High Temperature Electronics and Transducers

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Electronics for instrumentation and control systems are required to operate at ever increasing temperatures. Device operation at temperatures greater than 200 °C is required for a variety of present and next-generation control applications including oil field instrumentation and turbine engine control. However, the availability of integrated circuit products for high temperature operation is very limited, especially for temperatures in excess of 20O °C.

There has been some limited success achieving high temperature system operation with dielectrically isolated integrated circuits such as Operational Amplifiers, but since these parts were not designed specifically for high temperature operation their performance is compromised at temperatures exceeding 200 °C. Other methods of coping with high temperature environments include cooling systems and remotely locating the electronics. These 'work-around' techniques add cost, compromise reliability, and generally reduce system accuracies. Silicon Carbide, Gallium Arsenide, and other large band gap materials hold eventual promise of extended high temperature operation, but are not yet cost-effective for high volume applications. To date, no semiconductor manufacturer has developed and produced in volume a line of affordable products specifically targeted for high temperature operation.

Reliable High Temperature SOI Process

Honeywell's Solid State Electronics Center has developed a reliable and cost effective high temperature process designed to produce linear and digital integrated circuits capable of operation up to 300 °C. The process is an extension of a mature CMOS technology developed with more than ten years of United States Government funding to produce harsh environment radiation-hardened military and commercial space components. The process includes several modifications to allow production of reliable high temperature linear and digital integrated circuits. The oxide-isolated high temperature (HTMOS(TM)) process was developed specifically for designing affordable components intended for use in systems operating in severe high temperature environments. This Silicon-On-lnsulator CMOS process is a fully isolated 1.25µm Analog /0.7µm Digital process capable of using either SIMOX (Separation by Implantation of Oxygen), or BESOI (Bonded Etch Back Silicon On Insulator) wafer starting material. All junctions are bottomed-out to the isolation layer, thereby greatly reducing high temperature junction leakage, while maintaining transistor switching frequencies through reduced junction capacitance. Additionally, cross-talk susceptible transistors are laterally oxide isolated to eliminate leakage paths, cross-talk problems, and any possibility of SCR related latch-up. Junction doping adjustments have been made to assure normal transistor operation at 300 °C. Oxide thickness has been bolstered to assure long term reliability at elevated temperatures with up to 1 0 Volt supplies. The metals system includes two or three layers of interconnect each with a TiW barrier metal to eliminate metal spiking in the junctions at high temperatures and to improve electromigration resistance. The metal system is thoroughly characterized for electromigration at elevated temperatures, which allows the circuit designer to tailor conductor widths and resulting current densities for the lifetime requirements of the part.

The HTMOS(TM) high temperature process is the only production process to our knowledge, specifically designed for producing reliable high temperature integrated circuits.

The linear process is intended to evolve as circuit requirements demand. Existing enhancements for linear circuits include extending the operating supply voltage range, incorporating precision resistor and capacitor elements, and adding lateral bipolar transistors. Current linear products are designed for 10 Volt supply operation, which- provides a usable dynamic range for linear operation. Wider supply ranges arc desired and will be evaluated for future product development. Oxide isolated implanted-well resistors are available, providing low leakage and relatively supply immune qualities. For greater precision, laser trimmable thin-film chrome-silicon resistors are available with temperature coefficients less than 200 ppm/ °C and excellent ratio matching between resistors. A linear MOS capacitor constructed from an N+ polysilicon plate and an N+ bottom gate separated by the normal transistor gate dielectric is also available. These capacitors can provide (0.5% linearity over the entire supply range, 18 ppm/ °C temperature coeffcients, and excellent ratio matching between capacitors. The lateral bipolar devices provide large betas for constructing high gain devices. These modifications for high temperature linear operation provide an excellent process for producing reliable high temperature linear CMOS circuits.

Substantial testing of devices fabricated in this process has been performed to assure electromigration, dielectric integrity, device stability and packaging, are appropriate for producing reliable high temperature integrated circuits. Testing will continue, but results to date indicate the capability to produce integrated circuits rated for 225 °C operation with five-year lifetimes.

Reliable High Temperature Electronics

A Quad Operational Amplifier and Quad Analog Switch are the introductory products of the High Temperature Electronics Product Line. Production samples will be available in February 1995. These products are fabricated with the HTMOS(TM) process, and are designed and packaged specifically for use in systems operating in severe high temperature environments. The products provide guaranteed performance over the full -55 to +225 °C temperature range with five-year lifetimes, and operation to 300 °C with reduced lifetimes. Initial markets of interest include oil field drilling and instrumentation, turbine engine control, industrial process control, and electric power generation.

Table 1 QUAD OPERATIONAL AMPLIFIER ELECTRICAL CHARACTERISTICS

Parameter	Conditions[1]	Min	Typ	Max	Units
Supply voltage[2]	–55 to +225°C	4.75		11	V
Supply current (total package)	–55 to +225°C		4	10	mA
Max output voltage swing	Vs ±5V, R =10kΩ, C =20pF	–4.8		+4.8	V
Output short circuit current	Sink/Source[3]		10		mA
Input offset voltage	@ 25°C –55 to +225°C Drift with Temperature[4] Drift with Time[4]		2 3	6 7 15 100	mV mV μV/°C μV/Year
Noise	fo = 10 Hz[4] fo = 1 kHz[4] f = 0 to 10 Hz		100	500 55 100	nv/√Hz nv/√Hz μV, p-p
Input offset current	@ 25°C –55 to +225°C		0.01 10	0.1 30	nA
Input bias current	@ 25°C –55 to +225°C		0.01 40	0.1 100	nA
Input common-mode voltage range	–55 to +225°C, Vs = ±5V +250°C, Vs = ±5V	–5.3 –5.3		+2.5 +3.5	V
Open loop gain	R = 10kΩ, C = 20pF	110	115		dB
Common mode rejection ratio	[4]	90	100		dB
Power supply rejection ratio	±Vs	70	78		dB
Slew rate	R =10kΩ, C = 20pF[4]	2.0	4.0		V/μsec
Unity gain bandwidth	R =10kΩ, C = 20pF[4]	1.0	1.1		MHz
Phase margin	C = 20pF[4]	50	60		Degrees
Gain margin	C = 20pF[4]	10	12		dB
ESD protection	[4]	1000			V

[1] Unless otherwise noted, specifications apply for ±5V supply over –55 to + 225°C.
[2] Recommended split supply operation, ±5V. Recommended single supply operation, 0-10V.
[3] Ratings for a single amplifier of the quad.
[4] These parameters are guaranteed by design and not tested on each device.

Table 2 QUAD ANALOG SWITCH ELECTRICAL CHARACTERISTICS

Parameter	Conditions[1]	Min	Typ	Max	Units
Supply voltage[2]		4.75[3]	10	11	V
Supply current	All switches 'OFF'		8	100	μA
Analog voltage range		V–		V+	
Control input current[4]	All switches 'OFF'			±1	μA
High level input voltage		2.4			V
Low level input voltage				0.8	V
ON resistance	I = 1mA, V_A = 0 to V_{DD}			100	Ω
ON resistance matching	I = 1mA, V_A = 0 to V_{DD}			10	Ω
ON leakage current	V_A = 0 or V_{DD}			500	nA
OFF leakage current	V_A = 0 or V_{DD}			500	nA
Input capacitance[5]			12		pF
Feedthrough capacitance[5]			2		pF
Propagation delay	C = 50pF			25	ns
Switch turn-on time	C = 50pF, R = 1KΩ, 10%-90%			100	ns
Switch turn-off time	C = 50pF, R = 1KΩ, 10%-90%			200	ns

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

The Quad Operational Amplifier is a quadruple (four-to-a-package) high performance linear amplifier with a wide variety of uses including sensor interfacing, signal amplification, active filtering, signal buffering, and many others. This Operational Amplifier is a monolithic design capable of operating with both single and split supplies, is guaranteed latch-up free, and has input and output overload protection. All parts are screened at elevated temperatures to eliminate infant mortality. The device is available in a 14-lead standard pinout Ceramic Dual-ln- Line-Package (DIP), which also can be modified for surface mount applications. This Quad Operational Amplifier is a high reliability part designed specifically for applications with an extremely wide operating temperature range of-55 to +300 °C. These parts are guaranteed and tested over-55 to +225 °C and sell for just under S100 USA dollars in quantities of 1000. Table I shows specific device electrical characteristics.

The Quad Analog Switch is a four-to-a- package Analog Switch capable of switching either analog or digital signals, and can be used for a wide variety of uses including signal gating, modulation, chopping, demodulation, and multiplexing. This Analog Switch is a monolithic design guaranteed latch-up free, with individual switch controls, low cross-talk between switches, low control input current, and a worst case leakage at 225 °C of 500nA. All parts are screened at elevated temperatures to eliminate infant mortality. The device is available in a t4-lead standard pinout Ceramic Dual-ln-Line Package (DIP), which also can be modified for surface mount applications. This Quad Analog Switch is a high reliability part designed specifically for applications with an extremely wide operating temperature range of-55 to +300 °C. These parts are guaranteed and tested over-55 to +'725 °C and sell for just under Sl00 USA dollars in quantities of 1000. Table 2 shows specific device electrical characteristics.

Other HTMOS(TM) products currently under development include a Voltage Reference, 12-Bit Analog-to-Digital converter, 80C51 Microprocessor, and an assortment of ASIC products. The entire product line will be designed to provide guaranteed performance over the full<55 to +225 °C temperature range with five-year lifetimes, and operation to 300 °C with reduced lifetimes.

Integrated Pressure and Magnetic Transducers

We will also be integrating our HTMOS(TM) electronics products with our piezoresistive pressure and magnetoresistive magnetic sensors to create a line of high temperature transducer products. These are both silicon-based sensor technologies readily adaptable to our high temperature SOI process. The piezoresistive pressure sensors have already been produced and characterized over the -55 to +250 °C temperature range. The magnetoresistive magnetic sensors are currently being evaluated for high temperature linear (unsaturated) operation, and have been demonstrated to 250 °C for saturated operation.

Reliable High Temperature Pressure Transducers

Honeywell's introductory High Temperature Pressure Transducers combine oxide-isolated piezoresistive sensing elements with HTMOS(TM) electronics in a robust high temperature package. This complete high temperature solution provides an amplified and scaled output which should greatly improve the performance and operational efficiencies of systems operating in hostile high temperature environments.

The sensors use Honeywell's patented ion-implantation process for precision piezoresistive sensors. This process is being used to supply precision pressure transducers to major multinational aircraft, turbine engine, and petrochemical suppliers. When fabricated with our SOI process, these sensors provide precision performance and reliability as well as improved media compatibility and extended high temperature operation.

The electronics required for mid-accuracy high temperature high pressure transducers include operational amplifiers and precision resistors. The Honeywell mid-accuracy transducer design includes on-chip b feedback resistors and operational an integrated in the high temperature p

This configuration provides a temperature-compensated amplified output scaled application requirements. See Figure 1 for a representative circuit.

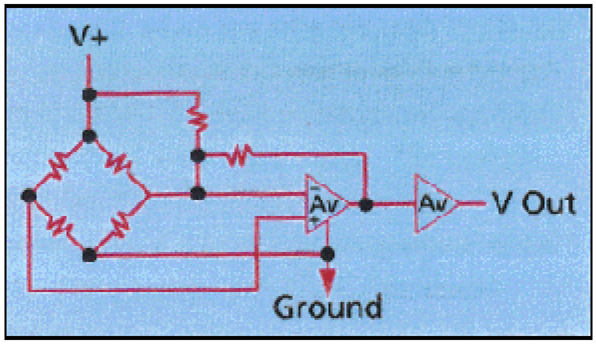

Figure 1

With the mechanization shown, transducers can be constructed to perform with ±1.5% full scale accuracy including all error sources over -40 to +200°, or ±2.0% full scale accuracy over -55 to +225 °C. Full scale accuracies of better than 0.5% may be achieved for 100 °C spans within the overall temperature band. This introductory product of the High Temperature Pressure Transducer Product Line will he offered for production sampling in July 1995. Initial markets of interest include oil field drilling and instrumentation, turbine engine control, industrial process control, and electric power generation.

Follow-on transducer products will include microprocessor integrated precision pressure transducers, and a variety of magnetic transducer products.

Summary

Honeywell's Solid State Electronics Center is developing a family of environmentally rugged electronics and pressure transducers designed specifically for high temperature operation. The initial product offerings provide robust high temperature performance over-55 to +225 °C with targeted operating lifetimes of five years at +225 °C, and reduced lifetime operation at +300 °C. Production samples of the Quad Operational Amplifier and Quad Analog Switch will be available in February 1995. Production samples of the pressure Transducer will be available in July 1995. Follow on products are intended to push the specified operating temperature envelope to 300 °C and operating lifetimes to ten years while enhancing performance. Rugged high temperature electronics and transducers are required for a variety of present and next generation control applications from oil field instrumentation to aircraft control.

For product literature please call 1-800-323-8295 or FAX your request to (612) 334-3384.

References

Brusius, P et al. (1994) "Reliable High Temperature SOI Process", Transactions Second International High Temperature Electronics Conference, Vol 1,11:15-19

Swenson, G et al (1994) "Highwell Temperature Pressure Transducer Capability", Transactions Second International High Temperature Electronics Conference, Vol 1, 111:3-9

About the Author

Gregg Swenson is a Senior Applications Engineer for High Temperature Products.