Earth Observation Telescope at L2 Final Report

Communications

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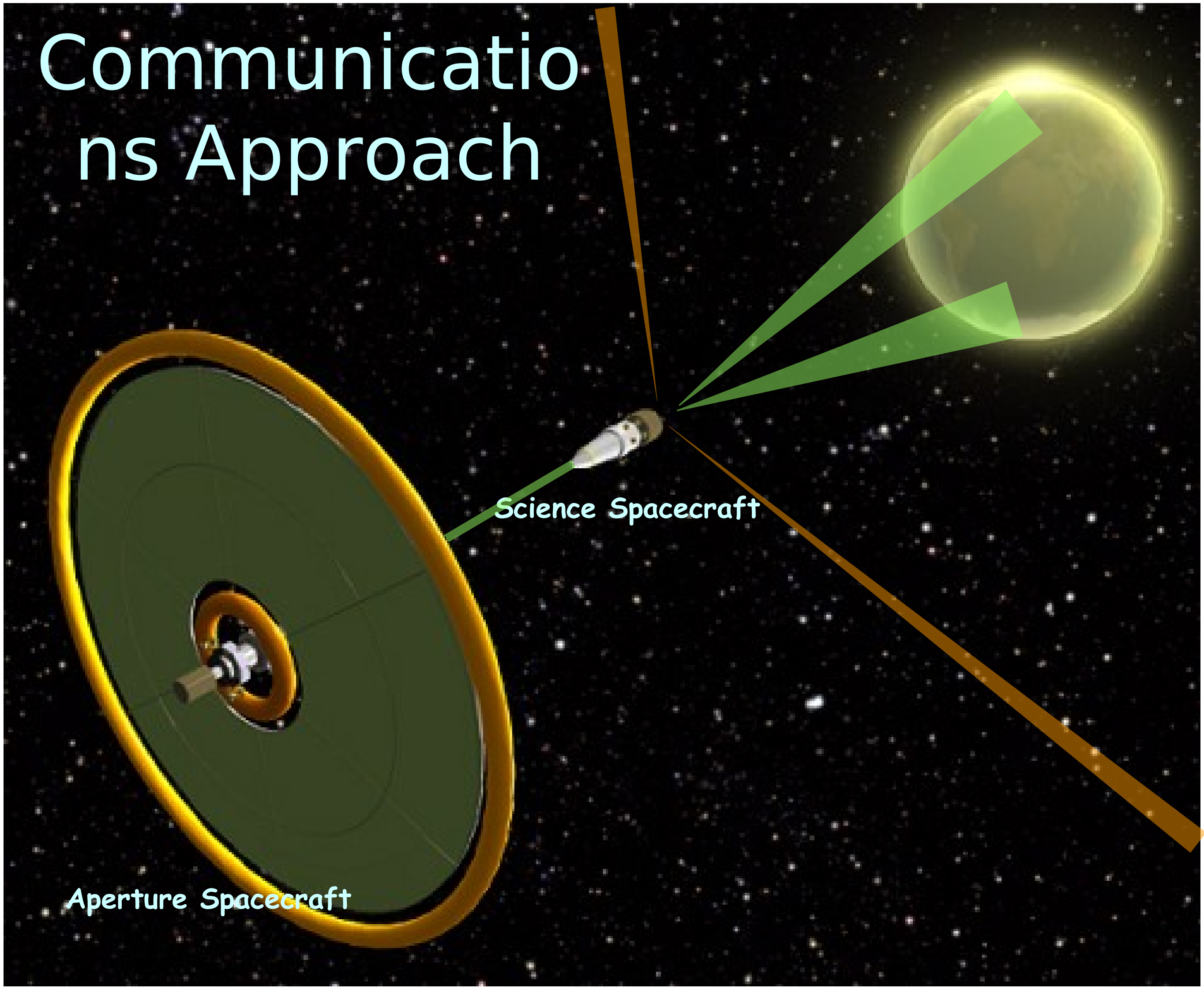
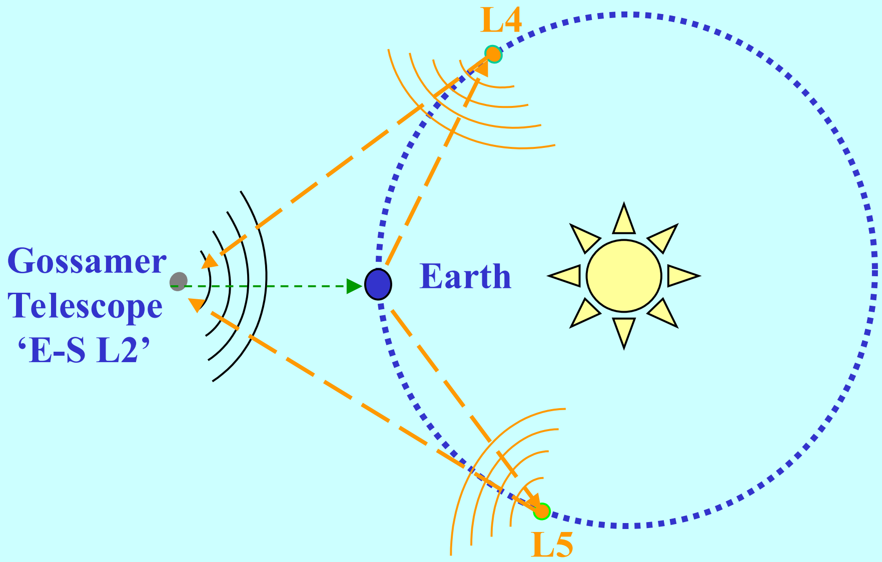
Earth-Sun L2 Gossamer Telescope



"Earth-Sun L2 Gossamer Telescope" Communications Architecture



ELEMENTS:

Aperture Spacecraft Communications

Science S/C Communications

Earth L4/L5 relay

Ground Stations@
Svalbard, Norway
McMurdo, Antarctic

Communications Overview

- Baseline option for Communications: Primarily for Science Spacecraft
  - (A) S-band Uplink / X-band downlink
    - S-Band transmit to S/C from Earth via Earth L4/L5 relay; X-Band science telemetry transmit to Earth stations at McMurdo, Antarctic *and* Svalbard, Norway

      Issues: (1) Data rate limited to 110 Mbps (*QPSK*) for X-band downlink

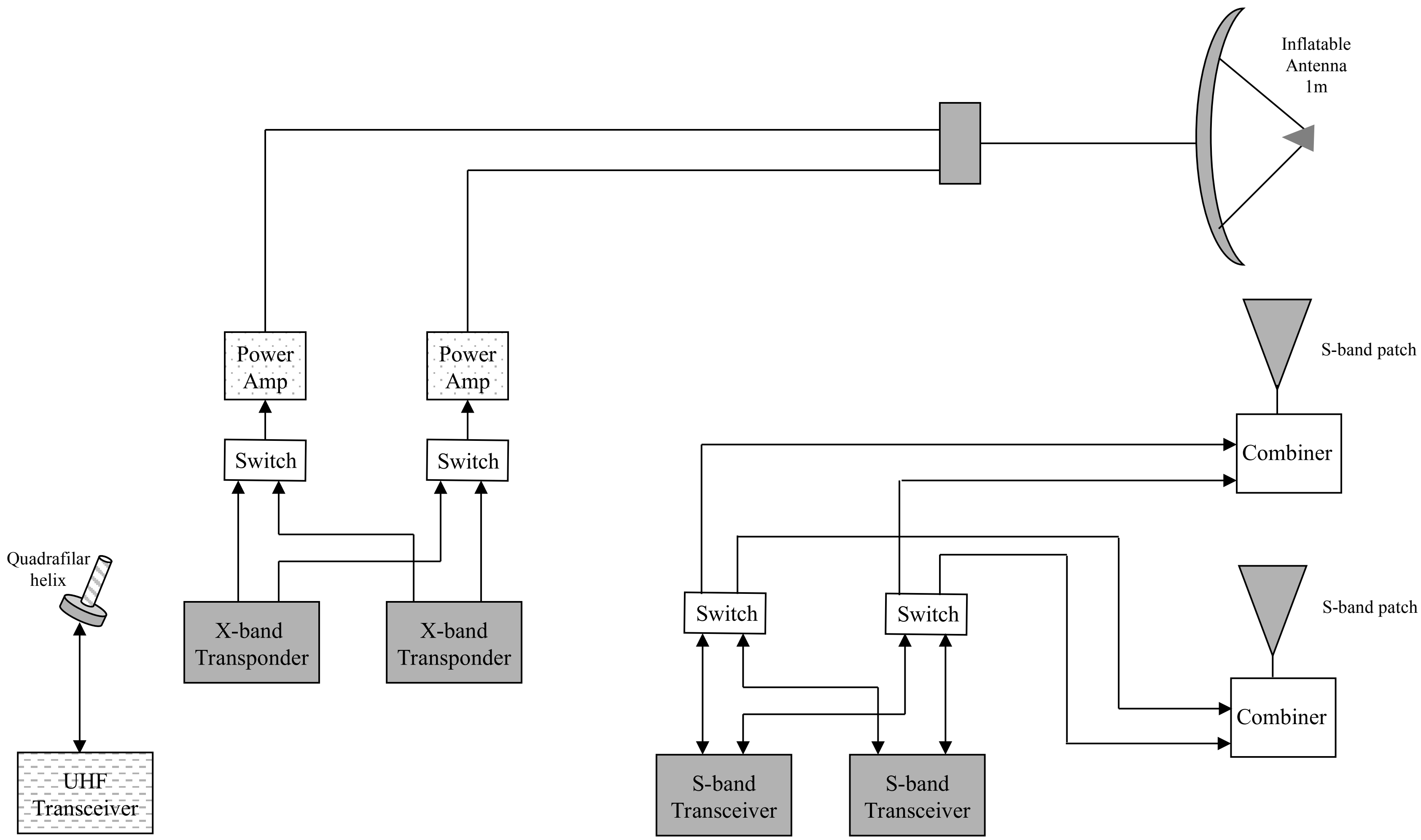
      (2) Coverage per site varies on seasonal variation of Earth w.r.t E-S L2

      (3) Placement of Relay Spacecraft at Earth L4 or L5 points for command uplink; can be alternately used for low rate telemetry off-loading and connection to DSN
    - UHF Crosslink to Aperture Spacecraft for command and position data transfers
- Baseline option for Communications: Aperture Spacecraft
  - (A) S-band Uplink & Downlink
    - S-Band transmit to S/C from Earth L4/L5 relay
  - (B) UHF Crosslink to science spacecraft
    - Crosslink for position and spacecraft Health and Status

Communications Overview
Primary Science Spacecraft

- Baseline Comm Approach
  - 1 meter inflatable antenna (.53kg/m^2), including feed; add gimbal
  - X-Band telemetry transceiver (QPSK modulation, operating at ~100 MBPS)
    - 100 Watt X-band RF Power Amplifier, ~ 50% efficiency) = 200Watts of Power
  - S-Band transceiver for commands and health/status telemetry
    - 3 watt RF output --> requires about 15 watts
    - S-band patch dipole antenna (two) for coverage
  - UHF transponder for crosslink communications with secondary Aperture spacecraft
    - 110-200 Milliwatt transmit power
    - Total of ~ 15 Watts of power
    - Quadrafilar Helix antenna
  - Telemetry ground stations at SvalBard, Norway and McMurdo, Antarctica
    - X-Band Antennas (11.3 m and 10m respectively, dual X,S capability)
    - Command transmission to Spacecraft directly (during transit) and via Earth L4/L5 relay(s) during operations.
    - X-band QPSK reception @ 50 Msps; effective data rate of 100 Mbps

Communications Overview
Primary Science Spacecraft



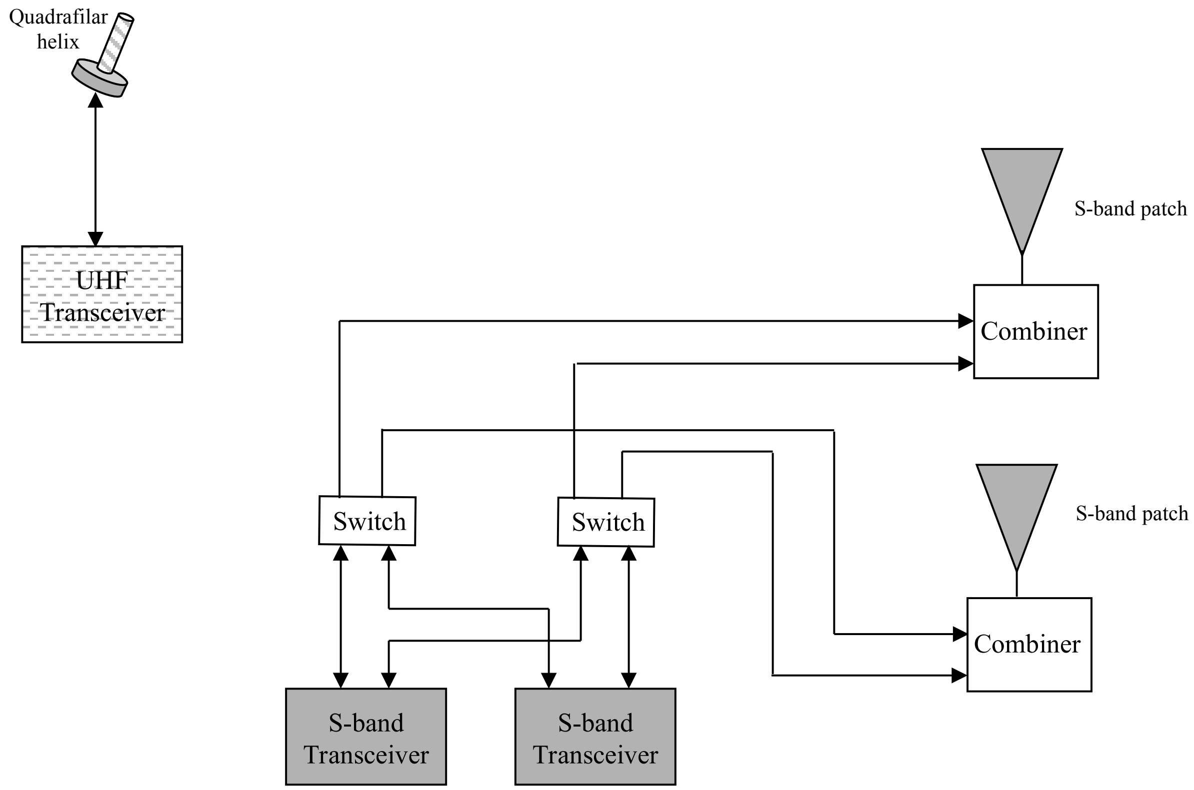
Science Spacecraft Communications

- Fully redundant (two strings shown)
- Inflatable Antenna technology
- Microwave Patch antenna technology
- Advanced Transceiver and Transponder technology
- Advanced modulation and coding

Communications Overview
Secondary Aperture Spacecraft

- Baseline Comm Approach
  - S-Band transceiver for commands and health/status telemetry
    - 3 watt RF output --> requires about 15 watts
    - S-band patch dipole antenna (two) for coverage
  - UHF transponder for crosslink communications with primary science spacecraft
    - Milliwatt transmit power
    - Total of ~ 15 Watts of power
    - Quadrafilar Helix antenna
  - Ground Stations at SvalBard, Norway and McMurdo, Antarctica
    - S-Band Antennas (11.3 m and 10m respectively) for commanding
    - Transmission to Spacecraft directly (during transit) and via Earth L4/L5 relay during operations (if necessary).

Communications Overview
Secondary Aperture Spacecraft



Aperture Spacecraft Communications

- Scaled down from science spacecraft reusing major components
- Fully redundant (two strings shown) S-band
- Microwave Patch antenna technology
- Advanced Transceiver technology
- Advanced Helical Antenna technology
- Advanced modulation and coding

System Design Drivers

- Available Power for Communications System on the Science spacecraft
- Available coverage time allowed for Ground Station usage (Svalbard & McMurdo)
- Technology achievement and usage of inflatable antennas (3 meter dia. For example)
- True throughput daily data allocation
- Navigation and pointing accuracy of co-located spacecraft at L2

Science Spacecraft Communications

- Mass and power can be reduced in the future

CBE

System	Quan-tity	Total Mass CBE (kg)	Average Power CBE (W)	Peak Power CBE (W)	Comments
Power Amplifier	2	6	65	200	100 Watt Tx Power
X-Band telemetry transceiver	2	6	12	18	
1 meter inflatable antenna and gimbal	1	2	0	0	(.53kg/m^2), including feed)
S-Band transceiver	2	6	6	15	for commands and health/status telemetry
S-band patch dipole antenna	2	1	0	0	For full coverage on uplink
UHF transponder	2	6	6	15	for crosslink communications with aperture spacecraft
Misc. Cables, switches,components	1	10	0	0	To allow redundant crossover communications capability -- (S-band, UHF and X-Band)
Quadrafilar UHF Helix antenna	1	8	0	0	
Totals		44	89	248	

Future

System	Quan-tity	Total Mass CBE (kg)	Average Power CBE (W)	Peak Power CBE (W)	Future readiness
Power Amplifier	2	3	40	125	2025
X-Band telemetry transceiver	2	3	6	9	2025
1 meter inflatable antenna and gimbal	1	2	0	0	2020
S-Band transceiver	2	3	3	7.5	
S-band patch dipole antenna	2	1	0	0	2012
UHF transponder	2	3	3	7.5	
Misc. Cables, switches,components	1	5	0	0.0	2012
Quadrafilar UHF Helix antenna	1	6	0	0	2020
Totals		26	52	149	

Aperture Spacecraft Communications

- Mass and power can be reduced in the future

CBE

System	Quan-tity	Total Mass CBE (kg)	Average Power CBE (W)	Peak Power CBE (W)	Comments
S-Band transceiver	2	6	6	15	for commands and health/status telemetry
S-band patch dipole antenna	2	1	0	0	For full coverage on uplink
UHF transponder	2	6	6	15	for crosslink communications with aperture spacecraft
Quadrafilar UHF Helix antenna	1	8	0	0	To allow redundant crossover communications capability -- (S-band, UHF and X-Band)
Misc. Cables, switches,components	1	10	0	0	
Totals		31	12	30	

Future

System	Quan-tity	Total Mass CBE (kg)	Average Power CBE (W)	Peak Power CBE (W)	Future Readiness
S-Band transceiver	2	3	3	7.5	2012
S-band patch dipole antenna	2	1	0	0	2012
UHF transponder	2	3	3	7.5	2012
Quadrafilar UHF Helix antenna	1	5	0	0	2012
Misc. Cables, switches,components	1	10	0	0	
Totals		22	6	15	

Coverage Analysis (DTE)

S/C Tx Power versus data rate Performance estimates

Earth-Sun L2 Gossamer Telescope to Earth Ground Stations				
Earth 70m DSN	Svalbard & McMurdo		Data Rate	Link Margin
	Power w/11.3m dish	Power w/10m dish	(Mbps)	(dB)
1watt	100 watt	100 watt	100	> 3.0
4watt	25 watt	25 watt	400	> 3.0
5watt			500	>= 3.0
10watt			1000	3.2
15watt			1500	3.2
20watt			2000	3.2

X-Band range (1watt row)

Ka Band range (4watt–5watt rows)

Rates may transition the move towards Optical Comms (10watt–20watt rows)

2.9×10^{12} bits per day = 100 Mbps @ 485 minutes/day — BASELINE Telemetry

***Approximately 8.1 hours per day, scheduled between two ground stations**

OR 40 Mbps @ 1215 minutes/day **(~ 24/7)**

130×10^{12} bits per day = 1.5 Gbps @ 1440 minutes/day

3.0 Gbps @ 720 minutes/day

$32.5^{*} \times 10^{12}$ bits per day = 375 Mbps @ 1440 minutes/day

750 Mbps @ 720 minutes/day

Optical Communications via TDRS-C derivative

* 4:1 compression

Science telemetry performance analysis

Daily baseline science data:

- ~ 2.9 $x10^{12}$ bits per day ; includes compression, Reed-Solomon, and telemetry format coding

Baseline Science Spacecraft telemetry communications:

- X-band (Earth Science) allocation for telemetry transmission
- 100 Watt Solid State RF Power Amplifier
- QPSK modulation @ 50 Msps = effective data rate (I+Q) of 100Mbps
- ≥ 3 dB link margin; .81 Eb/No; Mod Index 1.1; R-S FEC; BER 10^{-6}
- Downlink opportunities at Svalbard, Norway & McMurdo, Antarctica
- Use of 1 meter (dia.) Inflatable antenna technology on S/C
- Requires ~ 8.1 hours per day to ground station telemetry receivers

Ground Stations: Svalbard, Norway (11.3m antenna) & McMurdo, Antarctica (10m antenna)

- Seasonal variation gives up to 16 hours of daily ground station(s) coverage time
- Missed ground station contacts can be accommodated by increase in time on successive days

Future System Trades

- Ground Station usage versus "reality" to use GEO Relay Spacecraft
- Optical communications capability & S/C impacts versus RF
- Necessity of Earth L4 or L5 Relay for command uplink
  - What are the absolute issues of very small E-(S/C)-S angles for transmissions from Earth
- Use the Primary 25m mirror as a supplemental communications antenna?

Issues

- Frequency Spectrum management policy predictions for missions in 2020-2030 timeframe
- Burden of costs to implement relay spacecraft assets
- Interference of signals (RF or Optical) on Earth as L2 spacecraft transmits to GEO relays
- “SlowBoat” progress of NASA towards implementing changes to how things are done today
- Inflatable antenna technology maturation and implementation in Space communications
- Lower mass, higher power handling communications components
- Gimbaled antenna usage on Science spacecraft

Technology Roadmaps

Main advancements in technologies required for Communications

- Antennas
  - Inflatable X-band/Ka-band
  - Microstrip patch (S-band)
- Transponders
  - Micro-miniature electronics
- Transceivers
  - Comms on a chip
  - Low threshold reception
- Power Amplifiers
  - 50-70 % efficiency
- Packaging
  - Reduced mass & volume
  - Power dissipation capability
- Modulation/Coding
  - Advanced Eb/No thresholds
  - Very Low BER coding

Communications Roadmap

Mission?

Mission?

Mission?

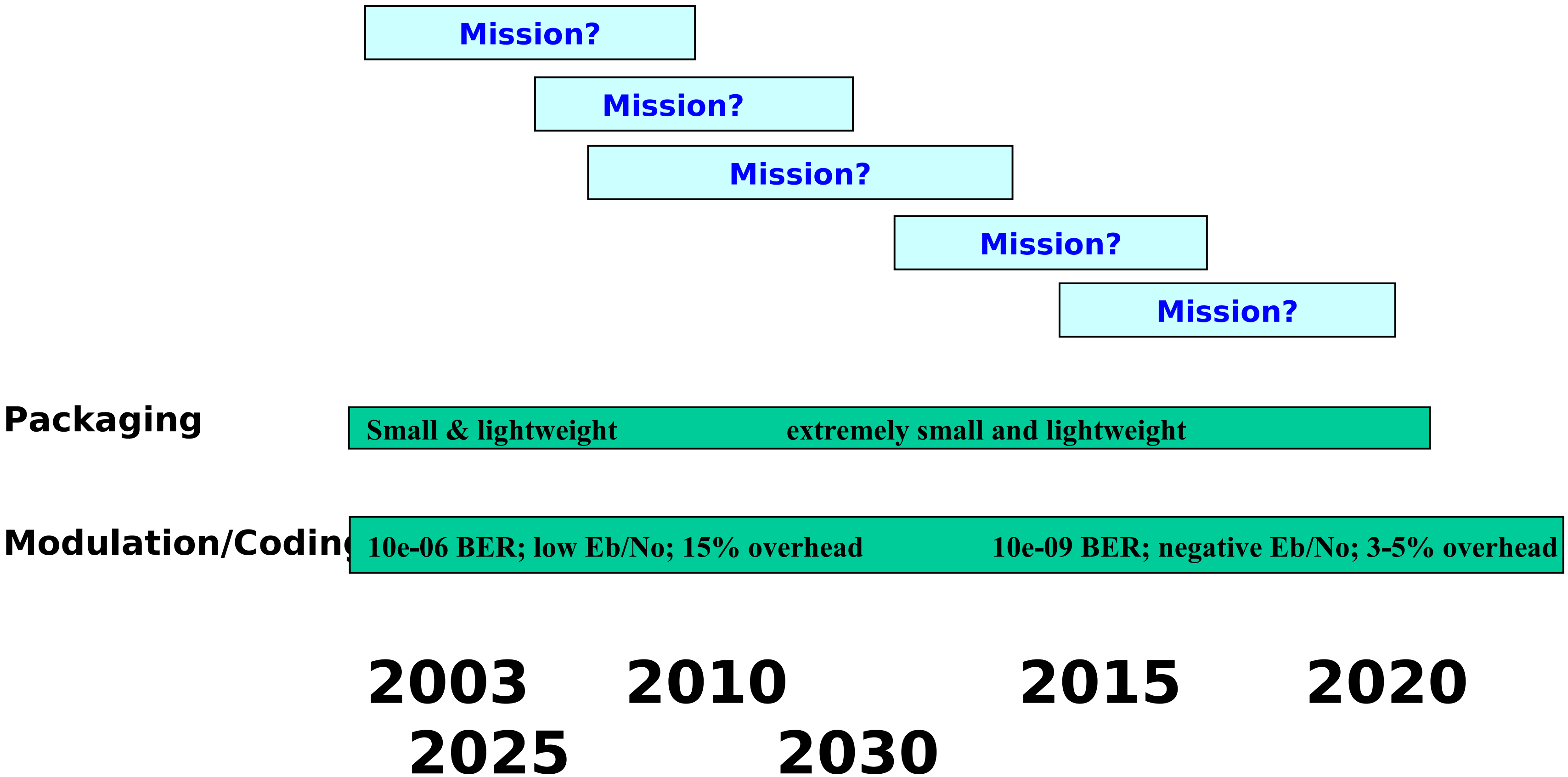
Mission?

Mission?

Antennas	Parabolic/omnis — Inflatables (rigid) /patches
Transponders	Medium mass / Power — Very Low Mass/Power
Transceivers	Medium mass/ Power; miniature electronics — Very Low Mass/Power; sub-micro miniature electronics
Power Amplifiers	30-40% efficient (100W) — 50-70% efficient (100+ Watts)

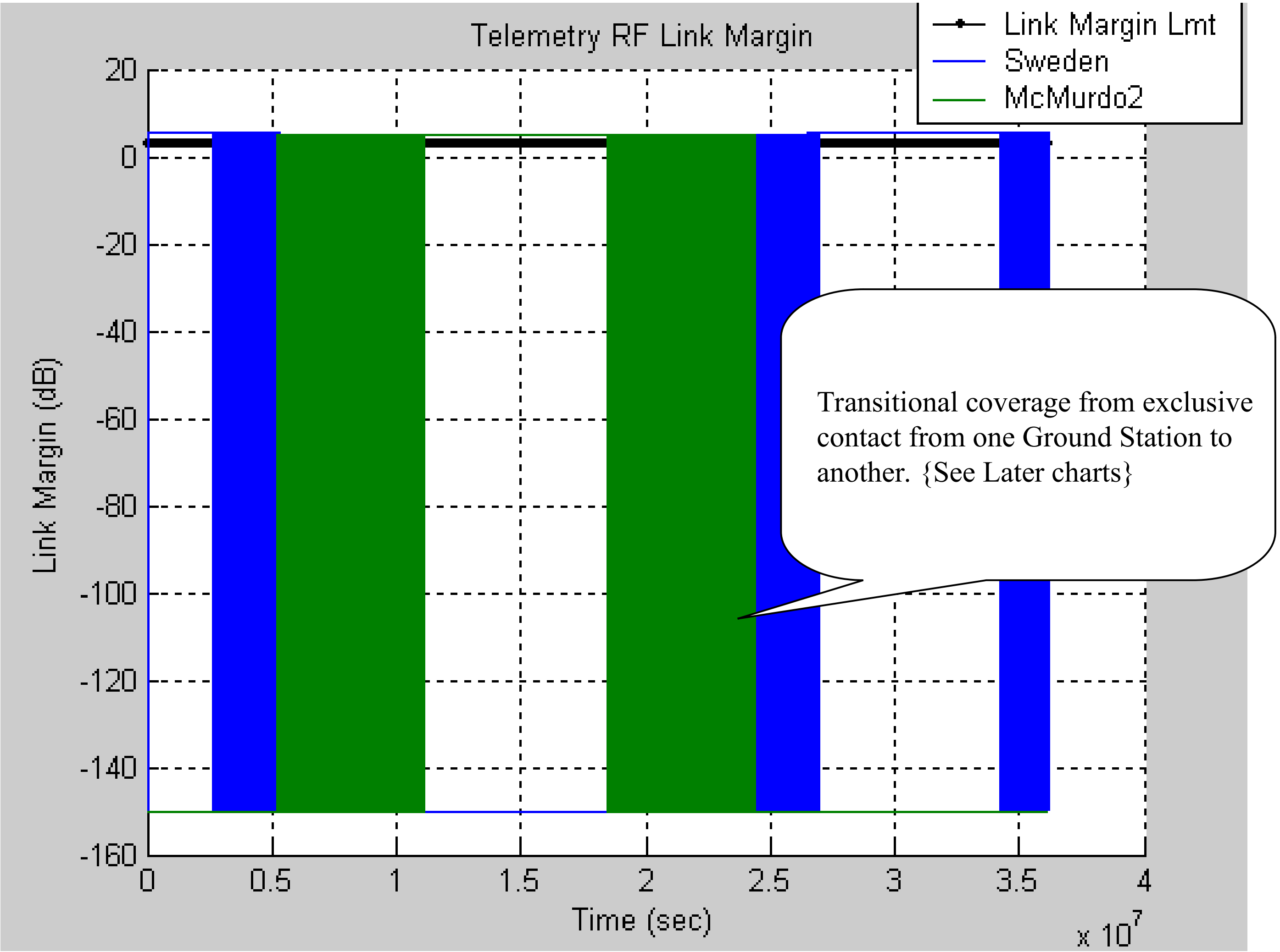
2003 2010 2015 2020 2025 2030

Communications Roadmap



Backup

Coverage and Link Margins



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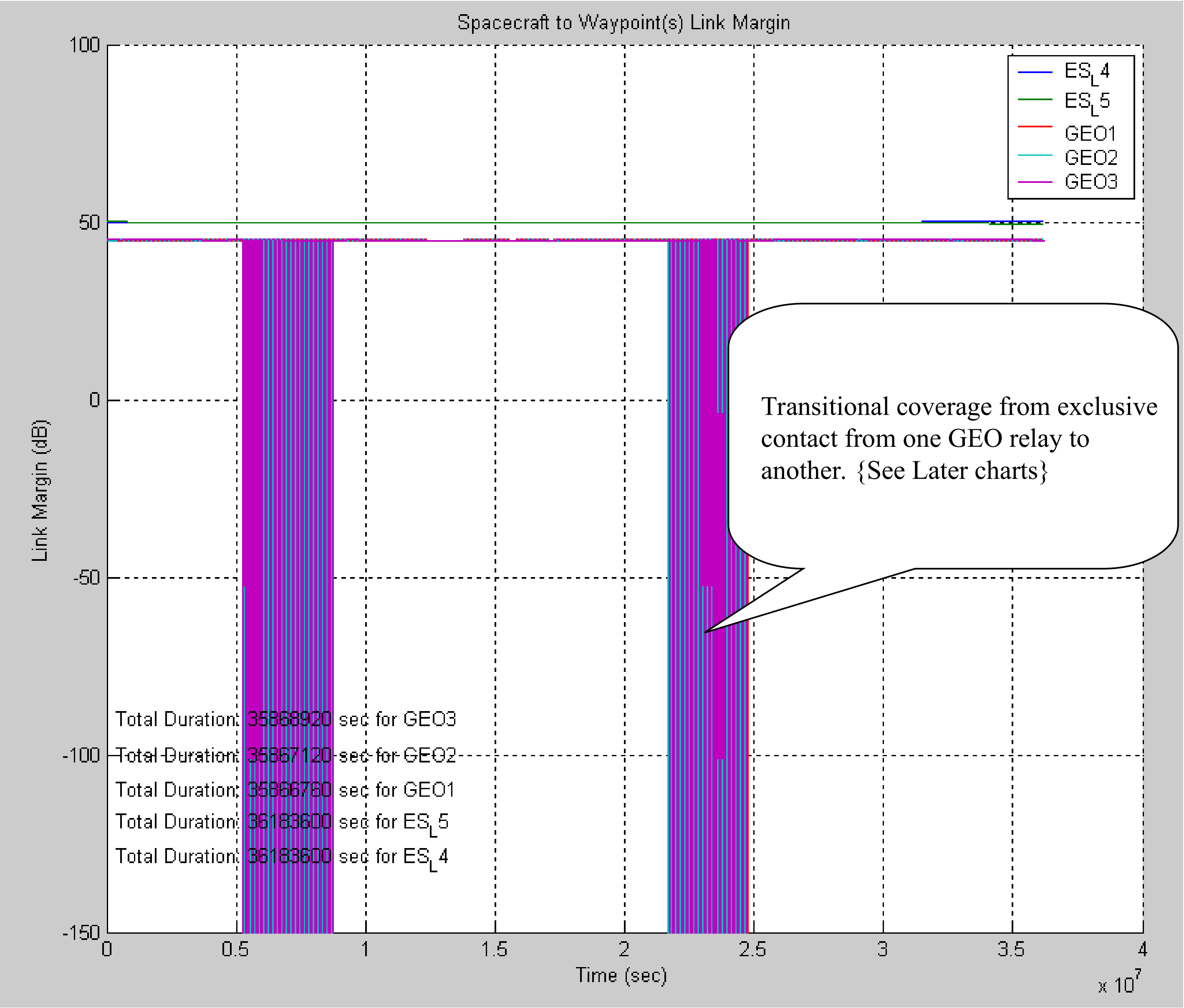

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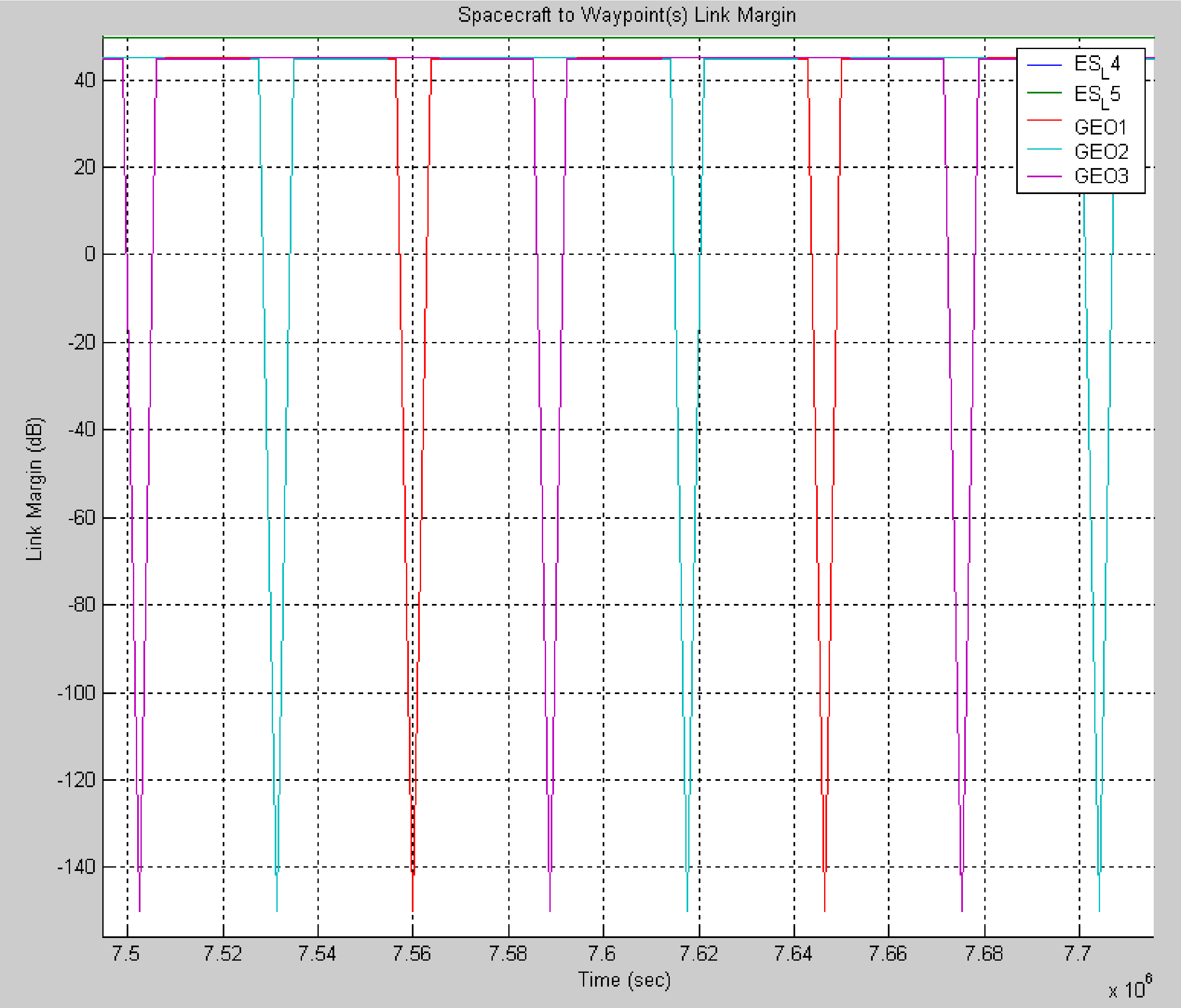

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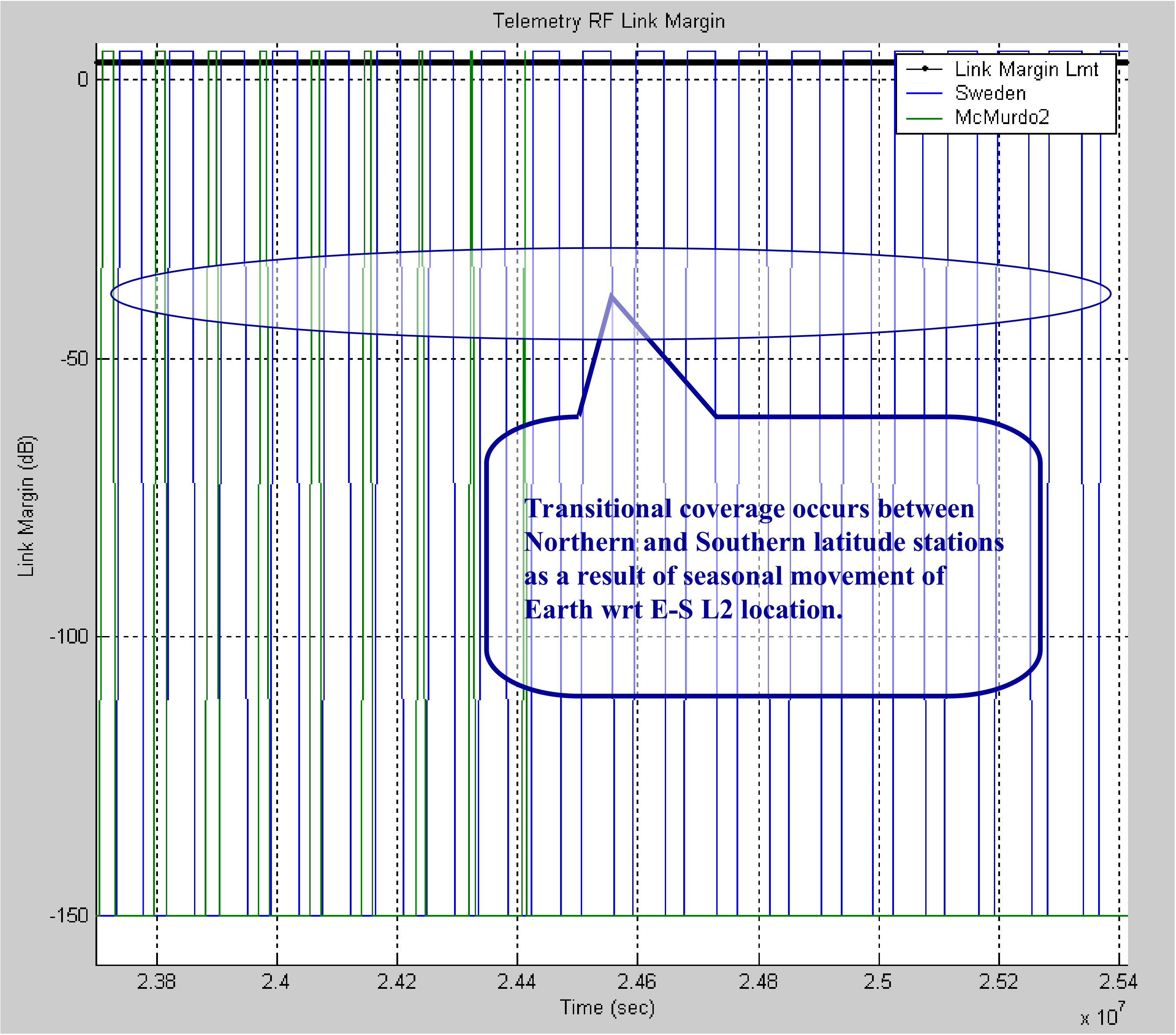

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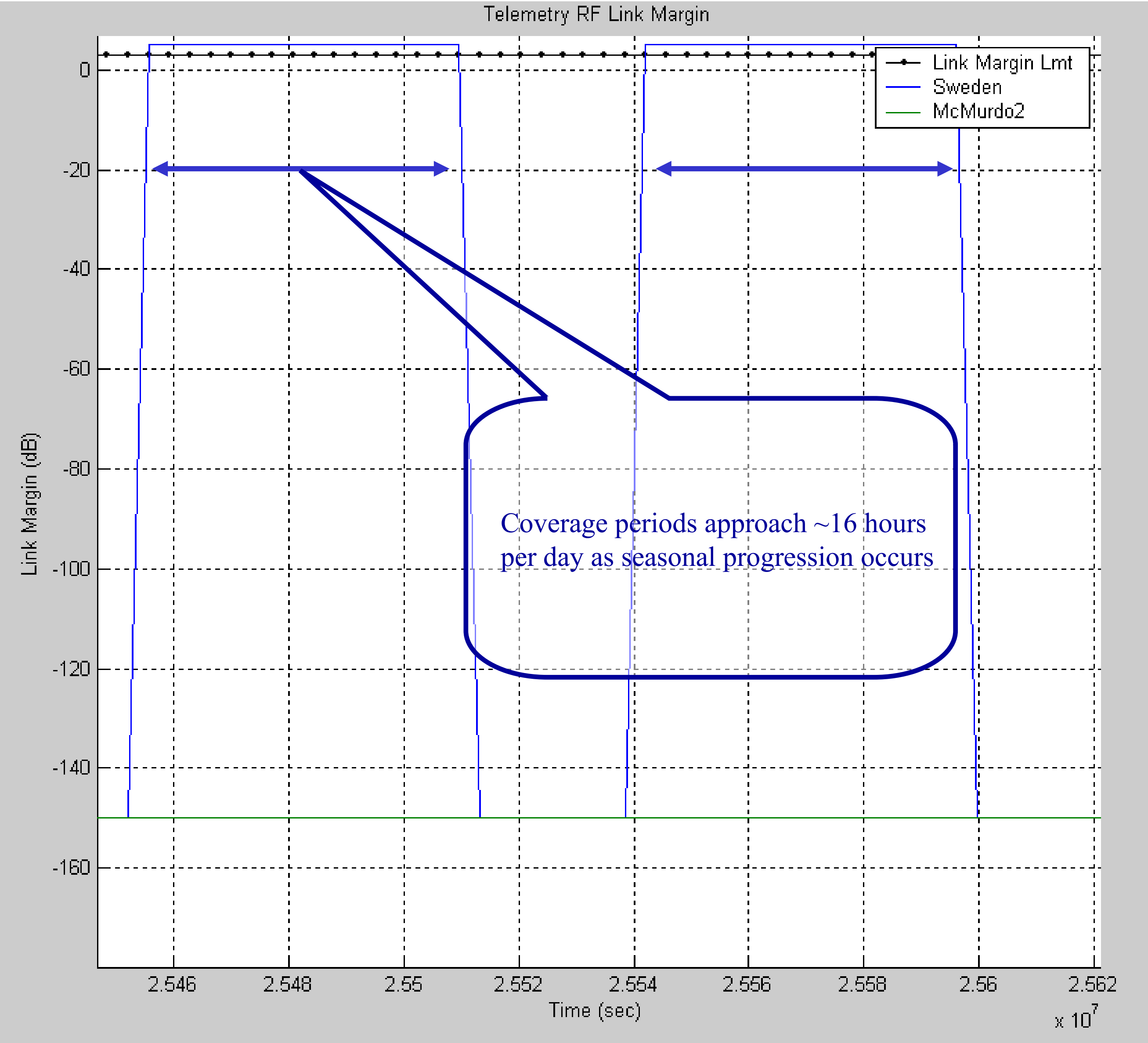

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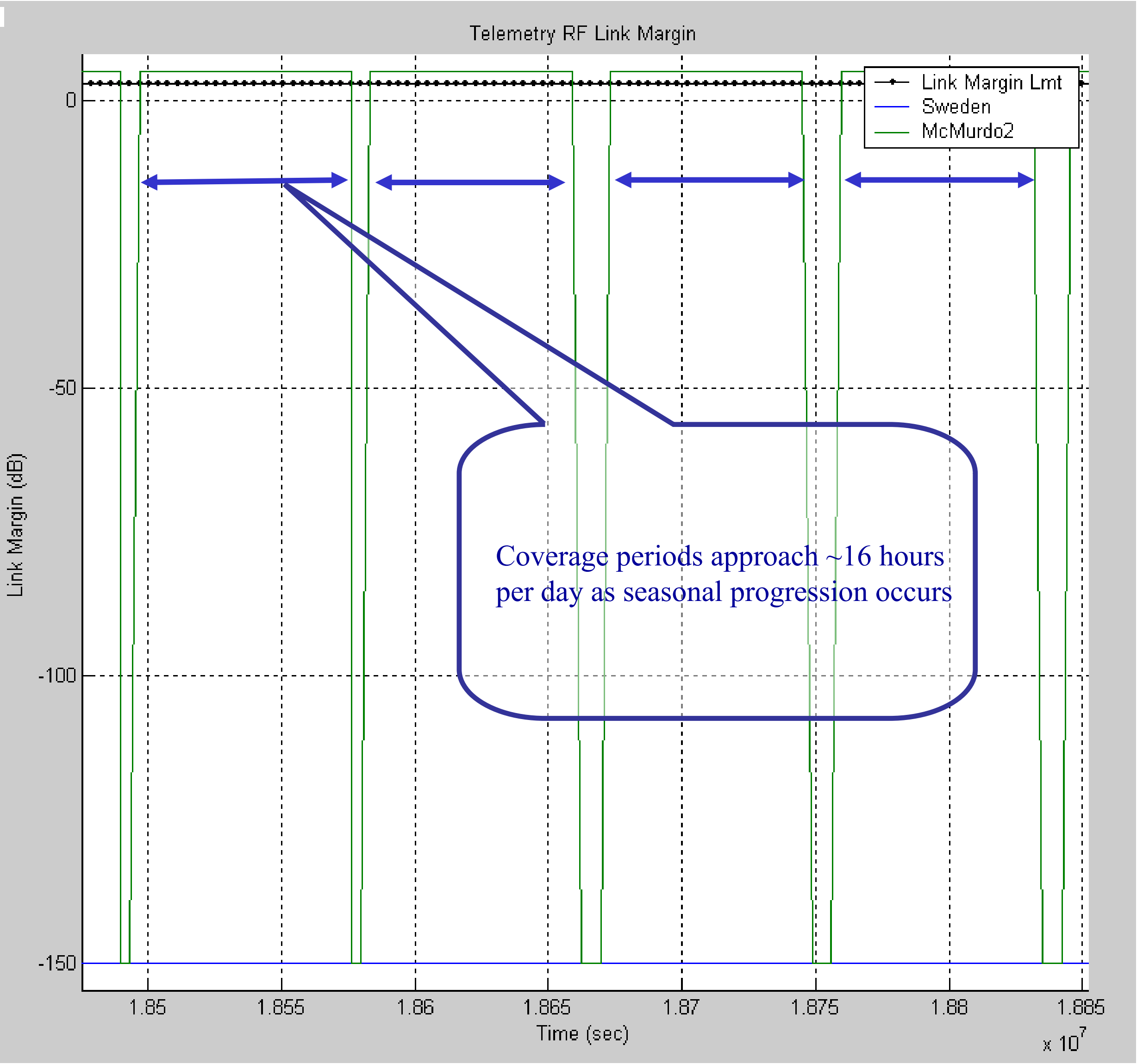
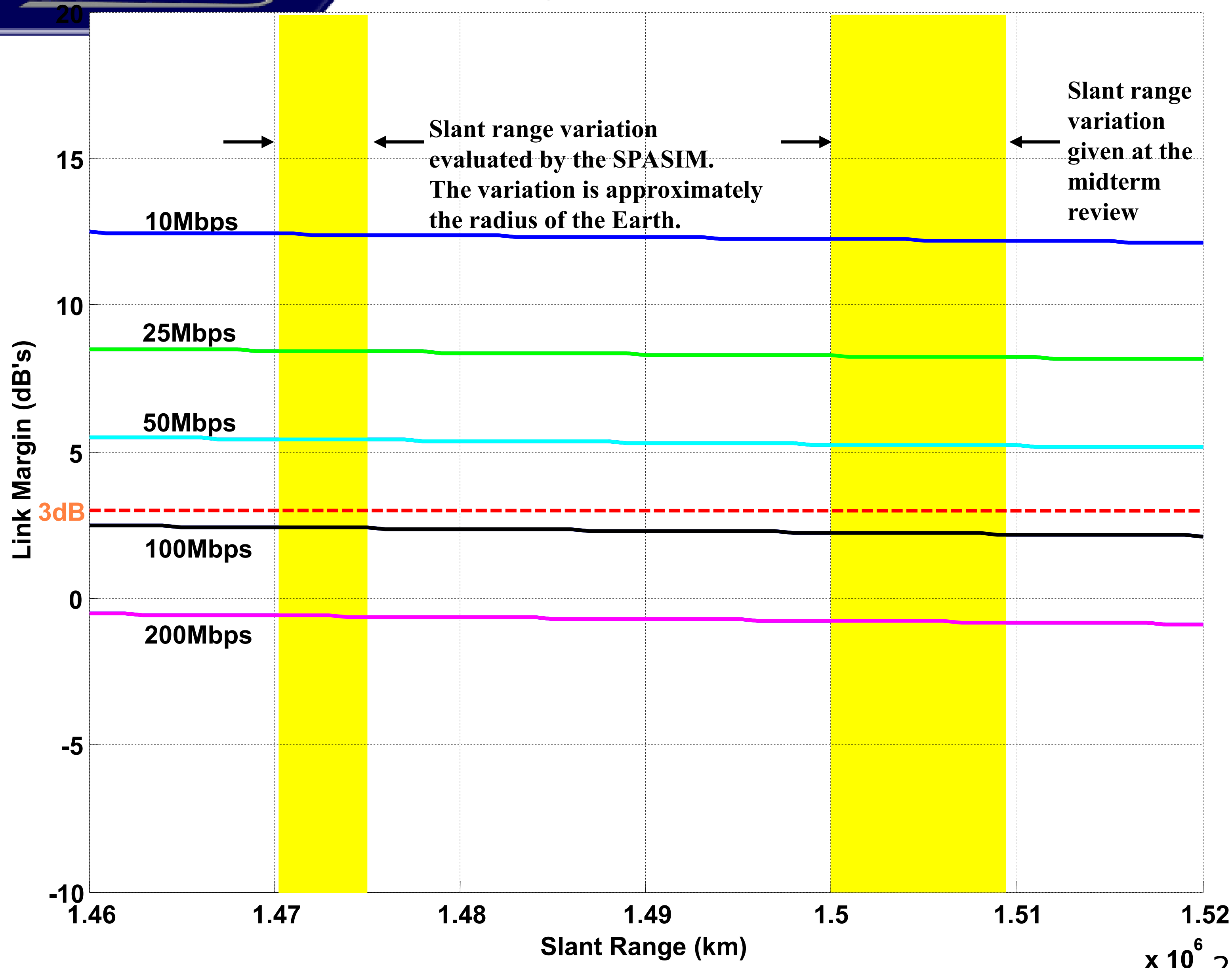
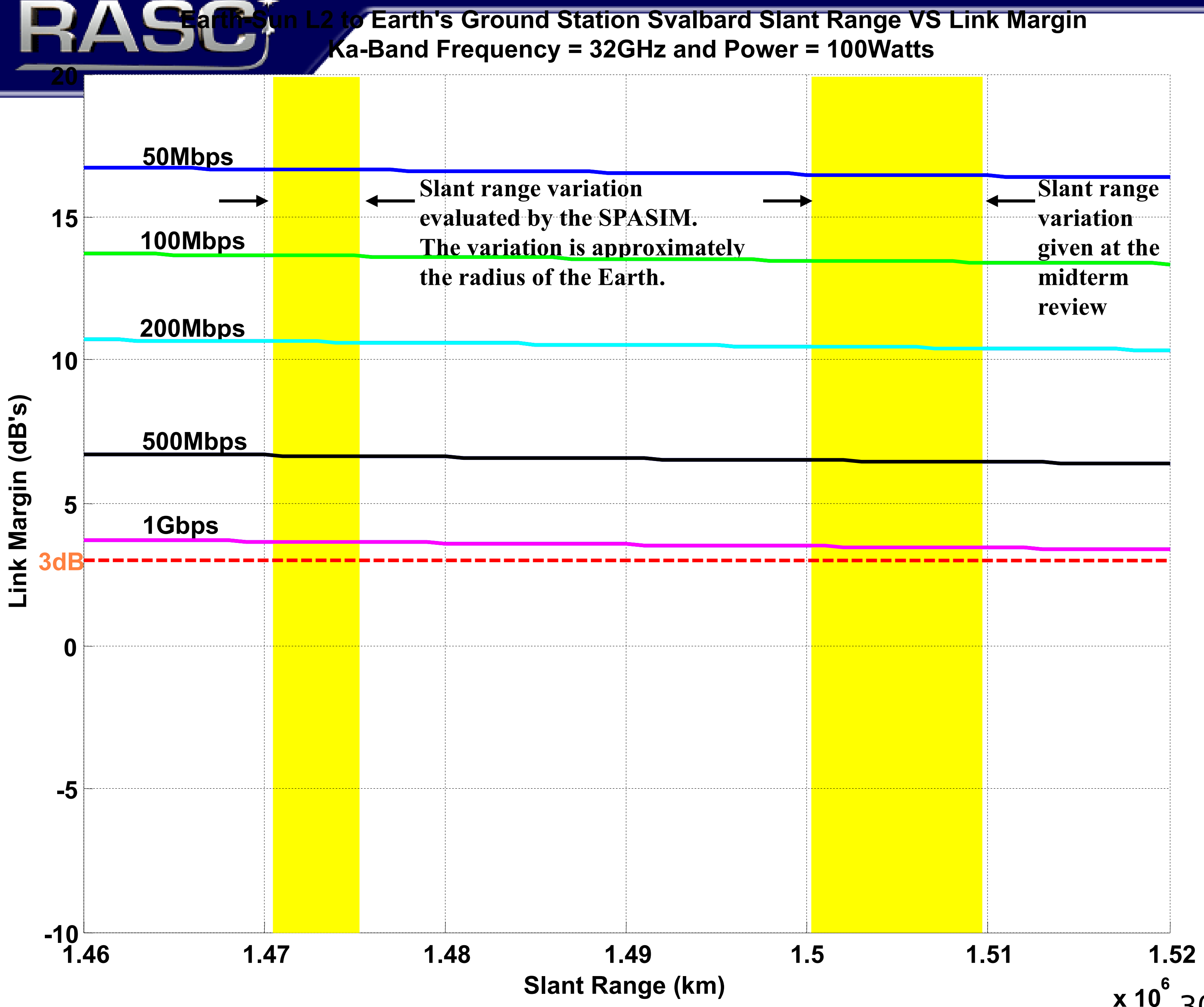


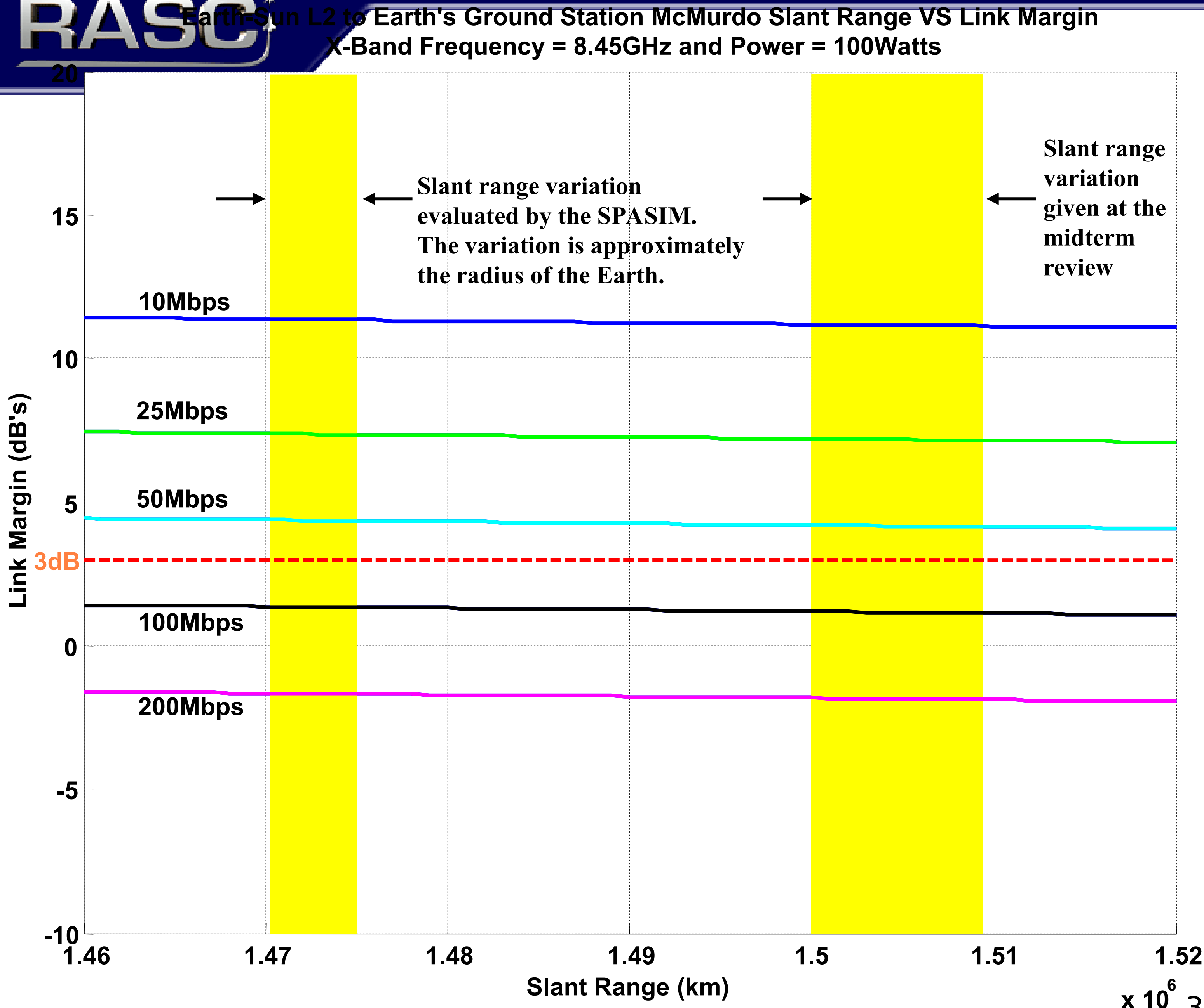
Fixed Comm Parameters	
E-S L2 Spacecraft Transmission Parameters	
Antenna Diameter	1m
Antenna Type	Dish
Line Losses	1dB
Modulation Index	1.1rad
Transmit Gain (X/Ka-Band)	36.4/48dBi
E-S L2 Spacecraft Receiver Parameters	
Sensitivity	-100dBm
Antenna Diameter	1m
Antenna Type	Dish
Receiver Gain (Ka-Band)	47.5dBi
Ant. System Noise Temp	350ºK
Antenna Pointing Error	1dB
Modulation Index	1.1rad
Earth's Ground Station Svalbard Parameters	
TX/RX Antenna Diameter	11.3m
Receiver Gain (X/Ka-Band)	57.4/69dBi
Transmit Gain (Ka-Band)	69.6dBi
RX System Noise Temp	160ºK
TX/RX Line Losses	1dB
WP Receive Reqd Eb/No	.81dB
WP Transmit Reqd Eb/No	2.2dB

Earth-Sun L2 to Earth's Ground Station Svalbard Slant Range VS Link Margin
X-Band Frequency = 8.45GHz and Power = 100Watts




Earth-Sun L2 to Earth's Ground Station Svalbard Slant Range VS Link Margin
Ka-Band Frequency = 32GHz and Power = 100Watts
50Mbps
100Mbps
200Mbps
500Mbps
1Gbps
3dB
Slant range variation evaluated by the SPASIM. The variation is approximately the radius of the Earth.
Slant range variation given at the midterm review
Link Margin (dB's)
Slant Range (km)
x 10^6
20
15
10
5
0
-5
-10
1.46
1.47
1.48
1.49
1.5
1.51
1.52

Fixed Comm Parameters	
E-S L2 Spacecraft Transmission Parameters	
Antenna Diameter	1m
Antenna Type	Dish
Line Losses	1dB
Modulation Index	1.1rad
Transmit Gain (X/Ka-Band)	36.4/48dBi
E-S L2 Spacecraft Receiver Parameters	
Sensitivity	-100dBm
Antenna Diameter	1m
Antenna Type	Dish
Receiver Gain (Ka-Band)	47.5dBi
Ant. System Noise Temp	350ºK
Antenna Pointing Error	1dB
Modulation Index	1.1rad
Earth's Ground Station McMurdo Parameters	
TX/RX Antenna Diameter	10m
Receiver Gain (X/Ka-Band)	56.3/67.9dBi
Transmit Gain (Ka-Band)	68.5dBi
RX System Noise Temp	160ºK
TX/RX Line Losses	1dB
WP Receive Reqd Eb/No	.81dB
WP Transmit Reqd Eb/No	2.2dB


Earth-Sun L2 to Earth's Ground Station McMurdo Slant Range VS Link Margin
X-Band Frequency = 8.45GHz and Power = 100Watts
Slant range variation evaluated by the SPASIM. The variation is approximately the radius of the Earth.
Slant range variation given at the midterm review
10Mbps
25Mbps
50Mbps
3dB
100Mbps
200Mbps
Link Margin (dB's)
Slant Range (km)
x 10^6
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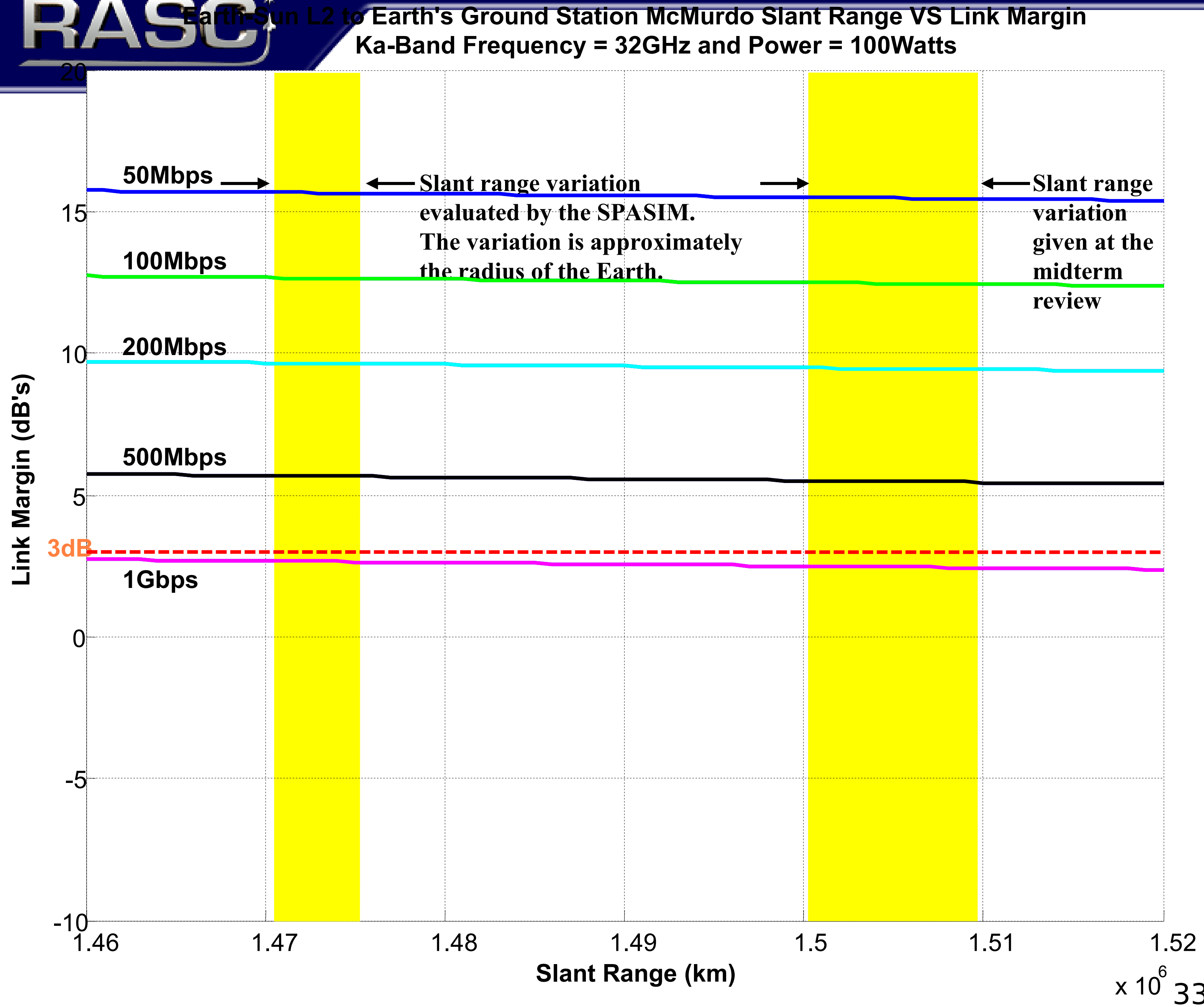
Earth-Sun L2 to Earth's Ground Station McMurdo Slant Range VS Link Margin
Ka-Band Frequency = 32GHz and Power = 100Watts
Link Margin (dB's)
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