Low Temperature Electronics for Space and Terrestrial Applications

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OUTLINE

1. Deep Space Temperature Requirements And Applications

2. Terrestrial Applications

2. Low Temperature Electronics at NASA GRC

3. Power Electronic Components, Circuits and Systems

4. Selected Results

Temperature Data for Planetary Missions

Distance from Sun	Spacecraft Temperature (Sphere, Abs. = 1, Emiss. = 1 Internal Power = 0)	
Mercury	448 K	175 °C
Venus	328 K	55 °C
Earth	279 K	6 °C
Mars	226 K	-47 °C
Jupiter	122 K	-151 °C
Saturn	90 K	-183 °C
Uranus	64 K	-209 °C
Neptune	51 K	-222 °C
Pluto	44 K	-229 °C

Deep Space Electronics Temperature Requirements

Requirements

- Electronics Capable of Low Temperature Operation
- High Reliability and Long Life Time
- Improved Energy Density and System Efficiency

Benefits of Low Temperature Electronics

- Survive Deep Space Hostile Cold Environments
- Eliminate Radioisotope and Conventional Heating Units
- Improve System Reliability by Simplified Thermal Management
- Reduce Overall Spacecraft Mass Resulting in Lower Launch Costs

Low Temperature Electronics Program

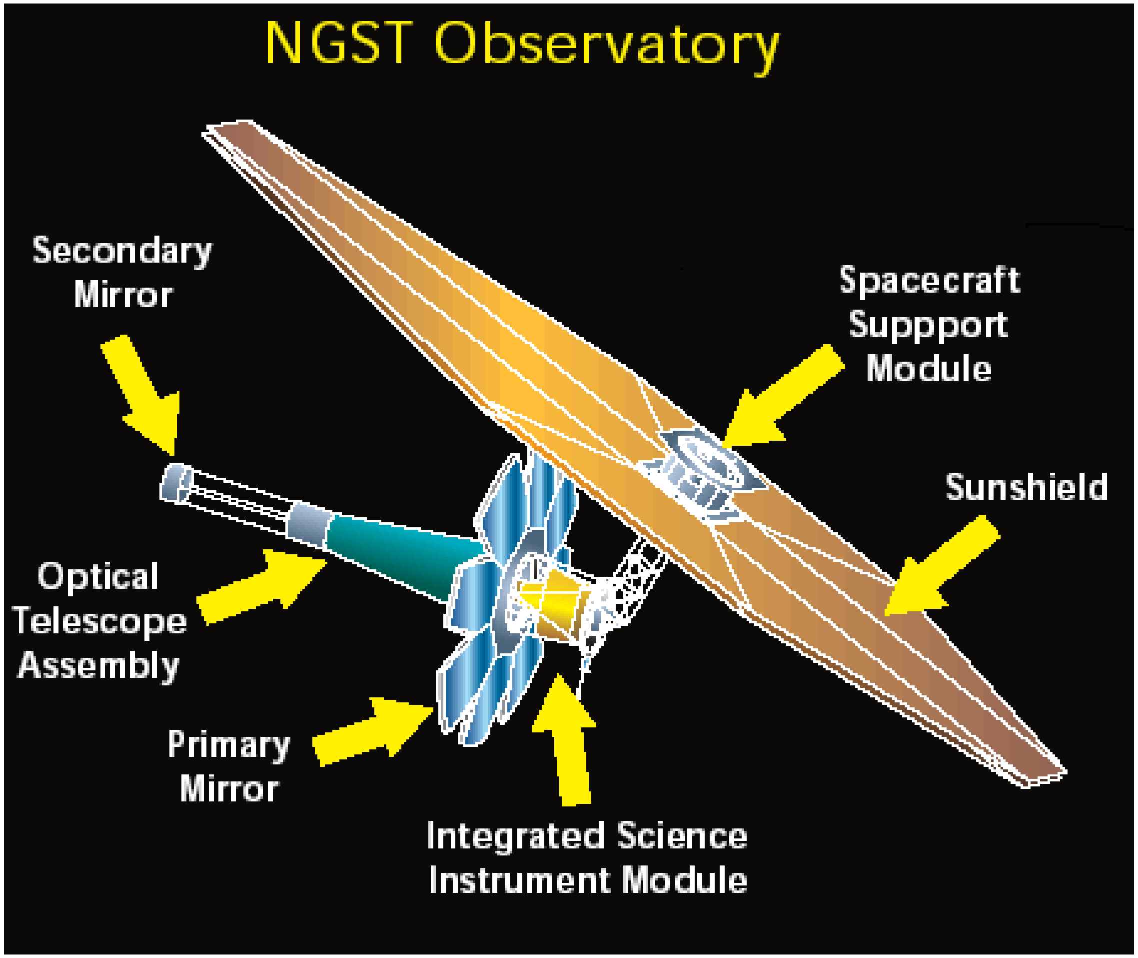
Goals

- Provide a technology base for the development of lightweight electronic components and systems capable of low temperature operation with long lifetimes
- Develop and characterize state-of-the-art components which operate at low temperatures
- Integrate advanced components into mission-specific low temperature circuits and systems
- Establish low temperature electronic database and transfer technology to mission groups

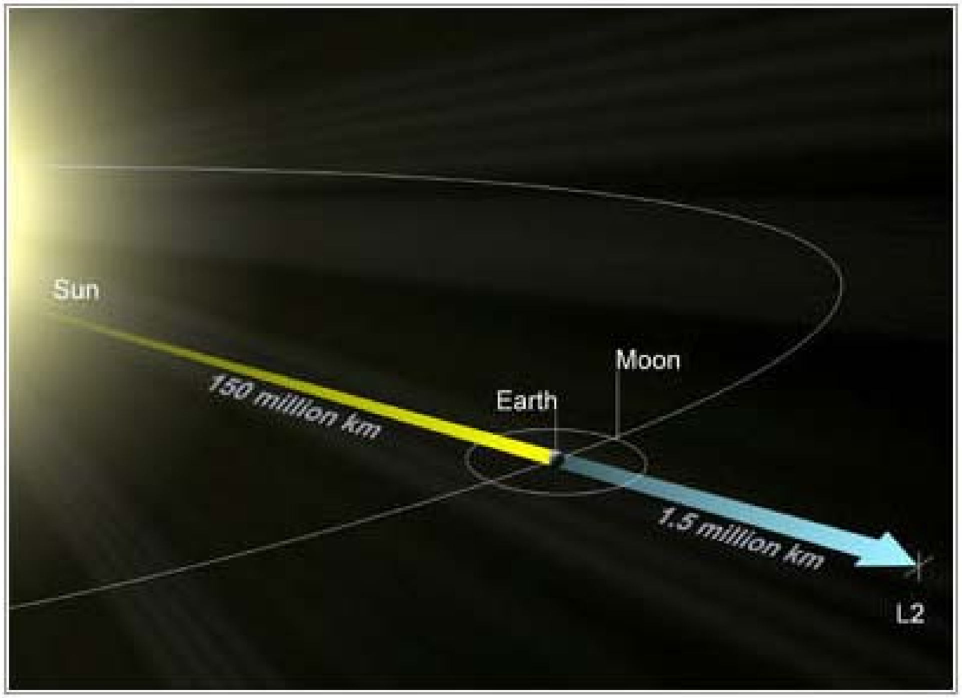
Space Applications of Low Temperature Electronics

- Mars 2003 Lander/Rover
- Mars Flyer
- JWST (NGST)
- Pluto Flyby
- Jupiter Probe

JAMES WEBB SPACE TELESCOPE (formerly NGST)



L2 Point – Location of JWST



4 June 2003
This is an illustration of the L2 point showing the distance between the L2 and the Sun, compared to the distance between Earth and the Sun.

Credits: ESA

Terrestrial Applications of Low Temperature Electronics

- SMES
- ICARUS
- AMANDA / ICE BURG
- Magnetic Levitation

SMES
Superconducting Magnetic Energy Storage

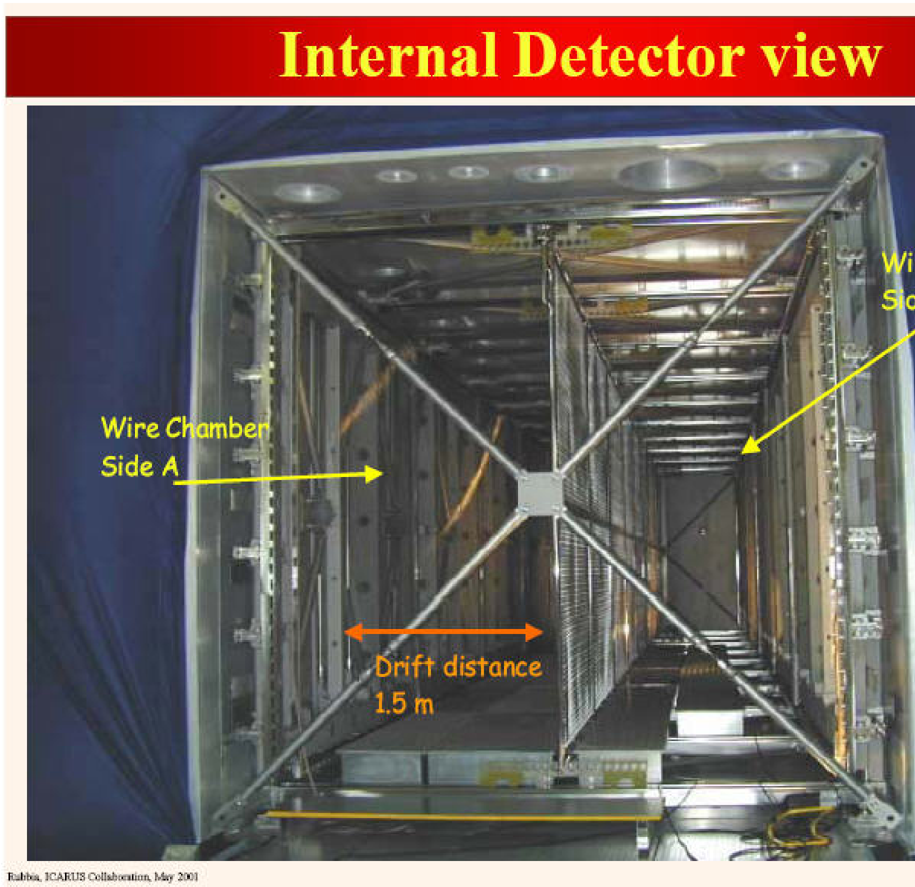
- An energy storage system, used by electric utilities, to stabilize voltages on power grids
- The energy storage device is about the size of a small number of 55 gallon drums
- Typical energy storage is about 1 MegaJoule
- System is mobile and about the size of a truck trailer
- Used by the Tennessee Valley Authority, PacifiCorp, Wisconsin Public Service, Scotland's Orkney Islands, and an aluminum foundry in Austria

ICARUS

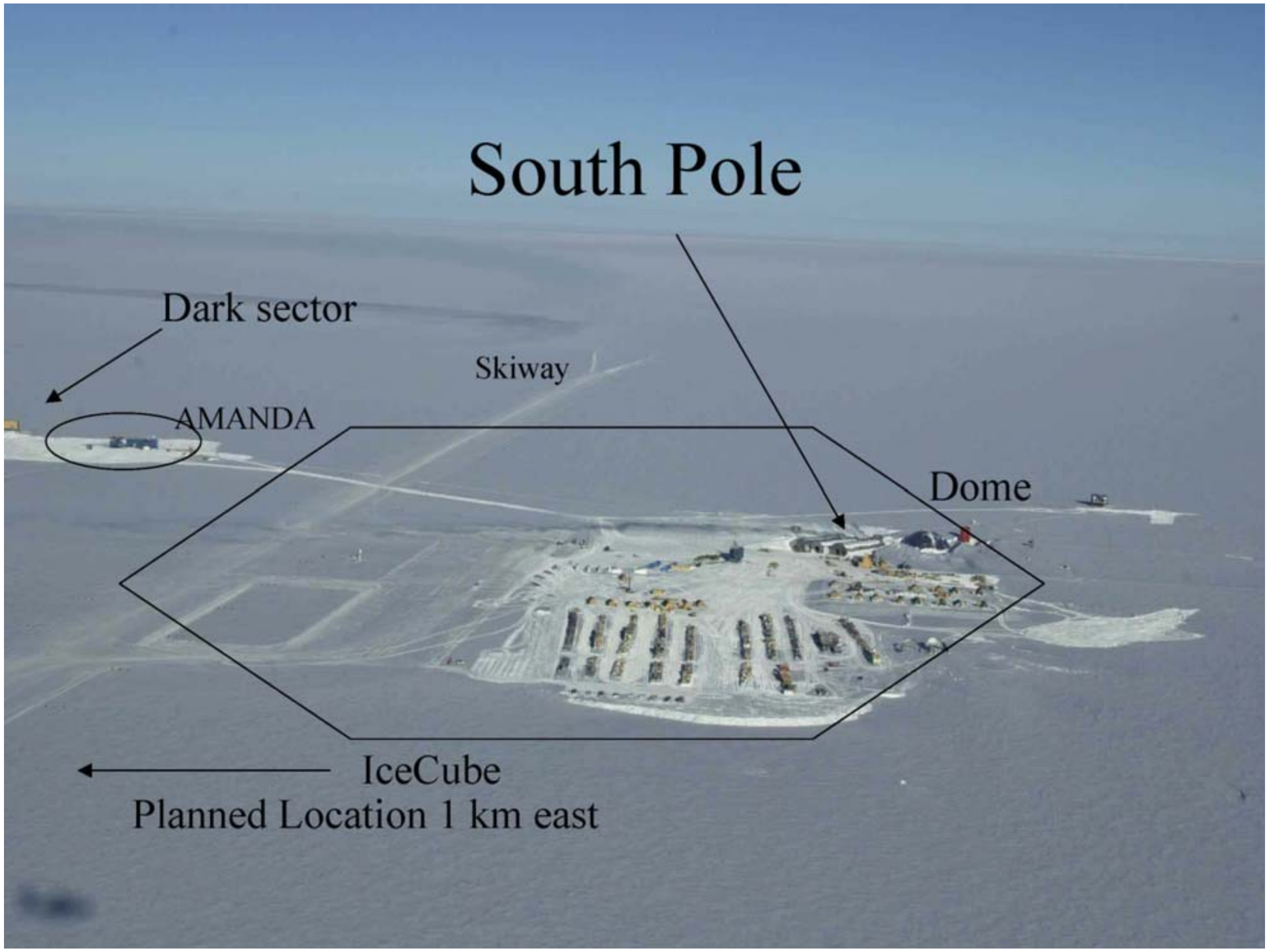
Imaging Cosmic and Rare Underground Signals

- A neutrino detector (no charge and very little mass)
- A large tank of liquid argon (-180 °C)
- Needs some electronic components to operate at (-180 °C)
- Located inside a mountain in northern Italy

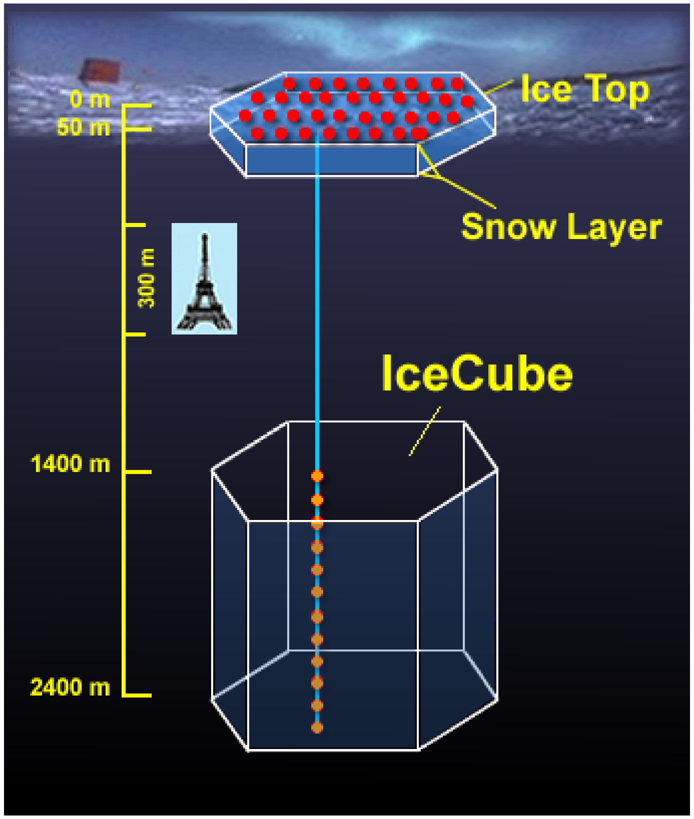
ICARUS

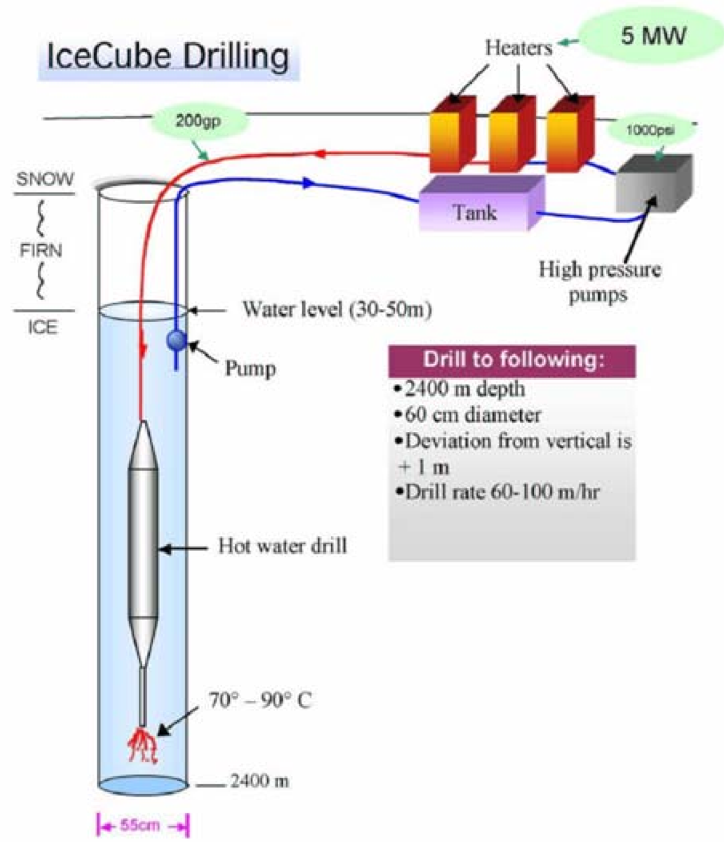

Internal Detector view
Wire Chamber
Side A
Drift distance
1.5 m
Rubbia, ICARUS Collaboration, May 2001

Amanda and Ice Cube Neutrino Detection System

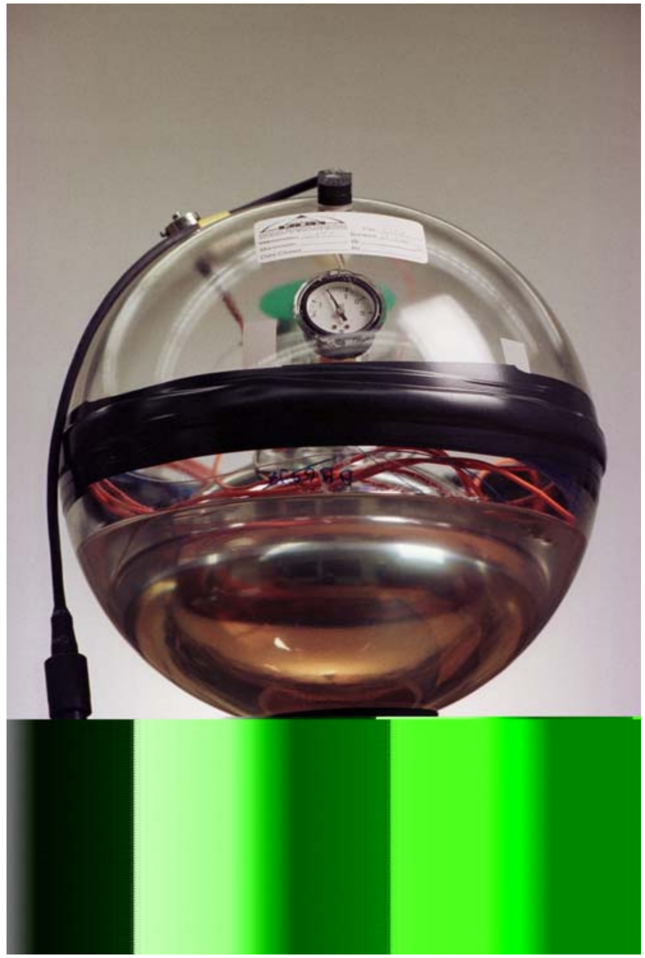


ICE CUBE NEUTRINO SENSOR SYSTEM
Ice Cube Sensor Configuration




IceCube Drilling
Heaters
5 MW
200gp
1000psi
SNOW
FIRN
ICE
Tank
High pressure pumps
Water level (30-50m)
Pump
Drill to following:
•2400 m depth
•60 cm diameter
•Deviation from vertical is + 1 m
•Drill rate 60-100 m/hr
Hot water drill
70° – 90° C
2400 m
55cm

AMANDA / ICE CUBE PHOTOMULTIPLIER SENSOR



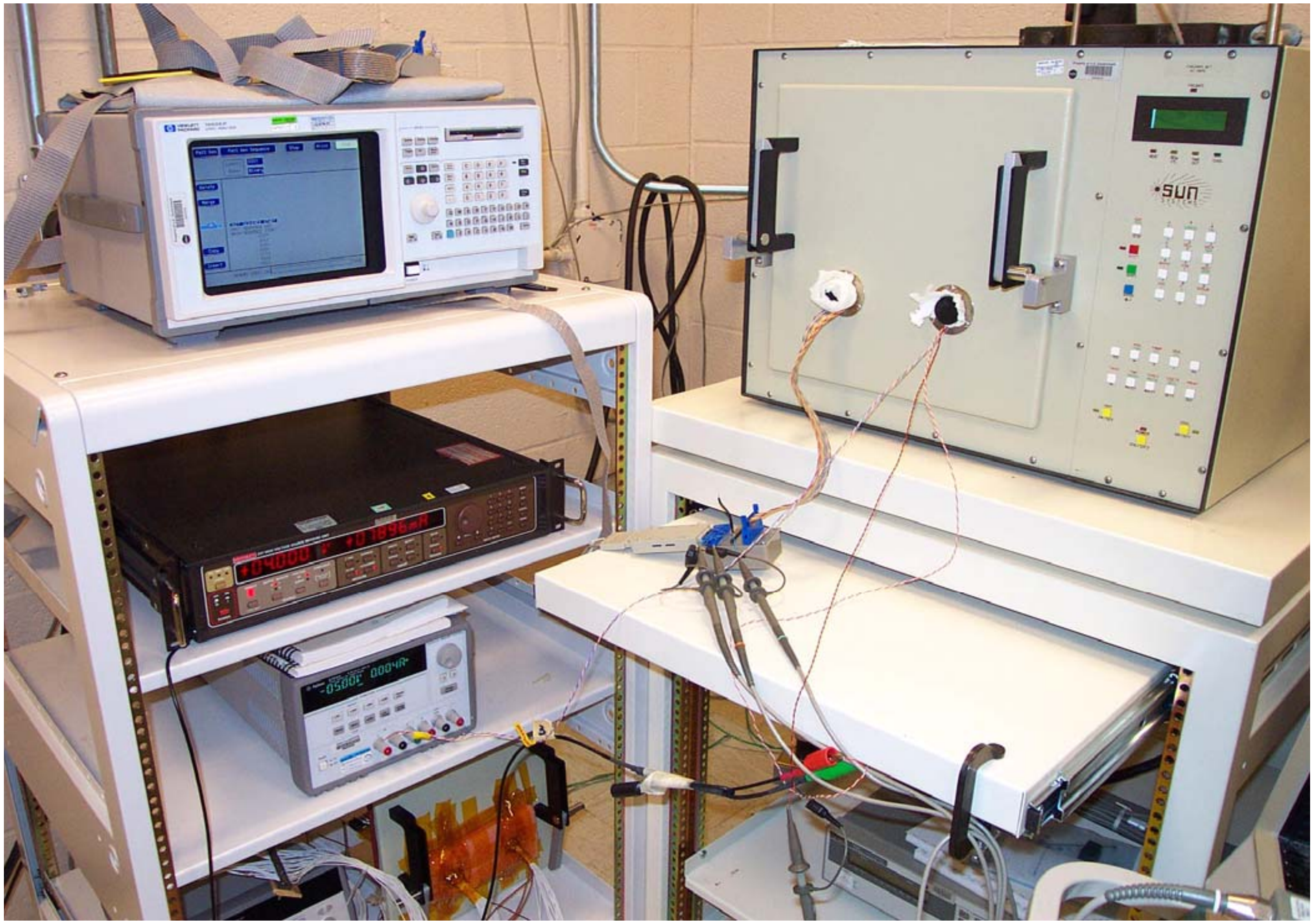
AMANDA NEUTRINO DETECTION SYSTEM
Inserting One Sensor into the Melted Hole

Low Temperature Electronics Program

Facilities

- Three environmental chambers
  - Programmable rate for thermal cycling and long term soaking
  - Simultaneous and automated operation
  - Temp range from –193 °C to +250C
- Ultra-low temperature environmental chamber for electronic testing to 20K
- Instrumentation to evaluate digital and analog circuits
- Computer controlled CV/IV semiconductor device characterization
- Inframetrix infrared camera system
- Multiple high voltage, HIGH current source measure units
- Two programmable precision RLC instruments
- Surface and volume resistivity chamber, film dielectric and capacitance test fixture, breakdown voltage test cell
- Passive components high-power test circuitry

Facilities

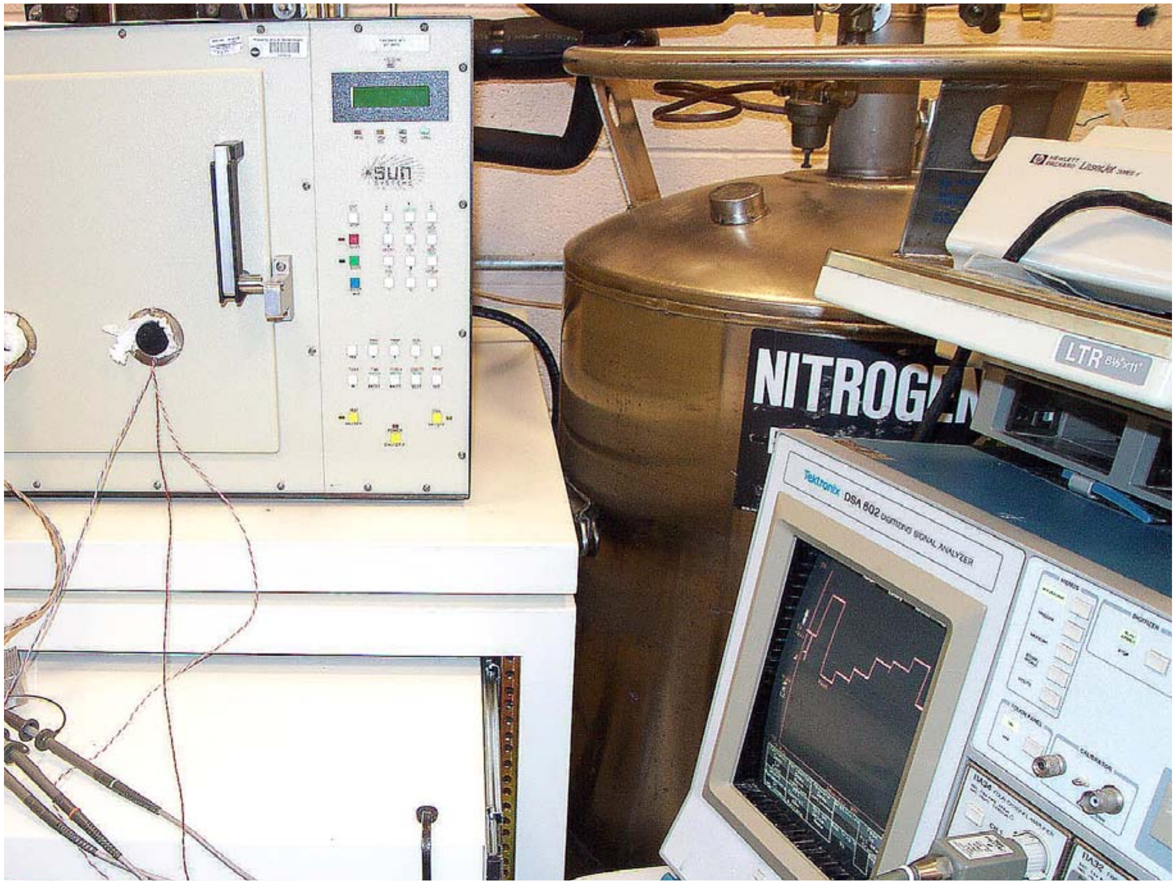


Commercial Off-the-Shelf 12-Bit Serial CMOS Analog-to-Digital Converter (Rated for Operation Between –40 °C and +85 °C)

Digital Outputs at Three Temperatures for Various Analog Inputs

Analog Input (V)	Digital Output (V) @ 25 °C	Digital Output (V) @ -100 °C	Digital Output (V) @ -190 °C
0	0.007	0.010	0.010
0.5	0.505	0.498	0.508
1	1.004	1.006	1.004
2	2.000	2.002	1.993
5	4.994	4.994	5.001
7.25	7.241	7.228	7.226
10	9.983	9.963	9.963
10.1	10.000	10.000	10.000

FACILITIES
Digital to Analog Test Setup



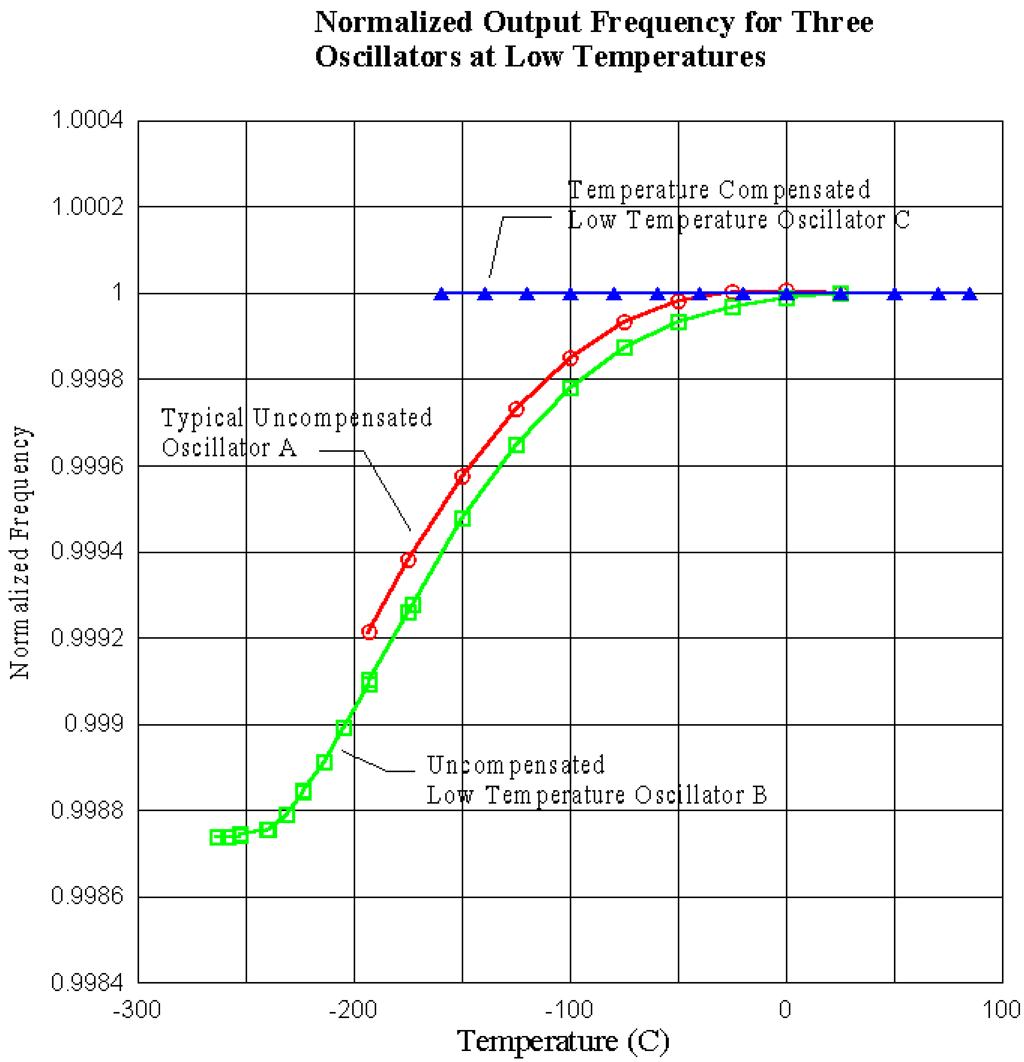
Low Temperature Electronics Program

Products

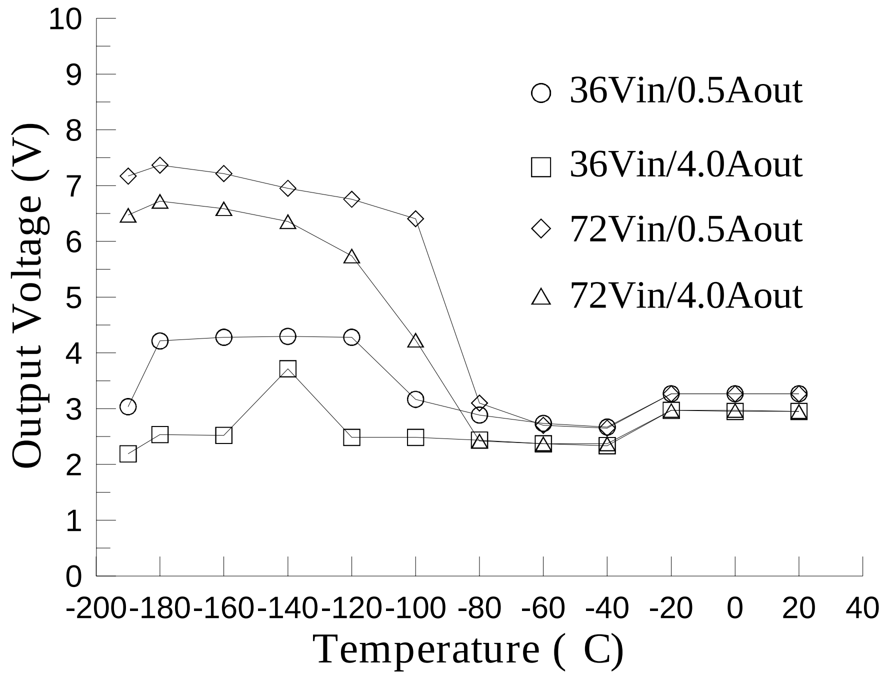
- **Components**
  - Magnetic Devices: Inductors & Transformers
  - Capacitors
  - Semiconductor Switches
  - Batteries
  - Transducers

- **Circuits**
  - DC/DC Converters
  - A/D Converters
  - Oscillators
  - PWM Control Circuits
  - Other ICs

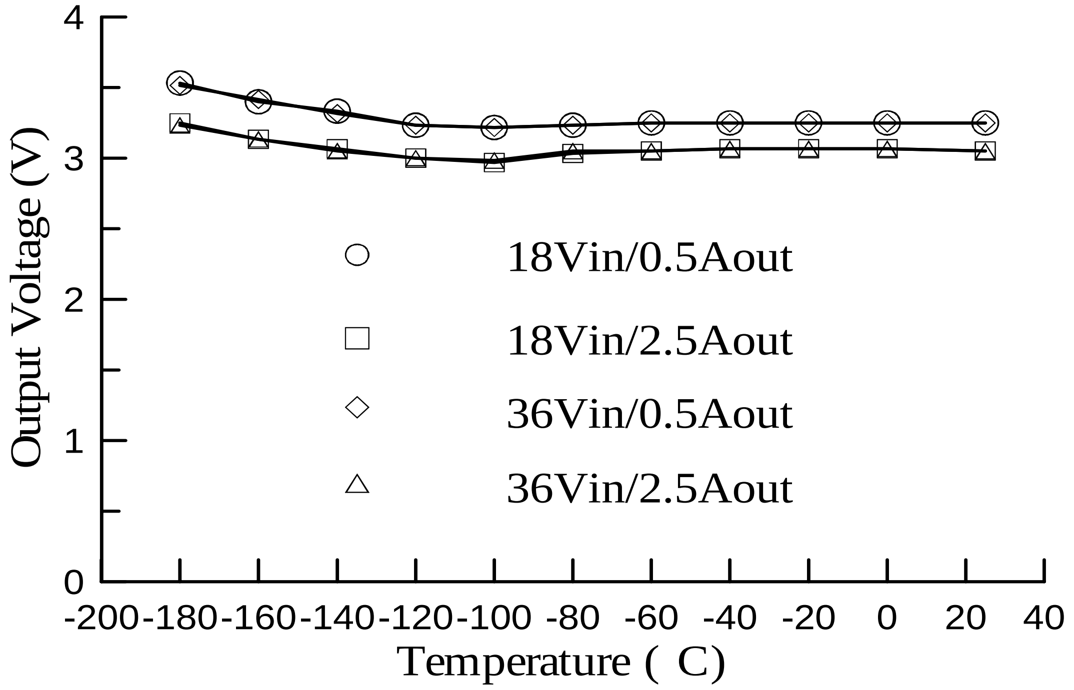
- **Systems**
  - Energy Storage
  - Power Conditioning
  - Communication & Control


Normalized Output Frequency for Three
Oscillators at Low Temperatures
Temperature Compensated
Low Temperature Oscillator C
Typical Uncompensated
Oscillator A
Uncompensated
Low Temperature Oscillator B
Normalized Frequency
Temperature (C)
1.0004
1.0002
1
0.9998
0.9996
0.9994
0.9992
0.999
0.9988
0.9986
0.9984
-300
-200
-100
0
100

Output Voltage of a DC/DC Converter at Various Temperatures



Output Voltage of Another DC/DC Converter At Various Low Temperatures



EXPERIMENTAL SETUP & RESULTS

COMMERCIAL DC-DC CONVERTER MODULES

- **SPECIFICATIONS**

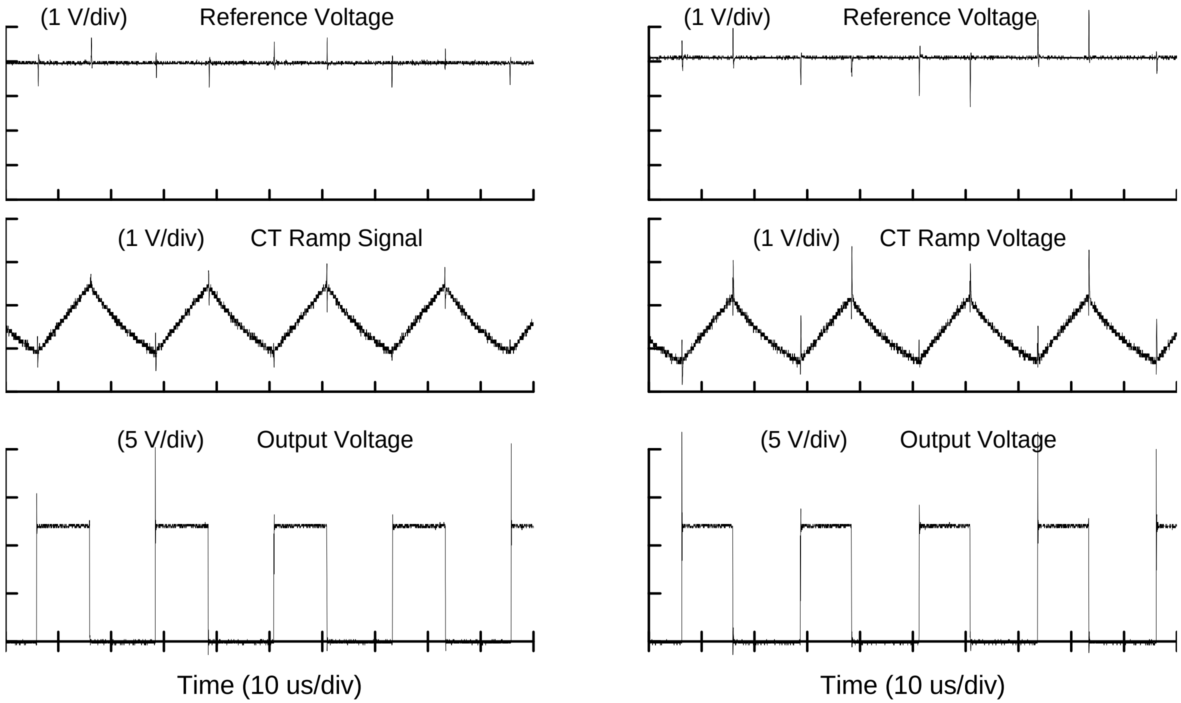
Module	Input Voltage (V)	Output Voltage (V)	Power (W)	Operating Temp (°C)
1	9 –36	3.3	10	-40 to 60
2	36-72	3.3	10	-40 to 85
3	18-36	3.3	10	-40 to 70
4	18-36	3.3	13	-40 to 85
5	9-36	3.3	10	-40 to 85

- **TEST TEMPERATURE RANGE:** **20°C to -190°C**
- **TEST PARAMETERS:**
  - **INPUT VOLTAGE: 9-72V** **- LOAD CURRENT: 0 – 3.0 A**
- **MEASURED PARAMETERS:**
  - **EFFICIENCY**
  - **OUTPUT VOLTAGE REGULATION**
  - **CURRENT RIPPLE CHARACTERISTICS**

EVALUATION SUMMARY OF SOME DC/DC CONVERTERS

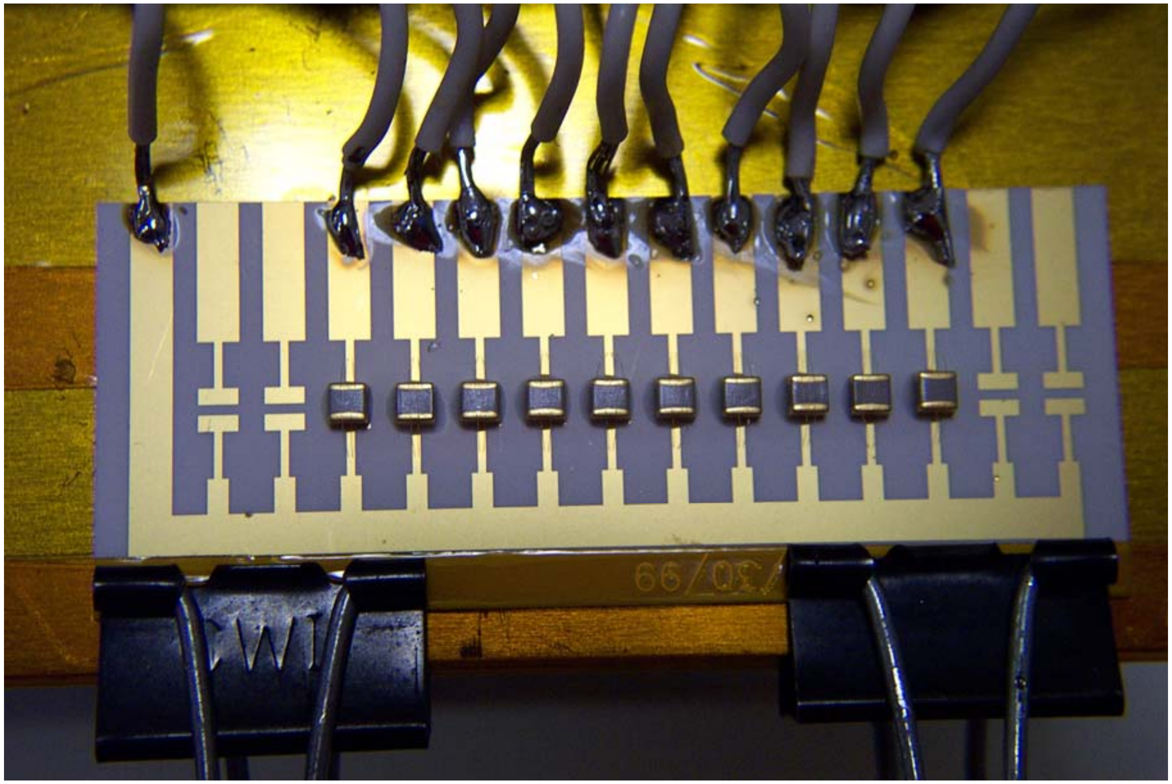
Converter Specifications					GRC Evaluations	
Mod #	Input Voltage (V)	Output Voltage (V)	Power (W)	Operating Temp. (°C)	Observations & Comments	Ceased Operation at (°C)
1	9 –36	3.3	10	-40 to 60	V_o dropped to 2.4 V at –140 °C; chip functioned down to –160 °C.	-160
2	36-72	3.3	10	-40 to 85	V_o lost regulation at –100 °C; converter still functioned to –196 °C.	-196
3	18-36	3.3	10	-40 to 70	Chip worked very well down to -120 °C. Input current oscillations occurred at all temperatures under heavy loading.	-120
4	18-36	3.3	13	-40 to 85	Oscillations in input current started at –80 °C.	-120
5	9-36	3.3	10	-40 to 85	Oscillations in input current observed at –140 °C under heavy loading.	-180

Output Waveforms of a Pulse Width Modulation Controller At Room Temperature and –190 °C



(a) Temperature = 25°C
(b) Temperature = -190°C

CAPACITORS

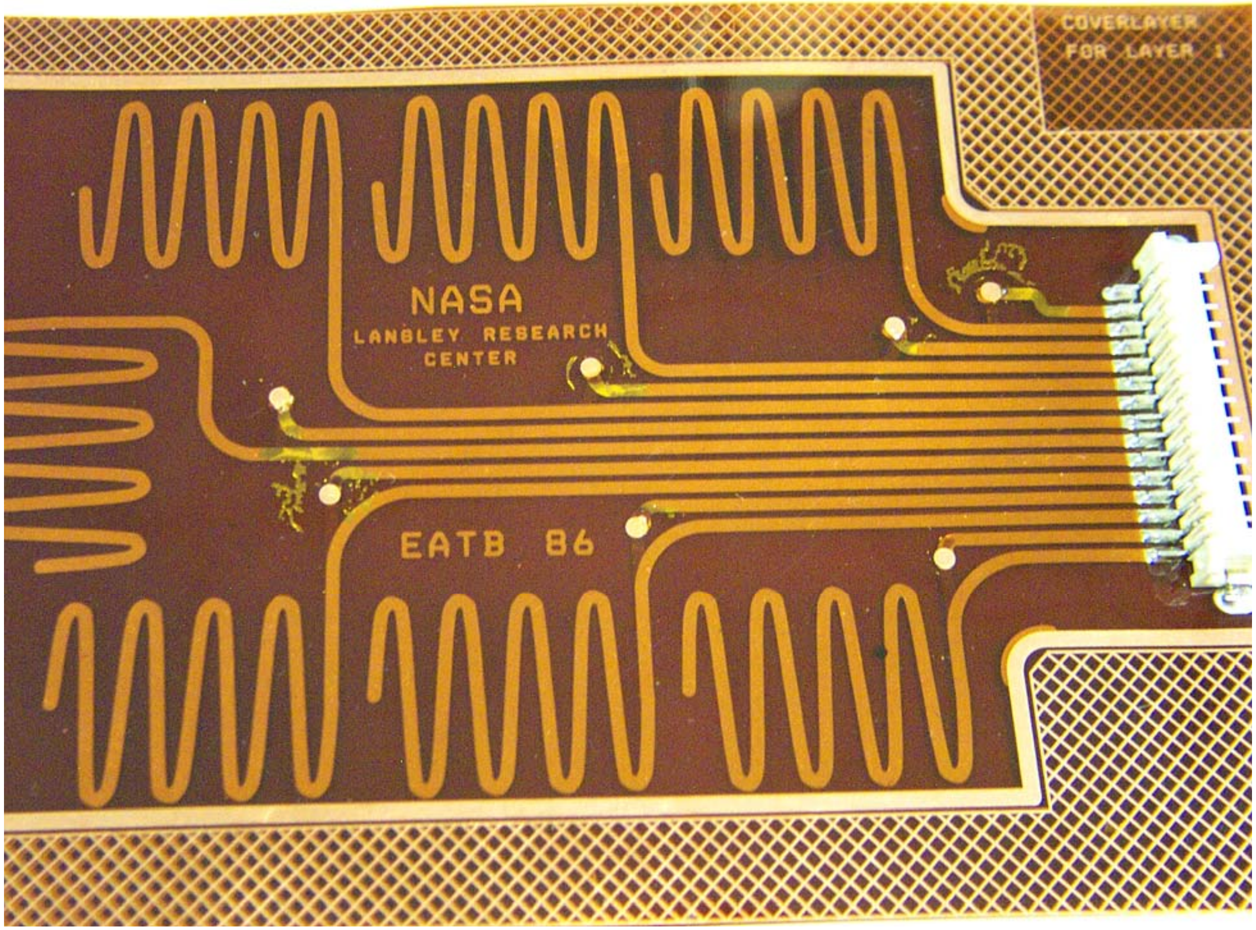


CAPACITORS (Continued)

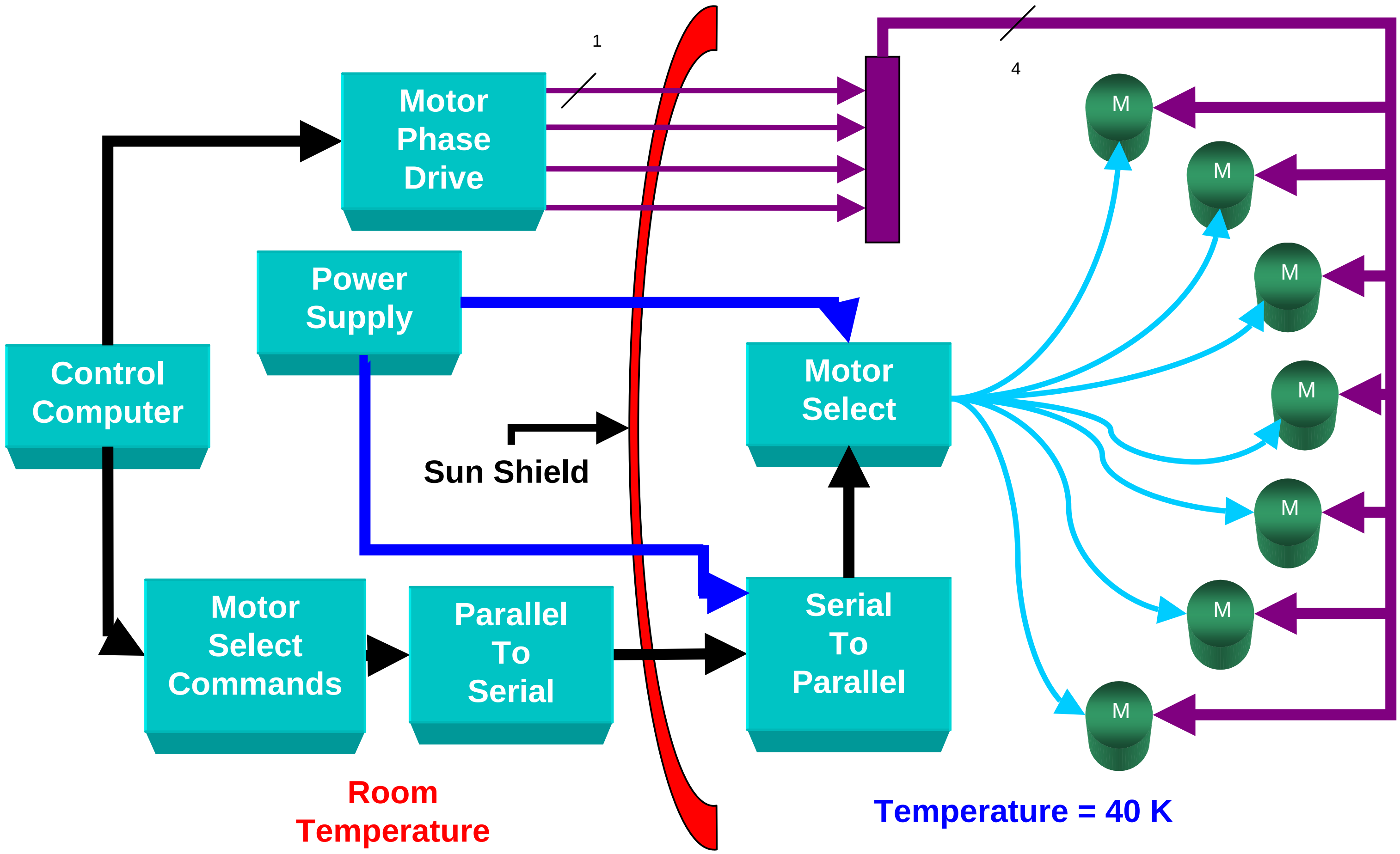
LEAKAGE CURRENT (nA)

Type	Unaged (RT)	Aged (RT)	In LN2
Polypropylene 1	1.80	1.20	0.02
Polypropylene 2	8.30	2.45	1.20
Polypropylene 3	9.50	5.00	0.06
Polycarbonate	3.20	2.64	0.14
Mica	7.10	10.80	0.10
Solid Tantalum	27.50	22.60	0.08

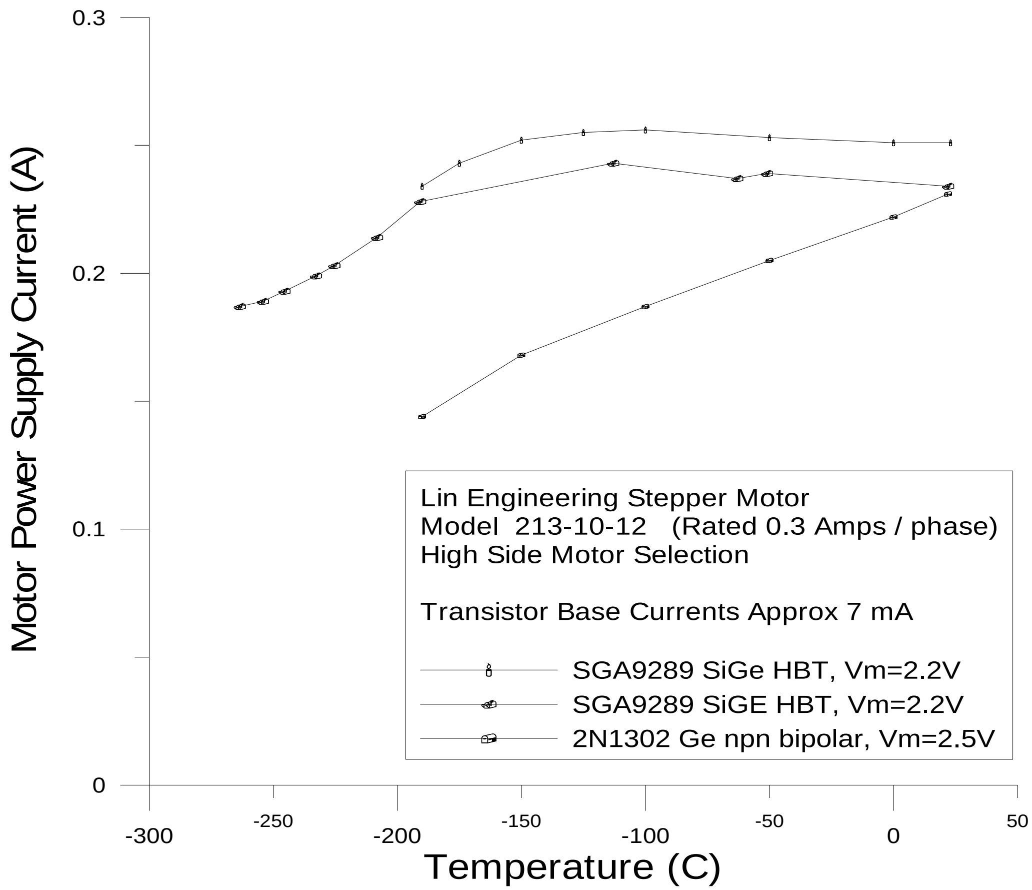
NASA Langley Laminated Flexible Printed Circuit Board



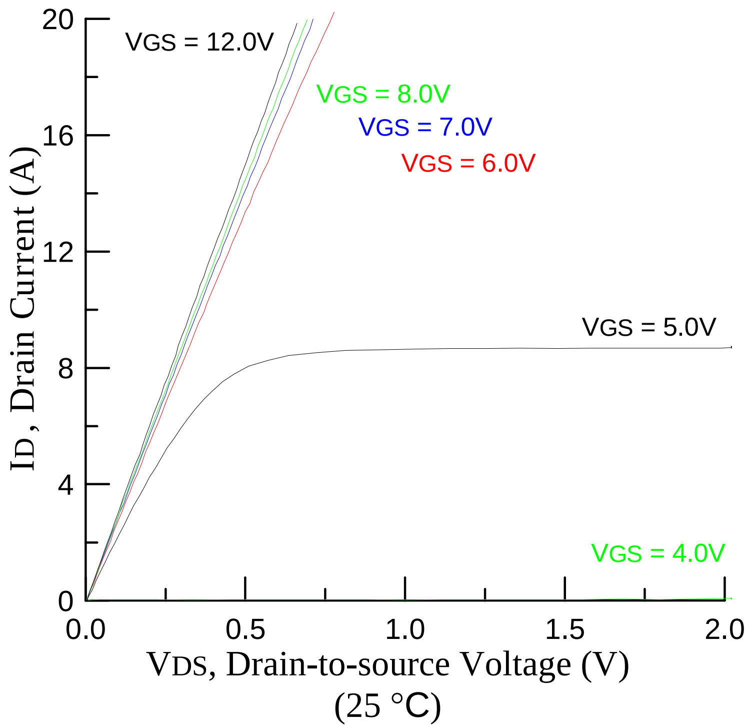
JAMES WEBB SPACE TELESCOPE MOTOR CONTROLLER

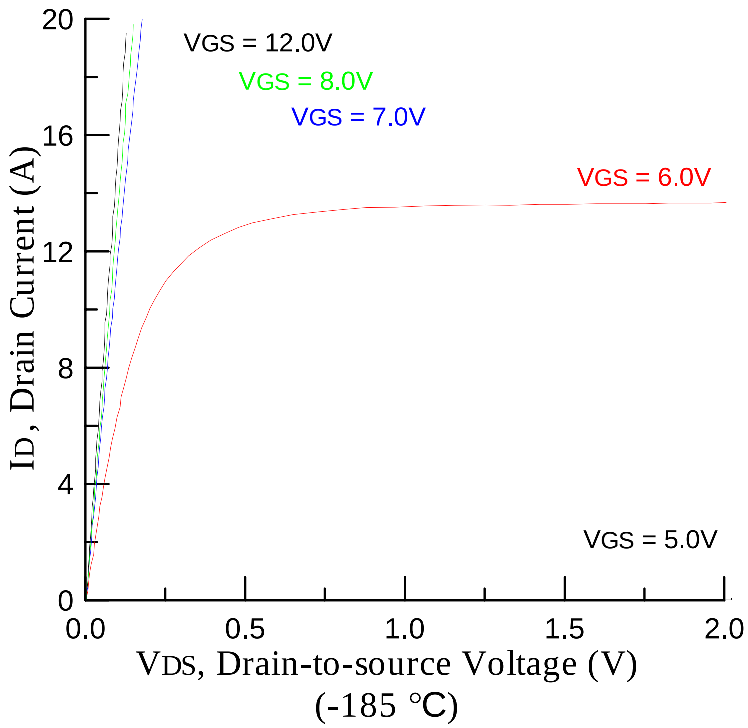


STEPPER MOTOR CONTROLLER / SELECTOR
SEMICONDUCTORS FOR USE AT ULTRALOW TEMPERATURES



Switching Characteristics of a MOSFET Device At Various Temperatures Before Cycling





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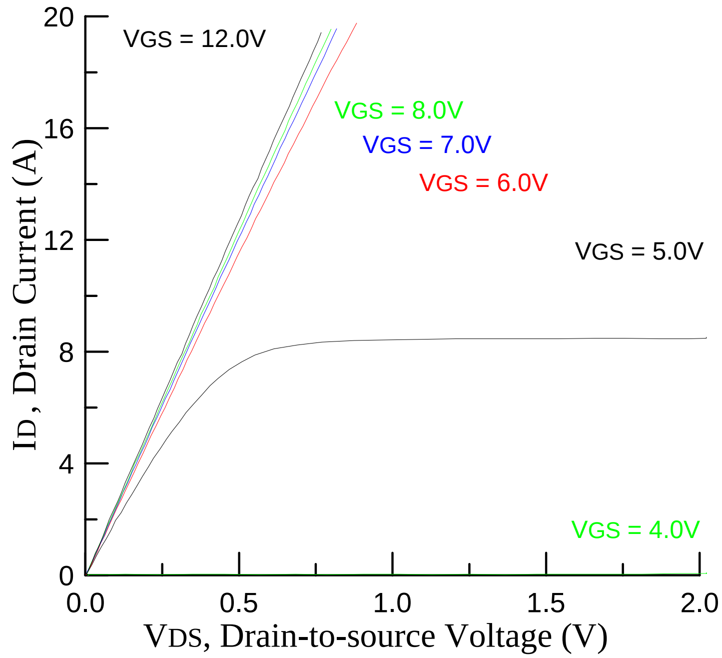
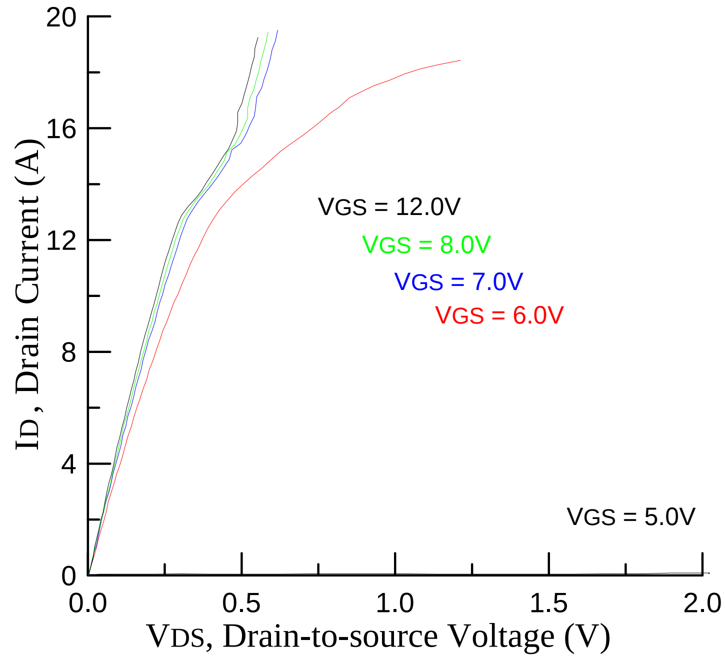


(25 °C)



(-125 °C)

CONCLUSIONS

- **LOW TEMPERATURE ELECTRONICS APPLICATIONS**
  - ➢ **DEEP SPACE MISSIONS**
  - ➢ **SATELLITES**
  - ➢ **CRYOGENIC INSTRUMENTATION**
- **CAN COMPONENTS SURVIVE?**
  - ➢ **EXTREME TEMPERATURES**
  - ➢ **HARSH ENVIRONMENTS**
- **NEED TO SATISFY :**
  - ➢ **COMPACTNESS**
  - ➢ **REDUCED WEIGHT**
  - ➢ **RELIABILITY**
  - ➢ **INCREASED EFFICIENCY**

CONCLUSIONS (Continued)

- **COTS COMPONENTS, DEVICES, CIRCUITS AND SYSTEMS HAVE BEEN CHARACTERIZED AT LOW TEMPERATURES**
  - **NEED-BASED**
  - **TECHNOLOGY-BASED**
  - **TEMPERATURE RANGE BEYOND SPECIFICATIONS (-40^{O}C OR -55 ^{O}C)**

- **ADVANCED COMPONENTS ARE INTEGRATED INTO MISSION-SPECIFIC LOW TEMPERATURE CIRCUITS AND SYSTEMS**
  - **MODIFY EXISTING**
  - **DEVELOP NEW TECHNOLOGIES**