Compact Low Power Avionics for the Europa Lander Concept and Other Missions to Ocean Worlds

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Jet Propulsion Laboratory
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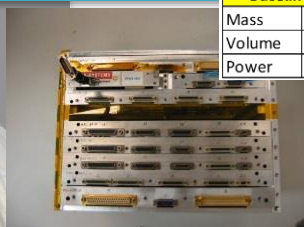
Compact, Low Power Avionics and Motor Control

STATUS QUO

- Standard 6U cPCI design
- Backplane and chassis required.
- High SWaP

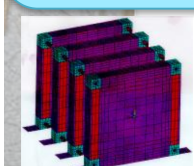
Baseline Lander Avionics		
Mass	14.13	Kg
Volume	11250	cc
Power	26	W



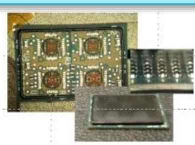
MSL Rover RPAM

NEW INSIGHTS

- Backplane free design
- Advanced packaging
- Organic Chip on Board substrates can survive extreme temperature cycles
- System on a Chip Processor



Backplane free chassis



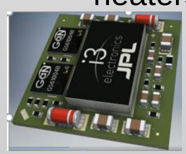
Chip On Board Packaging

PROBLEM / NEED BEING ADDRESSED

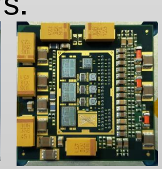
- Electronic assemblies take up a significant portion of spacecraft SWaP

PROJECT DESCRIPTION/APPROACH

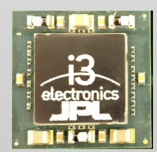
- Decrease the volume and mass, of electronic assemblies through:
  - the use of advanced packaging.
  - Chip on board technology
  - i3 CoreEZ advanced substrate.
- Reduce the power by:
  - the use of an efficient processor
  - on-board power management
  - minimizing power required for survival heaters.



Point of Load
1.6cm x 1.6cm



Resolver
3cm x 3ccm



Motor Driver
2.5cm x 2.5ccm

High Density Connectors

Advanced Packaging Leads to entire system on a single card

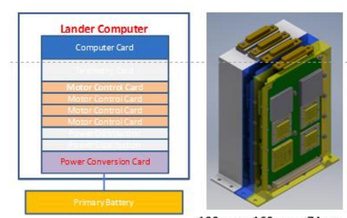
10cm x 10cm C&DH System

QUANTITATIVE IMPACT

- Reduced mass and volume allows for either:
  - More room for science instruments or
  - More room for batteries enabling longer mission life.
- Reduced survival and operating temperatures allow for longer mission life.

PROJECT GOAL

- Decrease the volume (10x), and mass (3x), power (2x) of electronic assemblies



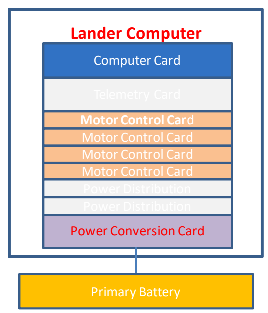
Europa Lander Motor Control

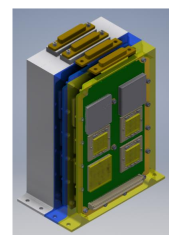
Baseline Lander Avionics		
Mass	14.13	Kg
Volume	11250	cc
Power	26	W

Tech Lander Avionics		
Mass	3.58	Kg
Volume	1159	cc
Power	13.44	W

Two Step Approach

- **Step 1: Advanced packaging – Electronics Mass & Volume Savings**
  - Europa Lander Project Baseline
    - A standalone centralized motor controller based upon this technology is incorporated into the 4.0 baseline intended to carry the project through MCR
    - Project is taking advantage of our mass and volume savings
    - Computer handles motor control functions.



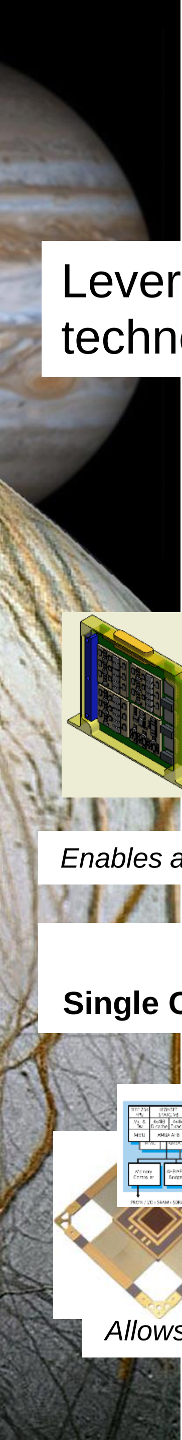


100mm x 160mm x 74mm

- **Step 2: Cold survivable electronics – Harness mass savings, along with power saving for heating**
  - The SMD COLDTECH proposal "Cold Survivable Distributed Motor Controller (CSDMC)" 2-year, $1.2M, PI: Gary Bolotin, was selected.
    - This proposal is aimed at developing a distributed motor controller
    - Proposal is based upon modules developed during this effort
    - Funding is now at JPL. Work started March 1, 2017

Step 1

Advanced packaging – Electronics Mass & Volume Savings

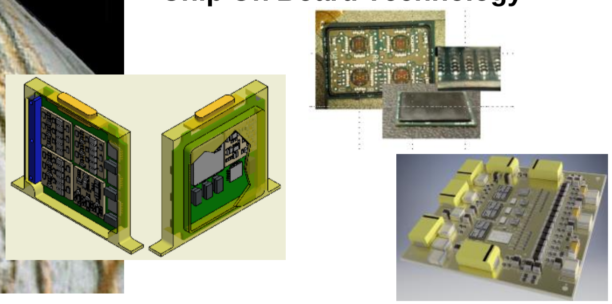


ADVANCED ELECTRONIC PACKAGING

Leverage advanced packaging, cold capable electronics and system on a chip technology to maximize the science return from the baseline Europa Lander.

Advanced Electronic Packaging

Chip On Board Technology



Enables a >10X improvement in board density

High Density Connectors

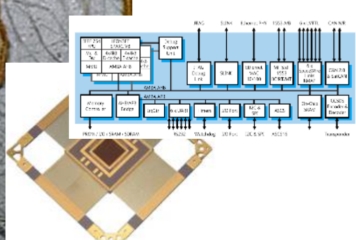
Up to 500 pins per connector
3x density of standard micro-D

Slice Based Design

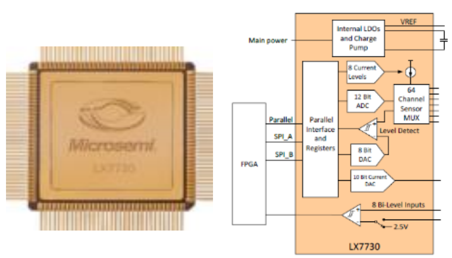
Eliminates backplane and chassis mass

System On A Chip

Single Chip Computer



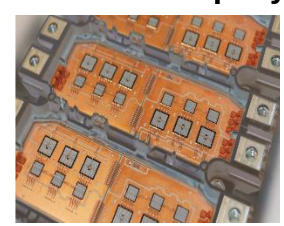
Single Chip Telemetry Collection



Allows for a single board command and data handling system

Cold Capable Electronics

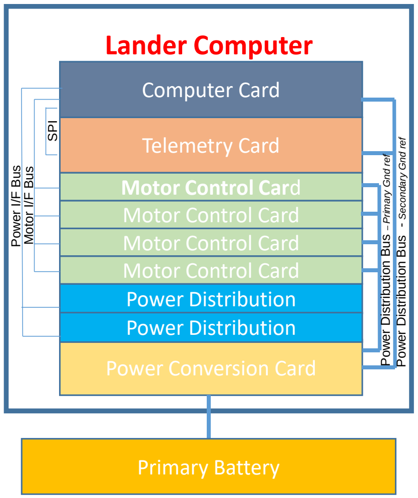
Conductive Epoxy



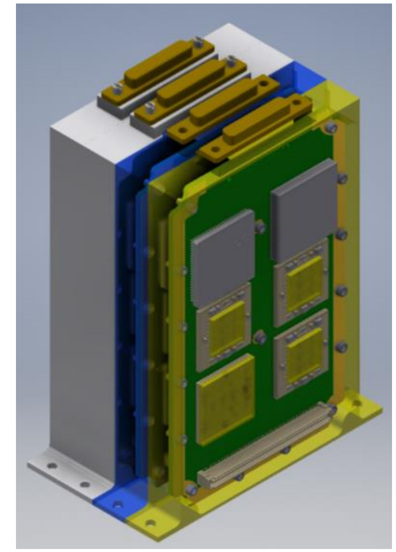
Allows for -200C survival temperatures

Centralized Design

Europa Lander Concept Baseline

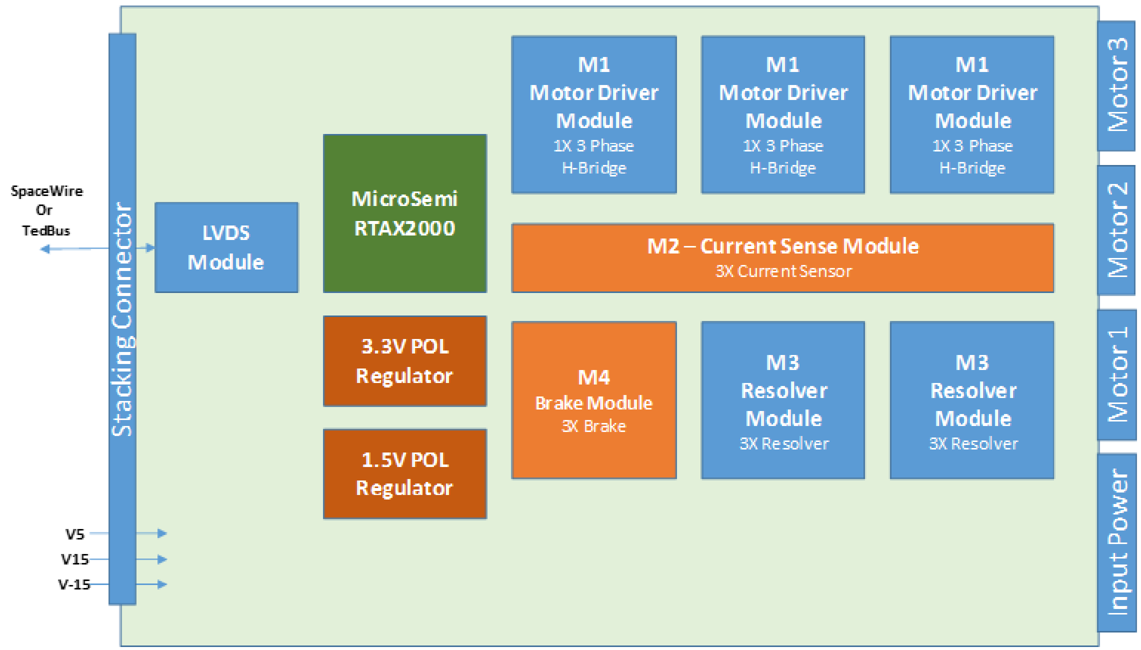


Stand Alone Motor Controller							
Mass (CBE: 3.05 kg, w/Uncertainty: 3.97 kg)							
Sub-sys.	Component	Type	# of Units	Each, kg	CBE Total, kg	Uncertainty, %	CBE + Contingency, kg
Stand Alone Motor Controller				Total	3.05	30%	3.97
	Computer Card HMC	Computer Card 3U	1	0.50	0.50	30%	0.65
	Motor Control Card HMC	Motor Card 3U	4	0.40	1.60	30%	2.08
	Power Conversion Card HMC	Power Conversion 3U	1	0.75	0.75	30%	0.98
	End Plate HMC	HMC End Plate 3U	2	0.10	0.20	30%	0.26
Volume (CBE: 2604.8 cc, w/Uncertainty: 3386.24 cc)							
Lander Computer			X	Y	Z	Total cc	
	Computer Card HMC	Computer Card 3U	100.00	160.00	26.40	422	
	Motor Control Card HMC #1	Motor Card 3U	100.00	160.00	25.00	400	
	Motor Control Card HMC #2	Motor Card 3U	100.00	160.00	25.00	400	
	Motor Control Card HMC #3	Motor Card 3U	100.00	160.00	25.00	400	
	Motor Control Card HMC #4	Motor Card 3U	100.00	160.00	25.00	400	
	Power Conversion Card HMC	Power Conversion 3U	100.00	160.00	26.40	422	
	End Plate HMC #1	HMC End Plate 3U	100.00	160.00	5.00	80	
	End Plate HMC #2	HMC End Plate 3U	100.00	160.00	5.00	80	
Power (CBE: 18 W, w/Uncertainty: 23.4 W - Worst Case) - Power Numbers are in work							
C&DH		Mode	Power	Uncertainty, %	CBE + Contingency, W		
	Computer Card HMC	Worst Case	6.00	30%	7.80		
	Motor Control Card HMC #1	Worst Case	2.25	30%	2.93		
	Motor Control Card HMC #2	Worst Case	2.25	30%	2.93		
	Motor Control Card HMC #3	Worst Case	2.25	30%	2.93		
	Motor Control Card HMC #4	Worst Case	2.25	30%	2.93		
	Power Conversion Card HMC	Worst Case	3.00	30%	3.90		
	End Plate HMC #1	N/A	0.00	30%	0.00		
	End Plate HMC #2	N/A	0.00	30%	0.00		
			18.00		23.40		



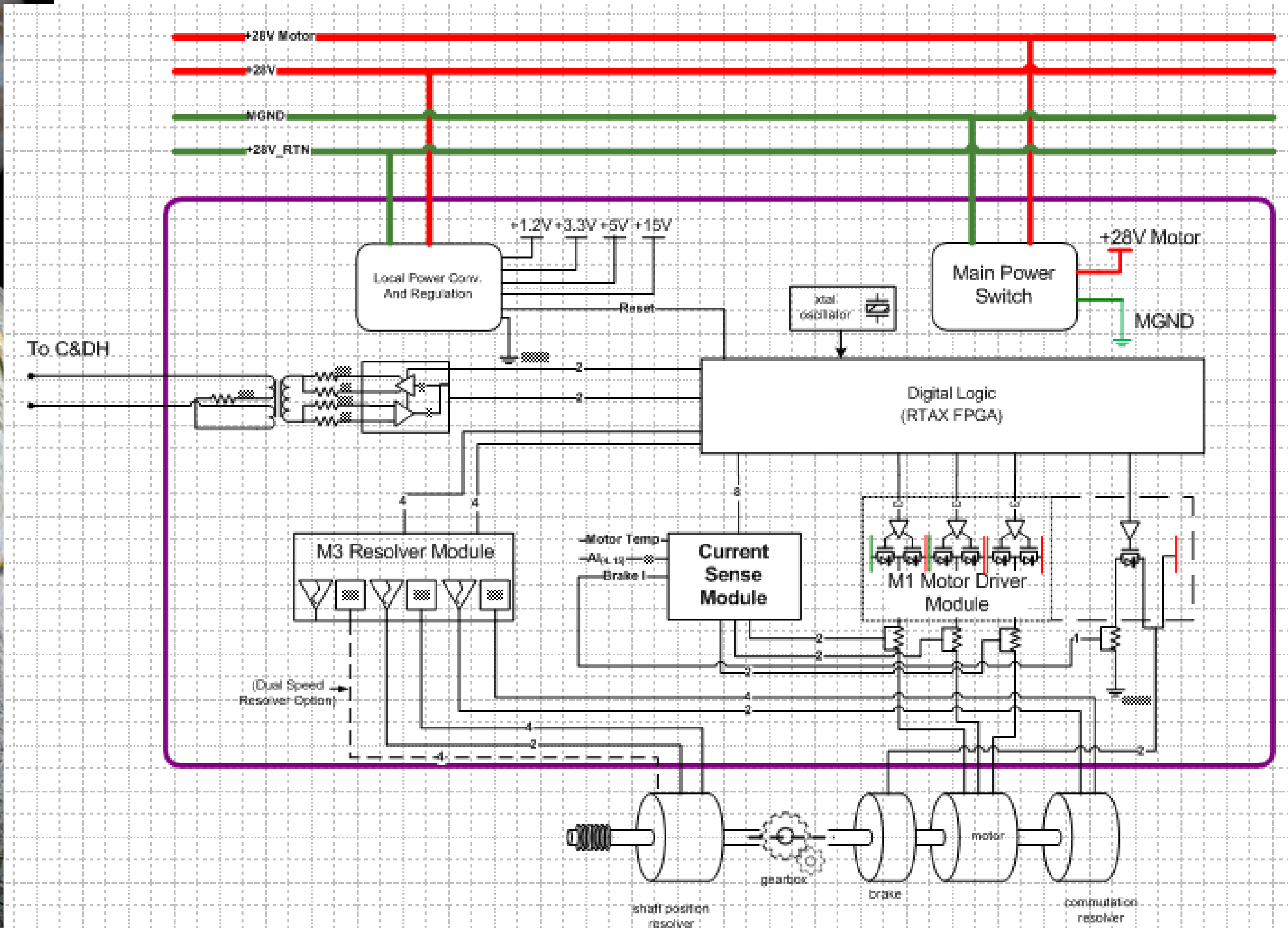
- These electronics are now baselined for the Europa Lander mission concept as a standalone motor controller. In this configuration we provide the motor control and motor control computation needs for the Europa Lander.
- This allows the Europa Lander to take advantage of our mass and volume savings
    - Each motor card can talk to three motors. Only one motor can run at a time.
    - Each resolver module can talk to 3 resolvers.
    - Each card has 2 resolver channels per motor.
    - One for commutation and one for output position. Six in total. All can be running at any given time.
    - There are 4 motor cards in the stack. This gives a total of twelve motors, and 24 resolver channels.

Motor Control Card

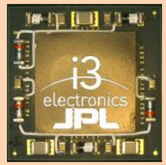
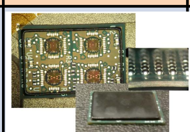
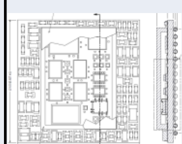
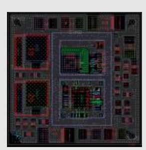


- **The design consists of our computer card along with enough Motor Control Cards necessary to control 12 motors.**
- **Each motor card can control up to three motors.**
- **Only one motor can run at a time per card.**
- **Our design allows for the position of each motor to monitored by two resolvers, one motor shaft and one on the output of the gear box. Each resolver module can talk to 3 resolvers. Each card has two resolver modules. Each card has 2 resolver channels per motor. One for commutation and one for output position. Six in total.**
- **There are four motor cards in the stack.**
- **This gives a total of 12 motors, and 24 resolver channels.**

Motor Control Card Block Diagram

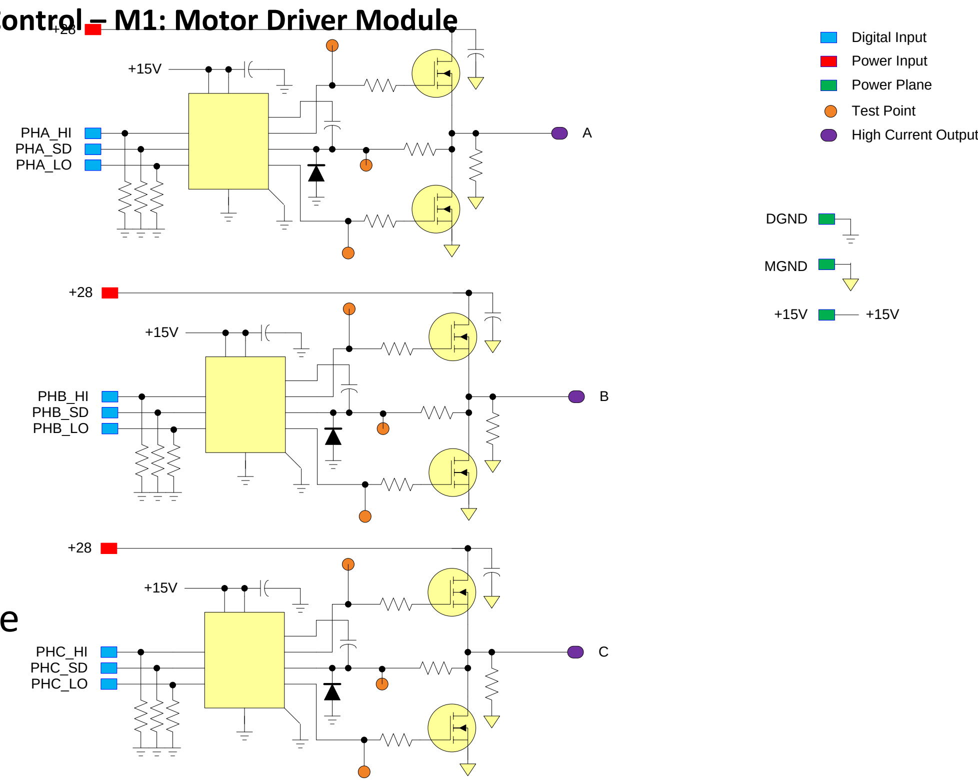


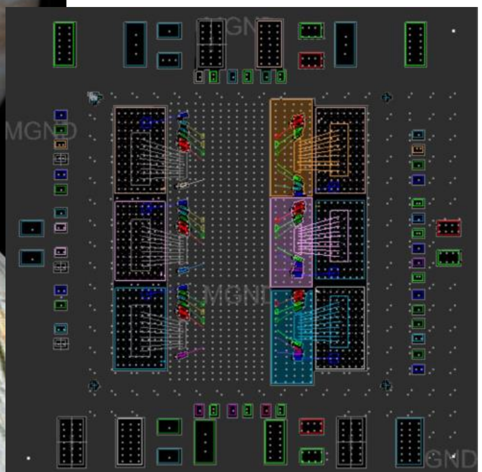
Motor Control Card - Modules

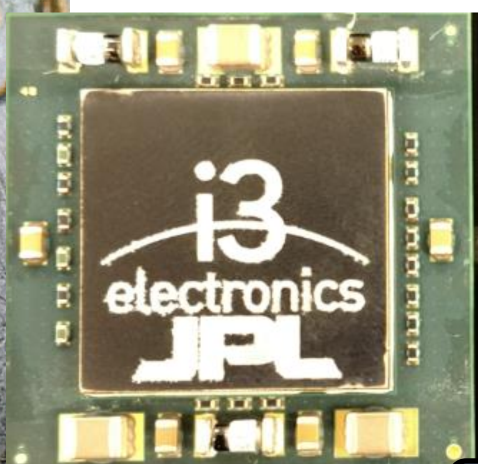
Funding Source	Technology	Picture	Heritage	Status	Current TRL	Ending TRL
GCD	Motor Driver Module		GCD – Ultra Low Temperature Electronics	Prototype module testing complete	5	5
	Resolver Module		GCD – Ultra Low Temperature Electronics	Prototype module testing complete	5	5
RTD	Low Voltage Differential Switching (LVDS) Module		JPL Internal R&TD funding	Prototype module testing complete	5	5
EL	Current Sense Module		Europa Lander	Circuit prototype	2	5
Proposed	Point of Load Regulator Module		NASA Coldtech	Circuit prototype complete Module design complete	3	5
	Isolated Converter Module		NASA Coldtech	Circuit design in progress	2	5

Motor Driver Module

I3 M1: Motor Driver Module - Status







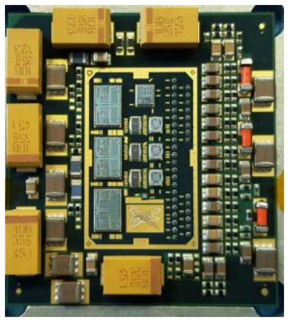
- S# - 001
- M1 Module

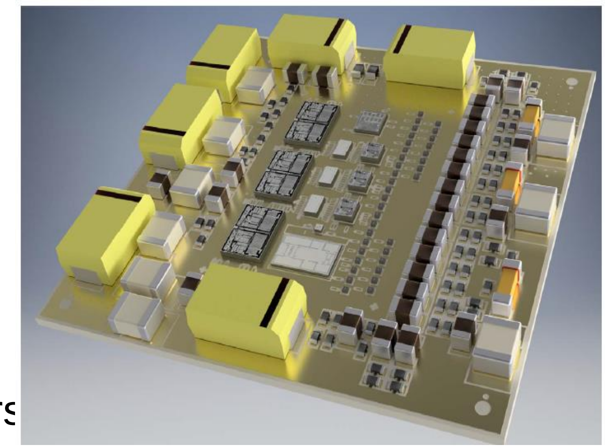
EUROPA LANDER
MOTOR CONTROL M1 MODULE
J. WATERS – Edited by Gary Bolotin
12 FEBRUARY 2016

7cm x 7cm worth of circuitry reduced to 2.5cm x 2.5cm

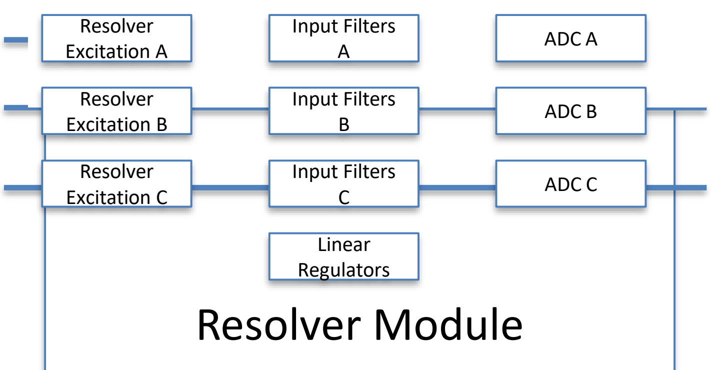
Resolver Module

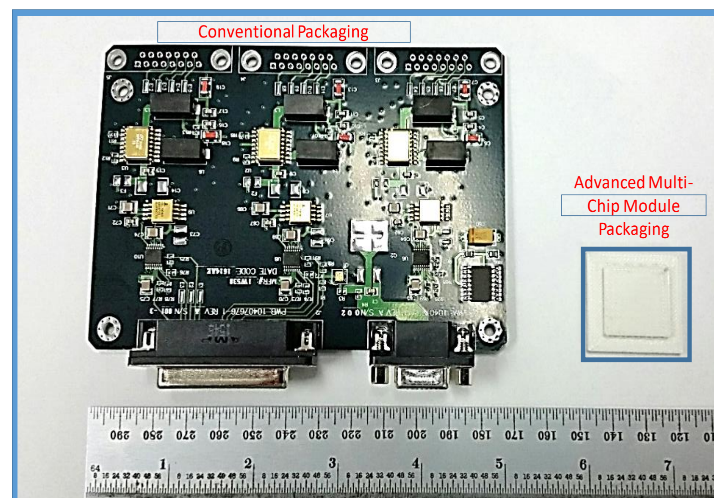
- Advanced Packaging – M3 – Resolver Module
  - Production of first module is complete. First part received at JPL 12/21/16.





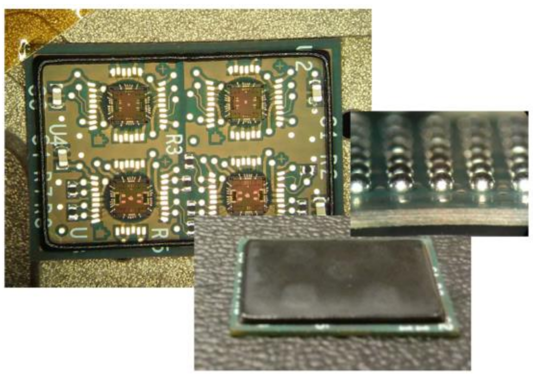
  - Single provides interface to 3 resolvers



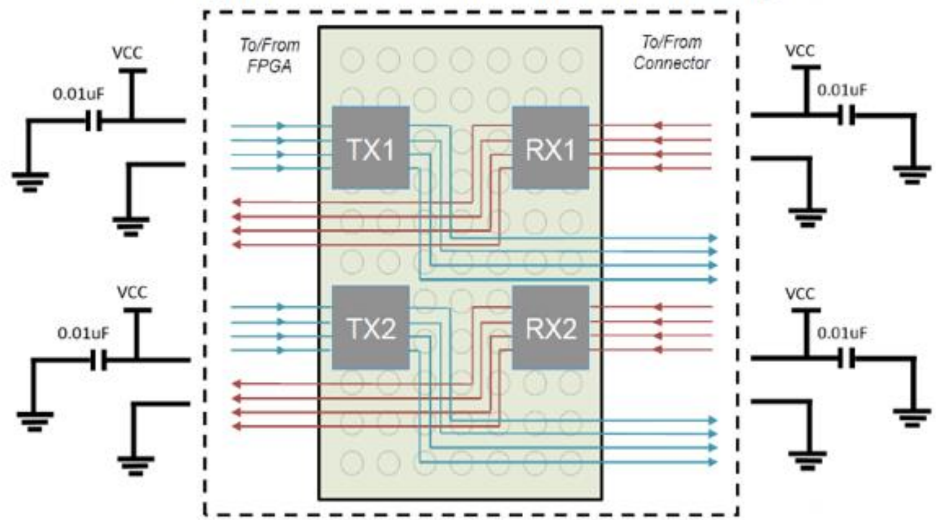


LVDS Module

- Developed under JPL's IRAD: 5x UNIBUS R&TD
- 2 Aeroflex LVDS receiver die
- 2 Aeroflex LVDS transmitter die
- On module bypass and termination
- 5x reduction in board area compared to conventional packaging
- 1.7 x 1.1 cm

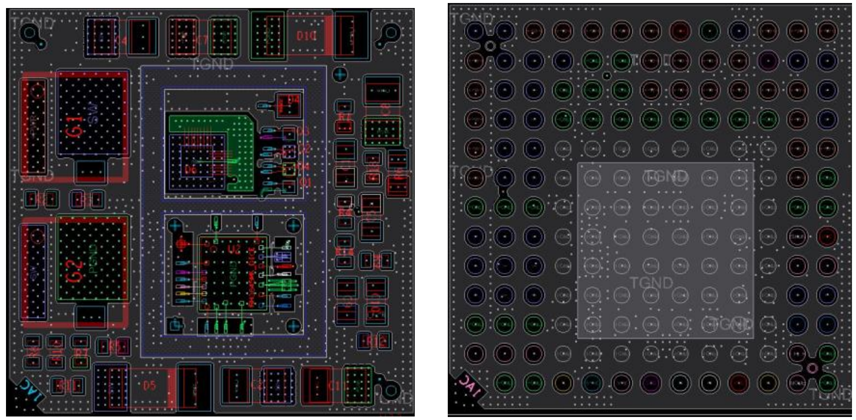


Signal Flow / VCC and Gnd Partitioning

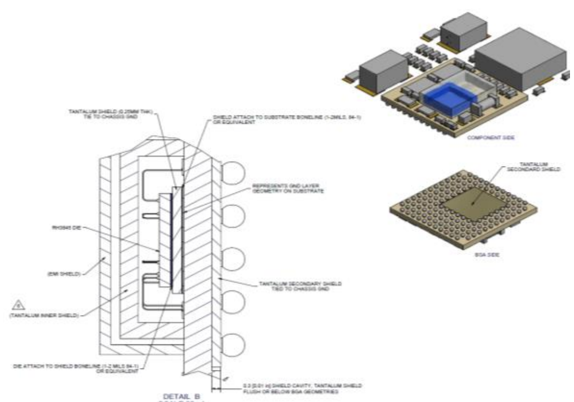


Technical Progress 5 of TBD

POL Module Design



The POL Module Placement is complete

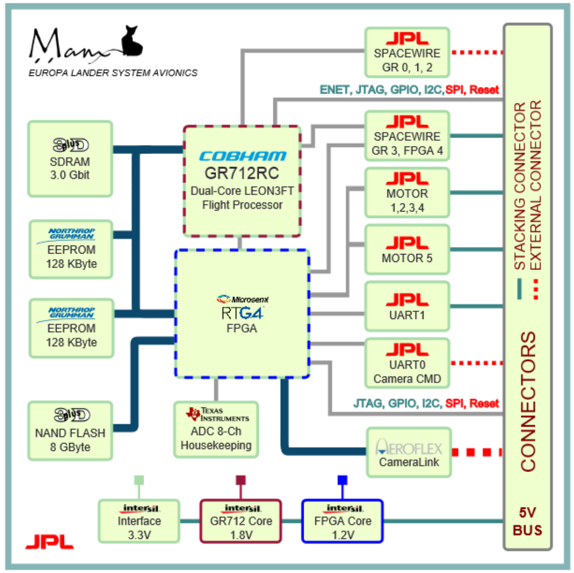


POL Module shield design is complete
Radiation analysis is complete

POL Module design is underway. The POL module design is scheduled to be complete by the

Manx: Low Power Computer

Processor	Gaisler Cobham GR712, Sparc, Dual-Core
FPGA	Microsemi RTG4
Radiation Environment Target	300 kRad TID
Operating Voltage	5V
Input Voltage (recommended)	5V
Input Voltage (limits)	5-TBD V
Spacewire Links	10 (5 scoped for Motor Control)
UARTS	2 (FPGA)
Peripherals	ENET, I2C, SPI, GPIO, CameraLink
Housekeeping	8ch ADC (Voltage, Temp, Current)
Non-Volatile Memory	8GBytes NAND, 128KBytes X 2 bootloader
Processor Memory	400MBytes SDRAM
Processor Clock Speed	100 MHz (configurable)
Connectors	100 Pin VerSI, 160 Pin Mezzanine



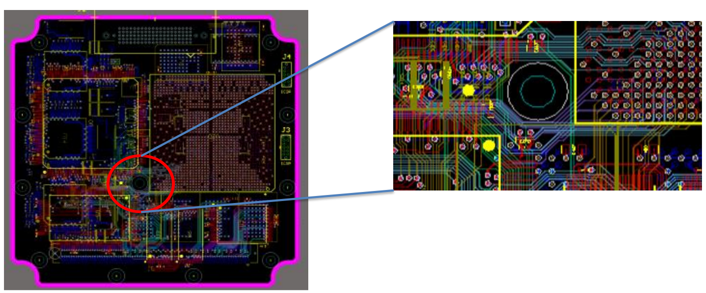
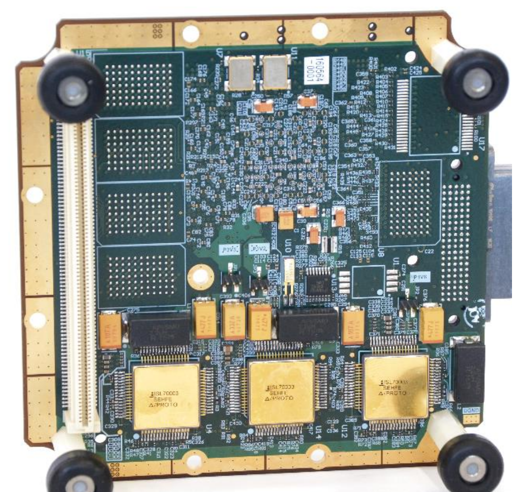


Illustration of Computer Card Wiring Density



A 10cm x 10cm single board command and data handling system

Step 2

Cold survivable electronics – Harness mass savings, along with power saving for heating

The Problem We Are Trying to Solve

- Conventional practice is to house actuator electronics in a protected, centralized, warm electronics box (WEB), requiring highly complex, point-to-point wiring to connect the drive and control electronics to the actuators and instruments, usually located at the system appendages.

MSL Wiring Harness

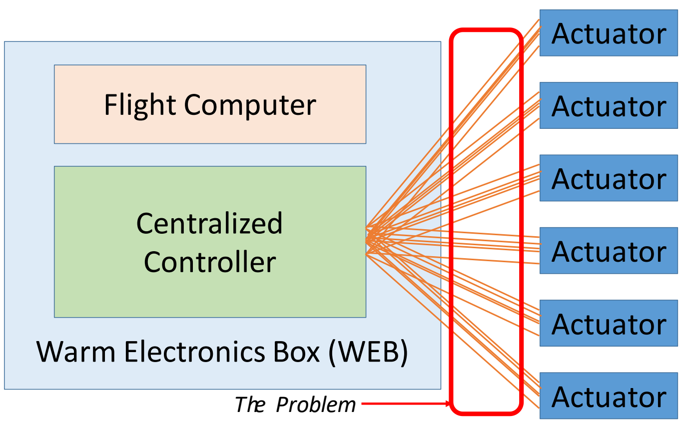
Integration and Test

MSL's Robotic Arm

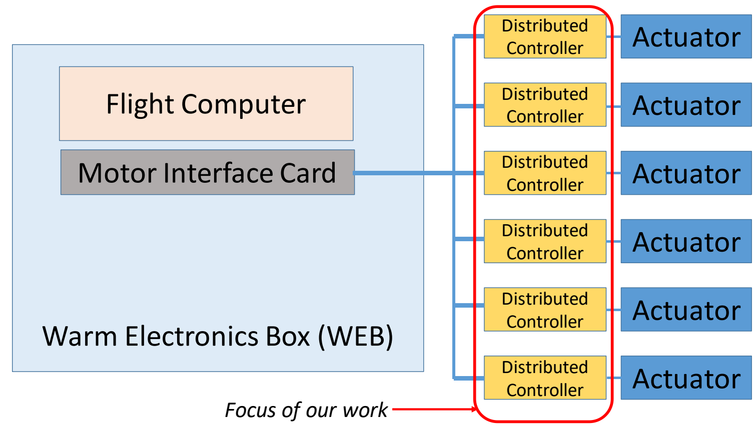
Illustration of cabling mass and complexity in current landed mission architectures across all subsystems and phases of development.

Our Solution: A Distrusted System

- We will solve this problem by utilizing a distributed motor control (DMC) technology that will minimize the dependency of the motor controller on the WEB, eliminate the point-to-point wiring, and reduce the wire count by two orders of magnitude with concomitant savings in mass, cost and complexity.



Current state a practice: Point to point



Proposed: Distributed Motor Control Electronics

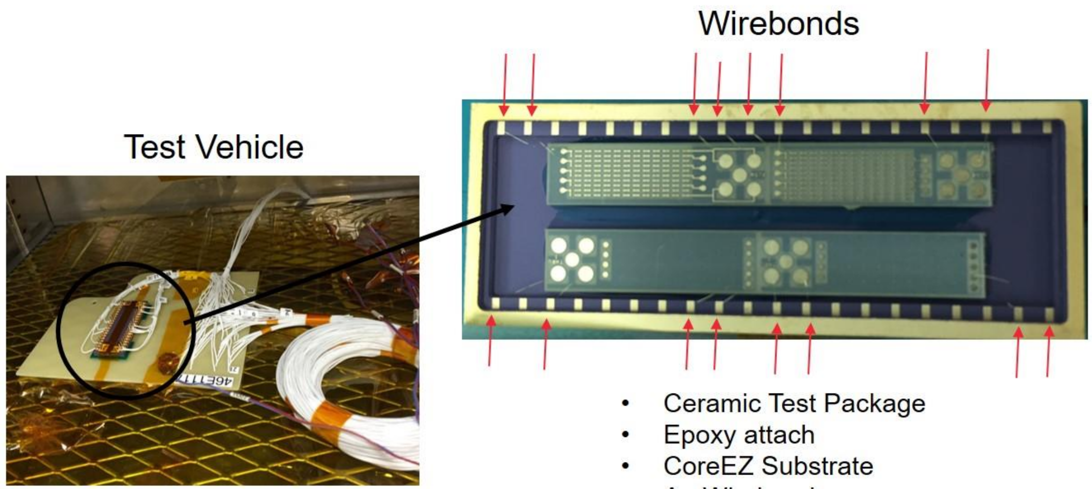
Distributing the controller electronics out at the actuators, and connecting them through a common power and interface bus.

Cold Capable Electronics

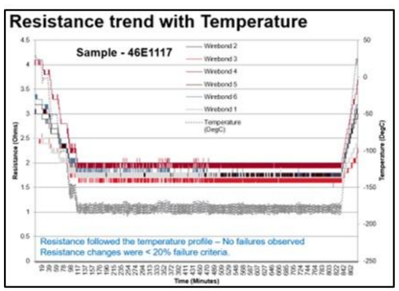
- Work in the area of cold cable electronics consisted of three major thrust areas.
  - The first was cryogenic testing of key components.
  - The second area was thermal cycle testing of packages representative of the type of packages proposed for the Europa Lander.
  - The third area was recommendation of design rules for cryogenic temperature cycles.

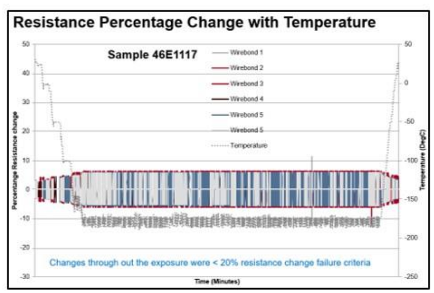
CRYOGENIC DAISY CHAIN SOLDER TESTING WITH COTS COMPONENTS

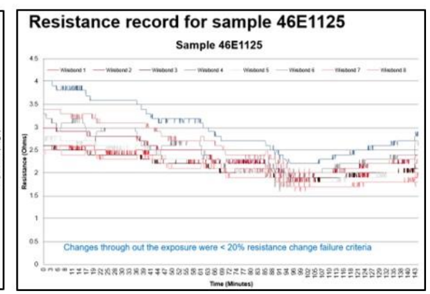
Tests were conducted to test the effectiveness of the i3 CoreEZ substrate / ENEPIG finish / Gold and Aluminum wire bonds



- Ceramic Test Package
- Epoxy attach
- CoreEZ Substrate
- Au Wirebonds





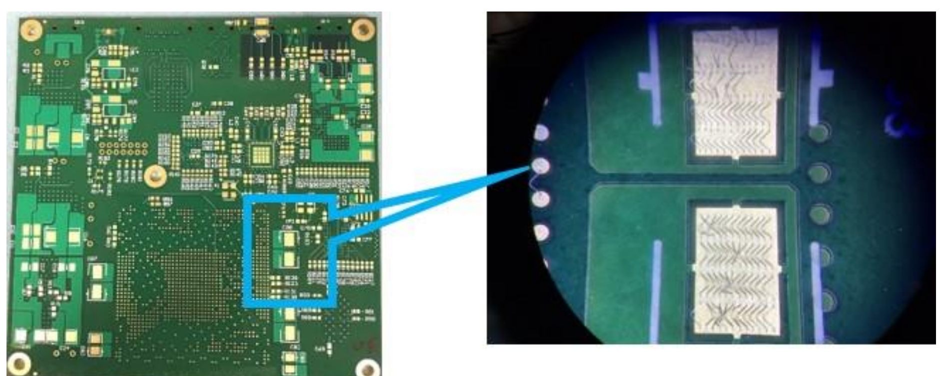


No anomalies found over the temperature ranges 25C to 0C to -50C to -100C to -150C to -180C with (20 hr soak) back to 25C (15 dwell @ each temperature).

- pass criteria was no more than a 20% increase in resistance at a specific temperature

Cryogenic testing of standard Polyimide Substrates with ENEPIG finish and Au and Aluminum 1mil wire bonds

- Efforts at JPL have qualified Electrolytic Au with gold and aluminum wire bonding to survive Martian environments using conventional polyimide substrate.
- A new SOA commercially available finish is required to achieve fabrication of fine features need for MCM solutions. ENEPIG was selected.
- After 500 thermal cycle (–55°C to 125°C) and 250 thermal cycles (–130°C to 85°C), no destructive wire bond pull test per MIL-STD-883 for 1 mil wire was observed to have values below the average pull strength minus three times the standard deviation or less than 3.0 grams.



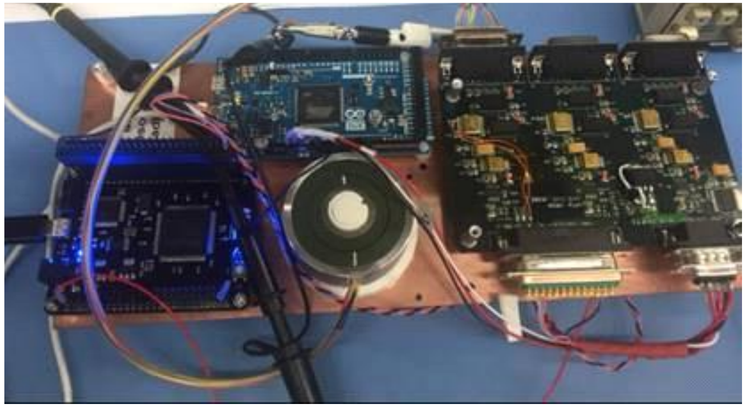
ENIPIG Wirebond Evaluation Sample Bond Locations

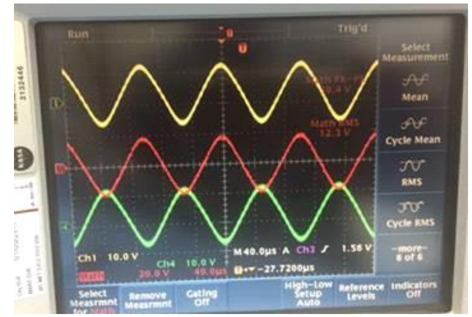
Summary

- Our LDVS, Motor Driver and Resolver Modules have all been designed, built and tested over the Mil-Spec. temperature ranges.
- These modules are ready to be incorporated into future designs for the potential Europa Lander and other missions concepts.
- Our computer card has been built and tested in an ambient temperature.
- There are two main areas of infusion for our technology.
  - Our avionics package is the baseline for motor control for the Europa Lander concept.
  - Another venue for infusion is through the selected COLDTECH proposal “Cold Survivable Distributed Motor Controller”.
- The potential Europa Lander delivery would include our motor control modules packaged into a motor control card along with our computer card.
- A NASA funded COLDTECH task called COLD SURVIVABLE DISTRIBUTED MOTOR CONTROLLER (CSDMC) will use our motor control modules as the basis for developing a motor control package capable of controlling one motor and packaged small enough to be distributed at the motors.

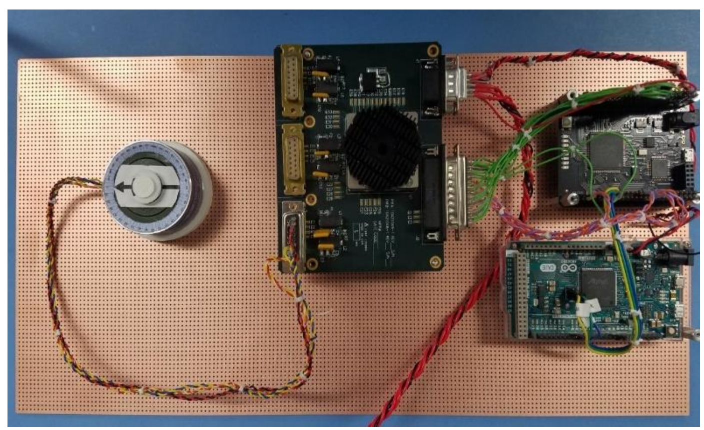
Backup

Resolver Module Testing





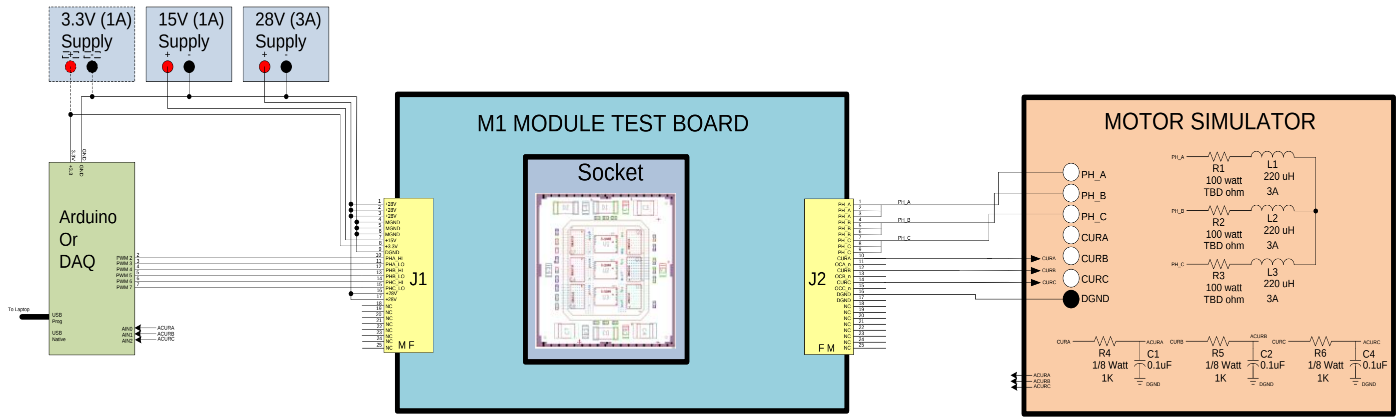
Resolver Module Breadboard

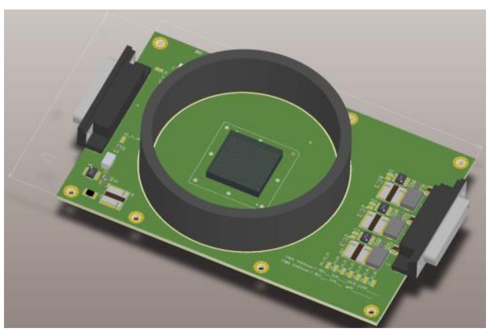


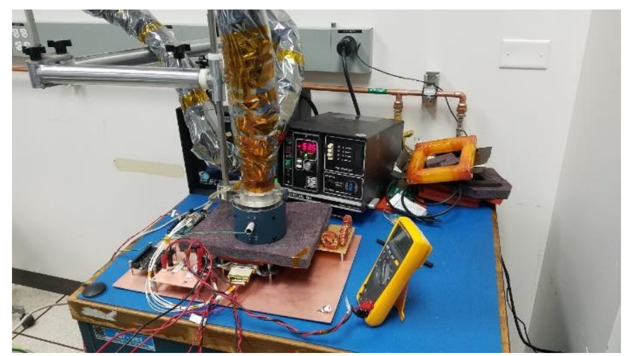
Resolver Module Test board

Module testing is complete

Motor Driver Module Testing







Module testing is complete

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