Ground Segment:

We are using the following ground stations for uplink and downlink. All of these stations are capable of uplink in S-Band and downlink in X-Band

Ground Station Name	Antenna Name	Antenna Diameter (metres)	Transmitted Frequency (MHz)	EIRP (dBW)	Received Frequency (MHz)	G/T (dB/K)	Tracking	Latitude/ Longitude
Punta Arenas	PA11	11.3	2025 – 2120	56	2200 – 2300 and 8025 - 8500	23 and 36	A,D,R	52.9° S 70.9° W
Kiruna, Sweden	KU2S	13	2025 – 2120	69	2200 – 2300 and 7600 - 8500	22.5 and 37.5	A,D	67.8791° N 21.0380° E
North Pole, Alaska	USAK05	11	2025 – 2120	65.4	2200 – 2300 and 8100 - 8400	23.2 and 34	A,D	64.8034° N 147.5006° W
Hartebeesthoek, South Africa	HBK02	10	2025 – 2120	65	2200 – 2400 and 8000 - 8400	19.1 and 30.5	A,D,R	25.8869° S 27.7067° E
South Point, Hawaii	USHI01	13	2025 – 2120	78	2200 – 2400 and 8000 - 8500	23.5 and 37.7	A,D,R	19.0140° N 155.6633° W
Dongara, Australia	AUWA01	13	2025 – 2120	68	2200 – 2400 and 8000 - 8500	23.5 and 37.7	A,D,R	29.0457° S 115.3487° E
Trollsat, Antarctica	TR3	7.3	2025 – 2120	51	2200 – 2400 and 7500 - 8500	19.4 and 32	A,D	72.00215° S 2.525012° E
Singapore, KSAT	S11	9.1	2025 – 2120	59	2200 – 2300 and 7985 - 8500	20.5 and 33.4	A,D	1.3962°N 103.8343°E
Virginia, Wallops	WG5	11.3	2025 – 2120	56	2200 – 2300 and	21.4 and 35	A,D,R	37.92626° N

					8025 - 8500			75.47556 1° W

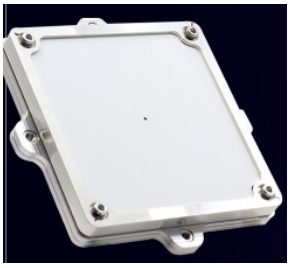
Space Segment:

Following are the specifications of Hardware devices we are using onboard our satellite

1. ECS X-Band Transmitter

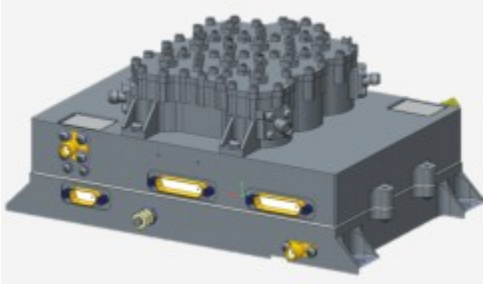
X-Band Transmitter	
Parameter	Value
Carrier Frequency	8220 MHz (factory settable 8.1 -8.5 Ghz)
Throughput	1 + Gbps
Output Power	2.5 W
Modulation	QPSK, 8PSK, 16APSK, 32APSK
Symbol Rate	250 Msymbl/s
Power Consumption	22W
Power Supply	12V
Control and Telemetry Interface	RS-422 or CMOS UART / CAN-2B

2. Anywaves X-Band Antenna:



X-Band Antenna	
Parameter	Value
Frequency Bands	8.025 GHz to 8.4 GHz
Bandwidth	> 375 MHz
Polarization	LHCP/RHCP
Reflection Coefficient	< -15 dB (all frequency band)
Half Power Beam Width	~ 40° (±20°)
Efficiency	> 88% (worst case)
Gain @ 8.2 GHz	11.5 dBi
Axial Ratio @ 8.2 GHz	< 3 dB from 0° to ±10°

3. S- Band TT&C Transceiver



S-Band TT&C Transceiver			
Transmitter		Receiver	
Tx Frequency Range	2200 to 2290 MHz	**Rx Frequency Range**	2025 to 2120 MHz
Tx Power Consumption	Less than 14W at 34.4 dBm RF-out	**Rx Power Consumption**	< 4W
TM Modulation Formats	QPSK, OQPSK, BPSK	**Rx Modulation Format / Data Rates**	PCM (NRZ-L)/PSK/PM 8 kHz (0.5, 1, 2 Kbps) & 16 kHz SC (1, 2, 4

			Kbps), PCM (NRZ-L)/BPSK (8 to 1024 kbps)
Output Power Range	0.2 to 3.16W (23 to 35 dBm)	**Input Power Range**	-135 to -40 dBm
Data Rate	32 to 1024 kbps BPSK, 1024 to 6250 kbps QPSK/OQPSK	**Rx Noise & Implementation Loss**	2 dB typical
Data Interfaces	Dual RS-422	**Carrier Acquisition Threshold**	-120 dBm
Encoding	Convolutional 1/2, NRZ-M, NRZ-L, PCM	**Carrier Acquisition Sweep Rate**	±32 kHz/s
Radiation Tolerance	10 KRad	**Carrier Tracking Range**	±150 kHz

4. S-Band Wide- Bandwidth Patch Antenna

S-Band Antenna	
Parameter	Value
Band Range	First range: 2025 to 2120 MHz, Second range: 2200 to 2300 MHz
Gain	6.5 dB typical
Total Bandwidth	195 MHz
Field of View (FOV)	120 degrees aperture
Vertical Beam	60 degrees
Horizontal Beam	60 degrees
Impedance	50 Ohms
Polarization	RHCP
Front-to-Back (F/B) Ratio	> 20 dB

RH/LH Isolation	14 dB typical
VSWR	< 1.20 for center band frequencies and < 1.85 for frequency range

Link Budget Calculation

a) Communication Uplink:

1. Calculation of FSPL (FSPL)

$$FSPL(dB) = 20\log_{10}(d) + 20\log_{10}(f) + 20\log_{10}(4\pi/c)$$

where, d: distance between the ground station and satellite

f: uplink frequency for transmission

c: speed of light in vacuum

2. Calculation of EIRP

$$FSPL(dB) = ¿P_{Tx} + G_{Tx}$$

3. Gain of Antenna

$G = 10\log_{10}¿$, where η is the efficiency factor ≈ 0.55, D is the diameter of the antenna

Following are the calculations for uplink in S-Band for the Kiruna ground station whose parameters are below:

Ground Station Name	Antenna Name	Antenna Diameter (metres)	Transmitted Frequency (MHz)	EIRP (dBW)	Received Frequency (MHz)	G/T (dB/K)	Tracking	Latitude/ Longitude
Kiruna, Sweden	KU2S	13	2025 – 2120	69	2200 – 2300 and 7600 - 8500	22.5 and 37.5	A,D	67.8791° N 21.0380° E

Substituting values of d = 900 * 10^3 m and f = 2072.5 MHz in equation 1, we get the value of $FSPL(dB)$ = 157.85dB

Substituting values for calculation for antenna gain in equation 3, where D = 13m and f = 2072.5 MHz, we get a gain G_{Tx} = 78.34 db

Received Power,

$$P_{Rx} = P_{Tx} + G_{Tx} + G_{Rx} - FSPL - Noise$$

P_{Rx}= 69dbW + 78.34 dB + 6.5dB - 157.85dB - 2dB = -6.01 dB

Given a receiver sensitivity threshold of -120 dBm, this value of received power is greater than the threshold which confirms that the link would work for telemetry, tracking and commanding the satellite.

b) Communication Downlink:

1. Calculation of FSPL (FSPL)

$$FSPL(dB) = 20\log_{10}(d) + 20\log_{10}(f) + 92.45$$

where, d: distance between the ground station and satellite

f: downlink frequency for reception

2. Gain of Ground station antenna (G_{Rx})

$$G_{Rx} = 20\log_{10}¿$$

where, d: distance between the ground station and satellite

f: downlink frequency for reception,

D: diameter of the antenna,

c: speed of light in vacumn

3. System Noise Temperature (T_{Sys})

$$T_{Sys} = \frac{290\,K}{10^{\frac{G/T}{10}}}$$

where G/T: gain over temperature ratio

4. Carrier to Noise ratio (C/N)

$$\frac{C}{N} = P_{Rx} - FSPL - 10\log_{10}(T_{Sys})$$

where P_{Rx}: $P_{Rx} = P_{Tx} + G_{Tx} + G_{Rx} - FSPL - Noise$ is the received power

Following are the calculations for downlink in X-Band for the Kiruna ground station whose parameters are below:

Ground Station Name	Antenna Name	Antenna Diameter (metres)	Transmitted Frequency (MHz)	EIRP (dBW)	Received Frequency (MHz)	G/T (dB/K)	Tracking	Latitude/ Longitude
Kiruna, Sweden	KU2S	13	2025 – 2120	69	2200 – 2300 and 7600 - 8500	22.5 and 37.5	A,D	67.8791° N 21.0380° E

Substituting values of d = 900 * 10^3 m and f = 8220 MHz in equation 1, we get the value of $FSPL(dB)$ = 229.83 dB

Substituting values for calculation for antenna gain in equation 2, where D = 13m and f = 8220 MHz, we get a gain G_{Tx} = 60.98 db

Hence, received power

$$P_{Rx} = P_{Tx} + G_{Tx} + G_{Rx} - FSPL$$

Substituting the values, P_{Rx} = 3.98 + 11.5 + 60.98 -229.83 dbW = -153.37 dBW

To calculate the $\frac{C}{N}$ ratio, the value of T_{Sys} for a G/T = 37.5 dB/K as given in Kiruna Ground station parameters is calculated as: $T_{Sys} = \frac{290}{10^{3.75}}$ = 0.05157 K

Substituting these values in equation 4 gives a $\frac{C}{N}$ ratio

$$\frac{C}{N} = -153.37\text{dBW} + 228.6 - 10\log_{10}(0.05157) = 88.10 \text{ dB-Hz}$$

Link Margin:

A positive link margin indicates reliable communication with robustness to noise and interference. A negative link margin indicates that the network may suffer from errors.

For our data transfer we are using the QPSK modulation scheme over others given it's power efficiency and robustness to noise and interference, that has a required $\frac{C}{N_0}$ around 10-12 db-Hz

$$\text{Link Margin (db)} = \text{Calculated } \frac{C}{N} \text{ ratio - required } \frac{C}{N_0}$$

This gives us a link margin of: 88.10 - 12 = 76.10 dB which is reliable for communication