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MINISTRY OF EDUCATION,
YOUTH AND SPORTS

FACULTY OF ELECTRICAL
ENGINEERING
UNIVERSITY
OF WEST BOHEMIA

ANTENNAS (KEI/ANT)

Link budget calculation – practical example and home exercises

Department of Electronics and Information Technology

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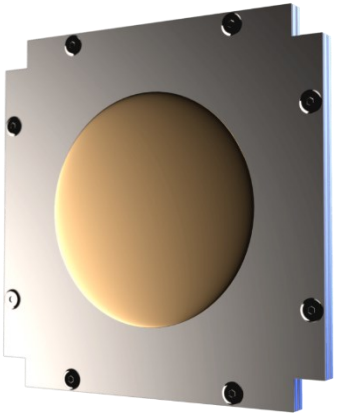
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Example of calculations

Can we download data from LEO satellite (altitude 500 km) equipped with a S-band Endurosat transmitter in DVB-S2 mode and planar antenna via a ground station equipped with a Ubiquity AF-2G24-S45 parabolic dish antenna and Kuhne Electronic KU LNA 2227A low noise amplifier if we require a bit error of less than 10^{-6} and data rate 2 Mbit/s from elevations 20° above horizon?

EnduroSat transmitter	**Endurosat antenna**	**Ubiquity dish antenna**	**Low noise amplifier**
Tx power max. 2W	gain 6 dBi	gain 24 dBi	noise figure 1.2 dB
DVB-S2 compliant		diameter 650 mm	gain 25 dB
QPSK, 8-PSK, 16-APSK			









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MODulation	CODing Rate	Ebi/No
		dB
QPSK	1/4	0.746
QPSK	1/3	0.588
QPSK	2/5	0.727
QPSK	1/2	1.049
QPSK	3/5	1.481
QPSK	2/3	1.887
QPSK	3/4	2.306
QPSK	4/5	2.674
QPSK	5/6	2.993
8PSK	3/5	2.996
QPSK	8/9	3.729
QPSK	9/10	3.895
8PSK	2/3	3.652
8PSK	3/4	4.431
16APSK	2/3	4.759
8PSK	5/6	5.408
16APSK	3/4	5.487
8PSK	8/9	6.464
8PSK	9/10	6.700
16APSK	4/5	6.025
16APSK	5/6	6.425
32APSK	3/4	7.044
16APSK	8/9	7.421
16APSK	9/10	7.607
32APSK	4/5	7.672
32APSK	5/6	8.132
32APSK	8/9	9.258
32APSK	9/10	9.563

$$P_{RX} = P_{TX} + G_{TX} - L_{TX} - L_{FS} - L_M + G_{RX} - L_{RX}$$

P_{RX} = received power (dBm)
P_{TX} = transmitter output power (dBm)
G_{TX} = transmitter antenna gain (dBi)
L_{TX} = transmitter losses (coax, connectors...) (dB)
L_{FS} = path loss, usually free space loss (dB)

$$L_{FS}(\text{dB}) = 20\log_{10}\left(4\pi\frac{\text{distance}}{\text{wavelength}}\right)$$

L_M = miscellaneous losses (fading margin, body loss, polarization mismatch, other losses...) (dB)
G_{RX} = receiver antenna gain (dBi)
L_{RX} = receiver losses (coax, connectors...) (dB)

$$P_n = 10\log_{10}\left(\frac{k.B.T}{1\ mW}\right)$$

T = Temperature in Kelvin

B = Bandwidth in Hz

k = Boltzmann's constant, $1.38064852 \times 10^{-23}\ m^2\ kg\ s^{-2}\ K^{-1}$

$$E_b/N_0 = P_{RX} - 10\log(v_p) - P_N + 10\log(B)$$

We select the most robust modulation and coding format from table and use equations above to verify received Eb/N_0.

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Example - S band downlink	NOTE:		Example - S band dowr	Date Data Last Modified:
Downlink Telemetry Budget:			Version: 2.5.5	2020 March 26
Parameter:	*Value:*	*Units:*	*Comments:*	
Spacecraft:				
Spacecraft Transmitter Power Output:	2,0	watts	This value is transferred from "Transmitters" W/S, Cell [E50]	
In dBW:	3,0	dBW	Transmitter power expressed in dB above one watt	
In dBm:	33,0	dBm	Transmitter power expressed in dB above one milliwatt	
Spacecraft Total Transmission Line Losses:	0,0	dB	This value is transferred from "Transmitters" W/S, Cell [I68]	
Spacecraft Antenna Gain:	6,0	dBi	This value is selected at "Antenna Gain" W/S, Cell [E41]	
Spacecraft EIRP:	9,0	dBW	Spacecraft Effective Isotropic Radiated Power (EIRP) [EIRP=Pt x Ltl x Ga]	
Downlink Path:				
Spacecraft Antenna Pointing Loss:	0,0	dB	This value is calculated in the "Antenna Pointing Losses" W/S, and trasferred from Cell [K85]	
S/C-to-Ground Antenna Polarization Loss:	0,0	dB	This value is calculated in the "Polarization Loss" W/S and is transferred from Cell [F60].	
Path Loss:	161,6	dB	Lp = 22 + 20LOG(D/λ); Transferred from "Frequency" W/S	
Atmospheric Loss:	0	dB	This value is transferred from "Atmos. & Ionos. Losses" W/S, Cell [D23]	
Ionospheric Loss:	0,0	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:	-152,6	dBW	This is the signal level received at the Earth in the vacinity of the ground station using an omnidirectional antenna.	
Ground Station (EbNo Method):				
------- Eb/No Method -------				
Ground Station Antenna Pointing Loss:	0,0	dB	This value is transferred from "Antenna Pointing Losses" W/S, Cell [K102]	
Ground Station Antenna Gain:	24,0	dBi	This value is selected at "Antenna Gain" W/S, Cell [E58]	
Ground Station Total Transmission Line Loss	0,0	dB	This value is transferred from the "Receivers" W/S, Cell [J123]	
Ground Station Effective Noise Temperature:	98	K	This value is calculated in the "Receivers" W/S and Transferred from Cell [J138]	
Ground Station Figure of Merrit (G/T):	4,1	dB/K	G/T = Ga-Ltl-10log(Ts). This is the uptimate measure of the receiver's performance.	
G.S. Signal-to-Noise Power Density (S/No):	80,1	dBHz	Boltzman's Constant: -228,6 dBW/K/Hz	
System Desired Data Rate:	2000000	bps	Operator selects this value. Be Careful! This is the data rate, not the symbol rate.	
In dBHz:	63,0	dBHz	This is simply = 10log(R); R= data rate	
Telemetry System Eb/No for the Downlink:	17,1	dB		
Demodulation Method Seleted:	QPSK		Values selected in "Modulation-Demodulation W/S, Cell [E30]	
Forward Error Correction Coding Used:	LDPC+BCH (DVB-S2), R=1/4		Value selected in "Modulation-Demodulation" W/S, also Cell [E30]	
System Allowed or Specified Bit-Error-Rate:	1,0E-06		The selected value is transferred from the "Modulation-Demodulation W/S, Cells [E33:E50]	
Demodulator Implementation Loss:	0	dB	This value is transferred from the "Modulation-Demodulation W/S, Cell[E52]	
Telemetry System Required Eb/No:	0,7	dB	The selected value is transferred from the "Modulation-Demodulation W/S, Cells [F33:F50]	
Eb/No Threshold:	0,7	dB	This is the result of the "Modulation-Demodulation" W/S and is transferred from Cell [H32]	
System Link Margin:	16,4	dB		

Link margin more than 16 dB… It is great, but is it real…? No, many aspects were neglected (link-budget-Sband_optimistic_1).

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Example - S band downlink	NOTE:		Example - S band dowr	Date Data Last Modified:
Downlink Telemetry Budget:			Version: 2.5.5	2020 March 26

Parameter:	*Value:*	*Units:*	*Comments:*
Spacecraft:			
Spacecraft Transmitter Power Output:	1,5	watts	This value is transferred from "Transmitters" W/S, Cell [E50]
In dBW:	1,8	dBW	Transmitter power expressed in dB above one watt
In dBm:	31,8	dBm	Transmitter power expressed in dB above one milliwatt
Spacecraft Total Transmission Line Losses:	0,3	dB	This value is transferred from "Transmitters" W/S, Cell [I68]
Spacecraft Antenna Gain:	6,0	dBi	This value is selected at "Antenna Gain" W/S, Cell [E41]
Spacecraft EIRP:	7,5	dBW	Spacecraft Effective Isotropic Radiated Power (EIRP) [EIRP=Pt x Ltl x Ga]
Downlink Path:			
Spacecraft Antenna Pointing Loss:	0,0	dB	This value is calculated in the "Antenna Pointing Losses" W/S, and trasferred from Cell [K85]
S/C-to-Ground Antenna Polarization Loss:	0,0	dB	This value is calculated in the "Polarization Loss" W/S and is transferred from Cell [F60].
Path Loss:	161,6	dB	Lp = 22 + 20LOG(D/λ); Transferred from "Frequency" W/S
Atmospheric Loss:	0	dB	This value is transferred from "Atmos. & Ionos. Losses" W/S, Cell [D23]
Ionospheric Loss:	0,0	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:	-154,1	dBW	This is the signal level received at the Earth in the vacinity of the ground station using an omnidirectional antenna.
Ground Station (EbNo Method):			
------- Eb/No Method -------			
Ground Station Antenna Pointing Loss:	0,0	dB	This value is transferred from "Antenna Pointing Losses" W/S, Cell [K102]
Ground Station Antenna Gain:	24,0	dBi	This value is selected at "Antenna Gain" W/S, Cell [E58]
Ground Station Total Transmission Line Loss	0,7	dB	This value is transferred from the "Receivers" W/S, Cell [J123]
Ground Station Effective Noise Temperature:	146	K	This value is calculated in the "Receivers" W/S and Transferred from Cell [J138]
Ground Station Figure of Merrit (G/T):	1,7	dB/K	G/T = Ga-Ltl-10log(Ts). This is the uptimate measure of the receiver's performance.
G.S. Signal-to-Noise Power Density (S/No):	76,2	dBHz	Boltzman's Constant: -228,6 dBW/K/Hz
System Desired Data Rate:	2000000	bps	Operator selects this value. Be Careful! This is the data rate, not the symbol rate.
In dBHz:	63,0	dBHz	This is simply = 10log(R); R= data rate
Telemetry System Eb/No for the Downlink:	13,2	dB	
Demodulation Method Seleted:	QPSK		Values selected in "Modulation-Demodulation W/S, Cell [E30]
Forward Error Correction Coding Used:	LDPC+BCH (DVB-S2), R=1/4		Value selected in "Modulation-Demodulation" W/S, also Cell [E30]
System Allowed or Specified Bit-Error-Rate:	1,0E-06		The selected value is transferred from the "Modulation-Demodulation W/S, Cells [E33:E50]
Demodulator Implementation Loss:	0	dB	This value is transferred from the "Modulation-Demodulation W/S, Cell[E52]
Telemetry System Required Eb/No:	0,7	dB	The selected value is transferred from the "Modulation-Demodulation W/S, Cells [F33:F50]
Eb/No Threshold:	0,7	dB	This is the result of the "Modulation-Demodulation" W/S and is transferred from Cell [H32]
System Link Margin:	12,5	dB	

Link margin more than 12 dB – losses in cables, connectors, real SWR of antenna (transmitter side and receiver side), not a full Tx-output from radio due to distortion avoiding. It is great, but is it real? No, still many aspects were neglected (link-budget-Sband_optimistic_2).

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Example - S band downlink	NOTE:		Example - S band downl	Date Data Last Modified:
Downlink Telemetry Budget:			Version: 2.5.5	2020 March 26
Parameter:	*Value:*	*Units:*	*Comments:*	
Spacecraft:				
Spacecraft Transmitter Power Output:	1,5	watts	This value is transferred from "Transmitters" W/S, Cell [E50]	
In dBW:	1,8	dBW	Transmitter power expressed in dB above one watt	
In dBm:	31,8	dBm	Transmitter power expressed in dB above one milliwatt	
Spacecraft Total Transmission Line Losses:	0,3	dB	This value is transferred from "Transmitters" W/S, Cell [I68]	
Spacecraft Antenna Gain:	6,0	dBi	This value is selected at "Antenna Gain" W/S, Cell [E41]	
Spacecraft EIRP:	7,5	dBW	Spacecraft Effective Isotropic Radiated Power (EIRP) [EIRP=Pt x Ltl x Ga]	
Downlink Path:				
Spacecraft Antenna Pointing Loss:	0,0	dB	This value is calculated in the "Antenna Pointing Losses" W/S, and trasferred from Cell [K85]	
S/C-to-Ground Antenna Polarization Loss:	0,0	dB	This value is calculated in the "Polarization Loss" W/S and is transferred from Cell [F60].	
Path Loss:	161,6	dB	Lp = 22 + 20LOG(D/λ); Transferred from "Frequency" W/S	
Atmospheric Loss:	0	dB	This value is transferred from "Atmos. & Ionos. Losses" W/S, Cell [D23]	
Ionospheric Loss:	0,0	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:	-154,1	dBW	This is the signal level received at the Earth in the vacinity of the ground station using an omnidirectional antenna.	
Ground Station (EbNo Method):				
------- Eb/No Method -------				
Ground Station Antenna Pointing Loss:	0,0	dB	This value is transferred from "Antenna Pointing Losses" W/S, Cell [K102]	
Ground Station Antenna Gain:	24,0	dBi	This value is selected at "Antenna Gain" W/S, Cell [E58]	
Ground Station Total Transmission Line Loss	0,7	dB	This value is transferred from the "Receivers" W/S, Cell [J123]	
Ground Station Effective Noise Temperature:	228	K	This value is calculated in the "Receivers" W/S and Transferred from Cell [J138]	
Ground Station Figure of Merit (G/T):	-0,2	dB/K	G/T = Ga-Ltl-10log(Ts). This is the uptimate measure of the receiver's performance.	
G.S. Signal-to-Noise Power Density (S/No):	74,2	dBHz	Boltzman's Constant: -228,6 dBW/K/Hz	
System Desired Data Rate:	2000000	bps	Operator selects this value. Be Careful! This is the data rate, not the symbol rate.	
In dBHz:	63,0	dBHz	This is simply = 10log(R); R= data rate	
Telemetry System Eb/No for the Downlink:	11,2	dB		
Demodulation Method Seleted:	QPSK		Values selected in "Modulation-Demodulation W/S, Cell [E30]	
Forward Error Correction Coding Used:	LDPC+BCH (DVB-S2), R=1/4		Value selected in "Modulation-Demodulation" W/S, also Cell [E30]	
System Allowed or Specified Bit-Error-Rate:	1,0E-06		The selected value is transferred from the "Modulation-Demodulation W/S, Cells [E33:E50]	
Demodulator Implementation Loss:	0	dB	This value is transferred from the "Modulation-Demodulation W/S, Cell[E52]	
Telemetry System Required Eb/No:	0,7	dB	The selected value is transferred from the "Modulation-Demodulation W/S, Cells [F33:F50]	
Eb/No Threshold:	0,7	dB	This is the result of the "Modulation-Demodulation" W/S and is transferred from Cell [H32]	
System Link Margin:	10,5	dB		

Link margin more than 10 dB – antenna noise temperature increased to 100 K due to side lobes on antenna radiation pattern and receiving of WiFi (interferences) from neighboor. It is still good, but is it real? No, still many aspects were neglected (link budget Sband_optimistic_2)

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Example - S band downlink	NOTE:		Example - S band dowr	Date Data Last Modified:
Downlink Telemetry Budget:			Version: 2.5.5	2020 March 26
Parameter:	*Value:*	*Units:*	*Comments:*	
Spacecraft:				
Spacecraft Transmitter Power Output:	1,5	watts	This value is transferred from "Transmitters" W/S, Cell [E50]	
In dBW:	1,8	dBW	Transmitter power expressed in dB above one watt	
In dBm:	31,8	dBm	Transmitter power expressed in dB above one milliwatt	
Spacecraft Total Transmission Line Losses:	0,3	dB	This value is transferred from "Transmitters" W/S, Cell [I68]	
Spacecraft Antenna Gain:	6,0	dBi	This value is selected at "Antenna Gain" W/S, Cell [E41]	
Spacecraft EIRP:	7,5	dBW	Spacecraft Effective Isotropic Radiated Power (EIRP) [EIRP=Pt x Ltl x Ga]	
Downlink Path:				
Spacecraft Antenna Pointing Loss:	3,0	dB	This value is calculated in the "Antenna Pointing Losses" W/S, and trasferred from Cell [K85]	
S/C-to-Ground Antenna Polarization Loss:	0,1	dB	This value is calculated in the "Polarization Loss" W/S and is transferred from Cell [F60].	
Path Loss:	161,6	dB	Lp = 22 + 20LOG(D/λ); Transferred from "Frequency" W/S	
Atmospheric Loss:	0	dB	This value is transferred from "Atmos. & Ionos. Losses" W/S, Cell [D23]	
Ionospheric Loss:	0,0	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:	-157,3	dBW	This is the signal level received at the Earth in the vacinity 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:	24,0	dBi	This value is selected at "Antenna Gain" W/S, Cell [E58]	
Ground Station Total Transmission Line Loss	0,7	dB	This value is transferred from the "Receivers" W/S, Cell [J123]	
Ground Station Effective Noise Temperature:	228	K	This value is calculated in the "Receivers" W/S and Transferred from Cell [J138]	
Ground Station Figure of Merrit (G/T):	-0,2	dB/K	G/T = Ga-Ltl-10log(T_s). This is the uptimate measure of the receiver's performance.	
G.S. Signal-to-Noise Power Density (S/No):	71,0	dBHz	Boltzman's Constant: -228,6 dBW/K/Hz	
System Desired Data Rate:	2000000	bps	Operator selects this value. Be Careful! This is the data rate, not the symbol rate.	
In dBHz:	63,0	dBHz	This is simply = 10log(R); R= data rate	
Telemetry System Eb/No for the Downlink:	8,0	dB		
Demodulation Method Seleted:	QPSK		Values selected in "Modulation-Demodulation W/S, Cell [E30]	
Forward Error Correction Coding Used:	LDPC+BCH (DVB-S2), R=1/4		Value selected in "Modulation-Demodulation" W/S, also Cell [E30]	
System Allowed or Specified Bit-Error-Rate:	1,0E-06		The selected value is transferred from the "Modulation-Demodulation W/S, Cells [E33:E50]	
Demodulator Implementation Loss:	0	dB	This value is transferred from the "Modulation-Demodulation W/S, Cell[E52]	
Telemetry System Required Eb/No:	0,7	dB	The selected value is transferred from the "Modulation-Demodulation W/S, Cells [F33:F50]	
Eb/No Threshold:	0,7	dB	This is the result of the "Modulation-Demodulation" W/S and is transferred from Cell [H32]	
System Link Margin:	7,3	dB		

Link margin more than 7 dB – antenna pointing loss (ground antenna and satellite antenna) and polarization loss. It is still acceptable, but is it real? No, still many aspects were neglected (link-budget-Sband_optimistic_4).

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Example - S band downlink	NOTE:		Example - S band dowr	Date Data Last Modified:
Downlink Telemetry Budget:			Version: 2.5.5	2020 March 26

Parameter:	*Value:*	*Units:*	*Comments:*
Spacecraft:			
Spacecraft Transmitter Power Output:	1,5	watts	This value is transferred from "Transmitters" W/S, Cell [E50]
In dBW:	1,8	dBW	Transmitter power expressed in dB above one watt
In dBm:	31,8	dBm	Transmitter power expressed in dB above one milliwatt
Spacecraft Total Transmission Line Losses:	0,3	dB	This value is transferred from "Transmitters" W/S, Cell [I68]
Spacecraft Antenna Gain:	6,0	dBi	This value is selected at "Antenna Gain" W/S, Cell [E41]
Spacecraft EIRP:	7,5	dBW	Spacecraft Effective Isotropic Radiated Power (EIRP) [EIRP=Pt x Ltl x Ga]
Downlink Path:			
Spacecraft Antenna Pointing Loss:	3,0	dB	This value is calculated in the "Antenna Pointing Losses" W/S, and trasferred from Cell [K85]
S/C-to-Ground Antenna Polarization Loss:	0,1	dB	This value is calculated in the "Polarization Loss" W/S and is transferred from Cell [F60].
Path Loss:	161,6	dB	Lp = 22 + 20LOG(D/λ); Transferred from "Frequency" W/S
Atmospheric Loss:	1,1	dB	This value is transferred from "Atmos. & Ionos. Losses" W/S, Cell [D23]
Ionospheric Loss:	0,0	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:	-158,4	dBW	This is the signal level received at the Earth in the vacinity 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:	24,0	dBi	This value is selected at "Antenna Gain" W/S, Cell [E58]
Ground Station Total Transmission Line Loss	0,7	dB	This value is transferred from the "Receivers" W/S, Cell [J123]
Ground Station Effective Noise Temperature:	228	K	This value is calculated in the "Receivers" W/S and Transferred from Cell [J138]
Ground Station Figure of Merrit (G/T):	-0,2	dB/K	G/T = Ga-Ltl-10log(T_S). This is the uptimate measure of the receiver's performance.
G.S. Signal-to-Noise Power Density (S/No):	69,9	dBHz	Boltzman's Constant: -228,6 dBW/K/Hz
System Desired Data Rate:	2000000	bps	Operator selects this value. Be Careful! This is the data rate, not the symbol rate.
In dBHz:	63,0	dBHz	This is simply = 10log(R); R= data rate
Telemetry System Eb/No for the Downlink:	6,9	dB	
Demodulation Method Seleted:	QPSK		Values selected in "Modulation-Demodulation W/S, Cell [E30]
Forward Error Correction Coding Used:	LDPC+BCH (DVB-S2), R=1/4		Value selected in "Modulation-Demodulation" W/S, also Cell [E30]
System Allowed or Specified Bit-Error-Rate:	1,0E-06		The selected value is transferred from the "Modulation-Demodulation W/S, Cells [E33:E50]
Demodulator Implementation Loss:	1	dB	This value is transferred from the "Modulation-Demodulation W/S, Cell[E52]
Telemetry System Required Eb/No:	0,7	dB	The selected value is transferred from the "Modulation-Demodulation W/S, Cells [F33:F50]
Eb/No Threshold:	1,7	dB	This is the result of the "Modulation-Demodulation" W/S and is transferred from Cell [H32]
System Link Margin:	5,2	dB	

Link margin more than 5 dB – attenuation in atmosphere gasses, implementation loss of demodulator and FEC decoder in receiver. It is still acceptable, but is it real? No, still many aspects were neglected (link-budget-Sband_optimistic_5).

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Example - S band downlink	NOTE:		Example - S band downl	Date Data Last Modified:
Downlink Telemetry Budget:			Version: 2.5.5	2020 March 26
Parameter:	*Value:*	*Units:*	*Comments:*	
Spacecraft:				
Spacecraft Transmitter Power Output:	1,5	watts	This value is transferred from "Transmitters" W/S, Cell [E50]	
In dBW:	1,8	dBW	Transmitter power expressed in dB above one watt	
In dBm:	31,8	dBm	Transmitter power expressed in dB above one milliwatt	
Spacecraft Total Transmission Line Losses:	0,3	dB	This value is transferred from "Transmitters" W/S, Cell [I68]	
Spacecraft Antenna Gain:	6,0	dBi	This value is selected at "Antenna Gain" W/S, Cell [E41]	
Spacecraft EIRP:	7,5	dBW	Spacecraft Effective Isotropic Radiated Power (EIRP) [EIRP=Pt x Ltl x Ga]	
Downlink Path:				
Spacecraft Antenna Pointing Loss:	3,0	dB	This value is calculated in the "Antenna Pointing Losses" W/S, and trasferred from Cell [K85]	
S/C-to-Ground Antenna Polarization Loss:	0,1	dB	This value is calculated in the "Polarization Loss" W/S and is transferred from Cell [F60].	
Path Loss:	161,6	dB	Lp = 22 + 20LOG(D/λ); Transferred from "Frequency" W/S	
Atmospheric Loss:	1,1	dB	This value is transferred from "Atmos. & Ionos. Losses" W/S, Cell [D23]	
Ionospheric Loss:	0,0	dB	This value is transferred from "Atmos. & Ionos. Losses" W/S, Cell [D47:D50]	
Rain Loss:	1,0	dB	This value should be estimated by the link model operator and place into Cell [B18]	
Isotropic Signal Level at Ground Station:	-159,4	dBW	This is the signal level received at the Earth in the vacinity 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:	24,0	dBi	This value is selected at "Antenna Gain" W/S, Cell [E58]	
Ground Station Total Transmission Line Loss	0,7	dB	This value is transferred from the "Receivers" W/S, Cell [J123]	
Ground Station Effective Noise Temperature:	390	K	This value is calculated in the "Receivers" W/S and Transferred from Cell [J138]	
Ground Station Figure of Merrit (G/T):	-2,6	dB/K	G/T = Ga-Ltl-10log(T_s). This is the uptimate measure of the receiver's performance.	
G.S. Signal-to-Noise Power Density (S/No):	66,6	dBHz	Boltzman's Constant: -228,6 dBW/K/Hz	
System Desired Data Rate:	2000000	bps	Operator selects this value. Be Careful! This is the data rate, not the symbol rate.	
In dBHz:	63,0	dBHz	This is simply = 10log(R); R= data rate	
Telemetry System Eb/No for the Downlink:	3,6	dB		
Demodulation Method Seleted:	QPSK		Values selected in "Modulation-Demodulation W/S, Cell [E30]	
Forward Error Correction Coding Used:	LDPC+BCH (DVB-S2), R=1/4		Value selected in "Modulation-Demodulation" W/S, also Cell [E30]	
System Allowed or Specified Bit-Error-Rate:	1,0E-06		The selected value is transferred from the "Modulation-Demodulation W/S, Cells [E33:E50]	
Demodulator Implementation Loss:	1	dB	This value is transferred from the "Modulation-Demodulation W/S, Cell[E52]	
Telemetry System Required Eb/No:	0,7	dB	The selected value is transferred from the "Modulation-Demodulation W/S, Cells [F33:F50]	
Eb/No Threshold:	1,7	dB	This is the result of the "Modulation-Demodulation" W/S and is transferred from Cell [H32]	
System Link Margin:	1,9	dB		

Link margin less than 2 dB – attenuation in rain and increase of antenna noise temperature due to rain. Theoretically, it is possible to communicate, but it is not practical due to low margin (link-budget-Sband_optimistic_6).

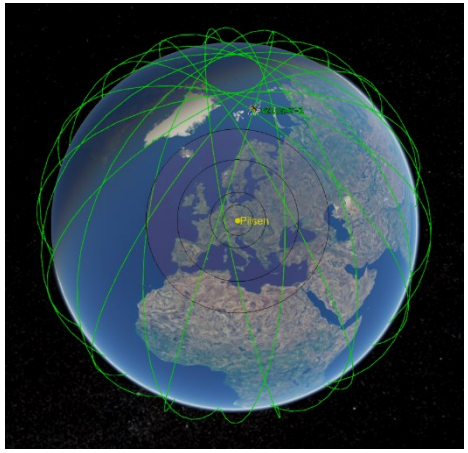
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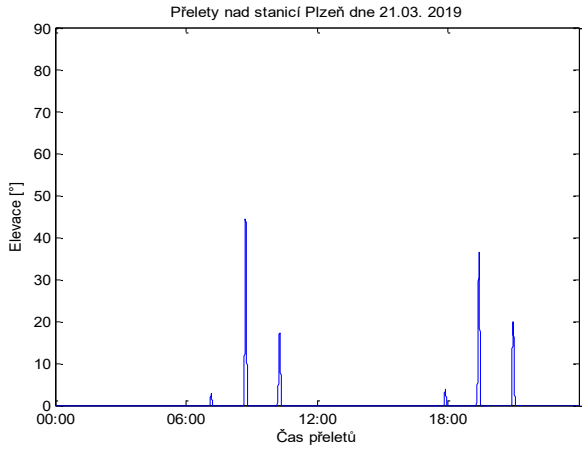
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Back to the task assignment…

Can we download data from an LEO satellite (altitude 500 km) equipped with an S-band Endurosat transmitter in DVB-S2 mode and planar antenna via a ground station equipped with a Ubiquity AF-2G24-S45 satellite dish and Kuhne Electronic KU LNA 2227A low noise amplifier if we require a bit error of less than 10^{-6} and a speed data transfer 2 Mbit/s from elevations 20° above horizon?

Is it practical to design communication with LEO satellite starting from 20° elevation?





1 ground station in central Europe satellite on LEO polar orbit with altitude 500 km
56 minutes in elevations above 0°
22 minutes in elevations above 10°
5 minutes in elevations above 30°

No, we only have two or three radio contacts a day instead of six and much less time to download data.

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Example - S band downlink	NOTE:		Example - S band downl	Date Data Last Modified:
Downlink Telemetry Budget:			Version: 2.5.5	2020 March 26

Parameter:	*Value:*	*Units:*	*Comments:*
Spacecraft:			
Spacecraft Transmitter Power Output:	1,5	watts	This value is transferred from "Transmitters" W/S, Cell [E50]
In dBW:	1,8	dBW	Transmitter power expressed in dB above one watt
In dBm:	31,8	dBm	Transmitter power expressed in dB above one milliwatt
Spacecraft Total Transmission Line Losses:	0,3	dB	This value is transferred from "Transmitters" W/S, Cell [I68]
Spacecraft Antenna Gain:	6,0	dBi	This value is selected at "Antenna Gain" W/S, Cell [E41]
Spacecraft EIRP:	7,5	dBW	Spacecraft Effective Isotropic Radiated Power (EIRP) [EIRP=Pt x Ltl x Ga]
Downlink Path:			
Spacecraft Antenna Pointing Loss:	3,0	dB	This value is calculated in the "Antenna Pointing Losses" W/S, and trasferred from Cell [K85]
S/C-to-Ground Antenna Polarization Loss:	0,1	dB	This value is calculated in the "Polarization Loss" W/S and is transferred from Cell [F60].
Path Loss:	166,4	dB	Lp = 22 + 20LOG(D/λ); Transferred from "Frequency" W/S
Atmospheric Loss:	1,1	dB	This value is transferred from "Atmos. & Ionos. Losses" W/S, Cell [D23]
Ionospheric Loss:	0,0	dB	This value is transferred from "Atmos. & Ionos. Losses" W/S, Cell [D47:D50]
Rain Loss:	1,0	dB	This value should be estimated by the link model operator and place into Cell [B18]
Isotropic Signal Level at Ground Station:	-164,2	dBW	This is the signal level received at the Earth in the vacinity 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:	24,0	dBi	This value is selected at "Antenna Gain" W/S, Cell [E58]
Ground Station Total Transmission Line Loss	0,7	dB	This value is transferred from the "Receivers" W/S, Cell [J123]
Ground Station Effective Noise Temperature:	390	K	This value is calculated in the "Receivers" W/S and Transferred from Cell [J138]
Ground Station Figure of Merrit (G/T):	-2,6	dB/K	G/T = Ga-Ltl-10log(Ts). This is the uptimate measure of the receiver's performance.
G.S. Signal-to-Noise Power Density (S/No):	61,8	dBHz	Boltzman's Constant: -228,6 dBW/K/Hz
System Desired Data Rate:	2000000	bps	Operator selects this value. Be Careful! This is the data rate, not the symbol rate.
In dBHz:	63,0	dBHz	This is simply = 10log(R); R= data rate
Telemetry System Eb/No for the Downlink:	-1,2	dB	
Demodulation Method Seleted:	QPSK		Values selected in "Modulation-Demodulation W/S, Cell [E30]
Forward Error Correction Coding Used:	LDPC+BCH (DVB-S2), R=1/4		Value selected in "Modulation-Demodulation" W/S, also Cell [E30]
System Allowed or Specified Bit-Error-Rate:	1,0E-06		The selected value is transferred from the "Modulation-Demodulation W/S, Cells [E33:E50]
Demodulator Implementation Loss:	1	dB	This value is transferred from the "Modulation-Demodulation W/S, Cell[E52]
Telemetry System Required Eb/No:	0,7	dB	The selected value is transferred from the "Modulation-Demodulation W/S, Cells [F33:F50]
Eb/No Threshold:	1,7	dB	This is the result of the "Modulation-Demodulation" W/S and is transferred from Cell [H32]
System Link Margin:	-2,9	dB	

Link margin negative (-3 dB) – communication since 5° of elevation is not possible due to low antenna gain (link-budget-Sband_realistic_small-antenna).

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Example - S band downlink	NOTE:		Example - S band dowr	Date Data Last Modified:
Downlink Telemetry Budget:			Version: 2.5.5	2020 March 26

Parameter:	Value:	Units:	Comments:
Spacecraft:			
Spacecraft Transmitter Power Output:	1,5	watts	This value is transferred from "Transmitters" W/S, Cell [E50]
In dBW:	1,8	dBW	Transmitter power expressed in dB above one watt
In dBm:	31,8	dBm	Transmitter power expressed in dB above one milliwatt
Spacecraft Total Transmission Line Losses:	0,3	dB	This value is transferred from "Transmitters" W/S, Cell [I68]
Spacecraft Antenna Gain:	6,0	dBi	This value is selected at "Antenna Gain" W/S, Cell [E41]
Spacecraft EIRP:	7,5	dBW	Spacecraft Effective Isotropic Radiated Power (EIRP) [EIRP=Pt x Ltl x Ga]
Downlink Path:			
Spacecraft Antenna Pointing Loss:	3,0	dB	This value is calculated in the "Antenna Pointing Losses" W/S, and trasferred from Cell [K85]
S/C-to-Ground Antenna Polarization Loss:	0,1	dB	This value is calculated in the "Polarization Loss" W/S and is transferred from Cell [F60].
Path Loss:	166,4	dB	Lp = 22 + 20LOG(D/λ); Transferred from "Frequency" W/S
Atmospheric Loss:	1,1	dB	This value is transferred from "Atmos. & Ionos. Losses" W/S, Cell [D23]
Ionospheric Loss:	0,0	dB	This value is transferred from "Atmos. & Ionos. Losses" W/S, Cell [D47:D50]
Rain Loss:	1,0	dB	This value should be estimated by the link model operator and place into Cell [B18]
Isotropic Signal Level at Ground Station:	-164,2	dBW	This is the signal level received at the Earth in the vacinity of the ground station using an omnidirectional antenna.
Ground Station (EbNo Method):			
------- Eb/No Method -------			
Ground Station Antenna Pointing Loss:	1,4	dB	This value is transferred from "Antenna Pointing Losses" W/S, Cell [K102]
Ground Station Antenna Gain:	35,7	dBi	This value is selected at "Antenna Gain" W/S, Cell [E58]
Ground Station Total Transmission Line Loss	0,7	dB	This value is transferred from the "Receivers" W/S, Cell [J123]
Ground Station Effective Noise Temperature:	390	K	This value is calculated in the "Receivers" W/S and Transferred from Cell [J138]
Ground Station Figure of Merrit (G/T):	9,1	dB/K	G/T = Ga-Ltl-10log(T_S). This is the uptimate measure of the receiver's performance.
G.S. Signal-to-Noise Power Density (S/No):	72,1	dBHz	Boltzman's Constant: -228,6 dBW/K/Hz
System Desired Data Rate:	2000000	bps	Operator selects this value. Be Careful! This is the data rate, not the symbol rate.
In dBHz:	63,0	dBHz	This is simply = 10log(R); R= data rate
Telemetry System Eb/No for the Downlink:	9,1	dB	
Demodulation Method Seleted:	QPSK		Values selected in "Modulation-Demodulation W/S, Cell [E30]
Forward Error Correction Coding Used:	LDPC+BCH (DVB-S2), R=1/4		Value selected in "Modulation-Demodulation" W/S, also Cell [E30]
System Allowed or Specified Bit-Error-Rate:	1,0E-06		The selected value is transferred from the "Modulation-Demodulation W/S, Cells [E33:E50]
Demodulator Implementation Loss:	1	dB	This value is transferred from the "Modulation-Demodulation W/S, Cell[E52]
Telemetry System Required Eb/No:	0,7	dB	The selected value is transferred from the "Modulation-Demodulation W/S, Cells [F33:F50]
Eb/No Threshold:	1,7	dB	This is the result of the "Modulation-Demodulation" W/S and is transferred from Cell [H32]
System Link Margin:	7,4	dB	

Link margin more than 7 dB – large 3 meter parabolic dish - communication since 5° will be possible with sufficient link margin to other unpredictable effects (link-budget-Sband_realistic_large-antenna).

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Resume

- rough calculations without details lead to overly optimistic results
  - cables and connectors are not perfect (attenuation and increase of thermal noise)
  - impedance matching of antennas is not perfect (RF signal reflection)
  - radiation diagram of antenna is not perfect (side lobes – reception of terrestrial noise)
  - pointing of antenna of satellite toward the ground station is not perfect (if any)
  - pointing of antenna of ground station toward the satellite is not perfect
  - polarizations of both antennas are not perfect (polarization loss)
  - weather is not perfect (humidity, rain – increase in attenuation and noise temperature)
  - atmosphere has gasses with attenuation dependend on frequency and signal path length
  - implementation of receiver (synchronization, demodulation, FEC decoding) is not perfect
  - outdoor RF equipment ages due to humidity, vibration, irradiation, thermal stress
  - man-made noise floor can vary dramatically, especially in urban area
- high gain antennas are not trouble-less solution
  - high gain antenna on the satellite side requires proper functionality of ADCS
  - high gain antenna on the ground station side requires precise and heavy duty antenna rotator
  - large parabolic dish has lower efficiency due to shape inaccuracies

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Home exercise 1

Simulation of 4 element collinear antenna and calculation of theoretical range of one-way communication between satellite with monopole antenna and ground station with collinear antenna.

- Design 4 elements collinear antenna array and monopole antenna. Simulate their radiation patterns and antenna gains.
- Try to use the same set-up as in example, only modify antennas on both sides and try to recalculate theoretically achievable data rate if the satellite is just above horizon (elevation near to 0°) and antennas are properly pointed.

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Home exercise 2

Simulation of planar 4x4 elements antenna array and calculation of theoretical range of one-way communication between satellite with monopole antenna and ground station with planar antenna.

- Design 4x4 elements planar antenna array and monopole antenna. Simulate their radiation patterns and antenna gains.
- Try to use the same set-up as in example, only modify antennas on both sides and try to re-calculate theoretically achievable data rate if the satellite is just above horizon (elevation near to 0°) and antennas are properly pointed.

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Home exercise 3

Simulation of 2.4 GHz one-way Lora link from the spacecraft with monopole antenna on the Moon surface and ground station with parabolic dish

- Find parameters of Lora communication modules and select the most robust communication format. Try to fill link budget calculator.
- What gain of the ground parabolic dish you need to establish link with minimal supported data rate of Lora module?

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