

# Distributed Motor Controller (DMC) for Operation in Extreme Environments

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March 6, 2012

IEEE Aerospace Conference, Big Sky, MT

# Agenda

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- 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

# BACKGROUND

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Motor Control Architectures

# Extreme environment missions



Mars  
Temperature Range  
[-125°C , 20°C]

Moon  
Temperature Range  
[-185°C , 120°C]

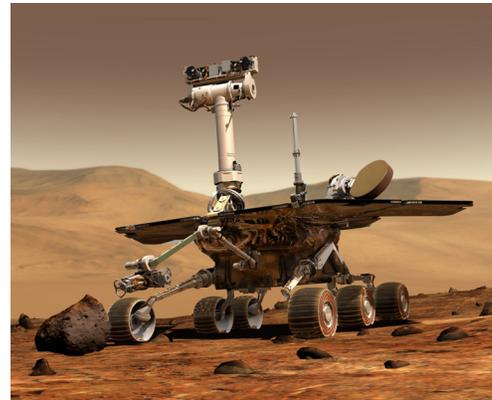


## Vulnerable to radiation

- Thin atmosphere
- Lack of magnetic field

Mars Science Laboratory [2011]

Mars Exploration Rover  
[2003]



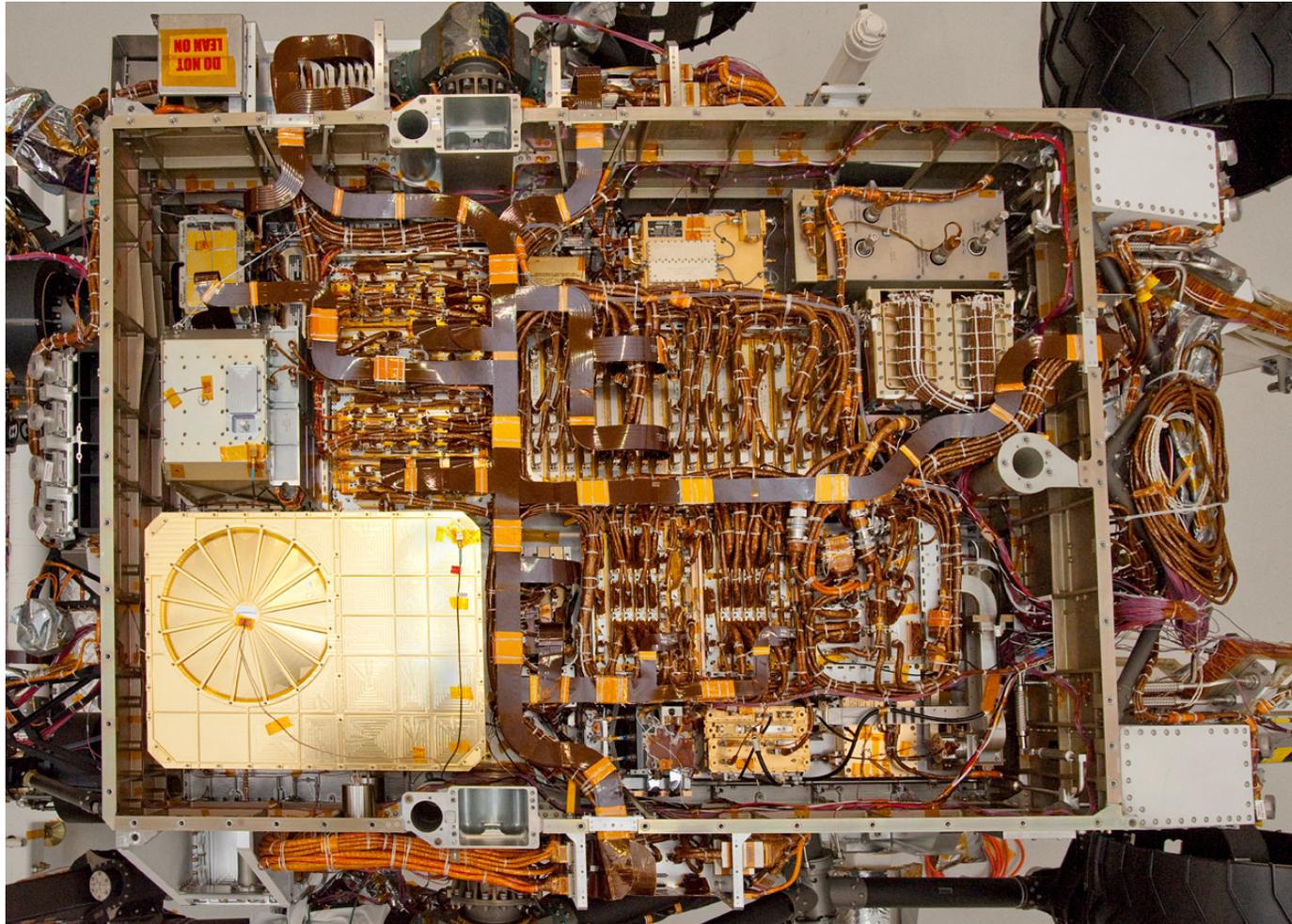
ATHLETE Lunar Rover [2010+]



20-25 actuators

60+ actuators

# Centralized Motor Control



MSL Warm Box top view

# Distributed Motor Control

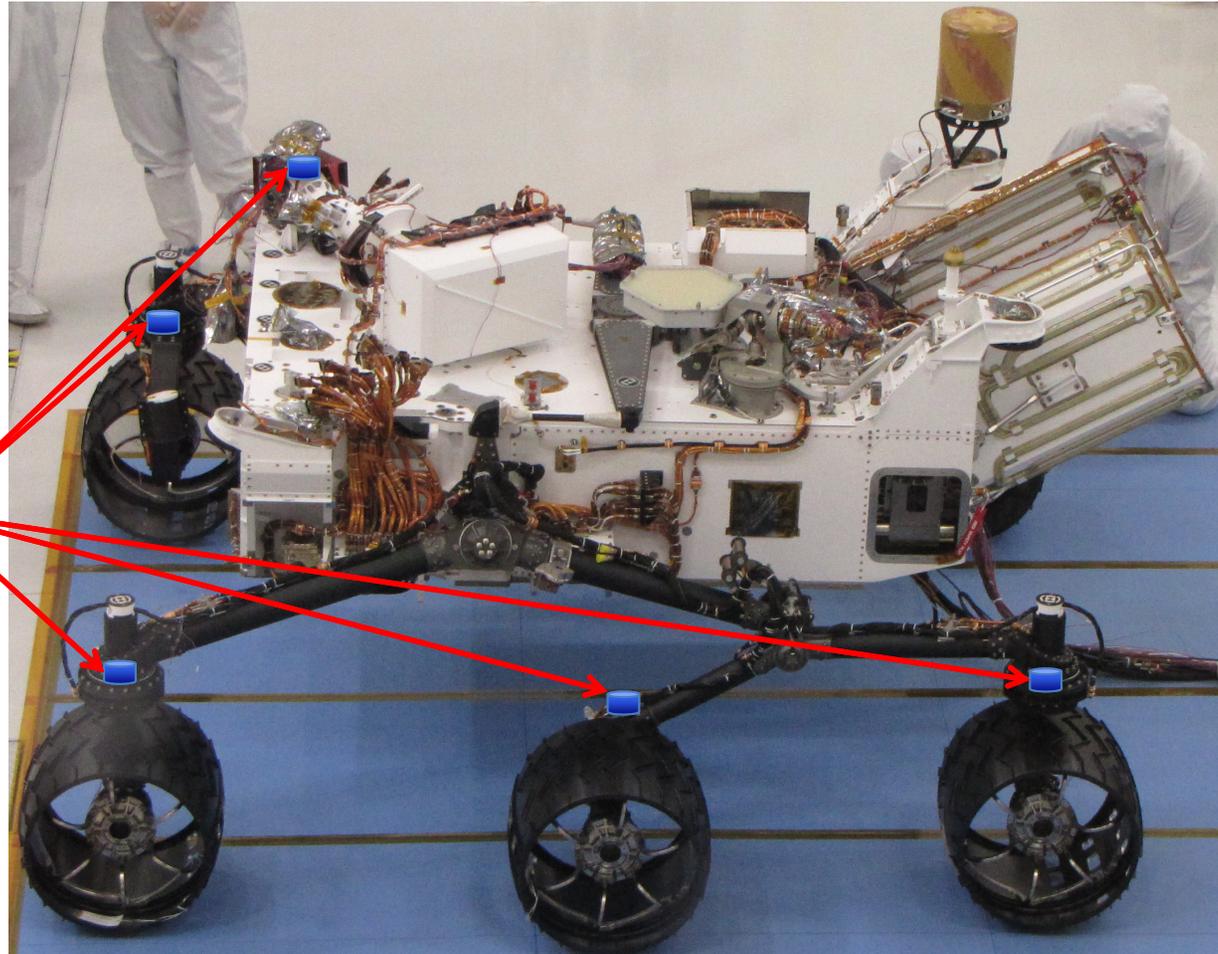
Reduction in Wiring

- Power Bus
- Network Bus

Localized  
Motor  
Controller

Hardware Specifications

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



Rover System	Pathfinder	MER	MSL	MSL w/DMC (Projected)
Total Wiring Mass	1.4 Kg	10.4 Kg	52.7 Kg	37 Kg
Actuator Wiring Mass	0.35 Kg	3.0 Kg	17.4 Kg	1.8 Kg
Percentage of Actuator Harness Mass	25 %	29 %	33 %	5 %

# DISTRIBUTED MOTOR CONTROLLER (DMC)

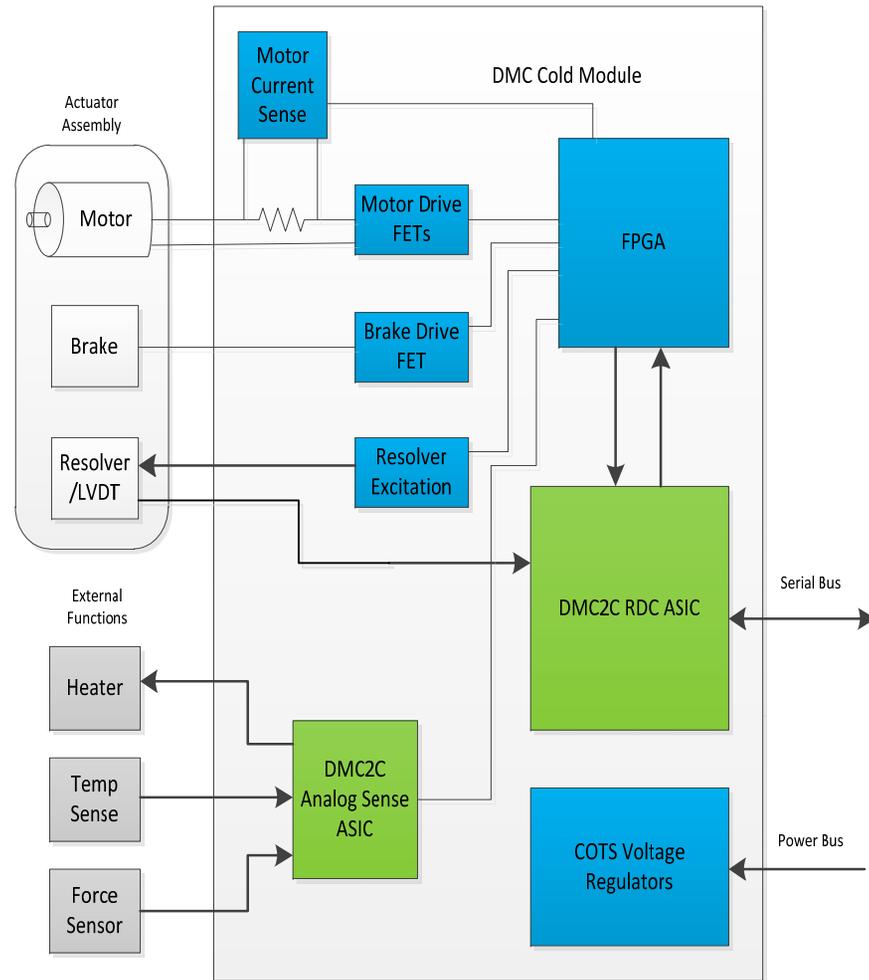
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Electronics architecture, ASIC design and Breadboard implementation

# DMC electronics architecture

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) 0.5um

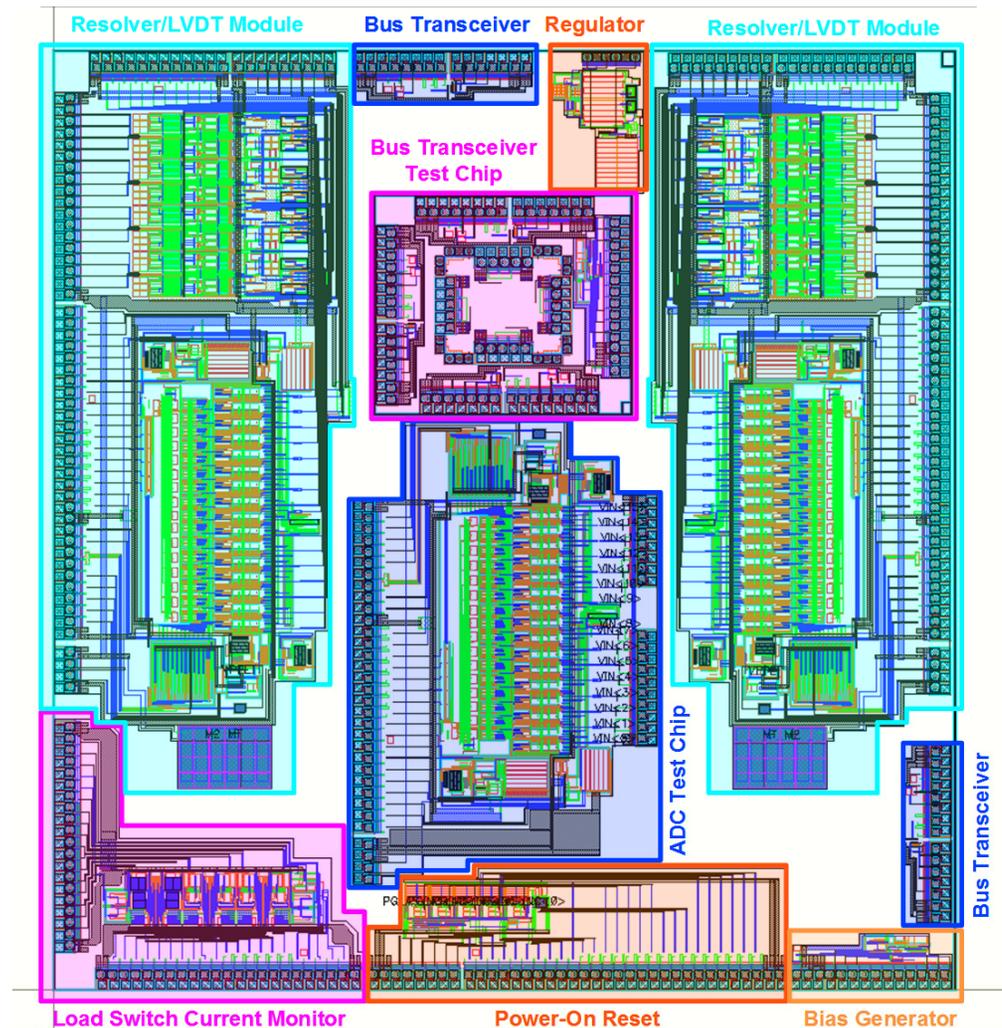
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IBM SiGe 5AM process technology is the key enabling feature

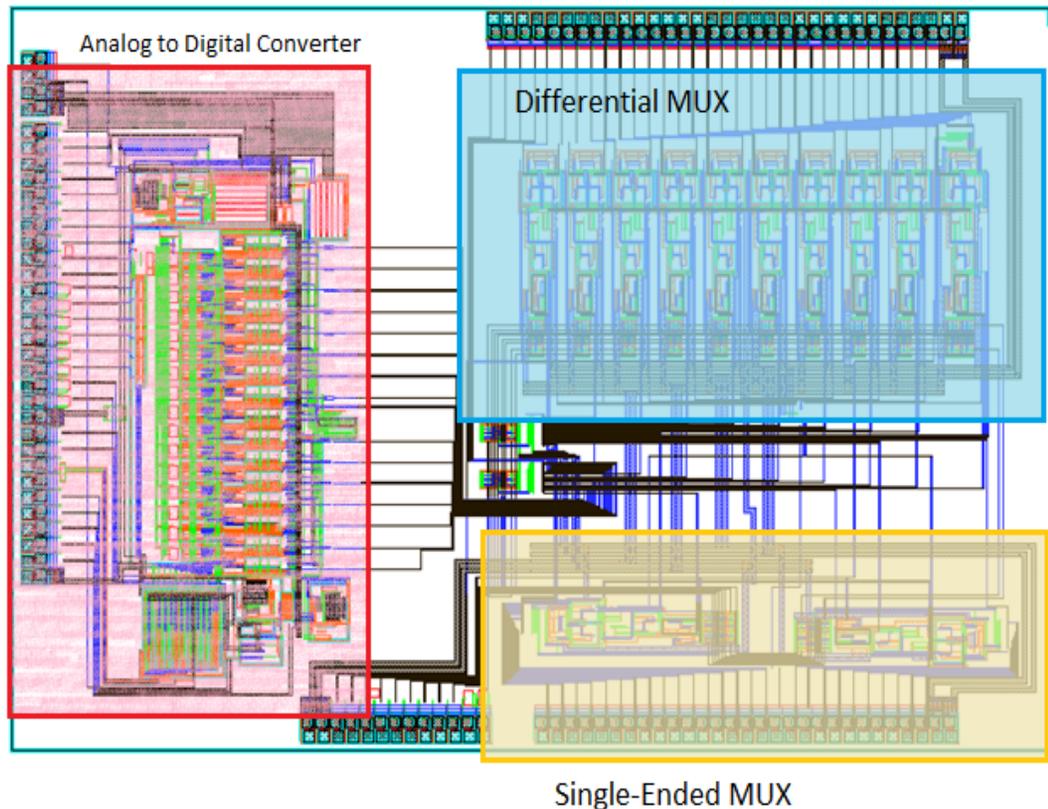
- Wide temperature (-150°C to +85°C) operation
- Radiation tolerant (> 100 kRad Total Integrated Dose)
- Excellent analog circuit performance
- Low cost
- Leveraging proven performance at temperature through past JPL (DMC-2 study) and NASA (Exploration Development Technology Program) efforts

# 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

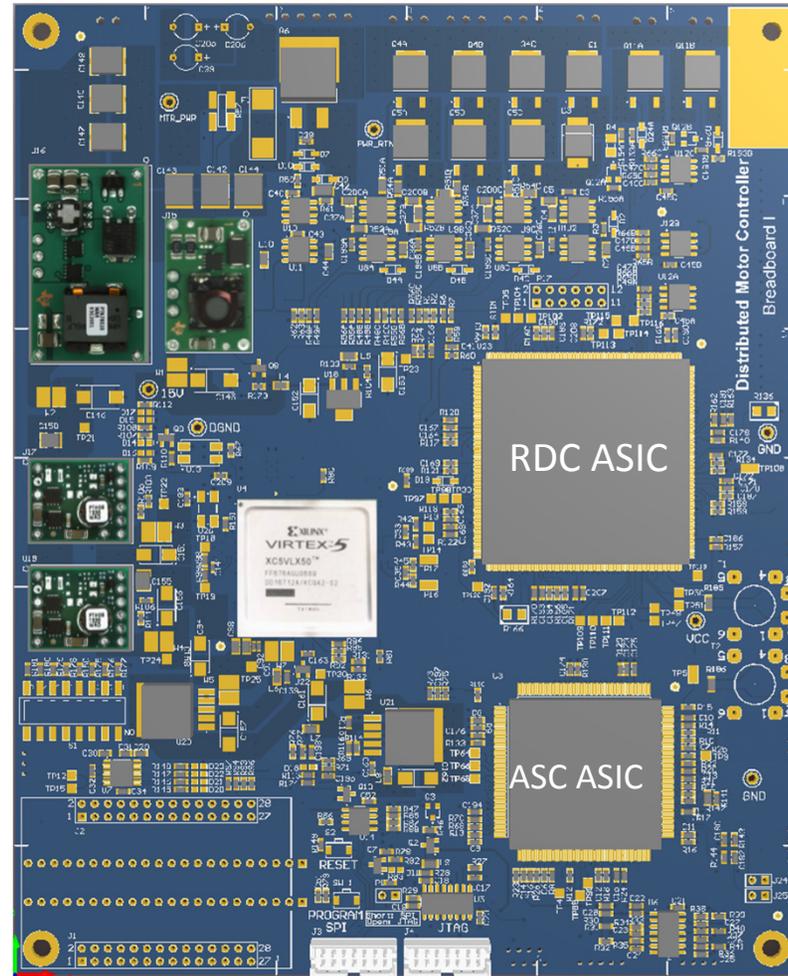
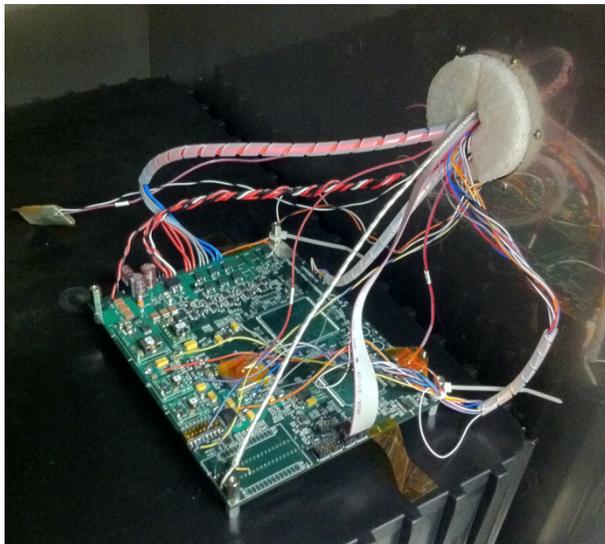


- Operates on single 3.3V supply
- Housekeeping chip to monitor system voltages/currents and motor telemetry
  - 16-input Differential and Single-ended MUXs with independent gain settings
  - Stimulus driver capable of providing 1.2V or 1mA to sensors external to chip
  - Serial digital communication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

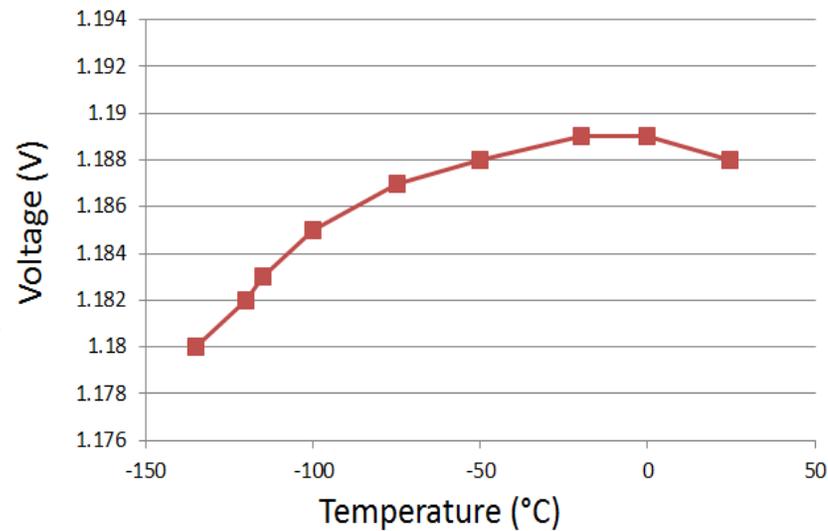
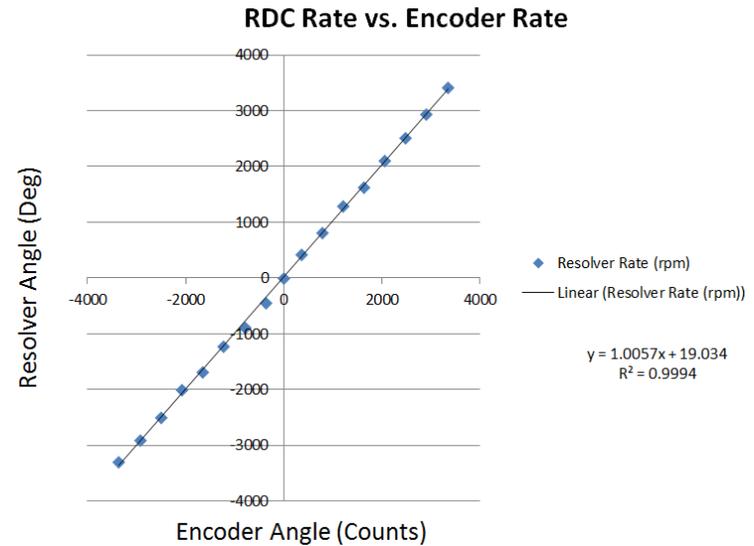
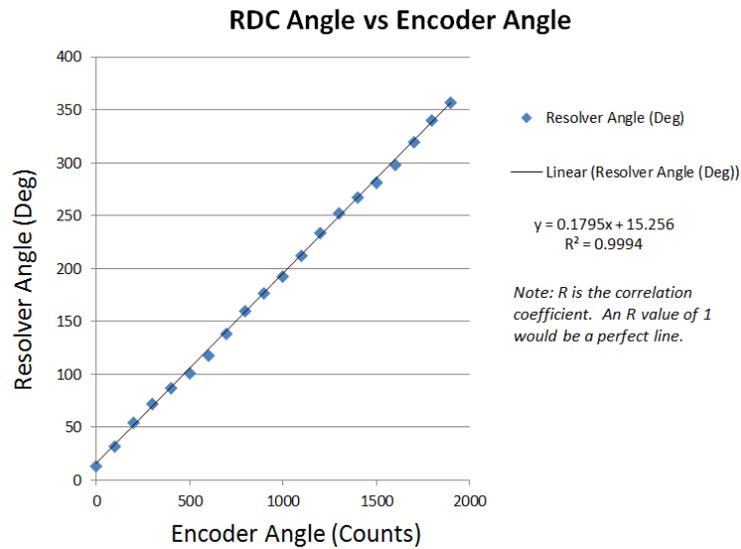


# TEST RESULTS

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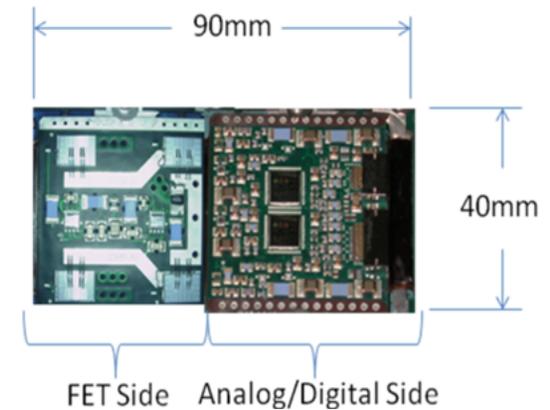
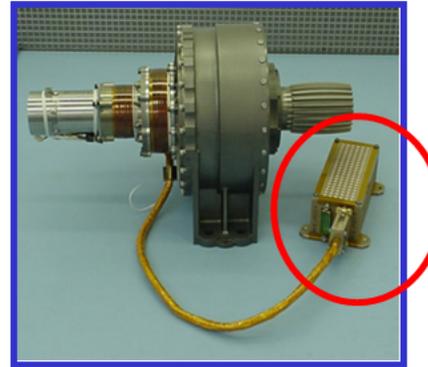
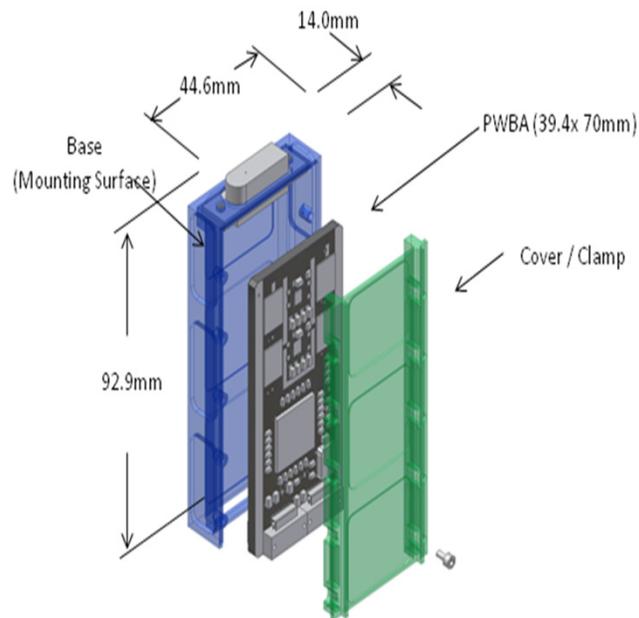
Operation of motor at  $-135^{\circ}\text{C}$

# Cold test results



# 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



# Contact

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# Acknowledgments

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We would like to thank the JPL Mars Focused Technology office and the Research and Technology Development office for their continued support of this task. We would also like to thank Zack Pannell, Ryan Diestelhorst, David Zhu, Michael Garret, Matthew Stein, Garen Der-Khachadourian, Robin Reil and Nazeeh Aranki for their considerable technical assistance.

The research described in this presentation was carried out at the Jet Propulsion Laboratory, California Institute of Technology, under contract with the National Aeronautics and Space Administration

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