S-Band CubeSat Communications with the Open System of Agile Ground Stations (OSAGS)

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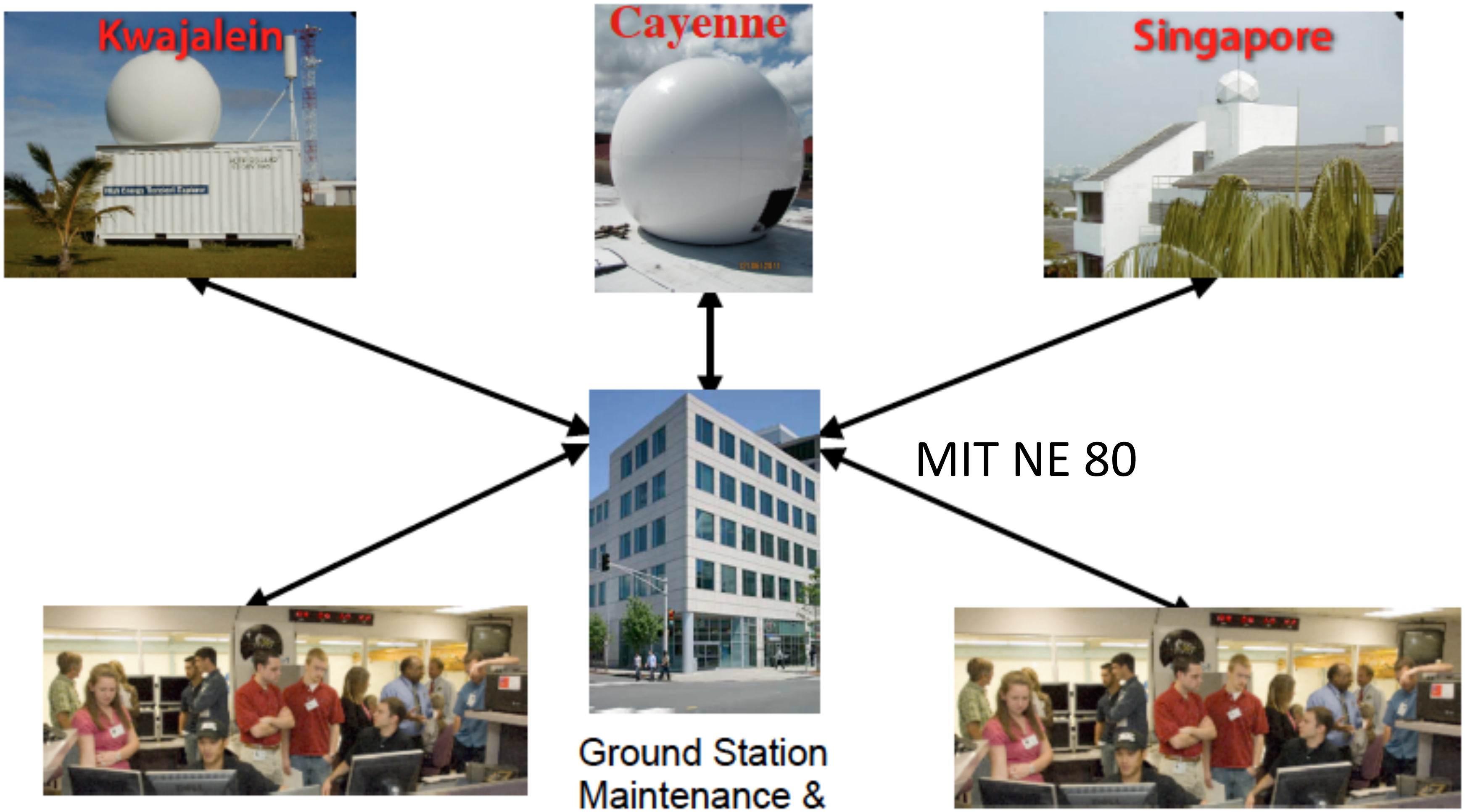
CubeSat Developer's Workshop
August 12, 2012

Overview

- OSAGS S-Band Ground stations
  - Location
  - Control center
  - Heritage
  - Parameters
  - Current status
- CubeSat Payload Telemetry System
  - Parameters
  - Status
- Operations and licensing

Location

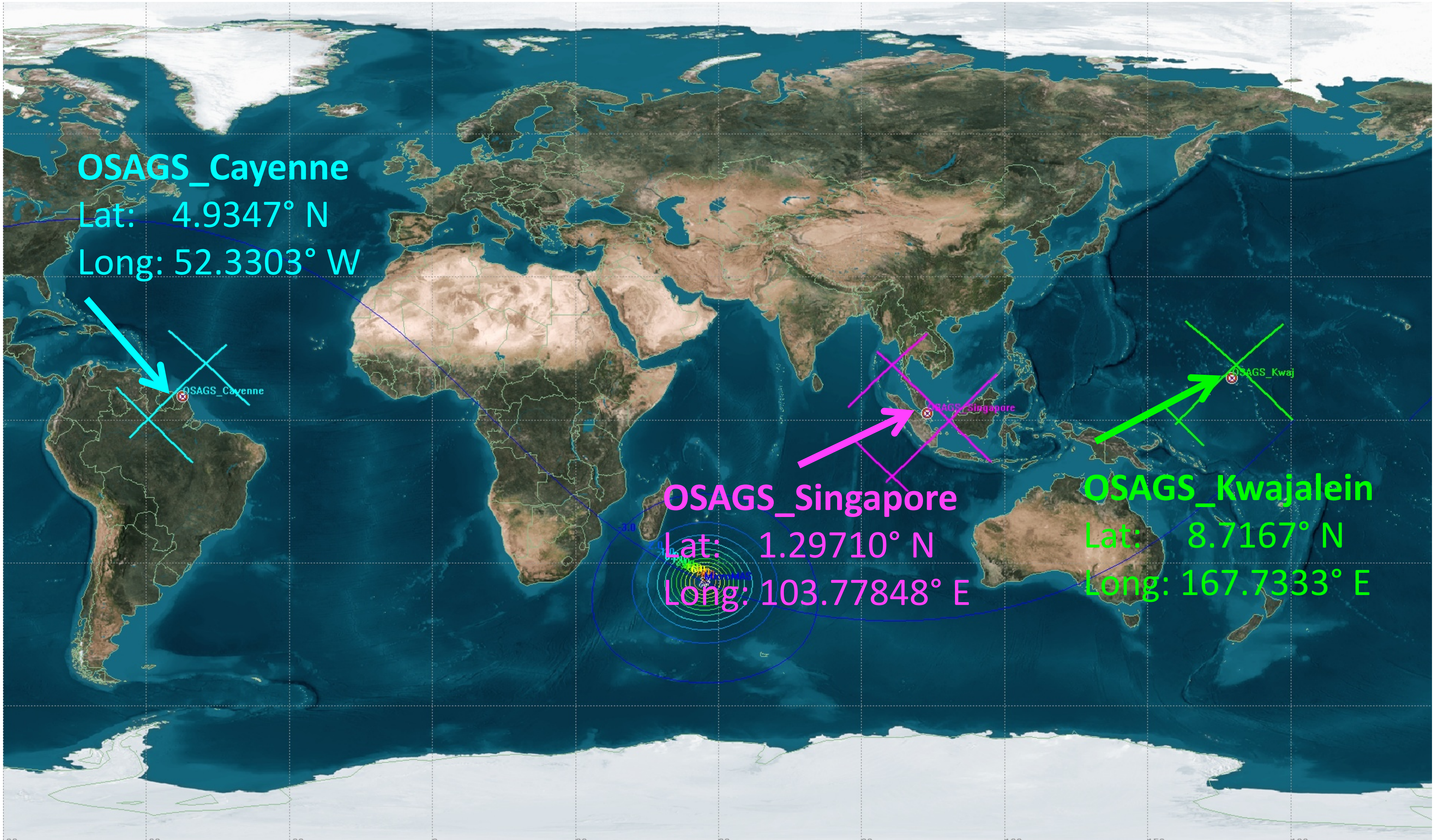


End-User #1
Mission Operations Center

Ground Station
Maintenance &
Management
Center (GSMMC)

End-User #2
Mission Operations Center

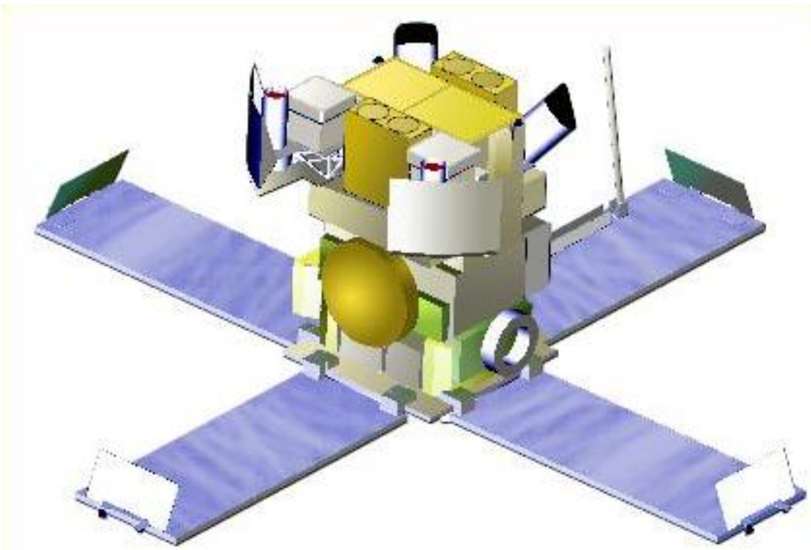
Location


OSAGS_Cayenne
Lat: 4.9347° N
Long: 52.3303° W
OSAGS_Cayenne
OSAGS_Singapore
Lat: 1.29710° N
Long: 103.77848° E
OSAGS_Singapore
OSAGS_Kwajalein
Lat: 8.7167° N
Long: 167.7333° E
OSAGS_Kwaj

OSAGS Heritage

- Ground stations originally successfully used to support the MIT HETE-2 mission
  - High Energy Transient Explorer (Oct. 2000)

- NASA SBIR with Espace to upgrade ground stations
  - Collaboration NASA ARC
  - Software defined radio
  - Available for nanosatellites and CubeSats



Ground Station Parameters

Parameter	Value	Units
Uplink Frequency	2.025 – 2.120	GHz
Downlink Frequency	2.200 – 2.300	GHz
Antenna Diameter	2.3	m
Antenna Gain	31	dBi
Polarization	RHCP	-
Transmit Power	15.44	dBW
Data Rate	< 3.5	Mbits/sec
G/T	6.9	dB/K

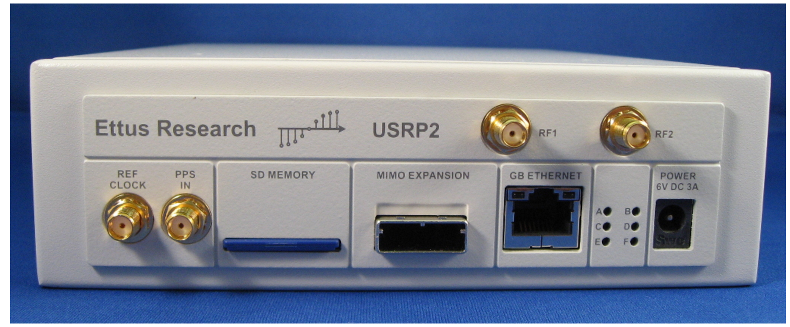
GS Link Budget Values

Parameter	Value	Units
Beamwidth	3.5	degrees
Efficiency	50	%
Back-lobe Gain	-30	dB
System Noise Temp	290	K
LNA Gain	0	dB
Antenna to LNA Loss	1	dB
LNA to Receiver Loss	0	dB
Pointing Loss*	1	dB

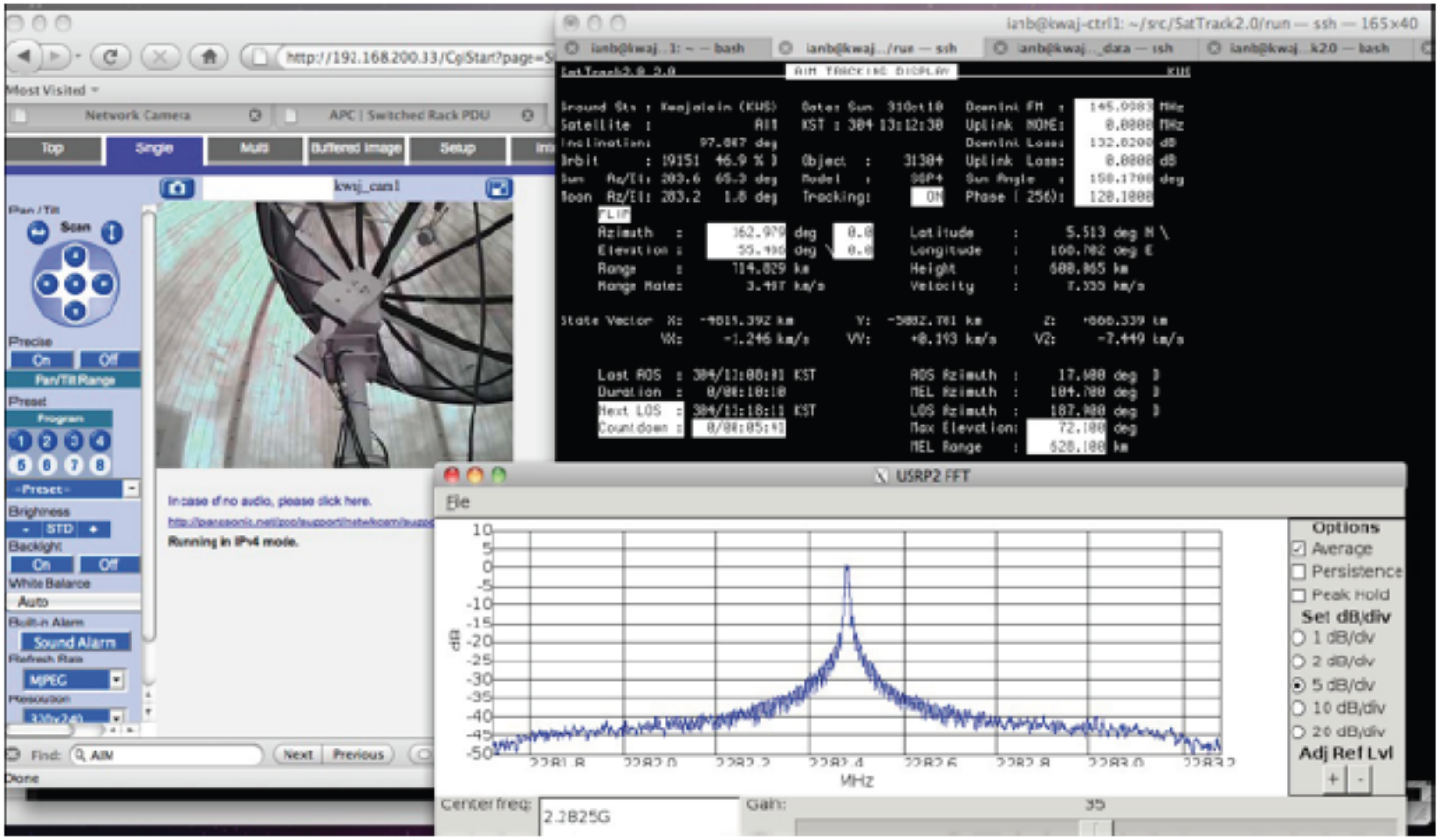
*pointing 30% of main lobe beamwidth

Upgrades in 2010-2011

- New:
  - 2.3 m antennas
  - Counterweights
  - Feed and feed arms
  - Diplexers (BPF)
  - LNA
  - 4 Ettus USRP2 **SDR** transceivers (redundancy)
- Reuses HETE-2 power amplifiers
- Can support several missions
  - 5 MHz NTIA S-band BW limit
  - Handles up to 3.5 Mbits/sec
- Remotely configurable



Interface

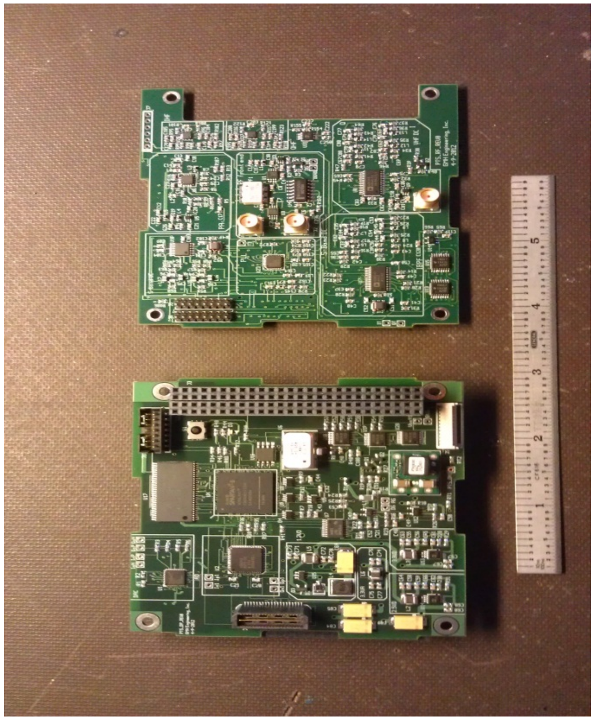


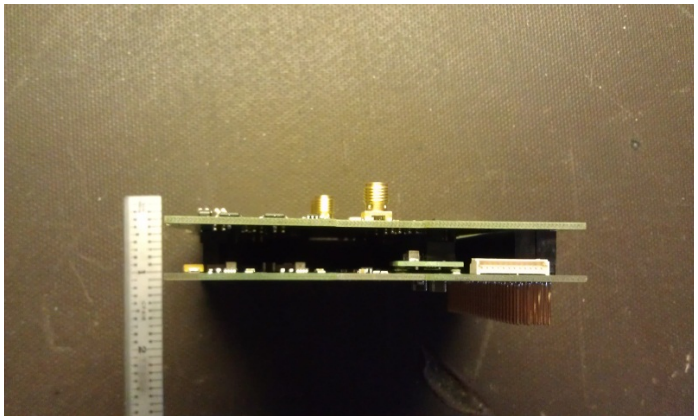
Network Camera
APC | Switched Rack PDU
Top
Single
Multi
Buffered Image
Setup
Precise
On
Off
Pan/Tilt Range
Preset
Brightness
Backlight
White Balance
Auto
Sound Alarm
MPEG
In case of no audio, please click here.
Running in IPv4 mode.
Find:
Next
Previous
Done
ianb@kwaj-ctrl1: ~/src/SatTrack2.0/run — ssh — 165x40
AIM TRACKING DISPLAY
USRP2 FFT
File
MHz
dB
Options
Average
Persistence
Peak Hold
Set dB/div
1 dB/div
2 dB/div
5 dB/div
10 dB/div
20 dB/div
Adj Ref Lvl
Center freq:
2.2825G
Gain:
35

S-Band Payload Telemetry System

- PTS
- RF Board + Digital Processing Board
  - 2 inputs, 2 outputs
  - Half-duplex

	Uplink	Downlink
Frequency	2.025-2.120 GHz	2.20-2.30 GHz
Data Rate	0.01 – 0.1 Mbps	0.01-1.0 Mbps
Power	2.0 W	3.6 W
Output Power	N/A	1.0 W
Modulation	BPSK, QPSK, OQPSK, CPFSK	
Standby Power: 0.75W		
Dimensions (LxWxH): 90.17mm x 95.89mm x 35mm		
Mass: 0.094kg		
Cost: $6000 per unit		





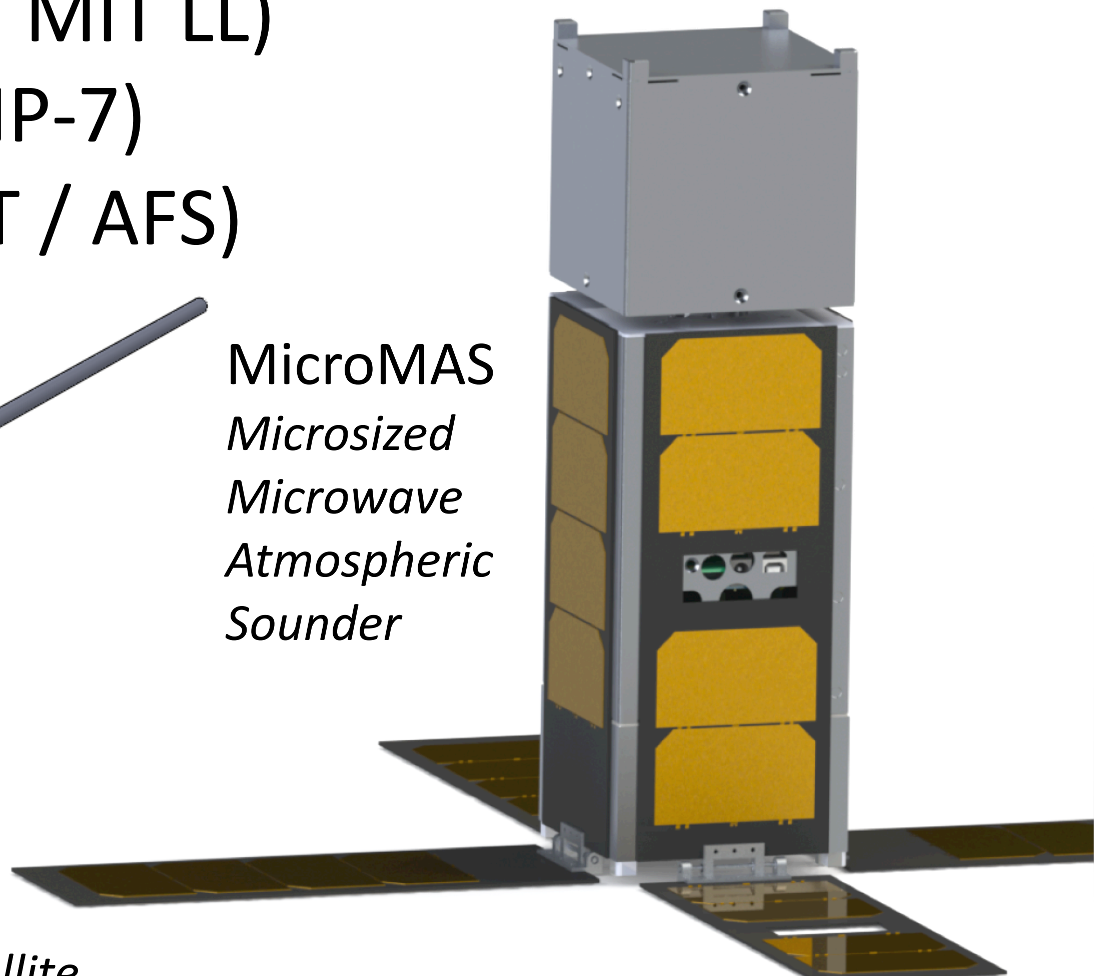
Additional HF/VHF Rx Capability

- Takes GPS clock input

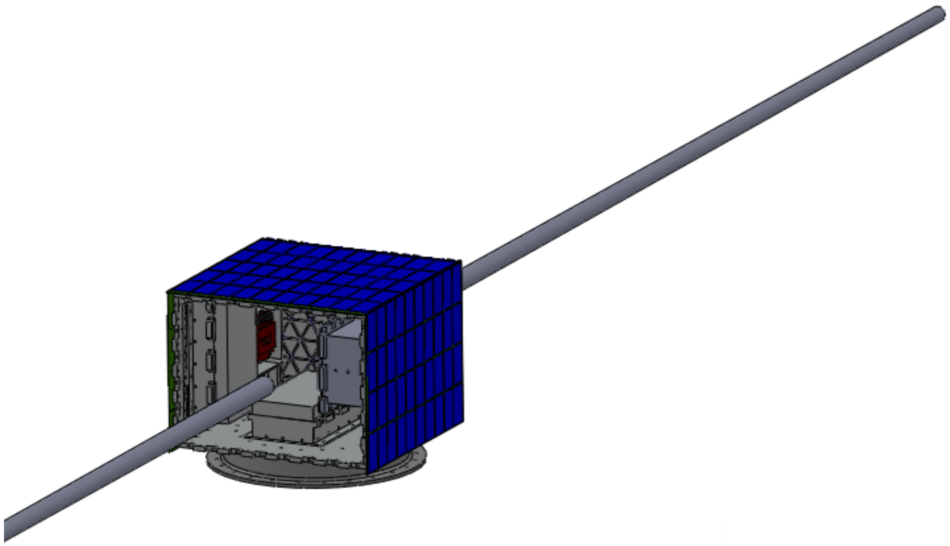
	HF Rx	VHF Rx
Frequency	100 kHz – 10 MHz selectable	60 MHz – 1 GHz selectable
Bandwidth	100 kHz – 10 MHz selectable	100 kHz – 10 MHz selectable
Sampling	14 bits I / Q up to 20 Ms/s	14 bits I / Q up to 20 Ms/s
Adjustable RF Gain	0 – 40 dB	0 – 44 dB
RF inputs	2	1
Power	1 W from 6 V supply	2.2 W from 6 V supply

MIT projects baselining PTS

- MicroMAS (MIT / MIT LL)
- TERSat (MIT / UNP-7)
- Mothercube (MIT / AFS)



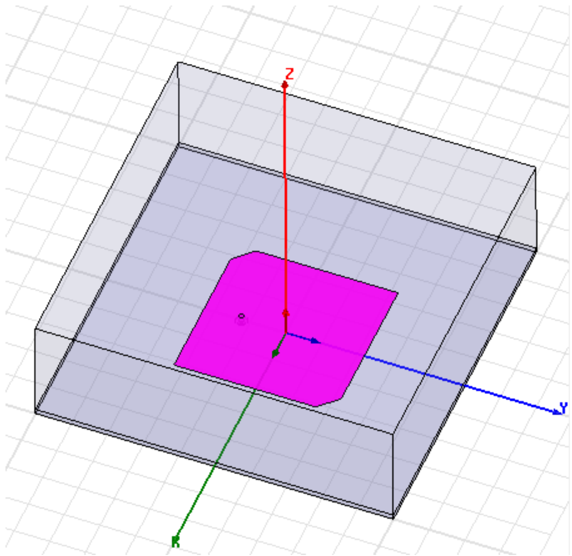
MicroMAS
Microsized
Microwave
Atmospheric
Sounder

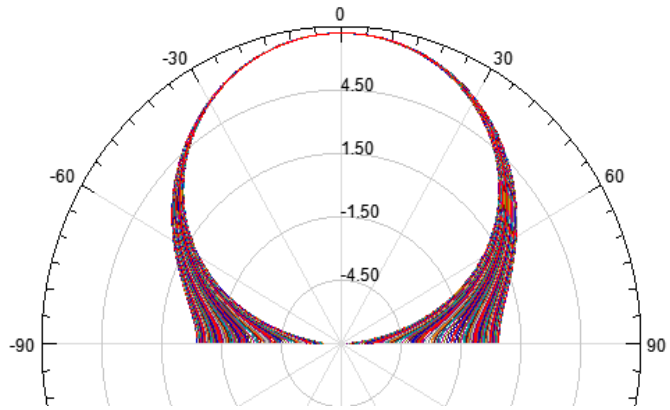


TERSat
Trapped Energetic Radiation Satellite

S-Band CubeSat Antenna Design

- Two custom patch antennas
  - Uplink, downlink
  - Truncated corners – RHC
  - Probe feed
    - SMA – coax – PTS board
  - Dielectric RT Duroid 5880
    - Thickness 1.57 mm
    - $\varepsilon_r = 2.2$
  - Mount on nadir facing body panels





S-Band CubeSat Antenna Design

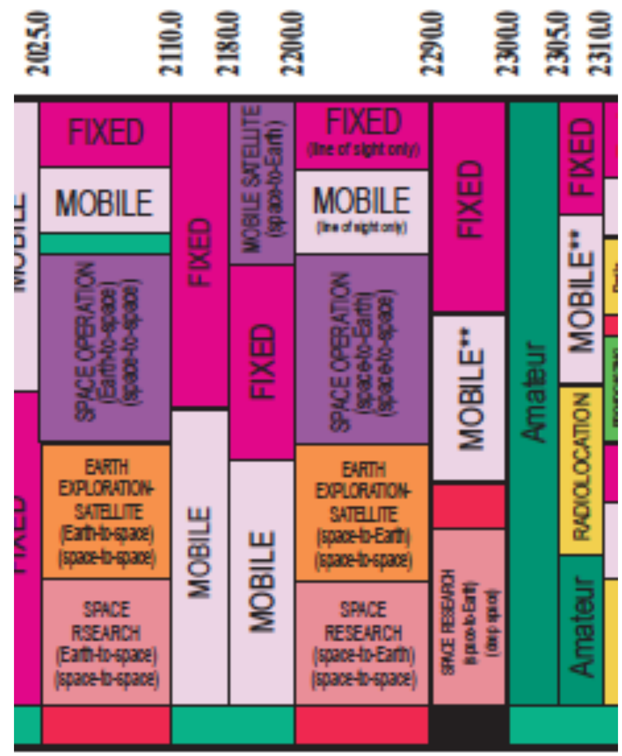
Parameter	Uplink Antenna	Downlink Antenna
Length	47 mm	43 mm
Corner Truncation	5.4 mm	4.9 mm
Center Frequency	2.088 GHz	2.27 GHz
Return Loss	-21.2 dB	-16.02 dB
Gain	7.20 dBi	7.45 dBi
Half-Power Angle	85 deg	84 deg
Bandwidth	38 MHz	35 MHz
Mass	11.2 g	11.08 g
Price	$350	$350

MicroMAS Link Budget S/C

- Frequency = 2.2 GHz
- Power = 0 dBW
- Antenna – Nadir Facing (Gaussian Gain Pattern)
- 3dB Beamwidth = 70°
- Main Lobe Gain = 7.4 dBi
- Efficiency = 50 %
- Polarization: RHCP
- Coded Data Rate: 694 kbps
- Information Rate: 347 kbps
- Modulation: OQPSK

Frequency Licensing

- 2.2—2.3 GHz S-band
- Gov’t. rights to spectrum
- Two approaches
  - DD-1494 with gov’t. sponsor
  - FCC Commercial Experimental License
- Foreign ground stations
  - OSAGS has established representatives at Singapore and Cayenne (France)



MicroMAS Coverage Study

Max P/L Data Rate to Bus & Required Storage Onboard Bus — ASSUME Constant 19.2 kbps — 7/20/2012 CBC

0°

		Gap	Access
300km	h = 300km, i = 0°	Gap	Access
	Mean (s)	2256.4	332.1
	Max (s)	2904.1	384.3
	Req P/L Rate (bps)	*19200*	
	Max P/L Rate (bps)	*44000*	
	Req. Storage (MB)	*18.50*	
400km	h = 400km, i = 0°	Gap	Access
	Mean (s)	2396.4	425.9
	Max (s)	3057.9	479.7
	Req P/L Rate (bps)	*19200*	
	Max P/L Rate (bps)	*52000*	
	Req. Storage (MB)	*22.25*	
500km	h = 500km, i = 0°	Gap	Access
	Mean (s)	2528.6	510.3
	Max (s)	3204.6	566.6
	Req P/L Rate (bps)	*19200*	
	Max P/L Rate (bps)	*58000*	
	Req. Storage (MB)	*25.63*	
600km	h = 600km, i = 0°	Gap	Access
	Mean (s)	2653.0	588.1
	Max (s)	3347.1	648.1
	Req P/L Rate (bps)	*19200*	
	Max P/L Rate (bps)	*62000*	
	Req. Storage (MB)	*28.13*	
700km	h = 700km, i = 0°	Gap	Access
	Mean (s)	2755.8	642.7
	Max (s)	3463.1	702.1
	Req P/L Rate (bps)	*19200*	
	Max P/L Rate (bps)	*65000*	
	Req. Storage (MB)	*30.63*	

30°

		Gap	Access
300km	h = 300km, i = 30°	Gap	Access
	Mean (s)	6442.2	282.3
	Max (s)	30314.9	412.0
	Req P/L Rate (bps)	*19200*	
	Max P/L Rate (bps)	*14500*	
	Req. Storage (MB)	*63.00*	
400km	h = 400km, i = 30°	Gap	Access
	Mean (s)	5579.3	346.5
	Max (s)	25229.3	501.7
	Req P/L Rate (bps)	*19200*	
	Max P/L Rate (bps)	*20250*	
	Req. Storage (MB)	*79.88*	
500km	h = 500km, i = 30°	Gap	Access
	Mean (s)	4921.2	398.7
	Max (s)	25842.9	584.8
	Req P/L Rate (bps)	*19200*	
	Max P/L Rate (bps)	*26000*	
	Req. Storage (MB)	*104.50*	
600km	h = 600km, i = 30°	Gap	Access
	Mean (s)	4170.2	414.4
	Max (s)	23049.7	663.1
	Req P/L Rate (bps)	*19200*	
	Max P/L Rate (bps)	*31100*	
	Req. Storage (MB)	*97.38*	
700km	h = 700km, i = 30°	Gap	Access
	Mean (s)	4452.9	497.6
	Max (s)	20865.7	715.5
	Req P/L Rate (bps)	*19200*	
	Max P/L Rate (bps)	*34800*	
	Req. Storage (MB)	*104.50*	

42°

		Gap	Access
300km	h = 300km, i = 42°	Gap	Access
	Mean (s)	8648.7	280.1
	Max (s)	30457.6	408.9
	Req P/L Rate (bps)	*19200*	
	Max P/L Rate (bps)	*10750*	
	Req. Storage (MB)	*58.00*	
400km	h = 400km, i = 42°	Gap	Access
	Mean (s)	7486.1	342.4
	Max (s)	31255.9	497.8
	Req P/L Rate (bps)	*19200*	
	Max P/L Rate (bps)	*15100*	
	Req. Storage (MB)	*72.75*	
500km	h = 500km, i = 42°	Gap	Access
	Mean (s)	6823.4	403.4
	Max (s)	26050.6	580.0
	Req P/L Rate (bps)	*19200*	
	Max P/L Rate (bps)	*19400*	
	Req. Storage (MB)	*105.88*	
600km	h = 600km, i = 42°	Gap	Access
	Mean (s)	5765.4	414.8
	Max (s)	26736.2	657.5
	Req P/L Rate (bps)	*19200*	
	Max P/L Rate (bps)	*23000*	
	Req. Storage (MB)	*92.63*	
700km	h = 700km, i = 42°	Gap	Access
	Mean (s)	6205.4	499.4
	Max (s)	27392.3	709.2
	Req P/L Rate (bps)	*19200*	
	Max P/L Rate (bps)	*25800*	
	Req. Storage (MB)	*102.50*	

60°

		Gap	Access
300km	h = 300km, i = 60°	Gap	Access
	Mean (s)	10953.0	273.7
	Max (s)	30476.2	402.7
	Req P/L Rate (bps)	*19200*	
	Max P/L Rate (bps)	*8250*	
	Req. Storage (MB)	*49.25*	
400km	h = 400km, i = 60°	Gap	Access
	Mean (s)	9589.5	337.3
	Max (s)	31241.6	490.1
	Req P/L Rate (bps)	*19200*	
	Max P/L Rate (bps)	*11750*	
	Req. Storage (MB)	*60.25*	
500km	h = 500km, i = 60°	Gap	Access
	Mean (s)	8374.6	365.1
	Max (s)	31984.8	570.8
	Req P/L Rate (bps)	*19200*	
	Max P/L Rate (bps)	*14600*	
	Req. Storage (MB)	*161.00*	
600km	h = 600km, i = 60°	Gap	Access
	Mean (s)	7290.7	404.6
	Max (s)	26835.6	646.7
	Req P/L Rate (bps)	*19200*	
	Max P/L Rate (bps)	*18100*	
	Req. Storage (MB)	*83.38*	
700km	h = 700km, i = 60°	Gap	Access
	Mean (s)	7719.5	478.9
	Max (s)	30099.6	697.5
	Req P/L Rate (bps)	*19200*	
	Max P/L Rate (bps)	*20200*	
	Req. Storage (MB)	*93.88*	

90°

		Gap	Access
300km	h = 300km, i = 90°	Gap	Access
	Mean (s)	12289.7	267.3
	Max (s)	30421.8	390.3
	Req P/L Rate (bps)	*19200*	
	Max P/L Rate (bps)	*7750*	
	Req. Storage (MB)	*41.13*	
400km	h = 400km, i = 90°	Gap	Access
	Mean (s)	10858.1	326.6
	Max (s)	41864.1	474.6
	Req P/L Rate (bps)	*19200*	
	Max P/L Rate (bps)	*10000*	
	Req. Storage (MB)	*46.38*	
500km	h = 500km, i = 90°	Gap	Access
	Mean (s)	9701.7	377.5
	Max (s)	37043.6	552.3
	Req P/L Rate (bps)	*19200*	
	Max P/L Rate (bps)	*13100*	
	Req. Storage (MB)	*91.00*	
600km	h = 600km, i = 90°	Gap	Access
	Mean (s)	8435.5	401.9
	Max (s)	29547.7	625.3
	Req P/L Rate (bps)	*19200*	
	Max P/L Rate (bps)	*15800*	
	Req. Storage (MB)	*96.75*	
700km	h = 700km, i = 90°	Gap	Access
	Mean (s)	8967.5	478.2
	Max (s)	27540.7	673.9
	Req P/L Rate (bps)	*19200*	
	Max P/L Rate (bps)	*17700*	
	Req. Storage (MB)	*82.75*	

* Req. P/L rate is the information rate output by the P/L assuming a constant 19.2kbps output rate from the P/L.

Max P/L (bps) is the **maximum amount of payload data (information) per second that can be **continuously** sent to the bus and downlinked without interruption.

***Req. Storage (MB) is the **maximum** amount of payload mission data that needs to be held for downlink at any given time assuming continuous payload operation @ the Max P/L Rate.

Assumptions:

MicroMAS Information Downlink Rate: 347kbps // Collection occurs during downlink time // **NO COMPRESSION**

Analysis shown is for 30 day period // Link Constraint: Eb/No > 7.5 dB, Elevation > 5°

MIT Campus Ground Station

- Effort to refurbish S-band dish on MIT building 54
  - Led by EAPS (Sara Seager), AeroAstro (Kerri Cahoy) and MIT Radio Club
  - 42.359758, -71.093556

MIT Hack the day Hitchhikers Guide to the Galaxy came out: “Don’t Panic”

Summary

- Open System of Agile Ground Stations
  - S-band
  - Increase data downlink from CubeSats
- Espace Payload Telemetry System
  - Fall 2012
- MIT Control Center; networked
- MIT Campus ground station refurbishment
- Contact:
  - fm@space.mit.edu (François Martel)
  - kcahoy@mit.edu

Acknowledgements

- MIT and MIT LL Microsized Microwave Atmospheric Satellite(MicroMAS) team
  - Especially IO, CC, and RK
- MIT Trapped Energetic Radiation Satellite (TERSat) team
- MIT Kavli Institute
- MIT and Aurora Flight Sciences Mothercube team

Related talks

- *Anne Marinan*
  - *Ad-hoc CubeSat Constellations*
    - *11:30 am Saturday, 8/11*
- Emily Clements
  - Trapped Energetic Radiation Satellite PQR (TERSat)
    - 9:25 am Monday, 8/13
- Bill Blackwell
  - Nanosatellites for Earth Environmental Monitoring: The MicroMAS Project
    - 3:15 pm Monday, 8/13
- Emily Clements
  - Trapped Energetic Radiation Satellite
    - 8:30 am Wednesday, 8/15
- Come say hi and visit our TERSat Booth!

Backup Slides

Abstract

- The Open System of Agile Ground Stations (OSAGS) consists of 3 equatorial S-band ground stations located in Kwajalein, Cayenne, and Singapore. The new OSAGS is the result of updates in 2010—2011 to the previously existing HETE-2 (High Energy Transient Explorer) ground stations by Espace, Inc., and was supported by the NASA Small Business Innovation Research (SBIR) program. OSAGS operates in the space exploration and operation bands of 2.025—2.0120 GHz uplink and 2.20—2.30 GHz downlink. The 2.3 m OSAGS ground stations can support numerous missions, handling communications requirements up to 3.5 Mbits per second. The system is based on Software Defined Radio (SDR) and the three ground stations are remotely configurable via the internet from a secure portal located on campus at MIT. The Espace, Inc. Payload Telemetry System (PTS) currently consists of a CubeSat-sized S-band transceiver, with additional HF/VHF/UHF receive capability. The prototype PTS units have been developed, and the first flight PTS units are scheduled for delivery in August 2012. We discuss applications of both the PTS and OSAGS for CubeSat missions, as well as operational considerations.

Link Budget

- Detailed link budget

MicroMAS Link Budget h=500 km i = 42°

Item	Symbol	Units	Downlink Worst Case	Downlink Best Case	Uplink Worst Case	Uplink Best Case	Comments
EIRP:							
Transmitter Power	P	dBW	0.00	0.00	15.44	15.44	0 dB is power output for Espace PTS Radio.
Transmitter Line Loss	L_l	dB	0.00	0.00	0.00	0.00	TBR: Attenuation and length of cable needed for accurate calculation (Assume negligible for now)
Transmit Antenna Gain (net)	G_t	dBi	1.00	7.40	31.68	31.68	TBR: Downlink transmit antenna gain is the requirement for onboard patch antennas. Antennas design is underway.
Equiv. Isotropic Radiated Power	EIRP	dBW	1.00	7.40	47.12	47.12	See SMAD eq. (13-5)
Receive Antenna Gain:							
Frequency	f	Ghz	2.25	2.25	2.08	2.08	Downlink Frequency: 2.25 GHz, mid point of 2.2 - 2.3 GHz range of OSAGS ground stations. Uplink Frequency is 2.075 GHz. Mid point of 2.025 - 2.120 GHz for OSAGS ground stations.
Receive Antenna Diameter	D_r	m	2.30	2.30	0.05	0.05	2.3 m diatmeter for OSAGS from Espace-OSAGS-PTS-Slides-2-21-2012.pdf from Francois Martel.
Receive Antenna efficiency	η	n/a	0.50	0.50	0.50	0.50	General Assumption
Receive Antenna Gain	G_r	dBi	31.68	31.68	6.00	-10.00	See SMAD eq. (13-18b)
Free Space Loss:							
Propagation Path Length	S	km	2,076.00	500.00	2,076.00	500.00	Based on Max Range from STK Analysis (Assuming a cutoff of Eb/No > 7.5, or Elevation > 5°)
Free Space Loss	L_s	dB	-165.84	-153.47	-165.13	-152.77	See SMAD eq. (13-23b)
Transmission Path and Pointing Losses:							
Transmit Antenna Pointing Loss	L_{pt}	dB	0.00	0.00	-1.00	0.00	Assume no antenna pointing loss on S/C since antenna is always nadir facing and does not point to the ground station.
Receive Antenna Pointing Loss	L_{pr}	dB	-0.50	-0.50	-0.50	0.00	Assumed based on conversations with OSAGS engineer.
Ionospheric Loss	L_{ion}	dB	-1.00	0.00	-1.00	0.00	Best: Assumed 0 to match STK simulation. Worst: Based on 3 years of atmospheric attenuation research prior to CASTOR program (CASTOR link budget)
Atmospheric Loss (H2O and O2 losses)	L_{atmo}	dB	-0.34	-0.34	-0.34	-0.34	Based on 3 years of atmospheric attenuation research prior to CASTOR program (CASTOR link budget)
Loss due to Rain	L_{rain}	dB	-2.00	-0.01	-2.00	-0.01	Based on 3 years of atmospheric attenuation research prior to CASTOR program (CASTOR link budget)
Demodulator Loss	L_{dmd}	dB	-0.15	0.00	-0.15	0.00	"derived from generic communication knowledge" (CASTOR link budget). TBR - Plan to Close loop with PTS Designer
Splitter Loss	L_{spl}	dB	0.00	0.00	0.00	0.00	Current MicroMAS design uses two patch antennas, one for uplink and one for downlink.
Implementation Loss		dB	-0.50	0.00	-2.00	-0.50	Best: Assumed 0, Worst: Assumed -2dB for OSAGS, -0.5dB for MicroMAS
Total Additional Losses		dB	-4.49	-0.85	-6.99	-0.85	
Data Rate:							
Data Rate	R	bps	694,444.00	694,444.00	25,600.00	25,600.00	Espace PTS max downlink data rate is 1 Mbps. Max uplink frequency is 0.1 Mbps. Original data downlink calculations were done with 115,200 bps, but MicroMAS will need as high a data rate as possible
Data Rate	10 log(R)	dBbps	58.42	58.42	44.08	44.08	
Boltzman's Constant:							
Boltzman's Constant	10 log(k)	dBW/(Hz*K)	-228.60	-228.60	-228.60	-228.60	
System Noise Temperature:							
Antenna Noise Temperature	T_{ant}	K	290.00	290.00	340.00	340.00	Conservative Estimate Uplink: per Alessandra's suggestions (290K from Earth + 50K from Cosmic Background = 340K)
Receiver Noise Temperature	T_r	K	0.00	0.00	0.00	0.00	
System Noise Temperature	T_s	K	290.00	290.00	340.00	340.00	Conservative Estimate
System Noise Temperature	10 log(T_s)	dBK	24.62	24.62	25.31	25.31	Conservative Estimate
E_b/N_o		dB	7.91	30.31	40.20	42.70	See SMAD eq. (13-14)
E_b/N_o required		dB	7.50	7.50	7.50	7.50	Required for BER = 10^{-5}. An Eb/No of 7.5 will yield a BER = 10^-5. This assumes no coding gain. Once we take credit for the coding gain, the numbers should get better.
Margin		dB	**0.41**	**22.81**	**32.70**	**35.20**	Looking for a value greater than or equal to 3dB, which we achieve once we take credit for the coding gain of approx 5.5dB (not shown here).

STK Link Budget Parameters

- Baseline Scenario Assumptions
  - h = 500km, T = 94.8 minutes
  - i = 42°
  - Scenario Time Period: 30 Days
- Rain Model: ITU-R P618-9
  - Rain Outage: 0.1%
  - Surface Temp: 24 ° C
- Atmospheric Absorption Model
  - Water Vapor: 7.5g/m3
  - Surface Temp: 24 ° C

30 Day Ground Trace