Lunar Rover Design for Commercial Exploration

"To generate technology & methods for lunar rovers and create a lunar rover design to satisfy a proposed commercial mission for mass participation and exploration"

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http://www.ri.cmu.edu/LRI

LRI Motivation

- Pioneering lunar venture for mass exploration
- Opens planetary exploration with commerce, science, education and entertainment
- Scenario for return on investment
- Compelling story of endeavor on the Moon
- Immersive video stream enables mass interaction
- Long traverse of moderate terrain with short time delay enable unprecedented robotic endeavor

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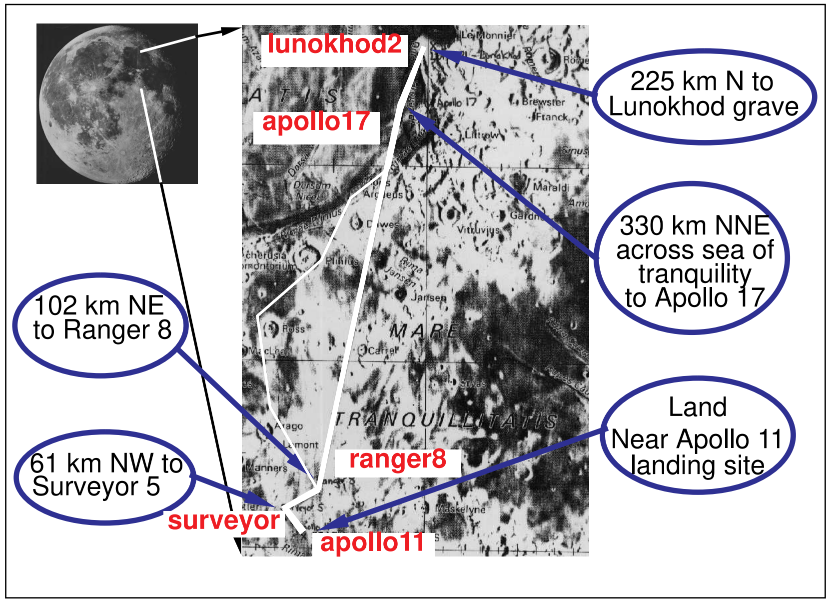
LRI Mission

Mission
2000 - 2002

2 Years
1000 km
HIIA Launch
600 kg mass



-180C to 150C

Dust & vacuum

Long day/night

Radiation

5 sec data loop

<u>Deliverables</u>

Live panoramic video
Rover telemetry
Rover status conversation
Hi quality stills

<u>Value to Customer</u>

Theme park rides, TV shows
Motion platforms, mission hotline
Interact with rover technology
Unique souvenirs, marketing

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Technical Challenges

Achieve high reliability and availability needs

Meet tight cost and time budgets

Operate in extreme lunar environment: Temp, dust, vac, rad

Stream downlink of ~6 Mbps for video & telemetry

Safeguard autonomously during amateur user operation

Locomote uncertain terrain of moderate difficulty

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Budgets

2 rovers, 2m x 2m x 1.5 m rover, Four wheeled;

Meets mass and volume budgets

Component	Cost ($M)	Power (W)	Mass (kg)
Locomotion	.8+1.45	50	42
Communication	3.3+2.7	102	17
Imagery/sensing	3.95+1.83	64	27
Computing	1.55+1.57	105	12
Power	2.6+5.2	-	45
Thermal	.8+3.6	-	40
Structure	.4+.45	-	12
TOTAL	13.4+15.85	400	195
WITH MARGINS	60 (2X)	420	205

System margins: Power [5% + 3% regulator loss + 15% DC-DC loss on electronics], Mass [5%], Cost [15% management, 15% contingency]

Design Features

- •Rational, driver & analysis based design
- •Detail includes primary contractors & budgets
- •Viable 2 rover scenario and programmatics to build them

- •Power: Plutonium power source & AMTEC cells
- •Comm: Phased array only, frequency changed
- •Imagery: Panosphere, wavelet compression
- •Computing: Adopted new DSP, custom board design
- •Locomotion: Detail based on analysis framework
- •Safeguarding: Radar sensing technology

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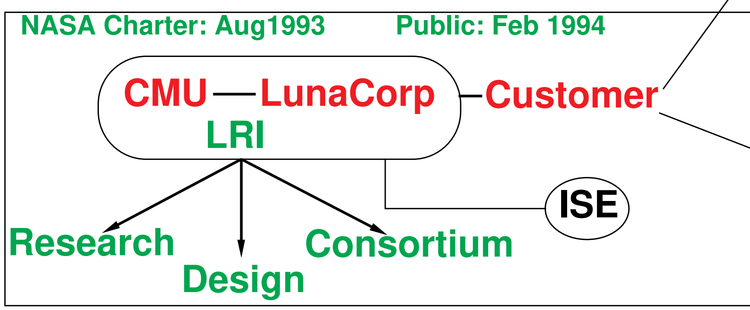
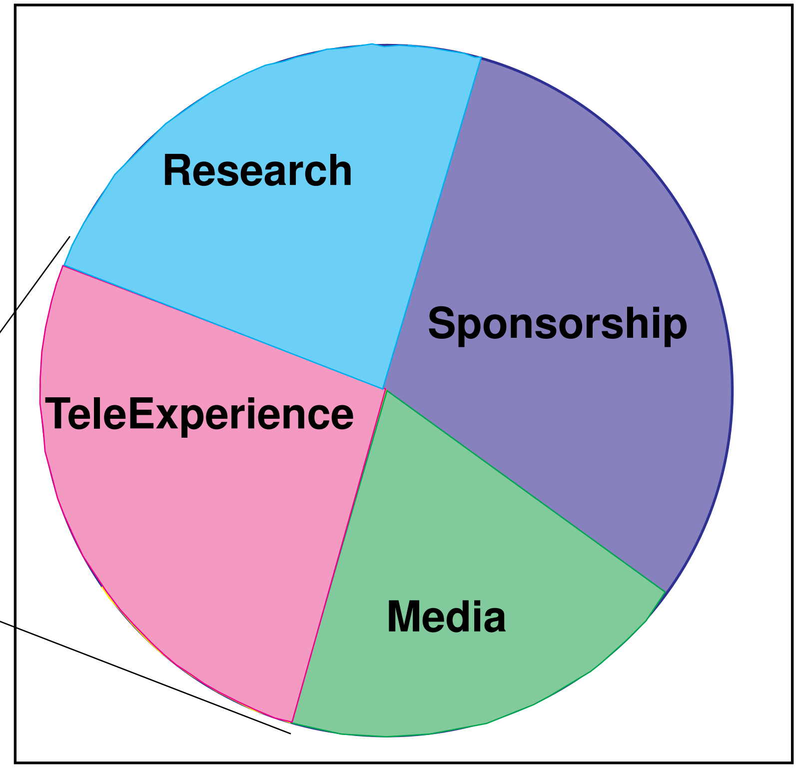
"Is there money on the Moon?"

Potential sponsers evaluating the expedition include:

- AT&T, other telecom
- Japanese trading Co.
- Universal Studios
- Smithsonian at Dulles
- Six Flags
- Future New Orleans park





Industry and Media interest is high

Potential sponsers excited and balk at being the first

TV and movie events show massive interest in Apollo & space

Recent Activity

Top down (system) level analysis to identify and solve the design drivers [Power, Comm, Locomotion, Imagery, Computing, Terrain Safeguarding]. The design then followed:

- •Requirements analysis and top down derivation
- •Mission Environment detail and key issues documented
- •Earth traverse development underway
- •TRIWG, conferences, media promulgation
- •Consortium active: FCB, At&T, Mitsubishi, Universal, ...
- •Russia-ISE contacts furthered: Lavochkin, LUTCH, Niitransmaash, McDonald Douglas
- •Legal wrangles keyed in: FCC application, RHU launch

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1995 Accomplishments

- Generated and reviewed viable design of flight article
- Increased industry/media interest in planetary exploration
- Identified key technologies to enable capable lunar mission
- Formulated Synergy: for mobile robot simulation, design
- Formulated LocSyn: robotable locomotion design tool
- Formulated PanoSphere: tele-experience design tool
- Formulated PreciComm: beam steering from mobots
- Formulated ROSE: for system analysis & code generation
- Published at four reviewed conferences
- 10 km Ratler traverse

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Computing

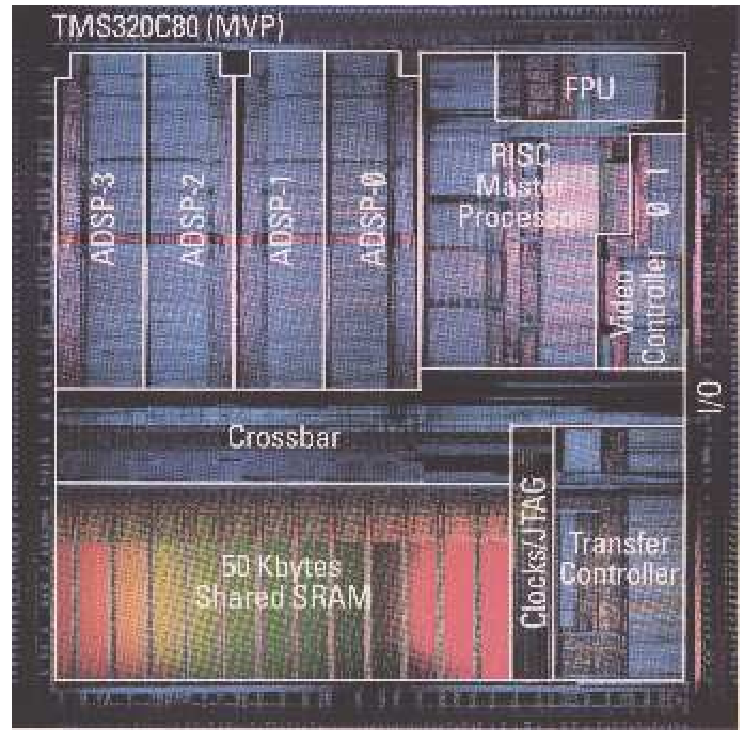
Compression drives needs

Radiation primary concern

DSP needed for compression

Programmatics suggest MCM

- C80 DSP (2 BOPS), can be hardened to 100 krad
- R3000 (Rad Hard)
- 6 x 3U VME cage



4 identical boards: Each with a R3000 central processor, a DSP modules (DSP + VRAM + direct camera interfaces), DRAM and I/O. 5th slot occupied by radar electronics. Sufficient to handle sensor fusion for terrain and position.

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Computing (2)

Component (#)	Cost ($M)	Power (W)	Mass (kg)	Margin used	Model and Vendor
VME cage	.1+.2	16.2	3.5	8%	
MCM (4)	1.4+.3	90	7.3	8%	TI, Anders., DDI, Harris
Cabling to power	.05+.075	-	.5	8%	

Primary issues to be addressed:

- Reducing computing needs w. focus on algorithms
- Designing from MCM block dia. to detail and rule checks
- Complete radiation tolerant/qualified parts list
- Quick PCB prototype for reality check
- Strategic alliance/enterprise to reduce mission cost

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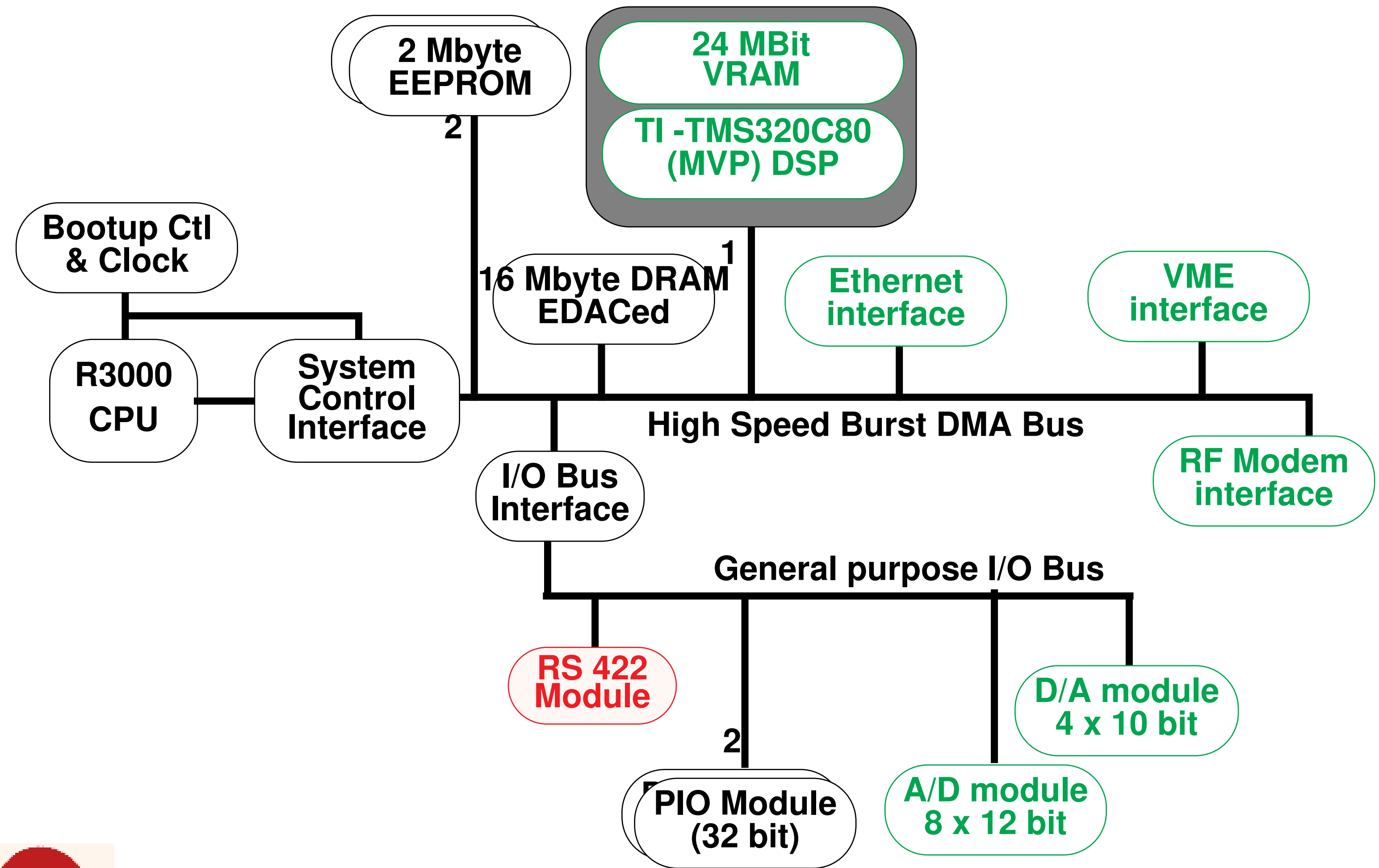
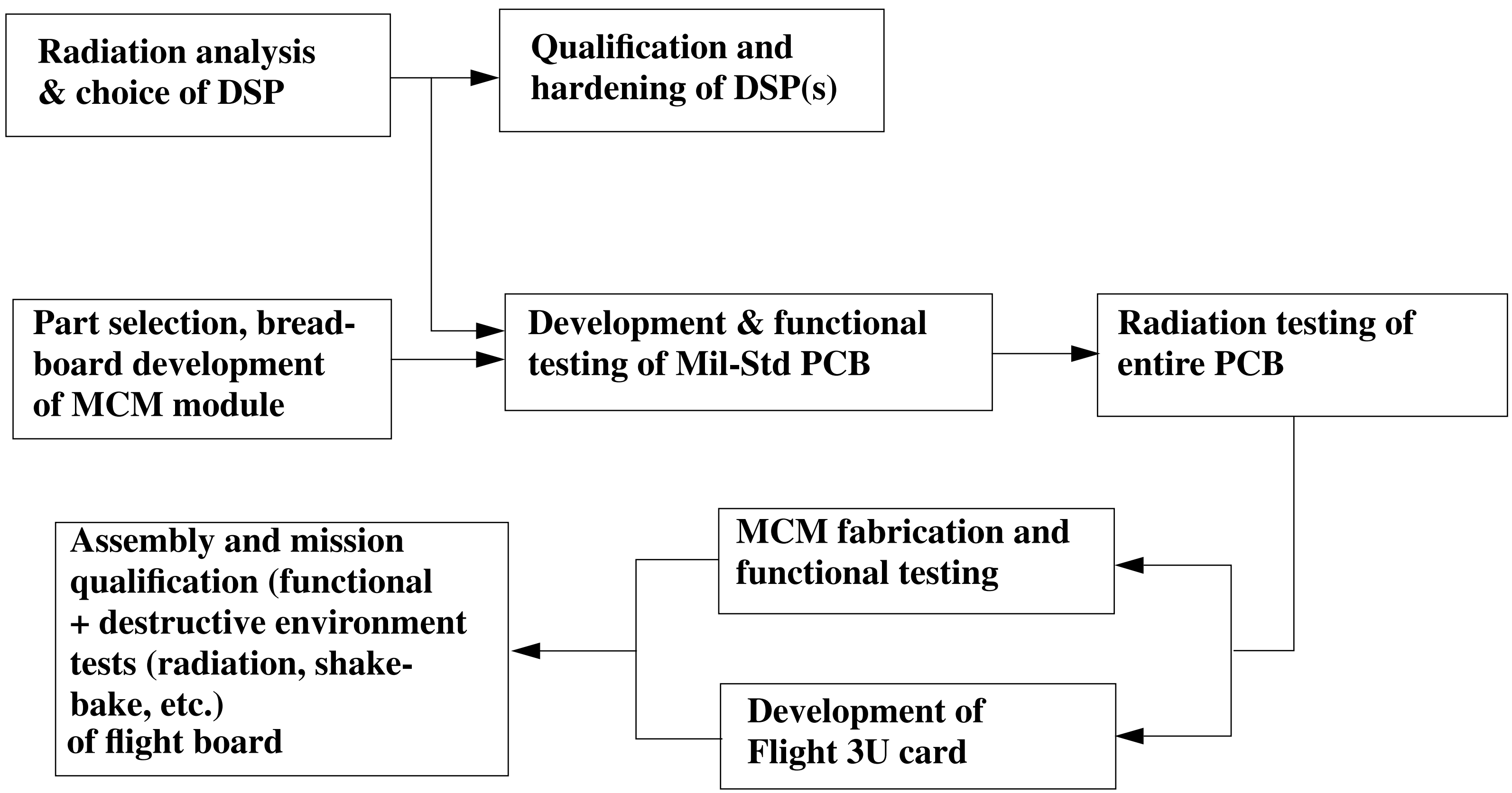
Computing Board Design



Computing Board Development

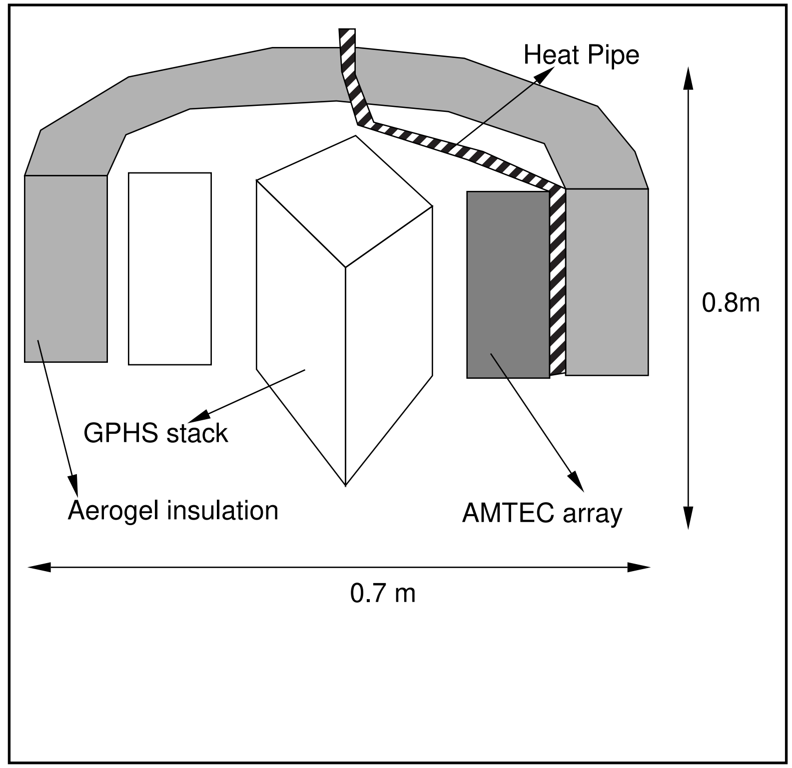


Power

Generate ~420W day+night

Meet thermal requirements

- •2800 W Plutonium RTG
- •18% AMTEC conversion
- •Radiative transfer to AMTEC
- •Heat pipes to low cost black body radiator
- •Radiator temp [500, 600k]
- •Size = 0.7m dia x 0.7m long



- •Highly reliable, no moving parts
- •Legal issues reportedly of low significance
- •Possibility of upgrade in AMTEC efficiency

Power (2)

Plutonium has a half life of 78+ yrs, performance is ~constant

Component (#)	Cost ($M)	Power (W)	Mass (kg)	Margin used	Model and Vendor
GPHS (12)	1+2	-	19.3	5%	LUTCH, Russia
AMTEC converter	1+2	-	14.7	5%	AMPS
Switching Regulator	.4+.4	-	4.3	8%	Matra Marconi
DC/DC (10)		-	1.1	8%	Interpoint
Capatteries (20)	.1+.2	-	2.3	13%	Evans
Cabling (59m)	.25	-	5.5	13%	

Primary issues to be addressed:

- Co-development initiative with JPL for leverage
- Integration scenario with LUTCH and D of Commerce
- Viability of heat pipes & aerogel at 600k & 1300k
- Detailed design, modeling, FEA (Str,Thr,Vib) and testing

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Thermal

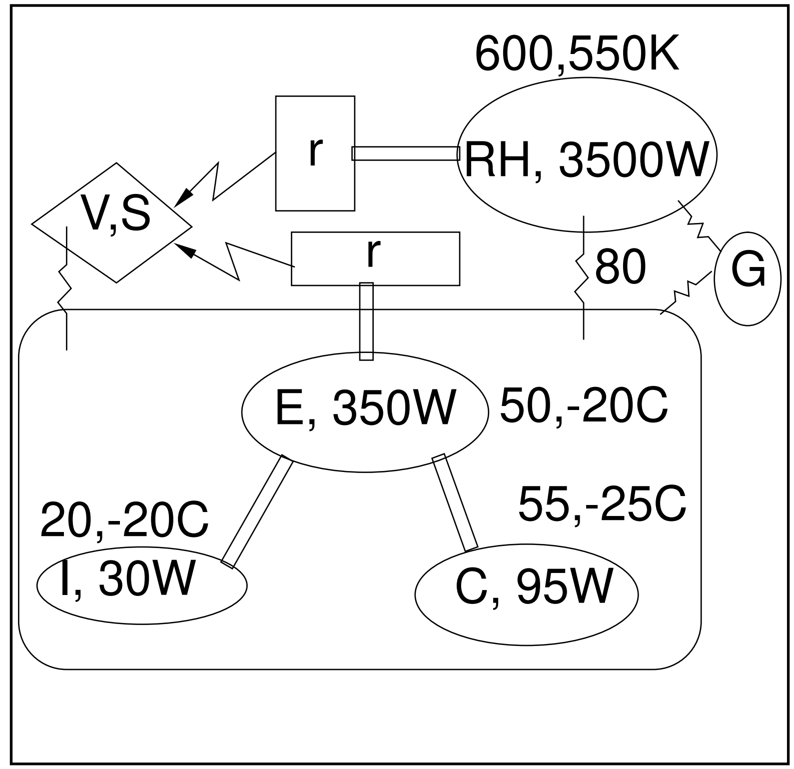
Electronics T [-50C,80C]

Comm T [-50C, 80C]

RTG T [400K,700K]

Camera T [-50C, 20C]

- Aerogel 0.02 W/k/m
- Heat pipes 100 W/k
- MLI, 0.1 - for integrity



The thermal control is mostly passive, requiring electronic heating/cooling for imagery hardware and constant heat at night into the Comm system. The electronics radiators are louvered using bimetallic strips that close at 0C, -20C

Thermal (2)

Component (#)	Cost ($M)	Power (W)	Mass (kg)	Margin used	Model and Vendor
Radiator (1+2)	.2+.9	-	5.4	8%	
Heat pipe	.2+.8	-	14.7	13%	Noren
Carbon Aerogel	.1+1.45	-	4.2	5%	JPL/BMDO
MLI	.1+.3	-	3.4	13%	Therm Electron Tech.
Joints	.2+.15	-	6.8	13%	

Primary Issues to be addressed:

- Locate vendors & verify component specs
- Analyze construction methods to detail the design
- Test radiators performance w/wo dust to improve model

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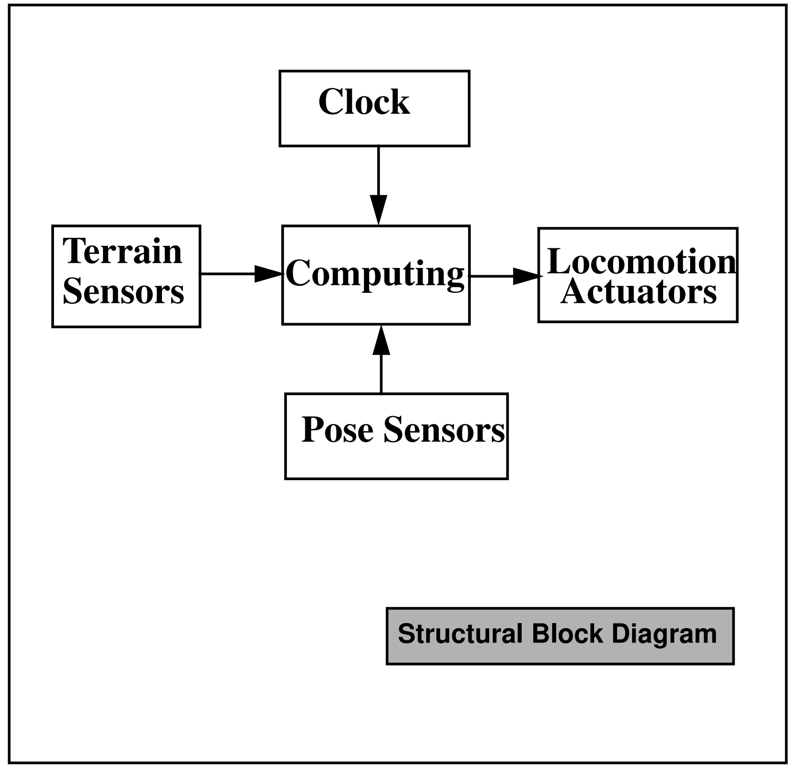
Terrain Safeguarding

Terrain sensing needs:

- 4cm grid
- 2cm accuracy
- range > 1m at pose of actuator commands
- Robust in lunar environment

Micro impulse radar sensing technology meets needs

C80 DSP for processing



Only sensor with environmental compatibility (heat, rad, dust)
Can cut through material/dust, enables mechanical shielding
Calibration of individual sensors needed due to analog nature

Terrain Safeguarding (2)

- Array of 60 sensors at each end, 10 spread along each side & bottom as well
- Each sensor provides range vs. intensity at 40 Hz
- Multiple sensors help localize range values & detect hazards
- C80 DSP used to process and generate local hazards

Primary issues to be addressed:

- Nascent technology, needs to be hardened for space
- Analog electronics; careful noise engineering needed
- Possible conversion to VLSI to save mass & power
- Radiating elements are large, need to find a way to create sensor banks

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Software

- Software generation strategy developed:
  - Develop hardware & functional models using OOA,
  - State models and transitions using Cadre teamworks
  - Analyze using ROSE - state model simulator
  - Translate to verified object stub code & headers
  - Generate code using “case” tool & algorithm library
- Analysis reveals 90% of system software for station keeping and exception handling
- Correctness important for reliability & availability
- Real time control & operating systems identified to be consonant with Cadre

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Launch Landing Scenario

- HIIA inserts 5040 kg Phobos into 100 km lunar orbit
- Phobos soft lands rovers onto the Moon
- ~50kg for non-rover interfaces
- 3 point mounting of rovers on ramps
- Ramps connected to each other and center structure
- BBQ rotation of craft during translunar stage
- Flexible, springy “raft” protects rovers during landing
- Skirt protects rovers from dust fall at landing
- Pyro disconnect of rovers from ramps on deployment
- Pure mechanical interface between lander-rover
- Lander/Earth activate rovers via omni
- Electronics turned on by timer after LEO injection

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