High-temperature electronics are needed to permit signal acquisition and feedback control in close proximity to sensors and actuators in engines, generators, and geothermal applications. Researchers in the MSIC Laboratory at Case have been working since 1994 to understand the fundamental limitations of low-cost, bulk CMOS technology, and to use design techniques to overcome these limitations. This research culminated in 2006, with publication of “A 300°C, 110-dB Sigma-Delta Modulator with Programmable Gain in Bulk CMOS,” at the highly regarded IEEE Custom Integrated Circuits Conf.

A patent for this technology was awarded in 2009, which has now been transitioned to Scientific Monitoring, Inc. Working in collaboration with MSIC engineers, SMI has leveraged two phases of SBIR awards to develop a high-temperature, 4-chip set based on the Case IP, for use in a Distributed, Full Authority Digital Engine Control (FADEC) system. Prototypes are presently in beta testing at a major aerospace corporation.

Researchers from the MSIC and Mino Laboratories at Case teamed in 2005 to begin development of an integrated circuit technology based on silicon carbide (SiC). This wide-bandgap semiconductor has potential for operation at the extreme temperatures (up to 600°C) found in systems that produce or consume very large quantities of energy, e.g. aerospace propulsion systems and nuclear reactors. The ability to provide embedded sensing and control of the high-energy system would enable a new paradigm of distributed control that could lead to increased fuel efficiency, reduced emissions, improved safety, and reduced maintenance downtime.

The team has set new benchmarks for high-performance, high-temperature SiC JFET amplifiers and logic circuits, and has published numerous papers at conferences and in journals, including the IEEE J. Microelectromechanical Systems, the Intl. Conf. on Silicon Carbide and Related Materials, the IEEE Compound Semiconductor IC Symp., and the IEEE Custom Integrated Circuits Conf.(CICC).
**HHT104 8-Input CMOS Sensor Interface IC**
The HHT104 is a dual-channel sensor interface IC that can operate at temperatures >150°C. Each channel consists of a differential input instrumentation amplifier (INA) and 2nd-order sigma-delta analog-to-digital converter (SD ADC) to enable single-chip interfacing between sensors and microprocessors. The INAs and SD ADCs employ switched-capacitor transconductance-stabilized circuitry, finite gain compensation, and correlated double sampling to provide superior performance at high temperature.

Analog multiplexing extends the number of selectable differential inputs to 8, with common-mode levels up to 12 VDC. The bit streams produced by the SD ADCs are digitally filtered in the microprocessor to provide a maximum resolution of 16 bits, or reduced resolution at higher sample rates, as determined by the microprocessor firmware. INA gain is controlled via a standard SPI serial interface.

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**HHT212 Quad CMOS Precision Current Driver**
The HHT212 is a high-temperature-capable IC (>150°C) that includes four 12-bit current-output digital-to-analog converters (IDACs) with complementary, high-voltage pull-up switches, grouped in pairs. An IDAC pair can be connected in parallel to sink twice the load current from a single-ended load, or cross-connected with the pull-up switches to form an H-bridge that can drive bipolar current through a common load.

The IDACs and switches are controlled via a SPI serial interface. A monolithic temperature-stabilized reference current is developed internally and scaled according to a 2-bit gain setting in the SPI control register to provide a maximum output of 300 mA per IDAC. A fixed reference current of 1 mA is made available for biasing of RTDs, etc.

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**HHT250 4-Channel CMOS PWM Driver IC**
The HHT250 has four pairs of complementary PMOS and NMOS switches that may be operated in several configurations, programmable via a SPI serial interface. In the switch mode, each transistor can supply up to 500 mA and may be individually controlled. This mode is useful for operating static loads such as relay coils and solenoids.

In the PWM mode, two individual PWM controllers may be configured to operate in full-bridge (four switches) or half bridge (two switches) operation. Unipolar and bipolar motors can be controlled in PWM mode, and programmable dead-band delay allows designers to trade power efficiency for increased holding torque in a given application. Maximum operating temperature exceeds 150°C.

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**Hybrid SiC JFET Amplifiers**
Noise considerations dictate a “minimal” amplifier integration in which a source-coupled (differential) pair of JFETs is integrated with the sensor in the high-temperature environment. This option was explored in detail via development of a variety of hybrid amplifiers that combined SiC JFET differential pairs with commercial, silicon amplifiers and passive components. The most advanced of these amplifiers used two fully differential gain stages to obtain a measured gain-bandwidth near 70 dB – 100 kHz, at 450°C. Packaging and wiring were limiting factors, motivating further integration of the amplifiers.

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**Integrated SiC JFET Amplifiers**
A family of fully integrated differential amplifiers has now been developed, ranging from a simple, high-yielding amplifier with relatively low performance, to a far more complex amplifier having significantly improved performance. The latter amplifier employs a two-stage topology with active loads, in which the 1st gain stage uses common-mode feedback biasing to stabilize the operating point. The 2nd gain stage and source-follower output stage are schematically identical to the simple amplifier that employs passive loads. The measured voltage gain at 575°C approaches 80 dB, and unity-gain bandwidth is nearly 3 MHz.

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**Integrated SiC JFET Logic Circuits**
Logic circuits are required to enable simple, embedded control of moderate (MSI) complexity. The MSIC/Mini team has recently demonstrated NAND, NOR, and inverter circuits providing high performance to temperatures as high as 550°C.

Using a topology analogous to the once popular Si NMOS depletion-mode technology, a very symmetric, sharp, and stable voltage transfer characteristic has been obtained. The logic threshold remains well centered in the input range of 0 V to ~12 V, and noise margin remains high for temperatures ranging from 25°C to 550°C. The NAND and NOR circuits use the same core structure and also function well.