MethaneSAT-1 Technical Narrative

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1 Scope

This Technical Appendix contains technical information regarding MethaneSAT's non-geostationary orbit (NGSO) satellite, as required by Section 25.114 and other sections of the Part 25 rules.

2 Description of Applicant

MethaneSAT is owned and operated by MethaneSAT LLC (MLLC), a wholly owned subsidiary of the non-profit Environmental Defense Fund (EDF) and is located in Austin, Texas. MethaneSAT's mission is to identify, quantify and source attribute global methane emissions, focused on the oil and gas and agriculture industries. The mission is 100% funded by philanthropic donations and the data from MethaneSAT, methane concentration and emission rates, will be made available free of charge to the public via a license agreement for non-commercial use.

3 Background and Mission Overview

Methane is a potent greenhouse gas, with more than 80 times the warming power of carbon dioxide during its first 20 years after being released into the atmosphere. Methane from human activities is causing at least a quarter of the warming our planet is experiencing today.

MethaneSAT is designed to locate and measure methane from human sources worldwide, giving both organizations and governments new ability to track, quantify, and reduce those emissions – and supplying the public with data to see that the job is being done. MethaneSAT will initially focus on methane emissions from oil and gas operations across the Earth, producing quantitative data that will enable both companies and countries to identify, manage, and reduce their methane emissions, slowing the rate at which our planet is warming.

MethaneSAT will employ an imaging spectrometer to separate the narrow band within the shortwave infrared spectrum where methane absorbs light. The mission employs a three-axis stabilized spacecraft in low Earth orbit to observe 200 km x 200 km targets on the ground. The planned mission duration is 60 months (5 years). At the end of its mission, the satellite will expend any remaining propellant (which is expected to be depleted during operations) and rely on atmospheric drag to fully deorbit the spacecraft.

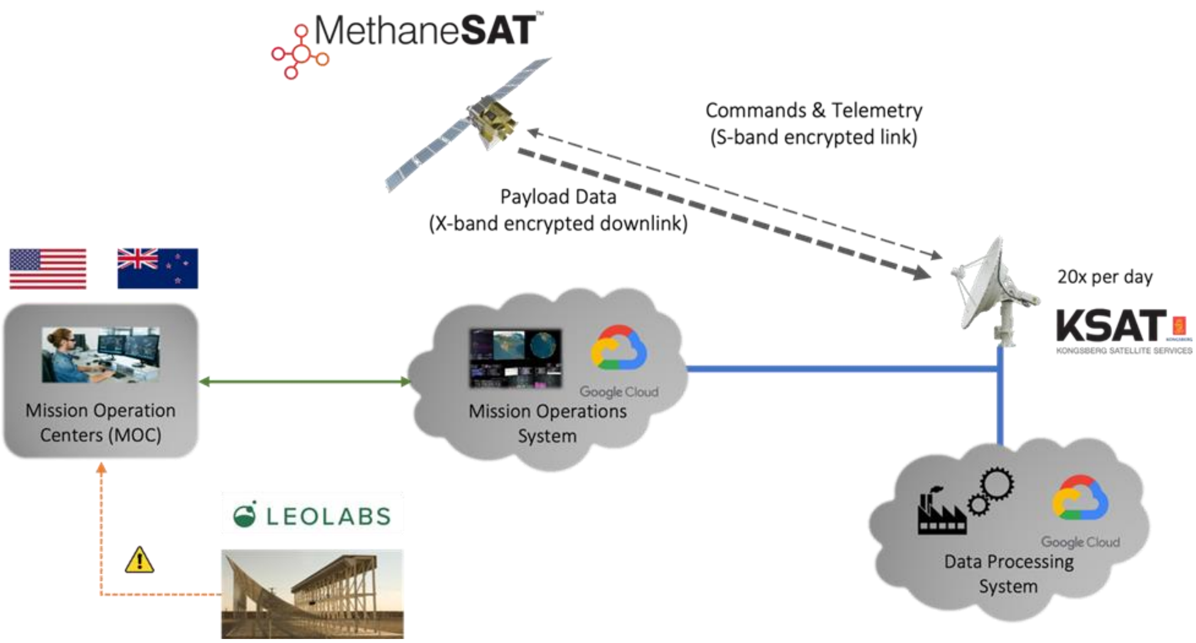

Figure 1. MethaneSAT System

4 Space Segment

The MethaneSAT flight system is comprised of the spacecraft bus (built by Blue Canyon Technologies) and the payload (designed and built by Ball Aerospace). The flight system will be launched on a SpaceX Falcon 9 Transporter rideshare mission. Only a single MethaneSAT satellite is planned under this license application request.

MethaneSAT collects information about methane emissions using a combination of two imaging spectrometers that comprise the payload. One spectrometer is focused on the methane (CH4) short wavelength infrared (SWIR) band, and the other on the oxygen (O2) SWIR band.

Table 1. MethaneSAT Spectrometers

Spectrometer	Wavelength Coverage
O_2 Spectrometer	1249 – 1305 nm
CH_4 Spectrometer	1605 – 1683 nm

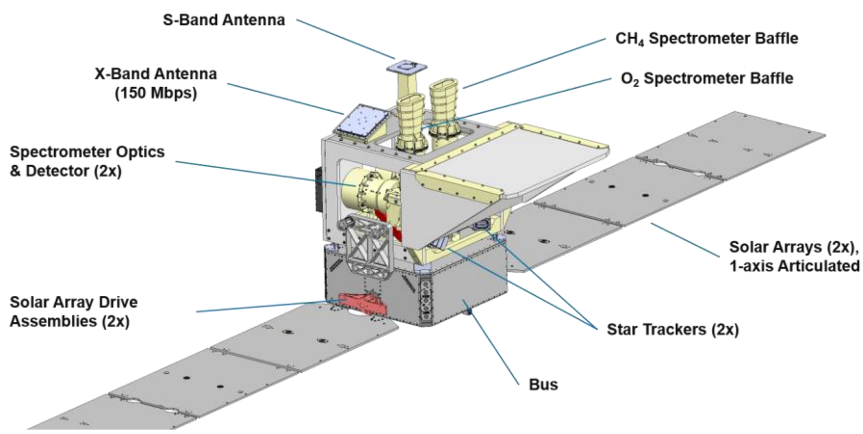

Figure 2. MethaneSAT Flight System

The two MethaneSAT spectrometers are of identical design. Incoming light passes through the objective assembly, is reflected off a mirror and onto the spectrometer grating. The diffracted light then is reflected into the detector assembly and onto the focal plane assembly (FPA) sensors.

MethaneSAT will operate in a Sun synchronous orbit from a planned altitude of 585 km. Based on the spectrometer design and FPA characteristics, MethaneSAT will have a ground resolution of roughly 100m x 400m per pixel at nadir. The spectrometer performance enables a low detection threshold to quantify small gradients in diffuse area aggregate emissions down to ~2 ppb for 1.5 km^2.

Note: MethaneSAT was granted a Tier 1 remote sensing license by NOAA's Commercial Remote Sensing Regulatory Affairs (CRSRA) office on 20 July 2020 to operate a private remote-sensing space system comprised of 1 satellite (NOAA File: MS-2020-L1).

5 Ground Segment

The MethaneSAT ground segment is composed of the ground stations, cloud-based mission operations system, mission operations centers, and the Science Data Processing System.

Ground stations are being provided under contract by Kongsberg Satellite Services (KSAT) using their global KSAT Lite network of ground stations. The ground station network supports satellite contacts as scheduled for each phase of the mission. Detailed ground station information can be found in section 6.3.

The spacecraft transmits payload and spacecraft engineering data to the ground station over an encrypted downlink, which then routes the data to the mission operations system hosted on the Google Cloud Platform (GCP) and to cloud-based based Science Data Processing System (SDPS) through a secure internet connection. Commands are sent from the mission operations

system to the MethaneSAT flight system via the KSAT ground antennas over an encrypted uplink.

The command-and-control portion of the mission operations system is provided by OpenC3 based on their flight-proven COSMOS C2 system. This same system is used during spacecraft bus and flight system integration and test. MLLC is providing mission planning and target scheduling software while Rocket Lab is providing additional software for the mission operations system which includes maintenance schedule (thrusts for orbit raising and station keeping, spacecraft bus maintenance activities), ground contact schedule, ephemeris (via orbit determination), procedure management, metrics reporting, maneuver planning, and collision avoidance.

MethaneSAT LLC has an agreement with the Government of New Zealand, through the Ministry of Business, Innovation and Employment (MBIE), to provide the mission operations for MethaneSAT. Multiple mission operations centers (MOCs) are planned for MethaneSAT, based on mission phase. MOCs will be located at Ball Aerospace in Boulder, CO for launch and commissioning, Rocket Lab in Auckland, New Zealand for the first year of post-launch operations, and the University of Auckland, in Auckland, New Zealand for operations after launch plus one year. A single MOC location has command authority as scheduled for designated portions of the mission, with the other location(s) serving as a redundant capability.

6 Operations and Services

6.1 Orbital Parameters

The following Table shows the orbital parameters for the MethaneSat-1 spacecraft.

Table 2. MethaneSAT-1 Orbital Parameters

Parameter	MethaneSAT-1
Apogee	525 km
Perigee	N/A - circular orbit
Inclination	97.47 (sun-synchronous)
Eccentricity	0 (circular)
Orbital Period	5704.0 seconds
LTDN	10:30 (+60 min)[1]
Orbital Type	NGSO

[1] Based on SpaceX Transporter-10 launch in January 2024

6.2 Orbital Debris

MethaneSAT is contracted with LeoLabs to provide independent tracking and space situational awareness for possible orbital conjunctions with other spacecraft or debris. MethaneSAT has conducted an Orbital Debris Assessment Report ("ODAR") in compliance with NASA-STD-8719.14, which is attached as a separate exhibit. As discussed in the submitted ODAR, the MethaneSAT-1 spacecraft is compliant with all applicable orbital debris requirements as listed in Section 25.114(d)(14).

6.3 Earth Stations

Ground stations will be provided under contract by Kongsberg Satellite Services (KSAT) using their global KSAT Lite network of ground stations. The primary ground station sites to be used for MethaneSAT are described in the table below.

Table 3: Ground Station Antenna Characteristics

KSAT Lite- Earth station characteristics					
Earth station Name	**Svalbard, Norway**	**Awarua, New Zealand**	**Punta Arenas, Chile**	**Hartebeesthoek, South Africa**	**Puertollano, Spain**
Earth Station Latitude (N)	78.2	-46.5	-53.0	-25.9	38.39
Earth Station Longitude (E)	15.3	168.4	-70.0	27.7	-4.11
Antenna diameter (m)	3.7	3.7	3.7	3.7	3.7
S-band uplink					
ES Tx power (W)	25.1	25.1	25.1	25.1	25.1
ES Tx gain (dBi)	35.4	35.4	35.4	35.4	35.4
S-band downlink					
ES Rx gain (dBi)	35.4	35.4	35.4	35.4	35.4
ES Rx Temp (K)	235	235	235	235	235
X-band downlink					
ES Rx gain (dBi)	47	47	47	47	47
ES Rx Temp (K)	95	95	95	95	95

7 Frequency plan

The satellites will carry data communications equipment to support Telemetry and Commanding operations (TTC).

The EESS S-band (2025-2110 MHz) is used for TTC commanding and telemetry operations, while the EESS X-band (8025-8400 MHz) for Payload data downlinks.

The MethaneSAT satellite network includes a mode where whenever the spacecraft enters Safe Mode (due to an anomalous event) a short transmission burst with satellite status data is sent periodically, at a rate of about 1s of transmission activity every two minutes (< 1% of duty-cycle). This beaconing operation is not active in nominal satellite operation and is expected not to be a frequent occurrence but can happen at any orbital location.

The transmission waveform parameters of the beacon are the same as the nominal TT&C S-band downlink: same carrier frequencies, same power levels, and same bandwidths.

The beacon feature is one that can be disabled from mission control.

Details on the TTC frequencies and channels are provided in the tables below.

Table 4. Spacecraft Frequencies

Usage	Link Direction	Frequency (MHz)
S-band TTC Uplink	Earth-to-space	2025.0-2110.0
S-band TTC Downlink	Space-to-Earth	2200.0-2290.0
X-band TTC Downlink	Space-to-Earth	8025.0-8400.0

7.1 TT&C Channels

The following tables list the S-band TTC channels planned for the MethaneSAT satellite network. This information is also provided in the accompanying Schedule S.

Table 5. Frequency Plan

Channel ID	Bandwidth (MHz)	Center Frequency (MHz)	Polarization
SBRX (S-band uplink)	0.2	2034.5	RHCP
SBTX (S-band downlink)	2.0	2234.5	RHCP
XBTX (X-band downlink)	270	8175	RHCP

8 Frequency Tolerance

The frequency tolerance requirements of Section 25.202(e) that the carrier frequency of each space station transmitter be maintained within 0.002% of the reference frequency will be met (20 ppm).

9 Out of Band Emissions

The out-of-band emission limits of Section 47 CFR 25.202(f)(1), (2), and (3) will be met, as well as the limits specified by:

Recommendation ITU-R SM.1541-6 (08/2015): Unwanted emissions in the out-of-band domain (annex 2 and annex 5)
https://www.itu.int/dms_pubrec/itu-r/rec/sm/R-REC-SM.1541-6-201508-I!!PDF-E.pdf

Recommendation ITU-R SM.329-12 (09/2012): Unwanted emissions in the spurious domain
https://www.itu.int/dms_pubrec/itu-r/rec/sm/R-REC-SM.329-12-201209-I!!PDF-E.pdf

10 Cessation of Emissions

All downlink transmissions can be turned on and off by ground commands, thereby achieving cessation of emissions from the satellite, as required by Section 25.207 of the FCC rules.

11 Power Flux Density (PFD) Analysis

This section provides required PFD analyses for the target operational orbit of 525 km.

11.1 PFD at the surface of the Earth in the 8025-8400 MHz band

Table 21-4 of the ITU Radio Regulations establishes that the PFD at the Earth's surface produced by emissions from an EESS space station in the 8025–8400 MHz band, including emissions from a reflecting satellite, for all conditions and for all methods of modulation, must not exceed the following values:

- -150 dB(W/m²) in any 4 kHz band for angles of arrival between 0 and 5° above the horizontal plane;
- -150 + 0.5(δ – 5) dB(W/m²) in any 4 kHz band for angles of arrival δ (in degrees) between 5° and 25° above the horizontal plane; and
- -140 dB(W/m²) in any 4 kHz band for angles of arrival between 25° and 90° above the horizontal plane.

These limits relate to the PFD that would be obtained under free-space propagation conditions. As provided in Schedule S, the PFDs at the Earth's surface produced by the MethaneSAT data transmissions satisfy the PFD limits in the ITU Radio Regulations for all angles of arrival.

11.2 PFD at the Geostationary Satellite Orbit in the 8025-8400 MHz Band

ITU Radio Regulation No. 22.5 specifies that in the 8025–8400 MHz frequency band, which the EESS using non-geostationary satellites shares with the fixed-satellite service (Earth-to-space), the maximum PFD produced at the geostationary satellite orbit (GSO) by any EESS space station shall not exceed -174 dB(W/m²) in any 4 kHz band.

The calculation below shows that the PFD produced by transmissions from the MethaneSAT satellite network does not exceed ITU limits even in a worst-case analysis.

The PFD at the GSO produced by the MethaneSAT transmission is:

PFD [dB(W/m² / 4 kHz)] = EIRP [dBW] – 71 – 20log10(D) – 10log10(BW) – 24, where:

- EIRP is the maximum EIRP of the transmission, in dBW;
- D is distance between the MethaneSAT satellite and the GSO, in km; and
- BW is the symbol bandwidth of the transmission, in MHz.

The minimum possible distance between a MethaneSAT satellite and the GSO is 35,786 - 525 = 35,261 km.

Under a hypothetical assumption that the MethaneSAT-1 satellite antenna is radiating at its peak EIRP directly toward the GSO, the PFD and the geosynchronous orbit is:

- TTC PFD at the GSO: 19.8 dBW - 71 - 20log10(35,261) - 10log10(270) - 24 = -190.46 dB(W/m²/4 kHz)

12 X-band Interference Analysis

Interference between the MethaneSAT-1 satellite downlinks and those of other EESS systems is very infrequent because EESS systems operating in the 8025–8400 MHz band normally transmit only in short periods of time while visible from the dedicated receiving earth stations. For interference to happen, satellites belonging to different systems would have to travel through the antenna beam of the receiving earth station and transmit at the same time. In the event of a precise alignment, interference can be avoided by coordinating the satellite transmissions so that they do not occur simultaneously.

In addition, MethaneSAT will maintain coordination agreements with NTIA that protect governmental space missions against harmful interference from operations of its MethaneSAT satellite network in this band. MethaneSAT also will maintain coordination agreements for foreign earth stations if required by the responsible foreign administration or local authorized users of the frequency bands.

MethaneSAT satellite transmissions will meet the limits specified by the ITU for protection of the Fixed Service in the 8025–8400 MHz band.

13 Satellite Antennas

The space station antenna radiation patterns are provided in Attachment A below.

Consistent with 47 C.F.R. § 25.114(c)(4)(vi)(B), MethaneSAT provides predicted antenna gain contours depicted on the surface of the earth at the anticipated initial earth station locations, as shown in Attachment B.

Additional technical characteristics of the proposed beams can be found in Schedule S.

Attachment A

Space Station Antenna Radiation Patterns

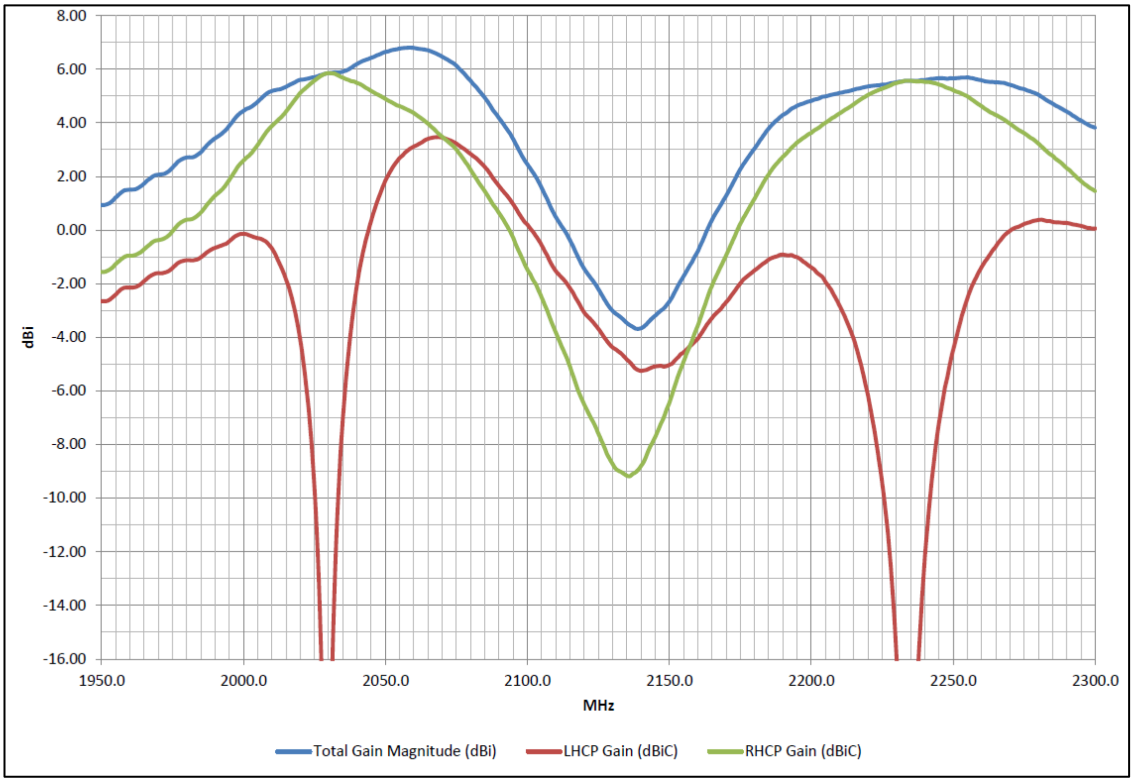

Figure 3. S-band Antenna Gain Pattern

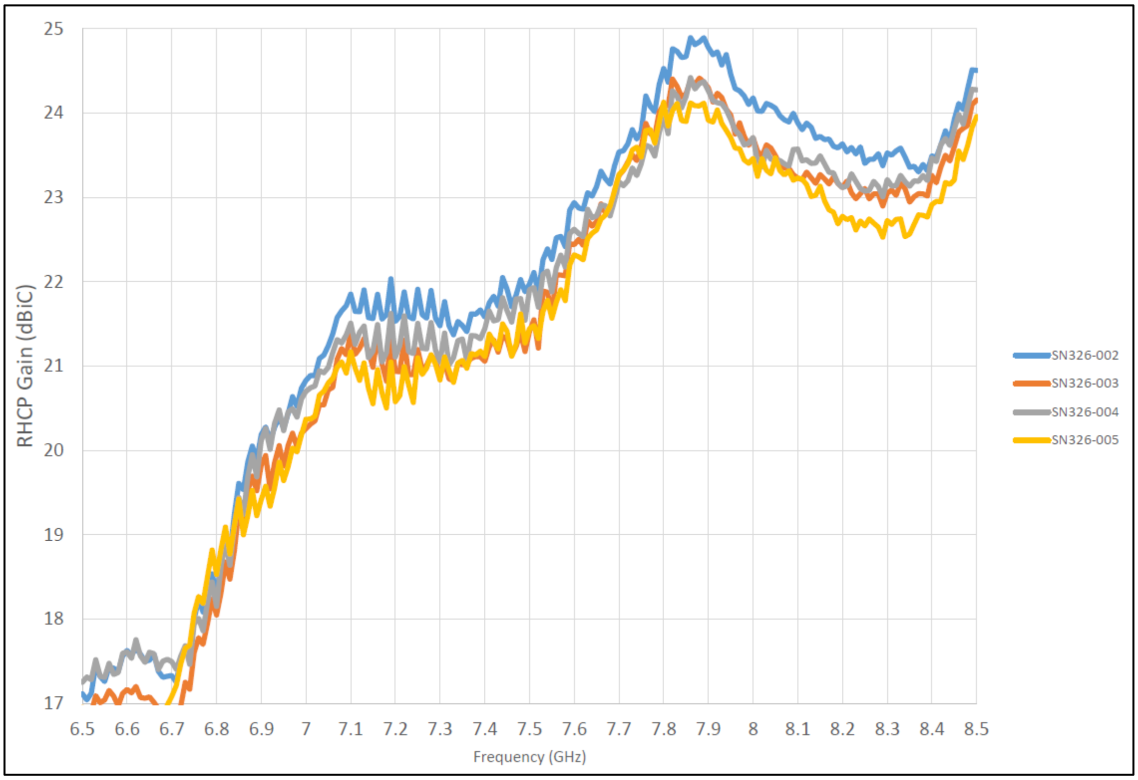

Figure 4. X-band Antenna Gain Pattern

Attachment B
Predicted Gain Contours

Consistent with 47 C.F.R. § 25.114(c)(4)(vi)(B), MethaneSAT provides predicted antenna gain contours depicted on the surface of the earth at the anticipated initial earth station locations as an annex to this technical narrative.

47 C.F.R. § 25.114(c)(4)(vi)(B): *For space stations in non-geostationary orbits, specify for each unique orbital plane the predicted antenna gain contour(s) for each transmit and receive antenna beam for one space station if all space stations are identical in the constellation. If individual space stations in the constellation have different antenna beam configurations, specify the predicted antenna gain contours for each transmit and receive beam for each space station type and orbit or orbital plane requested. The contours should be plotted on an area map with the beam depicted 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. The contour(s) should be plotted at 2 dB intervals down to 10 dB below the peak gain and at 5 dB intervals between 10 dB and 20 dB below the peak gain. For intersatellite links, specify the peak antenna gain and 3 dB beamwidth.*