Nanosatellite Communications at MIT

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Ground Stations for Nanosatellites Workshop
April 23, 2013

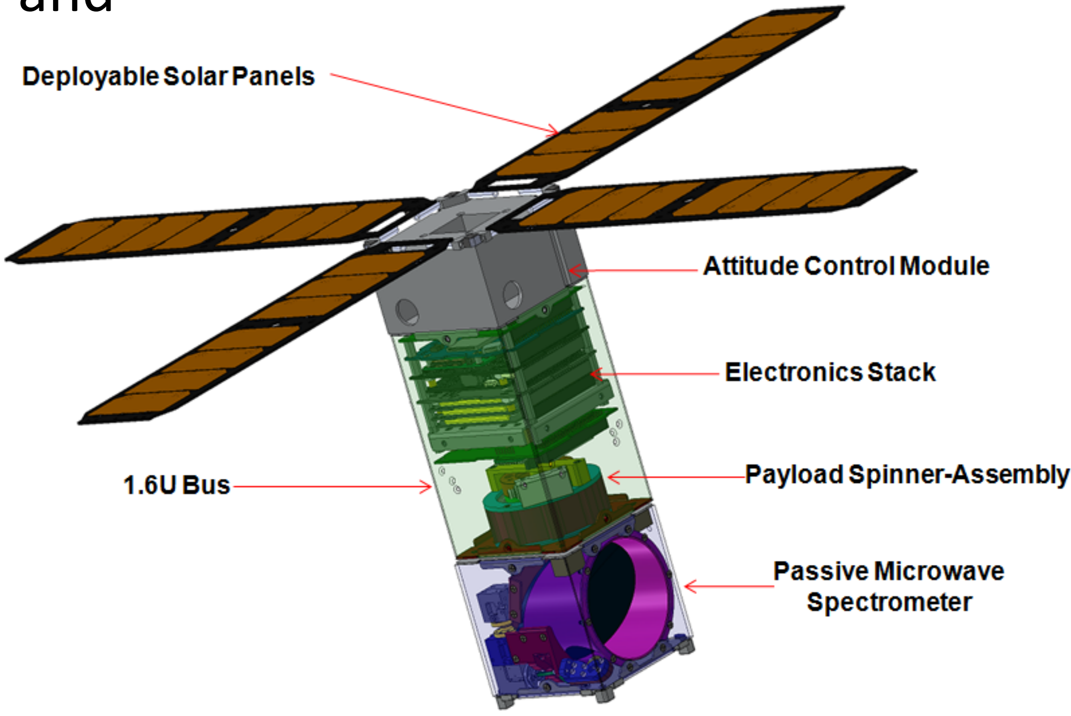
Outline

- MicroMAS comm. plan, ground stations
  - L3Com Cadet, Wallops
- MIT campus ground stations
  - UHF/VHF and S-band
- Distributed Satellite System (Mothercube)
  - E-space Payload Telemetry System, OSAGS
- General needs

MicroMAS Overview

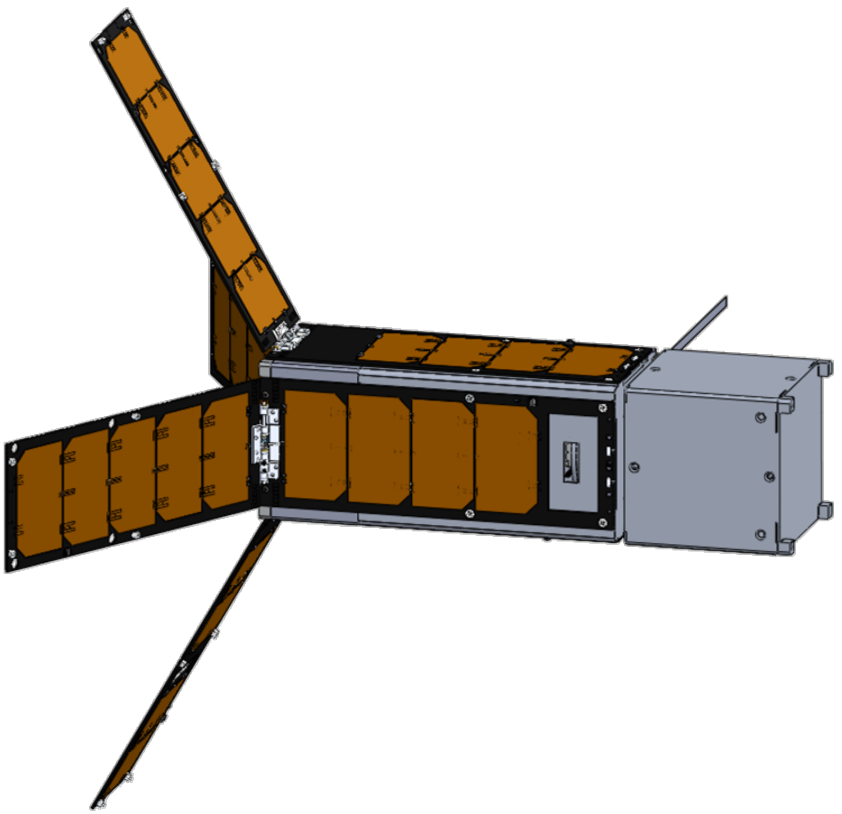
Launch a Single Satellite to Demonstrate the Core Element of a Transformative Sensing Architecture

- All-weather measurements of atmospheric temperature and precipitation
- High resolution 118-GHz spectrometer
- Dual-spinning 3U CubeSat



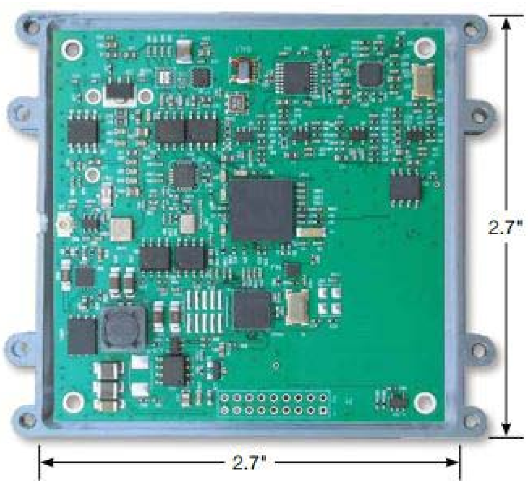
MicroMAS Objectives

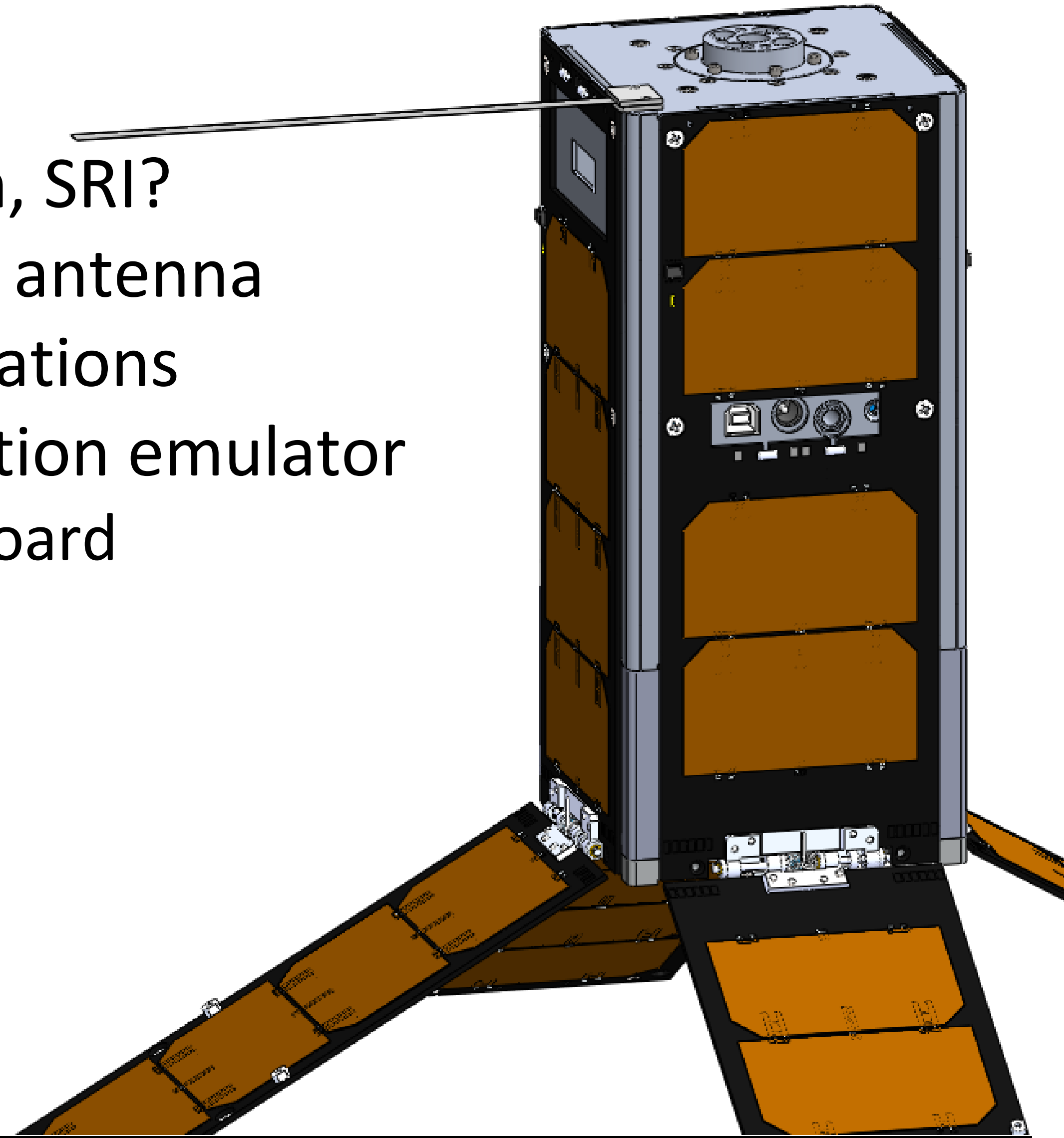
- Focus on hurricanes + severe weather
- 500-km orbit altitude
- 25-km pixel diameter at nadir (cross-track scan out to ±50°)
- 1 K absolute accuracy
  - 0.3 K sensitivity
- Geolocation error less than 10% of pixel diameter
- 20 kbps (avg) downlink
- 12 W (avg) power
- One year mission lifetime
- 2014 launch by NASA



MicroMAS Status

- L3Com Cadet modem
- Wallops ground station, SRI?
- Single? monopole tape antenna
- Preliminary HFSS simulations
- Assembling ground station emulator
  - USRP, CC1101 eval board



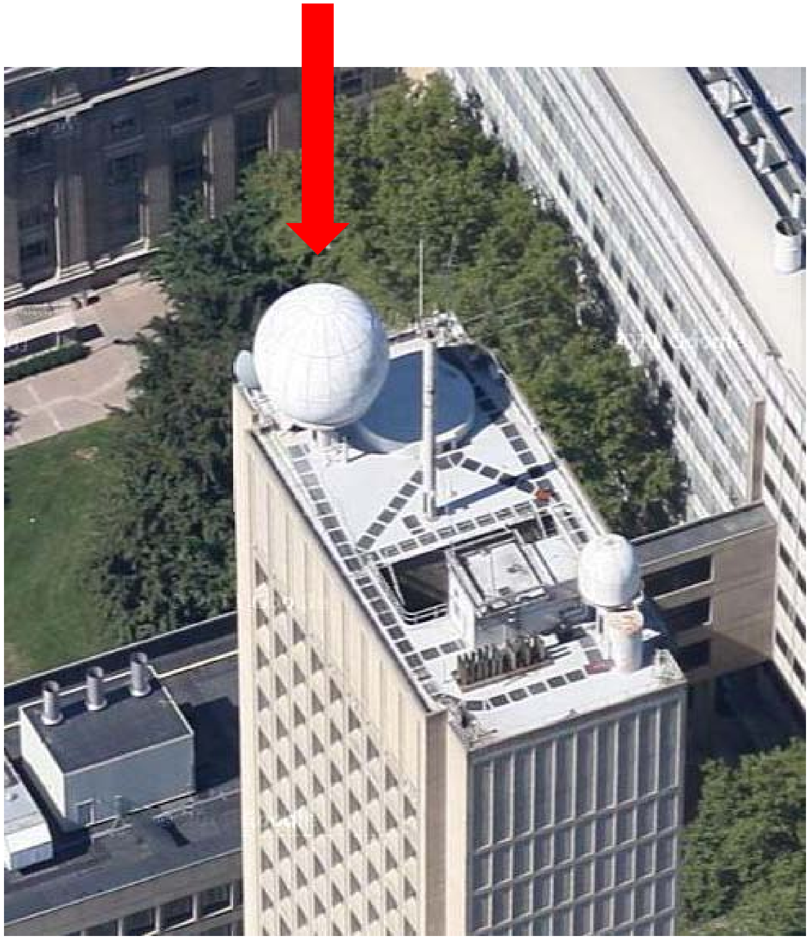


MIT Campus Ground Stations

- UHF/VHF Station
  - MIT Radio Society is assembling a “standard” ham band UHF/VHF station
  - Two AZ-EL steerable Yagi antennas
  - Undergoing final integration this spring
  - Located at W1MX station on Walker Memorial
- S-Band Station
  - Green Building 5.5 m dish
  - A much bigger project…

Green Dish: Ancient History

- 5.5 meter (18 ft) dish
- Originally installed for weather radar research
- Pedestal is World War 2 surplus SCR-584
- Two rounds of modifications
  - Bigger dish, radome (~1965)
  - Computer control (~1985)



Green Dish Details

SCR-584 Pedestal

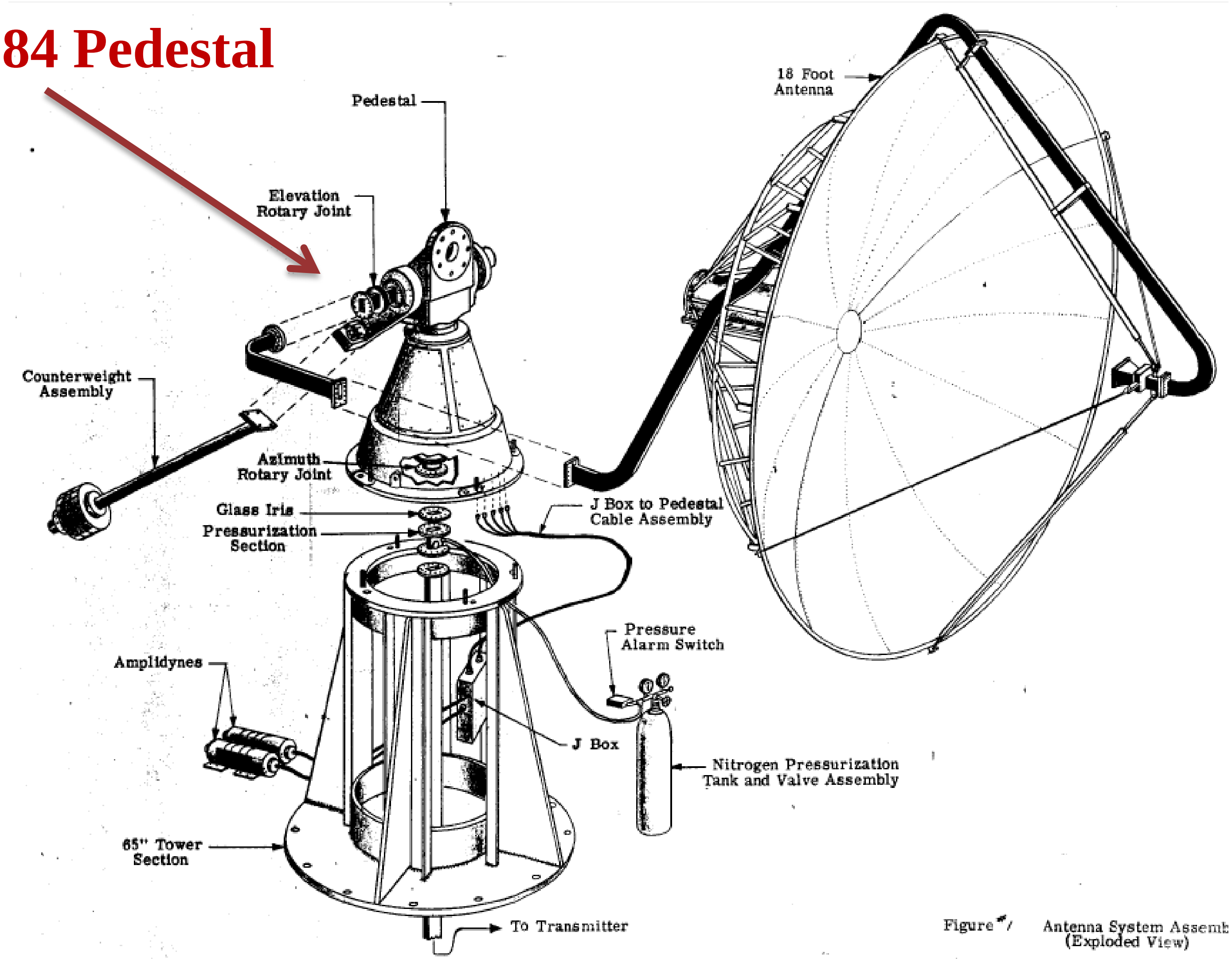


Figure #1 Antenna System Assemb (Exploded View)

Green Dish: Recent History

- MIT Radio Society gained access to the dish ~2005
  - Completed minor repairs, "changed oil"
  - Managed to slew the dish
  - Added offset CP feeds for 2304 MHz and 1296 MHz
- Primary feed is not useful
  - RG-48/U waveguide (2.6 – 4.0 GHz)
  - Badly corroded due to loss of N^2 purge
- Semi-functional, but certainly not reliable
  - Concerns about state of drive train (planetary gears, bearings, etc.)
  - Ancient drive electronics (amplidynes)

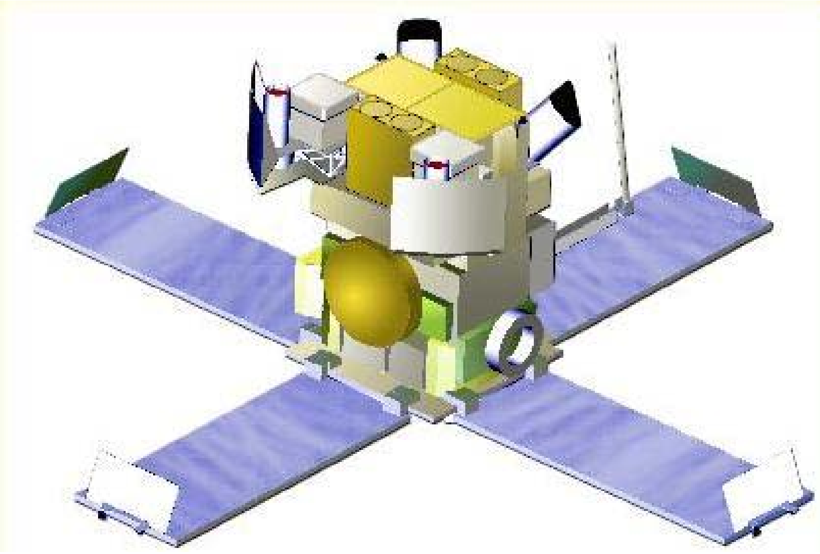
“Refurbishing” Part 1

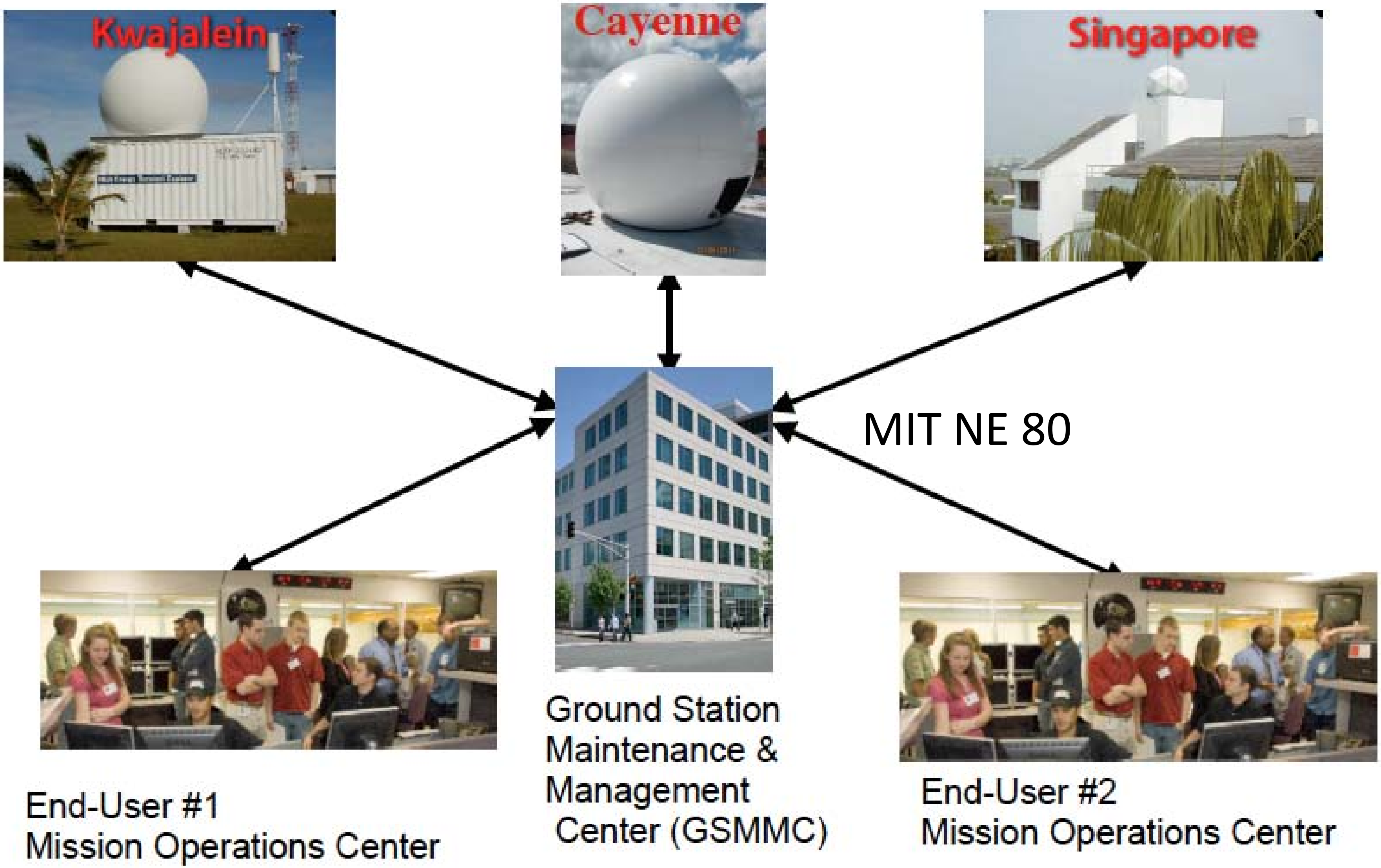
- Initial evaluation of dish by experts from Haystack, MIT Lincoln Lab, contractors
- Consensus
  - Robust hardware, internal inspection required
  - Drive train components (gears & bearings) could be expensive to replace
  - Try to get another SCR-584 to scavenge
- Where to find another SCR-584?

SCR-584 Found!

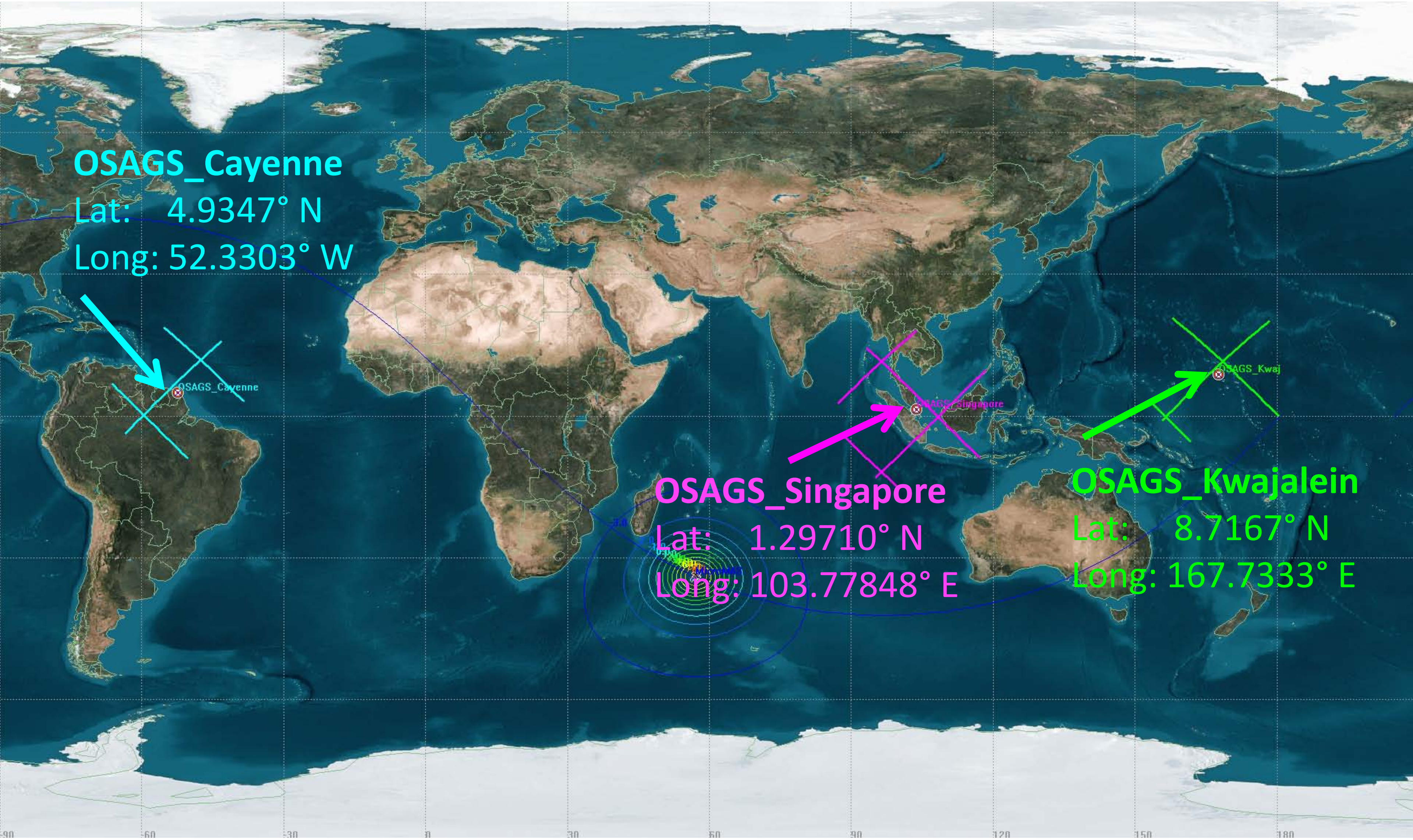
OSAGS Heritage

- OSAGS = Open System of Agile Ground Stations
- 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




Kwajalein
Cayenne
Singapore
MIT NE 80
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_Kwajalein
Lat: 8.7167° N
Long: 167.7333° E
OSAGS_Kwaj

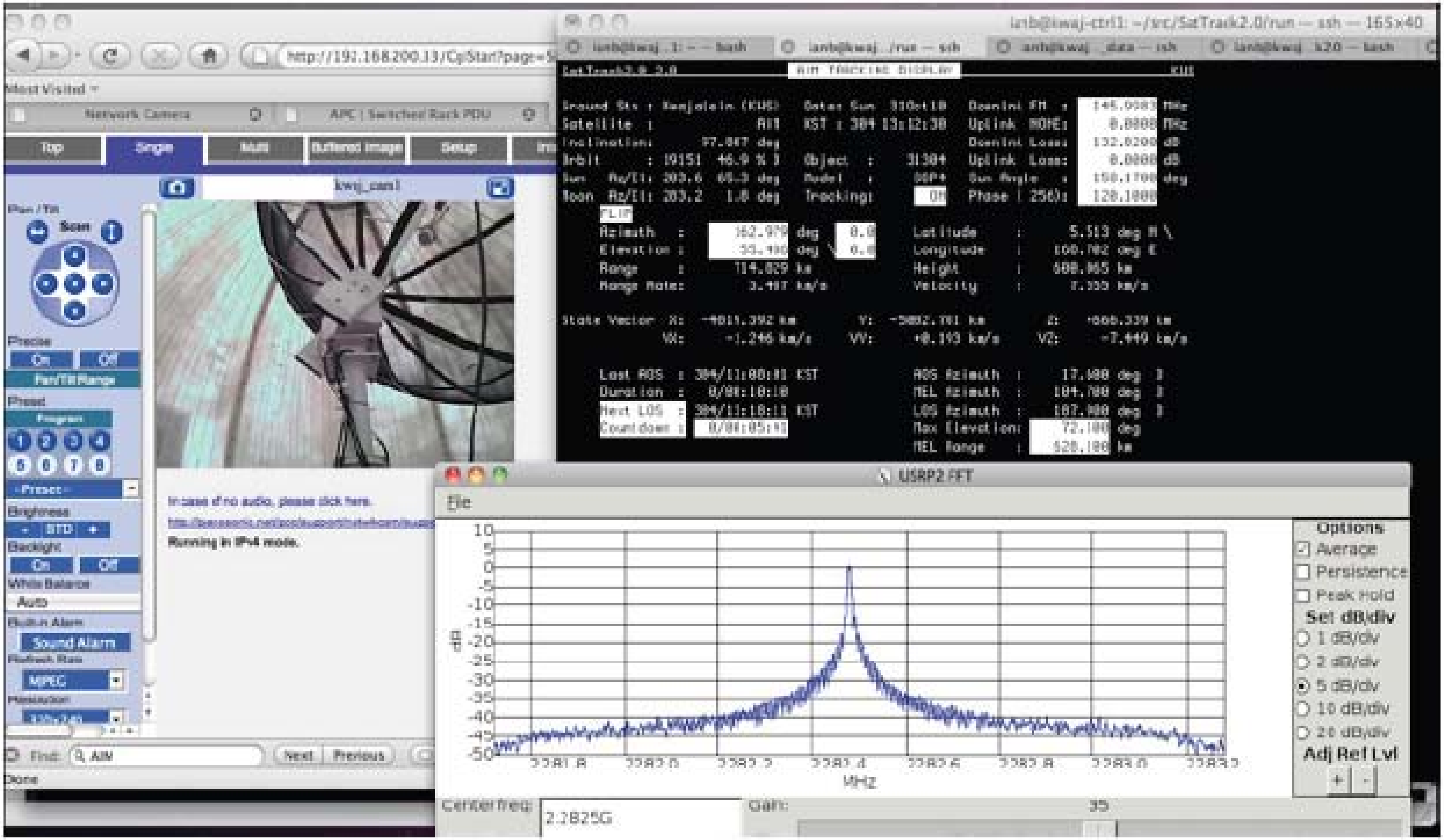
Ground Station Parameters

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

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

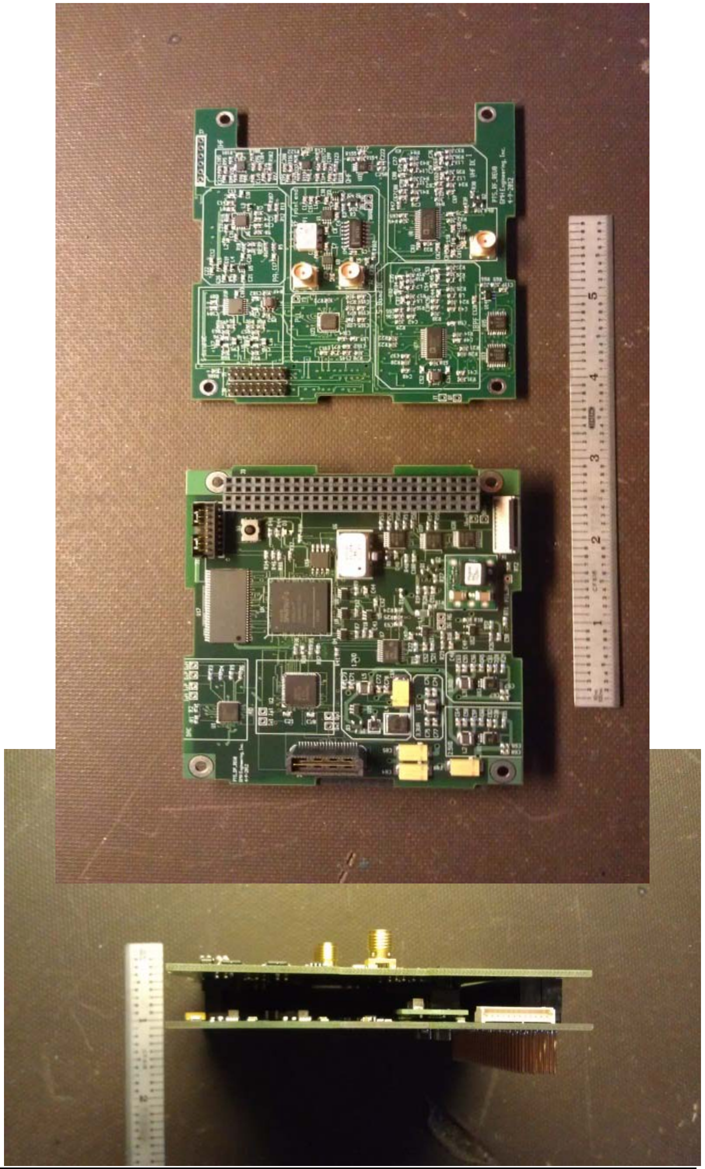
Interface


Network Camera
APC | Switched Rack PDU
Top
Single
Multi
Buffered Image
Setup
kwj_cam1
Preset
Brightness
Backlight
White Balance
Sound Alarm
In case of no audio, please click here.
Running in IPv4 mode.
Find:
Next
Previous
Done
SatTrack2.0 2.0
Satellite
Orbit
Azimuth
Elevation
Range
Range Rate
Latitude
Longitude
Height
Velocity
Last AOS
Duration
Next LOS
Count down
AOS Azimuth
MEL Azimuth
LOS Azimuth
Max Elevation
MEL Range
USRP2 FFT
File
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
MHz
dB
Center freq:
2.2825G
Gain:
35

S-Band Payload Telemetry System

- PTS = Payload Telemetry System
- 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		



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

General Needs at MIT

- MicroMAS
  - Ground station emulator
  - Testing, testing, testing
  - Mission data handling design from DICE?
- Licensing process ambiguity / schedule risk
- Green dish refurbishment
  - Grease monkey / gear head
  - New drive controls, feed system

Acknowledgements

- Utah State University
- SRI
- Haystack Observatory
- MIT Lincoln Lab
- MIT Radio Society
- Aurora Flight Sciences
- E-Space
- Dr. Sara Seager

Backup Slides

OSAGS Heritage

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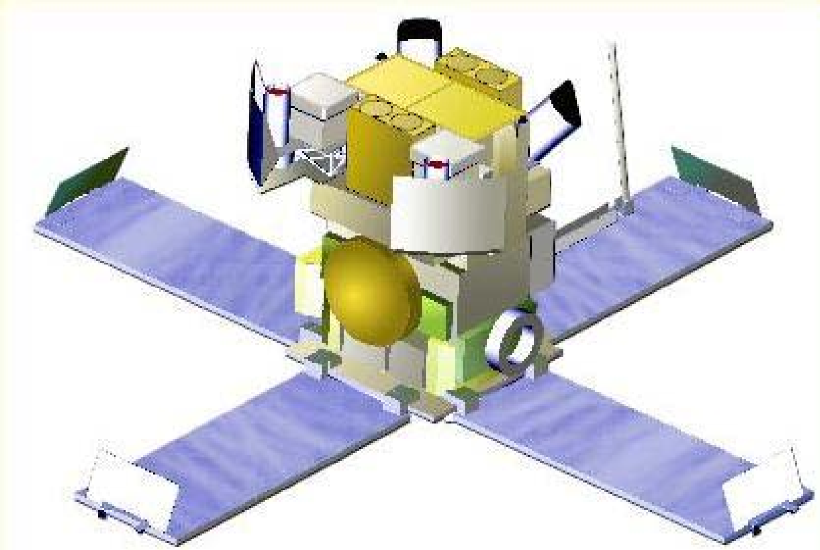


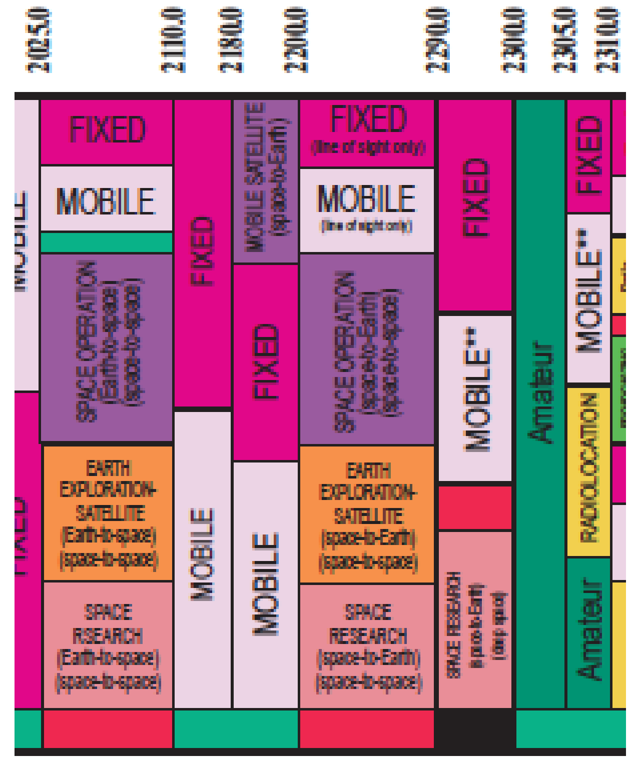
GS Link Budget Values

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

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)



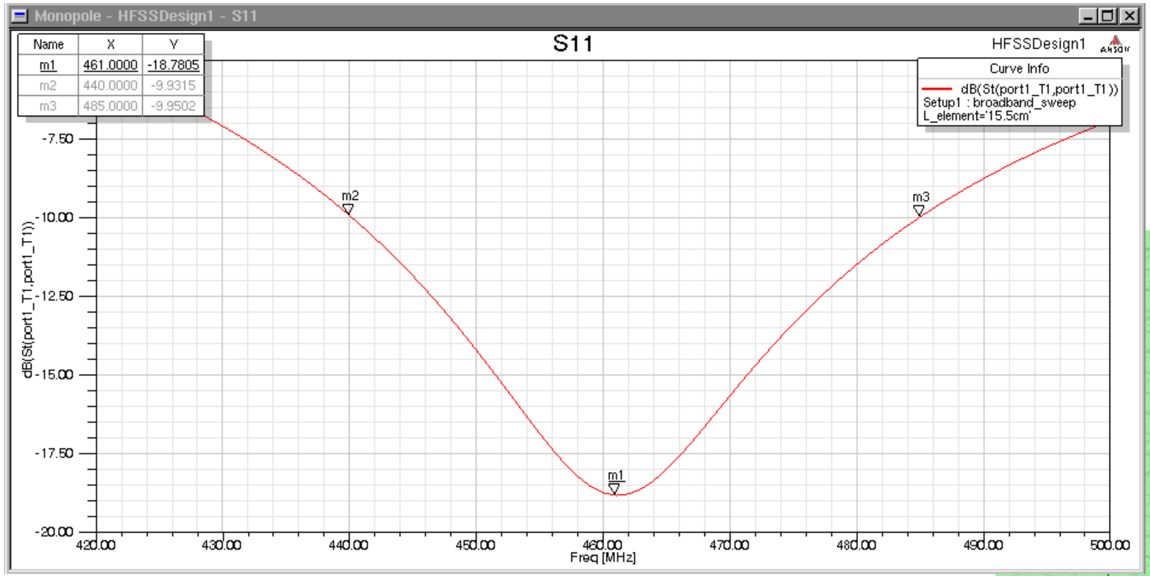
Link Budget

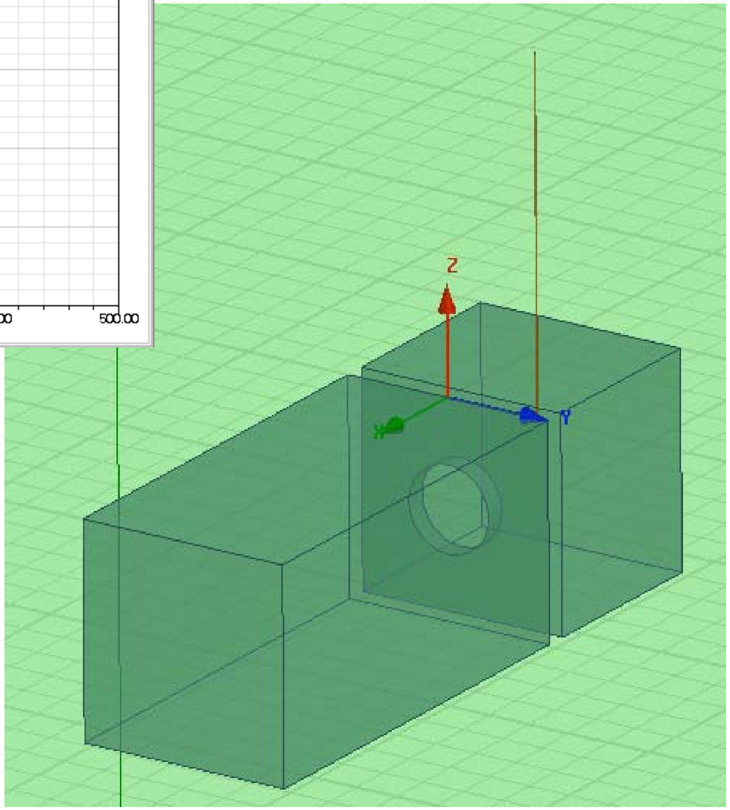
- Detailed link budget

MicroMAS Link Budget h=500 km i = 42°

Item	Symbol	Units	Downlink		Uplink		
			Worst Case	Best Case	Worst Case	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).

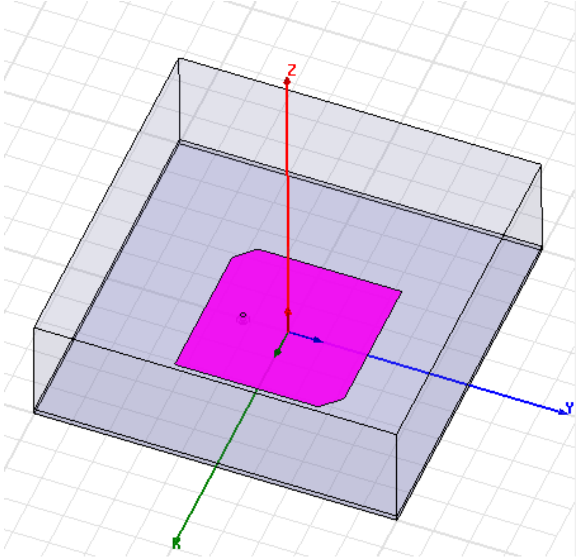
MicroMAS HFSS Model

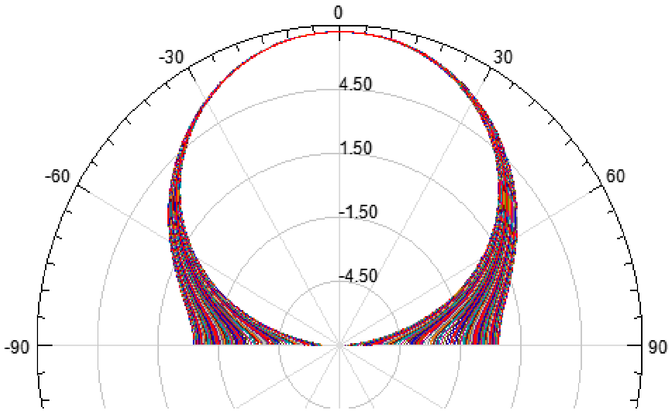




S-Band CubeSat Antenna Design

- 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