Electronic Components for Use in Extreme Temperature Aerospace Applications

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Electrical power management and control systems designed for use in planetary exploration missions and deep space probes require electronics that are capable of efficient and reliable operation under extreme temperature conditions. Space-based infra-red satellites, all-electric ships, jet engines, electromagnetic launchers, magnetic levitation transport systems, and power facilities are also typical examples where the electronics are expected to be exposed to harsh temperatures and to operate under severe thermal swings. Most commercial-off-the-shelf (COTS) devices are not designed to function under such extreme conditions and, therefore, new parts must be developed or the conventional devices need to be modified. For example, spacecraft operating in the cold environment of deep space carry a large number of radioisotope heating units in order to maintain the surrounding temperature of the on-board electronics at approximately 20 °C. At the other end, built-in radiators and coolers render the operation of electronics possible under hot conditions. These thermal measures lead to design complexity, affect development costs, and increase size and weight. Electronics capable of operation at extreme temperatures, thus, will not only tolerate the hostile operational environment, but also make the overall system efficient, more reliable, and less expensive.

The Extreme Temperature Electronics Program at the NASA Glenn Research Center focuses on research and development of electronics suitable for applications in the aerospace environment and deep space exploration missions. Research is being conducted on devices, including COTS parts, for potential use under extreme temperatures. These components include semiconductor switching devices, passive devices, DC/DC converters, operational amplifiers, and oscillators. An overview of the program will be presented along with some experimental findings.

Abstract for the *12th International Components for Military and Space Electronics Conference (CMSE 08)*, San Diego, California, February 11-14, 2008.

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OUTLINE

1. Deep Space Temperature Requirements and Applications

2. Extreme Temperature Electronics at NASA Glenn Research Center

3. Extreme Temperature Electronics Components and Circuits

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 (former)	44 K	-229 °C

Deep Space Electronics Temperature Requirements & Benefits

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

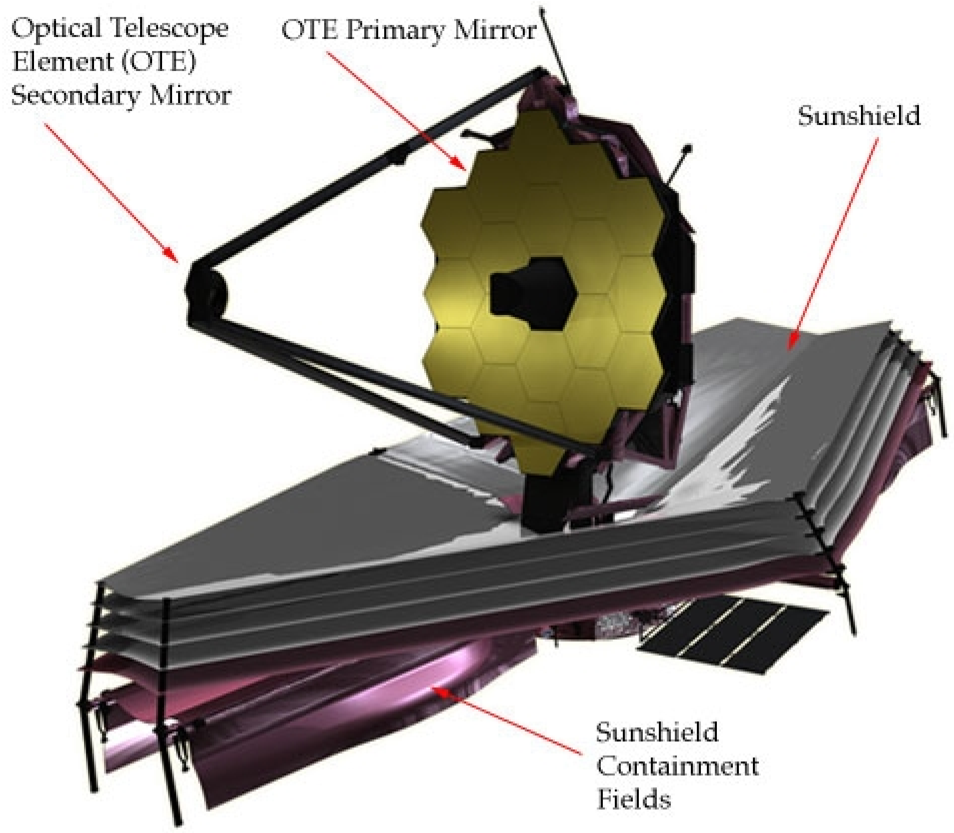
Goals

- Provide a technology base for the development of electronic systems capable of low temperature operation with long lifetimes
- 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
- Supported by the NASA Electronic Parts and Packaging Program (NEPP)

Space Applications of Low Temperature Electronics

- James Webb Space Telescope (-235°C)
- Lunar Pole Site (-235 °C)
- Mars Surface (-120 °C to 20 °C)
- Jupiter Probe (-151 °C)
- Pluto Flyby (-229 °C)

JAMES WEBB SPACE TELESCOPE



<u>High</u> Temperature Electronics Program

Goals

- Characterize state-of-the-art components for operation at high temperatures
- Develop circuits and sensors for use in high temperature environments associated with jet engines and high temperature space missions
- Supported by the NASA Fundamental Aeronautics / Subsonic Fixed Wing Program (Distributed Engine Control Task)

NASA Glenn Research Center
Extreme Temperature Electronics Program

Facilities

- Two environmental chambers
  Programmable rate for thermal cycling and long term soaking
  Simultaneous and automated operation
  Temp range from –193 °C to +250 °C
- 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

NASA Glenn Research Center
Extreme Temperature Electronics Program

Products

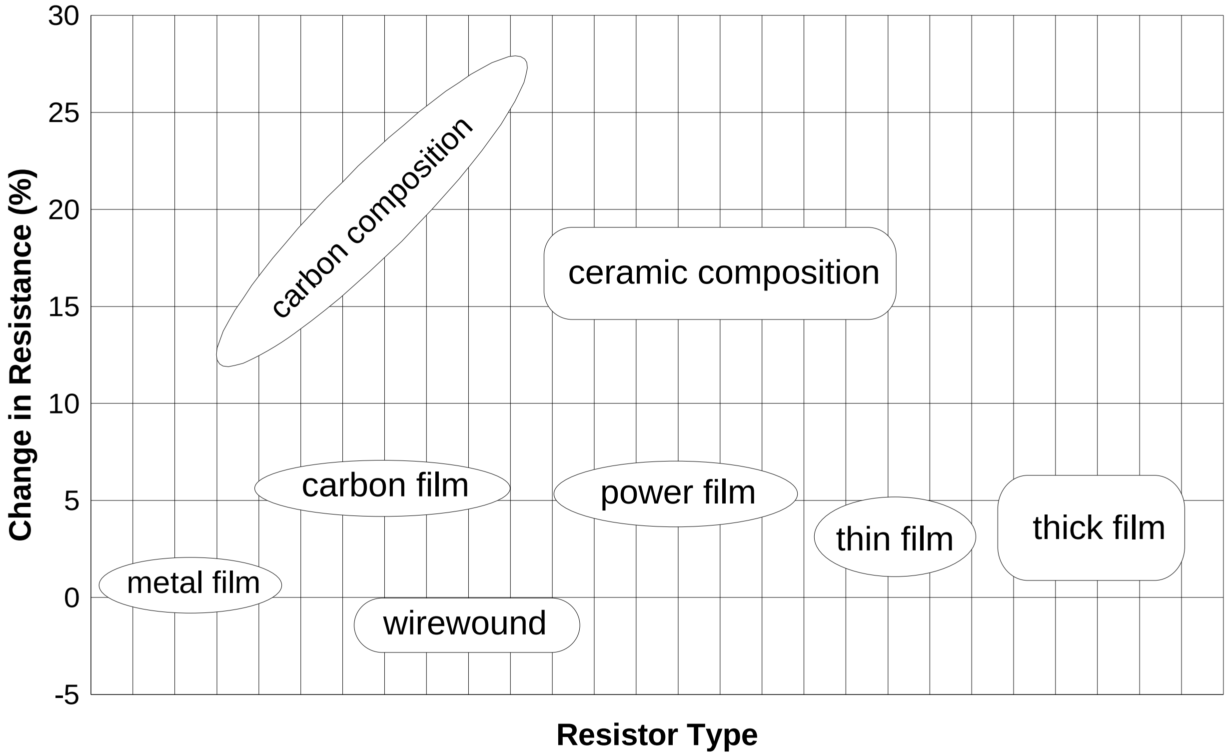
- **Components**
  Magnetic Devices: Inductors & Transformers
  Capacitors & Resistors
  Semiconductor Switches
  Batteries
  Transducers

- **Circuits**
  DC/DC Converters
  A/D Converters
  Oscillators
  PWM Control Circuits
  Motor Control

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

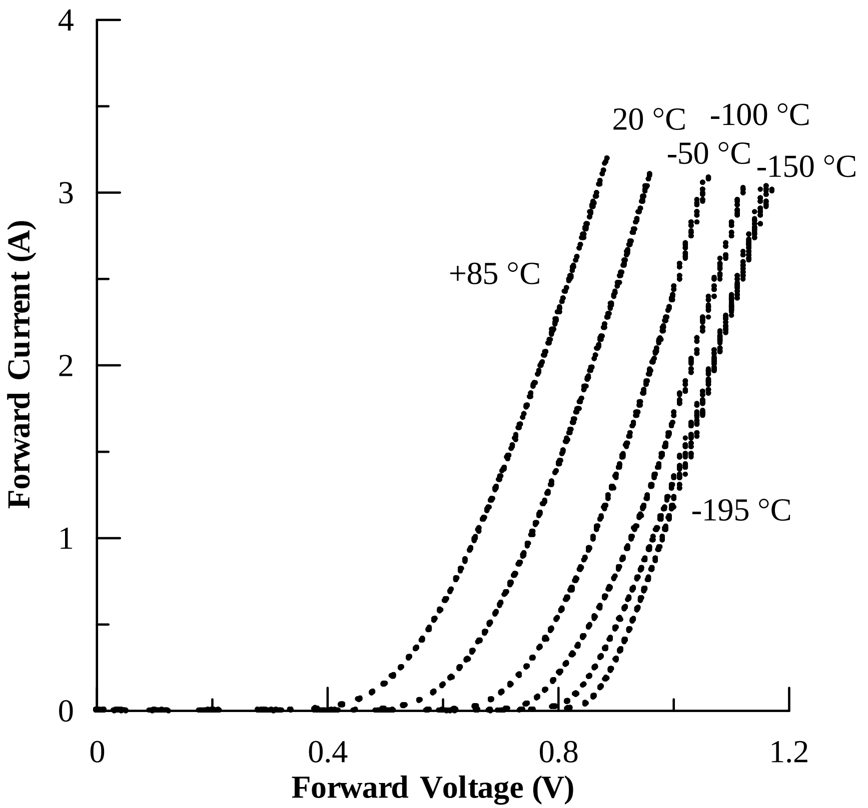
RESISTORS

Percent change in resistance at -190 °C versus resistor type

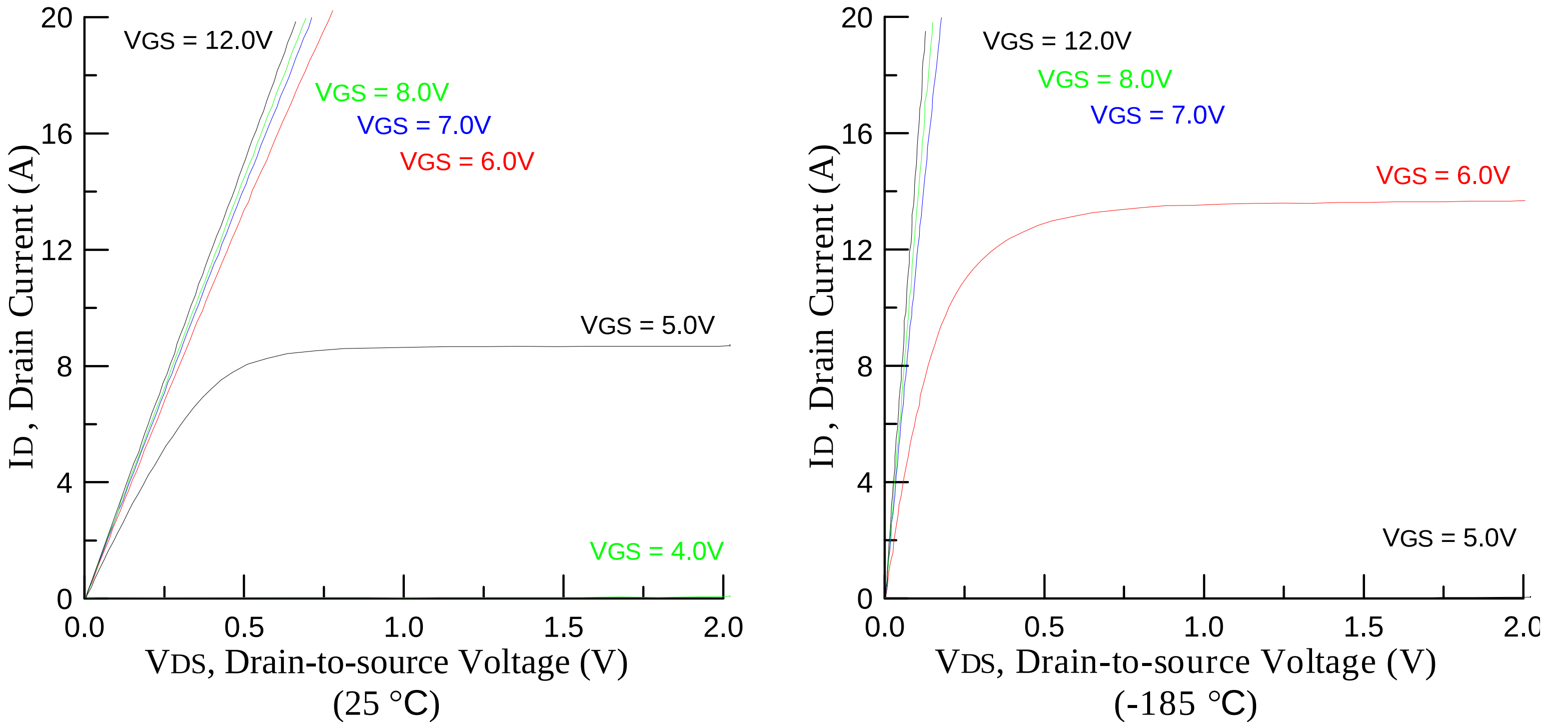


DIODES

Forward voltage-current characteristics of SiGe diodes as a function of temperature

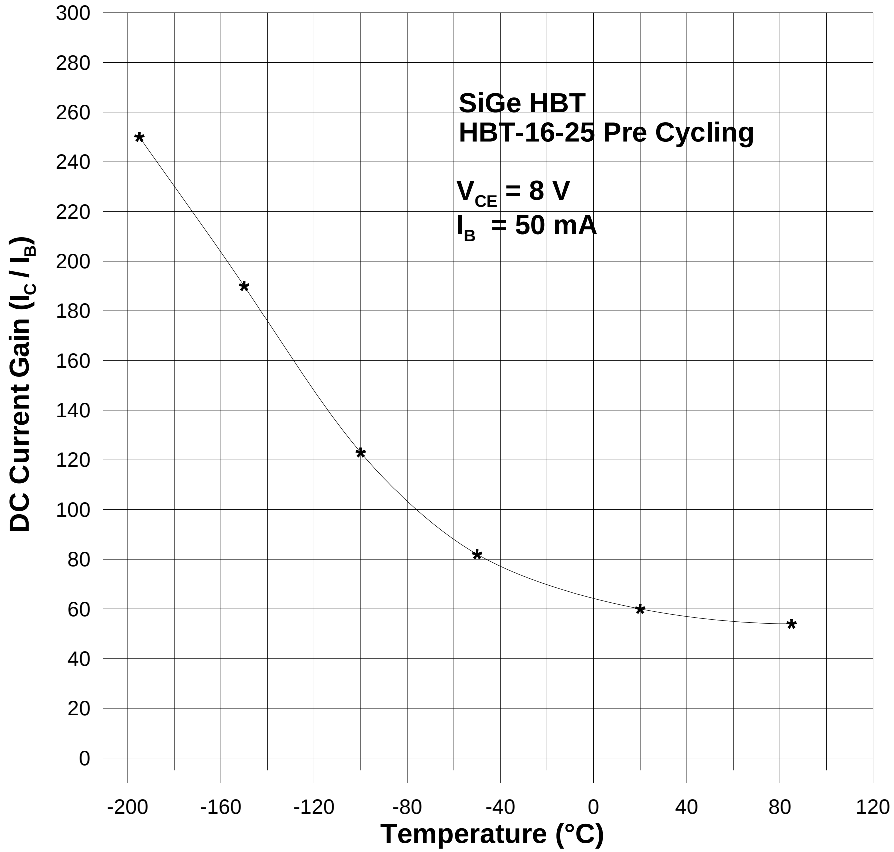


Switching Characteristics of an SOI MOSFET Device at Various Temperatures



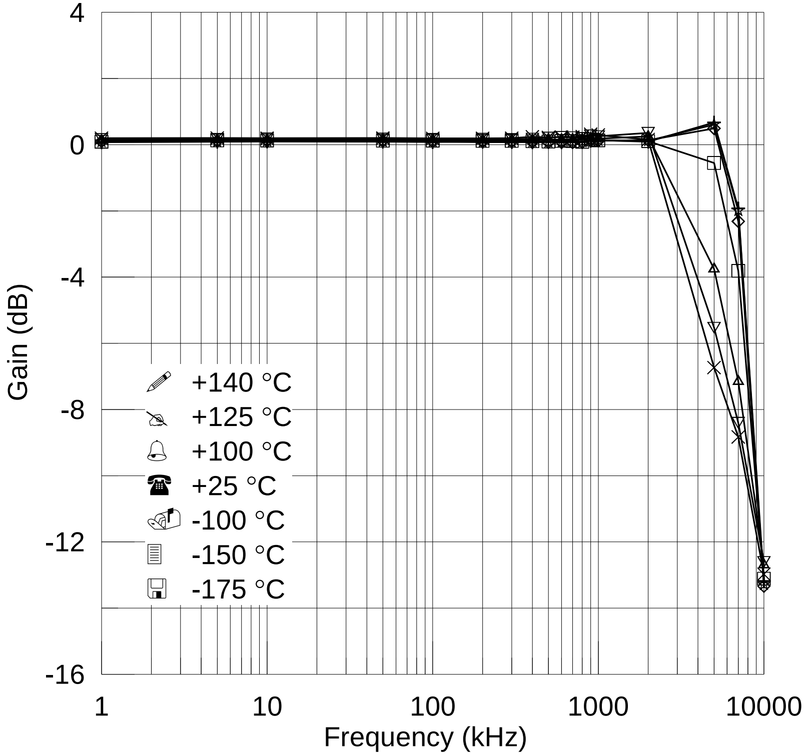
TRANSISTORS (Continued)

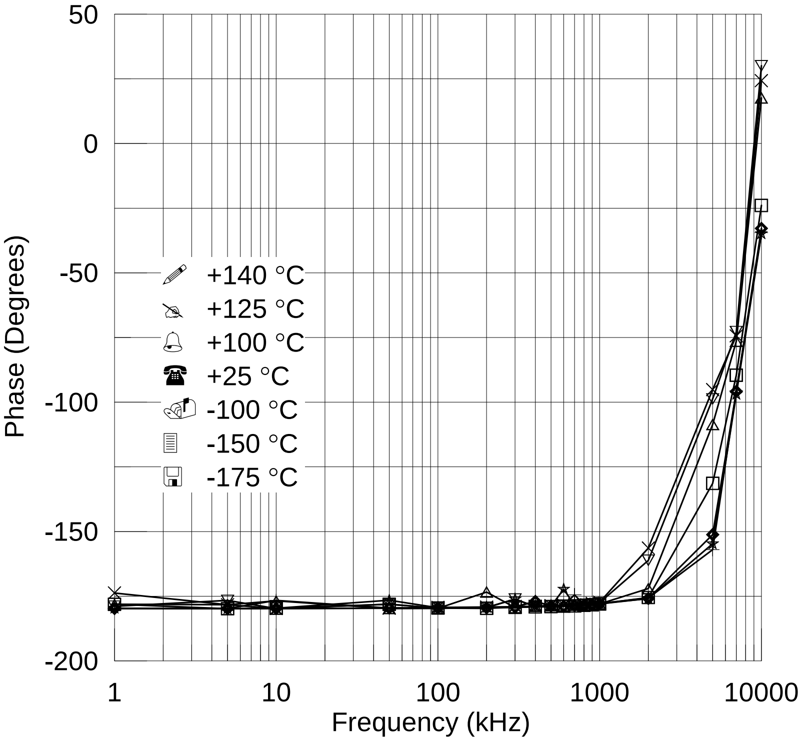
DC gain (I_C / I_B) as a function of temperature for a SiGe Heterojunction Bipolar Transistor (HBT)



OPERTIONAL AMPLIFIER

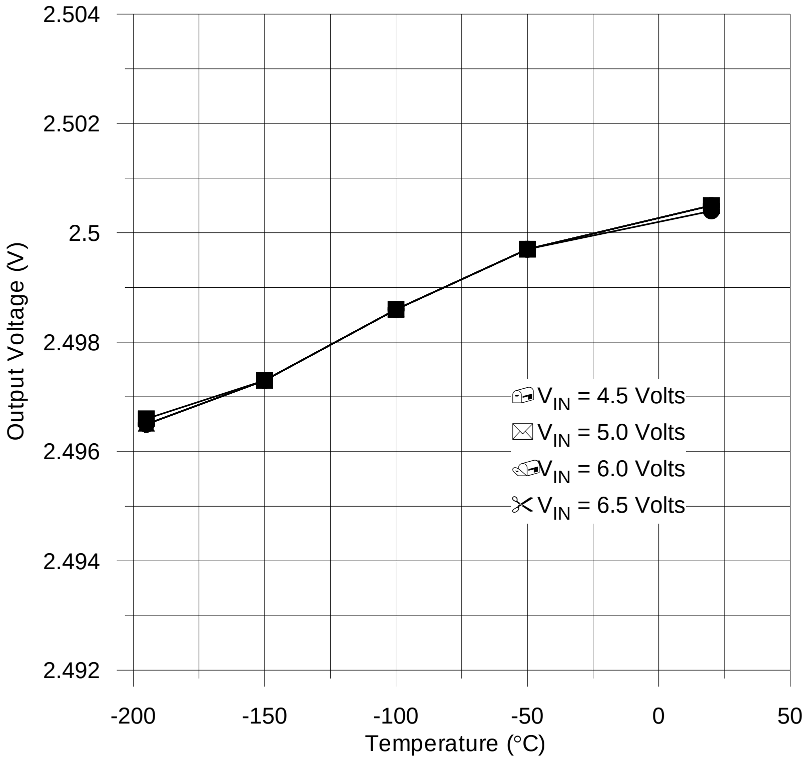
Gain & phase of SiGe/SOI OP Amp versus frequency at various temperatures

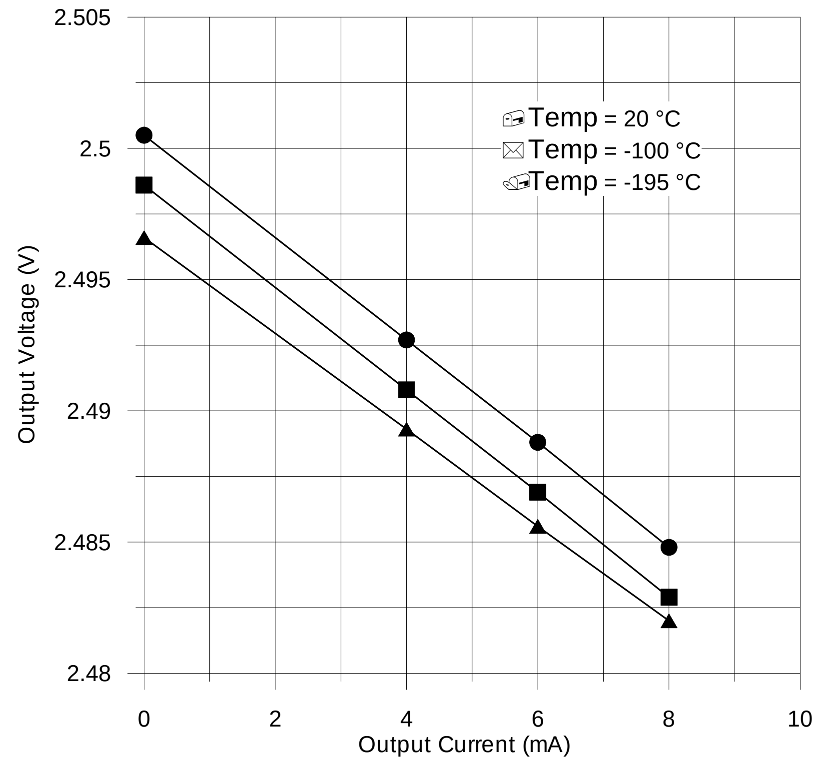




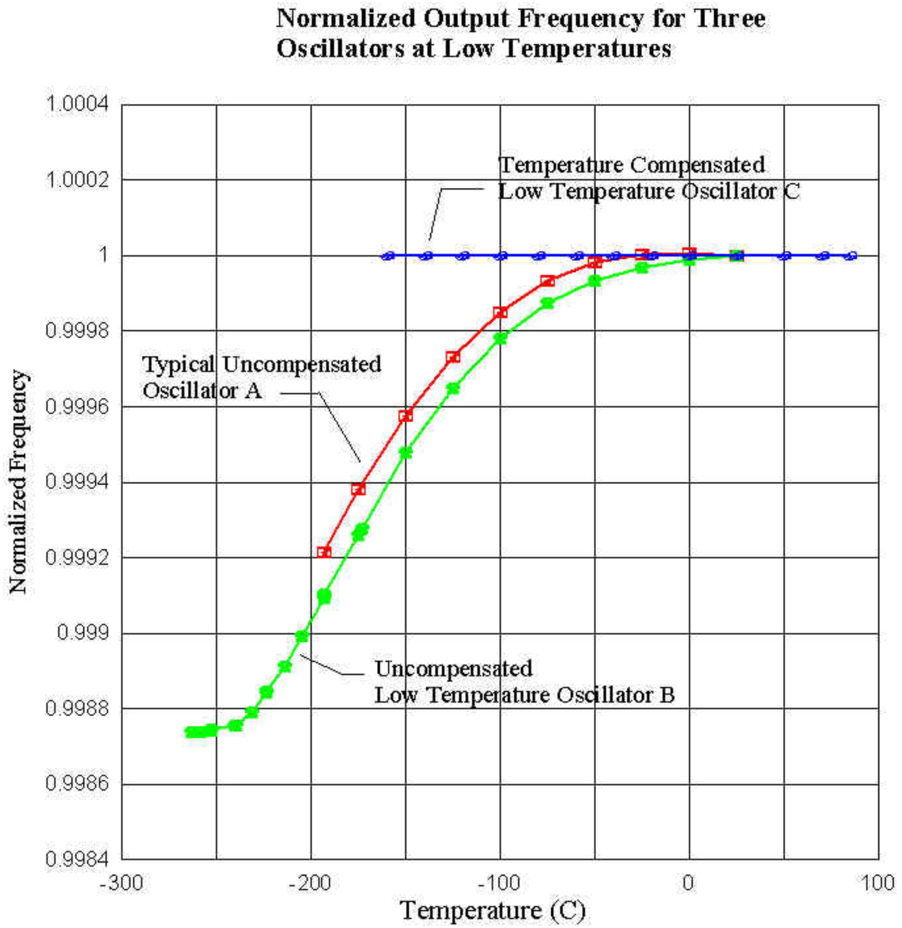
VOLTAGE REFERENCE

Output voltage & load regulation of X60008 reference as a function of temperature



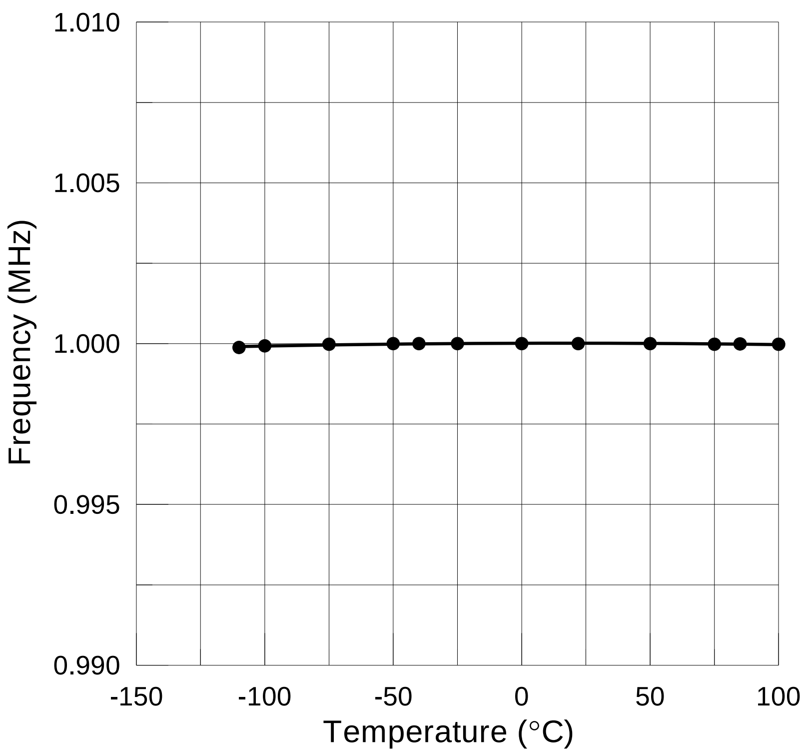


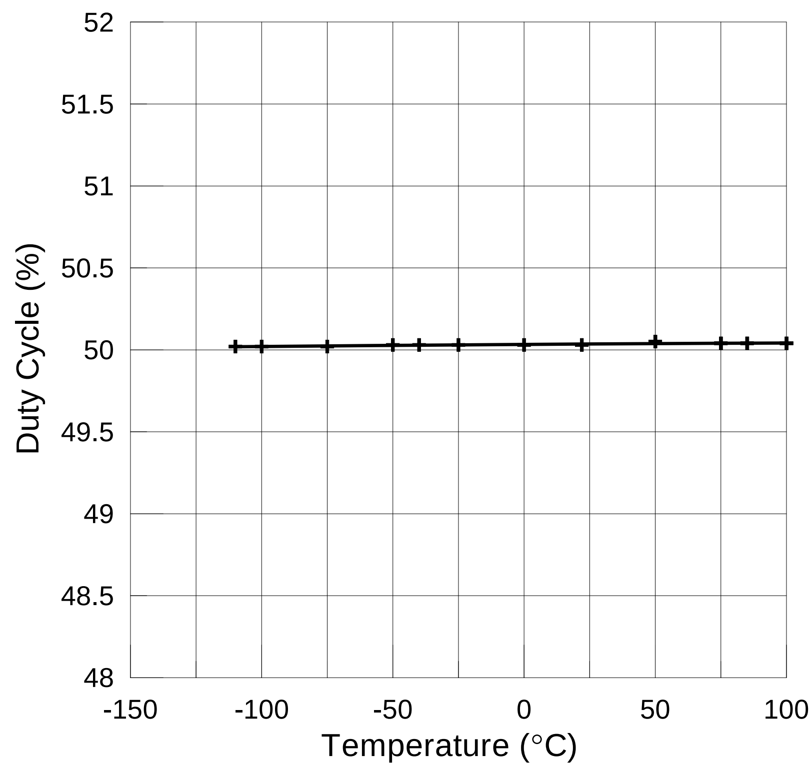
Operation of Three Oscillators at Low Temperatures



SILICON MEMS OSCILLATOR

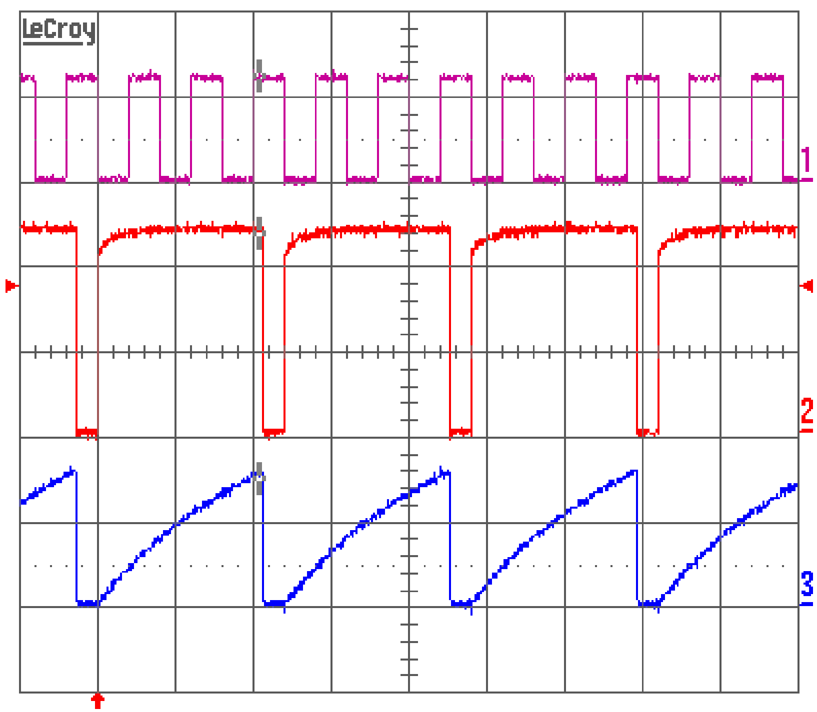
Frequency & Duty Cycle of Oscillator Output Versus Temperature



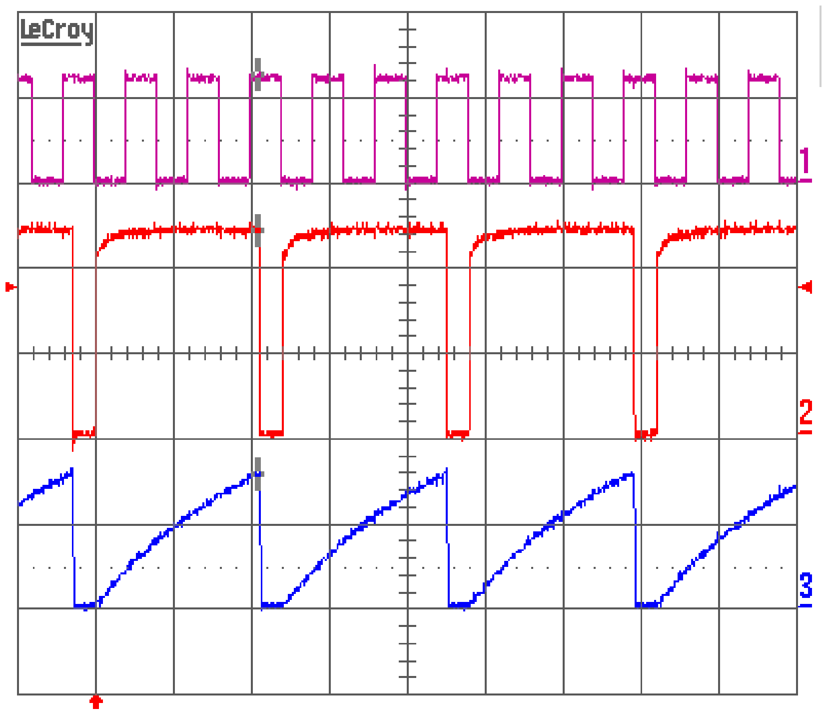


SILICON-ON-INSULATOR 555 TIMER

Waveforms of trigger (1), output (2), and threshold (3) signals

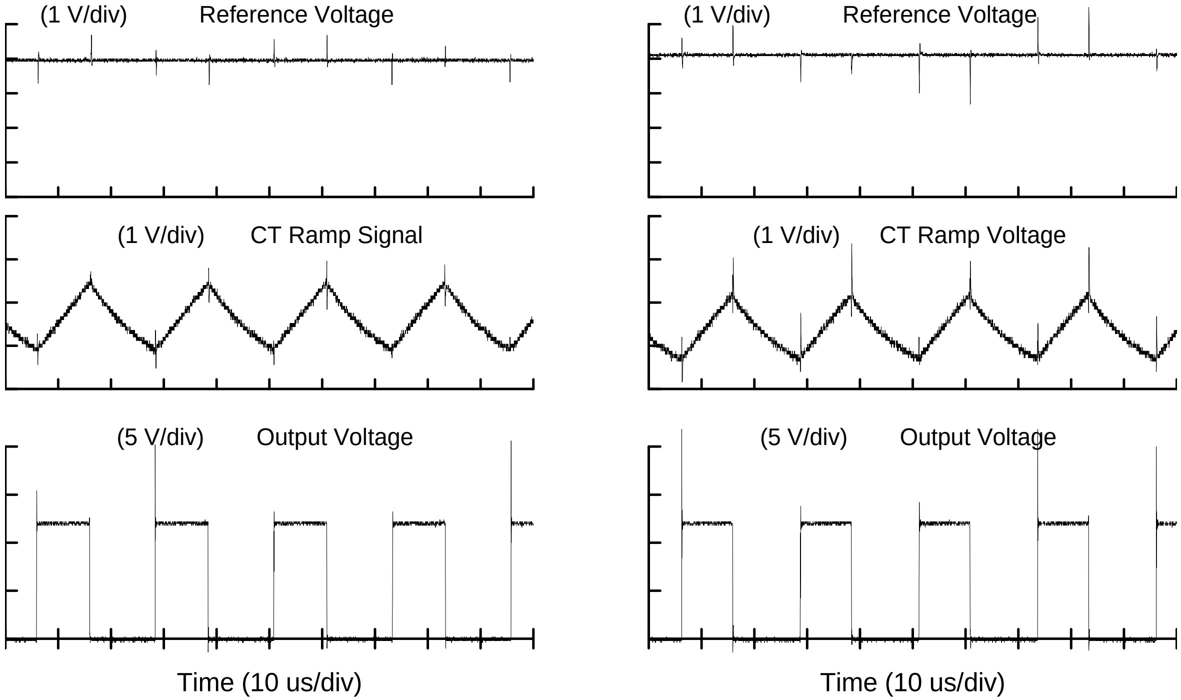


25 °C



-195 °C

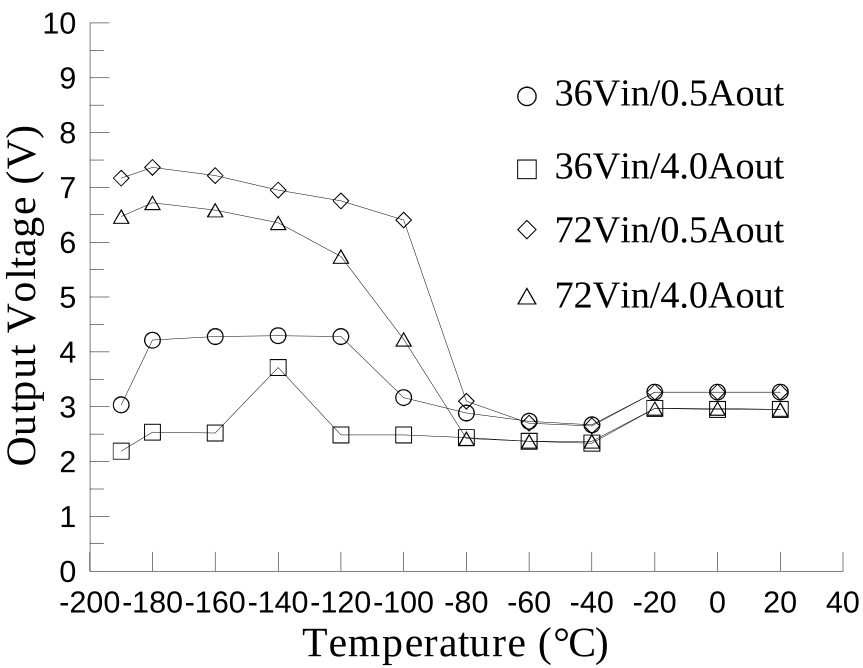
Output Waveforms of a Pulse Width Modulation Controller at Room Temperature and -190 °C

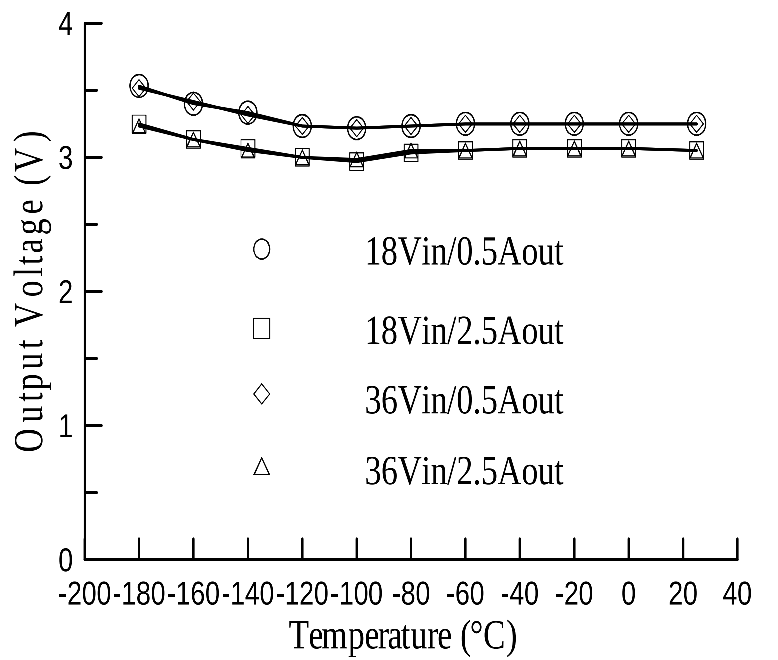


(a) Temperature = 25°C

(b) Temperature = -190°C

Output Voltages of Two Commercial DC/DC Converters at Various Temperatures





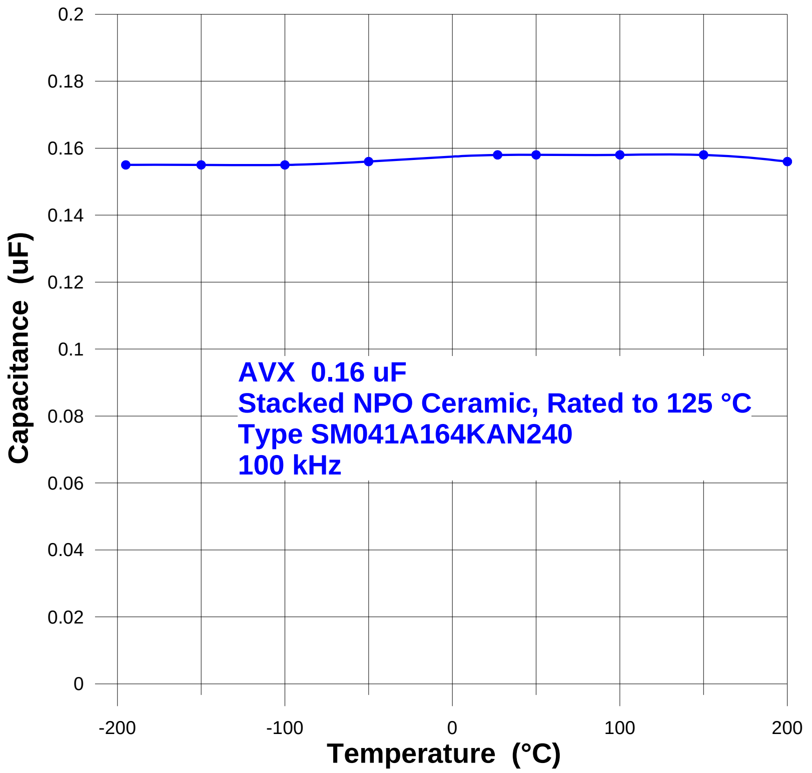
Commercial-Off-the-Shelf 12-Bit Serial CMOS A/D Converter (Rated for Operation Between -40 °C & +85 °C)

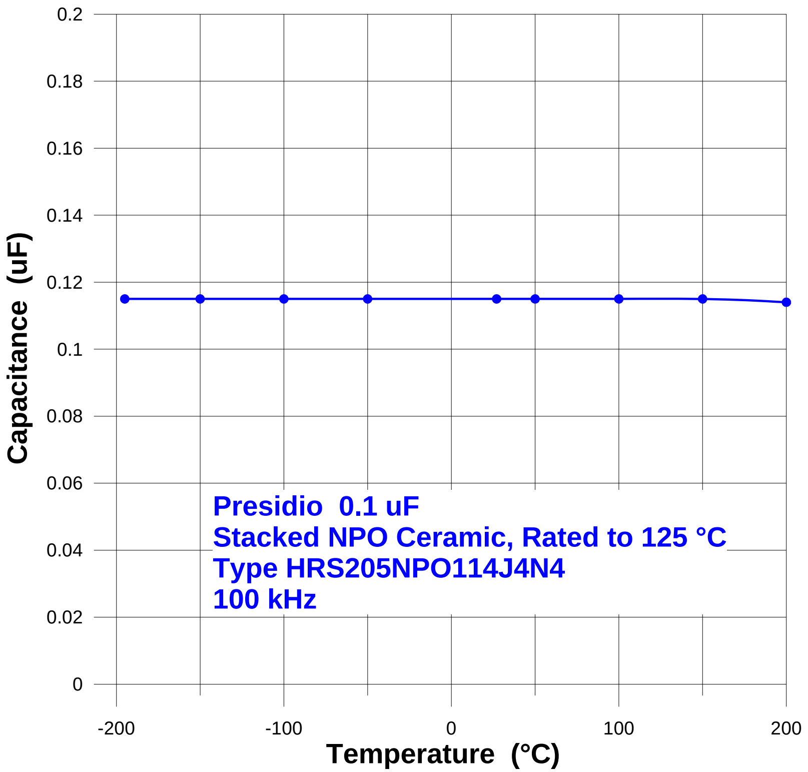
Digital Outputs at Three Temperatures

For Various Analog Inputs

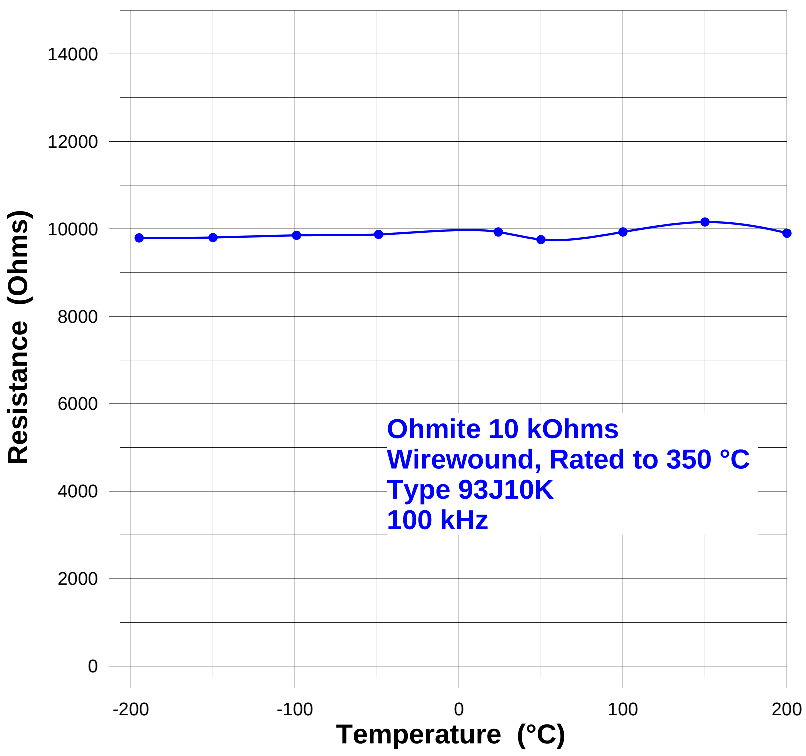
Analog Input (V)	Digital Output (V) @ 25 °C	Digital Output (V) @ -100 °C	Digital Output (V) @ -190 °C
0	0.007	0.010	0.010
0.5	0.505	0.498	0.508
1	1.004	1.006	1.004
2	2.000	2.002	1.993
5	4.994	4.994	5.001
7.25	7.241	7.228	7.226
10	9.983	9.963	9.963
10.1	10.000	10.000	10.000

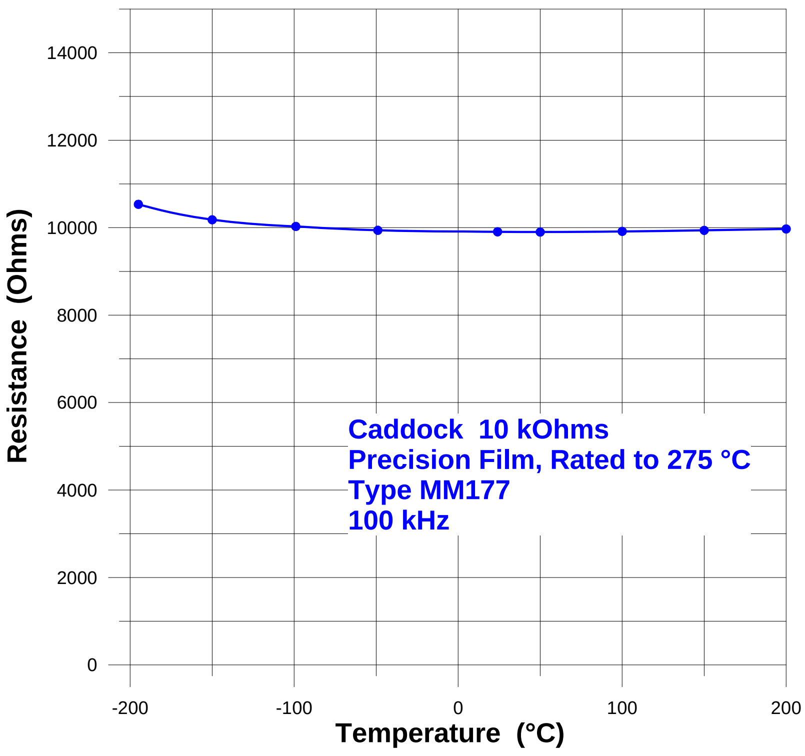
Capacitors for Wide Temperature Operation



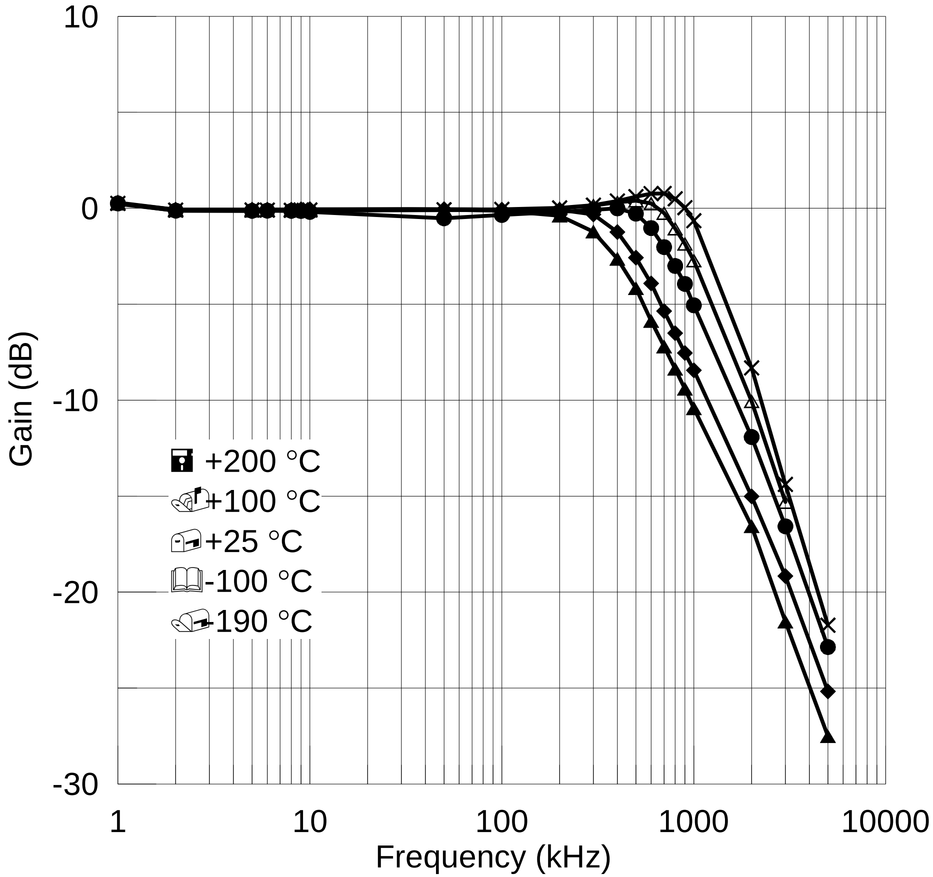


Resistors for Wide Temperature Operation





Operational Amplifier for Wide Temperature Operation



Things To Remember

LOW TEMPERATURE ELECTRONICS CAN BE DESIGNED FOR SPACE APPLICATIONS

- DEEP SPACE MISSIONS
- LUNAR, MARS
- SATELLITES
- CRYOGENIC INSTRUMENTATION

IMPROVEMENTS DUE TO LOW TEMPERATURE ELECTRONICS

- BETTER COMPACTNESS
- REDUCED WEIGHT
- RELIABILITY
- INCREASED EFFICIENCY

Things To Remember (Continued)

CIRCUITS HAVE BEEN DESIGNED TO OPERATE OVER THE WHOLE TEMPERATURE RANGE BETWEEN -190 °C AND +200 °C

THERE ARE ON-GOING EFFORTS AT NASA GLENN RESEARCH CENTER TO DESIGN MORE COMPLEX CIRCUITS THAT WILL OPERATE AT EVEN HIGHER TEMPERATURES