Engineering Workbook:	DOGE-1 Mission FCC & NOAA Licensing
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DOGE-1 Earth Station Vendors:	Goonhilly Earth Station, Matt Cosby, et al.
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DOGE-1 APOGEE: Assumes TLI Trajectory after LIM (Spacecraft propulsion disregarded)*

Parameter	Value	Unit	Notes
Orbit Height (Apogee)	420000	km	Assumes TLI Trajectory after LIM (Spacecraft propulsion disregarded)
Satellite Elevation	5	Degrees	Variable, Conservative assumption range is 0 to 90 degrees
Satellite Antenna Gain	16	dBi	Assumes upgraded X-band antenna ES 4x4 Patch Array[4]
Satellite Transmit Power	2.0	W	**Maximum per manufacturer's specification**
Transmission Distance	425768	km	
Satellite TX EIRP	18.5	dBW	Includes 0.5 dB loss Endurosat specifies in their link budget
Earth Radius	6371	km	
Boltzmann Constant	-228.6	dBW/K/Hz	
Downlink Frequency	8262.5	MHz	Maximum X-Band Frequency less one burdened Channel bandwidth
Bitrate	2000	kbit/s	Given: Endurosat X-Band Radio Specification - Min bit rate (2 Mbps)
Modulation	QPSK 1/4		
Coding/Framing Overhead	25.00%	-	
Coded Bitrate	2500	kbit/s	
Bandwidth Factor	1.2		
Downlink Bandwidth	3000	kHz	
Additional Propogation Loss	1	dB	Additional attentuation from propogation through the medium
Eb/No	0.746	dB	Reference QPSK 1/4 0.490243 -2.35
Implementation Loss	0.5	dB	Modem implementation loss
Required CNR	66.0	dB.Hz	
Carrier Wavelength	0.0363	m	
Free Space Loss	223.4	dB	
Additional Loss	0.5	dB	Misc. allowance
Total Path Loss	224.9	dB	
Ground Station G/T	46.8	dB/K	Goonhilly Earth Station GHY-6 (32 m diameter) Minimum to Close Link Budget
Final CNR	69.0	dB.Hz	
LINK MARGIN	**3.0**	dB	**Link Margin is over 3 dB**
LINK PFD	**-193.2**	dBW/m^2	Reference Max -135 dBW/m^2 for ITU compliance

NOTES:

* Trans Lunar Injection (TLI), Lunar Insertion Maneuver (LMI) -- Worst Case Spacecraft Propulsion Disregarded
1 - Ground Station G/T (dB/K): Goonhilly GHY6 46.8 dBW/K maximum, link closes at 46.8 dBW/K with over 3dB margin, AWS 30.5 dB/K maximum, link does not close, Antesky 25.6 dB/K maximum, does not close
2 - Radio will be off or on standby until compliance can be assured.
3 - SpaceX Orbit Target for DOGE-1, 5-31-2022 (TLI after LIM) All parameters osculating at payload separation. Evaluated in the Earth Equatorial, Prime Meridian, True-of-date frame Date: 2022-05-31 Time (UTC) 707249768.18 days Apogee alt: 420000.00 km Perigee alt: 400.40 km Inclination: 28.50 deg RAAN: -180.73 deg AoP: 189.94 deg True Anomaly: 39.98196228 deg
4 - Availability of ES 4x4 Antenna has not been confirmed. However, revised orbital parameters likely require it.
5 - NASA defined bandwidth limits: S-band -- 5 MHz (typical allocations are 1 (min), 3, or 5 (max) MHz. Exceptions for larger bandwidth are considered on a case-by-case basis. X-band -- 375 MHz (max) Exceptions for larger bandwidth are considered on a case-by-case basis. Ka-band -- 1.5 GHz (max) Exceptions for larger bandwidth are considered on a case-by-case basis.

DOGE-1 PERIGEE: Assumes TLI Trajectory after LIM (Spacecraft propulsion disregarded)*

Parameter	Value	Unit	Notes
Orbit Height (Perigee)	400.4	km	Assumes TLI Trajectory after LIM (Spacecraft propulsion disregarded)
Satellite Elevation	5	Degrees	Variable, Conservative assumption range is 0 to 90 degrees
Satellite Antenna Gain	16	dBi	Assumes upgraded X-band antenna ES 4x4 Patch Array[4]
Satellite Transmit Power	0.5	W	**Minimum per manufacturer's specification**
Transmission Distance	1805	km	
Satellite TX EIRP	12.5	dBW	Includes 0.5 dB loss Endurosat specifies in their link budget
Earth Radius	6371	km	
Boltzmann Constant	-228.6	dBW/K/Hz	
Downlink Frequency	8262.5	MHz	Maximum X-Band Frequency less one burdened Channel bandwidth
Bitrate	125000	kbit/s	Given: Endurosat X-Band Radio Specification -- Max bit rate (125 Mbps)
Modulation	QPSK 1/4		
Coding/Framing Overhead	25.00%	-	
Coded Bitrate	156250	kbit/s	
Bandwidth Factor	1.2		
Downlink Bandwidth	187500	kHz	
Additional Propogation Loss	1	dB	Additional attentuation from propogation through the medium
Eb/No	0.746	dB	Reference QPSK 1/4 0.490243 -2.35
Implementation Loss	0.5	dB	Modem implementation loss
Required CNR	84.0	dB.Hz	
Carrier Wavelength	0.0363	m	
Free Space Loss	175.9	dB	
Additional Loss	0.5	dB	Misc. allowance
Total Path Loss	177.4	dB	
Ground Station G/T	24	dB/K	Goonhilly Earth Station GHY-6 (32 m diameter) Minimum to Close Link Budget
Final CNR	87.7	dB.Hz	
LINK MARGIN	**3.7**	dB	**Link Margin is over 3 dB**
LINK PFD	**-156.8**	dBW/m^2	Reference Max -135 dBW/m^2 for ITU compliance[2]

NOTES:

* Trans Lunar Injection (TLI), Lunar Insertion Maneuver (LMI) -- Worst Case Spacecraft Propulsion Disregarded
1 - Ground Station G/T (dB/K): Goonhilly GHY6 46.8 dBW/K maximum, link closes at 46.8 dBW/K with over 3dB margin, AWS 30.5 dB/K maximum, link does not close, Antesky 25.6 dB/K maximum, does not close
2 - Radio will be off or on standby until compliance can be assured.
3 - SpaceX Orbit Target for DOGE-1, 5-31-2022 (TLI after LIM) All parameters osculating at payload separation. Evaluated in the Earth Equatorial, Prime Meridian, True-of-date frame Date: 2022-05-31 Time (UTC) 707249768.18 days Apogee alt: 420000.00 km Perigee alt: 400.40 km Inclination: 28.50 deg RAAN: -180.73 deg AoP: 189.94 deg True Anomaly: 39.98196228 deg
4 - Availability of ES 4x4 Antenna has not been confirmed. However, revised orbital parameters likely require it.
5 - NASA defined bandwidth limits: S-band -- 5 MHz (typical allocations are 1 (min), 3, or 5 (max) MHz. Exceptions for larger bandwidth are considered on a case-by-case basis. X-band -- 375 MHz (max) Exceptions for larger bandwidth are considered on a case-by-case basis. Ka-band -- 1.5 GHz (max) Exceptions for larger bandwidth are considered on a case-by-case basis.

Identifier	Value	Units & Description				
A.	8400	MHz Max				
B.	7900	MHz Min				
C.	500	MHz Maximum Available Bandwidth (Channels =1)				
D.	2.5	MHz Total Bandwidth (Bitrate X Overhead X Bandwidth Factor)	1	Recommend we stick with 375 MHz allocation request		
E.	8398.75	MHz Nominal Center Point Frequency Requested = (A - (D/2))	8262.5	Recommended Center Point Frequency		

Manufacturer Specified Data Rates								
Minimum Data Rate	0.0024	Mbps	=	2.4	kbps	=	2400	bps
Maximum Data Rate	125	Mbps	=	125000	kbps	=	125000000	bps

Manufacturer Specified Frequency Range	Frequency High (MHz)	Frequency Low (MHz)	Total Channel Bandwidth (MHz)
TX frequencies:	8400	7900	500

Manufacturer Specified Operational Bandwidth (Maximum)	60 MHz

Manufacturer Specified Data Rates								
Minimum Data Rate	0.0024	Mbps	=	2.4	kbps	=	2400	bps
Maximum Data Rate	125	Mbps	=	125000	kbps	=	125000000	bps

Manufacturer Specified Frequency Range	Frequency High (MHz)	Frequency Low (MHz)	Total Channel Bandwidth (MHz)
TX frequencies:	8400	7900	500

Manufacturer Specified Operational Bandwidth (Maximum)	60 MHz

ES X-Band Transmitter	https://www.endurosat.com/cubesat-store/cubesat-communication-modules/x-band-transmitter/
Frequency Range	7900 to 8400 MHz
Modulations	QPSK, 8-PSK, 16-APSK, 32-APSK
Spurious Emissions	< -60 dBc
Frequency Stability	+/- 1.0 ppm
Data bit rates:	up to 125 Mbps
Maximum Gross Datarate	150 Mbps
Mass	270 g
Tx Power	0.5-2 W (in-flight configurable)
Max RF power at output:	33 dBm at 18W
Firmware Updates	Local and remote (in-flight) secured application update
SD Card Slot	up to 32 GB
Wide Power Supply Range	12 to 24 V
Interfaces	UART/RS-485 for control and LVDS for data

ES X-Band Single Patch Antenna	https://www.endurosat.com/cubesat-store/cubesat-antennas/x-band-patch-antenna/
Pattern:	directional
Frequency Range	8025 - 8400 MHz
Half Power Beam Width (HPBW)	74 deg
Gain	6+ dBi over operational bandwidth
Polarization	Right Hand Circular
Mass	< 3 g
RF Power Handling	up to 4 W

ES X-Band 2X2 Patch Array	https://www.endurosat.com/cubesat-store/cubesat-antennas/x-band-patch-antenna/
Frequency Range	8025 - 8400 MHz
Half Power Beam Width (HPBW)	40 deg
Gain	12+ dBi over operational bandwidth
Polarization	Right Hand Circular
Mass	23.2 g
RF Power Handling	up to 4 W

ES X-Band 4X4 Patch Array	https://www.endurosat.com/cubesat-store/cubesat-antennas/x-band-patch-antenna/
Frequency Range	8025 - 8400 MHz
Half Power Beam Width (HPBW)	18 deg
Gain	16+ dBi over operational bandwidth
Polarization	Right Hand Circular Polarization (RHCP)
Mass	53 g
RF Power Handling	up to 4 W

NOTES:

(1)	NASA defined bandwidth limits: S-band -- 5 MHz (typical allocations are 1 (min), 3, or 5 (max) MHz. Exceptions for larger bandwidth are considered on a case-by-case basis. X-band -- 375 MHz (max) Exceptions for larger bandwidth are considered on a case-by-case basis. Ka-band -- 1.5 GHz (max) Exceptions for larger bandwidth are considered on a case-by-case basis.						

DOGE-1 APOGEE: Assumes TLI Trajectory after LIM (Spacecraft propulsion disregarded)*

Parameter	Value	Unit	Notes
Orbit Height (Apogee)	420000	km	Variable, Apogee SpaceX TLI Trajectory
Satellite Elevation	5	Degrees	Variable, Conservative assumption range is 0 to 90 degrees
Satellite Antenna Gain	0	dBi	Variable, Conservative assumption, spacecraft tumbling
Satellite Transmit Power	0.7	W	Given: GOMspace Specification AX2150 S-Band Radio Max Power Output
Transmission Distance	425768	km	Calculated
Satellite TX EIRP	-1.5	dBW	Calculated
Earth Radius	6371	km	Constant
Boltzmann Constant	-228.6	dBW/K/Hz	Constant
Downlink Frequency	2289.5	MHz	Variable, S-Band Frequency Nominal Center Point
Bitrate	2.4	kbit/s	Variable, value chosen to get link budget to close ***Low data rate***
Modulation	GMSK		
Coding/Framing Overhead	25.00%	-	Variable, Conservative assumption
Coded Bitrate	3	kbit/s	Calculated
Bandwidth Factor	1.35		Variable, Conservative assumption
Downlink Bandwidth	4.05	kHz	Calculated
Additional Propogation Loss	1	dB	Variable, Additional attentuation from propogation through the medium
Eb/N0	8.400	dB	GOMspace Specification
Implementation Loss	1	dB	Variable, Modem implementation loss
Required CNR	45.5	dB.Hz	Calculated
Carrier Wavelength	0.1310	m	Calculated
Free Space Loss	212.2	dB	Calculated
Additional Loss	0	dB	Variable,
Total Path Loss	213.2	dB	Calculated
Ground Station G/T	34.6	dB/K	See note 1 below. Goonhilly is the only link that closes
Final CNR	48.4	dB.Hz	Calculated
LINK MARGIN	**3.0**	dB	Calculated
LINK PFD	**-185.1**	dBW/m^2	Max -144.1 dBW/m^2 for ITU compliance

NOTES:

1 - Ground Station G/T (dB/K):
Goonhilly GHY6 up to 35.8 dB/K maximum, link closes at 34.6 dB/K with over 3dB margin
AWS up to 16.0 dB/K maximum, link budget does not close
Antesky up to 13.5 dB/K maximum, link budget does not close

2 - Radio will be off or on standby until compliance can be assured.

3 - SpaceX Orbit Target for DOGE-1, 5-31-2022 (TLI after LIM)
All parameters osculating at payload separation.
Evaluated in the Earth Equatorial, Prime Meridian, True-of-date frame

Date: 2022-05-31
Time (UTC) 707249768.18 days
Apogee alt: 420000.00 km
Perigee alt: 400.40 km
Inclination: 28.50 deg
RAAN: -180.73 deg
AoP: 189.94 deg
True Anomaly: 39.98196228 deg

4 - Reserved

5 - NASA defined bandwidth limits:
S-band -- 5 MHz (typical allocations are 1 (min), 3, or 5 (max) MHz. Exceptions for larger bandwidth are considered on a case-by-case basis.
X-band -- 375 MHz (max) Exceptions for larger bandwidth are considered on a case-by-case basis.
Ka-band -- 1.5 GHz (max) Exceptions for larger bandwidth are considered on a case-by-case basis.

DOGE-1 PERIGEE: Assumes TLI Trajectory after LIM (Spacecraft propulsion disregarded)*

Parameter	Value	Unit	Notes
Orbit Height (Perigee)	400.4	km	Variable, Perigee SpaceX TLI Trajectory: 210 km+120 km no transmit zone
Satellite Elevation	5	Degrees	Variable, Conservative assumption range is 0 to 90 degrees
Satellite Antenna Gain	0	dBi	Variable, Conservative assumption, spacecraft tumbling
Satellite Transmit Power	0.2	W	Given: GOMspace Specification AX2150 S-Band Radio Min Power Output
Transmission Distance	1805	km	Calculated
Satellite TX EIRP	-7.0	dBW	Calculated
Earth Radius	6371	km	Constant
Boltzmann Constant	-228.6	dBW/K/Hz	Constant
Downlink Frequency	2289.5	MHz	Variable, S-Band Frequency Nominal Center Point
Bitrate	90	kbit/s	Variable, value chosen to get link budget to close
Modulation	GMSK		
Coding/Framing Overhead	25.00%	-	Variable, Conservative assumption
Coded Bitrate	112.5	kbit/s	Calculated
Bandwidth Factor	1.35		Variable, Conservative assumption
Downlink Bandwidth	151.88	kHz	Calculated
Additional Propogation Loss	1	dB	Variable, Additional attentuation from propogation through the medium
Eb/N0	8.400	dB	GOMspace Specification
Implementation Loss	1	dB	Variable, Modem implementation loss
Required CNR	61.2	dB.Hz	Calculated
Carrier Wavelength	0.1310	m	Calculated
Free Space Loss	164.8	dB	Calculated
Additional Loss	0	dB	Variable,
Total Path Loss	165.8	dB	Calculated
Ground Station G/T	8.4	dB/K	Variable, See note 1 below
Final CNR	64.2	dB.Hz	Calculated
LINK MARGIN	**3.0**	dB	Calculated
LINK PFD	**-145.8**	dBW/m^2	Reference Max -144.1 dBW/m^2 for ITU compliance[2]

NOTES:

1 - Ground Station G/T (dB/K): link closes at 8.4 dB/K with over 3dB margin
Goonhilly GHY6 up to 35.8 dB/K maximum, link budget closes
AWS up to 16.0 dB/K maximum, link budget closes
Antesky up to 13.5 dB/K maximum, link budget closes

2 - Radio will be off or on standby until compliance can be assured.

3 - SpaceX Orbit Target for DOGE-1, 5-31-2022 (TLI after LIM)
All parameters osculating at payload separation.
Evaluated in the Earth Equatorial, Prime Meridian, True-of-date frame

Date: 2022-05-31
Time (UTC) 707249768.18 days
Apogee alt: 420000.00 km
Perigee alt: 400.40 km
Inclination: 28.50 deg
RAAN: -180.73 deg
AoP: 189.94 deg
True Anomaly: 39.98196228 deg

4 - Reserved

5 - NASA defined bandwidth limits:
S-band -- 5 MHz (typical allocations are 1 (min), 3, or 5 (max) MHz. Exceptions for larger bandwidth are considered on a case-by-case basis.
X-band -- 375 MHz (max) Exceptions for larger bandwidth are considered on a case-by-case basis.
Ka-band -- 1.5 GHz (max) Exceptions for larger bandwidth are considered on a case-by-case basis.

Identifier	Value	Units & Description			
A.	2290	MHz Max			
B.	2200	MHz Min			
C.	90	MHz Maximum Available Bandwidth (Channels =1)			
D.	0.004050	MHz Total Bandwidth (Bitrate X Overhead X Bandwidth Factor)	1	Recommend we request 1 MHz allocation	
E.	2289.997975	MHz Nominal Center Point Frequency Requested = (A - (D Rounded up to 1/2))	2289.5	Recommended Center Point Frequency	

Manufacturer Specified Data Rates								
Minimum Data Rate	0.0024	Mbps	=	2.4	kbps	=	2400	bps
Maximum Data Rate	0.09	Mbps	=	90	kbps	=	90000	bps

Manufacturer Specified Frequency Range	Frequency High (MHz)	Frequency Low (MHz)	Total Channel Bandwidth (MHz)
TX frequencies: 2200 MHz - 2290 MHz	2290	2200	90
RX frequencies: 2025 MHz - 2110 MHz	2110	2025	85

Manufacturer Specified Operational Bandwidth (Maximum)	0.065 MHz	=	65 kHz

GOMspace AX2150 S-Band Transmitter	
TX frequencies:	2200 MHz - 2290 MHz
RX frequencies:	2025 MHz - 2110 MHz
Modulation:	FSK/MSK/GFSK/GMSK
Data bit rates:	2.4 kbps to 90 kbps
Max RF power at output:	29 dBm at 0.8W

GOMspace AM2150P + AM2150 PS S-Band Antenna #1	
Pattern:	directional
Gain:	> -12 dBi in 85% of all directions, > 0 dBi in 20% of all directions
Polarisation:	RHCP

GOMspace AM2150P + AM2150 PS S-Band Antenna #2	
Pattern:	directional
Gain:	> -12 dBi in 85% of all directions, > 0 dBi in 20% of all directions
Polarisation:	RHCP

NOTES:

(1)	NASA defined bandwidth limits: S-band -- 5 MHz (typical allocations are 1 (min), 3, or 5 (max) MHz. Exceptions for larger bandwidth are considered on a case-by-case basis. X-band -- 375 MHz (max) Exceptions for larger bandwidth are considered on a case-by-case basis. Ka-band -- 1.5 GHz (max) Exceptions for larger bandwidth are considered on a case-by-case basis.

System Parameters: GOMspace AX2150 S-Band Transmitter			
Orbit Height	500	km	User Specified
Frequency Uplink	2110	MHz	Uplink: 2025-2110 MHz
Frequency Downlink	2290	MHz	Downlink 2200-2290 MHz
Bitrate Uplink	38.4	kbit/s	user bitrate (not including protocol overhead)
Bitrate Downlink	38.4	kbit/s	user bitrate (not including protocol overhead)
Modulation	GFSK		
Coding/framing overhead	25%		Reed-solomon and framing
Coded symbolrate uplink	48.0		Coded symbolrate/channel symbolrate
Coded symbolrate downlink	48.0		Coded symbolrate/channel symbolrate
Bandwidth Factor	1.35		Factor between signal bandwidth and symbol rate
Downlink Bandwidth	64.8	kHz	
Atmospheric Loss	0.0	dB	In addition to free-space loss
Sat. Ant. Gain for PDF	0.0	dBi	CCDF ~25%
Satellite TX Power	0.200	W	Max 0.7W for AX2150
Power Flux Density at Earth	-144.1	dBW /m2	Max -144 dBW /m2 for ITU compliance
Ground station EIRP	44	dBW	Data from customer
Ground station G/T (elev 20°)	12	dB/K	Data from customer
Required Link Margin	3	dB	Used for link probablity calculations

System Parameters: GOMspace AX2150 S-Band Transmitter -- TX power level			
Default: 2			
i		dBWatts	Watts
0: 28.5 dBm (700 mW)		28.5	708
1: 28 dBm (630 mW)		28	631
2: 27 dBm (500 mW)		27	501
3: 24 dBm (250 mW)		24	251
4: 21.5 dBm (140 mW)		21.5	141
5: 20 dBm (100 mW)		20	100
6: 17 dBm (50 mW)		17	50
7: 14 dBm (25 mW)		14	25

System Parameters: GOMspace AX2150 S-Band Transmitter -- Selectable Bitrates			
Default: 1			
Valid Values:			
2.4	kbit/s		
4.8	kbit/s		
9.6	kbit/s		
19.2	kbit/s		
38.4	kbit/s		
76.8	kbit/s		
90	kbit/s		

DOGE-1 APOGEE: Assumes TLI Trajectory after LIM (Spacecraft propulsion disregarded)*

Parameter	Value	Unit	Notes
Orbit Height (Apogee)	420000	km	Variable, per last available data from SpaceX[3]
Satellite Elevation	5	Degrees	Variable, Ground Station Dependent, range is 0 to 90 degrees
Transmission Distance	425768	km	Calculated
Ground Station TX EIRP[1]	77.2	dBW	Variable, See note 1 below Earth Station Specifications
Earth Radius	6371	km	Constant
Boltzmann Constant	-228.6	dBW/K/Hz	Constant
Uplink Frequency	2025.5	MHz	Variable, S-Band Frequency Nominal Center Point
Bitrate	90	kbit/s	Variable, value chosen is maximum bit rate
Coding/Framing Overhead	25.00%	-	Variable, value chosen based on nominal bit rate
Coded Bitrate	112.5	kbit/s	Variable, Conservative assumption
Bandwidth Factor	1.35		Given by GomSpace for the AX2150
Uplink Bandwidth	151.875	kHz	Calculated
Additional Propogation Loss	1	dB	Variable, Additional attentuation from propogation through the medium
Eb/No	8.400	dB	Given by GomSpace required for the AX2150, (Coded)
Implementation Loss	1	dB	Given by GOMSpace, modem implementation data
Required CNR (a.k.a C/No)	61.2	dBHz	Calculated
Carrier Wavelength	0.1481	m	Calculated
Free Space Loss	211.2	dB	Calculated
Additional Loss	0	dB	Variable,
Total Path Loss	212.2	dB	Calculated
Satellite G/T	-29.4	dB/K	Given by GomSpace for the AX2150 + AM2150P/PS
Final CNR	64.2	dBHz	Calculated
LINK MARGIN	**3.0**	dB	Calculated

NOTES:

1 - Equivalent Isotropic Radiated Power (EIRP)
Goonhilly GHY6 EIRP up to 77.2 dBW, link closes at 76.4 dBW with 3dB margin
AWS 53.0 dBW link does not close

2 - Radio will be off or on standby until compliance can be assured.

3 - SpaceX Orbit Target for DOGE-1, 5-31-2022 (TLI after LIM)
All parameters osculating at payload separation.
Evaluated in the Earth Equatorial, Prime Meridian, True-of-date frame

Date:	2022-05-31	
Time (UTC)	707249768.18	days
Apogee alt:	420000.00	km
Perigee alt:	400.40	km
Inclination:	28.50	deg
RAAN:	-180.73	deg
AoP:	189.94	deg
True Anomaly:	39.98196228	deg

4 - Reserved

5 - NASA defined bandwidth limits:
S-band -- 5 MHz (typical allocations are 1 (min), 3, or 5 (max) MHz. Exceptions for larger bandwidth are considered on a case-by-case basis.
X-band -- 375 MHz (max) Exceptions for larger bandwidth are considered on a case-by-case basis.
Ka-band -- 1.5 GHz (max) Exceptions for larger bandwidth are considered on a case-by-case basis.

DOGE-1 PERIGEE: Assumes TLI Trajectory after LIM (Spacecraft propulsion disregarded)*

Parameter	Value	Unit	Notes
Orbit Height (Perigee)	400.4	km	Variable, per last available data from SpaceX[3]
Satellite Elevation	5	Degrees	Variable, Ground Station Dependent, range is 0 to 90 degrees
Transmission Distance	1805	km	Calculated
Ground Station TX EIRP[1]	33.1	dBW	Variable, See note 1 below Earth Station Specifications
Earth Radius	6371	km	Constant
Boltzmann Constant	-228.6	dBW/K/Hz	Constant
Uplink Frequency	2109.5	MHz	Variable, S-Band Frequency Nominal Center Point
Bitrate	90	kbit/s	Variable, value chosen based on nominal bit rate
Coding/Framing Overhead	25.00%	-	Variable, Conservative assumption
Coded Bitrate	112.5	kbit/s	Calculated
Bandwidth Factor	1.35		Given by GomSpace for the AX2150
Uplink Bandwidth	151.875	kHz	Calculated
Additional Propogation Loss	4	dB	Variable, Additional attentuation from propogation through the medium
Eb/No	8.400	dB	Given by GomSpace required for the AX2150, (Coded)
Implementation Loss	1	dB	Given by GOMSpace, modem implementation data
Required CNR (a.k.a C/No)	61.2	dBHz	Calculated
Carrier Wavelength	0.1422	m	Calculated
Free Space Loss	164.1	dB	Calculated
Additional Loss	0	dB	Variable,
Total Path Loss	168.1	dB	Calculated
Satellite G/T	-29.4	dB/K	Given by GomSpace for the AX2150 + AM2150P/PS
Final CNR	64.2	dBHz	Calculated
LINK MARGIN	**3.0**	dB	Calculated

NOTES:

1 - Equivalent Isotropic Radiated Power (EIRP)
Goonhilly GHY6 EIRP up to 87.4 dBW, link closes at 33.1 dBW with 3dB margin
AWS EIRP up to 53.0 dBW, link closes at Perigee but not at Apogee

2 - Radio will be off or on standby until compliance can be assured.

3 - SpaceX Orbit Target for DOGE-1, 5-31-2022 (TLI after LIM)
All parameters osculating at payload separation.
Evaluated in the Earth Equatorial, Prime Meridian, True-of-date frame

Date:	2022-05-31	
Time (UTC)	707249768.18	days
Apogee alt:	420000.00	km
Perigee alt:	400.40	km
Inclination:	28.50	deg
RAAN:	-180.73	deg
AoP:	189.94	deg
True Anomaly:	39.98196228	deg

4 - Reserved

5 - NASA defined bandwidth limits:
S-band -- 5 MHz (typical allocations are 1 (min), 3, or 5 (max) MHz. Exceptions for larger bandwidth are considered on a case-by-case basis.
X-band -- 375 MHz (max) Exceptions for larger bandwidth are considered on a case-by-case basis.
Ka-band -- 1.5 GHz (max) Exceptions for larger bandwidth are considered on a case-by-case basis.

Identifier	Value	Units & Description				
A.	2110	MHz Max				
B.	2025	MHz Min				
C.	85	MHz Maximum Available Bandwidth (Channels =1)				
D.	0.151875	MHz Total Bandwidth (Bitrate X Overhead X Bandwidth Factor)	**1**	**Recommend we stick with 1 MHz minimum allocation request**		
E.	2109.924063	MHz Nominal Center Point Frequency Requested = (A - (D/2))	**2109.5**	**Recommended Center Point Frequency**		

Manufacturer Specified Data Rates								
Minimum Data Rate	0.0024	Mbps	=	2.4	kbps	=	2400	bps
Maximum Data Rate	0.09	Mbps	=	90	kbps	=	90000	bps

Manufacturer Specified Frequency Range	Frequency High (MHz)	Frequency Low (MHz)	Total Channel Bandwidth (MHz)
TX frequencies: 2200 MHz - 2290 MHz	2290	2200	90
RX frequencies: 2025 MHz - 2110 MHz	2110	2025	85

Manufacturer Specified Operational Bandwidth (Maximum)	0.065 MHz	=	65	kHz

GOMspace AX2150 S-Band Transmitter	
TX frequencies:	2200 MHz - 2290 MHz
RX frequencies:	2025 MHz - 2110 MHz
Modulation:	FSK/MSK/GFSK/GMSK
Data bit rates:	2.4 kbps to 90 kbps
Max RF power at output:	29 dBm at 0.8W

GOMspace AM2150P + AM2150 PS S-Band Antenna #1	
Pattern:	directional
Gain:	> -12 dBi in 85% of all directions, > 0 dBi in 20% of all directions
Polarisation:	RHCP

GOMspace AM2150P + AM2150 PS S-Band Antenna #2	
Pattern:	directional
Gain:	> -12 dBi in 85% of all directions, > 0 dBi in 20% of all directions
Polarisation:	RHCP

NOTES:

(1)	NASA defined bandwidth limits: S-band -- 5 MHz (typical allocations are 1 (min), 3, or 5 (max) MHz. Exceptions for larger bandwidth are considered on a case-by-case basis. X-band -- 375 MHz (max) Exceptions for larger bandwidth are considered on a case-by-case basis. Ka-band -- 1.5 GHz (max) Exceptions for larger bandwidth are considered on a case-by-case basis.

System Parameters: GOMspace AX2150 S-Band Transmitter			
Orbit Height	500	km	User Specified
Frequency Uplink	2110	MHz	Uplink: 2025-2110 MHz
Frequency Downlink	2290	MHz	Downlink 2200-2290 MHz
Bitrate Uplink	38.4	kbit/s	user bitrate (not including protocol overhead)
Bitrate Downlink	38.4	kbit/s	user bitrate (not including protocol overhead)
Modulation	GFSK		
Coding/framing overhead	25%		Reed-solomon and framing
Coded symbolrate uplink	48.0		Coded symbolrate/channel symbolrate
Coded symbolrate downlink	48.0		Coded symbolrate/channel symbolrate
Bandwidth Factor	1.35		Factor between signal bandwidth and symbol rate
Downlink Bandwidth	64.8	kHz	
Atmospheric Loss	0.0	dB	In addition to free-space loss
Sat. Ant. Gain for PDF	0.0	dBi	CCDF ~25%
Satellite TX Power	0.200	W	Max 0.7W for AX2150
Power Flux Density at Earth	-144.1	dBW /m2	Max -144 dBW /m2 for ITU compliance
Ground station EIRP	44	dBW	Data from customer
Ground station G/T (elev 20°)	12	dB/K	Data from customer
Required Link Margin	3	dB	Used for link probablity calculations

CALCULATING ERP and EIRP for X-Band

Antenna Gain (dBi)	Radiated Power	Transmitter Output Power (W)		Transmitter Output Power (W)	
		0.5		2.0	
		(dBW)	Watts	(dBW)	Watts
0	*Effective Radiated Power (ERP)*	-5.16	0.30	0.86	1.22
	Effective Isotropic Radiated Power (EIRP)	-3.01	0.50	3.01	2.00
6	*Effective Radiated Power (ERP)*	0.84	1.21	6.86	4.85
	Effective Isotropic Radiated Power (EIRP)	2.99	1.99	9.01	7.96
12	*Effective Radiated Power (ERP)*	6.84	4.83	12.86	19.33
	Effective Isotropic Radiated Power (EIRP)	8.99	7.92	15.01	31.70
16	*Effective Radiated Power (ERP)*	10.84	12.14	16.86	48.55
	Effective Isotropic Radiated Power (EIRP)	12.99	19.91	19.01	79.62

NOTES:

(1) Calculations made using http://sss-mag.com/calcdb.html JavaScript code for these calculators provided by Michael Davis.

CALCULATING ERP and EIRP for S-Band

Antenna Gain (dBi)	Radiated Power	Transmitter Output Power (W)		Transmitter Output Power (W)	
		0.2		0.7	
		(dBW)	Watts	(dBW)	Watts
0	*Effective Radiated Power (ERP)*	-9.14	0.12	-3.70	0.43
	Effective Isotropic Radiated Power (EIRP)	-6.99	0.20	-1.55	0.70
6	*Effective Radiated Power (ERP)*	-3.14	0.49	2.30	1.70
	Effective Isotropic Radiated Power (EIRP)	-0.99	0.80	4.45	2.79
12	*Effective Radiated Power (ERP)*	2.86	1.93	8.30	6.76
	Effective Isotropic Radiated Power (EIRP)	5.01	3.17	10.45	11.09
16	*Effective Radiated Power (ERP)*	6.86	4.85	12.30	16.99
	Effective Isotropic Radiated Power (EIRP)	9.01	7.96	14.45	27.87

NOTES:

(1) Calculations made using http://sss-mag.com/calcdb.html JavaScript code for these calculators provided by Michael Davis.

January 2021 Edition J-1 J.3.1
Annex J
Guidance for Determination of Necessary Bandwidth

Type of Service	Description of Emission	Formula	Reference Equation	Type of Signal	Sample Calculation	Emission Designator
GMSK	*Gaussian-filtered Minimum shift keying Gaussian MSK D = 0.25R Filter B_{3dB} T = 0.5*	*Bn = KR K = 1.03*	*Bn = KR Reference Eq. J-20*	*2 level Gaussian coherent phase FSK*	*R = 10 Mbps; Bn = 10.3 MHz*	*10M3F1D*
	S-Band Down	R = 2.4 kbps (lowest bit rate of radio)	2.472		R = 2.4 kbps; Bn = 2.472 kHz	2K47F1D
		R = 4.8 kbps	4.944		R = 4.8 kbps; Bn = 4.944 kHz	4K94F1D
		R = 9.2 kbps	9.476		R = 9.2 kbps; Bn = 9.476 kHz	9K48F1D
		R = 19.2 kbps	19.776		R = 19.2 kbps; Bn = 19.776 kHz	19K78F1D
		R = 38.4 kbps	39.552		R = 38.4 kbps; Bn = 39.552 kHz	39K55F1D
		R = 76.8 kbps	79.104		R = 76.8 kbps; Bn = 79.104 kHz	79K10F1D
		R = 90 kbps (highest bit rate of radio)	92.7		R = 90 kbps Bn = 92.7 kHz	92K7F1D
		R = 970 kbps (Total Channel Width)	*970*	*Accommodates up to 10 channels*	*R = .970 Mbps; Bn = 1 MHz*	*1M00F1D*
GPS	*Global Positioning System DSSS with BPSK spreading*	*B_n = 2KR/Log_2S K ≈ 1.17*	*Bn = 2KR/Log_2S Reference Eq. J-22*		*R = 10.23 Mbps; S = 2 B_n = 24 MHz*	*24M0G1D*
QPSK	*Constant envelop offset QPSK (OQPSK); Feher's patented QPSK (FQPSK-B, FQPSK-JR); shaped offset QPSK (SOQPSK- TG)*	*Bn = 0.78R K = 0.78*	*Bn = KR Reference Eq. J-23*	*Single channel data*	*R = 5 Mbps; Bn = 3.9 MHz*	*3M90G1D*
QPSK	*Quadrature Phase Shift Keying*	*B_n = 2KR/Log_2S R = kBps K ≈ 0.6 to 0.8 (typical, depending on filter roll-off factor)*	*Bn = 2KR/Log_2S Reference Eq. J-22*	*Data Link*	*Data Link R = 312 kbps; S = 4; k = 0.65 B_n = 203 kHz*	*203KG1D*
QPSK	X-Band Down	B_n = 2KR/Log_2S R= 2 Mbps (Lowest Bit Rate of Radio) K ≈ 0.6 to 0.8 (typical, depending on filter roll-off factor) ***RADIO MINIMUM BIT RATE***	1.30	Data Link	Data Link R = 2 Mbps; S = 4; k = 0.65 B_n = .65 MHz	65KG1D
QPSK		B_n = 2KR/Log_2S K ≈ 0.6 to 0.8 (typical, depending on filter roll-off factor) **RADIO MAXIMUM BIT RATE (OPERATING)**	81.25	Data Link	Data Link R = 125 Mbps; S = 4; k = 0.65 B_n = 40.625 MHz	40M63G1D
QPSK		B_n = 2KR/Log_2S K ≈ 0.6 to 0.8 (typical, depending on filter roll-off factor) ***RADIO MAXIMUM GROSS DATA RATE***	97.50	Data Link	Data Link R = 150 Mbps; S = 4; k = 0.65 B_n = 48.75 MHz	48M75G1D
QPSK		B_n = 2KR/Log_2S K ≈ 0.6 to 0.8 (typical, depending on filter roll-off factor) **TOTAL CHANNEL WIDTH**	375	Accommodates 1 Channel	Data Link R = 577 Mbps; S = 4; k = 0.65 B_n = 375 MHz	375MG1D

NOTES:

Bn = necessary bandwidth. For digital modulations, the necessary bandwidth is generally based on a more precise measure of bandwidth – the theoretical 99% occupied bandwidth. See Section 5.1.5 for the desired relationship of measured occupied bandwidth to necessary bandwidth. (See below)

K = An overall numerical factor which varies according to the emission and which depends upon the allowable signal distortion.

R = Total bit rate, which includes data, encoding, and any other overhead bits.

https://www.ntia.doc.gov/legacy/osmhome/redbook/5.pdf

5.1.5 Terminology
Definitions of Special Terms, Services, and Stations are contained in Chapter 6. Desired Relationship of Occupied Bandwidth to Necessary Bandwidth
The emission designator(s) associated in the authorization for any particular frequency assignment specifies the value of the necessary bandwidth of emission for the particular type(s) of transmission permitted. The values of necessary bandwidth are generally idealized. All reasonable effort shall be made in equipment design and operation by Federal agencies to maintain the occupied bandwidth of the emission of any authorized transmission as close to the necessary bandwidth as is reasonably practicable. (See Annex J for additional information concerning the method of calculating necessary bandwidth.)

Authorized Bandwidth
For purposes of this Manual, the term "authorized bandwidth" is defined as the necessary bandwidth (bandwidth required for the transmission and reception of intelligence) and does not include allowance for transmitter drift or doppler shift. See, in addition, Chapter 6 for the definitions of special terms including authorized bandwidth and mean power.

Resolution Bandwidth
Resolution bandwidth is the 3 dB bandwidth of the measurement system used, e.g., in power spectral density measurements. The appropriate resolution bandwidth of the measurement system varies depending on the modulation type and frequency band but should not be greater than the necessary bandwidth of the transmitter being measured.

Power (RR)
Power is designated as: peak envelope power (PX or pX). mean power (PY or pY), carrier power (PZ or pZ), p denotes power expressed in watts, P denotes power in dB relative to a reference level

Logarithm
In this chapter, Log=Log10