Distributed Motor Controller (DMC) for Operation in Extreme Environments

Jet Propulsion Laboratory, California Institute of Technology
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Agenda

• Background
  – Centralized motor control architecture
  – System resource trades of using distributed vs. centralized architecture

• Distributed Motor Controller (DMC)
  – DMC ASIC designs
  – Breadboard implementation

• Testing and Characterization

• Future Direction
Extreme environment missions

Mars
Temperature Range
[-125°C, 20°C]
Mars Exploration Rover [2003]
20-25 actuators

Mars Science Laboratory [2011]

Moon
Temperature Range
[-185°C, 120°C]
ATHLETE Lunar Rover [2010+]
60+ actuators

Vulnerable to radiation
• Thin atmosphere
• Lack of magnetic field

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Centralized Motor Control

MSL Warm Box top view
Distributed Motor Control

Reduction in Wiring
- Power Bus
- Network Bus

Localized Motor Controller

Hardware Specifications
- Wider Temperature
  -150°C, 85°C
- Radiation Tolerant

<table>
<thead>
<tr>
<th>Rover System</th>
<th>Pathfinder</th>
<th>MER</th>
<th>MSL</th>
<th>MSL w/DMC (Projected)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Wiring Mass</td>
<td>1.4 Kg</td>
<td>10.4 Kg</td>
<td>52.7 Kg</td>
<td>37 Kg</td>
</tr>
<tr>
<td>Actuator Wiring Mass</td>
<td>0.35 Kg</td>
<td>3.0 Kg</td>
<td>17.4 Kg</td>
<td>1.8 Kg</td>
</tr>
<tr>
<td>Percentage of Actuator Harness Mass</td>
<td>25 %</td>
<td>29 %</td>
<td>33 %</td>
<td>5 %</td>
</tr>
</tbody>
</table>
DISTRIBUTED MOTOR CONTROLLER (DMC)

Electronics architecture, ASIC design and Breadboard implementation
DMC electronics module includes:
- Two custom mixed-signal ASICs in IBM SiGe 0.5um
  - Resolver-to-Digital Converter (RDC) chip
  - Analog Sense chip
- COTS FPGA
- 10A motor drive power FETs and gate drivers
- Brake drive
- Resolver excitation for position feedback
- Onboard power regulation from single +28V supply
IBM Silicon Germanium (SiGe) 0.5μm

IBM SiGe 5AM process technology is the key enabling feature

- Wide temperature (-150°C to +85°C) operation
- Radiation tolerant (> 100 kRad Total Integrated Dose)
- Excellent analog circuit performance
- Low cost
- Leveraging proven performance at temperature through past JPL (DMC-2 study) and NASA (Exploration Development Technology Program) efforts
RDC ASIC

- Operates on single 3.3V supply
- Two Resolver/LVDT-to-Digital Converter circuits
  - Digitizes resolver waveforms to deduce motor position to 0.1°
- Load Switch controller
  - Gate driver for power MOSFET enable/disable
- Power-On reset
  - Monitors system voltages and flags FPGA if out of tolerance
- Bus Transceiver
  - 50 Mb/s galvanically-isolated redundant digital bus for communicating with host computer and other DMC modules
Analog Sense ASIC

- Operates on single 3.3V supply
- Housekeeping chip to monitor system voltages/currents and motor telemetry
  - 16-input Differential and Single-ended MUXs with independent gain settings
  - Stimulus driver capable of providing 1.2V or 1mA to sensors external to chip
  - Serial digital communication to FPGA
Breadboard

DMC Breadboard 1 (DBB1)
- Single +28V power bus input
- Virtex-5 FPGA
- RS-232 port for PC interface/control
- Power FETs for motor drive and switched power bus
TEST RESULTS

Operation of motor at -135°C
Cold test results

RDC Angle vs Encoder Angle

- Resolver Angle (Deg)
- Linear (Resolver Angle (Deg))

\[ y = 0.1795x + 15.256 \]

\[ R^2 = 0.9994 \]

Note: R is the correlation coefficient. An R value of 1 would be a perfect line.

RDC Rate vs. Encoder Rate

- Resolver Rate (rpm)
- Linear (Resolver Rate (rpm))

\[ y = 1.0057x + 19.034 \]

\[ R^2 = 0.9994 \]

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Future work

• Next iteration of mixed-signal ASIC to include
  • Single chip solution
  • Four channel switch-mode power supply controller
  • Fully serial interface between ASICs and FPGA
  • Motor phase current sense
• Digital ASIC from finalized FPGA code
• Extreme environment enclosure
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