Elefante Group, Inc.

Petition for Rulemaking

May 31, 2018

Appendices A - U

Appendix A

Elefante Group Stratospheric Platform Station
Technical Specifications

The technical specifications of the Stratospheric Platform Station (STRAPS) that has been used in compatibility analysis are provide below.

System Specifications

The following table summarizes primary system specifications of the Elefante Group STRAPS and nominal operating area.

Item	Units	System Design
User Uplink Band	GHz	21.5-23.6
User Downlink Band	GHz	25.25-27.5
Feeder Uplink Band	GHz	81-86
Feeder Downlink Band	GHz	71-76
Platform Type		Lighter Than Air
Nominal Platform Service Radius	km	70
Min Platform Altitude	km	18.3
Max Platform Altitude	km	21.3
Max Platform Flight Radius	km	10
# User Beams		Over 100
# Feeder Beams		10
CPE Density	CPE/km^2	Dependent on business case. For compatibility analyses, the worst-case scenario was always evaluated as described in the appropriate analysis Appendix.
Deployment environment		Urban, suburban, rural

User Terminals

Elefante Group will utilize two different User Terminals (UTs). Enterprise UTs will utilize the full bandwidth of 450 MHz. Consumer UTs will utilize small bandwidth within the entire beam channel size of 450 MHz. Commercially, Consumer UTs may be appropriate for use in small to medium sized businesses despite the name.

Item	**Units**	**System Design**	
Category		Consumer (Narrowband)	Enterprise (Fullband)
TX Band	GHz	21.5-24	21.5-25
RX Band	GHz	25.25-27.5	25.25-27.6
Bandwidth	MHz	5 to 20	450
Aperture Diameter	m	0.45	1
Boresite Gain	dBi	34	40.7
3dB Beamwidth	deg	3.35	1.6
Pattern		ITU-R F.1245	Custom (defined in table below)
Polarization		RHCP/LHCP	RHCP/LHCP
Clear sky EIRP spectral density	dB(W/MHz)	12	20
Hardware Max EIRP spectral density	dB(W/MHz)	26.4	25.6
Power control		Yes	Yes
Max Elevation Angle	deg	90	90
Min Elevation Angle	deg	12.5-16.6	12.5-16.6
Height above ground	m	10 typical	10 typical
Receiver Noise Density	dB(W/MHz)	-141.7	-141.7
Protection Criteria (I/N)	dB	-6	-6

User Beams

Different beam sizes will be used across the coverage area. Design values for center beams and outer beams are provided in the table below.

Item	Units	System Design	
Category		User (Center)	User (Outer)
TX Band	GHz	25.25-27.5	25.25-27.6
RX Band	GHz	21.5-24	21.5-25
Bandwidth	MHz	450	450
Aperture Diameter	m	0.05	0.17
Boresite Gain (bottom of band)	dBi	22	32
6dB Beamwidth	deg	13	5
Pattern		Custom (bound with ITU-R F.1245)	Custom (bound with ITU-R F.1245)
Polarization		RHCP/LHCP	RHCP/LHCP
Clear sky EIRP density	dB(W/MHz)	EIRP density adjusted to not exceed ground PFD vs elevation mask. Adopting FSS limits from 25.208 (c)	EIRP density adjusted to not exceed ground PFD vs elevation mask. Adopting FSS limits from 25.208 (c)
Hardware Max EIRP density	dB(W/MHz)	PFD limit + TBD weather margin	PFD limit + TBD weather margin
Power control		Yes	Yes
Max Elevation Angle	deg	90	20
Min Elevation Angle	deg	12.5	12.5
Height above ground	km	HAA	HAA
Receiver Noise Density	dB(W/MHz)	-141.7	-141.7
Protection Criteria (I/N)	dB	-6	-6

Feeder Links

Item	Units	System Design	
Category		Gateway	STRAPS
TX Band	GHz	81-86	71-76
RX Band	GHz	71-76	81-86
Bandwidth	MHz	5000	5000
Aperture Diameter	m	1	0.5
Boresite Gain	dBi	56.4	50.4
3dB Beamwidth	deg	0.22	0.44
Pattern		ITU-R F.1245	ITU-R F.1245
Polarization		RHCP/LHCP	RHCP/LHCP
Clear sky EIRP spectral density	dB(W/MHz)	5	-10.7
Hardware Max EIRP spectral density	dB(W/MHz)	24	14.3
Power control		Yes	Yes
Max Elevation Angle	deg	90	90
Min Elevation Angle	deg	45	45
Height above ground	m	10 typical	HAA
Receiver Noise Density	dB(W/MHz)	-136.4	-136.4
Protection Criteria (I/N)	dB	-6	-6

Custom Antenna Patterns

Enterprise (Full Band) User Terminal Antenna 1 m SOR Boresite gain: 40.66 dBi 3 dB Beamwidth: 1.6 deg	
Theta deg	**Gain Envelope dBi**
0	40.66
0.5	40.2
0.8	37.66
1	37.1
1.5	34.6
2	24.6
2.5	10
3	-5
3.5	-8.6
4	-11
4.5	-11.9
5	-14.3
5.5	-15
6	-15.5
6.5	-16.5
7	-17.6
7.5	-18.5
8	-19
8.5	-20
180	-20

Consumer (Narrow Band) User Terminal Antenna 0.45 m SOR Boresite gain: 34 dBi 3 dB Beamwidth: 3.4 deg	
Theta deg	**Gain Envelope dBi**
0	34
1	33
1.5	32
1.67	31
2	30
3	28
4	23
5	13
6	0
7	-10
8	-12.5
9	-13
10	-15
11	-16.5
12	-17
13	-18
14	-20
180	-20

Appendix B
Compatibility Analysis:
STRAPS User Uplink Interference into
Fixed Service in the
21.5 – 23.6 GHz Band
(Prepared by Lockheed Martin Corporation for Elefante Group, Inc.)

SUMMARY

- Elefante Group is proposing to access the 21.5-23.6 GHz band for User uplink communications from User Terminals (UTs) to Stratospheric Platform Stations (STRAPS) on a co-Primary basis.

- This study assesses the compatibility of STRAPS User uplinks with Fixed Service (FS) point to point microwave links which are authorized to operate in the 21.2-23.6[1] GHz band.

- Worst-case operating conditions are utilized for a bounding analysis: UTs are at maximum EIRP, and no atmospheric propagation or ground clutter losses are considered.

- Protection contours defining locations UTs could not operate and use spectrum licensed to a traditional FS link are proposed as both a method to demonstrate compatibility and to facilitate coordination.

- Protection contours calculated for FS receivers taken from FCC license data show both compatibility and viability of prior-coordination using the approach described.

- A streamlined approach for coordination is proposed.

PURPOSE OF THE STUDY

Elefante Group is proposing that the 21.5-23.6 GHz band be made available for Stratospheric-Based Communications Services (SBCS), operating as a Fixed service, in the uplink direction. (While not the purpose of this study, Elefante Group proposes that the 21.5-23.6 GHz band also be considered for use in the downlink direction.) All or part of this band is allocated in the federal and non-federal allocation to Fixed, Mobile, Space Research (earth-to-space), Space Research and Earth Exploration (passive), Radio Astronomy, and Inter-Satellite Service.

This study assesses the compatibility with other Fixed Service links of uplink transmissions from ground-based UTs to a multi-beam stratospheric platform, and assesses the potential for interference into traditional FS point to point microwave links to exceed the I/N Protection Criterion to determine if mitigation measures are necessary.

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[1] Elefante Group is also looking at the prospect for SBCS-UT uplinks in the 25.25-27.5 GHz band. Although such links are beyond the scope of the present compatibility study and discussion, Elefante Group believes a similar analysis and conclusions would largely apply to compatibility with FS links in the federal allocation in that band.

The proposed approach for coordinating with existing conventional FS receivers from SBCS-UT FS transmitters is to determine a protection contour around each receiver within a STRAPS footprint where the frequencies it is licensed for cannot be reused by SBCS-UTs serving a registered STRAPS absent further coordination. SBCS-UTs deployed within the protection contour will be permitted to use frequencies within the uplink band *excluding* the frequencies in the FS receiver license. SBCS-UTs deployed outside the protection contour of any existing FS link are permitted to use frequencies within the full uplink band. By analyzing and determining protection contours for all existing FS licenses in the FCC database that could be affected, SBCS-UTs would be deployed with restrictions on their use of shared spectrum appropriate and sufficient to protect existing links.

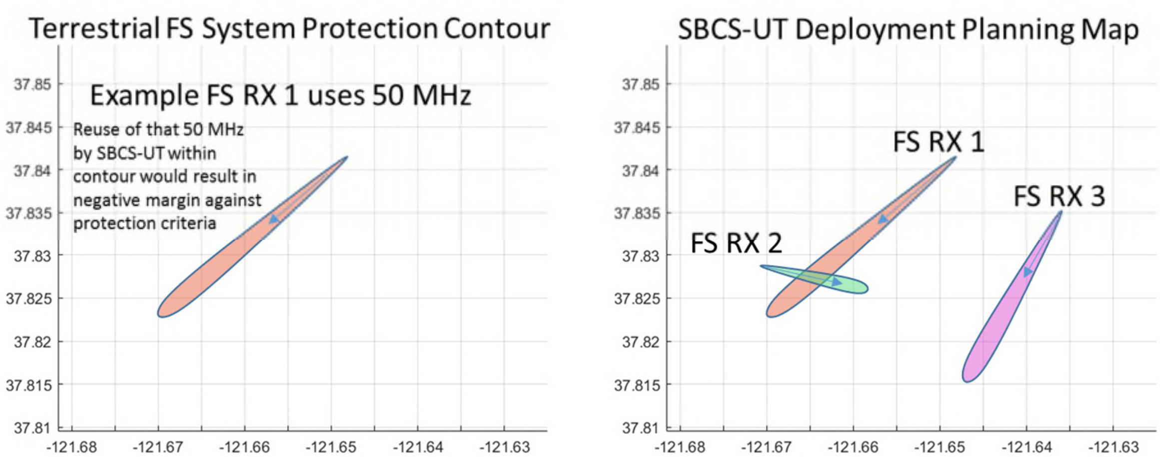

Figure 1: Notional protection contours. Left) a single FS RX will not permit re-use of its licensed frequency bands within some latitude/longitude contour. Right) SBCS-UT link deployment accounts for all protection contours within service area associated with STRAPS authorization. Network resource management prevents use of licensed FS frequencies by SBCS-UTs within their associated protection contours

OPERATIONAL CHARACTERISTICS OF TERRESTRIAL FS RECEIVERS

FS receiver data is gathered from the FCC license database. The database contains sufficient information on both transmit and receive locations on a path to determine all relevant receiver geometry (latitude, longitude, altitude, azimuth, and elevation) and spectrum use. Full receive gain patterns as a function of angle off boresite are not available, but boresite gain and 3 dB beamwidth are. For this initial analysis, patterns are approximated from the boresite gain per ITU-R F.1245. Per TSB-10F, B-2, default system noise figure is taken as 5 dB from which -134 dB(W/MHz) noise density is assumed. A harmful interference threshold of -6 dB interference to noise spectral density is used.

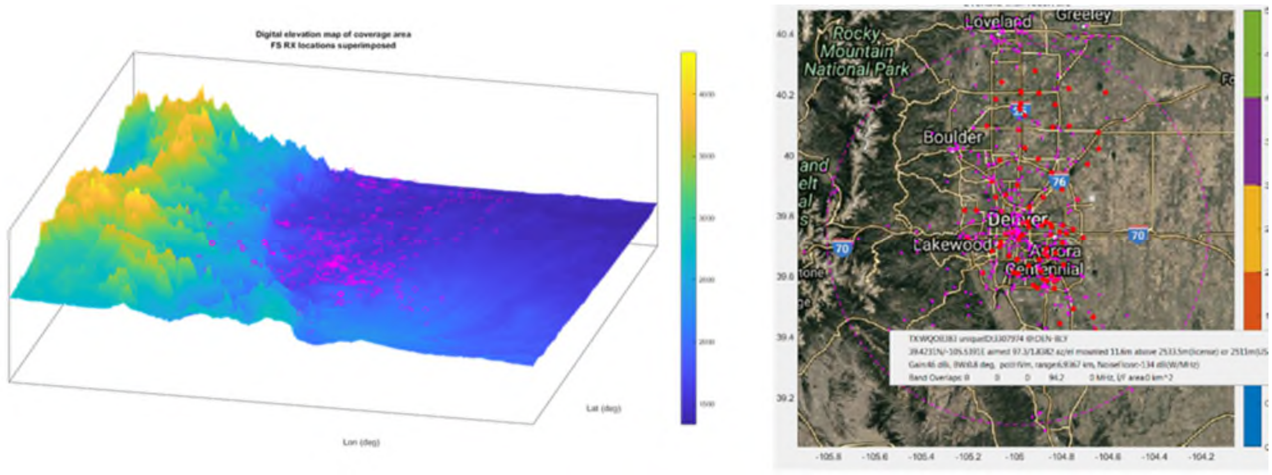

Figure 2: FCC data gathered for 80 km radius around Denver centered STRAPS. Left) Terrestrial FS receiver locations around Denver superimposed on a USGS digital elevation map, Right) Interactive map with receiver characteristics

OPERATIONAL CHARACTERISTICS OF SBCS

The SBCS will utilize STRAPS, UTs, and Gateway terminals to provide fixed services over a specific service area. Transmit characteristics of the Elefante Group STRAPS user uplink utilized in this study are given in Appendix 1.

The study will focus on the enterprise terminal because it operates at the proposed regulatory limit EIRP density for SBCS of 20 dB(W/MHz).

STUDY SCENARIO

Figure 3 illustrates the interference geometry applicable to this study.

- FS transmitters (TX) and FS receivers (RX) are distributed across the service area and adjacent regions forming links and pointed at each other. As described in license documentation, each FS RX is located at a specified latitude and longitude, mounted at a specified height. As derivable from license documentation, it is aimed in a specific azimuth and elevation direction.
- If a candidate UT location and the STRAPS location it points to is specified, then for any FS RX the relative geometry can be calculated: range, and off-boresight angle from each aperture to the other.

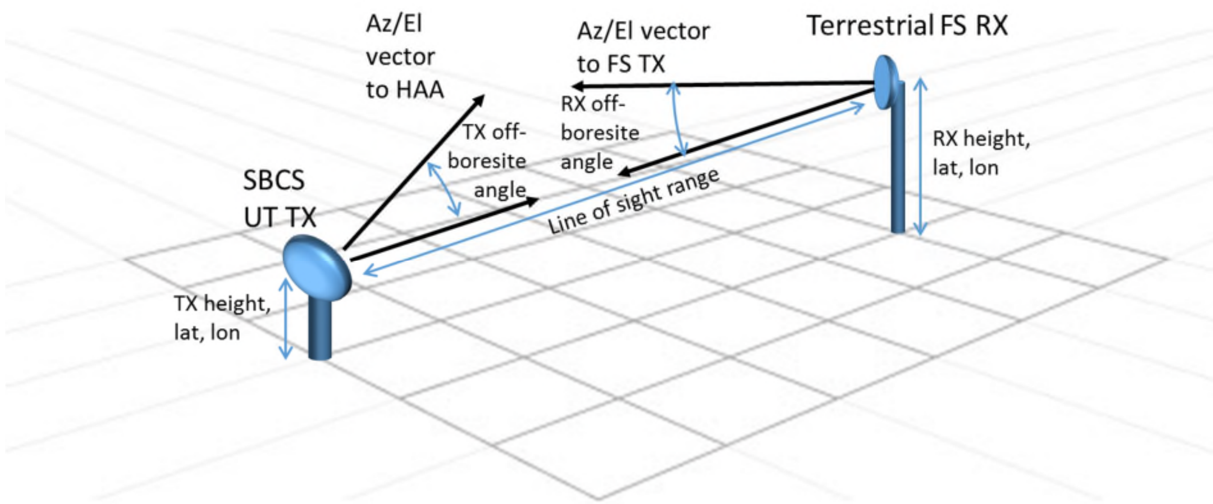

Figure 3: Geometry for high elevation SBCS user terminal interference transmission into terrestrial FS receiver

STUDY METHODOLOGY

The primary methodology of this study is the calculation of protection contours as described previously and illustrated in Figure 1. To develop a protection contour, interference margin is evaluated over a suitably fine grid of potential interferer locations surrounding an FS RX, and a contour drawn containing all points with negative margin.

To examine realistic deployments, a STRAPS location (latitude, longitude, altitude) and service area radius is defined and FS license data pulled from the FCC online database over a region extending some distance beyond the service area.

Geometric Calculations

To account for Earth curvature and local topography, a regular grid is developed in latitude and longitude with ground height derived from a USGS 10m resolution digital elevation map for height above the WSG84 geoid plus a height for transmitters above ground height. All grid points are converted to vectors in an Earth Centered Earth Fixed (ECEF) frame. Similarly, using their latitude, longitude, and height above sea level, ECEF vectors are derived for the victim receiver and STRAPS locations.

From these established geometric locations, vectors and angles are calculated:

- Vectors representing interferer antenna pointing directions (which track the STRAPS) are calculated by subtracting the grid vectors from the STRAPS vector and normalizing to unit vectors.
- A vector representing the victim antenna pointing direction is calculated from the victim location vector and azimuth and elevation angles.
- Vectors representing the path from the interferers to victim are calculated by subtracting the grid vectors from the victim vector. Their magnitude is used to determine range and they are normalizing for subsequent angle calculations.

- Angle of the victim off the boresites of the interferers is calculate by comparing their pointing direction vectors to their path vectors.
- Angle of the interferers off the boresite of the victim is calculate by comparing its pointing direction vector to the path vectors.

Interference Margin Calculation

With antenna gain data as a function of angle off boresite of interferer and victim in each other's coordinate frames and free space loss as a function of range, evaluation of the interference margin is readily calculable with the information in Figure 3.

Margin against harmful interference is calculated as:

I/N Margin = I/N threshold(dB) – (Interference density (dB(W/MHz)) – Noise floor density (db(W/MHz))

Neglecting propagation losses, interference density at the victim receiver is calculated as

> Interferer EIRP density at boresite (dB(W/MHz)) – (Interferer boresite gain – Interferer gain in Victim direction) – Free space loss + Victim gain in Interferer direction

Note: Worst-case assumptions for bandwidth overlap

To first analyze the worst-case scenario, in the current analysis the SBCS-UT bandwidth is assumed to completely overlap the victim bandwidth. In reality, SBCS-UTs with smaller bandwidth may not fully overlap the conventional FS receive channel and would contribute less interference than calculated above, with protection contours effectively adjusted to a smaller size accordingly.

Note: Worst-case assumptions for bandwidth overlap

The approach outlined here does not account for line of sight blockage from terrain, vegetation, or artificial structures, and does not account for partial blockage of the Fresnel zone. The exclusion of these factors in any given location may yield overly conservative results which could be accounted for in a real world site-specific coordination to potentially allow stations to be located in closer proximity. The approach does, however, include polarization mismatch loss between linearly polarized traditional FS and the circularly polarized UTs in the reference design.

Note: Multiple interferers

The methodology presented considers interference from a single interferer only. For SBCS geometry, where UTs are all pointed to the same STRAPS location, frequencies will not be reused by adjacent UTs as they would interfere with each other. To reuse frequency within the same service area different receive beams must be employed on the STRAPS, in which case the minimum separation distance on the ground to prevent interference between the two beams will be determined by the beamwidth of these beams projected to the ground, and is on the order of 7-10 kilometers for the EG reference design. Because this is larger than the calculated projection

contours, calculating the contours based on a single UT which injects the same EIRP density into all channels allocated to a FS receiver is entirely adequate.

STUDY RESULTS

Applying the method described above, analyses to date indicate SBCS-UTs can be deployed within areas with existing FS receive stations compatibly. As shown below, the protection areas are relatively small, and this is driven by the fact that 1) the SBCS-UT antennas are purposely designed for high rolloff within 10 degrees of boresite, 2) their high elevation angle, even at the edges of the service area, ensures they present more than 14 degrees off boresite except in very unique situations that are easily revealed in analysis. Thus, the protection contour is driven by the gain and range presented by the FS RX to the SBCS-UT backlobes, appearing as long, thin projections of the FS RX mainlobes to the terrain.

Because the protection areas are small, and the majority of links occupy at most a few 50 MHz channels, there is significant bandwidth remaining for SBCS-UT links (as well as, by extension, future conventional FS links) in all but the most congested areas where deployment of new FS links is also challenging.

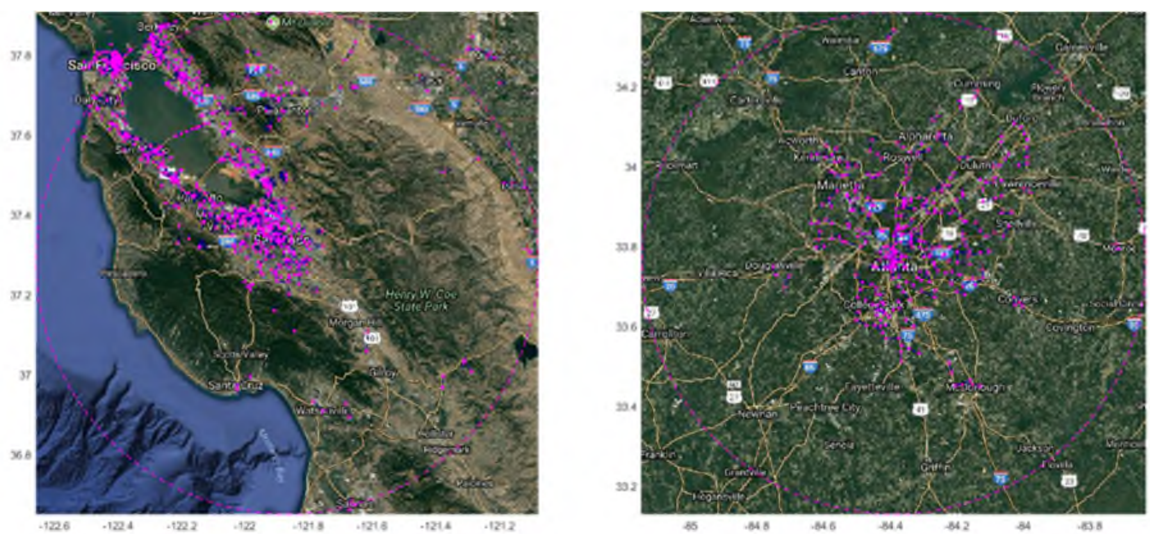

Figure 4: Comparison of FS RX station distribution within 70 km radius service area of STRAPS centered over San Jose (left) and Atlanta (right)

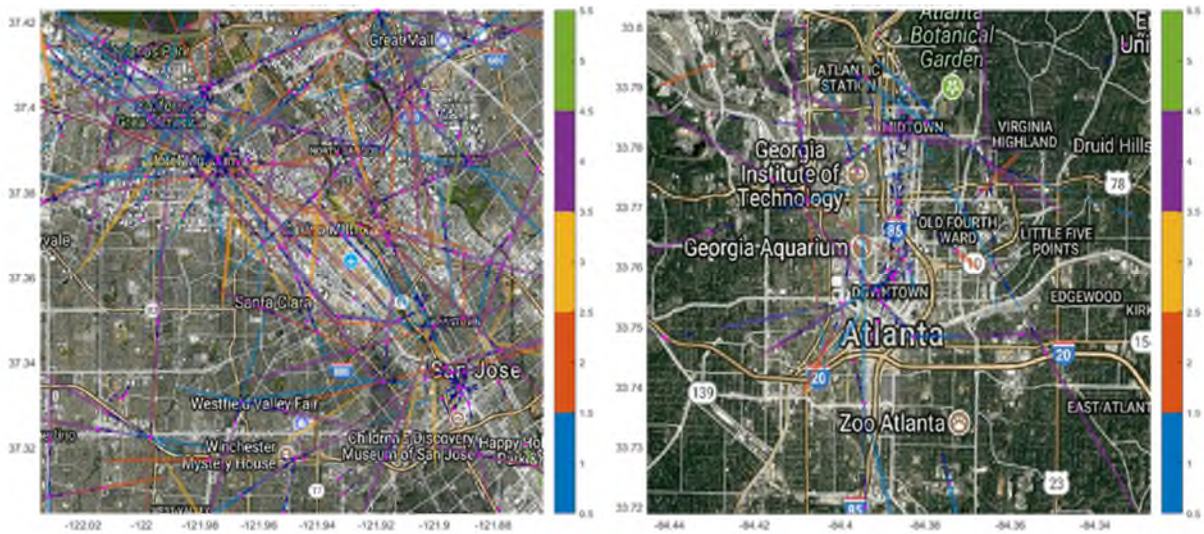

Figure 5: Highest density regions within coverage showing protection contours colored by planned STRAPS user beam bands they overlap. Left) heart of Silicon Valley. Right) downtown Atlanta

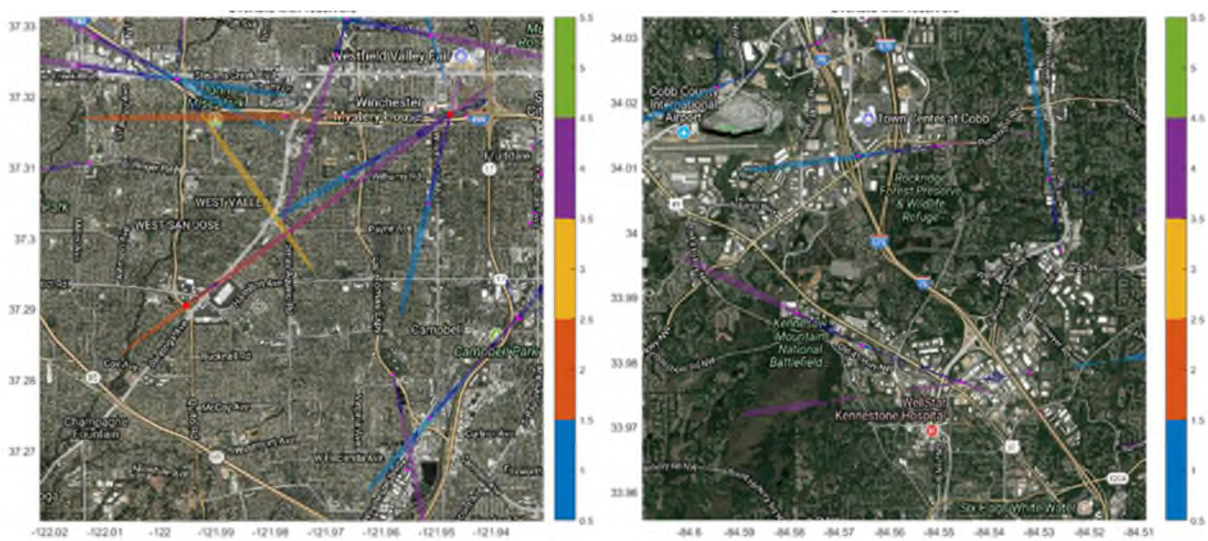

Figure 6: Suburban density regions within coverage showing protection contours colored by planned STRAPS user beam bands they fall overlap for San Jose (left) and Atlanta (right) centered STRAPS service areas

As an example of a specific protection contour calculation, consider a specific bi-directional point-to-point link in the Atlanta area and a STRAPS centered on Atlanta shown in Figure 7. The southern receiver would receive interference from an SBCS-UT located in the blue region if its transmission overlapped the 50 MHz the receiver is licensed for within the 1st (blue) band used by the SBCS. The northern receiver would receive interference from an SBCS-UT located in the purple region if its transmission overlapped the 50 MHz the receiver is licensed for within the 4th (purple) band used by the SBCS.

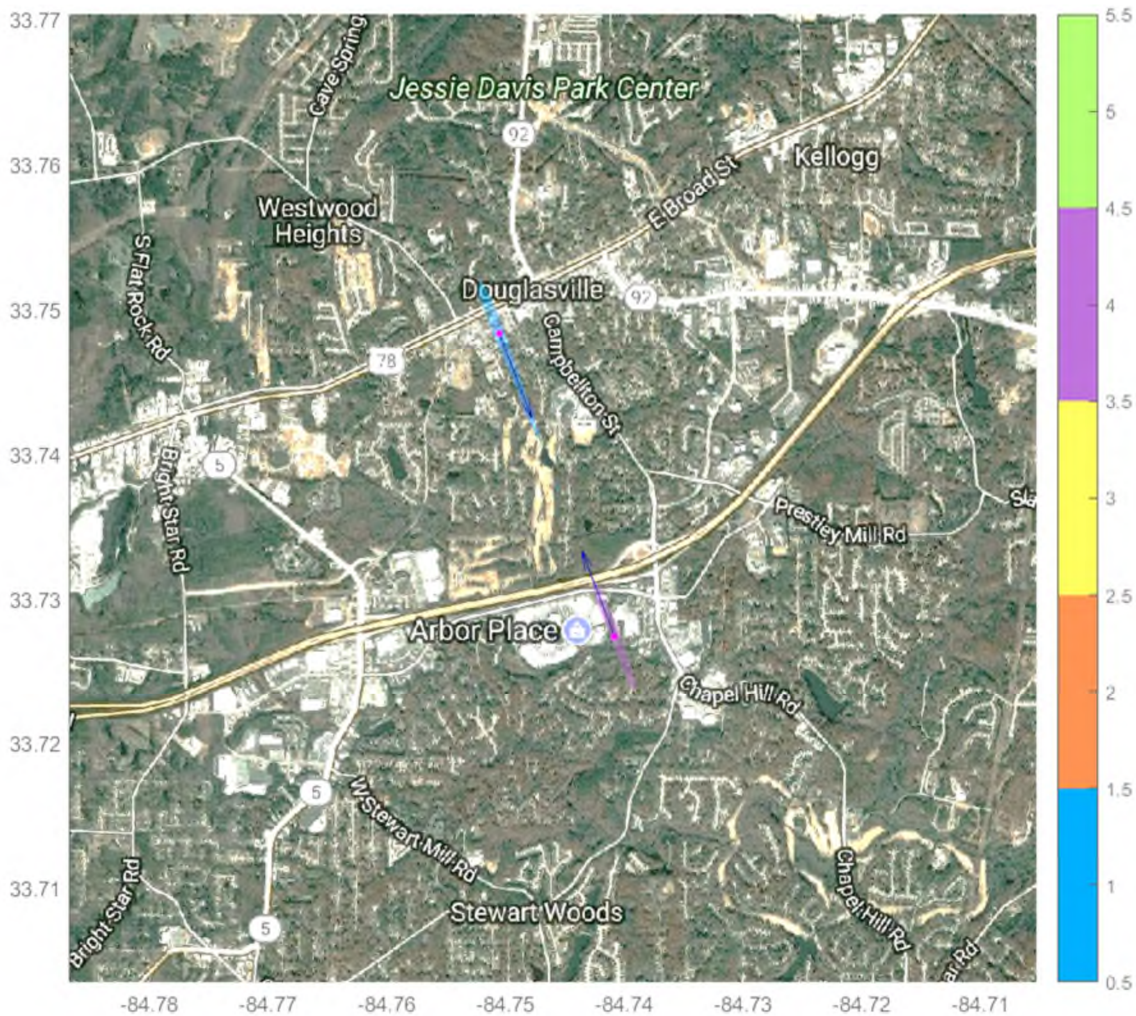

Figure 7: Example protection contours for bi-directional link described in text

Examining the northern receiver in more detail as the victim, we can examine the parameters affecting interference in more detail. The victim is located at 33.7484N/-84.7505E lat/lon 45.7m above a 364m ground height and aimed 158.8 deg in azimuth and -0.7 deg in elevation. It uses a 34.4 dBi, 3 deg 3 dB beamwidth antenna, which for this analysis is bounded using the ITU-R F.1245 pattern (which has a minimum backlobe of -10 dBi). Assuming a 5 dB noise figure it has a noise floor of -134 dB(W/MHz).

As shown below, the gain presented by the victim to possible interferer locations 10 m above the local terrain is as expected, a narrow sliver of high gain along the azimuth pointing direction. The interfering antenna is at an elevation angle higher than its mainlobe rolloff, and presents gain bounded by -20 dBi in any direction. Thus the interference reaching the receiver from possible interferer locations is highest along the azimuth pointing direction and falls off with increasing range. When compared to the -6 dB I/N criteria, the margin is negative over only a small area, representing a slice of a shopping mall parking lot and perhaps a few dozen homes.

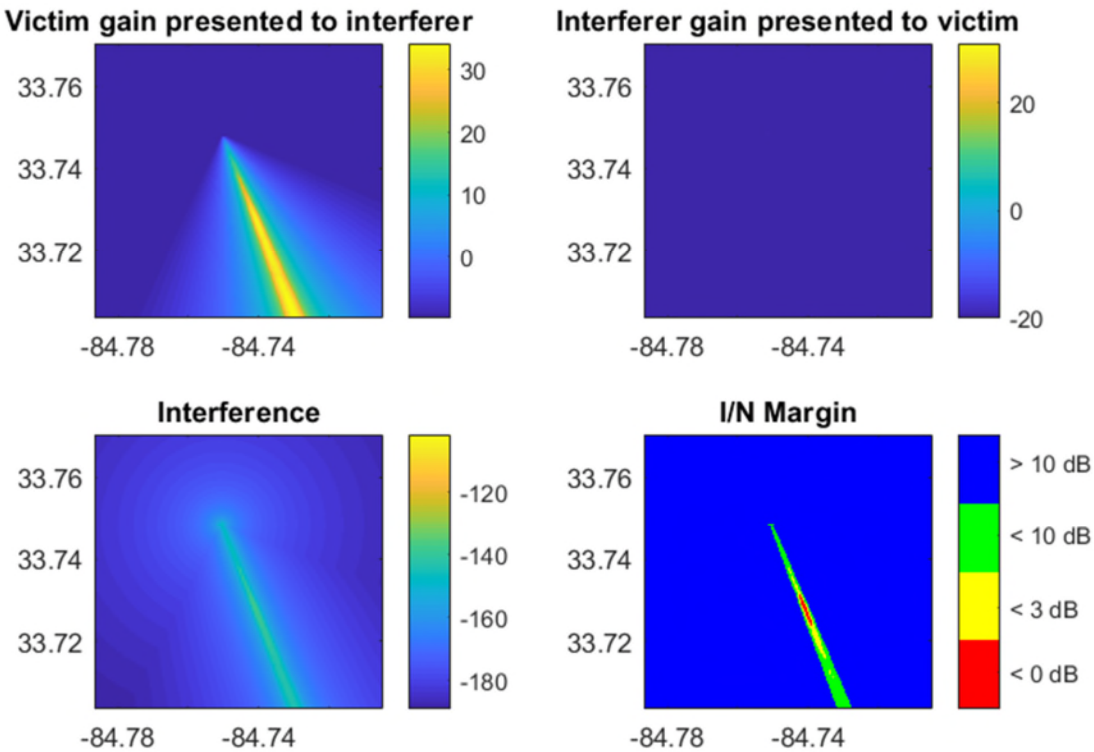

Figure 8: Components of the interference analysis for example link described in text illustrating why protection contour area is relatively small and manageable.

Not apparent from this analysis is the very localized protection area, extremely close to the receiver itself, where the interferer mainlobe would directly intersect the receiver (where the SBCS-UT, victim receive antenna, and STRAPS are on the same line so the SBCS-UT aims directly through the receive antenna when pointing at the STRAPS). Although entering the receiver backlobe, if the range and angle off the interferer boresite direction is not large enough, there will be an area on the ground where the interferer must not be placed. Although it does not show up on this plot because it is such a small area, it would be included as part of any protection contour.

DISCUSSION: STUDY RESULTS

This study demonstrates that proposed SBCS-UTs can operate compatibly with existing and future conventional FS receivers, and the use of protection contours can adequately protect them.

Key to compatibility is the difference in elevation angles, with SBCS-UTs always aimed at high elevations (minimum 15 degrees at STRAPS coverage area perimeter) and terrestrial FS receivers almost universally at lower elevation angles. Elefante Group expects that, in an urban deployment, where compatibility would be expected to be most at issue, most SBCS UT links would operate at higher elevation angles, as most deployments are expected within the center 50% of the operating area. Analysis demonstrates that the required protection contours in all but the most congested regions are small and exclude use of a small enough range of frequencies to

allow deployment by SBCS applications. In fact, SBCS-UT links, with boresites elevated above where they can aim directly at conventional FS locations or other SBCS-UT location, are likely to have more freedom to deploy given existing links than other conventional FS links would have. For similar reasons, deployment of SBCS-UT links will not have a material impact on future conventional FS deployments. Indeed, deployment of an SBCS-UT link will generally have less impact on future conventional FS deployments than a conventional FS link at the same location would have.

DISCUSSION: PROPOSED COORDINATION STREAMLINING

Based on the above, the following outlines an approach to streamlined coordination and licensing/registration of STRAPS and SBCS-UTs that Elefante Group would like to discuss with the FWCC in detail.

Existing Terrestrial FS Systems

STRAPS will be deployed at specific nominal fixed positions which will define the permitted service contour, which will trigger a comprehensive pre-coordination process for SBCS FS links within the platform footprint. The primary approach for coordinating with existing conventional FS receivers from SBCS-UT FS transmitters is to determine a protection contour around each receiver within a STRAPS footprint where the frequencies it is licensed for cannot be reused by SBCS-UTs serving a registered STRAPS absent further coordination. SBCS-UTs deployed within the protection contour will be permitted to use frequencies within the uplink band *excluding* the frequencies in the FS receiver license. SBCS-UTs deployed outside the protection contour of any existing FS link are permitted to use frequencies within the full uplink band. By analyzing and determining protection contours for all existing FS licenses in the FCC database that could be affected, SBCS-UTs would be deployed with restrictions on their use of shared spectrum appropriate and sufficient to protect existing links.

Adjacent channel interference is expected to be negligible, with > 50 dB out of band attenuation from the modem alone with negligible spectral regrowth from operating well off amplifier saturation, and with potentially additional filtering as necessary. A protection contour will be examined during the pre-coordination process for adjacent bands, however, and accounted for if non-negligible.

Future Terrestrial FS Systems

As terrestrial FS are coordinated and added to FCC license database, additional protection contours would be calculated, updating the pre-coordination results, and included in both SBCS spectrum planning ConOps and future UT deployments.

Motivation – Reduced Coordination Overhead for All

Elefante Group envisions that a STRAPS will be capable of connecting many thousands of UTs within a STRAPS service area. Extending the current coordination process to each SBCS-UT link, providing for notification and response, as every SBCS-UT is deployed, will be burdensome and logistically challenging for both SBCS licensees and FS point to point licensees. Elefante Group does not believe it necessary to inundate FS with thousands of prior coordination notices for SBCS-UTs, nor wait each time for a notice period to end before installing an overhead directed UT on a rooftop.

To streamline this process, we propose developing a compatibility calculation methodology with FWCC, derived from the methodology presented, that could be used when a STRAPS is deployed and updated as new FS links are deployed, to ensure that SBCS licenses may deploy SBCS-UT links over the allocated STRAPs band *excluding* the frequencies used by any FS receivers with protection contours that include that UT location.

Objective – Efficient Deployment of Consumer Terminals Conditioned by Coordination

As described in the performance characteristics table, there are two primary types of UTs in the EG system: 1) consumer terminals that will occupy only 5 to 25 MHz of the planned 450 MHz bands to be used by beams and 2) enterprise terminals that use up to the full 450 MHz available in the beam.

Consumer terminals will often be installed in a process similar to satellite dishes at residential locations and small businesses, and simplifying the flow from installation to operation is the primary motivation for the proposed streamlined process. In Elefante Group's case, the UT installation will be part of a wholesale service Elefante Group delivers to other providers, not directly to the residence or business end user, and the all Elefante Group terminals will be professionally installed. Two factors contribute to make giving SBCS licensees this flexibility quite practical.

1) Analysis has shown that because of their high elevation angles the protection contour required around an existing FS receiver for the frequencies it uses is quite small, representing a very small fraction of the footprint of a beam from the STRAPS.
2) Terminals placed within a protection contour can readily avoid the protected frequencies and still provide service. If the protected frequencies fall within the 450 MHz band assigned to the beam covering the location, the network system controller can readily assign UTs within that protection contour to a channel within the 450 MHz that does not overlap the protected FS frequencies.

This combination of readily assessing protection contours and ability to simply work around the protected frequencies presents a sufficiently low risk for harmful interference that commencement of operations upon installation of the STRAPS following service area pre-coordination (supplemented as other FS links are later deployed) seems merited and is fundamental to the streamlining described below.

The enterprise (larger bandwidth) terminals have less operational flexibility because they require access to up to a contiguous 450 MHz when active, so placement within the protection contour of a licensed FS receive station using any part of one of the 450 MHz bands prevents use of that channel. There will be fewer of these and, while an approach to expediting their deployment is desirable, it is not the focus of the discussion below.

Pre-Coordination and Registration for SBCS-UTs

Elefante Group envisions that SBCS providers will receive large area licenses, not licenses for specific STRAPS deployments. Specific STRAPS deployments would have to be registered before deployment occurs and coordinated with certain co-band incumbent users. However, in

the case of existing FS links, the SBCS licensee would pre-coordinate as described below for each STRAPS deployment once the location of the STRAPS is selected.

More specifically, the SBCS licensee will engage in pre-coordination of UT links in the 21.4-24.0 GHz (23 GHz) band based on the intended coverage area beneath the contemplated nominally-fixed position of the STRAPS. During this process, the licensee would not coordinate specific planned UT links but instead will notify all existing non-Federal FS licensees and applicants with coordinated links within the coverage area and provide an interference analysis in order to establish contours that must be protected on the frequencies within the 23 GHz band being used by the respective FS licensees, subject to methods that will permit compatibility around each license. Subsequent to such coordination, the SBCS licensee can deploy and register UT links in the STRAPS coverage area[2] consistent with the results of the prior coordination without further process.[3]

The pre-coordination and registration framework proposed by Elefante Group will permit rapid deployment of UT links allowing SBCS licensees to be highly responsive to customer requests with minimal delays while ensuring adequate protection of incumbent users (equivalent to the protection they now receive from later-deployed FS links following coordination) and the ability of traditional FS services to expand in the same manner they can today.

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[2] The registration of the UT links will facilitate coordination and deployment of other FS links on traditional ground-based systems compatibly with the UT links.

[3] As new traditional FS inks are coordinated and deployed after the UT links are pre-coordinated, the SBCS licensee would provide notification to the owner of the new FS links and update the pre-coordination.

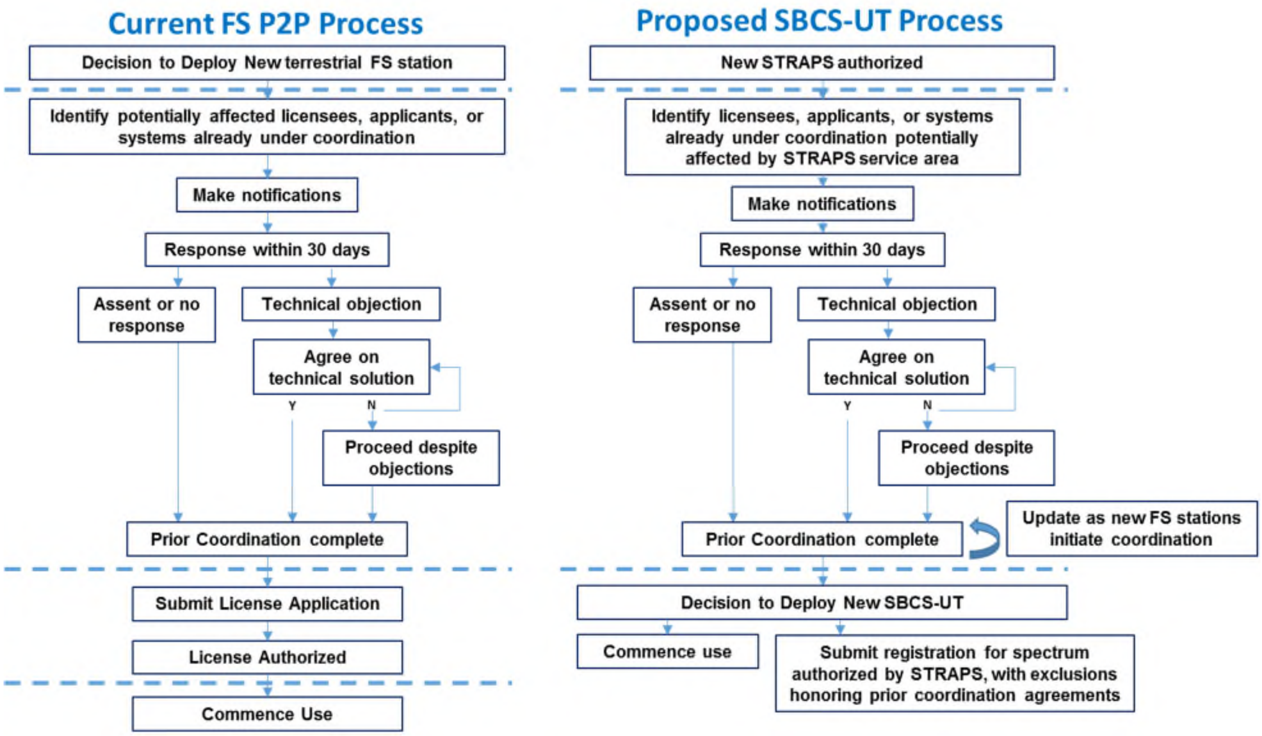


Figure 9: Comparison of current FS process to streamlined process. New SBCS-UT satisfying pre-coordination agreements with non-federal and federal users may be simultaneously activated and registered. SBCS-UT not satisfying pre-coordination agreements must go through further coordination with non-federal and/or federal users prior to deployment and registration.

SBCS Licensing and Coordination of Feeder Links in the E-Band

SBCS licensees should be able to obtain nationwide licenses as do FS operators in the 71-76 and 81-86 GHz ("70/80 GHz") bands today. Individual feeder link paths, both to and from the STRAPS, should be coordinated and registered much as are FS links in the E-Band today, including coordinating with federal links as described in the Part 101 rules.

Coordination of New Terrestrial FS with SBCS-UTs Deployed

SBCS overhead geometry, band diversity, and network resource management permit sharing with terrestrial FS with few instances of mutual exclusivity. As illustrated previously, the protection contours within which the spectrum licensed to an FS RX cannot be re-used by an SBCS-UT are small and primarily dependent on where the RX antenna pointing direction directs the mainlobe to intersect the local topography.

After a STRAPS and corresponding SBCS-UTs have been deployed, new FS terrestrial links will create additional constraints on band assignments for UTs that fall within their calculated protection contours. To accept the new FS RX without interfering with it, already deployed SBCS-UTs could operate under new constraints:

- If an uplink beam covering the 5-25 MHz consumer UTs uses a 450 MHz band that overlaps the band used by the FS RX, those terminals must be assigned to different parts

of the band. For example, a new FS RX using a 50 MHz channel would constrain one of the five 450 MHz uplink bands. If that band is used for the STRAPS beam serving terminals within the protection contour, they would have to be assigned a 5-25 MHz channel somewhere within the remaining 400 MHz available in the beam. SBCS-UTs in the beam but outside the protection contour would be assigned channels overlapping the 50 MHz used by the FS RX.

- Enterprise UTs utilizing the full 450 MHz channel that fall within the protection criteria would be unable to use the overlapped band at all. Maintaining the full 450 MHz would require the STRAPS user beam to use one of the other bands available to it (if they are clear of protection constraints), or to be assigned to a next-best adjacent STRAPS beam that uses a clear band. Alternately, the terminal could be designed to operate around the protected frequency at a sacrifice to capacity.

Through resource management of the user beam band assignments and FDM and TDM assignments of UTs, SBCS can absorb a significant number of constraints. Situations under which STRAPs might reject a coordination request by a subsequent FS link rather than adapt to the additional constraints include:

- If it would restrict a deployed enterprise UT from having a sufficient number of bands to both operate at its contracted capacity and exercise mitigations necessary to maintain compatibility with other services in the SBCS uplink band (which in some infrequent cases may require shifting uplinks in a localized area between two or more bands).
- If, due to extreme congestion in both terrestrial and STRAPs (situation dependent), the FS link would prevent band or channel assignment mitigations already being used to protect other FS receivers or other services.

In such situations, wherever possible, the SBCS provider might work with the initiating coordinator to identify an alternate range of frequencies or multi-hop path routing that would avoid the problem.

CONCLUSIONS

As demonstrated through the analysis detailed in this paper, SBCS is compatible with existing FS services in the proposed uplink and downlink bands. Critically:

- <u>Current licenses are adequately protected consistent with their status</u>. By identifying, through pre-coordination with traditional FS users, locations where SBCS UTs cannot use frequencies licensed to existing links or links already under coordination, SBCS UT deployments can be made smoothly and without disruption.
- <u>Future FS links are no more inhibited by SBCS than through current coordination with conventional FS links</u>. Protection criteria for registered SBCS-UTs will be readily determined from the registry database by new links initiating coordination. Because the high elevation angle of SBCS-UT links will project *significantly* lower EIRP towards terrestrial receivers, SBCS-UT links will actually present a technically easier coordination than traditional terrestrial FS transmitters. Traditional links can and do

project the EIRP of their mainlobes horizontally and require dramatically longer separation distances with other traditional fixed links (than will be the case with SBCS-UT links) before their frequencies can be reused.

Elefante Group is not seeking special treatment. The proposed streamlined coordination process requires that the same protection criteria used between existing FS links be met and honored by SBCS-UTs. Because the UT's have a considerable degree of frequency agility, they can be readily deployed and prevented from using frequencies that would interfere with existing links. The streamlined process seeks to take advantage of this channel reassignment capability, coupled with the due diligence of pre-coordination (which will be updated as new links are introduced (and old ones removed)), to speed SBCS-UT link deployment through a registration process while offering full protection to traditional fixed wireless links and enabling new traditional links to be configured (subject to coordination as is the case today).

REFERENCES:

ITU-R F.1245-2: Mathematical model of average and related radiation patterns for line-of-sight point-to-point fixed wireless system antennas for use in certain coordination studies and interference assessment in the frequency range from 1 GHz to about 70 GHz

Appendix C
Compatibility Analysis:
STRAPS User Uplink Interference into
NGSO Inter-Satellite Service Link in the
22.55 – 23.55 GHz Band
(Prepared by Lockheed Martin Corporation for Elefante Group, Inc.)

SUMMARY

- Elefante Group is proposing to access the 22.55–23.55 GHz band for User uplink communications from User Terminals (UTs) to Stratospheric Platform Stations (STRAPS) on a co-Primary basis.

- This study assesses the compatibility of STRAPS User uplinks with NGSO Inter-Satellite Service (ISS) which are authorized to operate in the 23.183–23.377 GHz band.

- Worst-case operating conditions are utilized for a bounding analysis: 1) all UTs simultaneously active and transmitting at power levels which achieve the highest data rates, and 2) maximum number of UTs operating to ensure that the entire 22.55-23.55 GHz band is fully occupied to guarantee overlap with the relatively narrow NGSO ISS channels.

- Bounding compatibility study results show that even though the worst-case geometry is unlikely and would be a transient condition, the NGSO ISS I/N Protection Criterion is met under worst-case operating conditions. No mitigation is necessary.

PURPOSE OF THE STUDY

Elefante Group is proposing that the 22.55–23.55 GHz band be made available for Stratospheric-Based Communications Services (SBCS), operating as a Fixed service, in the uplink direction. (While not the purpose of this study, Elefante Group proposes that the 22.55–23.55 GHz band also be considered for use in the downlink direction). All or part of this band is allocated in the federal allocation to Fixed, Mobile, Space Research (earth-to-space), and Inter-Satellite Service. Iridium possesses the only non-Federal ISS license in the 23 GHz band, specifically at 23.183-23.377 GHz which is used to crosslink Iridium’s low-earth orbiting satellites.

This study assesses the compatibility with NGSO ISS links of uplink transmissions from ground-based UTs to a multi-beam stratospheric platform.

This study assesses the potential for interference into NGSO ISS satellite receivers to exceed the I/N Protection Criterion to determine if mitigation measures are necessary.

OPERATIONAL CHARACTERISTICS OF NGSO ISS RECEIVERS

Operational characteristics of the NGSO ISS receivers utilized for this study are based on ITU-R S.1899 and shown in Table 1 with the satellite constellation geometry illustrated in Figure 1.

Table 1: NGSO ISS Link Receive Characteristics

Parameter	**Value**	**Notes**
Number of Satellite Planes	6	with 22 deg seam
Number of Satellites Per Plane	11	Equally spaced
Nominal Altitude	780 km	
Orbital Inclination	86.5 deg	
Orbital Plane Spacing	31.6 deg	
Frequency Range	23.183 – 23.377 GHz	Horizontal Polarization
Total Bandwidth	194 MHz	8x19 MHz channels (25 Khz spacing)
Rx Antenna Gain	36.6 dBi	
Rx Antenna Pattern	ITU-R S.1899	
Min. Elevation Angle	3 deg	Assumption
Satellite Receiver Noise Density	-139.2 dBW/MHz	877K
Protection Criterion	I/N < -16 dB	Exceedance <0.01% of time

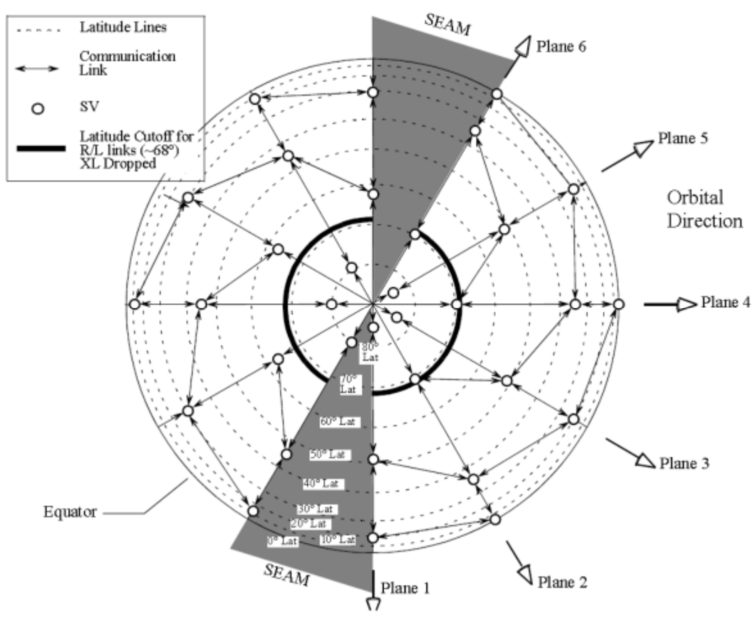


Figure 1: NGSO (Iridiun) Constellation Geometry
Ref: FCC File Number SAT-MOD-20131227-00148

OPERATIONAL CHARACTERISTICS OF SBCS

The SBCS will utilize STRAPS, UTs, and Gateway terminals to provide fixed services over a specific service area. Transmit characteristics of the Elefante Group STRAPS user uplink, used in this study, are given in Appendix 1.

For this study, worst-case operating and geometric conditions are utilized for a bounding analysis prior to considering, if appropriate, risk-based interference assessment using probability and statistical methods:

1) All UTs simultaneously active and transmitting at power levels which achieve the highest data rates, i.e. EIRP Density of 20 dBW/MHz for Enterprise UTs and 12 dBW/MHz for Consumer UTs.

2) Maximum number of UTs operating to ensure that the entire 22.55-23.55 GHz band is fully occupied to guarantee overlap with the relatively narrow NGSO 19 MHz ISS channels.

3) Worst-case geometric alignment between NGSO ISS receiver, STRAPS service area and UT.

STUDY SCENARIO

Figure 2 illustrates the interference geometry applicable to this study.

- UTs located across the coverage area transmit User Uplink signals to the associated STRAPS.
- NGSO satellite transmits the desired ISS link signal to another NGSO receive satellite which may be located within the same orbital plane or the adjacent orbital place. Note that ISS links are not maintained across the 22 deg seam in the satellite constellation.
- As the NGSO satellites move through their respective orbits, there will be instances of time during which the worst-case alignment for interference will occur when the NGSO ISS receiver is pointed over the center of the STRAPS coverage area and downwards from its local level by the maximum declination angle.
- UTs located at the edge of the STRAPS coverage area will have the smallest elevation angle and therefore the highest potential for interference when their boresight is co-aligned with the NGSO ISS receiver.
- A single-entry compatibility study is initially performed for each type of UT assuming the interference from the boresight pointed UT will dominate. Results are subsequently extrapolated to a multi-entry case to account from the aggregate interference from all UTs.

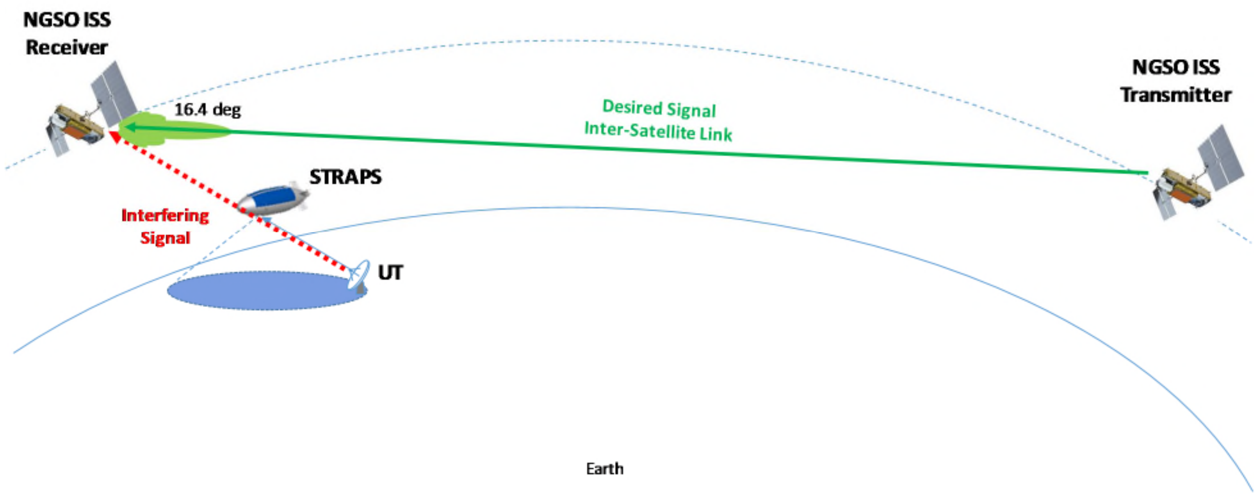


Figure 2: Interference Geometry

STUDY METHODOLOGY

As illustrated in

Figure 3, the worst-case interference geometry is setup by first calculating the maximum declination angle of the NGSO ISS receiver which will result in the highest receiver antenna gain looking towards the STRAPS.

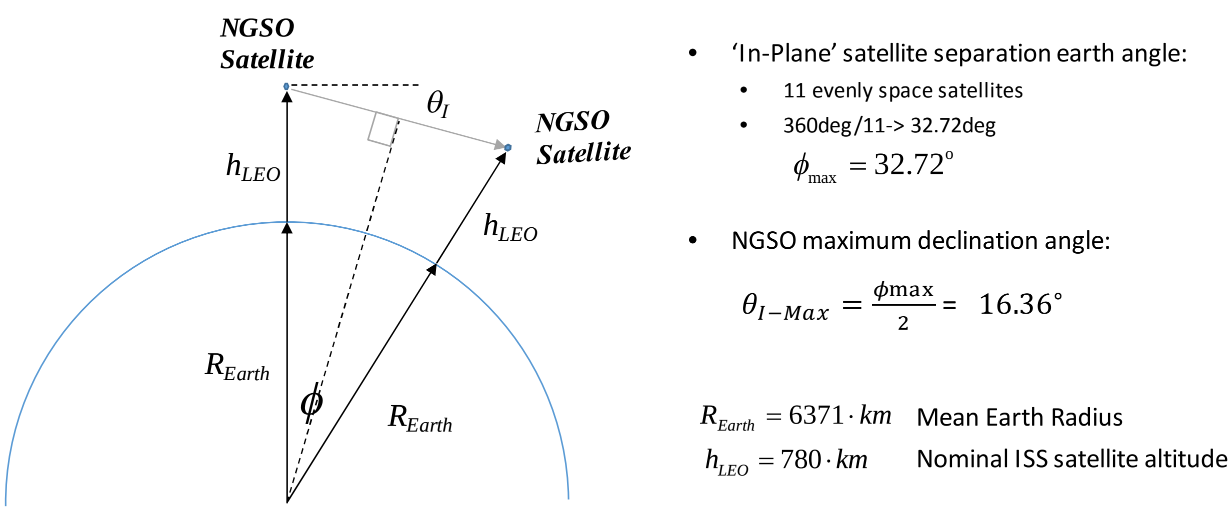


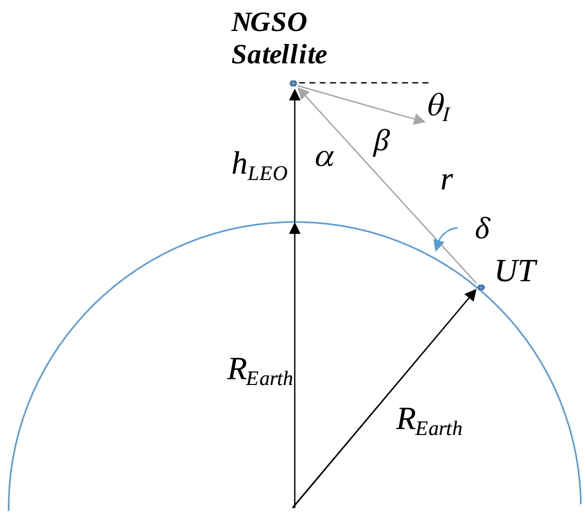
Figure 3: NGSO ISS Maximum Declination Angle

Note that the calculation shown is for in-plane satellite separation which represents the maximum earth angle and, therefore, the maximum declination angle in comparison to cross-plane satellite separation which will have a smaller earth angle. The separation between cross-plane satellites

depends on the latitude and staggering between satellites between adjacent orbital planes. Considering mid-latitudes, a 29.5-degree earth angle was calculated for receiver declination angle versus 32.72-degree earth angle for in-plane satellite separation.

As described above, the worst-case geometrical case includes the assumption that during the instance of time that the NGSO ISS receiver is at its maximum declination angle, there is a corresponding STRAPS service area so that the NGSO ISS receiver, STRAPS and the interfering UT are co-aligned.

Since the range from the UT to the NGSO ISS receiver and, therefore, the space loss increases with UT elevation angle while the NGSO ISS receiver antenna angle towards the UT decreases (antenna gain increases), the relationship between the three is derived to determine whether the range or UT elevation angle dominates the interference level. Figure 4 illustrates the corresponding geometry and equations for these calculations.



$$\alpha = \sin^{-1}\left(R_{Earth} \cdot \frac{\sin(\delta + 90°)}{R_{Earth} + h_{LEO}}\right)$$

$$\beta = 90° - \theta_I - \alpha$$

δ = UT Elevation Angle towards NGSO ISS receiver

β = NGSO ISS receiver antenna angle towards UT

$$r = \sqrt{(R_{Earth} + h_{LEO})^2 + (R_{Earth})^2 - 2 \cdot (R_{Earth} + h_{LEO}) \cdot R_{Earth} \cdot \cos(180° - (\delta + 90°) - \alpha)}$$

r = Range from UT to NGSO ISS receiver

Figure 4: Geometry for UT Elevation Angle & NGSO ISS Receiver Antenna Angle

The corresponding results for β angle and range as a function of δ angle are shown in

Figure 5.

The interference level is calculated for various UT elevation angles to determine the worst-case level.

For the initial single-entry compatibility study, the interference level from the UT into the NGSO ISS receiver is determined:

$$Io\left(\frac{dBW}{MHz}\right) = EIRP\ Density\ (\delta) - FSL - Gr\ (\beta) - 3dB\ polarization\ loss$$

where:

δ = Angle off UT (Interferer) boresight towards the NGSO ISS receiver

$Gr\ (\beta)$ = NGSO ISS (Victim) receive antenna gain off boresight towards UT

FSL = Free Space Loss between the UT and NGSO ISS receiver

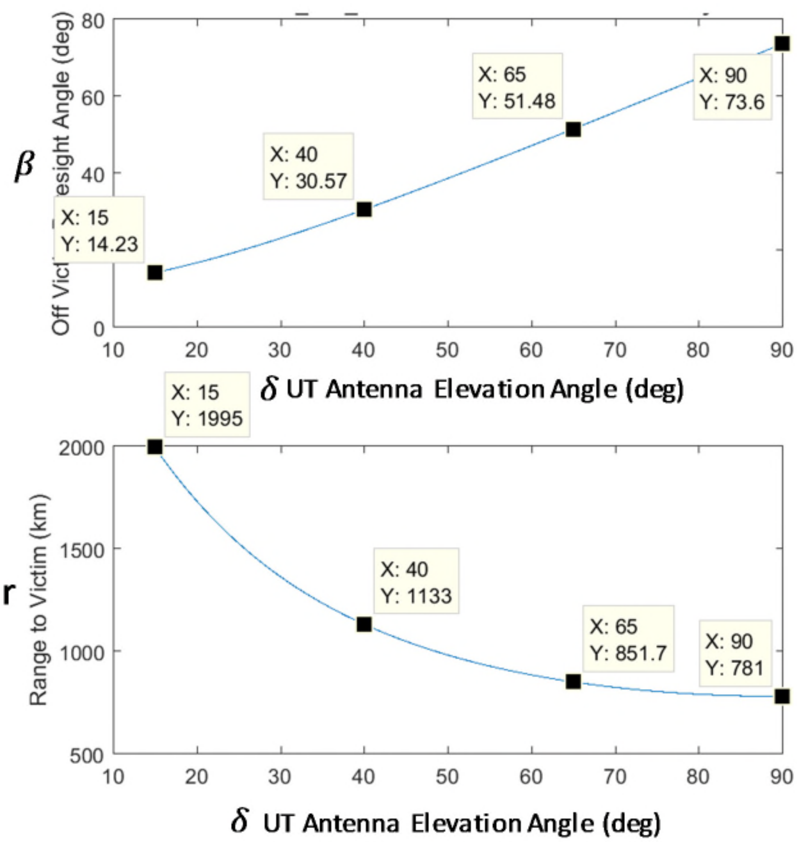


Figure 5: Results for UT Elevation Angle & NGSO ISS Receiver Antenna Angle

Therefore,

$$^{I}/_{N}\ Margin\ (dB) = {}^{I}/_{N}\ Threshold - (I_o - N_o)$$

where $^{I}/_{N}\ Threshold$ is the NGSO ISS Protection Criterion of -16 dB.

STUDY RESULTS

Results of the single-entry compatibility study are summarized in Table 2.

Table 2: Single Entry Compatibility Study Results

UT Elevation Angle, β (deg)	NGSO ISS Receiver Antenna Angle, δ (deg)	Range (km)	Consumer UT I/N Margin	Enterprise UT I/N Margin
15	14.23	1995	14.8 dB	6.5 dB
40	30.57	1133	18.2 dB	10.2 dB
65	51.48	852	19.4 dB	11.4 dB
90	73.6	781	18.1 dB	10.5 dB

Not surprisingly, the worst-case I/N Margin of 6.5 dB is for the UT at the edge of the STRAPS coverage area with the lowest elevation angle.

The worst-case scenario of UTs near the edge of the coverage area causing interference is not expected to occur with a high degree of probability because it requires the two Iridium satellite that are cross-linking to both be near the limb of the Earth relative to each other and aligned with the STRAPS and UT. Nonetheless, this analysis does not rely on the probability with which the worst-case geometry occurs because, even in the static worst-case scenario, the interference Protection Criteria are not exceeded. In the vast majority of cases, the geometries of most UTs, which will ordinarily have higher elevation angles, and therefore not be aligned with the maximum declination of the victim receiver, will reduce the impacts from any interfering signal received even further.

To assess the interference level from multiple UTs, the impact of the next closest UT to the worst-case UT at the edge of coverage using the same frequency band (color) is assessed. Assuming a 3.5-degree beam width at the edge of the coverage radius, the minimum angular difference between the worst-case interfering UT and next closest UTs as seen from the STRAPS will be 1.56 degrees. Normalized antenna gain patterns for Consumer and Enterprise UTs are illustrated in Figure 6 which indicate that the closest Enterprise UT will have a rejection of 20 dB and the closest Consumer UT will have a rejection of 8 dB. Considering the sharp antenna roll-off for both types of terminals, it's concluded that the remaining UTs will contribute negligibly to the aggregate interference level.

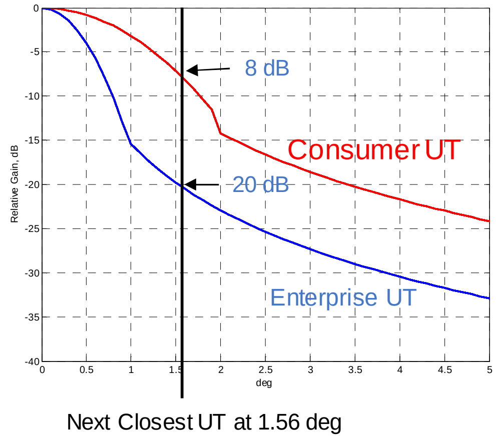


Figure 6: UT Normalized Antenna Gain vs Angle

Therefore, for the multi-entry case which accounts for interference contribution from all UTs, the worst-case I/N margin for Enterprise UTs is reduced by 0.04 dB from 6.46 dB for the single-entry analysis to 6.5 dB. Using a similar approach for the Consumer UT scenario, where the single-entry analysis results in a much larger margin of 14.8 dB, the multi-entry analysis still yields a satisfactory I/N margin of 14.2 dB.

CONCLUSIONS

Bounding compatibility study was performed using worst-case operational and geometric assumptions including all UTs simultaneously active, transmitting at maximum power and across the entire 22.55-23.55 GHz band, thus ensuring overlap with all NGSO ISS channels. Positive margin relative to the NGSO ISS I/N Protection Criterion is achieved under all conditions. In real world operations, the conservative assumptions behind this study and the dynamic nature of the Iridium constellation will ensure that the worst-case geometries are relatively infrequent and short-lived. Therefore, the already negligible impacts on ISS links would be reduced even further. No mitigation is necessary.

REFERENCES:

ITU-R S.1899: Protection criteria and interference assessment methods for non-GSO inter-satellite links in the 23.183-23.377 GHz band with respect to the space research service.

Appendix D
Compatibility Analysis:
STRAPS User Uplink Interference into
NGSO Return Link (LEO-to-MEO) Inter-Satellite Service Link in the
22.55 – 23.55 GHz Band
(Prepared by Lockheed Martin Corporation for Elefante Group, Inc.)

SUMMARY

- Elefante Group is proposing to access the 22.55–23.55 GHz band for User uplink communications from User Terminals (UTs) to Stratospheric Platform Stations (STRAPS) on a co-Primary basis.

- This study assesses the compatibility of STRAPS User uplinks with NGSO Return Link (LEO-to-MEO) Inter-Satellite Service (ISS) which are authorized to operate in the 22.55-22.95 GHz band.

- Worst-case operating conditions are utilized for a bounding analysis: 1) all UTs simultaneously active and transmitting at power levels which achieve the highest data rates, and 2) maximum number of UTs operating to ensure that the entire 22.55-23.55 GHz band is fully occupied to guarantee overlap with the LEO-to-MEO ISS channels.

- Bounding compatibility study results show that the worst-case geometry and operating conditions are unlikely and would be a transient condition, therefore a statistical analysis and/or coordination is required to ensure that the LEO-to-MEO ISS service is not impacted. Such analyses will be performed on a case-by-case basis and require additional knowledge of the Audacy's user systems.

PURPOSE OF THE STUDY

Elefante Group is proposing that the 22.55–23.55 GHz band be made available for Stratospheric-Based Communications Services (SBCS), operating as a Fixed service, in the uplink direction. (While not the purpose of this study, Elefante Group proposes that the 22.55–23.55 GHz band also be considered for use in the downlink direction). All or part of this band is allocated in the federal allocation to Fixed, Mobile, Space Research (earth-to-space), and Inter-Satellite Service. Audacy Corporation application for a non-Federal ISS license in the 23 GHz band is accepted for Filing, which is used to crosslink Audacy's LEO User Satellites with the MEO Relay satellites. Since the FCC filing contains insufficient information regarding LEO User satellite characteristics, this study is limited to potential interference into the MEO Relay satellites.

This study assesses the compatibility with NGSO LEO-to-MEO ISS links of uplink transmissions from ground-based UTs to a multi-beam stratospheric platform.

This study assesses the potential for interference into NGSO MEO satellite receivers to exceed the -10 dB DRS ISS I/N Protection Criterion which has been assumed to apply to Audacy's LEO-to-MEO return link to determine if mitigation measures are necessary.

OPERATIONAL CHARACTERISTICS OF NGSO ISS MEO RECEIVERS

Operational characteristics of the NGSO ISS MEO receivers utilized for this study are based on Audacy Corporation's FCC Application SAT-LOA-20161115-00117 and shown in Table 1 with the satellite constellation geometry illustrated in Figure 1 and Base service area illustrated in .

Table 1: NGSO ISS Link Receive Characteristics

Parameter	Value	Notes
Number of Satellite Planes	1	
Number of Satellites Per Plane	3	
Nominal Altitude	13,890 km	
Orbital Inclination	25.0 deg	
Frequency Range	22.550 – 22.950 GHz	LHCP & RHCP
Channel Bandwidth	50-100 MHz Base User 150-250 Mhz Advanced User	
LEO User Altitude	<1,500 km	160 km minimum satellite altitude assumed
Total Bandwidth	400 MHz	
Rx Antenna Peak Gain	36.2 dBi Base User 43.5 dBi Advanced User	BRL1, BRR1 ARL2, ARR2
Rx Antenna 3dB Beamwidth	2.6 deg Base User 1.1 deg Advanced User	
Rx Antenna Polarization	RHCP, LHCP	45 deg relative to Equatorial Plane
Rx Antenna Pattern	ITU-R S.672	Assumed typical based on other ISS links
G/T at Max Gain Point	10.0 dB/K Base User 18.0 dB/K Advanced User	
Satellite Receiver Noise Density	-142.4 dBW/MHz Base User -143.1 dBW/MHz Adv User	Calculated from G/T
Protection Criterion	I/N < -10 dB Exceedance <0.1% of visible time	ITU-R SA.1155 assumed to apply to Audacy's LEO-to-MEO return link

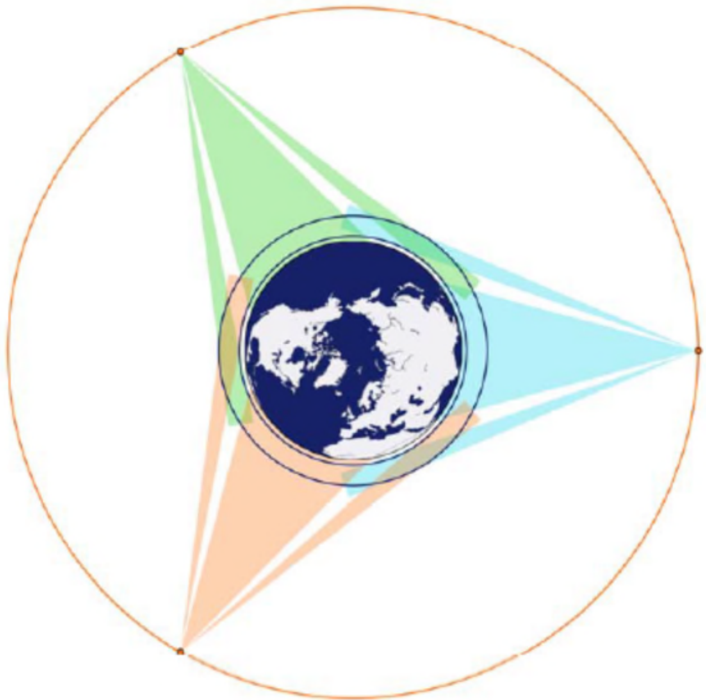


Figure 1: Top-down view of NGSO (Audacy) Base Service Area Geometry
Ref: FCC File Number SAT-LOA-20161115-00117

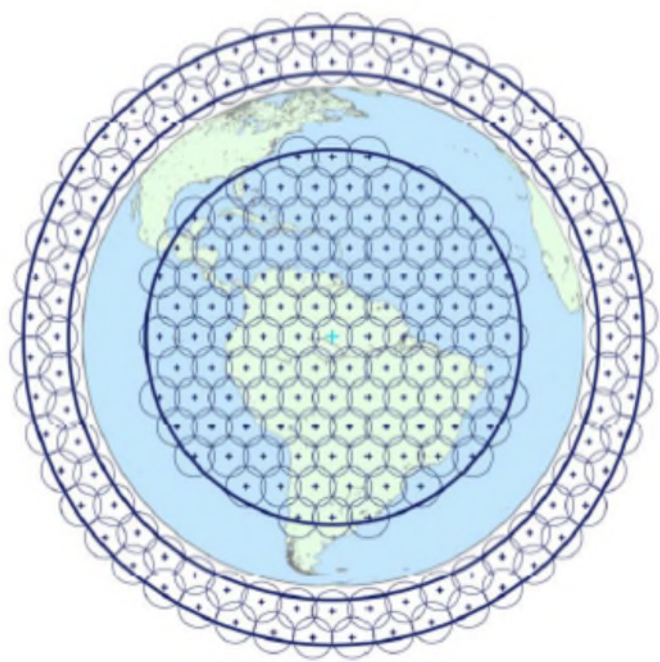


Figure 2: NGSO (Audacy) Single Relay Base Service Area
Ref: FCC File Number SAT-LOA-20161115-00117

OPERATIONAL CHARACTERISTICS OF SBCS

The SBCS will utilize STRAPS, UTs, and Gateway terminals to provide fixed services over a specific service area. Transmit characteristics of the Elefante Group STRAPS user uplink, used in this study, are given in Appendix 1.

For this study, worst-case operating and geometric conditions are utilized for a bounding analysis prior to considering, if appropriate, risk-based interference assessment using probability and statistical methods:

1) All UTs simultaneously active and transmitting at power levels which achieve the highest data rates, i.e. EIRP Density of 20 dBW/MHz for Enterprise UTs and 12 dBW/MHz for Consumer UTs.

2) Maximum number of UTs operating to ensure that the entire 22.55-23.55 GHz band is fully occupied to guarantee overlap with Audacy's narrower LEO-to-MEO ISS Base user and Advanced user channels.

3) Worst-case geometric alignment between MEO ISS receiver, STRAPS service area and UT.

STUDY SCENARIO

Figure 3 illustrates the interference geometry applicable to this study.

- UTs located across the coverage area transmit User Uplink signals to the associated STRAPS.
- Audacy LEO user satellite transmits the desired LEO-to-MEO ISS return link signal to the Audacy MEO relay satellite.
- As the LEO user satellite and the MEO relay satellite transverses through their respective orbits, there will be instances of time during which the worst-case alignment for interference will occur when the MEO ISS receiver is pointed directly down towards the STRAPS at the center of the coverage area.
- A UT located at the center of the STRAPS coverage area having the highest elevation angle and shortest distance to the MEO ISS receiver will have the highest potential for interference when its boresight is co-aligned with the MEO ISS receiver.
- A single-entry compatibility study is performed for each type of UT assuming the interference from the boresight pointed UT will dominate since this UT is assumed to transmit across the full STRAPS channel and the inter-beam spacing results in adequate isolation from the next closest UT.

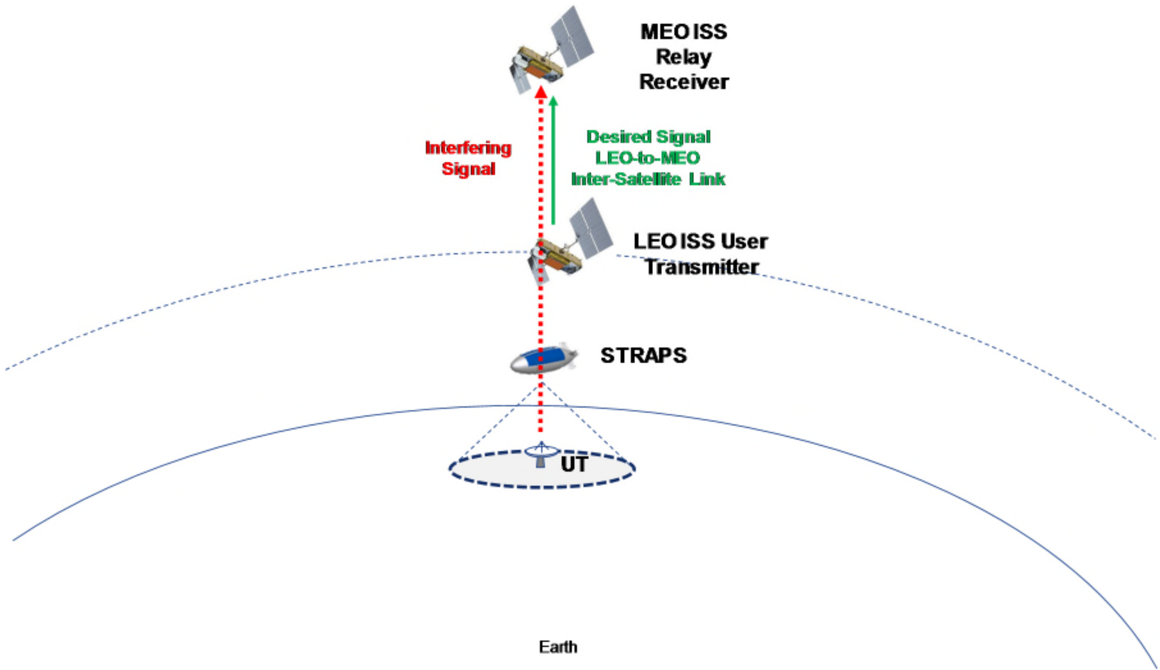


Figure 3: Worst-Case Interference Geometry

STUDY METHODOLOGY

As illustrated in **Error! Reference source not found.**, the worst-case static interference geometry is setup as follows:

Interfering UT elevation angle = 90 degrees (boresight pointed directly at MEO receiver)

Range from Interfering UT to MEO satellite = 13,890 km

MEO satellite boresight angle towards UT = 0 deg

Therefore, the interference level from the UT into the MEO ISS receiver is:

$$Io\left(\frac{dBW}{MHz}\right) = EIRP\ Density\ (\delta) - FSL - Gr\ (\beta)$$

where:

δ = Angle off UT (Interferer) boresight towards the MEO ISS receiver = 0 degrees

$Gr\ (\beta) = Gr\ (0\ deg)$ = MEO ISS (Victim) receive antenna peak boresight gain towards UT

FSL = Free Space Loss between the UT and MEO ISS receiver

Therefore,

$$^{I}/_{N}\ Margin\ (dB) = {}^{I}/_{N}\ Threshold - (I_o - N_o)$$

where $^{I}/_{N}\ Threshold$ is the DRS ISS Protection Criterion of -10 dB which is assumed to be applicable to the LEO-to-MEO ISS link.

STUDY RESULTS

Results of the worst-case single-entry compatibility study are summarized in Table 2.

Table 2: Worst-case Single-Entry Compatibility Study Results

UT Type	Audacy User Service	Worst-Case I/N Margin
Consumer	Base	-6.2 dB
Consumer	Advanced	-14.2 dB
Enterprise	Base	+1.8 dB
Enterprise	Advanced	-6.2 dB

Not surprisingly, during the instance of worst-case alignment of the UT transmitting directly into the MEO receiver boresight at the minimum range, the worst-case I/N Margins are generally negative.

Taking the worst-case scenarios with Advanced Audacy User service, Figure 4 and Figure 5 illustrate that the negative I/N margins occur for a very small range of UT and MEO off-boresight antenna angles where the yellow areas indicate regions of positive I/N margin therefore even a small offset in these angles as the MEO and user satellites move through their orbits, will significantly reduce the interference level.

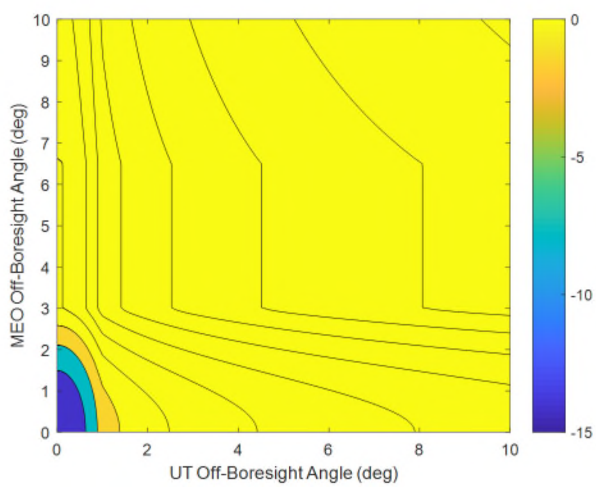


Figure 4: I/N Margin versus UT and MEO Boresight Angles – Enterprise UTs

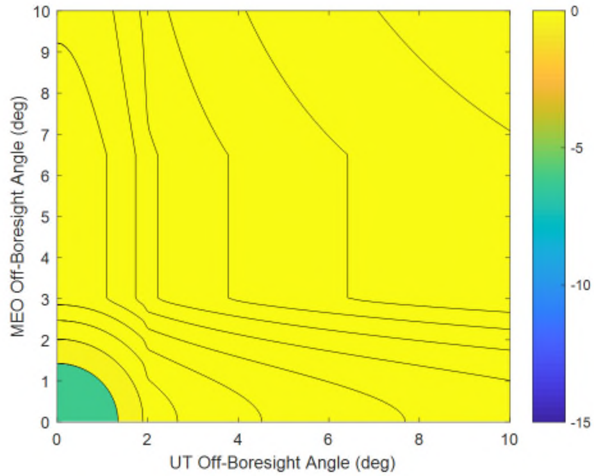


Figure 5: I/N Margin versus UT and MEO Boresight Angles – Consumer UTs

A more realistic scenario which takes into account the short duration transient nature of such worst-case alignment requires additional knowledge of the Audacy's user systems in order to perform a risk-based statistical compatibility analysis.

The following are excerpts from the Audacy's ex-parte dated 13 October 2017 which support the unlikely and transient likelihood of such worst-case alignment:

- Relays will not continuously radiate Earth's surface
- Statistically, most Network user satellites are at the poles and around the edge of the Earth: most Relay-User beams will not intersect Earth (see Figure 6)
- Relay beams only transmit/receive when User present
- Relay signals will not interfere with Fixed/Mobile systems: In-line geometries are rate and extremely transient

It should be noted that the likelihood of interference is also a function of the worst-case combination of the following:

- Overlap in bandwidth between SBCS system and Audacy's user system
- Geographic extend of the interference geometry; i.e. the intersection of STRAPS coverage area with the Audacy's MEO satellite beams
- The transient overlap in time between the Audacy user transmitting and UTs transmitting at the maximum power. It should be noted that the contact time for Audacy's over-the-horizon beams should be a lot longer than the corresponding time over Earth pointing beams

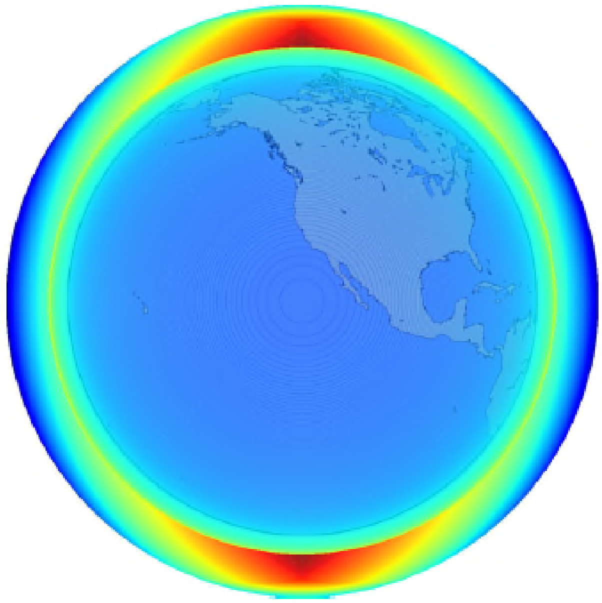


Figure 6: Audacy Heatmap Showing User Statistical User Distribution
Ref: Audacy Ex Parte dated 13 October 2017

CONCLUSIONS

Bounding compatibility study was performed using worst-case operational and geometric assumptions including all UTs simultaneously active, transmitting at maximum power and across the entire 22.55-23.55 GHz band, thus ensuring overlap with all Audacy's LEO-to-MEO ISS Return channels.

The bounding study conducted as a static analysis also assumed worst-case geometric alignment and shortest range between the Audacy MEO receiver and the UT located at the center of the STRAPS coverage area which are unlikely and transient events and result in negative I/N margins relative to the assumed I/N Protection Criteria.

A more realistic risk-based statistical analysis is appropriate and/or coordination is required to ensure that the LEO-to-MEO ISS service is not impacted. Such analyses will be performed on a case-by-case basis and require additional knowledge of the Audacy's user systems.

REFERENCES:

ITU-R S.1155: Protection Criterion related to the operation of data relay satellite systems

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

Audacy Ex Parte: Notice of Ex Parte Communication – Audacy Corporation, Application for Authority to Launch and Operate a Non-Geostationary Medium Earth Orbit Satellite System in the Fixed- and Inter-Satellite Services, IBSF File No. SAT-LOA-20161115-00117 dated 13 October 2017

Appendix E
Compatibility Analysis:
STRAPS User Uplink Interference into
Aeronautical Mobile Service Ground-to-Airborne Link in the
22.55 – 23.55 GHz Band
(Prepared by Lockheed Martin Corporation for Elefante Group, Inc.)

SUMMARY

- Elefante Group is proposing to access the 22.55–23.55 GHz band for User uplink communications from User Terminals (UTs) to Stratospheric Platform Stations (STRAPS) on a co-Primary basis.

- This study assesses the compatibility of STRAPS User uplinks with Federal Aeronautical Mobile Service (AMS) Ground-to-Airborne links which are authorized to operate in the 22.55–23.55 GHz band.

- Worst-case operating conditions are utilized for a bounding analysis: All UTs simultaneously active and transmitting at power levels which achieve the highest data rates.

- Bounding compatibility study results show that AMS I/N Protection Criterion is met if AMS Airborne is outside the 70 km radius STRAPS downlink beam coverage cone and transient interference might be noted otherwise. Interference can be fully mitigated by coordination which includes UTs not using frequencies and polarization which overlap with the AMS Airborne channel.

PURPOSE OF THE STUDY

Elefante Group is proposing that the 22.55–23.55 GHz band be made available for Stratospheric-Based Communications Services (SBCS), operating as a Fixed service, in the uplink direction. (While not the purpose of this study, Elefante Group proposes that the 22.55–23.55 GHz band also be considered for use in the downlink direction.) All or part of this band is allocated in the federal allocation to Fixed, Mobile, Space Research (earth-to-space), and Inter-Satellite Service.

This study assesses the compatibility with AMS Ground-to-Airborne links of uplink transmissions from ground-based UTs to a multi-beam stratospheric platform.

This study assesses the potential for interference into AMS Ground to exceed the I/N Protection Criterion to determine if mitigation measures are necessary.

OPERATIONAL CHARACTERISTICS OF AMS GROUND RECEIVERS

Receive characteristics of the AMS Ground Data Terminal (GDT) utilized for this study are based on the two systems illustrated in ITU-R M.2114 and are shown in Table 1 and Table 2.

Table 1: System 1 AMS Ground Data Terminal Receive Characteristics

Parameter	Value	Source
Frequency Range	22.9 – 23.3 GHz	ITU-R M.2114-0
Channel Bandwidth	580 MHz	ITU-R M.2114-0
Rx Antenna Gain	33 dBi	ITU-R M.2114-0
Rx Antenna Beam Width	2.7 deg	ITU-R M.2114-0
Rx Antenna Pattern	ITU F.1245-60% efficiency	Note (2)
Min. Elevation Angle	3 deg	Assumption
Earth Station Receiver Noise Density	-142.2 dBW/MHz	ITU-R M.2114-0, NF = 4 Assumed 0K sky temp
Protection Criterion	I/N < -6 dB	ITU-R M.2114-0

Table 2: System 2 AMS Ground Data Terminal Receive Characteristics

Parameter	Value	Source
Frequency Range	22.55 – 23.5 GHz	ITU-R M.2114-0
Channel Bandwidth	143 MHz	ITU-R M.2114-0
Rx Antenna Gain	33 dBi	ITU-R M.2114-0
Rx Antenna Beam Width	3.4 deg	Note (1)
Rx Antenna Pattern	ITU F.1245-60% efficiency	Note (2)
Min. Elevation Angle	3 deg	Assumption
Earth Station Receiver Noise Density	-143.0 dBW/Hz	ITU-R M.2114-0, NF = 3.5 Assumed 0K sky temp
Protection Criterion	I/N < -6 dB	ITU-R M.2114-0

(1) ITU-R M.2114 shows a single 7.2 deg beam width for 33 dBi and 46 dBi antennas which results in 146% - 653% antenna efficiency, therefore a typical 70% efficiency used to derive beam width from the peak antenna gain

(2) ITU-R M.2114 permits use of measured antenna pattern in lieu of ITU-R M.1851 (uniform distribution) pattern therefore a standard ITU antenna pattern was selected which approximates a typical commercial antenna with similar peak gain and beam width

OPERATIONAL CHARACTERISTICS OF SBCS

The SBCS will utilize STRAPS, UTs, and Gateway terminals to provide fixed services over a specific service area. Transmit characteristics of the Elefante Group STRAPS user uplink utilized in this study are given in Appendix 1.

For this study, worst-case operating conditions are utilized for a bounding analysis prior to considering, if appropriate, risk-based interference assessment using probability and statistical methods:

1) All UTs simultaneously active and transmitting at power levels which achieve the highest data rates, i.e. EIRP Density of 20 dBW/MHz for Enterprise UTs and 12 dBW/MHz for Consumer UTs

2) AMS Ground Receiver co-located with a UT encompassing the full Aeronautical channel bandwidth and operating in the same polarization.

3) UT uplinks operating in the same polarization as the Airborne downlink (Right Hand Circular Polarization)

STUDY SCENARIO

Figure 1 illustrates the interference geometry applicable to this study.

- UTs located across the coverage area transmit User Uplink signals to the associated STRAPS.
- AMS Airborne Data Terminal located at or below the STRAPS altitude, transmits the desired downlink signal to AMS Ground which may be located within or outside the STRAPS service coverage area.
- As the AMS Ground tracks the Airborne, there is a possibility that, at specific instances of time when the AMS Airborne passes through one of the UT uplink beams, interference could be picked up.
- The required separation distance between the AMS Ground and STRAPS coverage area for this bounding static scenario is determined to meet the Interference Protection Criterion.

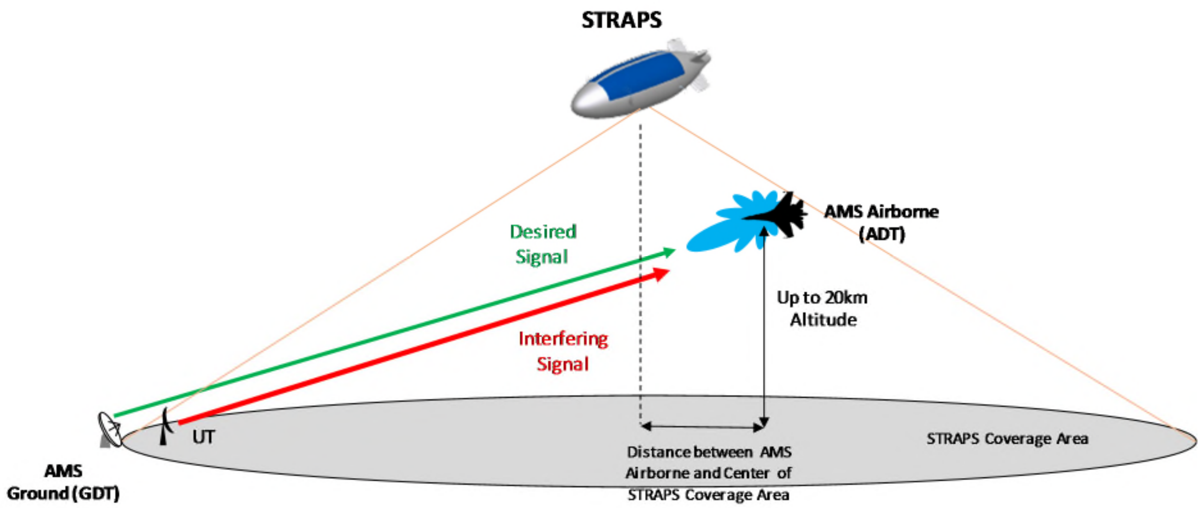


Figure 1: Interference Geometry

STUDY METHODOLOGY

Since the AMS Ground location relative to STRAPS coverage area is not known, the basic methodology for this study is for each possible altitude and location of the AMS Airborne, assume a fixed AMS Ground location and repeat the analysis, as necessary, for varying AMS Ground locations.

For each location of AMS Ground within the STRAPS coverage area, the aggregate interference from all the UTs is calculated by power summing the contribution from each of the UTs at each possible AMS Airborne altitude and range:

$$Io\left(\frac{dBW}{MHz}\right) = \sum_{i=1}^{N}[EIRP\ Density\ (\delta) - FSL - Gr\ (\beta)]_i$$

where:

N = Total number of UT's (260 for System 1 and 224 for System 2)

δ = Angle off i'th UT (Interferer) boresight towards the AMS Airborne

$Gr\ (\beta)$ = AMS Airborne (Victim) receive antenna gain off boresight towards i'th UT assuming AMS Airborne boresight is pointed towards AMS Ground

FSL = Free Space Loss between the i'th UT and AMS Airborne

Therefore,

$$I/_N\ Margin\ (dB) = I/_N\ Threshold - (I_o - N_o)$$

where $I/_N\ Threshold$ is the AMS Protection Criterion of -6 dB.

STUDY RESULTS

Results of the compatibility study for the AMS System-1 in ITU-R M.2114 are shown in Figure 2 and Figure 3 assuming the higher EIRP density Enterprise UTs and utilizing the baseline conservative UT transmit antenna pattern based on ITU-R F.1245-2 with the AMS Ground located at the center of the STRAPS coverage area. Similar results were obtained for System-2.

The shaded regions indicate relative location of AMS-Airborne where I/N Margin is negative and therefore coordination would be required to ensure overlapping frequencies and polarization are not utilized.

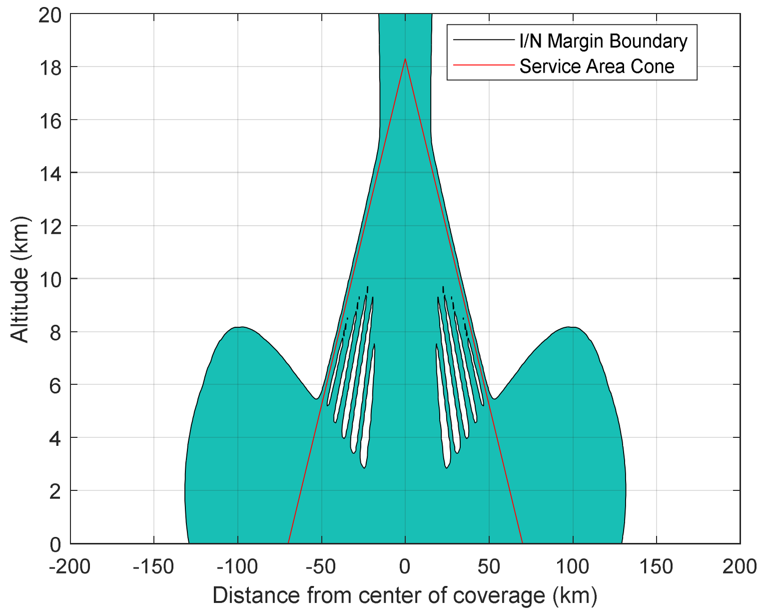


Figure 2: System 1 Compatibility Study Results
Enterprise UTs (ITU-R F.1245-2) - AMS Ground at 0 km (center)

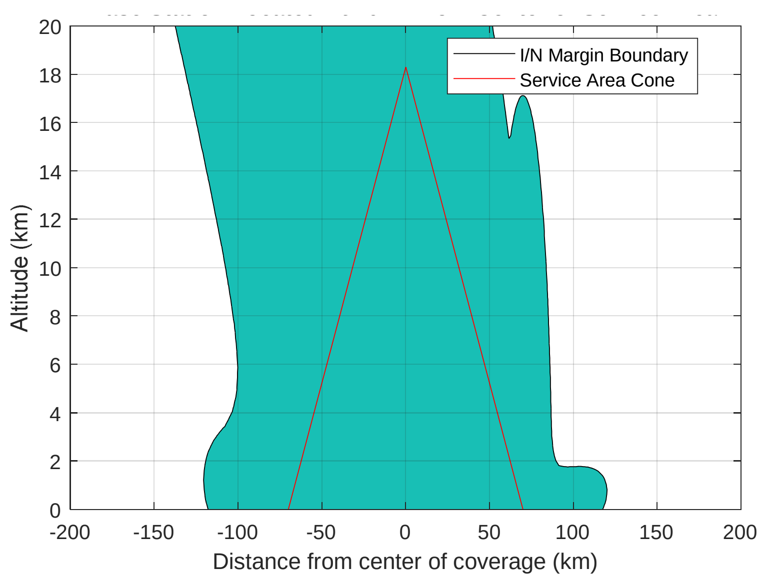


Figure 3: System 1 Compatibility Study Results
Enterprise UTs (ITU-R F.1245-2) - AMS Ground at 70 km (edge)

Since interference power from all UTs is power summed as received by the AMS Airborne, compatibility results are highly driven by UT transmit antenna side lobe and back lobe performance.

Figure 4 and Figure 5 show compatibility results for the same cases as Figure 2 and Figure 3 except with less conservative and more realistic UT transmit antenna patterns demonstrating significant reduction in the coordination regions. Similar results were obtained for System-2 and Consumer UTs.

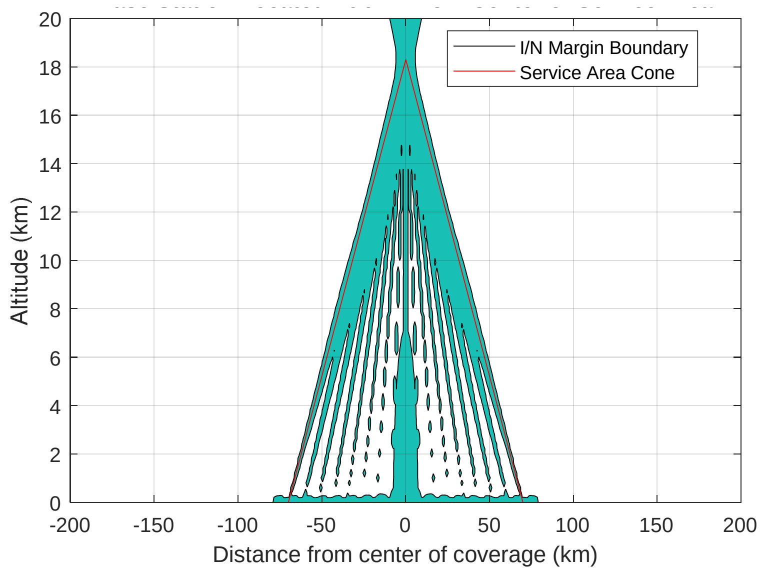


Figure 4: System 1 Compatibility Study Results
Enterprise UTs (realistic antenna) - AMS Ground at 0 km (center)

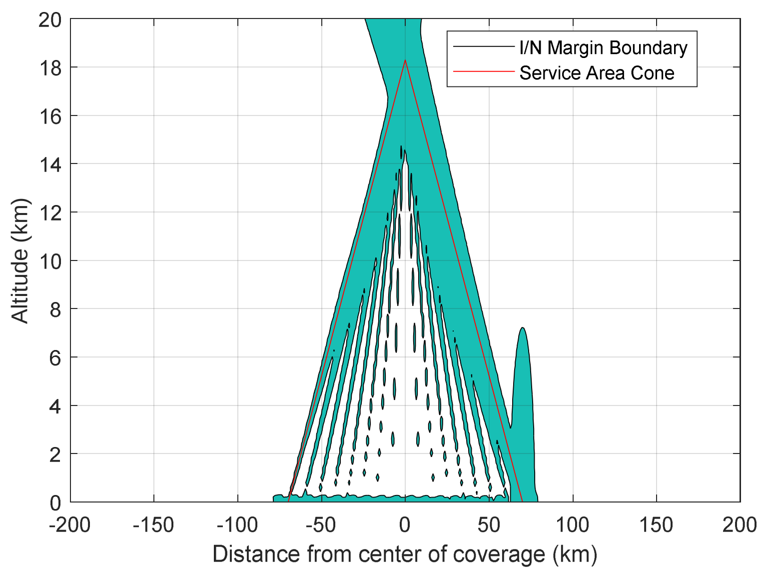


Figure 5: System 1 Compatibility Study Results
Enterprise UTs (realistic antenna) - AMS Ground at 70 km (edge)

CONCLUSIONS

Bounding compatibility study was performed using worst-case operational and geometric assumptions including all UTs simultaneously active, transmitting at maximum power and occupying the entire AMS Aeronautical channel bandwidth. Alternative UT transmit patterns were examined with the conclusion that improved antenna side lobe and back lobe performance can significantly reduce the region where coordination would be required to mitigate interference into AMS-Airborne.

Using a realistic UT transmit pattern, AMS I/N Protection Criterion is met if AMS Airborne is outside the 70 km radius STRAPS downlink beam coverage area cone and transient interference might be noted otherwise. Interference can be fully mitigated by coordination which includes UTs not using frequencies and polarization which overlap with the AMS Airborne channel.

REFERENCES:

ITU-R M. 2114-0: Technical and operational characteristics of and protection criterion for aeronautical mobile service systems in the frequency bands 22.5-23.6 GHz and 25.25-27.5 GHz

ITU-R F.1245-2: Mathematical model of average and related radiation patterns for line-of-sight point-to-point fixed wireless system antennas for use in certain coordination studies and interference assessment in the frequency range from 1 GHz to about 70 GHz

ITU-R M.1851: Mathematical models for radiodetermination radar systems antenna patterns for use in interference analyses

Appendix F
Compatibility Analysis:
STRAPS User Uplink Interference into
Federal Inter-Satellite Service Forward Link in the
22.55 – 23.55 GHz Band
(Prepared by Lockheed Martin Corporation for Elefante Group, Inc.)

SUMMARY

- Elefante Group is proposing to access the 22.55–23.55 GHz band for User uplink communications from User Terminals (UTs) to Stratospheric Platform Stations (STRAPS) on a co-Primary basis.

- This study assesses the compatibility of STRAPS User uplinks with Federal Inter-Satellite Service (ISS) Data Relay System (DRS) Forward links (DRS GSO to LEO) which are authorized to operate in the 22.55–23.55 GHz band.

- Worst-case operating conditions are utilized for a bounding analysis: 1) all UTs simultaneously active and transmitting at power levels which achieve the highest data rates and 2) maximum number of UTs operating to fully encompass the ISS DRS forward channel bandwidth and operating in the same polarization.

- Bounding compatibility study results show that since the worst-case geometry is unlikely and would be a transient condition, the DRS I/N and percentage exceedance time Protection Criteria are met under worst-case operating conditions. No mitigation is necessary.

PURPOSE OF THE STUDY

Elefante Group is proposing that the 22.55–23.55 GHz band be made available for Stratospheric-Based Communications Services (SBCS), operating as a Fixed service, in the uplink direction. (While not the purpose of this study, Elefante Group proposes that the 22.55–23.55 GHz band also be considered for use in the downlink direction.) All or part of this band is allocated in the federal allocation to Fixed, Mobile, Space Research (earth-to-space), and Inter-Satellite Service.

This study assesses the compatibility with Federal ISS DRS Forward links of STRAPS uplink transmissions from ground-based UTs to a multi-beam stratospheric platform.

This study assesses the potential for interference into DRS LEO satellite to exceed the I/N Protection Criteria to determine if mitigation measures are necessary.

OPERATIONAL CHARACTERISTICS OF DRS LEO RECEIVERS

Two different sets of DRS LEO receive characteristics were utilized for this study. Case 1 based on United States of America system characteristics in ITU-R SA1414-2 shown in Table 1 and Case 2 based on ITU-R M.2360 shown in Table 2. For both cases, the cited Protection Criteria are based on ITU-R SA.1155.

Table 1: Case 1-ISS DRS Forward Link LEO Receive Characteristics

Parameter	Value	Notes
Frequency Range	22.55 – 23.55 GHz	
Channel Bandwidth	50 MHz	ITU-R SA.1414-2
Rx Antenna Gain	47.0 dBi	ITU-R SA.1414-2
Rx Antenna Pattern	ITU-R S.672	Nominal -25 dB sidelobe level
Receiver Noise Density	-137.1 dBW/MHz	ITU-R SA.1414-2 1400K
Protection Criteria	I/N < -10 dB Exceedance <0.1% of visible time	ITU-R SA.1155

Table 2: Case 2-ISS DRS Forward Link LEO Receive Characteristics

Parameter	Value	Notes
Frequency Range	22.55 – 23.55 GHz	
Channel Bandwidth	50 MHz	ITU-R M.2360
Rx Antenna Gain	39.8 dBi	ITU-R M.2360
Rx Antenna Pattern	ITU-R S.672	Nominal -25 dB sidelobe level
Receiver Noise Density	-144.0 dBW/MHz	ITU-R M.2360 290K
Protection Criteria	I/N < -10 dB Exceedance <0.1% of visible time	ITU-R SA.1155

OPERATIONAL CHARACTERISTICS OF SBCS

The SBCS will utilize STRAPS, UTs, and Gateway terminals to provide fixed services over a specific service area. Transmit characteristics of the Elefante Group STRAPS user uplinks utilized in this study are given in Appendix 1.

For this study, worst-case operating conditions are utilized for a bounding analysis prior to considering, if appropriate, risk-based interference assessment using probability and statistical methods:

1) All UTs simultaneously active and transmitting at power levels which achieve the highest data rates, i.e. EIRP Density of 20 dBW/MHz for Enterprise UTs and 12 dBW/MHz for Consumer UTs.

2) Maximum number of UTs for each frequency reuse ("color") operating to ensure overlap with the relatively narrow 50 MHz DRS Forward Link bandwidth.

3) UT uplinks operating in the same polarization as the DRS Forward link (Right Hand and Left Hand Circular Polarization authorized)

STUDY SCENARIO

Figure 1illustrates the interference geometry applicable to this study.

- UTs located across the coverage area transmit User uplink signals to the associated STRAPS.
- DRS GSO satellite transmits the desired Forward link signal to the DRS LEO satellite. The compatibility study includes two representative DRS LEO altitudes, 400 km and 800 km.
- As the DRS LEO satellite moves through its orbit, there will be instances of time during which the worst-case alignment for interference will occur when the DRS LEO satellite, DRS GSO satellite and STRAPS service area are co-aligned, which will result in the highest level of interference (lowest margin relative to I/N Protection Criterion).
- If a risk-based interference assessment is required, the total visible time of the DRS LEO from the DRS GSO is utilized to determine the percentage of time that I/N Protection Criterion is exceeded.

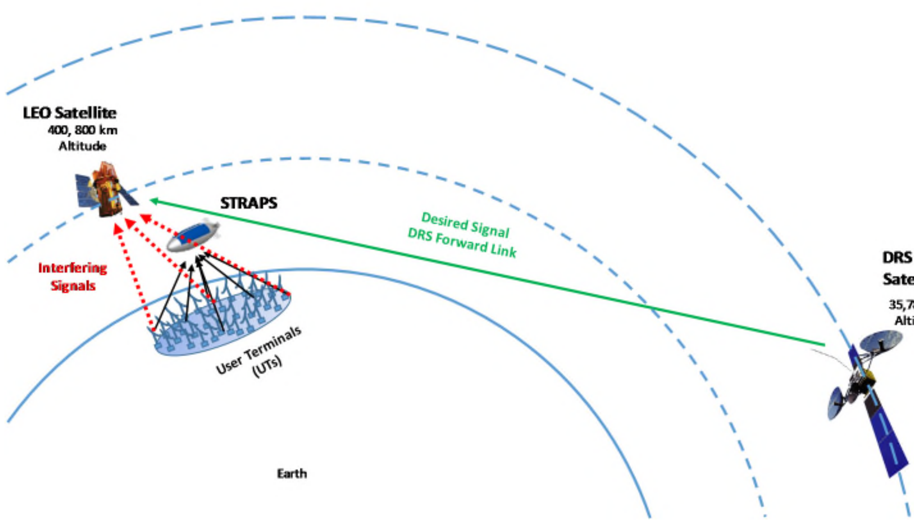


Figure 1: Interference Geometry

STUDY METHODOLOGY

As illustrated in Figure 2, the study geometry starts by placing UTs in an evenly distributed grid across the STRAPS coverage area separated by the typical distance between the same colored beams.

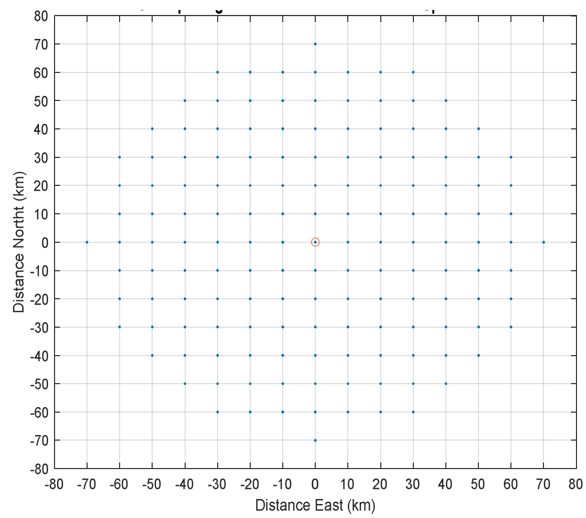


Figure 2: UT Ground Geometry

As illustrated in Figure 3, for the initial bounding analysis, the worst-case alignment between the DRS LEO satellite, DRS GSO satellite and STRAPS service area is assumed. Additionally, the DRS LEO orbit is offset to intersect through the center of the STRAPS coverage area which ensures that the UT at the center of the coverage area is in direct alignment with DRS LEO and DRS GSO.

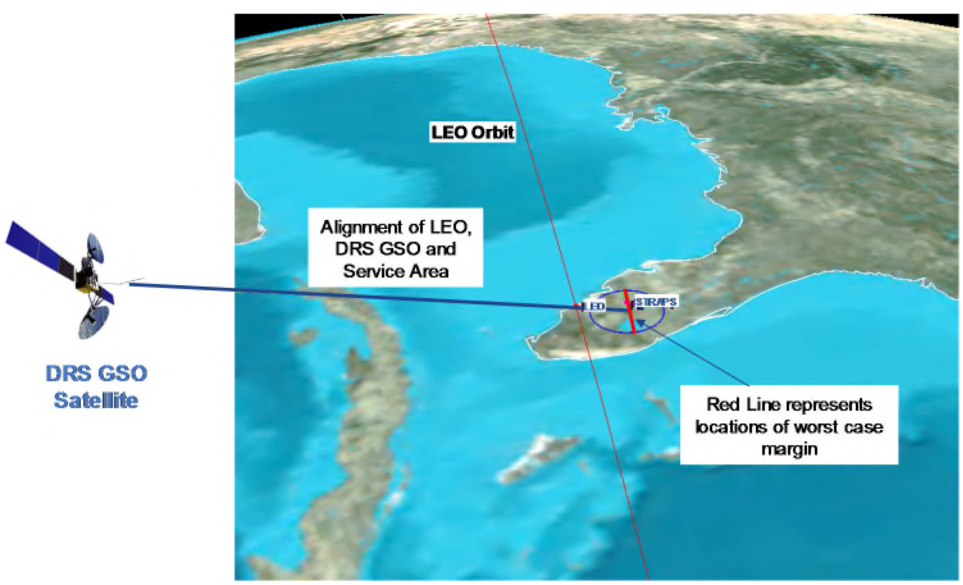


Figure 3: Worst-Case DRS & Coverage Area Alignment

The aggregate interference level into the DRS LEO is calculated by power summing the contribution from each of the UTs:

$$Io\left(\frac{dBW}{MHz}\right) = \sum_{i=1}^{N}[EIRP\ Density\ (\delta) - FSL - Gr\ (\beta)]_i$$

where:

N = Total number of UT's (135 to ensure DRS forward link channel is covered)

δ = Angle off i'th UT (Interferer) boresight towards the DRS LEO

$Gr\ (\beta)$ = DRS LEO (Victim) receive antenna gain off boresight towards i'th UT

FSL = Free Space Loss between the i'th UT and DRS LEO

Therefore,

$$I/_N\ Margin\ (dB) = I/_N\ Threshold - (I_o - N_o)$$

where $I/_N\ Threshold$ is the DRS Protection Criterion of -10 dB.

The study is conducted for typical DRS LEO altitudes of 400 km and 800 km and for Enterprise and Consumer UTs.

If the bounding analysis demonstrates negative margin relative to the I/N Protection Criterion, then a risk-based statistical analysis is performed by conducting a 30-day time domain simulation with a 6 second time increment to determine the percentage of time during which I/N Protection Criterion is exceeded; this is done by comparing the total time I/N Protection Criterion is exceeded to the total visible time between the DRS LEO and DRS GSO.

STUDY RESULTS

Results of the bounding compatibility study results are summarized in

Table 3 which shows the worst-case margin relative to the I/N <-10 dB Protection Criteria for the two DRS LEO cases with all combinations of UTs and DRS LEO altitudes of 400 km and 800km.

Positive I/N margin is noted for all cases except Case 2A with Enterprise UTs and 400 km DRS LEO altitude which shows a slightly negative margin. The time history of this case as the DRS LEO crosses the STRAPS coverage area is shown in Figure 4 illustrating that the negative I/N margin occurs during the highly unlikely instance of time during which the three UTs at the center of the STRAPS coverage area are aligned with the DRS LEO satellite.

Table 3: Bounding Compatibility Study Results

Case	UT Type	400 km LEO Altitude Minimum I/N Margin	800 km LEO Altitude Minimum I/N Margin
1A	Enterprise	+4.6 dB	+10.6 dB
1B	Consumer	+12.6 dB	+18.6 dB
2A	Enterprise	-2.2 dB	+3.8 dB
2B	Consumer	+5.8 dB	+11.8 dB

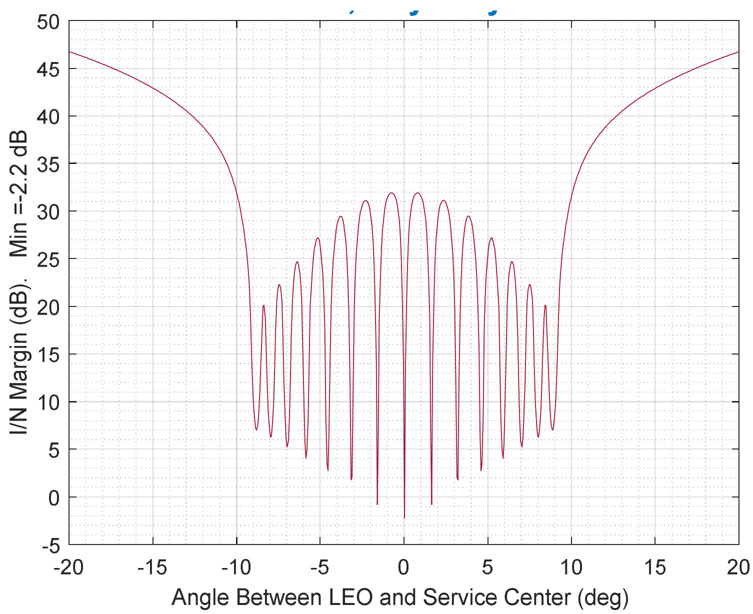


Figure 4: I/N Margin Time History for Worst-Case Bounding Case

As described above, for this case, a risk-based statistical analysis is performed by conducting a 30-day time domain simulation with a 6 second time increment, result of which is shown in Figure 5.

Results demonstrate positive margin for 100% of the time which indicates that the worst-case alignment utilized in the bounding analysis is highly unlikely and short-lived. Therefore, the I/N Protection Criteria of less than 0.1% exceedance of I/N Protection Criteria is met.

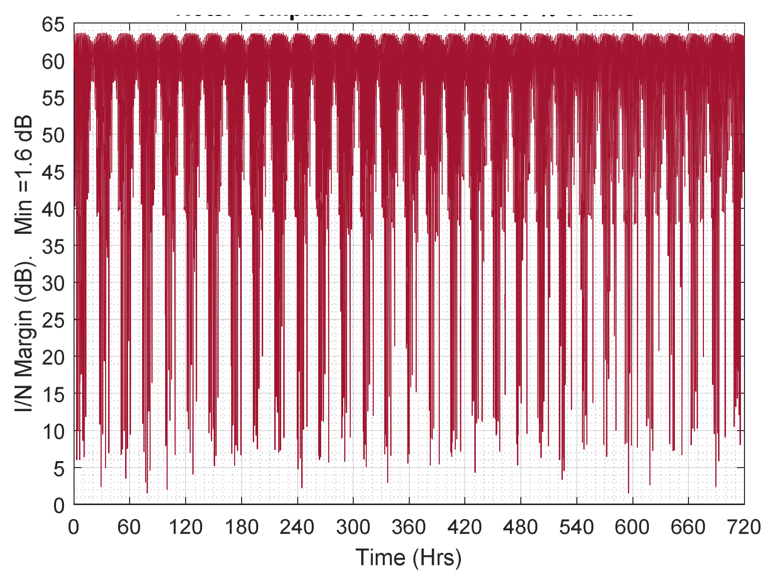


Figure 5: Risk-Based Statistical Analysis Results

CONCLUSIONS

Utilizing worst-case operational conditions and assuming worst-case geometric alignment bounding compatibility analysis shows positive margin against the DRS I/N margin relative to the I/N Protection Criterion for all but one case. For this case, the risk-based statistical compatibility study demonstrates that such worst-case geometric alignment is highly unlikely and short-lived and the corresponding 0.1%-time exceedance Protection Criterion is met. No mitigation is necessary for shared operation between UTs and DRS ISS forward link.

REFERENCES:

ITU-R S.1155: Protection Criterion related to the operation of data relay satellite systems

ITU-R SA 1414-2: Characteristics of data relay satellite systems

ITU-R M.2360: Sharing between GSO MSS and other services in the allocations in the 22 – 26 GHz range

ITU-R F.1245-2: Mathematical models of average and related radiation patterns for line-of-sight point-to-point fixed wireless systems antennas for use in certain coordination studies and interference assessments in the frequency range from 1 GHz to about 70 GHz

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

Appendix G
Compatibility Analysis:
STRAPS User Uplink Interference into
EESS Passive Sensing in the
21.2-21.4, 22.21-22.5, and 23.6-24 GHz Bands
(Prepared by Lockheed Martin Corporation for Elefante Group, Inc.)

SUMMARY

- Elefante Group is proposing to access the 21.5-23.6 GHz band for User uplink communications from User Terminals (UTs) to Stratospheric Platform Stations (STRAPS) on a co-Primary basis.

- This study assesses the compatibility of STRAPS User uplinks with EESS Passive sensors which has allocations to operate in the 21.2-21.4, 22.21-22.5, and 23.6-24 GHz bands.

- Worst-case operating conditions are utilized for a bounding analysis, in which all UTs are simultaneously active and transmitting at the maximum permitted EIRP density across their maximum bandwidth. Worst-case geometry is analyzed for a single STRAPS, and an unrealistically extreme bounding case is considered with worst-case geometry from thousands of STRAPS.

- Bounding compatibility study results show that conservative regulatory bounds on EIRP in the EESS bands can be developed that still permit practical UT design, and that it is reasonable to permit with a showing that the statistical protection criteria are met for specific SBCS implementations. Analysis also indicates that an active protection approach can permit in-band use of the 22.21-22.5 GHz band for UT uplink with negligible impact to EESS sensors.

PURPOSE OF THE STUDY

Elefante Group is proposing that the 21.5-23.6 GHz band be made available for Stratospheric-Based Communications Services (SBCS), operating as a Fixed service, in the uplink direction. (While not the purpose of this study, Elefante Group proposes that the 21.5-23.6 GHz band also be considered for use in the downlink direction). All or part of this band is allocated in the federal and non-federal allocation to Fixed, Mobile, Inter-Satellite services, Earth Exploration Satellite (passive), Space Research (passive), Radio Astronomy (passive).

This study assesses the compatibility with EESS passive sensing of uplink transmissions from ground-based UTs to a multi-beam stratospheric platform.

This study assesses the potential for interference into EESS passive sensing to exceed the I/N Protection Criterion to determine if mitigation measures are necessary.

PERFORMANCE AND OPERATIONAL CHARACTERISTICS OF EESS SENSORS

Operational characteristics of the EESS sensors utilized for this study are based on ITU-R RS.1861[1] and reproduced here for convenience. Table 1 presents characteristics of sensors in the 21.2-21.4 GHz band, Table 2 presents characteristics of sensors in the 22.21-22.5 GHz band, and

Table 3 presents characteristics of sensors in the 23.6-24 GHz band.

Table 1: 21.2-21.4 GHz EESS sensor operational and performance characteristics for interference analysis

	Sensor E1	**Sensor E2**
Sensor type	Mechanical nadir scan	Push-broom[(1)]
Orbit parameters		
Altitude	833 km	850 km
Inclination	98.6°	98°
Eccentricity	0	
Repeat period	9 days	
Sensor antenna parameters		
Number of beams	1 beam; 30 earth fields per 8 s scan period	90
Maximum beam gain	34.4 dBi	45 dBi
Reflector diameter	0.3 m	0.9 m
Polarization	V	H, V
–3 dB beamwidth	3.3°	1.1°
Instantaneous field of view	Nadir FOV: 48.5 km Outer FOV: 149.1 × 79.4 km	16 km × 2 282 km
Main beam efficiency	95%	
Off-nadir pointing angle	±48.33° cross-track	
Beam dynamics	8 s scan period	N/A (beams are unchanging)
Incidence angle at Earth		
–3 dB beam dimensions	45 km	16 km
Total FOV cross/along-track	Outer FOV: 149.1 × 79.4 km Nadir FOV: 48.5 km	100/1.1°

[1] Sensor R1 in the 22.21-22.5 GHz band is not described in ITU-R RS.1861, but was derived from US input contribution to WP 5C document WP5C/0455, which documents Study A conducted by the US in support of the ITU HAPS agenda item analysis of compatibility of a HAPS uplink in 21.4-22 GHz with EESS Passive sensing in nearby bands.

	Sensor E1	Sensor E2
Swath width	2 343 km	2 282 km
Sensor antenna pattern	−10 dBi back lobe gain	−12 dBi back lobe gain
Cold calibration ant. gain	34.4 dBi	35 dBi
Cold calibration angle (degrees re. satellite track)	90°	
Cold calibration angle (degrees re. nadir direction)	83°	
Sensor receiver parameters		
Sensor integration time	158 m	N/A
Channel bandwidth	270 MHz centred at 23.8 GHz	N/A
Measurement spatial resolution		
Horizontal resolution	45 km	16 km
Vertical resolution	N/A	16 km

(1) Push-broom is a concept that has not yet been implemented at this frequency.

Table 2: 22.21-22.5 GHz EESS sensor operational and performance characteristics for interference analysis

Parameter	Units	Sensor R1
Sensor type		Conical
Orbit parameters		
Altitude	km	854-863
Inclination	Degrees	98.6-98.8 [F16-F18]
Eccentricity		0.00083564, 0.00113399, 0.00099945
Repeat period	Days	9
Sensor antenna parameters		
Number of beams		1
Maximum beam gain	dBi	[38.2]
Reflector diameter	m	0.61
Polarization		V
–3 dB beamwidth	degrees	2.09 (max)
Instantaneous field of view	km x km (for ellipse) or km (for circle diameter at nadir)	46.5 x 73.6 (Footprint size due to 1x2 averaging)
Main beam efficiency	%	≥ 90
Off-nadir pointing angle	degrees	45
Beam dynamics	seconds	1.9

Parameter	**Units**	**Sensor R1**
Incidence angle at Earth	degrees	53.1
–3 dB beam dimensions	km	46.5 x 73.6 (Footprint size due to 1x2 averaging)
Total FOV cross/along-track	km x km (for ellipse) or km (for circle diameter at nadir)	Effective field of view (EFOV): 44.8 km (along scan) x 73.6 km (90° to scan); 1x2 spatial averaging
Swath width	km	1707
Sensor antenna pattern		Rec. ITU R RS.1813
Cold calibration antenna gain	dBi	NA
Cold calibration angle (degrees re. satellite track)	degrees	NA
Cold calibration angle (degrees re. nadir direction	degrees	NA
Sensor integration time	ms	4.22 (for a single {unaveraged} sample)
Channel bandwidth	MHz	450 MHz (max) centred at 22.235 GHz
Horizontal resolution	km	73.6
Vertical resolution	km	46.5

Table 3: 23.6-24 GHz EESS sensor operational and performance characteristics for interference analysis

	Sensor F1	Sensor F2	Sensor F3	Sensor F4	Sensor F5	Sensor F6	Sensor F7	Sensor F8
Sensor type	Conical scan			Mechanical nadir scan		Conical scan	Push-broom	Conical scan
Orbit parameters								
Altitude	817 km	705 km	828 km	833 km 822 km*	824 km	835 km	850 km	699.6 km
Inclination	20°	98.2°	98.7°	98.6° 98.7°*	98.7°	98.85°	98°	98.186°
Eccentricity	0	0.0015	0	0 0.001	0	0.002		
Repeat period	7 days	16 days	17 days	9 days 29 days*	9 days			16 days
Sensor antenna parameters								
Number of beams	1			30 earth fields per 8 s scan period	2	1	90	1
Reflector diameter	0.6 m	1.6 m	2.2 m	0.3 m 0.274 m*	0.203 m	0.6 m	0.9 m	48.5 dBi
Maximum beam gain	40 dBi	46.7 dBi	52 dBi	34.4 dBi	30.4 dBi	43 dBi	45 dBi	2.0 m
Polarization	H, V			V QV*	QV	H, V	H, V	

	Sensor F1	Sensor F2	Sensor F3	Sensor F4	Sensor F5	Sensor F6	Sensor F7	Sensor F8
−3 dB beamwidth	1. 81°	0.9°	0.64°	3.3°	5.2°	1.5°	1.1°	0.75°
Instantaneous field of view	63 km × 38 km	32 km × 18 km	18 km × 12 km	Nadir FOV: 48.5 km Outer FOV: 149.1 × 79.4 km 147 × 79 km*	Nadir FOV: 74.8 km Outer FOV: 323.1 × 141.8 km	36 km × 86 km	16 km × 2 282 km	26 km × 15 km
Main beam efficiency	96%	94.8%	95%					94%
Off-nadir pointing angle	44.5°	47.5°	46.6°	±48.33° cross-track	±52.725° cross-track	55.4°		47.5°
Beam dynamics	31.9 rpm	40 rpm	31.6 rpm	8 s scan period	8/3 s scan period cross-track; 96 earth fields per scan period	2.88 s scan period	90 resolution elements/ line	40 rpm
Incidence angle at Earth	52.3°	55°	53.63°	0° (nadir) 57.5°*		65°		55°
–3 dB beam dimensions	38.7 km (cross-track)	18 km (cross-track)	14.1 km (cross-track)	45 km 48 km*	76 km	22 km	16 km	15 km (cross-track)
Swath width	1 607 km	1 450 km	1 688 km	2 343 km 2 186 km*	2 503 km	2 000 km	2 282 km	1 450 km
Sensor antenna pattern	See Rec. ITU-R RS.1813	Fig. 9b[2]	See Rec. ITU-R RS.1813	Fig. 9c	See Rec. ITU-R RS.1813	–12 dBi back lobe gain	See Rec. ITU-R RS.1813	
Cold calibration ant. gain	N/A	32.1 dBi	N/A	34.4 dBi	30.4 dBi	N/A	35 dBi	32.4 dBi
Cold calibration angle (degrees re. satellite track)	N/A	115.5º	N/A	90° −90° ± 3.9°*	0	N/A	90°	115.5º
Cold calibration angle (degrees re. nadir direction)	N/A	97.0º	N/A	83°	82.175°	N/A	83°	N/A
Sensor receiver parameters								
Sensor integration time	1 ms	2.5 ms	1.2 ms	158 ms	18 ms	N/A	2.5 ms	
Channel bandwidth	400 MHz	400 MHz centred at 23.8 GHz	270 MHz centred at 23.8 GHz	400 MHz centred at 23.8 GHz	N/A	400 MHz centred at 23.8 GHz		
Measurement spatial resolution								
Horizontal resolution	40 km	18 km	17.6 km	45 km 48 km*	75 km	38 km	16 km	15 km
Vertical resolution	N/A	30 km	N/A	45 km 48 km*	75 km	38 km	16 km	25 km

Protection criteria for these sensors is -169 dBW max interference power over a 100 MHz reference bandwidth for sensors E1, E2, and R1, and -166 over a 200 MHz reference bandwidth for sensors F1-F8, not to be exceeded over more than 0.01% of the time or observation area.

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[2] In the absence of a mathematical formulation for antenna patterns described only by figures, values were transcribed from these figures and used to form a look-up table for interpolation during analyses.

OPERATIONAL CHARACTERISTICS OF SBCS

The SBCS will utilize STRAPS, UTs, and Gateway terminals to provide fixed services over a specific service area. Transmit characteristics of the Elefante Group STRAPS user uplink used in this study, are given in Appendix 1.

For this study, worst-case operating and geometric conditions are utilized for a bounding analysis prior to considering, if appropriate, risk-based interference assessment using probability and statistical methods:

1) All UTs simultaneously active and transmitting at power levels which achieve the highest data rates, i.e. EIRP Density of 20 dBW/MHz for Enterprise UTs and 12 dBW/MHz for Consumer UTs.
2) Worst-case geometric alignment between EESS sensor, STRAPS service area and UT.

STUDY SCENARIO

Figure 1 illustrates the interference geometry applicable to this study.

- UTs located across the coverage area transmit User Uplink signals to the associated STRAPS.
- EESS sensors are located on satellites with different orbital parameters. Sensors have beams that differ in gain and beamwidth depending on application. Beams have different scanning characteristics, including conical scans at a fixed off-nadir angle, cross-track scanning, and pushbroom.
- As the EESS sensors move through their respective orbits, there will be instances of time during which the worst-case alignment for interference will occur when the receive beam is pointed toward the center of the STRAPS coverage area and aligned exactly along the boresight of a transmitting UT.
- A single-entry compatibility study is initially performed for the highest EIRP density UT assuming the interference from the boresight pointed UT will dominate. Results are subsequently expanded to multi-entry cases to account from the aggregate interference from all UTs.

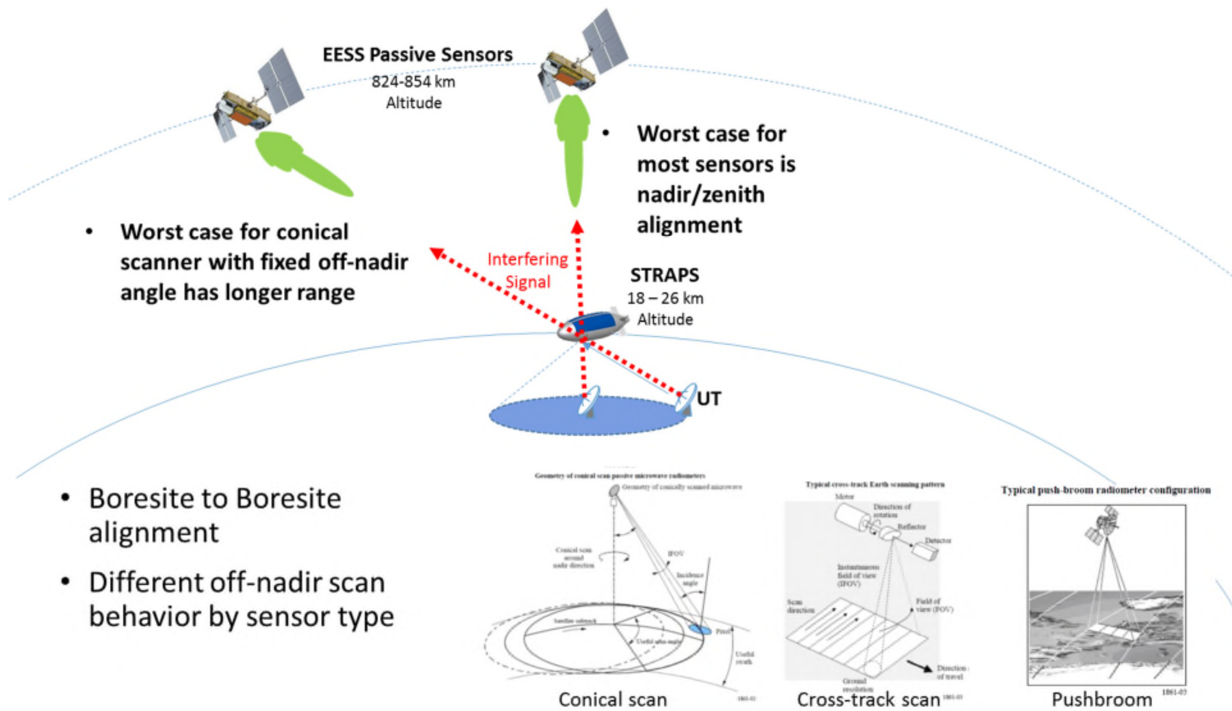


Figure 1: Interference geometry for UT and EESS orbital passive sensor systems

Three scenarios are considered for each sensor

- Worst case geometry for single entry UT to sensor. This case occurs when the boresight of the EESS sensor is aligned exactly with the boresight of a UT transmitter. Level of interference into the sensor is a function of the off-nadir angle the sensor is pointed when the alignment occurs.
- Worst case multi-entry from additional UTs serving a single STRAPS. Assuming the worst case single entry interference already exists, additional interference from additional UTs beyond the worst aligned one is calculated (and will be demonstrated as negligible).
- Unrealistic bounding case of multi-entry from multiple STRAPS within the sensor field of regard.

In addition, in the 22.21-22.5 GHz band which does not require protection from Fixed Service[3], the level of interference experienced by sensor R1 from currently licensed point to point microwave links is assessed when pointing at urban locations from different azimuth angles. In this case the alignment of the interferers is determined by their fixed azimuth and elevation pointing angles. The sensor conical scan operates at a fixed off-nadir angle, so its geometry varies only with azimuth to the urban location.

[3] Under US532, EESS in the 22 GHz band is not entitled to protection from fixed service systems operating consistent with the Table of Frequency Allocations. See 47 CFR §2.106, US532. Nonetheless, Elefante Group is pursuing an approach of compatibility with incumbent users and has examined the scenario of sharing with EESS in that band without taking into account issues of relative priority of access.

STUDY METHODOLOGY

Analysis of these scenarios using the proposed 20 dB(W/MHz) EIRP density limit on UT uplinks determines a required attenuation as a function of off-nadir angle the sensor beam is pointing[4]. This attenuation can be subtracted from the EIRP density and generalized to a maximum EIRP permitted over the EESS reference bands within their allocations; a design constraint that can be imposed through regulation on SBCS to ensure compatibility by rule.

Importantly, this analysis is for 100% satisfaction of the maximum interference criteria, and does not account for the statistical nature of the protection criteria that only required 99.99% satisfaction.

Figure **2** summarizes the approach and anticipated results of the analyses.

- The blue line represents the static worst case alignment, which will require less attenuation with increasing sensor off-nadir angle due to increasing range on the interference path, and thus permit a higher UT EIRP density at lower elevation angles.
- The magenta line represents interference from additional STRAPS, each with a UT aimed at the sensor. At nadir it will certainly require reduce the limit, and may require increased reduction with increasing off-nadir angle as the tilted incidence angle with the Earth can cause more STRAPS to be within the mainlobe of the sensor beam.
- The green line represents the notional result of a time dynamic analysis. In a time dynamic analysis, orbital motion of the sensor satellites, a realistic deployment scenario for STRAPS, and pointing and activity of UTs can all be considered to extract statistics on the likelihood of the worst case alignments and of multiple simultaneous worst case alignments. In many cases this will permit operation of UTs emitting a higher EIRP density in the EESS band.
-

[4] For the single entry case, interference and therefore required attenuation decrease with increasing off-nadir angle due to increasing range. In the multiple entry case, interference will decrease for a sufficiently high gain beam, which will roll off in gain rapidly and only include a few STRAPS locations in the mainlobe. If the beam has a large enough beamwidth, the spread of the mainlobe projected to the ground will expand with off-nadir angle to include more STRAPS with increasing off-nadir angle, overcoming the benefit of increasing range.

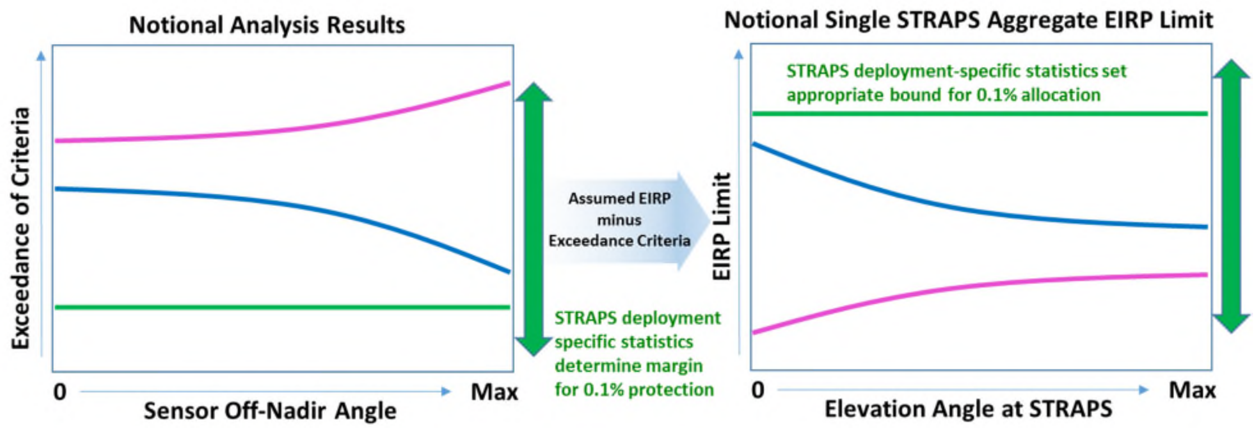


Figure 2: Notional results for studies. Exceedance of interference thresholds by UTs at maximum EIRP density determines maximum EIRP density to not exceed. Static worst case (blue) will require less attenuation with increasing sensor off-nadir angle and thus permit a higher UT EIRP density at lower elevation angles. Multiple entry STRAPS (magenta) may require more attenuation with increasing off-nadir angle. A time dynamic analysis (green) may determine the protection at a relaxed threshold.

Worst Case Geometry for Single Entry UT to Sensor

For this case a simple link calculation determines the interference power density at the sensor receiver, based on the maximum UT EIRP density, free space loss due to range, and the boresight gain of the sensor. Range as a function of sensor off-nadir angle is calculated based on the satellite altitude.

$$Io\left(\frac{dBW}{MHz}\right) = EIRP\ Density\ - FSL - Gr\ - 3dB\ polarization\ loss$$ [5]

This is added to the decibel reference bandwidth (e.g. 20 dB(MHz) for the 100 MHz bandwidth) to obtain interference power for comparison to the threshold.

Multiple Interfering UTs from One STRAPS

Efficient STRAPS implementations will seek to reuse spectrum by using multiple beams to spatially separate reuse of parts or all of the uplink band, allowing multiple UTs to transmit on the same frequency. If they are to reuse the same channel adjacent to the EESS band, they will need to be spatially separated enough to not interfere with each other, resulting in different elevation angles to the STRAPS and therefore different UT off-boresight angles presented to the orbital EESS sensor (i.e. two UTs can't both present maximum gain to the sensor).

Figure 3 illustrates the situation described above using sensor E2 as an example. Because the range from the UT to the sensor is much larger than the range from the UT to the STRAPS, the

[5] In this analysis the STRAPS UTs are assumed to use circular polarization, whereas the sensors use linear polarization. Because directional beams will have good axial ratios on their boresights, polarization mismatch loss is 3 dB in the single entry interference analysis. In the multi-entry interference analysis, where sensors will receive UT interference through their sidelobes and backlobes where axial ratio is not well controlled, mismatch loss is assumed to average 1.5 dB

angular separation between closest UTs seen from the STRAPS is approximately the same as the off-boresight angle the closest UT will present to the sensor.

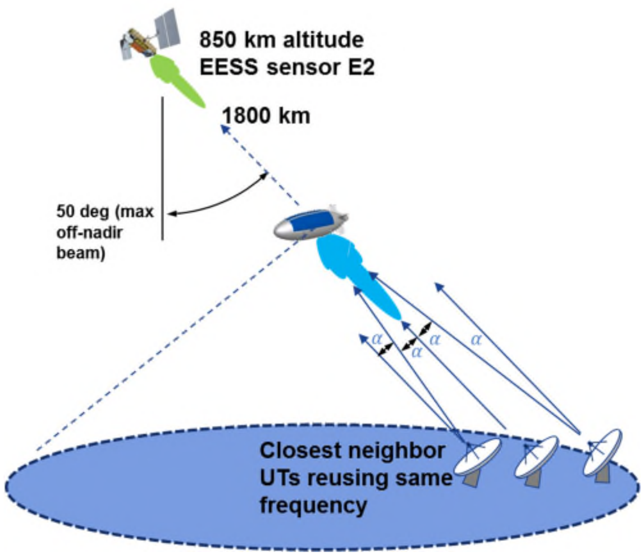


Figure 3 - Additional same channel UT interferers from single STRAPS location have minimum off-boresight angles from minimum separation for frequency reuse

To protect EESS sensors from multiple UTs associated with a single STRAPS, the regulatory limit for emissions in each EESS band sets the maximum *aggregate* EIRP density the SBCS system can emit as a function of elevation angle. It is up to the system designer to meet the requirement regardless of the SBCS architecture adopted or specifics of the implementation.

Practically, the aggregate requirement will have little impact on the SBCS system design. SBCS UTs will be regulatorily required to not exceed an EIRP density mask vs off-boresight angle, which ensures roll-off is sufficient for compatibility with other services and non-exclusive coverage from STRAPS (multiple STRAPS can serve the same market). The example used in analyses for this PFR has the 20 dB(W/MHz) peak roll-off from 0.5 degrees to a floor of -30 dB(W/MHz) at 8 deg, and will likely be reduced to 6 or 7 degrees based on additional analysis. Using the example EIRP density mask, if 500 additional UTs were active, but saw the sensor 8 or more degrees off boresight, and no roll-off of the sensor pattern is accounted for (sensor boresight gain presented to all UTs in the STRAPS service area), the total increase in EIRP density would be 0.02 dB. If the 6 nearest neighbor UTs to the primary interfering UT saw the sensor at 6 degrees off boresight the increase would be 0.03 dB. Clearly the additional interference from multiple UTs is negligible if they are sufficiently separated.

As an example of required separation: The EG reference design requires > 17 dB carrier to noise ratio to operate at the highest design data rate. Inter-beam interference, to not be a limiting factor, should be > 20 dB. Thus two simultaneous receive beams on the STRAPS reusing the same frequency would need to be pointed at least far enough apart to get 20 dB isolation between their pointing directions. The narrowest beam considered for outer beams in the System 6 receive beams, with 33 dBi boresight gain and the ITU-R F.1245 pattern, will require ~6 degrees of pointing separation to achieve 20 dB spatial isolation.

Regardless of technology improvements that might permit more directive STRAPS receive beams and thus closer spacing of co-channel UTs, a single SBCS system would still be regulatorily required to limit the aggregate EIRP density from all UTs in any particular direction.

Multiple Interfering UTs from Multiple STRAPS

Non-negligible multiple interference occurs if two or more different STRAPS platforms are physically separated but in view of an EESS sensor. If the primary interfering STRAPS location is at the boresight of the EESS sensor beam, the beam gain roll-off will determine the additional interference from the second STRAPS.

The minimum separation between the STRAPS platforms is determined by their own compatibility constraints. Required separation will vary depending primarily on each system's coverage area, but for practical systems, separation could typically be 40 km[6]. Figure 4 illustrates an example distribution of STRAPS within the field of regard of a sensor. In the single entry worst case, the sensor is aimed at nadir and has a UT aimed directly back. The worst case for multiple entry is when every other STRAPS in the field of regard also has a UT aimed directly at the sensor. The highest density of nearby STRAPS is a hexagonal array with 40 km centers.

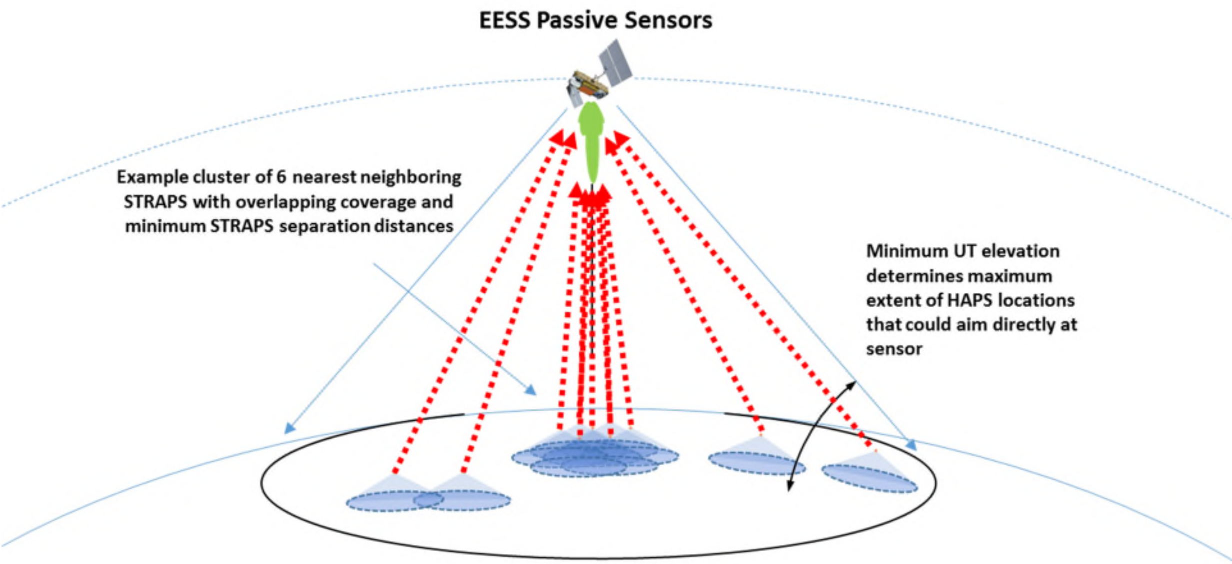


Figure 4: Multiple STRAPS deployed across area that could interfere. After single worst case interferer in sensor beam boresight, next highest interference comes from maximum of 6 nearest neighbors. Although statistically unlikely, bounding multiple interference case has UT aimed directly at sensor from every STRAPS location.

[6] See "Compatibility Analysis: STRAPS User Uplink Interference into Other STRAPS User Uplink (Peer to Peer Analysis) 21.5 – 24 GHz Band" and "Compatibility Analysis: STRAPS User Downlink Interference into Other STRAPS User Downlink (Peer to Peer Analysis) 25.25 – 27.5 GHz Band"

An extremely conservative analysis to bound the aggregate EIRP density for one SBCS system is to consider a grid of STRAPS separated by 40 km covering the entire Earth visible to the sensor, as shown in Figure 5. In this unrealistically extreme scenario, the worst case single entry interference is determined as before, but the interference from all other STRAPS is added to it. Thus up to 21,000 UTs (at the highest sensor altitude considered) operating at maximum EIRP density of 20 dB(W/MHz) are aimed directly at the sensor (or as close as their minimum elevation angle allows). No atmospheric losses are considered.

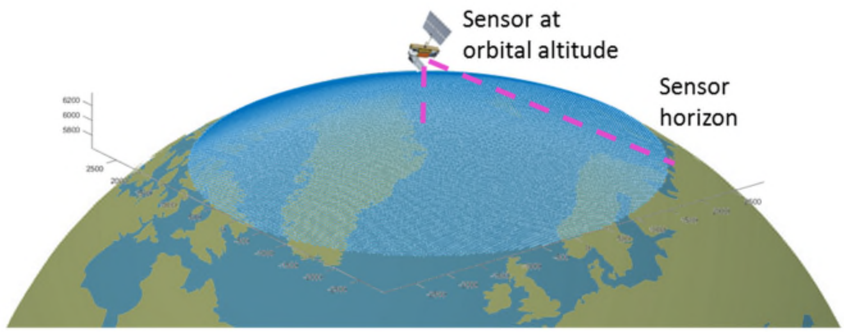


Figure 5: Grid of STRAPS locations with 40 km separation over the spherical cap of Earth visible to sensor

Figure 6 illustrates power received from the grid of SBCS systems. The analysis using the EG reference design uses a nominal 20 km altitude and 70 km service area radius setting minimum UT elevation angle at the edge of the service area to ~15 deg. Thus maximum power received at the sensor falls off from UTs that see the sensor below 15 deg and cannot aim directly at it. The sensor gain pattern determines

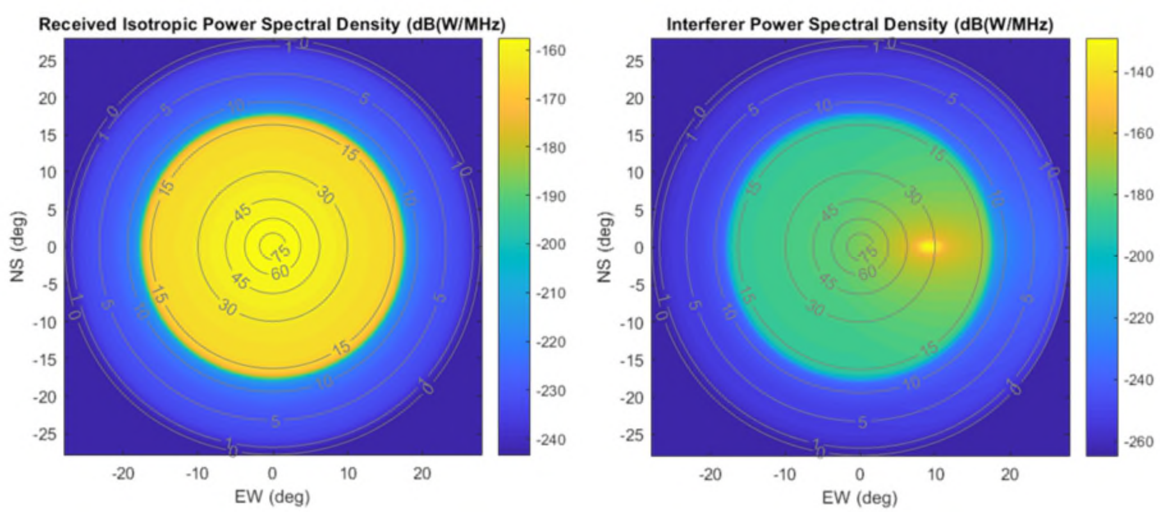


Figure 6: Power from grid of STRAPS. (left) Received power falls off rapidly at elevations below the minimum 15 deg elevation for UT pointing. (right) Sensor gain pattern amplifies signals differently based on location the boresight intersects the Earth.

Increase in Potential Interference over Background Interference From Fixed Service

The analysis determines aggregate interference of all FS transmitters around an urban location into three 100 MHz reference bands inside the EESS passive band: 22.2-22.3, 22.3-22.4, and 22.4-22.5 GHz), and determines the increase in interference due to an SBCS at the same location when an active protection scheme is followed. In the protection approach, an SBCS UT is only permitted to operate when the. In this active management approach SBCS channels overlapping the 22.21-22.5 GHz could be used when no EESS sensor in the band has line of sight to the service area[7]. When an EESS sensor does have line of sight to the service area and as it changes azimuth and elevation angle as viewed from the area, UT beams are selectively changed in channels to ensure no beam overlapping the band is aimed within 8 degrees of the sensor, ensuring more than 60 dB lower EIRP due to spatial isolation.

To determine interference to sensor R1 in the 22.21-22.5 GHz band from Fixed Service (FS) licensed in the 21.4-23.6 GHz FS allocation, FS transmitter data is gathered from the FCC license database. The database contains sufficient information on both transmit and receive locations on a path to determine all relevant transmitter geometry (latitude, longitude, altitude, azimuth, and elevation) and spectrum use. Full transmit gain patterns as a function of angle off boresight are not available, but boresight gain and 3 dB beamwidth are available. For this analysis, patterns are approximated from the boresight gain per ITU-R F.1245.

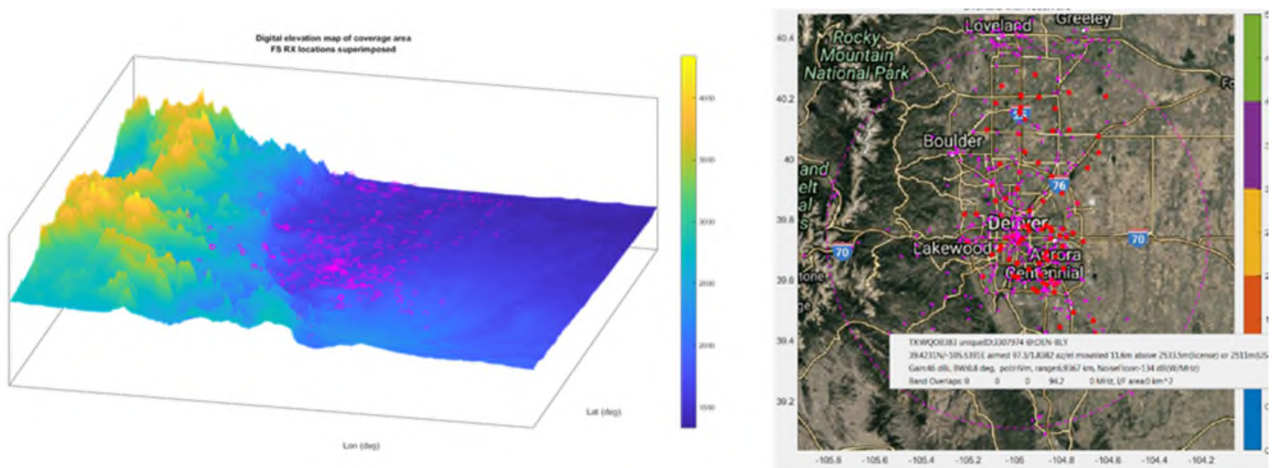


Figure 7: FCC data gathered for 80 km radius around Denver centered STRAPS. Left – Terrestrial FS transmitter locations around Denver superimposed on a USGS digital elevation map, Right – Map with transmit characteristics.

To conduct the analysis:

[7] There are currently 5 satellites carrying sensors in this band. Analysis indicates that over ~80% of the time no satellite has line of sight to an example CONUS location (Denver), and that multiple hour long windows are available each day.

- A target latitude and longitude is designated
- FS transmitters within 300 km are identified
- 100 different azimuths angles are generated spanning 0 to 360 degrees. An azimuth of 0 degrees corresponds to the conical scanning R1 sensor observing the target from the north, and azimuth of 180 degrees is from the south.
- At each azimuth angle each FS transmitter is considered
    - The range from the transmitter to the sensor, off-boresight angle the transmitter directs to the sensor, and off-boresight angle the sensor directs to the transmitter are calculated
    - The overlap between the transmitter channel and the reference bands is used to determine the EIRP entering each reference band.
    - The gain presented by the transmitter and sensor are interpolated from their respective gain patterns
    - The interferer power is then simply the EIRP – (UT boresight gain – UT presented gain) – Free space loss(range) + Sensor gain
- At each azimuth angle, the aggregate interference of all transmitters is summed in each reference band.

The interference is then compared to interference received from an SBCS UT at the maximum EIRP density but aimed 8 degrees away from the sensor. Increase in interference over existing FS interference is calculated as 10*log10(10^(Aggregate FS Interference/10)+10^(UT interference/10)) – Aggregate FS Interference.

STUDY RESULTS

Within each band, all sensor types are considered and the attenuation necessary for a nominal 20 dB(W/MHz) UT to meet the interference threshold criterion is determined for the single entry and the unrealistic bounding case. This attenuation can be subtracted from the nominal EIRP density to determine the maximum EIRP density a UT can emit in the EES band to never exceed the interference threshold.

21.2-21.4 GHz

Figure 8 illustrates results for sensors E1 and E2. Both sensors show the expected behavior for the single entry case. The necessary attenuation is at a maximum at nadir where space loss from range is smallest, and decreases with increasing off-nadir angle with increasing range. For the unrealistic bounding case, however, the sensors show different behaviors.

- Sensor E2 has a narrower beam and higher gain. Rapid gain roll-off means that contributions from additional STRAPS are less significant. Although the beam footprint expands at larger off-nadir angles to include more STRAPS closer to the center of the beam, the effect is not sufficient to overcome the increasing range loss except at the largest scan angles.
- Sensor E1 has a broader beam and lower gain. Although the single interferer interference is lower due to the lower gain, the shallower roll-off means that contributions from additional STRAPS off-boresight are more significant relative to the STRAPS at the

center. Thus at nadir the increase in necessary attenuation is greater. As the off-nadir angle increases and the beam footprint expands, contributions from multiple STRAPS increase at a rate greater than reduction from range loss.

The worst bounding case is 75 dB attenuation for Sensor E2 at nadir, which would require an emissions limit in this band of -35 dBW EIRP over a 100 MHz ref band.

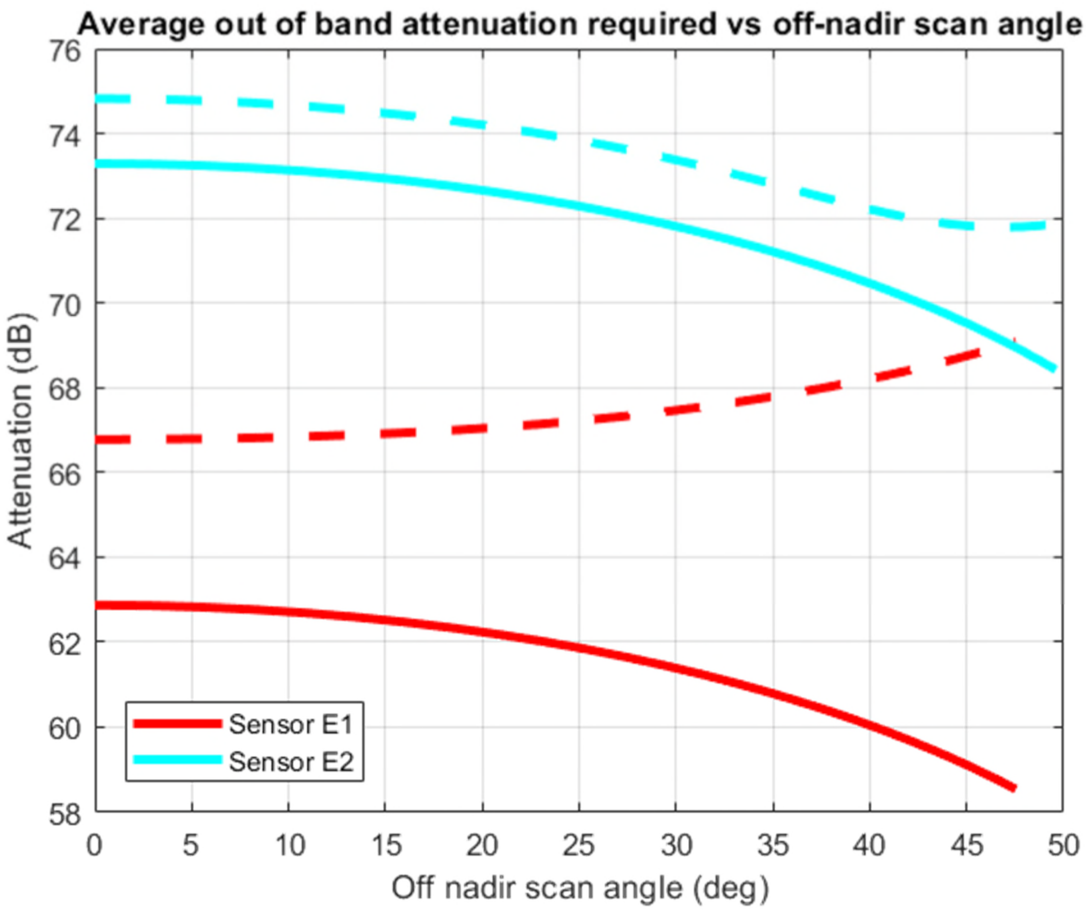


Figure 8: Results for sensors in the 21.2-21.4 GHz band. Single entry results (solid line) and unrealistically conservative multiple entry results (dashed line).

22.21-22.5 GHz

Figure 9 illustrates results for sensors R1. Although the curve vs off-nadir angle is shown, the sensor operates with a cylindrical scan at a constant 45 deg off-nadir angle.

The worst bounding case is 72 dB attenuation at 45 deg, which would require an emissions limit in this band of -32 dBW EIRP over a 100 MHz ref band.

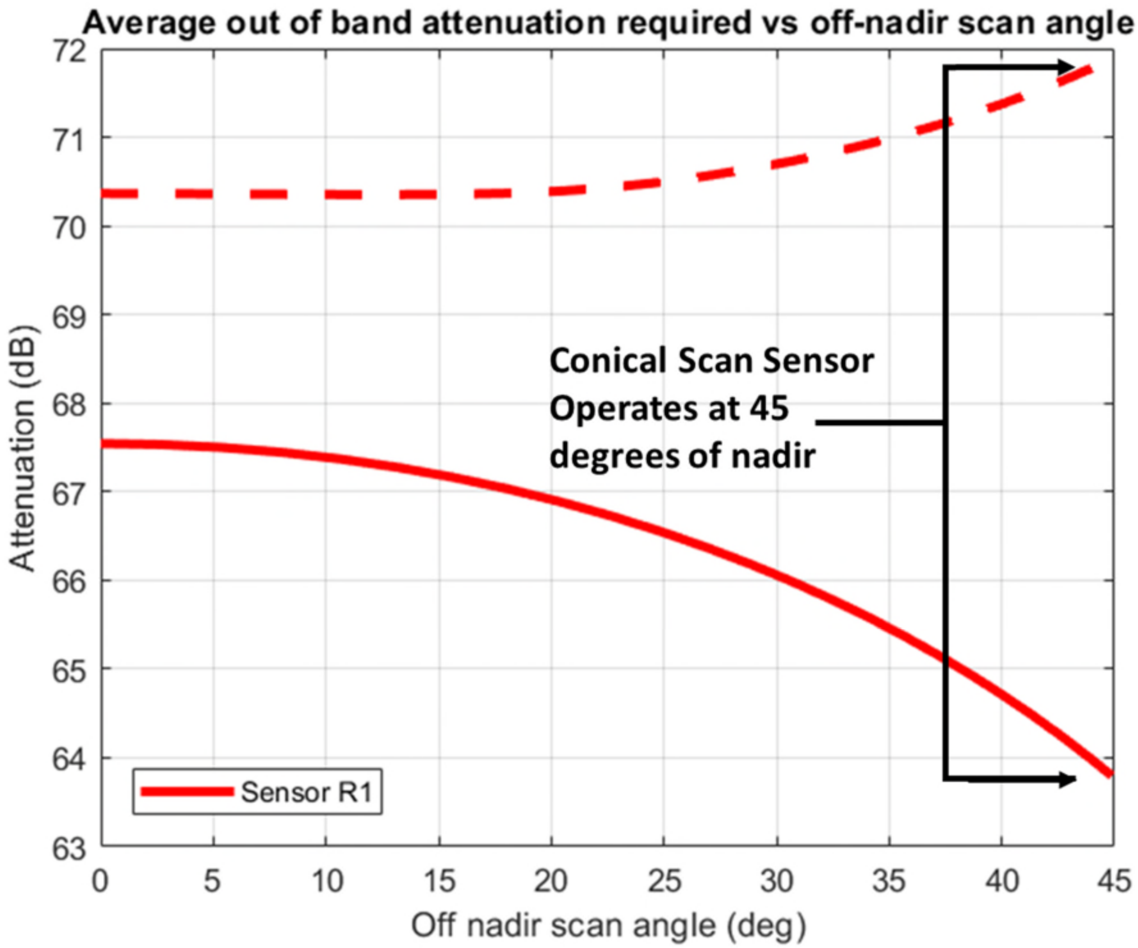


Figure 9: Results for sensors in the 22.21-22.5 GHz band.

23.6-24 GHz

Figure 10 illustrates results for sensors F1-F8. Five of the eight sensors are cylindrical scanners so show results only at their constant off-nadir angle.

The worst bounding case is 75.5 dB attenuation for sensor F3, which would require an emissions limit in this band of -32.5 dBW EIRP over a 200 MHz ref band.

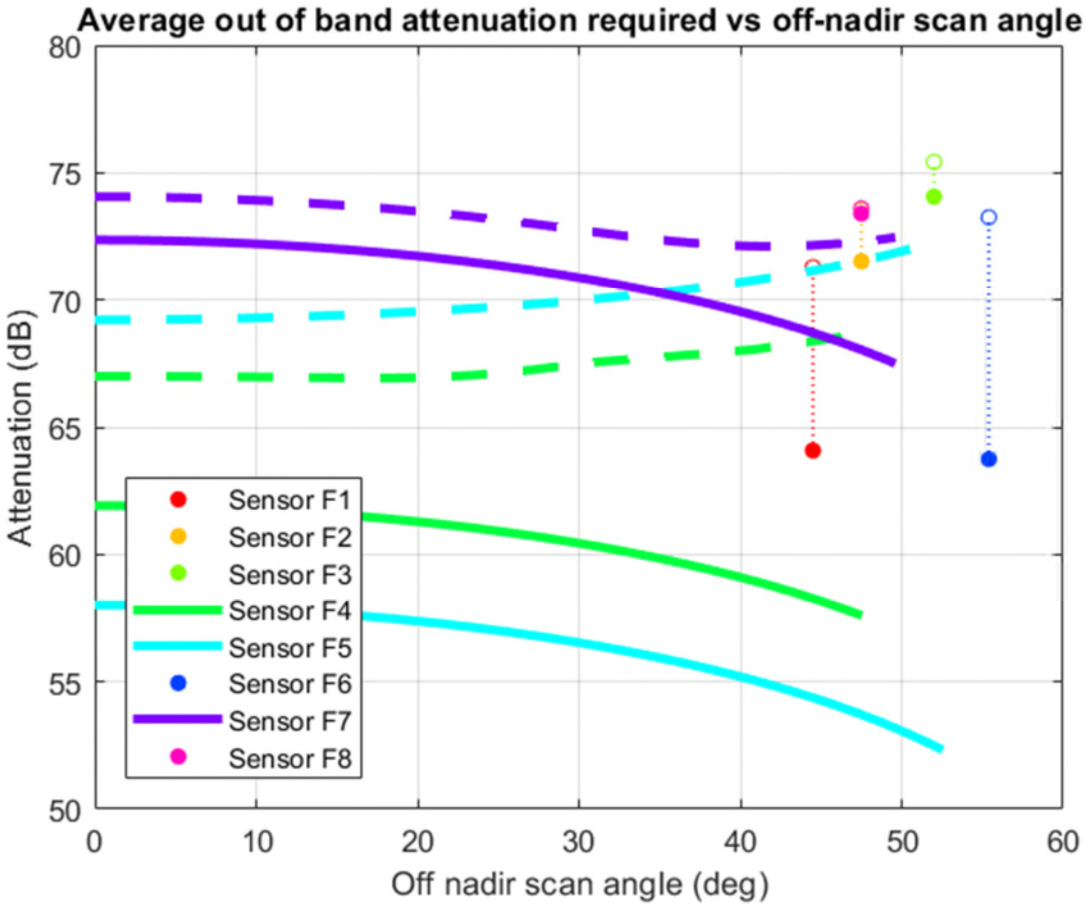


Figure 10: Results for sensors in the 23.6-24 GHz band

Increase in Potential Interference over Background Interference From Fixed Service

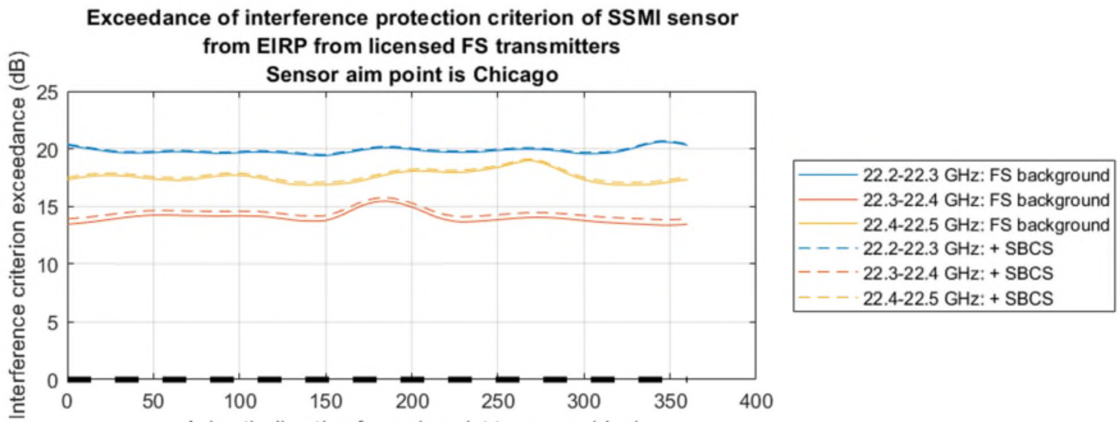
To satisfy the protection criteria for sensor R1[8] in the 22.21-22.5 GHz band, UT EIRP would require a very stringent -32 dB(W/100MHz) (multi-entry case) to -24 dB(W/100MHz) (single entry case) limit. While taking into account the domestic rule US532 and international 5.532 that precludes EESS from requiring protection from in-band Fixed or Mobile services and that SBCS-UT Ground Station use of the band would be from ground-based fixed terminals, SBCS-UT Ground Stations would seek to be less interfering than other Fixed stations based on their FCC authorizations. The SBCS-UT Ground Station would ensure that its boresight would not be within 8 degrees of a moving EESS sensor when using overlapping spectrum so that they would be exposed to no more than -20 dB(W/100 MHz)[9] which is 4 dB higher than the single entry level to ensure full protection.

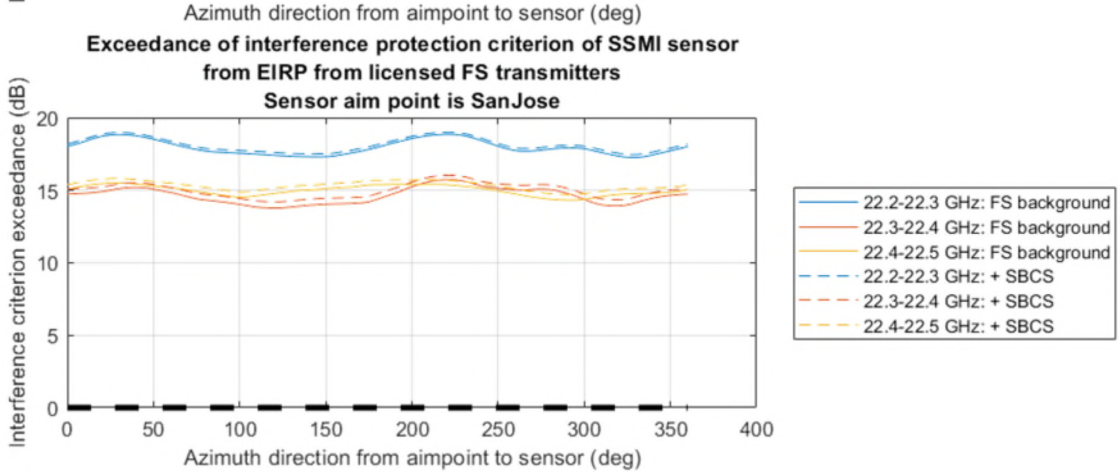
8 Representing the SSMI sensors flying on DMSP satellites, the only sensors in the 22.21-22.5 GHz band

9 When UTs operating at maximum power and without taking into account further losses due atmospheric losses or weather that would reduce exposure to the interference further.

To compare to interference they *currently accept* from urban centers (and are required to accept, as they are FS):

- Chicago projects between -10 dB(W/100MHz) and -3 dB(W/100MHz) toward SSMI sensors, exceeding the protection criteria by 14 dB to 21 dB. EG would increase background interference between 0.09 dB and 0.4 dB.
- San Jose projects between -10 dB(W/100MHz) and -6 dB(W/100MHz) toward SSMI sensors, exceeding the protection criteria by 14 dB to 18 dB. EG would increase background interference between 0.17 dB and 0.4 dB.
- Denver projects between -12 dB(W/100MHz) and -9 dB(W/100MHz) toward SSMI sensors, exceeding the protection criteria by 12 dB to 15 dB. EG would increase background interference between 0.3 dB and 0.6 dB.





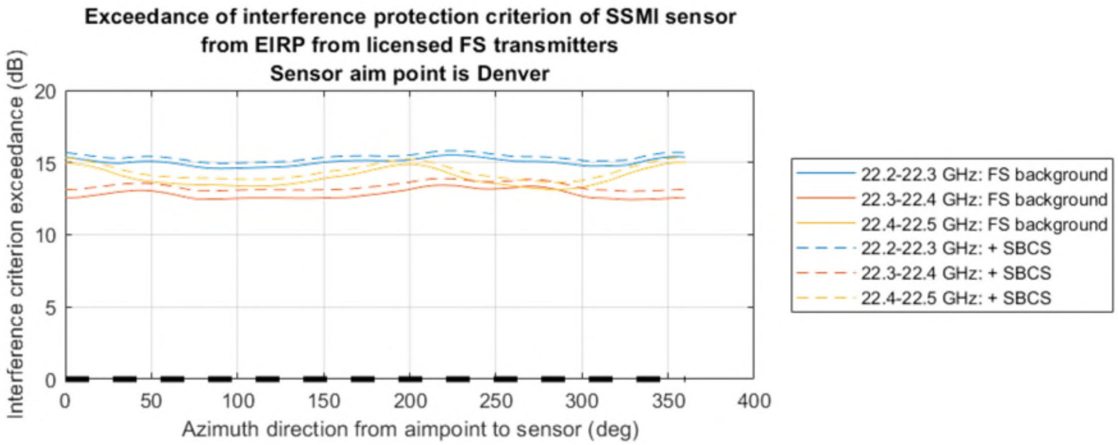


Figure 11: Exceedance of protection criteria in 22.21-22.5 GHz when sensor R1 aimed at three different urban centers. Exceedance into three different reference bands plotted as a function of azimuth angle to the sensor. Dashed lines indicated exceedance with additional interference from an SBCS-UT aimed 8 degrees away from sensor.

CONCLUSIONS

A compatibility study was performed using worst-case operational and geometric assumptions for single entry interference, including all UTs simultaneously active and transmitting at maximum power. In addition, an extremely unrealistic deployment of SBCS systems blanketing the Earth at minimum separation distance was used to demonstrate a bound on the increase in interference from multiple SBCS systems.

Emission limits toward sensors were derived for each passive sensing band that can be used to regulate aggregate emissions from an SBCS system. As described previously (Figure **2**), these limits are generalized but conservative. They can be refined to incorporate variation in the limit with elevation angle, and represent a point of departure for more sophisticated time dynamic and statistical analyses that can be applied to specific SBCS designs and incorporate the % time aspect of the protection criteria.

A limit on EIRP emitted toward EESS sensors in the passive bands is a superior approach to regulatory protection than detailed regulatory prescription of SBCS channel and guard band sizes, filter parameters, etc. This method specifies the metric that matters, and enables development of creative designs and different system architectures and implementations to compete in the marketplace, rather than mandating design details and a single solution or approach.

An active protection approach in which the 22.21-22.5 GHz band is not used by UTs aiming within 8 deg of an EESS sensor to minimize interference into the band is feasible. When a single SBCS-UT Ground Station is the dominant interferer (i.e. when the satellite scanner is not pointed towards a fixed station such as the examples above) then there would be a maximum 4 dB exceedance (much lower than the examples above from currently authorized fixed stations that are exceeding the protection criteria by as much as 21 dB). However, when they are already suffering interference from the more dominant interfering fixed station the additional interference for the single interferer cases we selected would increase the interference by 0.6 dB. We note that this is a comparison of the single uplink interferer case compared with existing

authorized single fixed station transmitters at maximum authorized levels. While we also recognize that there would be an aggregation of interference, we note that would also be true with respect to the traditional fixed stations that are not required to protect satellite passive measurements given the U.S. regulatory provision US532.

REFERENCES:

ITU-R RS.2017: Performance and interference criteria for satellite passive remote sensing

ITU-R RS.1861: Typical technical and operational characteristics of Earth exploration-satellite service (passive) systems using allocations between 1.4 and 275 GHz

ITU-R RS.1813: Reference antenna pattern for passive sensors operating in the Earth exploration satellite service (passive) to be used in compatibility analyses in the frequency range 1.4-100 GHz

Appendix H
Compatibility Analysis:
STRAPS User Uplink Interference into
Radio Astronomy Passive Sensing in the
22.01-22.21, 22.21-22.5, 22.81-22.86, 23.07-23.12 and 23.6-24 GHz Bands
(Prepared by Lockheed Martin Corporation for Elefante Group, Inc.)

SUMMARY

- Elefante Group is proposing to access the 21.5-23.6 GHz band for User uplink communications from User Terminals (UTs) to Stratospheric Platform Stations (STRAPS) on a co-Primary basis.

- This study assesses the compatibility of STRAPS User uplinks with the Radio Astronomy Service (RAS), which has allocations to operate in the 22.01-22.21, 22.21-22.5, 22.81-22.86, 23.07-23.12 and 23.6-24 GHz bands.

- Worst-case operating conditions are utilized for a bounding analysis, in which all UTs are simultaneously active and transmitting at the maximum permitted EIRP density across their maximum bandwidth.

- Bounding compatibility study results show that UTs operating in RAS bands must have line of sight blockage to not present harmful interference. UTs operating out of band must have sufficient out of band emission attenuation.

- Coordination can be conducted between STRAPS and individual RAS sites based on their unique topography to establish rules for maximum UT height to prevent line of sight interference paths.

PURPOSE OF THE STUDY

Elefante Group is proposing that the 21.5-23.6 GHz band be made available for Stratospheric-Based Communications Services (SBCS), operating as a Fixed service, in the uplink direction. (While not the purpose of this study, Elefante Group proposes that the 21.5-23.6 GHz band also be considered for use in the downlink direction). All or part of this band is allocated in the federal and non-federal allocation to Fixed, Mobile, Inter-Satellite services, Earth Exploration Satellite (passive), Space Research (passive), Radio Astronomy (passive).

This study assesses the compatibility with RAS of uplink transmissions from ground-based UTs to a multi-beam stratospheric platform.

This study assesses the potential for interference into RAS to exceed the I/N Protection Criterion to determine if mitigation measures are necessary.

PERFORMANCE CHARACTERISTICS OF RAS SENSORS

Performance characteristics of the RAS sensors utilized for this study are based on ITU-R RA.769 and reproduced here for convenience. Table 1 presents general characteristics for RAS common to all frequency observation bands. Table 2 presents specific PFD thresholds for interference when the RAS antenna presents 0 dBi gain to the interferer. The continuum observation centered on 23.8 GHz is the most sensitive to interference.

Table 1: General RAS characteristics for interference analysis

Parameter	Value	Source
Rx Antenna Gain	88 dBi	Approximated as max gain for 100 m referenced in ITU-R.769
Rx Antenna Beam Width	0.8 deg	Derived assuming 70% efficient antenna (1)
Rx Antenna Pattern	ITU-R SA.509	ITU-R SA.509
Min. Elevation Angle	5 deg	ITU-R RA.1513
Polarization	Co-polarized with interferer	Worst case
Total interference allocation	5%	ITU-R RA.1513
Single system interference allocation	2%	ITU-R RA.1513

Table 2: Band Specific Characteristics

Type	Center (GHz)	Bandwidth (MHz)	Threshold PFD dB(W/m^2/MHz)
Line	22.2	250	-156
Line	23.7	250	-155
Continuum	22.355	290	-171
Continuum	23.8	400	-173
VLBI	23.8		-123

OPERATIONAL CHARACTERISTICS OF SBCS

The SBCS will utilize STRAPS, UTs, and Gateway terminals to provide fixed services over a specific service area. Transmit characteristics of the Elefante Group STRAPS user uplink used in this study, are given in Appendix 1.

For this study, worst-case operating and geometric conditions are utilized for a bounding analysis prior to considering, if appropriate, risk-based interference assessment using probability and statistical methods:

1) All UTs simultaneously active and transmitting at power levels which achieve the highest data rates, i.e. EIRP Density of 20 dBW/MHz for Enterprise UTs and 12 dBW/MHz for Consumer UTs.
2) Worst-case geometric alignment between EESS sensor, STRAPS service area and UT.

Parameter	Value	Notes
Airship Altitude	21.3 km (maximum)	19.8 km (nominal)
Coverage Area	70 km radius	
Number of Beams	135 x 4 colors = 540 total	
Channel Bandwidth	450 MHz (consumer UTs < 25 MHz)	Per color/polarization
Airship Transmit PFD	Max PFD Limit	CFR Title 47 25.208(c); Rolloff beyond coverage area using ITU-F.1245 antenna pattern
UT Antenna Pattern	ITU-F. 1245	
UT Peak Antenna Gain	Enterprise: 24.5(22GHz), 25.6 (26 GHz) Consumer: 25.3 (22GHz), 26.4 (26 GHz)	
UT EIRP Density	Enterprise: 20 dBW/MHz Consumer: 12 dBW/MHz	Worst-case assumption: All UT's active and transmitting continuously at a power level to achieve the highest data rates.
Number of UT's in Service Area	Enterprise: 135 Consumer: 135 (equivalent UTs)	Each UT occupies full 450 MHz bandwidth; for worst-case analysis, number of UTs increased proportional to victim bandwidth

STUDY SCENARIO

Figure 1 illustrates the interference geometry applicable to this study.

- UTs located across the coverage area transmit User Uplink signals to the associated STRAPS.
- RAS receive interference at low elevation angles from UTs with line of sight to RAS site
- Worst-case geometry is when the RAS sensor is aimed in azimuth at the center of the service area and at minimum elevation angle.

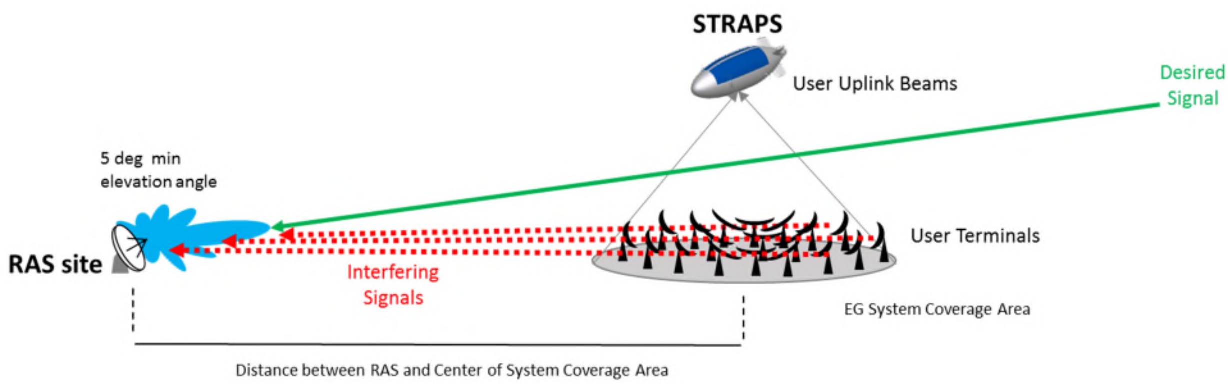


Figure 1: Interference geometry for UT and EESS orbital passive sensor systems

STUDY METHODOLOGY

Analysis of these scenarios using the proposed 20 dB(W/MHz) EIRP density limit on UT uplinks determines a required attenuation as a function of off-nadir angle the sensor beam is pointing. This attenuation can be subtracted from the maximum EIRP density and generalized to a maximum EIRP permitted over the RAS bands.

Multi-entry analysis is conducted with the following steps

- The maximum number of UTs that could operating in the same band are distributed on a grid contained within the STRAPS service area perimeter.
- The RAS sensor is positioned at various distances from the center of the STRAPS Service Area to determine the interference margin if out-of-band filtering were not applied. The RAS sensor is varied between 80 and 400 km from the center of a STRAPS service area that is nominally 70 km in radius, thus the RAS sensor is between 10 and 330 km from the edge of the service area.
- The amount of out-of-band filtering required to comply with the RAS specifications is determined as a function of the position of the RAS sensor relative to the STRAPS.

The extent of the service area is large enough that Earth curvature and topography are significant factors in determining how many of the UTs have line of sight to interfere with the RAS sensor, and UT and RAS sensor heights drive the distance of their relative horizons. As a bounding analysis, a uniform attenuation applied to all UTs is determined assuming no Earth blockage. Example uniform attenuations applied to UTs for different assumptions on UT and RAS sensor

height and including Earth blockage are conducted. Figure 2 illustrates UTs with line of sight to the RAS sensor on a spherical Earth if both are at 50m altitude[1].

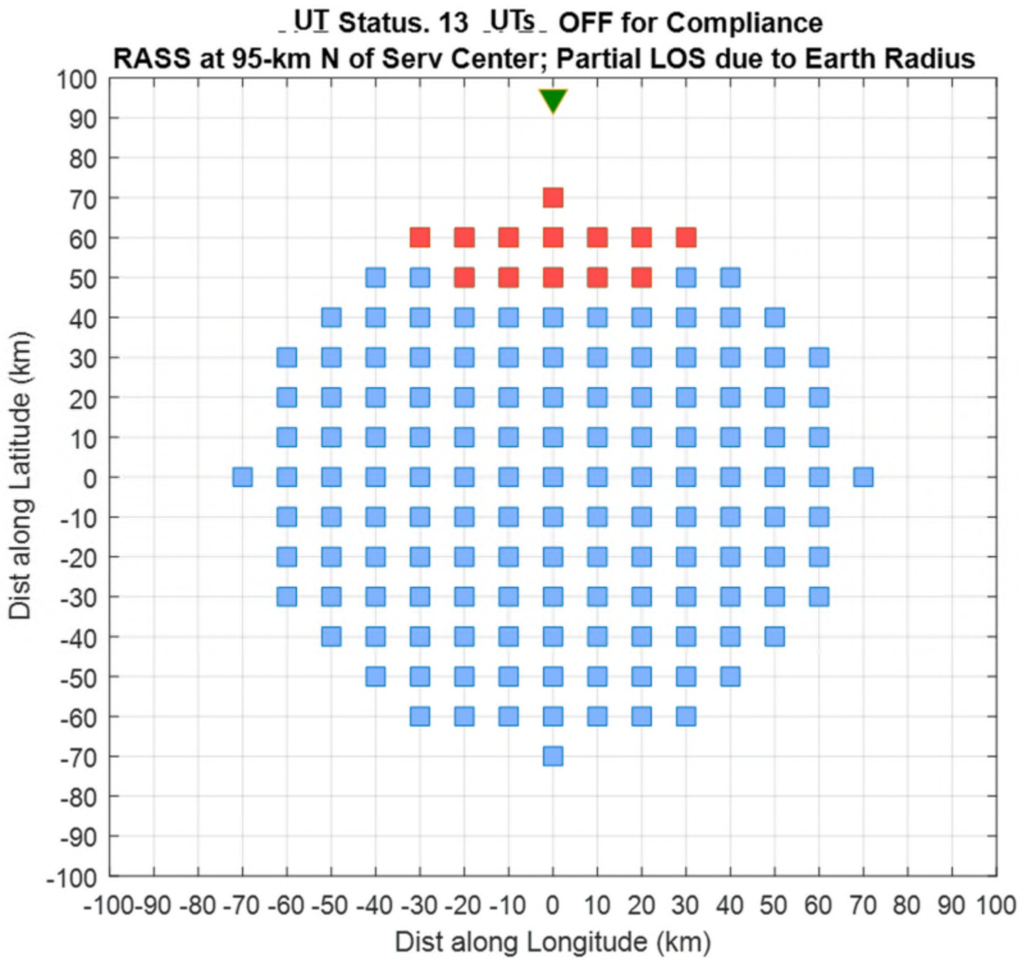


Figure 2: Example UT layout grid. Red UT locations have line of sight for a spherical Earth and 50m height UTs and RAS. Actual line of sight determined by actual height and topography

STUDY RESULTS

The bounding value where line of sight blockage is ignored shows the necessary attenuation from in-band values to RAS observation band decrease with increasing range if there was no Earth blockage. For various RAS and UT heights using a spherical Earth for line of sight blockage, the necessary attenuation decreases more rapidly with range as fewer UTs have line of sight, and ends when no UTs have line of sight to the RAS sensor.

[1] In practice consumer UTs will generally be installed on residential rooftops and enterprise UTs on towers or business rooftops, all typically lower than 50m

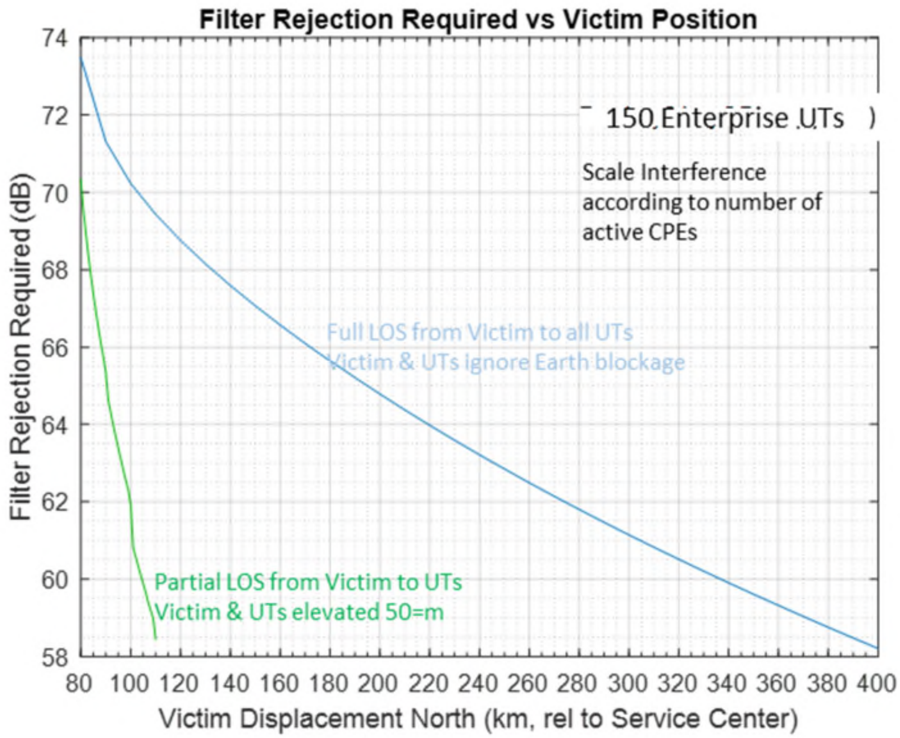


Figure 3: Out of band attenuation necessary for 20 dB(W/MHz) EIRP density UTs as a function of range of RAS site from STRAPS service area center. (blue) bounding case where Earth blockage is not taken into account. (green) example case where both UTs and RAS are elevated to 50m above a spherical Earth.

CONCLUSIONS

The principal conclusion is that out of band attenuation is driven by factors that will be largely RAS site specific including local topography and height of the observatory as well as the heights of UTs. It is proposed that during coordination preceding registration of a STRAPS location within the nominal coordination radius of a RAS site, a one-time coordination be undertaken. The coordination would use topography and RAS site height to determine contours of maximum UT height permissible to prevent line of sight between UTs and the RAS sensor. This would define how UTs overlapping protected RAS bands could be deployed.

Clearly in-band operation for UTs in line of sight is not feasible. However adjacent band UTs could operate while protecting RAS with sufficient out of band attenuation[2], but not under the described blanket agreement above. UTs operating on bands not overlapping protected RAS bands might operate in line of sight on a coordinated basis with a showing that out of band attenuation is sufficient to maintain aggregate interference within acceptable interference levels.

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[2] The pulse shaping filter of many commercially available modems is specified to provide greater than 50 dB attenuation a nominal distance from the passband, and additional filtering and natural roll-off make ~70 dB reasonably achievable with sufficient guard band.

REFERENCES:

ITU-R RA.769-2: Protection criteria used for radio astronomical measurements

ITU-R RA.1513-2: Levels of data loss to radio astronomy observations and percentage-of-time criteria resulting from degradation by interference for frequency bands allocated to the radio astronomy service on a primary basis

Appendix I
Compatibility Analysis:
STRAPS User Downlink Interference into
Aeronautical Mobile Service Airborne-to-Ground Link in the
25.25 – 27.5 GHz Band
(Prepared by Lockheed Martin Corporation for Elefante Group, Inc.)

SUMMARY

- Elefante Group is proposing to access the 25.25–27.5 GHz band for User downlink communications from Stratospheric Platform Stations (STRAPS) to User Terminals (UTs) on a co-Primary basis.

- This study assesses the compatibility of STRAPS User downlinks with Federal Aeronautical Mobile Service (AMS) Airborne-to-Ground links which are authorized to operate in the 25.25–27.5 GHz band.

- Worst-case operating conditions are utilized for a bounding analysis which include: 1) STRAPS transmitting at a level equal to the maximum Power Flux Density (PFD) limit as authorized for satellite downlinks into Fixed services, 2) STRAPS downlink channel fully encompassing the Aeronautical channel bandwidth and operating in the same polarization, and 3) AMS Ground Data Terminal (GDT) located anywhere including at the worst-case interference location in the center of the STRAPS system coverage area.

- Bounding compatibility study results show that AMS I/N Protection Criterion is met for >99% of the Field-of-View of the AMS Ground even under worst-case conditions. Therefore, the likelihood of harmful interference is minimal. No mitigation is recommended.

PURPOSE OF THE STUDY

Elefante Group is proposing that the 25.25–27.5 GHz band be made available for Stratospheric-Based Communications Services (SBCS), operating as a Fixed service, in the downlink direction. (While not the purpose of this study, Elefante Group proposes that the 25.25–27.5 GHz band also be considered for use in the uplink direction.) All or part of this band is allocated in the federal allocation to Fixed, Mobile, Earth Exploration Satellite (space-to-earth), Space Research (space-to-earth), and Inter-Satellite services, and Space Research and Inter-Satellite service in the non-federal allocation.

This study assesses the compatibility with AMS Airborne-to-Ground links of STRAPS downlink transmissions from a multi-beam stratospheric platform to ground-based UTs. There is the potential for interference into the AMS Ground when the AMS Airborne, AMS Ground and STRAPS are geometrically co-aligned.

This study assesses the potential for such interference into AMS Ground to exceed the I/N Protection Criterion to determine if mitigation measures are necessary.

OPERATIONAL CHARACTERISTICS OF AMS GROUND RECEIVERS

Receive characteristics of the AMS Ground utilized for this study are based on the two systems illustrated in ITU-R M.2114 and are shown in Table 1 and Table 2.

Table 1: System 1 AMS Ground Data Terminal Receive Characteristics

Parameter	**Value**	**Source**
Frequency Range	25.75 – 27.15 GHz	ITU-R M.2114-0
Channel Bandwidth	865 MHz	ITU-R M.2114-0
Rx Antenna Gain	46 dBi	ITU-R M.2114-0
Rx Antenna Beam Width	0.8 deg	Note (1)
Rx Antenna Pattern	APEREC026V01	Note (2)
Min. Elevation Angle	3 deg	Assumption
Earth Station Receiver Noise Density	-142.2 dBW/MHz	ITU-R M.2114-0, NF = 4
Protection Criterion	I/N < -6 dB	ITU-R M.2114-0

Table 2: System 2 AMS Ground Data Terminal Receive Characteristics

Parameter	**Value**	**Source**
Frequency Range	25.75 – 27.15 GHz	ITU-R M.2114-0
Channel Bandwidth	746 MHz	ITU-R M.2114-0
Rx Antenna Gain	33 dBi	ITU-R M.2114-0
Rx Antenna Beam Width	3.4 deg	Note (1)
Rx Antenna Pattern	ITU F.1245-60% efficiency	Note (2)
Min. Elevation Angle	3 deg	Assumption
Earth Station Receiver Noise Density	-141.4 dBW/Hz	ITU-R M.2114-0, NF = 4.5
Protection Criterion	I/N < -6 dB	ITU-R M.2114-0

(1) ITU-R M.2114 shows a single 7.2 deg beam width for 33 dBi and 46 dBi antennas which results in 146% - 653% antenna efficiency, therefore a typical 70% efficiency used to derive beam width from the peak antenna gain
(2) ITU-R M.2114 permits use of measured antenna pattern in lieu of ITU-R M.1851 (uniform distribution) pattern therefore a standard ITU antenna pattern was selected which approximates a typical commercial antenna with similar peak gain and beam width

OPERATIONAL CHARACTERISTICS OF SBCS

The SBCS will utilize STRAPS, UTs, and Gateway terminals to provide fixed services over a specific service area. Transmit characteristics of the Elefante Group STRAPS user downlink utilized in this study are given in Appendix 1.

For this study, worst-case operating conditions are utilized for a bounding analysis prior to considering, if appropriate, risk-based interference assessment using probability and statistical methods:

1) STRAPS located at a minimum altitude of 18.3 km and transmitting at the regulatory PFD limit as authorized for satellite downlinks in this band to protect interference into Fixed services per CFR Title 47 25.208(c) over the STRAPS 70 km radius coverage area.

2) STRAPS downlink channel fully encompassing the Airborne downlink channel bandwidth and across the full coverage area (not considering that coverage is provided by multiple channels "colors" which are spread across hundreds of beams and that the Airborne downlink allocated frequency range may not be fully occupied).

3) STRAPS downlink operating in the same polarization as the Airborne downlink (Right Hand Circular Polarization)

STUDY SCENARIO

Figure 1 illustrates the interference geometry applicable to this study.

- STRAPS transmits User Downlink signals to the associated coverage area
- AMS Airborne Data Terminal located at or below the STRAPS altitude, transmits the desired downlink signal to AMS Ground which may be located within or outside the STRAPS service coverage area.
- As the AMS Ground tracks the Airborne, there could be portions of its 360-degree Field of View (FOV) over which the STRAPS, AMS Ground and Airborne are sufficiently co-aligned so as to result in the interfering signal from the STRAPS being received by the AMS Ground.
- The potential interference occurs over a "Cone of Interference" which subtends a solid angle representing a percentage of possible AMS Ground FOV and is utilized as a metric to quantify the likelihood of interference.

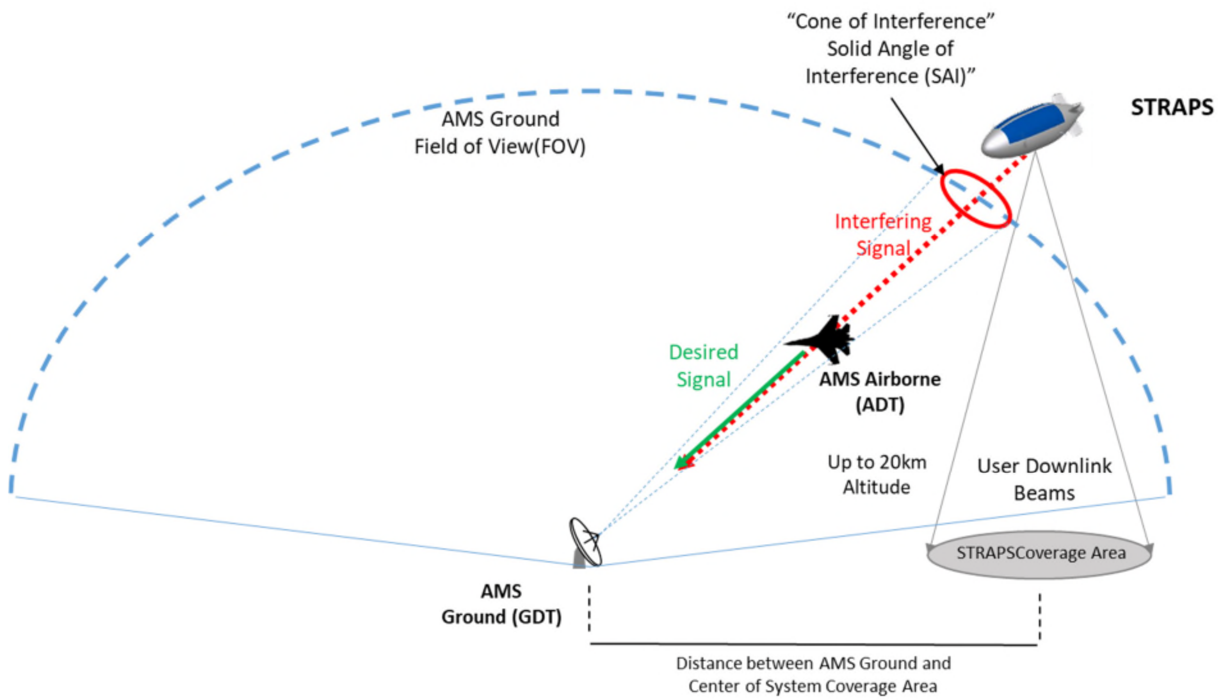


Figure 1: Interference Geometry

STUDY METHODOLOGY

The study starts by assuming the AMS Ground is at a fixed distance away from the center of the coverage area with the STRAPS transmitting at a level equal to the regulatory PFD limit that is authorized for satellite downlinks in this band to protect interference into Fixed services per CFR Title 47 25.208(c). The assumption is that the STRAPS service area is defined by a 70 km radius coverage area centered on the point below the STRAPS nominal fixed position as described below and illustrated in Figure 2 and Figure 3.

$$PFD\left(\frac{dBW}{m^2 * MHz}\right) = \begin{cases} -115 & 0 \le \delta < 5 \\ -115 + 0.5 * (\delta - 5) & 5 \le \delta < 25 \\ -105 & 25 \le \delta \le 90 \end{cases}$$

Where δ is the angle of arrival (in degrees) above the horizontal plane (elevation angle)

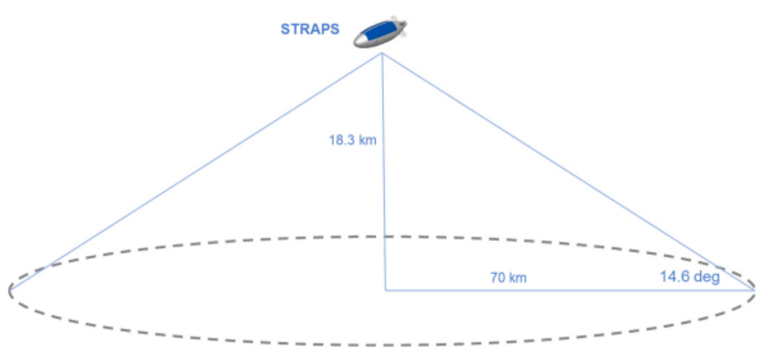


Figure 2: STRAPS Service Area Geometry

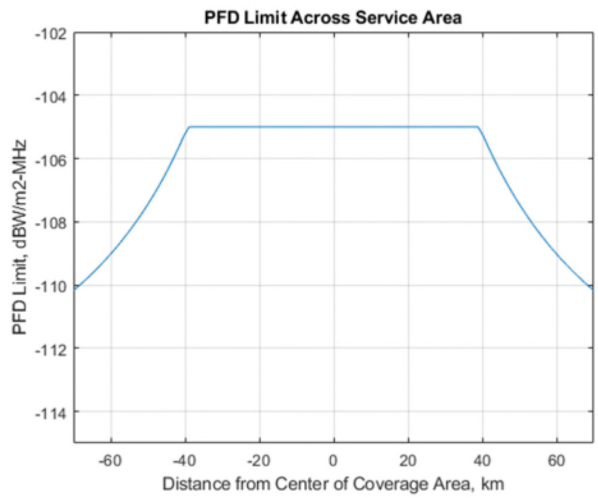


Figure 3: PFD Limit Across Service Area

PFD outside of the coverage area is calculated by starting with the PFD limit and rolling it off using the ITU-R F.1245 antenna pattern with peak antenna gain of 32.7 dB at the edge of coverage.

The corresponding STRAPS (Interferer) EIRP Density as a function of transmit antenna boresight angle is calculated as follows and illustrated in Figure 4.

$$EIRP\ Density\left(\frac{dBW}{MHz}\right) = PFD - 10 * \log(4 * \pi * r^2)$$

Where r is the distance from STRAPS to the ground distance away from the center of the coverage area

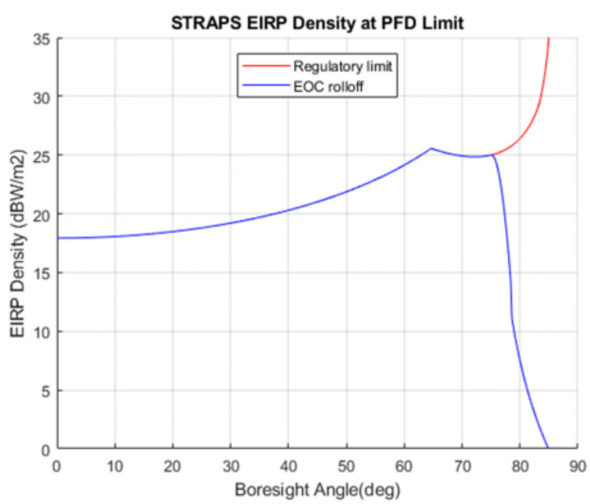


Figure 4: STRAPS EIRP Density at PFD Limit

The PFD is converted to receive interference power density, Io, at the AMS Ground as follows:

$$Io\left(\frac{dBW}{MHz}\right) = EIRP\ Density\ (\delta) - 10 * \log\left(\frac{\lambda^2}{4\pi}\right) + Gr\ (\beta)$$

where:

δ = Angle off STRAPS (Interferer) boresight towards the AMS Ground

$Gr\ (\beta)$ = AMS Ground (Victim) receive antenna gain off boresight towards STRAPS

λ = Wavelength

The received power density is subtracted from the receive noise power density and compared to the I/N Protection Criterion to determine the minimum AMS Ground receive antenna gain required to meet the I/N Protection Criterion.

Utilizing the AMS Ground receive antenna pattern, the minimum AMS Ground receive antenna gain is then converted to the angle over which interference would exceed the I/N Protection Criterion. Since the AMS Ground receive antenna pattern is symmetric about its boresight, the interference angle is converted into a Solid Angle of Interference (SAI).

The possible FOV of AMS Ground is calculated by assuming 360-degree azimuth coverage and a minimum elevation angle of 3 degrees.

The percent of FOV over which interference meets the I/N Protection Criterion is calculated as follows:

$$\%FOV\ Meets\ Protection\ Criteria = 1 - \frac{SAI\ (Solid\ Angle\ of\ Interference)}{FOV\ (Field\ of\ View)} * 100$$

The above metric approximates the likelihood that interference may exceed the protection Criterion.

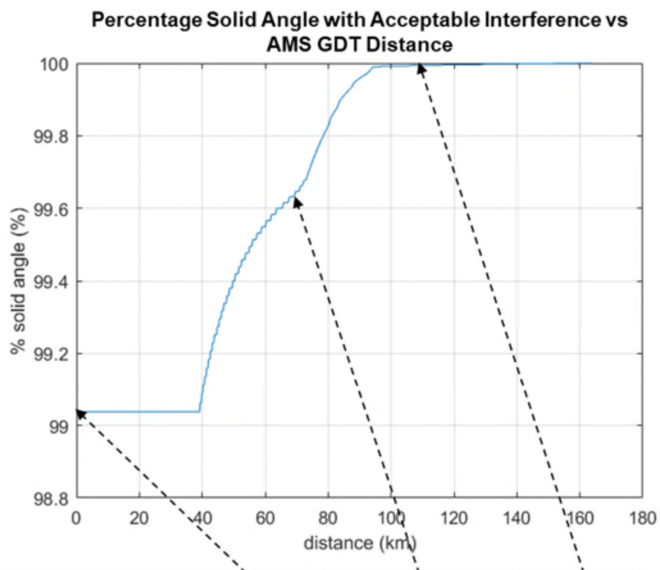
The above calculation is repeated for varying the distance of the AMS Ground relative to the center of the STRAPS coverage area.

STUDY RESULTS

Results of the compatibility study for the two AMS Systems in ITU-R M.2114 are shown in Figure 5 and Figure 6.

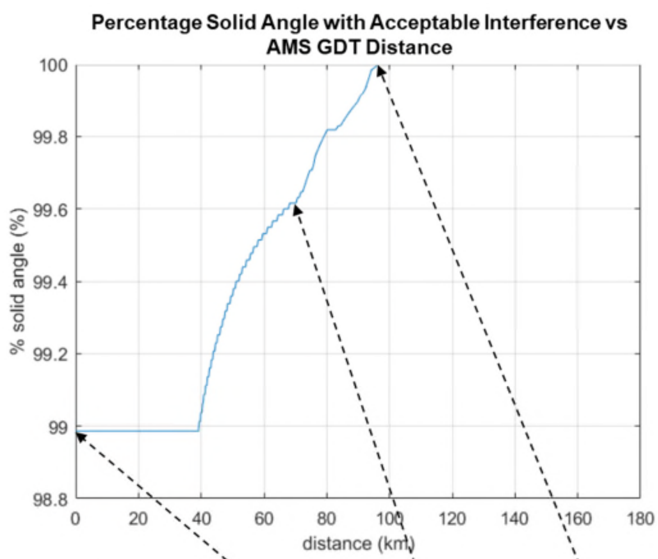
For System 1 and System 2, for the worst-case location of the AMS Ground situated in the center of the STRAPS coverage area, I/N Protection Criterion is met for 99% AMS Ground FOV.

I/N Protection Criterion is met over 100% of AMS Ground FOV if the AMS Ground is located at least 110 km from the center of the STRAPS coverage area for System 1 and 96 km for System 2.



AMS GDT Location	0 km(Center of EG Coverage Area)	70 km (Edge of EG Coverage Area)	~110 km
% FOV which Meets to I/N Protection Criteria	99%	>99.6%	100%

Figure 5: System 1 Compatibility Study Results



AMS GDT Location	0 km(Center of EG Coverage Area)	70 km (Edge of EG Coverage Area)	96 km
% FOV which Meets to I/N Protection Criteria	99%	>99.6%	100%

Figure 6: System 2 Compatibility Study Results

CONCLUSIONS

Utilizing worst-case operational conditions and assuming worst-case location of AMS Ground at the center of the STRAPS coverage area, the I/N Protection Criterion is met for 99% of the FOV of the AMS Ground. If the STRAPS is placed such that no AMS Ground is within 110 km, there is no harmful interference for 100% of the FOV of AMS Ground. Therefore, no mitigation is recommended for shared operation between STRAPS user downlink and AMS Airborne-to-Ground links.

Additionally, the less than 1% of the FOV interference from STRAPS user downlinks into an AMS Ground (deployed within 110 km of the center of the STRAPS coverage area) can be fully mitigated by STRAPS user downlink avoiding use of overlapping frequencies and polarization; coordination would be required in such cases to achieve such interference avoidance.

REFERENCES:

ITU-R M. 2114-0: Technical and operational characteristics of and protection Criterion for aeronautical mobile service systems in the frequency bands 22.5-23.6 GHz and 25.25-27.5 GHz

ITU-R F.1245-2: Mathematical model of average and related radiation patterns for line-of-sight point-to-point fixed wireless system antennas for use in certain coordination studies and interference assessment in the frequency range from 1 GHz to about 70 GHz

APEREC026V01: Recommendation ITU-R S.465-6 Receiving reference Earth station antenna pattern for earth stations in FSS in the frequency range from 2 to 31 GHz coordinated after 1993.

Appendix J
Compatibility Analysis:
STRAPS User Downlink Interference into
Federal Inter-Satellite Service Return Link in the
25.25 – 27.5 GHz Band
(Prepared by Lockheed Martin Corporation for Elefante Group, Inc.)

SUMMARY

- Elefante Group is proposing to access the 25.25–27.5 GHz band for User downlink communications from Stratospheric Platform Stations (STRAPS) to User Terminals (UTs) on a co-Primary basis.

- This study assesses the compatibility of STRAPS User downlinks with Federal Inter-Satellite Service (ISS) Data Rely System (DRS) Return links (LEO to DRS GSO) which are authorized to operate in the 25.25–27.5 GHz band.

- Worst-case operating conditions and interference geometry are utilized for a bounding analysis which include: 1) STRAPS transmitting at a level equal to the maximum Power Flux Density (PFD) limit as authorized for satellite downlinks into Fixed services, 2) Multiple STRAPS downlink channels operating simultaneously to fully encompass the DRS Return Channel and operating in the same polarization, and 3) STRAPS, DRS LEO satellite and DRS GSO satellite perfectly aligned to result in the maximum level of interference.

- Bounding compatibility study results show that DRS I/N Protection Criterion is met even under worst-case operating conditions and interference geometry. No mitigation is necessary.

PURPOSE OF THE STUDY

Elefante Group is proposing that the 25.25–27.5 GHz band be made available for Stratospheric-Based Communications Services (SBCS), operating as a Fixed service, in the downlink direction. (While not the purpose of this study, Elefante Group proposes that the 25.25–27.5 GHz band also be considered for use in the uplink direction.) All or part of this band is allocated in the federal allocation to Fixed, Mobile, Earth Exploration Satellite (space-to-earth), Space Research (space-to-earth), and Inter-Satellite services, and Space Research and Inter-Satellite service in the non-federal allocation.

This study assesses the compatibility with Federal ISS DRS Return links of STRAPS downlink transmissions from a multi-beam stratospheric platform to ground-based UTs.

This study assesses the potential for such interference into DRS GSO satellite to exceed the I/N Protection Criterion to determine if mitigation measures are necessary.

OPERATIONAL CHARACTERISTICS OF DRS GSO RECEIVERS

Receive characteristics and Protection Criteria of the DRS Return Link GSO receivers utilized for this study are based on the United States of America system characteristics in ITU-R SA1414-2 and shown in Table 1.

Table 1: ISS DRS Return Link GSO Receive Characteristics

Parameter	Value	Notes
Frequency Range	25.75 – 27.15 GHz	
Channel Bandwidth	<650 MHz	
Rx Antenna Gain	55.9 dBi	
Rx Antenna Pattern	ITU-R S.672	Nominal -25 dB sidelobe level
Receiver Noise Density	-139.2 dBW/MHz	870K
Protection Criteria	I/N < -10 dB (<0.1% time exceedance)	ITU-R SA.1155

OPERATIONAL CHARACTERISTICS OF SBCS

The SBCS will utilize STRAPS, UTs, and Gateway terminals to provide fixed services over a specific service area. Transmit characteristics of the Elefante Group STRAPS user downlink utilized in this study are given in Appendix 1.

For this study, worst-case operating conditions are utilized for a bounding analysis prior to considering, if appropriate, risk-based interference assessment using probability and statistical methods:

1) STRAPS located at a minimum altitude of 18.3 km and transmitting at the regulatory PFD limit as authorized for satellite downlinks in this band to protect interference into Fixed services per CFR Title 47 25.208(c) over the STRAPS 70 km radius coverage area.

2) Multiple STRAPS downlink channels operating simultaneously to fully encompass the DRS Return Channel and operating in the same polarization (not considering that coverage is provided by multiple channels “colors” which are spread across hundreds of beams and that the DRS return link allocated frequency range may not be fully occupied).

3) STRAPS downlink operating in the same polarization as the DRS Return link (Right Hand and Left Hand Circular Polarization authorized).

STUDY SCENARIO

Figure 1 illustrates the interference geometry applicable to this study.

- STRAPS transmits User Downlink signals to the associated coverage area.
- DRS LEO satellite transmits the desired Return link signal to the DRS GSO satellite.
- As the DRS LEO satellite moves through its orbit, there will be instances of time where the worst-case alignment for interference will occur when the STRAPS, DRS LEO satellite and DRS GSO satellite are co-aligned; i.e. as the DRS GSO satellite receiver tracks the DRS satellite, there will be instances of time when the DRS GSO receiver is pointed directly at the STRAPS.

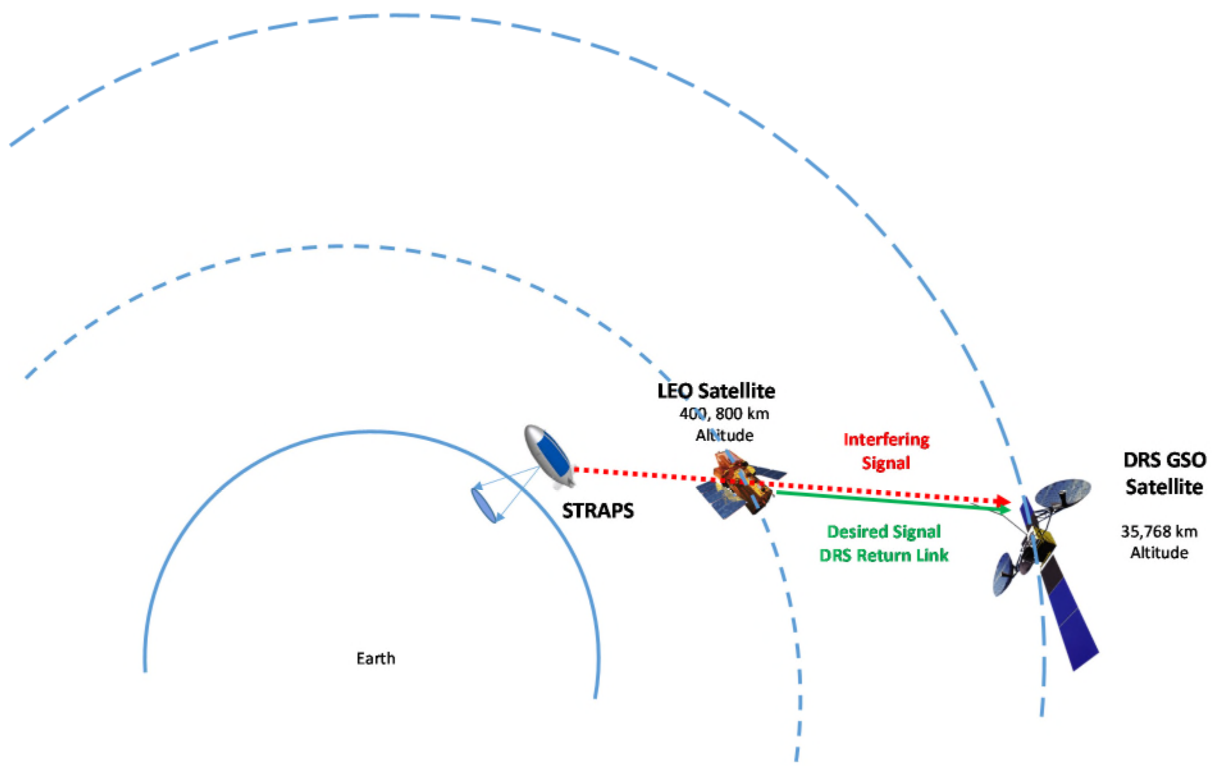


Figure 1: Interference Geometry

STUDY METHODOLOGY

The study starts by assuming the STRAPS is transmitting at a level equal to the regulatory PFD limit that is authorized for satellite downlinks in this band to protect interference into Fixed services per CFR Title 47 25.208(c). The assumption is that the STRAPS service area is defined by a 70 km radius coverage area centered on the point below the STRAPS nominal fixed position as described below and illustrated in Figure 2 and Figure 3.

$$PFD\left(\frac{dBW}{m^2 * MHz}\right) = \begin{cases} -115 & 0 \le \delta < 5 \\ -115 + 0.5 * (\delta - 5) & 5 \le \delta < 25 \\ -105 & 25 \le \delta \le 90 \end{cases}$$

Where δ is the angle of arrival (in degrees) above the horizontal plane (elevation angle)

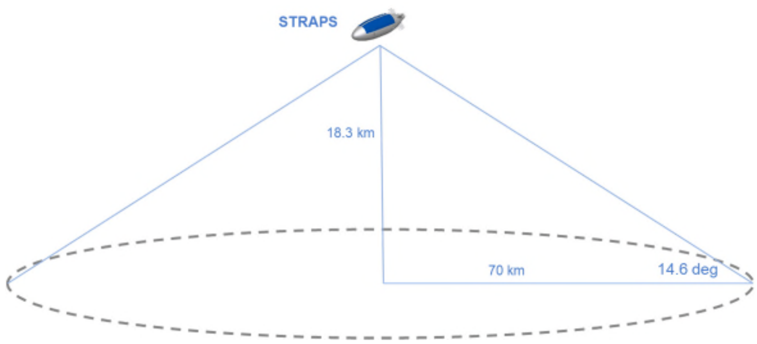


Figure 2: STRAPS Service Area Geometry

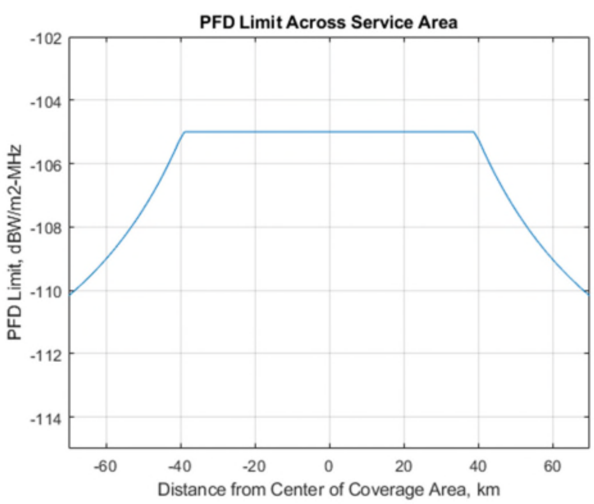


Figure 3: PFD Limit Across Service Area

PFD outside of the coverage area is calculated by starting with the PFD limit and rolling it off using the ITU-R F.1245 antenna pattern with peak antenna gain of 32.7 dB at the edge of coverage.

The corresponding STRAPS (Interferer) EIRP Density as a function of transmit antenna boresight angle is calculated as follows and illustrated in Figure 4.

$$EIRP\ Density\ \left(\frac{dBW}{MHz}\right) = PFD - \ 10 * \log(4 * \pi * r^2)$$

Where r is the distance from STRAPS to the ground distance away from the center of the coverage area

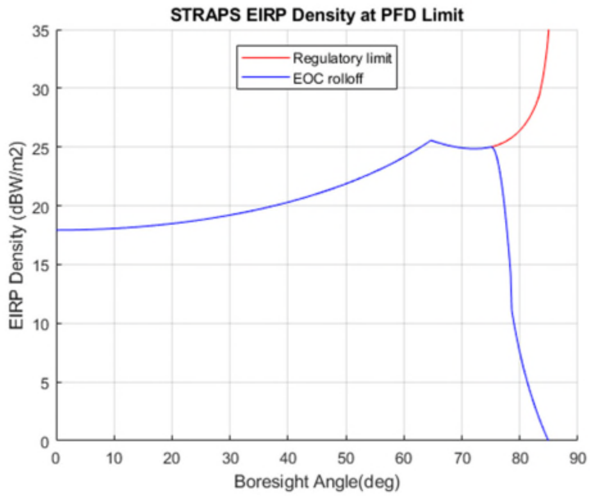


Figure 4: STRAPS EIRP Density at PFD Limit

The PFD is converted to receive interference power, I, as a function of range from STRAPS as follows:

$$I = \frac{PFD * \ 4 * \pi * R^2}{\left(4 * \pi * R/_{\lambda}\right)^2}$$

where R is the range and λ is the wavelength.

To set up the interference geometry, equations for the range from the STRAPS to the DRS GSO receiver were developed as a function of the STRAPS off-boresight angle. The minimum off-interferer boresight angle was anticipated to be the worst-case condition. However, since the corresponding range is longest for this case, I/N margins were evaluated across all possible STRAPS off-boresight angles as verification of the assumption.

The associated interference geometry is illustrated in Figure 5.

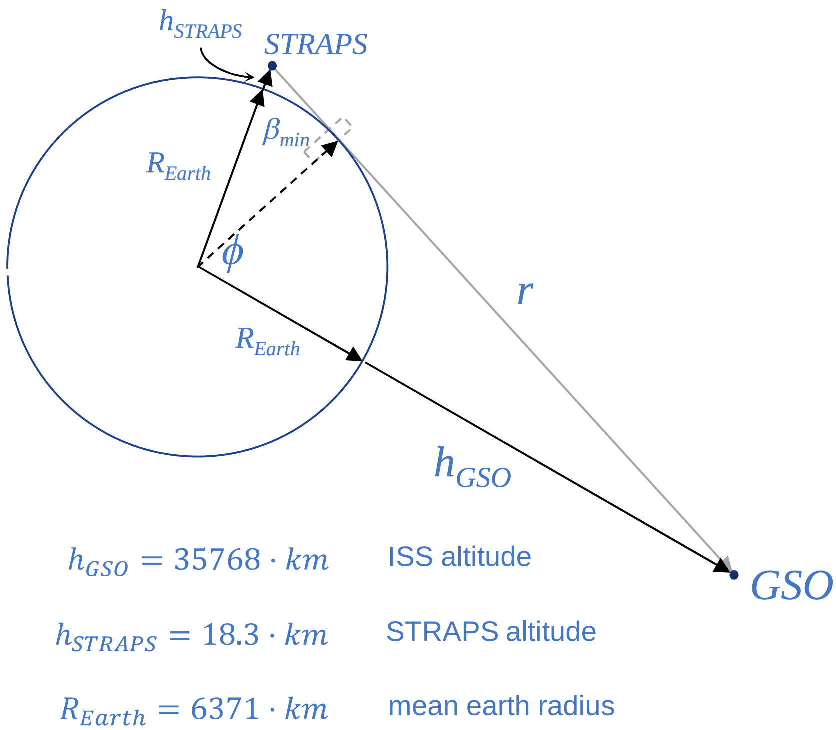


Figure 5: Interference Geometry

The minimum angle from STRAPS nadir to DRS GSO (off-interferer angle) will look just over the Earth limb.

$$\beta_{\min} = \sin^{-1}\left(\frac{R_{Earth}}{R_{Earth} + h_{STRAPS}}\right)$$

The maximum angle from the STRAPS nadir to DRS GSO will be 180 degrees when the DRS GSO is directly above the STRAPS.

$$\beta_{\max} = \pi$$

The STRAPS nadir to GSO angle will range between these extremes, and, for all cases, the DRS LEO is assumed to be co-aligned with the STRAPS and DRS GSO (either in between or on the far side of the STRAPS from the DRS GSO).

$$\beta_{\min} < \beta < \beta_{\max}$$

The DRS GSO receiver is then looking directly at the STRAPS and the off-victim boresight angle is zero. The Earth angle between the STRAPS and the DRS GSO may then be written as:

$$\phi = \pi - \beta - \sin^{-1}\left(\left(R_{Earth} + h_{STRAPS}\right) \cdot \frac{\sin(\beta)}{R_{Earth} + h_{GSO}}\right)$$

The range from the STRAPS to the DRS GSO may be written as:

$$r = \sqrt{(R_{Earth} + h_{STRAPS})^2 + (R_{Earth} + h_{GSO})^2 - 2 \cdot (R_{Earth} + h_{STRAPS}) \cdot (R_{Earth} + h_{GSO}) \cdot \cos(\phi)}$$

For each value of STRAPS off-boresight angle and associated range, the Interference Power Density, Io, is calculated:

$$Io \left(\frac{dBW}{MHz}\right) = EIRP\ Density\ (\delta) - FSL - Gr\ (\beta)$$

where:

δ = Angle off STRAPS (Interferer) boresight towards DRS GSO

$Gr\ (\beta)$ = DRS GSO (Victim) receive antenna gain off boresight towards STRAPS

FSL = Free Space Loss between the STRAPS and DRS GSO

Therefore,

$$I/_N\ Margin\ (dB) = I/_N\ Threshold - (I_o - N_o)$$

Where $I/_N\ Threshold$ is the DRS I/N Protection Criterion of -10 dB.

STUDY RESULTS

Results of the compatibility study are shown in Figure 6 and Figure 7. Figure 6 shows I/N Margin as a function of STRAPS off-boresight angle. Figure 7 shows I/N Margin as a function of the associated range from STRAPS to the DRS GSO.

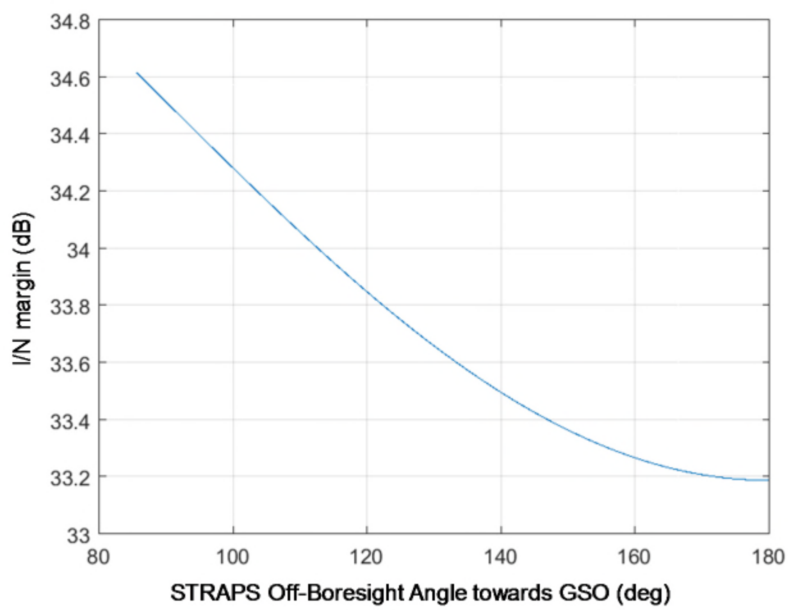


Figure 6: I/N Margin as a Function of DRS GSO Off-Boresight Angle

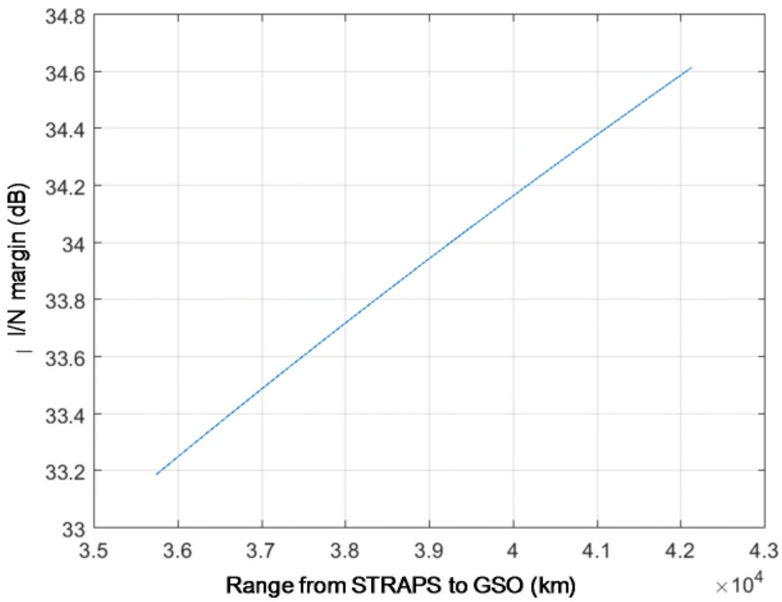


Figure 7: I/N Margin as a Function of STRAPS to DRS GSO Range

Results indicate that the maximum level of interference (minimal I/N Margin) occurs at the DRS GSO boresight angle of 180 degrees, which is when the DRS GSO is directly above the STRAPS. The associated I/N margin is greater than 33dB (I/N is -43 dB) as compared to the DRS I/N Protection Criterion of -10 dB.

CONCLUSIONS

Utilizing worst-case operational conditions and assuming worst-case geometric alignment which only occurs for a short time period when the DRS GSO satellite is directly overhead of the STRAPS, the resultant interference level is more than 33 dB below the DRS I/N Protection Criterion.

REFERENCES:

ITU-R S.1155: Protection Criterion related to the operation of data relay satellite systems

ITU-R SA 1414-2: Characteristics of data relay satellite systems

ITU-R F.1245-2: Mathematical models of average and related radiation patterns for line-of-sight point-to-point fixed wireless systems antennas for use in certain coordination studies and interference assessments in the frequency range from 1 GHz to about 70 GHz

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

Appendix K
Compatibility Analysis:
STRAPS User Downlink Interference into
Federal Earth Exploration Satellite Service (Space-to-Earth) Link in the
25.5 – 27.0 GHz Band
(Prepared by Lockheed Martin Corporation for Elefante Group, Inc.)

SUMMARY

- Elefante Group is proposing to access the 25.25–27.5 GHz band for User downlink communications from Stratospheric Platform Stations (STRAPS) to User Terminals (UTs) on a co-Primary basis.

- This study assesses the compatibility of STRAPS User downlinks with Earth Exploration Satellite Service (EESS) (Space-to-Earth) Link which are authorized to operate in the 25.5–27.0 GHz band.

- Worst-case operating conditions and interference geometry are utilized which include: 1) STRAPS transmitting at a level equal to the maximum Power Flux Density (PFD) limit as authorized for satellite downlinks into Fixed services and 2) STRAPS downlink channel fully encompassing the EESS allocated frequency range and operating in the same polarization.

- Compatibility study results show that for a given EESS mission, STRAPS located near the associated EESS Earth Station (ES) can be easily placed to ensure that EESS Interference Threshold is met.

PURPOSE OF THE STUDY

Elefante Group is proposing that the 25.25–27.5 GHz band be made available for Stratospheric-Based Communications Services (SBCS), operating as a Fixed service, in the downlink direction. (While not the purpose of this study, Elefante Group proposes that the 25.25–27.5 GHz band also be considered for use in the uplink direction.) All or part of this band is allocated in the federal allocation to Fixed, Mobile, Earth Exploration Satellite (space-to-earth), Space Research (space-to-earth), and Inter-Satellite services, and Space Research and Inter-Satellite service in the non-federal allocation.

This study assesses the compatibility with federal EESS (Space-to-Earth) Links of STRAPS downlink transmissions from a multi-beam stratospheric platform to ground-based UTs. EESS victim GEO and NGSO systems defined in Preliminary Draft New Report ITU-R SA.[EESS-METSAT CHAR] were utilized for this study; similar methodology and results are expected for other systems.

This study assesses the potential for such interference into an EESS ES to exceed the Interference Threshold so that the mitigation measures can be implemented to ensure that corresponding percent exceedance is met.

OPERATIONAL CHARACTERISTICS OF EESS SYSTEMS

Operational characteristics and Interference Threshold for 1) Solar Dynamics Observatory (SDO) GEO mission, 2) Satellite C (JPSS) Data Dissemination NGSO mission and 3) Satellite AZ (Generic) Stored Mission Data NGSO mission defined in Preliminary Draft New Report ITU-R SA.[EESS-METSAT CHAR], utilized for this study, are shown in Table 1, Table 2 and Table 3, respectively.

Table 1: Case: Solar Dynamics Observatory (SDO) GEO System Characteristics

Parameter	**Value**	**Notes**
Carrier Frequency	26.5 GHz	Note (1)
Data Rate	150 Mbps	Note (1)
Necessary Bandwidth	75 MHz	OQPSK based on above
Frequency Range	25.5 – 27.0 GHz	Note (1)
Mission	SDO Raw Data Downlink	Note (1)
EESS ES Location	White Sands, NM	WSC, Note (1)
Rx Antenna Gain	70.4 dBi	Note (1)
Rx Antenna Pattern	ITU-R F.699	Envelopes ITU-RR Appendix 7, Annex 3
Minimum Elevation Angle	3 deg	Assumed, worst-case
EESS ES Receiver Noise Temperature	-142 dBW/MHz	460.3K
Interference threshold (long-term, not to be exceeded >20% time)	-144.6 dBW/10 MHz (-154.6 dBW/MHz)	ITU-R SA.1160-3
Interference threshold (short-term, not to be exceeded >0.25% time)	-133.0 dBW/10 MHz (-143.0 dBW/MHz)	ITU-R SA.1160-3

(1) Annex 8 to Working Party 7B Chairman's Report 298-E, PRELIMINARY DRAFT NEW REPORT ITU-R SA.[EESS-METSAT CHAR] Characteristics to be used for assessing interference to systems operating in the Earth exploration-satellite and meteorological-satellite services, and for conducting sharing studies

Table 2: Case: Satellite C (JPSS) Data Dissemination NGSO System Characteristics

Parameter	Value	Notes
Carrier Frequency	25.7034 GHz	Note (1)
Encoded Data Rate	300 Mbps	Note (1)
Necessary Bandwidth	300 MHz	Note (1)
Frequency Range	25.5 – 27.0 GHz	Note (1)
Mission	Sat C Data Dissemination	Note (1)
Orbit Altitude	824 km	Note (1)
Orbit Inclination	98.7 deg	Note (1)
EESS ES Location	Fairbanks, AK	Note (1)
Rx Antenna Gain	67.0 dBi	Note (1)
Rx Antenna Pattern	ITU-R S.465-6	Note (1)
Minimum Elevation Angle	5 deg	Note (1)
EESS ES Receiver Noise Temperature	-143 dBW/MHz	363K
Interference threshold (long-term, not to be exceeded >20% time)	-140.0 dBW/10 MHz (-150.0 dBW/MHz)	ITU-R SA1026-5
Interference threshold (short-term, not to be exceeded >0.0125% time)	-116.0 dBW/10 MHz (-126.0 dBW/MHz)	ITU-R SA1026-5

(2) Annex 8 to Working Party 7B Chairman’s Report 298-E, PRELIMINARY DRAFT NEW REPORT ITU-R SA.[EESS-METSAT CHAR] Characteristics to be used for assessing interference to systems operating in the Earth exploration-satellite and meteorological-satellite services, and for conducting sharing studies

Table 3: Case: Satellite AZ (Generic) Stored Mission Data NGSO System Characteristics

Parameter	Value	Notes
Carrier Frequency	26.817 and 25.875 GHz	Note (1)
Encoded Data Rate	Up to 2000 Mbps	Note (1)
Necessary Bandwidth	2 x 750 MHz	Note (1)
Frequency Range	25.5 – 27.0 GHz	Note (1)
Mission	Sat AZ Stored Mission Data	Note (1)
Orbit Altitude	750 km	Note (1)
Orbit Inclination	98.7 deg	Typical polar
EESS ES Location	Worldwide (Generic)	Note (1)
Rx Antenna Gain	56.0 dBi & 63 dBi	Two cases
Rx Antenna Pattern	ITU-R S.465-6	Note (1)
Minimum Elevation Angle	5 deg	Note (1)
EESS ES Receiver Noise Temperature	-142.6 dBW/MHz	395K
Interference threshold (long-term, not to be exceeded >20% time)	-140.0 dBW/10 MHz (-150.0 dBW/MHz)	ITU-R SA1026-5
Interference threshold (short-term, not to be exceeded >0.0125% time)	-116.0 dBW/10 MHz (-126.0 dBW/MHz)	ITU-R SA1026-5

(3) Annex 8 to Working Party 7B Chairman's Report 298-E, PRELIMINARY DRAFT NEW REPORT ITU-R SA.[EESS-METSAT CHAR] Characteristics to be used for assessing interference to systems operating in the Earth exploration-satellite and meteorological-satellite services, and for conducting sharing studies

OPERATIONAL CHARACTERISTICS OF SBCS

The SBCS will utilize STRAPS, UTs, and Gateway terminals to provide fixed services over a specific service area. Transmit characteristics of the Elefante Group STRAPS user downlink utilized in this study are given in Appendix 1.

For this study, worst-case operating conditions are utilized for a bounding analysis prior to considering, if appropriate, risk-based interference assessment using probability and statistical methods:

1) STRAPS located at a minimum altitude of 18.3 km and transmitting at the regulatory PFD limit as authorized for satellite downlinks in this band to protect interference into Fixed services per CFR Title 47 25.208(c) over the STRAPS 70 km radius coverage area.

2) Multiple STRAPS downlink channels operating simultaneously to fully encompass the EESS allocated frequency range and operating in the same polarization (not considering

that coverage is provided by multiple channels "colors" which are spread across hundreds of beams).

3) STRAPS downlink operating in the same polarization as the EESS (Right Hand and Left Hand Circular Polarization authorized).

STUDY SCENARIO

Figure 1 illustrates the interference geometry applicable to this study.

- STRAPS transmits User Downlink signals to the associated coverage area.
- EESS satellite transmits the desired signal to the EESS ES
- For a given STRAPS and EESS ES location, as the EESS satellite moves through its orbit, there will be instances of time during which the worst-case alignment for interference will occur when the STRAPS, EESS satellite and EESS ES are co-aligned, i.e. as the EESS ES receiver tracks the EESS satellite, there will be instances of time when the EESS ES receiver is pointed directly at the STRAPS.
- If the relative location of the STRAPS and EESS ES are left as variables, the worst-case interference geometry described above will result in "Interference Shadows" where the Interference Threshold may be exceeded during the transient time.
- As the EESS satellite moves, the corresponding set of Interference Shadows can be expressed as "Protection Zones" where relative placement of STRAPS and EESS ES results in a percentage time where the Interference Threshold is exceeded which can then be compared to the allowable time exceedance.
- The long-term interference threshold is significantly lower than the short-term interference threshold; even though the percentage time of exceedance is much lower for the short-term interference threshold, compatibility analysis results are driven by the long-term interference threshold therefore all results are presented relative to the long-term interference threshold Protection Criteria.

STUDY METHODOLOGY

The study starts by assuming the STRAPS is transmitting at a level equal to the regulatory PFD limit that is authorized for satellite downlinks in this band to protect interference into Fixed services per CFR Title 47 25.208(c). The assumption is that the STRAPS service area is defined by a 70 km radius coverage area centered on the point below the STRAPS nominal fixed position as described below and illustrated in Figure 2 and Figure 3.

$$PFD\ \left(\frac{dBW}{m^2 * MHz}\right) = \begin{cases} -115 & 0 \leq \delta < 5 \\ -115 + 0.5 * (\delta - 5) & 5 \leq \delta < 25 \\ -105 & 25 \leq \delta \leq 90 \end{cases}$$

Where δ is the angle of arrival (in degrees) above the horizontal plane (elevation angle)

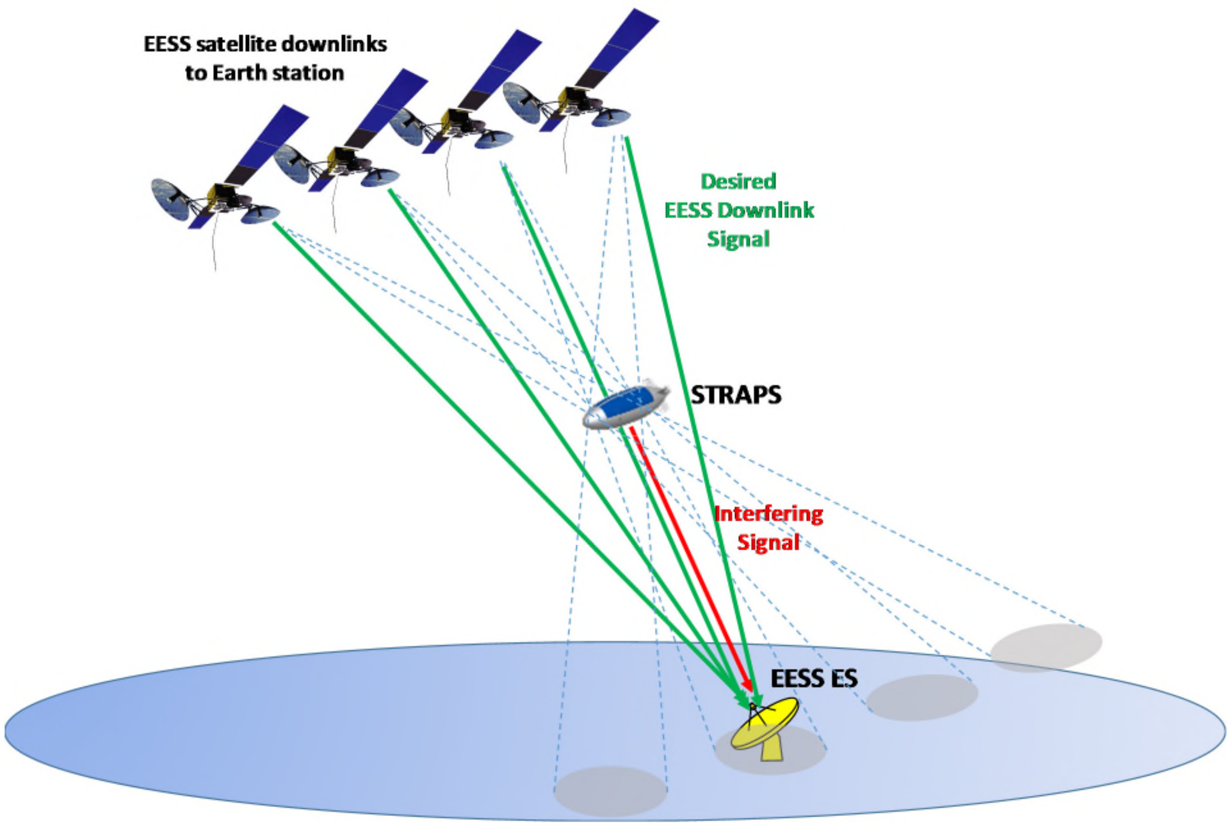


Figure 1: Interference Geometry

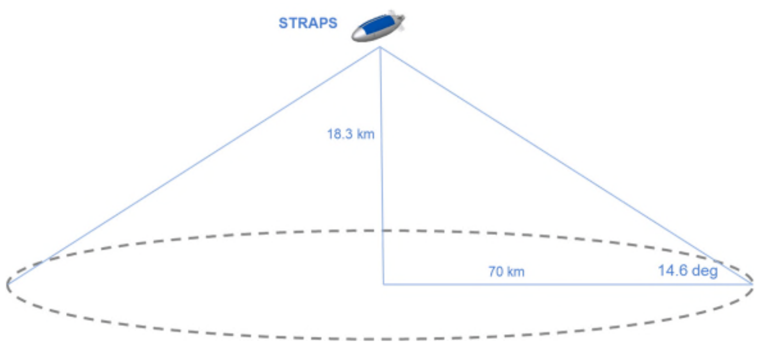


Figure 2: STRAPS Service Area Geometry

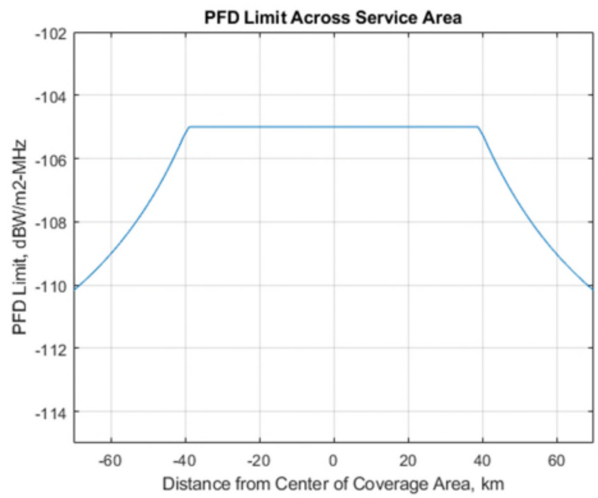


Figure 3: PFD Limit Across Service Area

PFD outside of the coverage area is calculated by starting with the PFD limit and rolling it off using the ITU-R F.1245 antenna pattern with peak antenna gain of 32.7 dB at the edge of coverage.

The corresponding STRAPS (Interferer) EIRP Density as a function of transmit antenna boresight angle is calculated as follows and illustrated in Figure 4.

$$EIRP\ Density\ \left(\frac{dBW}{MHz}\right) = PFD - \ 10 * \log(\ 4 * \pi * r^2)$$

Where r is the distance from STRAPS to the ground distance away from the center of the coverage area

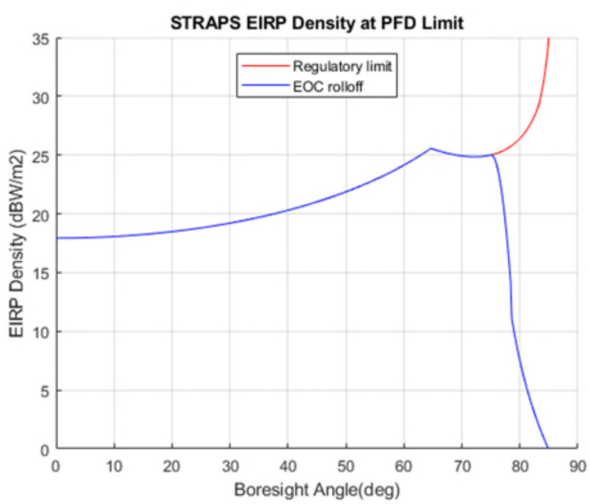


Figure 4: STRAPS EIRP Density at PFD Limit

For each EESS system, STRAPS is located at various positions around the corresponding EESS ES and the interference power density is calculated as a function of time as the EESS ES tracks the EESS satellite.

For each time step and STRAPS location, the corresponding STRAPS off-boresight angle and associated range from STRAPS to EESS ES are used to calculate the Interference Power Density, Io:

$$Io\left(\frac{dBW}{MHz}\right) = EIRP\ Density\ (\delta) - FSL - Gr\ (\beta)$$

where:

δ = Angle off STRAPS (Interferer) boresight towards EESS ES

$Gr\ (\beta)$ = EESS ES (Victim) receive antenna gain off boresight towards STRAPS

FSL = Free Space Loss between the STRAPS and EESS ES

Therefore,

$$Interference\ Margin\ (dB) = \ Io - \ Interference\ Threshold$$

For the EESS GEO system, the Interference Margin is calculated with varying relative positions of the EESS ES and STRAPS to determine the "Protection Zone" over which the Interference Margin is negative thus defining the STRAPS locations which should be avoided.

For the EESS NGSO systems, for each relative location of STRAPS and EESS ES, the Interference Margin needs to be calculated over the full visible orbital time period for the EESS mission to determine the fraction of time that the Interference Margin is negative which can then be compared to the exceedance criteria.

Due to the small fractions of time that interference is likely to occur, a statistical time domain simulation for such analysis would require a long time-series and small time increments to obtain the required accuracy therefore a probabilistic method is utilized as described below:

Calculate the Probability Density Functions (pdf's) for the NGSO satellite location for each NGSO system mission. Figure 5 shows an example result.

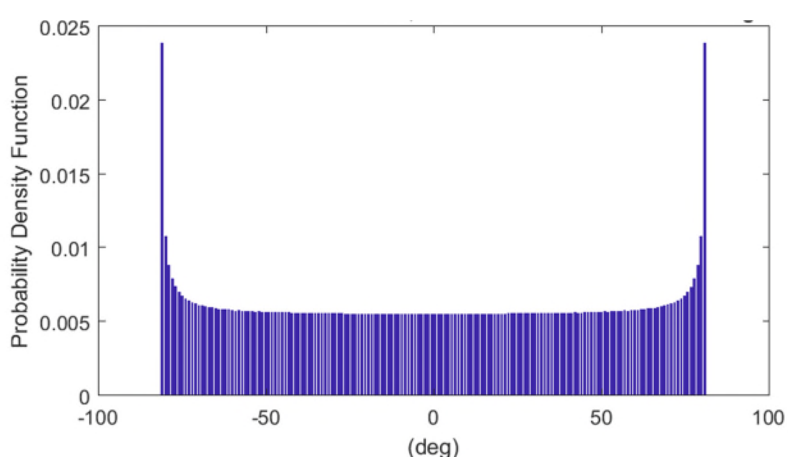


Figure 5: NGSO Satellite Probability Density Function (pdf)

Calculate (% Time Visible) for each possible relative ES location by integrating the pdf over all visible satellite positions.

Calculate (%Time Negative Margin) for each possible relative ES location by integrating the pdf over all satellite positions where Interference Margin is negative.

Determine the time exceedance as follows:

$$\%\, Time\ Exceedance = \frac{\%\text{Time Negative Margin}}{\%\ \text{Time Visible}}$$

The above calculation is repeated for all possible relative locations of STRAPS and EESS ES to determine placement of STRAPS to fully meet the Interference Threshold and permitted exceedance time.

Note that in all cases, the long-term Interference Threshold is utilized as worst-case since it represents the more stringent interference levels. Although the short-term Interference Threshold defines tighter %time exceedance, the corresponding interference level is much easier to meet and therefore is not a driver for the compatibility study.

STUDY RESULTS

Results of the compatibility study for the SDO GEO system is shown in Figure 6 which is an overlay of the Protection Zone on a geographical map of the area near the EES ES located at White Sands, NM with an example STRAPS location which ensures Interference Threshold with associated time exceedance is fully met.

Results of the statistical analysis performed for the NGSO Satellite C (JPSS) Data Dissemination NGSO system are shown in Figure 7 which illustrates that for a large majority of STRAPS locations, the Interference Threshold is exceeded less than 0.1% of time. The worst-case percentage exceedance is 0.27% if the STRAPS is placed in the small yellow band. In all situations, the Interference Threshold exceedance criteria is met regardless of STRAPS location.

The worst-case %time exceedance for each examined NGSO system is summarized in **Error! Reference source not found.** showing similar results.

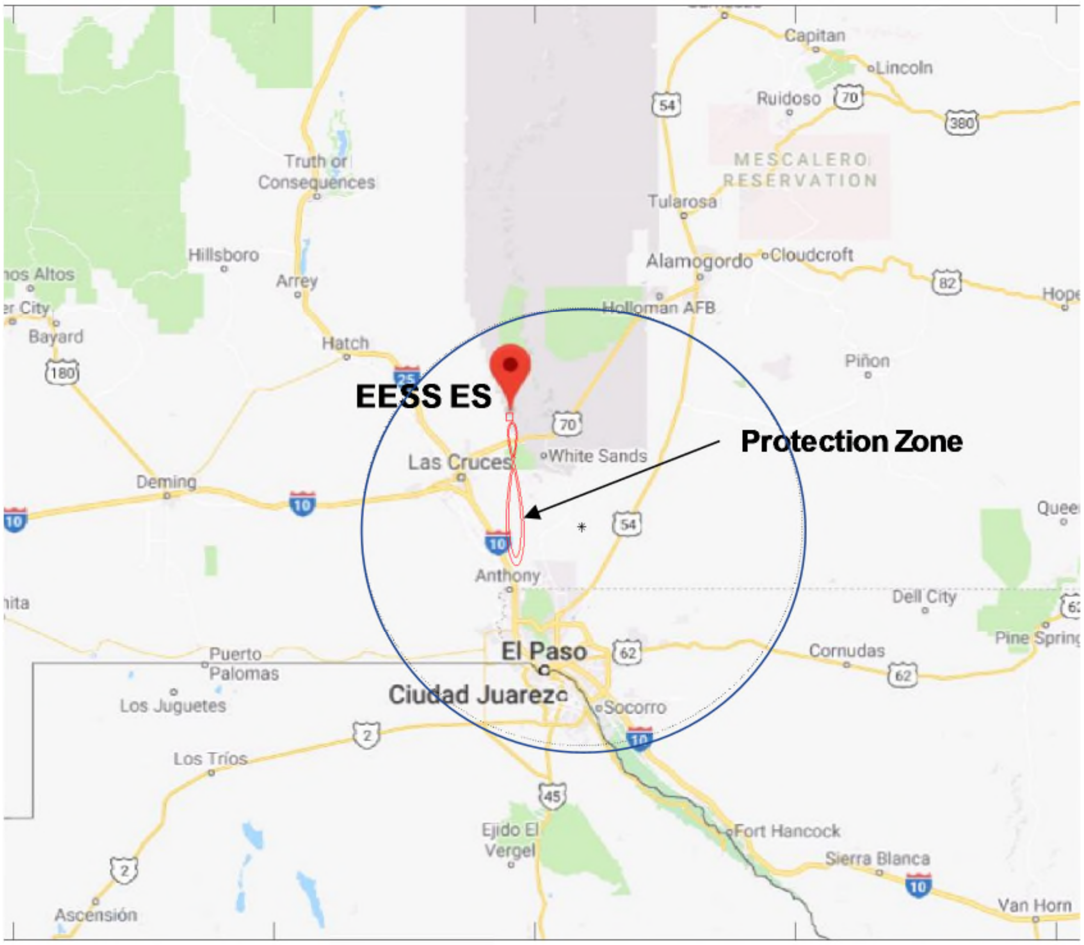


Figure 6: SDO GEO System – Example STRAPS Placement near White Sands EESS ES

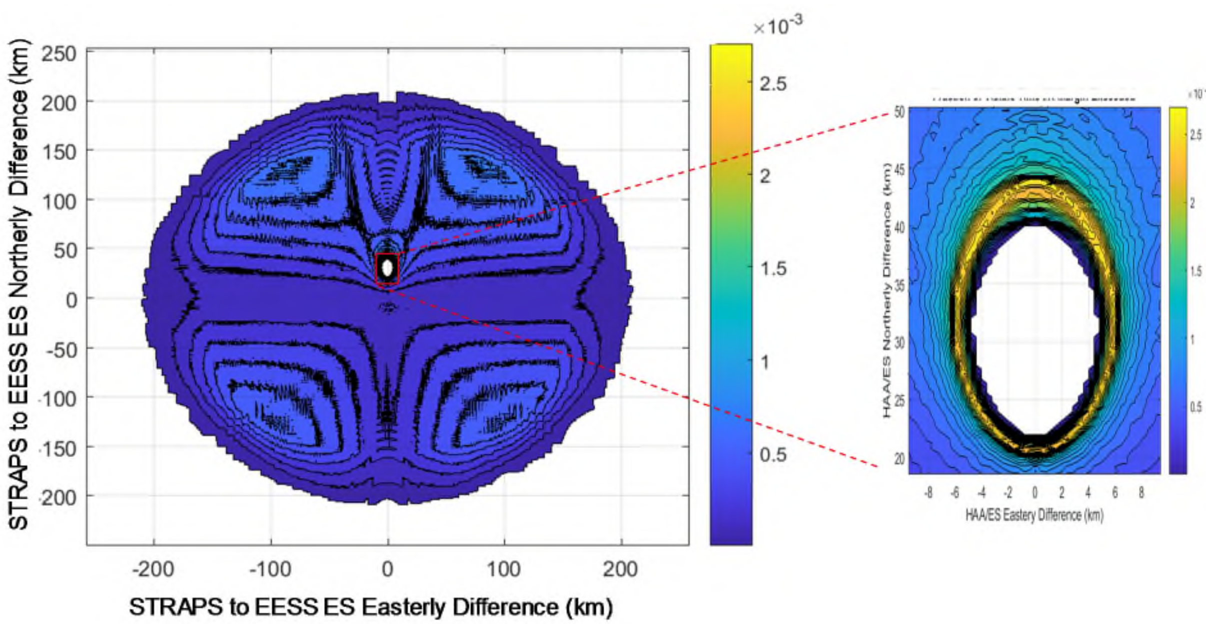


Figure 7: Sat C NGSO System – %Time Exceedance of Interference Threshold

Table 4: NGSO Systems Compatibility Study Results

NGSO System	Worst-Case %time Exceedance of Interference Threshold
Sat C-Data Dissemination	0.27%
Sat AZ-Mission Data (56 dBi Receive Antenna Gain)	0.27%
Sat AZ-Mission Data (63 dBi Receive Antenna Gain)	0.26%

CONCLUSIONS

For the EESS SDO GSO system, STRAPS located near the associated EESS ES can easily be placed to ensure that EESS Interference Threshold is met. For all EESS NGSO systems examined, EESS Interference Threshold exceedance criterion is met for all placements of STRAPS and therefore no mitigation is required.

REFERENCES:

ITU-R SA.1026-5: Aggregate interference criteria for space-to-Earth data transmission systems operating in the Earth exploration-satellite and meteorological-satellite services using satellites in low-Earth orbit

ITU-R SA.1160-3: Aggregate interference criteria for data transmission systems in the Earth exploration-satellite and meteorological-satellite services using satellites in the geostationary orbit

ITU-R F.699-7: Reference radiation patterns for fixed wireless system antennas for use in coordination studies and interference assessment in the frequency range from 100 MHz to about 70 GHz

ITU-R S.465-6: Reference radiation pattern for earth station antennas in the fixed-satellite service for use in coordination and interference assessment in the frequency range from 2 to 31 GHz

Appendix L
Compatibility Analysis:
STRAPS User Downlink Interference into
Federal Space Research Service (Space-to-Earth) Link in the
25.5 – 27.0 GHz Band
(Prepared by Lockheed Martin Corporation for Elefante Group, Inc.)

SUMMARY

- Elefante Group is proposing to access the 25.25–27.5 GHz band for User downlink communications from Stratospheric Platform Stations (STRAPS) to User Terminals (UTs) on a co-Primary basis.

- This study assesses the compatibility of STRAPS User downlinks with Space Research Service (SRS) (Space-to-Earth) Links which are authorized to operate in the 25.5–27.0 GHz band.

- Worst-case operating conditions and interference geometry are utilized which include: 1) STRAPS transmitting at a level equal to the maximum Power Flux Density (PFD) limit as authorized for satellite downlinks into Fixed services, 2) STRAPS downlink channel fully encompassing the SRS allocated frequency range and operating in the same polarization, and 3) STRAPS, SRS NGSO satellite and SRS Earth Station (ES) perfectly aligned to result in the maximum level of interference.

- Compatibility study results show that for a given SRS mission, STRAPS located near the associated SRS Earth Station can be easily placed to ensure that SRS I/N Protection Criteria are met.

PURPOSE OF THE STUDY

Elefante Group is proposing that the 25.25–27.5 GHz band be made available for Stratospheric-Based Communications Services (SBCS), operating as a Fixed service, in the downlink direction. (While not the purpose of this study, Elefante Group proposes that the 25.25–27.5 GHz band also be considered for use in the uplink direction.) All or part of this band is allocated in the federal allocation to Fixed, Mobile, Earth Exploration Satellite (space-to-earth), Space Research (space-to-earth), and Inter-Satellite services, and Space Research and Inter-Satellite service in the non-federal allocation.

This study assesses the compatibility with Federal SRS (Space-to-Earth) links of STRAPS downlink transmissions from a multi-beam stratospheric platform to ground-based UTs. SRS victim systems defined in ITU SA.1862-0 were utilized for this study; similar methodology and results are expected for other systems.

This study assesses the potential for such interference into an SRS Earth Station to exceed the I/N Protection Criterion so that the mitigation measures can be implemented to ensure that corresponding percent exceedance Protection Criteria is met.

OPERATIONAL CHARACTERISTICS OF SRS SYSTEMS

Operational characteristics and Protection Criteria for the LRO (Lunar Reconnaissance Orbiter) and James West Space Telescope (JWST) SRS systems defined in ITU-R SA.1862-0, utilized for this study, are shown in Table 1 and Table 2.

Table 1: Case: LRO System Characteristics

Parameter	**Value**	**Notes**
Center Frequency	25.65 GHz	ITU-R SA.1862-0
Data Rate	50 Mbps	ITU-R SA.1862-0
Channel Bandwidth	100 MHz	2 x 50 Mbps OQPSK
Frequency Range	25.5 – 27.0 GHz	Based on above
Mission	LRO Lunar	ITU-R SA.1862-0
SRS ES Location	White Sands, NM	WSC
Rx Antenna Gain	71.3 dBi	ITU-R SA.1862-0
Rx Antenna Pattern	ITU-R S.465-6	Note (1)
Minimum Elevation Angle	5 deg	Note (1)
Protection Criteria Unmanned Missions (0.1% exceedance) Manned Missions (0.001% exceedance)	< -156 dBW/MHz (I/N <-6 dB, No = -150 dBW/MHz,)	ITU-R SA.609-2

Table 2: Case: JWST System Characteristics

Parameter	**Value**	**Notes**
Center Frequency	25.65 GHz	ITU-R SA.1862-0
Data Rate	56 Mbps	ITU-R SA.1862-0
Channel Bandwidth	112 MHz	2 x 56 Mbps OQPSK
Frequency Range	25.5 – 27.0 GHz	ITU-R SA.1862-0
Mission	Lagrangian L2 Halo	ITU-R SA.1862-0
SRS ES Location	Goldstone, CA	
Rx Antenna Gain	77.8 dBi	Note (1)
Rx Antenna Pattern	ITU-R SA.509	Note (1)
Minimum Elevation Angle	5 deg	Note (1)
Protection Criteria Unmanned Missions (0.1% exceedance) Manned Missions (0.001% exceedance)	< -156 dBW/MHz (I/N <-6 dB, No = -150 dBW/MHz,)	ITU-R SA.609-2

(1) Annex 17 to Working Party 5C Chairman’s Report 410-E, Working Document towards Preliminary Draft New Report ITU-R [HAPS-25GHz], Sharing and compatibility studies of HAPS systems in the 24.25-27.5 GHz range

OPERATIONAL CHARACTERISTICS OF SBCS

The SBCS will utilize STRAPS, UTs, and Gateway terminals to provide fixed services over a specific service area. Transmit characteristics of the Elefante Group STRAPS user downlink utilized in this study are given in Appendix 1.

For this study, worst-case operating conditions are utilized for a bounding analysis prior to considering, if appropriate, risk-based interference assessment using probability and statistical methods:

1) STRAPS located at a minimum altitude of 18.3 km and transmitting at the regulatory PFD limit as authorized for satellite downlinks in this band to protect interference into Fixed services per CFR Title 47 25.208(c) over the STRAPS 70 km radius coverage area.

2) Multiple STRAPS downlink channels operating simultaneously to fully encompass the SRS allocated frequency range and operating in the same polarization (not considering that coverage is provided by multiple channels "colors" which are spread across hundreds of beams and that the SRS allocated frequency range is likely not fully occupied since the SRS channel bandwidths are typically smaller).

3) STRAPS downlink operating in the same polarization as the SRS (Right Hand and Left Hand Circular Polarization authorized).

STUDY SCENARIO

Figure 1 illustrates the interference geometry applicable to this study.

- STRAPS transmits User Downlink signals to the associated coverage area.
- SRS NGSO vehicle transmits the desired signal to the SRS ES.
- For a given STRAPS and SRS ES location, as the SRS NGSO moves relative to earth, there will be instances of time during which the worst-case alignment for interference will occur when the STRAPS, SRS NGSO and SRS ES are co-aligned, i.e. as the SRS ES receiver tracks the SRS NGSO, there will be instances of time when the SRS ES receiver is pointed directly at the STRAPS.
- If the relative location of the STRAPS and SRS ES are left as variables, the worst-case interference geometry described above will result in "Interference Shadows" where there the I/N Protection Criterion may be exceeded during the transient time.

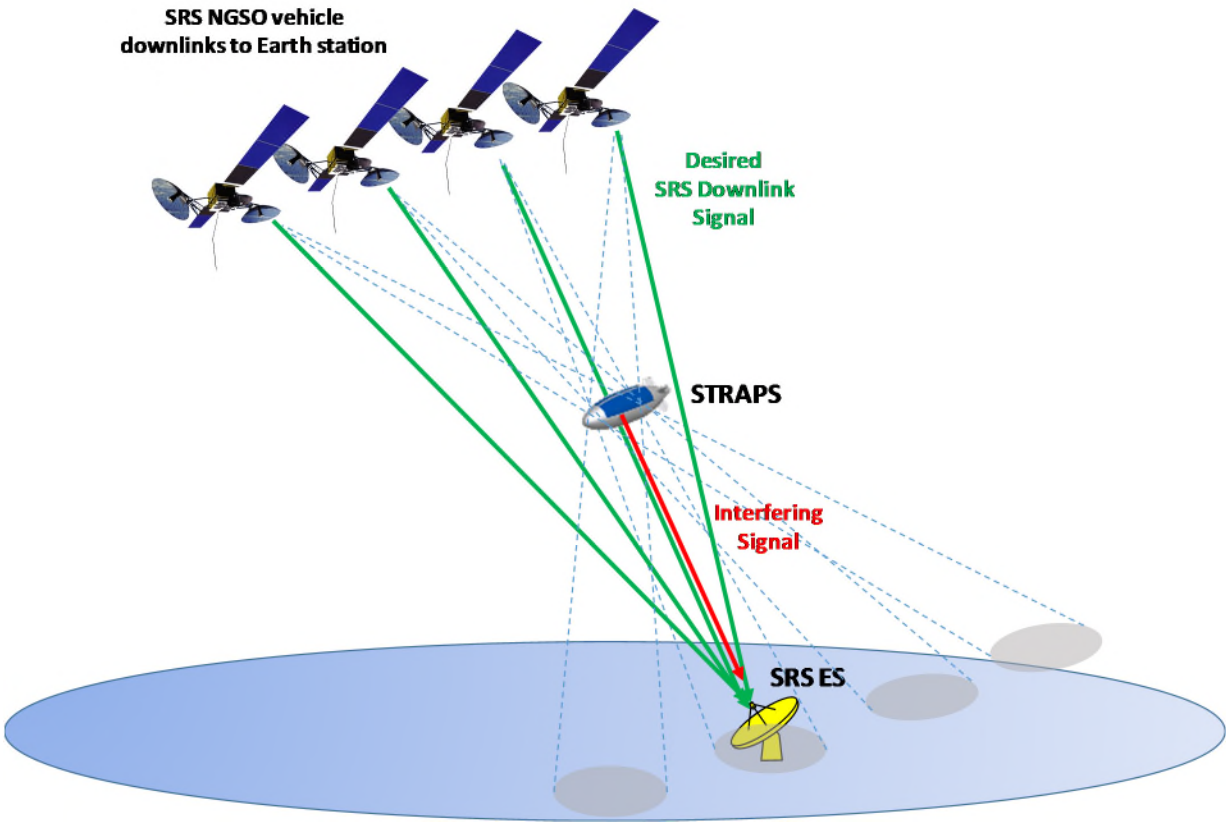


Figure 1: Interference Geometry

STUDY METHODOLOGY

The study starts by assuming the STRAPS is transmitting at a level equal to the regulatory PFD limit that is authorized for satellite downlinks in this band to protect interference into Fixed services per CFR Title 47 25.208(c). The assumption is that the STRAPS service area is defined by a 70 km radius coverage area centered on the point below the STRAPS nominal fixed position as described below and illustrated in Figure 2 and Figure 3.

$$PFD\left(\frac{dBW}{m^2 * MHz}\right) = \begin{cases} -115 & 0 \leq \delta < 5 \\ -115 + 0.5 * (\delta - 5) & 5 \leq \delta < 25 \\ -105 & 25 \leq \delta \leq 90 \end{cases}$$

Where δ is the angle of arrival (in degrees) above the horizontal plane (elevation angle)

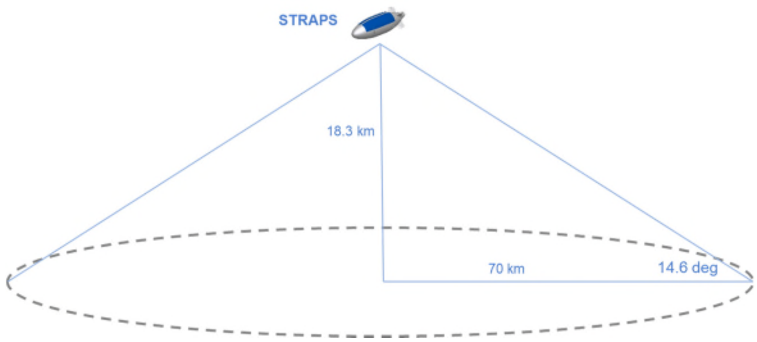


Figure 2: STRAPS Service Area Geometry

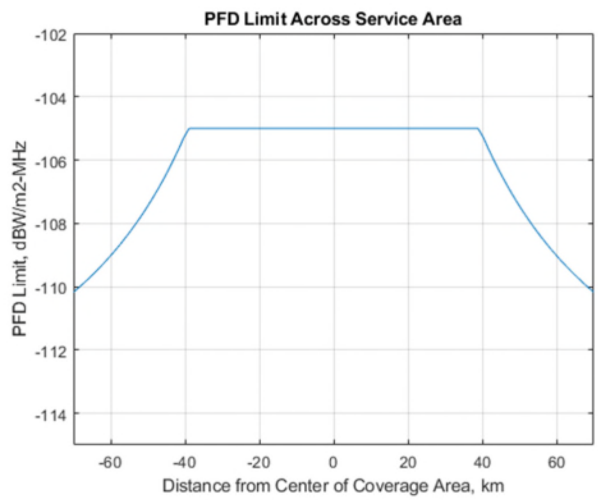


Figure 3: PFD Limit Across Service Area

PFD outside of the coverage area is calculated by starting with the PFD limit and rolling it off using the ITU-R F.1245 antenna pattern with peak antenna gain of 32.7 dB at the edge of coverage.

The corresponding STRAPS (Interferer) EIRP Density as a function of transmit antenna boresight angle is calculated as follows and illustrated in Figure 4.

$$EIRP\ Density\ \left(\frac{dBW}{MHz}\right) = PFD - \ 10 * \log(\ 4 * \pi * r^2)$$

Where r is the distance from STRAPS to the ground distance away from the center of the coverage area

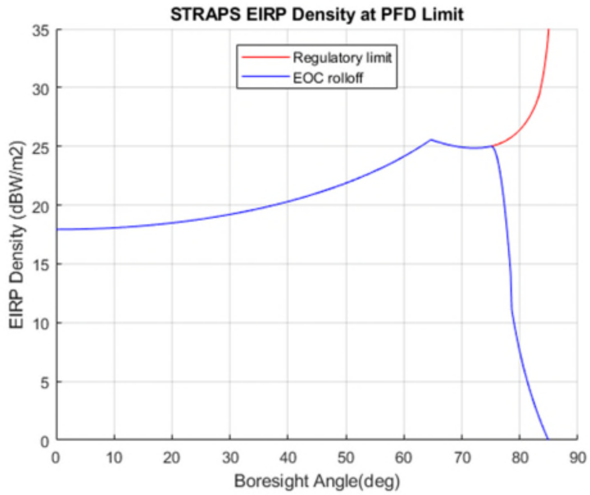


Figure 4: STRAPS EIRP Density at PFD Limit

For each SRS system, STRAPS is located at various positions around the corresponding SRS ES and the interference power density is calculated as a function of time as the SRS ES tracks the SRS NGSO.

For each time step and STRAPS location, the corresponding STRAPS off-boresight angle and associated range from STRAPS to SRS ES are used to calculate the Interference Power Density, Io:

$$Io\left(\frac{dBW}{MHz}\right) = EIRP\ Density\ (\delta) - FSL - Gr\ (\beta)$$

where:

δ = Angle off STRAPS (Interferer) boresight towards SRS ES

$Gr\ (\beta)$ = SRS ES (Victim) receive antenna gain off boresight towards STRAPS

FSL = Free Space Loss between the STRAPS and SRS ES

Therefore,

$$^{I}/_{N}\ Margin\ (dB) = {}^{I}/_{N}\ Threshold - (I_o - N_o)$$

Where $^{I}/_{N}\ Threshold$ is the SRS I/N Protection Criterion of -6 dB.

The calculation is repeated over the full visible orbital time period for the SRS mission to determine the fraction of time that the I/N Protection Criterion is exceeded for each STRAPS location. All STRAPS locations at which the 0.1% exceedance criterion is met are deemed as possible STRAPS locations at which the Protection Criteria are fully met.

STUDY RESULTS

Results of the compatibility study for the LRO system are shown in Figure 5 and Figure 6.

Figure 5 shows a contour map illustrating all possible STRAPS locations and the fraction of time the I/N Margin is negative. i.e. locating the STRAPS outside of the blue "Protection Zone" areas would ensure that 0.1% exceedance criterion is met.

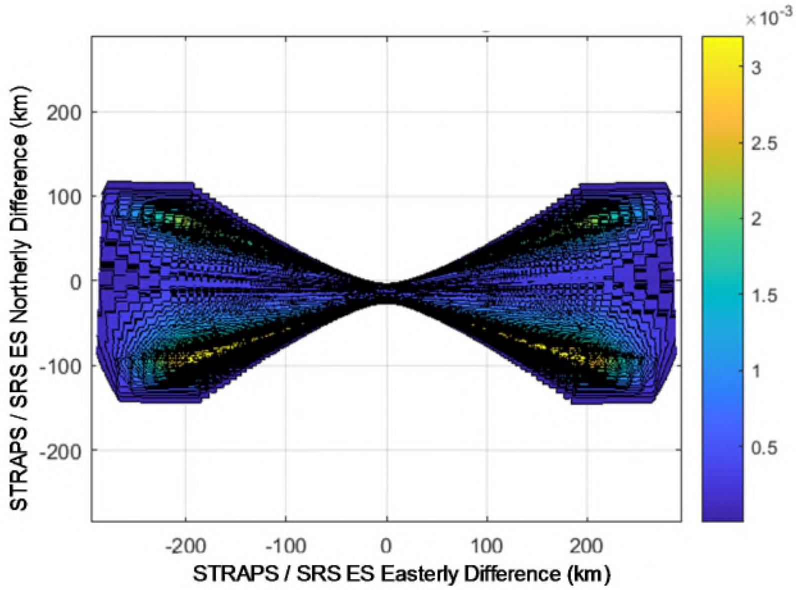


Figure 5: LRO System-Fraction of Time I/N Margin<0

Figure 6 is an overlay of the Protection Zone on a geographical map of the area near the LRO ES located at White Sands, NM with an example STRAPS location which ensures I/N Protection Criterion with <0.1% exceedance is fully met.

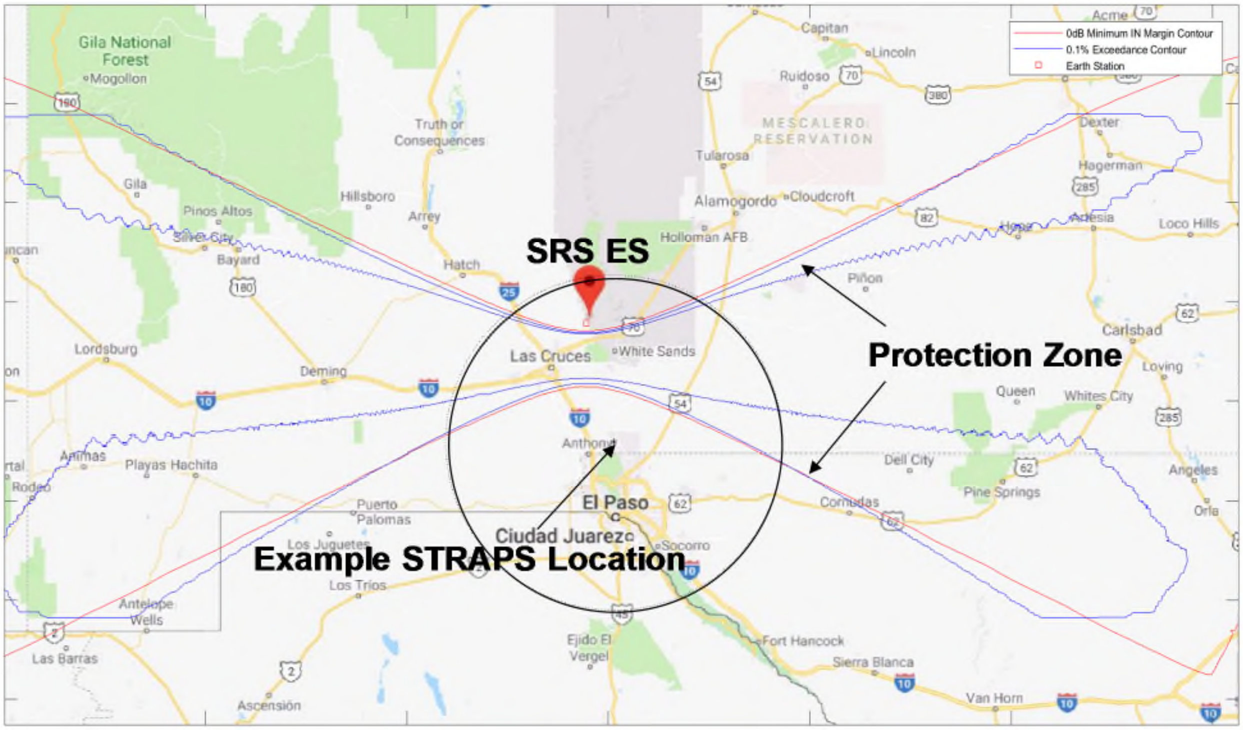


Figure 6: LRO System – Example STRAPS Placement near White Sands SRS ES

Similarly, Figure 7 illustrates the corresponding Protection Zone for the JWST system with the SRS ES located at Goldstone, CA. Again, placement of STRAPS can easily be accommodated to ensure that SRS Protection Criteria are met.

Figure 7: JWST System – STRAPS Protection Zone near Goldstone, CA

CONCLUSIONS

For a given SRS mission, STRAPS located near the associated SRS ES can be easily be placed to ensure that SRS I/N Protection Criteria are met.

REFERENCES:

ITU-R SA.1862-0: Guidelines for efficient use of the band 25.5-27.0 GHz by the Earth exploration-satellite service (space-to-Earth) and space research service (space-to-Earth)

ITU-R SA.609-2: Protection criteria for radiocommunication links for manned and unmanned near-Earth research satellites

ITU-R S.465-6: Reference radiation pattern for earth station antennas in the fixed-satellite service for use in coordination and interference assessment in the frequency range from 2 to 31 GHz

Appendix M
Compatibility Analysis:
STRAPS User Downlink Interference into
Radio Astronomy Passive Sensing in the
23.6-24 GHz Band
(Prepared by Lockheed Martin Corporation for Elefante Group, Inc.)

SUMMARY

- Elefante Group is proposing to access the 25.25–27.5 GHz band for User downlink communications from Stratospheric Platform Stations (STRAPS) to User Terminals (UTs) on a co-Primary basis.

- This study assesses the compatibility of STRAPS User downlinks out-of-band emissions with the Radio Astronomy Service (RAS), which has allocation to operate on a protected basis in the 23.6-24 GHz bands. The transmit and victim bands are separated by 1.25 GHz.

- Worst-case operating conditions and interference geometry are utilized for a bounding analysis which includes STRAPS transmitting at a level equal to the maximum Power Flux Density (PFD) limit as authorized for satellite downlinks into Fixed services.

- Study results show compatibility is achieved and protection criteria can be far exceeded.

PURPOSE OF THE STUDY

Elefante Group is proposing that the 25.25–27.5 GHz band be made available for Stratospheric-Based Communications Services (SBCS), operating as a Fixed service, in the downlink direction. (While not the purpose of this study, Elefante Group proposes that the 25.25–27.5 GHz band also be considered for use in the uplink direction.) All or part of this band is allocated in the federal allocation to Fixed, Mobile, Earth Exploration Satellite (space-to-earth), Space Research (space-to-earth), and Inter-Satellite services, and Space Research and Inter-Satellite service in the non-federal allocation.

This study assesses the compatibility with RAS observations of out-of-band STRAPS downlink transmissions from a multi-beam stratospheric platform to ground-based UTs.

This study assesses the potential for such interference to exceed the I/N and percentage data Protection Criteria to determine if mitigation measures are necessary.

PERFORMANCE CHARACTERISTICS OF RAS SENSORS

Performance characteristics of the RAS sensors utilized for this study are based on ITU-R RA.769 and reproduced here for convenience. Table 1 presents general characteristics for RAS common to all frequency observation bands. Table 2 presents specific PFD thresholds for interference when the RAS antenna presents 0 dBi gain to the interferer.

The continuum observation centered on 23.8 GHz is the most sensitive to interference. RAS also makes observations within other bands that are not allocated or protected, which will be addressed in the results section.

Table 1: General RAS characteristics for interference analysis

Parameter	Value	Source
Rx Antenna Gain	88 dBi	Approximated as max gain for 100 m referenced in ITU-R.769
Rx Antenna Beam Width	0.8 deg	Derived assuming 70% efficient antenna (1)
Rx Antenna Pattern	ITU-R SA.509	ITU-R SA.509
Min. Elevation Angle	5 deg	ITU-R RA.1513
Polarization	Co-polarized with interferer	Worst case
Total interference allocation	5%	ITU-R RA.1513
Single system interference allocation	2%	ITU-R RA.1513

Table 2: Band Specific Characteristics

Type	Center (GHz)	Bandwidth (MHz)	Threshold PFD dB(W/m^2/MHz)
Line	22.2	250	-156
Line	23.7	250	-155
Continuum	22.355	290	-171
Continuum	23.8	400	-173
VLBI	23.8		-123

OPERATIONAL CHARACTERISTICS OF SBCS

The SBCS will utilize STRAPS, UTs, and Gateway terminals to provide fixed services over a specific service area. Transmit characteristics of the Elefante Group STRAPS user downlink utilized in this study are given in Appendix 1.

For this study, worst-case operating conditions are utilized for a bounding analysis prior to considering, if appropriate, risk-based interference assessment using probability and statistical methods:

1) STRAPS located at a minimum altitude of 18.3 km and transmitting at the regulatory PFD limit as authorized for satellite downlinks in this band to protect interference into Fixed services per CFR Title 47 25.208(c) over the STRAPS 70 km radius coverage area.

2) Multiple STRAPS downlink channels operating simultaneously to fully encompass the DRS Return Channel and operating in the same polarization (not considering that coverage is provided by multiple channels "colors" which are spread across hundreds of beams and that the DRS return link allocated frequency range may not be fully occupied).

3) STRAPS downlink operating in the same polarization as the DRS Return link (Right Hand and Left Hand Circular Polarization authorized).

STUDY SCENARIO

Figure 1 illustrates the interference geometry applicable to this study.

- STRAPS transmits User Downlink signals to the associated service area.
- RAS observations conducted down to 5 deg minimum elevation angle over a 1.83 pi steradian solid angle.
- If PFD threshold is exceeded, RAS experiences interference when aimed within some angle of the STRAPS. This solid angle of interference (SAI) determines percent of RAS field of regard unavailable for observations satisfying protection criteria threshold.

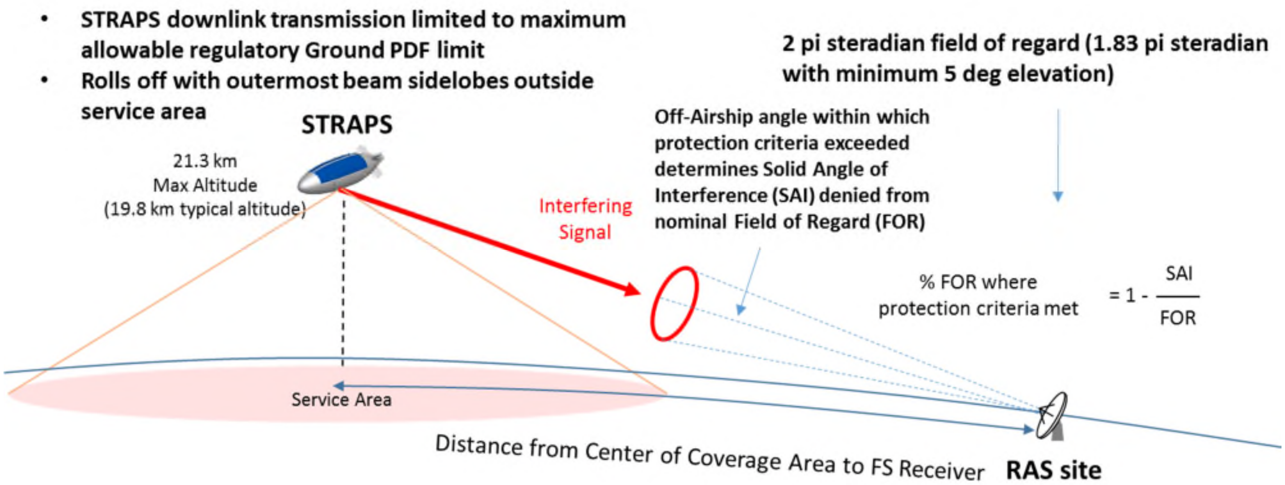


Figure 1: Interference Geometry

STUDY METHODOLOGY

The study starts by assuming the STRAPS is transmitting at a level equal to the regulatory PFD limit that is authorized for satellite downlinks in this band to protect interference into Fixed services per CFR Title 47 25.208(c). The assumption is that the STRAPS service area is defined by a 70 km radius coverage area centered on the point below the STRAPS fixed position as described below and illustrated in Figure 2 and Figure 3.

$$PFD\left(\frac{dBW}{m^2 * MHz}\right) = \begin{cases} -115 & 0 \leq \delta < 5 \\ -115 + 0.5 * (\delta - 5) & 5 \leq \delta < 25 \\ -105 & 25 \leq \delta \leq 90 \end{cases}$$

Where δ is the angle of arrival (in degrees) above the horizontal plane (elevation angle)

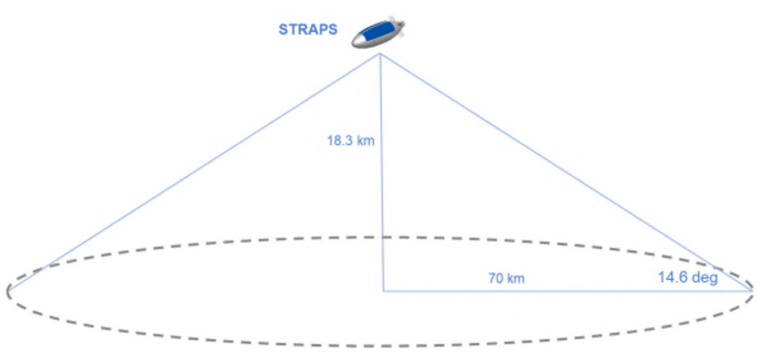


Figure 2: STRAPS Service Area Geometry

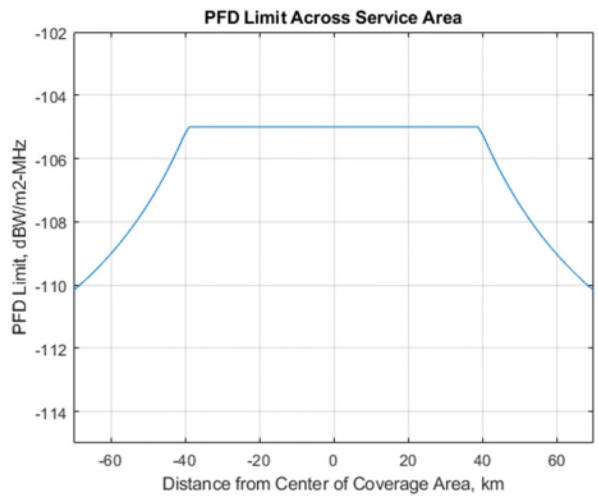


Figure 3: PFD Limit Across Service Area

PFD outside of the coverage area is calculated by starting with the PFD limit and rolling it off using the ITU-R F.1245 antenna pattern with peak antenna gain of 32.7 dB at the edge of coverage.

The corresponding STRAPS (Interferer) EIRP Density as a function of transmit antenna boresight angle is calculated as follows and illustrated in Figure 4.

$$EIRP\ Density\ \left(\frac{dBW}{MHz}\right) = PFD - \ 10 * \log(\,4 * \pi * r^2)$$

Where r is the distance from STRAPS to the ground distance away from the center of the coverage area

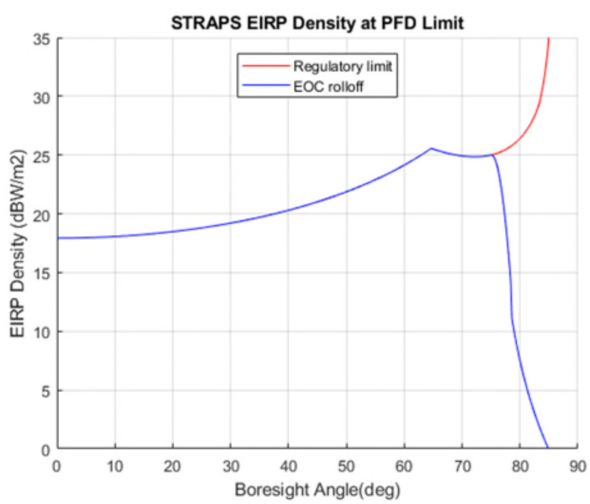


Figure 4: STRAPS EIRP Density at PFD Limit. Rather than generating EIRP sufficient to maintain the PFD limit outside the STRAPS service area (red), the EIRP tapers with the antenna pattern roll-off of the STRAPS beam directed toward the edge of the coverage area (blue).

The incident PFD is compared to the threshold PFD of -173 dB(W/MHz) for 23.6-24 GHz RAS observations. This threshold applies to the case of 0 dBi presented by the RAS sensor, whereas

actual gain presented can be as high as the RAS boresight gain of 88 dBi. Therefore, the interference margin is calculated as

Margin = Threshold PFD - Incident PFD – RAS gain

This relationship is used in two ways:

Bounding analysis: In a bounding analysis, the worst-case RAS gain is assumed and the out-of-band attenuation necessary to achieve 0 dB margin is determined as a function of RAS separation distance from the service area center.

- At separations where the STRAPS appears above the minimum 5 deg elevation the gain presented is the boresite gain.
- At greater separations, the gain presented is the minimum off-boresight gain presented when the RAS is aimed at 5 deg elevation and in azimuth toward the STRAPS.

Interference Criteria analysis: This analysis assesses the percent data loss due to observations with negative interference margin.

- Because RAS gain is a function of angle off boresight, the margin relationship is used to determine the angle the RAS sensor must maintain off the STRAPS to achieve positive margin given an incident PFD.
- In turn, as shown in Figure 1, the required angle is used to calculate the solid angle of interference, which is compared to the RAS field of regard solid angle to determine % observing area where margin would be exceeded. Assuming an equal weighting of observations over the entire field of regard, this serves as a proxy for % data with negative interference margin.
- By surveying separation distance and incident PFD attenuation values, contours of percent data with negative margin can be determined.

STUDY RESULTS

Although results for the bounding analysis indicate extreme attenuation is necessary to enable RAS observations directly toward the STRAPS, the narrow, pencil beam of the RAS sensor allows the percent data loss criteria to be met with significant margin.

Figure 5 depicts the bounding analysis results. Because of the high sensitivity and gain of the RAS sensor, over 150 dB attenuation would be necessary if the STRAPS operated directly above the RAS at 0 km separation. The degree of attenuation follows the downlink PFD limit as it rolls off to the 70 km service area edge, then rolls off more rapidly with the roll-off of the outermost beam until the RAS site at 200 km separation, where the STRAPS is observed at 5 deg elevation. Beyond 200 km, the roll-off follows the RAS gain pattern, benefiting slightly from increased range loss as well, until the RAS site passes below the horizon of the STRAPS at ~525 km separation.

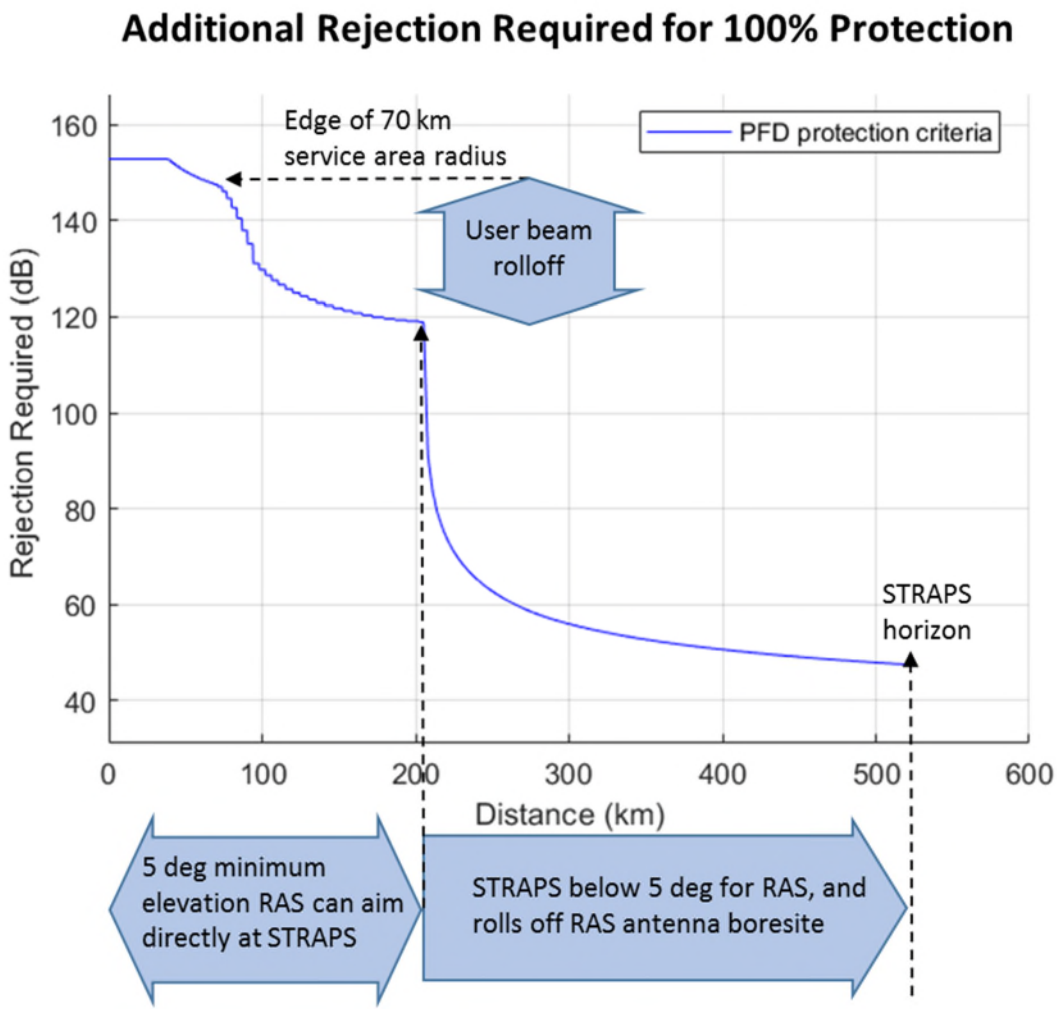


Figure 5: Additional out-of-band attenuation necessary to enable RAS observations at closest boresight angle to STRAPS

Figure 6 depicts the bounding analysis results. This analysis determines the solid angle where observations would receive interference exceeding the threshold and demonstrates how important the narrow, high gain RAS beam is to limiting the extent of that solid angle. Because the beam is so narrow, the RAS gain presented to an interferer drops dramatically at only small angles off its boresight.

Results indicate that at a separation distance of 0 km (the STRAPS directly over the RAS site), out-of-band emissions 75 dB lower than in-band would be sufficient to interfere with only 1% of observation data vs the 2% allocation for a single system. As indicated by the SBCS UT uplink to RAS analysis, however, line of sight from terminals operating in the service area (which in this analysis is 70 km) cannot be allowed to the RAS site. As an example, if 40 km separation between the service area and the RAS site is necessary for the uplink compatibility and 70 to 90 dB out-of-

band attenuation is achieved[1], interference on the order of 0.001% to 0.1% could reasonably be achieved.

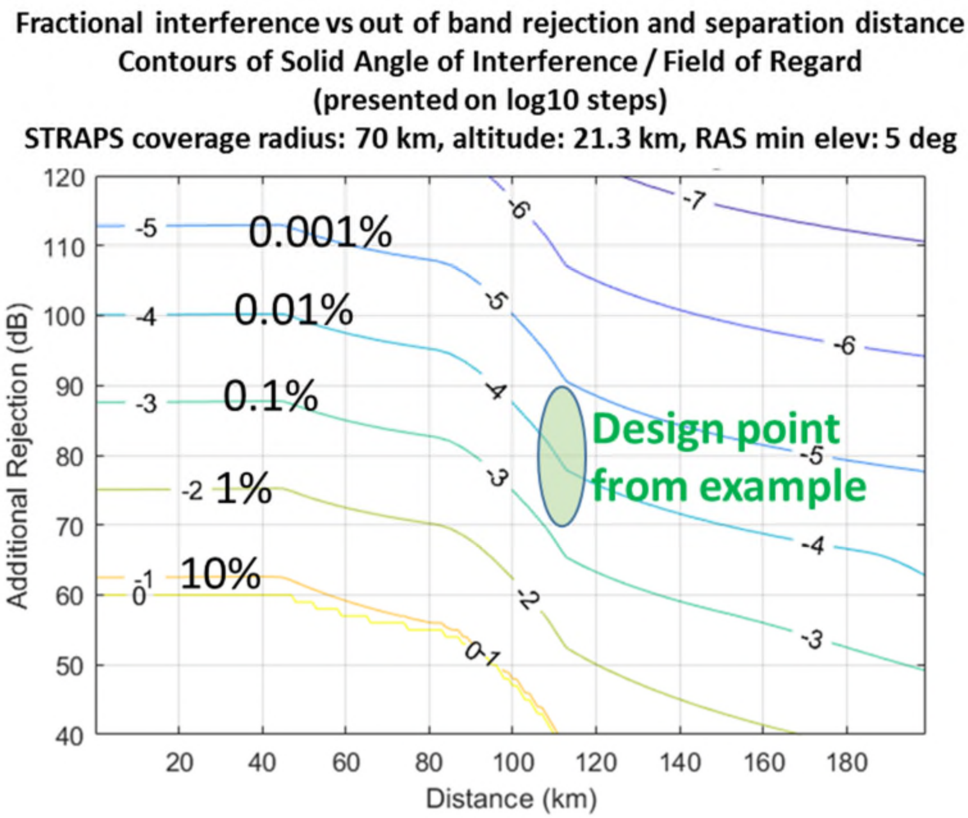


Figure 6: Contours of % RAS data loss (compared to 2% protection criterion) as a function of separation distance and attenuation of the out-of-band downlink signal over 1.25 GHz separation between bands.

CONCLUSIONS

This analysis demonstrates compatibility between the proposed STRAPS downlink and RAS, with the protection criteria met (and far exceeded under example deployment scenarios).

As previously noted, RAS observations are not limited to the bands allocated and protected for RAS. For observatories to protect sensitive RAS receivers from unexpectedly high power when observing within or close to the 25.25-27.5 STRAPS downlink band, it is important to know the maximum PFD that could be incident on them and the direction of its source in order to plan observations. The database of registered STRAPS will include the service area, STRAPS location and the control volume around it where downlink is authorized. STRAPS deployed within the coordination radius of RAS sites will already be engaged in coordination as described in the analysis on compatibility with RAS in the SBCS user uplink band.

[1] The pulse shaping filter of many commercially available modems is specified to provide greater than 50 dB attenuation a nominal distance from the passband, and additional filtering and natural roll-off make ~70 dB reasonably achievable for adjacent bands. With 1.25 GHz band separation, 70-90 dB is a reasonable assumption.

REFERENCES:

ITU-R RA.769-2: Protection criteria used for radio astronomical measurements

ITU-R RA.1513-2: Levels of data loss to radio astronomy observations and percentage-of-time criteria resulting from degradation by interference for frequency bands allocated to the radio astronomy service on a primary basis

Appendix N
Compatibility Analysis:
STRAPS User Downlink Interference into
Aeronautical Mobile Service Ground-to-Airborne Link in the
22.55 – 23.55 GHz Band
(Prepared by Lockheed Martin Corporation for Elefante Group, Inc.)

SUMMARY

- Elefante Group is proposing to access the 22.55–23.55 GHz band for User downlink communications from Stratospheric Platform Stations (STRAPS) to User Terminals (UTs) on a co-Primary basis.

- This study assesses the compatibility of STRAPS User downlinks with Federal Aeronautical Mobile Service (AMS) Ground-to-Airborne links which are operating in the 22.55–23.55 GHz band.

- As an initial step, worst-case operating conditions are utilized for a bounding analysis which include: 1) STRAPS transmitting at a level equal to the maximum power flux density limit as authorized for satellite downlinks into Fixed services, 2) multiple STRAPS downlink channels operating simultaneously to fully encompass the AMS uplink channel and operating in the same polarization, and 3) AMS Ground located anywhere relative to the STRAPS system coverage area which result in the worst-case interference level.

- Bounding compatibility study results show that AMS I/N Protection Criterion is met under all conditions except during a possible transient condition if the Airborne passes close to STRAPS. Therefore, the likelihood of harmful interference is minimal. No mitigation is recommended.

PURPOSE OF THE STUDY

Elefante Group is proposing that the 22.55–23.55 GHz band be made available for Stratospheric-Based Communications Services (SBCS), operating as a Fixed service, in the downlink direction. (While not the purpose of this study, Elefante Group proposes that the 22.55–23.55 GHz band also be considered for use in the uplink direction). All or part of this band is allocated in the federal allocation to Fixed, Mobile, Space Research (earth-to-space), and Inter-Satellite Service.

This study assesses the compatibility with Aeronautical Mobile Service (AMS) Ground-to-Airborne links of STRAPS downlink transmissions from a multi-beam stratospheric platform to ground-based UTs.

This study assesses the potential for interference into AMS Ground to exceed the I/N Protection Criterion to determine if mitigation measures are necessary.

OPERATIONAL CHARACTERISTICS OF AMS GROUND RECEIVERS

Receive characteristics of the AMS Ground Data Terminal (GDT) utilized for this study are based on the two systems illustrated in ITU-R M.2114 and are shown in Table 1 and Table 2.

Table 1: System 1 AMS Ground Data Terminal Receive Characteristics

Parameter	Value	Source
Frequency Range	22.9 – 23.3 GHz	ITU-R M.2114-0
Channel Bandwidth	580 MHz	ITU-R M.2114-0
Rx Antenna Gain	33 dBi	ITU-R M.2114-0
Rx Antenna Beam Width	2.7 deg	ITU-R M.2114-0
Rx Antenna Pattern	ITU F.1245-60% efficiency	Note (2)
Min. Elevation Angle	3 deg	Assumption
Earth Station Receiver Noise Density	-142.2 dBW/MHz	ITU-R M.2114-0, NF = 4 Assumed 0K sky temp
Protection Criterion	I/N < -6 dB	ITU-R M.2114-0

Table 2: System 2 AMS Ground Data Terminal Receive Characteristics

Parameter	Value	Source
Frequency Range	22.55 – 23.5 GHz	ITU-R M.2114-0
Channel Bandwidth	143 MHz	ITU-R M.2114-0
Rx Antenna Gain	33 dBi	ITU-R M.2114-0
Rx Antenna Beam Width	3.4 deg	Note (1)
Rx Antenna Pattern	ITU F.1245-60% efficiency	Note (2)
Min. Elevation Angle	3 deg	Assumption
Earth Station Receiver Noise Density	-143.0 dBW/Hz	ITU-R M.2114-0, NF = 3.5 Assumed 0K sky temp
Protection Criterion	I/N < -6 dB	ITU-R M.2114-0

(1) ITU-R M.2114 shows a single 7.2 deg beam width for 33 dBi and 46 dBi antennas which results in 146% - 653% antenna efficiency, therefore a typical 70% efficiency used to derive beam width from the peak antenna gain
(2) ITU-R M.2114 permits use of measured antenna pattern in lieu of ITU-R M.1851 (uniform distribution) pattern therefore a standard ITU antenna pattern was selected which approximates a typical commercial antenna with similar peak gain and beam width

OPERATIONAL CHARACTERISTICS OF SBCS

The SBCS will utilize STRAPS, UTs, and Gateway terminals to provide fixed services over a specific service area. Transmit characteristics of the Elefante Group STRAPS user downlink utilized in this study are given in Appendix 1.

For this study, worst-case operating conditions are utilized for a bounding analysis prior to considering, if appropriate, risk-based interference assessment using probability and statistical methods:

1) STRAPS located at a minimum altitude of 18.3 km and transmitting at the regulatory Power Flux Density (PFD) limit as authorized for satellite downlinks in this band to protect interference into Fixed services per CFR Title 47 25.208(c) over the STRAPS 70 km radius coverage area.

2) STRAPS downlink channel fully encompassing the Airborne downlink channel bandwidth and across the full coverage area (not considering that coverage is provided by multiple channels "colors" which are spread across hundreds of beams and that the Airborne downlink allocated frequency range may not be fully occupied).

3) STRAPS downlink operating in the same polarization as the Airborne downlink (Right Hand Circular Polarization)

STUDY SCENARIO

Figure 1 illustrates the interference geometry applicable to this study.

- STRAPS transmits User Downlink signals to the associated coverage area
- AMS Ground, AMS Airborne and STRAPS co-aligned so they are in the same geometric plane
- AMS Ground Data Terminal which may be located within or outside the STRAPS service coverage area transmits the desired uplink signal to AMS Airborne Data Terminal which may be anywhere at or below the STRAPS altitude.
- The highest level of interference from the STRAPS downlink into the AMS Airborne will occur when the boresight angle of the AMS Airborne towards the STRAPS is smallest. This corresponds to the smallest elevation angle for the AMS Ground which is assumed to be 3 degrees.

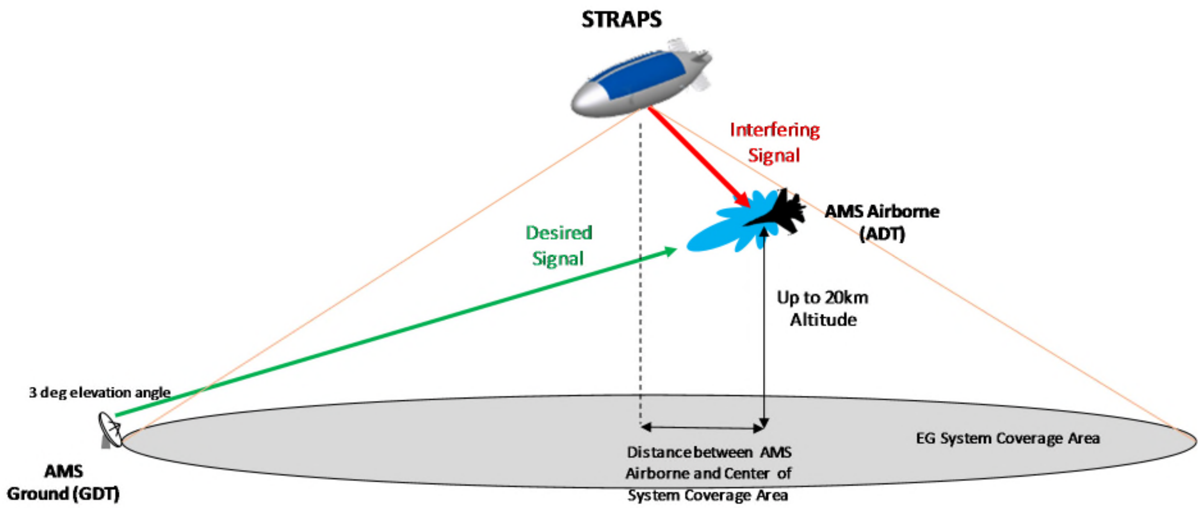


Figure 1: Interference Geometry

STUDY METHODOLOGY

Since the AMS Ground location relative to STRAPS coverage area is not known, the basic methodology for this study is for each possible altitude and location of the AMS Airborne, assume that the AMS Ground is located at the corresponding worst-case location to result in the highest interference level. i.e. the AMS Ground location is moved along with the AMS Airborne location to maintain the 3-degree minimum elevation angle for the AMS Ground. Although such a scenario is not realistic, it does permit determination of the largest zone of possible interference for the Airborne.

The study starts by assuming the STRAPS is transmitting at a level equal to the regulatory PFD limit that is authorized for satellite downlinks in this band to protect interference into Fixed services per CFR Title 47 25.208(c). The assumption is that the STRAPS service area is defined by a 70 km radius coverage area centered on the point below the STRAPS nominal fixed position as described below and illustrated in Figure 2 and Figure 3.

$$PFD\left(\frac{dBW}{m^2 * MHz}\right) = \begin{cases} -115 & 0 \le \delta < 5 \\ -115 + 0.5 * (\delta - 5) & 5 \le \delta < 25 \\ -105 & 25 \le \delta \le 90 \end{cases}$$

Where δ is the angle of arrival (in degrees) above the horizontal plane (elevation angle)

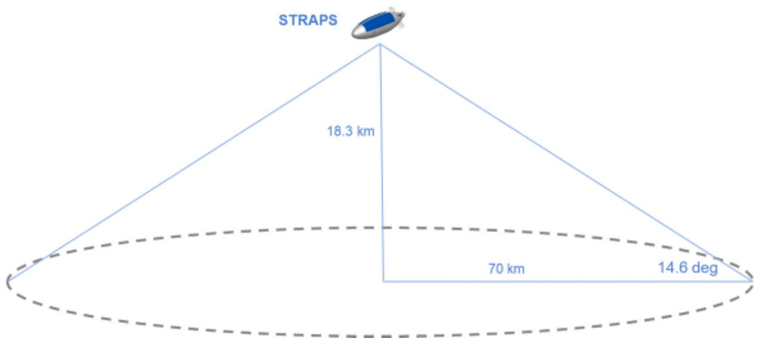


Figure 2: STRAPS Service Area Geometry

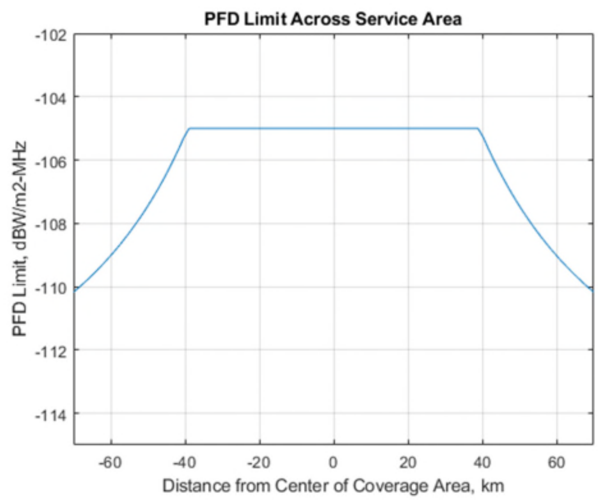


Figure 3: PFD Limit Across Service Area

PFD outside of the coverage area is calculated by starting with the PFD limit and rolling it off using the ITU-R F.1245 antenna pattern with peak antenna gain of 32.7 dB at the edge of coverage.

The corresponding STRAPS (Interferer) Effective Isotropic Radiated Power (EIRP) Density as a function of transmit antenna boresight angle is calculated as follows and illustrated in Figure 4.

$$EIRP\ Density\ \left(\frac{dBW}{MHz}\right) = PFD - \ 10 * \log(\, 4 * \pi * r^2)$$

Where r is the distance from STRAPS to the ground distance away from the center of the coverage area

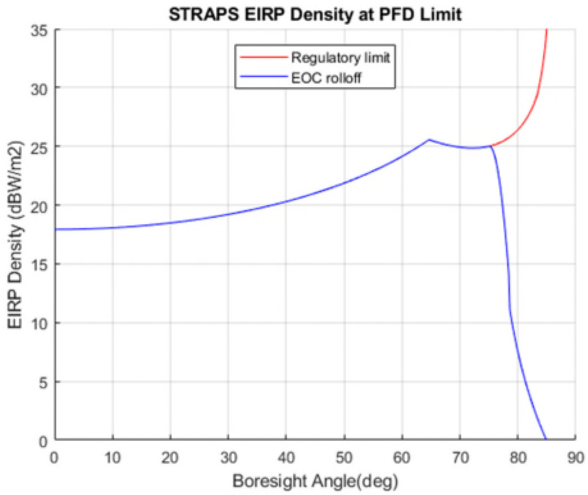


Figure 4: STRAPS EIRP Density at PFD Limit

For each possible altitude and location of AMS Airborne relative to the center of STRAPS coverage area, the Interference Power Density, Io, is calculated:

$$Io\left(\frac{dBW}{MHz}\right) = EIRP\ Density\ (\delta) - FSL - Gr\ (\beta)$$

where:

δ = Angle off STRAPS (Interferer) boresight towards the AMS Airborne

$Gr\ (\beta)$ = AMS Airborne (Victim) receive antenna gain off boresight towards STRAPS assuming an AMS Ground elevation angle of 3 degrees. i.e. AMS Ground relocated with each position of AMS Airborne

FSL = Free Space Loss between the STRAPS and AMS Airborne

Therefore,

$$I/_N\ Margin\ (dB) = I/_N\ Threshold - (I_o - N_o)$$

Where $I/_N\ Threshold$ is the AMS Protection Criterion of -6 dB.

STUDY RESULTS

Results of the compatibility study for the two AMS Systems in ITU-R M.2114 are shown in Figure 5 and Figure 6 which illustrate the I/N Margin as a function of lateral and vertical separation distance between the AMS Airborne and STRAPS.

For System 1 and System 2, I/N Protection Criterion is met under all conditions except if the Airborne passes close to STRAPS. For reference, also illustrated is the keep out zone as suggested by FAA rules (Standard vertical separation of 5000ft (~1500m) for aircraft above 60,000ft (18.3 km) and lateral separation >5nm (9km) typical for aircraft enroute).

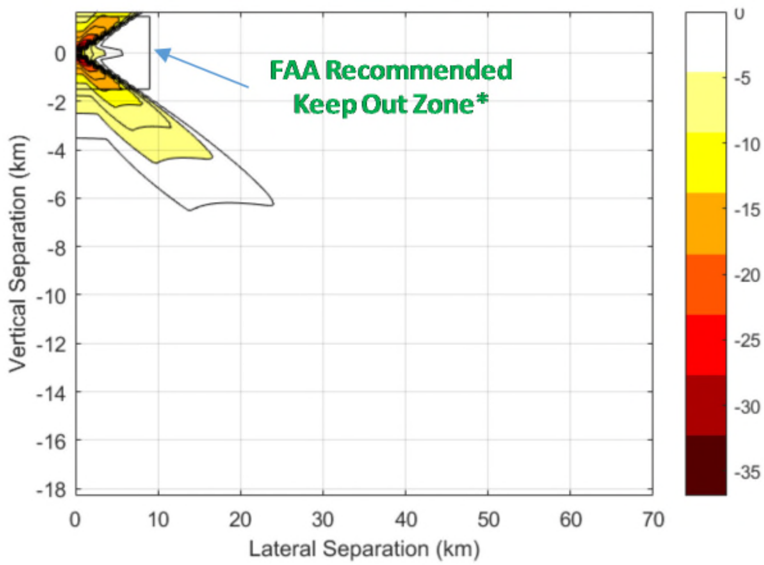


Figure 5: System 1 Compatibility Study Results

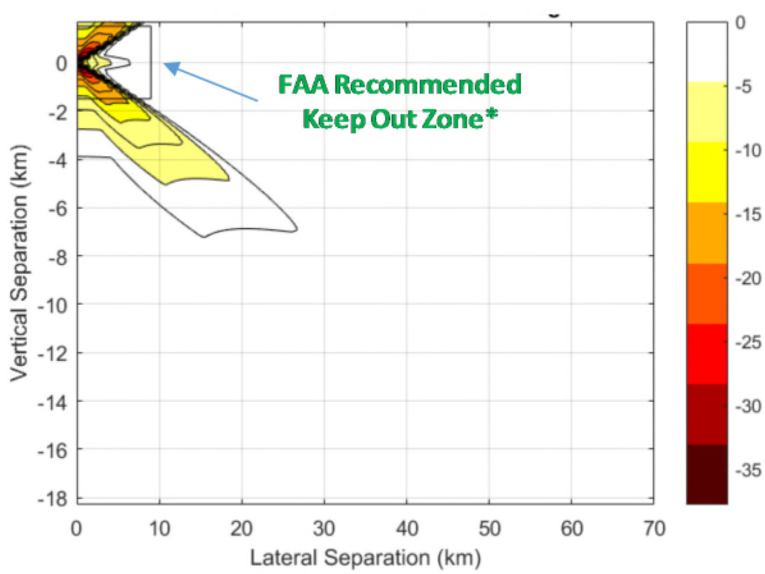


Figure 6: System 2 Compatibility Study Results

CONCLUSIONS

Bounding study was performed using worst-case operational and geometric assumptions including AMS Ground relocated with movement of the AMS Airborne to maintain a worst-case interference angle (not realistic).

Even under such extreme assumptions, AMS I/N Protection Criterion is met except during a possible transient condition if the Airborne passes close to STRAPS which means that the likelihood of harmful interference is minimal. Therefore, no mitigation is recommended for shared operation between STRAPS user downlink and AMS Ground-to-Airborne links.

REFERENCES:

ITU-R M. 2114-0: Technical and operational characteristics of and protection criterion for aeronautical mobile service systems in the frequency bands 22.5-23.6 GHz and 25.25-27.5 GHz

ITU-R F.1245-2: Mathematical model of average and related radiation patterns for line-of-sight point-to-point fixed wireless system antennas for use in certain coordination studies and interference assessment in the frequency range from 1 GHz to about 70 GHz

ITU-R M.1851: Mathematical models for radiodetermination radar systems antenna patterns for use in interference analyses

Appendix O
Compatibility Analysis:
STRAPS User Downlink Interference into
Federal Inter-Satellite Service Forward Link in the
22.55 – 23.55 GHz Band
(Prepared by Lockheed Martin Corporation for Elefante Group, Inc.)

SUMMARY

- Elefante Group is proposing to access the 22.55–23.55 GHz band be available for User downlink communications from Stratospheric Platform Stations (STRAPS) to User Terminals (UTs) on a co-Primary basis.

- This study assesses the compatibility of STRAPS User downlinks with Federal Inter-Satellite Service (ISS) Data Relay System (DRS) Forward links (DRS GSO to LEO) which are authorized to operate in the 22.55–23.55 GHz band.

- As an initial step, worst-case operating conditions and interference geometry are utilized for a bounding analysis which include: 1) STRAPS transmitting at a level equal to the maximum power flux density limit as authorized for satellite downlinks into Fixed services, 2) multiple STRAPS downlink channels operating simultaneously to ensure that the entire 22.55-23.55 GHz band is fully occupied to guarantee overlap with the relatively narrow DRS Forward Channel and operating in the same polarization, and 3) STRAPS, DRS LEO satellite and DRS GSO satellite perfectly aligned and located to result in the maximum level of interference.

- Bounding compatibility study results show that even though the worst-case geometry is unlikely and would be a transient condition, the DRS I/N Protection Criterion is met under worst-case operating conditions. No mitigation is necessary.

PURPOSE OF THE STUDY

Elefante Group is proposing that the 22.55–23.55 GHz band be made available for Stratospheric-Based Communications Services (SBCS), operating as a Fixed service, in the downlink direction. (While not the purpose of this study, Elefante Group proposes that the 22.55–23.55 GHz band also be considered for use in the uplink direction.) All or part of this band is allocated in the federal allocation to Fixed, Mobile, Space Research (earth-to-space), and Inter-Satellite Service.

This study assesses the compatibility with Federal ISS DRS Forward links of STRAPS downlink transmissions from a multi-beam stratospheric platform to ground-based UTs.

This study assesses the potential for interference into DRS LEO satellite to exceed the I/N Protection Criterion to determine if mitigation measures are necessary.

OPERATIONAL CHARACTERISTICS OF DRS LEO RECEIVERS

Two different sets of DRS LEO receive characteristics were utilized for this study. Case 1 based on United States of America system characteristics in ITU-R SA1414-2 shown in Table 1 and Case 2 based on ITU-R M.2360 shown in Table 2. For both cases, the cited Protection Criteria are based on ITU-R SA.1155.

Table 1: Case 1-ISS DRS Forward Link LEO Receive Characteristics

Parameter	**Value**	**Notes**
Frequency Range	22.55 – 23.55 GHz	
Channel Bandwidth	50 MHz	ITU-R SA.1414-2
Rx Antenna Gain	47.0 dBi	ITU-R SA.1414-2
Rx Antenna Pattern	ITU-R S.672	Nominal -25 dB sidelobe level
Receiver Noise Density	-137.1 dBW/MHz	ITU-R SA.1414-2 1400K
Protection Criteria	I/N < -10 dB Exceedance <0.1% of visible time	ITU-R SA.1155

Table 2: Case 2-ISS DRS Forward Link LEO Receive Characteristics

Parameter	**Value**	**Notes**
Frequency Range	22.55 – 23.55 GHz	
Channel Bandwidth	50 MHz	ITU-R M.2360
Rx Antenna Gain	39.8 dBi	ITU-R M.2360
Rx Antenna Pattern	ITU-R S.672	Nominal -25 dB sidelobe level
Receiver Noise Density	-144.0 dBW/MHz	ITU-R M.2360 290K
Protection Criteria	I/N < -10 dB Exceedance <0.1% of visible time	ITU-R SA.1155

OPERATIONAL CHARACTERISTICS OF SBCS

The SBCS will utilize STRAPS, UTs, and Gateway terminals to provide fixed services over a specific service area. Transmit characteristics of the Elefante Group STRAPS user downlink utilized in this study are given in Appendix 1.

For this study, worst-case operating conditions are utilized for a bounding analysis prior to considering, if appropriate, risk-based interference assessment using probability and statistical methods:

1) STRAPS located at a minimum altitude of 18.3 km and transmitting at the regulatory Power Flux Density (PFD) limit as authorized for satellite downlinks in this band to protect interference into Fixed services per CFR Title 47 25.208(c) over the STRAPS 70 km radius coverage area.

2) Multiple STRAPS downlink channels operating simultaneously to ensure that the entire 22.55-23.55 GHz band is fully occupied to guarantee overlap with the relatively narrow 50 MHz DRS Forward Channel. This condition does not take benefit of the fact that STRAPS coverage is provided by multiple channels "colors" which are spread across hundreds of beams and that the DRS forward link channel doesn't necessary overlap with such usage.

3) STRAPS downlink operating in the same polarization as the DRS Forward link (Right hand and Left Hand Circular Polarization authorized).

STUDY SCENARIO

Figure 1illustrates the interference geometry applicable to this study.

- STRAPS transmits User Downlink signals to the associated coverage area
- DRS GSO satellite transmits the desired Forward link signal to the DRS LEO satellite. The compatibility study includes two representative DRS LEO altitudes, 400 km and 800 km.
- As the DRS LEO satellite moves through its orbit, there will be instances of time during which the worst-case alignment for interference will occur when the STRAPS, DRS LEO satellite and DRS GSO satellite are co-aligned, i.e. as the DRS LEO satellite receiver tracks the DRS GSO satellite, there will be instances of time when the DRS LEO receiver is pointed directly at the STRAPS. Note that such a geometric situation in highly unlikely and short-lived since:
    - The DRS GSO satellite must be visible to the STRAPS and low on the horizon
    - The DRS LEO satellite must be trying to communicate via a link to the DRS GSO satellite across the limb of the earth (~5 deg equivalent ground elevation angle)
    - The DSR LEO satellite, DRS GSO satellite and STRAPS are co-aligned which adds additional position constraints
    - The range from the DRS LEO satellite to STRAPS must be minimum

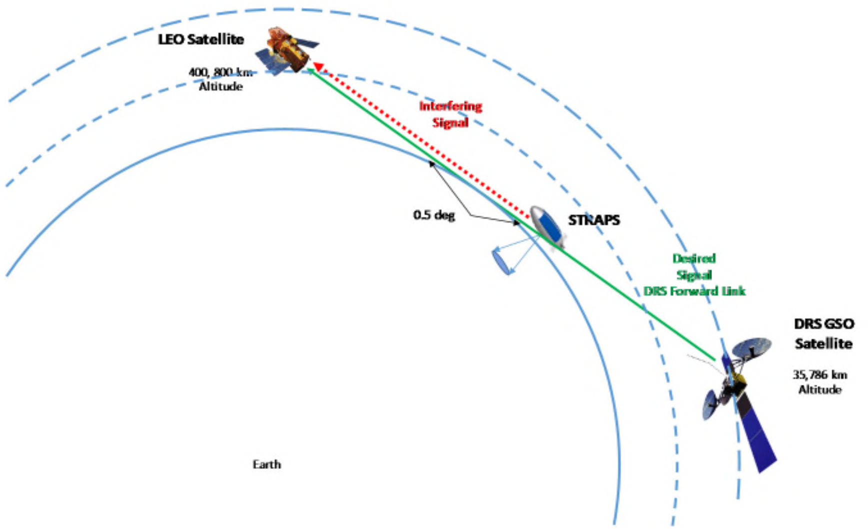


Figure 1: Interference Geometry

STUDY METHODOLOGY

The study starts by assuming the STRAPS is transmitting at a level equal to the regulatory PFD limit that is authorized for satellite downlinks in this band to protect interference into Fixed services per CFR Title 47 25.208(c). The assumption is that the STRAPS service area is defined by a 70 km radius coverage area centered on the point below the STRAPS nominal fixed position as described below and illustrated in Figure 2 and Figure 3.

$$PFD\left(\frac{dBW}{m^2 * MHz}\right) = \begin{cases} -115 & 0 \leq \delta < 5 \\ -115 + 0.5 * (\delta - 5) & 5 \leq \delta < 25 \\ -105 & 25 \leq \delta \leq 90 \end{cases}$$

Where δ is the angle of arrival (in degrees) above the horizontal plane (elevation angle)

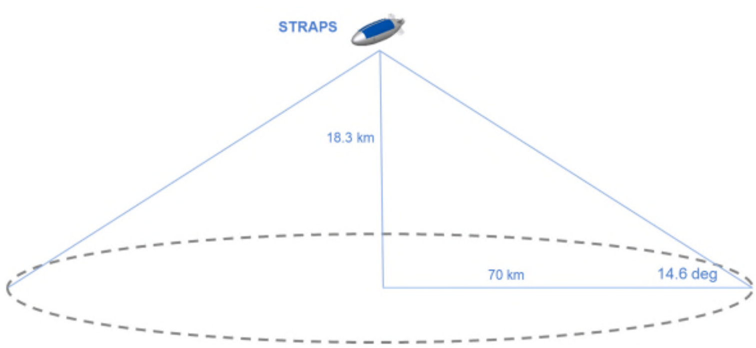


Figure 2: STRAPS Service Area Geometry

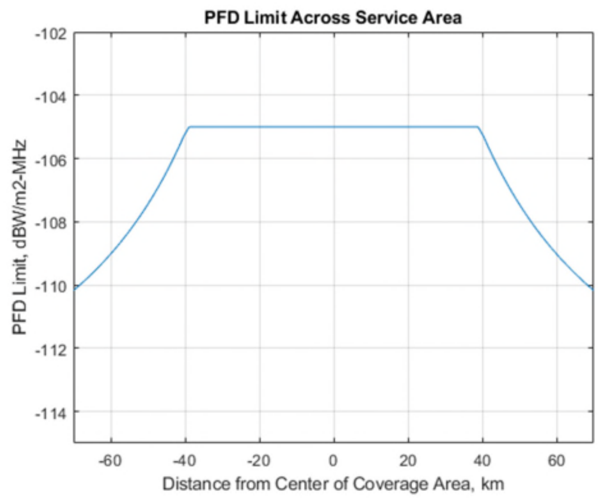


Figure 3: PFD Limit Across Service Area

PFD outside of the coverage area is calculated by starting with the PFD limit and rolling it off using the ITU-R F.1245 antenna pattern with peak antenna gain of 32.7 dB at the edge of coverage.

The corresponding STRAPS (Interferer) EIRP Density as a function of transmit antenna boresight angle is calculated as follows and illustrated in Figure 4.

$$EIRP\ Density\ \left(\frac{dBW}{MHz}\right) = PFD - \ 10 * \log(\,4 * \pi * r^2)$$

Where r is the distance from STRAPS to the ground distance away from the center of the coverage area

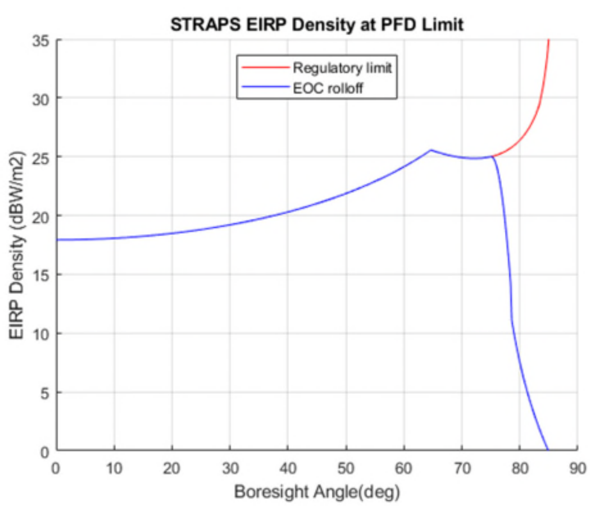


Figure 4: STRAPS EIRP Density at PFD Limit

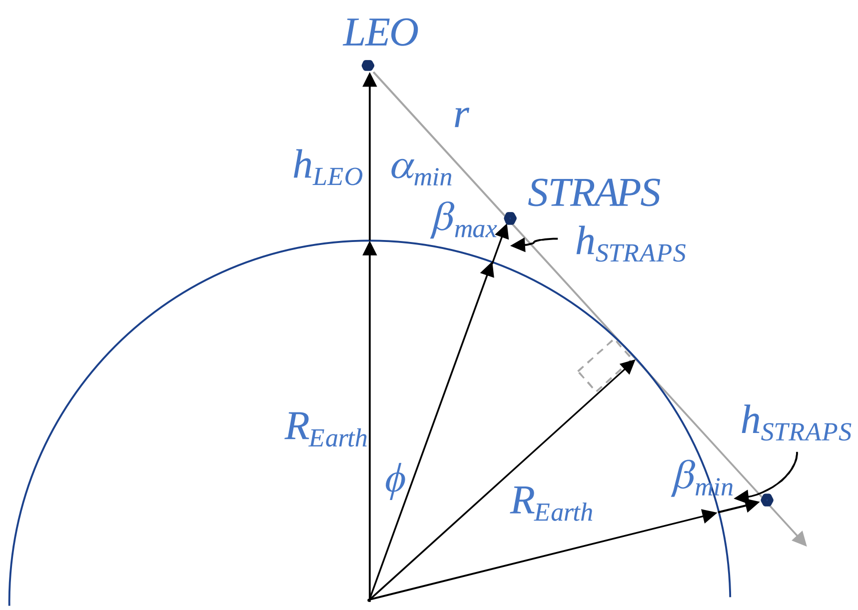
The PFD is converted to receive interference power, I, as a function of range from STRAPS as follows:

$$I = \frac{PFD * \ 4 * \pi * R^2}{\left(4 * \pi * R/_{\lambda}\right)^2}$$

where R is the range and λ is the wavelength.

The worst-case interference geometry occurs when the DRS LEO is transmitting directly through the STRAPS to the DRS GSO located across the limb of the earth. In this scenario, the STRAPS interference transmission into the DRS LEO is via its antenna back lobes.

The associated interference geometry is illustrated in Figure 5.



$h_{LEO} = 400km/800km$ DRS LEO altitude

$h_{STRAPS} = 19.8\ km$ STRAPS altitude

$R_{Earth} = 6371\ km$ mean earth radius

Figure 5: Interference Geometry

The minimum angle from the DRS LEO nadir to its boresight pointed at the DRS GSO is assumed to just go across the limb of the earth.

$$\alpha_{\min} = \sin^{-1}\left(\frac{R_{Earth}}{R_{Earth} + h_{LEO}}\right)$$

An STRAPS at fixed altitude can intersect the Line of Sight between the DRS LEO and DRS GSO at two points. The corresponding off-boresight angle from the STRAPS towards the DRS LEO is given by:

$$\beta_{\min} = \sin^{-1}\left(\frac{R_{Earth}}{R_{Earth} + h_{STRAPS}}\right)$$

$$\beta_{\max} = \pi - \beta$$

For a STRAPS at any range between these points, the potential exists for the DRS LEO, STRAPS, and DRS GEO to be co-aligned and the STRAPS off-boresight angle towards the DRS LEO to be zero.

Note that for ranges beyond the maximum, the STRAPS will be occluded from the DRS LEO by the limb of the Earth. For ranges less than the minimum, the STRAPS off-boresight angle towards the DRS LEO will be non-zero.

The range from the STRAPS to the DRS LEO is used to determine the Free Space Loss and is calculated as follows:

$$r = \sqrt{\left(R_{Earth} + h_{LEO}\right)^2 + \left(R_{Earth} + h_{STRAPS}\right)^2 - 2\cdot\left(R_{Earth} + h_{LEO}\right)\cdot\left(R_{Earth} + h_{STRAPS}\right)\cdot\cos\left(180^\circ - \alpha - \beta\right)}$$

In order to determine the antenna gain of the DRS LEO satellite towards the STRAPS, the corresponding off-boresight angle is calculated as follows:

$$\alpha = \sin^{-1}\left(\left(R_{Earth} + h_{STRAPS}\right)\cdot\frac{\sin\left(\beta\right)}{R_{Earth} + h_{LEO}}\right)$$

Due to the above described geometry restrictions, the corresponding possible values of range (r) and DRS LEO off-boresight angle (α) are limited. Figure 6 illustrates the results for a DRS LEO altitude of 400 km.

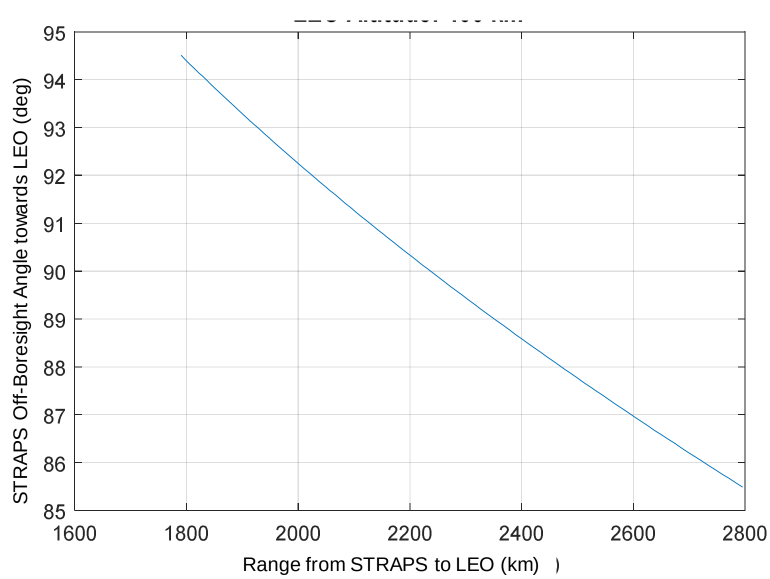


Figure 6: DRS LEO Off-Boresight Angle vs. Range to STRAPS

For each value of STRAPS off-boresight angle and associated range, the Interference Power Density, Io, is calculated:

$$Io\ \left(\frac{dBW}{MHz}\right) = EIRP\ Density\ (\delta) - FSL - Gr\ (\beta)$$

where:

δ = Angle off STRAPS (Interferer) boresight towards DRS LEO

$Gr\ (\beta)$ = DRS LEO (Victim) receive antenna gain off boresight towards STRAPS

FSL = Free Space Loss between the STRAPS and DRS LEO

Therefore,

$$I/_{N}\ Margin\ (dB) = I/_{N}\ Threshold - (I_o - N_o)$$

Where $I/_{N}\ Threshold$ is the DRS I/N Protection Criterion of -10 dB.

STUDY RESULTS

Detailed results of the compatibility study for Case 1 with the DRS LEO satellite at a 400 km altitude are shown in Figure 7 which illustrates that the minimum I/N margin of 16.5 dB occurs at the shortest range between the STRAPS and the DRS LEO satellite.

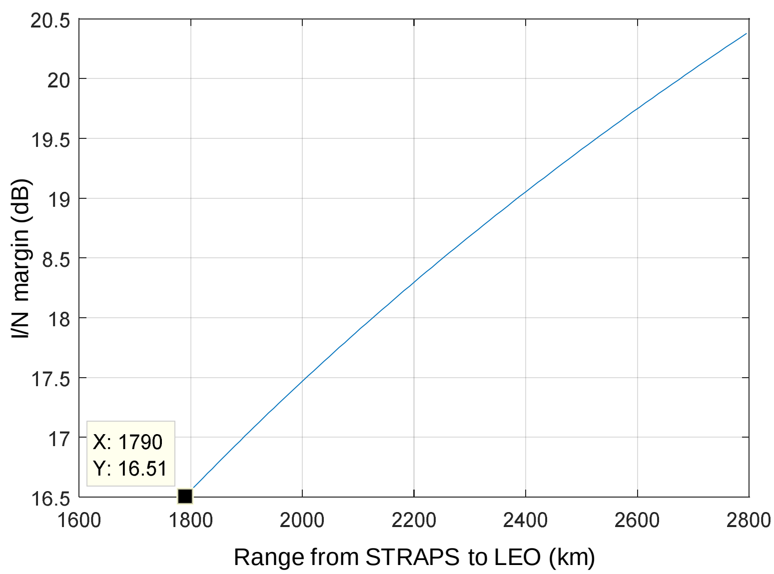


Figure 7: I/N Margin as a Function of STRAPS to LEO Range

Corresponding worst-case I/N margins for the other combination of cases and LEO altitudes are shown in Table 3

Table 3: Worst-case I/N Margin

Case	400 km LEO Altitude	800 km LEO Altitude
1	16.5 dB	20.4 dB
2	16.9 dB	20.7 dB

The worst-case I/N margin is 16.5 dB (I/N is -26.5 dB) as compared to the DRS I/N Protection Criterion of -10 dB. Results indicate relative insensitivity of the worst-case interference performance to DRS LEO receive system characteristics and to the DRS LEO altitude.

CONCLUSIONS

Utilizing worst-case operational conditions and assuming worst-case geometric alignment which is highly unlike and short-lived, the resultant interference level is more than 16.5 dB below the DRS I/N Protection Criterion. No mitigation is necessary for shared operation between STRAPS and DRS ISS forward link.

REFERENCES:

ITU-R S.1155: Protection Criterion related to the operation of data relay satellite systems

ITU-R SA 1414-2: Characteristics of data relay satellite systems

ITU-R M.2360: Sharing between GSO MSS and other services in the allocations in the 22 – 26 GHz range

ITU-R F.1245-2: Mathematical models of average and related radiation patterns for line-of-sight point-to-point fixed wireless systems antennas for use in certain coordination studies and interference assessments in the frequency range from 1 GHz to about 70 GHz

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

Appendix P
Compatibility Analysis:
STRAPS User Uplink Interference into
Aeronautical Mobile Service Airborne-to-Ground Link in the
25.25 – 27.5 GHz Band
(Prepared by Lockheed Martin Corporation on behalf of Elefante Group, Inc.)

SUMMARY

- Elefante Group is proposing that the 25.25–27.5 GHz band be available for User uplink communications from User Terminals (UTs) to Stratospheric Platform Stations (STRAPS) on a co-Primary basis.

- This study assesses the compatibility of STRAPS User uplinks with Federal Aeronautical Mobile Service (AMS) Airborne-to-Ground links which are authorized to operate in the 25.25–27.5 GHz band.

- Worst-case operating conditions are utilized for a bounding analysis which include: 1) All UTs simultaneously active and transmitting at power levels which achieve the highest data rates, 2) Maximum number of UTs operating to fully encompass the Aeronautical channel bandwidth and operating in the same polarization, 3) Clear line of sight from all UTs to AMS Ground Data Terminal (GDT) with no benefit from attenuation due to terrain, foliage, buildings or earth curvature and 4) AMS GDT pointed directly toward the center of a STRAPS service area, directly in-line with an evenly distributed grid of UTs and at the minimum elevation angle.

- Bounding compatibility study results show that AMS I/N Protection Criterion is met unless the AMS Ground is located very close to a UT and pointed directly at the UT. Interference can be fully mitigated via coordination by ensuring that the few offending UTs avoid use of overlapping frequencies/polarization if AMS Ground is deployed within STRAPS coverage area.

PURPOSE OF THE STUDY

Elefante Group is proposing that the 25.25–27.5 GHz band be made available for Stratospheric-Based Communications Services (SBCS), operating as a Fixed service, in the uplink direction. (While not the purpose of this study, Elefante Group proposes that the 25.25–27.5 GHz band also be considered for use in the downlink direction.) All or part of this band is allocated in the federal allocation to Fixed, Mobile, Earth Exploration Satellite (space-to-earth), Space Research (space-to-earth), and Inter-Satellite services, and Space Research and Inter-Satellite service in the non-federal allocation.

This study assesses the compatibility with Aeronautical Mobile Service (AMS) Airborne-to-Ground links of uplink transmissions from ground-based UTs to a multi-beam stratospheric platform. There is the potential for interference into the AMS Ground if UTs are placed close to the AMS Ground.

This study assesses the potential for such interference into AMS Ground to exceed the I/N Protection Criterion to determine if mitigation measures are necessary.

OPERATIONAL CHARACTERISTICS OF AMS GROUND RECEIVERS

Receive characteristics of the AMS Ground utilized for this study are based on the two systems illustrated in ITU-R M.2114 and are shown in Table 1 and Table 2.

Table 1: System 1 AMS Ground Data Terminal Receive Characteristics

Parameter	Value	Source
Frequency Range	25.75 – 27.15 GHz	ITU-R M.2114-0
Channel Bandwidth	865 MHz	ITU-R M.2114-0
Rx Antenna Gain	46 dBi	ITU-R M.2114-0
Rx Antenna Beam Width	0.8 deg	Note (1)
Rx Antenna Pattern	APEREC026V01	Note (2)
Min. Elevation Angle	3 deg	Assumption
Earth Station Receiver Noise Density	-142.2 dBW/MHz	ITU-R M.2114-0, NF = 4
Protection Criterion	I/N < -6 dB	ITU-R M.2114-0

Table 2: System 2 AMS Ground Data Terminal Receive Characteristics

Parameter	Value	Source
Frequency Range	25.75 – 27.15 GHz	ITU-R M.2114-0
Channel Bandwidth	746 MHz	ITU-R M.2114-0
Rx Antenna Gain	33 dBi	ITU-R M.2114-0
Rx Antenna Beam Width	3.4 deg	Note (1)
Rx Antenna Pattern	ITU F.1245-60% efficiency	Note (2)
Min. Elevation Angle	3 deg	Assumption
Earth Station Receiver Noise Density	-141.4 dBW/Hz	ITU-R M.2114-0, NF = 4.5
Protection Criterion	I/N < -6 dB	ITU-R M.2114-0

(1) ITU-R M.2114 shows a single 7.2 deg beam width for 33 dBi and 46 dBi antennas which results in 146% - 653% antenna efficiency, therefore a typical 70% efficiency used to derive beam width from the peak antenna gain

(2) ITU-R M.2114 permits use of measured antenna pattern in lieu of ITU-R M.1851 (uniform distribution) pattern therefore a standard ITU antenna pattern was selected which approximates a typical commercial antenna with similar peak gain and beam width

OPERATIONAL CHARACTERISTICS OF SBCS

The SBCS will utilize STRAPS, UTs, and Gateway terminals to provide fixed services over a specific service area. Transmit characteristics of the Elefante Group STRAPS user uplinks utilized in this study are given in Appendix 1.

For this study, worst-case operating conditions are utilized for a bounding analysis prior to considering, if appropriate, risk-based interference assessment using probability and statistical methods:

1) All UTs simultaneously active and transmitting at power levels which achieve the highest data rates, i.e. EIRP Density of 20 dBW/MHz for Enterprise UTs and 12 dBW/MHz for Consumer UTs

2) Maximum number of UTs for each frequency reuse ("color") operating to fully encompass the Aeronautical channel bandwidth. i.e. 260 UTs for System 1 and 224 UTs for System 2.

3) UT uplink operating in the same polarization as the Airborne downlink (Right Hand Circular Polarization)

4) Clear line of sight all UTs to AMS Ground Receiver with no benefit from attenuation due to terrain, foliage, buildings or earth curvature.

5) AMS Ground receiver pointed at the minimum elevation angle which results in the maximum received interference level.

STUDY SCENARIO

Figure 1 illustrates the interference geometry applicable to this study.

- UTs located across the coverage area transmit User Uplink signals to the associated STRAPS.
- AMS Airborne Data Terminal located at or below the STRAPS altitude, transmits the desired downlink signal to AMS Ground which may be located within or outside the STRAPS service coverage area.
- As the AMS Ground tracks the Airborne, there is a possibility that at specific instances of time when the AMS Ground is pointed directly at a UT and the AMS Ground elevation angle is the lowest (3 deg) resulting in the maximum level of interference from UTs.
- The required separation distance for this bounding static scenario is determined in order to meet the Interference Protection Criterion.

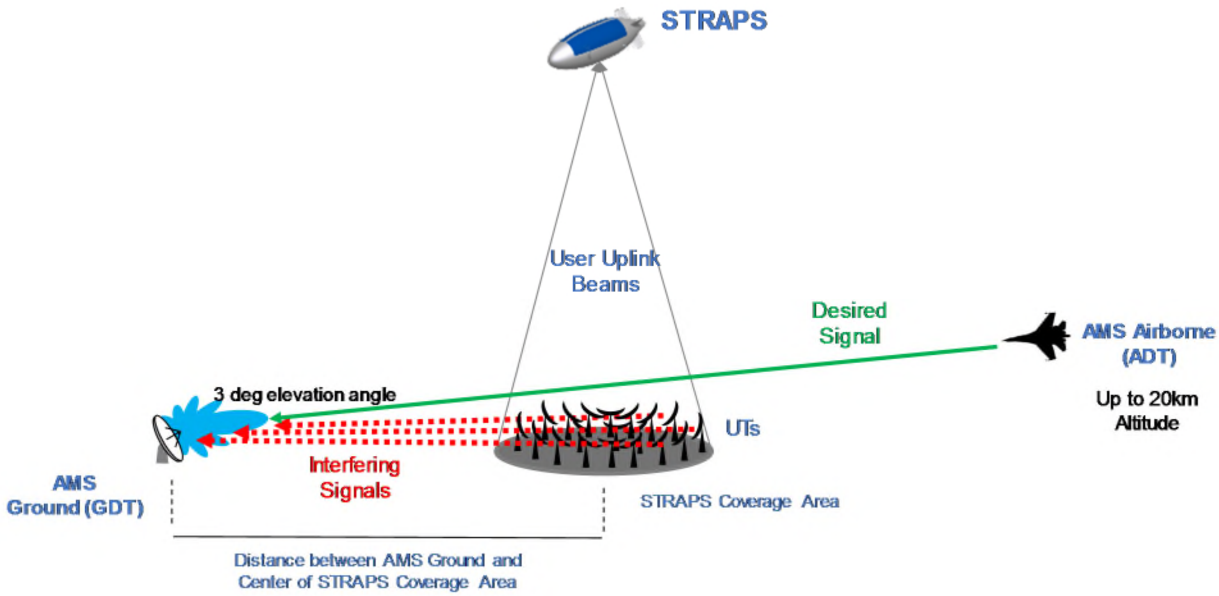


Figure 1: Interference Geometry

STUDY METHODOLOGY

As illustrated in Figure 2, the study geometry starts by placing UTs in an evenly distributed grid across the STRAPS coverage area separated by the typical distance between the same colored beams; all UTs point towards the STRAPS located at the center resulting in the outermost UTs having the lowest elevation angle. AMS Ground location is varied within and outside STRAPS coverage area and pointed in a fixed (arbitrarily selected to be northerly pointed) direction at the minimum elevation angle.

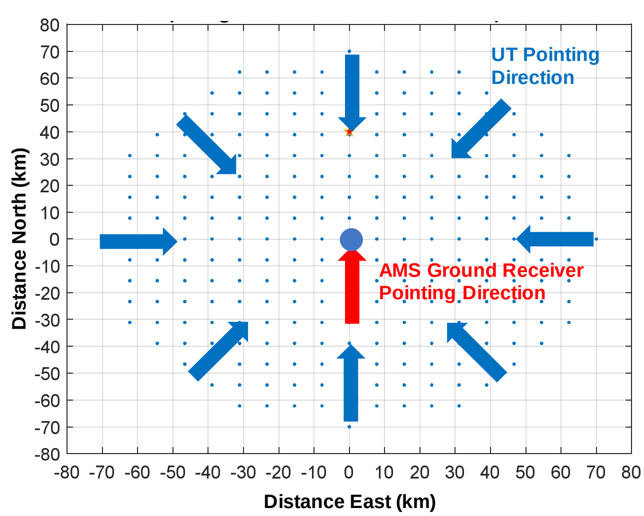


Figure 2: UTs and AMS Ground Geometry

To account for worst-case topography, blockage of the UTs due to the earth's curvature is avoided by placing the AMS Ground 50m higher than the UTs.

For each AMS Ground location, the aggregate interference level into AMS Ground is calculated by power summing the contribution from each of the UTs:

$$Io\left(\frac{dBW}{MHz}\right) = \sum_{i=1}^{N}[EIRP\ Density\ (\delta) - FSL - Gr\ (\beta)]_i$$

where:

N = Total number of UT's (260 for System 1 and 224 for System 2)

δ = Angle off i'th UT (Interferer) boresight towards the AMS Ground

$Gr\ (\beta)$ = AMS Ground (Victim) receive antenna gain off boresight towards i'th UT assuming an AMS Ground elevation angle of 3 degrees

FSL = Free Space Loss between the i'th UT and AMS Ground

Therefore,

$$I/_N\ Margin\ (dB) = I/_N\ Threshold - (I_o - N_o)$$

where $I/_N\ Threshold$ is the AMS Protection Criterion of -6 dB

STUDY RESULTS

Results of the compatibility study for AMS System-1 and System-2 in ITU-R M.2114 using Enterprise and Consumer UTs are shown in Figure 3 through Figure 6 where the white areas indicate where the I/N Protection Criterion is met and colored areas indicate negative I/N Margin where coordination would be required.

In all cases, Protection Criterion is met for nearly all locations of AMS Ground except for small narrow Coordination Regions within the coverage area where the UTs and AMS Ground are close to each other and directly pointed towards each other's boresight.

CONCLUSIONS

Utilizing worst-case operational conditions and assuming worst-case pointing direction for AMS Ground, the I/N Protection Criterion is met for all locations of AMS Ground except small narrow Coordination regions within the coverage area. Note that besides the low likelihood of AMS Ground located within these Coordination Regions, the condition of AMS pointing in the worst-case azimuth direction and elevation angle is highly unlikely and transient as it tracks AMS Airborne.

Therefore, no mitigation is recommended for share operation between UT user uplink and AMS Airborne-to-Ground links.

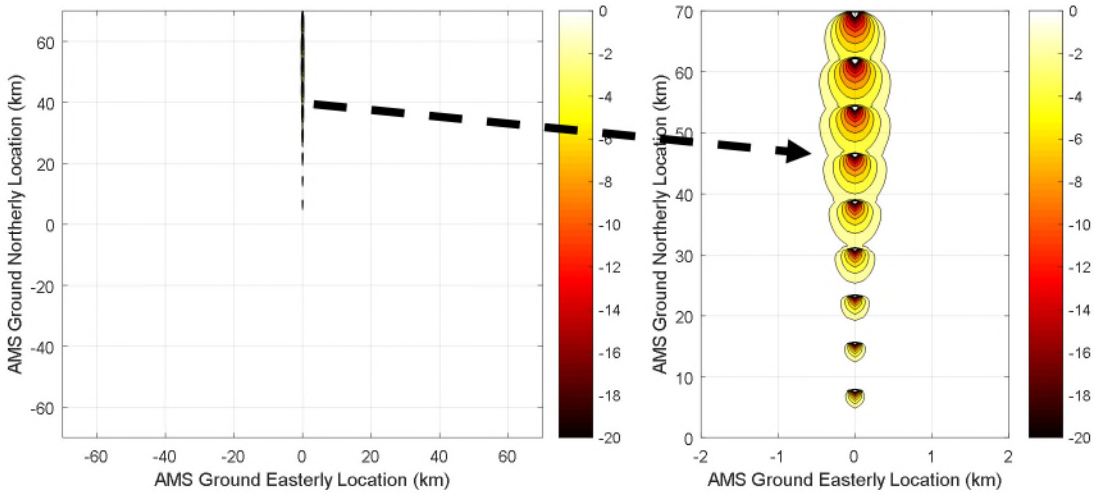


Figure 3: System-1, Enterprise UTs: I/N Margin vs AMS Ground Location

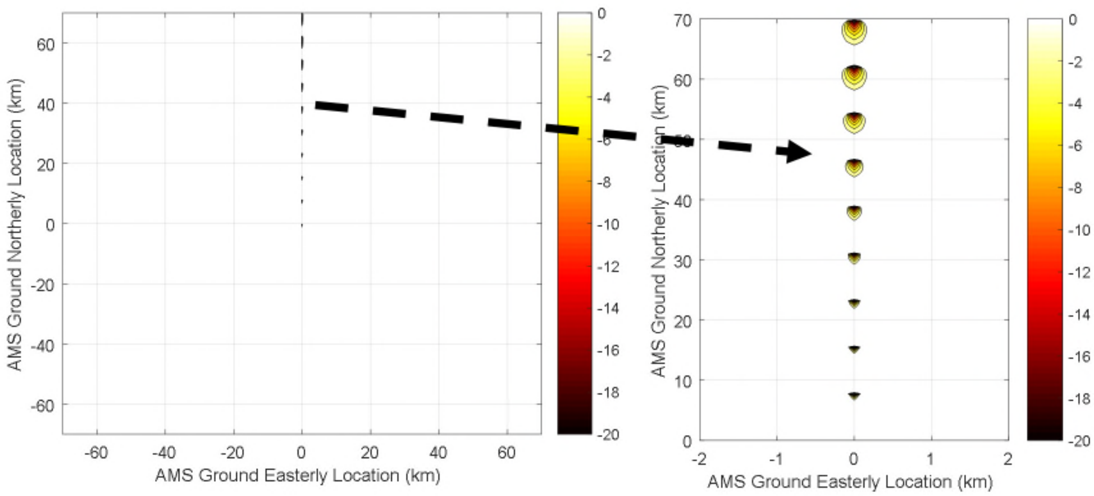


Figure 4: System-1, Consumer UTs: I/N Margin vs AMS Ground Location

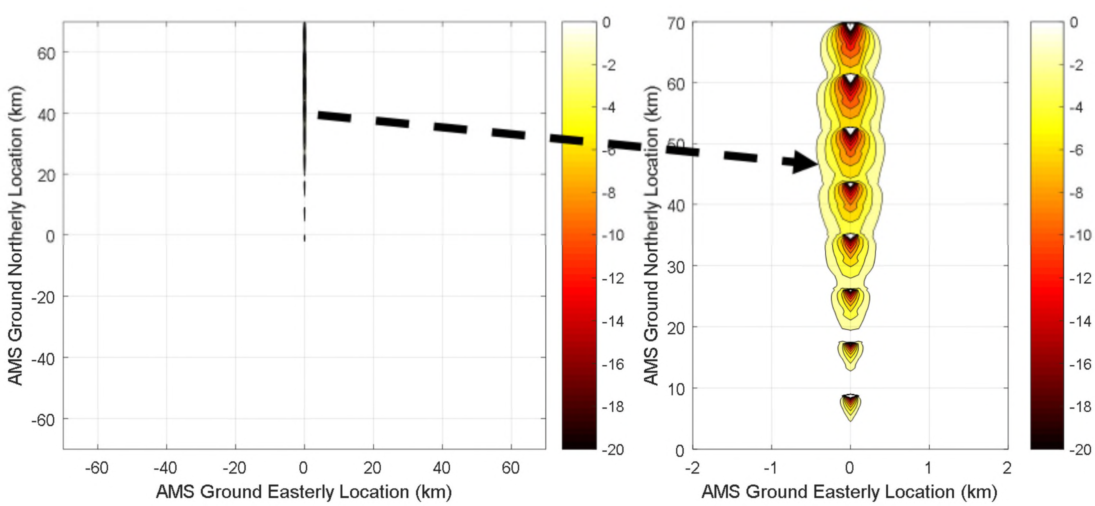


Figure 5: System-2, Enterprise UTs: I/N Margin vs AMS Ground Location

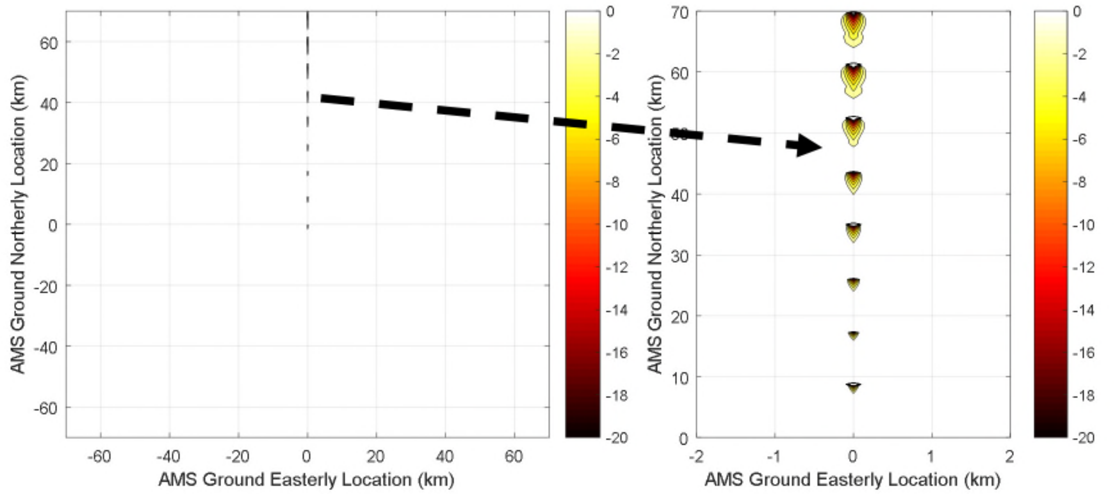


Figure 6: System-2, Consumer UTs: I/N Margin vs AMS Ground Location

REFERENCES:

ITU-R M. 2114-0: Technical and operational characteristics of and protection Criterion for aeronautical mobile service systems in the frequency bands 22.5-23.6 GHz and 25.25-27.5 GHz

ITU-R F.1245-2: Mathematical model of average and related radiation patterns for line-of-sight point-to-point fixed wireless system antennas for use in certain coordination studies and interference assessment in the frequency range from 1 GHz to about 70 GHz

APEREC026V01: Recommendation ITU-R S.465-6 Receiving reference Earth station antenna pattern for earth stations in FSS in the frequency range from 2 to 31 GHz coordinated after 1993.

Appendix Q
Compatibility Analysis:
STRAPS User Uplink Interference into
Federal Inter-Satellite Service Return Link in the
25.25 – 27.5 GHz Band
(Prepared by Lockheed Martin Corporation for Elefante Group, Inc.)

SUMMARY

- Elefante Group is proposing to access the 25.25–27.5 GHz band for User uplink communications from User Terminals (UTs) to Stratospheric Platform Stations (STRAPS) on a co-Primary basis.

- This study assesses the compatibility of STRAPS User uplinks with Federal Inter-Satellite Service (ISS) Data Relay Systems (DRS) Return links (LEO to DRS GSO) which are authorized to operate in the 25.25–27.5 GHz band.

- Worst-case operating conditions are utilized for a bounding analysis: 1) All UTs simultaneously active and transmitting at power levels which achieve the highest data rates, 2) Maximum number of UTs operating to fully encompass the ISS DRS channel bandwidth and operating in the same polarization and 3) Four ISS Return links operating simultaneously with four independent LEO satellites.

- Bounding compatibility study results show that since the worst-case geometry is unlikely and would be a transient condition, the DRS I/N and percentage exceedance time Protection Criteria are met under worst-case operating conditions. No mitigation is necessary.

PURPOSE OF THE STUDY

Elefante Group is proposing that the 25.25–27.5 GHz band be made available for Stratospheric-Based Communications Services (SBCS), operating as a Fixed service, in the uplink direction. (While not the purpose of this study, Elefante Group proposes that the 25.25–27.5 GHz band also be considered for use in the downlink direction.) All or part of this band is allocated in the federal allocation to Fixed, Mobile, Earth Exploration Satellite (space-to-earth), Space Research (space-to-earth), and Inter-Satellite services, and Space Research and Inter-Satellite service in the non-federal allocation.

This study assesses the compatibility with Federal ISS DRS return links of STRAPS uplink transmissions from ground-based UTs to a multi-beam stratospheric platform.

This study assesses the potential for such interference into DRS GSO satellite to exceed the I/N Protection Criterion to determine if mitigation measures are necessary.

OPERATIONAL CHARACTERISTICS OF DRS GSO RECEIVERS

Receive characteristics and Protection Criteria of the DRS Return Link GSO receivers utilized for this study are based on the United States of America system characteristics in ITU-R SA1414-2 and shown in Table 1.

Table 1: ISS DRS Return Link GSO Receive Characteristics

Parameter	Value	Notes
Frequency Range	25.75 – 27.15 GHz	
Channel Bandwidth	<650 MHz	
Rx Antenna Gain	55.9 dBi	
Rx Antenna Pattern	ITU-R S.672	Nominal -25 dB sidelobe level
Receiver Noise Density	-139.2 dBW/MHz	870K
Protection Criteria	I/N < -10 dB (<0.1% time exceedance)	ITU-R SA.1155

OPERATIONAL CHARACTERISTICS OF SBCS

The SBCS will utilize STRAPS, UTs, and Gateway terminals to provide fixed services over a specific service area. Transmit characteristics of the Elefante Group STRAPS user uplinks utilized in this study are given in Appendix 1.

For this study, worst-case operating conditions are utilized for a bounding analysis prior to considering, if appropriate, risk-based interference assessment using probability and statistical methods:

1) All UTs simultaneously active and transmitting at power levels which achieve the highest data rates, i.e. EIRP Density of 20 dBW/MHz for Enterprise UTs and 12 dBW/MHz for Consumer UTs.

2) Maximum number of UTs for each frequency reuse ("color") operating simultaneously to full encompass the DRS Return Channel (not considering that coverage is provided by multiple channels "colors" which are spread across hundreds of beams and that the DRS return link allocated frequency range may not be fully occupied); i.e., to fully occupy 650 MHz of DRS return link bandwidth of 650 MHz, 195 UTs are assumed to be transmitting.

3) UT uplinks operating in the same polarization as the DRS Return link (Right Hand and Left Hand Circular Polarization authorized).

STUDY SCENARIO

Figure 1 illustrates the interference geometry applicable to this study.

- UTs located across the coverage area transmit User uplink signals to the associated STRAPS.
- DRS LEO satellite transmits the desired return link signal to the DRS GSO satellite.
- As the DRS LEO satellite moves through its orbit, there will be instances of time where the worst-case alignment for interference will occur when the DRS LEO satellite, DRS GSO satellite and STRAPS service area are co-aligned; i.e., as the DRS GSO satellite receiver tracks the DRS satellite, there will be instances of time when the DRS GSO receiver is pointed directly at the user terminals in the middle of the STRAPS service area.
- For the risk-based interference assessment, the total visible time of the DRS LEO from the DRS GSO is utilized to determine the percentage of time that I/N Protection Criterion is exceeded.
- From the authorized DRS GSO locations in ITU-R SA.1276-5, compatibility study is performed with the DRS GSO located at the two nominal CONUS East and West locations and at a center (currently not utilized) location as illustrated in Figure 2. The location of the corresponding STRAPS service area is selected with the highest elevation angles towards DRS GSO resulting in the maximum interference level.

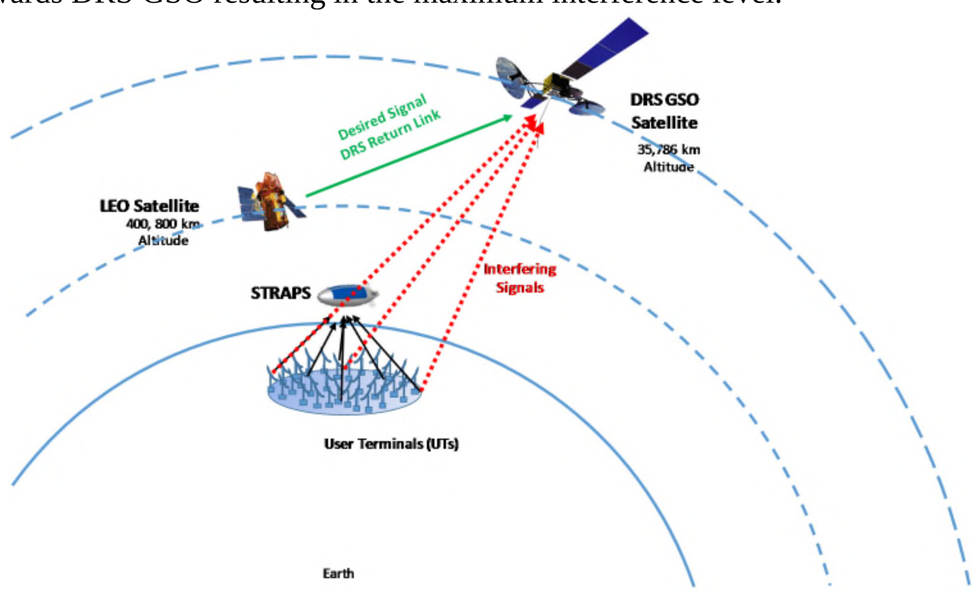


Figure 1: Interference Geometry

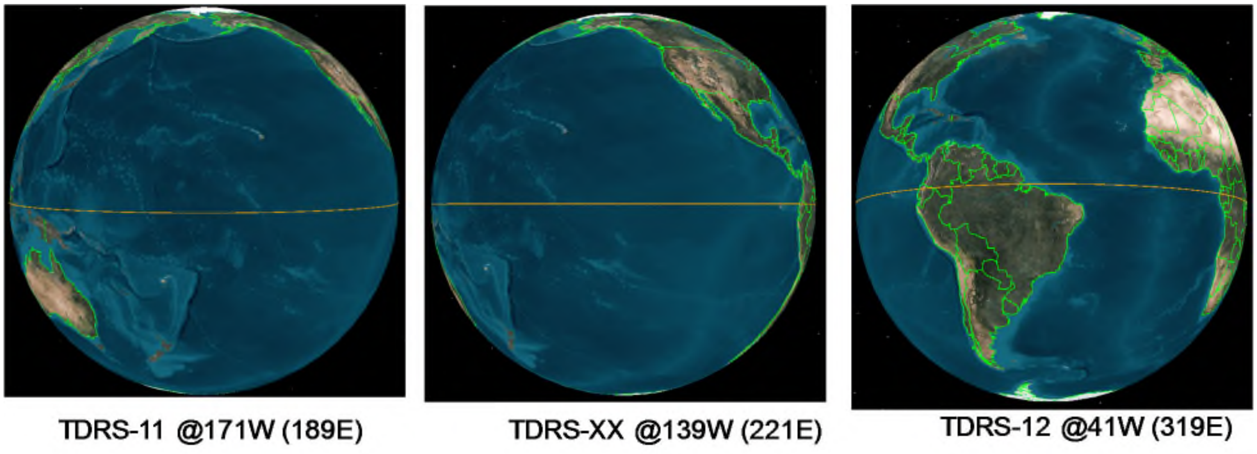


Figure 2: DRS GSO Orbital Locations & CONUS Field of View

STUDY METHODOLOGY

As illustrated in Figure 3, the study geometry starts by placing UTs in an evenly distributed grid across the STRAPS coverage area separated by the typical distance between the same colored beams.

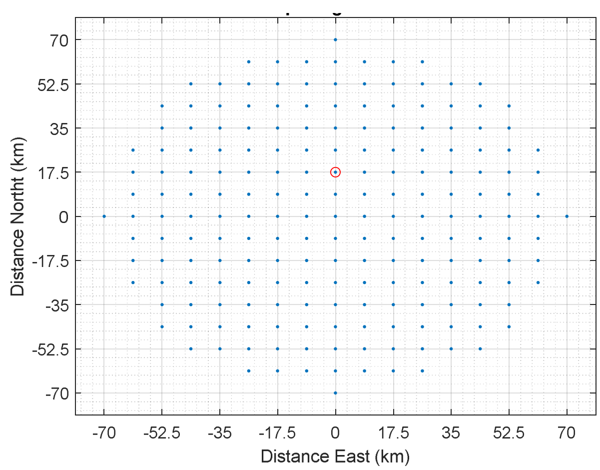


Figure 3: UT Ground Geometry

Figure 4 illustrates the worst-case alignment between the DRS LEO satellite, DRS GSO satellite and STRAPS service area. The DRS LEO orbit is offset to intersect through the center of the STRAPS coverage area which ensures that the UT at the center of the coverage area is in direct alignment with DRS LEO and DRS GSO which results in the highest level of interference.

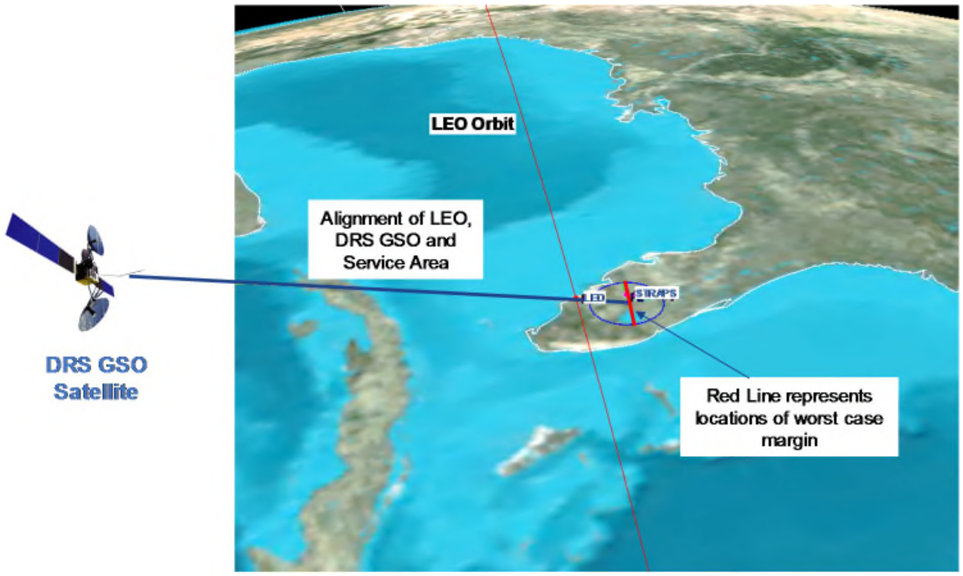


Figure 4: Worst-Case DRS & Coverage Area Alignment

The aggregate interference level into the DRS GSO is calculated by power summing the contribution from each of the UTs:

$$Io\left(\frac{dBW}{MHz}\right) = \sum_{i=1}^{N} [EIRP\ Density\ (\delta) - FSL - Gr\ (\beta)]_i$$

where:

N = Total number of UT's (195 to ensure DRS return link channel is covered)

δ = Angle off i'th UT (Interferer) boresight towards the DRS GSO

$Gr\ (\beta)$ = DRS GSO (Victim) receive antenna gain off boresight towards i'th UT

FSL = Free Space Loss between the i'th UT and DRS GSO

Therefore,

$$^{I}/_{N}\ Margin\ (dB) = {}^{I}/_{N}\ Threshold - (I_o - N_o)$$

where $^{I}/_{N}\ Threshold$ is the DRS Protection Criterion of -10 dB.

Although the worst-case operational conditions along with the worst-case alignment illustrated in Figure 4 are highly unlikely and a transient condition, a static compatibility analysis was performed for this geometry which indicated that DRS I/N Protection Criterion can be exceeded. Therefore, a risk-based time statistical analysis is performed by conducting a 30-day time domain simulation with a 6 second time increment to determine the percentage of time during which I/N Protection

Criterion is exceeded by comparing the total time I/N Protection Criterion is exceeded to the total visible time between the DRS LEO and DRS GSO.

The study is conducted for using bounding combinations of Enterprise and Consumer UTs, DRS GSO satellite locations and STRAPS service area locations.

Since the DRS GSO can maintain multiple simultaneous return links, the aggregate interference as received by four different DRS return links (400 & 800 km altitude with 30 and 60 deg inclination angle) and the aggregate time of exceeding the I/N Protection Criterion is determined for the compatibility study.

STUDY RESULTS

Results of the compatibility study are summarized in Table 2. Figure 5 illustrates example I/N time-domain results for Case 5.

Table 2: Compatibility Study Results

Case	DRS-GSO Location	Service Area Location	UT Type	% Time I/N <-10dB Protection Ratio is Met
1	171W	San Diego	Enterprise	99.9997%
2	41W	Florida	Enterprise	99.993%
3	139W	Florida	Enterprise	99.965%
4	139W	San Diego	Enterprise	100.000%
5	139W	Florida	Consumer	99.982%

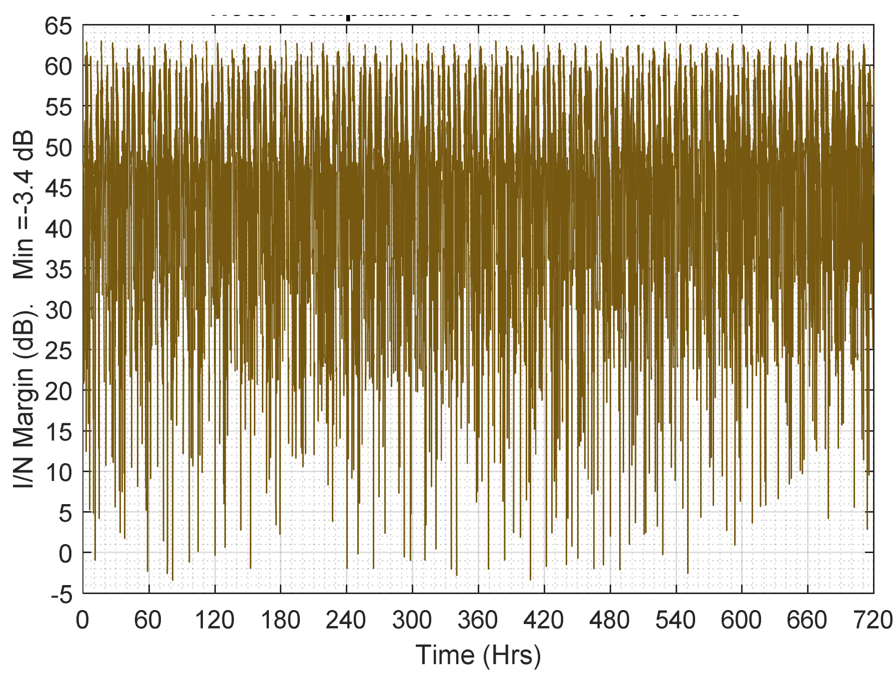


Figure 5: Case 5 Example Time Domain Simulation: I/N Margin vs Time

In all cases, even under the worst-case operational conditions, the % time exceedance is significantly less than the 0.1% I/N protection Criteria.

CONCLUSIONS

Utilizing worst-case operational conditions including all UTs transmitting continuously at the maximum power and occupying the entire DRS return channel bandwidth and assuming four simultaneous DRS return links, the DRS I/N Protection Criteria are met. No mitigation is necessary for shared operation between UTs and DRS ISS return link.

REFERENCES:

ITU-R S.1155: Protection Criterion related to the operation of data relay satellite systems

ITU-R SA 1414-2: Characteristics of data relay satellite systems

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

ITU-R SA.1276-5 Orbital locations of data relay satellites to be protected from the emissions of fixed service systems operating in the band 25.25-27.5 GHz

Appendix R
Compatibility Analysis:
STRAPS User Uplink Interference into
Earth Exploration Satellite Service (Space-to-Earth) Link in the
25.5 – 27.0 GHz Band
(Prepared by Lockheed Martin Corporation for Elefante Group, Inc.)

SUMMARY

- Elefante Group is proposing to access the 25.25–27.5 GHz band for User uplink communications from User Terminals (UTs) to Stratospheric Platform Stations (STRAPS) on a co-Primary basis.

- This study assesses the compatibility of STRAPS User uplinks with Earth Exploration Satellite Service (EESS) (Space-to-Earth) which are authorized to operate in the 25.5–27.0 GHz band.

- Worst-case operating conditions are utilized for a bounding analysis: 1) all UTs simultaneously active and transmitting at power levels which achieve the highest data rates and 2) maximum number of UTs operating to fully encompass the EESS allocated frequency range and operating in the same polarization.

- Bounding compatibility study results show that ensuring a minimum separation distance between UTs and EESS Earth Station (ES) will ensure that EESS Interference Threshold is met even under worst-case pointing assumptions of UTs pointing directly at the EESS ES boresight. Considering the relatively few locations of EESS ES's in the 26 GHz band and their general location away from highly populated areas, it is highly unlikely that a UT would be located close to and pointed at the EESS ES boresight however in such cases, Protection Criteria is met by coordination.

PURPOSE OF THE STUDY

Elefante Group is proposing that the 25.25–27.5 GHz band be made available for Stratospheric-Based Communications Services (SBCS), operating as a Fixed service, in the uplink direction. (While not the purpose of this study, Elefante Group proposes that the 25.25–27.5 GHz band also be considered for use in the downlink direction.) All or part of this band is allocated in the federal allocation to Fixed, Mobile, Earth Exploration Satellite (space-to-earth), Space Research (space-to-earth), and Inter-Satellite services, and Space Research and Inter-Satellite service in the non-federal allocation.

This study assesses the compatibility with Federal EESS (Space-to-Earth) links of STRAPS downlink transmissions from ground-based UTs to a multi-beam stratospheric platform.

This study assesses the potential for such interference into EESS ES to exceed the Interference Threshold so that the mitigation measures can be implemented to ensure that corresponding percent exceedance is met.

OPERATIONAL CHARACTERISTICS OF EESS SYSTEMS

Operational characteristics and Interference Threshold for 1) Solar Dynamics Observatory (SDO) GEO mission, 2) Satellite C (JPSS) Data Dissemination NGSO mission and 3) Satellite AZ (Generic) Stored Mission Data NGSO mission defined in Preliminary Draft New Report ITU-R SA.[EESS-METSAT CHAR], utilized for this study, are shown in Table 1, Table 2 and Table 3, respectively.

Table 1: Case: Solar Dynamics Observatory (SDO) GEO System Characteristics

Parameter	**Value**	**Notes**
Carrier Frequency	26.5 GHz	Note (1)
Data Rate	150 Mbps	Note (1)
Necessary Bandwidth	75 MHz	OQPSK based on above
Frequency Range	25.5 – 27.0 GHz	Note (1)
Mission	SDO Raw Data Downlink	Note (1)
EESS ES Location	White Sands, NM	WSC, Note (1)
Rx Antenna Gain	70.4 dBi	Note (1)
Rx Antenna Pattern	ITU-R F.699	Envelopes ITU-RR Appendix 7, Annex 3
Minimum Elevation Angle	3 deg	Assumed, worst-case
EESS ES Receiver Noise Temperature	-142 dBW/MHz	460.3K
Interference threshold (long-term, not to be exceeded >20% time)	-144.6 dBW/10 MHz (-154.6 dBW/MHz)	ITU-R SA.1160-3
Interference threshold (short-term, not to be exceeded >0.25% time)	-133.0 dBW/10 MHz (-143.0 dBW/MHz)	ITU-R SA.1160-3

(1) Annex 8 to Working Party 7B Chairman’s Report 298-E, PRELIMINARY DRAFT NEW REPORT ITU-R SA.[EESS-METSAT CHAR] Characteristics to be used for assessing interference to systems operating in the Earth exploration-satellite and meteorological-satellite services, and for conducting sharing studies

Table 2: Case: Satellite C (JPSS) Data Dissemination NGSO System Characteristics

Parameter	**Value**	**Notes**
Carrier Frequency	25.7034 GHz	Note (1)
Encoded Data Rate	300 Mbps	Note (1)
Necessary Bandwidth	300 MHz	Note (1)
Frequency Range	25.5 – 27.0 GHz	Note (1)
Mission	Sat C Data Dissemination	Note (1)
Orbit Altitude	824 km	Note (1)
Orbit Inclination	98.7 deg	Note (1)
EESS ES Location	Fairbanks, AK	Note (1)
Rx Antenna Gain	67.0 dBi	Note (1)
Rx Antenna Pattern	ITU-R S.465-6	Note (1)
Minimum Elevation Angle	5 deg	Note (1)
EESS ES Receiver Noise Temperature	-143 dBW/MHz	363K
Interference threshold (long-term, not to be exceeded >20% time)	-140.0 dBW/10 MHz (-150.0 dBW/MHz)	ITU-R SA1026-5
Interference threshold (short-term, not to be exceeded >0.0125% time)	-116.0 dBW/10 MHz (-126.0 dBW/MHz)	ITU-R SA1026-5

(2) Annex 8 to Working Party 7B Chairman's Report 298-E, PRELIMINARY DRAFT NEW REPORT ITU-R SA.[EESS-METSAT CHAR] Characteristics to be used for assessing interference to systems operating in the Earth exploration-satellite and meteorological-satellite services, and for conducting sharing studies

Table 3: Case: Satellite AZ (Generic) Stored Mission Data NGSO System Characteristics

Parameter	Value	Notes
Carrier Frequency	26.817 and 25.875 GHz	Note (1)
Encoded Data Rate	Up to 2000 Mbps	Note (1)
Necessary Bandwidth	2 x 750 MHz	Note (1)
Frequency Range	25.5 – 27.0 GHz	Note (1)
Mission	Sat AZ Stored Mission Data	Note (1)
Orbit Altitude	750 km	Note (1)
Orbit Inclination	98.7 deg	Typical polar
EESS ES Location	Worldwide (Generic)	Note (1)
Rx Antenna Gain	56.0 dBi & 63 dBi	Two cases
Rx Antenna Pattern	ITU-R S.465-6	Note (1)
Minimum Elevation Angle	5 deg	Note (1)
EESS ES Receiver Noise Temperature	-142.6 dBW/MHz	395K
Interference threshold (long-term, not to be exceeded >20% time)	-140.0 dBW/10 MHz (-150.0 dBW/MHz)	ITU-R SA1026-5
Interference threshold (short-term, not to be exceeded >0.0125% time)	-116.0 dBW/10 MHz (-126.0 dBW/MHz)	ITU-R SA1026-5

(3) Annex 8 to Working Party 7B Chairman's Report 298-E, PRELIMINARY DRAFT NEW REPORT ITU-R SA.[EESS-METSAT CHAR] Characteristics to be used for assessing interference to systems operating in the Earth exploration-satellite and meteorological-satellite services, and for conducting sharing studies

OPERATIONAL CHARACTERISTICS OF SBCS

The SBCS will utilize STRAPS, UTs, and Gateway terminals to provide fixed services over a specific service area. Transmit characteristics of the Elefante Group STRAPS user uplinks utilized in this study are given in Appendix 1.

For this study, worst-case operating conditions are utilized for a bounding analysis prior to considering, if appropriate, risk-based interference assessment using probability and statistical methods:

1) All UTs simultaneously active and transmitting at power levels which achieve the highest data rates, i.e. EIRP Density of 20 dBW/MHz for Enterprise UTs and 12 dBW/MHz for Consumer UTs.

2) Maximum number of UTs for each frequency reuse ("color") operating simultaneously to fully encompass the EESS allocated frequency range and operating in the same polarization

(not considering that coverage is provided by multiple channels “colors” which are spread across hundreds of beams).

3) UT uplinks operating in the same polarization as the EESS link (Right Hand and Left Hand Circular Polarization authorized).

STUDY SCENARIO

Figure 1 illustrates the interference geometry applicable to this study.

- UTs located across the coverage area transmit User uplink signals to the associated STRAPS.
- EESS satellite vehicle transmits the desired signal to the EESS ES.
- For a given STRAPS and EESS ES location near one of the UTs, as the EESS satellite transverses through its orbit, there will be instances of time during which the worst-case alignment for interference will occur when the EESS satellite, EESS ES and the boresight of the nearby UT are nearly aligned, i.e. as the EESS ES receiver tracks the EESS satellite, there will be instances of time when the EESS ES receiver is pointed almost directly at the closely located UT.
- The total visible time of the EESS satellite from the EESS ES is utilized to determine the percentage of time that the Interference Threshold is exceeded and compared to the allowable time exceedance.
- The long-term interference threshold is significantly lower than the short-term interference threshold; even though the percentage time of exceedance is much lower for the short-term interference threshold, the separation distance between the EESS Receiver and the UT is driven by the long-term interference threshold therefore the compatibility study results are based on the long-term interference threshold Protection Criteria.

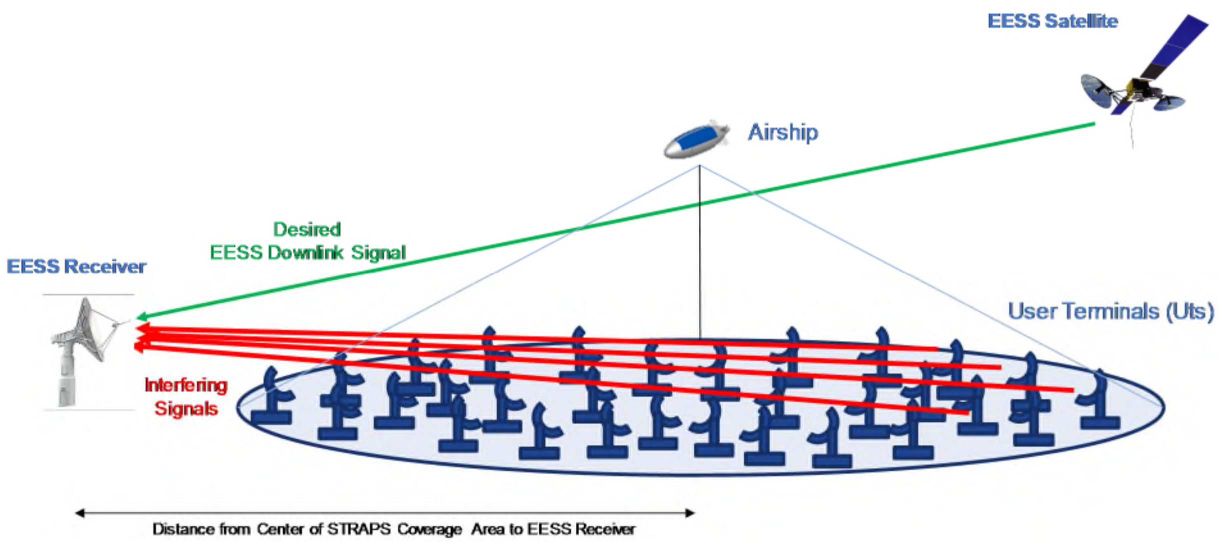


Figure 1: Interference Geometry

STUDY METHODOLOGY

As illustrated in Figure 2, the study geometry starts by placing UTs in an evenly distributed grid across the STRAPS coverage area separated by the typical distance between the same colored beams.

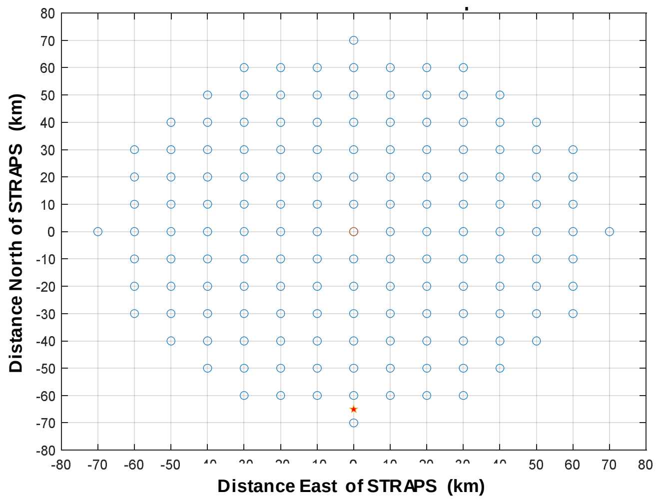


Figure 2: UT Ground Geometry

For a given STRAPS and EES ES location near one of the UTs, the aggregate interference level into the EESS ES is calculated by power summing the contribution from each of the UTs:

$$Io\left(\frac{dBW}{MHz}\right) = \sum_{i=1}^{N} [EIRP\ Density\ (\delta) - FSL - Gr\ (\beta)]_i$$

where:

N = Total number of UT's (135 to ensure EESS allocated bandwidth is encompassed)

δ = Angle off i'th UT (Interferer) boresight towards the EESS ES

$Gr\ (\beta)$ = EESS ES (Victim) receive antenna gain off boresight towards i'th UT

FSL = Free Space Loss between the i'th UT and EESS ES

Therefore,

$$Interference\ Margin\ (dB) = \ Io - \ Interference\ Threshold$$

The calculation is repeated over the full visible orbital time period for the EESS mission to determine the fraction of time that the Interference Threshold is exceeded for each EESS ES location and compared to the allowable time exceedance.

STUDY RESULTS

As an illustration of the study methodology, the yellow and red areas in Figure 3 indicate the portions of time during the EESS satellite orbit when the interference into the EESS ES exceeds the Interference Threshold which is then used to determine the percentage of time exceedance as a function of the visible time. For the illustrated case, the EESS ES was located at 1.5 km north of the UT located at the southernmost edge the STRAPS coverage area which represents the worst-case relative location where the long term 20% allowable exceedance time is met.

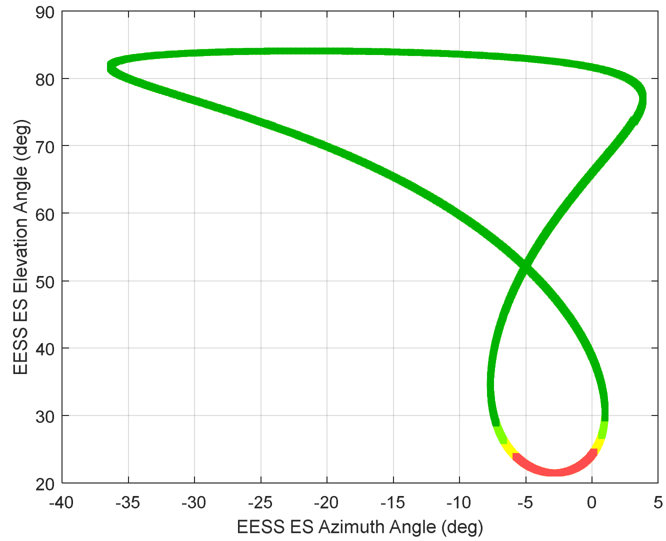


Figure 3: Worst-Case Results - EESS ES Interference Angles for LRO Case (EESS ES 1.5 km North of the Southernmost Enterprise UTs)

Results of the Compatibility Analysis for EESS ES placement anywhere within the STRAPS coverage area are shown in Figure 4. These results are for the SDO case with a grid of Enterprise UTs representing the highest EIRP density. The red and orange colored areas indicate keep out zones for the EESS ES to meet the long-term Interference Threshold while meeting the <20% exceedance criterion.

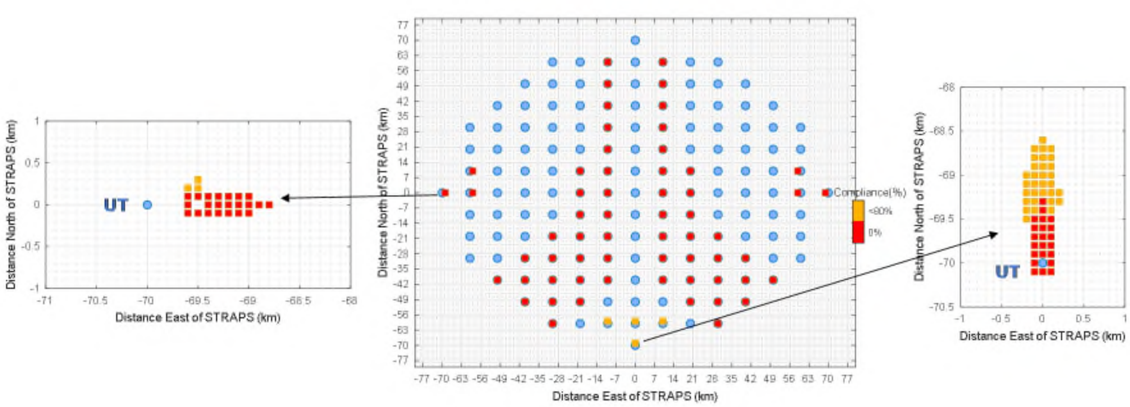


Figure 4: LRO Case - EESS ES Keep Out Areas within STRAPS Coverage Area (Enterprise UTs)

The LRO case results indicate that the Protection Criteria are met at all locations except if the EESS ES is located close to and in front of the boresight of the Enterprise UT. At the worst-case

location at the southmost portion of the STRAPS coverage area, the Protection Criteria are met by ensuring that the Enterprise UT is not placed within 1.5 km and facing the EESS ES.

As the detailed inserts in Figure 4 indicate, if the EESS ES is located slightly offset from the ES boresight, the worst-case distance to meet the Protection Criteria is significantly reduced.

Results for Sat C (JPSS) case, Sat Z (Low Receive Gain) and Sat Z (High Receive Gain) are shown in Figure 5, Figure 6 and Figure 7, respectively for Enterprise UTs indicating the worst-case keep out distance of 2.0 km with the UT placed facing the EESS ES.

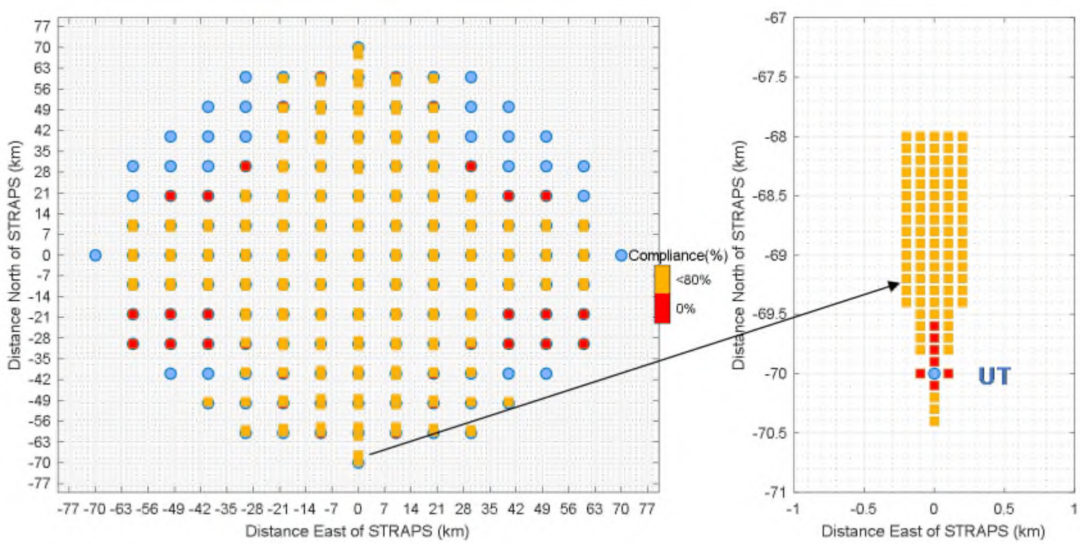


Figure 5: Sat C (JPSS) Case - EESS ES Keep Out Areas within STRAPS Coverage Area (Enterprise UTs)

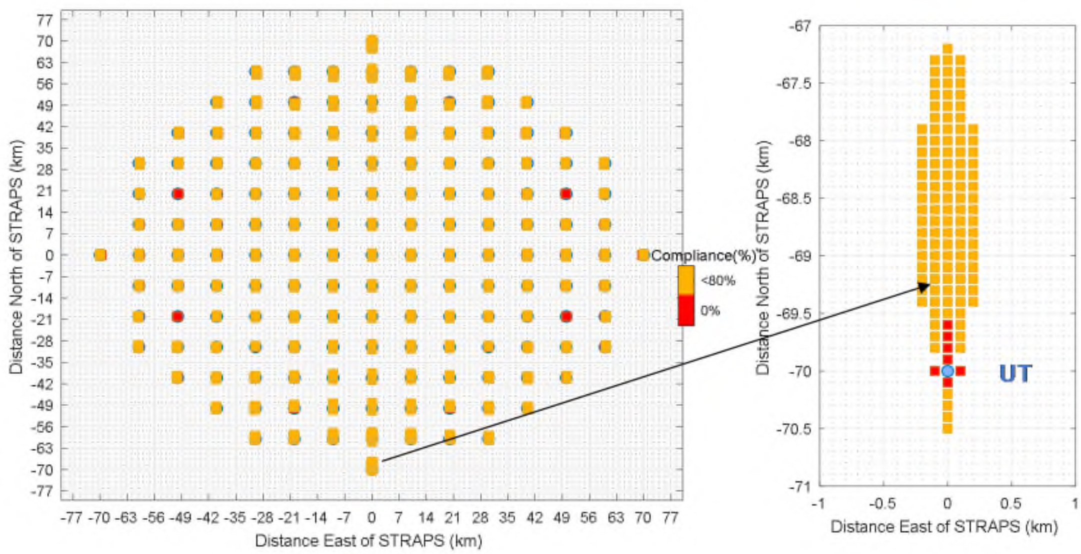


Figure 6: Sat Z (Low gain) Case - EESS ES Keep Out Areas within STRAPS Coverage Area (Enterprise UTs)

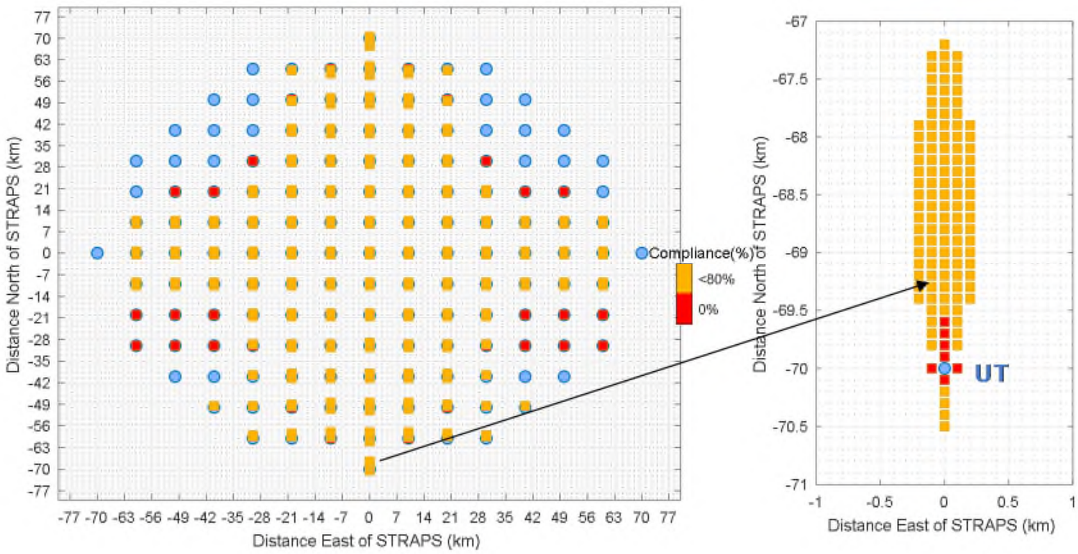


Figure 7: Sat Z (Hi Gain) Case - EESS ES Keep Out Areas within STRAPS Coverage Area (Enterprise UTs)

Similar results are obtained for Consumer UTs; the corresponding worst-case results at the southmost location are shown in Figure 8. For the worst-case EESS ES orientation with the UT facing the EESS ES, the Protection Criteria are met by ensuring that the Consumer UT is not placed within 3.2 km. Like the Enterprise UT case, the worst-case distance to meet the Protection Criteria is significantly reduced if the UT is located slightly offset from the ES boresight.

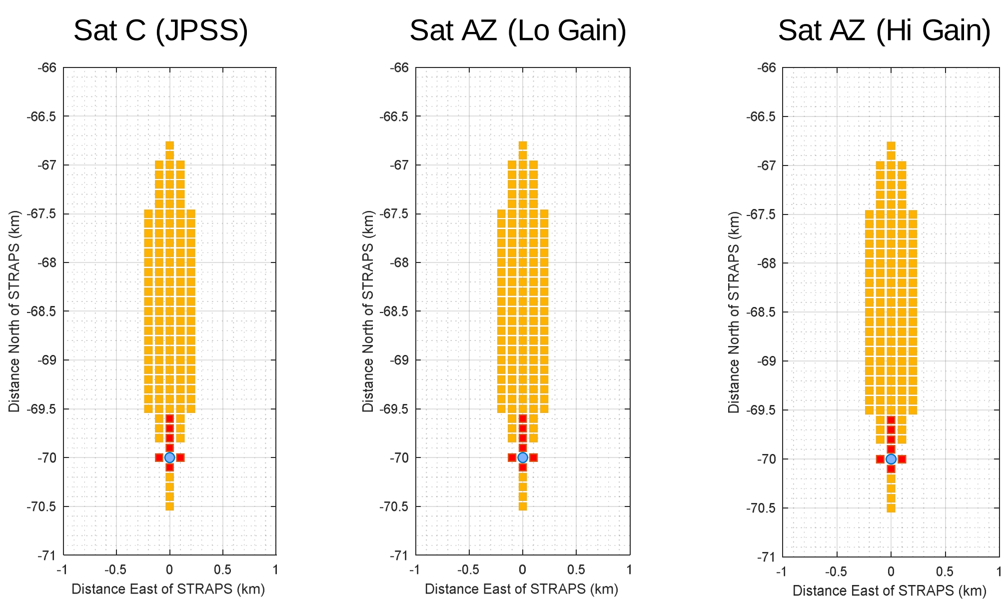


Figure 8: Compatibility Analysis Worst-Case Results (Consumer UTs)

In all cases, Protection Criteria are also met for all EES ES locations outside the STRAPS coverage area.

CONCLUSIONS

For each of the analyzed EESS missions, a keep out zone for Enterprise and Consumer UTs has been determined to ensure that EESS Protection Criteria are met under worst-case operating conditions and assuming that EESS ES could be located within the STRAPS coverage area. In general, the EESS Earth Stations currently operating in the 26 GHz frequency are located in somewhat lower populated areas where UT placement close to EESS ES is unlikely.

EESS Protection Criteria is met under all conditions if the EESS ES is outside the 70 km STRAPS coverage area. EESS Protection Criteria is also met by ensuring compliance to the keep out zones if the UT is located close to the EESS ES. Additional flexibility is obtained by the ability to locate the STRAPS to minimize the likelihood of worst-case boresight alignment of the closest UT with the EESS ES.

In a rare circumstance, coordination may be required the first level of which would include the SBCS getting information about EESS missions including basic EESS satellite orbital parameters, EESS Earth Stations being utilized and frequency bands so that any closely located UTs can avoid use of overlapping frequencies and polarization during short periods of time over each orbital period.

REFERENCES:

ITU-R SA.1026-5: Aggregate interference criteria for space-to-Earth data transmission systems operating in the Earth exploration-satellite and meteorological-satellite services using satellites in low-Earth orbit

ITU-R SA.1160-3: Aggregate interference criteria for data transmission systems in the Earth exploration-satellite and meteorological-satellite services using satellites in the geostationary orbit

ITU-R F.699-7: Reference radiation patterns for fixed wireless system antennas for use in coordination studies and interference assessment in the frequency range from 100 MHz to about 70 GHz

ITU-R S.465-6: Reference radiation pattern for earth station antennas in the fixed-satellite service for use in coordination and interference assessment in the frequency range from 2 to 31 GHz

Appendix S
Compatibility Analysis:
STRAPS User Uplink Interference into
Federal Space Research Service (Space-to-Earth) Link in the
25.25 – 27.5 GHz Band
(Prepared by Lockheed Martin Corporation for Elefante Group, Inc.)

SUMMARY

- Elefante Group is proposing to access the 25.25–27.5 GHz band for User uplink communications from User Terminals (UTs) to Stratospheric Platform Stations (STRAPS) on a co-Primary basis.

- This study assesses the compatibility of STRAPS User uplinks with Federal Space Research Service (SRS) (Space-to-Earth) which are authorized to operate in the 25.5–27.0 GHz band.

- Worst-case operating conditions are utilized for a bounding analysis: 1) all UTs simultaneously active and transmitting at power levels which achieve the highest data rates and 2) maximum number of UTs operating to fully encompass the SRS allocated frequency range and operating in the same polarization.

- Bounding compatibility study results show that ensuring a minimum 2.2 km separation distance between UTs and SRS Earth Station (ES) will ensure that SRS Protection Criteria are met even under worst-case pointing assumptions of UTs pointing directly at the SRS ES boresight. Considering the relatively few and remote locations of SRS ESs, it is highly unlikely that a UT would be located close to and pointed at the SRS ES boresight however in such cases, Protection Criteria are met by coordination.

PURPOSE OF THE STUDY

Elefante Group is proposing that the 25.25–27.5 GHz band be made available for Stratospheric-Based Communications Services (SBCS), operating as a Fixed service, in the uplink direction. (While not the purpose of this study, Elefante Group proposes that the 25.25–27.5 GHz band also be considered for use in the downlink direction.) All or part of this band is allocated in the federal allocation to Fixed, Mobile, Earth Exploration Satellite (space-to-earth), Space Research (space-to-earth), and Inter-Satellite services, and Space Research and Inter-Satellite service in the non-federal allocation.

This study assesses the compatibility with Federal SRS (Space-to-Earth) links of STRAPS downlink transmissions from ground-based UTs to a multi-beam stratospheric platform.

This study assesses the potential for such interference into SRS ES to exceed the I/N Protection Criterion so that the mitigation measures can be implemented to ensure that corresponding percent exceedance Protection Criterion is met.

OPERATIONAL CHARACTERISTICS OF EESS SYSTEMS

Operational characteristics and Protection Criteria for the LRO (Lunar Reconnaissance Orbiter) and James West Space Telescope (JWST) SRS systems defined in ITU-R SA.1862-0, utilized for this study, are shown in Table 1 and Table 2.

Table 1: Case: LRO System Characteristics

Parameter	Value	Notes
Center Frequency	25.65 GHz	ITU-R SA.1862-0
Data Rate	50 Mbps	ITU-R SA.1862-0
Channel Bandwidth	100 MHz	2 x 50 Mbps OQPSK
Frequency Range	25.5 – 27.0 GHz	Based on above
Mission	LRO Lunar	ITU-R SA.1862-0
SRS ES Location	White Sands, NM	WSC
Rx Antenna Gain	71.3 dBi	ITU-R SA.1862-0
Rx Antenna Pattern	ITU-R S.465-6	Note (1)
Minimum Elevation Angle	5 deg	Note (1)
Protection Criteria Unmanned Missions (0.1% exceedance) Manned Missions (0.001% exceedance)	< -156 dBW/MHz (I/N <-6 dB, No = -150 dBW/MHz,)	ITU-R SA.609-2

Table 2: Case: JWST System Characteristics

Parameter	Value	Notes
Center Frequency	25.65 GHz	ITU-R SA.1862-0
Data Rate	56 Mbps	ITU-R SA.1862-0
Channel Bandwidth	112 MHz	2 x 56 Mbps OQPSK
Frequency Range	25.5 – 27.0 GHz	ITU-R SA.1862-0
Mission	Lagrangian L2 Halo	ITU-R SA.1862-0
SRS ES Location	Goldstone, CA	
Rx Antenna Gain	77.8 dBi	Note (1)
Rx Antenna Pattern	ITU-R SA.509	Note (1)
Minimum Elevation Angle	5 deg	Note (1)
Protection Criteria Unmanned Missions (0.1% exceedance) Manned Missions (0.001% exceedance)	< -156 dBW/MHz (I/N <-6 dB, No = -150 dBW/MHz,)	ITU-R SA.609-2

(1) Annex 17 to Working Party 5C Chairman’s Report 410-E, Working Document towards Preliminary Draft New Report ITU-R [HAPS-25GHz], Sharing and compatibility studies of HAPS systems in the 24.25-27.5 GHz range

OPERATIONAL CHARACTERISTICS OF SBCS

The SBCS will utilize STRAPS, UTs, and Gateway terminals to provide fixed services over a specific service area. Transmit characteristics of the Elefante Group STRAPS user uplinks utilized in this study are given in Appendix 1.

For this study, worst-case operating conditions are utilized for a bounding analysis prior to considering, if appropriate, risk-based interference assessment using probability and statistical methods:

1) All UTs simultaneously active and transmitting at power levels which achieve the highest data rates, i.e. EIRP Density of 20 dBW/MHz for Enterprise UTs and 12 dBW/MHz for Consumer UTs.

2) Maximum number of UTs for each frequency reuse ("color") operating simultaneously to fully encompass the SRS allocated frequency range and operating in the same polarization (not considering that coverage is provided by multiple channels "colors" which are spread across hundreds of beams and that the SRS link allocated frequency range is likely not fully occupied since the SRS channel bandwidths are typically smaller).

3) UT uplinks operating in the same polarization as the SRS link (Right Hand and Left Hand Circular Polarization authorized).

STUDY SCENARIO

Figure 1 illustrates the interference geometry applicable to this study.

- UTs located across the coverage area transmit User uplink signals to the associated STRAPS.
- SRS NGSO vehicle transmits the desired signal to the SRS ES.
- For a given STRAPS and SRS ES location near one of the UTs, as the SRS NGSO moves relative to earth, there will be instances of time during which the worst-case alignment for interference will occur when the SRS NGSO, SRS ES and the boresight of the nearby UT are nearly aligned, i.e. as the SRS ES receiver tracks the SRS NGSO, there will be instances of time when the SRS ES receiver is pointed almost directly at the closely located UT.
- The total visible time of the SRS NGSO from the SRS ES is utilized to determine the percentage of time that I/N Protection Criterion is exceeded and compared to the <0.1% Protection Criterion.

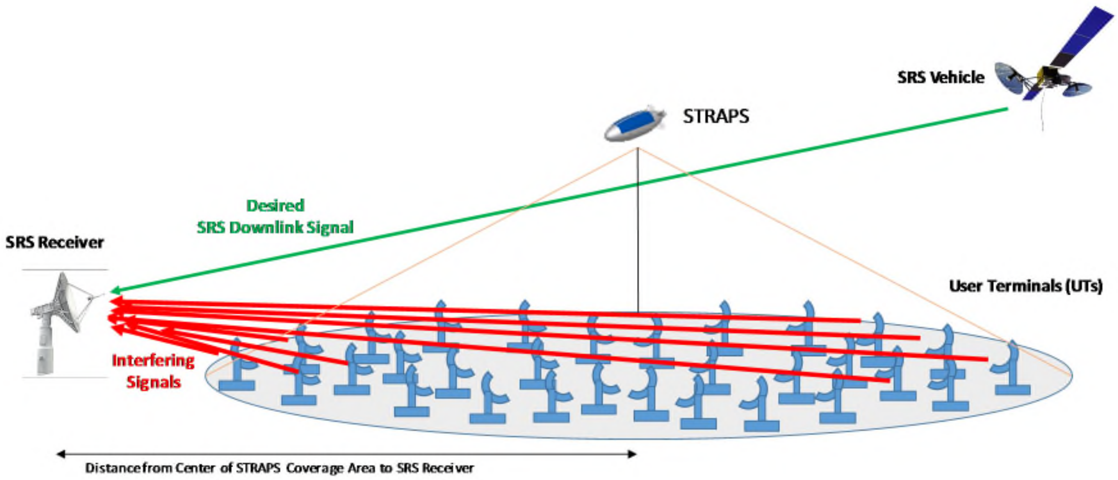


Figure 1: Interference Geometry

STUDY METHODOLOGY

As illustrated in Figure 2, the study geometry starts by placing UTs in an evenly distributed grid across the STRAPS coverage area separated by the typical distance between the same colored beams.

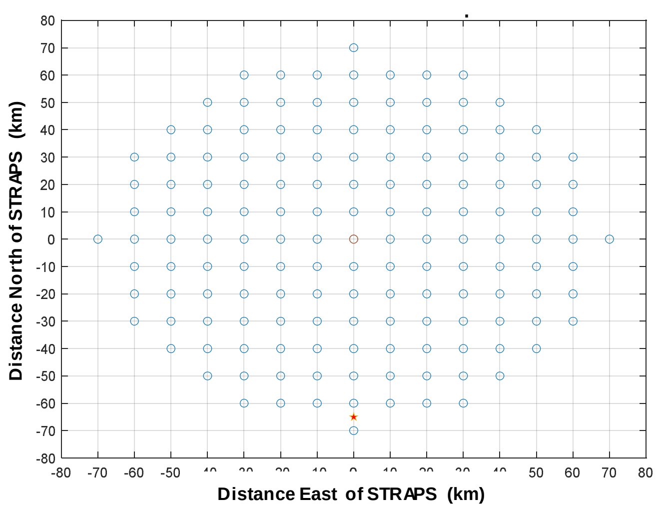


Figure 2: UT Ground Geometry

For a given STRAPS and SRS ES location near one of the UTs, the aggregate interference level into the SRS ES is calculated by power summing the contribution from each of the UTs:

$$Io\left(\frac{dBW}{MHz}\right) = \sum_{i=1}^{N} [EIRP\ Density\ (\delta) - FSL - Gr\ (\beta)]_i$$

where:

N = Total number of UT's (135 to ensure SRS allocated bandwidth is encompassed)

δ = Angle off i'th UT (Interferer) boresight towards the SRS ES

$Gr\ (\beta)$ = SRS ES (Victim) receive antenna gain off boresight towards i'th UT

FSL = Free Space Loss between the i'th UT and SRS ES

Therefore,

$$I/_N\ Margin\ (dB) = I/_N\ Threshold - (I_o - N_o)$$

where $I/_N\ Threshold$ is the SRS Protection Criterion of -6 dB.

The calculation is repeated over the full visible orbital time period for the SRS mission to determine the fraction of time that the I/N Protection Criterion is exceeded for each SRS ES location. All SRS ES locations at which the 0.1% exceedance criterion is met are deemed as possible SRS ES locations at which the Protection Criteria are fully met.

STUDY RESULTS

As an illustration of the study methodology, the red areas in Figure 3 indicate the portions of time during the 30-day lunar orbit when the interference into the EESS ES exceeds the I/N Protection Criterion which is then used to determine the percentage of time exceedance as a function of the visible time. For the illustrated case, the EESS ES was located 71 km east of the center of the STRAPS coverage area and the associated percentage time of compliance was 98.5%

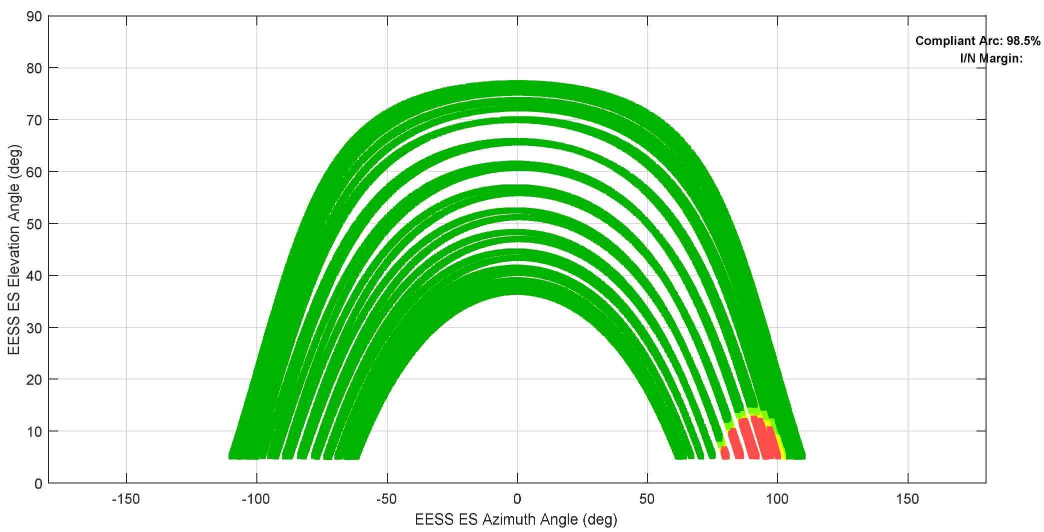


Figure 3: Example Results - EESS ES Interference Angles for LRO Case (EESS ES at 71 km East of Coverage Area, Enterprise UTs)

Initial result of the Compatibility Analysis for SRS placement anywhere within the STRAPS coverage area is shown in Figure 4. These results are for a 30-day simulation of the LRO case with a grid of Enterprise UTs representing the highest EIRP density. The colored areas indicate keep out zones for the SRS ES to meet the I/N Protection Criterion while meeting the <0.1% exceedance criterion.

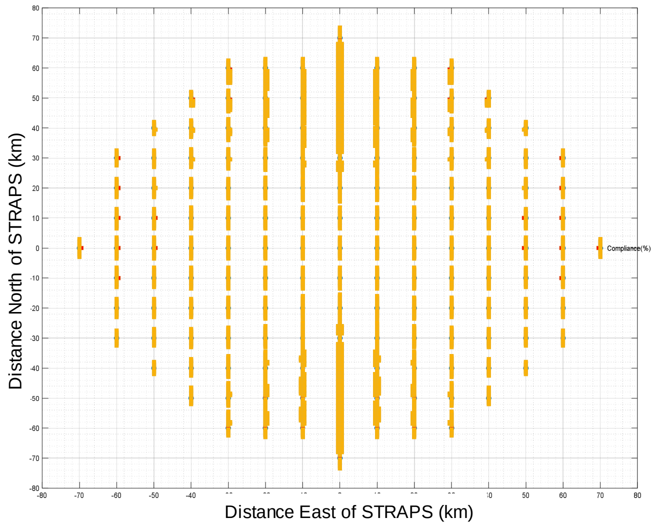


Figure 4: SRS Keep Out Areas within STRAPS Coverage Area (Enterprise UTs)

The results indicate that UT placement relative to the SRS ES is feasible (with restrictions) while still meeting the Protection Criteria, however such a scenario is highly unlikely since SRS ES are generally located in less populated areas, in this case, White Sands, NM. Therefore, a more realistic scenario of SRS ES being located outside of the STRAPS coverage area is examined.

For the LRO case, it was noted that relative SRS ES placement in the East-West direction was worst-case and, therefore, the percentage of compliance as a function of distance from the center of a STRAPS coverage area was examined. Figure 5 illustrates the results which demonstrate that if the SRS ES is at least 2.2 km from the edge of the 70 km radius STRAPS coverage area then SRS Protection Criteria are fully met.

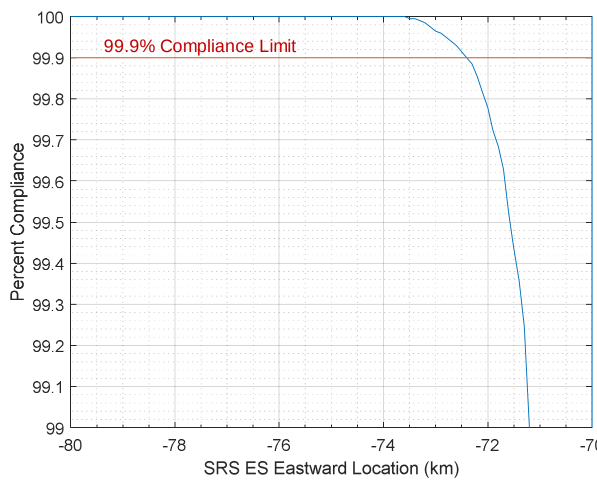


Figure 5: Percent Compliance Versus Distance from Center of STRAPS Coverage Area (Enterprise UTs)

A comparative study was also performed for Consumer UTs which have 8 dB lower EIRP density which decreases the interference level however the percentage of time of exceedance is longer due

to the broader beam. However, the result as illustrated in Figure 6 show the same 2.2 km minimum separation distance, as the Enterprise UT case.

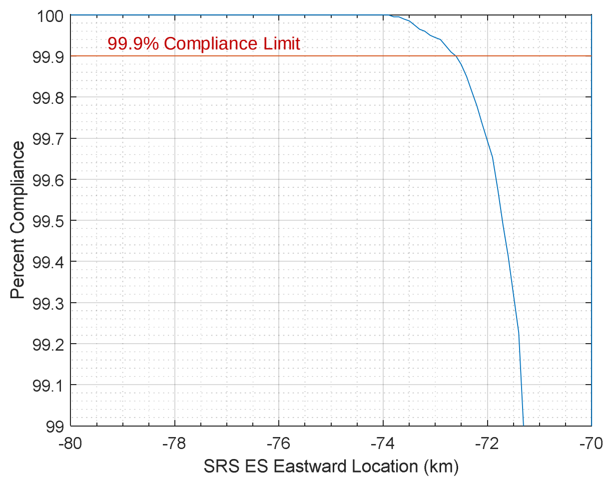


Figure 6: Percent Compliance Versus Distance from Center of STRAPS Coverage Area (Consumer UTs)

Although the detailed statistics might be slightly difference, similar results for the minimum distance are expected for the JWST case with the SRS ES located at Goldstone, CA.

CONCLUSIONS

For a given SRS mission, a separation distance of 2.2 km between Enterprise or Consumer UTs and SRS ES can be maintained to ensure that SRS I/N Protection Criteria are met even under worst-case operating conditions. Considering the relatively few and remote locations of SRS ESs, maintaining a separation distance between an SRS and STRAPS service area will ensure I/N Protection Criteria are met. Additional flexibility is obtained by the ability to locate the STRAPS to minimize the likelihood of worst-case boresight alignment of the closest UT with the SRS ES.

In the highly unlikely circumstance of UT placement close to the SRS ES, coordination may be required the first level of which would include the SBCS getting information about SRS missions including basic SRS vehicle orbital parameters, SRS Earth Stations being utilized and frequency bands so that any closely located UTs can avoid use of overlapping frequencies and polarization during short periods of time over each visible period.

REFERENCES:

ITU-R SA.1862-0: Guidelines for efficient use of the band 25.5-27.0 GHz by the Earth exploration-satellite service (space-to-Earth) and space research service (space-to-Earth)

ITU-R SA.609-2: Protection criteria for radiocommunication links for manned and unmanned near-Earth research satellites

ITU-R S.465-6: Reference radiation pattern for earth station antennas in the fixed-satellite service for use in coordination and interference assessment in the frequency range from 2 to 31 GHz

Appendix T
Compatibility Analysis:
STRAPS User Uplink Interference into
Other STRAPS User Uplink
(Peer to Peer Analysis)
21.5 – 23.6 GHz Band
(Prepared by Lockheed Martin Corporation for Elefante Group, Inc.)

SUMMARY

- Elefante Group is proposing that the 21.5–23.6 GHz band be available for User uplink communications from User Terminals (UTs) to Stratospheric Platform Stations (STRAPS) on a co-Primary basis.

- This study assesses the compatibility of STRAPS User uplinks with other STRAPS User uplinks authorized to operate in the 21.5–23.6 GHz band.

- Worst-case operating conditions and interference geometry are utilized for a bounding analysis which include: 1) UTs transmitting at a level equal to the maximum proposed EIRP across the entire allocated band (complete overlap in bandwidth at all locations within service areas regardless of actual implementation of uplink beams, 2) STRAPS are located within their control volumes in worst case alignment to result in the maximum level of interference.

- Bounding analysis results show that the proposed STRAPS I/N Protection Criteria is met even under worst-case operating conditions and interference geometry at separation distances permitting at minimum 61% overlap between STRAPS service areas with the same radius, and likely could be coordinated to yield overlaps up to 70% and higher.

- This high degree of overlap permits multiple STRAPS from one or more operators to serve the same market in the same spectrum on a non-exclusive basis.

- The results of this bounding-scenario analysis provide strong indications that risk-based assessments, coordination, and mitigation would readily lead to even more overlap without harmful interference.

PURPOSE OF THE STUDY

Elefante Group is seeking access to the 21.5–23.6 GHz band for Stratospheric-Based Communications Services ("SBCS"), operating as a Fixed service, in the uplink direction. (While not the purpose of this study, Elefante Group proposes that the 21.5–23.6 GHz band also be considered for use in the downlink direction.) All or part of this band is allocated in the federal and non-federal allocation to Fixed, Mobile, Inter-Satellite services, Earth Exploration Satellite (passive), Space Research (passive), Radio Astronomy (passive).

This study assesses the compatibility of SBCS-UT uplinks to a STRAPS with other nearby STRAPS receiving uplinks, using two differing SBCS reference designs to illustrate compatibility.

(Lockheed Martin has separately looked at other compatibility scenarios in the 25.25–27.5 GHz band.)

This study assesses the potential for such interference, assuming worst case operating conditions, to exceed the I/N Protection Criterion to determine if harmful interference is present and whether performance of a risk-based analysis and/or mitigation measures should be explored.

OPERATIONAL CHARACTERISTICS OF SBCS

The SBCS will utilize STRAPS, UTs, and Gateway terminals to provide fixed services over a specific service area. Transmit characteristics of the Elefante Group SBCS system utilized in this study are given in Appendix A.

For this study, worst-case operating conditions are utilized for a bounding analysis prior to considering, if appropriate, risk-based interference assessment using probability and statistical methods:

1) STRAPS are registered to a nominally fixed location specified by latitude, longitude, and altitude, and are authorized to operate only within a cylindrical control volume centered on the nominally fixed location and specified by a height and radius. They serve UTs within a service area specified by a radius around the latitude and longitude of the nominally fixed location.
2) UTs transmit at a maximum EIRP density of 20 dB(W/MHz), a limit proposed for SBCS to promote compatibility with other services in the same bands to reduce the need for separate coordination with them.
3) Interfering UTs transmitting intentionally to one STRAPS and Victim receivers on a different STRAPS are assumed to fully overlap each other in bandwidth and operate in the same polarization (not taking into account that coverage is provided by multiple channels "colors" which are spread across hundreds of beams and that the channels used by specific Interferer UTs may not overlap the channels or use the same polarization used in the STRAPS receive beam presented to them).

Table 1 provides the performance for the Elefante Group proposed STRAPS and those of a notional System 6 being proposed through the International Telecommunications Union work on high altitude platform station as a basis for system performance assessments.

Table 1: STRAPS Performance Characteristics for Interference Analysis

Associated SBCS System	EG Reference Design		System 6
Nominal altitude (km)	19.8	19.8	23
Minimim altitude (km)	18.3	18.3	20
Maximum altitude (km)	21.3	21.3	26
Service area	70	50	50

Associated SBCS System	EG Reference Design		System 6
Receive beam gain (dBi)	24.9, 28, 33[1]	24.9, 28, 33	28.1
Receive beam pattern	ITU-R F.1245	ITU-R F.1245	ITU-R F.1891
Receiver Noise Density (dBW/MHz)	-140.5	-140.5	-140.8
Protection Criterion I/N (dB)[2]	-6	-6	-6

OPERATIONAL CHARACTERISTICS OF SBCS USER TERMINALS

Receive characteristics and Protection Criterion for representative UT for two systems are presented in Table 2. To consider compatibility between the Elefante Group reference design and a different representative system, the well-documented notional System 6 is considered.

Table 2: SBCS-UT Performance Characteristics for Interference Analysis

Associated SBCS System	EG Reference Design				System 6[3]		
UT Aperture Size (cm)	45	45	100	100	35	60	120
Frequency Range (GHz)	21.5-23.6	21.5-23.6	21.5-23.6	21.5-23.6	21.4-22	21.4-22	21.4-22
UT Antenna Gain (dBi)[4]	38	33.7	45	40.5	37.5	42.2	48.2
UT Antenna Pattern	ITU-R F.1245 Example roll-off mask	EM Modeled	ITU-R F.1245 Example roll-off mask	EM Modeled	ITU-R F.1245 Example roll-off mask	ITU-R F.1245 Example roll-off mask	ITU-R F.1245 Example roll-off mask
Boresight EIRP density (dBW/MHz)	12	12	20	20	12.5	17.2	23.2

Figure 1 presents antenna patterns for all UTs under study. ITU-R F.1245 bounds a uniformly illuminated aperture. The electromagnetic modeled patterns represent tapered aperture illumination which significantly reduces sidelobes, but reduces main lobe gain and steepness of main lobe roll-off, and represents an extreme case of a trade between the two. While compatibility

[1] The EG reference design uses different gains at different location within the service area. Gain is based on off-nadir angle from the STRAPS, with more directive beams are used toward the outer parts of the service area and less directive beams are used toward the center. In this analysis the three gains are used for beam aimed between 0 and 8 degrees, 8 and 30 degrees, and 30 degrees to the edge of the service area.

[2] I/N protection threshold of -6 dB selected to be consistent with other Fixed Service protection criteria.

[3] Values taken or derived from ITU working party 5C documentation. “Deployment and technical characteristics of broadband high altitude platform stations in the bands 6 440-6 520 MHz, 6 560-6 640 MHz, 21.4 22.0 GHz, 24.25-27.5 GHz, 27.9-28.2 GHz, 31.0-31.3 GHz, 38.0 39.5 GHz, 47.2-47.5 GHz and 47.9-48.2 GHz to be used in sharing and compatibility studies”, Annex 14 to Document 5C/410-E (Working Party 5C Chairman’s Report), 24 November 2017.

[4] Gain for EG reference design UTs is specified at the lowest frequency to ensure the broadest pattern, which is the worst case for this interference scenario. The frequency at which boresight gain is evaluated for System 6 terminals is unspecified in the documentation. Variation in pattern breadth over the frequency range, however, is not significant enough to have a large effect on analysis results.

between adjacent STRAPS depends on the roll-off of the Victim UT main lobe, compatibility with other services is very dependent on minimizing sidelobes. For example, a UT aimed typically no lower than 15 degrees in elevation will present potential interference toward a terrestrial receiver on a horizontal path from at closest 15 degrees off boresight, so the controlling the sidelobe level at that angle is critical for ensuring protection from harmful interference to other terrestrial stations.

The two-fold objective of 1) ensuring that SBCS will operate compatibly with existing non-SBCS services (obviating the need for coordination with them) and 2) ensuring that co-channel SBCS deployments are possible in the same geographic area, and can be readily coordinated with each other, a regulatory maximum EIRP density mask is appropriate, provided it does not hamper potential SBCS performance levels. Fortunately, this is achievable. An example mask which bounds a broader main lobe than the ITU-R F.1245 pattern provides is presented in Figure 2. Because it has lower sidelobes than the F.1245 pattern (reflecting use of an aperture illumination that is tapered to sacrifice main lobe gain and roll-off rate in exchange for lower sidelobes), this example mask will be revised after further analysis is conducted to arrive at a final mask that maximizes SBCS sharing while fully addressing compatibility with other services.

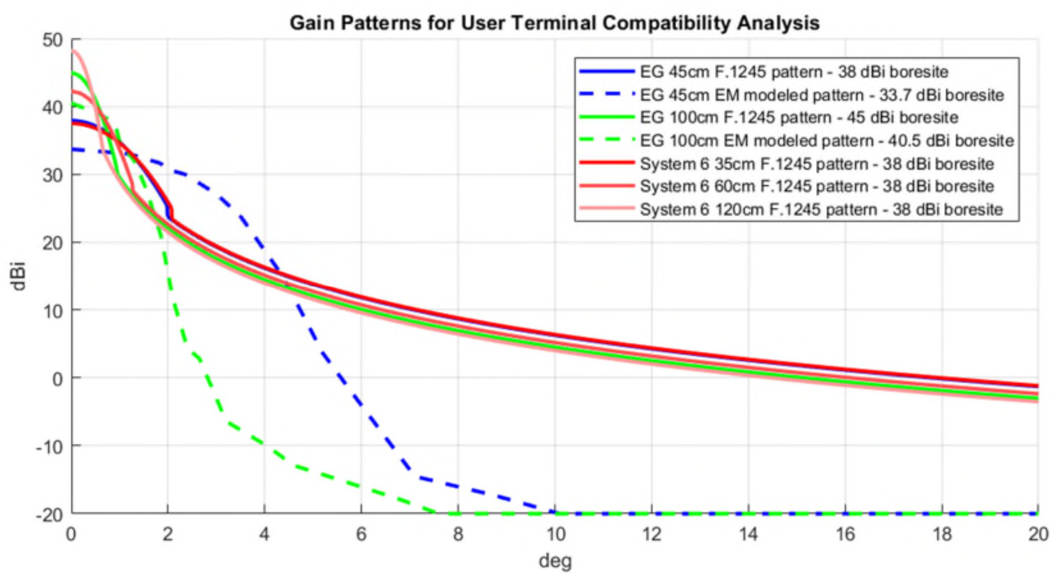


Figure 1: Antenna gain patterns for SBCS-UTs. ITU-R F.1245 bounds a uniformly illuminated aperture. EM modeled patterns represent tapered aperture illumination which significantly reduces sidelobes, but reduces main lobe gain and steepness of main lobe roll-off.

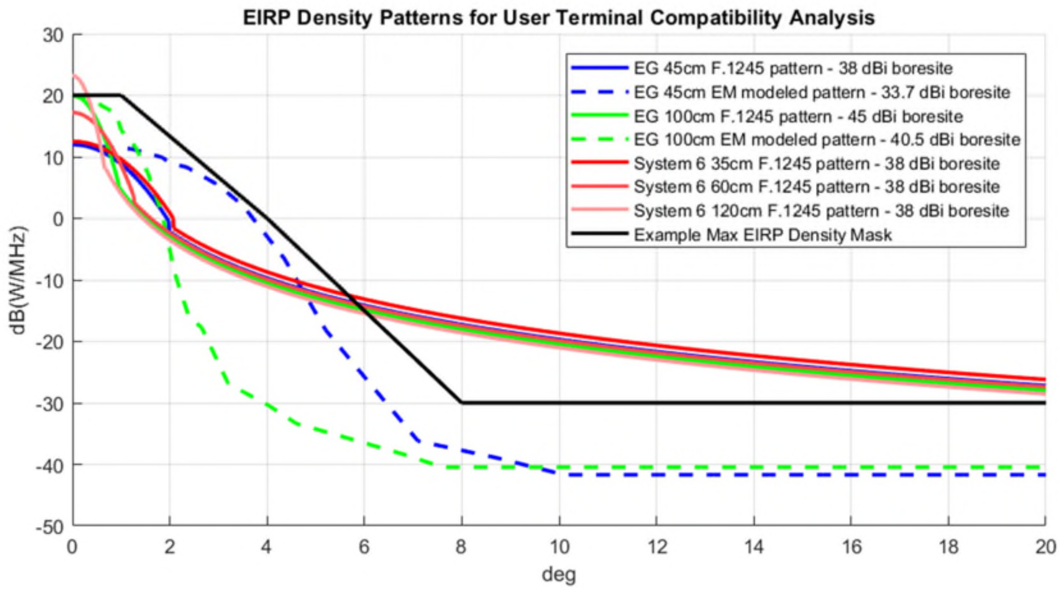


Figure 2: EIRP density patterns for SBCS-UTs. Example maximum EIRP density for possible regulatory mask used in analysis.

STUDY SCENARIO

Figure 3 illustrates the interference geometry applicable to this study.

- "Interfering STRAPS" is the STRAPS with which potentially Interferer UTs intend to communicate (to distinguish it from the Victim STRAPS). The Victim STRAPS receives transmissions from the Interferer UTs that interfere with signals from the UTs it is intended to receive transmission from, with the potential interference transmitted at some angle off the Interferer UT's boresight.
- Interference into the Victim STRAPS receive beams is cumulative; it includes all co-channel Interferer UTs.
- STRAPS operate only within a control volume centered on their nominally fixed position, described as a range of latitude, longitude, and altitude.
- Distance between the nominally fixed location of the respective STRAPS is varied parametrically to assess compatibility versus separation distance.

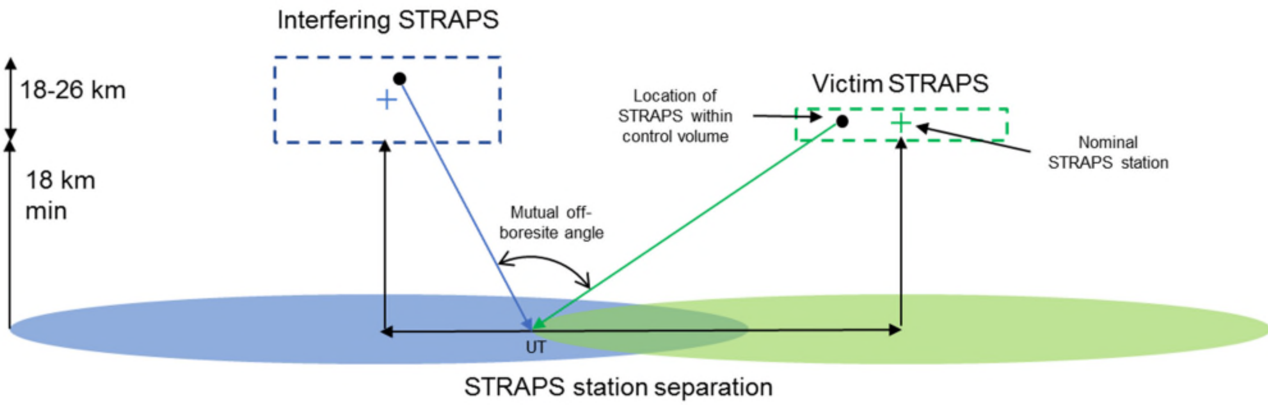


Figure 3: Interference Geometry (not to scale). STRAPS operate within authorized control volume centered on their nominally fixed location. UTs track their assigned STRAPS but transmit interference to an adjacent STRAPS. Interference is primarily dependent on the off-boresight angle presented from interfering UTs toward Victim STRAPS.

As depicted in Figure 4, a receive beam on the Victim STRAPS will receive from its own UT which is intentionally pointed at it. It will also receive potential interference from any interfering UTs that are intentionally transmitting to a neighboring STRAPS. Interfering UTs will transmit toward the Victim STRAPS at some angle off their boresight, and enter the Victim STRAPS receive beam at a variety of angles off its boresight (and in the worst case directly through its boresight).

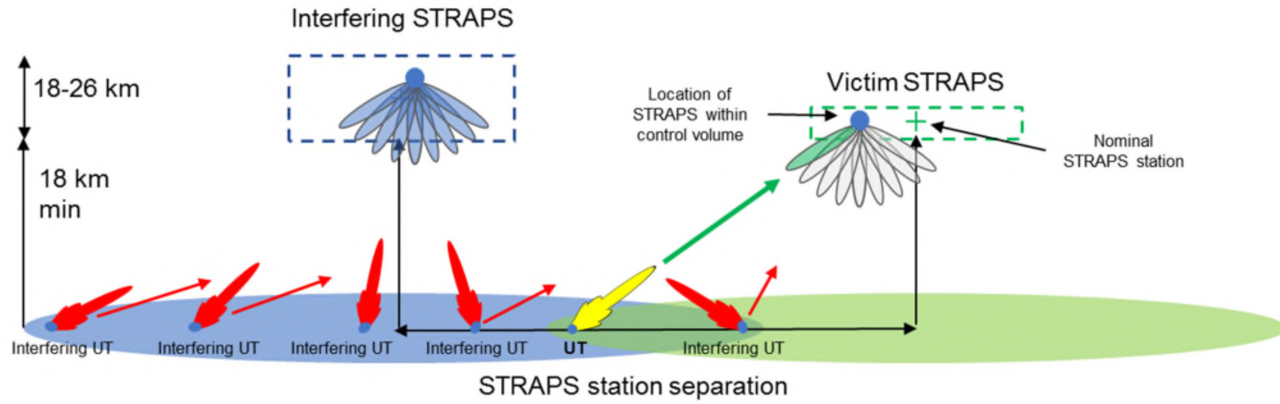


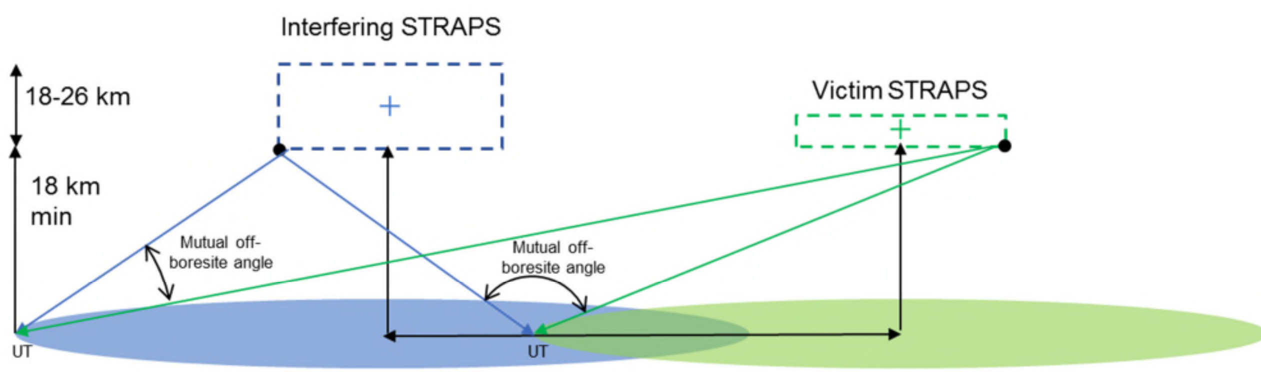
Figure 4: Multiple interfering UTs from an adjacent STRAPS each contribute interference transmitted off their boresights into each beam of the Victim STRAPS that is using the same frequency. Interference enters the STRAPS receive beam from a variety of angles off the receive beam boresight.

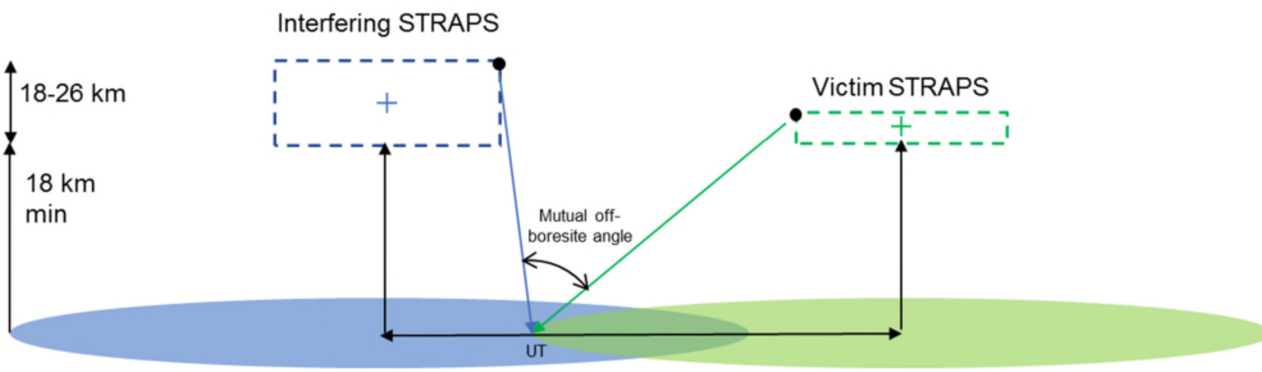
To bound the range of possible interference levels, four specific relative positions of the STRAPS within their control volumes are analyzed. These include:

- <u>Nominal case</u>: Both STRAPS are centered at their nominal locations.
- <u>Best case</u>: Both STRAPS are at their farthest possible separation within their control volume and at minimum altitude. This maximizes the off-boresight angle from interfering UTs into the Victim STRAPS. *See* Figure 5 Top.

- Worst case for overlapping region: Both STRAPS are at their smallest possible separation within their control volume and at maximum altitude. For interfering UTs tracking the interfering STRAPS and located between the two STRAPS, this minimizes the off-boresight angle to the Victim STRAPS. *See* Figure 5 Middle.
- Worst case for outer edge of coverage: Both STRAPS are at their smallest possible separation within their control volume with the Interferer at maximum altitude and the Victim at minimum altitude. This minimizes the off-boresight angle interfering UTs on the far side of their service area have to the Victim STRAPS. Analysis determined that this interference is significantly mitigated by the roll-off of Victim STRAPS receive beam gain to points outside the Victim service area, so this case is no longer considered. *See* Figure 5 Bottom.

In both worst-case situations, to achieve smallest possible horizontal separation (a minimum of 1 km assumed) when control volumes overlap, the STRAPS are separated by 1 km with the midway point at the average of the easternmost limit of the interfering STRAPS control volume and the westernmost limit of the Victim STAPS control volume.





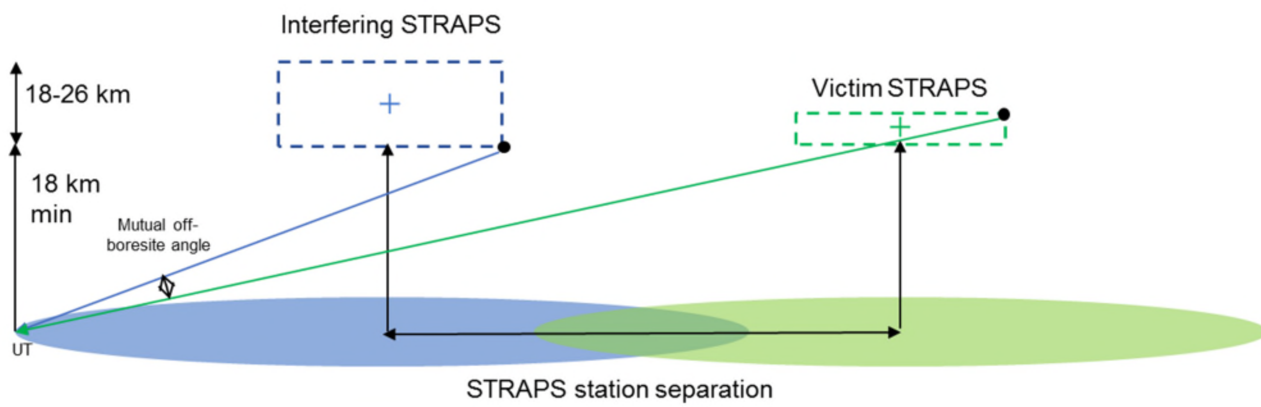


Figure 5: Bounding interference geometries. (Top) Best case. Maximizes off-boresight angle from Interferers across the interfering STRAPS service area. (Middle) worst case geometry interfering UTs within overlap region, (Bottom) worst case geometry for interfering UTs at far edge of Interferer service area,

To examine interactions between a range of SBCS operations and to test possible rules, several remaining parameters are varied in the scenarios. These include reference SBCS system, UT aperture size, and UT gain pattern model:

Victim and Interferer SBCS system combinations are drawn from the following SBCS reference missions. For each system, several UTs types are considered. Small apertures will have lower gain roll-off with off-boresight angle and therefore less reduction from their boresight EIRP density presented toward the Victim STRAPS, but larger apertures may present more interference when off-boresight angles are smaller.

- EG reference design, with a 70 km service area radius and 45 cm and 100 cm UTs.
- EG reference design but with a 50 km service area radius.
- System 6 reference design drawn from ITU HAPS proceedings, with a 50 km service area radius and 35 cm, 60 cm, and 120 cm UTs.

To test the effect of potential rules for antenna masks on sharing and compatibility between SBCS with overlapping coverage, the study also varies the antenna pattern model, with analyses conducted using:

- ITU-R F.1245 for bounding user terminal patterns.
- Patterns with lower sidelobes derived from EM modeling.
- An example bounding EIRP density mask.

STUDY METHODOLOGY

For each scenario, the study assesses the percentage of the Victim service area with a negative margin against the I/N protection criterion as a function of separation distance between the nominally fixed locations of the Interferer UT and Victim STRAPS.

The study assumes that there are a finite number of Interferer UTs distributed across the interfering STRAPS service area that can operate on the same frequency. In the EG reference design, in which a beam laydown pattern divides the service area into hundreds of simultaneously active beams, up to 135[5] UTs could transmit on the same band simultaneously. In the System 6 design, up to 4 UTs would transmit on the same band simultaneously. In both cases, the UTs must be physically separated far enough that the frequency can be reused by different user receive beams on the same STRAPS. Considering only UTs intended to operate with a single STRAPS, the STRAPS receive beam will receive from the UT within the beam's nominal coverage area, but will receive interference from other co-channel UTs distributed across other beams within its own service area as interference. This is the self-interference a system reusing frequency experiences. Roll-off of the receive beam to reduce the level of interfering signals and level of acceptable interference determines the number of simultaneous co-channel UTs the system can serve.

In practice, a reuse scheme may use polarization diversity as well, which will halve the number of co-channel interferers assuming the Victim uses one or both of the polarizations employed by the interfering UTs. For the bounding purposes of this study, no polarization diversity is assumed, and the System 6 design is assumed to use the same number of UTs as the Elefante Group reference design.

To set up the interference geometry for analysis:

- The nominally fixed location separation distance, service area radii, and locations of the STRAPS within their control volumes are defined (using the worst-case geometry described above, as well as the STRAPS nominally fixed position or best case geometry to examine sensitivity).
- The nominally fixed location separation distance and respective service areas of the two STRAPS are used to determine bounds for a grid of sample points on the ground that includes both service areas. These represent potential locations for UTs.
- At each sample ground point on the grid the following are determined:
  - Elevation angle to desired STRAPS
  - Elevation angle to Victim STRAPS
  - Range to Victim STRAPS
  - Angle between vectors to both STRAPS
  - Distance to center of desired STRAPS nominally fixed position
  - Distance to center of Victim STRAPS service area center nominally fixed position

  Geometric calculations are based on Earth Centered Earth Fixed (ECEF) vectors so Earth curvature is properly accounted for.
- Overlap percentage between the service areas is determined by comparing the number of grid points that are in both service areas to the number of grid points in each service area. Note that the percentage of overlap will be different when adjacent STRAPS have different design service areas (a smaller area that fits entirely within the other can have 100% overlap, whereas the larger design service area has a maximum potential overlap below 100%).

[5] Exact number of maximum co-channel UTs depends on number of beams, number of bands (i.e., frequency reuse), and whether polarization diversity is employed. The number here conservatively assumes that the Victim system is equally sensitive to all beams in the same band regardless of polarization, so likely overestimates by a factor of 2.

To calculate interference levels that would be experienced by a Victim STRAPS receive beam aimed at a desired UT at any of the sample grid points:

- EIRP density presented by each of the interfering UTs toward the Victim STRAPS is calculated using the angle between vectors to both STRAPS at each UT location and the beam pattern of the interfering UT to determine roll-off from the maximum EIRP density of the UT.
- Received Isotropic Power (RIP) from each interfering UT is determined by subtracting free space loss from the EIRP it projects toward the Victim.
- For each UT, every sample point is assessed for the angle the Victim STRAPS would see between that point and the UT. Thus, the angle is 0 at the point where the interfering UT is immediately below (at the nadir) of the STRAPS, and increases in all directions away from it.
- This angle, along with the Victim receive pattern, is used to determine gain presented by the Victim toward the interfering UT as a function of which grid point the receive beam is aimed at, i.e. for a grid point seen by the Victim as 10 degrees away from the interfering UT, the gain presented by that beam is whatever gain the pattern yields 10 degrees off boresight. Note that the Elefante Group reference design includes gain and, therefore, beam patterns changing as a function of off-nadir angle as described in footnote 1.
- Interference from each UT into a beam transmitted from any sample point on the grid is calculated by adding the RIP to the gain.
- Interference from all UTs is summed, yielding a map of total interference received by the Victim as a function of where it is pointed across the grid.
- To determine the Interferer to Victim noise floor ratio (I/N) and evaluate margin against the -6 dB I/N compatibility criteria, the margin is calculated as compared to the I/N criteria – (Interferer power – Noise floor).

To compare results in a meaningful way, for a single case the % of the Victim service area that has negative protection criteria margin is plotted versus separation distance of the nominally fixed locations and versus % of the Victim service area that overlaps the Interferer service area, and curves for all 4 bounding geometries are overlaid to illustrate the range of results.

STUDY RESULTS

Results are presented as follows:

1) Details of an example analysis case.
2) Graphical results to compare parametric variation for several cases.
3) A summary table of figures of merit for all cases.

Example Analysis

To illustrate the analysis method, intermediate results for a single example analysis are presented. The case examined here is interference from a STRAPS using the Elefante Group reference design control volume and a 70 km service radius into a STRAPS using the System 6 design control volume and a 50 km service radius. The interfering UTs use the 100 cm aperture with the ITU-R F.1245 pattern. The geometry is the worst case for receiving interference from terminals in the

overlapping area between the two STRAPS, as illustrated at the top of Figure 5, and the separation between nominally fixed positions of the STRAPS is 30 km.

Key geometry is pictured in Figure 6. Importantly, this geometric bounding case places the actual STRAPS platforms as close together as possible within the constraints of the permitted operating control volume around the latitude, longitude, and altitude of their nominally fixed positions.

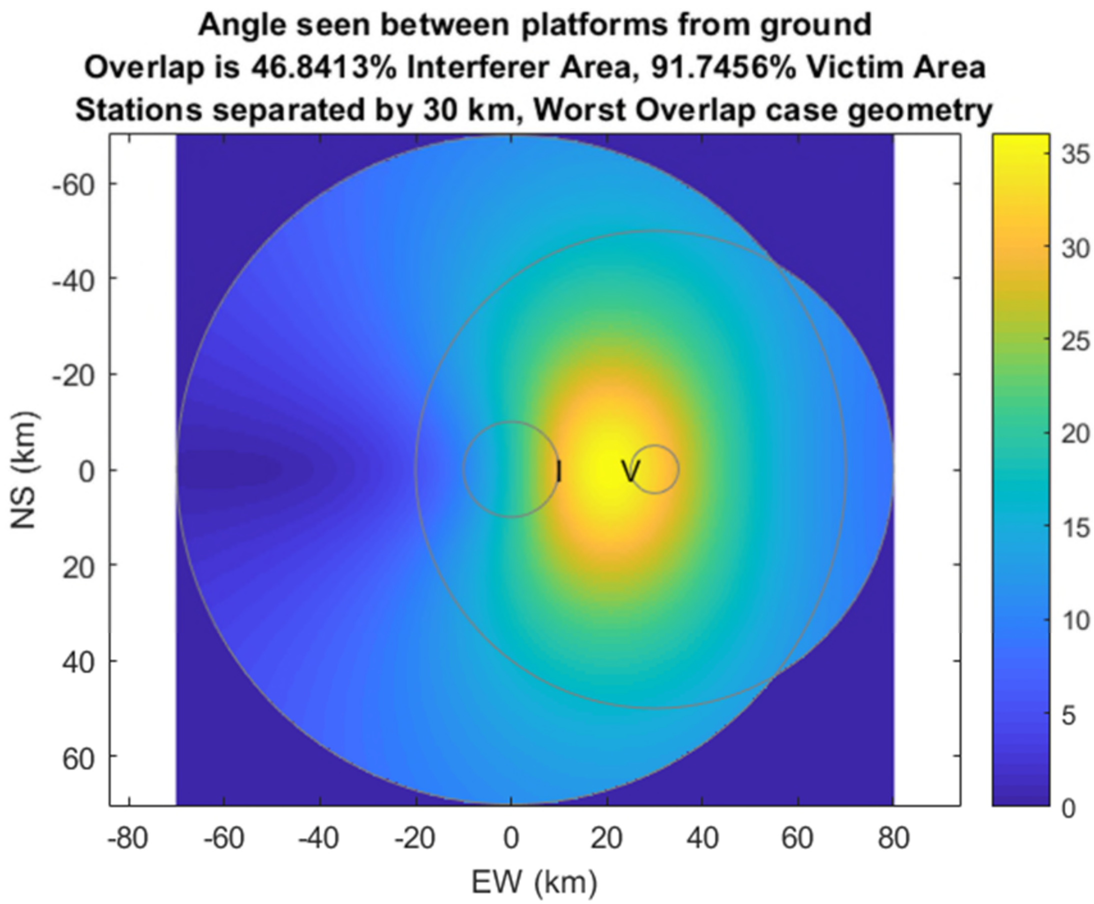


Figure 6: Overlap of 70 km Interferer service area and 50 km Victim service area with nominally fixed location separation of 40 km. Worst case geometry for overlapping regions places Interferer (I) at easternmost limit of 10 km radius control volume and victim (V) at westernmost limit of 5 km radius control volume; 25 km actual separation between platforms. Plot shows magnitude of angle between STRAPS as seen from potential User Terminal locations on the ground, ranging from largest between the two (~36 deg) to smallest at the westernmost edge of the Interferer service area.

Figure 7 illustrates the layout of interfering UTs. The 137[6] UTs are placed on a rectangular grid on 10.5 km centers. In practice, the beams and the UTs simultaneously reusing frequency will not be on a rectangular grid, but will rather be closer together toward the center of the service area and further apart toward the edges. For most relative geometries, this will produce less interference for STRAPS with non-overlapping control volumes, so is suitably bounding.

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[6] 135 UTs on a rectangular grid do not fit evenly into a circular service area so, conservatively, 137 are used instead.

Figure 7 also shows the RIP from all UTs at the victim STRAPS. A comparison with Figure 6 shows that the RIP is primarily driven by the angle of the victim off the boresight of the Interferer UTs, and secondarily by the range and free space loss. RIP is much higher from the western side of the interfering STRAPS service area where the off boresight angle approaches 0 degrees.

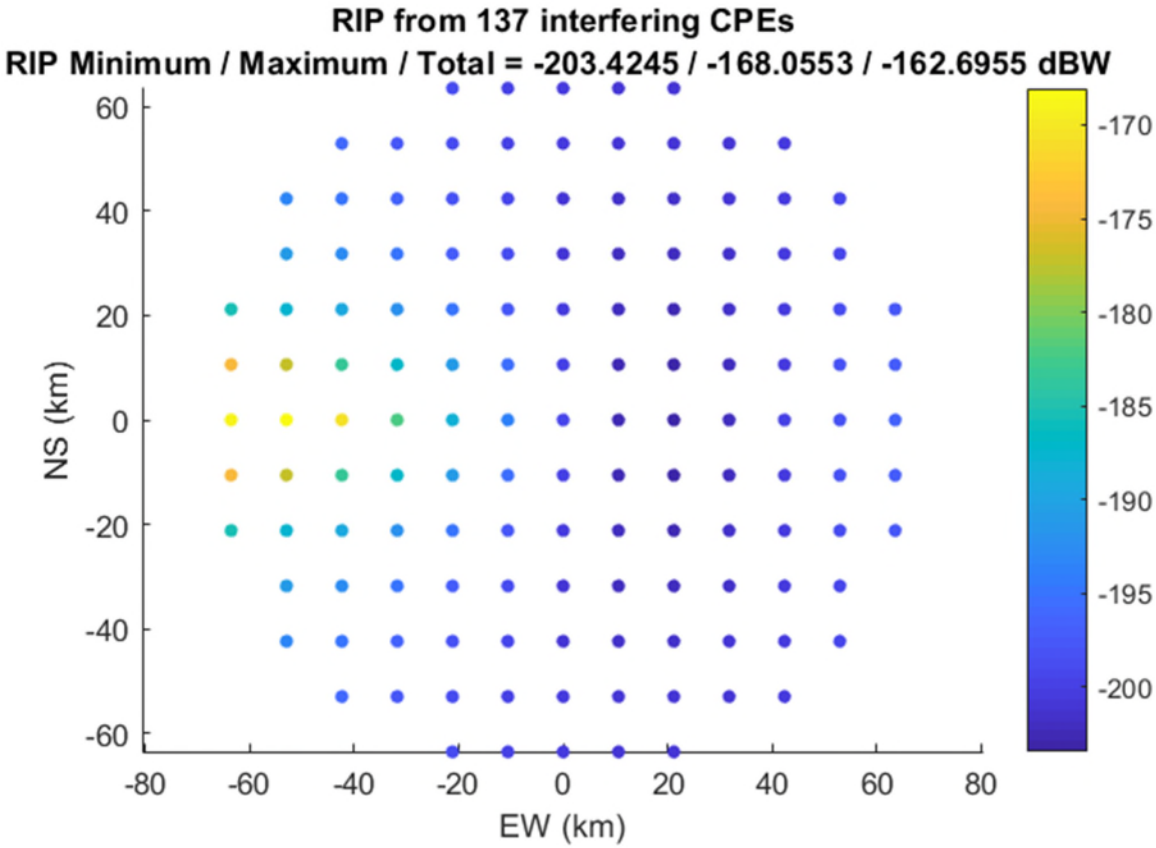

Figure 7: Interfering UTs and Received Isotropic Power (RIP) they project to the victim STRAPS. UTs with smaller angles project more RIP. Large variation in RIP received and total RIP at victim (from all incoming angles) are dominated by a few terminals.

Figure 8 shows the angle grid points as seen from a single UT and the resulting gain projected toward the UT as a function of the direction the victim STRAPS received beam is aimed. Angle is zero at the UT location, and increases with distance. Receive gain is maximum when the beam is aimed at the UT location, and rolls off rapidly with angle away from the Interferer.

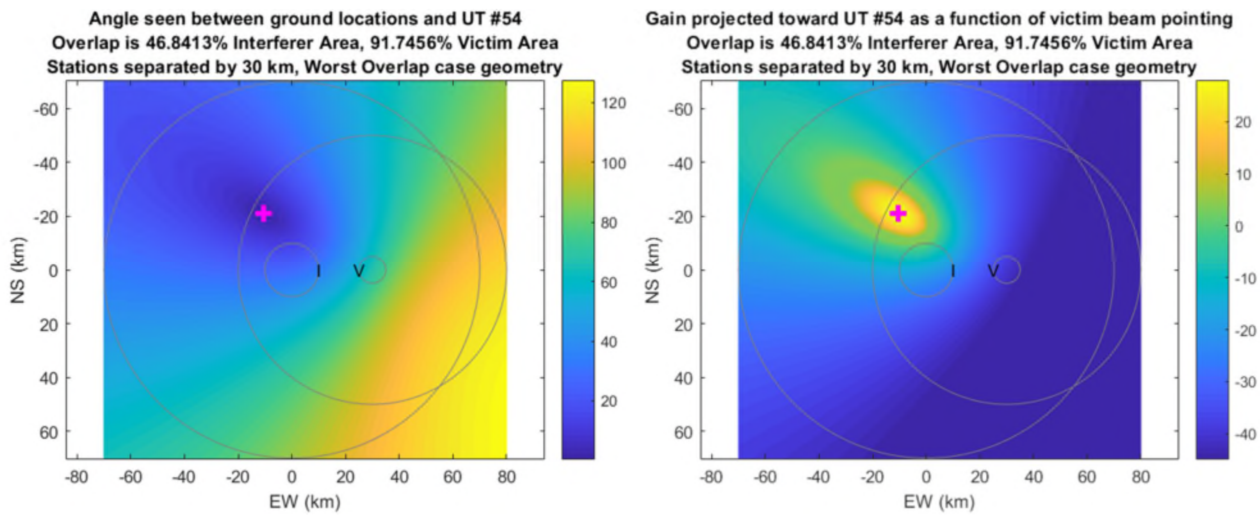

Figure 8: For one example UT (located at magenta cross): (left) Angle in STRAPS frame between UT location and other ground locations. (right) Gain receiver projects toward UT based on receive beam boresight pointing.

The total interference from the UT as a function of pointing direction for the victim STRAPS receiver is the addition of the RIP and projected gain, and the aggregate interference from all UTs is the sum of these, as illustrated in Figure 9. Importantly, although interfering UTs outside the victim service area contribute to the aggregate interference, the STRAPS receiver is restricted to pointing within the victim STRAPS service area so does not point directly at them, limiting their impact.

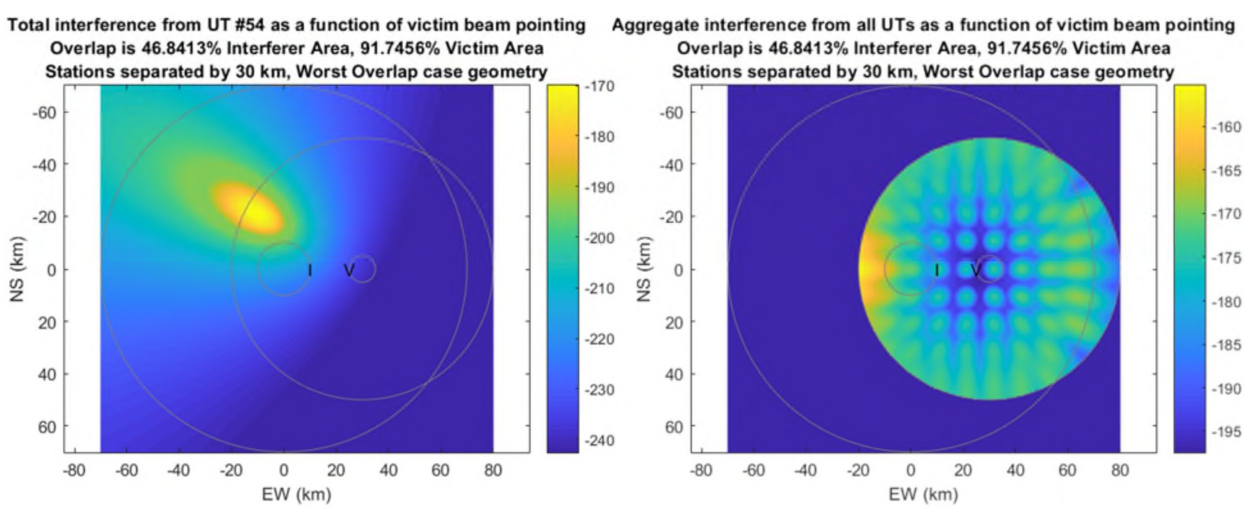

Figure 9: Interference received as a function of pointing direction of victim receive beam. Left – Beam receives maximum interference when aimed directly at UT. Right – Aggregate interference from all UTs peaks when beam aimed at individual UTs, and is higher toward westernmost UTs that are aimed closer to the victim.

Finally, margin against the I/N protection criteria can be evaluated, as shown in Figure 10. Margin varies across the service area, with local minima where the STRAPS receiver is aimed directly at interfering UTs, with the lowest margins from interfering UTs that aim closer to the victim

STRAPS. However, margin is positive across the entire victim service area, with a minimum of 8 dB.

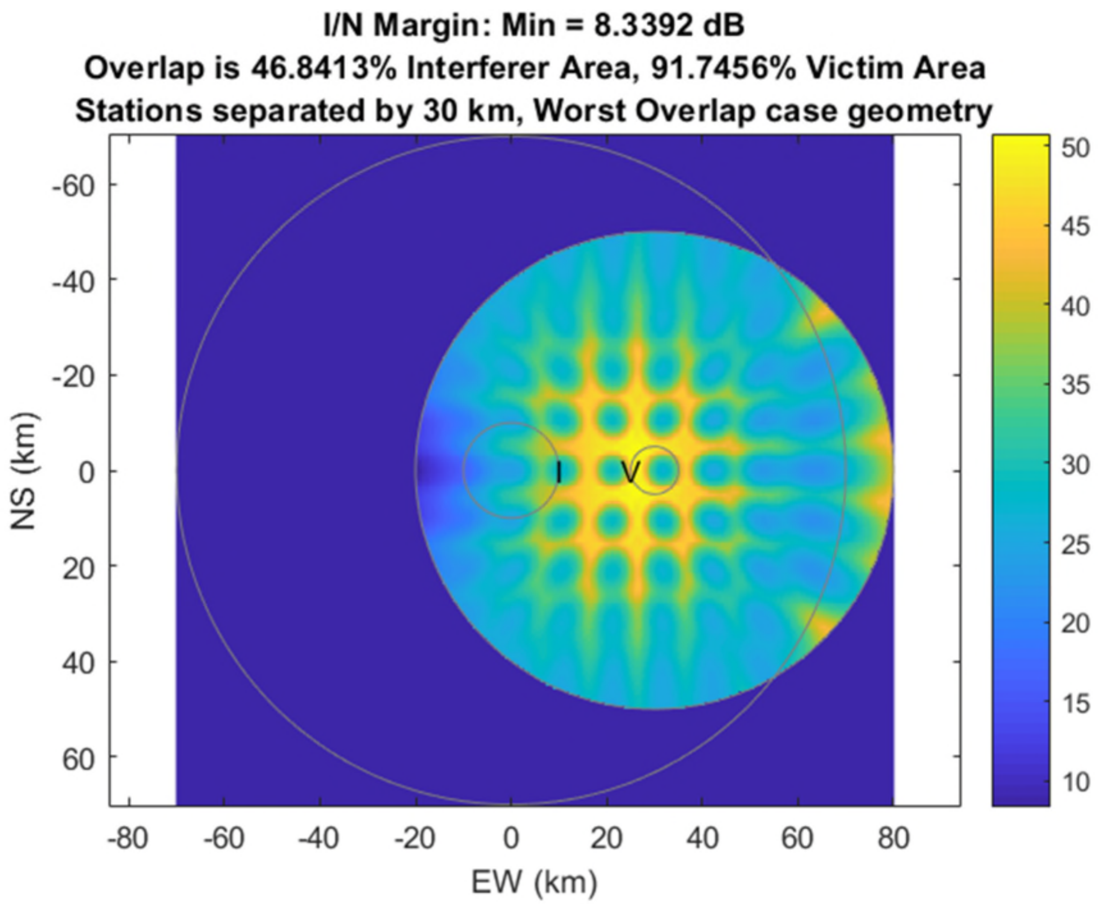

Figure 10: Margin against protection criteria as a function of receive beam pointing direction. In this example, 0% of the victim service area has negative margin, therefore 100% of the victim service area is usable.

In the reciprocal case shown in Figure 11 where the Interferer and victim roles are reversed, the minimum margin across the larger 70 km service is similarly close to 8 dB. In no case is the margin negative even under worst case geometry of the STRAPS within their control volumes, therefore distance separation distance of 30 km is deemed fully compatible.

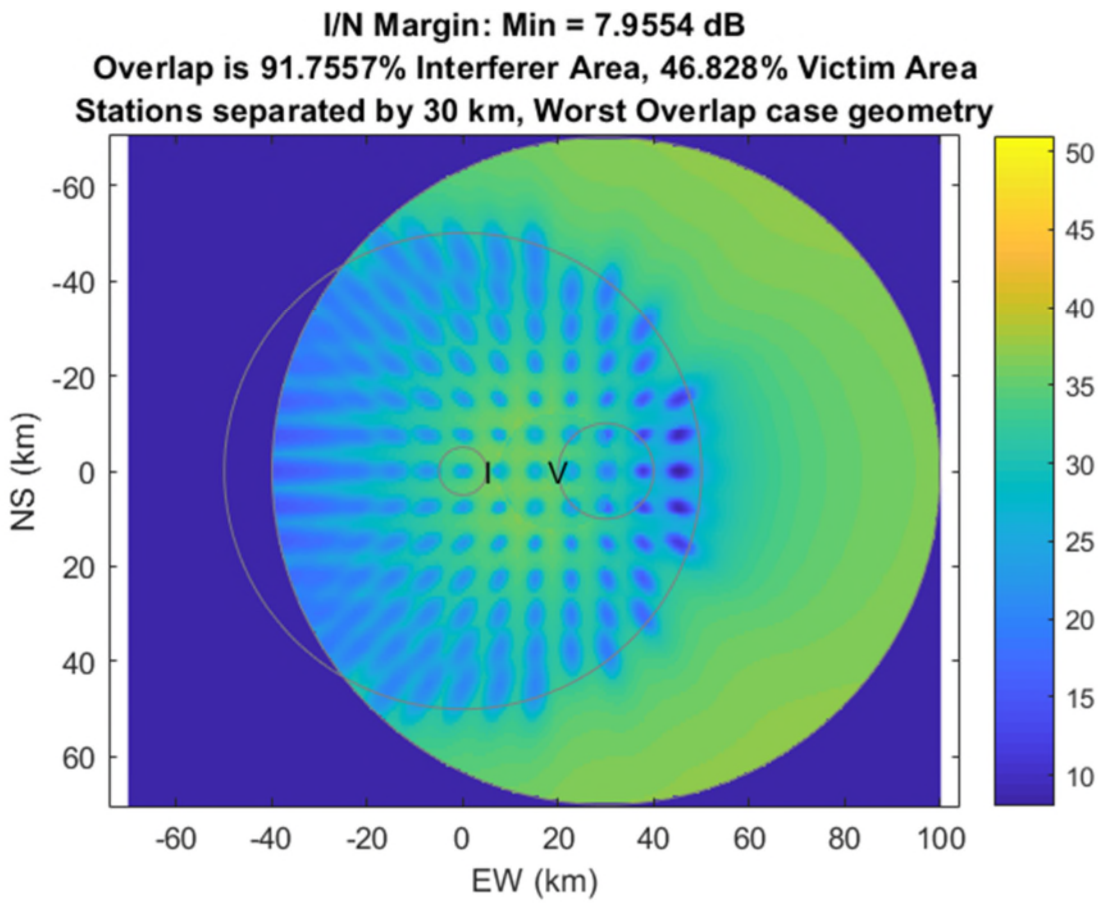

Figure 11: Margin against protection criteria as a function of receive beam pointing direction. In this example, 0% of the victim service area has negative margin; therefore 100% of the victim service area is usable.

Parametric Analysis

The previously described scenario can be evaluated parametrically as a function of separation distance between the STRAPS' nominally fixed positions. In Figure 12 (left) the previous example is in the "Worst Overlap" curve (See Figure 5) evaluated at 30 km separation, where there is no part of the service area with negative margin.

For this scenario, the "Worst Overlap" geometry is the limiting case establishing minimum separation distance for 100% of the victim service area to be at positive margin down to a minimum separation of 27 km.

The "Worst Edges" geometry (see Figure 5) forces the two STRAPS to be at the same altitude, minimizing the off-boresight angle interfering UTs direct at the victim STRAPS. Note that for that geometry, when the control volumes overlap (starting at a 10 + 5 = 15 km nominally fixed location separation distance for these two systems), the STRAPS are set to 1 km apart (as described previously) and a maximum of ~75% overlap area at negative margin is reached.

Note that if the platforms could remain exactly at their nominally fixed positions, the minimum separation would be as close as 12 km before any negative margin is seen, with the 3.2 km difference in nominally fixed location altitudes contributing to the compatibility.

Importantly, these bounding cases represent non-dynamic extremes of a statistical spectrum. For illustration, a marker indicates where the worst-case geometry could impact 10% of the service area at 19 km separation if the STRAPS are located at the worst relative geometry within their control volumes. If the chances of the geometry occurring are determined to be < 1%, a 1% chance of whatever reduction in capacity the 10% negative margin produces may be deemed acceptable by a STRAPS operator. Where one STRAPS operator is coordinating two STRAPS it controls, it may be able to implement mitigations to further reduce the probability of adverse geometries. Where two different STRAPS operators are coordinating, they may accept different risk criteria. Additionally, to operate closer to an existing STRAPS, a new platform might voluntarily accept a small area of outage within its nominal service area radius, or small area of reduced data rates and capacity.

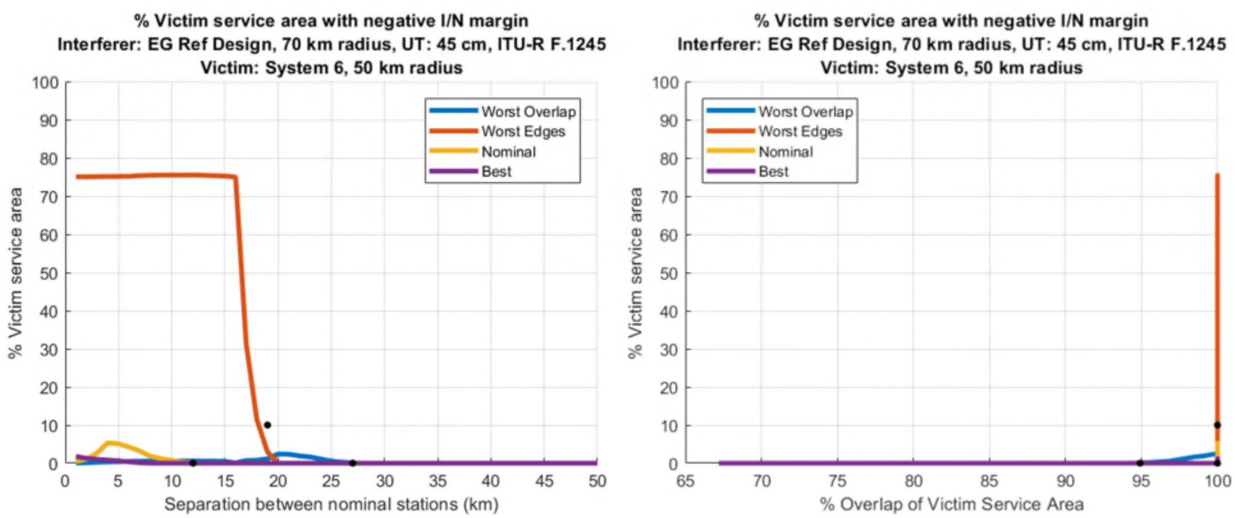

Figure 12: Parametric analysis of victim compatibility vs separation distance for each of the four geometric bounding cases. Left – % of victim service area with a negative protection criterion margin decreases with increasing distance. Right – % of victim service area with a negative protection criterion margin decreases with % overlap with Interferer service area.

Figure 12 (right) presents the same results versus percentage of the victim service area that overlaps the Interferer. For the worst-case geometry, 95% overlap corresponds to the closest separation to maintain 0% area with negative margin. Decreasing separation to 20 km allows 100% overlap with 10% of the service area at negative margin in the worst geometric alignment. The "Nominal" curve in this representation is less meaningful. In the "Nominal" geometry, with the platforms centered on their nominally fixed locations, there is no negative margin until they are within 12 km of each other. Because the 50 km service area radius overlaps 100% with the 70 km service area radius when they are < 20 km separate, the graph of negative margin area vs % overlap appears as a vertical line at 100% overlap.

As another example, two EG reference type STRAPS designs covering 70 km are considered, but with narrower UT beams from nearly uniformly illuminated apertures. Figure 13 illustrates margin

across the victim service area at 33 km, the closest separation distance where positive margin is maintained.

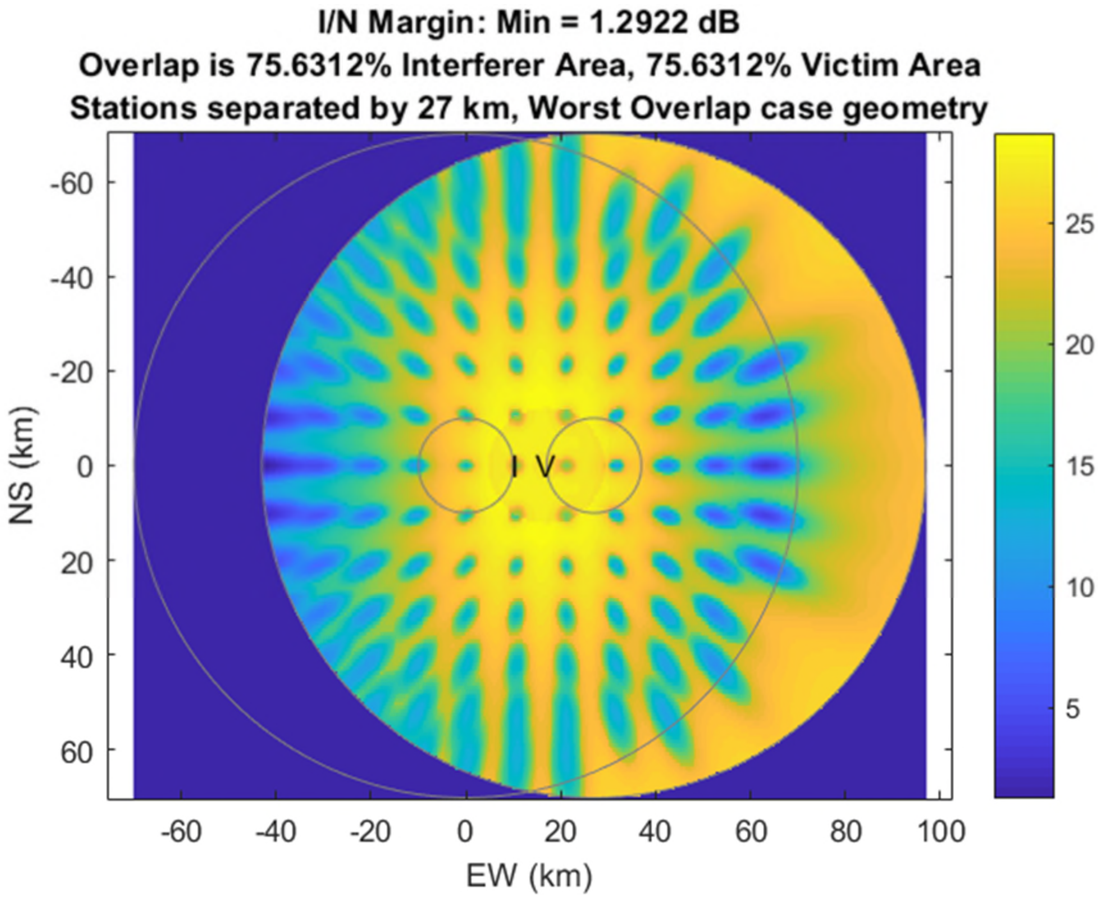

Figure 13: Overlap of two EG reference design 70 km service area STRAPS with nominally fixed location separation of 33 km. Worst case geometry for edge regions places Interferer (I) at easternmost limit of 10 km radius control volume and victim (V) at westernmost limit of 5 km radius control volume; 18 km actual separation between platforms. Minimum margin is close to 0 dB.

As illustrated in

Figure 14, in this case the absolute area of overlap is actually greater, but the percent of overlapping area is smaller.

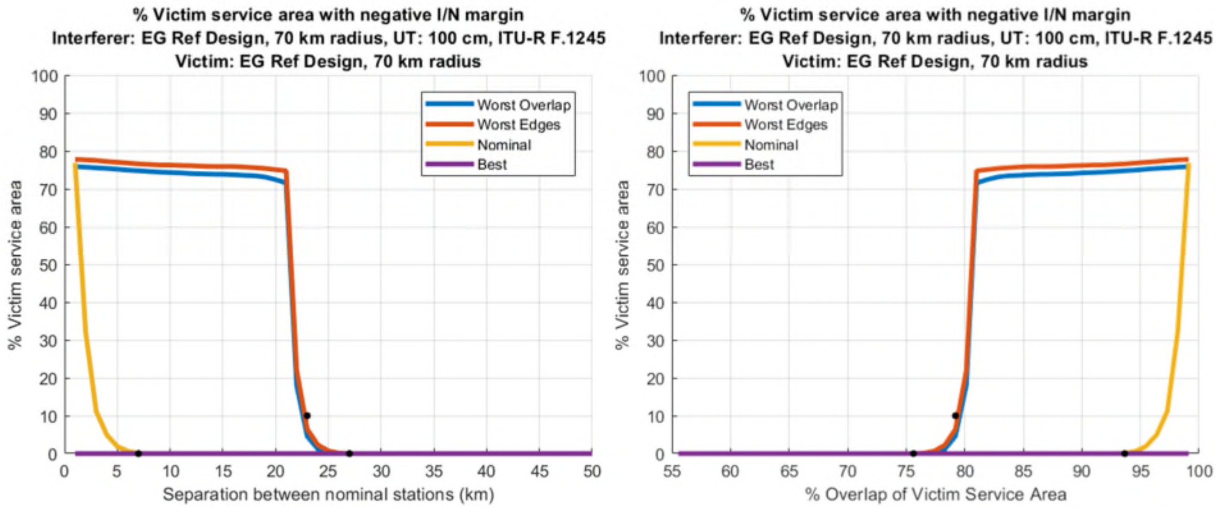

Figure 14: Parametric analysis of victim compatibility vs separation distance for each of the four geometric bounding cases. Two EG reference designs.

Summary Results

The analyses described above were applied to all the cases as shown in Table 3.

Table 3: Summary results for cases described in Study Scenario section. Minimum separation and % of service area overlap for different bounding geometry and % negative margin criteria. Cases include different Interferers and Victims with different service area radii, and different user terminal antenna assumptions.

Interferer			Victim		Worst case - 0% victim area impacted		Worst case - 10% victim area impacted		Nominal case - 0% victim area impacted	
Source	Service area radius (km)	Antenna Pattern	Source	Service area radius (km)	Min Separation (km)	% Overlap	Min Separation (km)	% Overlap	Min Separation (km)	% Overlap
EG Ref Design	70	45 cm, ITU-R F.1245	EG Ref Design	70	28	74.7	24	78.3	8	92.8
EG Ref Design	70	45 cm, modeled	EG Ref Design	70	35	68.6	27	75.6	17	84.6
EG Ref Design	70	100 cm, ITU-R F.1245	EG Ref Design	70	27	75.6	23	79.2	7	93.7
EG Ref Design	70	100 cm, modeled	EG Ref Design	70	29	73.9	25	77.4	9	91.9
EG Ref Design	70	Example EIRP mask	EG Ref Design	70	35	68.6	27	75.6	17	84.6
EG Ref Design	50	45 cm, ITU-R F.1245	EG Ref Design	70	27	48.4	23	50.3	5	51.0
EG Ref Design	50	45 cm, modeled	EG Ref Design	70	35	43.9	26	48.9	11	51.1
EG Ref Design	50	100 cm, ITU-R F.1245	EG Ref Design	70	27	48.4	23	50.3	4	51.0
EG Ref Design	50	100 cm, modeled	EG Ref Design	70	27	48.4	24	49.9	5	51.0
EG Ref Design	50	Example EIRP mask	EG Ref Design	70	35	43.9	26	48.9	11	51.1
EG Ref Design	70	45 cm, ITU-R F.1245	EG Ref Design	50	26	95.9	23	98.5	6	100.0
EG Ref Design	70	45 cm, modeled	EG Ref Design	50	31	90.6	26	95.9	13	100.0
EG Ref Design	70	100 cm, ITU-R F.1245	EG Ref Design	50	25	96.8	23	98.5	5	100.0
EG Ref Design	70	100 cm, modeled	EG Ref Design	50	26	95.9	25	96.8	7	100.0
EG Ref Design	70	Example EIRP mask	EG Ref Design	50	31	90.6	27	94.9	13	100.0
EG Ref Design	50	45 cm, ITU-R F.1245	EG Ref Design	50	24	69.8	23	71.0	5	93.7
EG Ref Design	50	45 cm, modeled	EG Ref Design	50	27	66.1	25	68.6	10	87.3
EG Ref Design	50	100 cm, ITU-R F.1245	EG Ref Design	50	23	71.0	22	72.2	4	94.9
EG Ref Design	50	100 cm, modeled	EG Ref Design	50	24	69.8	23	71.0	5	93.7
EG Ref Design	50	Example EIRP mask	EG Ref Design	50	28	64.9	25	68.6	10	87.3
EG Ref Design	70	45 cm, ITU-R F.1245	System 6	50	27	94.9	19	100.0	12	100.0
EG Ref Design	70	45 cm, modeled	System 6	50	29	92.9	22	99.1	16	100.0
EG Ref Design	70	100 cm, ITU-R F.1245	System 6	50	27	94.9	18	100.0	12	100.0
EG Ref Design	70	100 cm, modeled	System 6	50	28	93.9	20	100.0	14	100.0
EG Ref Design	70	Example EIRP mask	System 6	50	30	91.7	22	99.1	17	100.0
EG Ref Design	50	45 cm, ITU-R F.1245	System 6	50	27	66.1	18	77.2	11	86.0
EG Ref Design	50	45 cm, modeled	System 6	50	30	62.4	21	73.5	16	79.8
EG Ref Design	50	100 cm, ITU-R F.1245	System 6	50	27	66.1	17	78.5	10	87.3
EG Ref Design	50	100 cm, modeled	System 6	50	29	63.6	18	77.2	12	84.8
EG Ref Design	50	Example EIRP mask	System 6	50	31	61.2	21	73.5	16	79.8
System 6	50	35 cm, ITU-R F.1245	EG Ref Design	70	26	48.9	18	51.0	10	51.1
System 6	50	60 cm, ITU-R F.1245	EG Ref Design	70	26	48.9	18	51.0	10	51.1
System 6	50	120 cm, ITU-R F.1245	EG Ref Design	70	25	49.4	17	51.1	10	51.1
System 6	50	Example EIRP mask	EG Ref Design	70	28	47.9	21	50.9	13	51.0
System 6	50	35 cm, ITU-R F.1245	EG Ref Design	50	26	67.3	18	77.2	11	86.0
System 6	50	60 cm, ITU-R F.1245	EG Ref Design	50	26	67.3	18	77.2	11	86.0
System 6	50	120 cm, ITU-R F.1245	EG Ref Design	50	25	68.6	17	78.5	10	87.3
System 6	50	Example EIRP mask	EG Ref Design	50	27	66.1	23	71.0	13	83.5

Results Discussion

Achievable Overlap: In all cases, significant overlap is achievable with positive margin on the protection criterion. From the two service area sizes analyzed, 50 km radius and 70 km radius (2x the area), analyses can be grouped generally into the interactions between different service area radii, with a range of worst case and 10% negative margin area results based on the different systems and UT characteristics examined:

- 70 km Victim of 70 km Interferer (maximum of 100% overlap):
  Absolute worst-case ranges from 69 to 76% overlap.
  10% negative margin ranges from 76 to 79% overlap.
- 50 km Victim of 70 km Interferer (maximum of 100% overlap):
  Absolute worst-case ranges from 90 to 97% overlap.
  10% negative margin ranges from 95 to 100% overlap.
- 70 km Victim of 50 km Interferer (maximum of ~50% overlap):
  Absolute worst-case ranges from 44 to 49% overlap.
  10% negative margin ranges from 49 to 51% overlap.
- 50 km Victim of 50 km Interferer (maximum of ~100% overlap):
  Absolute worst-case ranges from 61 to 71% overlap.
  10% negative margin ranges from 69 to 78% overlap.

Influence of UT Antenna: UT antenna peak EIRP density and main lobe roll-off drives the variation between the minimum and maximum possible service area overlap. For a given aperture size, a uniformly illuminated aperture assumption like ITU-R F.1245 produces the highest boresight gain and sharpest main lobe roll-off, but at the cost of higher sidelobes (as well as, typically, lower efficiency). The "45 cm, modeled" and "100 cm, modeled" apertures are the result of electromagnetic modeling of a reflector/feed system designed to reduce sidelobes at the expense of broadening the main beam. Sidelobe reduction is critical to improved compatibility with some of the other non-SBCS systems operating in the same band (and described in other analyses), but beam broadening negatively impacts sharing between STRAPS.

The "example EIRP mask" pattern is the result of bounding the EIRP density of the modeled apertures with a simple envelope and includes additional margin beyond the modeled patterns which reduces allowable overlap. In all cases it sets the bound on the smallest amount of overlap permitted, indicating that the main lobe of the patterns is more important to the results than the sidelobes (which are lower than for the mask than the ITU-R F.1245 based patterns). Further analysis will determine the extent the required roll-off of a mask to be used as a regulatory limit can be increased to approach the ITU-R F.1245 results while maintaining compatibility with other services and realistic apertures for SBCS UTs.

CONCLUSIONS

Even under the worst-case bounding assumptions applied to this analysis, a range of practical SBCS systems can be deployed with sufficient overlap that multiple STRAPS can serve a particular market. Use of a risk-based analysis, coordination, and mitigation techniques would increase the practical area of overlap even more.

The lower the peak EIRP density of the interfering UTs, the smaller the impact on Victim service area. Further, the smaller both STRAPS control volumes can be, due to improved station-keeping, the more the service area of a STRAPS can overlap with other STRAPS without receiving interference. For a particular separation distance, compatibility depends on a trade between the peak EIRP density of the interferers and the gain vs beamwidth of the Victim STRAPS receive beams. Victim systems with larger service areas and larger control volumes are more sensitive to

interference, and systems with higher EIRP density will tend to cause more interference to neighboring systems. Market incentives to be less susceptible to interference and a regulatory framework (i.e., the adoption of appropriate limits) can readily address all three points.

Because STRAPS perform station-keeping within a control volume around their nominally fixed location, interference between neighboring systems is not entirely deterministic. As a result, the results of this study are an appropriate point of departure for a risk-based assessment. Further, in coordination, operators have the option to increase overlap between systems by accepting some risk of degradation to their maximum performance, and operators have mechanisms to design their business around or with such conditions.

REFERENCES:

ITU-R F.1245-2: Mathematical models of average and related radiation patterns for line-of-sight point-to-point fixed wireless systems antennas for use in certain coordination studies and interference assessments in the frequency range from 1 GHz to about 70 GHz

Annex 14 to Document 5C/410-E (Working Party 5C Chairman's Report), 24 November 2017 "Deployment and technical characteristics of broadband high altitude platform stations in the bands 6 440-6 520 MHz, 6 560-6 640 MHz, 21.4 22.0 GHz, 24.25-27.5 GHz, 27.9-28.2 GHz, 31.0-31.3 GHz, 38.0 39.5 GHz, 47.2-47.5 GHz and 47.9-48.2 GHz to be used in sharing and compatibility studies": Performance characteristics for a stratospheric system proposed by Facebook for ITU HAPS agenda item compatibility studies ("System 6")

Appendix U
Compatibility Analysis:
STRAPS User Downlink Interference into
Other STRAPS User Downlink
(Peer to Peer Analysis)
25.25 – 27.5 GHz Band
(Prepared by Lockheed Martin Corporation for Elefante Group, Inc.)

SUMMARY

- Elefante Group (EG) is proposing to access the 25.25–27.5 GHz band for User downlink communications from Stratospheric Platform Stations (STRAPS) to User Terminals (UTs) on a co-Primary basis.

- This study assesses the compatibility of STRAPS User downlinks with other STRAPS User downlinks operating in the 25.25–27.5 GHz band.

- As an initial step, worst-case operating conditions and interference geometry are utilized for a bounding analysis which include: 1) the interfering STRAPS transmits at a level equal to the maximum Power Flux Density (PFD) limit[1] as authorized for satellite downlinks into Fixed services across the entire allocated band (assuming complete overlap in bandwidth at all locations within service areas regardless of actual implementation of downlink beams), 2) STRAPS are located within their control volumes (defined by station-keeping) in worst case alignment to result in the maximum level of interference.

- Bounding analysis results show that the proposed Stratospheric-Based Communications Services (“SBCS”) I/N Protection Criterion of -6 dB is met even under worst-case operating conditions and interference geometry at separation distances permitting at minimum 47% overlap between STRAPS service areas with the same radius, and likely up to at least 65% with coordination.

- This high degree of overlap permits multiple STRAPS from one or more operators to serve the same market in the same spectrum on a non-exclusive basis.

- The results of this bounding-scenario analysis provide strong indications that risk-based assessments, coordination, and mitigation would readily lead to even more overlap without harmful interference.

- Critical to this compatibility is the ability for UTs to present lower gain toward neighboring STRAPS from which they could receive interference. Thus, a regulatory requirement is proposed for minimum roll-off of UT receive gain patterns to expect protection.

PURPOSE OF THE STUDY

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[1] Results and conclusions are drawn from the realistic case of roll-off outside service area, but for bounding comparison the case where STRAPS transmit at maximum permitted PFD even outside their service area (no roll-off outside service area) is considered.

Elefante Group is proposing that the 25.25–27.5 GHz band be made available for SBCS operating as a Fixed service, in the downlink direction. (While not the purpose of this study, Elefante Group proposes that the 25.25–27.5 GHz band also be considered for use in the uplink direction.) All or part of this band is allocated in the federal allocation to Fixed, Mobile, Earth Exploration Satellite (space-to-earth), Space Research (space-to-earth), and Inter-Satellite services, and Space Research and Inter-Satellite service in the non-federal allocation.

This study assesses the compatibility of STRAPS downlinks with other nearby STRAPS downlink transmissions to UTs, using two differing SBCS reference designs to illustrate compatibility. (Lockheed Martin has separately looked at other compatibility scenarios in the 25.25–27.5 GHz band.)

This study assesses the potential for such interference to exceed the I/N Protection Criterion to determine if mitigation measures are necessary.

OPERATIONAL CHARACTERISTICS OF SBCS

The SBCS will utilize STRAPS, UTs, and Gateway terminals to provide fixed services over a specific service area. Full characteristics of the Elefante Group STRAPS user downlink utilized in this study are given in Appendix A.

For this study, worst-case operating conditions are utilized for a bounding analysis prior to considering, if appropriate, risk-based interference assessment using probability and statistical methods:

1) STRAPS are registered to a nominally fixed location specified by latitude, longitude, and altitude, and are authorized to operate only within a cylindrical control volume centered on the nominally fixed location and specified by a height and radius. UTs would nominally be placed within a defined service area that could vary slightly based on local topology and practical pointing limits of the UT.
2) It is assumed that STRAPS transmit at the regulatory PFD limit as authorized for satellite downlinks in this band to protect interference into Fixed services per CFR Title 47 25.208(c) over the STRAPS service area (detailed in Study Methodology section).
3) Interfering and Victim STRAPS[2] are assumed to fully overlap each other in bandwidth and operate in the same polarization at every potential Victim UT location (not taking into account that coverage is provided by multiple channels "colors" which are spread across hundreds of beams and that the channels used by specific Victim UTs may not overlap the interference presented to them at all).

Table 1 provides the performance for the Elefante Group proposed STRAPS and those of a notional System 6 being proposed through the International Telecommunications Union work on high altitude platform stations as a basis for system performance assessments. System 6 is used to

[2] Although the victim for this study of downlink interference is clearly the UT, the term "Victim STRAPS" will be used to refer to the STRAPS these victim UTs link to to distinguish it from the Interferer STRAPS.

consider compatibility between the Elefante Group reference design and a different, well-documented representative system.

Table 1: STRAPS Performance Characteristics for Interference Analysis

Associated SBCS System	EG Reference Design		System 6
Nominal altitude (km)	19.8	19.8	23
Minimum altitude (km)	18.3	18.3	20
Maximum altitude (km)	21.3	21.3	26
PFD limit	FSS: 25.208 (c)	FSS: 25.208 (c)	FSS: 25.208 (c)
Service area radius (km)	70	50	50

OPERATIONAL CHARACTERISTICS OF SBCS USER TERMINALS

Receive characteristics and Protection Criterion for representative UT for two systems are presented in Table 2. To consider compatibility between the Elefante Group reference design and a different representative system, another well-documented system is considered.

Table 2: SBCS-UT Performance Characteristics for Interference Analysis

Associated SBCS System	EG Reference Design				System 6[3]		
UT Aperture Size (cm)	45	45	100	100	35	60	120
Frequency Range (GHz)	25.25 – 27.5	25.25 – 27.5	25.25 – 27.5	25.25 – 27.5	24.25-27.5	24.25-27.5	24.25-27.5
UT Antenna Gain (dBi)[4]	38	33.7	45	40.5	37.5	42.2	48.2
UT Antenna Pattern	ITU-R F.1245 Example roll-off mask	EM Modeled	ITU-R F.1245 Example roll-off mask	EM Modeled	ITU-R F.1245 Example roll-off mask	ITU-R F.1245 Example roll-off mask	ITU-R F.1245 Example roll-off mask
Receiver Noise Density (dBW/MHz)	-140.5	-140.5	-140.5	-140.5	-143.2	-143.2	-143.2
Protection Criterion[5] I/N (dB)	-6	-6	-6	-6	-6	-6	-6

[3] Values taken or derived from ITU working party 5C documentation. “Deployment and technical characteristics of broadband high altitude platform stations in the bands 6 440-6 520 MHz, 6 560-6 640 MHz, 21.4 22.0 GHz, 24.25-27.5 GHz, 27.9-28.2 GHz, 31.0-31.3 GHz, 38.0 39.5 GHz, 47.2-47.5 GHz and 47.9-48.2 GHz to be used in sharing and compatibility studies”, Annex 14 to Document 5C/410-E (Working Party 5C Chairman’s Report), 24 November 2017.

[4] Gain for EG reference design UTs is specified at the lowest frequency to ensure the broadest pattern, which is the worst case for this interference scenario. The frequency at which boresight gain is evaluated for System 6 terminals is unspecified in the documentation. Variation in pattern breadth over the frequency range, however, is not significant enough to have a large effect on analysis results.

[5] I/N protection threshold of -6 dB selected to be consistent with other Fixed Service protection criteria.

With PFD from any interfering STRAPS limited to a common maximum constraint, the degree of interference between two systems is governed by the spatial isolation the Victim UT can achieve by presenting boresight gain toward its intended STRAPS but rolled off gain to the interfering STRAPS seen off-boresight. Although multiple UT apertures sizes are presented in Table 2, only the smallest aperture size for each system is used in this analysis since they will be far more sensitive to interference than the larger, more directive main lobe patterns.

Figure 1 presents antenna patterns for all UTs. ITU-R F.1245 bounds a uniformly illuminated aperture. The modeled emission patterns represent tapered aperture illumination which significantly reduces sidelobes, but reduces main lobe gain and steepness of main lobe roll-off and represents an extreme case of a trade between the two. While compatibility between adjacent STRAPS depends on the roll-off of the Victim UT main lobe, compatibility with other services is highly dependent on minimizing sidelobes. For example, an UT aimed typically no lower than 15 degrees in elevation will present interference toward a terrestrial receiver on a horizontal path from at least 15 degrees off boresight.

The two-fold objective of 1) ensuring through regulatory limits that SBCS will protect other services (rather than requiring coordination with them) and 2) ensuring that SBCS STRAPS deployments can be readily coordinated with each other, will require a regulatory gain roll-off mask. An example mask which bounds a broader main lobe than the ITU-R F.1245 pattern provides is presented in Figure 2. Because it has lower sidelobes than the F.1245 pattern (reflecting use of an aperture illumination that tapered to sacrifice main lobe gain and roll off rate in exchange for lower sidelobes), this mask likely has significant margin providing protection of other services, and further analysis will be conducted to arrive at a final mask that maximizes SBCS sharing while fully addressing compatibility with other services.

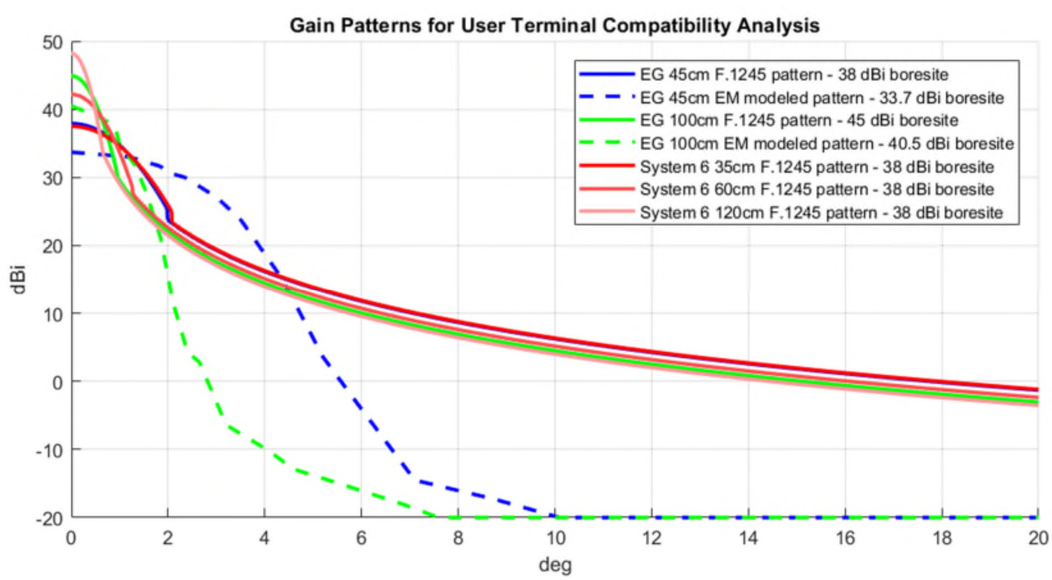


Figure 1: Antenna gain patterns for SBCS-UTs. ITU-R F.1245 bounds a uniformly illuminated aperture. EM modeled patterns represent tapered aperture illumination which significantly reduces sidelobes, but reduces main lobe gain and steepness of main lobe roll-off.

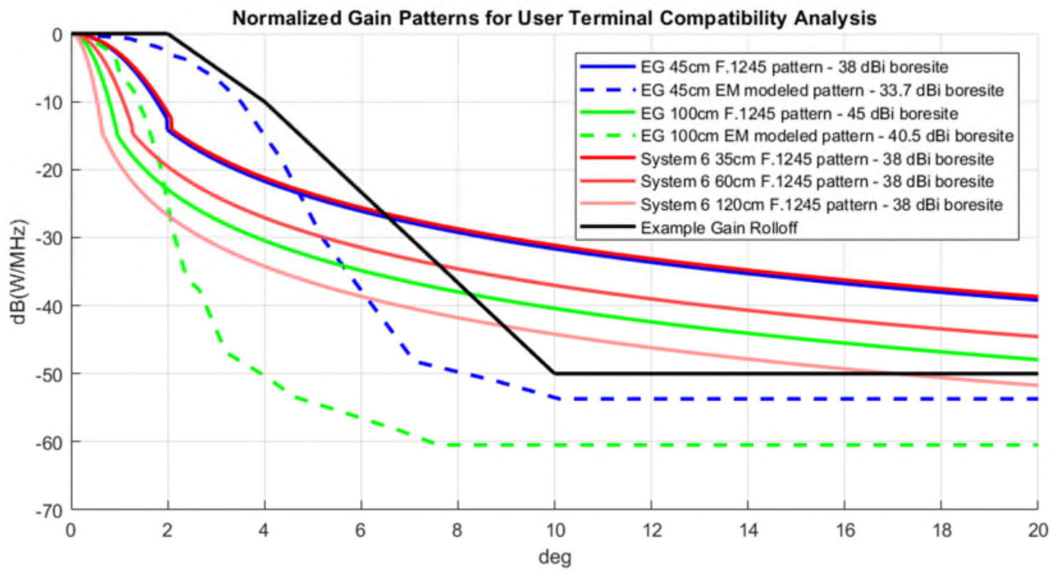


Figure 2: Normalized antenna gains. Example gain roll-off mask bounds worst case (shallowest) roll-off.

STUDY SCENARIO

Figure 3 illustrates the worst-case interference geometry applicable to this study.

- Interferer and Victim STRAPS transmits User downlink signals to their respective overlapping service areas.
- STRAPS operate only within the authorized control volume centered on their nominally fixed latitude, longitude, and altitude. Proposed limits for SBCS are 18 to 26 km altitude and 10 km radius, with realistic STRAPS anticipated to operate over smaller ranges.
- Distance between the nominally fixed locations of the STRAPS is varied parametrically to assess compatibility as a function of separation distance.

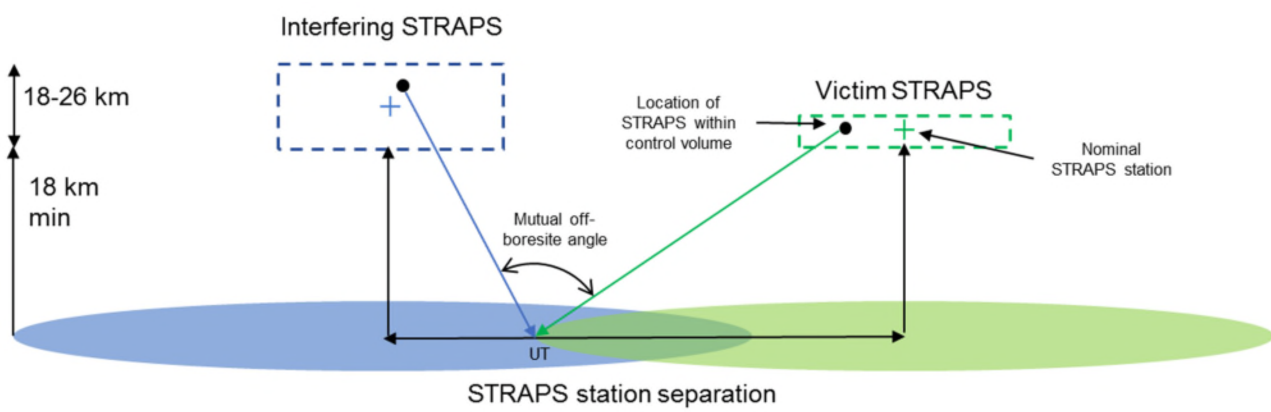
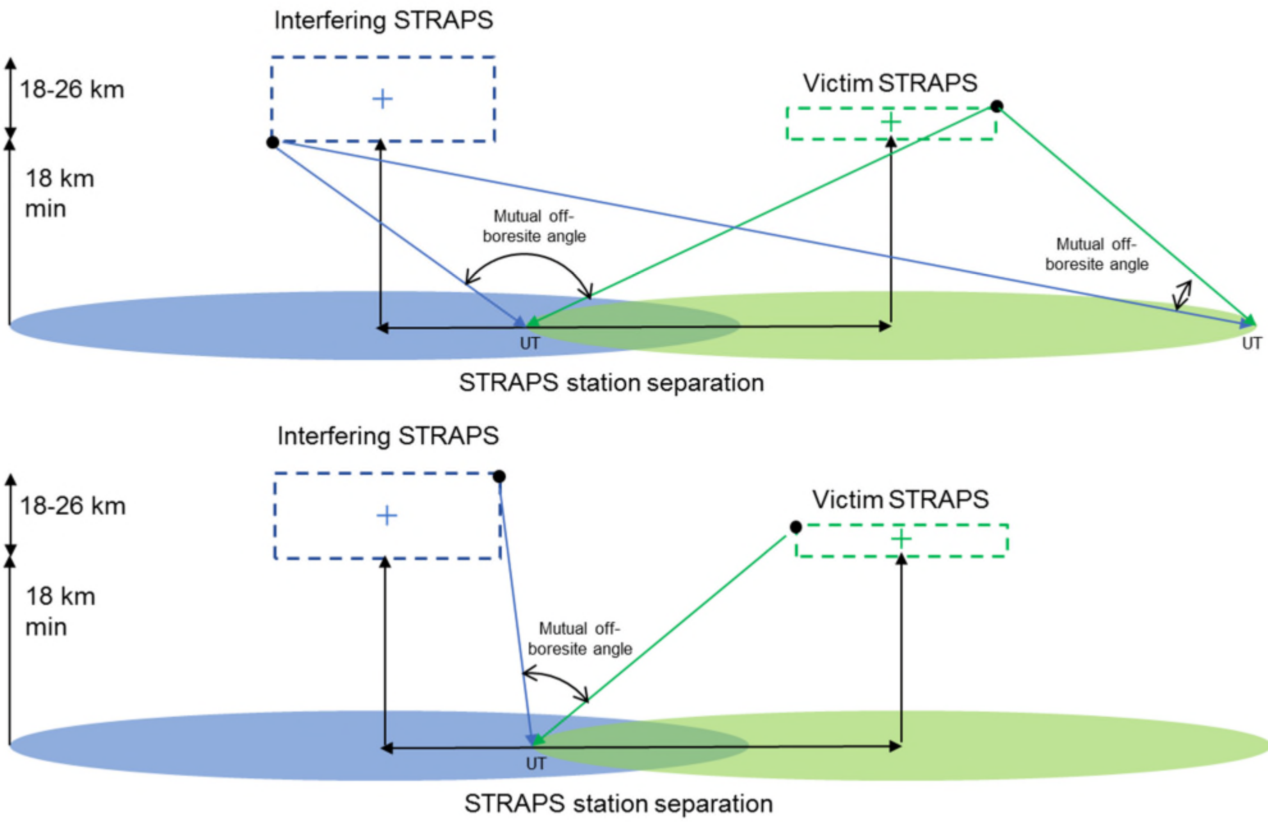


Figure 3: Interference Geometry (not to scale). STRAPS operate within authorized control volume centered on their nominally fixed location. UTs track their assigned STRAPS but can potentially receive interference from an adjacent STRAPS. Interference is primarily dependent on the mutual off-boresight angle from which Victim UTs receive interfering signals.

To bound the range of possible interference levels, four specific relative positions of the STRAPS within their control volumes are analyzed. These include a:

- Nominal case: Both STRAPS are centered at their nominally fixed locations.
- Best case: Both STRAPS are at their farthest possible separation within their control volume and the Interferer is at minimum altitude. The off-boresight angle to the interfering STRAPS is maximized for UTs in the service area overlap region when the Victim STRAPS is at minimum altitude, and for UTs at the far edge of the Victim service area when the Victim STRAPS is at maximum altitude. *See* Figure 4Top.
- Worst Overlap: Both STRAPS are at their smallest possible separation within their control volume and at maximum altitude. For UTs tracking the Victim and located between the two STRAPS, this set of conditions minimizes the off-boresight angle to the interfering STRAPS. *See* Figure 4 Middle.
- Worst Edges: Both STRAPS are at their smallest possible separation within their control volume with the Interferer at maximum altitude and the Victim at minimum altitude. For UTs tracking the Victim and located in the Victim service area farthest from the Interferer, this minimizes the off-boresight angle to the interfering STRAPS. *See* Figure 4 Bottom.



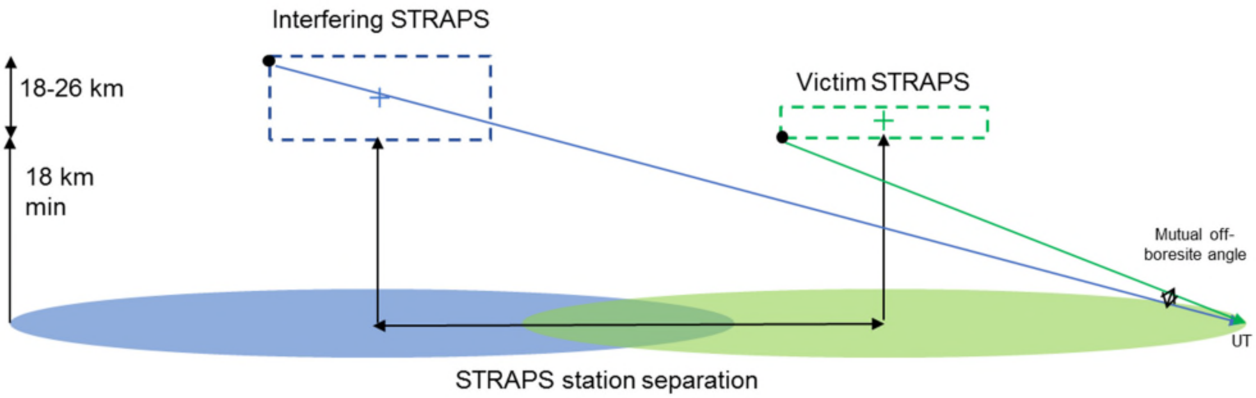


Figure 4: Bounding interference geometries. Top – Best case, maximizes smallest off-boresight angle at far edge of Victim service area. Middle – Worst case geometry for UTs within overlap region. Bottom – Worst case geometry for UTs at far edge of Victim service area.

To examine interactions between a range of SBCS operations and to test possible rules, several remaining parameters are varied in the scenarios.

Victim and Interferer SBCS system combinations are drawn from the following SBCS reference missions. For each system, the UTs with smallest antenna aperture are used because these will be most susceptible to interference. Larger apertures should have more directive beams and improved gain roll-off than smaller apertures at the same off-boresight angle.

- EG reference design, with a 70 km service area radius and 45 cm UTs.
- EG reference design but with a 50 km service area radius.
- System 6 reference design drawn from ITU HAPS proceedings, with a 50 km service area radius and 35 cm UTs.

To test the effect of potential rules for antenna masks and PFD limits outside the services area on sharing and compatibility between SBCS with overlapping coverage, the study also varies:

- Antenna pattern model: Analyses are conducted using:
  - ITU-R F.1245 for bounding user terminal patterns
  - Patterns with lower sidelobes derived from EM modeling
  - An example bounding gain roll-off mask
- PFD roll-off outside service area: For bounding, the study is conducted assuming the interfering STRAPS projects the full elevation angle dependent PFD limit proposed for the rulemaking over the entire visible Earth. In practical systems, PFD will roll off outside the service area based on the selected pattern beams for each implementation.

STUDY METHODOLOGY

For each scenario, the study assesses the percentage of the Victim service area with a negative margin against the I/N protection criterion as a function of separation distance between the nominally fixed locations of the Interferer and Victim.

The study starts by assuming the interfering STRAPS is transmitting at a level equal to the regulatory PFD limit that is authorized for satellite downlinks in this band to protect interference into Fixed services per CFR Title 47 25.208(c).

$$PFD\ \left(\frac{dBW}{m^2 * MHz}\right) = \begin{cases} -115 & 0 \le \delta < 5 \\ -115 + 0.5 * (\delta - 5) & 5 \le \delta < 25 \\ -105 & 25 \le \delta \le 90 \end{cases}$$

Where δ is the angle of arrival (in degrees) above the horizontal plane (elevation angle)

The assumption for the Elefante Group reference design is that the STRAPS service area is defined by a 70 km radius circle centered on the point immediately below the STRAPS nominally fixed position as described below and illustrated in Figure 5 and Figure 6.

Elevation angle is relative to the position of the STRAPS within the control volume and the location of the UT. At a fixed UT location, elevation varies with STRAPS motion.

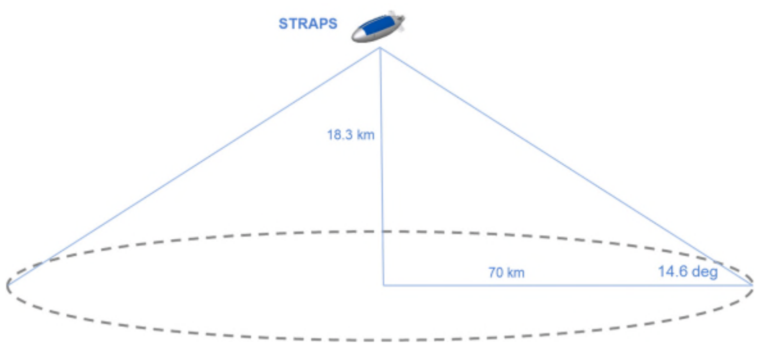


Figure 5: STRAPS Service Area Geometry

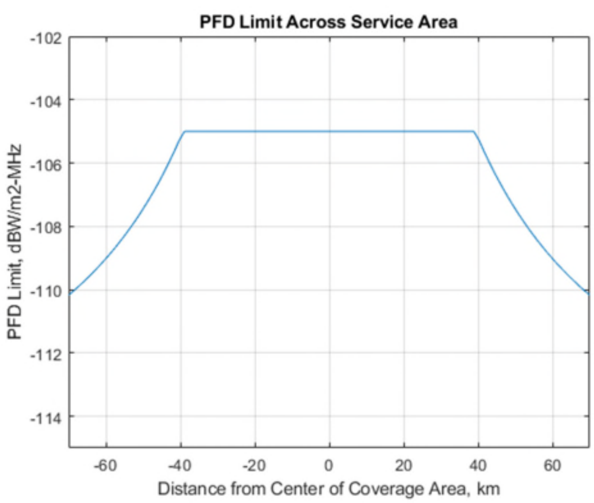


Figure 6: PFD Limit across Service Area When STRAPS Centered on Nominally Fixed Location at 18.3 km Altitude

In practice, PFD outside the service area will fall below the limit because practical STRAP radio designs will not waste energy there. For the Elefante Group reference design, PFD outside of the

coverage area is normally bounded by starting with the PFD limit and rolling it off using the ITU-R F.1245 antenna pattern with peak antenna gain of 32.7 dB at the edge of coverage. For bounding cases, the PFD can be assumed at the limit beyond the service area as well.

The PFD is converted to received isotropic power (RIP) as a function of range from STRAPS as follows:

$$RIP = \frac{PFD * \lambda^2}{4\pi}$$

where λ is the wavelength.

To set up the interference geometry for the compatibility study:

- The nominally fixed location separation distance, service area radii, and locations of the STRAPS within their control volumes are defined (using the worst-case geometry described above, as well as the nominal case or best-case geometry, described above, to examine sensitivity).
- The nominally fixed location separation distance and service areas of the two STRAPS are used to determine bounds for a grid of ground sample points that includes both service areas. These represent potential locations for UTs.
- At each ground sample point on the grid the following are determined:
    - Elevation angle to interfering STRAPS.
    - Elevation angle to Victim STRAPS.
    - Angle between vectors to both STRAPS.
    - Distance to center of interfering STRAPS service area center.
    - Distance to center of Victim STRAPS service area center.

  Geometric calculations are based on Earth Centered Earth Fixed (ECEF) vectors so Earth curvature is properly accounted for.
- Overlap percentage between the service areas is determined by comparing the number of grid points that are in both service areas to the number of grid points in each service area. Note that the percentage of overlap will be different when STRAPS have different service areas (a smaller area that fits entirely within the other can have 100% overlap, whereas the larger area has a maximum potential overlap below 100%).

To calculate interference levels that would be experienced by potential Victims UTs at the sample grid points:

- Maximum PFD from the Interferer is calculated as a function of elevation angle to the Interferer.
- Victim spatial isolation from the Interferer PFD is calculated by determining the Victim antenna gain based on the angle between STRAPS vectors and subtracting from the corresponding boresight gain.
- To determine the Interference to Noise ratio (I/N) and evaluate margin against the -6 dB I/N Protection Criteria, the PFD is converted to RIP as described previously, which is added to the gain presented by the Victim to the Interferer to get Interferer power. I/N criteria – (Interferer power – Noise floor) yields the margin. This value is independent of how the Victim chooses to operate the link.

To compare results in a meaningful way, the percentage of the Victim service area where there is negative protection criteria margin is plotted versus separation distance of the STRAPS, and versus the percentage of the Victim service area that overlaps the Interferer service area.

STUDY RESULTS

Results are presented as follows:

1) Details of an example analysis case
2) Graphical results to compare parametric variation for several cases.
3) A summary table with figures of merit for all cases.

Example Analysis

To illustrate the compatibility study method, intermediate results for a single example analysis are presented:

- Interferer STRAPS: Elefante Group reference design control volume with 70 km service radius and downlink transmitting at the PFD limit.
- Victim STRAPS: System 6 design control volume with 50 km service radius using UTs with the example gain roll-off mask.
- Geometry is the worst case for Victim terminals in the overlapping area between the two STRAPS, as illustrated in the middle diagram of Figure 4; the corresponding Victim and Interferer angle contours from the UT perspective are shown in Figure 7. Importantly, this geometric bounding case places the actual STRAPS platforms as close together as possible within the constraints of the permitted operating control volume around the latitude, longitude, and altitude of the nominally fixed locations.

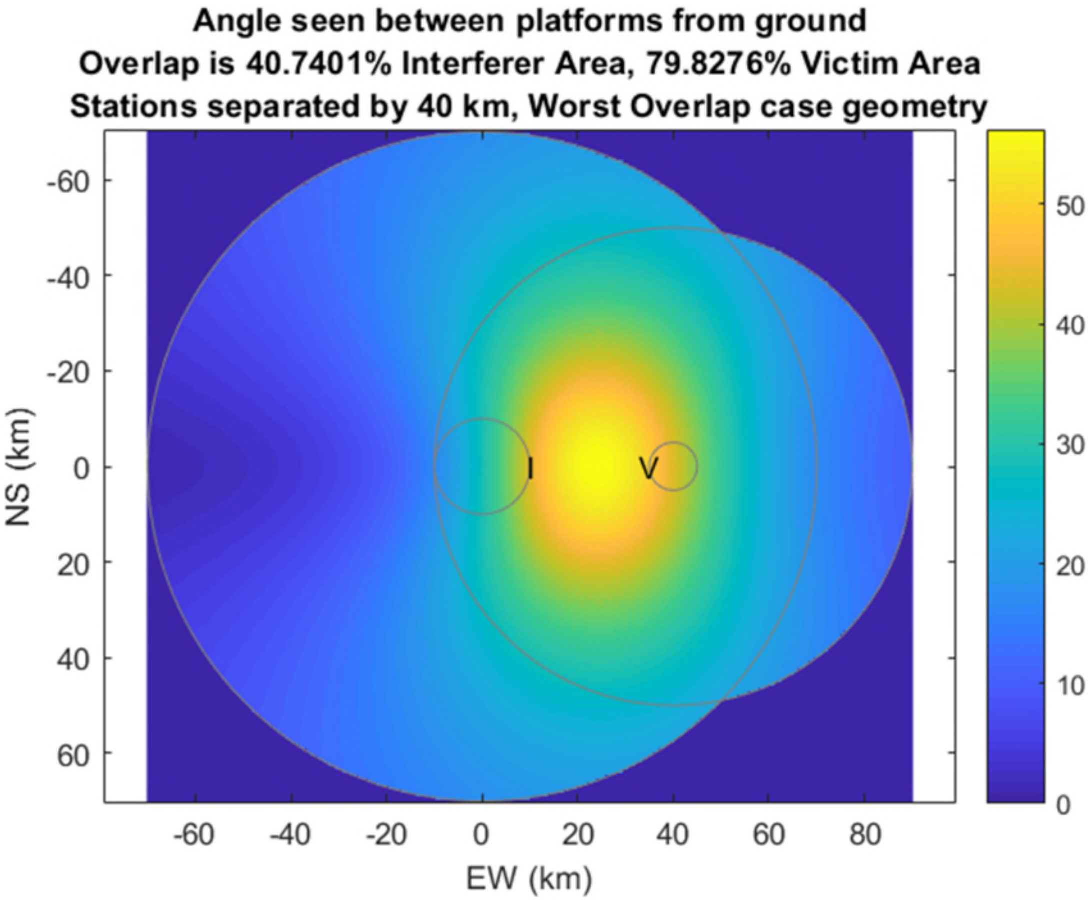


Figure 7: Overlap of 70 km Interferer service area and 50 km Victim service area with nominally fixed location separation of 40 km. Worst case geometry for overlapping regions paces Interferer (I) at easternmost limit of 10 km radius control volume and Victim (V) at westernmost limit of 5 km radius control volume; 25 km actual separation between platforms. Plot shows magnitude of angle between STRAPS as seen from potential User Terminal locations on the ground, ranging from largest between the two (~54 deg) to smallest at the westernmost edge of the Interferer service area.

Figure 8 illustrates incident PFD. These example systems use directive beams to cover their service areas, so PFD outside the service areas rolls off as the pattern of a beam aimed at the edge of the service area. Importantly, this causes a reduction in power toward the farthest part of the Victim coverage, where the angle of the Interferer off the Victim boresight is the smallest. Similarly, considering the case of mutual compatibility, the PFD from the Victim is extremely attenuated due to roll-off beyond edge of coverage at the farthest locations within the Interferer service area.

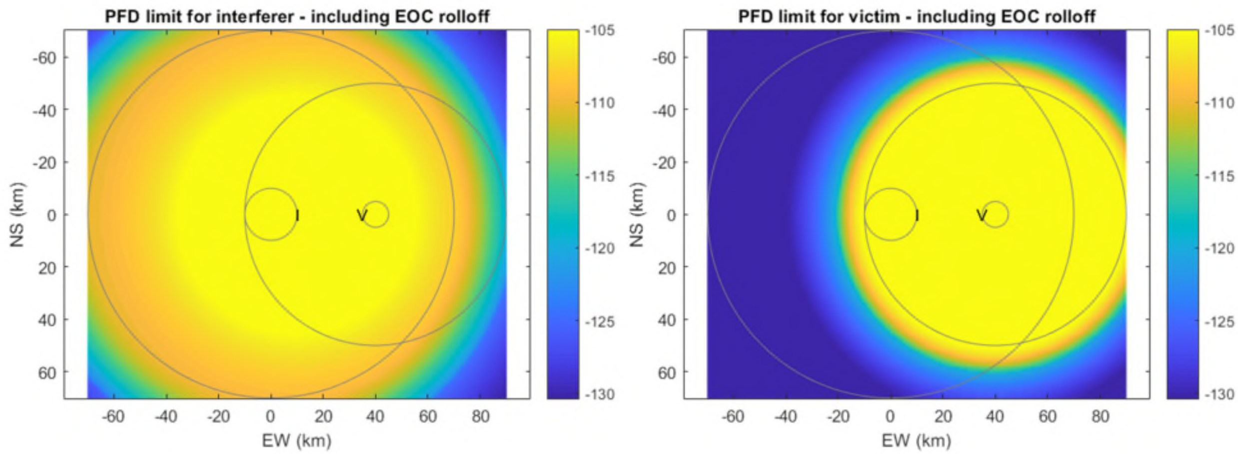


Figure 8: PFD on potential UT locations from other STRAPS. Left – PFD from Interferer incident across sample area. Right – PFD from "Victim" across sample area. PFD is at max limit across entire Interferer service area and rolls off outside based on STRAPS downlink beam roll-off.

Using the incident power and the gain the Victim presents to the Interferer (calculated from off-boresight angle presented to the Interferer), the total power into the Victim receiver is calculated, compared to the noise of the receiver and compared to the I/N protection criteria to determine I/N margin. Margin for the Victim at this separation and worst case relative geometry is positive, with a minimum of 17.8 dB across the service area.

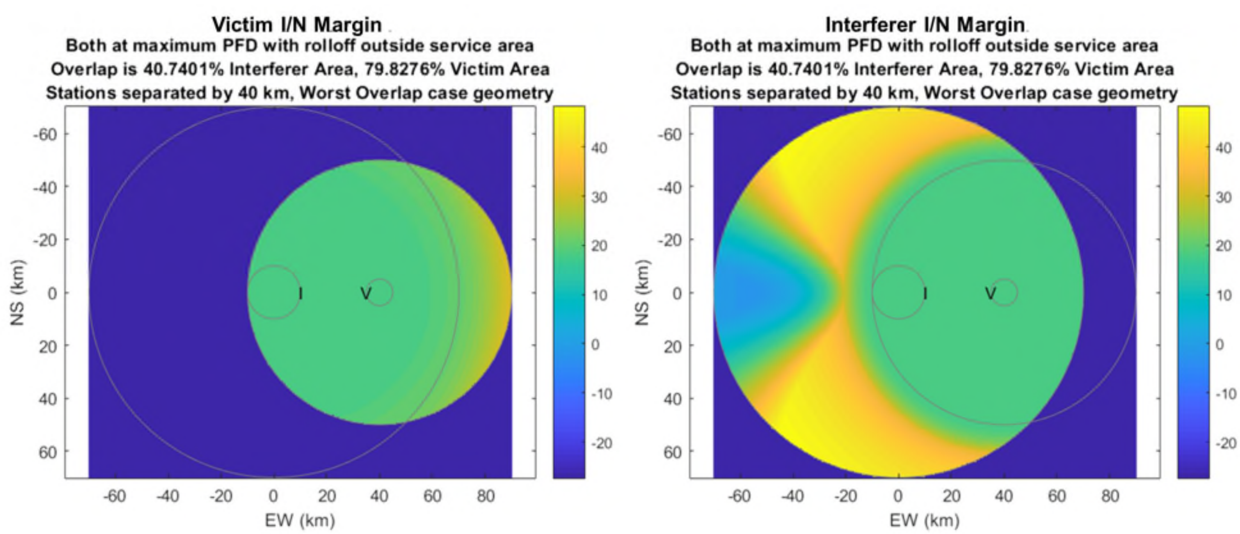


Figure 9: Margin to -6 dB I/N protection criterion. Left – Margin across Victim service area. Right - Reciprocal case: margin across "Interferer" service area due to interference from "Victim."

To investigate mutual compatibility, the reciprocal analysis (Figure 9, right) reverses the Interferer and Victim. In this case, the larger 70 km service area STRAPS experiences a negative margin over 2.2% of the service area with a margin as low as -2.5 dB, so mutual compatibility would require a larger separation between nominally fixed locations. Geometrically, the 70 km service area STRAPS, which in this example has a maximum altitude of 21.3 km, is at a disadvantage

because the 50 km service area STRAPS can be at a maximum height almost 5 km higher and thus appear closer to the boresight of a user terminal in the negative margin area. It should be noted that this negative margin drives the carrier-to-Interferer ratio to a 26 dB minimum, which can force a lower rate link when compounded with other signal to noise ratio impairments. Because this does not necessarily represent a loss of service, however, and may in fact represent a very modest reduction, it should be noted that these results are pre-coordination, and that the process of coordination between SBCS providers allows further improvement in overlap.

Parametric Analysis

The previously described scenario can be evaluated parametrically as a function of separation distance between the STRAPS nominal fixed locations. In Figure 10 (left), the previous example is in the "Worst Overlap" curve (corresponding to the geometry in Figure 4, middle) evaluated at 40 km separation where no part of the service area has a negative margin. For this scenario, the "Worst Edges" geometry (Figure 4, bottom) is the actual worst- case, requiring a separation of 40 km or greater to prevent any interference to the Victim. Note that if the STRAPS could remain exactly at their nominally fixed locations, the minimum separation would be < 20 km[6]. Importantly, these bounding cases represent extremes of a statistical range. For illustration, a marker indicates where the worst-case geometry would impact 10% of the service area at 30 km separation. If the chances of the geometry occurring are determined to be < 1%, a 1% chance of whatever reduction in capacity the 10% negative margin produces may be deemed acceptable by a STRAPS operator for coordination purposes. Where one STRAPS operator is coordinating two STRAPS it controls, it may be able to implement mitigations to further reduce the probability of adverse geometries. Where two different STRAPS operators are coordinating, they may accept different risk criteria. Additionally, to operate closer to an existing STRAPS, depending on the characteristics of the market in question, a new platform might voluntarily accept a small area of outage within its nominal service area radius, or small area of reduced data rates and capacity, if there is an overall net gain from a coverage perspective.

[6] SBCS operators have internal incentives to minimize variance from nominally fixed locations because it simplifies aspects of the systems (including UT pointing control and network management algorithms) that can reduce cost. As station-keeping improves and the control volumes decrease in size, the practical separation that is achievable approaches this minimum separation limit and maximum service area overlap.

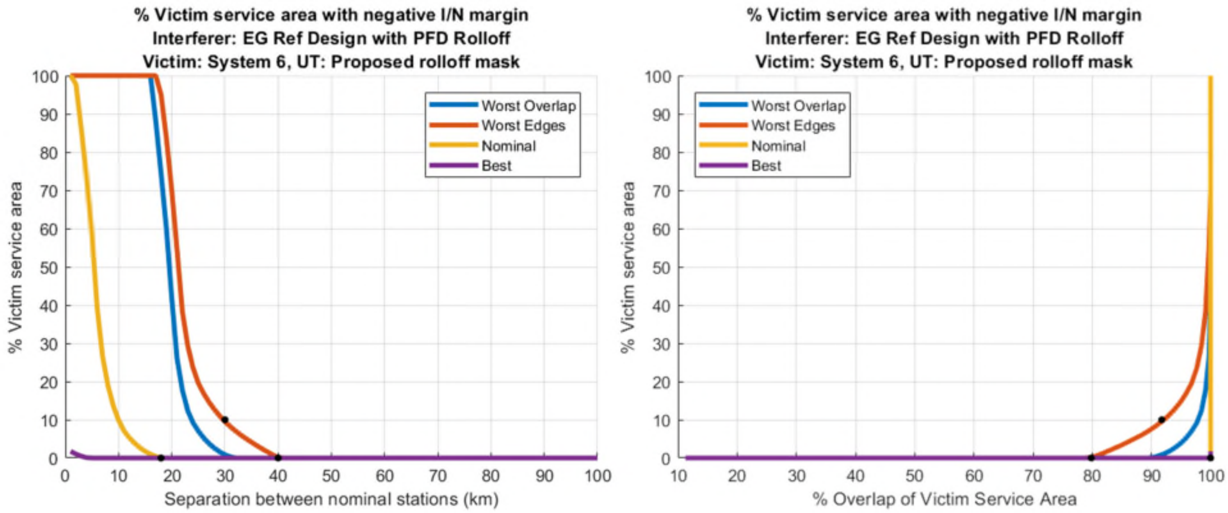


Figure 10: Parametric analysis of Victim compatibility versus separation distance for each of the four geometric bounding cases. Left – % of Victim service area with a negative protection criterion margin decreases with increasing distance. Right – % of Victim service area with a negative protection criterion margin decreases with % overlap with Interferer service area.

Figure 10 (right) presents the same results versus % of the Victim service area that overlaps the Interferer. For the worst-case geometry, 80% overlap corresponds to the closest separation to maintain 0% area with negative margin. Decreasing separation to 30 km allows 92% overlap with 10% of the service area at negative margin in the worst-case geometry (without regard to the statistical probability of that case). The "Nominal" curve in this representation is less meaningful. In the "Nominal" geometry, with the platforms maintaining their nominally fixed locations, there is no negative margin until they are within 20 km of each other. Because the 50 km service area radius overlaps 100% with the 70 km service area radius when they are < 20 km separate, the graph of negative margin area versus % overlap appears as a vertical line at 100% overlap. Note that two STRAPS purposely maintaining the same altitude or a smaller range in altitude difference reduce the potential impact of outlying geometric cases and would exhibit the ability to be closer together and overlap coverage closer to the nominal case.

As another example, two Elefante Group reference designs with 70 km service area radius at similar altitudes are considered, however with narrower UT beams from nearly uniformly illuminated apertures.

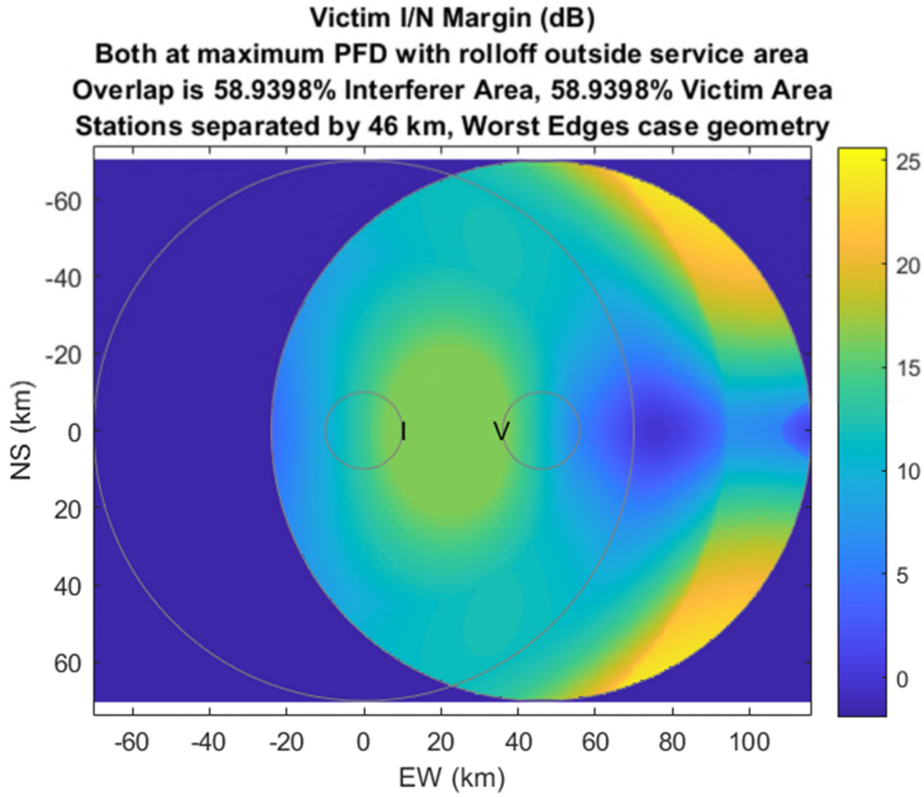


Figure 11: Overlap of two EG reference design 70 km service area STRAPS with nominal fixed location separation of 40 km. Worst case geometry for edge regions places Interferer (I) at easternmost limit of 10 km radius control volume and Victim (V) at westernmost limit of 5 km radius control volume; 31 km actual separation between platforms. Minimum margin is just below 0 dB.

As illustrated in Figure 11, in this case the absolute area of overlap is greater, although the percentage of overlapping area may be smaller. This is further illustrated in Figure 12.

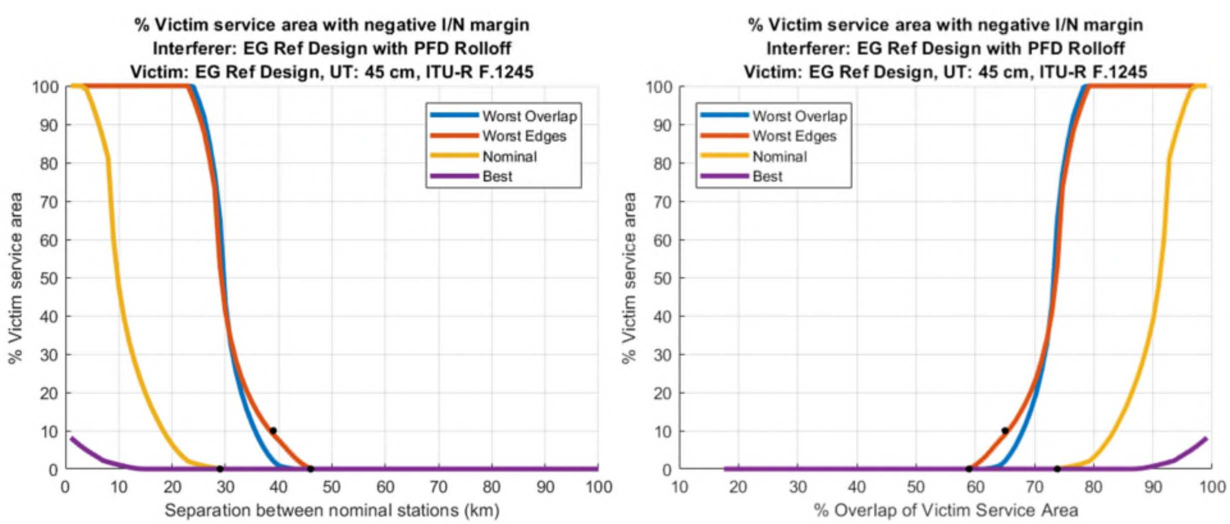


Figure 12: Parametric analysis of Victim compatibility vs separation distance for each of the four geometric bounding cases. Two EG reference designs.

Summary Results

The analyses described above were applied to all the cases as shown in Table 3.

Table 3: Summary results for cases described in Study Scenario section. Minimum separation and % of service area overlap for different bounding geometry and % negative margin criteria. Cases include different Interferers and Victims with different service area radii, and different user terminal antenna assumptions. All STRAPS roll off downlink PFD outside their service areas.

Interferer			Victim			Worst case - 0% victim area impacted		Worst case - 10% victim area impacted		Nominal case - 0% victim area impacted	
Source	Service area radius (km)	PFD rolloff outside service area	Source	Service area radius (km)	Antenna Pattern	Min Separation (km)	% Overlap	Min Separation (km)	% Overlap	Min Separation (km)	% Overlap
EG Ref Design	70	Y	EG Ref Design	70	45 cm, ITU-R F.1245	46	58.9	39	65.0	29	73.9
EG Ref Design	70	Y	System 6	50	35 cm, ITU-R F.1245	38	82.3	34	87.1	22	99.1
System 6	50	Y	EG Ref Design	70	45 cm, ITU-R F.1245	47	36.2	29	47.4	23	50.3
EG Ref Design	70	Y	EG Ref Design	50	45 cm, ITU-R F.1245	46	72.2	41	78.6	22	99.1
EG Ref Design	50	Y	EG Ref Design	70	45 cm, ITU-R F.1245	43	38.8	34	44.5	29	47.4
EG Ref Design	70	Y	EG Ref Design	70	45 cm, modeled	56	50.5	38	65.9	23	79.2
EG Ref Design	70	Y	System 6	50	35 cm, ITU-R F.1245	38	82.3	34	87.1	22	99.1
System 6	50	Y	EG Ref Design	70	45 cm, modeled	50	34.3	30	46.8	22	50.6
EG Ref Design	70	Y	EG Ref Design	50	45 cm, modeled	49	68.4	36	84.8	16	100.0
EG Ref Design	50	Y	EG Ref Design	70	45 cm, modeled	41	40.1	33	45.1	17	51.3
EG Ref Design	70	Y	EG Ref Design	70	Example rolloff mask	60	47.2	42	62.4	26	76.5
EG Ref Design	70	Y	System 6	50	Example rolloff mask	40	79.8	30	91.7	18	100.0
System 6	50	Y	EG Ref Design	70	Example rolloff mask	55	31.1	32	45.7	25	49.4
EG Ref Design	70	Y	EG Ref Design	50	Example rolloff mask	52	64.6	41	78.6	23	98.5
EG Ref Design	50	Y	EG Ref Design	70	Example rolloff mask	46	36.9	35	43.9	23	50.3

Results Discussion

Achievable Overlap: In all cases, significant overlap is achievable with positive margin on the protection criterion proceeding from worst-case geometries. From the two service area sizes analyzed, analyses can be grouped generally into the interactions between different service area radii, with a range of worst case and 10% negative margin area results based on the different systems and UT characteristics examined:

- 70 km Victim of 70 km Interferer (maximum of 100% overlap):
  - Absolute worst-case: 47 to 59% overlap
  - 10% negative margin: 62 to 65% overlap
- 50 km Victim of 70 km Interferer (maximum of 100% overlap):
  - Absolute worst-case: 65 to 82% overlap
  - 10% negative margin: 79 to 87% overlap.
- 70 km Victim of 50 km Interferer (maximum of 50% overlap)
  - Absolute worst-case: 31 to 39% overlap
  - 10% negative margin: 44 to 47% overlap.

Influence of UT Antenna: UT antenna pattern main lobe roll-off drives a large variation between the minimum and maximum possible service area overlap. For a given aperture size, a uniformly illuminated aperture assumption like ITU-R F.1245 produces the highest boresight gain and sharpest main lobe roll-off, but at the cost of higher sidelobes. The “45 cm, modeled” apertures are the result of electromagnetic modeling of a reflector/feed system designed to reduce sidelobes at the expense of broadening the main beam. Sidelobe reduction is critical to improved

compatibility with some of the other non-SBCS systems operating in the same band (and described in other analyses), but the beam broadening, as would be expected, negatively impacts sharing between STRAPS.

The "example roll-off mask" pattern is the result of bounding the modeled apertures with a simple envelope and includes additional reduction of roll-off which reduces allowable overlap. Further analysis will determine the extent the required roll-off of a mask to be used as a regulatory limit can be increased to approach the ITU-R F.1245 results while maintaining compatibility with other services and realistic apertures for UTs.

Table 4: Summary results for cases described in Study Scenario section. Same cases as Table 3, but STRAPS downlink does not roll off outside service area. Overlap is significantly reduced, reinforcing need to regulate roll-off outside service area to promote sharing.

Interferer			Victim			Worst case - 0% victim area impacted		Worst case - 10% victim area impacted		Nominal case - 0% victim area impacted	
Source	Service area radius (km)	PFD rolloff outside service area	Source	Service area radius (km)	Antenna Pattern	Min Separation (km)	% Overlap	Min Separation (km)	% Overlap	Min Separation (km)	% Overlap
EG Ref Design	70	N	EG Ref Design	70	45 cm, ITU-R F.1245	87	26.3	47	58.1	36	67.6
EG Ref Design	70	N	System 6	50	35 cm, ITU-R F.1245	47	71.0	34	87.1	22	99.1
System 6	50	N	EG Ref Design	70	45 cm, ITU-R F.1245	100	5.7	52	33.0	53	32.3
EG Ref Design	70	N	EG Ref Design	50	45 cm, ITU-R F.1245	64	49.6	44	74.8	23	98.5
EG Ref Design	50	N	EG Ref Design	70	45 cm, ITU-R F.1245	87	11.9	47	36.2	36	43.3
EG Ref Design	70	N	EG Ref Design	70	45 cm, modeled	87	26.3	41	63.3	31	72.1
EG Ref Design	70	N	System 6	50	35 cm, ITU-R F.1245	47	71.0	34	87.1	22	99.1
System 6	50	N	EG Ref Design	70	45 cm, modeled	100	5.7	41	40.1	48	35.6
EG Ref Design	70	N	EG Ref Design	50	45 cm, modeled	58	57.0	36	84.8	16	100.0
EG Ref Design	50	N	EG Ref Design	70	45 cm, modeled	87	11.9	41	40.1	31	46.3
EG Ref Design	70	N	EG Ref Design	70	Example rolloff mask	100	17.5	48	57.2	45	59.8
EG Ref Design	70	N	System 6	50	Example rolloff mask	48	69.7	30	91.7	18	100.0
System 6	50	N	EG Ref Design	70	Example rolloff mask	100	5.7	51	33.6	64	25.3
EG Ref Design	70	N	EG Ref Design	50	Example rolloff mask	71	41.1	42	77.3	23	98.5
EG Ref Design	50	N	EG Ref Design	70	Example rolloff mask	100	5.7	48	35.6	45	37.5

CONCLUSIONS

Even under the worst-case assumptions applied to this analysis, practical SBCS systems can be deployed with sufficient overlap that multiple STRAPS can serve the same market.

The more directive the user terminal antennas, the smaller the service area, and the smaller the control volume can be, the more the service area of a STRAPS would overlap with other STRAPS without receiving harmful interference (i.e., negative margin relative to IPC). Conversely, systems with less directive terminals, larger service areas, and larger control volumes are more sensitive to interference and may cause more interference to neighboring systems. Market incentives and, if need be, a regulatory framework (by imposing minimum technical requirements) can readily address all three points.

It is critical to note that this study does not perform a risk based, or statistically driven analysis. Were it to do so, the results would be even more favorable. Because STRAPS perform station-keeping within a control volume around their nominally fixed locations, interference between neighboring systems is not entirely deterministic and is subject to risk-based assessment. In coordination, operators will have the option to increase overlap between systems by accepting

some risk of degradation to their maximum performance in return for a larger area of overlap and have mechanisms to design their business around or with such conditions.

REFERENCES:

ITU-R F.1245-2: Mathematical models of average and related radiation patterns for line-of-sight point-to-point fixed wireless systems antennas for use in certain coordination studies and interference assessments in the frequency range from 1 GHz to about 70 GHz

Annex 14 to Document 5C/410-E (Working Party 5C Chairman's Report), 24 November 2017 "Deployment and technical characteristics of broadband high altitude platform stations in the bands 6 440-6 520 MHz, 6 560-6 640 MHz, 21.4 22.0 GHz, 24.25-27.5 GHz, 27.9-28.2 GHz, 31.0-31.3 GHz, 38.0 39.5 GHz, 47.2-47.5 GHz and 47.9-48.2 GHz to be used in sharing and compatibility studies": Performance characteristics for a stratospheric system proposed by Facebook for ITU HAPS agenda item compatibility studies ("System 6")