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TECHNICAL REPORT

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

Reference
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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

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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

References are either specific (identified by date of publication and/or edition number or version number) or non-specific. For specific references, only the cited version applies. For non-specific references, the latest version of the referenced document (including any amendments) applies.

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The following referenced documents are necessary for the application of the present document.

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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.

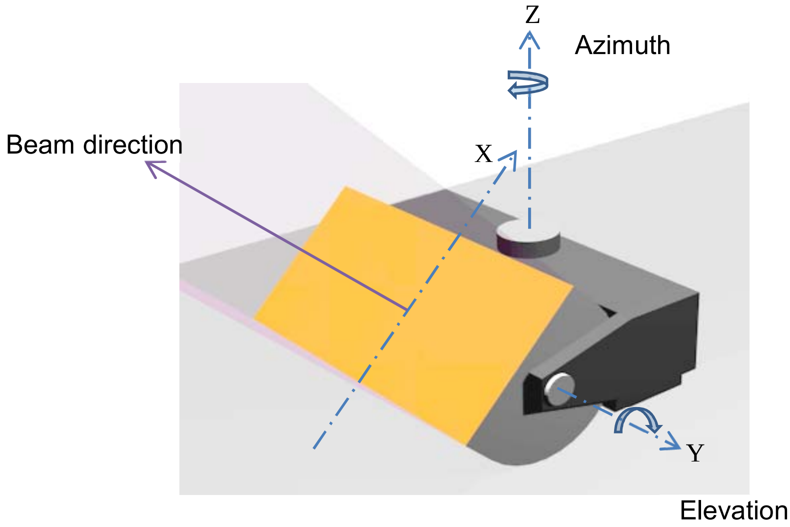



**Figure 2: MS-FA antenna overview**

## 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.



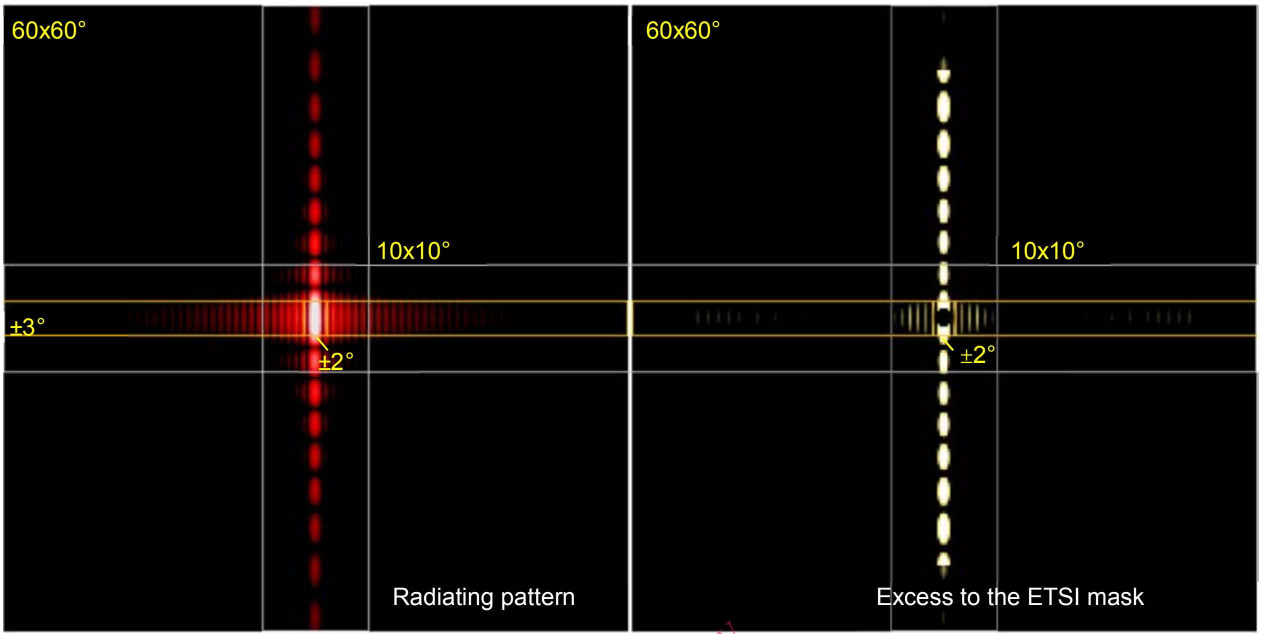
## 5.1.3 Describe the specific non conformant issues

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**

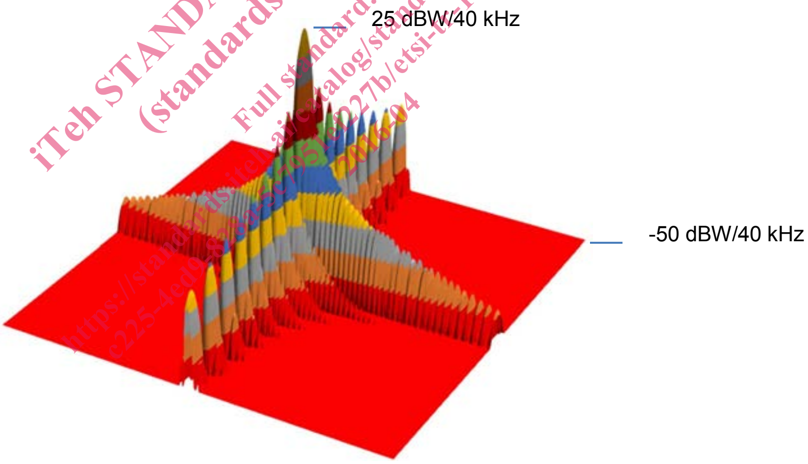
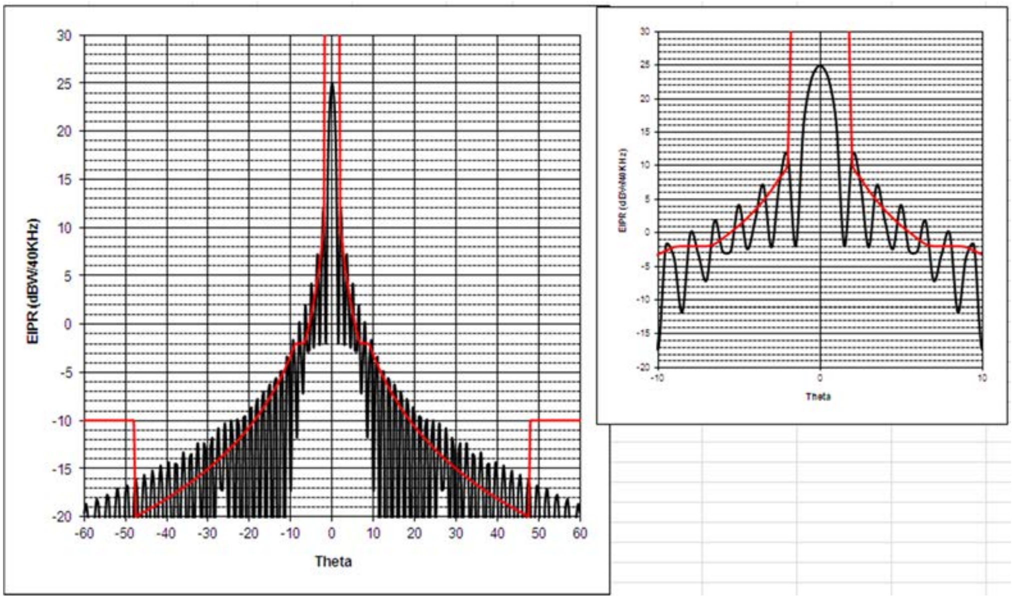
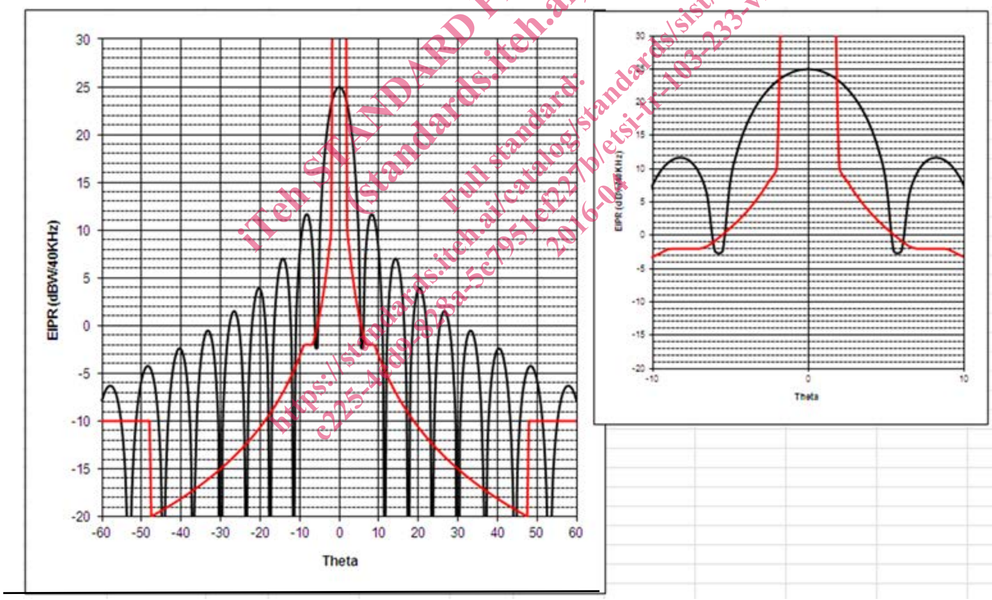



**Figure 4: MS-FA radiating pattern 3D view**




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.

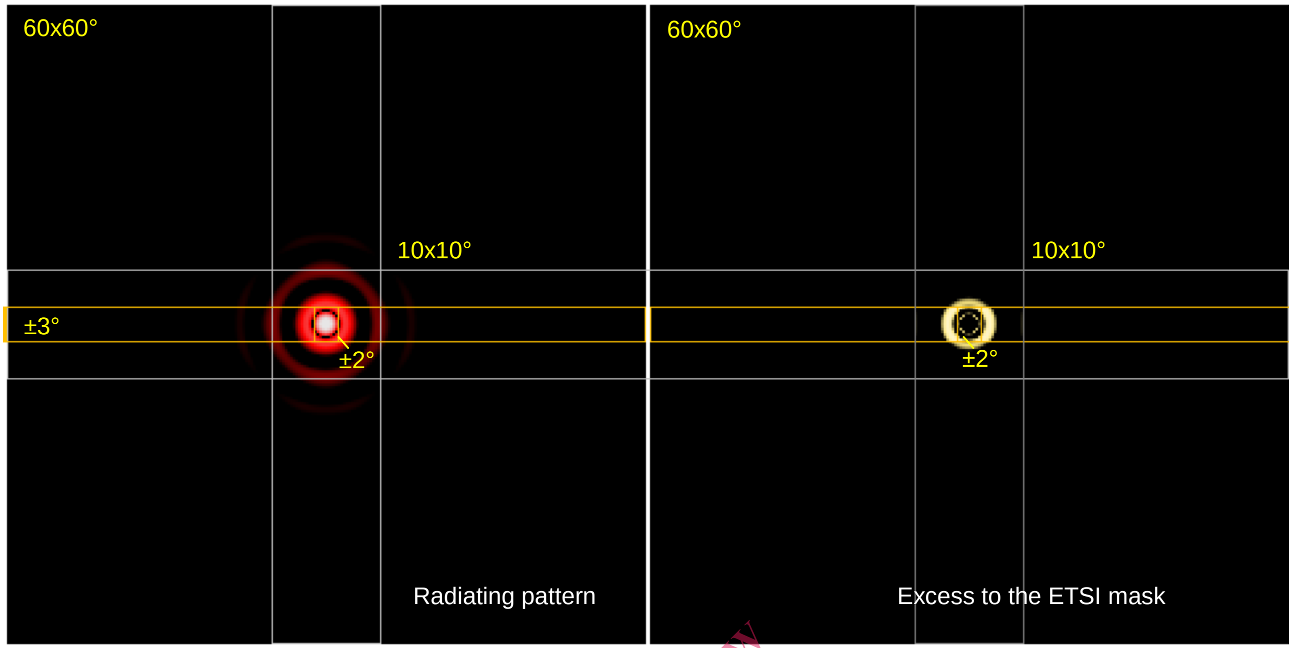



**Figure 7: Radiating pattern circular dish 30 cm**

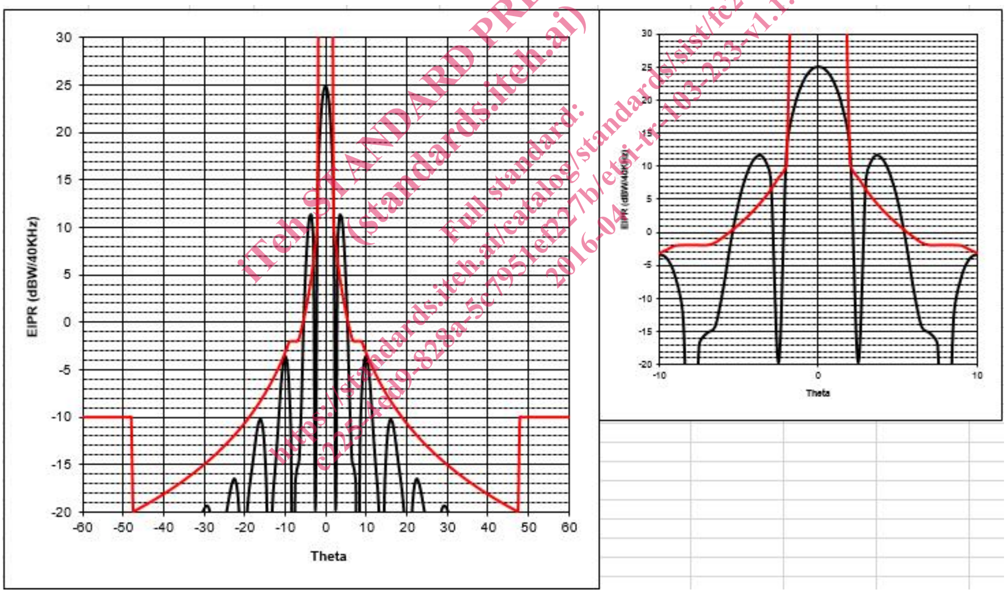



**Figure 8: Radiating pattern circular dish 12' (30 cm)**

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.