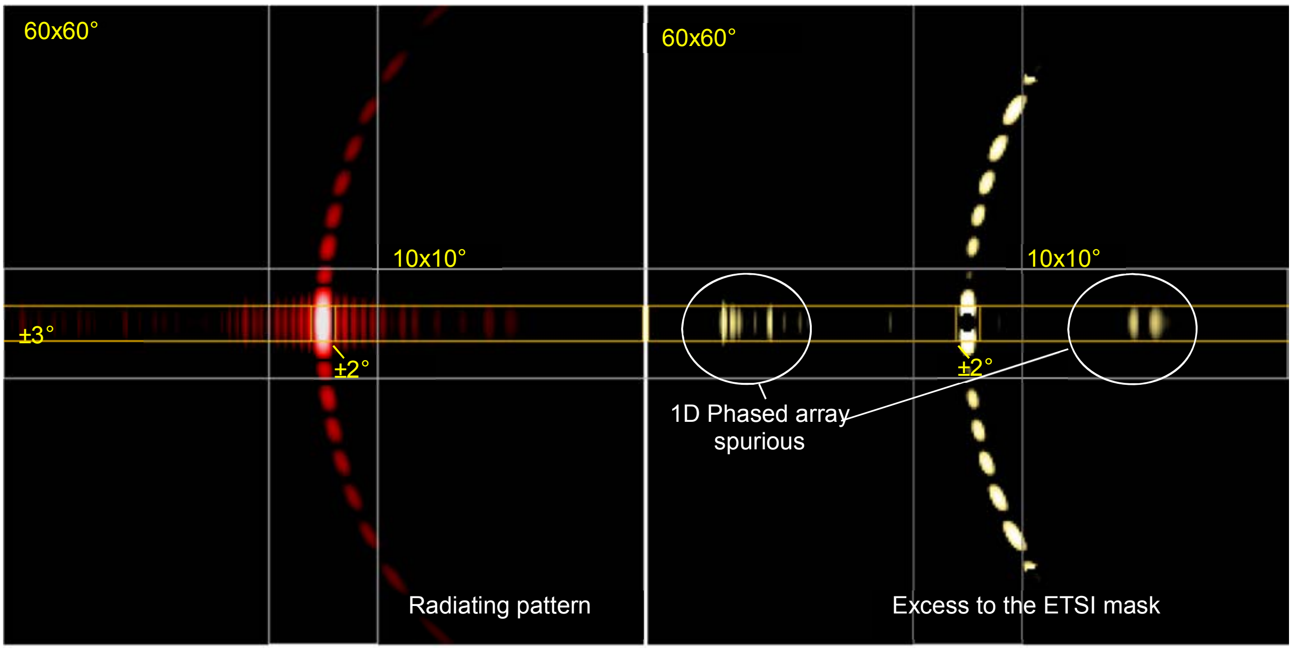


Figure 20: HS-VA radiating pattern escan = 30°

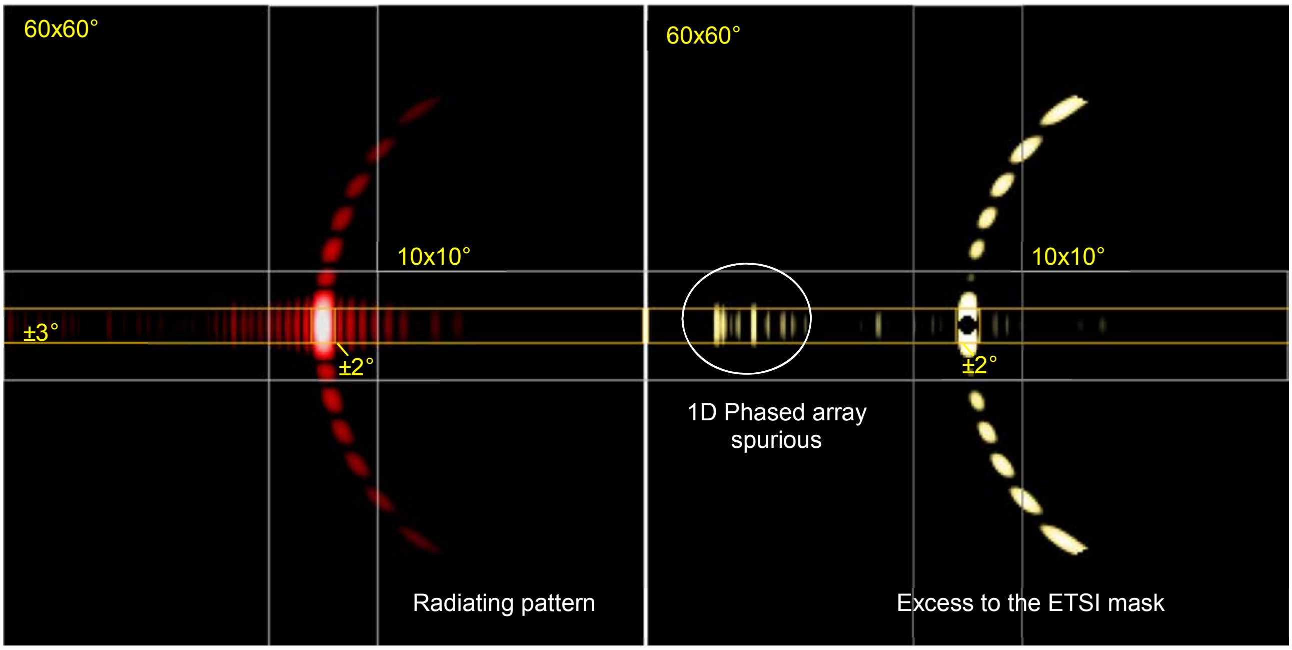


Figure 21: HS-VA radiating pattern escan = 45°

A commonplace feature of phased arrays is the upsurge of spurious sidelobes due to the radiating elements amplitude/phased inaccuracy (typically 0,5 dB and 3° RMS). This point is highlighted on Figure 22.

The radiating pattern can suffer from several other impairments: grating lobes, radome transmission and reflections, platform's body masks, etc., that are not described here.

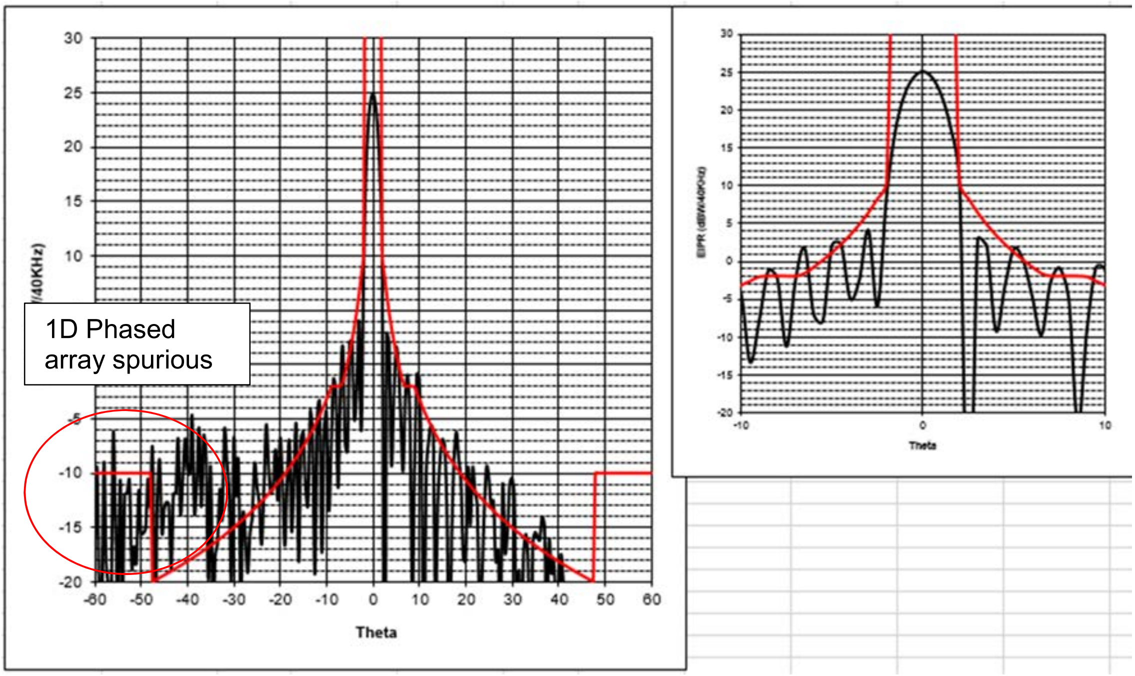


**Figure 22: HS-VA radiating pattern escan = 45° horizontal cut (broadside)**

## 5.3 Electrically Steered, Variable Aperture

### 5.3.1 Define the antenna

An ES-VA antenna is shown on Figure 23. The radiating panel is of rectangular shape (yellow) and is mounted flat/horizontal on the top of the platform's body. The antenna beam is aimed electrically (2D) toward the target satellite.

- The XY plane is the radiating panel referential. For convenience, the X axis is assumed to be aligned with the platform heading direction. The Z axis is the panel boresight direction that is vertical to the platform's body.

An Elevation over Azimuth scheme is appropriate to describe the beam steering: Azimuth rotation around the Z axis and escan axis playing the antenna elevation axis. Where the Azimuth axis mechanical, the ES-VA antenna would performs like an MS-FA antenna with the elevation axis being electric instead of mechanical. A skew angle is thus derived a similar way. Since the ES-VA antenna is a full 2D phased type, the radiating panel is fixed on the platform body, as if the mechanical Azimuth mechanical rotation above is simultaneously compensated by a mechanical contra-rotation of the same magnitude. There is no physical rotation, but the "Azimuth contra-rotation" effect is anyway quite visible on the antenna radiating pattern (the cross shaped sidelobes are rotating following the Azimuth contra-rotation angles). It is a specific feature of the ES-VA antenna with regard to MS-FA antenna.

The variants to the ES-VA antenna are:

1) The radiating panel is a 1D phased array that mechanically turns around the Azimuth axis, the radiating panel following the escan axis. This is actually a MS-FA antenna with an electric Elevation axis.

2) The radiating panel is of circular shape. There "Azimuth contra-rotation" effect exists but is not visible becaused of the circular symetry.

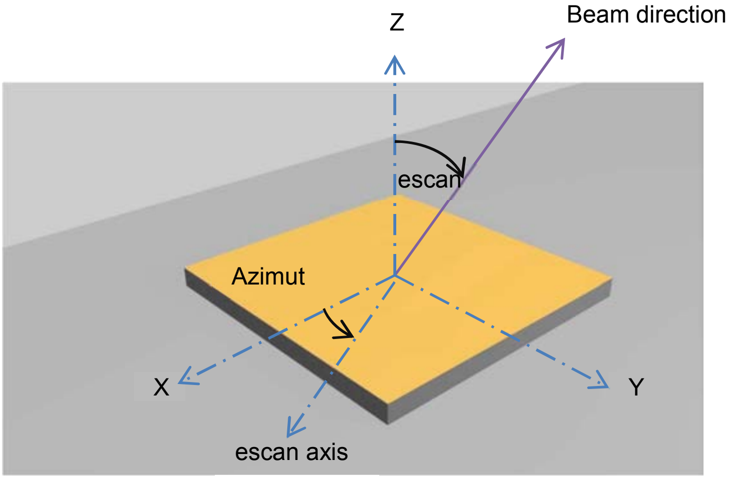


**Figure 23: A square shaped ES-VA Antenna overview**

## 5.3.2 Define the motivation of the special shape/characteristic

The ES-VA is a dream design because of its being almost conformal to the platform's body with no moving part.

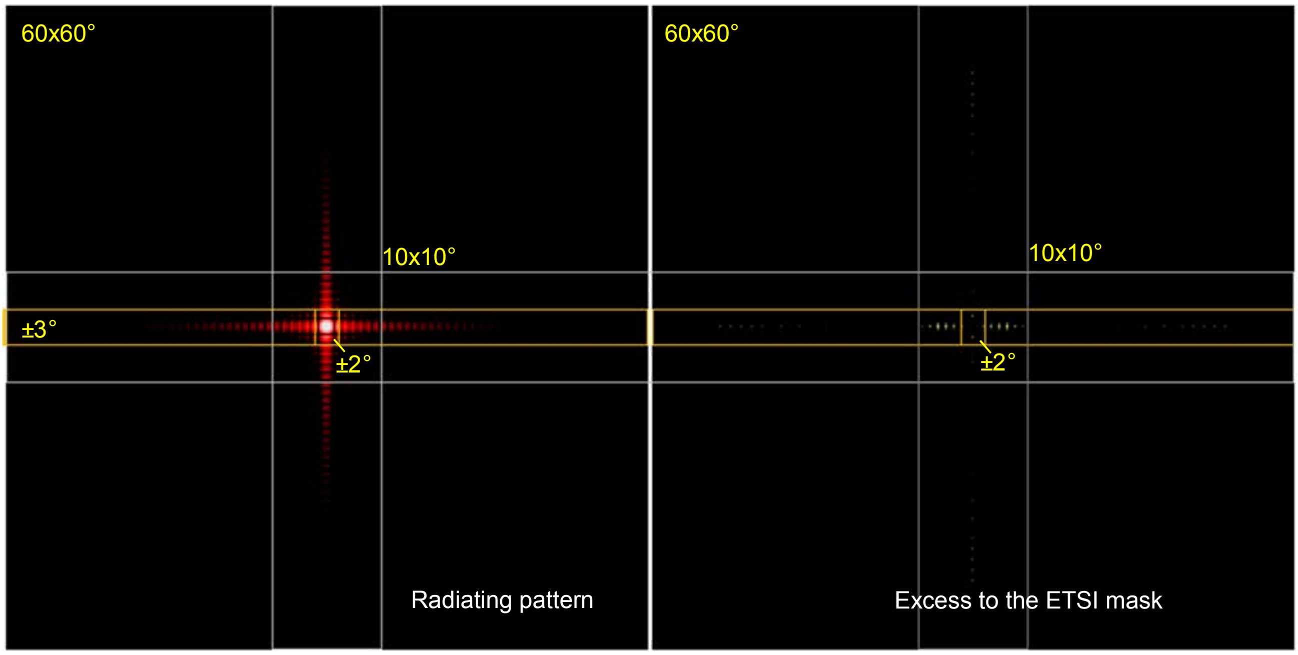
It suffers radiating pattern performance losses when the escan angle increases beyond 60°.

## 5.3.3 Describe the specific non conformant issues

A 40 × 40 cm Ka band square shaped radiating panel is considered for the analysis.

The analysis is performed for an average 25 dBW/40 kHz on axis EIRP density at 30 GHz.

Figure 24 provides a simulated radiating pattern (left) and compares it to the ETSI mask (right, excess areas in white). The azimuth angle and the electric scan angle are set to 0°. The horizontal and vertical cuts are provided on Figure 26.



NOTE: The ±3° limits along the vertical axis indicates the GSO arc assuming the satcom is located on the satellite meridian with its azimuth axis vertical.
The ±2° limits along the horizontal axis indicates the frontier wirh the adjacent GSO satellites.
The 3 dB relaxation on the ETSI mask is taken into account where applies.
Assumptions: 40 × 40 cm panel, 25 dBW/40 kHz on axis EIRP, 30 GHz, no radome.

**Figure 24: Square shaped ES-VA radiating pattern escan = azimuth = 0° 2D view**

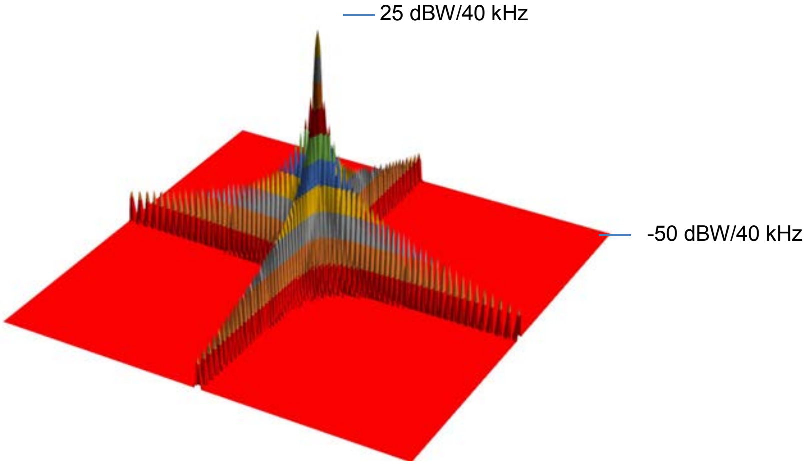
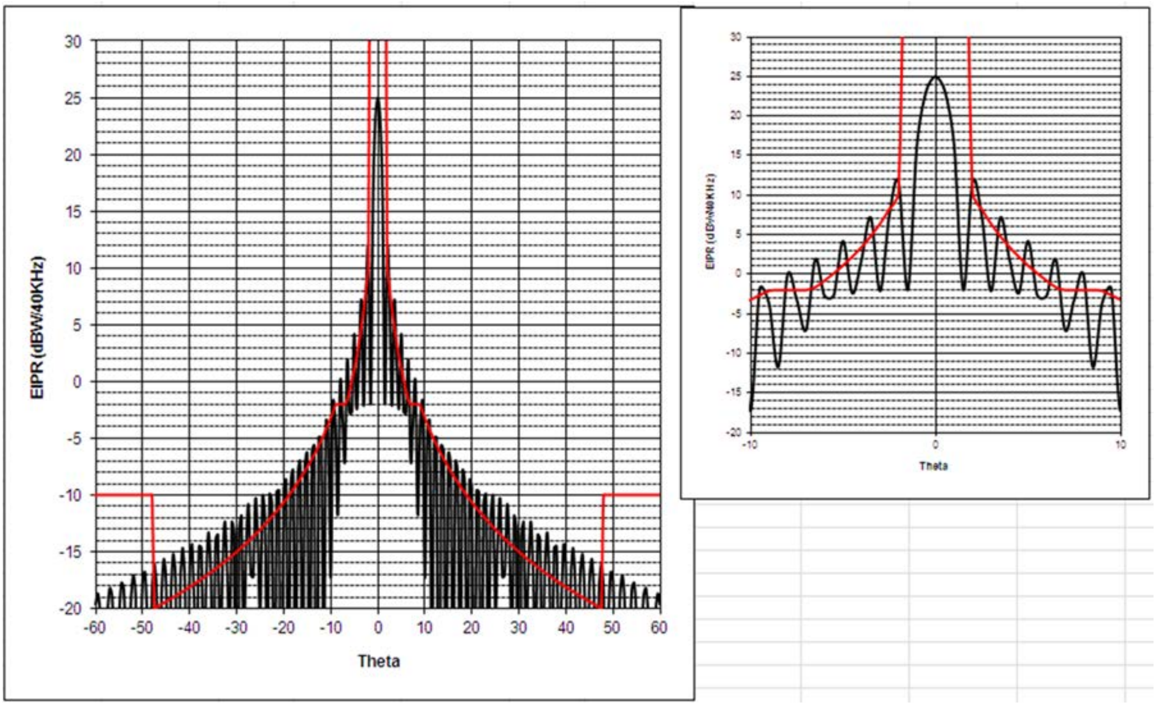


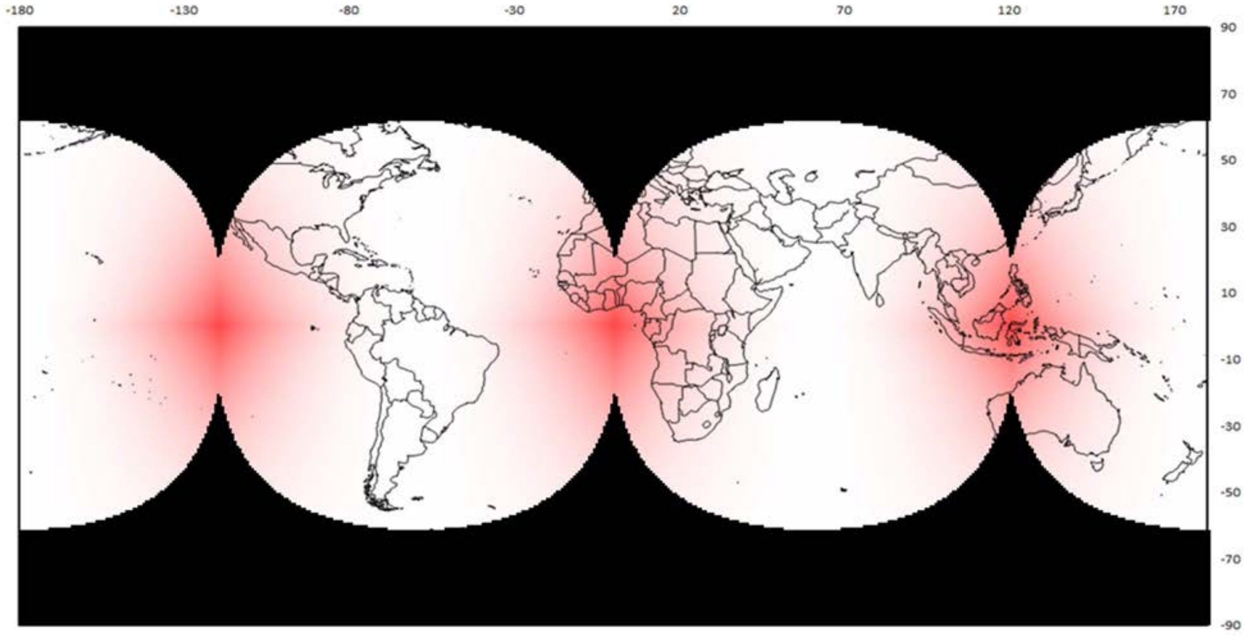
Figure 25: Square shaped ES-VA radiating pattern escan = azimuth = 0° 3D view



NOTE: ETSI mask (in red): no relaxation and ±0,2° margin taken for the aiming accuracy.

Figure 26: Square shaped ES-VA Radiating pattern escan = 0° horizontal cut (e.g. following radiating panel broadside)

The operational area is restricted to locations where the satellite shows a sufficient elevation angle as shown on Figure 27.



NOTE: 3 GSO satellites 120° spaced starting from 63,3° East. The colored black/red/white mask provides an indication of the terminal permitted EIRP density (The clearer the higher the EIRP density).

**Figure 27: ES-VA antenna EIRP density map on the Earth terminal location**

Figure 28 shows that the radiating pattern fairly complies with the ETSI mask as long as the escan angle is less than 60°.

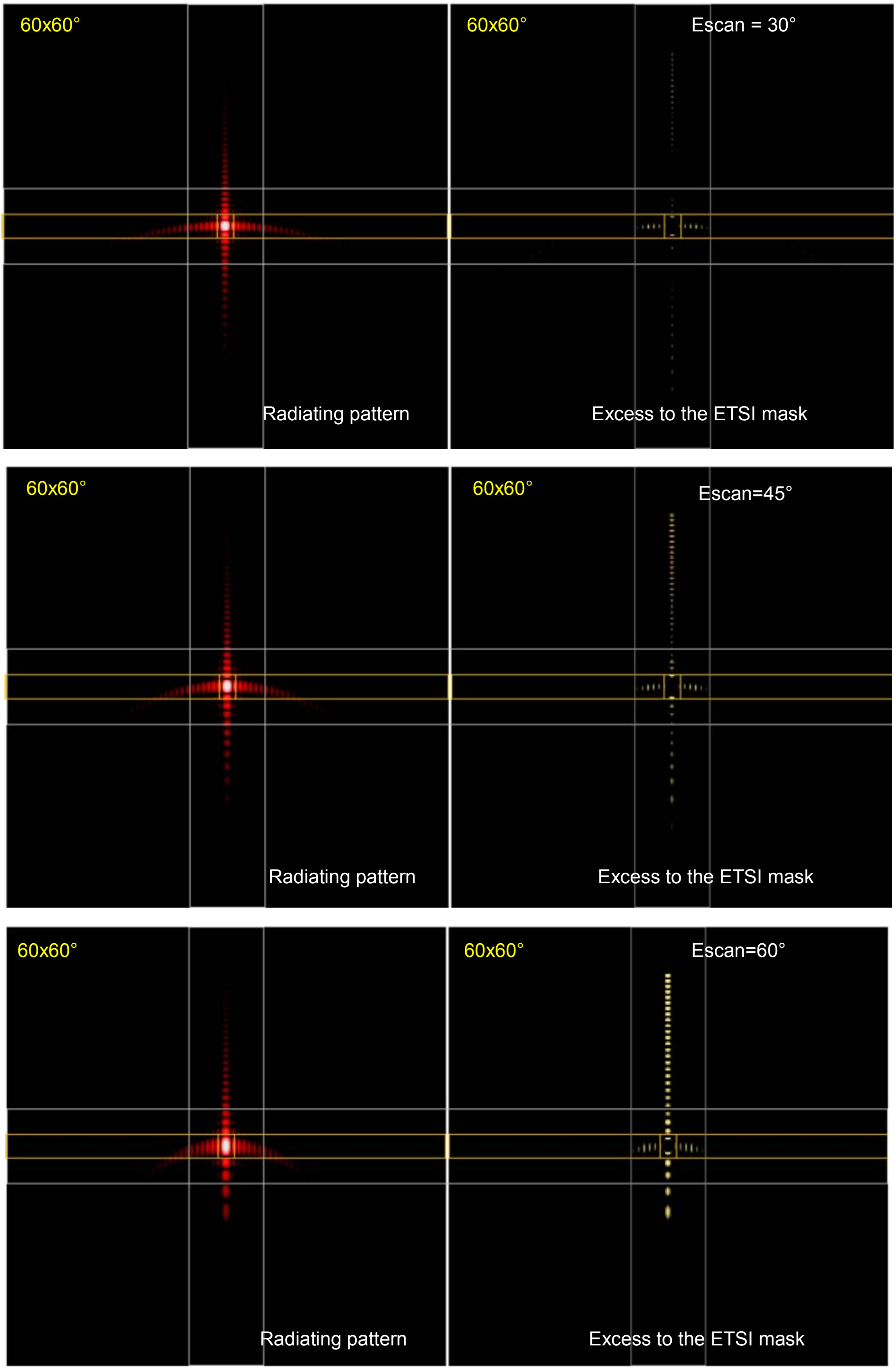


Figure 28: Square shaped ES-VA radiating patterns azimuth = 0°

Figure 29 highlights the cross shaped sidelobes being sensitive to the the related "Azimuth contra-rotation" effect.

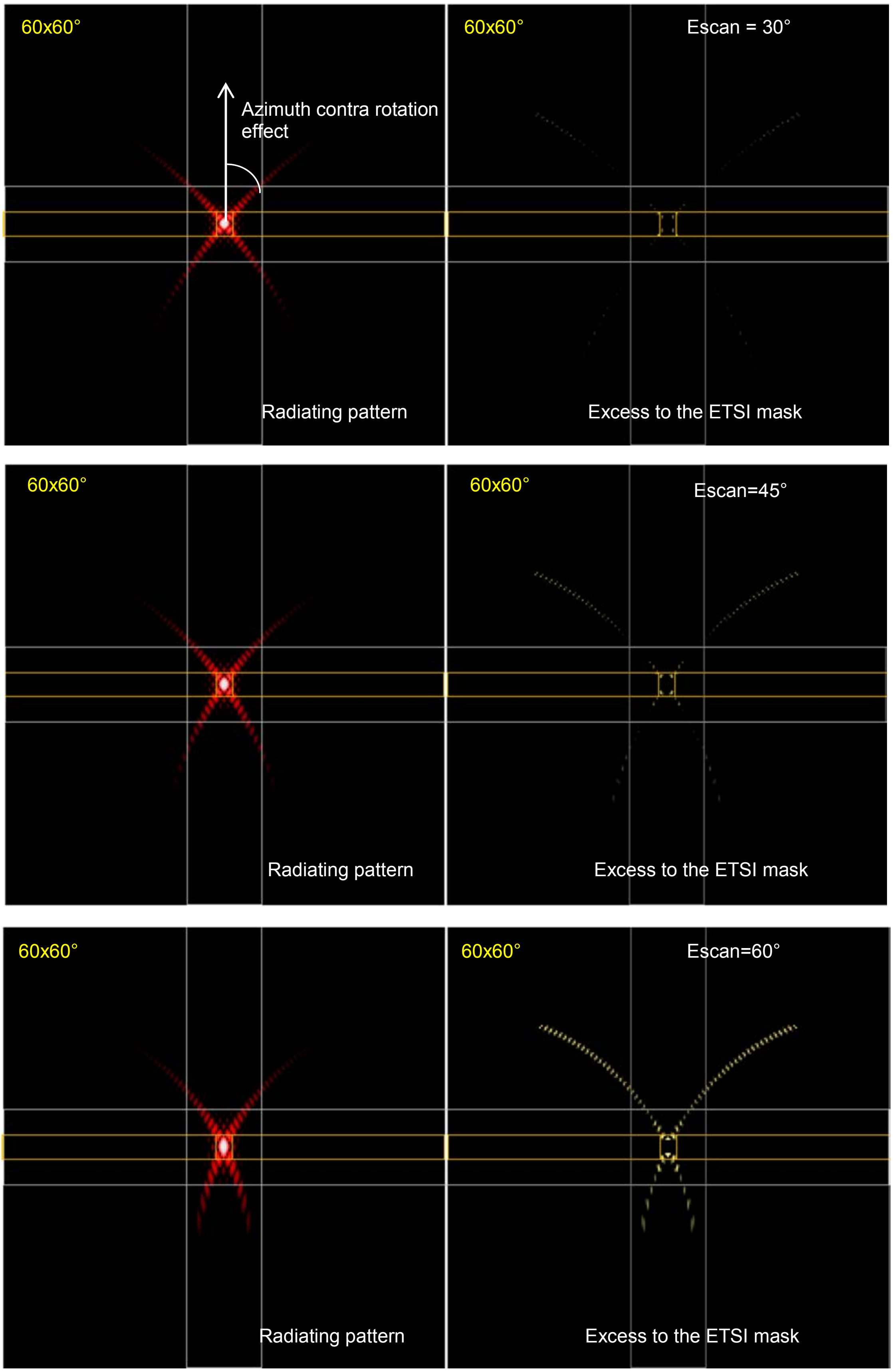


Figure 29: Square shaped ES-VA radiating patterns azimuth = 45°

Figure 30 provides a radiating pattern for escan = 75° and azimuth = 0°. The radiating pattern compares to the MS-FA antenna pattern of Figure 3, save for the downward directions. To some extent, an ES-VA antenna performs like an MS-FA antenna with an electric Elevation axis.

Figure 31, Figure 32 and Figure 33 provide other simulated radiating patterns.

Figure 34 provides a simulated radiating pattern for a circular shaped radiating panel to compare with.

The radiating pattern can suffer from several other impairments: spurious sidelobes, grating lobes, radome transmission and reflections, platform's body mask, etc., that are not described here.

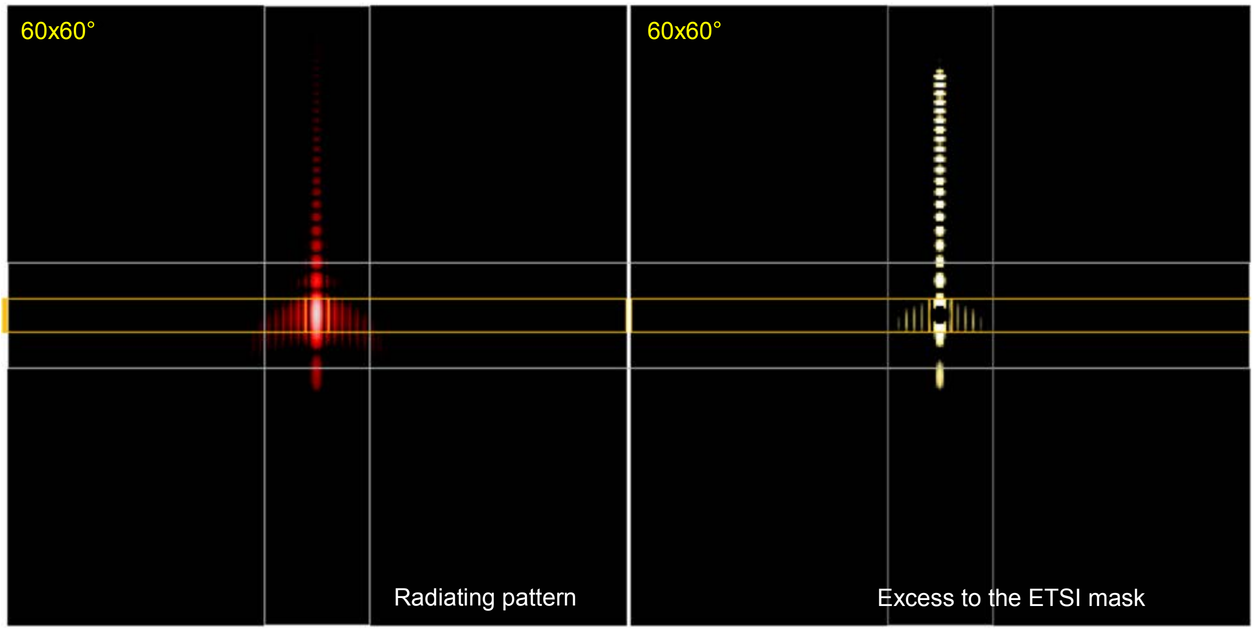


Figure 30: Square shaped ES-VA radiating pattern escan = 75° azimuth = 0° 2D view

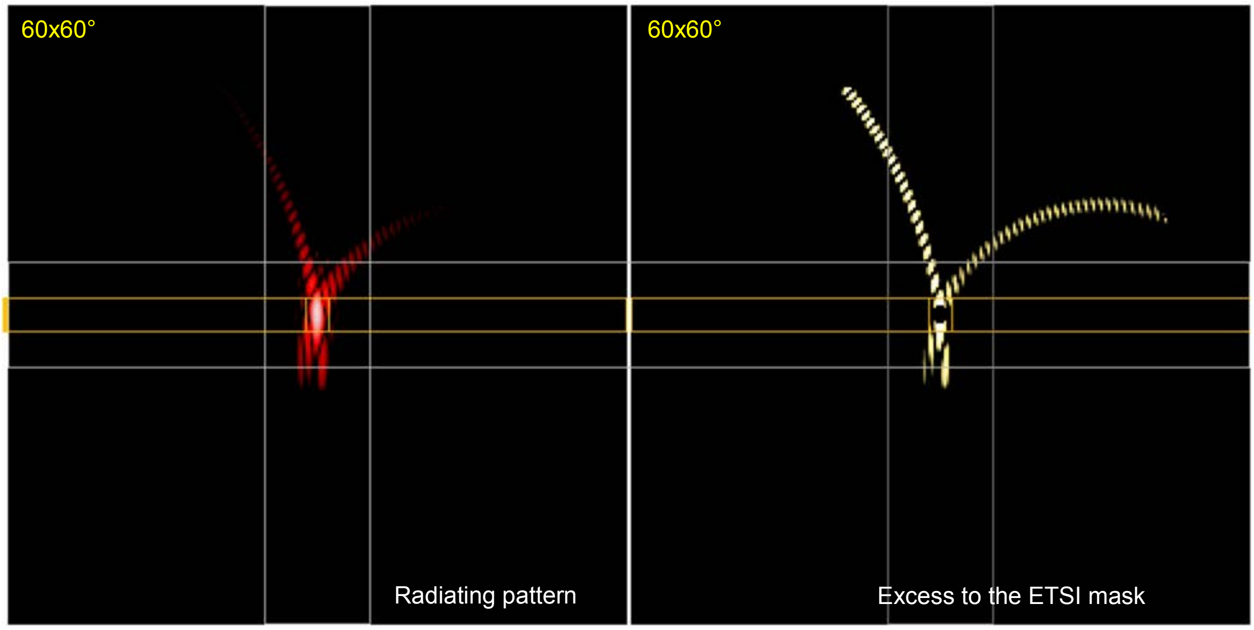


Figure 31: Square shaped ES-VA radiating pattern escan = 75° azimuth = 30° 2D view

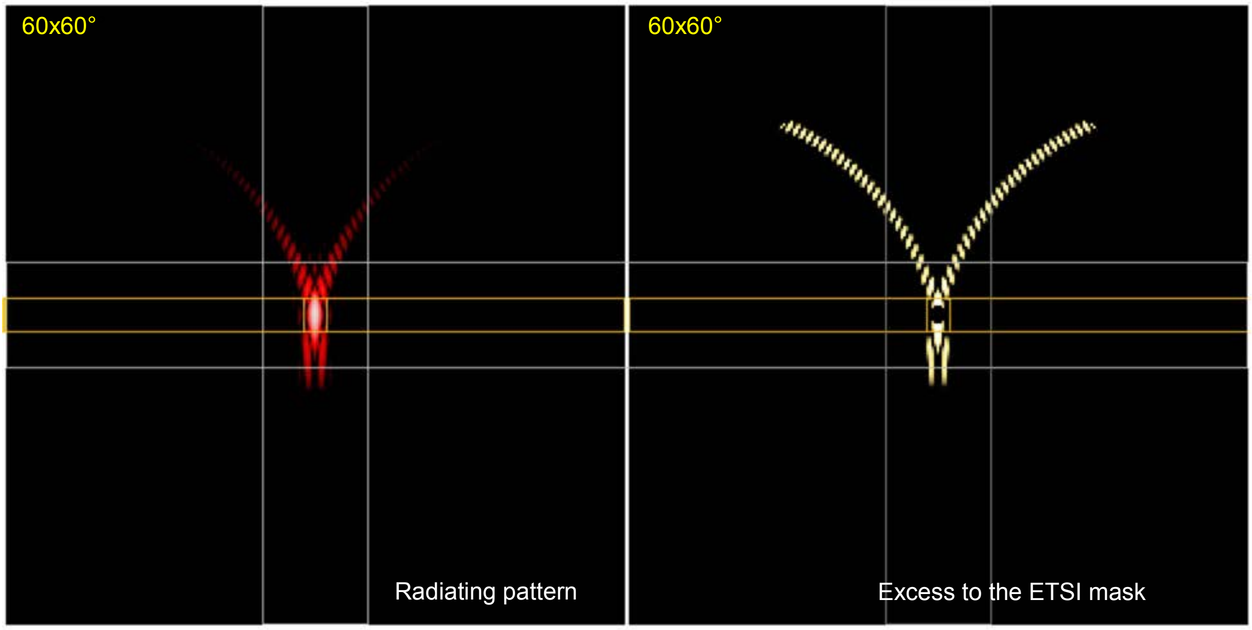


Figure 32: Square shaped ES-VA radiating pattern escan = 75° azimuth = 45° 2D view

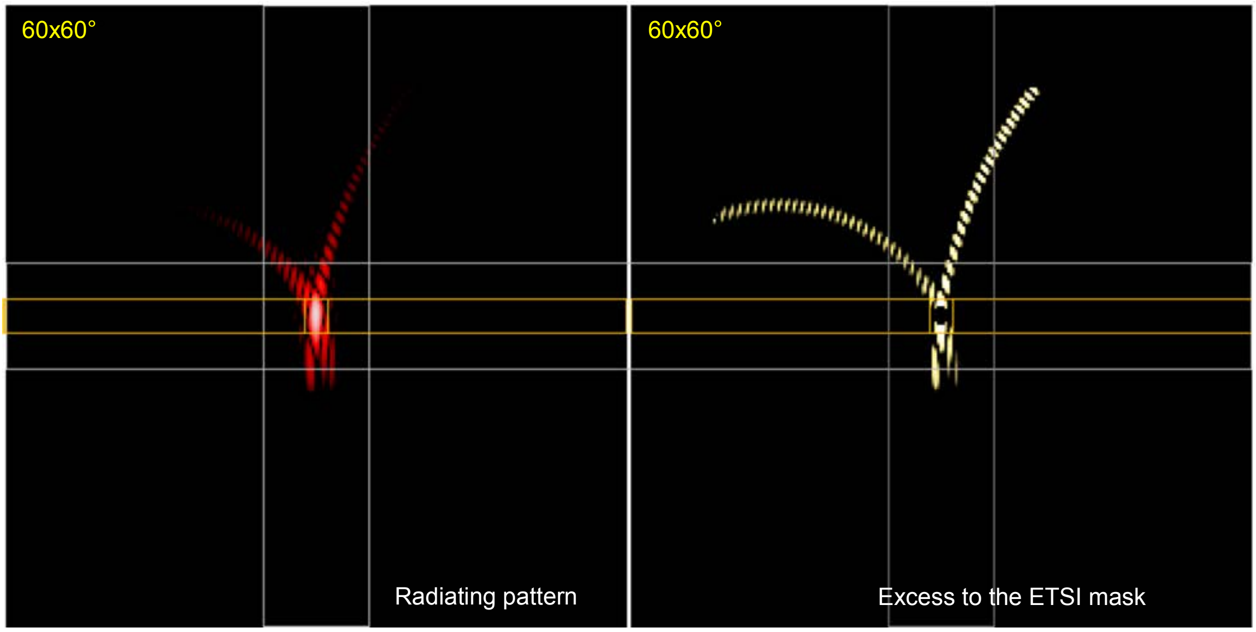


Figure 33: Square shaped ES-VA radiating pattern escan = 75° azimuth = 60° 2D view

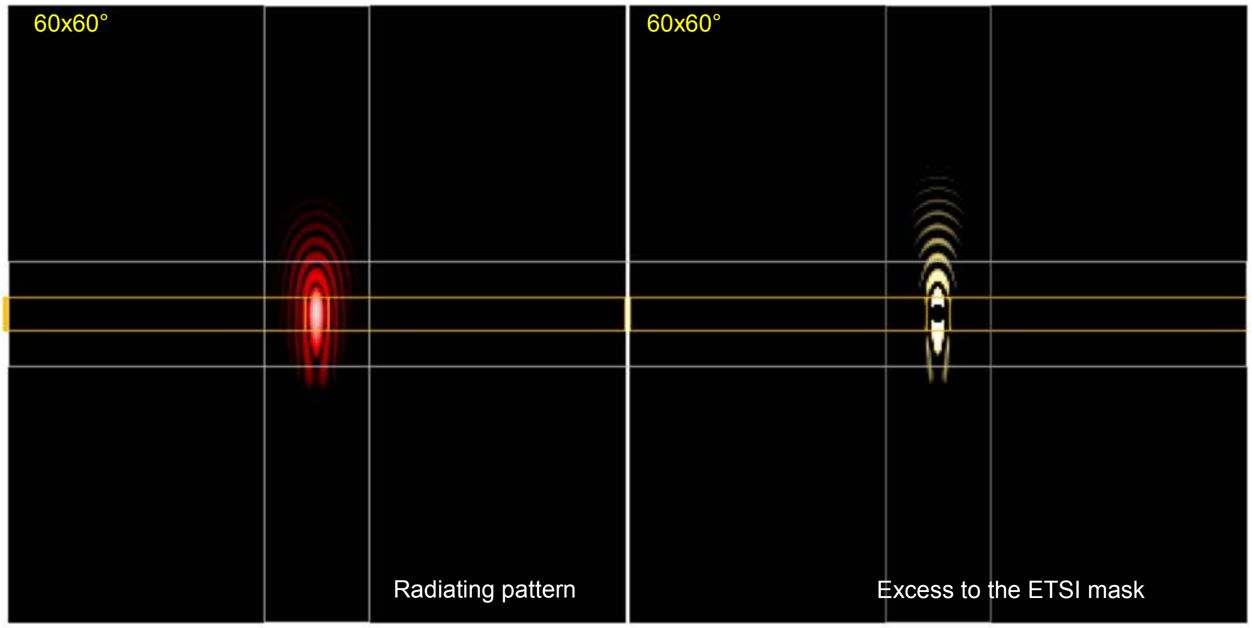


**Figure 34: Circular ES-VA radiating panel escan = 75° 2D view**

## 5.4 Conclusion

The radiating pattern of a low profile satcom antenna for mobile platforms is poorly directive in the directions that follow the narrow side of the radiating panel (and/or in the direction that follows the elevation toward the target satellite). Hence, the operations on the target satellite are skew sensitive.

A commonplace approach is to consider the off-axis EIRP density regulatory masks on the GSO arc only (e.g. ignoring the NGSO satellites):

- The MS-FA antenna can operate as long as the skew does not exceed a maximum, say ±45°. Furthermore MS-FA antennas cannot operate at the satellite nadir because of the azimuth gimbal lock effect.
- The HS-VA antenna can operate everywhere as long as the target satellite is in view and as long as the electric escan angle does not exceed its maximums (say ±45°).
- The ES-VA antenna requires a large radiating panel surface to operate at a minimum satellite elevation (say 20°).

The antenna radiating pattern can suffer from several impairments, from spurious sidelobes, grating lobes, radome transmission and reflections, platform's body masks.

Furthermore, the platform is moving and banking.

The NGSO satellites should be taken into account as potential victims systems. The same for terrestrial systems.

The "non-conformance area" (NCA) method, described in the following chapter, intends to address all these issues.

# 6 Analysis Methods & Procedures

## 6.1 Definition of the "non-conformance-areas" (NCA) method

### 6.1.1 The NCA method for "free space" radiating pattern

A "non-conformance-area" (NCA) is an area of preferably simple geometric shape modelling the antenna radiating pattern in the directions where the ETSI mask is exceeded.

For understanding, an example is provided hereafter for the MS-FA antenna case.

Figure 35 shows two NCAs defined on a MS-FA antenna free space radiating pattern: "high level" NCA (in red) and "low level" NCA (in yellow). The red NCA models the antenna main lobe with a 2 × 8° rectangular beam and an EIPR density of 25 dBW/40 kHz. The yellow NCA models the antenna sidelobes with a 2 × 96° rectangular beam and an EIRP density of 3 dBW/40 kHz.

Figure 36 provides a view of the two NCAs in the 2D plane of the antenna radiating pattern

Figure 37 provides a 3D view of the NCAs with regard to the platform.

Figure 38 provides a view of the NCAs from the platform, assuming the satcom antenna is aimed toward its target GSO satellite.

Figure 39 provides a view of the NCAs from the target GSO satellite.

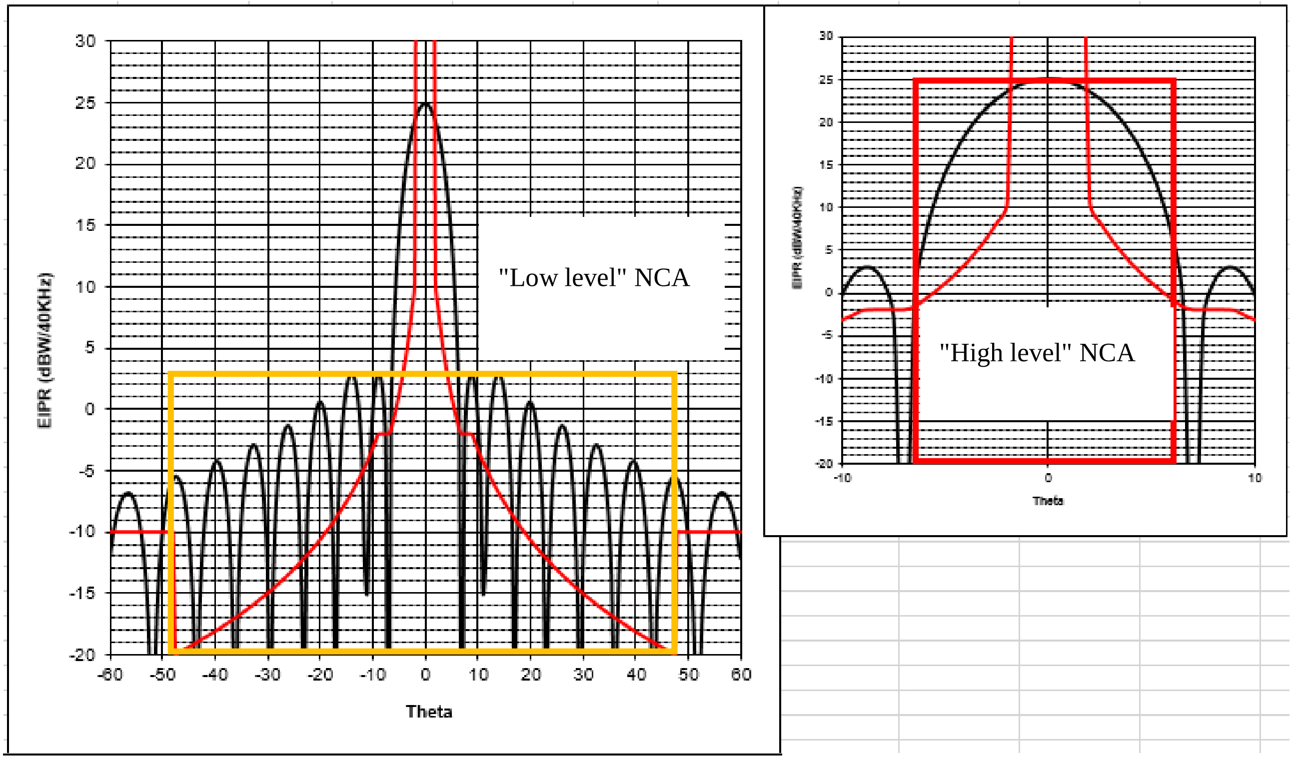


Figure 35: NCAs for MS-FA case 1D view

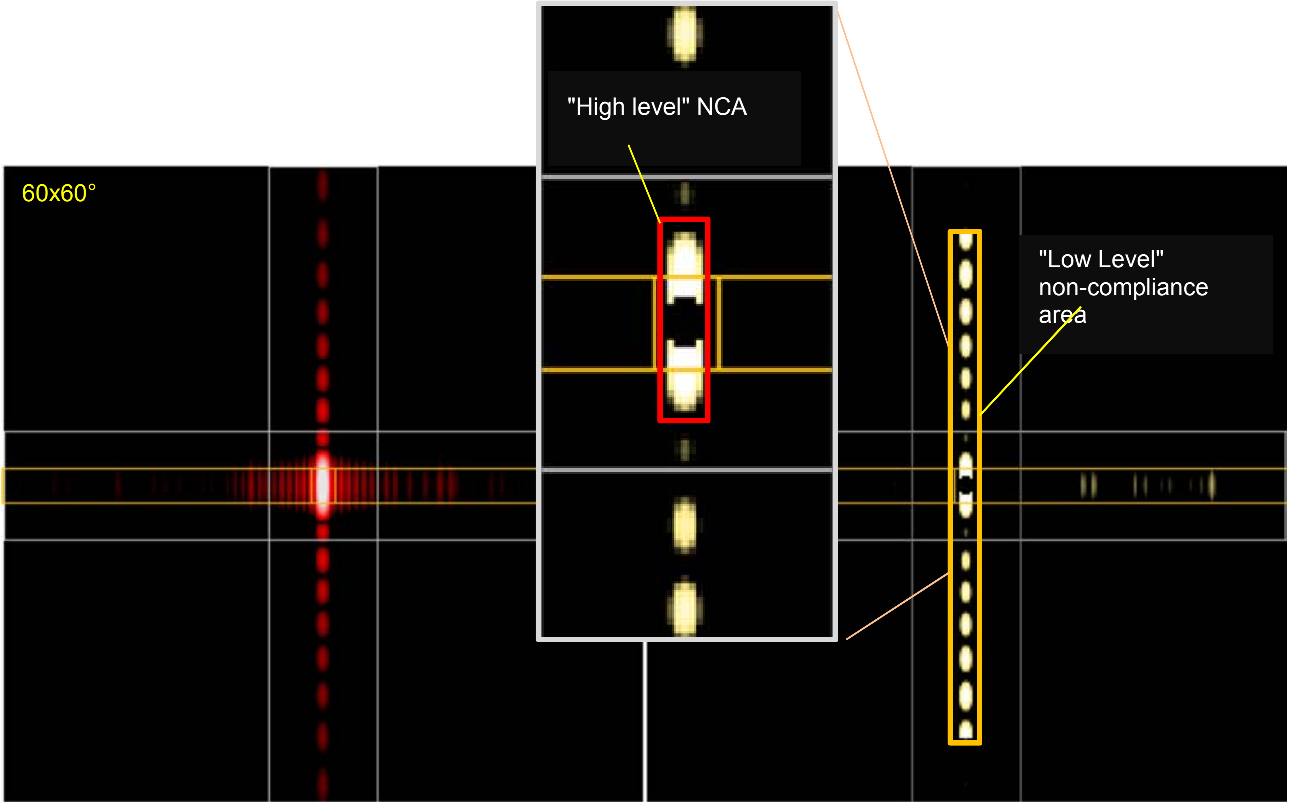


Figure 36: NCAs for an MS-FA case 2D view

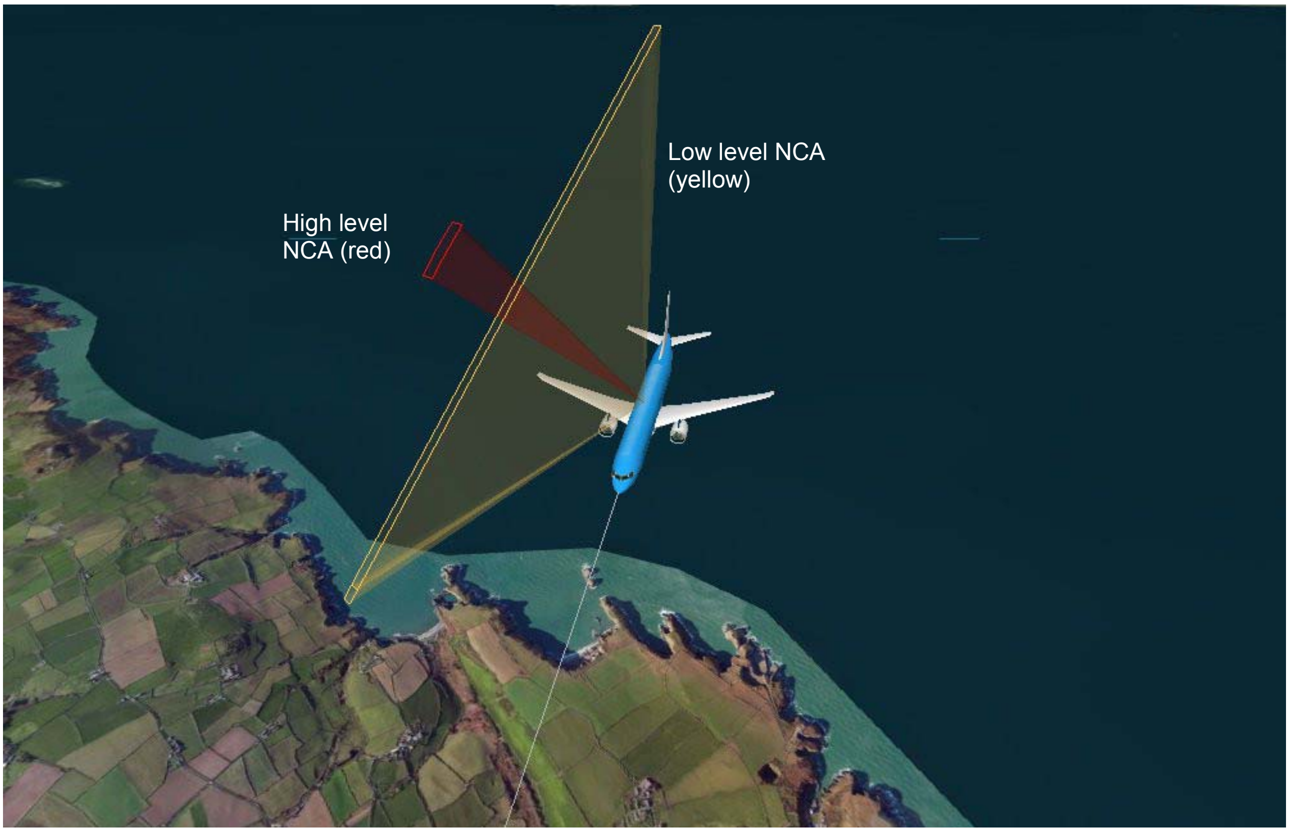


Figure 37: NCAs for an MS-FA antenna 3D view

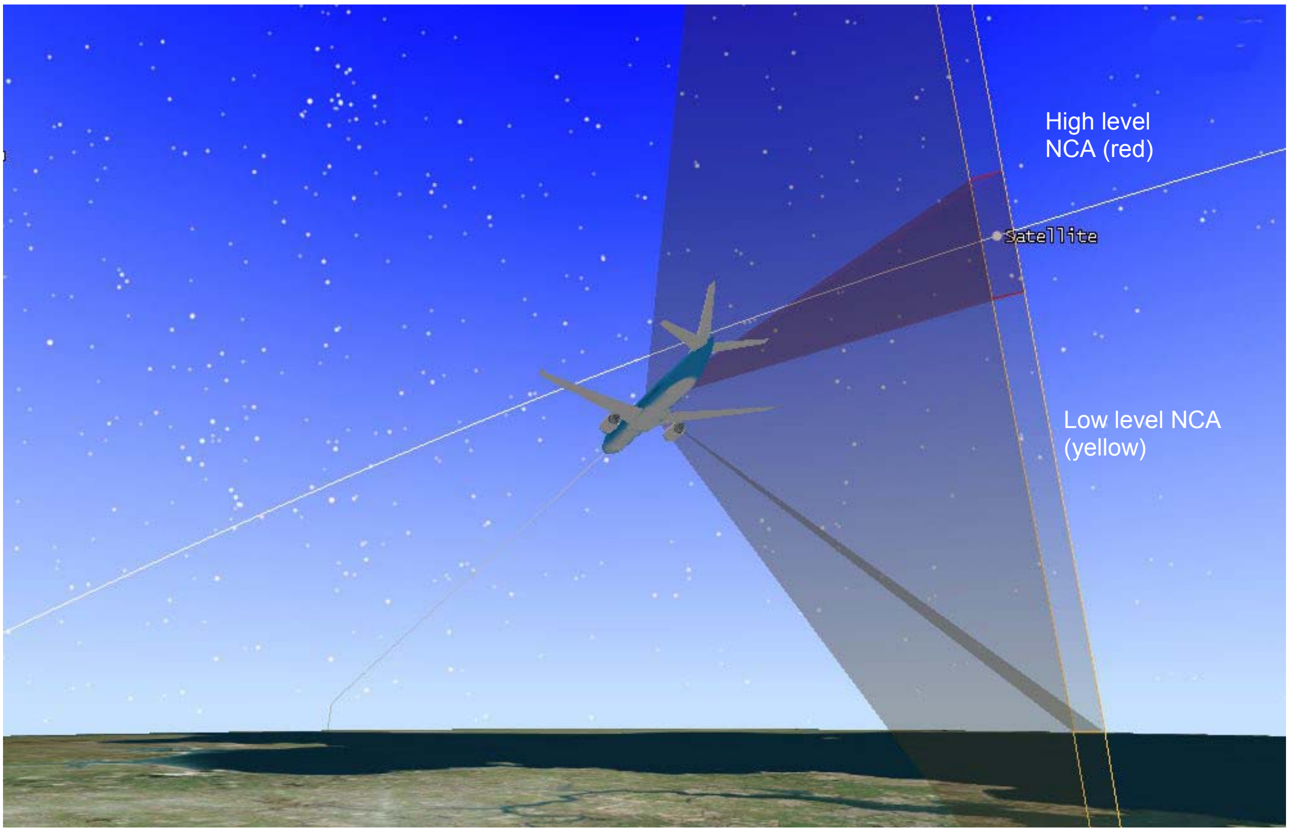


Figure 38: NCAs for an MS-FA antenna as viewed from the platform

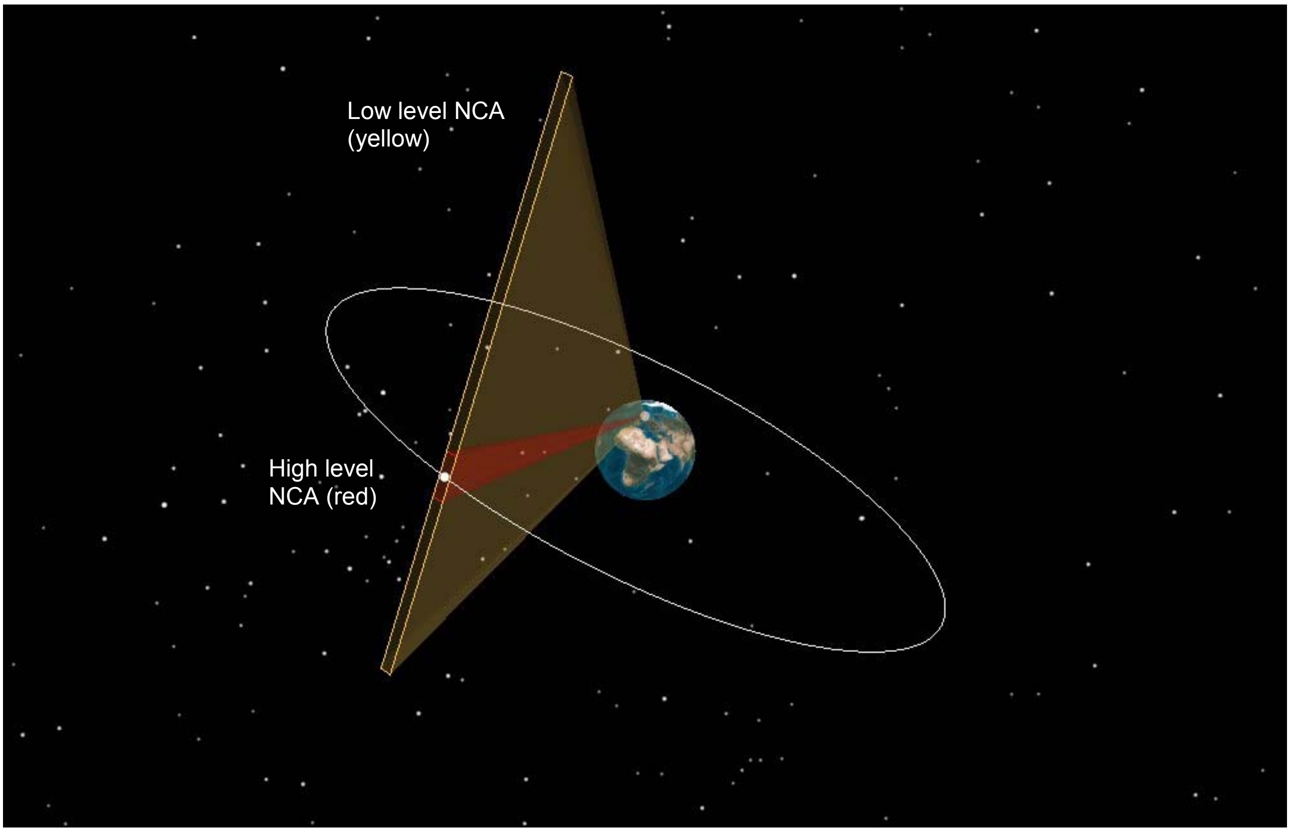


Figure 39: NCAs for an MS-FA as viewed from the satellite

## 6.1.2 The NCA method for "in-situ" measurement

### 6.1.2.1 Motion of the platform

The antenna attitude in space depends on the antenna aiming policy, the platform attitude and heading, the respective positions of the target satellite and the victims systems.

Figure 40 (snapshots movie like series) shows an aircraft in a coordinated turn bearing a MS-FA satcom antenna modelled by the 2 NCAs defined in clause 6.1.1. The variation of the skew angle is quite visible. The skew angle depends on the aircraft pitch and roll.

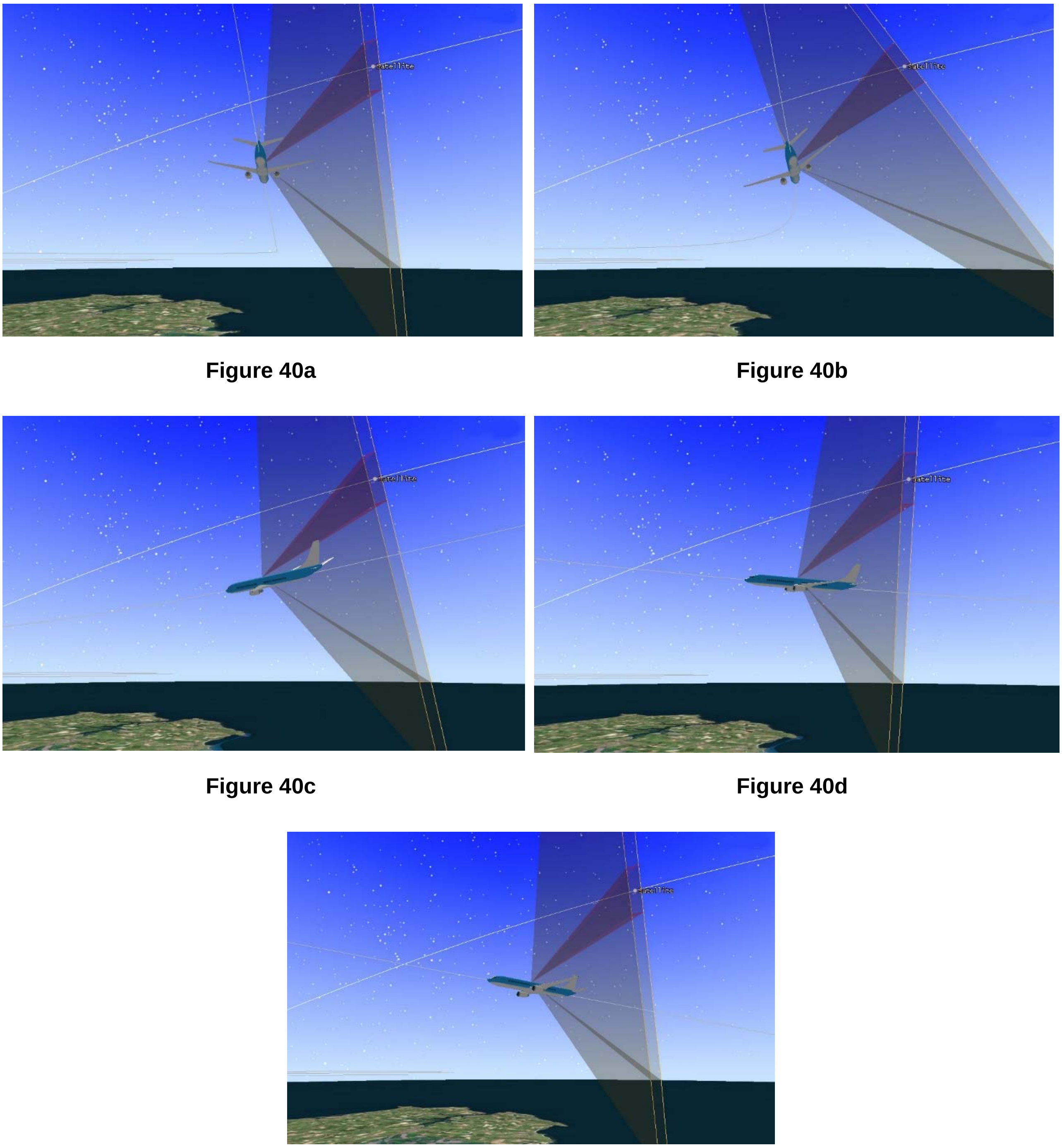


Figure 40a

Figure 40b

Figure 40c

Figure 40d

Figure 40e

Figure 40: Effect of an aircraft coordinated turn on the antenna skew

### 6.1.2.2 Installation of the antenna on the platform

The installation of the antenna on the platform modifies its free space radiating pattern in several ways.

The radome produces a tapering on the antenna aperture that inflates the main lobe, modifies the level of the sidelobes and generates backward reflexions.

Figure 41, extracted from the ECC report 184 [i.9], provides an assessment of the masking effect of an aircraft fuselage.

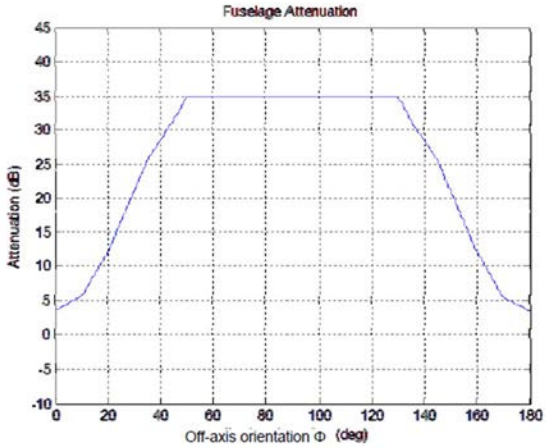


**Figure 41: Aircraft fuselage mask per ECC report 184 [i.9]**

Figure 42 and Figure 43 shows the implementation of an aircraft fuselage mask (the yellow dashed line).

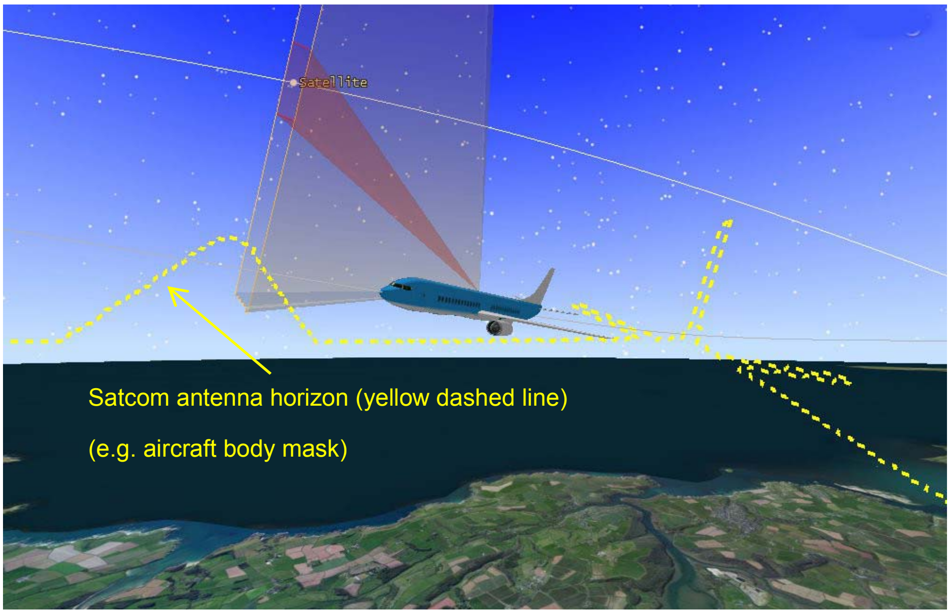


**Figure 42: Implementation of platform masks with NCAs as viewed from the platform**

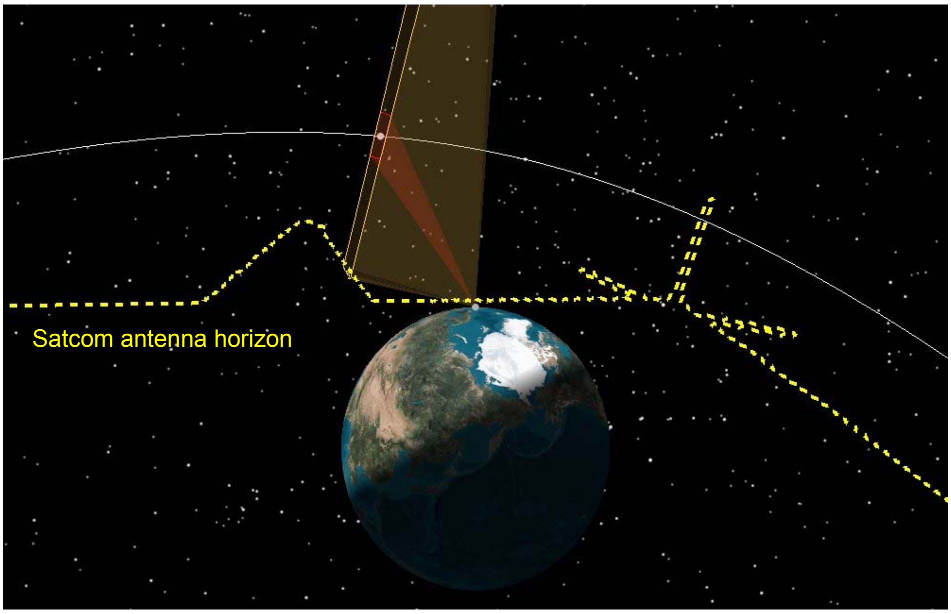


**Figure 43: Implementation of platform masks with NCAs as viewed from space**

# 6.2 Implementing the NCA method

## 6.2.1 The NCA method for MS-FA antenna

An MS-FA antenna has a cross shaped radiating pattern that can be easily modelled with a plain rectangular NCA.

On Figure 44, a rectangular "high level" NCA (red) surrounds the main lobe. A "low level" NCA (yellow) surrounds the narrow side sidelobes.

Method for MS-FA has been discussed in clause 6.1.1 (Figure 36, Figure 37, Figure 38, Figure 39 and Figure 40).

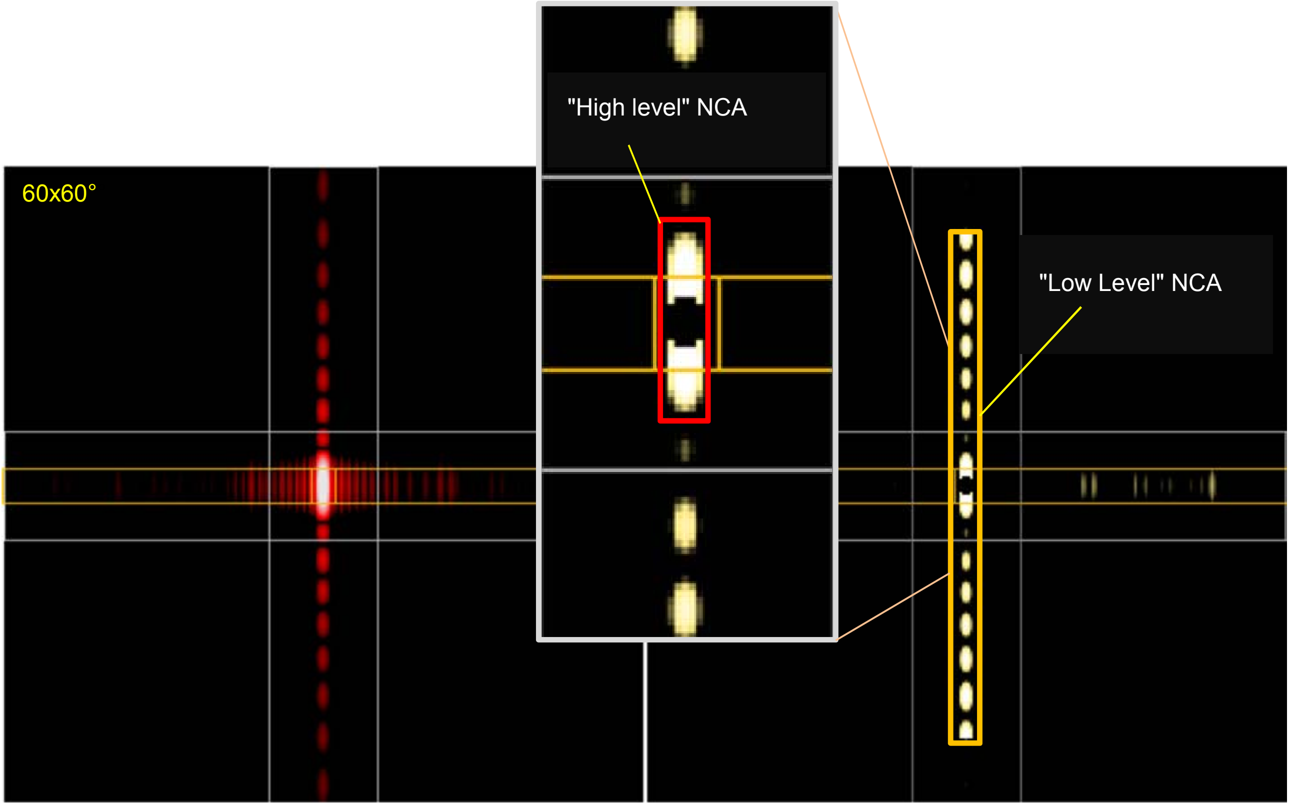


Figure 44: NCAs for the MS-FA antenna

### 6.2.2 The NCA method for HS-VA antenna

An HS-VA antenna has a cross-shaped radiating pattern (Figure 45) similar to an MS-FA antenna. The non-conformance-areas (NCAs) are defined a similar way with the adjustments as follow.

The "high level" NCA (red) slightly inflates with escan and in the escan direction. The "low level" NCA (yellow) takes an elliptic shape.

Phased arrays can have spurious sidelobes that are "covered" by the dedicated NCA on the right side of the Figure 45.

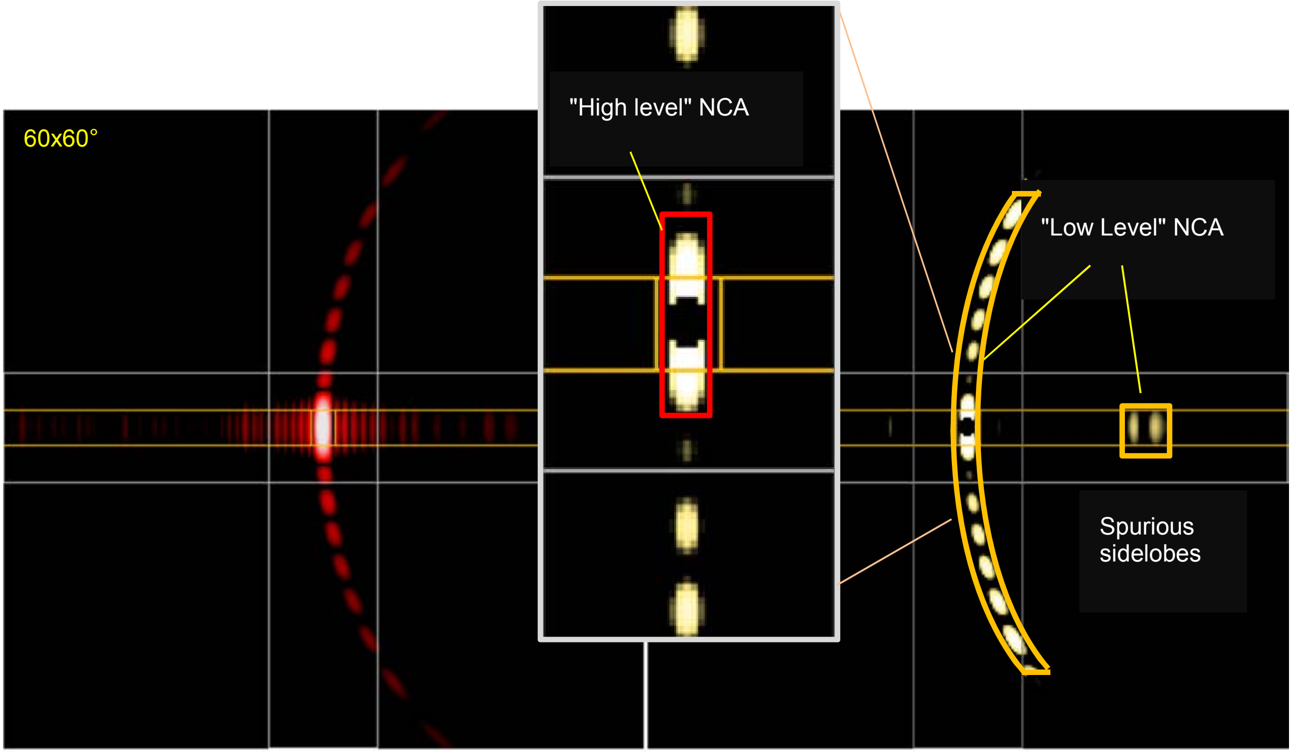


Figure 45: NCAs for the HS-VA antenna escan = 30°

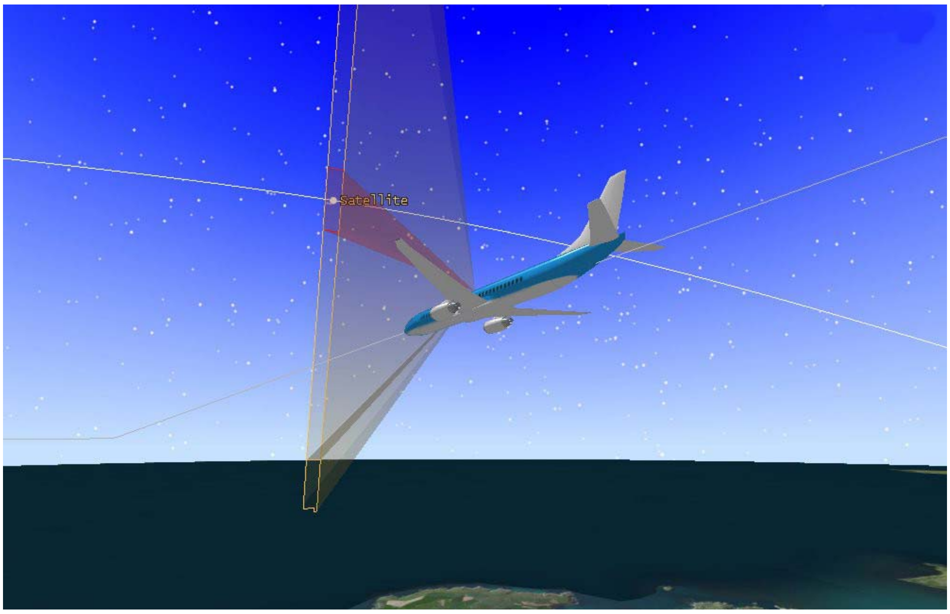


Figure 46: NCAs for the HS-VA antenna escan = 0° as viewed from the platform

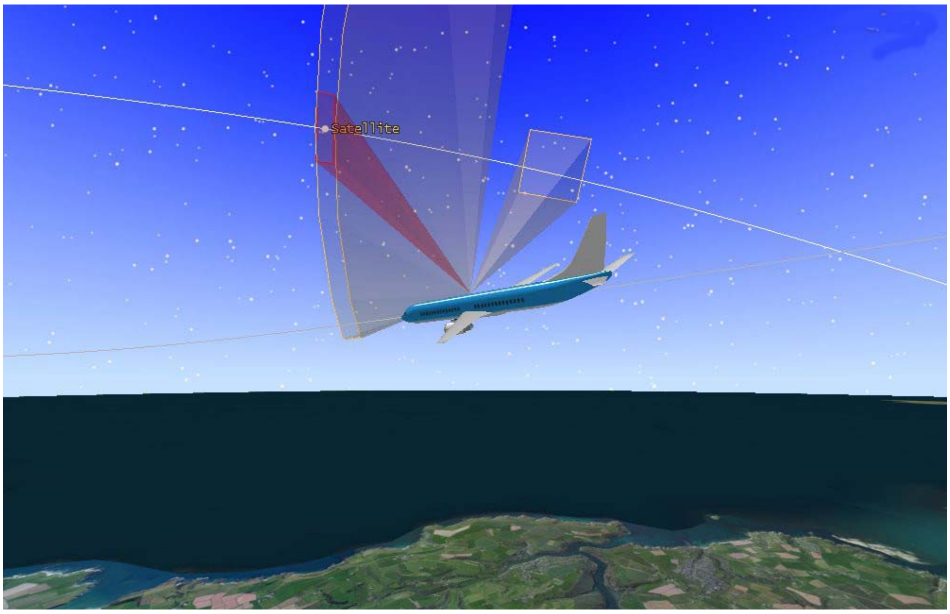


**Figure 47: NCAs for the HS-VA antenna escan = 30° as viewed from the platform**

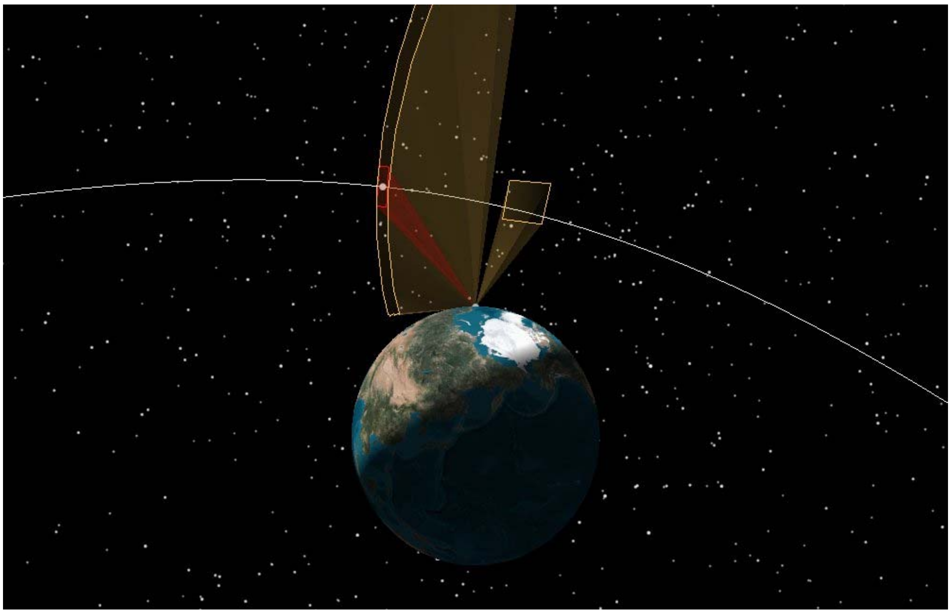


**Figure 48: NCAs for the HS-VA antenna escan = 30° as viewed from space**

### 6.2.3 The NCA method for ES-VA antenna

NCAs are defined following the method used for the HS-VA antenna. Figure 49 shows a "high level" NCA in red and a "low level" NCA in yellow. The "low level" NCA has a warped cross shaped pattern, which follows elliptic curves. The NCAs are platform heading and attitude sensitive.

ES-VA antenna may have spurious sidelobes and grating lobes that are not shown on Figure 49.

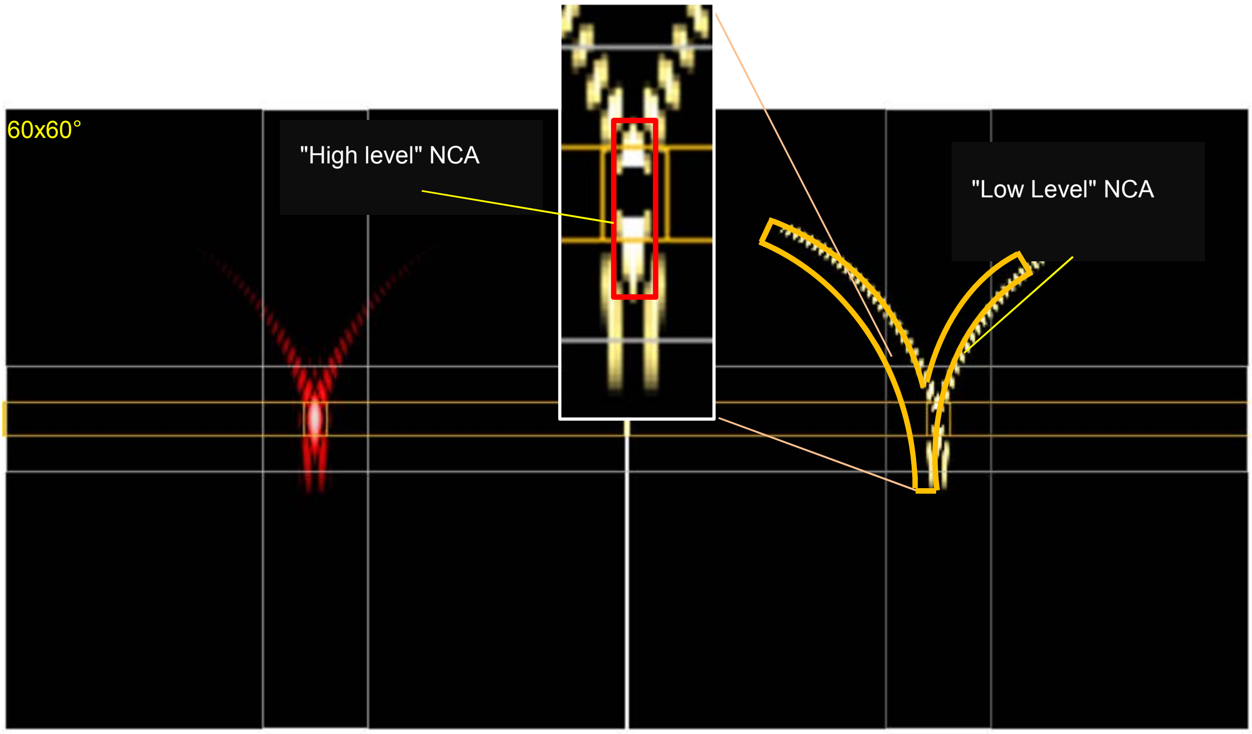


Figure 49: NCAs for the ES-VA antenna escan = 75° azimuth = 30°

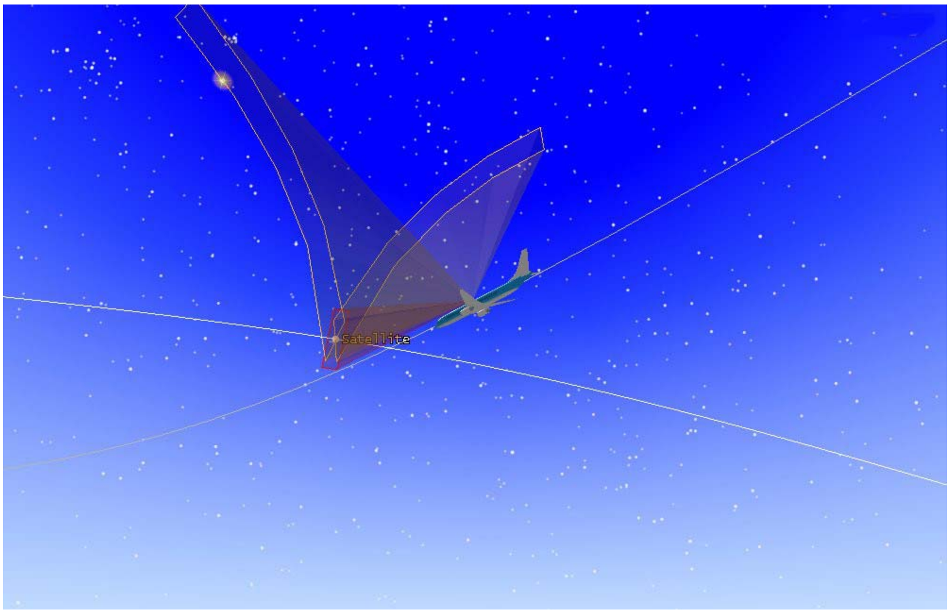


Figure 50: NCAs for the ES-VA antenna escan = 75° azimuth = 30° as seen by the platform

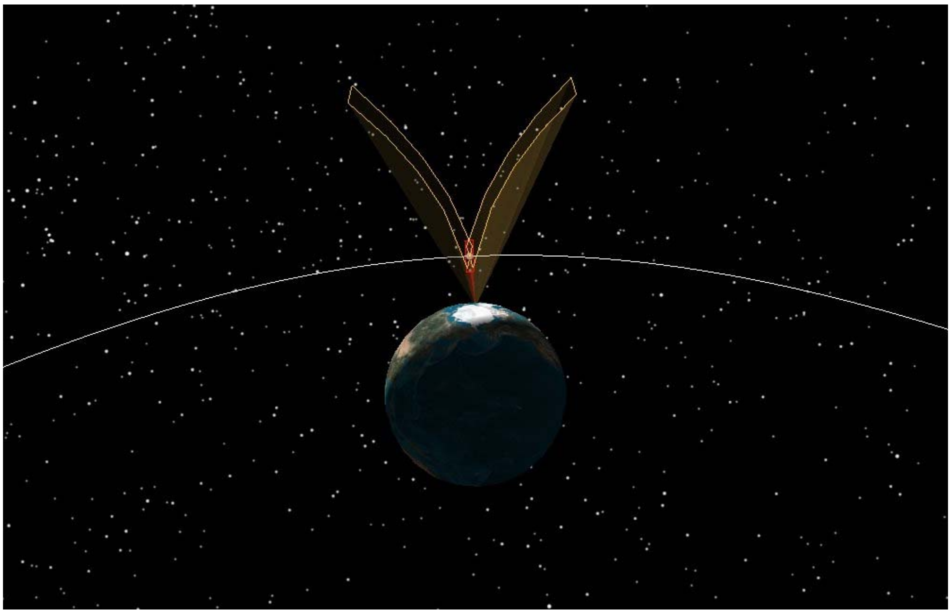


Figure 51: NCAs for the ES-VA antenna escan = 75° azimuth = 30° as seen from space

### 6.2.4 Conclusion about the NCA method

The NCA method permits to work out a simple model of the antenna radiating pattern for the purpose of an interference **occurrences** analysis in the scope of a non-conformance to the ETSI mask.

The directions of attention are the directions where the ETSI off-axis EIRP density mask is exceeded.

There is no rule for defining NCAs save pragmatism and accuracy. On one hand, the model should be as refined as required. On the other hand it should be kept as simple as possible for the ease of understanding.

The NCA method applies to any satcom antennas type and can be extended to reception replacing EIRP density by antenna gain.

Clause 7 illustrates the benefit of the NCA method for the sharing with others system issue.

# 7 Sharing with Other Systems

## 7.1 Current Regulatory Environment

The applicable standards listed in clause 2 define off-axis EIRP density masks for earth stations operating on GSO satellites. There are coarsely summarized hereafter.

Recommendation ITU-R S.524-9 [i.3] GSO off-axis EIRP density mask:

- Ku band: 12,75 GHz to 13,25 GHz and 12,75 GHz to 14,5 GHz:

| | |
|---|---|
| - 2,5° ≤ phi ≤ 7° | 39-25 log (phi) dBW/40 kHz |
| - 7° < phi ≤ 9,2° | 18 dBW/40 kHz |
| - 9,2° < phi< 48° | 42-25 log (phi) dBW/40 kHz |
| - 48° < phi ≤ 180° | 0 dBW/40 kHz |

  "phi" being the topocentric separation angle between the traffic satellite and the potential victim satellite.

- Ka band: 27,5 to 30 GHz:

| | |
|---|---|
| - 2° ≤ phi ≤ 7° | 19-25 log (phi) dBW/40 kHz |

  - 7° < phi ≤ 9,2° -2 dBW/40 kHz
  - 9,2° < phi< 48° 22-25 log (phi) dBW/40 kHz
  - 48° < phi ≤ 180° -10 dBW/40 kHz

  "phi" is the topocentric separation angle between the target satellite and the potential victim satellite. These masks can anyway be exceeded by 3 dB outside 3° of the GSO arc.

Note that these masks are "clear sky" masks. They can be exceeded in presence of adverse atmospheric propagation (rain, fog, clouds) as long as the PFD limit (Power density flux in W/($m^2$ × MHz) at the victim satellite under clear sky conditions is not exceeded.

ETSI GSO off-axis EIRP density mask:

- Ku band: -6 dB below the Recommendation ITU-R S.524-9 [i.3] mask inside ±3° of the GSO arc. Recommendation ITU-R S.524-9 [i.3] mask outside ±3° of the GSO arc.
- Ka band: identical to the Recommendation ITU-R S.524-9 [i.3] mask.

FCC off-axis EIRP density mask:

- Ku band:
  - -14 dB below the Recommendation ITU-R S.524-9 [i.3] mask from 1,5° to 85°.
  - -4 dB below the Recommendation ITU-R S.524-9 [i.3] mask from 85° to 180°.
- Ka band: -0,5 dB below the Recommendation ITU-R S.524-9 [i.3] mask, after shifting the 9,2° step to 9,23°.

The EIRP density masks are typically decaying with the angle "phi". This reflects the state of the art for symmetrically shaped antennas (for instance parabolic antennas).

Of interest is the permitted off-axis EIRP density that can be transmitted by an Earth station to a victim satellite immediately adjacent to its target satellite. They are provided in Table 1.

### Table 1: Maximum permitted EIRP density to the adjacent satellite

| Standard | Adjacent satellite separation | Max. permitted EIRP density clear sky to the adjacent satellite |
|---|---|---|
| ITU-R S.524-9 Ku (see Recommendation ITU-R S.524-9 [i.3]) | 2,5° | 29,1 dBW/40 kHz |
| ETSI Ku AES (see ETSI EN 302 186 [i.7]) | 2,5° | 23,1 dBW/40 kHz |
| FCC VMES ESV ESAAs Ku (see FCC ESAAS 47 CFR 25.227 [i.2]) | 1,5° | 20,6 dBW/40 kHz |
| ITU-R S.524-9 Ka (see Recommendation ITU-R S.524-9 [i.3]) | 2° | 11,5 dBW/40 kHz |
| ETSI Ka ESOMP (see ETSI EN 303 978 [i.8]) | 2° | 11,5 dBW/40 KHz |
| FCC FSS Ka (see FCC 47 CFR 25.138 [i.1]) | 2° | 11,0 dBW/40 kHz |

Table 1 can be compared with Table 2 that provides the EIRP density that meets the victim satellite noise level in clear sky condition. For instance, a Ka band earth station transmitting an off-axis EIRP of 11,5 dBW/kHz to a 20 dB/K G/T victim GSO satellite produces an approximately 3 dB G/T degradation to that victim GSO satellite while conforming to the ETSI/FCC masks.

### Table 2: EIRP density clear sky that meets the victim satellite noise level

| Frequency band | Victim GSO satellite G/T | EIRP clear sky that meets the victim satellite noise level |
|---|---|---|
| Ku band 14 GHz | 2 dB/K | 22,8 dBW/40 kHz |
| Ku band 14 GHz | 14 dB/K | 10,8 dBW/40 kHz |
| Ka band 30 GHz | 10 dB/K | 21,4 dBW/40 kHz |
| Ka band 30 GHz | 20 dB/K | 11,4 dBW/40 kHz |

The formulae used in Table 2 is $EIRPdensity(W/Hz) = \frac{4\pi}{\lambda^2} \cdot \frac{kT}{G} \cdot 4\pi d^2$ where λ is the wavelength, k is the Boltzmann constant, "d" is the interfering earth station to the victim satellite distance #40 000 km, "G/T" is the victim satellite G/T.

The $4\pi d^2/G$ ratio is approximately the spot surface on the Earth; Table 2 is thus valid for a NGSO satellite that has the same spot surface as a GSO satellite spot showing the G/T of Table 2.

Referring to No 22.5D of the ITU Radio Regulations [i.4], a system of NGSO earth stations can transmit an interfering aggregate EIRP (clear sky) to the GSO arc up to -2 dBW/40 kHz for Ku band, and up to 0 dBW/40 kHz for Ka band.

## 7.2 Pragmatic Sharing Approach

### 7.2.1 General

As long as there is no victim system in the directions of a NCA, there is no possible illegitimate interference occurrence for that direction. When a victim system happens to be in the direction of a NCA, an interference event can occurs while the interferer is not conforming. This event is called a "hit". The interferer should normally stop transmission.

The rationale underlying the NCA method suggests a pragmatic sharing approach based on the statistic of the "hits".

To illustrate the benefit of this method, the following assumptions are taken in this clause:

- An aeronautical satcom on board an aircraft cruising at 30 000 feet and 800 km/h and zig-crossing the US territory from 130W to 60W longitude and 10N to 50N latitude (Figure 52).
- The target GSO satellite is located at 115.1W longitude (Figure 53).
- The target satellite is surrounded by two adjacent victim GSO satellites ±2° apart.
- The satcom antenna is a MS-FA antenna type, with a radiating pattern showing:
    - A high level NCA 2 × 8° (red) (Figure 53 and Figure 54).
    - A low level NCA 2 × 96° (yellow) (Figure 53 and Figure 54).

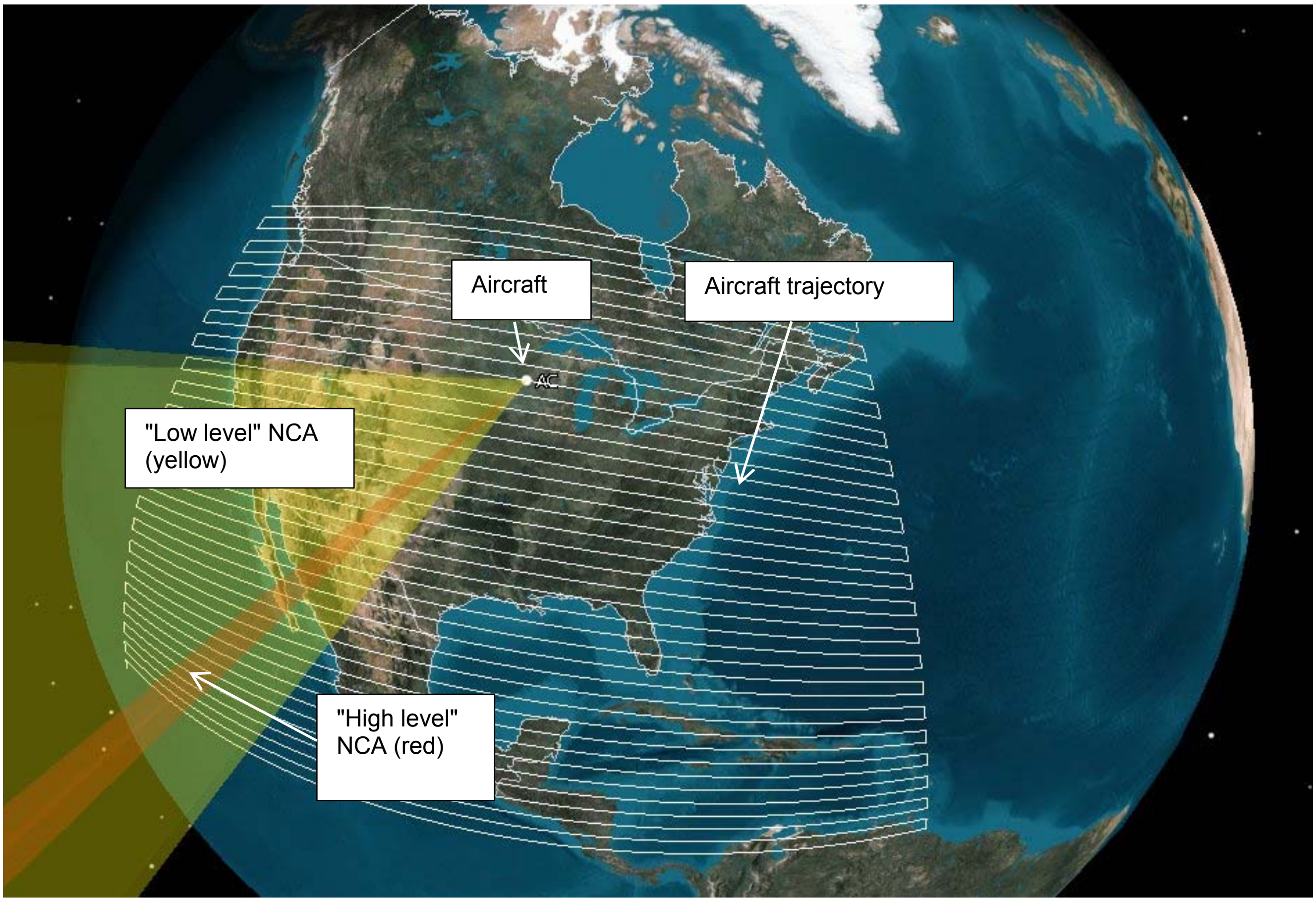


Figure 52: Aircraft trajectory study case

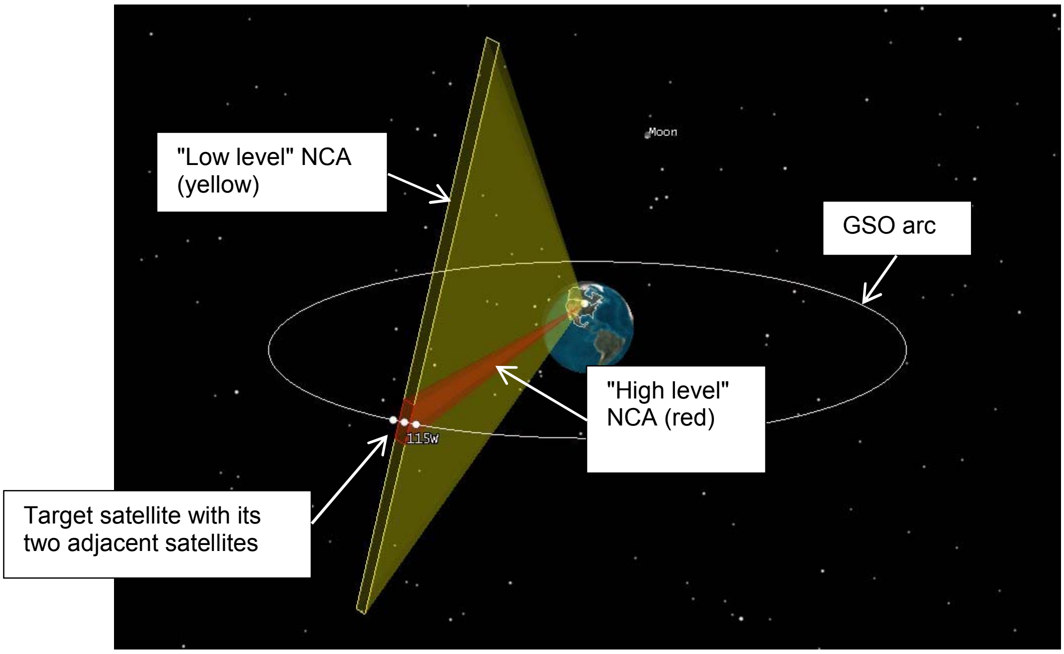


Figure 53: NCAs viewed from space

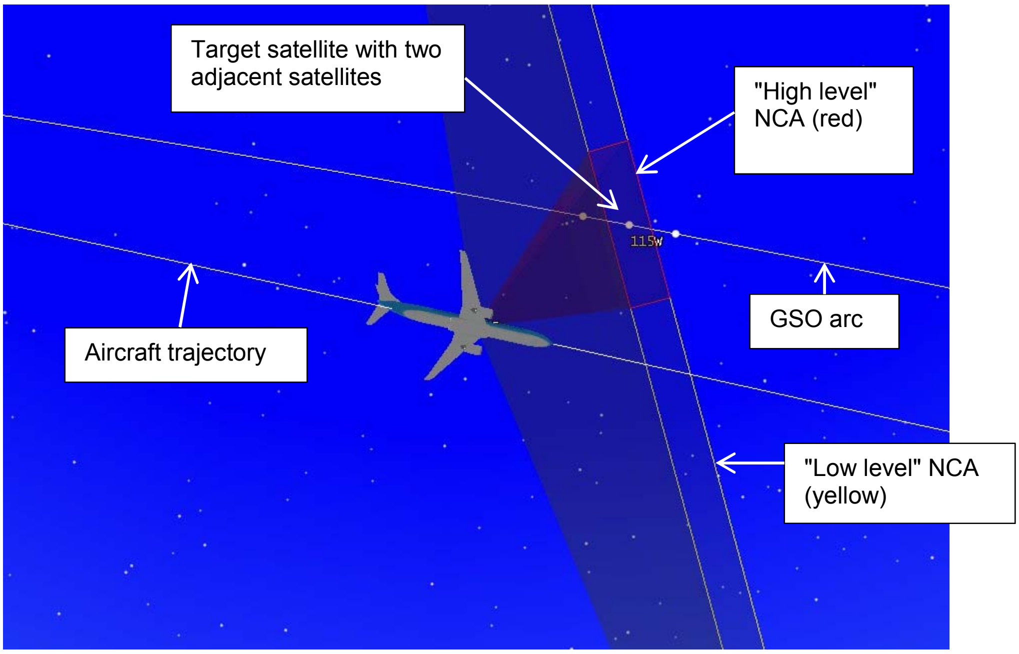


**Figure 54: NCAs viewed from the aircraft**

### 7.2.2 Terrestrial Systems

Figure 55 shows the case of a hit to a terrestrial systems case. The "low level NCA" of the airborne satcom antenna is transmitting in the direction of the receive beam of a victim LOS station (assumed to be a #10° half angle cone).

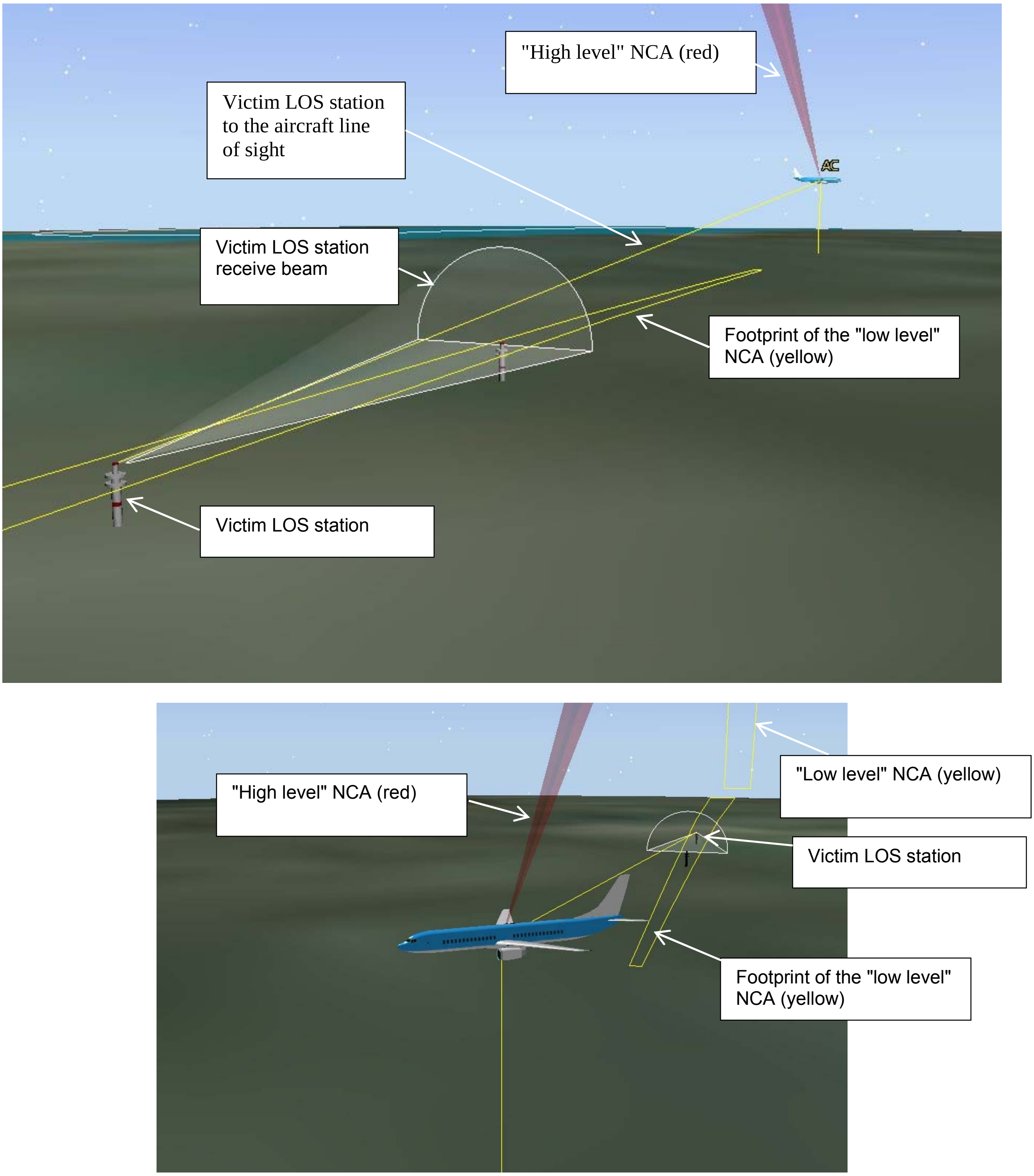


**Figure 55: A terrestrial system hit case**

Figure 55 shows the places on the aircraft trajectory where the hit occurs (yellow marks on the aircraft trajectory). The hit duration actually depends on the aircraft heading. The magnitude of the hit depends on the distance between the aircraft and the victim LOS station. The LOS station location and its receiver characteristics are not always know, while the aircraft can be in line of sight of a LOS station as far as 400 km as shown on Figure 57. Mastering hits to terrestrial systems requires the knowledge of the LOS stations position and sensitivity.

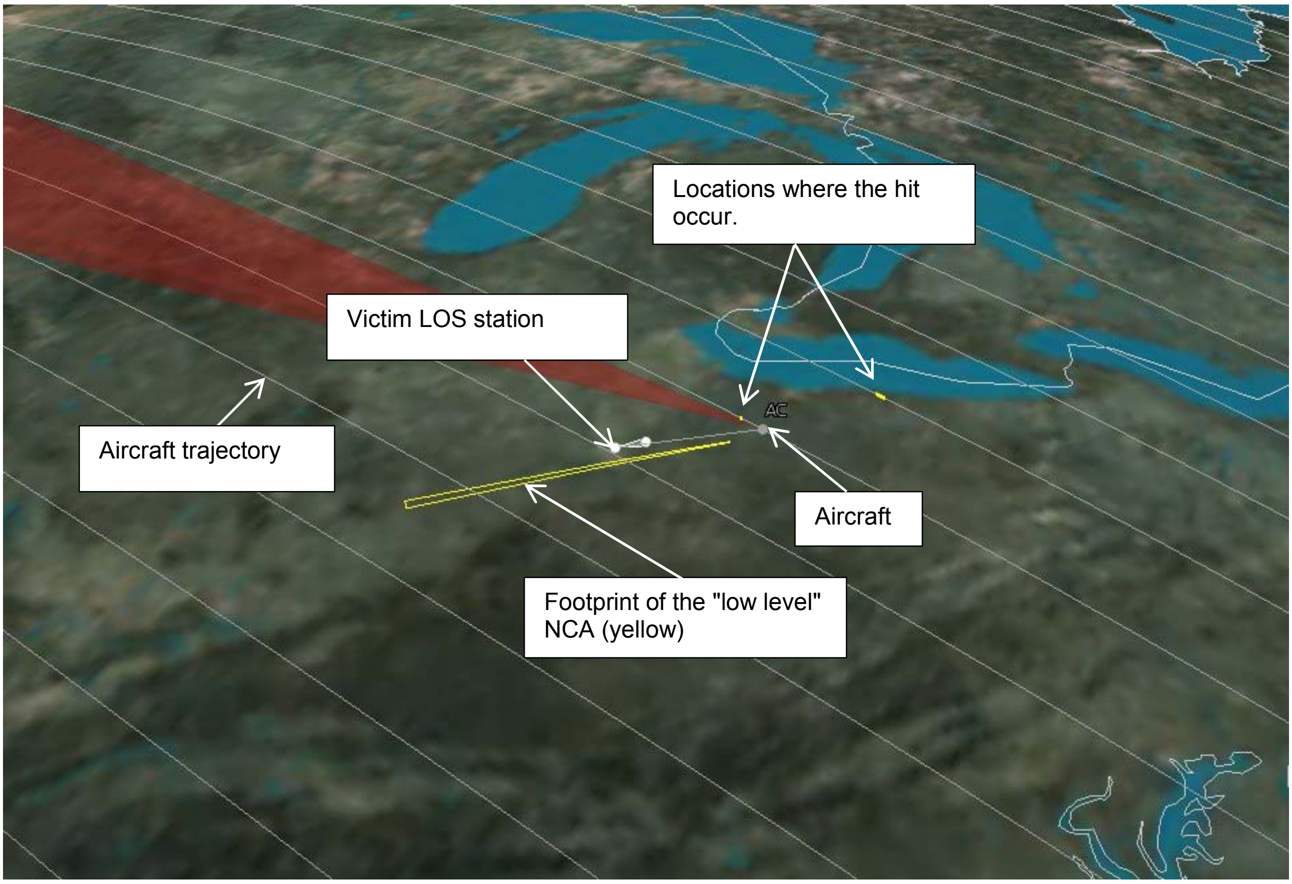


Figure 56: Hit analysis for a terrestrial system

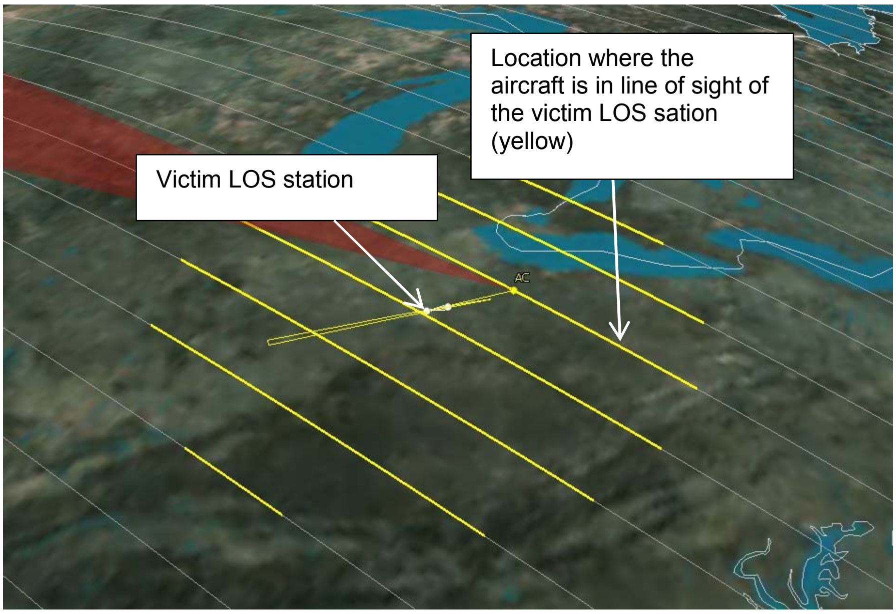
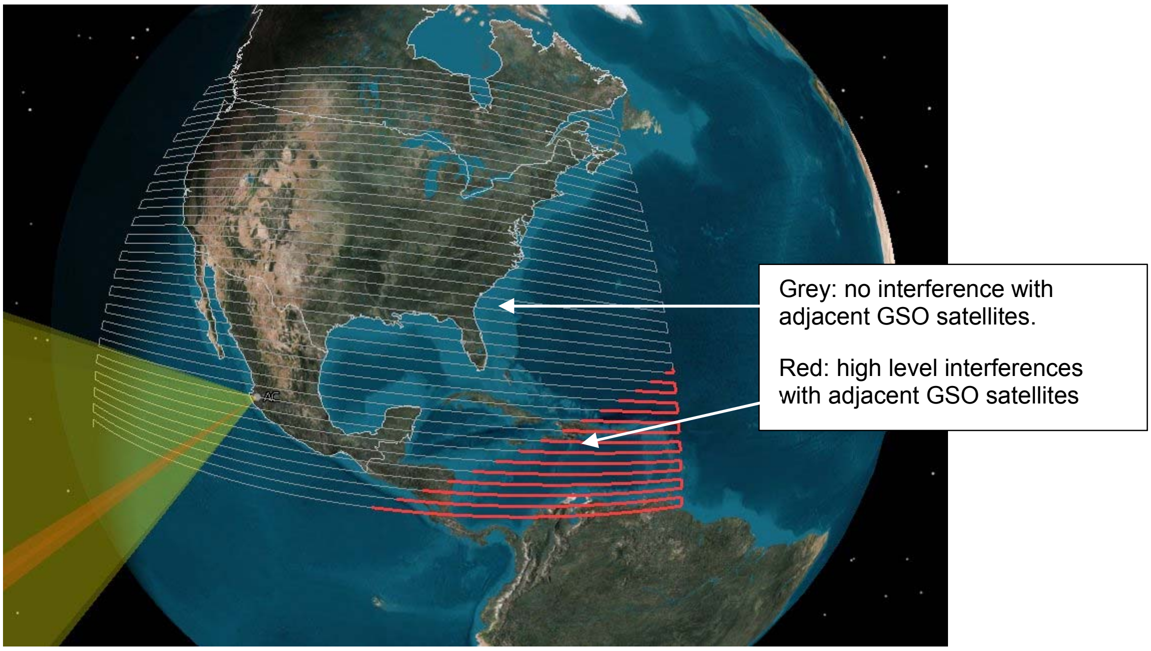


Figure 57: Aircraft locations in line of sight of the victim LOS station

### 7.2.3 Adjacent GSO Networks

Figure 58 shows the places on the aircraft trajectory (red) where hits with the adjacent satellites occur. For ease of understanding, the Figure 59 shows a no hit case and Figure 60 and Figure 61 show a hit case. The hits are "high level" (involve the "high revel NCA) and they occur when the skew exceeds 60°. There is no "low level" hit. The grey to red frontier follows a cross centred on the target satellite nadir. The satcom can be operated on the "grey" area without any harm to the adjacent GSO satellites.



Grey: no interference with adjacent GSO satellites.

Red: high level interferences with adjacent GSO satellites

Figure 58: Locations where the hits with the adjacent GSO satellites occur

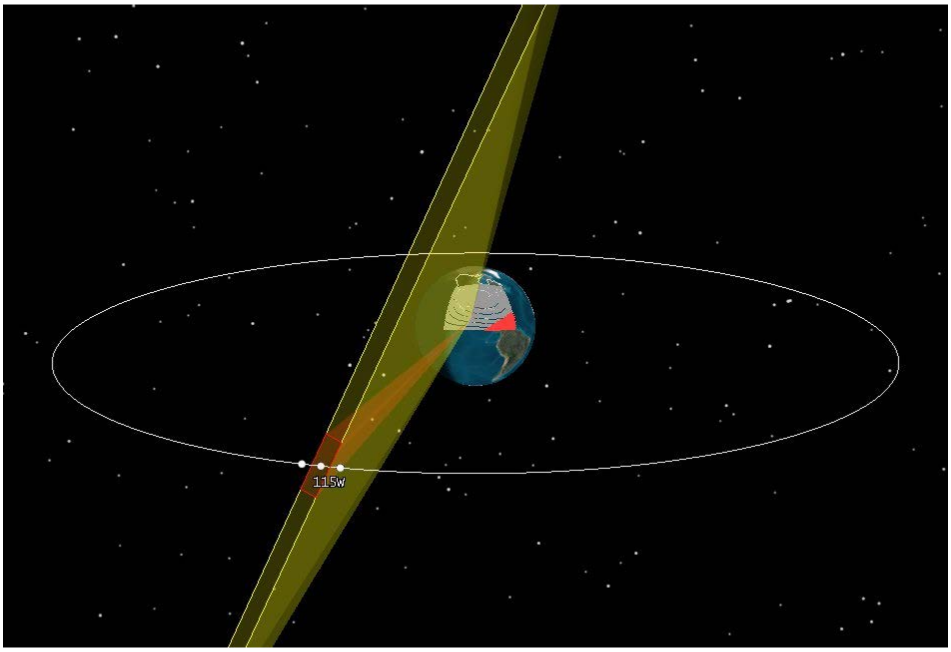


Figure 59: No hit case with the adjacent GSO satellites

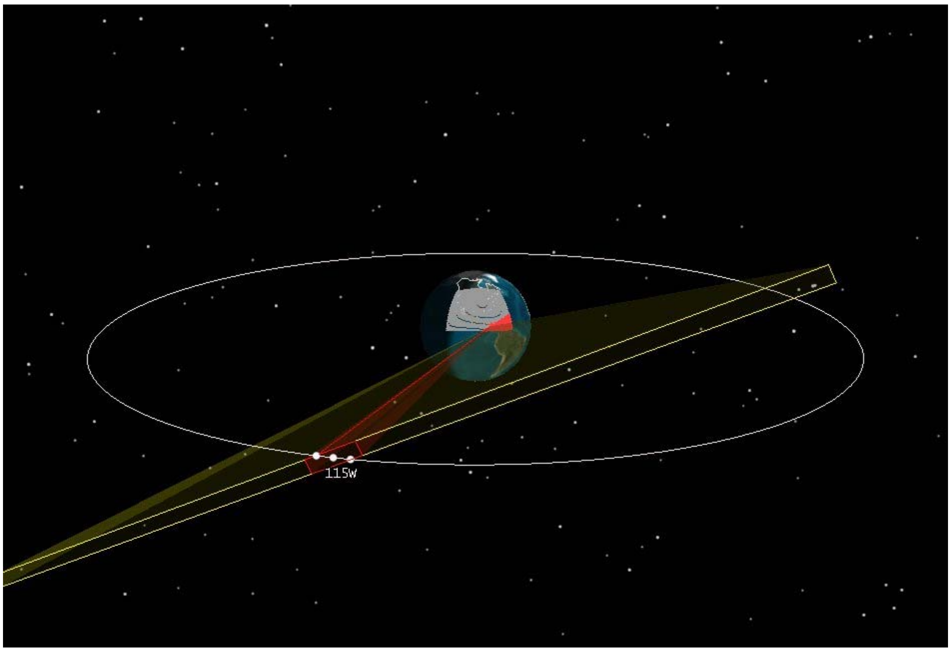


Figure 60: High level hit case with the adjacent GSO satellites viewed from space

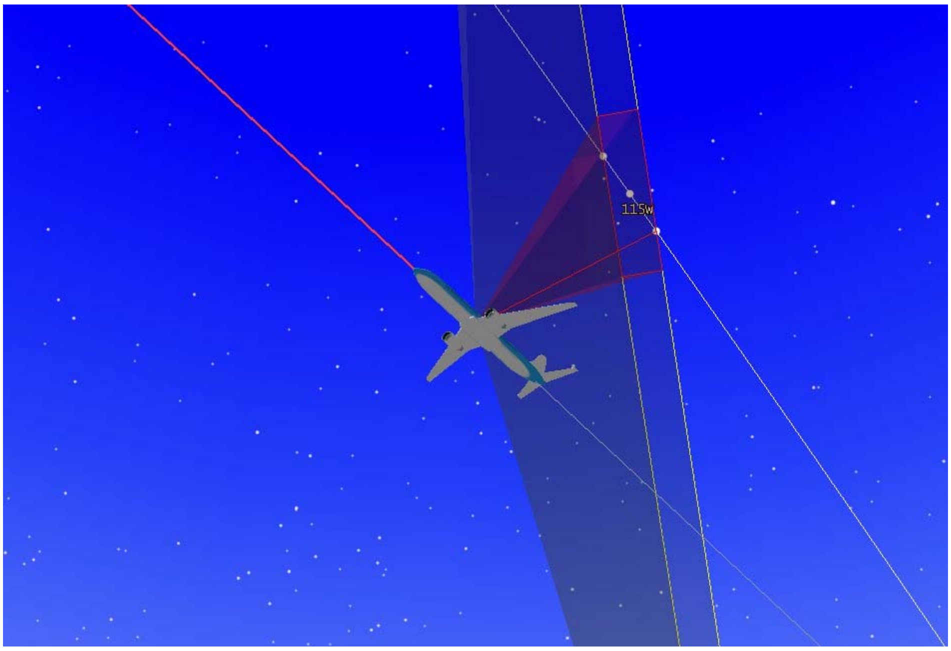


Figure 61: High level hit case with the adjacent GSO satellites viewed from the aircraft

### 7.2.4 NGSO Systems

#### 7.2.4.1 MEO case

An eight satellites MEO constellation (O1 to O8) flying over the equator at altitude of 8 062 km is considered as the victim system on Figure 62.

Figure 63 shows the places on the aircraft trajectory (yellow) where "low level" hits occur. It is pointed out that these positions are variable and depend on time. The frequency and average durations of the hits are anyway significant.

Under the current assumptions, the hits duration is approximately 68/cos (skew) seconds. Hits occur approximately every 45 minutes. The hit duration does not exceed 136 seconds as low as the skew is less than 60°.

A low level hit case is shown on Figure 64.

There is no "high level" hit under the current assumptions. High level hit may occur when the aircraft is in the vicinity of the equator.

Figure 63 assumes that the MEO satellites receiver is omnidirectional. Existing MEO satellites implements mobiles antennas and handovers between satellites to operate fixed spot beams on the ground. Figure 65 shows an example of such a spot beam (shown during handover). The hits occur only in the vicinity of the spot beam.

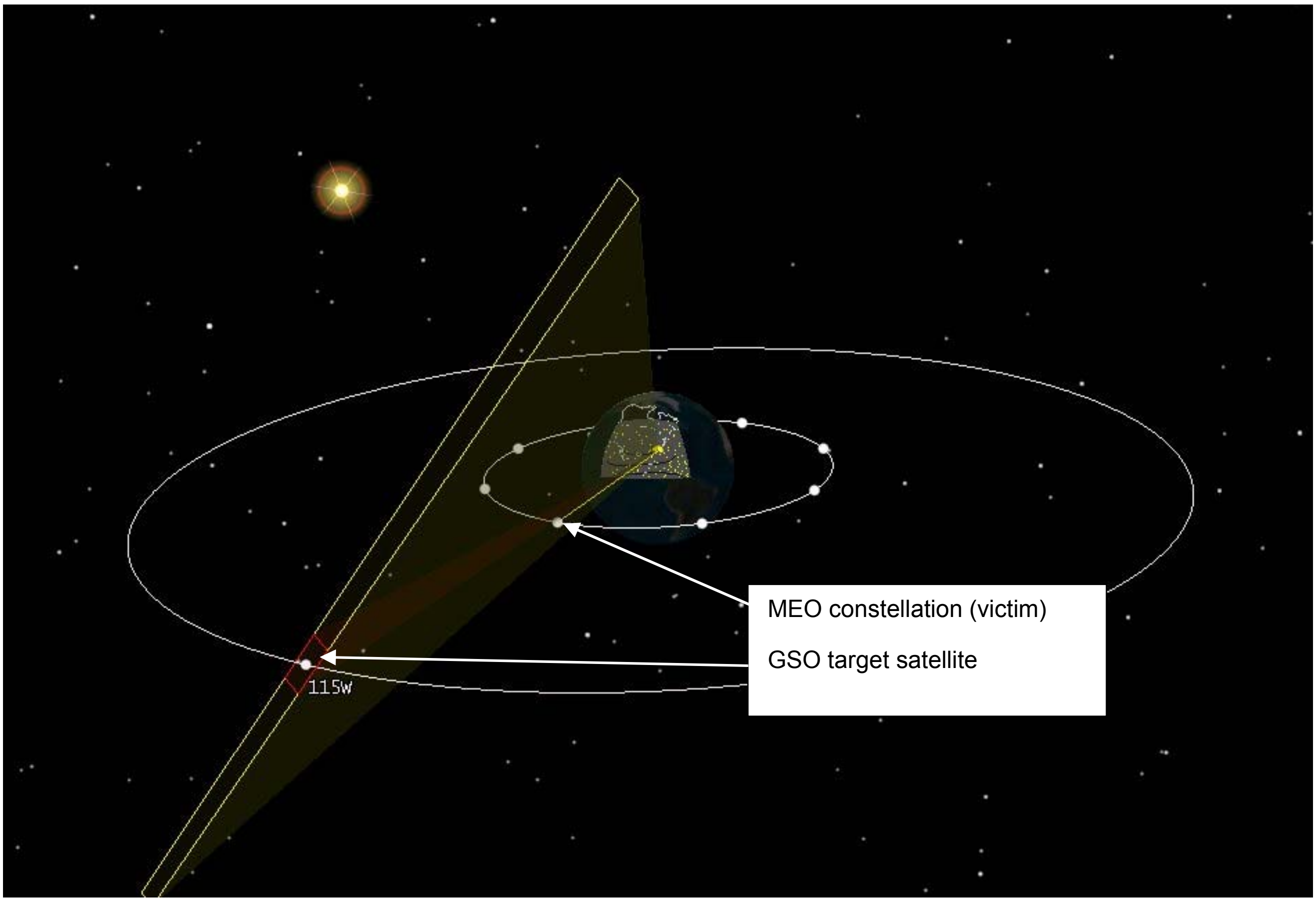


Figure 62: A MEO constellation as a candidate victim system for hits

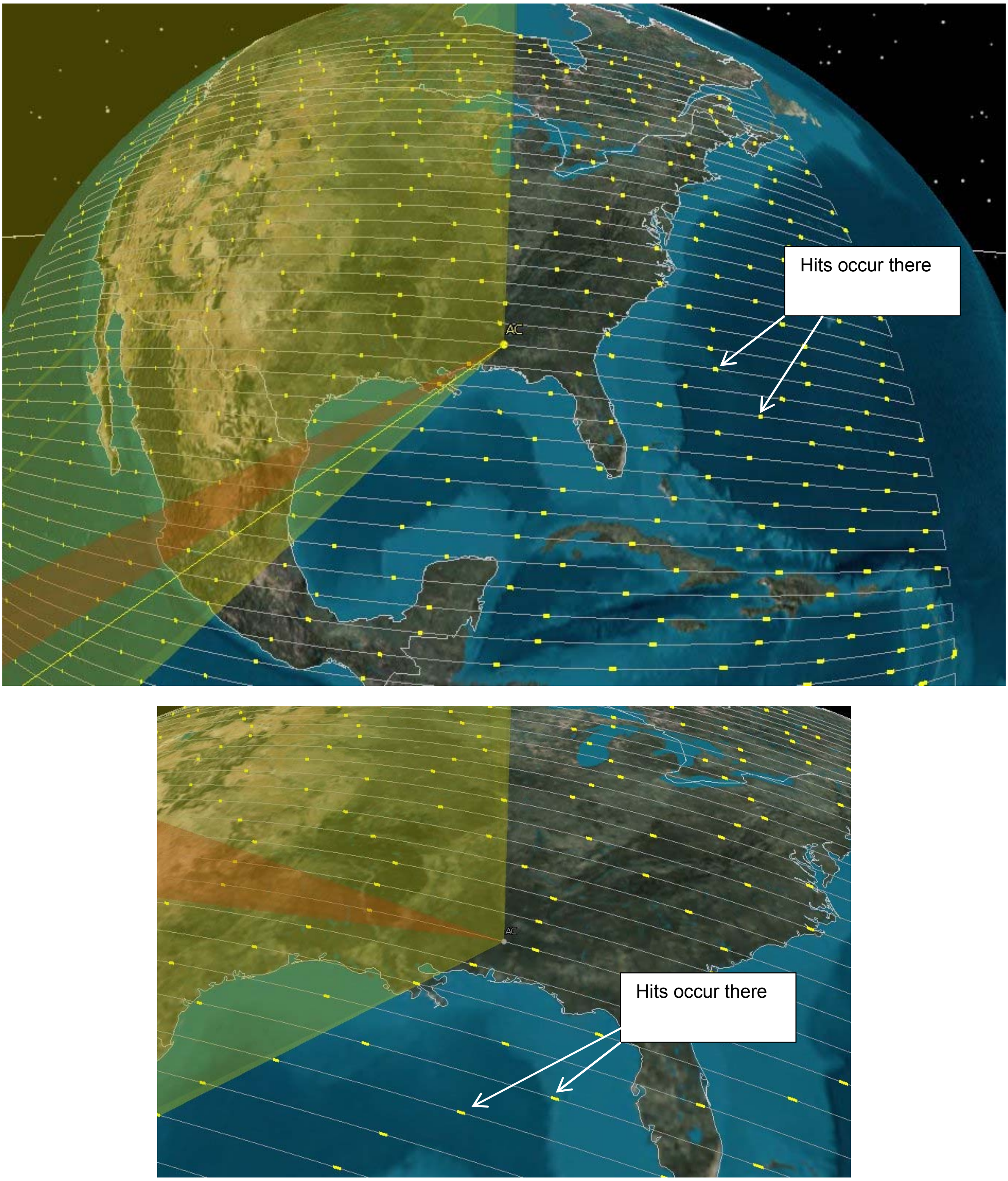
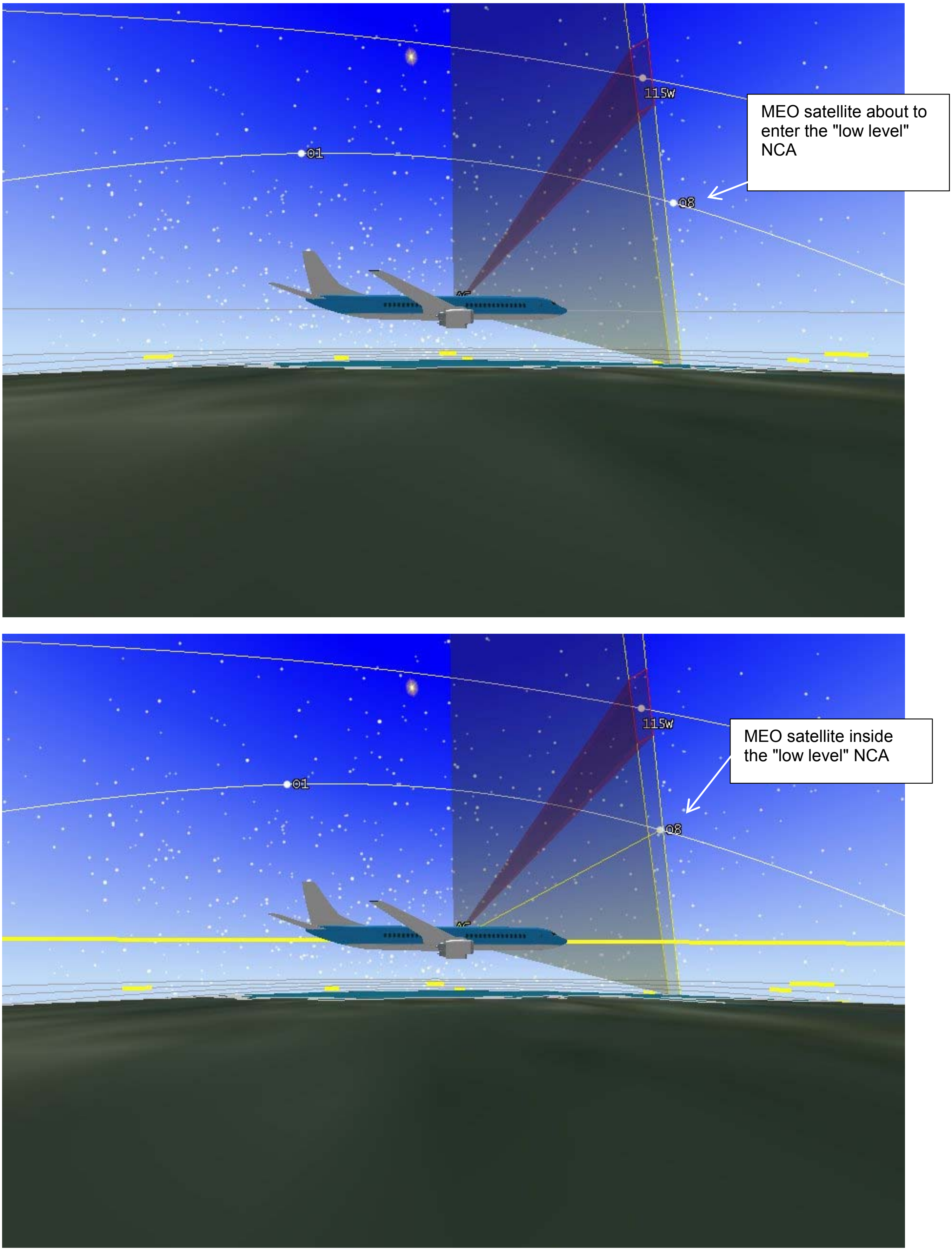


Figure 63: Areas where hits to the MEO satellites are produced



MEO satellite about to enter the "low level" NCA

MEO satellite inside the "low level" NCA

Figure 64: A low level hit to a MEO satellite case

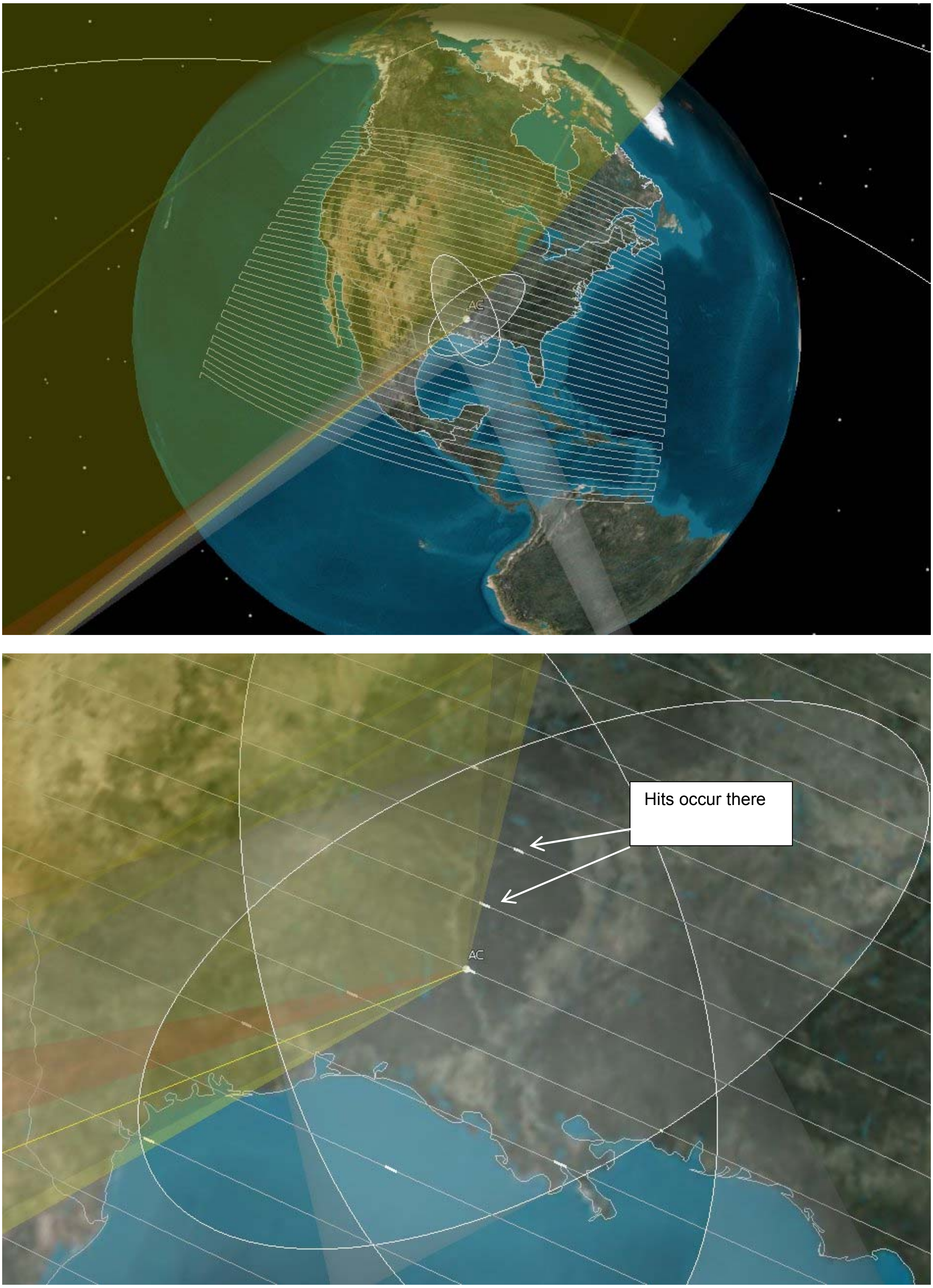


Figure 65: A fixed spot beam generated by a MEO constellation and related hits

### 7.2.4.2 LEO case

A 66 satellites LEO constellation flying at an altitude of 784 km with an inclination of 86.4° is considered as the victim system on the Figure 66.

Figure 67 shows the places on the aircraft trajectory (yellow) where the hits occur.  It is pointed out that these positions are variable and depend on time.

Under the current assumptions, 95 % of the hits have duration less that 50 s, with an average occurrence of one hit every 10 to 20 minutes. 10 % of the hits are "high level" with duration less than 38 s.

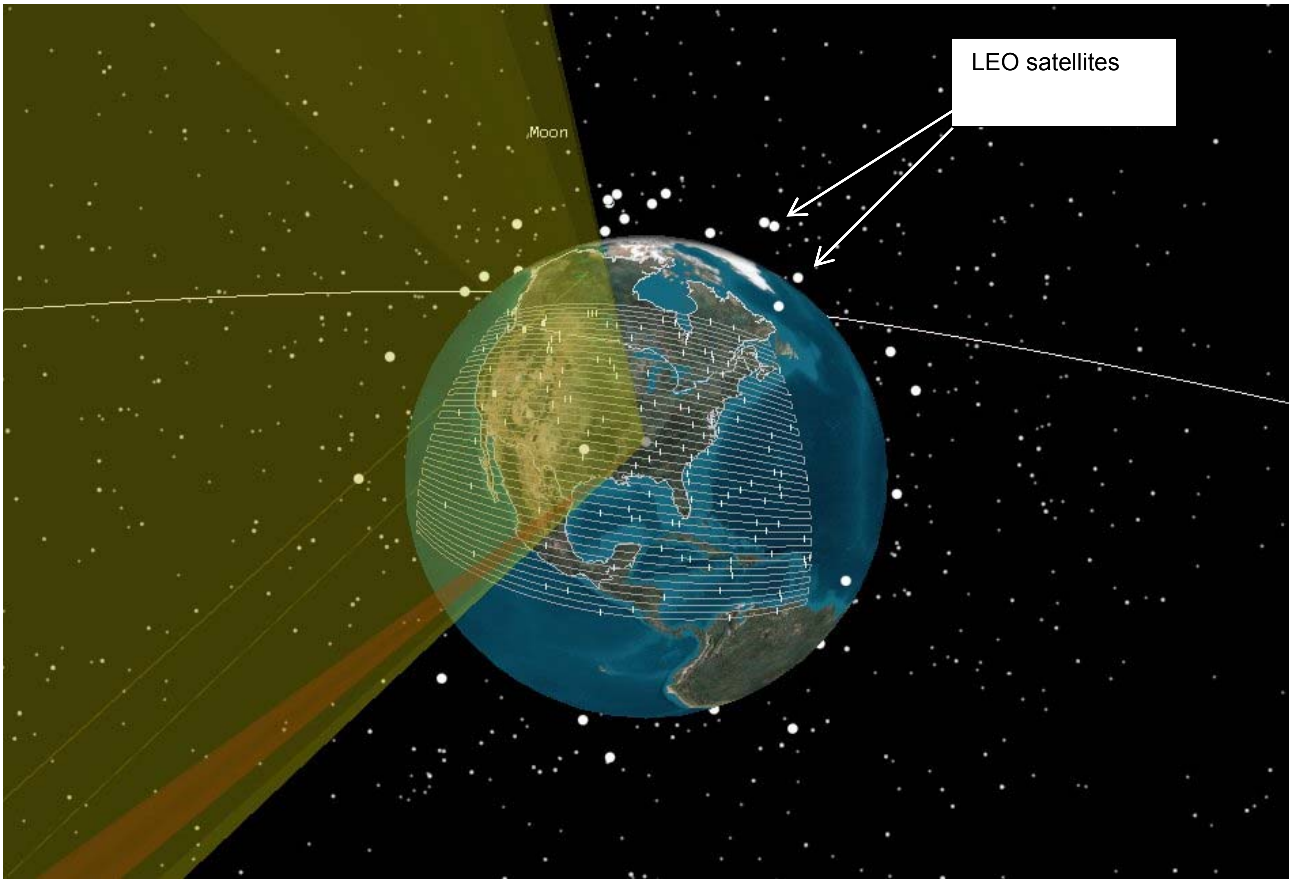


**Figure 66: A LEO constellation as a candidate victim for hits**

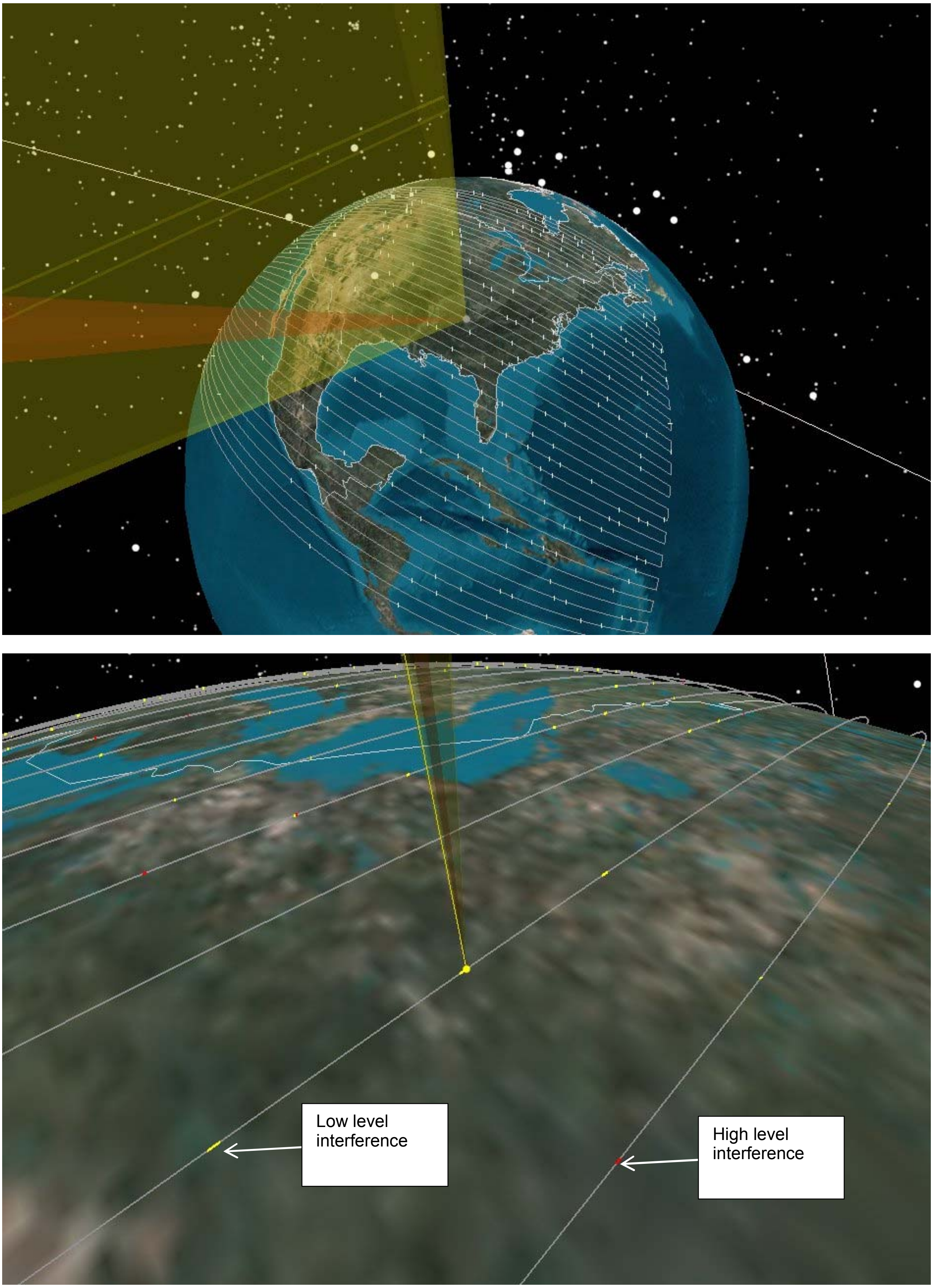


Figure 67: Areas where hits to the LEO satellites are produced

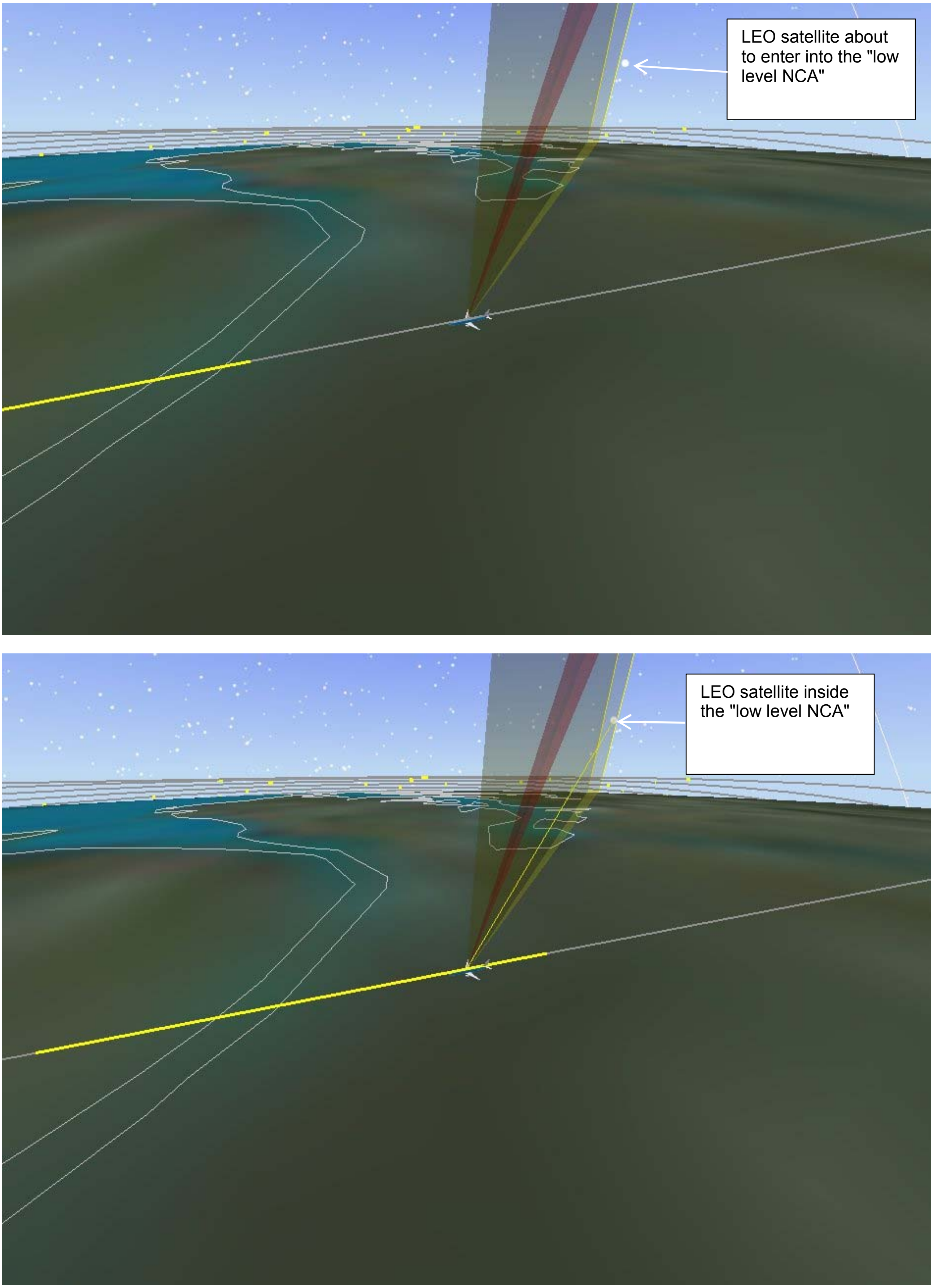


Figure 68: A low level hit case to a LEO satellite

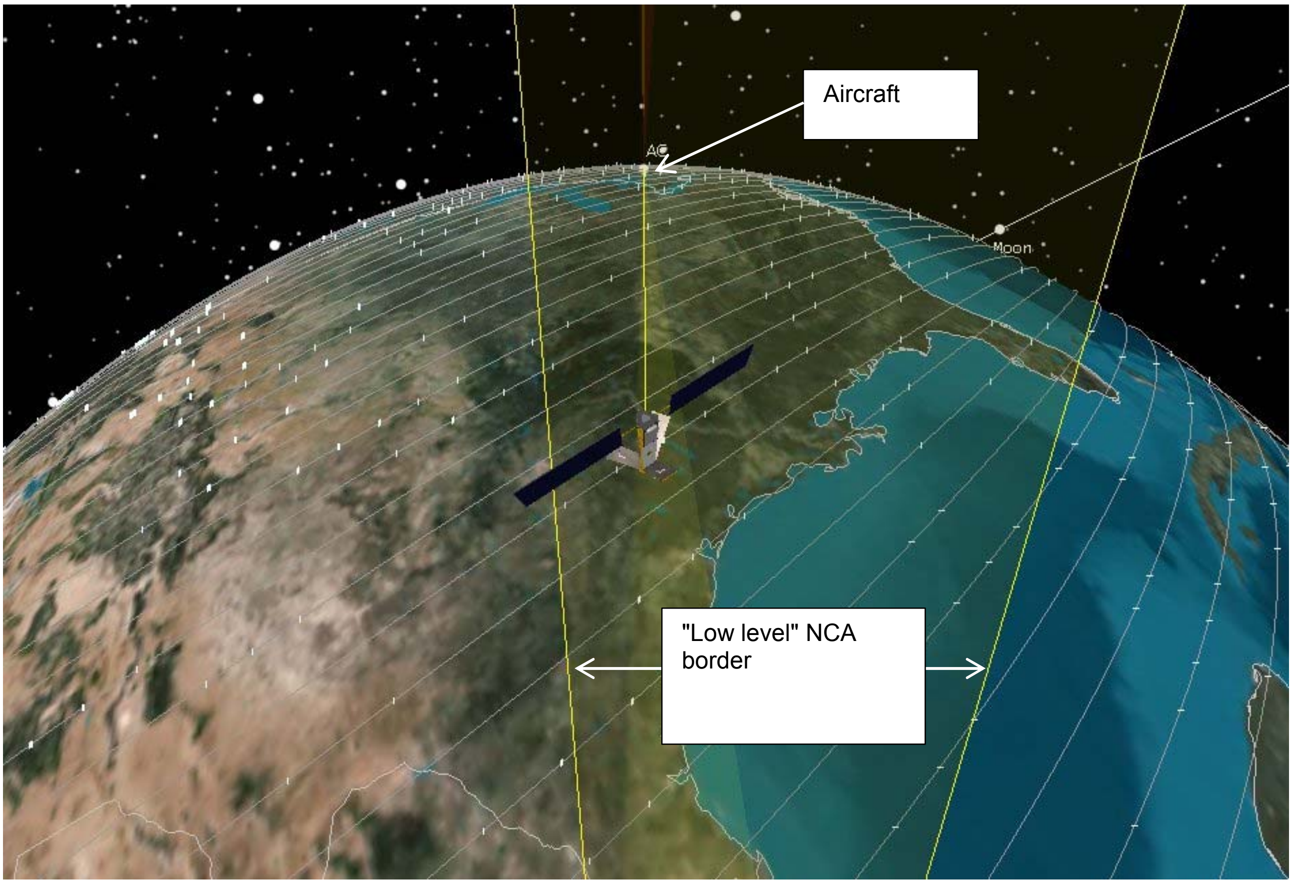


Figure 69: A low level hit case to a LEO satellite

# 8 Conclusions

It has been shown how the NCA method can be used to deal with the non-conformances to the ETSI off-axis EIRP mask coming from small asymmetric satcom antennas for mobile applications.

The NCA identifies in which specific conditions a hit occurs in the context of a non-conformance to the ETSI mask. It provides an indication of the order of magnitude of the hit. It provides a statistic on the hits occurrences in terms of average frequency and durations.

The NCA method assumes implicitly that the transmission is switched off when a hit occurs. For a softer corrective action such as reducing the EIRP density to an acceptable level, further interference analysis should be performed.

The study cases provided in the present document shows that a satcom service can be commercially viable despite the satcom antenna showing non-conformances. The NCA method is fruitful to provide the required explanations to regulation bodies or other stakeholders involved in this issue.

The NCA method is simple. It is generic and can apply to any kind of antenna. It can apply to receive antennas were the EIRP density requirement replaced by a gain requirement. It can be implemented on commercial simulation softwares. Its only weakness is some awareness of the victims systems geographical position is required. This is reasonably the case for satellites, but not for the terrestrial systems.

The NCA method paves the way to a pragmatic sharing approach respectful to the regulation. The non-conformances are highlighted, not ignored.

One can feel a philosophical shift in promoting a rationale in favour of the deployment of satcom antennas that show non-conformances. But the authorization is still in the regulation bodies hands. The next step is to the regulation bodies to consider the NCA method.

# Annex A: Bibliography

Ka band standards:

- ETSI EN 303 979: "Satellite Earth Stations and Systems (SES); Harmonised Standard for Earth Stations on Mobile Platforms (ESOMP) transmitting towards satellites in non-geostationary orbit, operating in the 27,5 GHz to 29,1 GHz and 29,5 GHz to 30,0 GHz frequency bands covering the essential requirements of article 3.2 of the Directive 2014/53/EU".

Ku band standards:

- FCC VMES 47 CFR 25.226 Blanket licensing provisions for domestic, U.S. Vehicle-Mounted Earth Stations (VMESs) receiving in the 10.95-11.2 GHz (space-to-Earth), 11.45-11.7 GHz (space-to-Earth), and 11.7-12.2 GHz (space-to-Earth) frequency bands and transmitting in the 14.0-14.5 GHz (Earth-to-space) frequency band, operating with Geostationary Satellites in the Fixed-Satellite Service.
- FCC ESV 47 CFR 25.222 Blanket Licensing provisions for Earth Stations on Vessels (ESVs) receiving in the 10.95-11.2 GHz (space-to-Earth), 11.45-11.7 GHz (space-to-Earth), 11.7-12.2 GHz (space-to-Earth) frequency bands and transmitting in the 14.0-14.5 GHz (Earth-to-space) frequency band, operating with Geostationary Orbit (GSO) Satellites in the Fixed- Satellite Service.
- ETSI EN 301 427: "Satellite Earth Stations and Systems (SES); Harmonised Standard for low data rate Mobile satellite Earth Stations (MESs) except aeronautical mobile satellite earth stations, operating in the 11/12/14 GHz frequency bands covering the essential requirements of article 3.2 of the Directive 2014/53/EU".

# History

| Document history | | |
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| V1.1.1 | April 2016 | Publication |
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