# Evaluation of COTS SiGe, SOI, & Mixed Signal Electronic Parts for Extreme Temperature Use in NASA Missions

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# Introduction

- ***Brief description of NEPP Task # 11-281 (Continuing) "Reliability of SiGe, SOI, and Advanced Mixed Signal Devices for Extreme Temperature Space Missions"***

- ***Goal, approach, schedule, and status of Task***

- ***Technical highlights***

- ***Plans***

# NEPP Task # 11-281 (Continuing)
# Reliability of SiGe, SOI, and Advanced Mixed Signal Devices for Extreme Temperature Space Missions

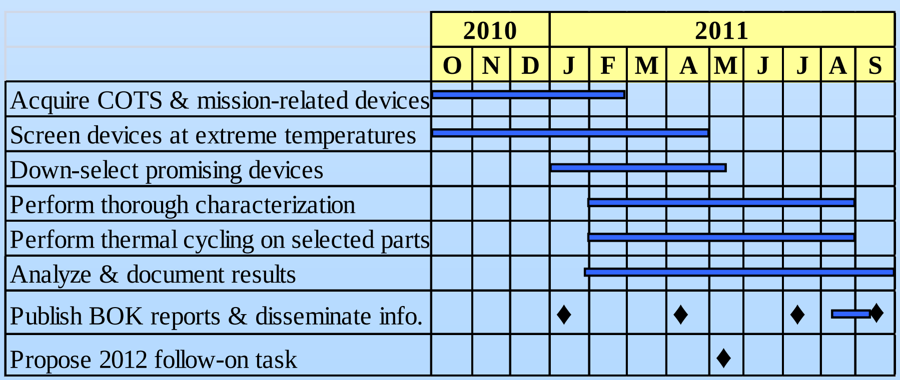
## Description:

***Space exploration missions require electronics that operate under extreme temperatures. SiGe devices utilize band gap engineering in their design to enable low temperature operation, and SOI parts offer good radiation tolerance and high temperature operation capability. This task focuses on establishing reliability of SiGe, SOI, and advanced mixed signal devices for use in extreme temperature space exploration missions. COTS parts and flight-like hardware will also be evaluated by determining their performance under extreme temperatures and thermal cycling. The generated data will establish safe operating areas and identify degradation modes, and the information will be disseminated to mission planners and system designers to establish risk factors associated with the use of such parts at extreme temperature in space applications.***

## FY11 Plans:

- ***Identify and acquire COTS parts and flight-like hardware.***
- ***Determine part/circuit operational requirements.***
- ***Conduct screening tests at extreme temperatures.***
- ***Perform combined thermal/electrical tests.***
- ***Determine the effects of wide temperature thermal cycling.***
- ***Collaborate and cooperate with other centers.***
- ***Publish reports and disseminate information.***

## Schedule:




## Deliverables:

- ***Issue technical reports documenting reliability of selected SiGe, SOI, and advanced mixed signal devices for extreme temperature operation.***
- ***Publish results on NEPP website and at professional conferences and disseminate information to mission planners and system designers.***
- ***Submit quarterly progress reports.***

# Goals

- Establish a technology base for the development of electronic systems, using COTS parts, capable of extreme temperature operation for space exploration missions

- Disseminate information and transfer technology to NASA mission groups and aerospace designers

## Silicon Germanium (SiGe)

**Utilizes band-gap engineering to tailor properties such as preventing carrier freeze-out**

**e.g. Diodes, HBT's, Op Amps, VCO's**

## Silicon-on-Insulator (SOI)

**Offers reduced leakage current, high temperature capability, improved radiation tolerance, & less power consumption**

**e.g. Timers, Op Amps, Logic, MOSFET's, Drivers, $V_{REF}$**

## Advanced Mixed Signal

**Employs new material & design technologies to enhance performance and improve reliability**

**e.g. MEMS Oscillators, VCO's, Converters, $V_{REG}$**

# NASA Applications

| Target | Temperature (°C) |
|---|---|
| Venus | +480 |
| Lunar Surface | -230 → +120 |
| Mars Surface | -125 → +20 |
| Jupiter | -160 → +300 |
| Europa (Jupiter) | -160 → -120 |
| Titan (Saturn) | -180 → -150 |

# Expected Impact to Community

## Traditional approach to extreme temp operation

- Passive or active thermal control
- Warm electronic box
- Radioisotope heater units

## Impact of “extreme temperature electronics”

- Simplify thermal management
- Improve energy density and system efficiency
- Improve reliability
- Reduce overall system mass
- Reduce development and launch costs

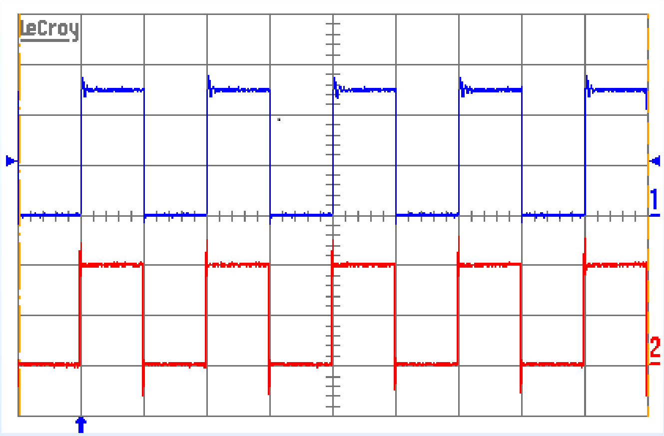
# Status/Schedule

| | 2010 | | | 2011 | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | O | N | D | J | F | M | A | M | J | J | A | S |
| Acquire COTS & mission-related devices | | | | | | | | | | | | |
| Screen devices at extreme temperatures | | | | | | | | | | | | |
| Down-select promising devices | | | | | | | | | | | | |
| Perform thorough characterization | | | | | | | | | | | | |
| Perform thermal cycling on selected parts | | | | | | | | | | | | |
| Analyze & document results | | | | | | | | | | | | |
| Publish tech reports & disseminate info. | | | | ♦ | | | ♦ | | | ♦ | | ♦ |
| Propose 2012 follow-on task | | | | | | | | ♦ | | | | |

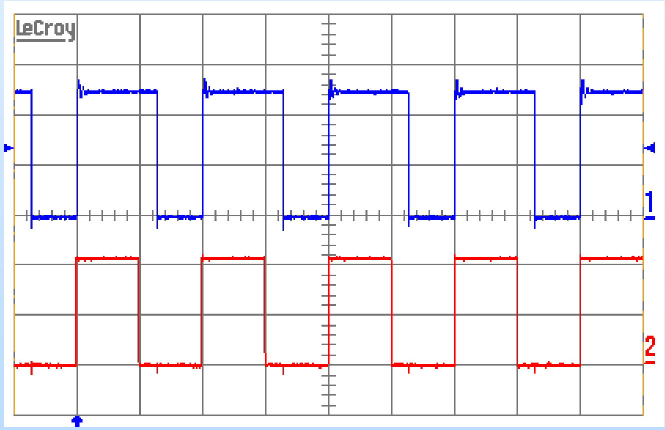
# FY11 Highlights/Accomplishments

- **Submitted deliverable test report "Performance of Micropower Voltage Reference ADR3430 Under Extreme Temperatures"**
- **Submitted deliverable test report "Stability of Crystal Oscillator, Type Si530, Inside and Beyond Its Specified Operating Temperature Range"**
- **Submitted deliverable test report "Evaluation of Fairchild's Gate Drive Optocoupler, Type FOD3150, under Wide Temperature Operation"**
- **Submitted deliverable test report "Test Results of Selected COTS DC/DC Converters Under Cryogenic Temperatures – A Digest"**

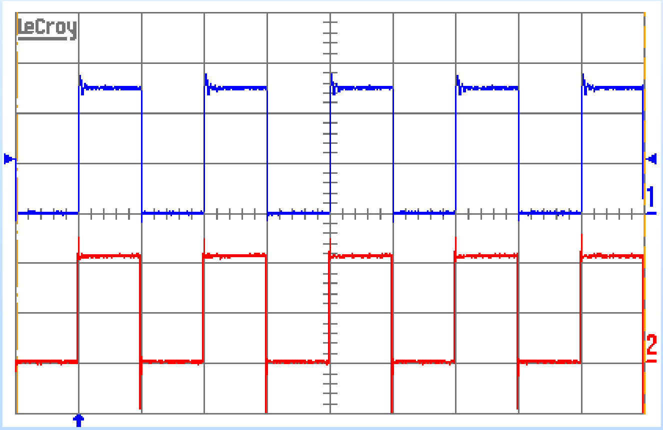
# Gate drive optocoupler, type FOD3150




@ 23 °C



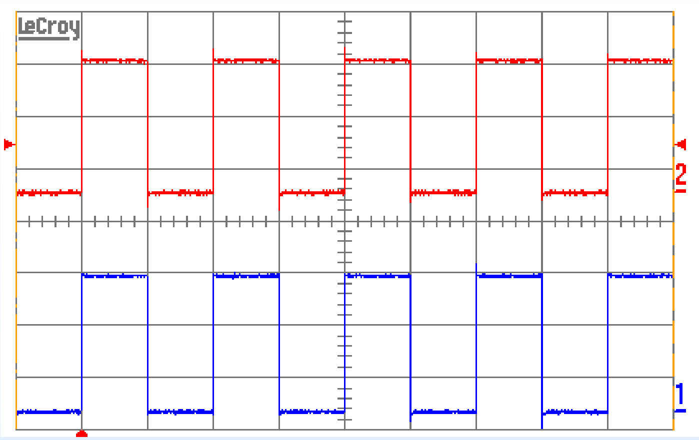

@ -190 °C



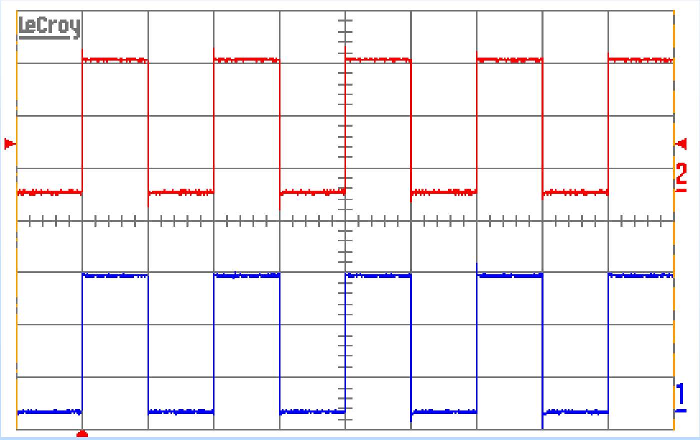

@ +110 °C

**Input (red) and output (blue) signals at various temperatures**

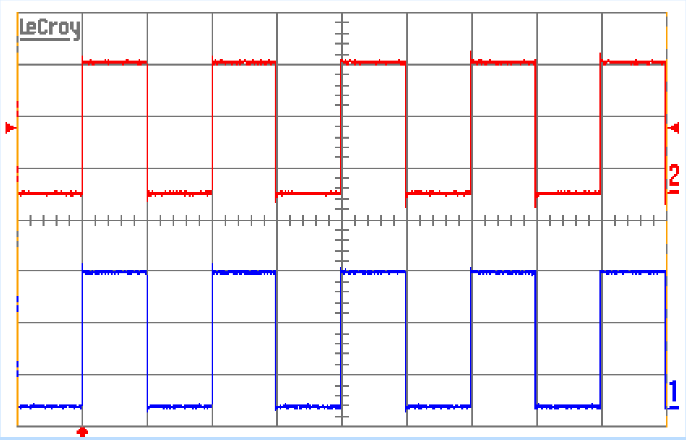
# GMR (Giant Magneto-Resistive) digital isolator, type IL510




@ 23 °C



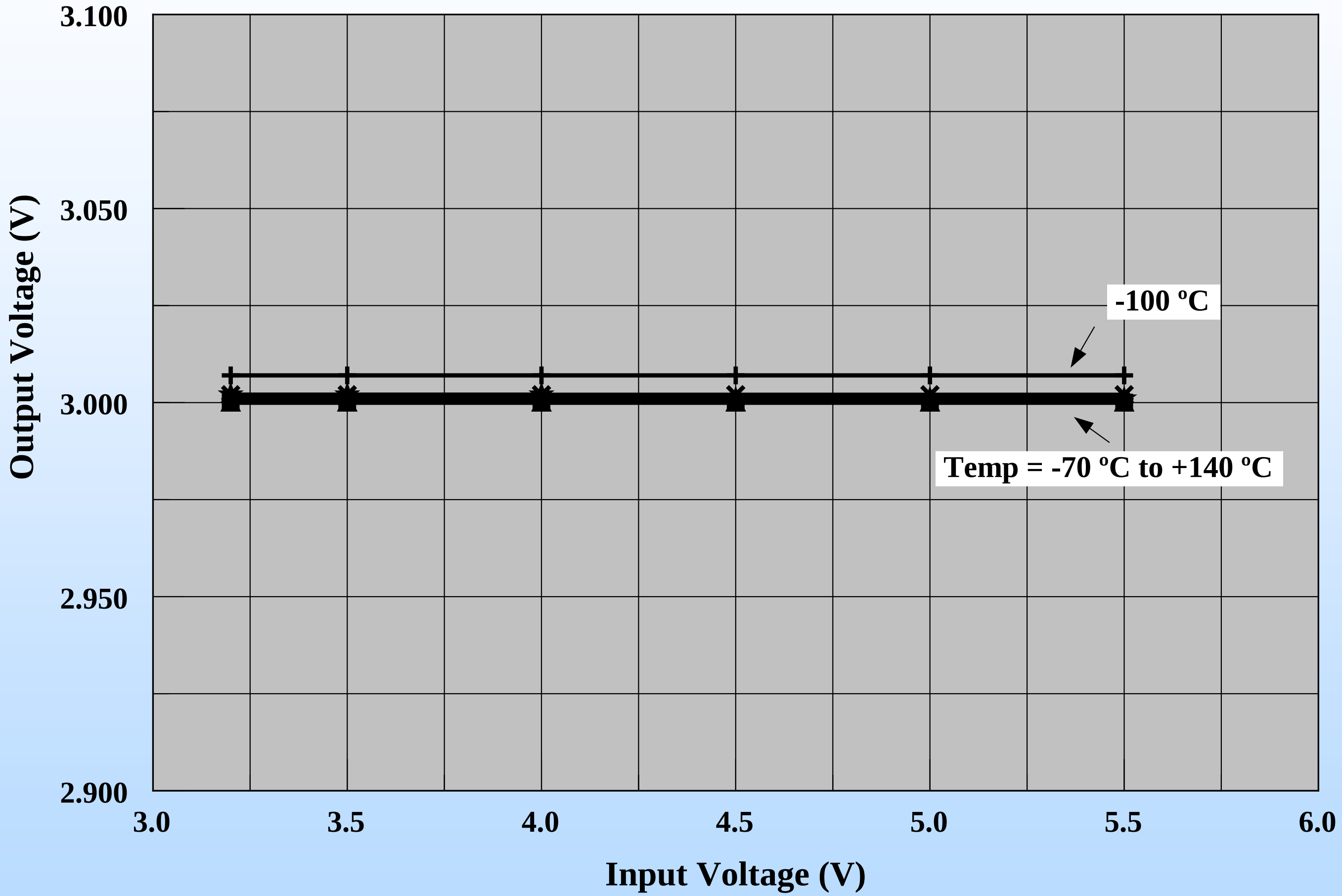

@ -190 °C




@ +120 °C

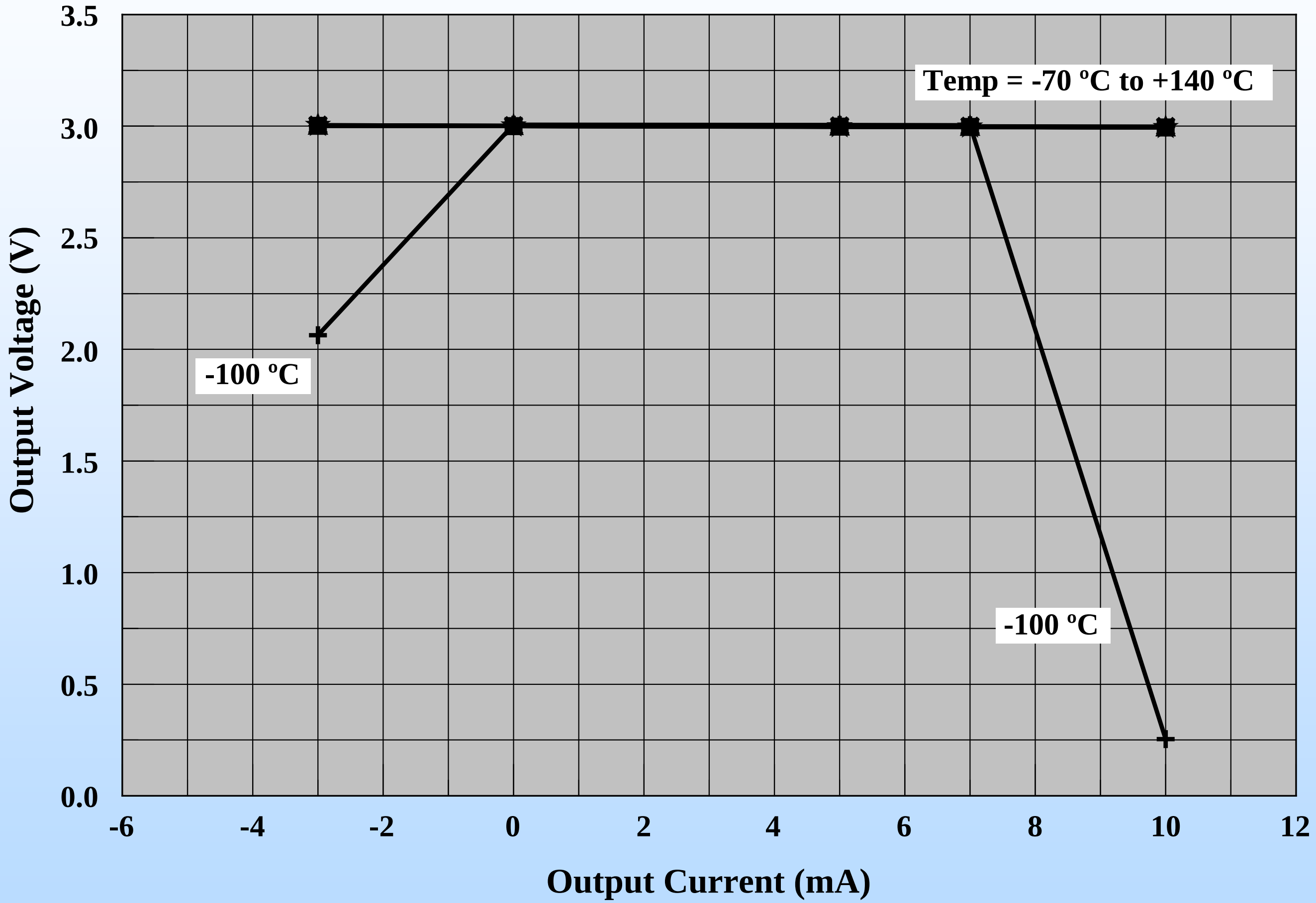
**Input (blue) and output (red) signals at various temperatures**

# High accuracy voltage reference, type ADR3430



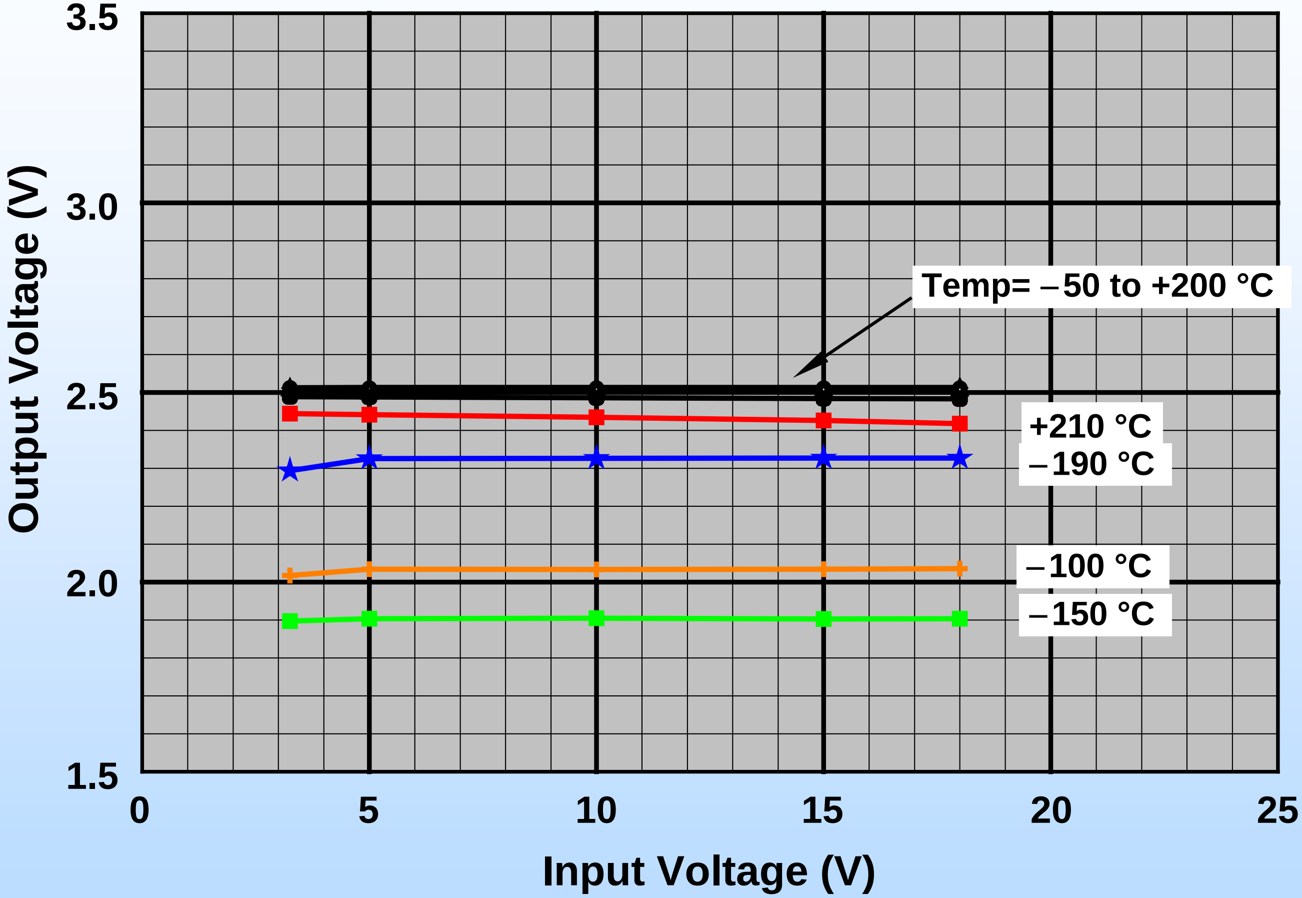

**Excellent stability of output from -70 °C to +140 °C.**

# High accuracy voltage reference, type ADR3430



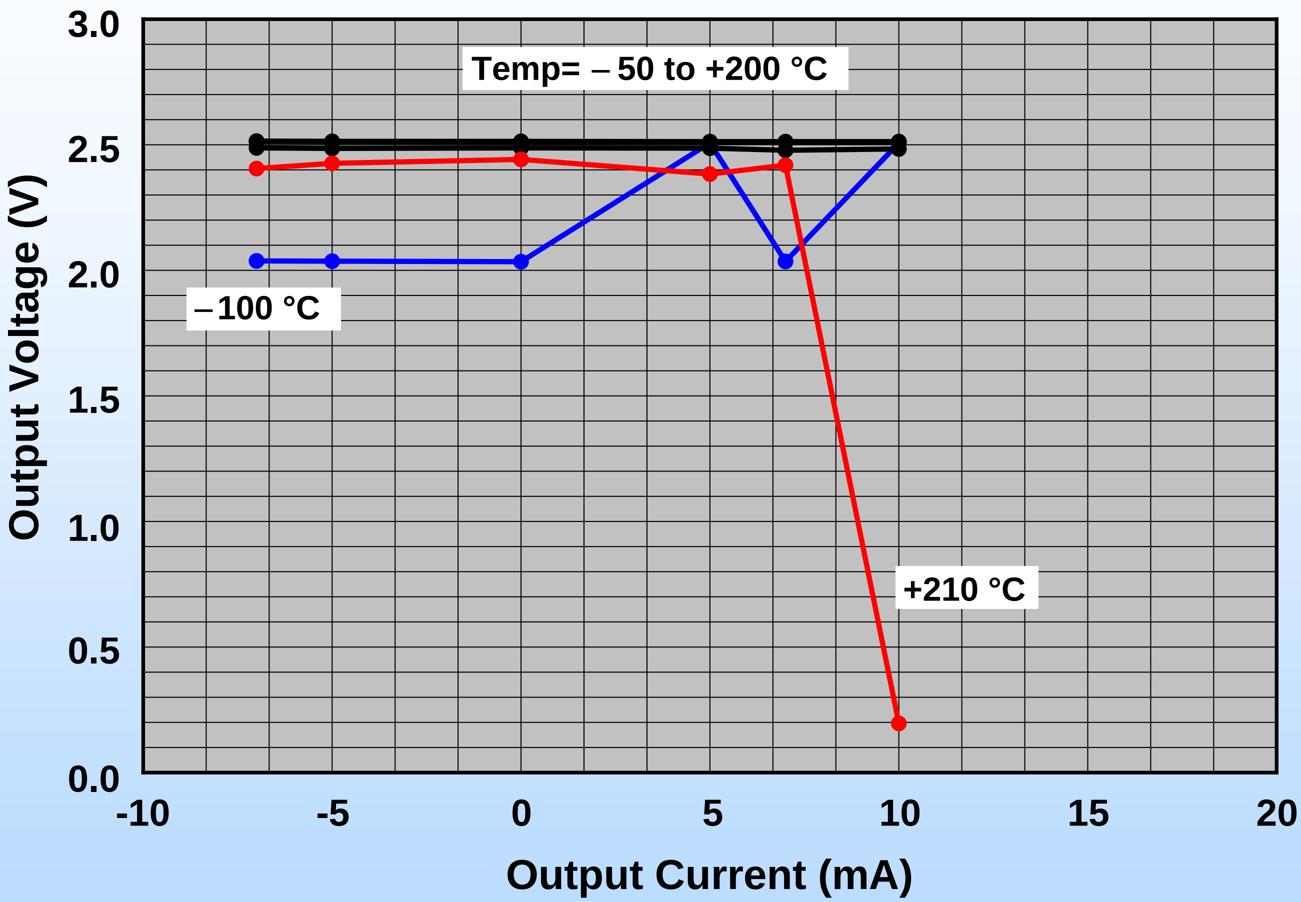

## Load regulation versus temperatures with $V_{IN}$= 3.5 V

# Precision voltage reference, type REF5025-HT



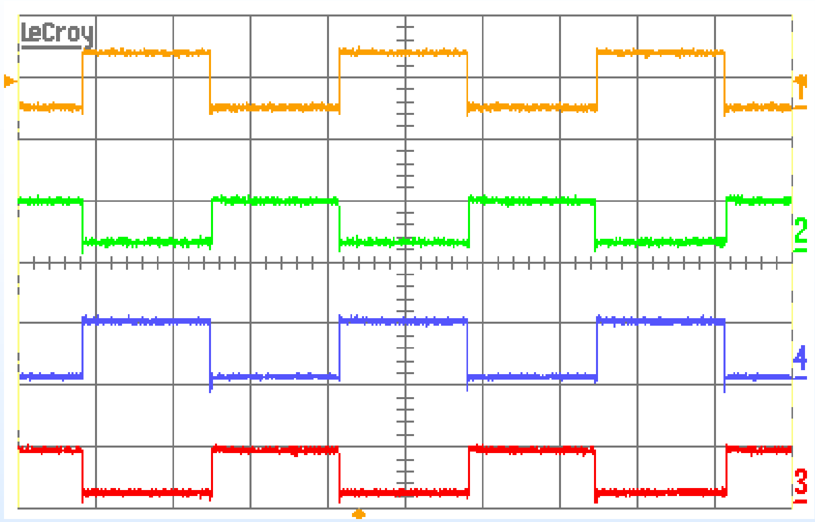

**Good stability in output voltage from -50 °C to +200 °C**

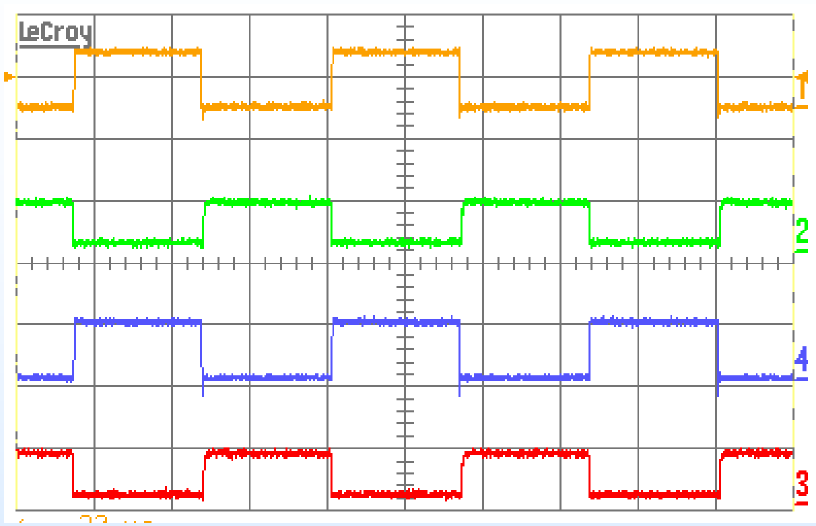
# Precision voltage reference, type REF5025-HT




**Load regulation versus temperatures with $V_{IN}$= 5 V**

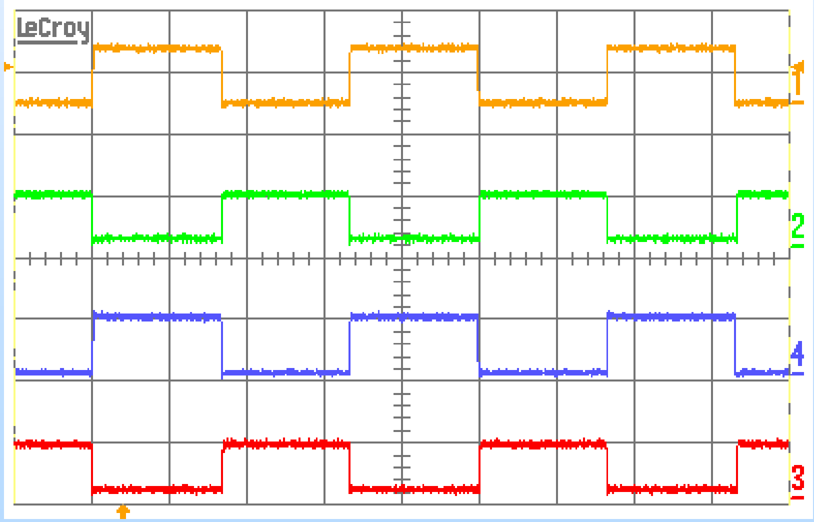
# CISSOID HYPERION SOI full-bridge driver, type CHT-FBDR




+25°C

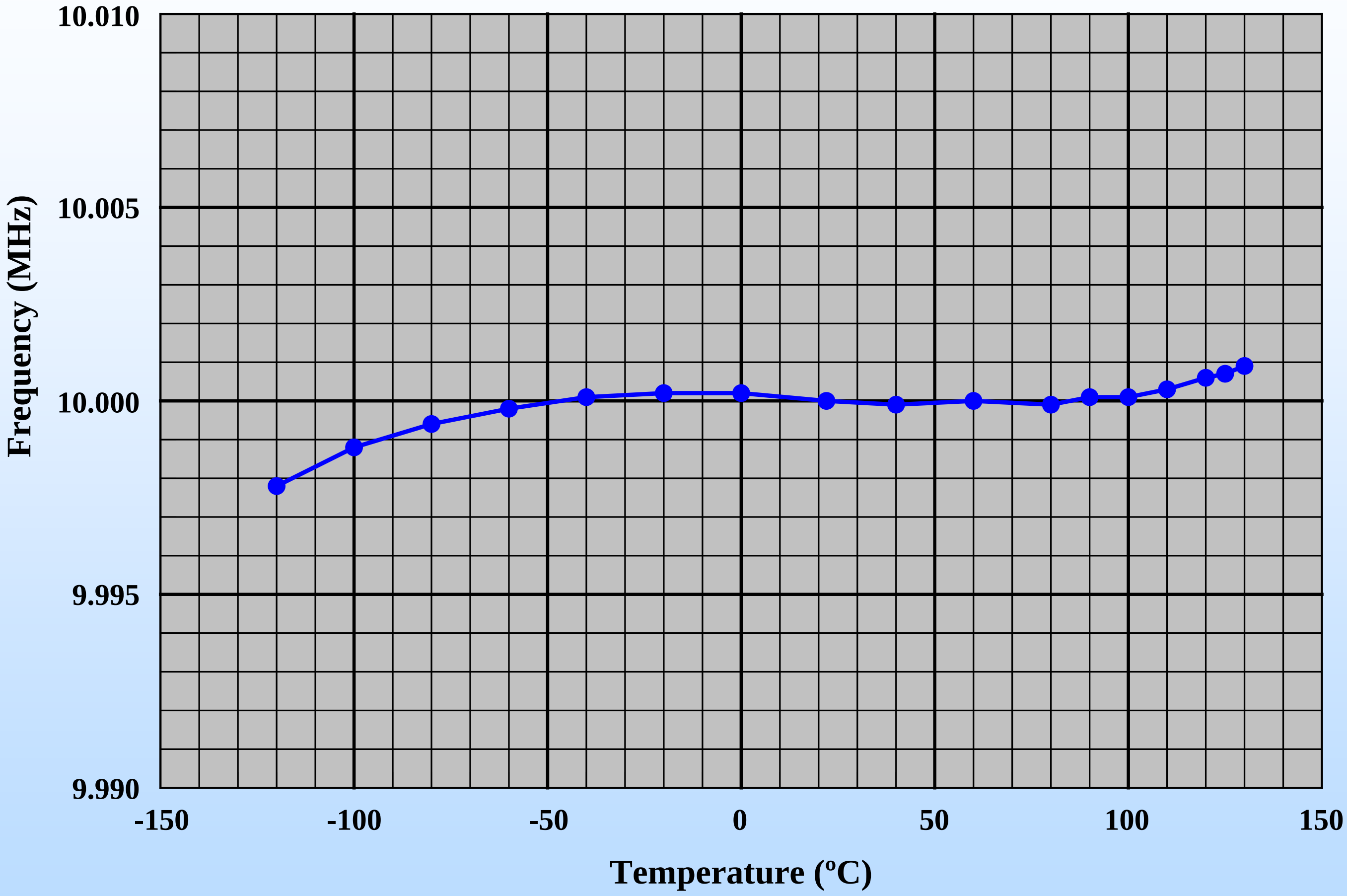
-190°C




+225°C

**No effect of temperature on operation of this SOI full-bridge driver.**

# Crystal oscillator, type Si530




**Good frequency stability from -120 °C to +130 °C.**

# Crystal oscillator, type Si530

| T(°C) | Cycling | f (MHz) | Duty cycle (%) | $T_{rise}$ (ns) | $T_{fall}$ (ns) | $I_S$ (mA) |
|---|---|---|---|---|---|---|
| +130 | pre | 10.0009 | 49.88 | 3.14 | 2.84 | 71.11 |
| | post | 10.0008 | 49.87 | 3.14 | 2.84 | 70.71 |
| 22 | pre | 10.0000 | 49.84 | 2.80 | 2.41 | 62.37 |
| | post | 10.0000 | 49.81 | 2.83 | 2.42 | 62.45 |
| -120 | pre | 9.9978 | 49.79 | 2.53 | 2.16 | 57.63 |
| | post | 9.9978 | 49.79 | 2.48 | 2.11 | 57.53 |

**No effect of thermal cycling from -120 °C to +130 °C.**

# COTS silicon oscillators

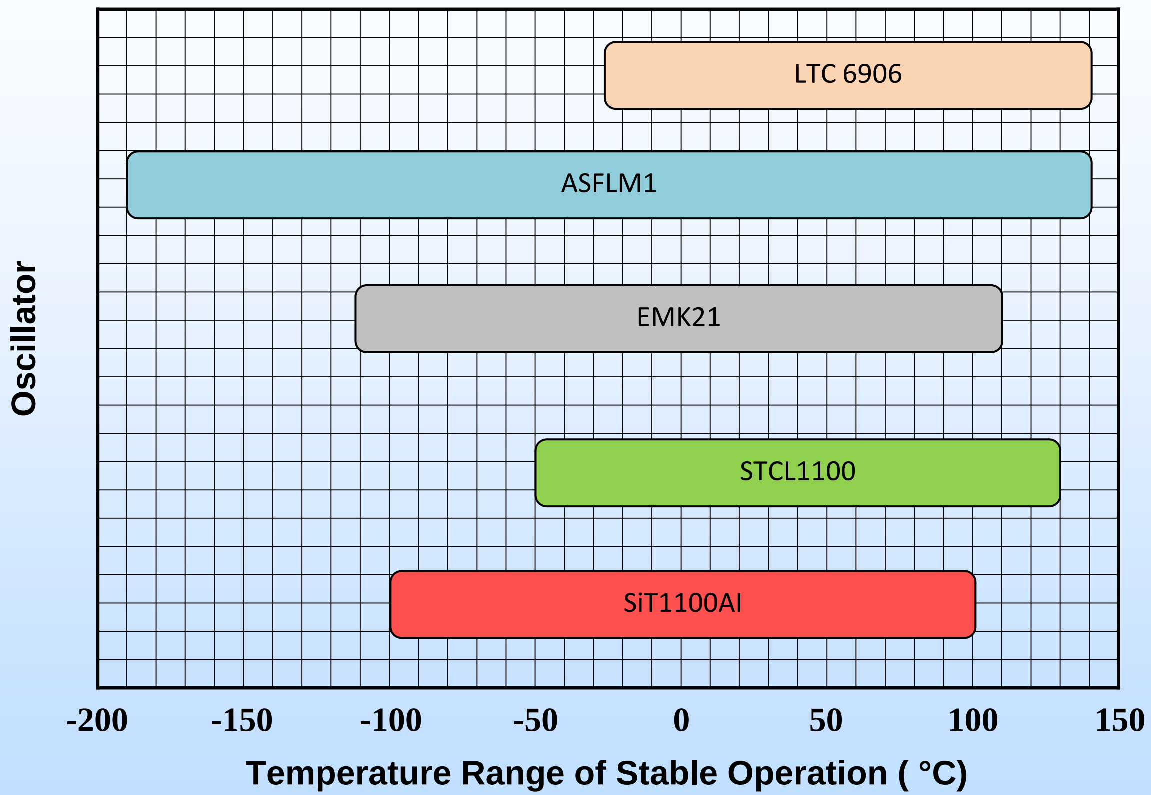
| Parameter | LTC6906H | ASFLM1 | EMK21 | STCL1100 | SiT1100AI |
|---|---|---|---|---|---|
| Manufacturer | Linear Tech | Abracon | Ecliptek | STMicroelectronics | SiTime |
| Type | Si | Si MEMS | Si MEMS | Si | Si MEMS |
| Oper. volt (V) | 2.25 to 5.5 | 3.0 | 1.8 | 5.0 | 1.8 |
| Freq. (MHz) | 0.01 to 1 | 1.8432 | 1 | 10 | 1 |
| Oper. temp. (°C) | -40 to +125 | 0 to +70 | -40 to +85 | -20 to +85 | -40 to +85 |
| Duty cycle (%) | 45 to 55 | 45 to 55 | 50 ±5 | 40 to 60 | 40 to 60 |
| Freq. tol. (ppm) | [drift±0.005%/°C] | ±50 | ±50 | [accuracy ±1.5 %] | ±50 |
| Output $t_R/t_F$ (ns) | 25 | 5 | 2 | 5 | 2 |
| Package | Plastic SOT-23 | Plastic QFN | Plastic QFN | Plastic SOT23-5L | Plastic QFN |
| Part # | LTC6906HS6 | ASFLM1-1.8432-C | EMK21H2H-1.000M | STCL1100YBF-CWY5 | SiT1100AI-33-18S |
| Lot number | 5K77 / LTBJN | AB C0729 | 0020 | 10A Y832 | 20643 |

# COTS silicon oscillators

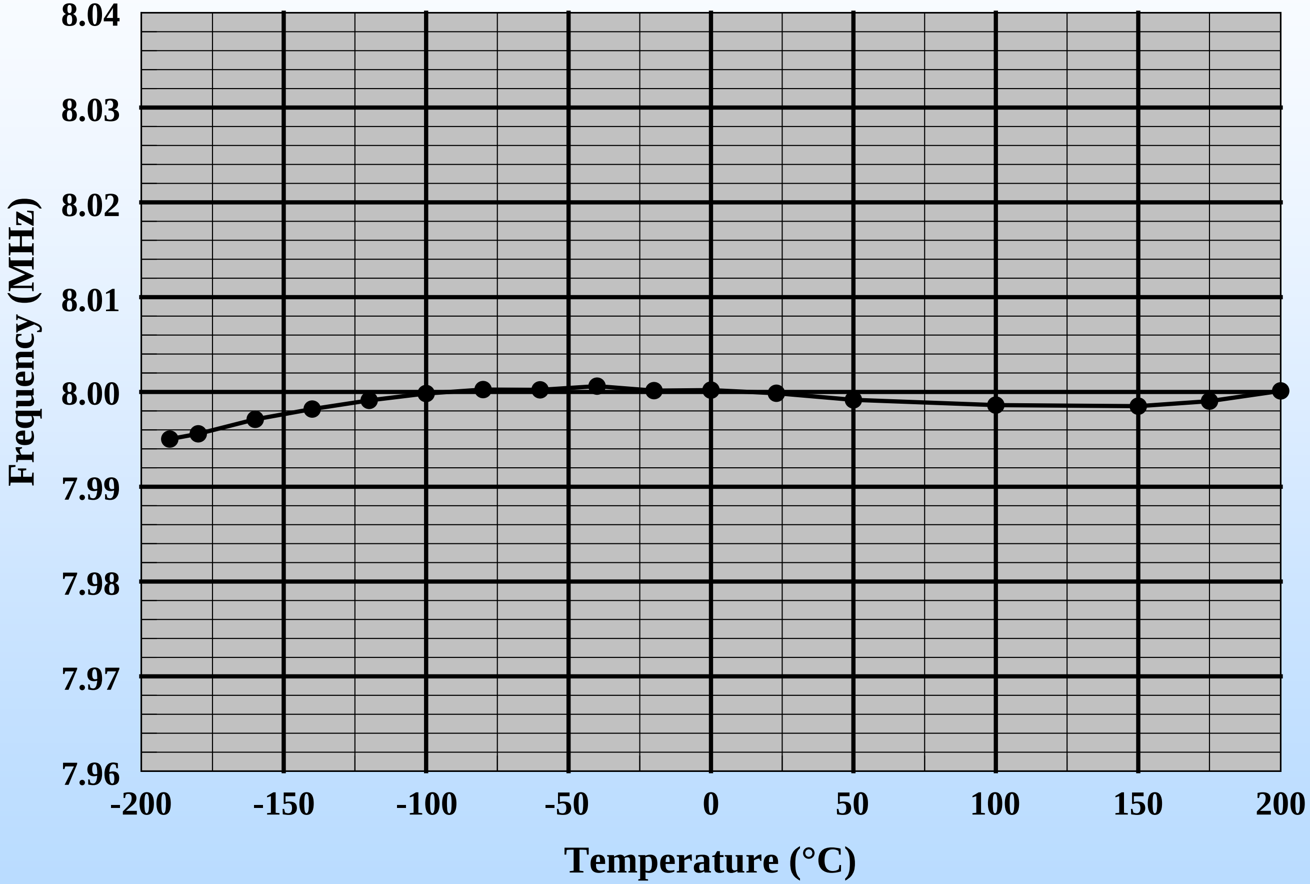
| Device | T(°C) | Cycling | f (MHz) | Duty cycle (%) | $T_{rise}$ (ns) | $T_{fall}$ (ns) | $I_S$ (mA) |
|---|---|---|---|---|---|---|---|
| LTC6906 | 22 | pre | 99.990 | 50.12 | 50 | 51 | 0.054 |
| | | post | 99.981 | 50.11 | 49 | 51 | 0.054 |
| | -55 | pre | 103.964 | 50.15 | 47 | 49 | 0.058 |
| | | post | 103.639 | 50.13 | 47 | 50 | 0.058 |
| | +140 | pre | 99.485 | 50.17 | 56 | 59 | 0.049 |
| | | post | 99.473 | 50.18 | 55 | 58 | 0.049 |
| ASFLM1 | 22 | pre | 1.8432 | 49.94 | 49.94 | 12.4 | 10.9 |
| | | post | 1.8432 | 49.94 | 49.94 | 12.0 | 10.4 |
| | -190 | pre | 1.8469 | 49.92 | 49.92 | 11.7 | 10.5 |
| | | post | 1.8467 | 49.93 | 49.93 | 11.4 | 10.1 |
| | +140 | pre | 1.8425 | 49.94 | 49.94 | 13.6 | 11.4 |
| | | post | 1.8426 | 49.94 | 49.94 | 13.5 | 11.2 |
| EMK21 | 22 | pre | 1.00002 | 50.04 | 3.0 | 2.8 | 11.40 |
| | | post | 1.00000 | 50.04 | 2.9 | 2.8 | 11.29 |
| | -112 | pre | 0.99987 | 50.02 | 2.7 | 2.6 | 10.63 |
| | | post | 0.99987 | 50.02 | 2.6 | 2.5 | 10.56 |
| | +110 | pre | 1.00001 | 50.05 | 3.2 | 3.1 | 11.65 |
| | | post | 1.00001 | 50.05 | 3.1 | 3.0 | 11.63 |
| STCL1100 | 21 | pre | 10.0413 | 44.09 | 6.77 | 5.31 | 2.18 |
| | | post | 10.0290 | 44.03 | 6.86 | 5.36 | 2.20 |
| | -195 | pre | 5.1197 | 48.62 | 12.56 | 9.09 | 1.01 |
| | | post | 5.1159 | 48.67 | 12.67 | 9.19 | 1.03 |
| | +130 | pre | 10.0322 | 42.80 | 8.78 | 6.96 | 2.29 |
| | | post | 10.0312 | 42.80 | 8.66 | 6.84 | 2.28 |
| SiT1100AI | 21 | pre | 1.00000 | 50.03 | 1.8 | 1.8 | 11.15 |
| | | post | 1.00001 | 50.03 | 2.0 | 2.1 | 11.20 |
| | -110 | pre | 0.99988 | 50.02 | 1.7 | 1.6 | 10.32 |
| | | post | 0.99992 | 50.02 | 1.8 | 1.8 | 10.40 |
| | +100 | pre | 0.99998 | 50.04 | 1.9 | 1.9 | 11.19 |
| | | post | 0.99998 | 50.04 | 1.8 | 1.8 | 11.21 |

## Pre- and post-cycling characteristics of oscillators

# COTS silicon oscillators



# New COTS Crystal oscillator, type CXOMHT




**Good frequency stability from -190 °C to +200 °C.**

## New COTS Crystal oscillator, type CXOMHT

| T(°C) | Cycling | f (MHz) | Duty cycle (%) | $T_{rise}$ (ns) | $T_{fall}$ (ns) | $I_S$ (mA) |
|---|---|---|---|---|---|---|
| -190 | pre | 7.99502 | 49.98 | 3.07 | 2.94 | 1.86 |
| | post | 7.99455 | 49.98 | 3.04 | 2.91 | 1.84 |
| 23 | pre | 7.99985 | 50.02 | 3.21 | 3.27 | 2.1 |
| | post | 7.99987 | 50.04 | 3.23 | 3.29 | 2.1 |
| +200 | pre | 8.0001 | 50.27 | 3.58 | 4.44 | 2.08 |
| | post | 8.00022 | 50.28 | 3.64 | 4.52 | 2.09 |

**No effect of thermal cycling from -190 °C to +200 °C.**

# New COTS Crystal oscillator, type CXOMHT

| Temp (°C) | Soak time (hr) | Frequency (MHz) | Duty cycle (%) | Rise time (ns) | Fall Time (ns) | Current (mA) |
|---|---|---|---|---|---|---|
| -190 | 1 | 7.99455 | 49.98 | 3.04 | 2.91 | 1.84 |
| +23 | 1 | 7.99987 | 50.04 | 3.23 | 3.29 | 2.10 |
| +200 | 1 | 8.00022 | 50.28 | 3.64 | 4.52 | 2.09 |
| +210 | 1 | 8.00084 | 50.30 | 3.67 | 4.64 | 2.13 |
| +225 | 1 | 8.00199 | 50.35 | 3.72 | 4.77 | 2.21 |

**Short-term extended high-temperature exposure.**

# COTS resistors @ 1kHz

| Type | Value (Ω) | Resistance (Ω) at 25 °C | Resistance (Ω) at -190 °C | % Change in Resistance at -190 °C |
|---|---|---|---|---|
| Metal Film | 10 | 10.00 | 9.99 | 0.0 |
| | 1K | 999.15 | 1001.86 | 0.3 |
| Wirewound | 10 | 9.70 | 9.62 | -0.9 |
| | 1K | 984.80 | 979.31 | -0.6 |
| Thin Film | 33 | 33.07 | 34.32 | 3.8 |
| | 1K | 995.41 | 1007.88 | 1.3 |
| Thick Film | 100 | 99.99 | 105.42 | 5.4 |
| | 1K | 998.70 | 1003.22 | 0.5 |
| Carbon Film | 10 | 9.96 | 10.46 | 5.1 |
| | 1K | 980.30 | 1035.83 | 5.7 |
| Carbon Composition | 15 | 14.65 | 16.34 | 11.6 |
| | 1K | 1013.29 | 1296.54 | 28.0 |
| Ceramic Composition | 10 | 9.49 | 10.99 | 15.8 |
| | 1K | 993.09 | 1167.51 | 17.6 |
| Power Film | 10 | 10.00 | 10.48 | 4.9 |
| | 1K | 996.20 | 1037.06 | 4.1 |

# COTS resistors @ 1kHz

| Type | Value (Ω) | Pre-cycling resistance at 25 °C (Ω) | Post-cycling resistance at 25 °C (Ω) |
|---|---|---|---|
| Metal Film | 10 | 10.00 | 10.00 |
| | 1K | 999.15 | 999.30 |
| Wirewound | 10 | 9.70 | 9.70 |
| | 1K | 984.80 | 984.79 |
| Thin Film | 33 | 33.07 | 33.06 |
| | 1K | 995.41 | 995.01 |
| Thick Film | 100 | 99.99 | 99.98 |
| | 1K | 998.70 | 998.68 |
| Carbon Film | 10 | 9.96 | 9.96 |
| | 1K | 980.30 | 980.13 |
| Carbon Composition | 15 | 14.65 | 14.78 |
| | 1K | 1013.29 | 1015.93 |
| Ceramic Composition | 10 | 9.96 | 9.95 |
| | 1K | 993.09 | 992.31 |
| Power Film | 10 | 10.00 | 9.99 |
| | 1K | 996.20 | 996.01 |

# COTS DC/DC converter modules

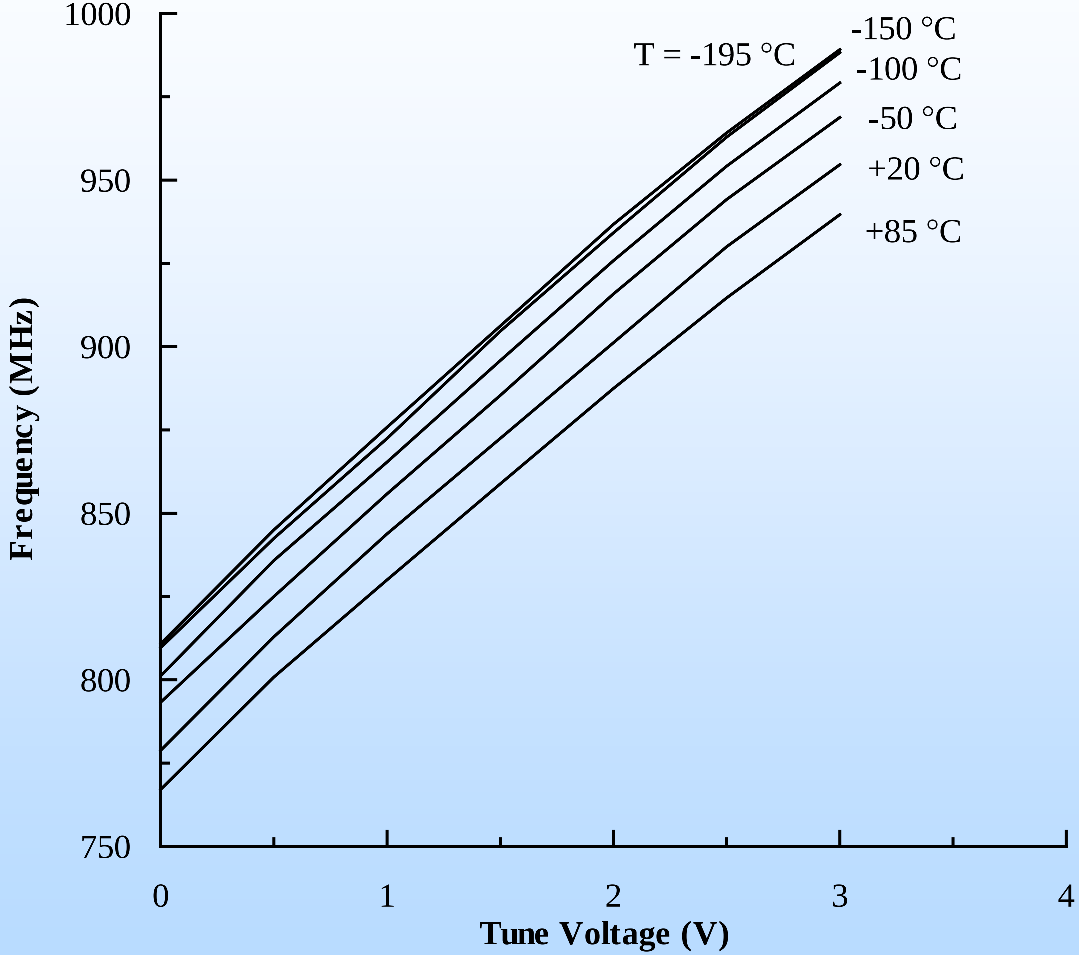
| Manufacturer | Part Number | Input Voltage (V) | Output Voltage (V) | Rated Power (W) | Operating Temperature (°C) |
|---|---|---|---|---|---|
| Astrodyne | ASD10-12S3 | 9 - 36 | 3.3 | 10 | -40 to 60 |
| Power Trend | PT4110A | 36 - 72 | 3.3 | 10 | -40 to 85 |
| Lambda | PM10-24S03 | 18 - 36 | 3.3 | 10 | -40 to 70 |
| Power One | DFA20E24S3.3 | 18 - 36 | 3.3 | 13 | -40 to 85 |
| CDI | 1003S12HN | 9 - 36 | 3.3 | 10 | -40 to 85 |
| Interpoint | SMHF283R3S/KR | 16 - 40 | 3.3 | 15 | -55 to 125 |
| Calex | 24S3.15HE | 18 - 36 | 3.3 | 75 | -40 to 100 |
| SynQor | PQ48050HNA30 | 36 - 75 | 3.3 | 100 | -40 to 115 |
| Vicor | V48C12C150A | 36 - 75 | 12 | 150 | -20 to 100 |

# COTS DC/DC converter modules

| Converter | Operating Temp (°C) | Experimental Observations | Decisive* Temp (°C) |
|---|---|---|---|
| Astrodyne | -40 to 60 | $V_{out}$ dropped to 2.4 V at –140 °C. Chip functioned down to –160 °C. | -160 |
| Power Trend | -40 to 85 | $V_{out}$ lost regulation at –100 °C. Converter still functioned to –195 °C. | ---- |
| Lambda | -40 to 70 | Chip worked very well down to -120 °C. Input current oscillations occurred at all temperatures under heavy loading. | -120 |
| Power One | -40 to 85 | Oscillations in input current started at –80 °C. | -120 |
| CDI | -40 to 85 | Oscillations in input current observed at –140 °C under heavy loading. | -180 |
| Interpoint | -55 to 125 | Low frequency oscillations with high peaks observed in input current at –120 °C and below. | -160 |
| Calex | -40 to 100 | Although the module ceased to work at -40 °C during steady state, it worked down to -100 when tested under a step change in load from full to no-load and vice-versa. | -40 |
| SynQor | -40 to 115 | Output voltage increased as temperature was lowered below 20 °C. | -80 |
| Vicor | -20 to 100 | Oscillation in input current started at –40 °C; more noticeable under heavy load conditions. | -120 |

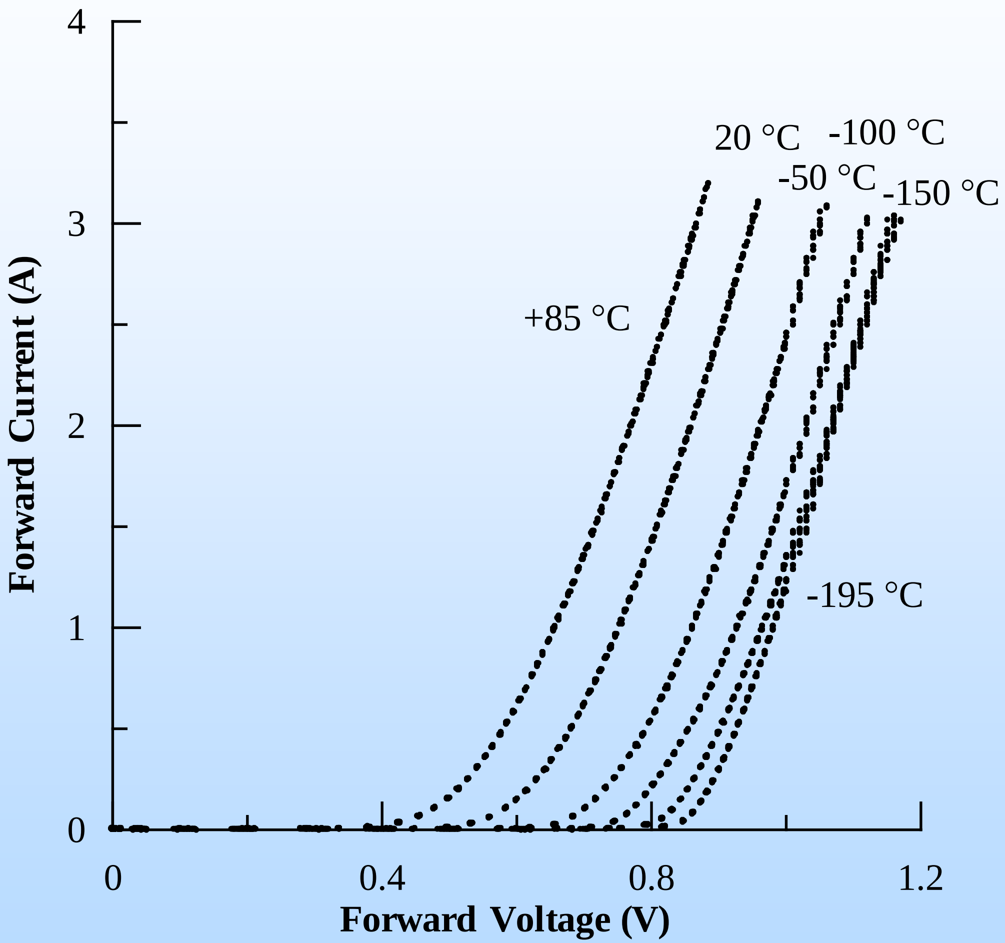
* Temperature at which module ceased to operate but recovered afterwards

# Output frequency of a SiGe VCO, type MAX2622



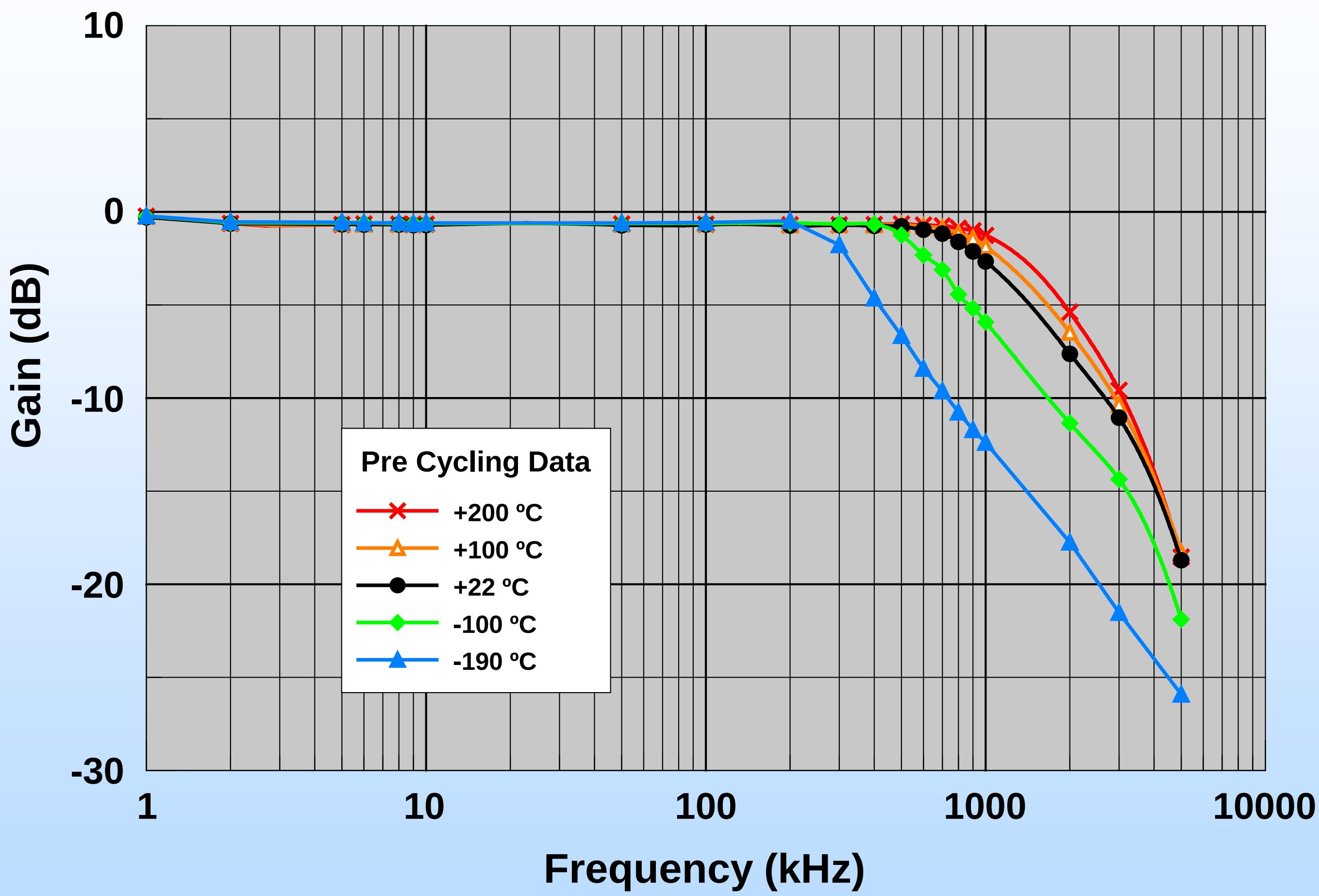

**SiGe voltage controlled oscillator operating over wide temperature range.**

# Forward V-I characteristics of a SiGe diode, type SG 21-41




**SiGe diode operated successfully to -195 °C with increase in forward voltage drop.**

# SOI operational amplifier , type HTOP-01




**Cryogenic operation of a 200 °C rated silicon-on-insulator op amp.**

# GaN Technology

| Company | Product | Part # | Specifications | Status/Comments |
|---|---|---|---|---|
| International Rectifier | High Frequency Integrated Power Stage | iP2010<br>ip2011 | 7 to 13.2 Vin; 0.6 to 5.5 Vout; 30 A Iout, 3 MHz<br>7 to 13.2 Vin; 0.6 to 5.5 Vout; 20 A Iout, 5 MHz | IR: available $6-$9/ea.<br>Avnet: 16-week lead time<br>Flip chip LGA package; RoHS<br>POL application |
| Cree | HEMT | CGH40006P | 28 V rail, 6 GHZ, 8 W, 65 % efficiency,<br>-40 to +150 ºC | Available $78/ea @ Digikey<br>RF & microwave applications |
| Efficient Power Conversion/ Microsemi | FET (enhancement mode) | EPC2001<br>EPC2015 | 100 $V_{DS}$, 7 mΩ $R_{ON}$, 25 A $I_D$,<br>-40 to +125 ºC<br>40 $V_{DS}$, 4 mΩ $R_{ON}$, 33 A $I_D$,<br>-40 to +150 ºC<br>Rad hard | Available within next 4 months<br>$2-$3/ea. (standard)<br>Flip chip LGA package; RoHS |
| Integra Technologies | HEMT | IGN2731M25<br>IGN2731M50 | S-band 2.7 GHz to 3.1 GHz; 25 W, 50 V, 50 % efficiency,<br>-40 to +150 ºC<br>S-band 2.7 GHz to 3.1 GHz; 50 W, 50 V, 50 % efficiency,<br>-40 to +150 ºC | Contact company for availability<br>Radar applications<br>Ceramic flanged package<br>Gold metal system |
| Transphorm | Diodes Switches | | | Startup company1997<br>Foundry |

*The listing above cites up-to-date information collected through industry, web, and literature searches. Although recent, it is not conclusive, however, as not all companies manufacturing GaN-based devices or institutions performing research on this technology are listed above.*

# GaN Technology

| Company | Product | Part # | Specifications | Status/Comments |
|---|---|---|---|---|
| Triquint Semiconductor | Transistors | | | Foundry |
| GaN Systems | Diodes<br>Switches | | | Foundry<br>Device development |
| Nitronex | RF & Power Transistors | Several | DC to GHz; 5 W to 200 W; -65 to +150 ºC | Call distributor |
| Velox | Diodes/FETs | | | Startup company |
| Sanken Electric | FET/Diodes | | | Demonstrated operation<br>Not available yet |
| Fuji/Furukawa | FET/Diodes | | | Devices in 2012 |
| Fujitsu | FET/HEMT | | High voltage/efficient power supplies | Not available yet |
| Microsemi | RF Transistor | 2729GN | GaN-on-SiC; 2.7 to 3.5 GHz | Call for quote |
| Aethercomm | GaN Amplifier | SSPA 0.5-2.5-50 | High power; 500 MHz to 2.5 GHz; -40 to +85ºC | Call for quote |

*The listing above cites up-to-date information collected through industry, web, and literature searches. Although recent, it is not conclusive, however, as not all companies manufacturing GaN-based devices or institutions performing research on this technology are listed above.*

## Advantages of GaN Technology

- *Low ON-resistance*
- *High speed*
- *Low noise figure*
- *High power density*
- *High current density*
- *Low parasitic capacitance*
- *High breakdown voltage*
- *High switching frequency*
- *Near zero forward voltage for diode*
- *Negligible charge storage*
- *High operating temperature*
- *Exceptional carrier mobility*

## Issues with GaN Technology

- *New Technology*
- *Compatibility*
- *Defects/Dislocations*
- *Choice of substrate*
- *Cost*

# Test facilities at NASA Glenn Research Center


**There is a 240 liter liquid nitrogen dewar on the right,**
**and there are two environmental chambers in the background.**

# Plans for FY12

- Identify and acquire GaN, SiGe, SOI, SiC, and advanced mixed signal electronic parts with potential for use in extreme temperature space missions.  (Q1-Q2 FY12)
- Setup test facilities, determine part operational requirements, and establish test matrix.  (Q1-Q2 FY12)
- Cooperate with NASA and other aerospace centers.  (Q1-Q4 FY12)
- Perform testing on acquired compound semiconductor, SOI, advanced mixed signal parts, and flight-like hardware over an extended temperature range.  (Q1-Q4 FY12)
- Determine performance of promising parts under wide temperature thermal cycling.  (Q3-Q4 FY12)
- Document data and disseminate information to the NASA designers and mission planners.  (Q4 FY12)
- Publish results on NASA NEPP Website, in technical journals, and at engineering conferences.  (Q4 FY12)