The Tomorrow Companies, Inc.

Updated Technical Narrative

1. Introduction

In accordance with the FCC's Part 25 Rules, this Technical Narrative documents pertinent information of The Tomorrow Companies, Inc. (Tomorrow.io) Weather Constellation, including but not limited to the constellation's orbital configuration, facilities, operations, services, interference, and orbital debris mitigation compliance. This information is intended to supplement the technical parameters specified in Tomorrow.io's Schedule S and in the Tomorrow.io Orbital Debris Assessment Report (ODAR).

2. The Tomorrow.io Weather Constellation

Tomorrow.io's planned non-geostationary orbit ("NGSO") Earth Exploration Satellite Service ("EESS") system consists of eighteen 6U identical (25.114(a)(2)) satellites, designed to have an estimated operational lifetime of five years (25.114(c)(10)), and distributed across nine planes at 550 km. Each of the eighteen space stations will host a twelve-channel, passive, millimeter-wave microwave sounder payload, commonly referred to as a radiometer, developed collaboratively by MIT Lincoln Laboratories (MIT LL) and Tomorrow.io, built by Tomorrow.io, and integrated into a spacecraft based on a Blue Canyon Technologies (BCT) standardized 6U bus design. Atmospheric temperature, humidity and precipitation structures gathered from the sounder payload will be downlinked and then used in the first-ever commercial, near real-time weather monitoring and forecasting system to inform critical industry sectors like aviation, agriculture, logistics, energy and utilities, to name a few.

Ten of the eighteen Tomorrow.io spacecraft will be distributed in sun-synchronous orbits (SSO) at various local time of ascending nodes (LTANs), whereas the other eight spacecraft will orbit at the same altitude, but at 45 degree inclinations. A breakdown of the orbital parameters, plane counts, satellites (or space stations), per plane is provided in Table 1.

Table 1. Tomorrow.io's Weather Constellation Orbital Parameters

Plane	Satellites per Plane	Inclination	LTAN / RAAN (estimates)
1	2	SSO	1100 LTAN
2	2	SSO	0600 LTAN
3	2	SSO	2300 LTAN
4	2	SSO	1700 LTAN
5	2	SSO	0500 LTAN
6	2	45°	30°
7	2	45°	120°
8	2	45°	210°
9	2	45°	300°

Tomorrow.io notes that an altitude of 550 km has a relatively low spatial density of existing debris compared to orbital altitudes around 700 - 900 km and 1400 - 1500 km.[1]

2.1 Space Segment

Tomorrow.io is partnering with leading smallsat manufacturer BCT, as well as MIT Lincoln Labs, to ensure that each spacecraft is designed and manufactured with state-of-the-art smallsat communications and radiometry technology, respectively. The communications system consists of a software defined radio (SDR) transceiver for S-band reception for commanding the vehicle, and X-band transmissions primarily for downlinking passively received sounder payload data that is stored and then forwarded onto visible ground stations, along with telemetry.

[1] Brigo, T.P., Celestino, C.C, and Moraes, R.V., "A brief scenario about the 'space pollution' around the Earth", Journal of Physics: Conference Series. Vol. 465. No. 1. IOP Publishing, 2013.

The on-board SDR operates in two predefined modes: a High Rate (Nominal) Mode and a Low Rate (Contingency) Mode. The Nominal Mode is used during most operations, whereas the Contingency Mode is used during launch and early operations (LEOP), commissioning, and in safe mode. Safe mode is triggered when the bus hasn't received commands from the ground for twenty-four hours, the bus transitions to safe mode due to some unrelated fault, the bus resets, or the bus receives a command to change modes.

Figure 1 provides a rendering of a single Tomorrow.io Microwave Sounder Satellite.

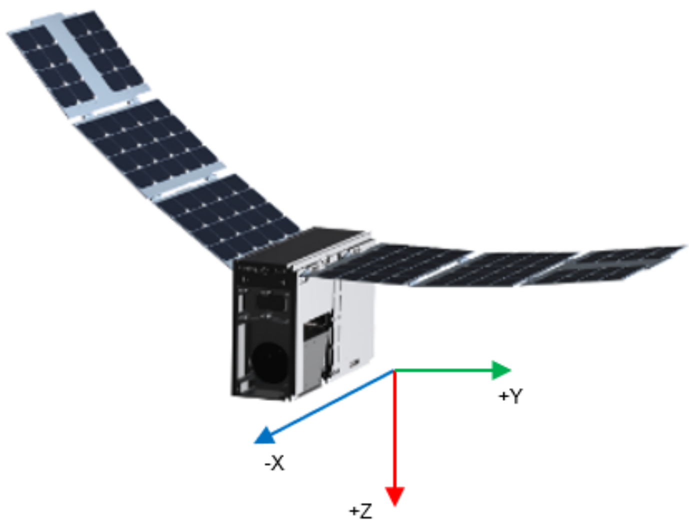


Figure 1. Tomorrow.io Microwave Sounder Satellite

Each microwave sounder collects measurements between 90 - 205 GHz with two receivers using the W-, F-, and G-bands, and has a twelve-channel spectrometer that rotates about the x-axis at 30 RPM with a swath width of ~2000 km. Temperature sounding occurs near 118 GHz and moisture sounding occurs near 183 GHz. The specific instrument was developed as an operational version of the proven microwave sounder technology that is flying on NASA's

Time-Resolved Observations of Precipitation structure and storm Intensity with a Constellation of Smallsat (TROPICS) mission.[2]

Each spacecraft measures approximately 24 cm x 36.5 cm x 13.6 cm in volume and approximately 12 kg in mass, and is equipped with: 1) two deployable solar panel wings, 2) an avionics system consisting of an IMU, GPS module, Electrical Power System (EPS) control module, and battery packs, 3) a BCT Software Defined Radio (SDR) known as an SDR-X transceiver (which supports both S-band and X-band), 4) one X-band antenna and one S-band antenna, and 5) an attitude determination and control system (ADCS) with a star tracker, three reaction wheels and torque rods, and requisite control modules.

2.2 Ground Segment

Tomorrow.io will work with third-party ground station network (GSN) vendors, to procure ground station as a service (GSaaS) for its S-band uplinks and X-band downlinks. Tomorrow.io's GSN provider is responsible for all manufacturing and operations for the ground station network. Table 2 provides the locations of the baselined earth stations (ES), including expected future sites (denoted with a *) and backup sites (denoted with **).

Table 2. S-/X-band Earth Stations (ES) Baselined for Tomorrow.io Operation

GS #	City	Country	# of Passes per Day
1	Athens	Greece	45
2	Awarua	New Zealand	40

[2] NASA's TROPICS Mission, https://tropics.ll.mit.edu/CMS/tropics/Mission-Overview

3	**Fairbanks**	**Alaska, USA**	**20**
4	Hartebeesthoek	South Africa	35
5	Jeju*	S. Korea	45
6	Inuvik	Canada	60
7	**Maui***	**Hawaii, USA**	**35**
8	Maspalomas*	Spain	40
9	Mauritius	Mauritius	35
10	Panama*	Panama	30
11	Mingenew	Australia	45
12	Puertollano	Spain	0
13	Singapore*	Singapore	30
14	Punta Arenas	Chile	50
15	Svalbard	Norway	70
16	Troll**	Antarctica	0
17	Tromsø	Norway	20

Of the seventeen ES globally, two are located in the United States. These two ESs are bolded in Table 2. These antennas will span 3.7 m in diameter and maintain elevation angles above 10 degrees, conforming with 25.205(a) of the Commission's Rules.

3. Facilities, Operations and Services

This section defines the facilities, operations, services and how the uplink frequencies are connected to the downlink frequencies for Tomorrow.io's Weather Constellation in accordance with 25.114(d)(1) of the Commission's Rules.

3.1 Facilities

In addition to manufacturing services, Tomorrow.io will work with BCT to also provide operations support. Unlike traditional networks, BCT does not rely on physical ground network facilities or operations centers, but instead hosts such facilities in the cloud. All of these virtual operations have heritage and are properly secured and maintained against unauthorized access, ensuring the security of all satellite commands, as required in 25.271 of the Commission's rules.

Tomorrow.io will access the BCT network through a Virtual Private Network (VPN), and instruct BCT which commands to transmit to the payload. Tomorrow.io will receive all payload data as well as corresponding spacecraft telemetry, and will perform science based post-processing of the weather-related measurements.

3.2 Operations

This section documents the launch, in-orbit, and end-of-life mission operations of the Tomorrow.io Weather Constellation. Prior to launch, Tomorrow.io will register with the U.S. Space Force's 18th Space Control Squadron ("18th SPCS") or the appropriate successor entity (25.114(d)(v)(B)), and share information regarding initial spacecraft deployment, ephemeris and planned maneuver information. Tomorrow.io notes that for their past experimental mission they have engaged with the 18th SPCS, and so will expeditiously engage again. Tomorrow.io will also maintain a complete and accurate set of current and planned radiofrequency transmissions for their satellites and will provide any necessary technical information to other space station satellites in order to identify and promptly resolve any potential causes of radio frequency interference between systems.

3.2.1 Launch

The Tomorrow.io satellites are scheduled to launch in pairs on multiple SpaceX Falcon 9 rideshare missions out of either Cape Canaveral, Florida or Vandenberg Air Force Base, California between Q1 2024 through Q3 2025. Table 3 provides an overview of the Tomorrow.io Weather Constellation launch schedule, showing that each pair of satellites are destined for a specific plane.

Table 3. Tomorrow.io Launch Schedule

Space Station	**Launch Window**	**Inclination**
1, 2	Jan. 1 - Feb. 29, 2024	SSO
3, 4	Apr. 30, 2024 - Apr. 30, 2026	45 deg.
5, 6	June 1 - July 31, 2024	SSO
7, 8	Aug. 1 - Oct. 30, 2024	SSO
9, 10	Nov. 30, 2024 - Nov. 30, 2026	45 deg
11, 12	Feb. 1- Mar 31, 2025	SSO
13, 14	Feb. 28, 2025 - Feb. 28, 2027	45 deg.
15, 16	May 31, 2025 – May 31, 2027	45 deg.
17, 18	June 1 - July 31, 2025	SSO

With this launch schedule, Tomorrow.io will comply with 25.164(b) of the Commission's Rules, which requires fifty-percent of the constellation to be deployed and operational within six years of authorization (25.164(b)(1)), and the remainder of the constellation to be deployed and operational within nine years after authorization (25.164(b)(2)).

3.2.2 In-orbit Operations

Given that there will not be an on-board propulsion system, orbital parameters will not be maintained (25.114(d)(14)(iv)(A)(4)). However, Tomorrow.io notes that each satellite is larger than 10 cm in their smallest dimension, and is therefore assumed to be trackable per 25.114(d)(14)(v). In accordance with 25.114(d)(14)(v)(A), Tomorrow.io will monitor the location of satellites passively utilizing TLEs and the GPS module (with a position error tolerance of less than 10 meters RMS). At appropriate intervals, Tomorrow.io will also propagate trajectories of all spacecraft to enhance the quality of conjunction predictions with other space stations (25.114(d)(14)(iv)(A)(2)).

After separation from the launch vehicle, each spacecraft will wait thirty minutes prior to turning on. Then it will autonomously de-tumble and enter a safe sun-tracking mode. Attitude modes use a combination of sensors and actuators (one magnetometer, one gyroscope, three sun-sensors, three reaction wheels, three torque rods, and one star tracker) to perform maneuvers and orient the spacecraft. The four primarily ADCS Modes are summarized in Table 4.

Table 4. Tomorrow.io ADCS Modes

ADCS Module	Description
Sun Safe	The spacecraft will track the sun vector on its -Z body axis to generate sufficient power to charge up the batteries with the

	payload off
Downlink	The spacecraft will perform a slew to track the corresponding ground station as long as line of sight is available.
Charge/Standby	The spacecraft will track the sun vector to generate power to charge batteries
Science Operations	During nominal payload operations, the spacecraft will hold the specified attitude for the allowed duty cycle per orbit before slewing into sun tracking mode to recharge the batteries. The spacecraft will track on the radiometer boresight within 5-10 degrees of nadir, with various scan angles used to complete the mission.

As previously mentioned, Tomorrow.io will also work throughout the course of its mission to update orbital information with 18th SPCS (25.114(d)(v)(C)), and upon receipt of a space situational conjunction warning, review and take all possible steps to assess collision risk and mitigate collision risks if necessary ((25.114)(d)(iv)(A)(5). Additionally, in compliance with 25.207, each Tomorrow.io space station will be capable of ceasing radio emissions via ground command to ensure definite cessation of emissions

Tomorrow.io's Weather Constellation will not incorporate in-orbit spares, as a means for reducing the risk of orbital debris. Should Tomorrow.io deploy on-ground spare satellites, it will comply with relevant 25.113 rules for station construction, deployment approval and operation of spare satellites. Tomorrow.io notes that its spares will be identical to the other space vehicles in its Weather Constellation.

3.2.2.1 Frequency Plan

To offer an explanation of how uplink frequencies are connected to downlink frequencies (25.114(d)(1)), Tomorrow.io will uplink commands in S-band, and downlink telemetry and microwave sounder payload data in X-band, both under Earth Exploration Satellite Service (EESS). As required in 25.114(c)(7) and 25.114(c)(4)(i), the frequency bands, channel bandwidths, and polarizations of the Tomorrow.io Weather Constellation are provided in Table 5. The channel center frequencies are provided in the Schedule S.

Table 5. Frequency and Channel Information (25.114)(c)(7))

	S-band (space-to-Earth)	**X-band (Earth-to-space)**
Type of Service	Command	Telemetry Sounder Payload
Frequency Bands (MHz)	2025 - 2110	8025-8400
Channel Bandwidth	200 kHz (200K0G1D) 10 kHz (10K0G1D)	8 MHz (8M00G1D) 800 kHz (800KG1D)
Polarization	RHCP	RHCP
Modulation	BPSK	OQPSK
Coverage	Global	Global
Data Rate	200 kbps, Nominal 10 kbps, Contingency	4 Mbps, Nominal 400 kbps, Contingency

In accordance with 25.202(g)(2), Tomorrow.io will utilize the minimum bandwidth necessary to meet its mission goals, to ensure overall efficient use of spectrum resources and to minimize interference into other satellite networks. Part 25.202(g)(1) of the Commission's Rules stipulates that telemetry, tracking and command signals may be transmitted at frequencies other than the band edge if the transmissions cause no greater interference and require no greater protection than the communications traffic on the satellite network. Tomorrow.io ensures that its command and telemetry signals will not cause greater interference and will not require greater protection than the communications traffic on the satellite network.

3.2.3 End-of-Life

In accordance with 25.283, after the Tomorrow.io spacecraft have demonstrated all relevant technologies and completed payload operations, the spacecraft will be decommissioned in a safe state, batteries will be discharged, and the vehicle will deorbit passively (25.114(d)(14)(v)(B)). At end of life, planned disposal will occur via natural orbital decay, and therefore will be classified as un-controlled, atmospheric re-entry (25.114(d)(14)(vii)(D)(2)(i).

Since the spacecraft does not have a propulsion capability and plans to deorbit passively, the reliability of deorbit is 100% and meets the stated requirement of 0.9. The time to passively deorbit following completion of mission execution is under five years and therefore compliant with recently introduced orbital debris requirements from FCC-CIRC2209-01 (25.114(d)(14)(vii)(D)(1)).

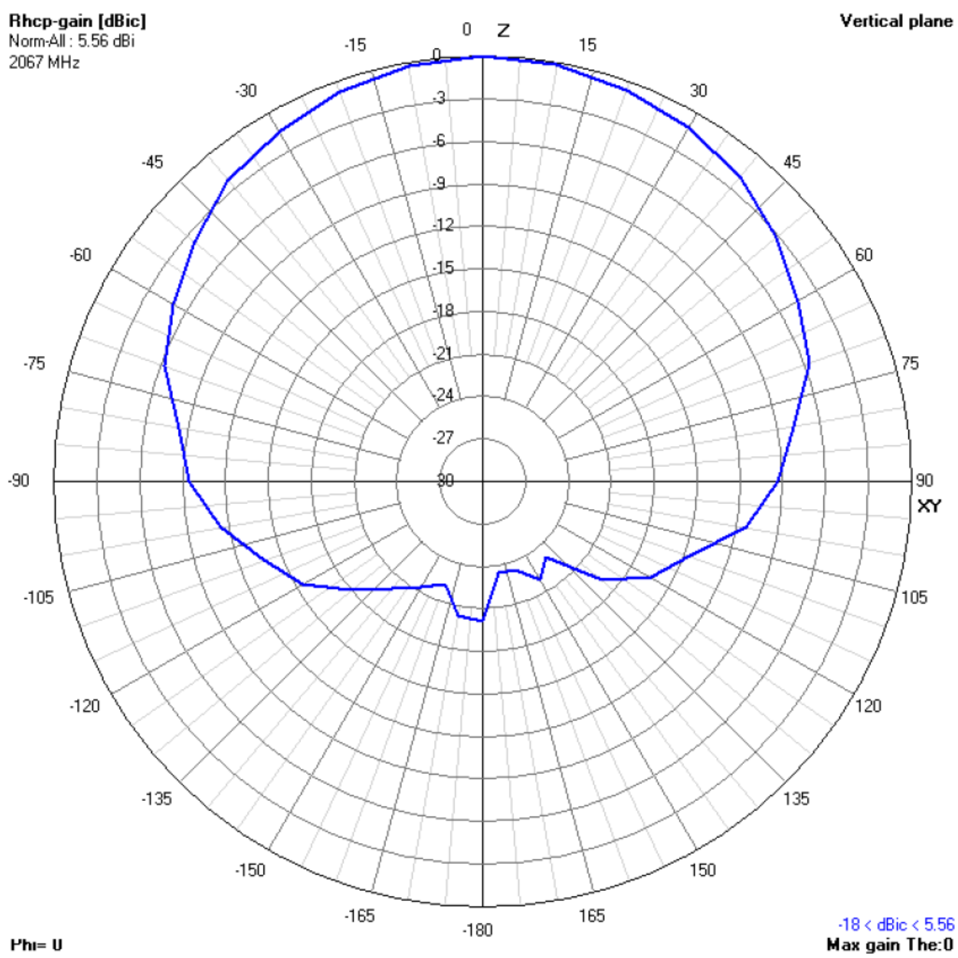
During this passive decay, the spacecraft will pass through the orbit altitude of the ISS. The spacecraft does not possess propulsion capability but can employ differential drag techniques to adjust the rate of orbital decay. Tommorow.io will also continue to provide updated ephemeris data to 18th Space Control Squadron and any other operators involved in a conjunction warning.

3.3 Services

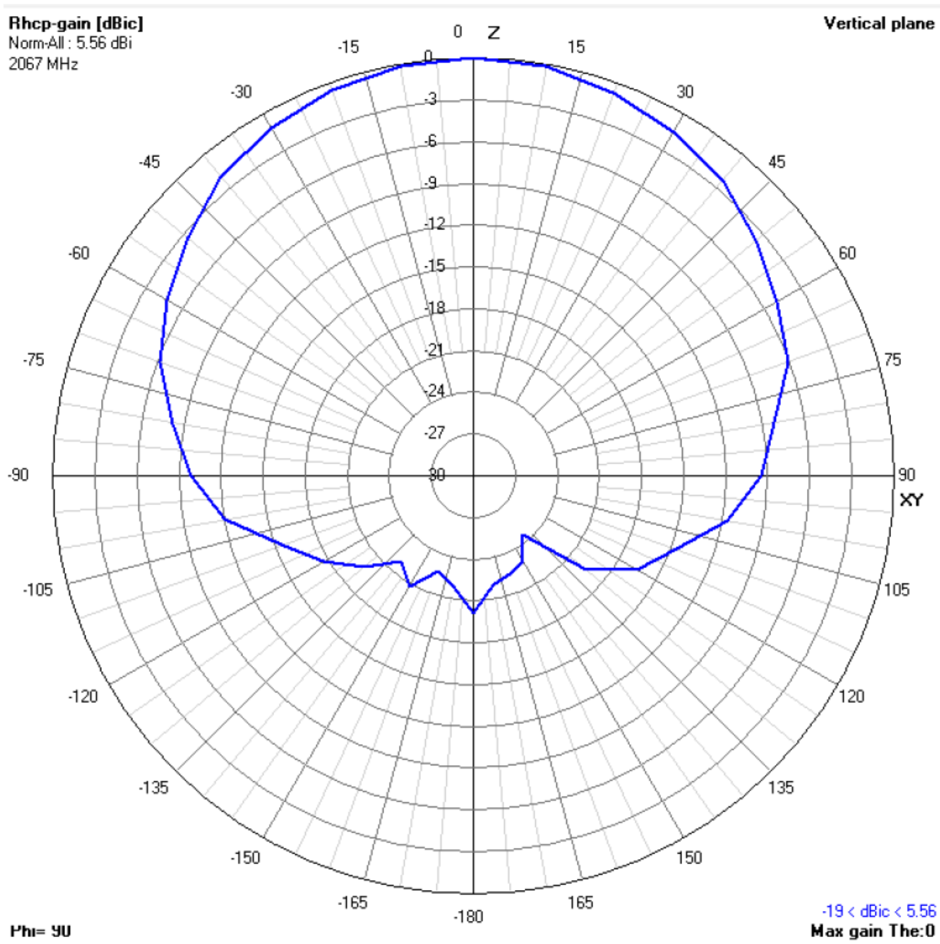
The sounders within the Tomorrow.io Weather Constellation will provide remote sensing capabilities to relate the temperature, humidity and precipitation structures of the atmosphere and offer low-latency weather data for both numerical weather prediction and long-range weather forecasts. The weather data will be provided directly to the Department of Defense, U.S. government, and other commercial users.

4. Space Station Antenna Gain Contours

BCT-supplied antenna patterns in Figure 2(a,b) are provided for S-band Receive (Rx) antenna, with (a) and (b) depicting orthogonal projections with a -18 dBiC and -19 dBiC null, respectively.



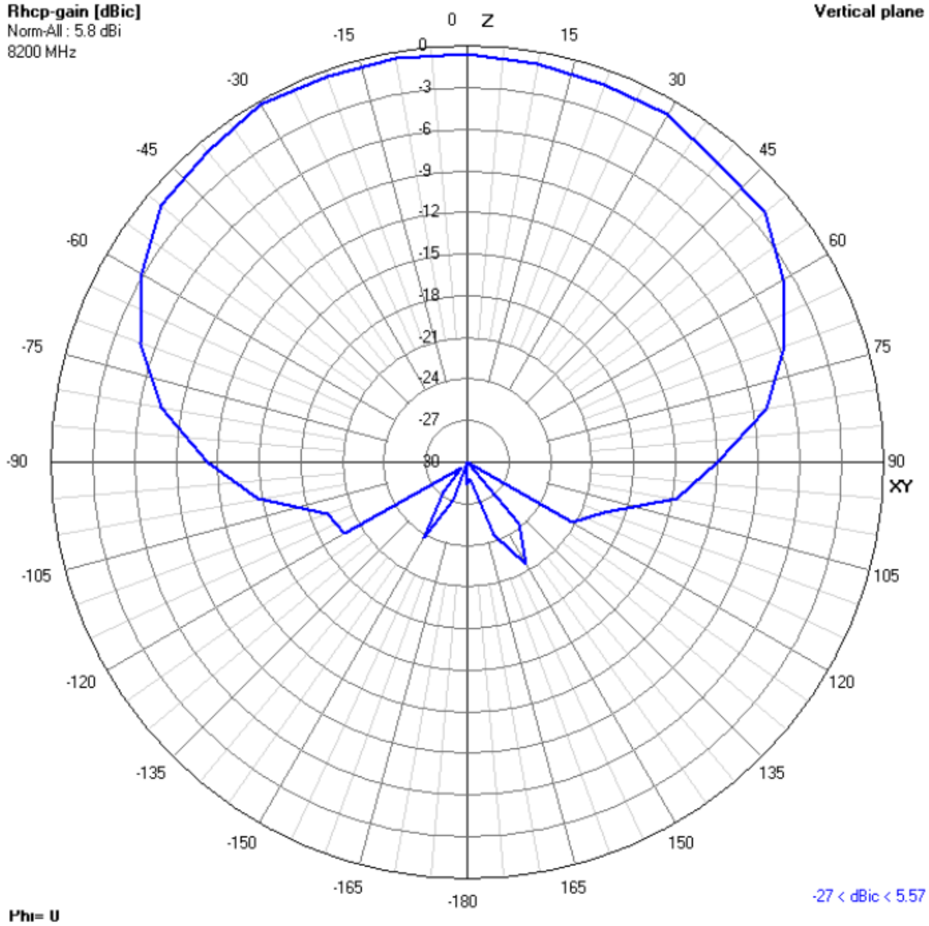
(a)



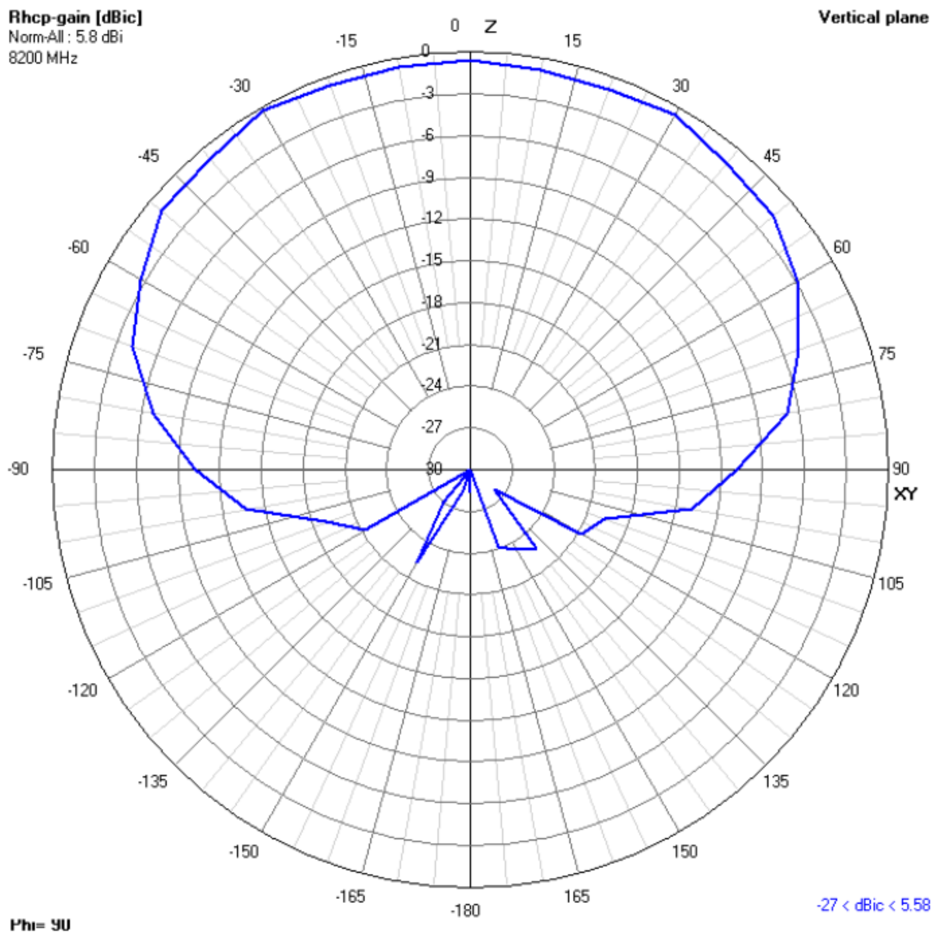
(b)

Figure 2(a,b). BCT S-band Antenna Gain Pattern for two Orthogonal Cuts (a) at a phi of 0 degrees with a -18dBiC null and (b) at a phi of 90 degrees with a -19 dBiC null

Similarly, Figure 3(a,b) provides two orthogonal gain patterns for the X-band downlink space station transmissions, with (a) at a phil of 0 degrees and (b) at a phi of 90 degrees.


Rhcp-gain [dBic]
Norm-All : 5.8 dBi
8200 MHz
Vertical plane
Z
XY
0
15
30
45
60
75
90
105
120
135
150
165
-180
-165
-150
-135
-120
-105
-90
-75
-60
-45
-30
-15
0
-3
-6
-9
-12
-15
-18
-21
-24
-27
-30
Phi= 0
-27 < dBic < 5.57

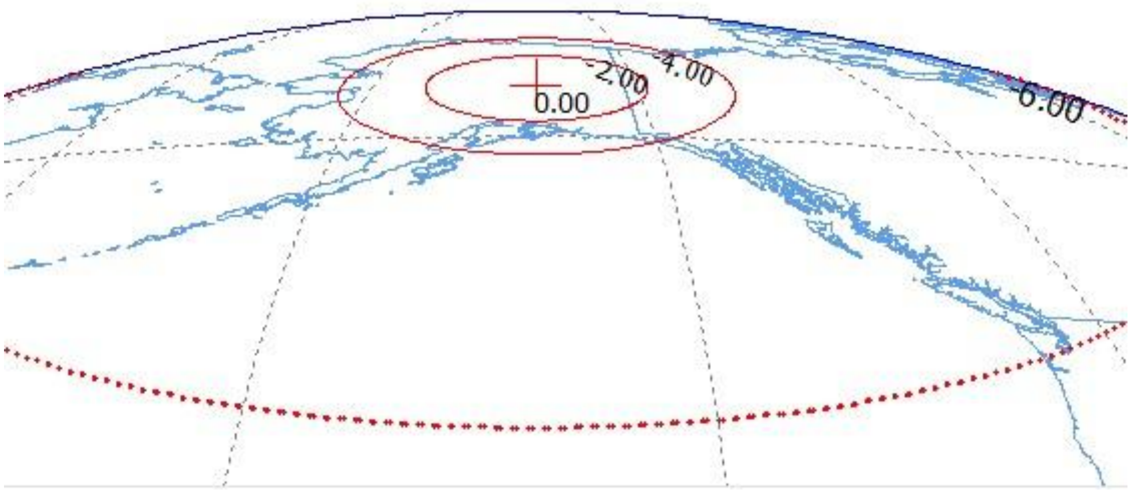
(a)



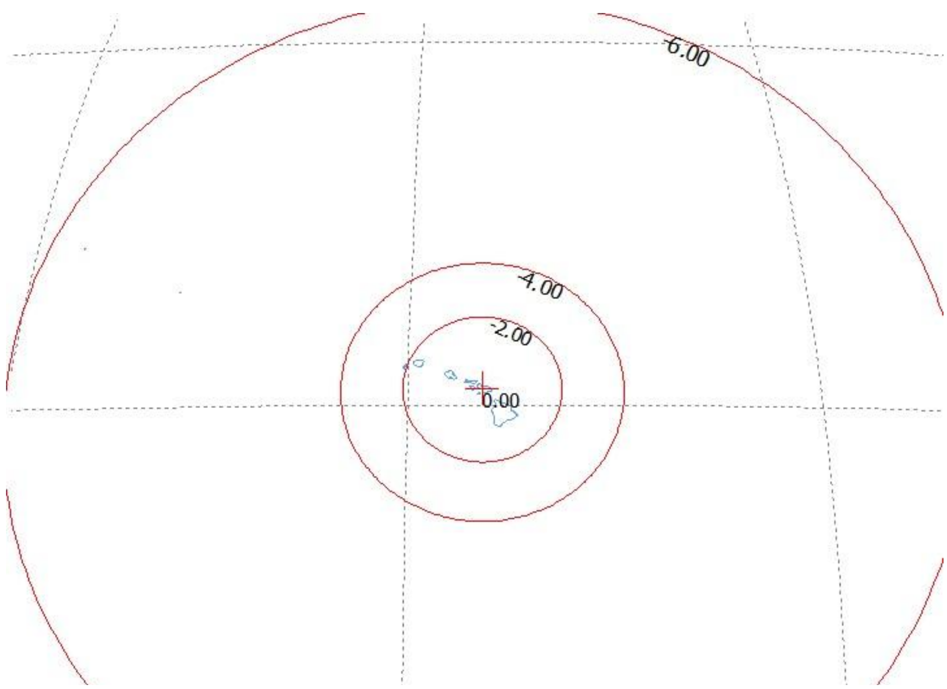
(b)

Figure 3(a,b). BCT X-band Antenna Gain Pattern for two Orthogonal Cuts (a) at a phi of 0 degrees and (b) at a phi of 90 degrees

As the Commission requires in 25.114(c)(4)(vi)(B), this section also provides the predicted antenna gain contours for each unique orbital plane for each transmit and receive beam. Contours are depicted on an area map with the beam shown on the surface of the earth with the space stations' peak antenna gain pointed at nadir to a latitude and longitude within the proposed service area. Furthermore, each contour is shown at 2 dB intervals down to either 4 dB or 6 dB below the peak gain. While the regulation states to show intervals of 2 dB down to 10 dB below the peak gain and at 5 dB intervals between 10 - 20 dB below the peak gain, the nature of the antenna, and orbital altitude of the spacecraft limit the visibility of the contours in the schematics. Data for the gain contours are also embedded in the Schedule S in the form of GXT files. S-band receive gain contours are provided in Figure 4(a,b) over (a) Alaska and (b) Hawaii.



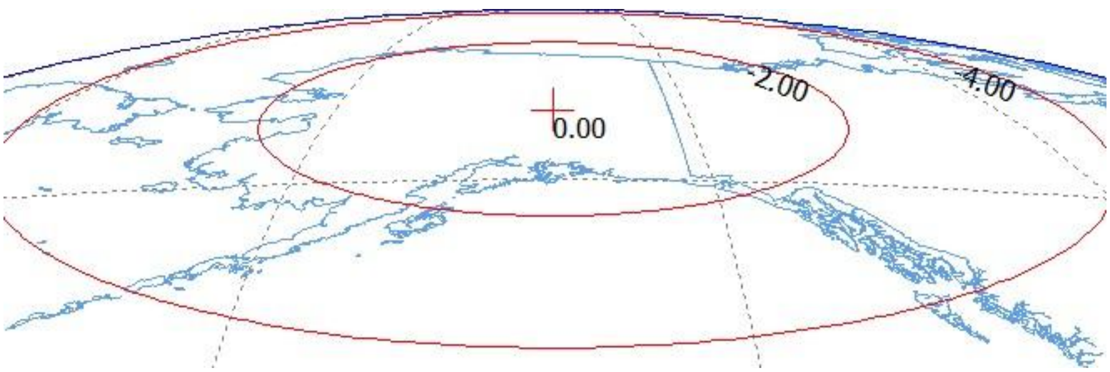
(a)



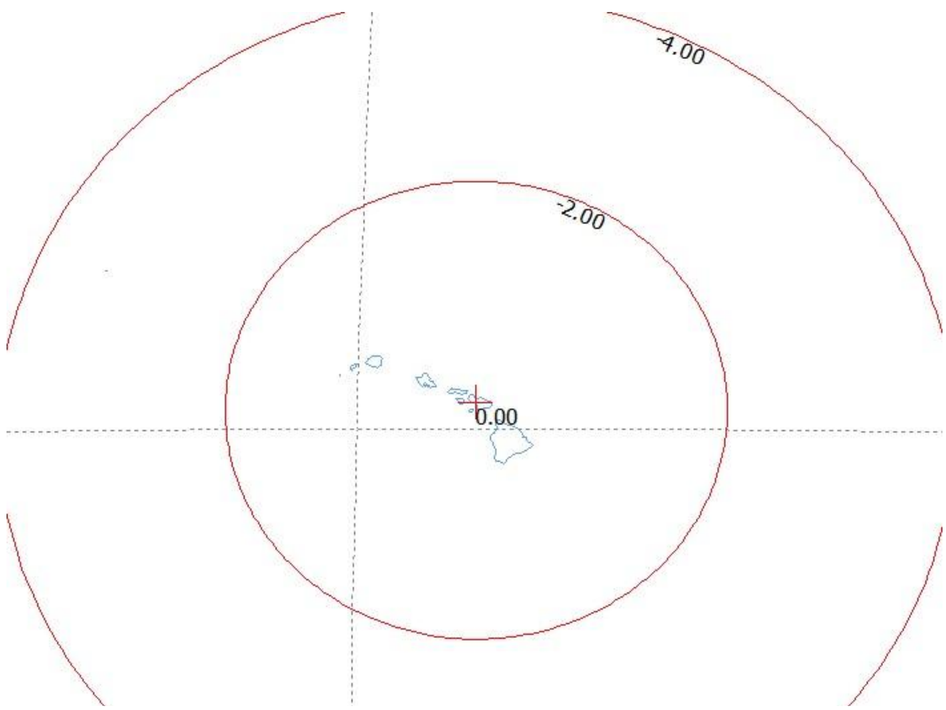
(b)

Figure 4(a,b). S-band receive uplink gain contours over (a) Alaska and (b) Hawaii

X-band transmit gain contours are provided in Figure 5(a,b) over (a) Alaska and (b) Hawaii.



(a)



(b)

Figure 5(a,b). X-band transmit downlink gain contours over (a) Alaska and (b) Hawaii

5. Interference Mitigation and Coexistence

Tomorrow.io remains committed to coordination and to collaborative operations of its constellation and will optimize the efficient use of allocated spectrum in order to coexist with other space-based and terrestrial users without causing harmful interference.

5.1 Coordination

Tomorrow.io is not only committed to coordinating its proposed operations, earth station locations and frequency usage, it has already engaged government stakeholders (USAF, NTIA, NOAA, NASA and the Navy) for pre-coordination activities for this mission. Tomorrow.io has also conducted coordination for a previous mission, so is aware and dedicated to the necessary steps for collaboratively engaging with other operators.

In accordance with 25.273, of the Commission's Rules, Tomorrow.io will not transmit in any manner that causes unacceptable interference to authorized transmissions of another licensee, and as previously mentioned will maintain complete and accurate technical details of current and planned transmissions to aid in the prompt correction of any potential interference, should it occur.

Additionally, since Tomorrow.io is working with industry leading GSN providers with established and operational networks, compliance with 25.203(h), which requires that earth station locations be selected to avoid interference between NGSO systems and between NGSO and GSO systems, is assured.

5.2 Protection of Terrestrial Networks by NGSO Systems

While the Commission's rules do not specify a PFD limit in the 8025-8400 MHz band, the ITU codifies limits under Radio Regulations No. 21.16. As such, the maximum PFD levels for the Tomorrow.io transmissions were calculated for the 8025-8400 MHz band, and are included in the Schedule S. The analysis in this section demonstrates that the downlink PFD levels of the Tomorrow.io carriers do not exceed the ITU limits. Figure 6 illustrates the results of this PFD analysis for the X-band downlink during Contingency operations - when the peak EIRP is 3 dBW, the emission bandwidth is 400 kHz[3], and the satellite is at the operational orbital altitude of 500 km. An altitude of 500 km, as opposed to the initial orbital altitude of 550 km, was simulated to show that Tomorrow.io can still meet PFD limits at a lower operational altitude, given that the altitude will naturally decay with time.

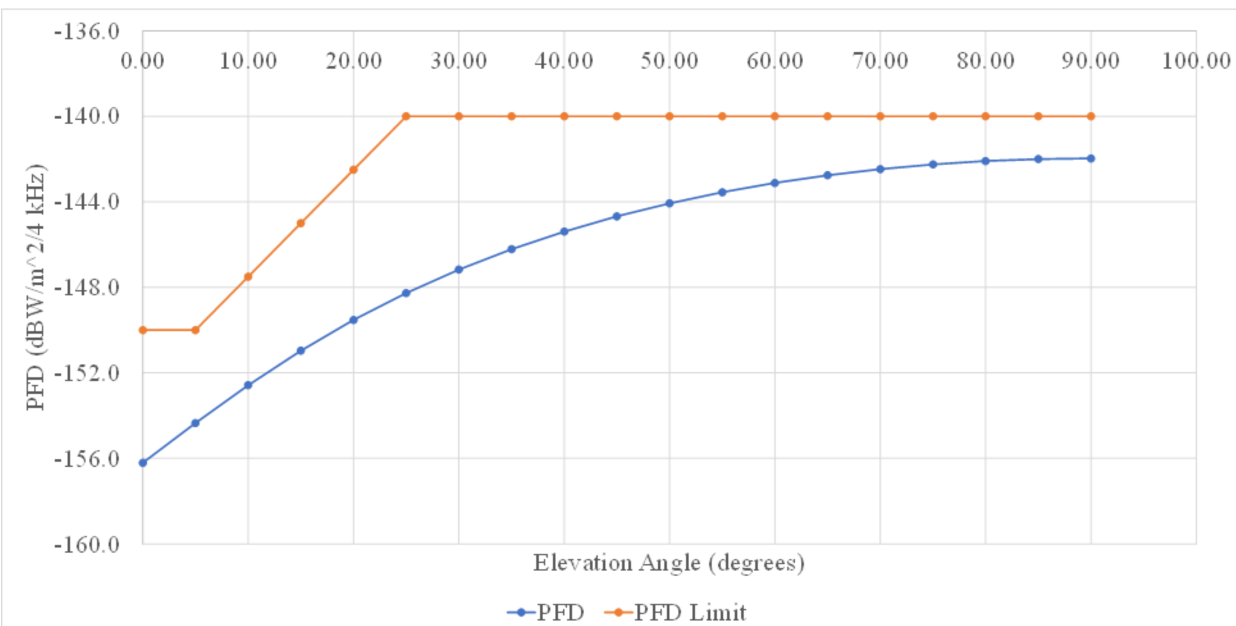


Figure 6. X-band space-Earth (Contingency Operations)

[3] The actual emission bandwidth, as reported in the Schedule S and the ITU API filing, is 800kHz, however, an "effective" emission bandwidth of 400kHz is used when computing PFD in order to capture the maximum PFD in any 4 kHz of bandwidth. Dividing the peak EIRP by 400 kHz reflects the maximum PFD in any 4kHz.

Similar to the analysis presented in Figure 6 for Contingency Operations, Figure 7 illustrates the results of this PFD analysis for the X-band downlink during Nominal operations at a conservative altitude, as well as a conservative bandwidth. For this assessment, a peak EIRP of 9 dBW along with an emission bandwidth of 4 MHz[4] and orbital altitude of 500 km were simulated. This PFD analysis assumes maximum EIRP in any pointing direction (to account for cases where satellite body steering and three-axis stabilization are temporarily interrupted).

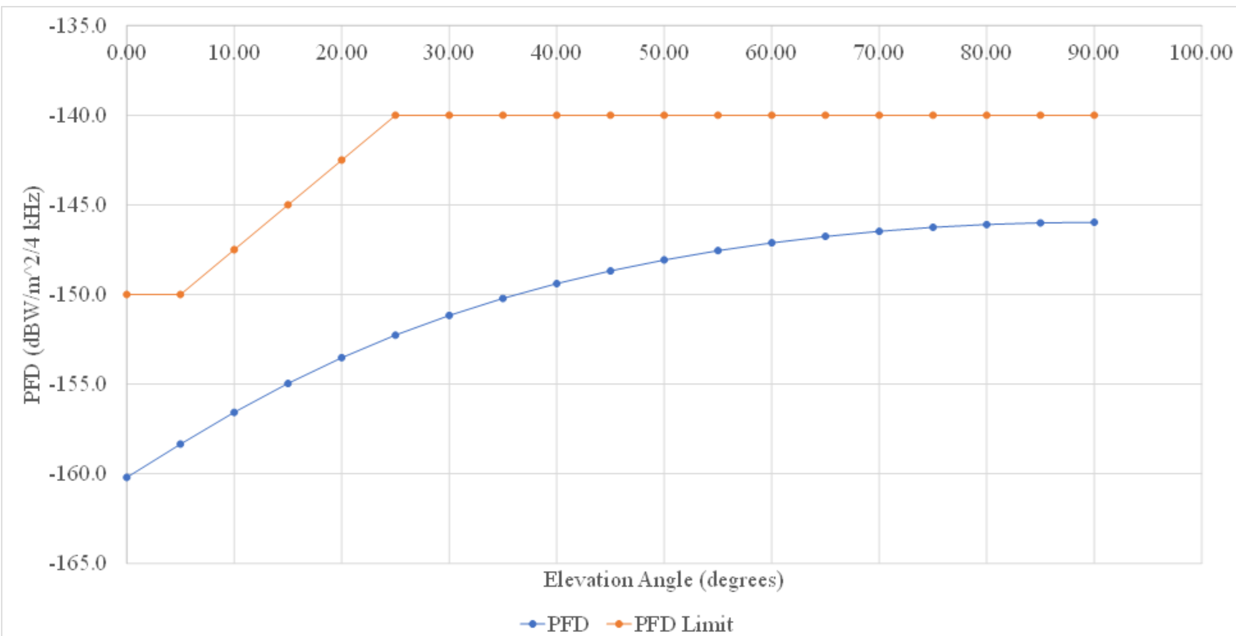


Figure 7. X-band space-Earth (Nominal Operations)

5.3 Protection of GSO Networks by NGSO Systems

Article 22.5 of the ITU Radio Regulations defines the protection criteria for GSO systems using the 8025-8400 MHz for Earth-to-space FSS services. The protection criteria for this scenario is that the PFD at the GSO arc must not exceed -174 dBW/m^2/4 kHz at the GSO arc.

[4] The actual emission bandwidth, as reported in the Schedule S and the ITU API filing, is 8MHz, however, an "effective" emission bandwidth of 4MHz is used when computing PFD in order to capture the maximum PFD in any 4 kHz of bandwidth. Dividing the peak EIRP by 4MHz reflects the maximum PFD in any 4kHz.

Analysis of the two operational modes (Contingency and Nominal) demonstrates that in either operational mode, this protection criteria is satisfied with margin from a conservative maximum operational altitude of 600 km:

Contingency Operations PFD at GSO arc: -180.1 dBW/m^2/4 kHz

Nominal Operations PFD at GSO arc: -184.1 dBW/m^2/4 kHz

6. Orbital Debris Mitigation Plan

In accordance with 25.114(d)(14), this section, along with previous sections on operational procedures, contains a high-level overview of the design and operational strategies Tomorrow.io will use to mitigate orbital debris. Additionally, an Orbital Debris Assessment Report (ODAR) has been provided to validate with NASA's Debris Assessment Software (DAS) that the Tomorrow.io mission complies with NASA's NS 8719.14 requirements and limits the amount of debris released during normal operations. An updated ODAR is not required based on completion of the Critical Design Review (CDR).

Tomorrow.io is building its constellation to meet all space safety requirements and will incorporate best technologies and practices for safe space operations. In summary, there will be no planned debris released, and no on-board fuel or fluids, which largely prevents accidental explosions or the release of liquids that will persist in droplet form (25.114(d)(iii)).

Tomorrow.io is committed to safe operation of its constellation and to collaboratively working with operators to develop sustainable space safety practices and policies for the satellite industry.

ENGINEERING CERTIFICATION

I hereby certify that I am the technically qualified person responsible for the preparation of the engineering information contained in this Application of Tomorrow.io for Authority to Launch and Operate a Non-Geostationary Weather Constellation, that I am familiar with the Commission's Part 25 rules, that I have either prepared or reviewed the engineering information submitted in this application, and that it is complete and accurate to the best of my knowledge and belief.

/s/ Dr. John Springmann
Dr. John Springmann
VP, Space & Sensors
Tomorrow.io
Date: March 28, 2023