COMMUNICATION AND COVERAGE ANALYSIS FOR A NETWORK OF SMALL SATELLITES AROUND MARS

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OUTLINE

- Introduction
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  - Project Goal
- Analysis
  - Constellation Configuration
  - Coverage Analysis
  - Bandwidth and Hardware Components
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  - Link analysis
  - Network capacity
- Conclusion and future work

MOTIVATION

Introduction | Analysis | Conclusion

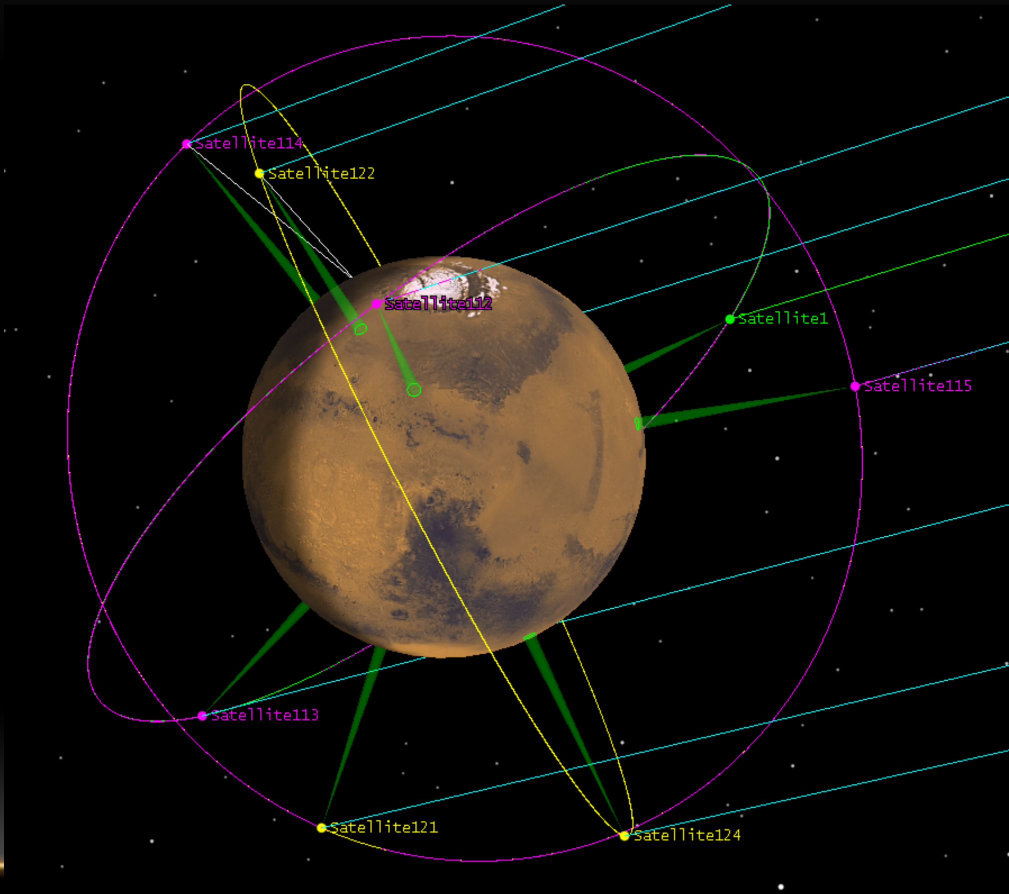
- COST and SCHEDULE: Small satellites and CubeSats can be designed and fabricated with considerable cost and time savings with respect to larger and more complex spacecraft
- SCALABILITY: Multiple replica of the same small satellite or CubeSat can be used to design satellite constellations to support the exploration of different targets in the solar system, especially Mars.
- MARS EXPLORATION: The landing of MSL (Mars Science Laboratory) in 2013 and the current proposed Mars 2020 show that Mars is a target of great interest in the exploration of the solar system and that it will be likely explored by an increasing number of landers and rovers in the future.
- AUGMENT CURRENT MARS DATA RELAY: A network of satellites to facilitate data relay for mobile and fixed assets on the Mars surface is of paramount importance as the current satellites orbiting the planet are becoming old and exposed to potential failures.
- EMERGENCY COMMUNICATION AND TELEMETRY: A network of small satellites can provide “multiple access points/low data rate services” which can be useful for emergency communication.

PROJECT GOAL

- Develop a simulated study for a network of small satellites orbiting Mars to use as satellite relays for future Mars exploration
  - Identify suitable orbits and perform coverage analysis
  - Identify bandwidths and hardware components compatible with CubeSat technology
  - Develop link analysis study

MISSION CONCEPT: ORBIT CONFIGURATION

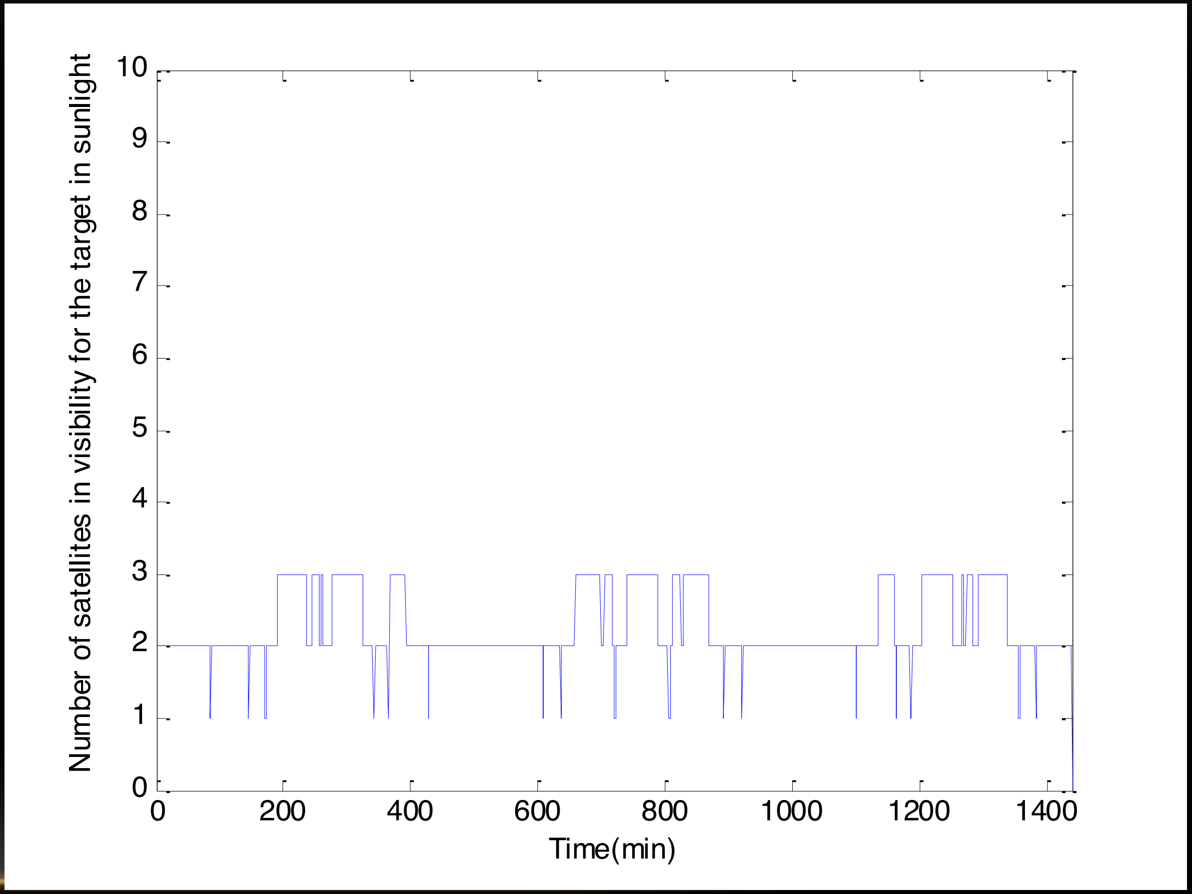
- This concept includes a network of 9 satellites
- Polar orbits: selected for maximize solar power collection
  - H=3600 Km
  - i=115.7
  - RAAN=[0 120 240]
  - W=[0 120 240; 40 160 280; 80 200 320];
- One target point on the Mars surface (STK), global coverage in Matlab.



COVERAGE ANALYSIS

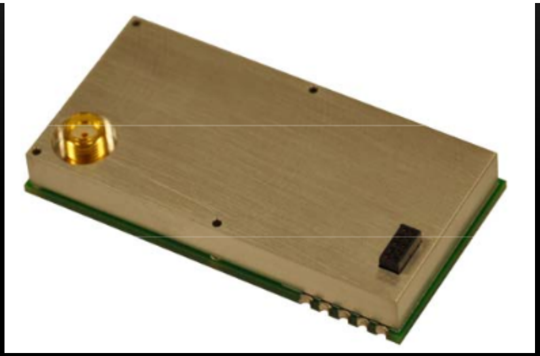
COVERAGE ANALYSIS: MARS TARGET

- The access between the target and each of the satellite is computed
- Continuous coverage of the target
- The target is simultaneously seen by 1 to 3 satellites all the time.

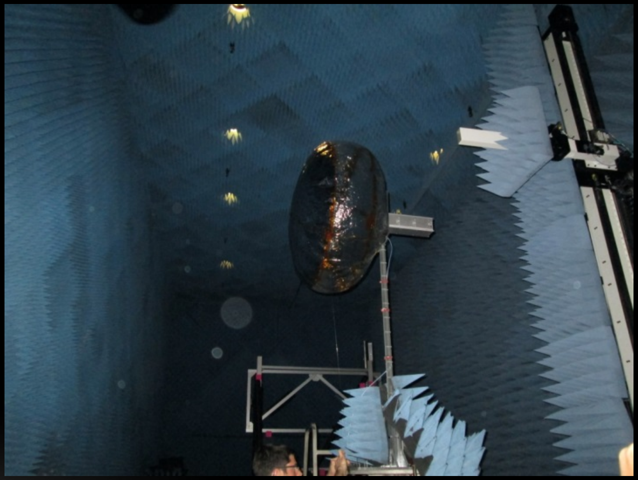


BANDWIDTH SELECTION AND HARDWARE

- 6U CubeSat could be realized using for the most part (power, structure, controls) commercially available products
- 2 telecommunication bandwidths could be considered
- UHF for the proximity link:
  - UHF antenna: monopole or dipole
  - UHF transceiver: commercially available (AstroDev)
- The X-Band is considered for the mars-to-Earth link. It requires a certain EIRP to be closed with respect to the Earth Station.
  - X-Band amplifier: 10 W power, developed at Aerospace Corporation
  - X-Band antenna: inflatable or deployable



Li-1 radio [Courtesy of Astrodev]



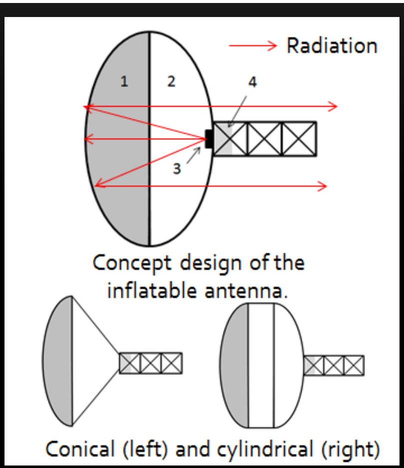
Inflatable antenna, gain 30 dB [Babuscia et al., 2013]

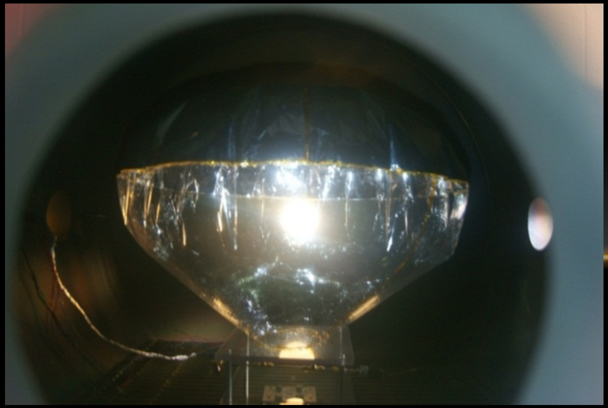
INFLATABLE ANTENNA

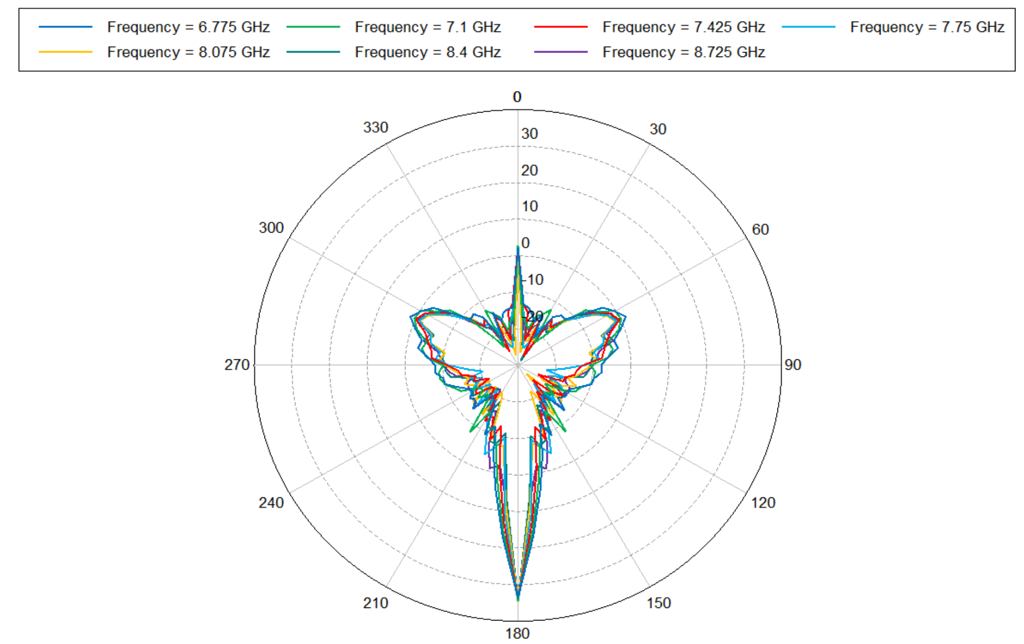
Introduction	Analysis	Conclusion

- Inflatable volume with one side reflective, metalized Mylar (1), other side clear Mylar (2) with a patch antenna (3) at the focus.
- Stored in a volume (4) less than 1U in size.
- Antenna passively inflated with a small amount of a sublimating powder.
- 2 versions: conical and cylindrical to minimize deformation of the parabolic shape of the reflective section.
- Radiation analysis at X-Band shows ~30 dB gain

(Simulations with both HFSS and FEKO)





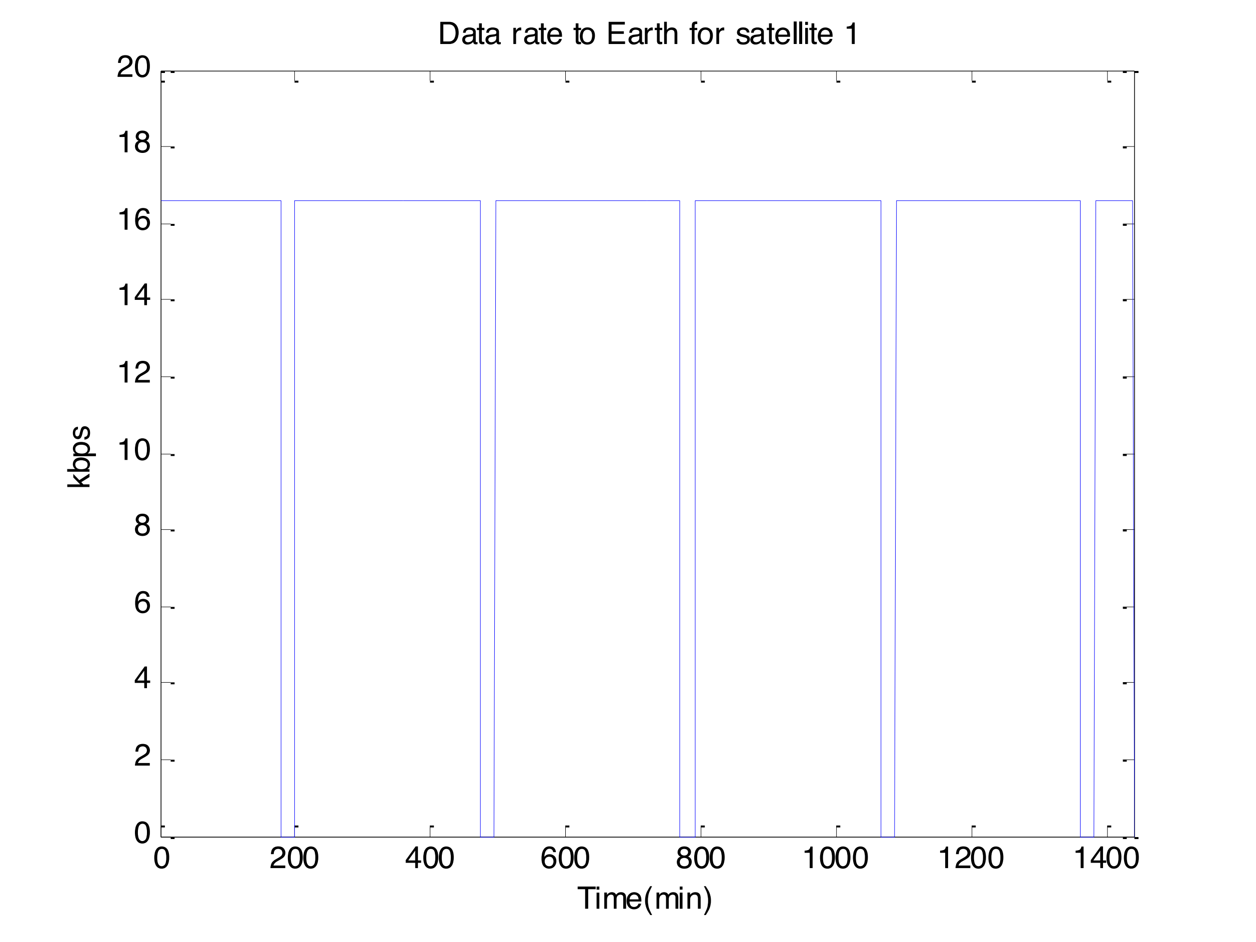


LINK ANALYSIS: SATELLITE-EARTH LINK

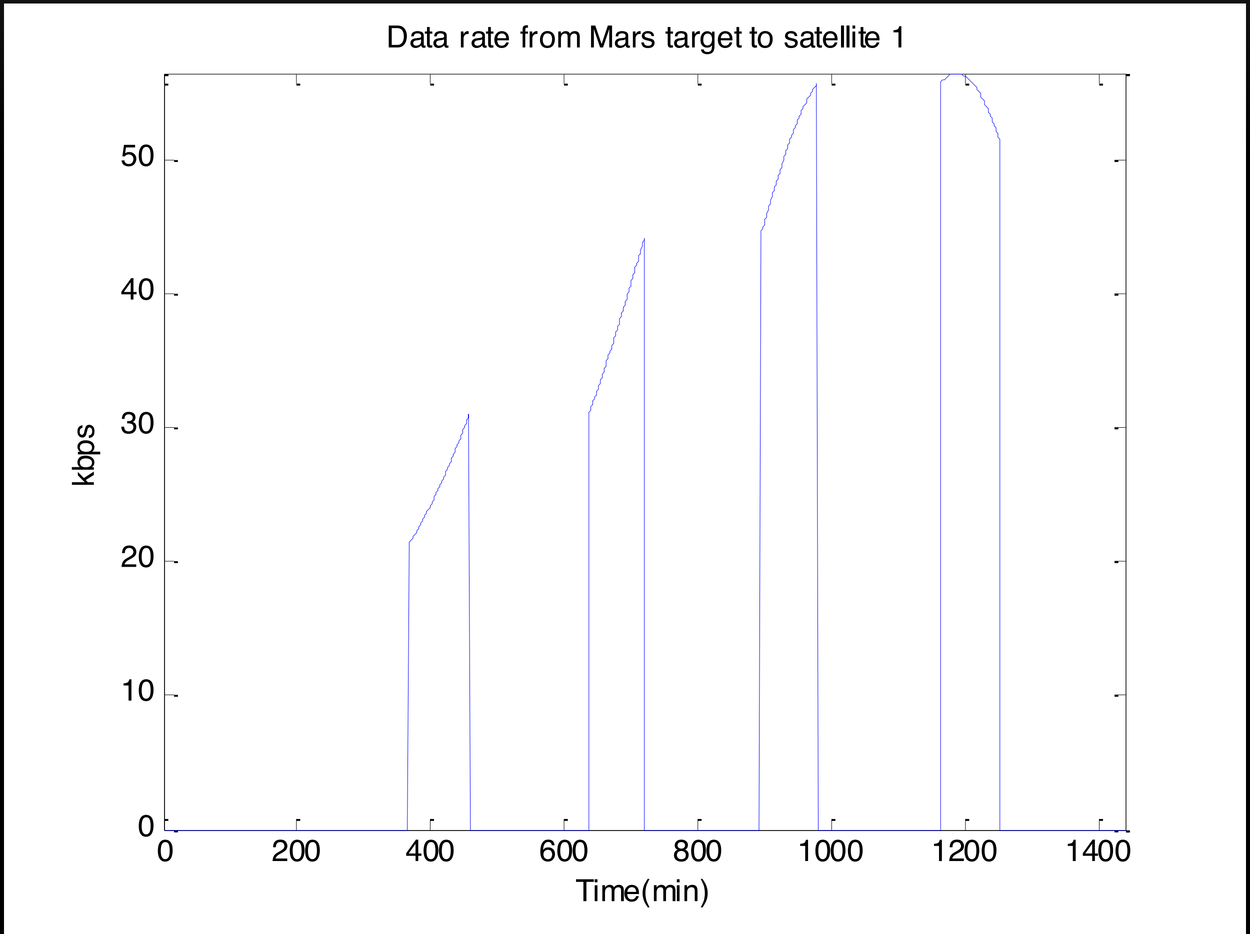
- Link Analysis assumptions:
  - On board: inflatable antenna +10 W amplifier
  - On ground: 70 m DSN (same results with 34 m and 2 m inflatable antenna)
  - LDPC coding
  - Worst and best case scenario computed with respect to propagation path length

Item	Units	Downlink Worst Case	Downlink Best Case	Uplink Worst Case	Uplink Best Case
Transmitter Power	dBW	10.00	10.00	17.00	24.00
Line Loss/Waveguide Loss	dB	-0.50	-0.50	-0.70	-0.50
Transmit Antenna Gain	dBi	30.00	30.00	72.41	72.40
Equiv. Isotropic Radiated Power	dBW	39.50	39.50	88.71	95.90
Frequency	GHz	8.40	8.40	7.10	7.10
Receive Antenna Gain	dBi	73.87	73.86	30.00	30.00
Propagation Path Length	km	400,000,000.00	200,000,000.00	400,000,000.00	200,000,000.00
Additional Losses	dB	-2.10	-2.10	-2.10	-2.10
Data Rate	bps	6,000.00	25,000.00	2,500.00	50,000.00
System Noise Temperature	K	25.58	25.58	340.00	340.00
E_b/N_o	dB	4.36	4.84	4.40	4.60
E_b/N_o required	dB	1.80	1.80	1.80	1.80
Margin	**dB**	**2.56**	**3.04**	**2.60**	**2.80**

TYPICAL DATA RATE: DIRECT TO EARTH LINK

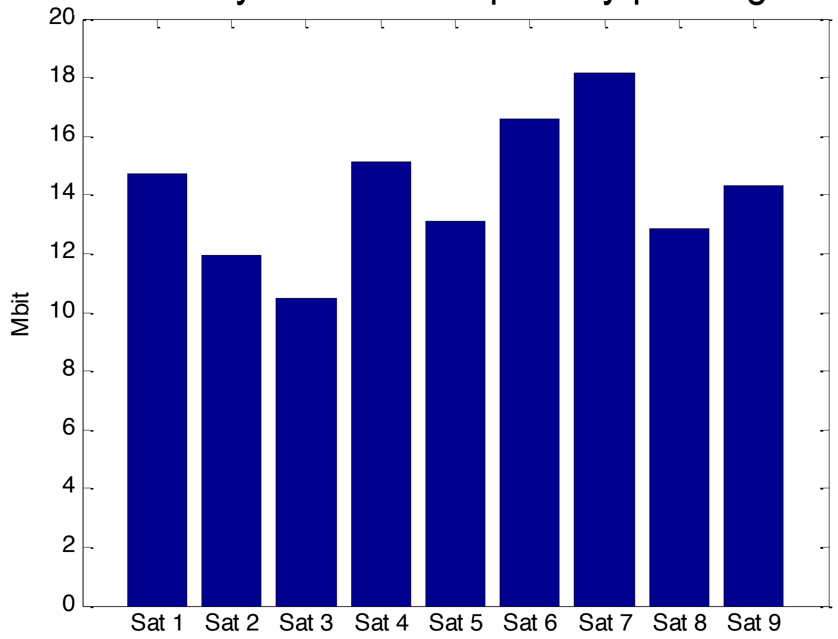


TYPICAL DATA RATE: PROXIMITY LINK

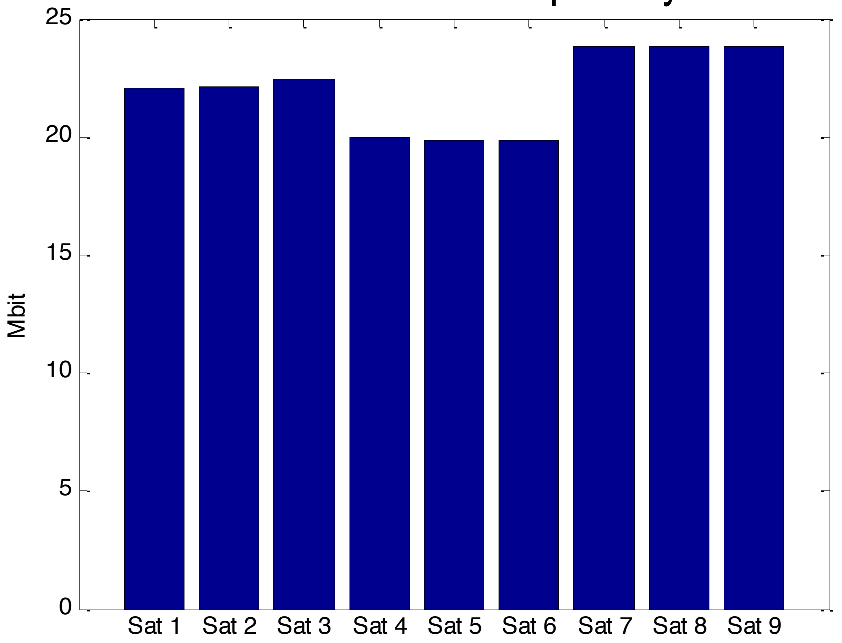


NETWORK CAPACITY

Proximity link: 128 Mb per day per target



Direct to Earth: 200 Mb per day



CONCLUSIONS AND FUTURE WORK

- A concept for a small satellite relay networks around Mars is described: the network could support multiple targets on the surface and it could provide emergency communication services to augment the existing relay infrastructure.
- Coverage analysis shows that the orbit selections allows an almost complete coverage for the Mars surface
- Link analysis shows that the link could be closed at long distance
- The network capacity study shows that approximately 128 Mbit per day could be acquired from a single Mars target and 200Mb per day could be directly relayed to Earth
- Future work will focus on
  - Study the optimal amount of satellites and their optimal orbit configuration (altitude vs. data trade off)
  - Develop a preliminary concept design for the 6U CubeSat
  - Further mature the inflatable antenna technology

ACKNOWLEDGMENTS

- Part of this work was performed at the Jet Propulsion Laboratory, California Institute of Technology, under a contract with the National Aeronautics and Space Administration

THANK YOU

QUESTIONS?

REFERENCES

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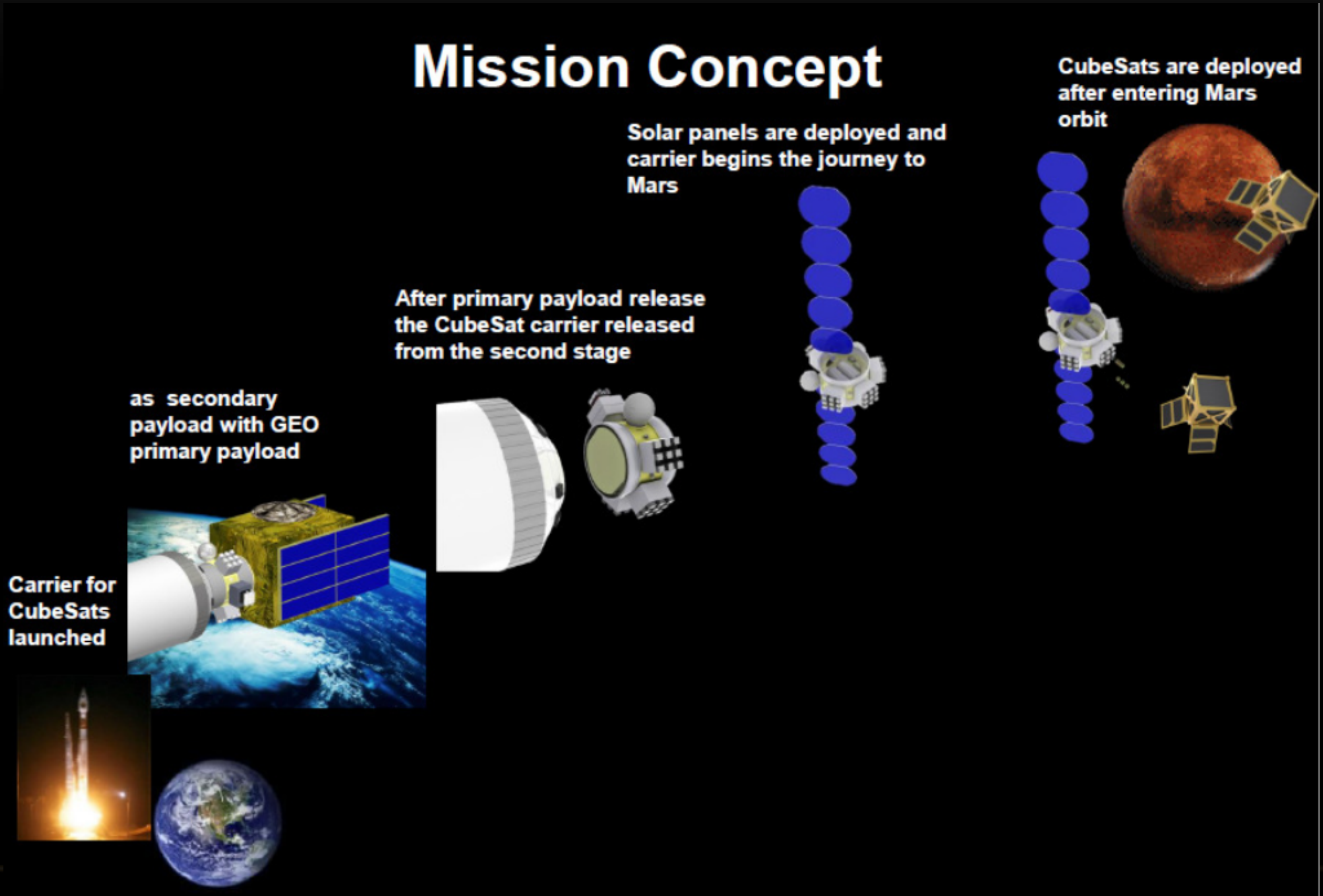
- A. Babuscia, M. Van de Loo, Q. J. Wei, S. Pan, S. Mohan and S. Seager, "Inflatable Antenna for CubeSat: Fabrication, Deployment and Results of Experimental Tests," IEEE Aerospace Conference, Big Sky, Montana, 2014.
- C. Duncan, “Iris for INSPIRE CubeSat Compatible, DSN Compatible Transponder” 27th Annual AIAA/USU Small Satellite Conference, Logan, Utah, 2013.
- A. Chin, C. Clark, “Class F GaN Power Amplifiers for CubeSat Communication Links”, IEEE Aerospace Conference, Big Sky, Montana, 2013
- AstroDevelopment, LLc, http://www.astrodev.com/public_html2/

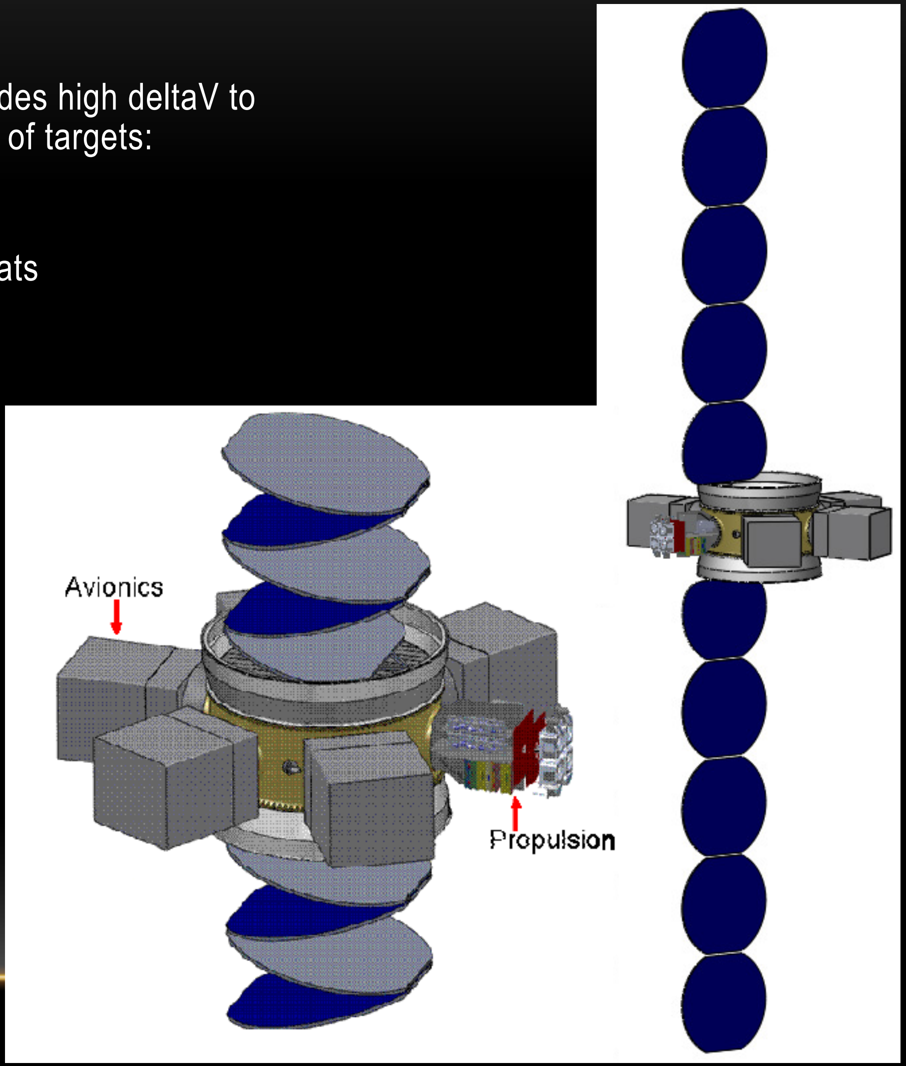
BACK UP

MULE MISSION CONCEPT (ULA)

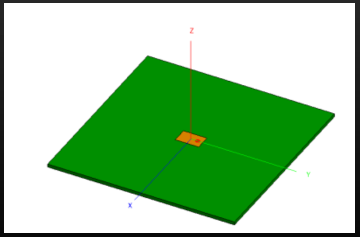


LAUNCH OPPORTUNITIES: MULE (DEVELOPED BY ULA)

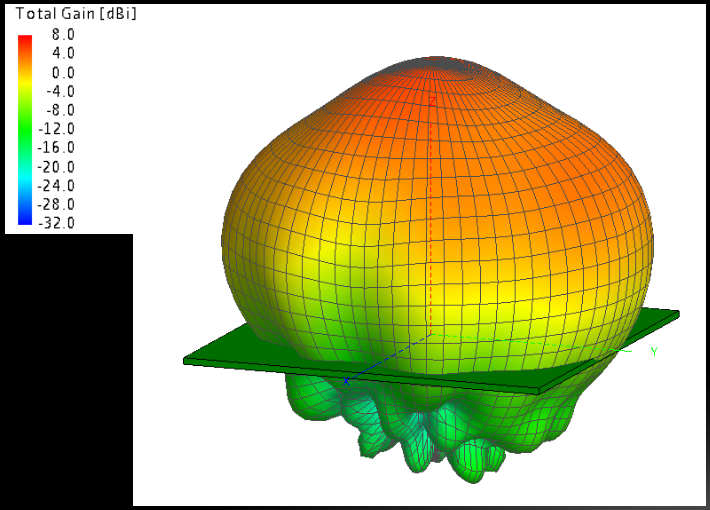
- MULE (Multi-payload Utility Lite Electric) stage provides high deltaV to perform delivery of ESPA class payloads to a variety of targets:
  - Delivery to Earth Escape (Lunar, NEO, Mars)
  - Delivery of a constellation: up to 20 6U CubeSats
  - High delta-V
  - Solar electric propulsion
- Developed by:
  - ULA
  - BUSEK
  - Oakman Aerospace
  - Adaptive Launch Solutions
- Status: in development
- Proposed cost of launches: ~around 30 M$

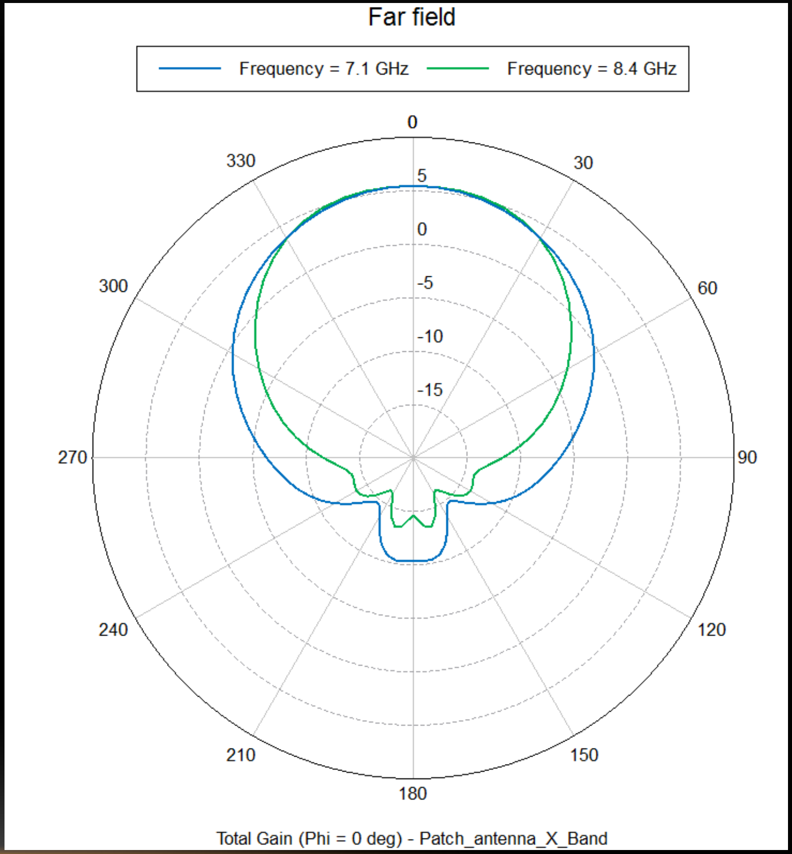


INFLATABLE ANTENNA: EXTENSION TO THE X-BAND



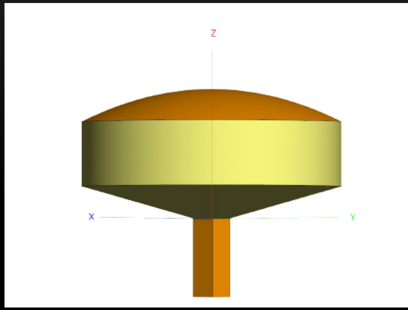
- New patch antenna design and simulation
- The antenna is designed using Copper as the conductor and RT/Duroid 5880 as the dielectric (1.057mm thick). The dimensions of the antenna are:
  - Antenna dimension: 9.5 x 9.5 x 0.1057 cm
  - Conductive surface:
    - Width=0.7417 cm
  - Length=1.1363 cm
- The design was optimized with SONNET
- The final radiation modeling was performed using FEKO

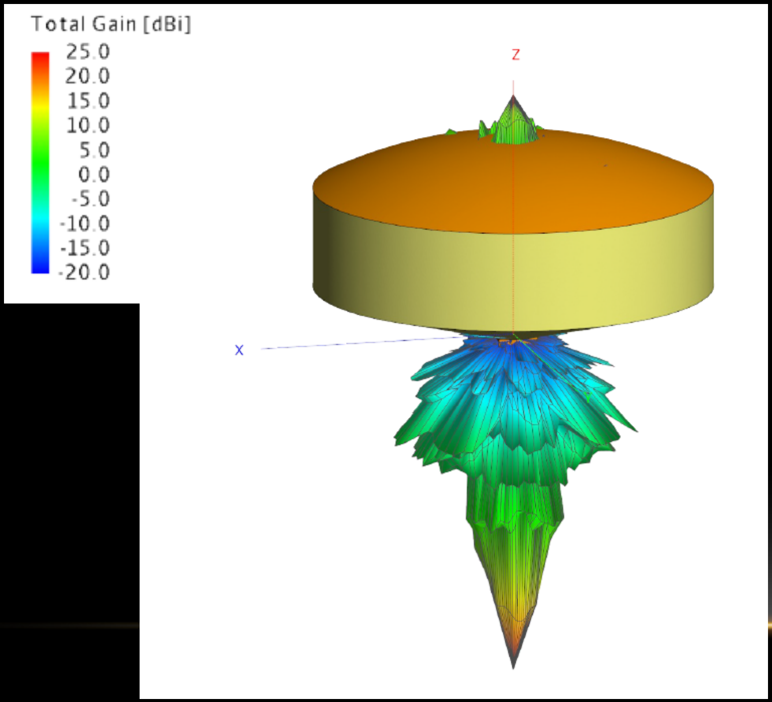


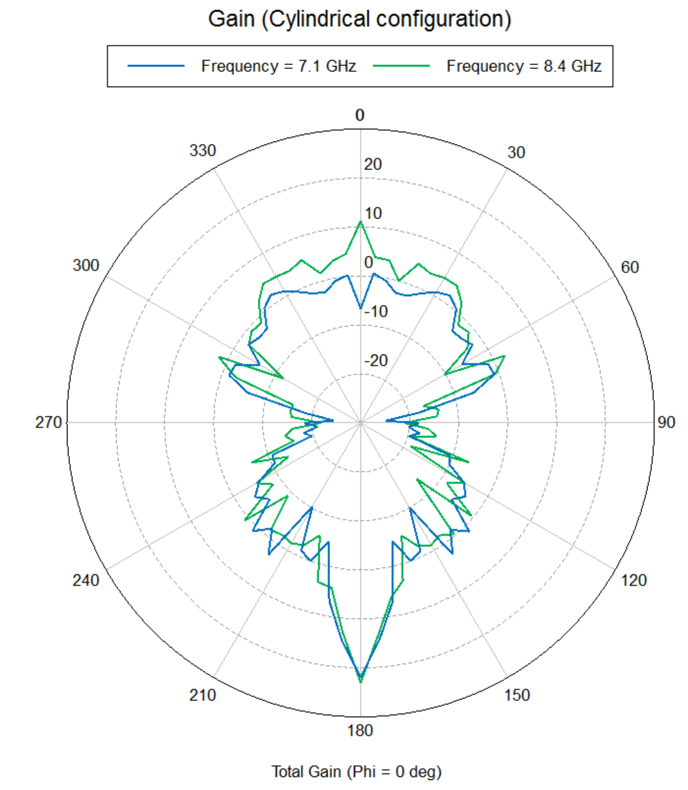


SIMULATION OF INFLATABLE ANTENNA IN THE X-BAND: CYLINDRICAL SHAPE

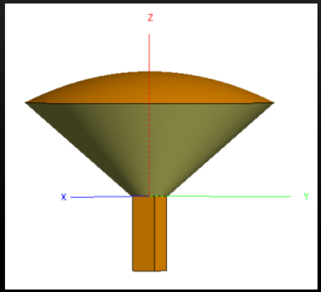
- Inflatable antenna at X Band (8.4 GHz) achieves 23 dB gain for the cylindrical shape (simulations done in FEKO, MoM/FEM)



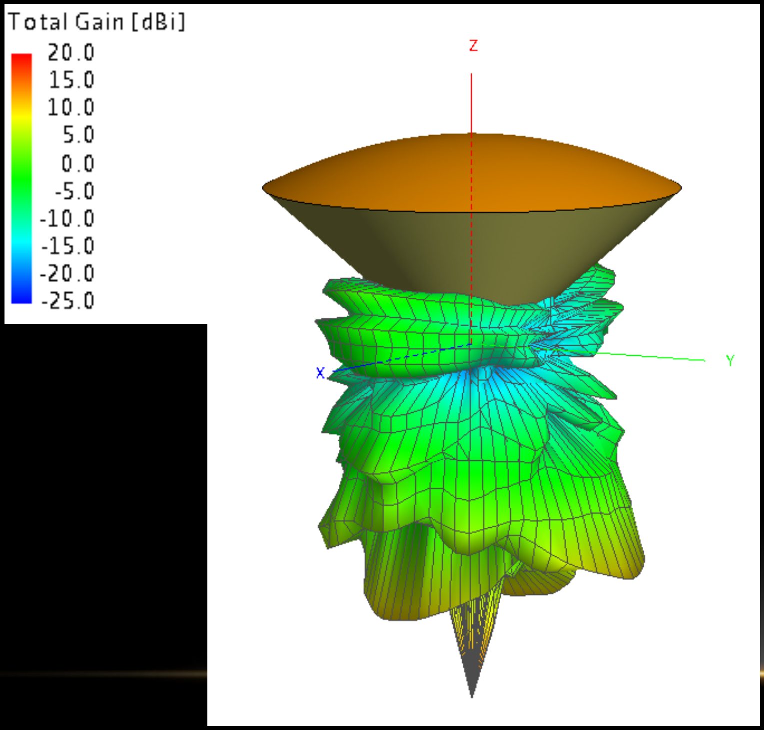


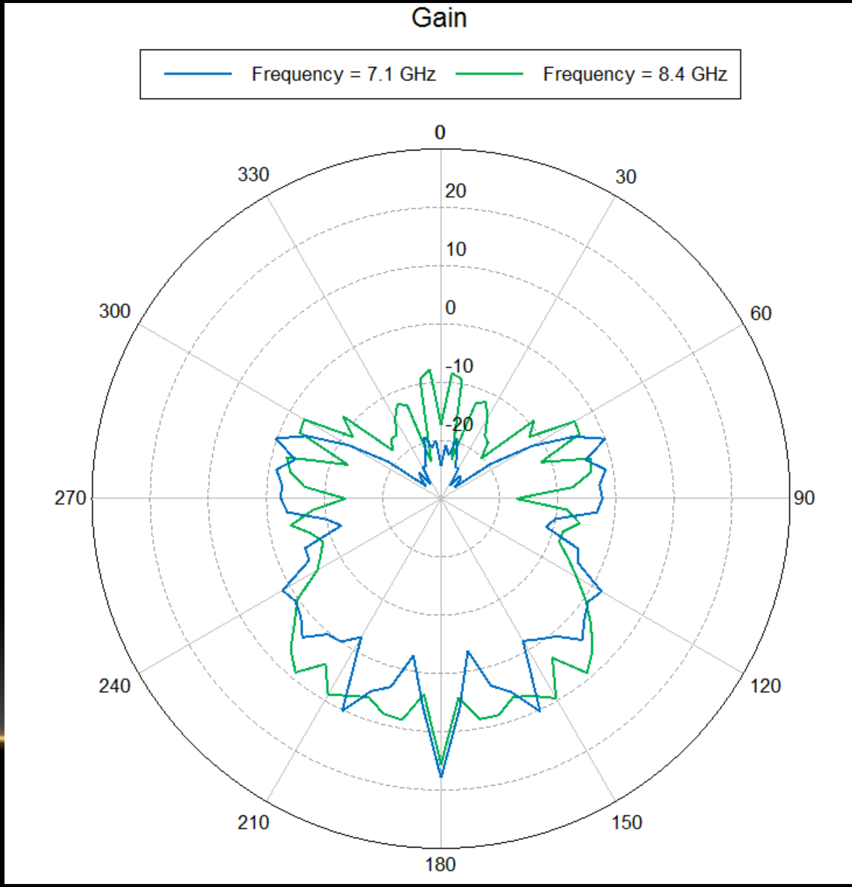


SIMULATION OF INFLATABLE ANTENNA IN THE X-BAND: CONICAL SHAPE

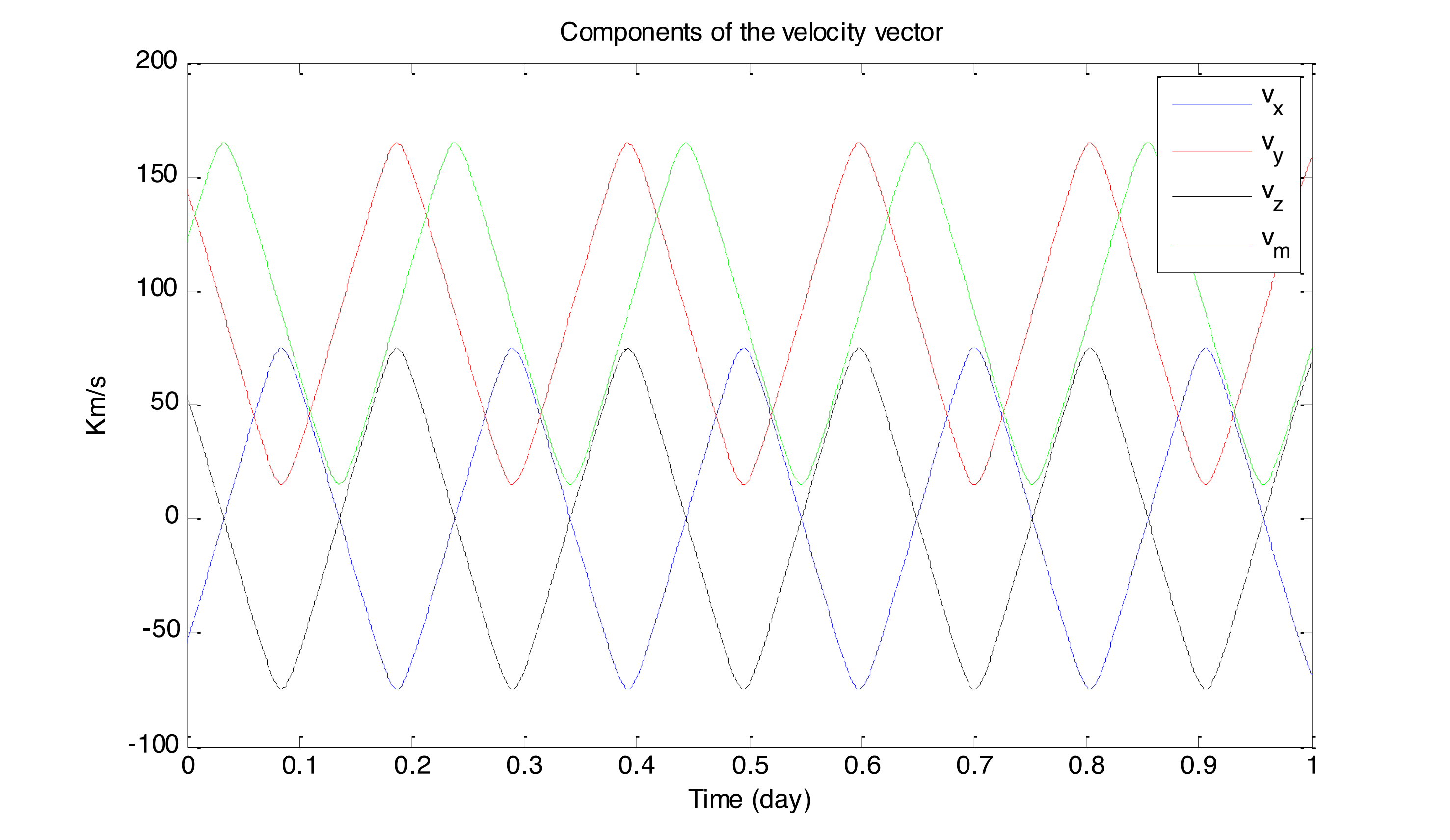


- Inflatable antenna at X Band (8.4 GHz) achieves 18 dB gain for the conical shape (simulations done in FEKO, MoM/FEM)

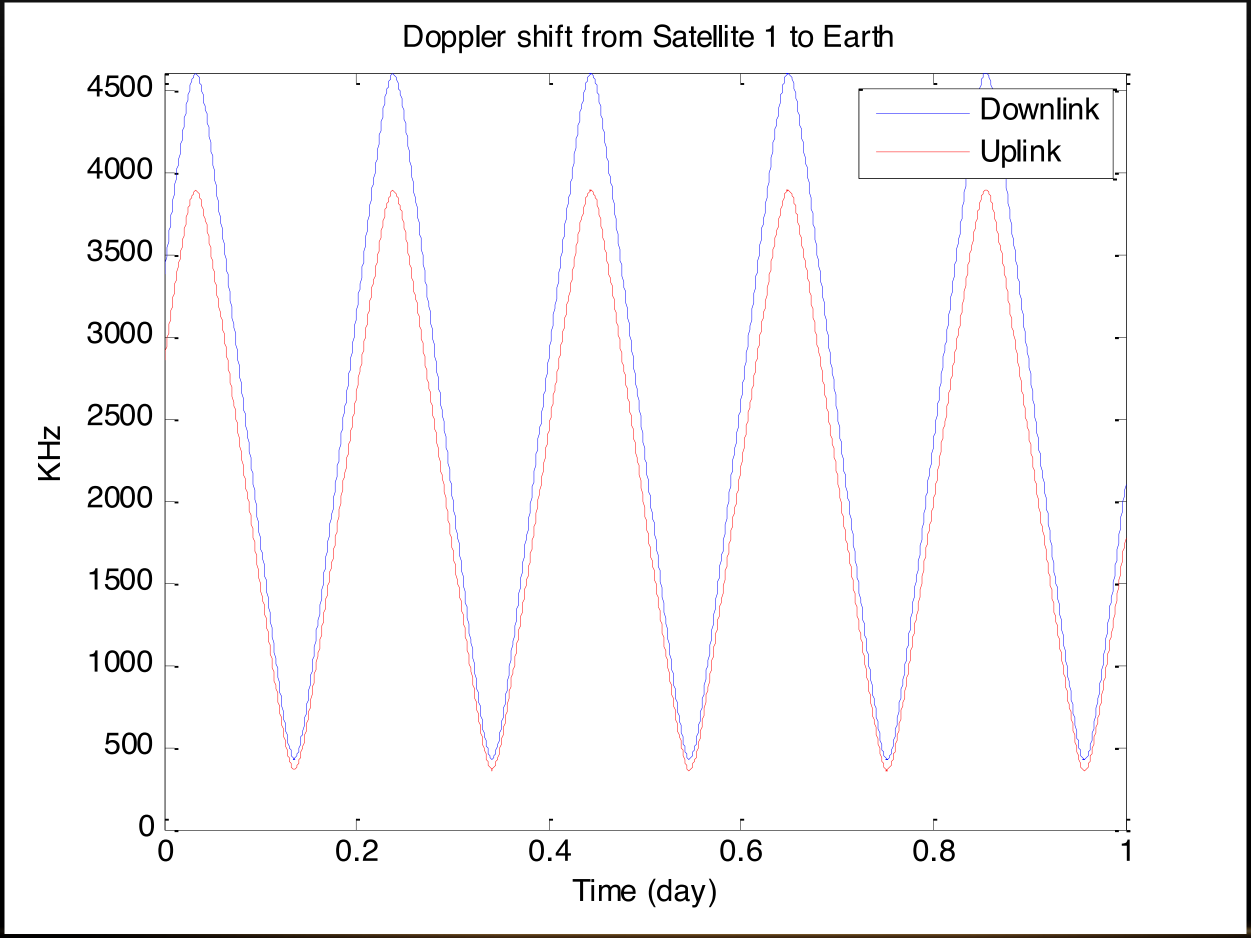




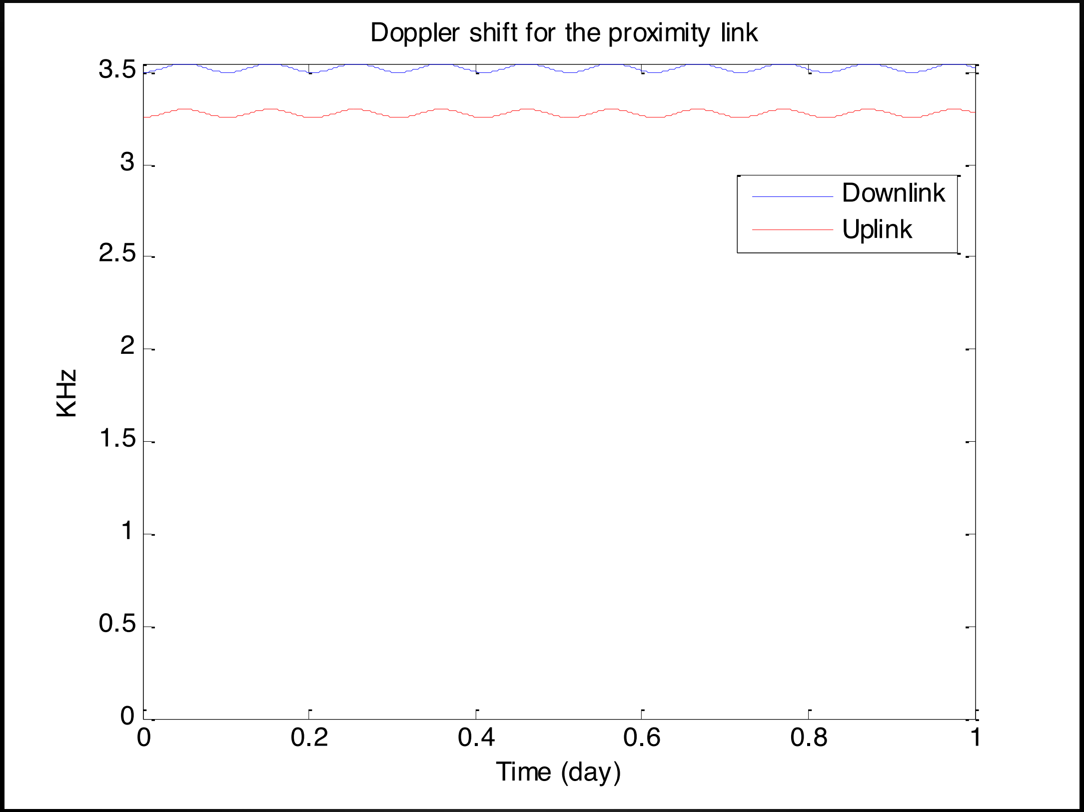
DOPPLER ANALYSIS: EARTH-MARS LINK



DOPPLER ANALYSIS

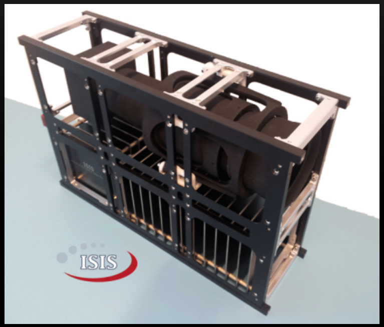


PROXIMITY LINK: DOPPLER

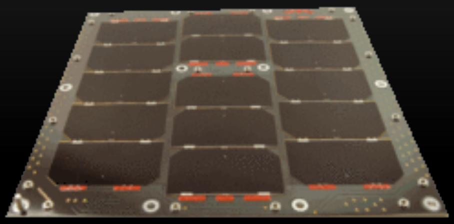


CONCEPT FOR SPACECRAFT DESIGN

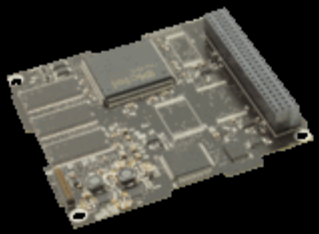
- 6U CubeSat can be realized using commercially available products
- UHF-Band channel → proximity link
- X-Band channel → long range link
- Structure, Power system, ADCS and avionics can be designed using state of the art components:
  - Structure: Isis
  - Power system: Clyde Space
  - Avionic board: GomSpace
  - Control system: MAI 400



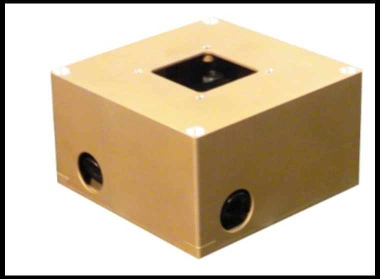
ISIS 6U Structure [Courtesy of Isis]



6U Solar panel [Courtesy of Clyde Space]

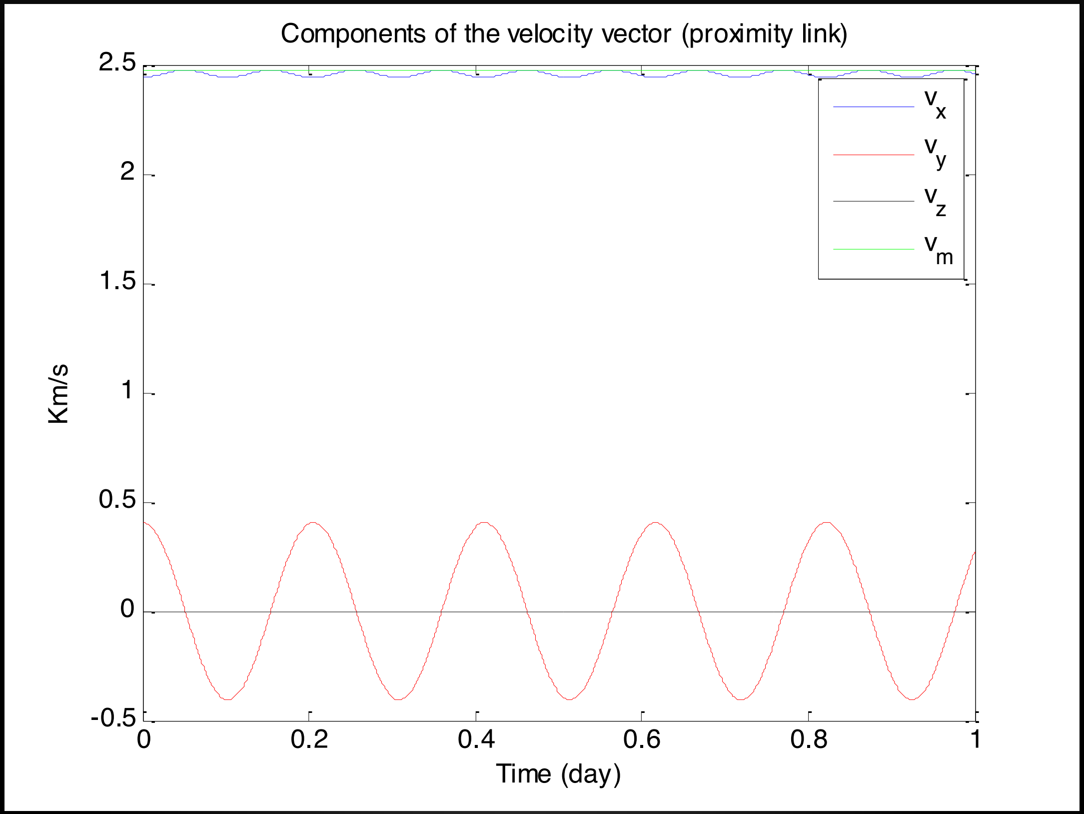


Avionic board [Courtesy of Clyde Space]



MAI 400 [Maryland Aerospacce]

PROXIMITY LINK: VELOCITY



INFLATABLE ANTENNA: FABRICATION AND TEST

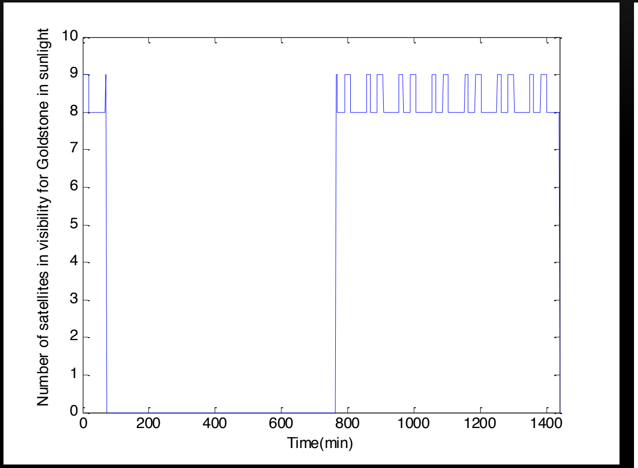
LINK ANALYSIS: SATELLITE-EARTH LINK

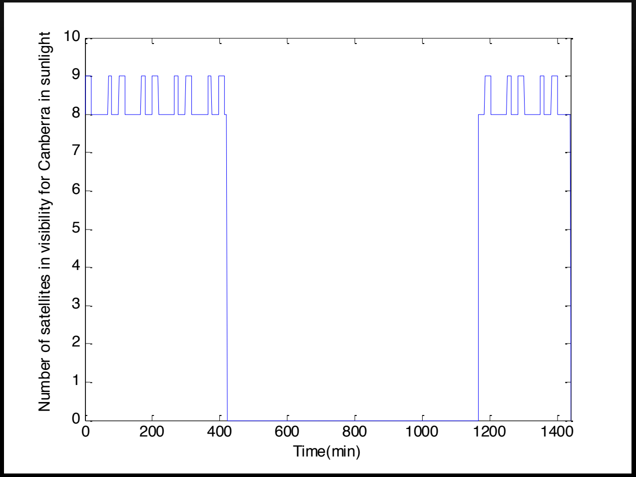
- Link Analysis assumptions:
  - On board: inflatable antenna +10 W amplifier
  - On ground: 70 m DSN
  - LDPC coding
  - Worst and best case scenario computed with respect to propagation path length

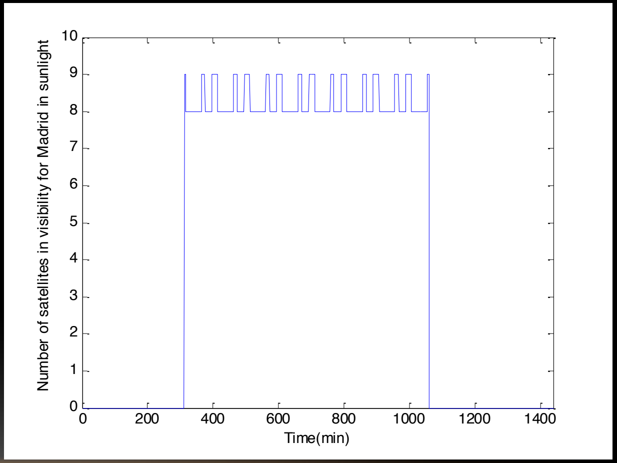
Item	Symbol	Units	Downlink Worst Case	Downlink Best Case	Upli
Transmitter Power	P	dBW	10.00	10.00	
Line Loss/Waveguide Loss	L_l	dB	-0.50	-0.50	
Transmit Antenna Gain (net)	G_t	dBi	30.00	30.00	
Equiv. Isotropic Radiated Power	EIRP	dBW	39.50	39.50	
Frequency	f	GHz	8.40	8.40	
Receive Antenna Diameter	D_r	m	70.00	70.00	
Receive Antenna efficiency	η	n/a	0.64	0.64	
Receive Antenna Gain	G_r	dBi	73.87	73.86	
Propagation Path Length	S	km	400,000,000.00	200,000,000.00	
Free Space Loss	L_s	dB	-282.98	-276.96	
Transmit Antenna Pointing Loss	L_{pt}	dB	-1.00	-1.00	
Receive Antenna Pointing Loss	L_{pr}	dB	-0.40	-0.40	
Ionospheric Loss	L_{ion}	dB	-0.10	-0.10	
Atmospheric Loss (H2O and O2 losses)	L_{atmo}	dB	-0.20	-0.20	
Loss due to Rain	L_{rain}	dB	-0.40	-0.40	
Total Additional Losses		dB	-2.10	-2.10	
Data Rate	R	bps	700.00	2,500.00	
Antenna and Receiver Noise Temperature	T_{ant}	K	20.80	20.80	
Sky Noise Temperature	Tsky	K	4.78	4.78	
System Noise Temperature	T_s	K	25.58	25.58	
E_b/N_o		dB	4.36	4.84	
E_b/N_o required		dB	1.80	1.80	
Margin		**dB**	**2.56**	**3.04**	

COVERAGE AND SUNLIGHT ANALYSIS: EARTH STATIONS

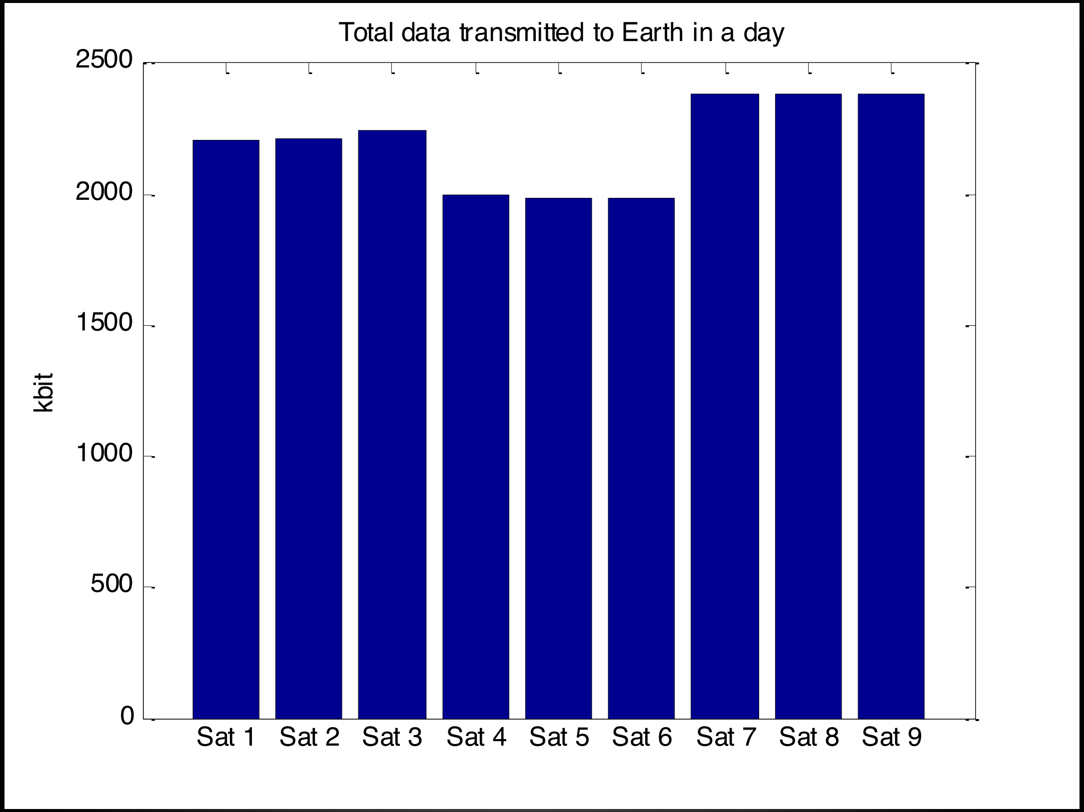
- For each satellite the coverage with respect to each of the 3 DSN stations is computed
- The coverage is considered only when the satellite is in sunlight
- The union of the three coverage sets is then used to compute the data rate profile







NETWORK CAPACITY: LONG DISTANCE (19 MBIT TOTAL)



LINK ANALYSIS: PROXIMITY LINK

Item	Symbol	Units	Downlink Worst Case	Downlink Best Case	Uplink Worst Case	Uplink Best Case
Transmitter Power	P	dBW	0.00	0.00	0.00	0.00
Line Loss/Waveguide Loss	L_l	dB	-0.50	-0.50	-0.50	-0.50
Transmit Antenna Gain (net)	G_t	dBi	0.00	0.00	0.00	0.00
Equiv. Isotropic Radiated Power	EIRP	dBW	-0.50	-0.50	-0.50	-0.50
Frequency	f	GHz	0.43	0.43	0.40	0.40
Receive Antenna Gain	G_r	dBi	0.00	0.00	0.00	0.00
Propagation Path Length	S	km	6,200.00	3,600.00	6,200.00	3,600.00
Free Space Loss	L_s	dB	-160.97	-156.25	-160.36	-155.64
Transmit Antenna Pointing Loss	L_{pt}	dB	-2.00	-2.00	-2.00	-2.00
Receive Antenna Pointing Loss	L_{pr}	dB	-2.00	-2.00	-2.00	-2.00
Ionospheric Loss	L_{ion}	dB	0.00	0.00	0.00	0.00
Atmospheric Loss (H2O and O2 losses)	L_{atmo}	dB	0.00	0.00	0.00	0.00
Loss due to Rain	L_{rain}	dB	0.00	0.00	0.00	0.00
Total Additional Losses		dB	-4.00	-4.00	-4.00	-4.00
Data Rate	R	bps	8,500.00	25,000.00	5,000.00	12,500.00
Antenna and Receiver Noise Temperature	T_{ant}	K	54.00	54.00	155.00	155.00
Sky Noise Temperature	Tsky	K	29.00	29.00	29.00	29.00
System Noise Temperature	T_s	K	83.00	83.00	184.00	184.00
E_b/N_o		**dB**	**4.65**	**4.68**	**4.10**	**4.84**
E_b/N_o required		**dB**	**1.80**	**1.80**	**1.80**	**1.80**
Margin		**dB**	**2.85**	**2.88**	**2.30**	**3.04**

COVERAGE ANALYSIS