HTMOS(TM): Affordable High Temperature Product Line

Gregg Swenson & Bruce Ohme

Abstract:

Honeywell is introducing an affordable line of High Temperature Electronics intended for reliable use in systems operating in severe high temperature environments. The HTMOS(TM) line of electronics incorporates Honeywell's oxide-isolated high temperature processing and high temperature circuit design methodologies to develop components which are specified over -55 to +225 °C and offer operation up to 300 °C. In 1995 Honeywell began production deliveries of quad operational amplifiers and quad analog switches. In 1996 production will begin on a voltage reference, 83C51 microcontroller, 256K SRAM, and linear regulator. Future additions will complete a line of electronics for high temperature system design. All introductory products are designed for 5 years of continuous operation at 225 °C. Initial reliability data has been obtained with dynamic operation of analog switches, SRAM's, and operational amplifiers at 250 and 300 °C. The HTMOS(TM) product line is targeted for high temperature instrumentation and distributed control systems found in emerging oil field, turbine engine, industrial process, avionics, and automotive applications.

Introduction

Several existing and emerging applications require electronics operating in temperatures in excess of 200 °C. Yet, there are very few electronic components that offer reliable performance in temperatures above 175 °C. An affordable and reliable electronics product line designed and specified for -55 to +225 °C operation should provide a significant technological edge for designers of high temperature systems.

High temperature system designers have used a variety of application dependent methods to compensate for the lack of a reliable high temperature electronics product line. These methods have included bake screening large numbers of parts searching for a small percentage of useful high temperature devices, enclosing entire circuit boards in cooling flasks, remotely locating the electronics, keeping high temperature system exposure very brief, circulating cooling fluid around the electronics, or avoiding the high temperature environment altogether. These methods have had a variety of undesirable effects including, poor reliability, short system life, high technical personnel labor costs, system inaccuracies, frequent expensive downtime, and countless opportunities lost due to the lack of key decision making data from the high temperature environments [3].

Reliable High Temperature HTMOS (TM) Processes

Honeywell's Solid State Electronics Center has developed reliable and affordable high temperature processes designed to produce linear, digital, and mixed-mode integrated circuits capable of operation from -55 to 300 °C [1, 2]. The processes are an extension of a mature CMOS technology with proven performance and reliability in radiation hardened military and commercial space applications. The oxide-isolated, high temperature HTMOS(TM)) processes were developed specifically for designing affordable electronics for use in severe high temperature environments.

The processes include several modifications to allow affordable production of reliable high temperature linear, digital and mixed-mode integrated circuits. Table 1 outlines several features of the HTMOS processes and their corresponding benefits for high temperature circuits. Transistor IV curves shown in Figures 1-4 exemplify performance of the 10V linear HTMOS (TM) process.

Table 1. HTMOS(TM) Process Features and High Temperature Benefits

Process Features	High Temperature Benefits
5-10V, 1.2µm, 2 metal linear 5V, 1.2µm, 2 metal mixed-mode 5V, 0.8µm, 3 metal digital	Proven manufacturable linear, digital and mixed-mode high temperature processes
Complete oxide isolation of all transistors	100x reduction in leakage current, latchup immunity, 20% faster than standard CMOS
Vtn/Vtp adjustments	Low leakage, 10V 300°C operation
TiW barrier layer on all metals/contacts	Eliminate metal spiking with increased tolerance to electromigration
Trenched twin-well technology	Eliminate cross-talk, independent control of transistor body and switching thresholds
Trimmable precision CrSi resistors	0-180ppm/°C TCR, low VCR, trimmed ratio matching to 0.01%
Linear Capacitor (N++ to gate poly)	Low leakage at high temperatures, 1% linearity over 10 volt range, ratio matching to 0.1%

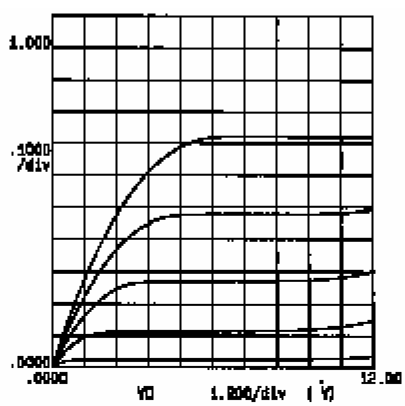


Figure 1. 350°C 16/5 NMOS Drain-to-Source

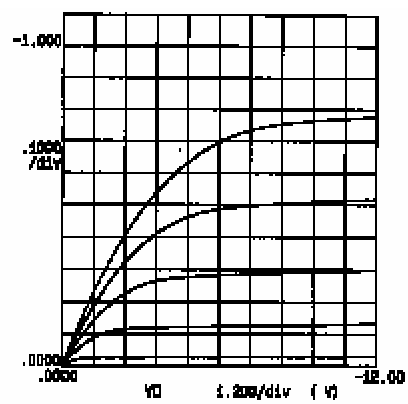
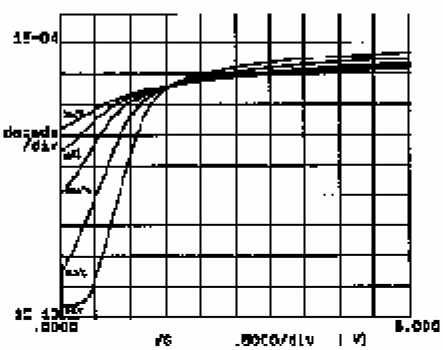
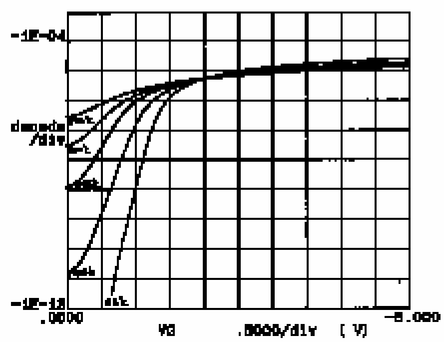


Figure 2. 350°C 15/3 PMOS Drain-to-Source





Affordable High Temperature Products

Honeywell is developing an affordable and reliable electronics product line based on the HTMOS(TM) processes. These products will provide datasheet specified performance over a broad temperature range (-55 to +225 °C) with five year lifetimes, and operation to 300 °C with reduced lifetimes. A Quad Operational Amplifier and Quad Analog Switch are in production, as the introductory products of this product line.

Tables 2 shows the performance parameters to which each production quad operational amplifier is tested prior to shipment. These parts have shown operation to temperatures as high as 350 °C, with several thousand hours of dynamic operation at temperatures in excess of 250 °C. Detailed performance curves are available in the standard production datasheet.

Table 3 shows the performance parameters to which each production quad analog switch is tested. These parts have shown 80 ohms of ON resistance and less than 2µA of leakage current with 10 volt supplies at 300 °C. Figure 5 exhibits typical performance of ON resistance vs temperature from -55 to +300 °C. Figure 6 indicates lifetime vs. temperature for these parts assuming steady state biasing conditions. A figure of merit for an analog switch operating at high temperature is the product of off-state leakage and on-state resistance. This figure of merit equates to 160µV for the quad analog switch at 225 °C. This is 500 times better than the figure of merit measured for a commercial CMOS part fabricated in a bulk silicon process. This improvement is indicative of the necessity of oxide isolation for silicon IC's operating above 200 °C.

Table 2. Quad Operational Amplifier Electrical Characteristics

Sym	Parameter	Conditions (1)	Min	Typ	Max	Units
V_{DD}	Supply Voltage (2)	-55 to +225°C	5.0		11	V
I_{DD}	Supply Current (total package)	-55 to +225°C		2 (25°C)	6 (225°C)	mA
V_O	Max. Output Voltage Swing	Vs ±5V, R =10kΩ, C =20pF	-4.8		+4.8	V
I_O	Output Short Circuit Current	Sink/Source (3)		15		mA
V_{IO}	Input Offset Voltage	@ 25°C -55 to +225°C Drift with Temp. (4) Drift with Time (4)		2 10	 7 15 100	mV mV µV/°C µV/Year
N	Noise	fo = 10 Hz (4) fo = 1 kHz (4) f = 0 to 10 Hz (4)		200 30 8		nV/√Hz nV/√Hz µV, p-p
I_{IO}	Input Offset current	@ 25°C -55 to +225°C		0.01 5	0.1 30	nA
I_B	Input Bias Current	@ 25°C -55 to +225°C		0.01 10	0.1 40	nA
V_{CM}	Input Common-Mode Voltage Range	-55 to +225°C, Vs=±5V +250°C, VS = ±5V	- Vs - Vs		+VS -2.2 +VS -1.5	V
A_{VOL}	Open Loop Gain	R = 10kΩ, C = 20pF	100	115		dB
CMRR	Common Mode Rejection Ratio	(4)	80	95		dB
PSRR	Power Supply Rejection Ratio	±Vs	80	95		dB
SR	Slew Rate	R =10kΩ, C =20pF (4)	0.9 (-55°C)	1.4 (25°C)	3.8 (225°C)	V/µsec
UGB	Unity Gain Bandwidth	R =10kΩ, C =20pF (4)	1.3 (-55°C)	1.4 (25°C)	1.8 (225°C)	MHz
ØM	Phase Margin	C = 20pF (4)	50	60		Degrees
AM	Gain Margin	C = 20pF (4)	8			dB
ESD	ESD Protection	(4)	2000			V

(1) Unless otherwise noted, specifications apply for ± 5V supply from -55 to +225°C.
(2) Recommended supplies are ± 5V or 0-10V. Contact factory for low-voltage operation specifications.
(3) Rating for a single amplifier of the quad. For steady-state biasing conditions, 10mA is the maximum recommended.
(4) These parameters are guaranteed by design and not tested on each device. Human body model, 1.5Ω in series with 100pF.

Table 3. Quad Analog Switch Electrical Characteristics

Symbol	Parameter	Conditions (1)	Min	Typ	Max	Units
V_{DD}	Supply Voltage (2)		4.75 (3)		11	V
I_{DD}	Supply Current	All Switches "OFF"		1	5	μA
V_{IN}	Analog Voltage Range		V-		V+	
I_I	Control Input Current (4)	All Switches "OFF"			±1	μA
V_{IH}	High Level Input Voltage		$0.6 \cdot V_{DD}$			V
V_{IL}	Low Level Input Voltage				$0.4 \cdot V_{DD}$	V
R_{ON}	ON Resistance	I = 1mA, V_{IN} = 0 to VDD			100	Ω
ΔR_{ON}	ON Resistance Matching	I = 1mA, V_{IN} = 0 to VDD			12	Ω
$I_{(ON)}$	ON Leakage Current	V_{IN} = 0 or VDD			500	nA
$I_{(OFF)}$	OFF Leakage Current	V_{IN} = 0 or VDD			500	nA
C_I	Input Capacitance (5)			12		pF
C_F	Feedthrough Capacitance (5)			2		pF
T_{PD}	Propagation Delay	C = 50pF			25	ns
T_{ON}	Switch Turn-on Time	C = 50pF, R = 1KΩ			100	ns
T_{OFF}	Switch Turn-off Time	C = 50pF, R = 1KΩ			200	ns

(1) Specifications apply for ±5V ± 10% from -55 to +225°C.
(2) Recommended split supply operation, ±5V. Single supply operation, 10 V.
(3) Contact factory for low voltage operation specifications.
(4) Rating for a single control pin of the quad.
(5) These parameters are guaranteed by design and not tested on each device.

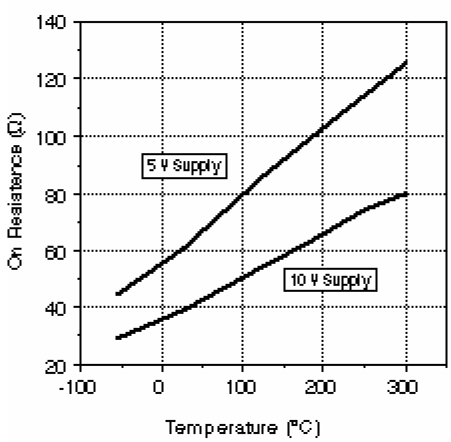


Figure 5. Quad Analog Switch "ON" Resistance vs. Temperature

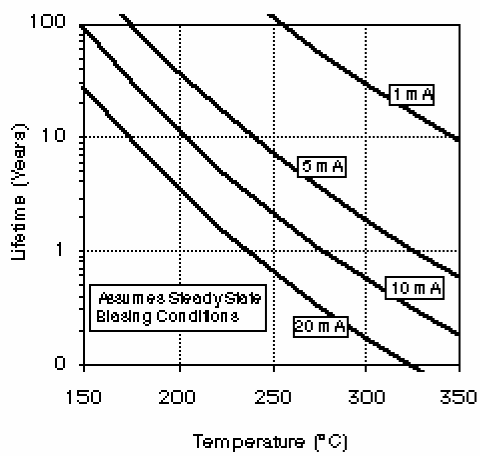


Figure 6. Quad Analog Switch Lifetime vs. Temperature

Scheduled 1996 Introductions

Additional products currently under development scheduled for 1996 release include an 83C51 8-bit microcontroller, 32Kx8 SRAM, 5.0V voltage reference, and linear regulator. The 83C51 microcontroller currently in fabrication, will be pin equivalent to the Intel 8XC51FC microcontoller and was jointly developed with the Boeing Defense & Space Group Solid State Electronics Development Organization, of Seattle Washington. The 32Kx8 SRAM design was modified from an existing product of Honeywell's radiation hardened Space Components Product Line, and is also currently in fabrication. The 5.0V voltage reference production design was recently released for fabrication. Prototype voltage reference performance is shown in Figure 7. The improved voltage reference design will be integrated with control circuitry and a purchased high temperature qualified power device to provide a hybrid high temperature linear regulator. Each of these new components will be specified for -55 to +225 °C operation with higher temperature reduced performance.

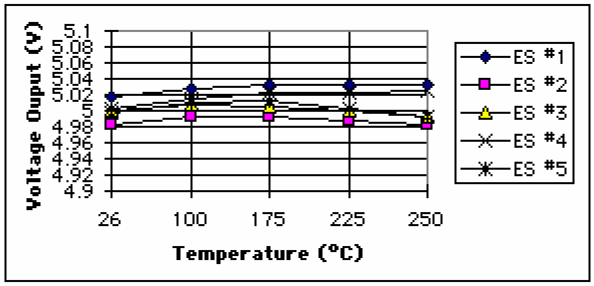


Figure 7. Prototype 5.0V Voltage Reference Performance

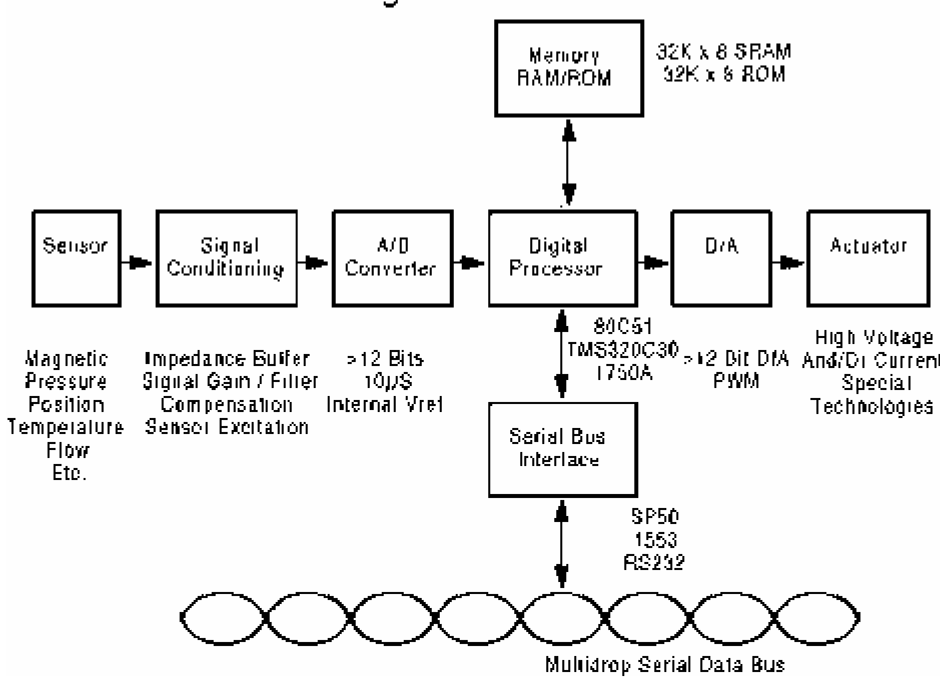
Complete High Temperature Product Line

Honeywell intends to fill out a line of high temperature electronics for data collection, instrumentation, and distributed control systems operating over very broad operating temperatures up to 300 °C. Figure 8 shows the generic building blocks required for a generic distributed control system. System requirements vary significantly due to application specifics; however, the basic functions shown are common to many high temperature electronic systems. Honeywell intends to complete a line of electronics compatible with the needs of down-hole oil well, turbine engine, avionics, and eventual automotive system designers.

Many additional qualified high temperature components are necessary to build reliable affordable systems ready to be placed in extreme temperature service. Many of these additional components are available such as resistors, small value capacitors, boards, and wire. Other items are either very limited or nonexistent for high temperature use, such as large value capacitors, nonvolatile memory, EEPROM, power transistors, batteries, connectors, inductors, and others. The authors wish to identify companies developing these system-limiting components.

Figure 3.

Generic Block Diagram Of Distributed Control



Reliability Shown

There are a number of issues to consider to assure reliable high temperature systems [1]. This paper will cover the items of concern for reliable high temperature HTMOS(TM) integrated circuits; namely electromigration, dielectric integrity, device stability, and packaging.

Honeywell has characterized its' existing AlCu with TiW barrier metal system for several years at temperatures of 250 °C. Data has shown that current product line lifetime requirements of 5 years operation at 225 °C and 0.5 year lifetime at 300 °C can be met by managing the current density in the metal lines. Figure 2 shows the 10mA current capability of the quad analog switch determined by conductor geometry and electromigration limitations. Product lifetimes in excess of 5 years at 300 °C will require a new metal system such as tungsten or molybdenum which is currently under development.

Dielectric integrity studies up to 300 °C have shown a stable and repeatable process as shown in [1]. Device stability has proven acceptable for introductory products and will be better characterized with 1996 product introductions such as the voltage reference and linear regulator.

A variety of wire bond pull, hermeticity, long term bake, and temperature cycling tests were carried out prior to releasing the operational amplifier and analog switch to production. Each new product must be evaluated with high temperature qualification in mind as different component types require different package types and assembly operations. For example, a new high input impedance version of the high temperature standard operational amplifier requires an alternate package due to inadequate dielectric characteristics of the standard CERDIP package. Another limitation of current packages is high temperature accelerated oxidation of the external pins. This is not a problem for components permanently mounted, but can cause problems in testing. One long term solution is gold metalization of external leads.

Reliability data includes 50,000 device hours on 64K SRAMs and 80,000 device hours on operational amplifiers at 250 °C or above [3]. The operational amplifiers were over-biased at 14 volts with a 1MHz square wave signal at temperatures of 250-300 °C. Using a conservative 0.5eV activation energy and 2x over-voltage acceleration factor, we have calculated FIT rates of better than 2000 and MTBF's of better than 50 years for 225 °C operation. Reliability evaluations continue.

Summary

Honeywell has developed reliable and affordable processing and design methodologies for producing linear, digital, and mixed-mode integrated circuits capable of operation from -55 to 300 °C. The initial products are specified from -55 to +225 °C with degraded performance operation to 300 °C, and include a quad operational amplifier and quad analog switch. Additional products scheduled for 1996 release include an 83C51 8-bit microcontroller, 32Kx8 SRAM, 5.0V voltage reference and linear regulator.

Acknowledgments

This work was performed at Honeywell's Solid State Electronics Center with co-funding. Special thanks to the high temperature product development team, especially Mark Larson, who supplied test results.

References

[1] Brusius, P. G., et al, "Reliable High Temperature SOI Process," Transactions Second International High Temperature Electronics Conference, Vol. 1, pp II-15, June 1994.

[2] Brusius, P. G., et al,"SOI Devices for High Temperature Applications," Transactions Third International High Temperature Electronics Conference, June 1996.

[3] Gingerich, B. L., "A Reliable High Temperature Product Line," 6th High Temperature Electronics Meeting, Sponsored by the Institute of Space and Astronautical Science in Japan, March 12, 1996.

Solid State Electronics Center 12001 State Highway 55, Plymouth, MN 55441
(800) 323-8295