Solar Imaging Radio Array (SIRA)

Data Systems
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Topics

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Overview

- **Use X-Band for Command/Telemetry**
  - 14m ground terminal in Greenbank W VA (NRAO)
  - Sequentially dump each of 16 Microsats for 25 minutes by either on-board stored commands or ground command @ 8 Mbps
- **Use DSN for Launch Phase Support**
- **Use UHF for intersatellite ranging**
- **Use VHF for intersatellite timing**

Driving Requirements & Assumptions

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- **Launch: October 1, 2009**
- **Mission Life: 2 year required, 4 year goal**
- **Orbit:**
  - Distant Retrograde Orbit (DRO) at ~500,000 Km from Earth
  - Orbit inclination relative to the ecliptic should be approx 20 degrees
- **Pointing Type: 3-axis stabilized**
- **Launch Vehicle: Delta II**
- **16 Microsats in a spherical 25 Km constellation**
- **Intersatellite ranging & timing**
  - Ranging at 3m accuracy
  - Timing accuracy at 5 microsec
- **Maximize the amount of science data collected**
- **Housekeeping rate = 2 Kbps**
- **CCSDS @ 15%**

Driving Requirements & Assumptions

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- **Data storage = 20 Gbits / spacecraft /(2 days)**
- **Latency: 24 hours from collection to completion of level zero processing**
- **BER = 10-5**
- **16 identical spacecraft**
  - Relative timing to 5 microsec between all s/c
  - Knowledge of Microsat positions to 3 m
- **Power/Weight/Cost are critical**
- **Limited redundancy**
- **Dumps commanded from ground**
- **Infrequent commanding**
- **Assumed to be Space Science mission (vs Earth Science)**

Selected Configuration & Rationale

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- **Each of 16 Microsat within a sphere of 25 km will collect data for 24 hours**
  - Each Microsat will dump data to a ground terminal in Green Bank, West Virginia, sequentially at the same frequency for approx 25 minutes each
  - Ranging for each Microsat with the ground will be done for 5 minutes every 10 days with the DSN at X Band
- **The total amount (all 16 Microsats) of science data collected will be 20 Gbytes/day**
  - Instrument Data Collection Rates: 1.92 Mbps average (over 24 hours less 25 minutes when dumping)
  - Data Rate Per Microsat: ~120 kbps
  - Merged with housekeeping at 2 kbps
  - CCSDS overhead of 15%
  - Reed-Solomon encoded
- **X-Band will be used for command & telemetry via a HGA for science dumps**
  - X-Band transponders at 8 watts RF
  - 0.6 M fixed mounted HGA
  - Spacecraft will always be pointed so that the HGA is pointed toward the ground terminal
  - Telemetry rate at 8 Mbps
  - 25 minutes/day needed to dump each Microsat
  - Command rate at 2 Kbps with 0.01 watts of power

Selected Configuration & Rationale

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- **X-Band backup for emergencies thru Omni's**
  - Telemetry at 4 Kbps/Command < 1 bps
  - Command at 2 Kbps from the DSN 34m
- **Ranging between the 16 Microsats will be done via a UHF tone ranging system**
  - Tone frequencies at approx 0.35,2.83,39.68 & 277.78 Khz
  - All Microsats will have the capability to transmit and receive a single carrier frequency
  - This system will use 0.1 watt of RF power with omni antennas
- **1 Mbps timing signal will be transmitted via VHF from a Master Microsat to the others for relative timing correlation between the Microsats**
  - Three Microsats will be designated as Masters (for redundancy) with the ability to transmit and receive the same frequency to the other 15 Microsats

Selected Configuration & Rationale

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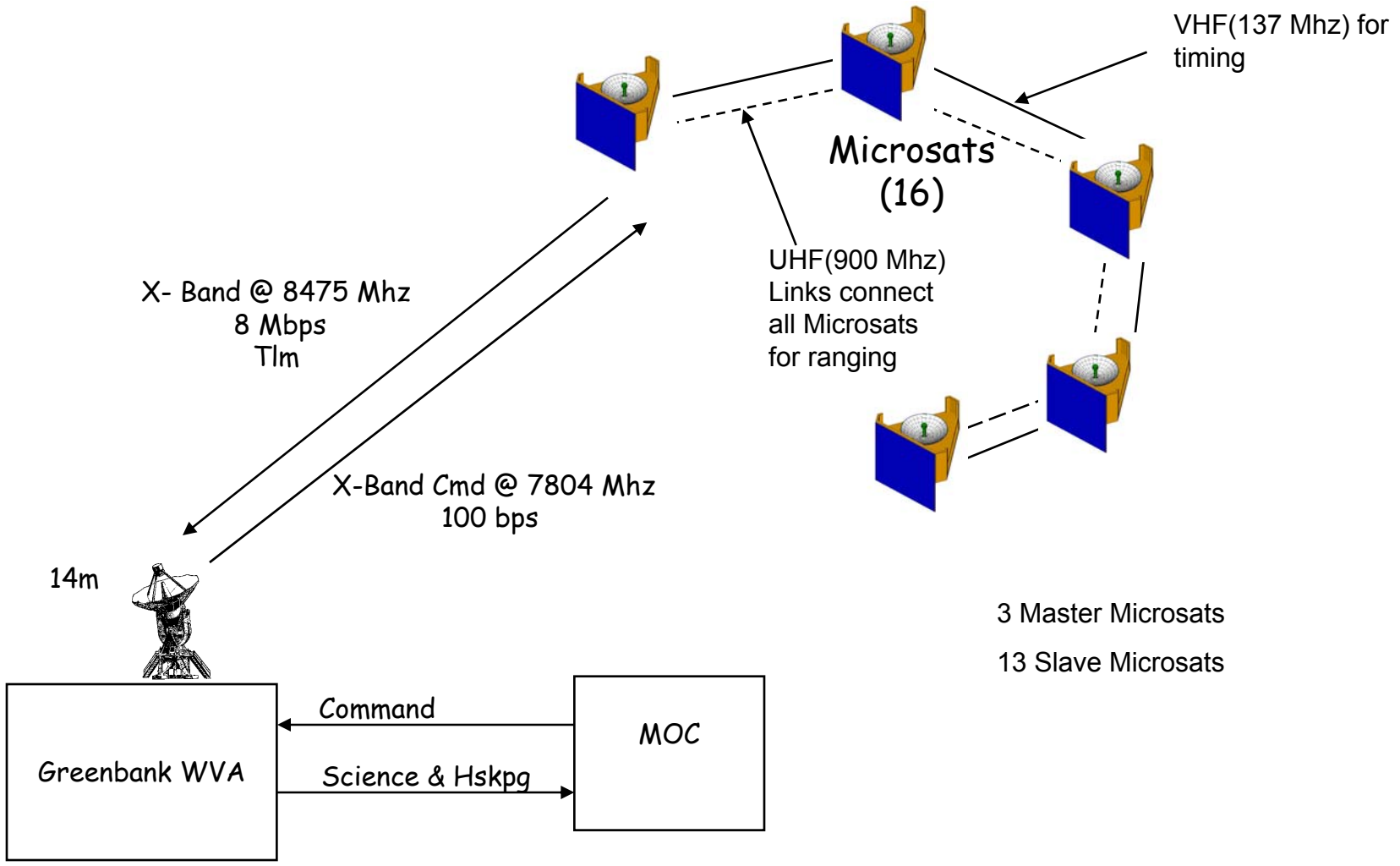

Selected Configuration (3 Masters)

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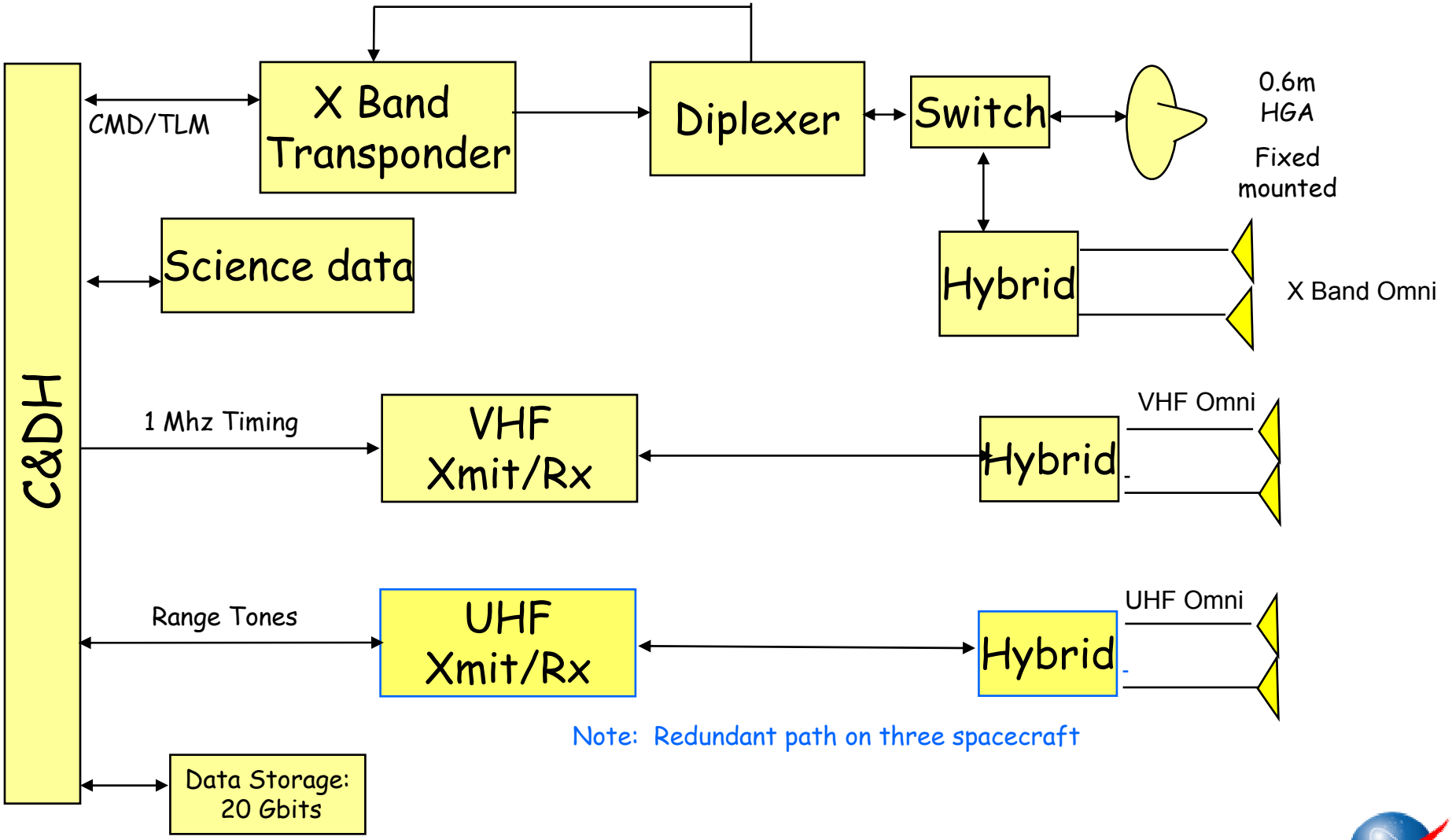

Note: Redundant path on three spacecraft

Selected Configuration (13 Slaves)

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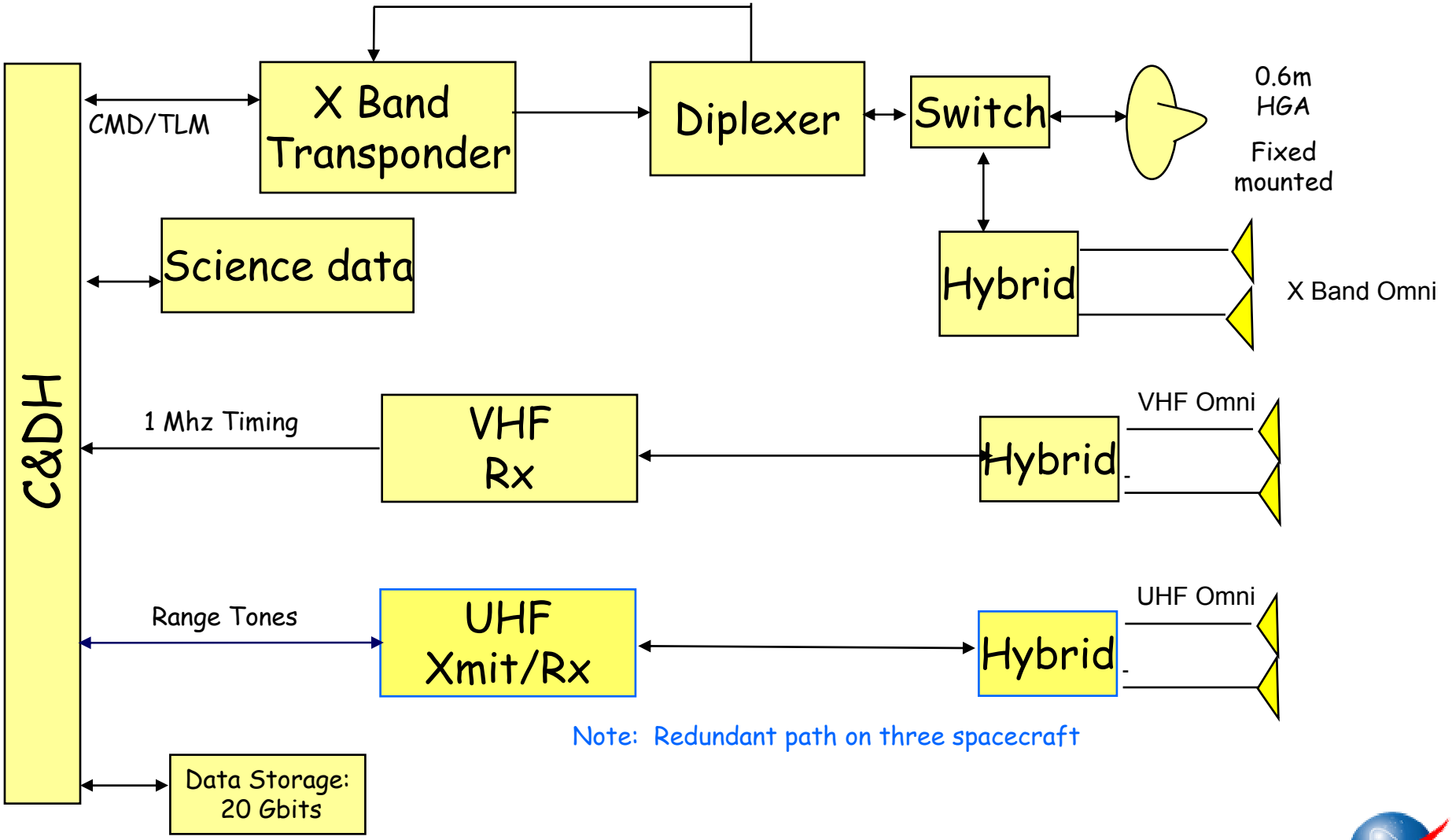

Note: Redundant path on three spacecraft

Frequency Plan

Masters (3)		Slaves (13)
T_2 VHF Timing (137 Mhz)	→	R_2 VHF Timing
R_2 VHF Timing (137 Mhz)		
T_1 UHF Ranging (900 Mhz)	→	R_1 UHF Ranging
R_1 UHF Ranging	←	T_1 UHF Ranging
X Band (7800/8475 Mhz)		X Band (7800/8475 Mhz)

Launch & Early Orbit Phase

- Continuous DSN support for X Band TT &C for first 12 hrs
- Intermittent DSN support during trans -Lunar phase (approx 2 days)
- Continuous support during Lunar fly-by for 12 hrs
- Coast phase support for approx 2 days for 8 hrs/day
- Correction burn support for approx 8 hrs continuous support
- Final coast phase for 2 days with intermittent support
- Final insertion burn support for 1 day
- To accomplish this it is assumed that all Microsat receivers are on & a single transmitter will be selected with proper orientation to Earth

An Operational Approach

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- **Science data dumps**
  - All 16 Microsats will dump stored data every day
    - Each Microsat will be commanded on/off by either stored or ground commands
    - 25 minutes/Microsat sequentially via X Band to 14m Greenbank W VA ground terminal
      - Total estimated time is 7 hrs
      - Total visibility is approx 8-10 hrs (assumes no lunar eclipses)
    - Data will be stored on -site & sent at reduced rates over dedicated NISN circuits to GSFC
- **Timing**
  - VHF intersatellite link from Master to Slave Microsats
  - Uses 1 Mbps signal
- **Intersatellite ranging**
  - UHF with range tones
  - Each Microsat will perform ranging to other 15 Microsats simultaneosly
  - Process repeated for all remaining Microsats
- **DSN ranging to constellation**
  - Uses X/X Band with 34m
  - Each Microsat will be commanded into the transponder mode to perform coherent ranging
  - Each Microsat will be done sequentially for approx 5 minutes & then commanded into transceiver mode

Signal Margins

Mode	Data Rate	Margin (dB)	Comments
Ground 14 M X-Band Downlink	8 MBPS	3.1	HGA
Ground 14 M X-Band Uplink (0.01 Watt)	2 Kbps	4.3	HGA
Ground 34 M DSN (5 KW)	2 Kbps ranging	12.5 positive	Emergencies Every 10 days
Ground 14 M X-Band Downlink	4 Kbps	2.8	Omni
VHF Crosslink	1 Mbps	4.0	Omni-Omni

Component Power/Mass/Cost Summary

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Component	Power (peak/avg)	Mass	Cost
X -Band Transponder	40/9 watts	4 Kg	$1000 K
X-Band Omni antenna (2)	-----	2 Kg	$100 K
X-band HGA	-----	5 Kg	$400 K
VHF (2) & UHF(2) Omnis		4 Kg	$200 K
VHF Xmit/Rx (3 Microsats) VHF receiver (13 Microsats)	9/8 8	3 Kg 1 Kg	$300 K $150 K
UHF Transceiver	9/8	3 Kg	$300 K
Hybrids(3), Diplexer Cabling and switches		4 Kg	$300 K
Total	58/25 watts	25 Kg (3 s/c) 23 Kg (13 s/c)	$2.1 M (3 Microsats) $1.95 M (13 Microsats)
Total (16 Microsats)		374 Kg	$31.65 M

Ground Station Costs

- **Total costs: $3.6/4.4M**
- **Engineering mods to existing 14m = $2.8M**
  - Uplink command capability = $300K
  - Downlink telemetry capability = $2.5M
    - Includes redundant receive H/W
    - Includes RAID storage
    - Includes workstation & associated S/W
    - General refurbishment
    - Assumes all existing infrastructure (power etc) is available
- **M&O 2/4 years for 14m**
  - 2 myrs @ 150K= $600/1200K
- **DSN costs = $240/380K**
  - Includes 5 min ranging contact/10 days/Microsat & pre/post setup
  - Assumes that all 16 Microsats will do ranging sequentially within 1.5 hrs
  - Includes launch and early orbit costs

Total Mission Costs 2/4 years

- **Total mission costs for 2/4 years = $35.2/$36.0M**
  - Refurbishing/augmenting existing 14m antenna
  - Only recurring M&O costs assumed for 1 shift operation
  - Costs based on 2003 dollars
  - Does not include Mission Operations/NISN costs
  - Includes 5 min ranging contact/10 days/Microsat & pre/post setup
  - Assumes that all 16 Microsats will do ranging sequentially within 1.5 hrs

Rationale for X-Band Design

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- **S-Band design:**
  - Would require more Microsat EIRP increasing power requirements
  - Would limit the downlink data rate to 5 Mbps due to S-Band channel allocations
  - Would double the ground station costs due to increased support necessary
- **Ka-Band design:**
  - Would require X/Ka transponders at an additional mission cost of ~$8 M
  - Would incur DSN costs of $2/$4 M (Assuming a data rate of 100Mbps)
  - Would require new Ka ground infrastructure (DSN considering adding Ka capability at a cost of $20 M)
  - Advantages of Ka if the infrastructure existed:
    - Increased data rate which would mean more science data.
    - Smaller power requirement on Microsat (~25 watts less)

Commercial Ground Station Option

- **Total mission cost is $5.5/$8.7 M for 2/4 years**
- **Commercial ground station cost $3.25/$6.25 for 2/4 years****
  - Based on $600/hour for 7 hours/day
  - Includes start-up cost of $250 K
- **Commercial ground stations do not have X-Band uplink**
  - Estimated cost to upgrade two stations is $2 M
- **Commercial ground stations do not have X-Band ranging**
  - DSN ranging is still required at a cost of $240/480 K

**** Cost savings may be realized by sharing the use of the 11 meter antenna at Berkeley**

Risk Assessments (X Band System Failure)

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- **X Band system failure-low risk for single Microsat**
  - If transponder fails on one Microsat that Microsat is no longer any good
- **Impact to mission is very low**
  - Mission can be successful with less than 16 Microsats
- **No mitigation is required**

Risk Assessments (failure of ground terminal)

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- Failure of ground station is medium during the 4 year timeframe
- Mission impact is loss of mission
- Fall back plan is to use the DSN or a combination of the DSN and commercial sites
- Mitigation is to build/lease a second ground station or do planning before launch to ensure backup availability.

Risk Assessments (failure of Microsats)

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- Failure of three master Microsats is low
- Mission impact is failure of mission
- No fallback plan
- Mitigation is to build more master Microsats

Risk Assessments (Loss of timing capability)

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- Loss of timing is low risk for single Microsat
- Impact to mission is low due to 16 Microsats
- Mitigation has been designed in by designing 3 Master Microsats

Risk Assessments (Loss of Ranging capability)

- Loss of ranging is low risk for single Microsat
- Impact to mission is low due to 16 Microsats
- There is no fallback or mitigation plan

Options 1 & 2

- **No change to design if either Options 1 or 2 are selected.**

Back-Up Charts

- **Signal Margin Calculations**
  - **X-Band 8Mbps Downlink HGA**
  - **X-Band 4 Kbps Downlink Omni**
  - **X-Band 100 bps Uplink HGA**
  - **X-Band 100bps Uplink Omni**
  - **UHF crosslink**

SIRA X-Band 14 M Downlink HGA (8 Mbps)

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*** DOWNLINK MARGIN CALCULATION***

GSFC C.L.A.S.S. ANALYSIS #1 DATE & TIME: 8/26/ 3 16:40:19 PERFORMED BY: R. VENTO

LINKID: SIRA

FREQUENCY: 8480.0 MHz RANGE: 500000.0 km POLARIZATION: RHCP

MODULATION: QPSK

I CHANNEL		Q CHANNEL	
DATA RATE:	4000.000 kbps	DATA RATE:	4000.000 kbps
CODING:	RS ENCODED	CODING:	RS ENCODED
BER:	1.00E-05	BER:	1.00E-05

14 meter ground at 100 deg
0.6M S/C antenna

PARAMETER	VALUE		REMARKS
01. USER SPACECRAFT TRANSMITTER POWER - dBW	9.03		NOTE A; 8.0 WATTS
02. USER SPACECRAFT PASSIVE LOSS - dB	2.00		NOTE A
03. USER SPACECRAFT ANTENNA GAIN - dBi	31.94		NOTE A
04. USER SPACECRAFT POINTING LOSS - dB	0.50		NOTE A
05. USER SPACECRAFT EIRP - dBWi	38.47		1 - 2 + 3 - 4
06. POLARIZATION LOSS - dB	0.30		NOTE A
07. FREE SPACE LOSS - dB	224.99		NOTE B
08. ATMOSPHERIC LOSS - dB	0.23		NOTE B; EL: 10.0 DEG
09. RAIN ATTENUATION - dB	0.54		NOTE B; ITU MODEL; EXC: 1.00% RRATE .01%: 49.07 mm/hr; RHGT: 4.2 km
10. MULTIPATH LOSS - dB	0.00		NOTE A
11. GROUND STATION ANTENNA GAIN - dBi	59.30		NOTE B; 14.0 M, EFF: 55.0%
12. GROUND STATION PASSIVE LOSS - dB	0.00		NOTE A
13. GROUND STATION POINTING LOSS - dB	0.00		NOTE A
14. SYSTEM NOISE TEMPERATURE - dB-DEGREES-K	20.00		NOTE A
15. GROUND STATION G/T - dB/DEGREES-K	39.30		11 - 12 - 13 - 14
16. BOLTZMANN'S CONSTANT - dBW/(Hz*K)	-228.60		CONSTANT
17. RECEIVED CARRIER TO NOISE DENSITY - dB/Hz	80.31		- 6 - 7 - 8 - 9 - 10 + 15 - 16
	I CHANNEL	Q CHANNEL	
18. I-Q CHANNEL POWER SPLIT LOSS - dB	3.01	3.01	NOTE B; 1.00 TO 1.00
19. MODULATION LOSS - dB	0.00	0.00	NOTE A
20. DATA RATE - dB-bps	66.02	66.02	NOTE A
21. DIFFERENTIAL ENCODING/DECODING LOSS - dB	0.00	0.00	NOTE A
22. USER CONSTRAINT LOSS - dB	0.00	0.00	NOTE A
23. RECEIVED Eb/No - dB	11.28	11.28	17 - 18 - 19 - 20 - 21 - 22
24. IMPLEMENTATION LOSS - dB	2.00	2.00	NOTE A
25. REQUIRED Eb/No - dB	6.17	6.17	I: NOTE B; Q: NOTE B
26. REQUIRED PERFORMANCE MARGIN - dB	0.00	0.00	NOTE A
27. MARGIN - dB	3.11	3.11	23 - 24 - 25 - 26

NOTE A: PARAMETER VALUE FROM USER PROJECT - SUBJECT TO CHANGE
NOTE B: FROM CLASS ANALYSIS IF COMPUTED

SIRA X-Band 14 M Downlink Omni (4 Kbps)

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*** DOWNLINK MARGIN CALCULATION***
GSFC C.L.A.S.S. ANALYSIS #1 DATE & TIME: 8/27/ 3 10: 4:30 PERFORMED BY: R. VENTO
LINKID: SIRA

FREQUENCY: 8480.0 MHz RANGE: 500000.0 km

MODULATION: BPSK
DATA RATE: 4.000 kbps
CODING: RATE 1/2 WITH RS ENCODING
BER: 1.00E-05

14 meter antenna at 100 deg

PARAMETER	VALUE	REMARKS
01. USER SPACECRAFT TRANSMITTER POWER - dBW	9.03	NOTE A; 8.0 WATTS
02. USER SPACECRAFT PASSIVE LOSS - dB	4.00	NOTE A
03. USER SPACECRAFT ANTENNA GAIN - dBi	-3.00	NOTE A
04. USER SPACECRAFT POINTING LOSS - dB	0.00	NOTE A
05. USER SPACECRAFT EIRP - dBWi	2.03	1 - 2 + 3 - 4
06. POLARIZATION LOSS - dB	0.50	NOTE A
07. FREE SPACE LOSS - dB	224.99	NOTE B
08. ATMOSPHERIC LOSS - dB	0.23	NOTE B; EL: 10.0 DEG
09. RAIN ATTENUATION - dB	0.54	NOTE A
10. MULTIPATH LOSS - dB	0.00	NOTE A
11. GROUND STATION ANTENNA GAIN - dBi	59.30	NOTE B; 14.0 M, EFF: 55.0%
12. GROUND STATION PASSIVE LOSS - dB	0.00	NOTE A
13. GROUND STATION POINTING LOSS - dB	0.00	NOTE A
14. SYSTEM NOISE TEMPERATURE - dB-DEGREES-K	20.00	NOTE A
15. GROUND STATION G/T - dB/DEGREES-K	39.30	11 - 12 - 13 - 14
16. BOLTZMANN'S CONSTANT - dBW/(Hz*K)	-228.60	CONSTANT
17. RECEIVED CARRIER TO NOISE DENSITY - dB/Hz	43.67	5- 6 - 7 - 8 - 9 - 10 + 15 - 16
18. MODULATION LOSS - dB	0.00	NOTE A
19. DATA RATE - dB-bps	36.02	NOTE A
20. DIFFERENTIAL ENCODING/DECODING LOSS - dB	0.00	NOTE A
21. USER CONSTRAINT LOSS - dB	0.00	NOTE A
22. RECEIVED Eb/No - dB	7.65	17 - 18 - 19 - 20 - 21
23. IMPLEMENTATION LOSS - dB	2.00	NOTE A
24. REQUIRED Eb/No - dB	2.90	NOTE B
25. REQUIRED PERFORMANCE MARGIN - dB	0.00	NOTE A
26. MARGIN - dB	2.75	22 - 23 - 24 - 25

NOTE A: PARAMETER VALUE FROM USER PROJECT - SUBJECT TO CHANGE
NOTE B: FROM CLASS ANALYSIS IF COMPUTED

SIRA X-Band 14 M Uplink HGA (2 Kbps)

Integrated Mission Design Center

*** UPLINK MARGIN CALCULATION***
GSFC C.L.A.S.S. ANALYSIS #1 DATE & TIME: 8/27/ 3 14: 1:15 PERFORMED BY: R.VENTO
LINKID: SIRA

FREQUENCY: 7804.0 MHz RANGE: 500000.0 km

MODULATION: BPSK
DATA RATE: 2.000 kbps
CODING: RATE 1/2 CODED
BER: 1.00E-05

ground is 14 M with 0.01 Watt

PARAMETER	VALUE	REMARKS
01. GROUND STATION TRANSMITTER POWER - dBW	-20.00	NOTE A; 0.0 WATTS
02. GROUND STATION PASSIVE LOSS - dB	1.00	NOTE A
03. GROUND STATION ANTENNA GAIN - dBi	58.58	NOTE A
04. GROUND STATION POINTING LOSS - dB	0.00	NOTE A
05. GROUND STATION EIRP - dBWi	37.58	1 - 2 + 3 - 4
06. POLARIZATION LOSS - dB	0.30	NOTE A
07. FREE SPACE LOSS - dB	224.27	NOTE B
08. ATMOSPHERIC LOSS - dB	0.23	NOTE A
09. RAIN ATTENUATION - dB	0.54	NOTE A
10. MULTIPATH LOSS - dB	0.00	NOTE A
11. USER SPACECRAFT ANTENNA GAIN - dBi	31.22	NOTE B; 0.6 M, EFF: 55.0%
12. USER SPACECRAFT PASSIVE LOSS - dB	0.00	NOTE A
13. USER SPACECRAFT POINTING LOSS - dB	0.50	NOTE A
14. SYSTEM NOISE TEMPERATURE - dB-DEGREES-K	26.99	NOTE A
15. USER SPACECRAFT G/T - dB/DEGREES-K	3.73	11 - 12 - 13 - 14
16. BOLTZMANN'S CONSTANT - dBW/(Hz*K)	-228.60	CONSTANT
17. RECEIVED CARRIER TO NOISE DENSITY - dB/Hz	44.57	5- 6 - 7 - 8 - 9 - 10 + 15 - 16
18. MODULATION LOSS - dB	0.00	NOTE A
19. DATA RATE - dB-bps	33.01	NOTE A
20. DIFFERENTIAL ENCODING/DECODING LOSS - dB	0.00	NOTE A
21. USER CONSTRAINT LOSS - dB	0.00	NOTE A
22. RECEIVED Eb/No - dB	11.56	17 - 18 - 19 - 20 - 21
23. IMPLEMENTATION LOSS - dB	3.00	NOTE A
24. REQUIRED Eb/No - dB	4.25	NOTE B
25. REQUIRED PERFORMANCE MARGIN - dB	0.00	NOTE A
26. MARGIN - dB	4.31	22 - 23 - 24 - 25

NOTE A: PARAMETER VALUE FROM USER PROJECT - SUBJECT TO CHANGE
NOTE B: FROM CLASS ANALYSIS IF COMPUTED

SIRA VHF Crosslink Omni (1 Mps)

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*** DOWNLINK MARGIN CALCULATION***
GSFC C.L.A.S.S. ANALYSIS #1 DATE & TIME: 8/27/ 3 13:21:51 PERFORMED BY: R. VENTO
LINKID: SIRA

FREQUENCY: 136.0 MHz RANGE: 25.0 km

MODULATION: BPSK
DATA RATE: 1000.000 kbps
CODING: RATE 1/2 CODED
BER: 1.00E-05

PARAMETER	VALUE	REMARKS
01. USER SPACECRAFT TRANSMITTER POWER - dBW	-10.00	NOTE A; 0.1 WATTS
02. USER SPACECRAFT PASSIVE LOSS - dB	4.00	NOTE A
03. USER SPACECRAFT ANTENNA GAIN - dBi	-6.00	NOTE A
04. USER SPACECRAFT POINTING LOSS - dB	0.00	NOTE A
05. USER SPACECRAFT EIRP - dBWi	-20.00	1 - 2 + 3 - 4
06. POLARIZATION LOSS - dB	0.50	NOTE A
07. FREE SPACE LOSS - dB	103.07	NOTE B
08. ATMOSPHERIC LOSS - dB	0.00	NOTE A
09. RAIN ATTENUATION - dB	0.00	NOTE A
10. MULTIPATH LOSS - dB	0.00	NOTE A
11. GROUND STATION ANTENNA GAIN - dB	-6.00	NOTE A
12. GROUND STATION PASSIVE LOSS - dB	4.00	NOTE A
13. GROUND STATION POINTING LOSS - dB	0.00	NOTE A
14. SYSTEM NOISE TEMPERATURE - dB-DEGREES-K	24.77	NOTE A
15. GROUND STATION G/T - dB/DEGREES-K	-34.77	11 - 12 - 13 - 14
16. BOLTZMANN'S CONSTANT - dBW/(Hz*K)	-228.60	CONSTANT
17. RECEIVED CARRIER TO NOISE DENSITY - dB/Hz	70.26	5- 6 - 7 - 8 - 9 - 10 + 15 - 16
18. MODULATION LOSS - dB	0.00	NOTE A
19. DATA RATE - dB-bps	60.00	NOTE A
20. DIFFERENTIAL ENCODING/DECODING LOSS - dB	0.00	NOTE A
21. USER CONSTRAINT LOSS - dB	0.00	NOTE A
22. RECEIVED Eb/No - dB	10.26	17 - 18 - 19 - 20 - 21
23. IMPLEMENTATION LOSS - dB	2.00	NOTE A
24. REQUIRED Eb/No - dB	4.25	NOTE B
25. REQUIRED PERFORMANCE MARGIN - dB	0.00	NOTE A
26. MARGIN - dB	4.01	22 - 23 - 24 - 25

NOTE A: PARAMETER VALUE FROM USER PROJECT - SUBJECT TO CHANGE
NOTE B: FROM CLASS ANALYSIS IF COMPUTED