Space Avionics and Microsystems

by

Dr. Leon Alkalai
Space Avionics and Microsystems Program Manager
Division Technologist, Avionic Systems and Technologies Division
NASA's Jet Propulsion Laboratory
California Institute of Technology

November 15th, 2003
To improve life here
To extend life to there
To find life beyond

To understand and protect our home planet
To explore the universe and search for life
To inspire the next generation of explorers
...as only NASA can
Space Science Themes

Astronomical Search for Origins

THE BODIES IN OUR SOLAR SYSTEM

Structure and Evolution of the Universe

Sun Earth Connection

Understand the Geospace Environment

Regional Dynamics
Advanced **Avionics** Enables Essential Capabilities for Future Solar System Exploration Missions

**Precision & Safe Landings on Planets & Small Bodies**

**Robotic Sample Selection & Return**

Advanced Avionics Systems are an essential element of all future autonomous robotic space exploration missions and a JPL core competency.
Surviving Extended Periods in Extreme Environments

<table>
<thead>
<tr>
<th>Mission</th>
<th>Low Temp.</th>
<th>High Temp.</th>
<th>High Radiation Levels</th>
<th>High Pressure</th>
<th>Other Environmental Conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Venus Surface Exploration and Sample Return</td>
<td>460°C</td>
<td>90 Barr</td>
<td>90 Barr</td>
<td>90 Barr</td>
<td>Sulphuric acid clouds at 50 km 97% CO2 at the surface</td>
</tr>
<tr>
<td>Giant Planets Deep Probes</td>
<td>-160°C</td>
<td>5 MMRad</td>
<td>5 MMRad</td>
<td>5 MMRad</td>
<td>2-10% Methane Clouds Dust Solid/liquid surface</td>
</tr>
<tr>
<td>Comets/Sample Return</td>
<td>-140°C</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Titan In-Situ</td>
<td>-180°C</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Europa Pathfinder Lander</td>
<td>-160°C</td>
<td></td>
<td></td>
<td></td>
<td>½ dosage during mission ‘pump-down’ and ½ during prime mission</td>
</tr>
</tbody>
</table>

Exploration of Extreme Environments requires a comprehensive look at advanced thermal management techniques, high and low temperature electronics, radiation hard electronics, and advanced qualification methods.

Neptune and Triton

Giant Planet Deep Probes

Space Avionics and Microsystems Briefing, 11-15
X2000 Deep Space Avionics – Current SOA

- **Architecture Description**
  - Processor: RAD750, 116 Mhz
  - Mass Memory: 4 Gb (Flash), 2 NVM Cards
  - Local Bus: PCI, 33 Mhz, 32 bit
  - Communication Interfaces
    - IEEE 1394a, 100 Mbps (Serial Data Bus)
    - Phillips I2C, 100 Kbps (Engineering Bus)
    - Mil-Std-1553
    - RS422 UART,
    - RS422 Asynchronous Interface,
    - RS422 Synchronous Serial Interface (SDST)
  - “Smart” Solid-State Power Switching
    - 3-Dimensional High-Density Packaging
  - High Efficiency Power Converters
- **Mechanical Description**
  - Form Factor: Compact PCI (cPCI) 3U
  - Card Cage, Commercial cPCI Connectors
  - Micro-D Front Panel Connectors
  - Custom 1394 Connector (3 Port)
- **Metrics**
  - Mass: dual redundant ~ 60 kg
  - Power: fully redundant ~ 120 – 200 Watts
Avionics Development for future Embedded Missions

- X2000 Deep Space Avionics represents SOA in high performance and high reliability Rad Hard Avionics for SSE

- Future Mars Scouts, Planetary Ascent Vehicles, Small (Nano) Rovers, etc. require low-mass, low-cost, low-power and high performance avionics for low to moderate radiation environments:

<table>
<thead>
<tr>
<th></th>
<th>Mass (kg)</th>
<th>Power (W)</th>
<th>Performance (MIPS)</th>
<th>Storage (Gb)</th>
<th>Re-configurable Logic (HW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>X2000</td>
<td>30-60</td>
<td>100-200</td>
<td>120-240</td>
<td>&gt; 2</td>
<td>No – only ASICs</td>
</tr>
<tr>
<td>Mobility Avionics</td>
<td>1-10</td>
<td>1-10</td>
<td>100 – 1000</td>
<td>1 - 10</td>
<td>Yes – Xilinx Virtex II Pro FPGA</td>
</tr>
</tbody>
</table>

Complete CDH for Rocky 8

Space Avionics and Microsystems Briefing, 11-15-03, Dr. Leon Alkalai
Advanced Microsystems Enable Future New Mission Capabilities

Advanced Microsystems will enable new capabilities for future space exploration missions.

Advanced Surface Mobility

Sub Surface Probes

- Antenna
- Sun Sensor
- Descent Accelerometer
- Transceiver
- Mars Surface
- Batteries
- Flex Cable Connection (Data Path)
- Impact Accelerometer
- Sample Collector
- Water Experiment
- Drill Motor
- Instrument Electronics
- Power Electronics
- Temperature Sensors
- Microcontroller

Space Avionics and Microsystems Briefing, 11-15-03, Dr. Leon Alkalai
Micro Spacecraft Components and Sub-System Technology Development at JPL

- MEMS Gyros & Accelerometers (IMU)
- MEMS and APS based Sun sensors & Star Trackers
- MEMS Micro Thrusters & MEMS Micro Valves
- MEMS Piezo-Electric Actuators
- Integrated micro-electronics & digital/analog
- Multi-Functional Structures
- Advanced Thermal Management Techniques
- On-board Spacecraft Autonomy
- Advanced LiI Batteries for low temperatures
- Advanced Solar Array Architectures and Cells
- Re-configurable Avionics Hardware
- LIDAR and other payload technologies
- Science and Spacecraft Sensors and Instruments
The Microdevices Laboratory (MDL) is a state-of-the-art facility focused on creating the building blocks enabling NASA’s vision of smaller, faster, cheaper spacecraft.

MDL Facilities include: Class 10 cleanroom; E-beam and optical lithography; MBE, MOCVD, LPCVD growth systems; RIE systems; and full processing and characterization capabilities.

For more information: http://csmt.jpl.nasa.gov/

### Microinstruments and MEMS devices
- Surface / Bulk / LIGA micromachining
- Microinstruments including:
  - micro gyroscope
  - micro propulsion
  - micro valves
  - adaptive optics
  - micro instruments

### Superconducting Devices
- Mixer arrays for sub-mm astronomy and atmospheric chemistry
- SIS and hot electron bolometer mixers
- Far infrared bolometers
- Lo-Tc and hi-Tc materials and devices

### Photonic Systems
- Tunable diode lasers for spectroscopy
  - Narrow linewidth
  - Ambient temperature
  - λ out to 2.06 μm
- Laser arrays for high rate communications (10's GB/sec)
- Laser metrology systems for optical & radar interferometers
- Integrated optoelectronics
- Unique diffractive optics

### Infrared & Ultraviolet Focal Plane Arrays
- Quantum well Infrared photodetector (QWIP) arrays based on GaAs/AlGaAs
- Enhanced UV / X-ray CCDs via MBE δ-doping
- Micromachined thermal infrared detector arrays
- GaN growth & devices

### Power Generation & Storage
- Lithium Battery Development
- Thermoelectric Materials
- AMTEC
- Advanced Solar Cells
- Direct Methanol Fuel Cells
MEMS Picosat Inspector (MEPSI) Stack

- All boards conform coated (Uralane 5750)

DC DC converter
IMU bottom board
IMU upper board
Radio Board (RF)
Radio board (digital)
Flight Computer
Memory

spacers

IMU daughterboard (1 of 2)
Recent Accomplishment:
Fully Assembled 3-axis MEMS-Gyro IMU

Simultaneous 3-axis read-out of rotation rate by 5°/sec about horizontal axis and 10°/sec about vertical axis simultaneously

- Demonstration of high performance: 0.1°/hr bias stability, 0.008°/rt-hr angle random walk with post-resonator gyro design.
- Successful vacuum packaging of gyros.
- 3-axis integration of gyros and accels into IMU.
- Integrated assembly demonstrated.
Recent Accomplishment:
Technology Infusion of Micro Sun Sensor

**Technology Product**

- Apertures
- Mask
- Focal Plane

**Product Objectives**

Develop a low mass (<10 grams) and low power (<20 mW) micro sun sensor (25 x 25 x 4 mm) with 100° field of view (FOV), 0.04° accuracy for next generation of space applications including small, micro-spacecraft and large mass-sensitive spacecraft.

**Customer:**
Mars Science Laboratory (09)

**Technology Infusion**

An agreement was signed between the Micro Spacecraft Technology project and the Mars Technology Program to co-fund technology infusion of the micro sun-sensor into the Mars Surface Laboratory (2009) mission:

- Funding available in FY 04 and 05

*Space Avionics and Microsystems Briefing, 11-15-03, Dr. Leon Alkalai*
MAST Goal
Develop a space qualified micro star tracker for micro/nano spacecrafts. The star tracker will have 100 x mass x power improvement over present state of the art star trackers e.g. for EO.

MAST functionality
• Acquisition mode: stores position of 700 brightest pixels
• Bright pixel exclusion zones in acquisition mode
• Tracking mode: tracks 8 windows simultaneously
• I²C interface to spacecraft computer
• Star catalog in spacecraft computer
• Spacecraft computer commands windows on MAST
• Spacecraft computer calculates centroids/quaternions

MAST Block diagram (only 2 chips)

APS Chip Unique Technology
• Operating Voltage: 3.3 Volt (20 mW)
• Tracks and exposes 8 windows simultaneously
• Read noise in tracking mode: 5 e⁻
• Read noise in full frame mode: 30 e⁻
• Includes all control logic
• Includes 13 bit A/D converter

Space Avionics and Microsystems Briefing, 11-15-03, Dr. Leon Alkalai
Spacecraft Microsystems for future missions
Guidance, Navigation and Control

Miniature Gyro

MEMS IMU
- <1 in³
- 0.1 deg/h
- <1 W

Meso IMU
- <10 in³
- 0.01 deg/h
- <1W

Miniature Star Tracker and Imager
- Radiation Tolerant
- Scientific Imaging
- Light weight and low power
- Autonomous Operation
- Hazard Avoidance

Miniature Sun Sensor

Miniature Micro-Navigator

Space Avionics and Microsystems Briefing, 11-13-03, Dr. Leon Alkalai
Recent Accomplishments:
MEMS Micro-cooler

- **Microcooler Concept:**
  - Microscale heat exchanger
  - Uses liquid flow through microchannels
  - Designed for microspacecraft components

- **Benefits of the Microcooler:**
  - MEMS fabricated and packaged
  - Robust and simple design
  - Low mass and size

- **Performance goals:**
  - Power density $\geq 25$ W/cm$^2$
  - Device temperature $< 80^\circ$C
  - Pressure drop across heat sink $< 1$ psi

- **Key Accomplishments:**
  - Recent tests show 23 W/cm$^2$ of heat removal
  - Device temp. kept under goal of 80$^\circ$C
  - Flowrate- 25 ml/min
  - Pressure drop across device $\sim 0.35$ psi

*Space Avionics and Microsystems Briefing, 11-15-03, Dr. Leon Alkalai*
Integrated MEMS Microvalve for Micropropulsion

Objectives:
Demonstrate integrated, fast, low power, high-pressure MEMS microvalves for future micropropulsion systems

Applications:
- Micropropulsion for Microspacecraft
- NASA Sun-Earth-Connection
- NASA Solar System Exploration
- DARPA Picosat, AF Micro/Nanosats

Demonstrated

<table>
<thead>
<tr>
<th>Requirements</th>
<th>Target</th>
<th>Demonstrated to Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>Leak Rate</td>
<td>0.005 sccm/He</td>
<td>$10^{-4}$ sccm/He @ 800psi</td>
</tr>
<tr>
<td>Inlet Pressure</td>
<td>300 ~ 3000 psi</td>
<td>0 ~ 1000 psi</td>
</tr>
<tr>
<td>Actuation Speed</td>
<td>&lt; 10 ms</td>
<td>&lt; 10 ms</td>
</tr>
<tr>
<td>Power</td>
<td>&lt; 1 W</td>
<td>~ 4 mW to hold</td>
</tr>
<tr>
<td>Package Weight</td>
<td>&lt; 10 g</td>
<td>~ 10 g</td>
</tr>
<tr>
<td>Temperature</td>
<td>0 ~ 75 °C</td>
<td>Not tested yet</td>
</tr>
</tbody>
</table>

Space Avionics and Microsystems Briefing, 11-15-03, Dr. Leon Alkalai
Recent Accomplishments
Vaporizing Liquid Micro-thruster (VLM)

- **VLM concept**
  - Liquid propellant, pressure-fed
  - Vaporize propellant in thin-film heater assembly
  - Exhaust gaseous propellant to produce thrust

- **Benefits of the VLM**
  - Liquid propellant storage (compact).
  - Extremely small and light.
  - Amenable to on-chip integration schemes.
  - Scalable to very small thrust and impulse bits.

- **Performance goals:**
  - Isp: 50-100 sec
  - Thrust: $\mu$N to $< 0.5$mN
  - Power: $< 2$ W
  - Mass/Size: few grams/ 1 cm$^2$

- **Key Accomplishments:**
  - Demonstrated feasibility of concept (vaporization at 1.1 W, 0.2 g/hr water flow rate, est. 128 $\mu$N thrust).
Miniaturized Power Sources

Task Objective:
Develop microdevices for:
- $mW/mm^3$ power (vs. $mW/cm^3$)
- harsh environment capability
- long lifetime (> 10 years)
- on-chip integration (single or array)

Thermoelectrics:
Key advantages: Long life operation, full scalability, on-chip integration
Major challenges: Microfabrication technology development, integration with high temperature heat sources/heat sink

Alpha-voltaics:
Key advantages: High conversion efficiency and specific power
Major challenges: Selection of optimal semiconductor material, design and fabrication of highly efficient, long life device
Thin Film Micro-Batteries

- Solid state micro-batteries batteries (50 - 100 μm)^2 were successfully fabricated and cycled. These are the smallest solid state batteries ever reported.
- Developed microfabrication processing steps to accommodate 300°C anneal of cathode films for doubled capacity and flattened discharge voltage.
- Micro-batteries selected as JPL Technology Spotlight for February 2001

Space Avionics and Microsystems Briefing, 11-15-03, L. Alkalai
Future Applications & Benefits of Using Micro Systems and Micro Spacecraft in Space

**Constellation of Micro Spacecraft**

- Micro Satellites enable constellations
- Global Coverage if necessary
- Autonomous On Board Control
- Minimize access time to information
- Coordinated observations
- Fault Adaptive Systems
- Emerging Sensor Networks Technologies