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Proximity Link Design and Performance Options for a Mars Areostationary Relay Satellite

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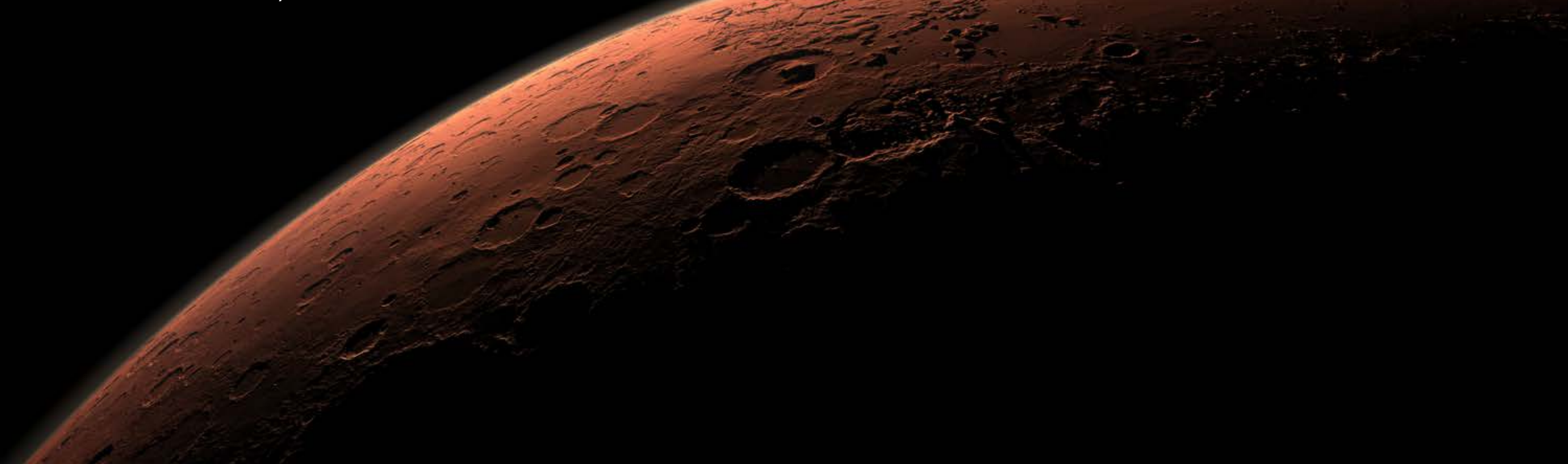


Outline

- Introduction
- Current Mars Relay Network Architecture
- Relay From Mars Areostationary Orbit
- Relay Link Design and Performance Options
  - RF
  - Optical
- Additional Relay Service Considerations
- Conclusion

Key Characteristics of Current Mars Relay Orbiters

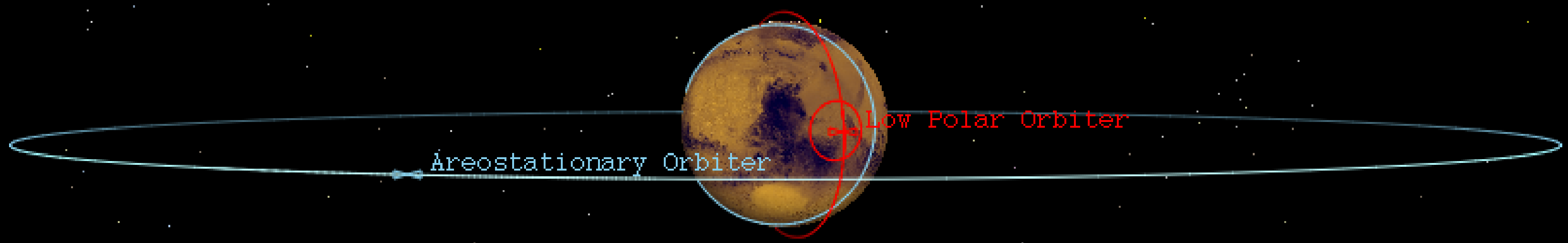
- Hybrid science-relay orbiters
- Simple omnidirectional UHF proximity links
- Short, intermittent contacts
- Instantaneous data rates up to 2 Mb/s

	ODY	MEX	MRO	MAVEN	ExoMars/TGO
Orbit	390x460 km i=93 deg	365x10,500 km i=87 deg	250x320 km i=93 deg	150x6200 km i=74 deg	400 km circular i=74 deg
Avg Contacts/Sol[1]	2.6	2.0	2.1	2.5	2.6
Avg Pass Duration (min)	9	124	7	81	10
Max Gap Time (hrs)	12.7	25.1	26.0	21.0	12.7
Avg Data Return[2] (Mb/sol)	111	83	327	177	587

[1]Contact statistics shown for Curiosity rover at Gale Crater site (4.5 deg S Latitude), assuming a 10 deg elevation mask.
[2]Data return based on best two passes per sol (if available), with each pass constrained to 30-min maximum duration. Link model includes 3 dB link margin.

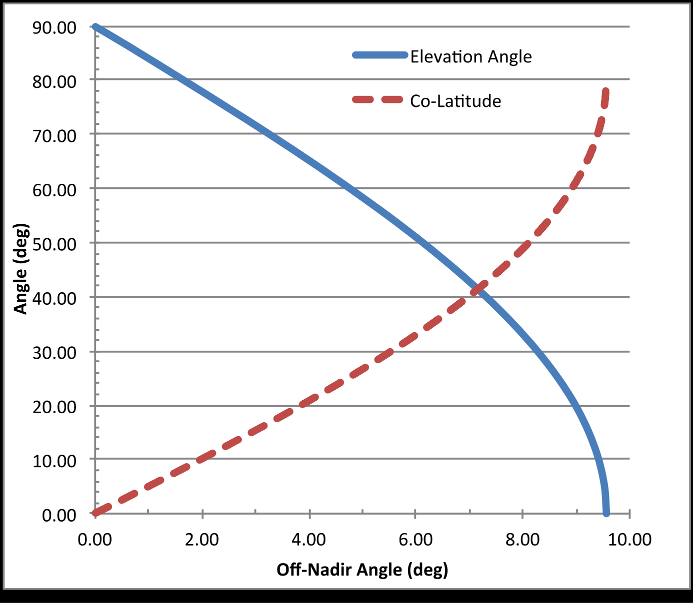
Areostationary Orbit

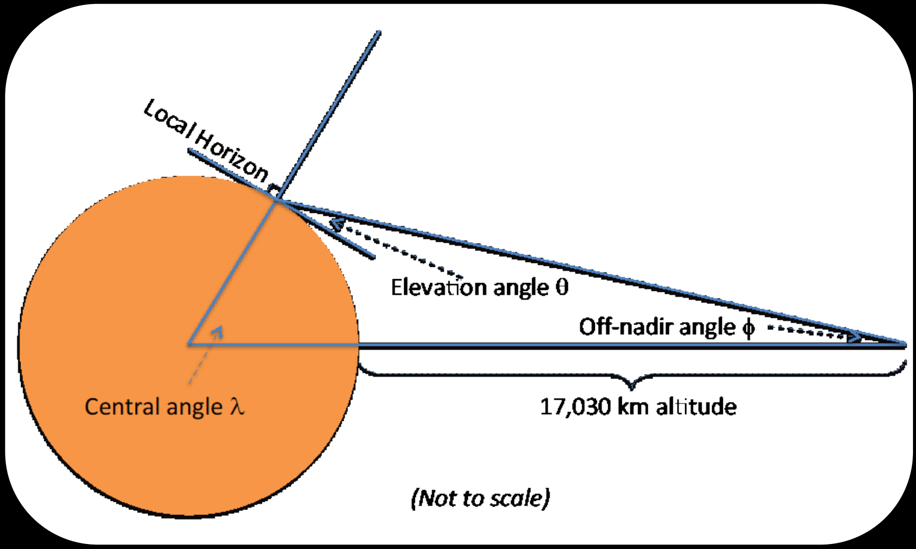
- Mars-equivalent of an Earth geostationary satellite
  - Circular, equatorial orbit
  - 1-sol period
  - 17,030 km altitude
  - Continuous view of one region of Mars
  - Large slant range demands increased antenna gain for directional proximity links



Coverage Geometry from Areostationary Orbit

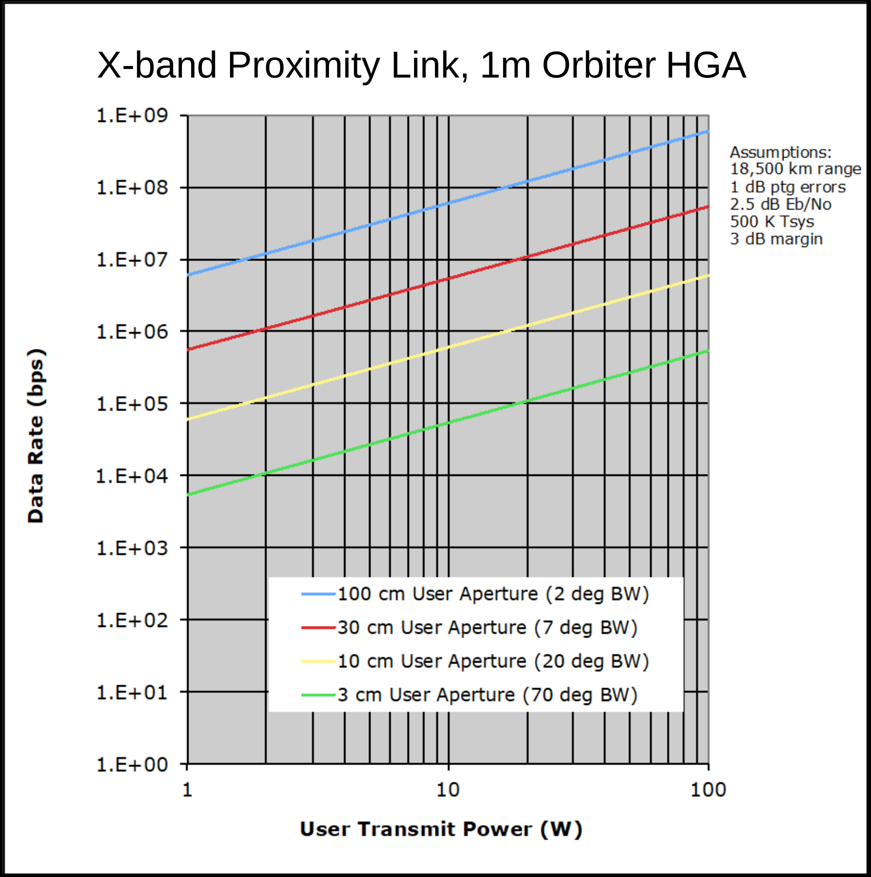
- From areostationary orbit, a relay orbiter can view a significant fraction of one hemisphere of Mars
- Mars subtends ~19 deg from areostationary orbit
- For 10 deg min elevation angle, relay orbiter can continuously view ~33% of the planet
  - ± 71 deg latitude at orbiter longitude
  - ± 71 deg longitude range at equator
- For landing sites with ± 30 deg of equator, orbiter elevation angle is always >50 deg

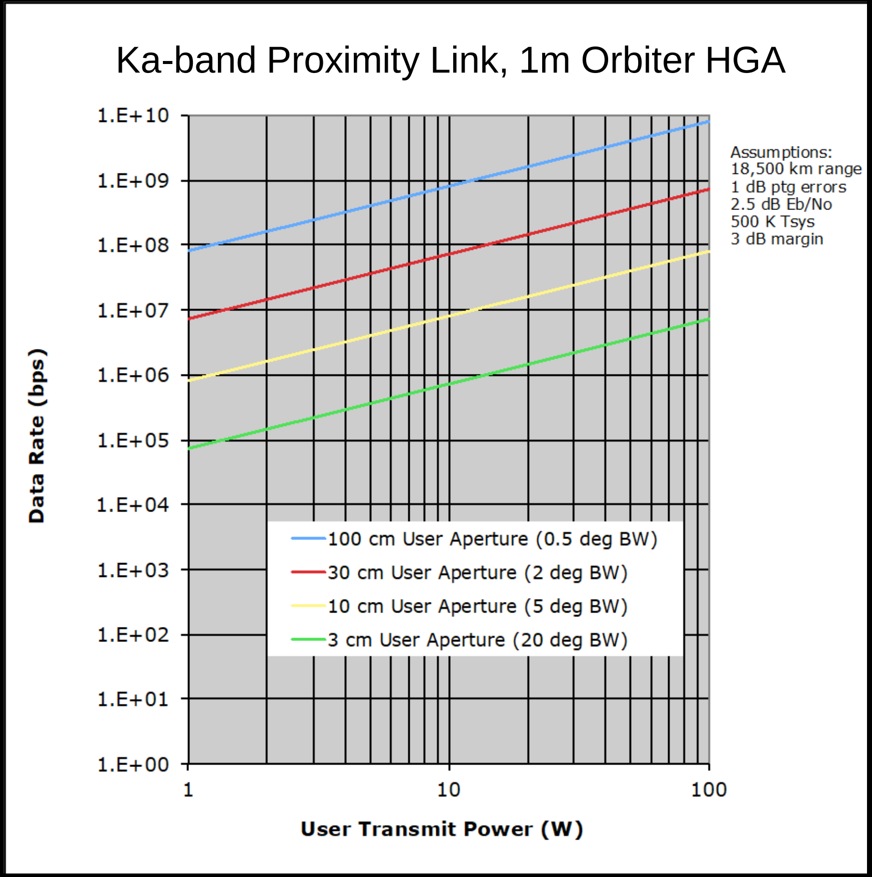




RF Proximity Link Performance

- Consider X/Ka prox links, allowing lander to get dual use (prox/DTE) from a common telecom subsystem





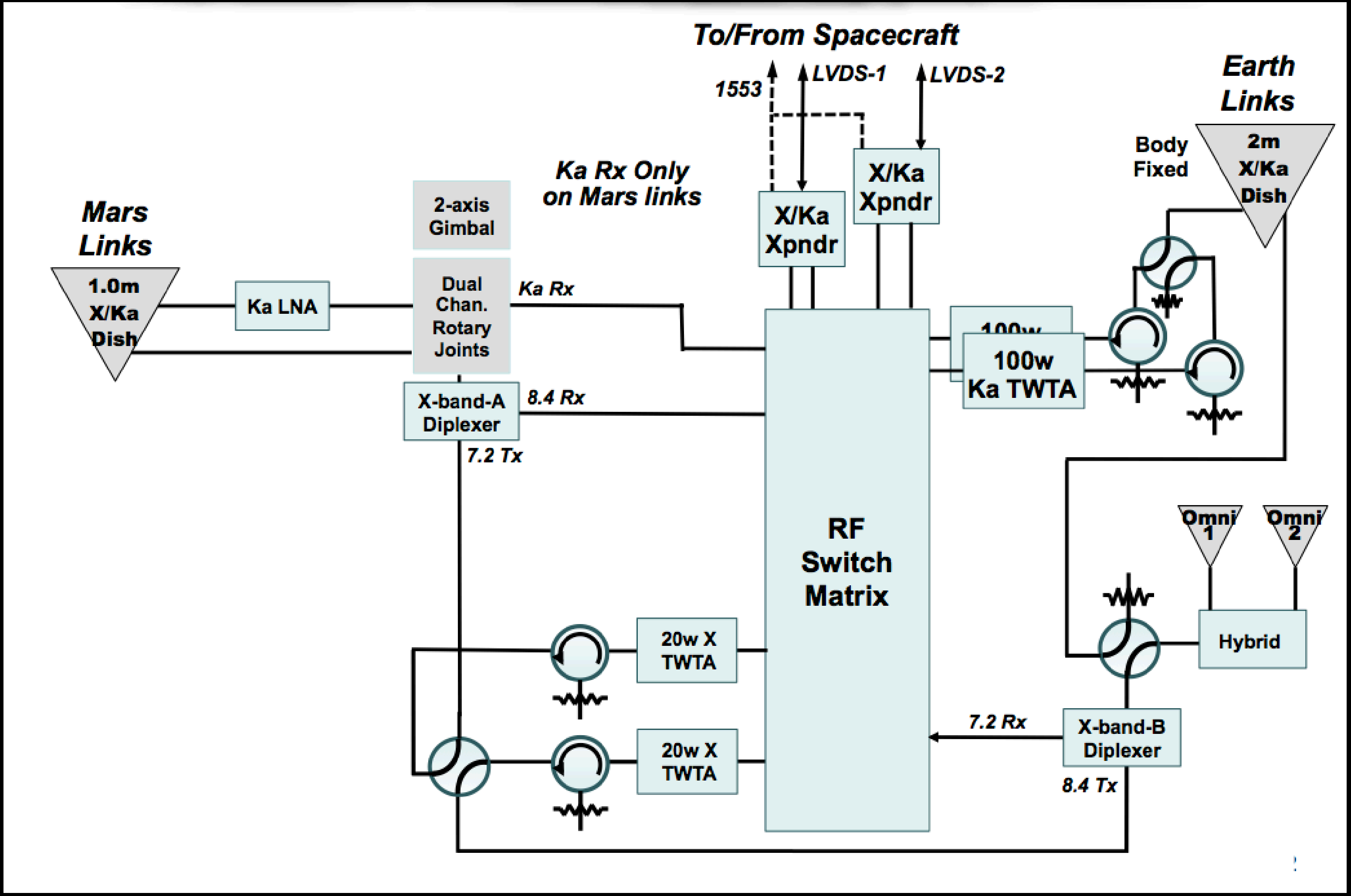
Notional Orbiter RF Proximity Link Design

- 1 m gimbaled X/Ka antenna
  - 20 W X-band transmit (7.2 GHz)
  - X/Ka receive (8.4/32 GHz)
- Optional X-band MGA
  - 14 dBi coverage
  - ± 12 deg off-nadir, covers full Mars disk and low-altitude orbiters out to 1000 km altitude
  - Supports 24/7 low-rate command/control/monitor links, and demand-access service scheduling
- Optional UHF MGA
  - 10 dBi MGA
  - Low-rate support to heritage UHF band (16 kb/s from MSL-class UHF system

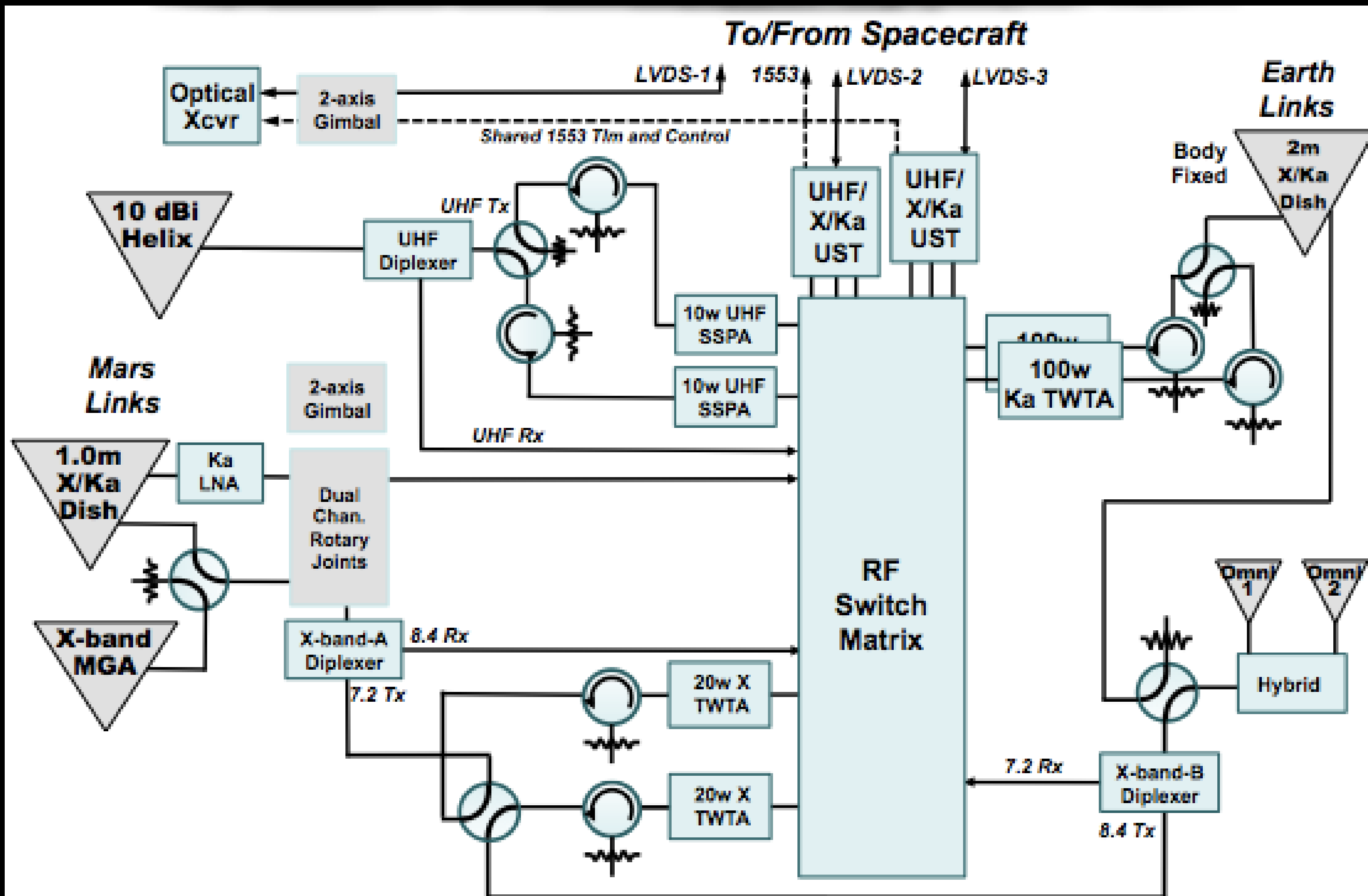
Relay Return Link Data rate to 1m dish			
Surface Tx Configuration	10cm 5w RF	20cm 10w RF	30cm 15w RF
X-band	240 kbps	1.8 Mbps	5.8 Mbps
Ka-band	2.9 Mbps	22 Mbps	70 Mbps

Relay Return Link Data Rate to 14 dBi horn			
Surface Tx Configuration	10cm 5w RF	20cm 10w RF	30cm 15w RF
X-band	1 kbps	8 kbps	16 kbps

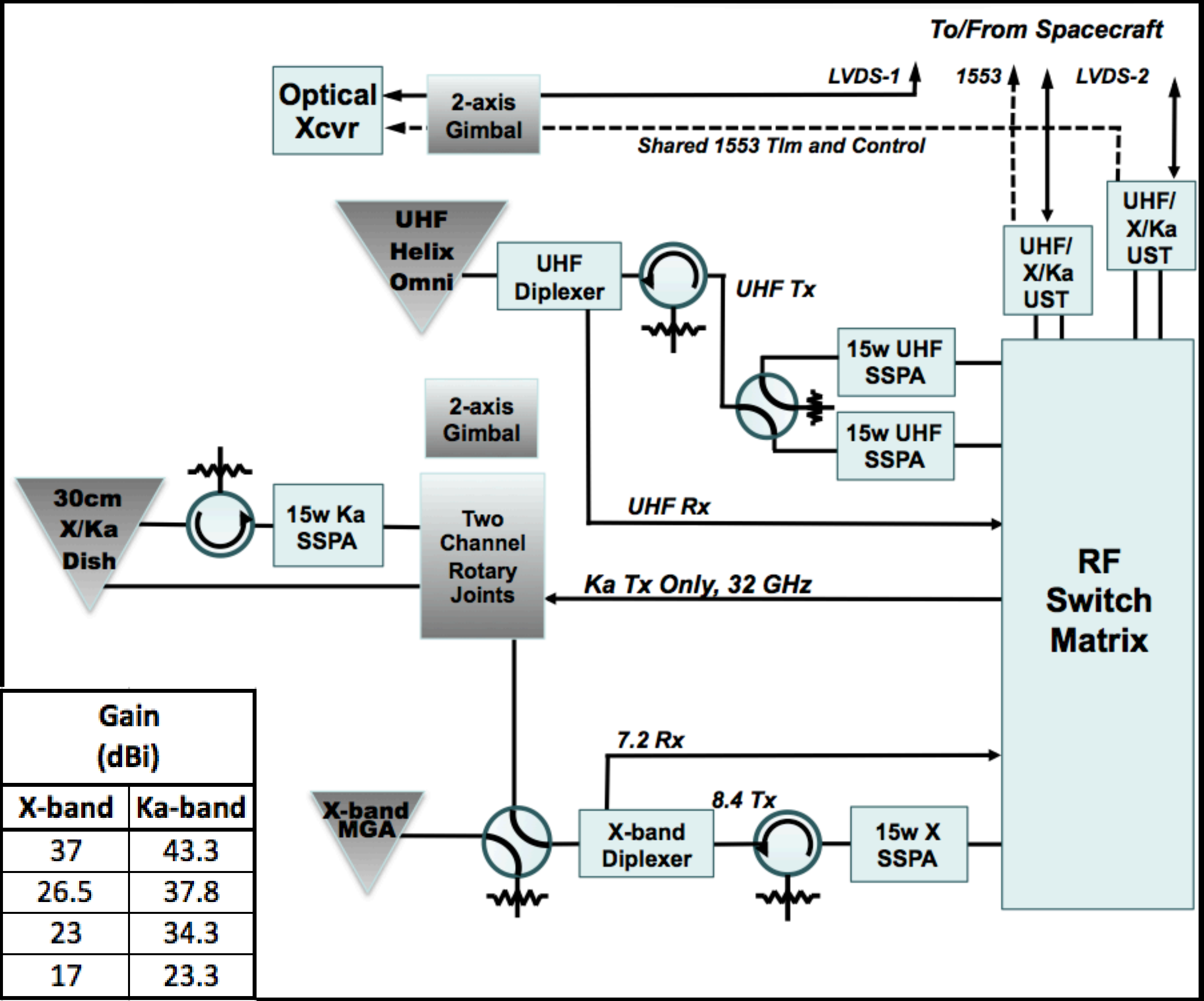
Minimal Mars Areostationary Orbiter RF Telecom Design



Enhanced Mars Areostationary Orbiter RF/Optical Design



RF/Optical User Telecom Subsystem

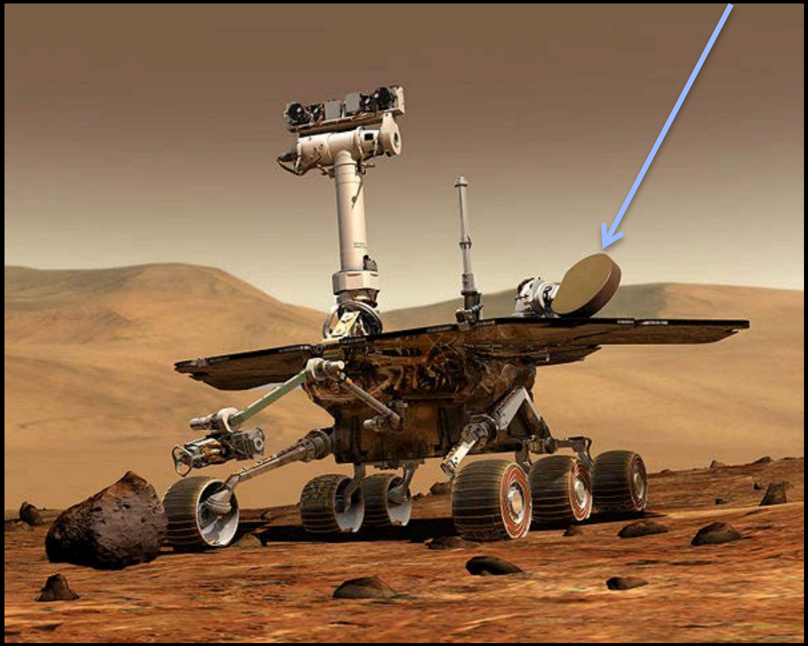


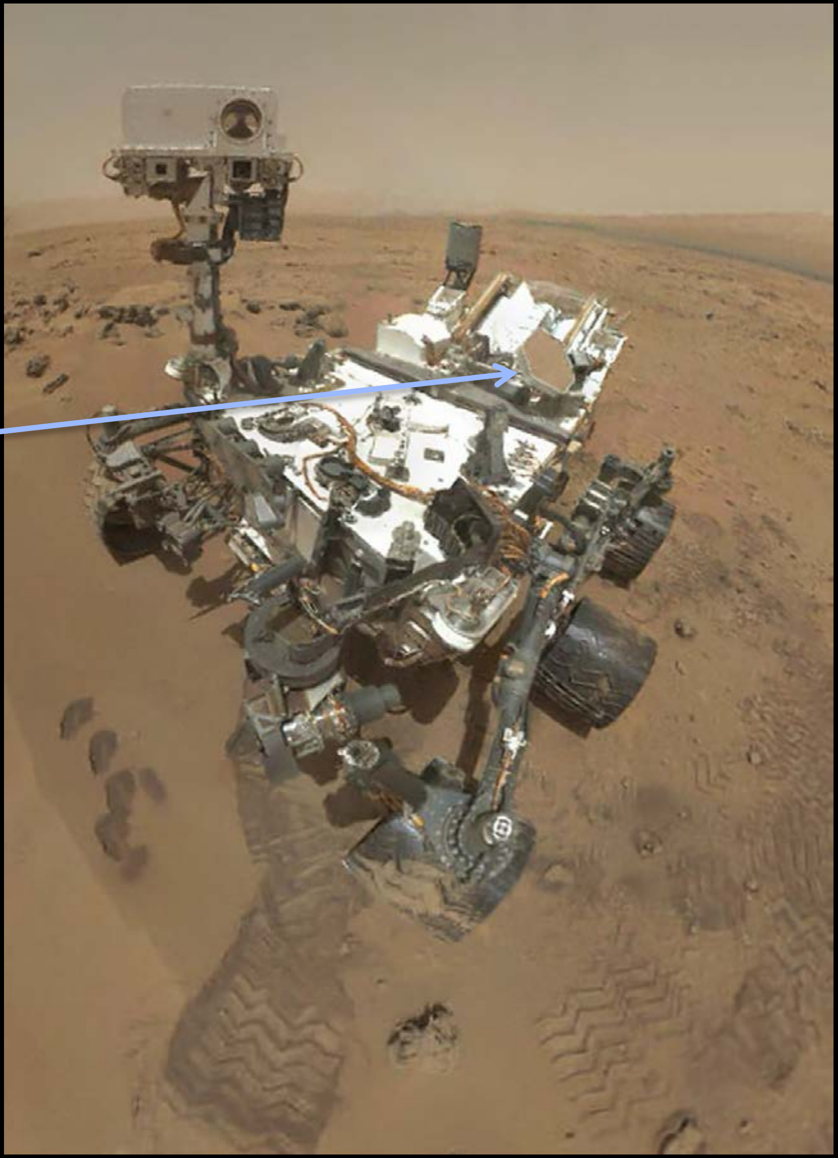
Dish Antenna	Mass (kg)	1 dB Beamwidth (deg)		Gain (dBi)	
		X-band	Ka-band	X-band	Ka-band
1m Composite	1.2	+/- 0.7°	+/- 0.2°	37	43.3
30cm Aluminum	1.2	+/- 2.3°	+/- 0.7°	26.5	37.8
20cm Aluminum	0.50	+/- 3.5°	+/- 1.0°	23	34.3
10cm Aluminum	0.20	+/- 6.9°	+/- 2.0°	17	23.3

MER/MSL-Heritage Comm Capability

- Existing MER/MSL rovers incorporate an X-band DTE link w/ 15 W SSPA and 30 cm gimbaled HGA, very similar to the class of directional user proximity links proposed here

Rover HGA

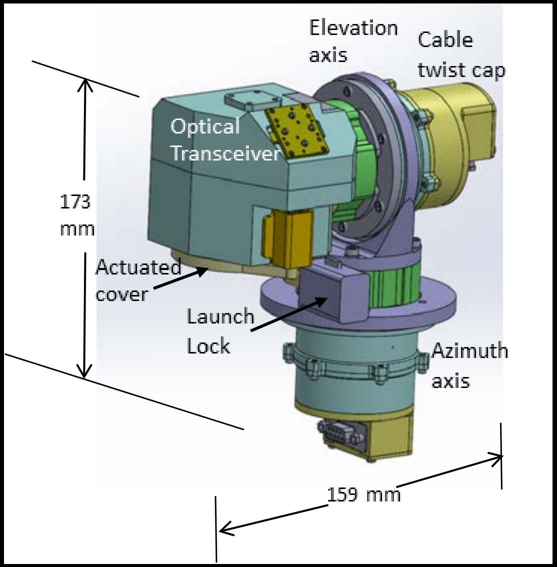


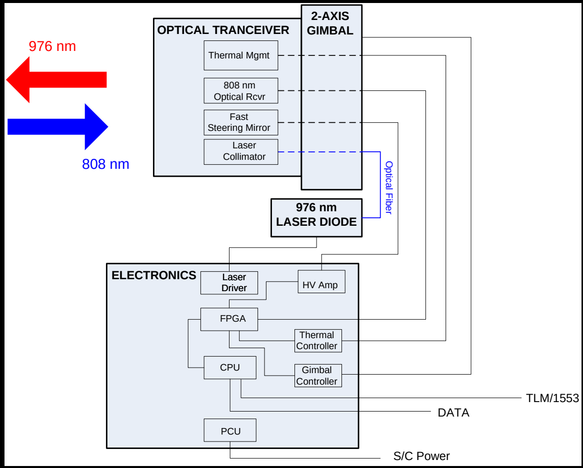


Areostationary Proximity Link Optical Transceiver

- Orbiter
  - 5-10 cm aperture options
  - 5-10 kg, 44-56 W DC power
- Lander
  - 5 cm aperture
  - <5 kg
  - 1-2 W txmt power options, 56-65 W DC power
- Low-complexity architecture
  - Optical receiver with avalanche photo-diode front-end
  - Quad PIN detector for acq/trk
- Prox link rates up to 50 Mb/s (including 5 dB atmospheric attenuation and additional 7.5 dB link margin for pointing loss and/or deeper atmospheric fades

		Areostationary Orbiter Tx 980 nm	5 cm dia. (Mb/s)	10 cm dia. (Mb/s)
Surface Asset Tx 808 nm	5 cm dia.	1W	5	20
		2W	15	50

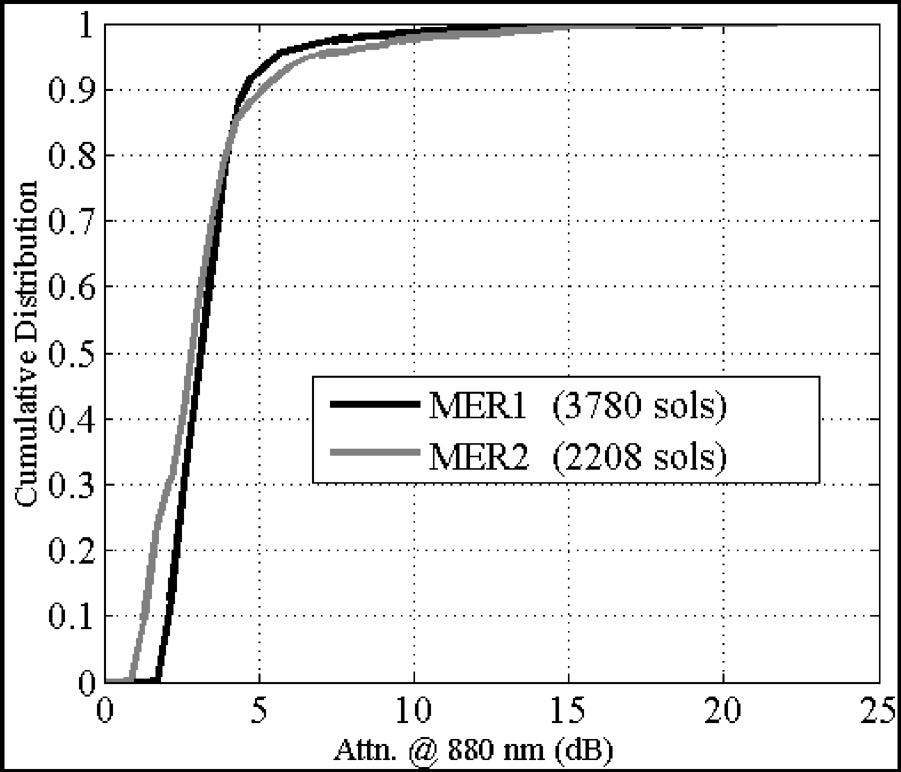




(Orbiter configuration; lander swaps txtm/rcv wavelengths)

Mars Atmospheric Attenuation

- MER opacity data over a decade of operations have been analyzed to establish zenith attenuation cumulative distribution
- At 880 nm, zenith attenuation is <5 dB 90% of the time



Additional Relay Service Considerations

- Service scheduling
  - Today's low-altitude orbiters with small orbiter footprint and short intermittent contacts results in simple scheduling
  - Areostationary orbiters may have multiple assets simultaneously in view
  - X-band MGA can support demand-access service interface
    - User requests service (duration, freq band, data rate, modulation, coding)
    - Orbiter responds with service commitment, either providing immediate service or scheduling a future time for service
- Tracking and navigation services
  - Today's low-altitude orbiters can provide ~10 m position info based on Doppler signature over several overflights
  - Lack of orbiter-lander Doppler signature for areostationary orbit limits this technique
  - However, range measurements contrain lander to a "small circle" on Mars, providing info on one dimension of surface location
  - In addition, Doppler/range measurements from areostationary orbit to low-altitude orbiting users can provide strong user orbit information

Conclusions

- Areostationary relay orbiters can offer continuous, high-bandwidth relay services to landers and low-altitude orbiters
- The longer slant range to areostationary orbit demands higher-frequency directional RF or optical links
- RF and optical designs illustrate capability for high-perfomrance links from small landed user relay payloads
  - X: 30 cm/15 W txmt: 6 Mb/s
  - Ka: 30 cm/15 W txmt: 70 Mb/s
  - Optical: 5 cm/2 W txmt: 50 Mb/s

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