SPACEX

Planar Arrays Communicating With Non-GSO Satellites

March 2023

Leszek M Langiewicz
David R. Novotny

Planar Arrays Communicating With Non-GSO Satellites

Disclaimer

- The content of this presentation is provided for a general educational purpose only whereas, SpaceX makes no representation or warranties regarding the accuracy or completeness of the information.
- Herewith, SpaceX assumes no responsibility for a content of this presentation and use of this information shall be at your own discretion.
- For validity of this information, you should seek independent guidance with respect to your particular facts and circumstances.

ESA for NGSO Satellite Systems

Agenda

- GSO & NGSO Satellites
- NGSO Satellite Network & Satellite Earth Stations
- 1st Standard for User Terminal - EN ETSI 303 981
- Electronically Steerable Antenna ESA & Maximum Permissible Exposure MPE

ESA for NGSO Satellite Systems

NGSO & GSO Satellites

Geostationary Satellite Systems GSO

- A geostationary satellite is an earth-orbiting satellite, placed at an altitude of ~36,000 km directly over the equator, that revolves in the same direction the earth rotates (west to east).
- The term geostationary comes from the fact that such satellite appears nearly stationary in the sky as seen by a ground-based observer.

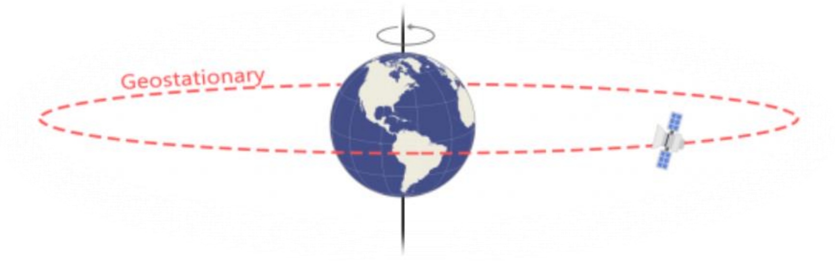
Non-Geostationary Satellite Systems

- Medium Earth Orbits (MEO) altitudes are between 8,000 – 20,000 km above the Earth
- Low Earth Orbits (LEO) altitudes are between 400 – 2,000 km above the Earth.
- Non-GSO satellites move across the sky during their orbit around the Earth
- Non-GSO satellite systems require a fleet of satellites, generally called “constellations", to provide continuous service from these altitudes.

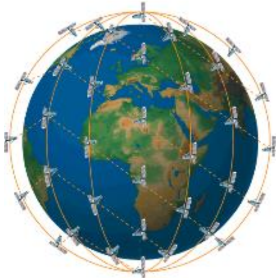
ESA for NGSO Satellite Systems

NGSO & GSO Satellites

GSO Satellite System



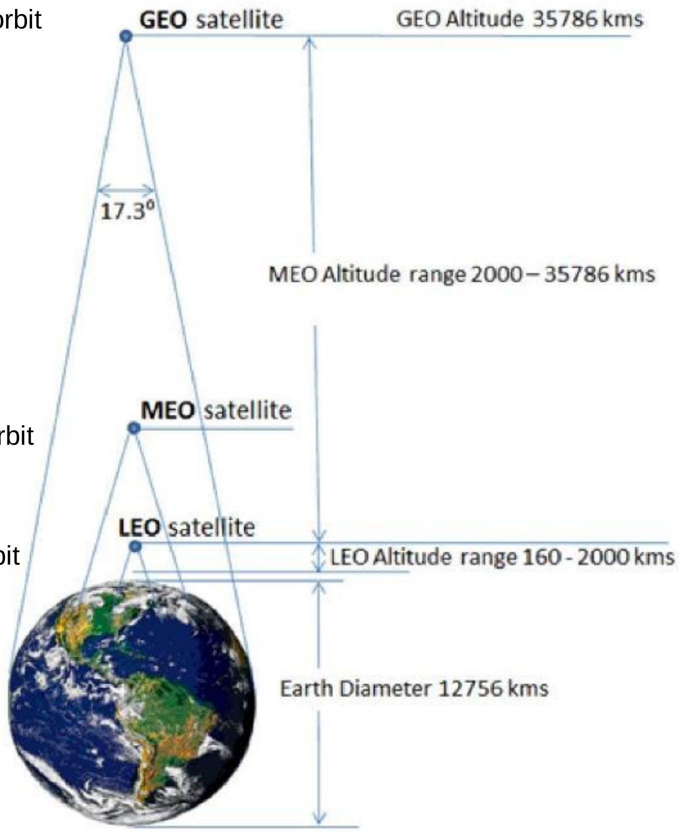
Non-GSO Satellite System



35786 km orbit / 24 hour orbit / max 0 °/sec

2000 km orbit / 2.1 hour orbit / max 0.2 °/sec

500 km orbit / 1.5 hour orbit / max 0.87 °/sec

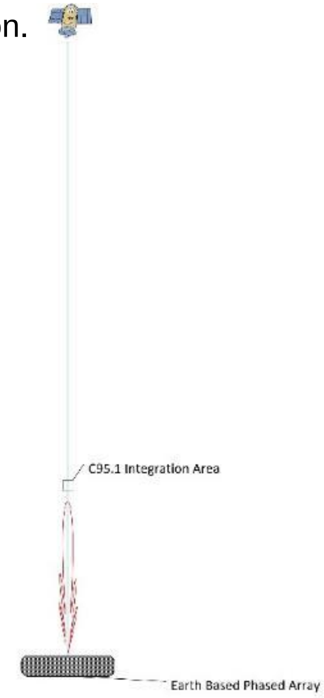


ESA for NGSO Satellite Systems

NGSO & GSO Satellites

GEO Communication

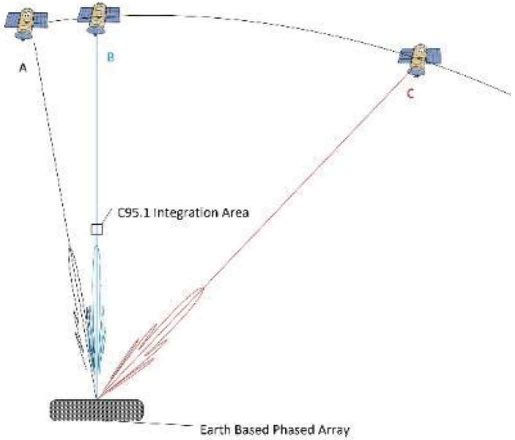
- Satellite is fixed position.



Angular velocity : 0 °/sec

LEO Communication

- Satellite … g with speed o … am moving a

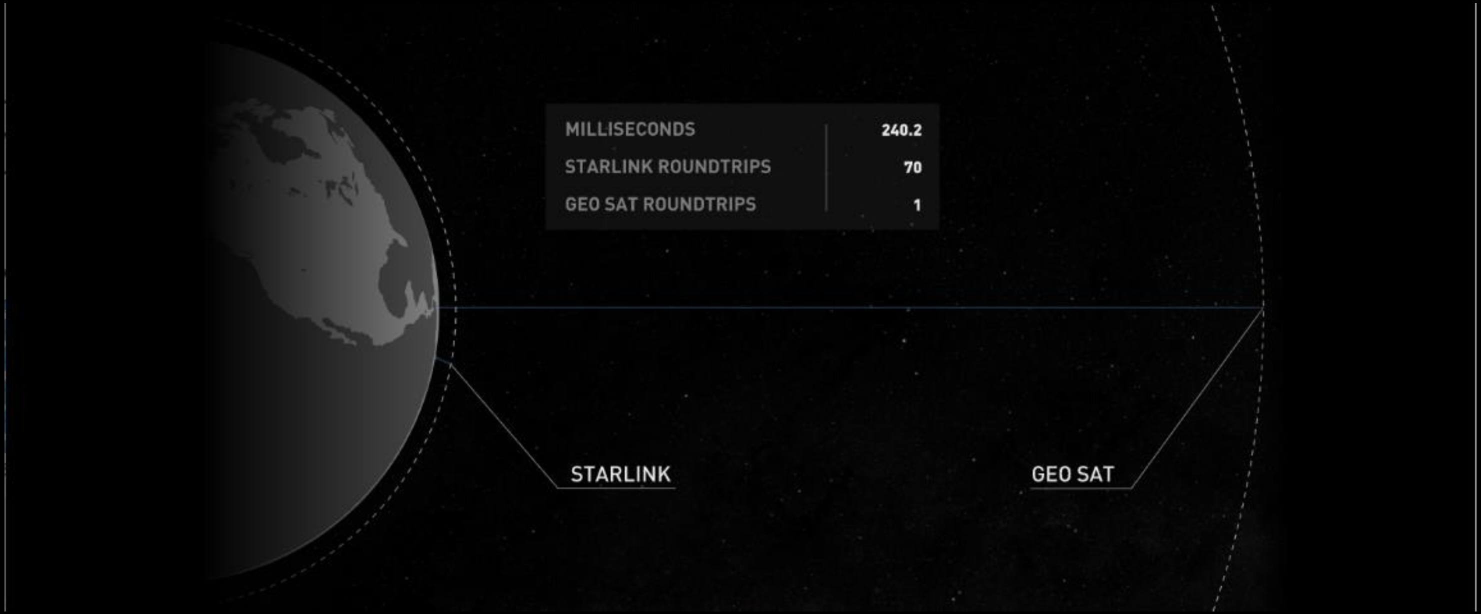


500km orbit Max Angular velocity : ~0.8 °/sec

ESA for NGSO Satellite Systems

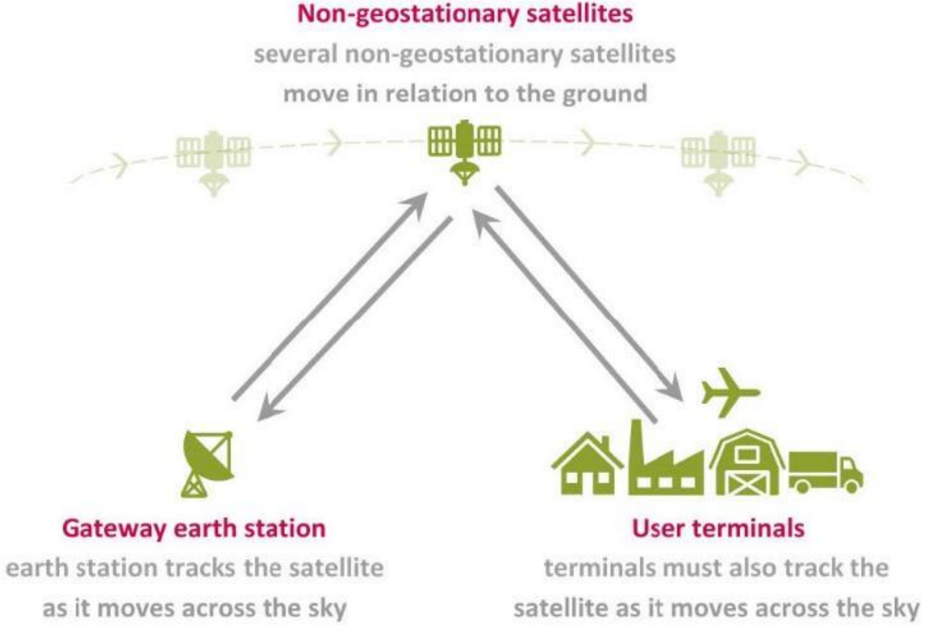
NGSO & GSO Satellites

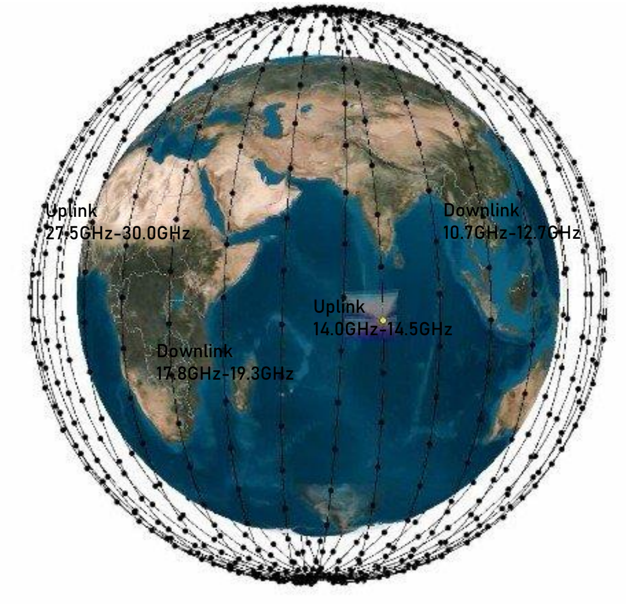
- The GSO satellite internet service with satellite on an orbit at 35,786km having very high latency
- LEO Satellite constellation of network of satellites on orbit at ~550km, latency significantly lower



ESA for NGSO Satellite Systems

NGSO Satellite Network





GROUND STATIONS

- Ka-band to connect with ground stations, typical ground station has number of antennas

SATELLITE

- The communication satellites are the small sat-class in Low Earth Orbit (LEO) at altitude of ~550km

USER TERMINAL

- A flat phased array antennas tracking the satellites

SATELLITE CONSTELLATION

- LEO communication satellites are the small sat-class in low Earth orbit (LEO) at an altitude of 550 km with initial constellation of thousands cross-linked satellites

*Constellation pattern for OneWeb's system

ESA for NGSO Satellite Systems

User Terminal – Standards & Regulations

- New Technology
  - Commercialized Electronically Steered Flat Array Antenna
- First standard for ESA for NGSO Satellite Systems
  - EN ETSI 303 981 – Development and Publication
  - Other regulators slowly working on updating their regulations

ESA for NGSO Satellite Systems

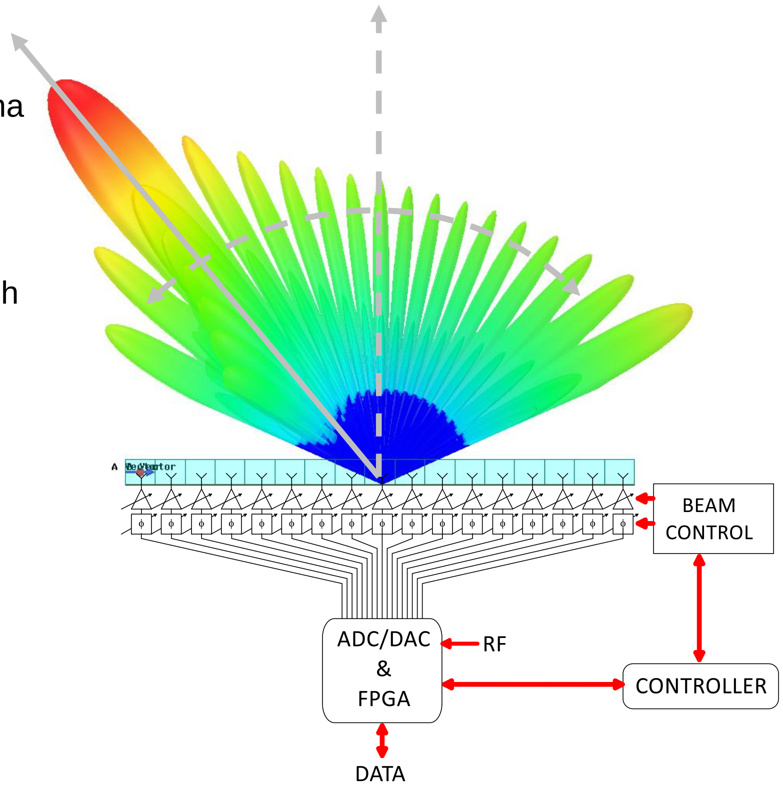
New Technology – Electronically Steered Flat Array Antenna

- An Electronically Steerable Antenna or ESA is an array of antenna elements that can be electronically steered to point in different directions without moving the antenna itself

- ESA as a flat module consist many small identical antennas, each one capable of transmitting and receiving, called phased array antennas because of their working principle

- Digital Beamforming (DBF): A phased array has a digital receiver/exciter at each element in the array, a signal at each element is digitized by the receiver/exciter

- As a ESA becomes larger in size, the beam formed gets more directional and smaller in angle allowing for more directed performance over longer ranges



ESA for NGSO Satellite Systems

EN ETSI 303 981 – Development and Publication

ETSI Technical Committee (TC) Satellite Earth Stations and Systems (SES)

- In Dec of 2018 SES WG assigned New Work Item for development of EN 303 981
    - To develop technical characteristics and methods of measurements for Fixed and in-motion Wide Band Earth Stations communicating with non-geostationary satellite systems (WBES) in the 11 GHz to 14 GHz frequency bands
    - Combine new requriements (SpaceX) with earlier published EN 303 980 (OneWeb) in new standard

ESA for NGSO Satellite Systems

EN ETSI 303 981 – Development and Publication

EN ETSI 303 981 Conformance requirements

- Antenna beam pointing
- Off-axis spurious radiation
- On-axis spurious radiation
- Carrier suppression
- Cessation of emissions
- Location and Identification of the WBES
- Control and Monitoring Functions
- Receive antenna off-axis gain pattern
- Blocking performance
- Adjacent Signal Selectivity
- Image frequency rejection

ESA for NGSO Satellite Systems

EN ETSI 303 981 – Development and Publication Schedule

- 2018-12 TC SES assigned New Work Item for development of EN 303 981
- 2020-05 European Council Assessment
- 2021-04 ETSI Publication EN ETSI 303 981 v1.2.1
- 2022-03 Citation in the Official Journal OJ
- 2022-10 ETSI Publication EN ETSI 303 981 v1.3.1
- 2023-03 Citation in the Official Journal OJ - in progress

Note: EN ETSI 303 981 framework being adopted by other regulators

ESA for NGSO Satellite Systems

ESA MPE

Introduction

The commercialization of ESA (2D phased array antennas) communicating with LEO satellite constellations has unveiled fundamental differences between fixed beam and scanning phased array antennas for assessing the RF exposure.

Since ESA communicating with LEO satellites requires constant beam movement, the RF exposure at any point in space changes with time.

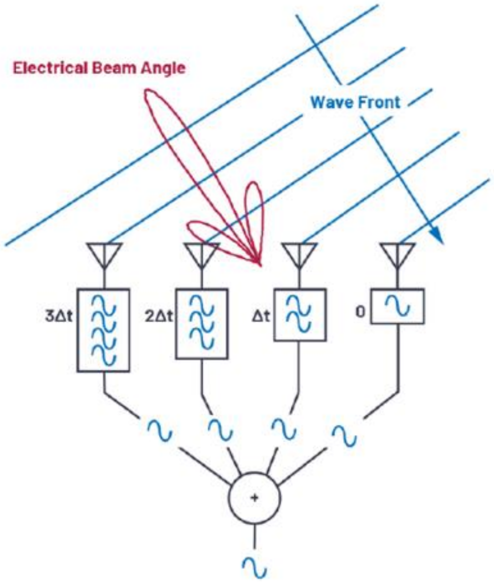
Also, ESA following the Satellite Earth Stations and Systems (SES) regulations, do not transmit unless they are receiving enabling commands from a satellite – so the blockages stop communication and transmissions reducing the time-averaged power flux even further.

Thus, such complex RF pattern, pointing and operational modes leads to a introduction of a illumination duty cycle, that weighs time-averaged power density by the proportion of time the beam is on a target area.

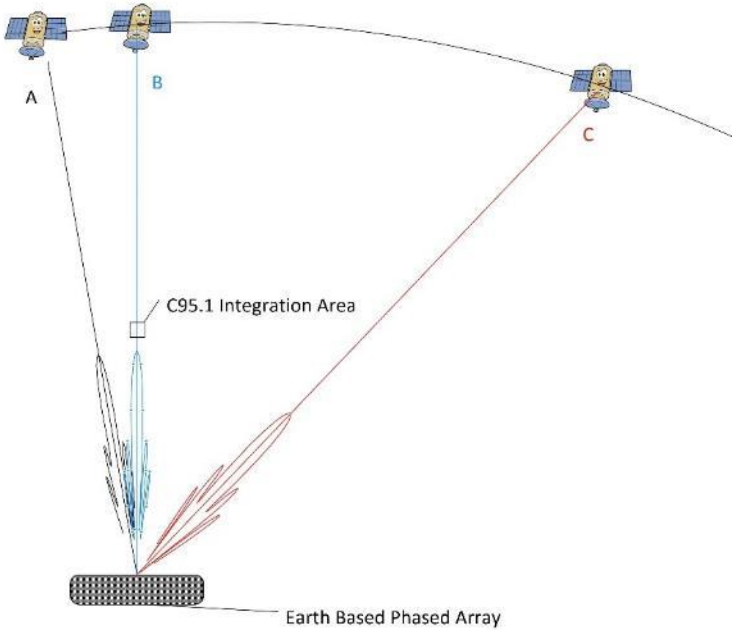
ESA for NGSO Satellite Systems

ESA MPE

- ESA Beam Forming



- ESA Beam Scanning



ESA for NGSO Satellite Systems

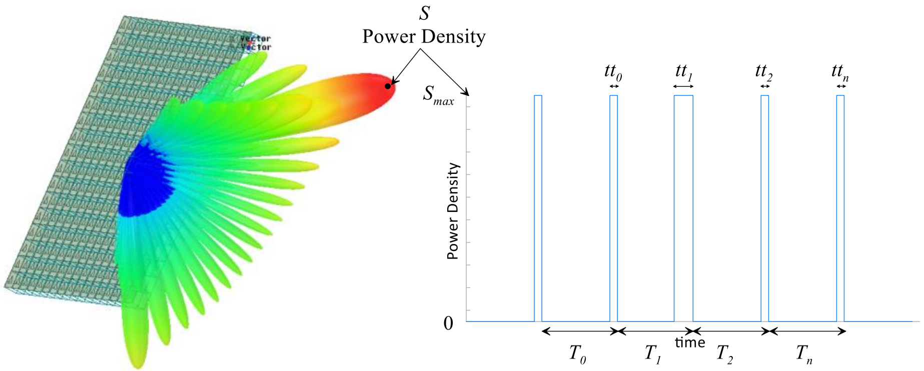
ESA MPE - Duty Cycle

- Maximum Duty Cycle, *DTx*, is considered a "Source-based" limitation of a device.

- Protocol or device hardware/software enforces a maximum limit that may not be exceeded by the operator.

- Since power is not "ON", the time averaged exposure can be lessened by the "ON time" to period ratio.

$$S_{avg} = \frac{\int_{T_{n-1}}^{T_{n-1}+T_n} S(t)\,\partial t}{T_n - T_{n-1}} = DT_x S_{max}$$



- Illumination is a spatial vs temporal duty cycle

$$S_{avg} = DT_x DT_{ill} S_{max}$$

ESA for NGSO Satellite Systems

ESA MPE

Power Density & illumination

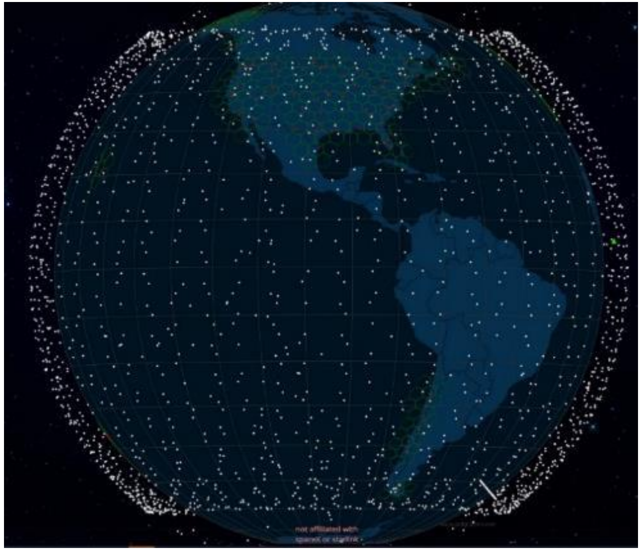
- The on/off duty cycle, DT_x, is considered a “source-based” modifier to the emitted energy or inherit to the operation of the device.
- The illumination factor, DT_{ill}, and is defined as the ratio of time that the beam is illuminating a target area. We propose that it is a similarly inherit system property and modifier to the time-averaged power density.

	Fixed Beam “Source-Based”	**ESA-NGSO “Source-Based”**
Power Density in the Far Field	$S_{ff} = DTx\, S_{max@R_{ff}}$	$S_{ff} = DT_{\mathrm{ill}FF} DTx\, S_{max@R_{ff}}$
Power Density in the Near Field	$S_{nf} = DTx\, S_{max@R_{nf}}$	$S_{nf} = DT_{\mathrm{ill}NF} DTx\, S_{max@R_{nf}}$

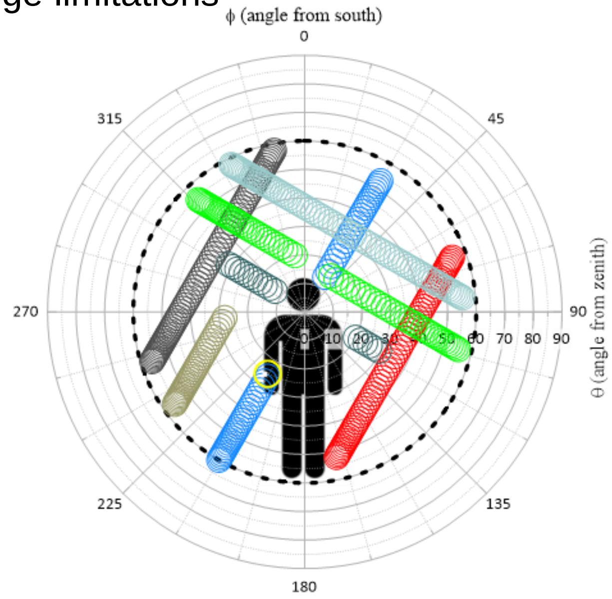
ESA for NGSO Satellite Systems

ESA MPE - Trajectory vs time for a LEO Constellation

- Multiple satellites in view at any time
- Trajectories generally do not repeat on transfer to next satellite



- Single Track will illuminate a spot for 5 sec at 90° and 20 sec at 25° elevation
- MPE exposure averaged over 6-min or 30-min period.
- Trajectories limited by blockages and scan range limitations



18

ESA for NGSO Satellite Systems

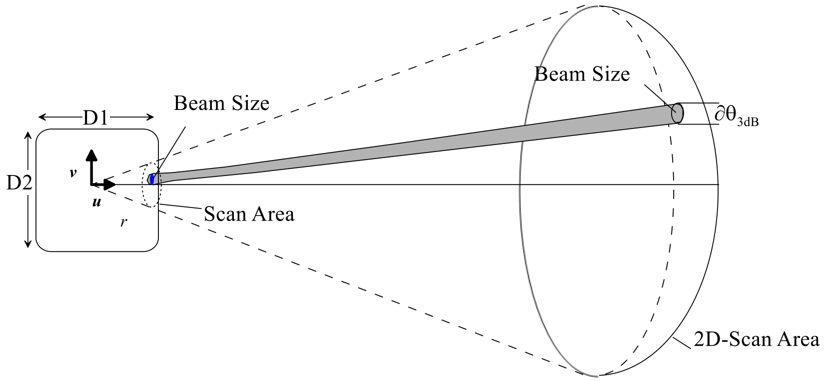
ESA MPE - Illumination Factor

2D Dt_{ill} Illumination Factor Definition

- 1D scanning antenna illumination factor is noted in C95.1 Annex F.
- The ratio of time that the beam is illuminating an area:

$$DT_{ill} = \frac{BeamSize}{Scan\ Area}.$$

- The solid angle of the scan area in the near-field and the far field are the same.
- The relative spot size can be larger in the near-field because the beam is not fully focused



ESA for NGSO Satellite Systems

ANFR – Surveillance Testing

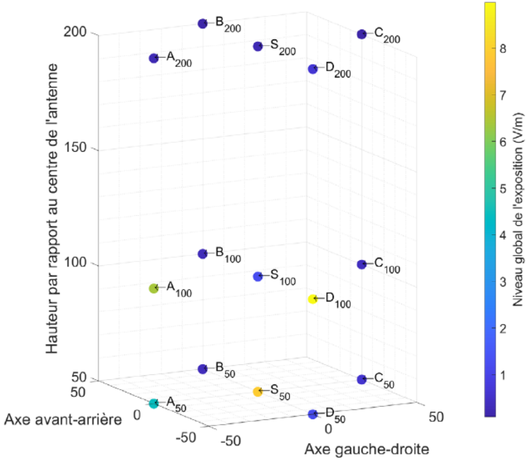
- Etude de l’exposition aux ondes électromagnétiques du kit de communication au réseau Starlink – ANFR – February 2022
  Study of exposure to electromagnetic waves from the Starlink network communication kit.

- Reported Parameters:

Freq	14-14.5 GHz
EIRP	38.2 dBW
Gain Max	34.8 dBi
Gain Min	32.2 dBi
Power - Broadside	0.76 Watts
Power – max tilt	4.06 Watts
Duty Cycle	11%

$$\text{Margin} = 20\ \log_{10}\left(\frac{61\,\frac{\text{V}}{\text{m}}}{8.98\,\frac{\text{V}}{\text{m}}}\right) > 16\ \text{dB}$$

H=2 m		B_{200}	
		0,09	
	A_{200}	S_{200}	C_{200}
	0,24	0,23	0,09
		D_{200}	
		0,66	
H=1 m		B_{100}	
		0,33	
	A_{100}	S_{100}	C_{100}
	6,38	**1,21**	0,37
		D_{100}	
		8,98	
H=50 cm		B_{50}	
		0,36	
	A_{50}	S_{50}	C_{50}
	4,44	**7,92**	0,58
		D_{50}	
		1,23	



ESA for NGSO Satellite Systems

ANFR – Surveillance Testing

General analysis:

The exploratory measurement shows that the maximum measured level is 8.98 V/m at position D100. However, the measurements also show great variability in the level of exposure, especially between the S100 position compared to the A100 and D100 positions. This variability is explained by the fact that the beam formed by the antenna is not static and constantly scans the sky in order to follow the satellite with which it communicates.

In addition, the antenna can change the satellite with which it communicates during a transmission, as evidenced by the substantial speed at which Starlink satellites rotate. *

Exploratory measure:

The measurements were made by requesting the uplink of the Starlink system, i.e. by loading a file of one gigabyte in a loop in order to ensure that the antenna radiates continuously during the measurements.

It was also necessary to find a clever way to position the probe without disturbing the beam of the satellite dish too much. Indeed, an obstacle across the beam of the antenna, even as thin as the tripod that supports the probe, is enough to cut off communication and radioelectric radiation.*

*Google translation of: Direction de la Surveillance du marché et de l’Exposition du public, "Etude de l’exposition aux ondes électromagnétiques du kit de communication au réseau Starlink," L’Agence nationale des fréquences (ANFR), Maisons Alfort, 2022.

Contacts

Leszek Langiewicz | Compliance Manager

Space Exploration Technologies Corp. (SPACEX)

1 Rocket Rd., Hawthorne, CA 90250

LESZEK M. LANGIEWICZ graduated from Electronic Science Institute, Wroclaw, Poland, in Computer Systems and received a B.S. degree in electrical engineering from Concordia College and University. His carrier started at Absopulse Electronics and continued at Nortel/Nortel Networks, Phogenix, Encad/Kodak, HP as Regulatory Compliance Manager for a broad spectrum of products for consumer, commercial, and telecom applications. He is an associate member of Technical Committee (TC) of TC ETSI SES Satellite Earth Stations and Systems, IEC/TC108, UL/CSA THC and an IEEE Senior Member. Since 2020, he has been with SpaceX managing the Starlink Product Compliance team.

David R. Novotny | Electromagnetic Environmental Effects Principal Engineer

Space Exploration Technologies Corp. (SPACEX)
1 Rocket Rd., Hawthorne, CA 90250

DAVID R. NOVOTNY received the B.S. and M.S. degrees in electrical engineering from the University of Colorado, Boulder, in 1990 and 1996. From 1990 to 2020, he was a researcher at the National Institute of Standards and Technology in Boulder, CO. His work in electromagnetics included antenna design, EM field generation, antenna and probe calibrations, and EM propagation. He was awarded the Department of Commerce Gold Medal for security and performance analysis of the ePassport, the Silver Medal for using coordinated robotics for antenna characterization, and Bronze Medals for RF shielding of the Space Shuttle, Wireless propagation in industrial environments, and RF security of electronic documents. Since 2020 he has been with the Electromagnetic Environmental Effects Group at SpaceX, where he has enjoyed working on tasks for Falcon, Dragon, Starship and Starlink.