STARLINK

BY ELECTRONIC FILING

April 29, 2024

NGSO Team
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Re: Kepler Communications Inc: application for NGSO earth station network licence: KEPLER-NET-1

Dear Ofcom NGSO Team,

In response to Ofcom's request for comment on Kepler Communications Inc.'s application for an NGSO earth station network licence, Starlink submits its deep concerns with Kepler's ability to coexist in the Ku-band spectrum and protect UK citizens. Specifically, Kepler cannot meet condition 2 for network licenses, which requires operators to continually coordinate the use of shared spectrum.[1] Moreover, Kepler has submitted an error-ridden analysis that underestimates the interference it will cause to other operators, including Starlink. This interference has the potential to cause significant service degradation to UK citizens that depend on Starlink's high-speed, low-latency broadband internet.

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[1] Ofcom, *Statement: Non-geostationary satellite systems: Licensing updates*, 10 December 2021, at 38 ("NGSO Updates") (License Condition 2: "The Licensee shall cooperate with all NGSO Licensees such that each satellite system (comprising the satellites, earth stations and user terminals) can co-exist and operate within the United Kingdom without causing harmful radio interference to each other, such that network services can be provided to end users.")

Kepler's Technical Analysis is Deeply Flawed. A Corrected Interference Analysis Shows Crippling Interference from Kepler

In the absence of a coordination agreement, Kepler's license application includes an analysis that claims to show Kepler is able to coexist with Starlink in the Ku-band despite its inability to coordinate. Yet, Kepler's submission includes only cursory technical information and a deeply flawed analysis rife with serious errors.[2]

As discussed below, Kepler wrongly claimed that "[g]iven the ITU filings, the worst affected links have been simulated."[3] Kepler did not use the worst affected Starlink earth station from the STEAM-1 ITU MOD6 filing.[4] Kepler also did not use Starlink satellite beam parameters that would result in the worst affected link. Similarly, when describing its own system, Kepler made unexplained assumptions that underestimate the potential interference it will cause. For instance, Kepler used only antenna gain values (and therefore EIRP density values) for both its uplink and downlink analysis that were less than the maximum values allowed under its KELYPSIS ITU filing. Instead, Kepler should have showed the impact to Starlink of operating at its KELYPSIS filing limits as well.

As an initial matter, Kepler wrongly used a large high-gain Starlink antenna specification with a diameter of 1.47 m and an assumed gain of 44.0 dBi from STEAM-1. Instead, Kepler should have used a Starlink user terminal antenna that is more susceptible to interference such as Starlink's V3 (a/k/a UT2) user terminal, which has much smaller 0.52 m diameter and much lower 34.6 dBi gain.[5] Kepler also used a Starlink satellite EIRP of 37.3 dBW (11 dBW satellite transmit power and 26.3 dBi satellite antenna gain) over 116 MHz bandwidth, leading to a -43.34 dBW/Hz EIRP density, instead of the lower -52.3 dBW/Hz value in STEAM-1.[6] Kepler's initial errors had a cascading effect throughout Kepler's analysis. For instance, Kepler used a Starlink EIRP density that is higher by nearly 9 dB in downlink than the maximum allowed EIRP density for a comparable-gain beam under Starlink's STEAM-1 ITU filing and higher by nearly 11 dB in uplink than the maximum allowed in Starlink's publicly available earth station application for its V3 user terminal. As a result, Kepler's analysis significantly overstated Starlink's signal strength at its satellite and at its user terminal, and therefore significantly underestimated the level of interference Kepler would cause to Starlink's users.

To correct Kepler's analyses, Starlink used only publicly available information to show the increase in unavailability (short-term interference) and the degradation in time-averaged spectral efficiency, also known as throughput degradation (long-term interference), caused by a collocated Kepler earth station. Starlink first corrected the parameter errors relating to Starlink. Starlink then ran two dynamic simulations in uplink (Case 1 and Case 2) and two in downlink (Case 1 and Case 2) using these corrected Starlink parameters. Case 1 in each direction uses the Kepler transmit power and antenna gain values in Kepler's Ofcom showing, and Case 2 uses the maximum values for these parameters from Kepler's KELYPSIS ITU filing. To confirm, Starlink did not change any other assumptions about Kepler's system for the Case 1 analyses, and the only assumptions about the Kepler system that Starlink changed for the Case 2 analyses were the maximum Kepler antenna gain and corresponding transmit power in each direction.

Starlink's results are summarized in Table 1 below. Starlink found the expected interference to be much higher than Kepler estimates, particularly the interference into the uplink from Starlink user terminals to its satellites.

[2] Ofcom, *Non-geostationary satellite systems: Licensing guidance*, 10 December 2021, at sec 3.7 ("As coordination discussions can take many months, we would wish to see evidence that they are progressing in a timely fashion and that both parties are participating constructively.")

[3] Kepler Response to Ofcom's Informal Request for Information, at 2.

[4] Reference herein to the STEAM-1 ITU filing is to STEAM-1 MOD6. Kepler did not use the worst affected link in the STEAM-1 filing, which is Starlink earth station ES-AY. For the analyses presented here, Starlink uses its V3 user terminal, which is not as susceptible to Kepler interference as Starlink ES-AY but is more susceptible than the Starlink earth station Kepler used in its submission to Ofcom. *See* Attachment SESLIC2021070801019 (Nov. 10, 2021), https://fcc.report/IBFS/SES-LIC-20210708-01019/13393269 (V3 (a/k/a UT2) user terminal blanket licence).

[5] Starlink's V3 user terminal is similar to earth station ES-DY in Starlink's STEAM-1 filing.

[6] This EIRP density of -52.3 dBW/Hz is for beams DA324Y and DB324Y in the STEAM-1 filing.

Table 1. Comparison of Interference into Starlink System from Kepler System:

Location	Link	Analysis by / Case	Objective C/N = 0 dB				
			Availability w/o KEPLER (%)	Availability w/ KEPLER (%)	Reduction in Availability (%)	Increase in Unavailability (%)	Avg. Throughput Degradation (due to KEPLER interference) (%)
London, England (51.5080°N, -0.0952°E)	Uplink	KEPLER	-	-	-	0.01	0.80
		STARLINK Case-1	99.999	99.352	0.648	6511.653e+10	35.470
		STARLINK Case-2	99.999	98.824	1.176	11822.719e+10	45.570
	Downlink	KEPLER	-	-	-	0.00	0.06
		STARLINK Case-1	99.994	99.974	0.020	329.195	0.294
		STARLINK Case-2	99.993	99.930	0.064	937.389	0.525

Kepler's uplink operations, even with the Kepler system parameters it used for its Ofcom analysis but corrected Starlink parameters (Case 1), threaten to cause more than 0.6% decrease in availability to Starlink as a result of a large number of in-line events from Earth to space, and a massive 35% long-term throughput degradation. This interference from Kepler in the uplink would significantly degrade the Starlink quality of service that consumers and business in the United Kingdom experience.

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Technical Annex

As described above, Starlink ran two dynamic simulations in the uplink (Case 1 and Case 2) and two in the downlink (Case 1 and Case 2). Case 1 in each direction uses the Kepler transmit power and antenna gain values in Kepler's Ofcom showing, and Case 2 uses the maximum values for these parameters from Kepler's KELYPSIS ITU filing.

Orbital Configurations

Starlink simulated co-frequency interference from the Kepler system (Table A-1) into the Starlink STEAM-1 system (Table A-2) and a Starlink V3 user terminal (UT) located at London, England (51.5080°N, -0.0952°E) and collocated with a Kepler earth station. The satellite orbital configurations are the same as Kepler used in its submission to Ofcom:

Table A-1. Kepler Orbital Parameters

Orbital Altitude (km)	575
Inclination (deg)	97.7°
Orbital Planes	7
Satellites per Plane	20

Table A-2. Starlink Orbital Parameters

Orbital Altitude (km)	550	540	570	560	560
Inclination (deg)	53°	53.2°	70°	97.6°	97.6°
Orbital Planes	72	72	36	6	4
Satellites per Plane	20	22	22	20	58

Simulation Design

To demonstrate the interference that Kepler's system could cause, Starlink designed its simulation steps to allow use of a dual interference metrics as Kepler did—increase in unavailability for short-term interference and degradation of time-averaged spectral efficiency for long-term interference.

Regarding the simulation methodology, Starlink performed each of four time-domain simulations at one second time steps over sixty days. At each time step of a simulation, both the C/N and carrier-to-noise plus interference ("C/(N+I)") values are calculated, whether for a Starlink uplink (from a Starlink UT) or a Starlink downlink (to a Starlink UT), where the Kepler system is the interference source. For the C/N and C/(N+I) values calculated at a time step, Starlink incorporates all atmospheric attenuation characteristics (see Recommendation ITU-R P.618 and references therein) that systems may experience, including degradation due to atmospheric gases, rain, cloud cover, and scintillation. Each calculated C/N and C/(N+I) value at a time step is recorded in an array, where these paired values are accumulated over the simulation duration. These arrays for Starlink uplink and downlink operations were then sorted and processed into cumulative distribution functions ("CDFs"), which allow for calculation of short-term and long-term interference of the four cases.

For each case, five figures of merit are provided to show the impact of interference from Kepler into Starlink' service. The first two are the availability percentages without and with Kepler at an objective C/N of 0 dB as well the graphical figure from which these values were derived, which demonstrate how interference impacts Starlink's C/N. The third is the reduction in availability due to Kepler, which is the difference between the availability percentages without and with Kepler at this objective C/N. The fourth is the increase in unavailability due to Kepler at this objective C/N. And the fifth is the degradation of Starlink's time-averaged spectral efficiency, showing Starlink's throughput loss due to Kepler interference.

Assumptions

Starlink assumes that both the Starlink and Kepler systems maintain constant Effective Isotropic Radiated Power ("EIRP") for both uplink and downlink transmissions. Starlink also assumes complete bandwidth overlap and a single receive polarization to enable analysis on a per-Hertz basis without the potential for discrimination. The interference simulations use a random pointing strategy as a proxy for simulating satellite selection for both the Starlink and Kepler systems. Under a random pointing strategy, the simulation randomly selects a SpaceX satellite in view and a Kepler satellite in view of the collocated earth station location from the pools of eligible satellites at each timestep (i.e., every one second).

Parameters, and Results

Table A-3 to A-10 and Figure 1 to Figure 4 specify the parameters, provide the analysis summary, and display the analysis graphically for Case 1 and 2 in each direction. The parameters for each case below are specified in a table just before that case summary and graphical analysis are presented. **In each case studied the Starlink parameters specified below are corrected compared to the parameters Kepler used.**

Table A-3. Uplink Case 1 Analysis Specification (with specifications for Kepler GW-1 Earth station as used in Kepler's analysis submitted to Ofcom):

Starlink Uplink Parameter	Kepler	Starlink
Carrier Frequency [GHz]	14.25	
Ground Station Gain [dBi]	52.2 (GW-1 from KELYPSIS)	34.6 (Starlink UT2 FCC Blanket licence)[8]
EIRP density [dBW/Hz]	5.2 [Note: 23 dBW-10log10(10MHz) +52.2 dBi]	-39.6 (Starlink UT2 FCC Blanket licence)
Noise Temperature [K]	-	424.0
Satellite Gain [dBi]	-	35.9 (UC359Y from STEAM-1)
Satellite Beam Pattern	-	ITU-R S.1528 LEO
Ground Station Beam Pattern	APENST806V01, coef A = 29	AP8
Ground Station Minimum Elevation [deg]	10.0	25.0

[8] Attachment SESLIC2021070801019 (Nov. 10, 2021), https://fcc.report/IBFS/SES-LIC-20210708-01019/13393269 (V3 (a/k/a UT2) user terminal blanket licence).

Table A-4. Uplink Case 1 Analysis Summary:

	Objective C/N = 0 dB				
	Availability w/o Kepler (%)	Availability w/ Kepler (%)	Decrease in availability (%)	Increase in unavailability (%)	Avg. Throughput Degradation (due to Kepler interference) (%)
Uplink: Case 1	99.999	99.352	0.648	6511.653e+10	35.470

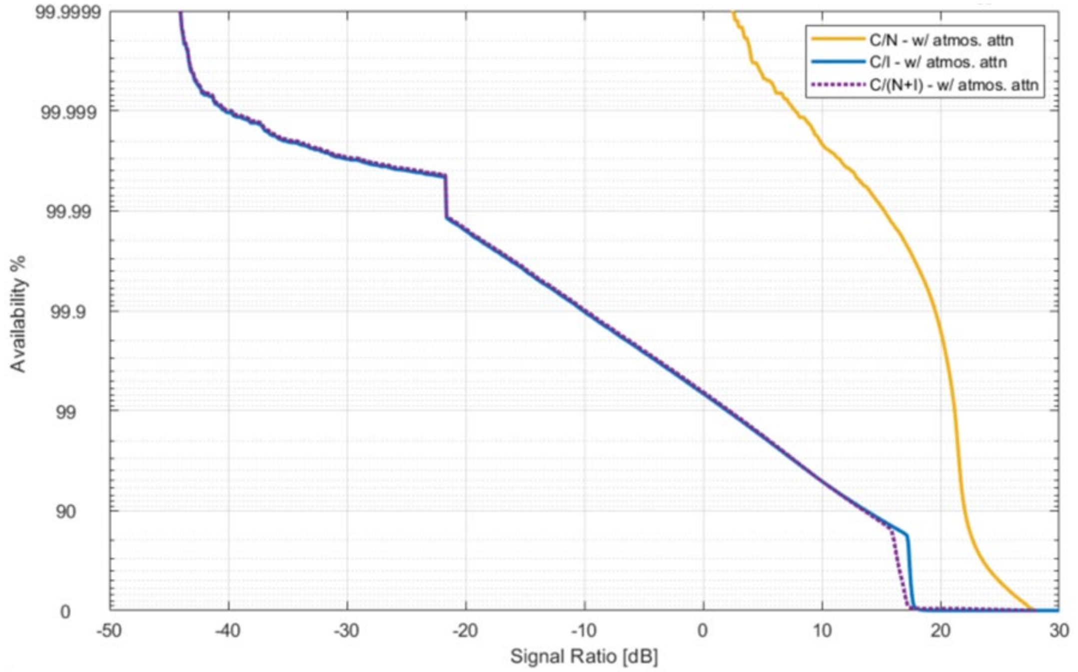

Figure 1. Uplink Case 1: C/N, C/I & C/(N+I) of Starlink System

Table A-5. Uplink Case 2 Analysis Specification (with specifications for Kepler's GW-2 Earth station with maximum transmit antenna gain and EIRP density in the KELYPSIS filing):

Starlink Uplink Parameter	Kepler	Starlink
Carrier Frequency [GHz]	14.25	
EIRP density [dBW/Hz]	11.6 [Note: 26 dBW-10log10(10MHz)+55.6 dBi]	-39.6 (Starlink UT2 FCC Blanket licence)
Noise Temperature [K]	-	424.0
Satellite Gain [dBi]	-	35.9 (UC359Y from STEAM-1)
Satellite Beam Pattern	-	ITU-R S.1528
Ground Station Gain [dBi]	55.6 (GW-2 from KELYPSIS)	34.6 (Starlink UT2 FCC Blanket licence)
Ground Station Beam Pattern	APENST806V01, coef A = 29	AP8
Ground Station Minimum Elevation [deg]	10.0	25.0

Table A-6. Uplink Case 2 Analysis Summary:

	Objective C/N = 0 dB				
	Availability w/o Kepler (%)	Availability w/ Kepler (%)	Decrease in availability (%)	Increase in unavailability (%)	Avg. Throughput Degradation (due to Kepler interference) (%)
Uplink: Case 2	99.999	98.824	1.176	11822.719e+10	45.570

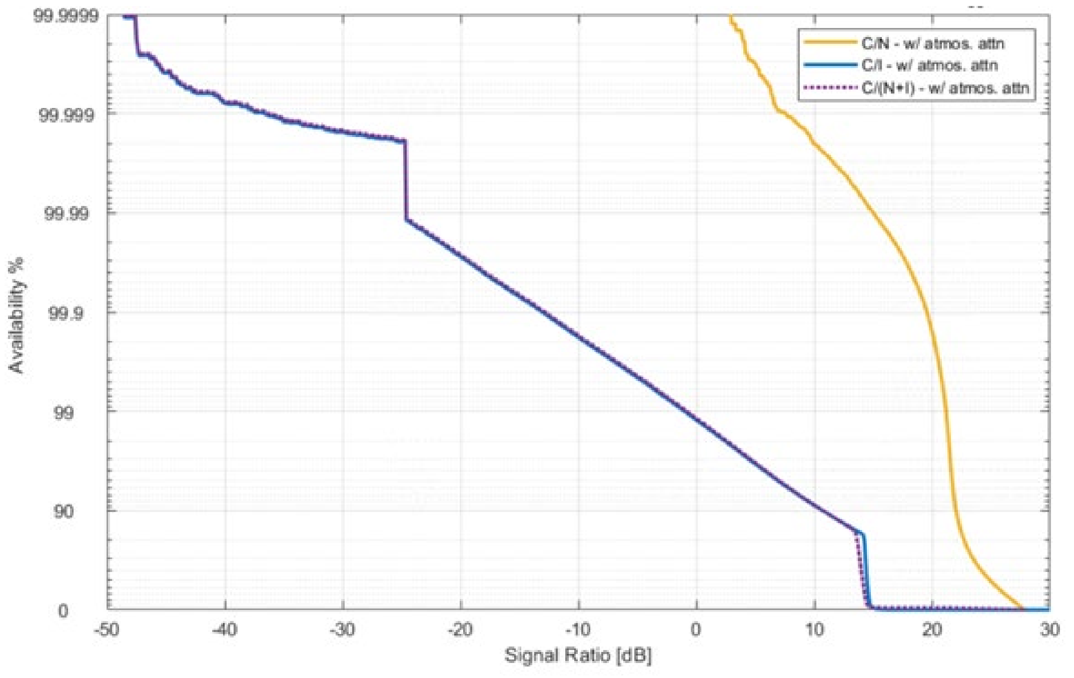

Figure 2. Uplink Case 2: C/N, C/I & C/(N+I) of Starlink System

Table A-7. Downlink Case 1 Analysis Specification (with specifications for the Kepler satellite antenna as used in Kepler's analysis submitted to Ofcom):

Starlink Downlink Parameter	Kepler	Starlink
Carrier Frequency [GHz]	11.70	
EIRP Density[dBW/Hz]	-51.5 dBW/Hz [Note: -8.7 dBW-10log10(10MHz) +27.2 dBi]	-52.3 dBW/Hz (DA324Y, DB324Y from STEAM-1)
Noise Temperature [K]	-	374.0
Satellite Gain [dBi]	27.2 (O2P2BA from KELYPSIS)	32.4 (DA324Y, DB324Y from STEAM-1)
Satellite Beam Pattern	ITU-R S.1528	ITU-R S.1528
Ground Station Gain [dBi]	-	33.2 (Starlink UT2 FCC Blanket licence)
Ground Station Beam Pattern	-	AP8
Ground Station Minimum Elevation [deg]	10.0	25.0

Table A-8. Downlink Case 1 Analysis Summary:

	Objective C/N = 0 dB				
	Availability w/o Kepler (%)	Availability w/ Kepler (%)	Decrease in availability (%)	Increase in unavailability (%)	Avg. Throughput Degradation (due to Kepler interference) (%)
Downlink: Case 1	99.994	99.974	0.020	329.195	0.294

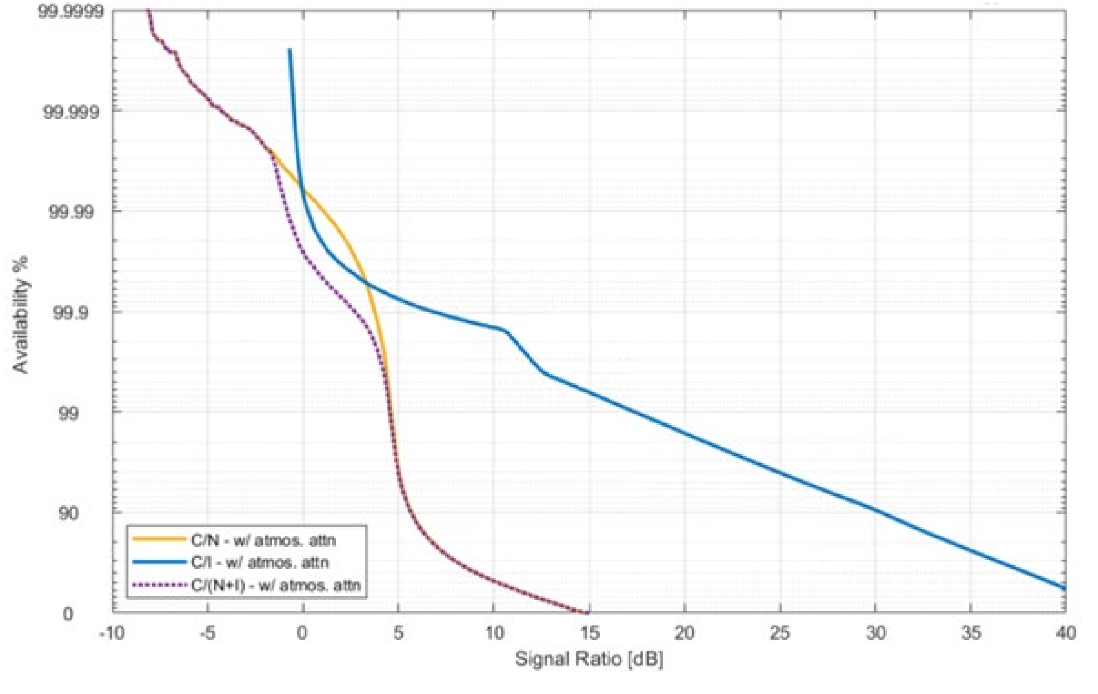

Figure 3. Downlink Case 1: C/N, C/I & C/(N+I) of Starlink System

Table A-9. Downlink Case 2 Analysis Specification (with specifications for Kepler's maximum satellite transmit antenna gain and EIRP in the KELYPSIS filing):

Starlink Downlink Parameter	Kepler	Starlink
Carrier Frequency [GHz]	11.83	
EIRP Density[dBW/Hz]	-48.3 dBW/Hz (Note: -11.8 dBW-10log10(10MHz) +33.5 dBi)	-52.3 dBW/Hz (DA324Y, DB324Y from STEAM-1)
Noise Temperature [K]	-	374.0
Satellite Gain [dBi]	33.5 (O3P4BA from KELYPSIS)	32.4 (DA324Y, DB324Y from STEAM-1)
Satellite Beam Pattern	ITU-R S.1528	ITU-R S.1528
Ground Station Gain [dBi]	-	33.2 (Starlink UT2 FCC Blanket licence)
Ground Station Beam Pattern	-	AP8
Ground Station Minimum Elevation [deg]	10.0	25.0

Table A-10. Downlink Case 2 Analysis Summary

	Objective C/N = 0 dB				
	Availability w/o Kepler (%)	Availability w/ Kepler (%)	Decrease in availability (%)	Increase in unavailability (%)	Avg. Throughput Degradation (due to Kepler interference) (%)
Downlink: Case 2	99.993	99.930	0.064	937.389	0.525

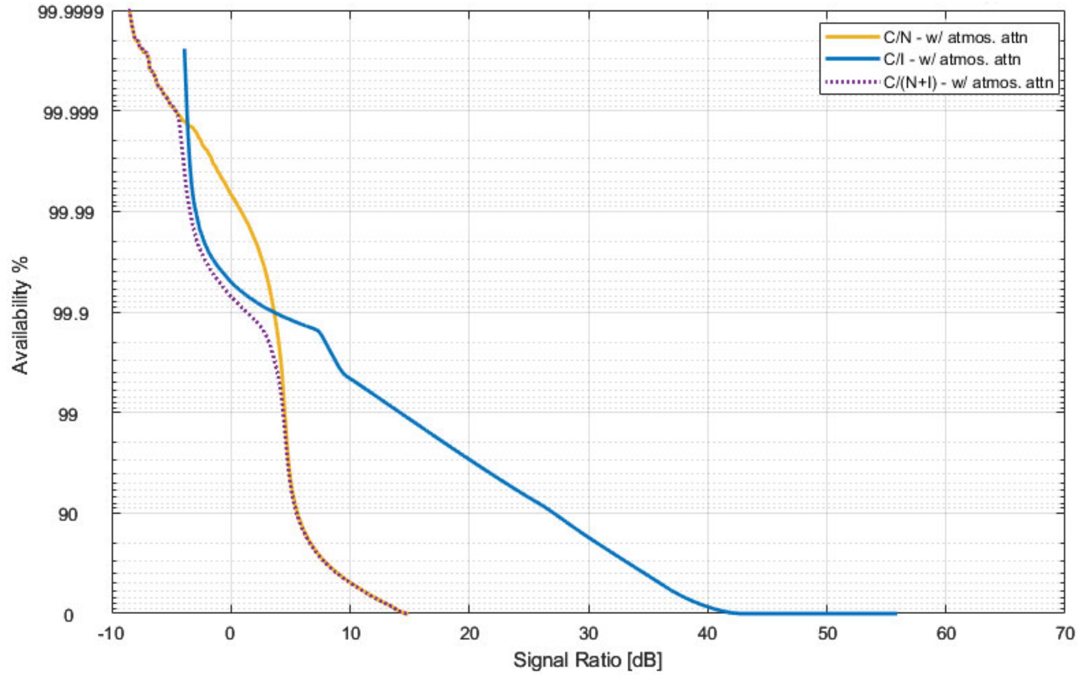

Figure 4. Downlink Case 2 C/N, C/I & C/(N+I) of Starlink System