Thermal Management and Power Packaging for Spacecraft of the Next Millennium

Presented at International Workshop on Integrated Power Packaging

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Topics

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- Space power management systems -- what they're supposed to do
- Power management systems evolution -- from Cassini to X2000 and Beyond
- Packaging issues/technologies
- Thermal management issues/approaches
- Summary

Key Functions of Space Power Systems

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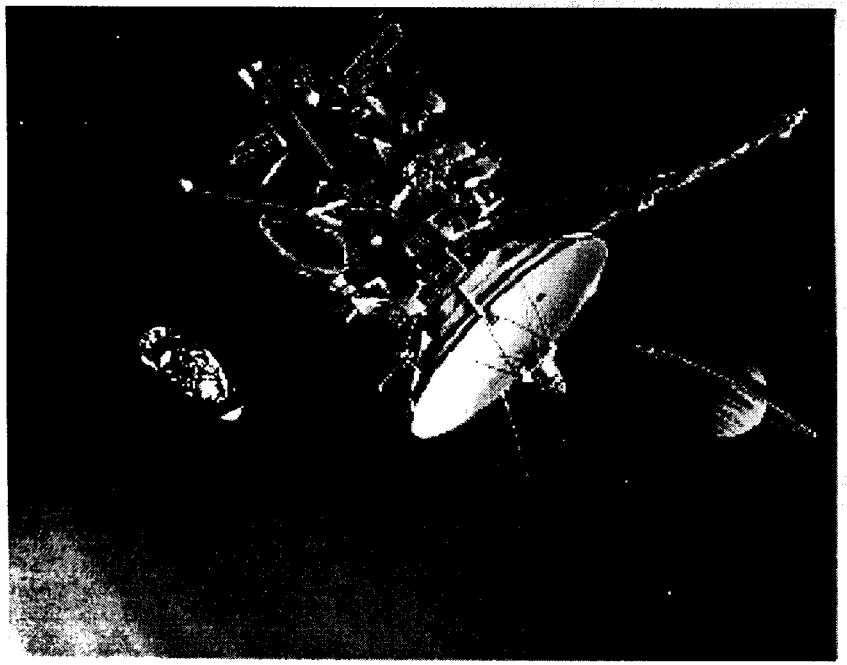
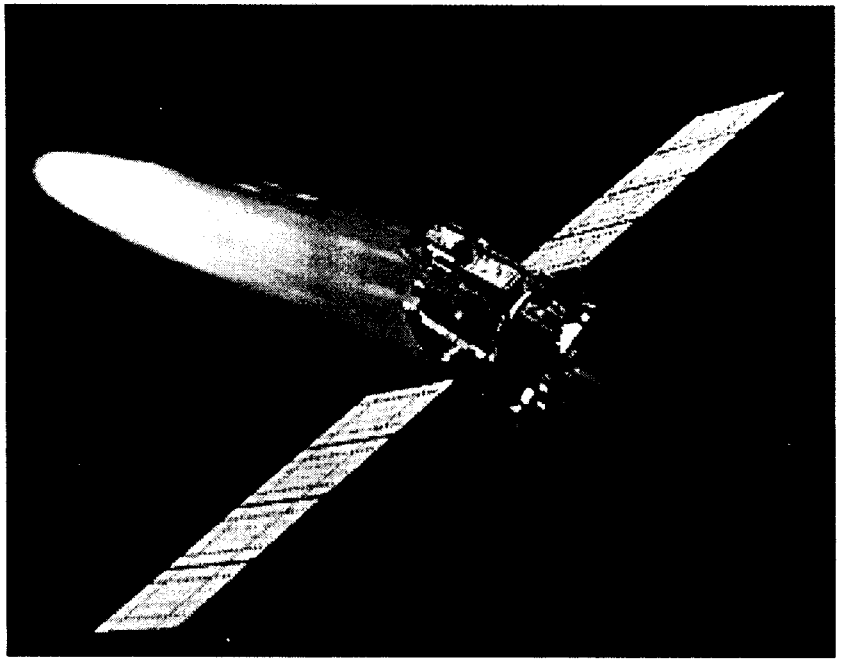
Cassini

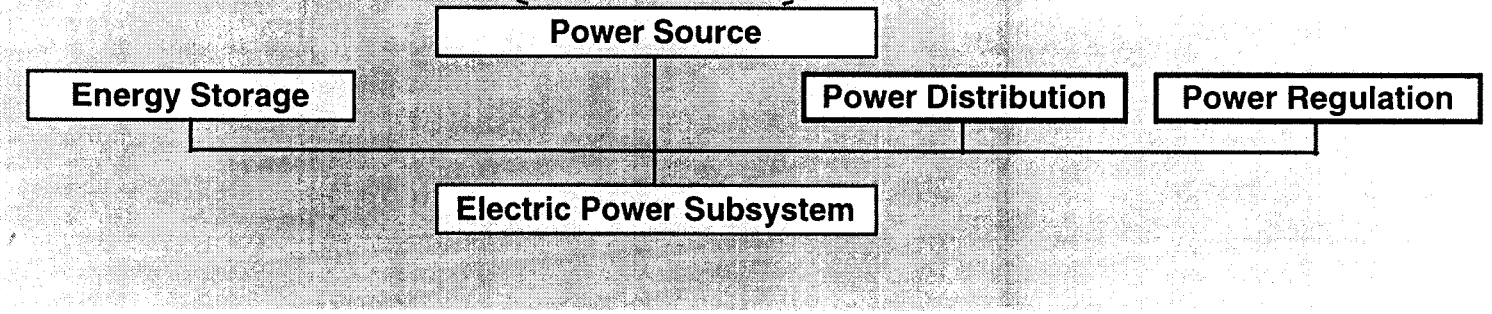


Radio-Isotope Thermal Generator (RTG)

Deep Space One



Solar Photovoltaic



Key Functions of Space Power Management Subsystems

- **Power Distribution**
  - Cabling, fault protection and switches to turn power on/off to spacecraft loads
  - Isolate loads from bus noise and regulate power to load against disturbances from the load and the bus
  - Protect the power distribution system from load failures
- **Power Regulation**
  - Control solar arrays/RTGs
  - Regulate spacecraft bus voltage
  - Battery charging

Space Power Management System Evolution

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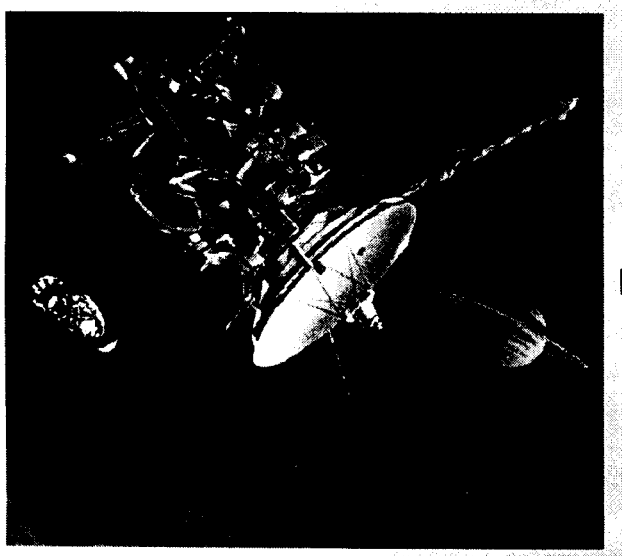
1980s



Cassini

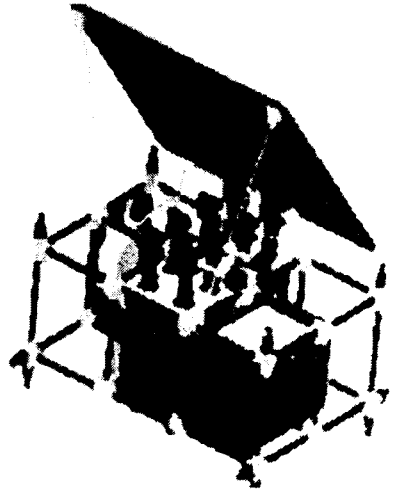
8 Power Distribution Subassemblies
2 Power Control Subassemblies
2 Pyro Distribution Subassemblies
1 Shunt Regulator Subassembly
2 Pyro Drive Electronics Slices
Power: 900 W
Power System Mass: 222 kg

Late 1990s

Europa Orbiter

6 Power Distribution Slices
6 Valve Drive Electronics Slices
2 Power Control Slices
2 Battery Control Slices
2 Pyro Drive Electronics Slices
Power: 150 W
Power System Mass: 20 kg

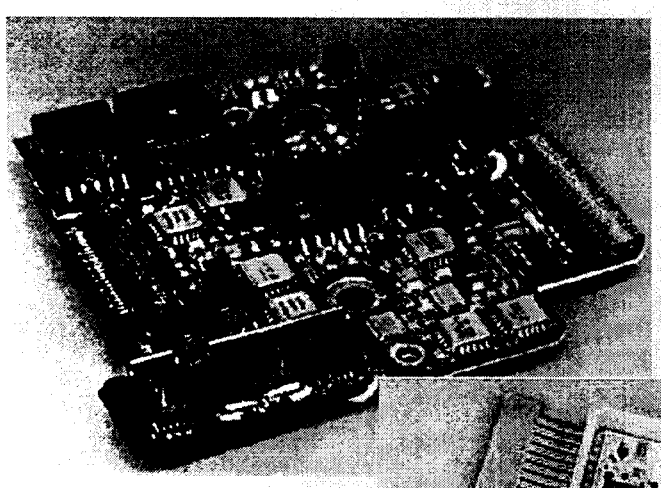
2000 and Beyond



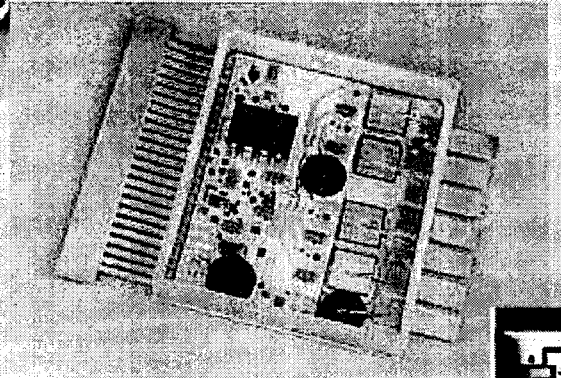
SGMS

Distribution Power Switching
Power Converter Slices
Valve and Pyro Drive Slice
Battery Control Slice
Power: 50 W
Power System Mass: 10 kg

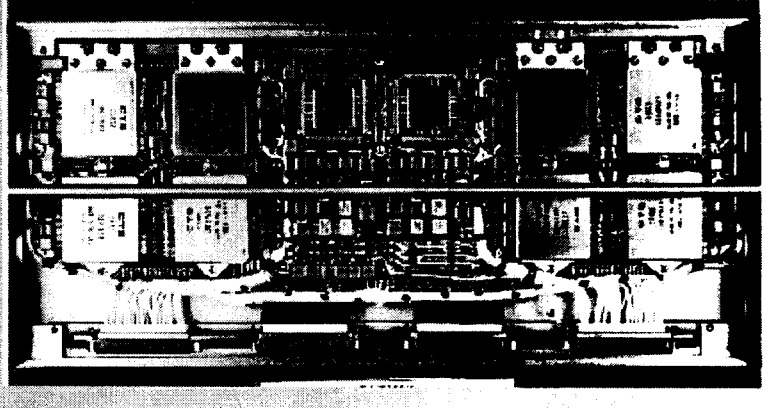
Physical Characteristics of Typical Power Management Electronic Assemblies



Large, Odd-Shaped Components Compared to Single-Chip IC Packages



Thick, Wide Package Leads for Heavy Currents



Bolted-Down Packages For Low Resistance Thermal Interfaces

Space Power Management Systems Must Survive in Severe Environments – Radiation

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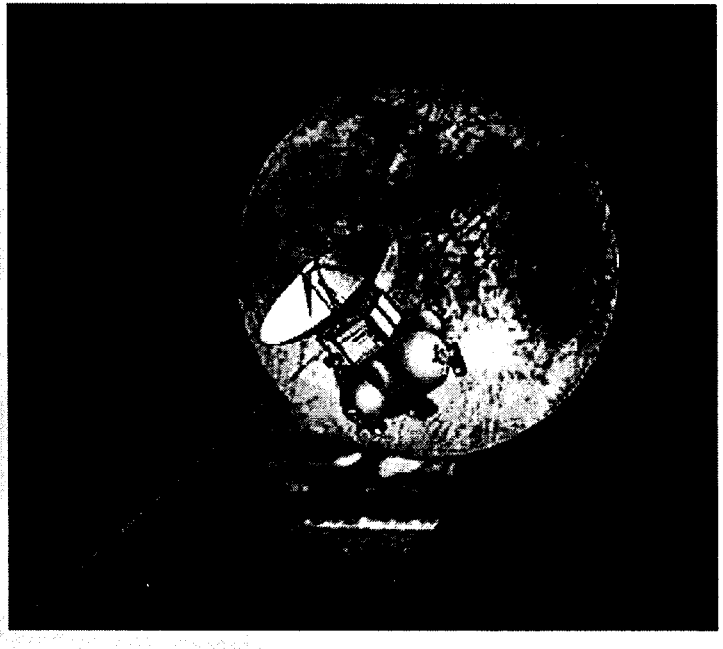
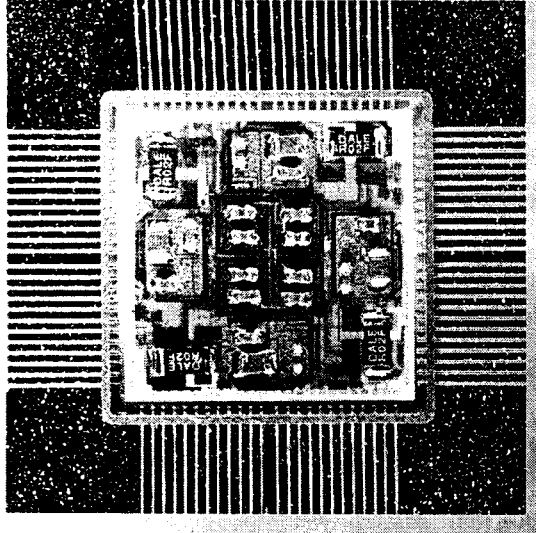
Europa Orbiter



Power Activation and Switching Module



4 mrad TID at Die Level

Space Power Management Systems Must Survive in Severe Environments--Impact Shock

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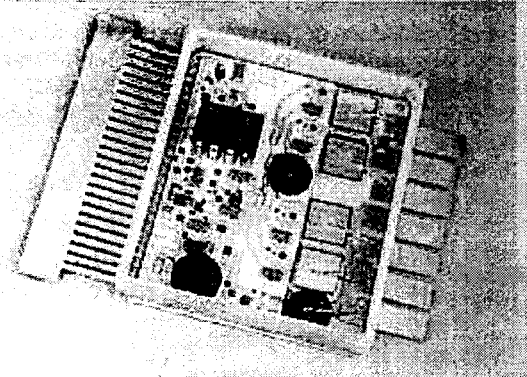
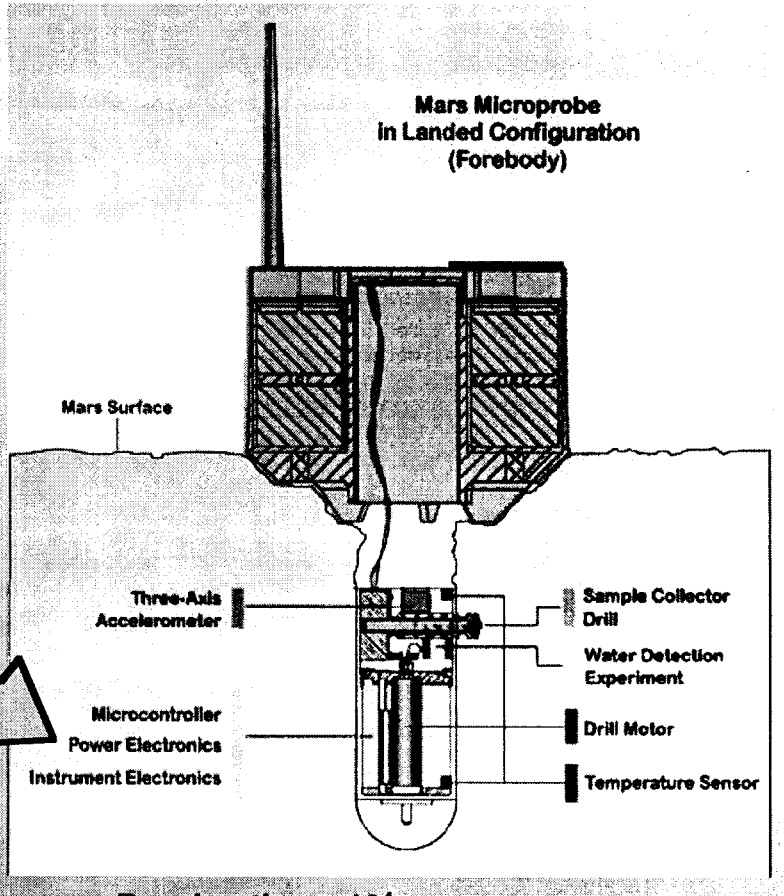
Power Management Electronics



Deep Space 2 – Mars Microprobe



Deceleration = 10^4 g
Temperature Range: -120C to +50C

Candidate Packaging Technologies for Future Spacecraft

- MCM-D
- MCM-L
- MCM-D/L
- Chip-on-Board
- Single-chip Packages
  - Ball Grid Arrays
  - Chip Scale Packages
- Flip Chip

Typical Examples of MCM-D for Space Power Management Subsystems

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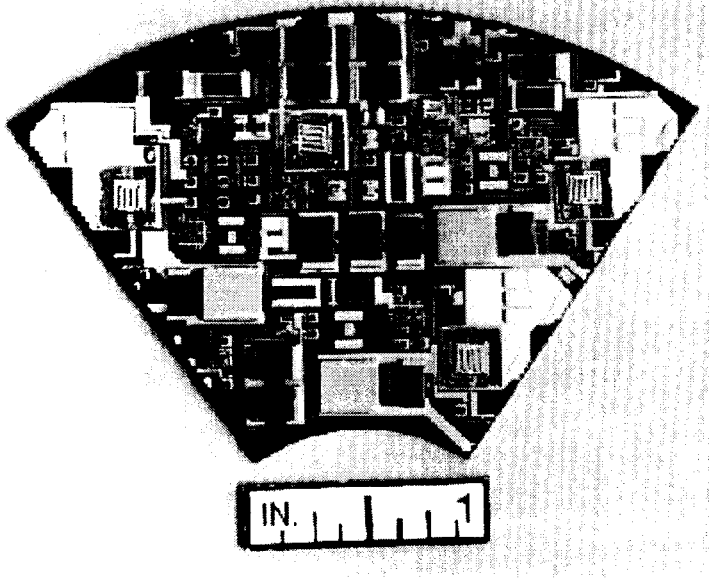
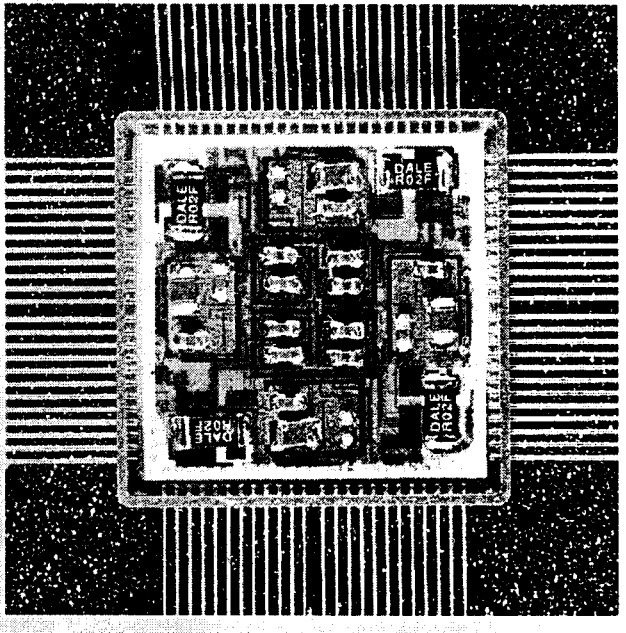
"Chips Last" Approach



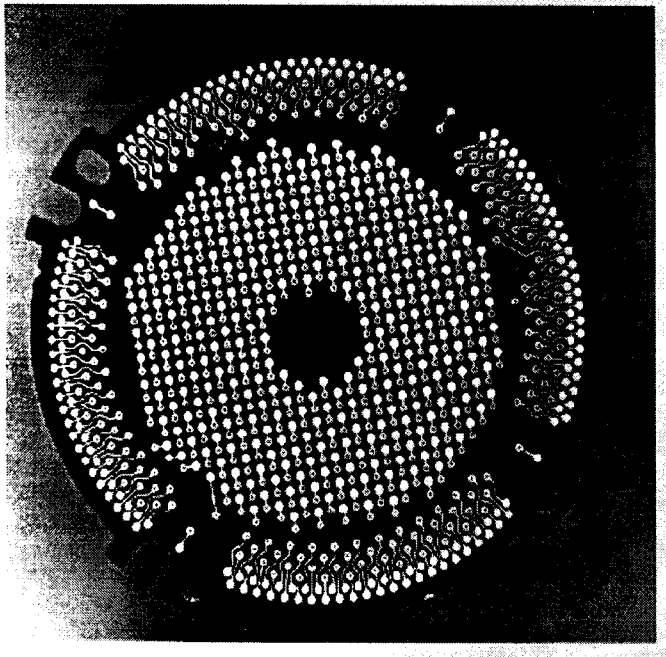
BMDO Interceptor Missile Application

"Chips First" Approach

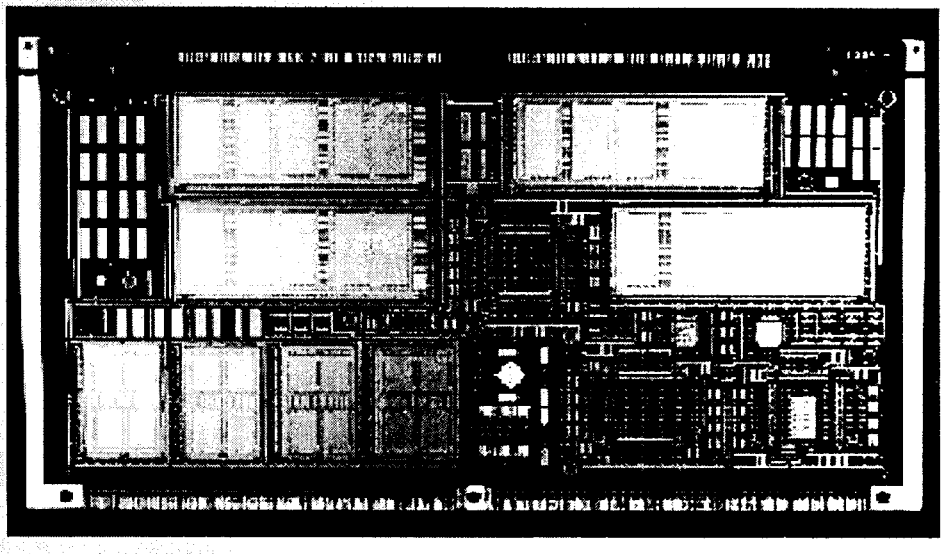


Deep Space 1 Power Activation and Switching Module (PASM)

Typical Examples of MCM-D/L



Fine "Microvia" Layer
Over Core PWB



2 to 3 Layer MCM-D Decals Attached
to Selected Areas on Core PWB

MCM D/L Offers Tailorability of Board Layout to Achieve MCM-D Component Density at PWB Prices

Chip-on-Board Comes in Several Varieties

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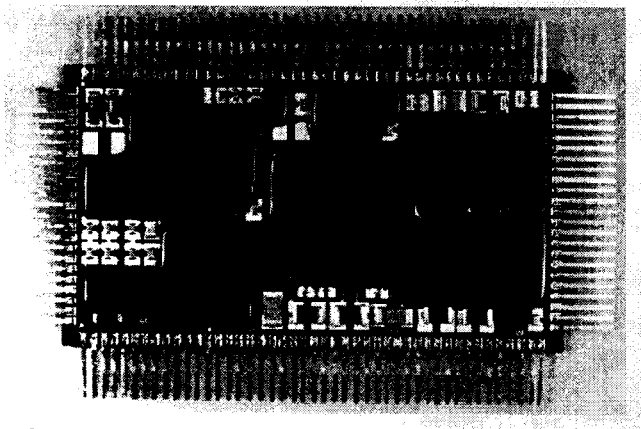
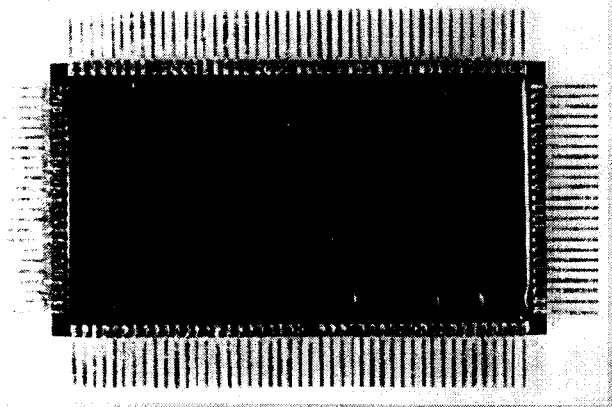
Non-reworkable Approaches

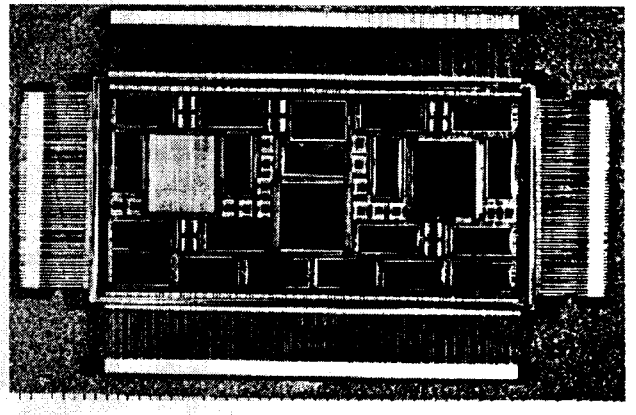


Partial Encapsulant Coverage of Components



Total Encapsulant Coverage of All Components

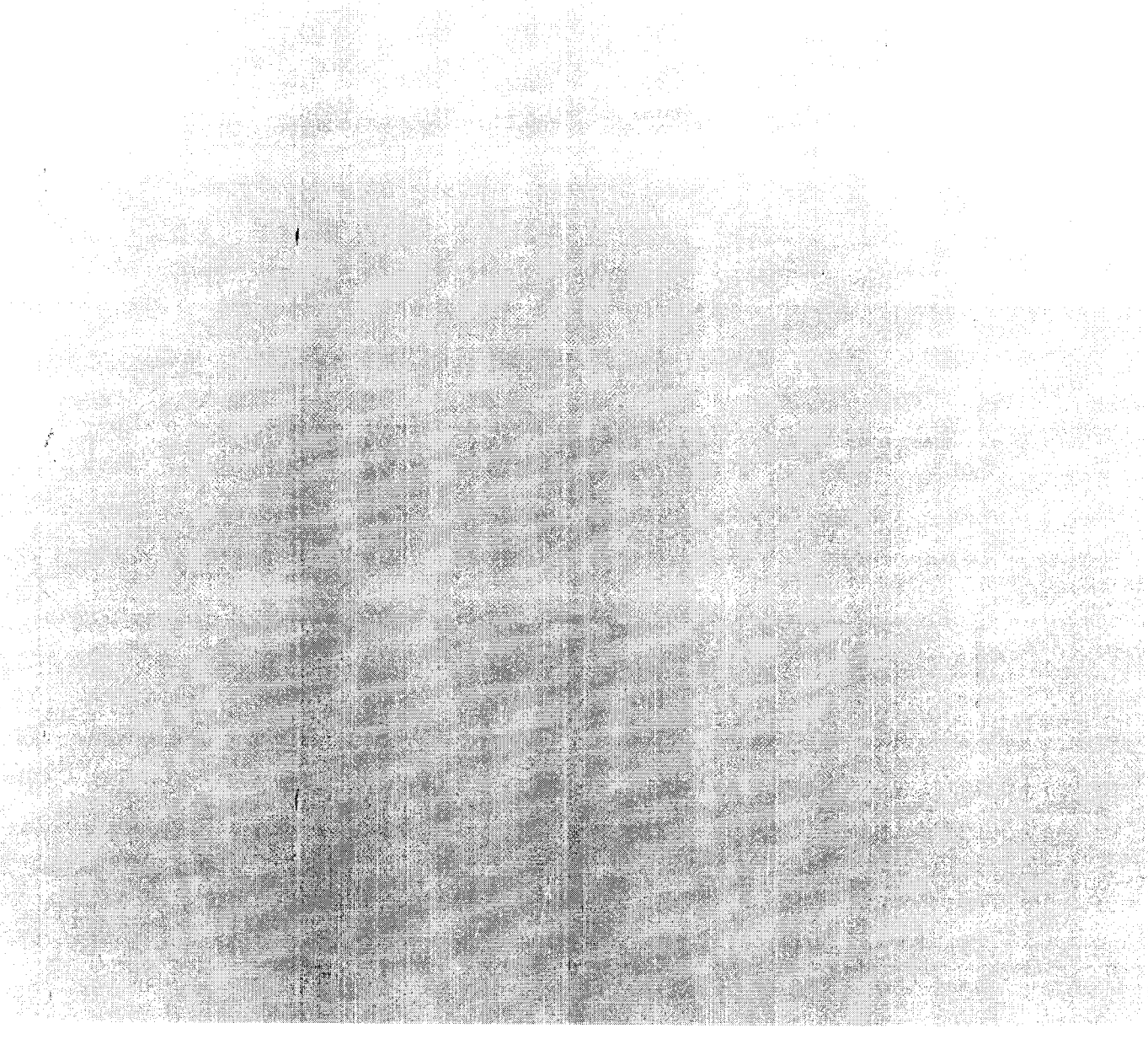
Reworkable Approach



Encapsulant Covers Top of Die Only

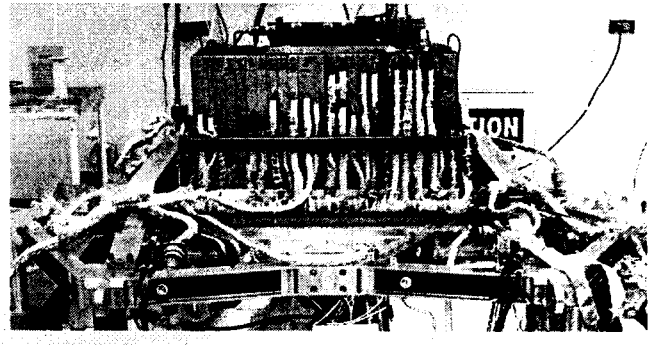
Non-reworkable Approaches Offer Low Cost; Reworkable Approaches Permit Electrical Test/Component Replacement After Encapsulation

Evolution of Single Chip Packages

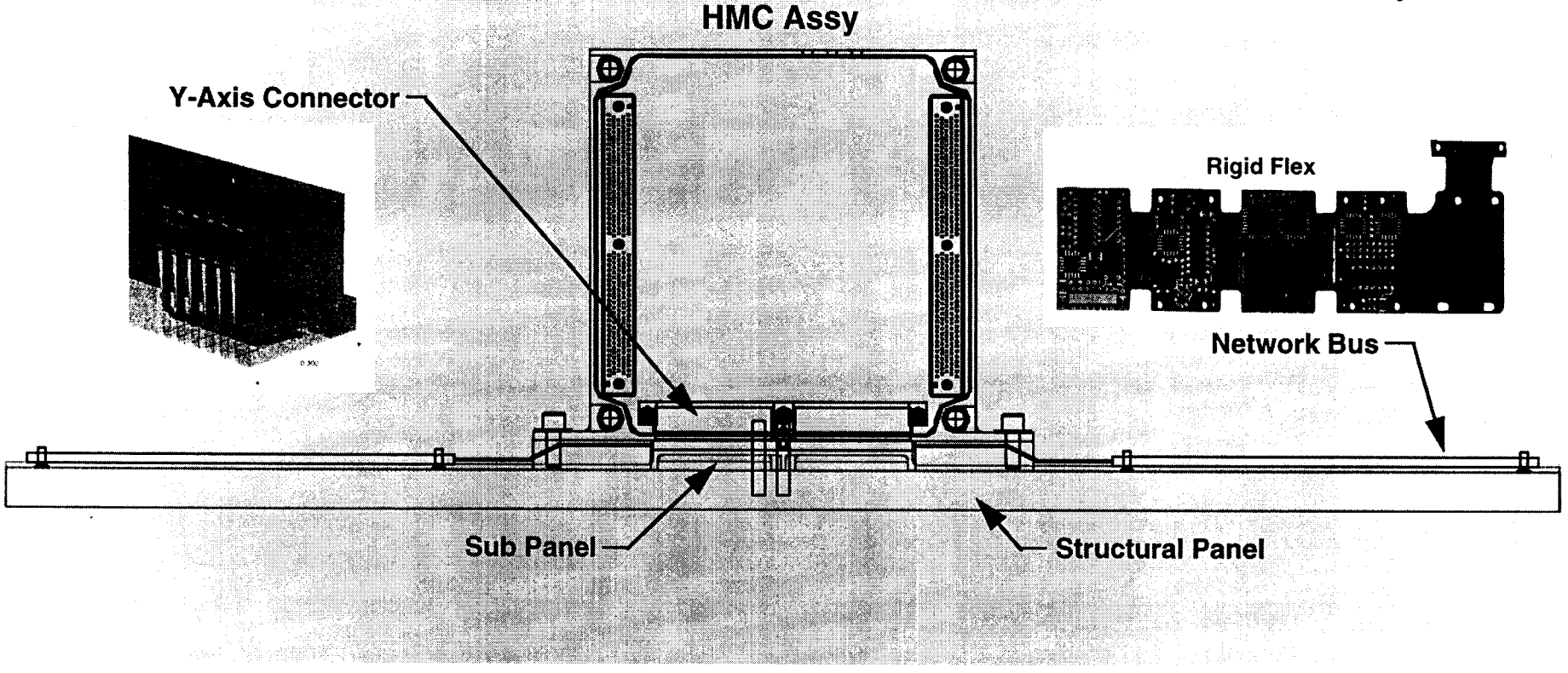


Near-Term Approach to Avionics Systems Packaging for NASA Spacecraft

- Enable technology for "System on a Chip"
- Free up internal spacecraft volume
- Minimize traditional cabling mass (~30 – 60% improvement)
- *Maintain rework capability*



MPF – IEM/Base Pedal Assy



Near-Term Approach to Avionics Systems Packaging for NASA Spacecraft: Preliminary Layouts

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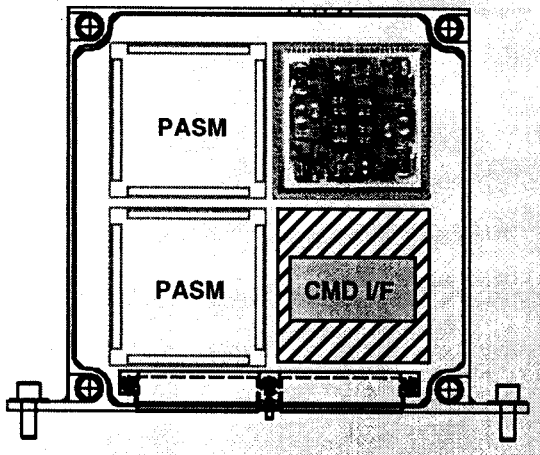
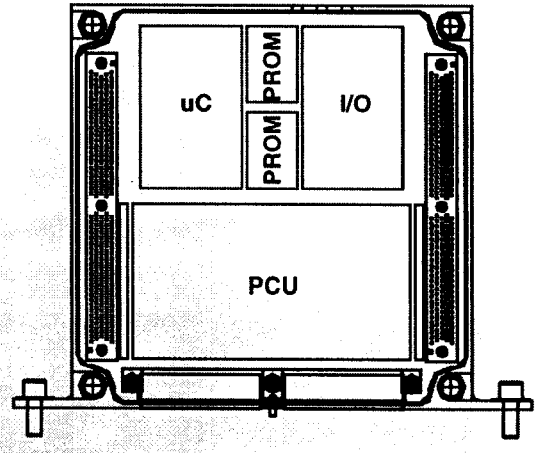
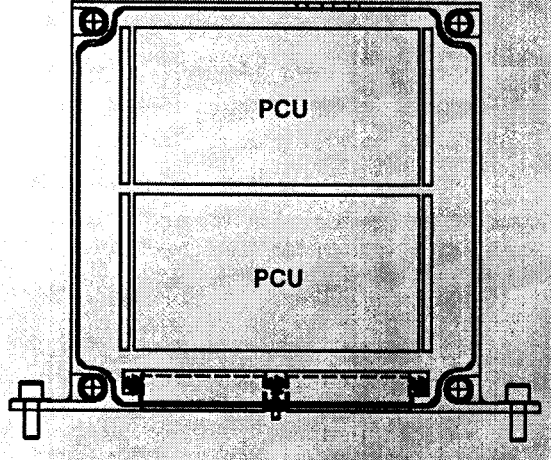
Layout Power Switch Slice (PSS)



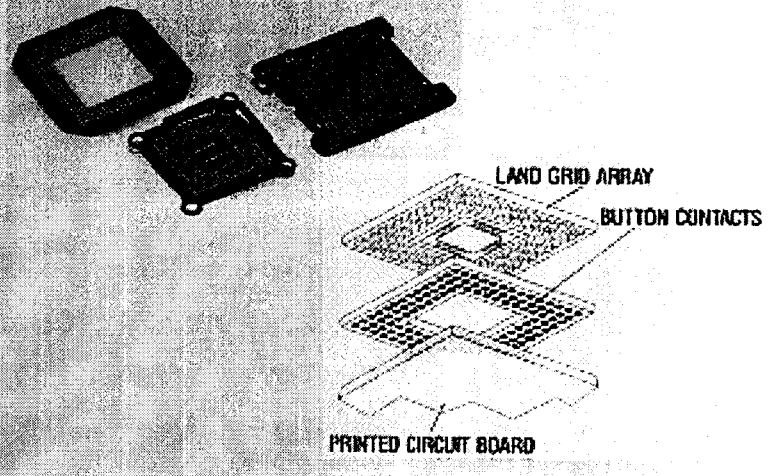
Layout Micro Controller Slice (MCS)



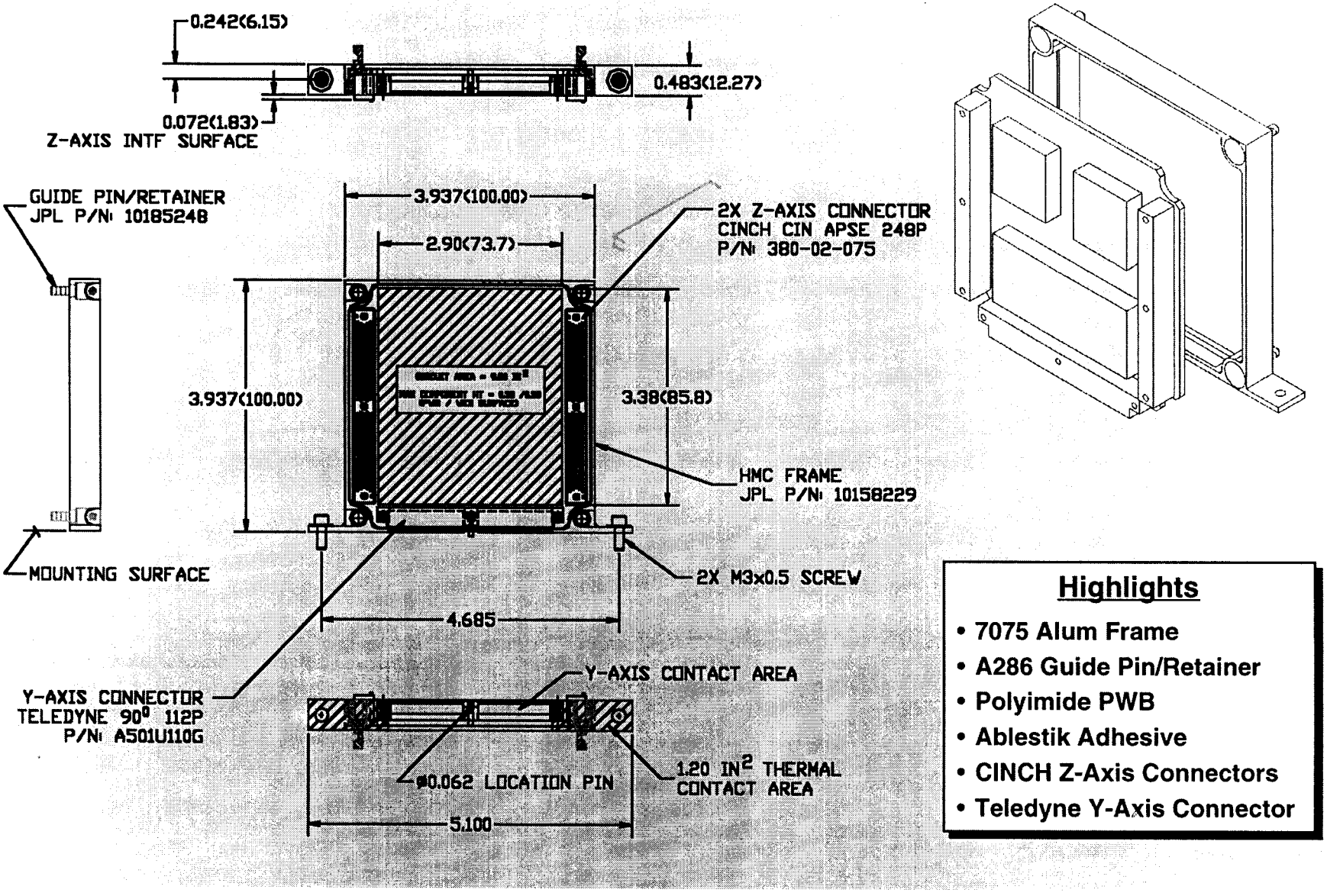
Layout Power Converter Assy (PCA)



Proposed Interposer for Component to Board Interconnect System



Single Wide Slice - Horizontal Mounted Cube (HMC)



Highlights

- 7075 Alum Frame
- A286 Guide Pin/Retainer
- Polyimide PWB
- Ablestik Adhesive
- CINCH Z-Axis Connectors
- Teledyne Y-Axis Connector

Possible Intermediate Steps in Evolution of Space Power Management Systems

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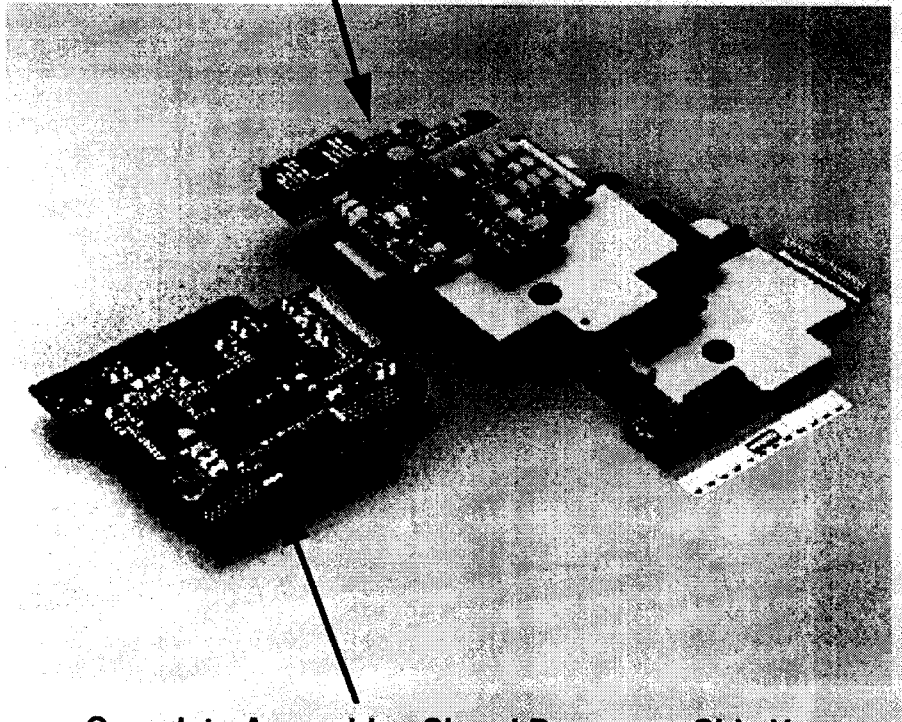
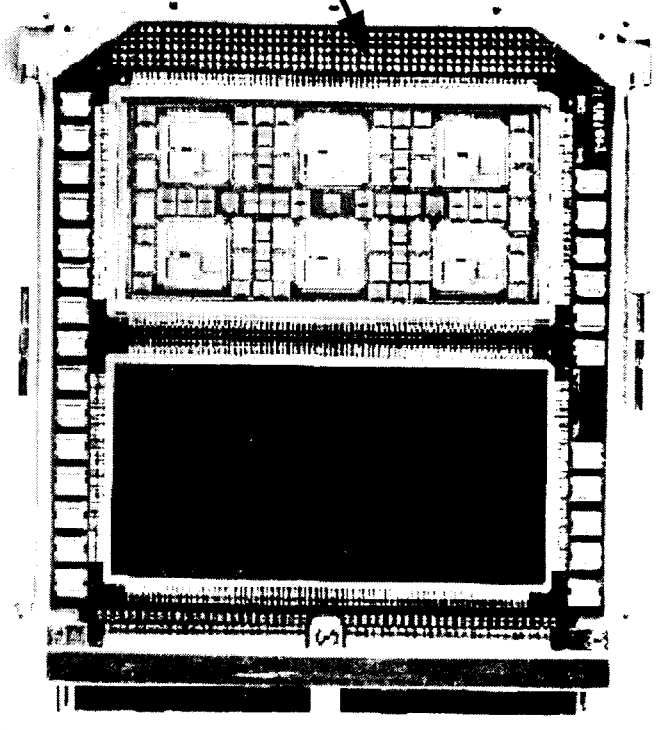
Exploded Assembly: Power Supply Side Up



Complete Assembly: Signal Processor Side Up

Combined Signal Processing/Power Management In a Single Electronics Assembly

Space For Power Supply Components



Combined Signal Processing/Power Management on a Single PWB

Power Management Aspects for Systems-on-a-Chip

- Key technologies for tight integration of the power system on chip
  - Micro-transformers
  - Thin film components (capacitors, etc.)
  - Distributed on-chip power system
  - On-chip power supply
  - Monolithic power switches and converters
- Advantages of on-chip power management
  - Reduced interference, electromagnetic emissions and noise
  - Reduced system size
  - Higher speed

Thermal Management Issues

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- Thermal management is usually dead last on the system design priority list
- Current technology trends indicate lower power dissipation at the system level as well as less space to get rid of waste heat
- Quick, accurate methodology for predicting power dissipation is required
- What will be the temperature sensitivity of electrical performance parameters to temperature as systems-on-a-chip reach maturity?

Approaches to Thermal Management for Spacecraft Electronics

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- Conduction/thermal radiation
- Heat pipes
- Convective cooling
  - Cold plates (including microchannels)
  - Direct impingement on power dissipating components
- High thermal conductivity coatings on power dissipating components

Heat Pipes for Electronics Cooling Come in Two Basic Varieties

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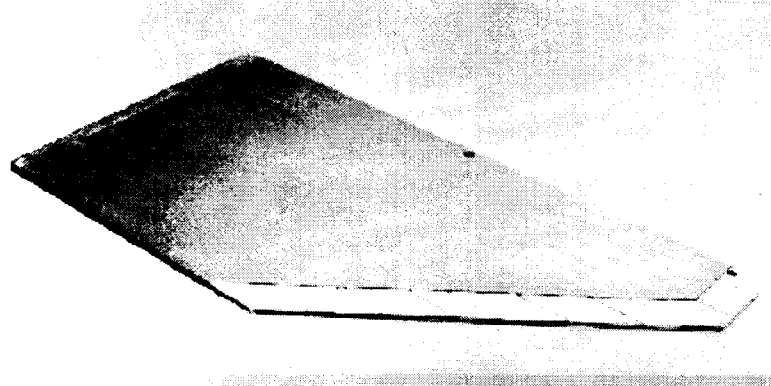
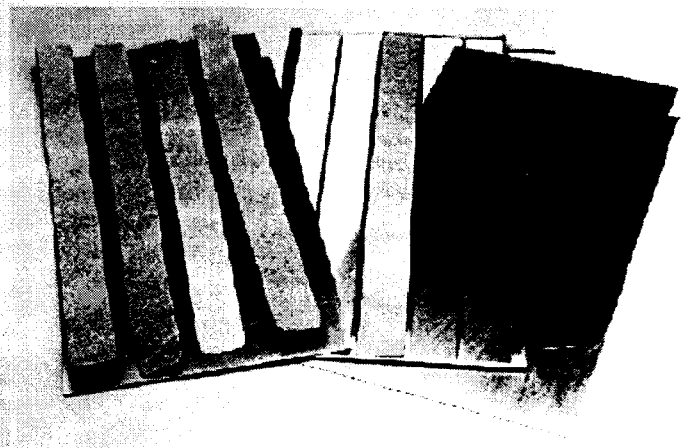
Embedded



Individual Heat Pipes Inserted into Cold Plate Frame

- Lower Performance
- Lower Cost
- Heavier

Vapor Chamber



Interconnected Chambers in Cold Plate Frame

- Higher Performance
- Higher Cost
- Lighter

Heat Pipes Require Careful Design and Attention to Detail

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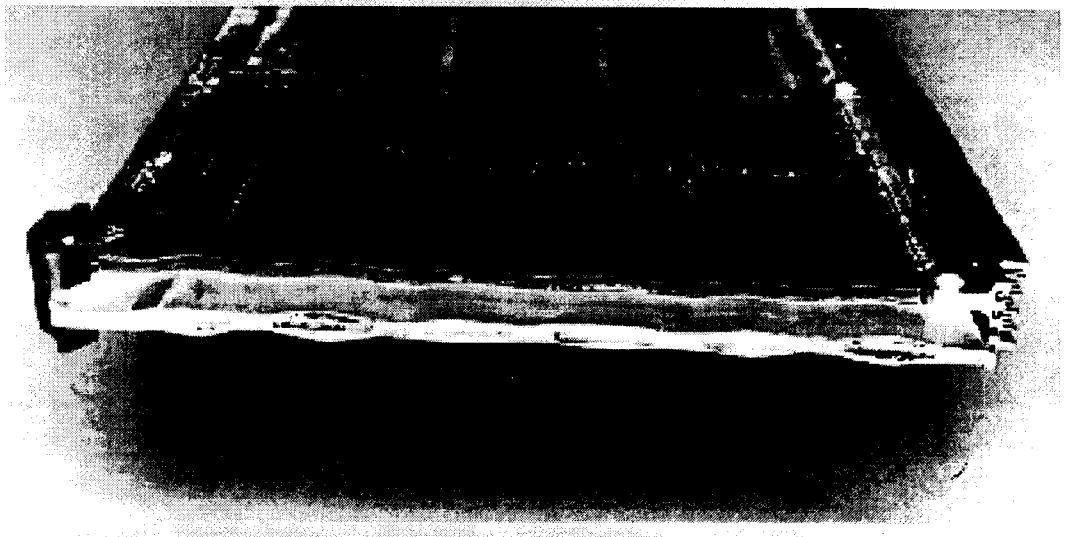
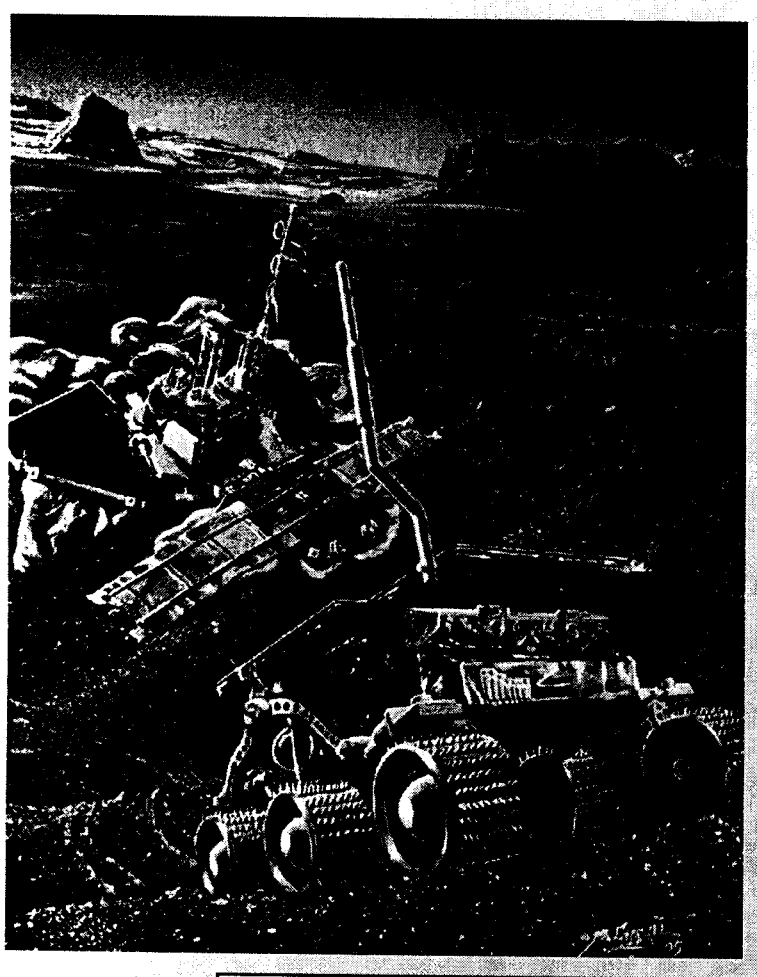
Monel/Methanol Embedded Heat Pipes
Thermal Cycled from -55 to 125 C

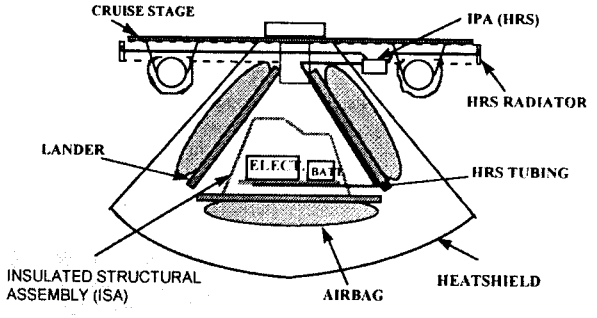


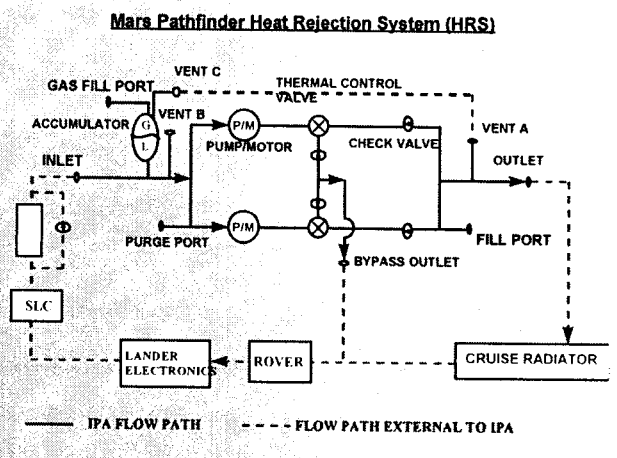
Things to Consider for Successful Application of Heat Pipes to Microelectronics Thermal Management

- Operating temperature
- Environmental temperature range
- Fluid compatibility with heat pipe wall and wick materials
- Area for heat transfer out of the heat pipe
- Post processing of electronic assembly after heat pipe fabrication

Convective Cooling of Spacecraft Electronics was Demonstrated on the Mars Pathfinder







- Successfully flew on Pathfinder
- 18 months of continuous operation on JPL Life Test Bed Setup
- Uses mechanical centrifugal pumps to circulate Freon-11 in the Spacecraft

Summary

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- Power management subsystems on NASA spacecraft are evolving towards smaller, lighter form factors
  - Component size is decreasing
  - Advanced packaging permits closer component spacing
- Thermal management issues need to be dealt with earlier in the design cycle
  - Power dissipation decreasing with time, space to get rid of heat decreasing even faster
  - Thermal issues resulting from progress in "system-on-a-chip" need to be understood, defined for the design community, and solutions found if required

Acknowledgments

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