

Exhibit E –SoFIE UHF Link Budget Analysis Results

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The SoFIE mission uses a UHF uplink and downlink capability to command the spacecraft and receive health and status telemetry, respectively (9600 bps). To ensure continuous operational availability and reliable telemetry download, the link budget is evaluated under a worst-case geometric scenario using the AMSAT/IARU Annotated Link Model System (V2.5.5). All calculations assume the spacecraft is positioned at its maximum slant range and at a minimum operational horizon elevation angle of 10° relative to the ground station.

Uplink Technical Analysis

The uplink path establishes the command-and-control loop from the primary ground station transmitter to the SoFIE CubeSat receiver. Calculations demonstrate that the ground station's Effective Isotropically Radiated Power provides sufficient signal energy per bit over noise density, or Eb/No, at maximum slant range to maintain link closure using BPSK modulation.

SoFIE		NOTE:	SoFIE	Date Data Last Modified:
Uplink Command Budget:			Version: 2.5.5	2016 October 20
Parameter:	Value:	Units:	Comments:	
Ground Station:				
Ground Station Transmitter Power Output:	20.0	watts	This value is transferred from "Transmitters" W/S, Cell [E15].	
In dBW:	13.0	dBW	Transmitter power expressed in dB above one watt	
In dBm:	43.0	dBm	Transmitter power expressed in dB above one milliwatt	
Ground Stn. Total Transmission Line Losses:	3.6	dB	This value is transferred from "Transmitters" W/S, Cell [I33]	
Antenna Gain:	13.3	dBi	This value is selected at "Antenna Gain" W/S, Cell [E11]	
Ground Station EIRP:	22.7	dBW	Ground Station Effective Isotropic Radiated Power (EIRP) [EIRP=Pt x Lt l x Ga]	
Uplink Path:				
Ground Station Antenna Pointing Loss:	0.1	dB	This value is calculated in the "Antenna Pointing Losses" W/S, and transferred from Cell [K43]	
Gnd-to-S/C Antenna Polarization Losses:	3.0	dB	This value is calculated in the "Polarization Loss" W/S and is transferred from Cell [F40].	
Path Loss:	149.9	dB	Lp = 22 + 20LOG(D/λ); Transferred from "Frequency" W/S	
Atmospheric Losses:	2.1	dB	This value is transferred from "Atmos. & Ionos. Losses" W/S, Cell [D23]	
Ionospheric Losses:	0.4	dB	This value is transferred from "Atmos. & Ionos. Losses" W/S, Cell [D47:D50]	
Rain Losses:	0.0	dB	This value should be estimated by the link model operator and place into Cell [B18]	
Isotropic Signal Level at Spacecraft:	-132.8	dBW	This is the signal level received in space in the vicinity of the spacecraft using an omnidirectional antenna.	
Spacecraft (Eb/No Method):				
----- Eb/No Method -----				
Spacecraft Antenna Pointing Loss:	0.3	dB	This value is transferred from "Antenna Pointing Losses" W/S, Cell [K63]	
Spacecraft Antenna Gain:	3.1	dBi	This value is selected at "Antenna Gain" W/S, Cell [E24]	
Spacecraft Total Transmission Line Losses:	2.0	dB	This value is transferred from the "Receivers" W/S, Cell [J52]	
Spacecraft Effective Noise Temperature:	600	K	This value is calculated in the "Receivers" W/S and Transferred from Cell [J67]	
Spacecraft Figure of Merit (G/T):	-26.6	dB/K	G/T = Ga-Lt-10log(Ts). This is the ultimate measure of the receiver's performance.	
S/C Signal-to-Noise Power Density (S/No):	68.9	dBHz	Boltzman's Constant: -228.6 dBW/K/Hz	
System Desired Data Rate:	9600	bps	Operator selects this value. Be Careful! This is the data rate, not the symbol rate.	
In dBHz:	39.8	dBHz	This is simply = 10log(R); R= data rate	
Command System Eb/No:	29.1	dB		
Demodulation Method Selected:	BPSK		Values selected in "Modulation-Demodulation W/S, Cell [E3]	
Forward Error Correction Coding Used:	AX 25 BCH FEC		Value selected in "Modulation-Demodulation" W/S, also Cell [E3]	
System Allowed or Specified Bit-Error-Rate:	1.0E-05		The selected value is transferred from the "Modulation-Demodulation W/S, Cells [E6:E23]	
Demodulator Implementation Loss:	2.0	dB	This value is transferred from the "Modulation-Demodulation W/S, Cell[E25]	
Telemetry System Required Eb/No:	7.2	dB	The selected value is transferred from the "Modulation-Demodulation W/S, Cells [F6:F23]	
Eb/No Threshold:	9.2	dB	This is the result of the "Modulation-Demodulation" W/S and is transferred from Cell [H32]	
System Link Margin:	19.9	dB		

Spacecraft Alternative Signal Analysis Method (SNR Computation):		NOTE:
***** SNR Method *****		
Spacecraft Antenna Pointing Loss:	0.3 dB	This value is transferred from "Antenna Pointing Losses" W/S, Cell [K63]
Spacecraft Antenna Gain:	3.1 dBi	This value is selected at "Antenna Gain" W/S, Cell [E24]
Spacecraft Total Transmission Line Losses:	2.0 dB	This value is transferred from the "Receivers" W/S, Cell [J52]
Spacecraft Effective Noise Temperature:	600 K	This value is calculated in the "Receivers" W/S and Transferred from Cell [J67]
Spacecraft Figure of Merit (G/T):	-26.6 dB/K	G/T = Ga-Lti-10log(Ts). This is the ultimate measure of the receiver's performance.
Signal Power at Spacecraft LNA Input:	-131.9 dBW	$P_s = P_{iso} + G_a - L_{pt} - L_{ti}$; This is the signal power that has arrived at the ground station receiver.
Spacecraft Receiver Bandwidth:	14,811 Hz	Signal Spectrum Must Pass Through This Data Filter. NOTE:
Spacecraft Receiver Noise Power (Pn = kTB)	-159.1 dBW	$P_n = K + 10\log(T_s) + 10\log(B)$. This is the total noise power arriving at the ground station receiver.
Signal-to-Noise Power Ratio at G.S. Rcvr:	27.2 dB	$P_s/P_n = P_s(\text{in dBW}) - P_n(\text{in dBW})$
Analog or Digital System Required S/N:	9.2 dB	If system is digital, use values from "Modulation-Demodulation" W/S. If analog, use appropriate value from text book.
System Link Margin	18.0 dB	

Figure 1: UHF Command Uplink Path under Worst-Case 10° Horizon Elevation Angle using the AMSAT/IARU Model.

Downlink Technical Analysis

The downlink path dictates the transmission of spacecraft health telemetry from the SoFIE CubeSat back to the ground station. Calculations demonstrate that the spacecraft's Effective Isotropically Radiated Power provides sufficient signal energy per bit over noise density, or E_b/N_o , at maximum slant range to maintain link closure using BPSK modulation.

SoFIE		NOTE:	SoFIE	Date Data Last Modified:
Downlink Telemetry Budget:			Version: 2.5.5	2016 October 20
Parameter:	Value:	Units:	Comments:	
Spacecraft:				
Spacecraft Transmitter Power Output:	1.0 watts		This value is transferred from "Transmitters" W/S, Cell [E50]	
In dBW:	0.0	dBW	Transmitter power expressed in dB above one watt	
In dBm:	30.0	dBm	Transmitter power expressed in dB above one milliwatt	
Spacecraft Total Transmission Line Losses:	2.2 dB		This value is transferred from "Transmitters" W/S, Cell [I68]	
Spacecraft Antenna Gain:	3.1 dBi		This value is selected at "Antenna Gain" W/S, Cell [E41]	
Spacecraft EIRP:	0.9	dBW	Spacecraft Effective Isotropic Radiated Power (EIRP) [EIRP=P _t x L _{tl} x G _a]	
Downlink Path:				
Spacecraft Antenna Pointing Loss:	0.3 dB		This value is calculated in the "Antenna Pointing Losses" W/S, and transferred from Cell [K85]	
S/C-to-Ground Antenna Polarization Loss:	3.0 dB		This value is calculated in the "Polarization Loss" W/S and is transferred from Cell [F60].	
Path Loss:	149.9 dB		L _p = 22 + 20LOG(D/λ); Transferred from "Frequency" W/S	
Atmospheric Loss:	2.1 dB		This value is transferred from "Atmos. & Ionos. Losses" W/S, Cell [D23]	
Ionospheric Loss:	0.4 dB		This value is transferred from "Atmos. & Ionos. Losses" W/S, Cell [D47:D50]	
Rain Loss:	0.0 dB		This value should be estimated by the link model operator and place into Cell [B18]	
Isotropic Signal Level at Ground Station:	-154.8	dBW	This is the signal level received at the Earth in the vicinity of the ground station using an omnidirectional antenna.	
Ground Station (EbNo Method):				
----- Eb/No Method -----				
Ground Station Antenna Pointing Loss:	0.1 dB		This value is transferred from "Antenna Pointing Losses" W/S, Cell [K102]	
Ground Station Antenna Gain:	13.3 dBi		This value is selected at "Antenna Gain" W/S, Cell [E58]	
Ground Station Total Transmission Line Losses:	2.0 dB		This value is transferred from the "Receivers" W/S, Cell [J123]	
Ground Station Effective Noise Temperature:	400 K		This value is calculated in the "Receivers" W/S and Transferred from Cell [J138]	
Ground Station Figure of Merit (G/T):	-14.7 dB/K		G/T = G _a -L _{ti} -10log(T _s). This is the ultimate measure of the receiver's performance.	
G.S. Signal-to-Noise Power Density (S/No):	59.1	dBHz	Boltzman's Constant: -228.6 dBW/K/Hz	
System Desired Data Rate:	9600	bps	Operator selects this value. Be Careful! This is the data rate, not the symbol rate.	
In dBHz:	39.8	dBHz	This is simply = 10log(R); R= data rate	
Telemetry System Eb/No for the Downlink:	19.3	dB		
Demodulation Method Selected:	BPSK		Values selected in "Modulation-Demodulation W/S, Cell [E30]	
Forward Error Correction Coding Used:	AX 25 BCH FEC		Value selected in "Modulation-Demodulation" W/S, also Cell [E30]	
System Allowed or Specified Bit-Error-Rate:	1.0E-05		The selected value is transferred from the "Modulation-Demodulation W/S, Cells [E33:E50]	
Demodulator Implementation Loss:	2	dB	This value is transferred from the "Modulation-Demodulation W/S, Cell [E52]	
Telemetry System Required Eb/No:	7.2	dB	The selected value is transferred from the "Modulation-Demodulation W/S, Cells [F33:F50]	
Eb/No Threshold:	9.2	dB	This is the result of the "Modulation-Demodulation" W/S and is transferred from Cell [H32]	
System Link Margin:	10.1	dB		
Ground Station Alternative Signal Analysis Method (SNR Computation):				
----- SNR Method -----				
Ground Station Antenna Pointing Loss:	0.1 dB		This value is transferred from "Antenna Pointing Losses" W/S, Cell [K102]	
Ground Station Antenna Gain:	13.3 dBi		This value is selected at "Antenna Gain" W/S, Cell [E58]	
Ground Station Total Transmission Line Losses:	2.0 dB		This value is transferred from the "Receivers" W/S, Cell [J123]	
Ground Station Effective Noise Temperature:	400 K		This value is calculated in the "Receivers" W/S and Transferred from Cell [J138]	
Ground Station Figure of Merit (G/T):	-14.7 dB/K		G/T = G _a -L _{ti} -10log(T _s). This is the ultimate measure of the receiver's performance.	
Signal Power at Ground Station LNA Input:	-143.5	dBW	P _s = P _{iso} +G _a -L _p -L _{ti} ; This is the signal power that has arrived at the ground station receiver.	
Ground Station Receiver Bandwidth (B):	14,811	Hz	Signal Spectrum Must Pass Through This Data Filter	
G.S. Receiver Noise Power (P _n = kTB)	-160.9	dBW	P _n = K + 10log(T _s) + 10log(B). This is the total noise power arriving at the ground station receiver.	
Signal-to-Noise Power Ratio at G.S. Rcvr:	17.4	dB	P _s /P _n = P _s (in dBW) - P _n (in dBW)	
Analog or Digital System Required S/N:	9.2	dB	If system is digital, use values from "Modulation-Demodulation" W/S. If analog, use appropriate value from text book.	
System Link Margin	8.2	dB		

Figure 2: UHF Telemetry Downlink Path under Worst-Case Spacecraft Slant Range using the AMSAT/IARU Model.

Summary

The calculated uplink margin of **(19.9dB)** and downlink margin of **(10.1dB)** confirms that the SoFIE mission maintains closing communication links under Worst-Case 10° Horizon Elevation Angle.