Electronics for Mars Exploration
Rover and Beyond

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outline

- Background – Mars
  - Planetary info
  - climate
- Why its hard
  - missions
- Rover electronics - overall
- REM
- CEM
- LEM
outline

- Movie1 – first steps
- Discoveries - pictures
- Future Mars missions
The Mars Science Strategy: “Follow the Water”

- Understand the potential for life elsewhere in the universe
- Characterize the present and past climate and climate processes
- Understand the geological processes affecting Mars’ interior, crust, and surface
- Develop the knowledge & technology necessary for eventual human exploration
Interplanetary Trajectory

MER-A Open
Launch 30 May 2003
Arrival 4 Jan 2004

Earth at arrival
Earth at mission end
Mars at mission end

Earth at launch
Mars at arrival

View from Ecliptic North Pole
20 day tick marks
Mars is Hard!!

<table>
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<th></th>
<th>USA</th>
<th>USSR/Russia*</th>
<th>Successful</th>
<th>Failure</th>
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<tr>
<td></td>
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<td>15</td>
<td>4</td>
<td>11 (5 LV)</td>
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<td>3</td>
<td>3</td>
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<td></td>
<td>-</td>
<td>8</td>
<td>0**</td>
<td>8 (2 LV)</td>
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<td>Totals</td>
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<td>23</td>
<td>15</td>
<td>26</td>
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37% 63%

* Japanese Nozomi mission is expected to arrive in Dec 2003

** Mars 3 in 1971 apparently transmitted for 20 sec after landing but no significant information was returned
Mars Exploration Rover Recipe
(the simple formula!?)

1) Start with Mars Pathfinder design

2) Add Athena Payload

3) Make rover independent of lander

4) Combine

5) Repeat for second rover

... how hard can it be?
Athena Payload and Cameras

- **Pancam** – high-resolution (16°×16°) color panchromatic stereo cameras
- **Mini-TES** – a mid-infrared point spectrometer
- **Microscopic Imager** – close-up imaging of rock and “soil”
- **Mössbauer Spectrometer** – analysis of iron in rocks
- **Alpha Particle X-Ray Spectrometer** – detects elements in rocks and “soils”
- **Rock Abrasion Tool** – used to remove outer surface of rocks for analysis of non-weathered rock material
- **Magnets and calibration targets** – To collect iron containing dust and for comparison to known sources
- **Engineering cameras**
  - **Navcam** – wide-angle stereo cameras (45°×45°) used for traverse planning
  - **Hazcam** – very wide-angle (120°×120°) stereo cameras used for identifying potential hazards to rover driving and arm movement
Rover Deployed on Mars

- 179 kg
- 1.54 m from ground to Pancam eye level
MER Major Elements

1.7 m

2.65 m
Rover Configuration Overview

Rover Deployed Configuration

- UHF Antenna
- Low Gain Antenna
- High Gain Antenna
- Warm Electronics Box (WEB)
- Deployable Solar Arrays (delivery date changing)
- PanCam Mast Assembly (June)
- Rover Equipment Deck (RED)
- Instrument Deployment Device and Science Instrument Turret (MER-1 TO GO THRU TESTING WITHOUT IDD)
- Rocker Bogie Mobility System (Apr-May)
S/C Functionality Allocated to Avionics

- Uplink Command Processing and Distribution
  - From the SDST
  - From the UHF
- Downlink Data Handling
  - To SDST
  - To UHF Sequence Storage and Control
- S/C Time Maintenance and Distribution
- Collecting and formatting S/C payload data
- Measurement of engineering data
  - Voltages, Temps, discretes, etc.
- Storage of science and engineering data
- Attitude Control of the S/C
  - Cruise
  - EDL
  - Surface Operations

April 22, 2004
S/C Functionality Allocated to Avionics

- Articulated and Mobility Device Control
- Surface Operations Behaviors
  - Rover Hazard Avoidance
  - Visual odometry
  - Uplink/downlink communications support
- Autonomous Control Services
  - EDL
  - Battery SOC
- System Level Fault Protection
- Subsystem Level Fault Protection
- Single Centralized Processing Platform for entire S/C
Avionics Development Activities

- Electronics for the Flight System
  - Rover Electronics Module (REM)
  - Cruise Stage Electronics Module (CEM)
  - Lander Electronics Module (LEM)
- Guidance, Navigation and Control
  - Algorithms (Cruise, EDL, Surface Ops)
  - Sensors (Star Scanner, Sun Sensor, IMU)
- Flight Software for all mission phases
  - Operating System and infrastructure
  - Command, Telemetry, and Operations Interface
  - GN&C Flight Software
  - Mobility Software
- GSE and BTE Development
- Integration and Test for all Items above (Test software and Test procedures, etc.)
- MOS/GDS Support
Avionics Logical Block Diagram
Allocation of REM Functions

- NVM/Camera Board
  - Interfaces to the processor via the VME bus
  - Interfaces to the Cameras
  - Provides EDAC protected EEPROM for two copies of the boot image for flight software (4MByte each)
  - Provides 256 Mbytes of Flash memory for science & sequence products
Allocation of REM Functions

- Motor Control Boards (2 boards per REM)
  - Allows control of 12 motors simultaneously
  - Has a stepper motor controller on each card
  - Includes motor protection logic (stall detection)
  - Interfaces to processor via VME bus
Allocation of REM Functions

- **Payload Board**
  - Provides Engineering data collection
  - Analog-to-Digital conversion
  - Interfaces to discrete devices
  - Provides interface to battery control board for Wake-up-timer functions
  - Provides interfaces to science payload (APXS, Moessbauer, Mini-TES, MicroImager)
  - Provides interface to IMU
Allocation of REM Functions

- **RAD6K Board**
  - 20 MHz processor used to provide the services required of the S/C during each mission phase.
  - Interfaces to IO via VME bus
  - 128 MB DRAM (with EDAC)
  - 3 MB of EEPROM (without EDAC)
Allocation of REM Functions

- **Telecom Board**
  - Interfaces to the SDSTs and the UHF radio command and telemetry lines
  - Interfaces to the LEM, CEM, SDSTs, & GSE using a modified 1553B interface
  - Provides the S/C time maintenance hardware (Timing Unit, Mission Clock, Wake-Up-Timer)
  - Provides an Ethernet test interface
Allocation of CEM Functions

- **CREU**
  - Provides Engineering data collection
  - Analog-to-Digital conversion
  - Provides command path to CSID
  - Provides I/F to processor in REM

- **CSID**
  - I/F Drivers to Star Scanner, Sun Sensor, Thrusters
  - Switched power for Catbed Heaters
Allocation of CEM Functions

- CPCU
  - Converts 30 Volt S/C power to voltages needed by other CEM components
    - +12V, -12V, +5V, 26.5V
  - Expands Analog capability of the REU with its own A-to-D converter
    - Adds [27] external temps
    - Adds [24] additional voltage inputs

- CPDU
  - Provides switched 30 Volt S/C power to clients
Lander Electronics Module (LEM)
_allocation of LEM Functions

- **LREU**
  - Provides Engineering data collection
  - Analog-to-Digital conversion
  - Provides command path to LSID
  - Provides I/F to processor in REM

- **LSID**
  - I/F Drivers to RADAR-A, RADAR-B, MIMU, and LPSIF
  - Switched power for Heaters and other loads

- **LPDU**
  - Provides switched 30 Volt S/C power to clients
  - Generates voltages need by LREU and LSID

April 22, 2004

NBA
REM Functional Tests

April 22, 2044
REM Environmental Tests

Thermal-Vacuum

Vibration-X/Y Axis

April 22, 2004
This stunning image mosaic of the "Columbia Hills" shows a large portion of the first 360-degree panorama taken after the Mars Exploration Rover Spirit arrived at the hills in late August.
'Hank's Hollow' Sparkles

This false-color composite panoramic camera image highlights mysterious and sparkly dust-like material that is created when the soil in this region is disturbed. NASA's Mars Exploration Rover Spirit took this image on sol 165 (June 20, 2004) in "Hank's Hollow,"
Deep Hole in 'Clovis'

At a rock called "Clovis," the rock abrasion tool on NASA's Mars Exploration Rover Spirit cut a 9-millimeter (0.35-inch) hole
Santa Anita Panorama

This color mosaic taken on May 21, 25 and 26, 2004, by the panoramic camera on NASA's Mars Exploration Rover Spirit
Blueberries on Mars

The first outcrop rock Opportunity examined up close was finely-layered, buff-colored and in the process of being eroded by windblown sand. Embedded in it and on top of it like blueberries in a muffin were little spherical grains.
The Texture of 'El Capitan'

This image, taken by the panoramic camera on the Mars Exploration Rover Opportunity, shows a close up of the rock dubbed "El Capitan," located in the rock outcrop in "Eagle Crater" at Meridiani Planum, a bit right of center, in the upper portion of the outcrop.
This is a cropped portion of the approximate true-color panorama, dubbed "Lion King," which shows "Eagle Crater" and some of the surrounding plains of Meridiani Planum. It was obtained by the Mars Exploration Rover Opportunity's panoramic camera.
Endurance Crater's Dazzling Dunes (false-color)
NASA's Mars Exploration Rover Opportunity captured this view of "Burns Cliff" after driving right to the base of the southeastern portion of the inner wall of "Endurance Crater."
Future Rovers

- More capable
  - Drill deep under surface
- Faster
  - Investigate wider area
- Autonomous
  - Hazard avoidance and navigation
- Reliable
  - Self diagnostics and fault recovery
- Smarter
  - On-board analysis
Future Rovers

- More Power
  - Nuclear Power TNGs
- More computer power
  - Fill processing gap: 100x improvement using COTs
- Distributed processing
  - Reduce complexity
- Reconfiguarable
  - Same hardware used for different tasks and avoiding failed hardware components
- Evolvable
  - Futuristic hardware adapting to surroundings
Autonomy
Mars Exploration Program
Launch Year

2001
NASA Mars Odyssey
ESA Mars Express
Japanese Nozomi Orbiter

2003

2005
NASA Mars Reconnaissance Orbiter

2007
Italian G.Marconi Telecom Orbiter
French PREMIER-07 Science Orbiter

2009
Italian / NASA Science Orbiter

...Next Decade
SAR recon orbiter
More Recon
More MSR?
Get samples
First MSR
Explore local diversity

Science pathways responsive to discovery
Multi-scout Orbiter & Landers
Life Inference

NASA Smartlander & Rover

French-led Netsandars

Deep drilling into subsurface
Search for life with life inference

NASA Mars Exploration Rover

NASA Competed Scout Mission
Packaging Challenges

- Packaging for ambient temperature
  - Temperature cycling
  - -120 -> +20 degrees at Mars
  - Worse at moon
- Dense packaging
  - Chip-on-Board, 3D stack
- Thermal control