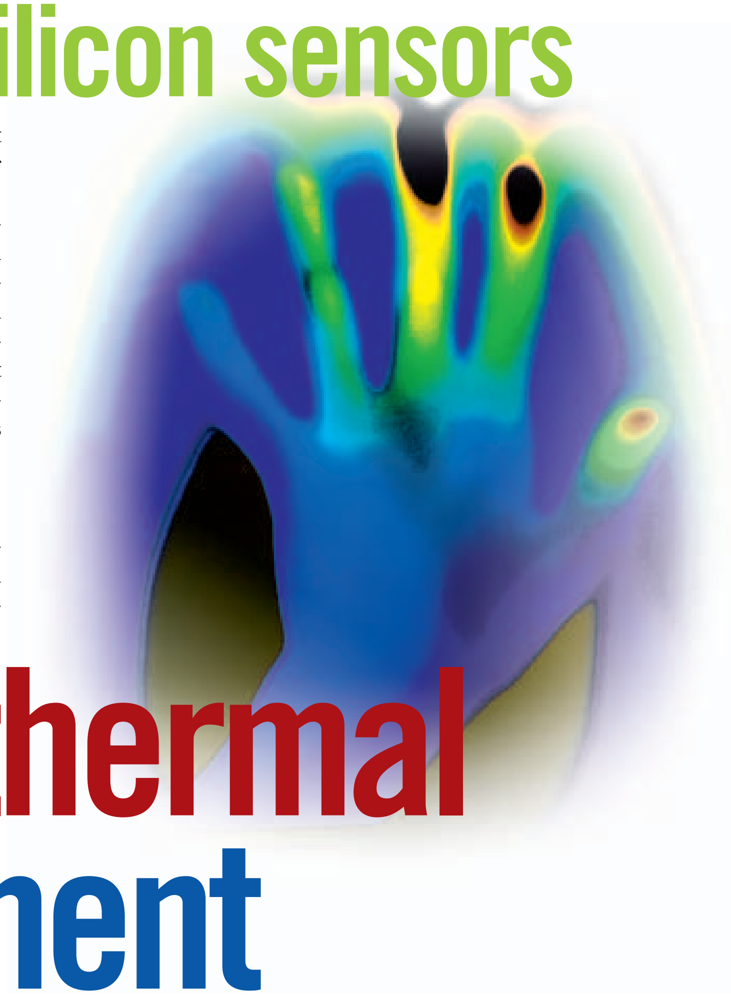
Silicon sensors harness thermal management

By David Marsh, Contributing Technical Editor



FROM AUTOMOTIVE CLIMATE CONTROL TO PRESERVING THE PROCESSORS IN YOUR WORKSTATION, GAUGING TEMPERATURE IS BY FAR THE MOST COMMON PHYSICAL MEASUREMENT. TODAY'S DIGITAL-OUTPUT ICs AND CONTACTLESS INFRARED SENSORS ENABLE APPLICATIONS WITH EASE OF USE THAT CHALLENGES TRADITIONAL ANALOGUE TECHNIQUES.

Of all the physical measurements that electronic systems make, temperature is by far the most common. The applications are universal and grow continually, because virtually all classes of today's designs require thermal monitoring or management. Obvious examples include desktop PCs and servers, in which increasing power density confronts acoustic-noise considerations. But thermal sensors appear everywhere, from systems in your car to wireless base stations and telecommunications racks to industrial process control, where half-a-degree Celsius can easily make the difference between correct product formulation and failure. It's this universality that accounts for the thermal-sensor market size, which currently stands at some $1 billion annually. As a result, semiconductor vendors are showing renewed interest in an area that you may have thought dormant for some time. And, because thermal issues impact your entire product-design cycle, you can't avoid a discipline that's most often been the preserve of thermal-management specialists.

Traditional thermal-monitor devices include RTDs (resistance-temperature-detectors), thermistors, and thermocouples. Each of these devices has strengths, ranging from an RTD's accuracy, to a thermocouple's wide range, to a ther-

AT A GLANCE

- ▷ Industrial applications force sensor diversity.
- ▷ Thermal-management issues drive sensor growth.
- ▷ Silicon temperature sensors simplify applications.
- ▷ Analogue sensors still have a place.
- ▷ PWM outputs give ground to serial-digital formats.
- ▷ A new bus architecture complements SMBus.

mistor's low cost. Equally, these sensors suffer from the disadvantages of high cost, poor stability, and limited range, respectively. For these reasons and more, silicon-based sensors emerge as most designers' choice for the automotive-, consumer-, and industrial-temperature ranges. Until recently, however, applying any sensor required you to have considerable analogue circuitry expertise. Today, the relentless shift from analogue to digital models drives vendors to offer solutions that are far easier to use than previous-generation products. Where first-generation digital-output devices typically provided a microcontroller with PWM (pulse-width-modulation) streams that you had to translate in software, you may now benefit from sensors that report results in serial-digital formats. Such ICs frequently include programmable setpoint facilities and logic outputs for undertemperature and overtemperature sensing that challenge inflexible analogue comparators. And if simple setpoint-temperature monitoring fits the bill, chips are available that work in stand-alone mode—ideal for simple alarms or situations in which a microcontroller is overkill. At the other complexity extreme, devices such as Maxim's DS1616 combine a temperature sensor with a multiplexed three-input ADC and a real-time clock to build a data recorder subsystem with a 2k-point memory—and all for less than $4.65 (1000).

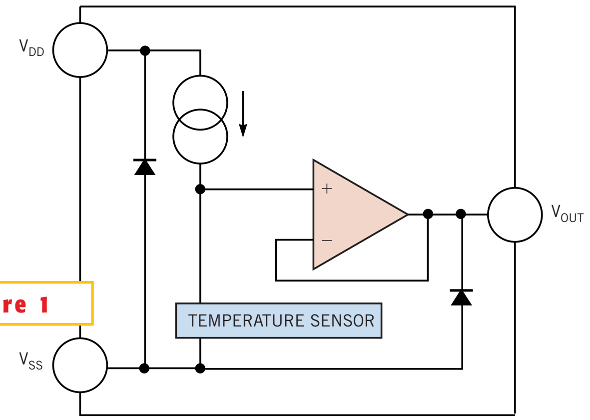
ANALOGUE SENSORS ARE ALIVE AND WELL

But don't think that analogue temperature sensors are dead; they're far from it. A growing raft of applications requires an analogue voltage to perform, for example, temperature compensation for a mobile radio's VCO (voltage-controlled oscillator). And, of course, analogue circuitry lurks beneath the hood of every digital-output temperature sensor. Almost invariably, the sensing element is a silicon diode or diode-connected transistor that provides a temperature-dependent voltage change. Typically, a constant current source biases the diode to generate a voltage of around 0.55V at room temperature. Although the voltage across the diode changes inversely and nonlinearly with rises in absolute temperature, the characteristic slope is approximately linear from about −50 to +150°C. At the lower extremity, a representative component may have sensitivity close to −2.2 mV/°C, rising to −2.3 mV/°C at 25°C and on to −2.4 mV/°C at +175°C. Unfortunately, these values vary between device types, and no universal response curve exists. Thus, applications that require accuracies better than, say, ±5°C from −40 to +85°C require some form of normalization, although modern fabrication techniques often obscure this step. One technique employs a differential measurement between two diodes operating at different bias currents to derive temperature values, because the differential voltage is less prone to process variations than a single diode's response.

The humble silicon diode's low-temperature tolerance and wide output-voltage range can suit niche applications, such as electron microscopy and spectrometry, which demand cryogenic measurements. Specialist vendors, such as Lake Shore Cryotronics, offer characterized diodes that can eliminate the need for calibration in many applications. For example, the company's DT-670 has a useful operating range of −1.4° to +500°K (−271 to +227°C). With measurement repeatability typically better than ±0.02°K and a calibrated accuracy of ≤±0.03°K from 25°K to room temperature, the DT-670 offers the best measurement performance of any silicon diode to date. But don't forget that diodes aren't the only form of silicon-based temperature sensor; both Infineon Technologies and Philips Semiconductors offer low-cost devices that employ the "spreading-resistance" principle to detect temperature (**Reference 1**). One advantage of Infineon's KTY series is that the response curve is accurately characterized to present uncorrected accuracies of less than 2% from −0°C to +50°C, and less than 5% from −50°C to +150°C.

The necessity for support circuitry and some form of calibration often makes the simple diode approach unattractive, as well as uncompetitive on cost grounds. Consider what's involved in just biasing the diode—particularly if the bias circuitry experiences the same temperature excursions as the sensor. Temperature-stable constant-current sources traditionally require a temperature-stable voltage reference, a precision resistor, and an op amp. Integrated equivalents, such as National Semiconductor's LM134 family, exist but add cost and complexity. Also, a diode produces a less-than-1V level that changes relatively little. If you don't use an amplifier and want to interface directly to an ADC, you may wish to consider stacking multiple diodes in series. This approach can raise the output voltage to somewhere close to the centre

Figure 1



Seiko's S-8110/8120 series follows the classic constant-current-source and sensor circuit with an op-amp source buffer.

of an ADC's range, where its performance is best. It also multiplies the signal excursion to ease resolution issues, especially in the presence of noise.

Alternatively, you can configure current sources, such as the LM134 as analogue-output temperature sensors, with minimal support circuitry. The vendor specifies the LM234 grade for this purpose. Similarly, the now-mature AD590 from Analog Devices outputs a current that's proportional to absolute temperature (or "PTAT," as you see on some data sheets). Newly available in a 0.15-in.-wide, eight-pin SOIC, this two-terminal device works from a supply voltage of 4 to 30V dc. Its high-impedance output particularly suits remote-sensing applications, in which a twisted-pair cable suffices for distances tens of meters from the receiving circuitry. The PTAT transfer characteristic is 1 μA/°K and is laser-trimmed to 298.2 μA at 25°C (298.2°K). Four product grades provide accuracy as tight as ±1°C and maximum nonlinearity of ±0.3°C over the device's −55 to +150°C range. With the 25°C error calibrated out, the lowest cost SOIC device manages ±3°C accuracy and ±1.5°C nonlinearity for less than $1.25 (1000), compared with less than $3 for the same device in its original TO-52 metal can.

Other linear voltage-output devices

ONE-WIRE BUS TAKES THE HEAT

As new microprocessors and graphics chips push thermal and acoustic constraints in commodity PCs, there's new impetus for thermal-management engineers to consider sensor and control architectures. Working in partnership with Intel, National Semiconductor has designed the SensorPath bus exclusively for such applications. Work is ongoing with standards committees for formal adoption, but, in the meantime, it's likely to become another de facto industry standard. With intimate access to Intel's product plans, National Semiconductor's engineers have designed SensorPath to accommodate contemporary and future needs. Such needs may shortly embrace adaptive voltage and clock-frequency regulation to constrain power dissipation and ultimately, liquid cooling systems. But regardless of the thermal-management mechanics, many of today's and any of these future schemes require multiple sensors distributed across a motherboard. This requirement potentially challenges SMBus in both traffic and pc-board-routing issues. Also, a dedicated sensor bus offers the opportunity to redefine I/O locations to standardize software development.

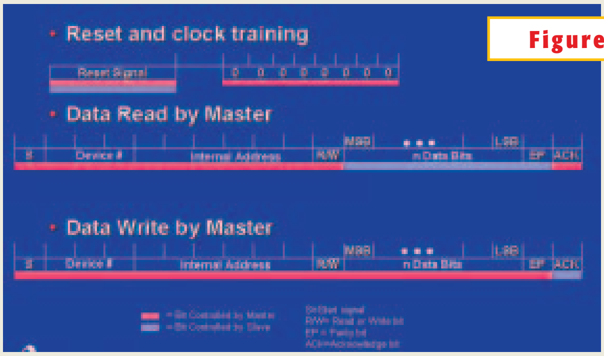


Figure A

The SensorPath bus achieves single-wire operation with a simple message-exchange protocol that employs pulse-width coding.

SensorPath offloads traffic from the SMBus onto a single-wire digital bus that's controlled by a dedicated I/O chip. The scheme accommodates as many as seven devices per bus, each of which can accommodate three functions. As well as temperature sensing, possible functions include system-voltage sensing (with or without core-voltage support) and support for EEPROM devices. Uwe Kopp, National Semiconductor's European marketing manager for its data-conversion-systems group, explains that in common with SMBus, SensorPath employs master/slave architecture; however, SensorPath masters exchange data with slaves using an unusual pulse-width-coding scheme. A "0" data bit is the shortest at 11.8 to 17.0 μsec, and a "1" occupies 30.7 to 42.5 μsec. A "start" bit is 63.7 to 87 μsec long, attention requests take 130 to 180 μsec and reset is the longest pulse at 236 to 370 μsec. Thus, the minimum tolerance for the 360-kHz reference oscillator is more than ±15% to allow for low-cost oscillators. The maximum operating frequency of 100 kHz retains compatibility with SMBus.

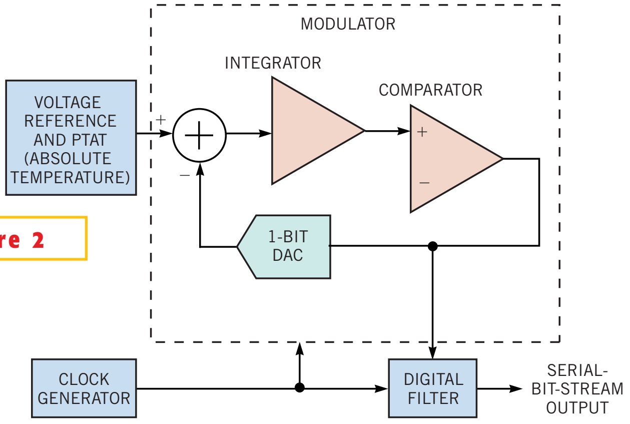
The data-exchange protocol is simple, with the master initiating a transfer with a start bit and device number, followed by a data field. Slaves respond with an acknowledge signal and can also signal the master via an attention sequence (**Figure A**). A minimum bus-inactive period of 7.1 μsec separates data exchanges. Each device on the bus senses attention requests, which allows the protocol to negotiate and regain control in case of bus contention. Both masters and slaves can force a reset; hence, a single wire accommodates all data-transfer requirements. Devices can use hard-wired addresses to save register space and die area, or respond to programmable addresses that the master issues. In each case, the master has to send an appropriate address to talk to a device.

Suiting desktop PCs, the PC8374L Super I/O controller integrates SensorPath bus support and legacy peripherals (serial, parallel, floppy disk, and PS/2), together with glue-logic functions, such as flash-memory and floppy-disk write protection. The PC8374L is now available for sampling in a 128-pin PQFP, and full production is scheduled for the first quarter of 2004; its guide price is less than $2 (1000). The PC87427 controller targets servers, adding features such as support for as many as eight fans and automatic BIOS switching to a backup image in case of corruption. Available now, it also occupies a 128-pin PQFP and costs approximately $8 (1000).

Either I/O controller interfaces with the complementary LM-95010 and LM96010 temperature sensors. The LM95010 has an on-chip temperature monitor and four hardware-programmable addresses. Accuracy is ±3°C from 0 to 125°C with 0.25°C resolution. Available for sampling now, it uses an eight-pin MSOP and costs less than $0.85 (1000). The LM96010 similarly measures its on-chip temperature as well as the temperature of two remote diodes, which it can resolve within a −55 to +140°C range. The 14-pin TSSOP package also accommodates inputs for all PC-standard voltage rails, which the chip's 9-bit sigma-delta ADC measures to within ±2%. With full production scheduled for the first quarter of 2004, the LM96010 will cost less than $1.30 (1000).

include the LM135 series, which is available from vendors including National Semiconductor, STMicroelectronics, and Texas Instruments. This three-terminal device works like a temperature-sensitive zener diode, with the third terminal providing a trim input. The PTAT characteristic is set to 10 mV/°K to produce 2.98V at 25°C; dynamic impedance is 0.5Ω for 1-mA bias current. Because the bias current can vary between 450 µA and 5 mA with little effect on accuracy, you don't need constant-current biasing. Assuming that you trim out its residual error at 25°C, the commercial-grade LM335 can better ±1°C accuracy over a 100°C range; prices start at less than $0.40 (1000) for an eight-pin SOIC. Alternative low-impedance voltage sources include Seiko's S-8110/S8120 family, which is built in CMOS technology. Able to operate from supplies as low as 2.4V dc and consuming just 4.5 µA, these chips particularly suit use in portables. Internally, the devices contain a sensor, a constant-current source, and an op amp (**Figure 1**). The output characteristic is typically −8.5 mV/°C and linear to within ±0.5% from −20 to +80°C. The output-voltage range spans 1.95V at −30°C to 0.88V at +100°C. Package availability comprises a standard three-lead SOT-23 and the smaller, four-lead SC82-AB package, which shrinks the 1-mm-tall device into a 2×2.1-mm footprint. Prices range from less than $0.20 (1000) for the ±5°C-accurate S-8110, to less than $0.30 (1000) for the S-8120, which meets ±2.5°C.

Figure 2



Analog Devices' TMP05 demonstrates the first-order sigma-delta topology that's popular within PWM-output temperature sensors.

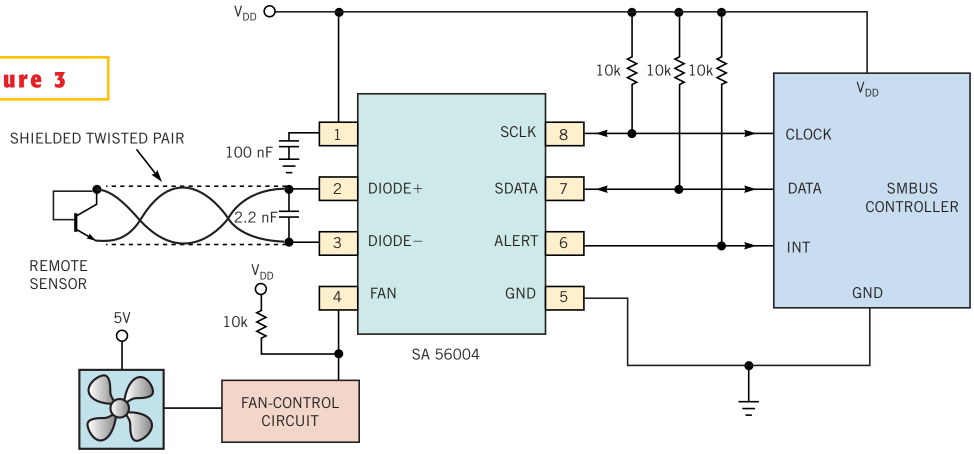
DIGITAL OUTPUTS

If you're interfacing with a microcontroller that has spare ADC inputs, you may consider using an analogue-output sensor for lowest component cost. Depending on the microcontroller's architecture, this approach can also reduce code size and complexity when compared with implementing a serial-digital or PWM interface in software. If you choose the ADC route, consider the sensor's output-voltage range and choose a conversion resolution that maintains specified accuracy, and remember that accuracy and resolution are different things. For example, if you have a system that runs from a 3.3V-dc rail, and you choose Seiko's S-8120, you need to encode its 130°C range into a 1.07V span. That span is equivalent to 8.23 mV/°C and requires a 9-bit ADC for single-degree resolution; because the device is specified to ±2.5°C, an 8-bit ADC suits an uncorrected measurement. But if you can calibrate the system and want to preserve the device's ±0.5% linearity specification, a 10-bit converter with a real-world accuracy of 1 LSB is more appropriate. Also, remember to quantify the system's noise level and assess any filter requirements, because fluctuations of only a few millivolts influence the measurement. Other issues that sometimes surface include matching the sensor's output impedance to the ADC's input. Some ADCs present significant input capacitance that slows measurement response and, in a worst-case scenario, can stimulate instability in driving amplifiers. In the case of the S-8120, the data sheet warns against sinking load current into the output pin, so assume that the device is suitable only as a voltage source.

Such considerations help explain the popularity of digital-output sensors. The traditional interface is a PWM stream that's typically generated by an on-chip sigma-delta ADC. This converter architecture is simple and easy to integrate, and it provides good resolution. A recent example is the TMP05 from Analog Devices. Available in two grades and requiring no user calibration, this chip is accurate to as little as ±1°C from 0 to 70°C; its operational range is −40 to +150°C. Setting the state of the chip's function pin selects continuous or one-shot measurements, which can lower power consumption to 2.57 µW for a 1-Hz repetition rate. Internally, a sample-and-hold circuit captures the temperature sensor's output to supply a summing stage that closes a feedback loop comprising an integrator, a comparator, and a single-bit DAC (**Figure 2**). For each measurement cycle, feedback action drives the integrator's output toward zero by varying the duty cycle of the comparator's output in response to input voltage changes. Capable of 0.02°C resolution, the ADC oversamples the integrator's output relative to the input voltage to improve noise performance by spreading quantization noise over a wider bandwidth. A digital filter encodes the comparator's output to produce a rectangular signal; measuring the duty cycle of this signal and applying a simple formula returns the temperature in degrees Celsius.

The standard method for determining duty cycle employs a microcontroller counter/timer channel to measure the periods between signal transitions. For the TMP05, the high time is static at around 40 msec, and the low time varies with temperature. Because the chip generates high and low periods each cycle, the ratio between these periods yields the measurement. Thus, the technique is immune to longer term clock frequency errors in the device or in the measuring microcontroller's timing subsystem. Paul Errico, product marketing manager for thermal and systems management products at Analog Devices, also highlights the TMP05's ability to interface with others: "Customers are finding that it's now necessary to monitor multiple circuit-board nodes to implement an effective thermal-management strategy." To obviate the requirement for each chip to have dedicated microcontroller pins and to simplify pc-board routing, an ingenious scheme allows multiple TMP05s to op-

Figure 3



Philips' SA56004 reads its own temperature and that of a remote junction, such as a microprocessor's thermal diode.

erate in a daisy-chain mode. Wiring each chip's function pin high allows you to cascade a chip's output to the convert/input pin of the next chip in the chain; the last chip's output drives the microcontroller's timer/counter channel. The microcontroller initiates *n* conversions by setting the first chip's convert/input pin high for less than 34 μsec from a GPIO (general-purpose I/O) line; thus, the scheme costs two microcontroller pins. The first chip takes a reading and outputs it, with each next chip acting as a noninverting buffer; when the first chip's reading completes, it issues a start command to the second chip by outputting a 17-μsec pulse. This sequential trigger-read sequence repeats until each chip has issued a result. (Usefully, the vendor includes a C-code example in the device's data sheet, although you'll find more general PWM application information on Smartec's site.) The logic-level output TMP05 and the open-drain TMP06 are now available for sampling in a choice of five-lead SOT-23 or SC-70 packages. The guide price is less than $0.65 (1000), and full production is scheduled before the end of this year.

Despite PWM's popularity, noise can couple into the signal and distort data in hostile environments. A purely digital signal is less prone to such errors. Widely adopted but respectively sponsored by Intel, Motorola, and Philips, three serial-digital interfaces—SMBus (system-management-bus), SPI (serial-peripheral interface), and I^{2}C (inter-integrated circuit)—dominate today's temperature-measurement applications. Don't expect a full implementation of these protocols in temperature-sensor ICs, because it's the data-transfer mechanism that's important. For example, the Philips specification for I^{2}C-bus devices describes unique 7- or 10-bit addresses for each chip, fields of which are programmable to allow multiple instances of the same device type per bus (**Reference 2**). In practice, National Semiconductor's ubiquitous I^{2}C-compatible LM75 and its replicates, such as Maxim's DS75, Micrel's MIC184, and Microchip's TCN75, employ a 3-bit address input that you can hardwire to allow as many as eight devices per bus.

Notice, too, that I^{2}C and SMBus devices are typically interchangeable for clock speeds less than or equal to 100 kHz, with SMBus appearing as an I^{2}C subset (**references 3** and **4**). Both buses employ a two-wire connection for clock and bidirectional data lines, and the three-wire SPI separates data-input and -output pins. SPI-compatible devices also employ a traditional single chip-select input, so you'll need dedicated GPIO lines for multiple devices. Recent SPI-compatible product releases include the ADT7301 from Analog Devices, a true 13-bit device with a guaranteed accuracy of ±0.5°C from 0 to 70°C. User resolution aside, the 13-bit successive-approximation-register ADC facilitates factory trims that guarantee this accuracy level. Sampling now, packaging is six-lead SOT-23s or eight-pin MSOPs (micro-small-outline-packages); the guide price is less than $1 (1000).

PCs NEED FLEXIBLE THERMAL MANAGEMENT

Although I^{2}C and SPI devices target universal applications, their SMBus equivalents focus on temperature monitoring and control tasks in PCs and other equipment that has adopted Intel's SMBus as a de facto standard. Applications range from on/off and variable-speed fan control, to throttling back processors at the onset of overtemperature conditions. But if it's simple fan control that you need, consider stand-alone digital-thermostat ICs. Such ICs can also suit applications in consumer goods and industrial controls in which logic-level status suffices and microcontroller control is inappropriate. Maxim and its Dallas brand have an exceptionally wide range of digital-thermostat products, such as the MAX6501/10 family, which includes factory- and resistor-set devices with single or dual outputs, together with a selection of logic-level interfaces. The company also offers a variety of products—such as its MAX666x series, which includes integrated fan-drivers capable of switching 250 mA—that target fan control. Also in its digital-thermostat line, the newly announced DS1626 meets industrial accuracy needs of ±0.5°C from 0 to 70°C to provide undertemperature and overtemperature status, together with a programmable hysteresis flag. You program the eight-pin device's flash memory over a three-wire interface; when set, a microcontroller can read the trigger and results via this interface, or the DS1626 can operate in stand-alone mode. The guide price is less than $1.40 (1000) in a proprietary eight-pin μSOP package that occupies a 3×5-mm footprint.

Other vendors with dedicated fan-control products include Micrel, Microchip (which acquired TelCom Semiconductor's extensive product portfolio

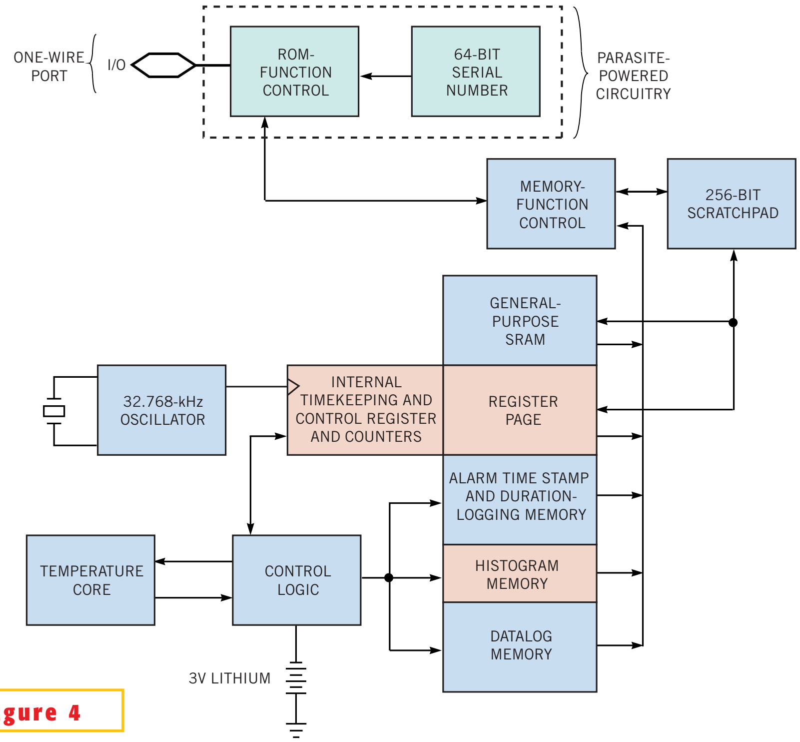


Figure 4

The Thermocron iButton packs a self-sufficient thermal datalogger into a rugged two-terminal stainless-steel can.

in 2000), and Philips Semiconductors. Philips' new SA56004 is similar to National Semiconductor's LM86/89/90 family and demonstrates several representative features, including an on-chip temperature sensor and the ability to read the remote sensor diode that many microprocessors incorporate (**Figure 3**). The chip offers 11-bit resolution that's equivalent to 0.125°C, with ±1°C accuracy over the critical 60 to 100°C range. Communications are both I^2C-bus- and SMBus-compatible, with the option of using the chip's "alert" output to implement the SMBus' ARA (alert-response-address) interrupt. Available now, the SA56004 costs less than $0.60 (1000) in SO-8 and eight-pin TSSOPs.

The trend to implement variable-speed fan controls continues, because this approach offers improvements in both thermal management and noise attenuation. Micrel's recent MIC502 is a stand-alone chip that generates a low-frequency PWM signal to provide fan-speed control that's proportional to temperature. An external thermistor/resistor network generates an analogue input of 30 to 70% of V_{CC} that modulates a 0 to 100% signal of typically 30-Hz carrier frequency. Because the chip drives a saturated bipolar or MOSFET power switch, it can accommodate a range of voltage and current levels that are independent of its own 4.5 to 13.2V-dc supply range. Other features include a fan start-up timer, overtemperature-detection output, and a low-power sleep mode with a user-determined threshold. The guide price for a standard eight-pin DIP or SOIC is less than $1.50 (1000) mark.

NEEDS STIMULATE DIVERSE SOLUTIONS

Given an appropriate sensor IC, the SMBus provides the infrastructure for the intelligent-control strategy that thermal-management engineers increasingly demand. Now at version 2.0, the SMBus was originally designed to facilitate communications between intelligent battery packs and chargers but increasingly serves as a general-purpose serial connection for motherboard components and PCI slots. As a result of this success, the architecture is gradually becoming less than optimal for thermal-management tasks (see **sidebar** "One-wire bus takes the heat"). But, although most temperature-sensor products exist to command an action, some devices tackle "passive" tasks, such as thermal monitoring and data recording. Examples include Maxim's DS1616 thermal datalogger subsystem, as well as its unique line of Dallas iButton products. The Thermocron iButton family is a rugged, self-contained datalogger that

FOR MORE INFORMATION...

For more information on products such as those discussed in this article, contact any of the following manufacturers directly, and please let them know you read about their products in *EDN*.

Analog Devices
www.analog.com

Dexter Research
www.dexterresearch.com

Fuji and Company Piezo Science
www.fuji-piezo.com

Infineon Technologies
www.infineon.com

Intel
www.intel.com

Lake Shore Cryotronics
www.lakeshore.com

Maxim Integrated Products
www.maxim-ic.com

Melexis
www.melexis.com

Micrel Semiconductor
www.micrel.com

Microchip
www.microchip.com

Motorola Semiconductor
www.mot-sps.com

National Semiconductor
www.national.com

Philips Semiconductors
www.semiconductors.philips.com

Raytek
www.raytek.com

Seiko Instruments
www.sii-ic.com

Semitec
www.semitec.co.jp

Smartec
www.smartec.nl

STMicroelectronics
www.st.com

Texas Instruments
www.ti.com

comes in a two-terminal stainless-steel can that you can safely deploy in hazardous or hostile environments. Data transfers use the vendor's proprietary "1-Wire" protocol; internal power comes from a 3V lithium source, with automatic switching to "parasite mode" to take power from a programming adapter or device reader when present (**Figure 4**). The top-capability DS1921G takes as many as 2048 measurements at configurable 1- to 255-minute intervals, storing the results in value and histogram formats. The histogram provides 63 data bins with a resolution of 2°C. You can configure the device to record the temperature of out-of-range events as well as the start time, duration, and whether the temperature was high or low. Each chip has a unique 64-bit identity and 512 bytes of memory that can store information such as the target object's identity. The DS1921G is available now for less than $8 (1000).

Further demonstrating temperature-sensor diversity, infrared sensors from vendors such as Dexter Research, Fuji and Co, Melexis, Semitec, and Smartec enable noncontact temperature measurements. Although Melexis markets its product for applications in automotive climate controllers, more traditional uses include measurements in hazardous and intrinsically safe areas. But you may find applications closer to your own benchtop—for example, how do you measure the temperature in the centre of a tiny surface-mount power transistor and gain a view of the temperature gradient across the surrounding pc board? The classic solution employs expensive thermal-imaging cameras and analysis software. But for less than $400, you can gauge the chip's surface temperature with a tight-focus, noncontact thermometer, such as Raytek's model ST80, and assess thermal gradients by recording measurements at incremental distances from the chip's centre. Here, a collimating lens focuses the infrared "black-body" radiation from the object of interest onto a detector that converts the temperature signal into a voltage. Examples of such detectors include thermopiles, which generate a dc output that's proportional to incident radiation; pyroelectric detectors, whose output is proportional to the rate of change in incident radiation (effectively an ac output); and quantum detectors, such as silicon and InGaAs (indium-gallium-arsenide) photodiodes.

Of these detectors, thermopiles enjoy very flat spectral response, typically at the expense of temperature-coefficient problems due to the construction materials. For the near future, watch for micromachined all-silicon devices that promise higher sensitivity, lower cost, smaller size, and lower temperature coefficients than traditional thermopiles. For now, conventional examples include Smartec's SMTIR9902, which comprises 100 thermal junctions on a silicon substrate. Like a thermocouple, its operation takes advantage of the Seebeck effect, whereby the junction between any two materials in the thermoelectric series generates a voltage proportional to the difference between the junction temperatures. In Smartec's device, the thermoelectric materials comprise BiSb (bismuth-antimony) and NiCr (nickel-chromium) alloys. An etched thin-film layer separates the thermal junction's blackened hot side, which receives the incoming radiation, from the cold side beneath; connecting the thermal junctions in series produces an output sensitivity that's equivalent to 110V/W. A reference Ni thermistor of 1 kΩ at 0°C measures the chip's ambient temperature, allowing you to compensate the thermoelectric materials' temperature coefficient of some −0.52%/°K. The SMTIR9902's detection range is −40 to +100°C, and the device is available now in a TO-5 can for approximately $6 (1000).□

References

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3. "System management bus (SMBus) specification," Version 2.0, August 2000, www.smbus.org.
4. "Comparing the I^2C bus to the SMBus," application note AN356, Maxim Integrated Products, www.maxim-ic.com.

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