#155 June 2003

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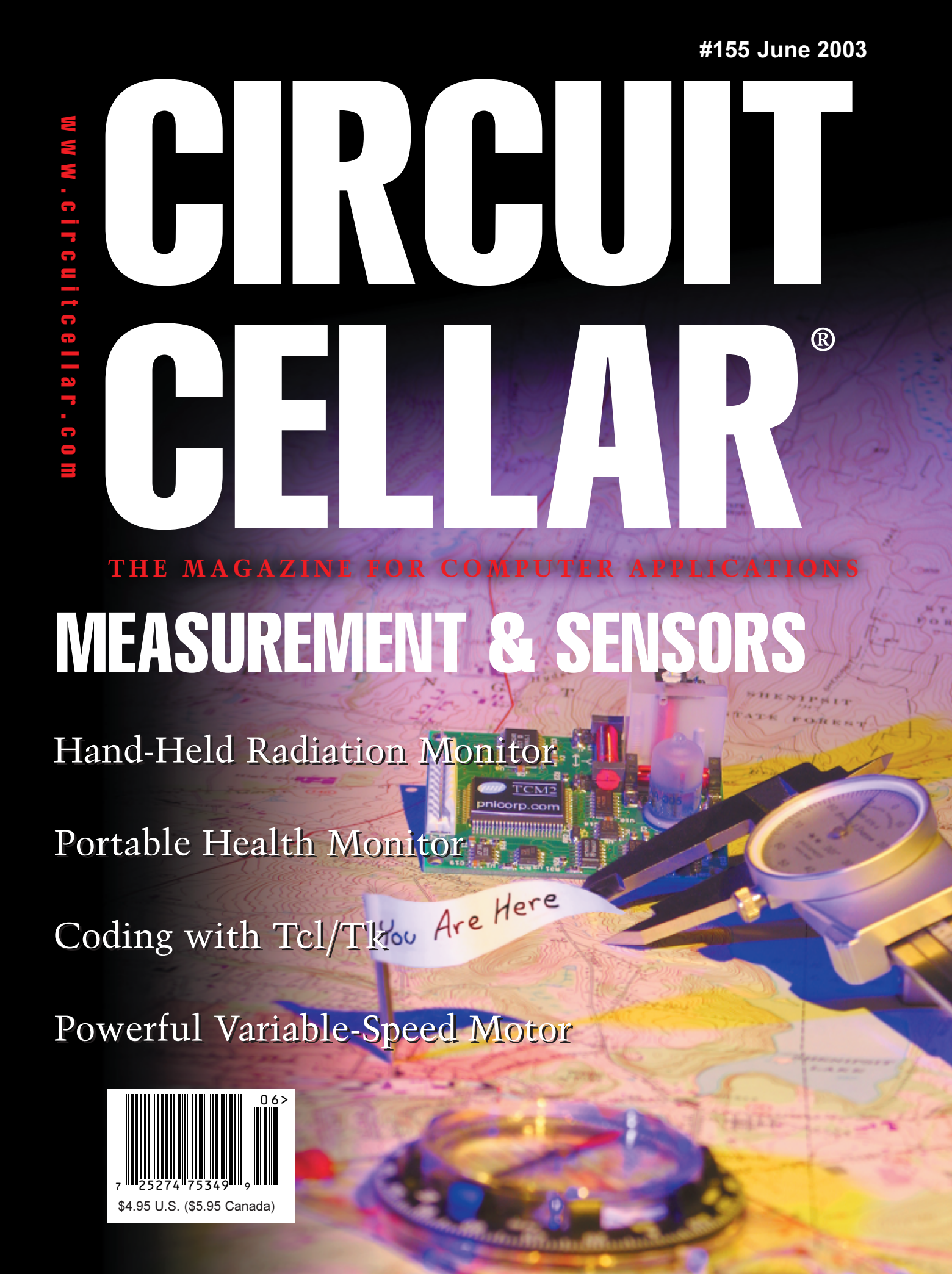
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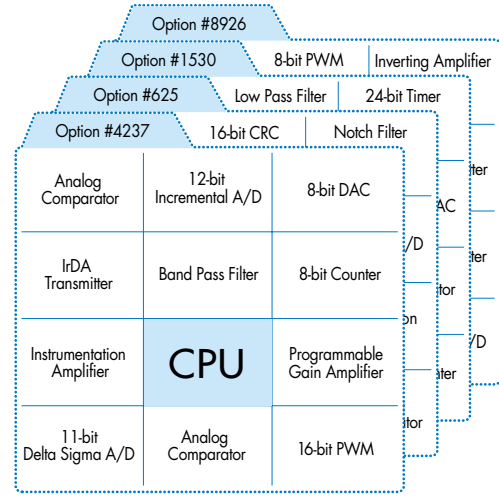
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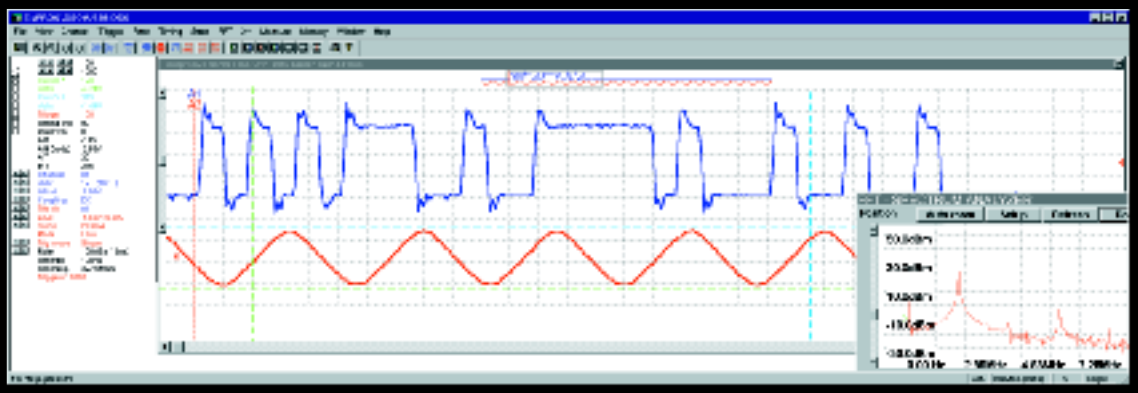

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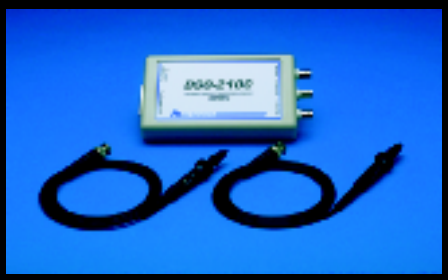
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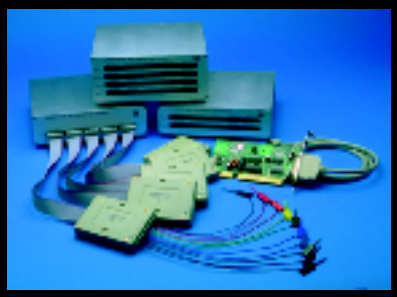


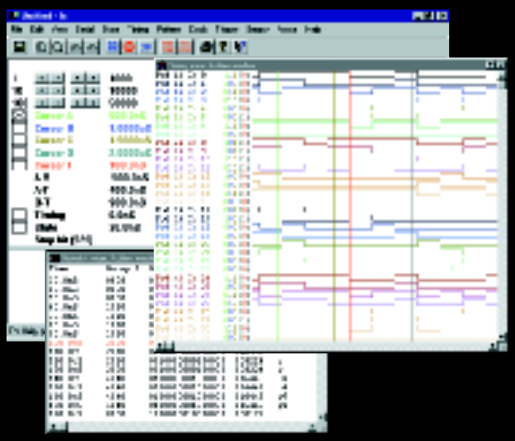
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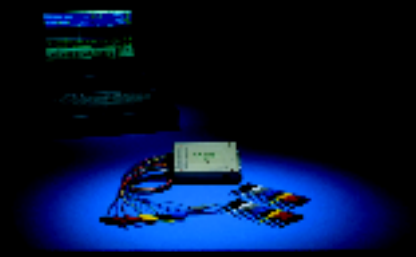


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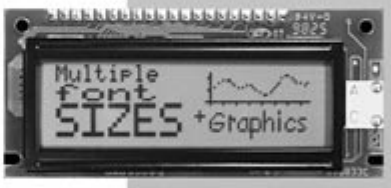
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# TASK MANAGER

## Change is Good

As you look through the June issue, you'll notice some changes. We've changed the layout, added some color, and modified some fonts. Rest assured though, the changes are cosmetic. Our content is the same, just in a new package. We figured it was time for, well, not quite a facelift, but something more like a Botox injection. We've had pretty much the same design since '92, so we were ready for an update.

When we talked about updating the look, we knew we didn't want anything radically different. We aren't interested in becoming a different magazine. We have a simple goal: to provide quality editorial and advertising. So, we'll continue doing just that. You see, some changes are good!

It's funny to hear myself say that, because usually I say change is bad. In fact, I'm the kind of person who cringes at the thought of change. Last week, I went to a restaurant only to discover that the chef had decided to ax my favorite meal, which was the only reason I went there in the first place. I showed up for Sunday brunch, but there's no longer a brunch menu. Now, besides the lunch menu, there's just one strange omelet special served with spicy fries and cooked carrots and broccoli. Who eats ham-potato-asparagus omelets with spicy fries? I was horribly disappointed, and repulsed to boot.

Unfortunately, the brunch debacle came on the heels of another upsetting change. Last weekend, I also went to visit my parents, who still live in the tiny Connecticut town where I grew up. The town boasts three stoplights on Main Street, and one more blinking yellow light on another busy street. Those of us who grew up there know the roads like the backs of our hands. Most of the houses in the center of town are Colonials, and there are more antiques dealers than any other kind of proprietor. It's the kind of place where nothing changes, everything is quaint, and people like it that way. That was, until hoards of "urban sprawlers" started gobbling up all of the open space in the name of cookie-cutter cul-de-sacs. Now, the roads are clogged with their behemoth SUVs and the fields are lined with their nearly identical gigantic homes. These are the people who favor anything larger—super-size it all, they say.

On the roads, the only thing we used to deal with were the New Yorkers who drive up on weekends to go antiquing. But with the steep rise in numbers of drivers, new stop signs have popped up without notice. I had to slam on the brakes to heed one of those new stop signs; at that point, I looked around and realized I didn't recognize the area anymore. It was disconcerting to say the least. Sure, there are the pressing issues of inadequate water and sewer lines to handle the developments, and over-crowded classrooms bursting at the seams with new kids. But, it's the little things that can drive a person insane, right?

On the other hand, sometimes it's the little things that make all the difference the other direction, too. Despite my animosity toward change, I've been rooting for the updates you see in this issue, and I'm happy with the results of our little Botox treatment. Feel free to drop me an e-mail to let me know what you think.

jennifer.huber@circuitcellar.com



Cover: The TCM2 compass module is manufactured by PNI Corp. (www.pnicorp.com) of Santa Rosa, California, maker of OEM and consumer products based on magnetic and other sensor technologies.


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# June 2003: Measurement & Sensors

## FEATURES


10 **Remote Health-Monitoring System**
*Victor Kremin*
*PSoC Design Challenge 2002 Winner*

26 **Mad Dash for Flash Cash Design Contest Winners' Announcement**

30 **Construct a Hand-Held Radiation Monitor**
*Mikhail Galeev*

40 **Build a Graphical User Interface with Tcl/Tk**
*Peter Hiscocks & James Gaston*

50 **Time-Triggered Technology**
*George Novacek*


## COLUMNS


18 **ROBOTICS CORNER**
**The Altmotor**
*Christopher Dix*

46 **ABOVE THE GROUND PLANE**
**Battery Power**
Feeding the Z3801A
*Ed Nisley*

60 **APPLIED PCs**
**E-Field Evaluation Module**
*Fred Eady*

68 **FROM THE BENCH**
**Encore!**
Zilog's Z8 Flash Memory-Based Micro
*Jeff Bachiochi*

78 **SILICON UPDATE**
**Good Vibrations**
*Tom Cantrell*


## DEPARTMENTS


4 **TASK MANAGER**
**Change is Good**
*Jennifer Huber*

8 **NEW PRODUCT NEWS**
edited by *John Gorsky*

9 **TEST YOUR EQ**
edited by *Dave Tweed*

94 **INDEX OF ADVERTISERS**
July Preview

96 **PRIORITY INTERRUPT**
**Opening E-mails from HairyAI**
*Steve Ciarcia*







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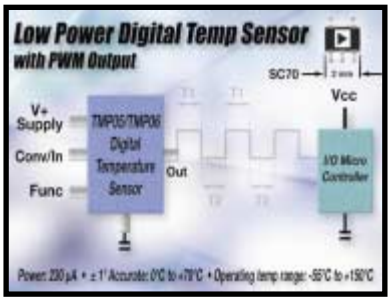
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# NEW PRODUCT NEWS

Edited by John Gorsky

## HIGH-ACCURACY DIGITAL TEMPERATURE SENSORS

The **TMP05** and **TMP06** provide accuracy for low-power, small-packaged temperature sensors. Both devices offer single-wire PWM outputs and a combination of low power consumption and a small package size. They are ideal for battery and portable applications found in the industrial process control, consumer, instrumentation, and medical industries.




The output of the TMP05 and TMP06 is a square wave with a duty cycle that's proportional to the absolute temperature. Both devices offer accuracy to ±1°C maximum from 0° to 70°C, an operating temperature range from –55° to 150°C, and a supply-voltage range of 2.7 to 5.5 V. They are available in space-saving, five-lead SC-70 and SOT-23 packages.

Both devices offer three modes of operation: Daisy Chain (allowing designers to connect any number of TMP05/06 sensors to the same microcontroller); Continuously Converting; and One-Shot mode, which reduces the power consumption to 8.25 µW. The TMP05 has a push-pull output (CMOS/TTL), while the TMP06 has an open-drain output.

Both the TMP05 and TMP06 are priced at **$0.95** per unit in 1000-piece quantities and are now available for sampling.

**Analog Devices, Inc.**
**(781) 937-1428**
**www.analog.com**

## I/O EXPANSION IC

The **MC33993** adds switch monitoring, LED and FET drivers, and programmable wake-up to low-pin-count microcontrollers. The IC interfaces with an MCU through a four-pin serial peripheral interface. By using the analog multiplex feature of the device, up to 22 analog signals may be sent to one MCU ADC input.

The device's 22 I/O pins also may be configured for the following purposes: to detect the status of a switch contact, either opened or closed; to provide an analog value to a buffered output; to drive an LED or the gate of an FET; or to provide switched power to a low-current sensor.

The device is also designed to allow logic-level MCUs to directly interface with system voltages from –14 to 26 V. This makes the device ideal for a wide variety of automotive, industrial, and commercial applications.

The MC33993 offers a wide range of features including: 22 switch inputs (14 switch-to-ground inputs and eight programmable switch-to-power or switch-to-ground inputs); contact wetting for switch reliability; multiple device connection in daisy-chain fashion using the SPI; 25-kV ESD capable; low-power wakeup on switch state change; and a timer for wake-up.

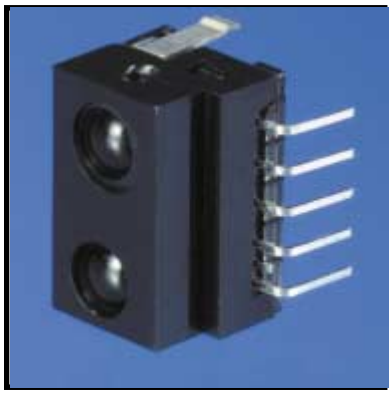
The device is housed in a 32-lead SOIC. Unit pricing starts at **$1.50** for 10,000-piece quantities. An evaluation board (part number KIT33993DHEVB) is available for **$99** and includes Motorola's SPIGen graphical user interface software and documentation.




**Motorola, Inc.**
**www.motorola.com**

## DISTANCE SENSOR

Improvements in performance and package size have led to the introduction of the new **GP2Y0D340K**, a compact 9.6 mm × 15 mm × 8.7 mm standard distance measuring sensor with a range of 10 to 40 cm. Start-up delay is only 10 ms with 7-ms response time, so the sensor can be cycled on/off quickly. Other key features include 35-mA current consumption and a trigger distance of 40 cm.



Applications include battery-operated mobile devices, industrial automation and robotics, and electronic sanitary equipment such as faucets, soap dispensers, towel dispensers, and hand dryers.

The device is now available for approximately **$4** each in quantities of 10,000 pieces. A customized version of the GP2Y0D340K, which is available in 50,000-piece quantities, can be modified to adjust the trigger distance (10 to 40 cm) and current consumption based on application requirements.

**Sharp Corp.**
**www.sharp-world.com**

# CIRCUIT CELLAR

## Test Your EQ

Edited by Dave Tweed

Although the technology has been around for a while, there are still challenges in the field of temperature sensing as a result of continued innovations in sensor manufacturing and improvements in the sensor interfaces. There are two abasic classes of temperature sensors: contact and noncontact. The contact type can be further divided into electrical and nonelectrical. The entire classification tree of temperature sensors is represented in the following table:

| Contact | | | Noncontact |
|---|---|---|---|
| Electrical | | Nonelectrical | Radiation pyrometer |
| Binary | Continuous | Bimetallic strip (dial)<br>Mercury/alcohol capillary<br>Gas/vapor bulb<br>Specific gravity (Galileo) | |
| Bimetallic disk<br>Bimetallic strip | Thermocouple<br>Thermistor<br>RTD<br>PN junction<br>Bulk silicon<br>Fiber optics | | |

Answer the following problems pertaining to temperature sensors.

*Contributor: Rajanish Kamat*

**Problem 1**—Where are the bimetallic disc-type sensors typically found?

**Problem 2**—Which is the most accurate type of electronic temperature sensor?

**Problem 3**—Which is the most sensitive type of electronic temperature sensor?

**Problem 4**—What are some of the commonly available types of thermocouples?

**What's your EQ?—The answers are posted at www.circuitcellar.com/eq.htm**

**You may contact the quizmasters at eq@circuitcellar.com**







PSoC Design Challenge 2002 Cypress MicroSystems Contest

CONTEST ENTRY

# Remote Health-Monitoring System

*The uses for Victor's award-winning health-monitoring system are endless. Rehabilitation technicians, athletic trainers, and emergency-response crews would all benefit from having his portable monitoring system on-site. In this article, Victor describes what he was shooting for when he started the design and explains how he built the system.*

Having the ability to remotely monitor a person's health would be useful in a number of cases. For instance, cardiac disease patients undergoing rehabilitation often need their hearts monitored around the clock. But traditional clinical systems are stationary, and they limit a patient's ability to move around. A remote health-monitoring system would facilitate patient mobility.

A remote system would also be useful for trainers running athletic training programs. On-line data analysis would allow trainers to optimize an athlete's training load and permit them to determine the most suitable workout scheme. Such a system would ultimately help athletes reach their goals in competition.

You could also use a remote-monitoring device in dangerous work environments. Firefighters and rescuers would find such a system useful in low-oxygen scenarios in which they're at risk of losing consciousness. Note that there are reported incidents of rescuers losing their lives during earthquakes and terrorist events because they focused too closely on their jobs and paid little attention to their dangerous working conditions.

Monitoring rehab patients, athletes, and rescuers requires a small, autonomous remote health-monitoring system. The system I designed allows you to remotely obtain information concerning an individual's health and predict hazardous situations in advance.

## THE MONITOR'S SENSORS

I wanted to develop a portable, autonomous health-monitoring system that could be used in Online and Offline modes. Offline mode is used when real-time data analysis isn't required (e.g., when diagnosing some cardiac illnesses).

Before starting this project, I had to select the appropriate sensor types. I decided to limit the monitor's sensor set to the following types: electrocardiogram (ECG) electrodes, optical pulsometer sensors, and micromechanical (MEMS) accelerometer sensors.

ECGs provide information concerning the state of a person's heart. On-line analysis can help predict the beginning of dangerous situations in anyone being monitored.

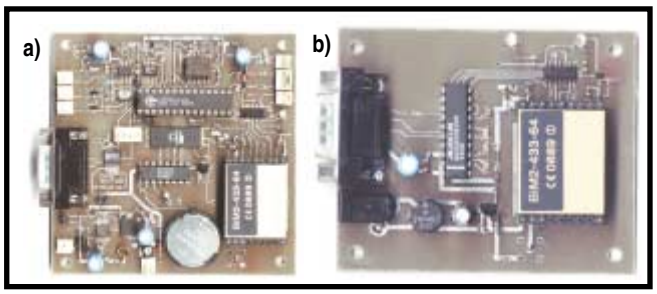



**Photo 1**—*Here, you see the autonomous unit (**a**) and the communication module (**b**). You can find the PSoC microprocessor, MEMs accelerometer, flash memory, and real-time counter with back-up battery in the autonomous unit. The Radiometrix transceivers are on both boards.*

Nowadays, pulsometers are based on the modulation of tissue light absorption levels, which are caused by the varying blood volume. But you can determine more than the heart rate, which can be accomplished with a conventional pulsometer. By performing the measurements in red and infrared light bands and then comparing the obtained results, you can determine blood-oxygen saturation levels, which give you important information regarding a person's respiratory activity. In addition, by performing light-absorption signal waveform analysis, you can determine the state of a person's lungs and heart, and establish when someone transitions into a state of unconsciousness (or sleep). Note that a pulsometer sensor is located on an arm or finger, or it's embedded in an ear clip.

A MEMS accelerometer provides information concerning an individual's acceleration. You can use it to effectively determine pace rates or even momentary speed. This kind of sensor provides important information for sports trainers, in particular, monitoring athletes such as pole vaulters and biathletes.

## DEVICE FLOW CHART

My monitoring system consists of two parts: a portable, autonomous unit that you can carry, and a data communication module that enables bidi-

rectional communication with the autonomous unit (see Photo 1). To upload collected data in Offline mode, the autonomous unit can perform the data exchange directly with a PC via a high-speed serial interface. Table 1 illustrates the monitor's technical characteristics.

As I developed the system, I focused a lot of attention on component reuse, because the multiple sensor types must be supported in the single device. Figure 1 illustrates the autonomous unit's flowchart. The monitor supports several operational modes, which are primarily differentiated by input signal sources and post-collection data processing. Now, I'll describe how the device functions in the main operational modes.

| Features | Specifics |
|---|---|
| Supported sensor types | ECG electrodes, LED and infrared light pulse sensors, and a micro-mechanical accelerometer |
| Data collection modes | Online, Offline, and Combined mode |
| Radio data-link operation frequency | 433 MHz |
| Radio transceiver operation range | Up to 300 m in open space, up to 50 m in buildings. A higher range can be obtained with active antennas. |
| Wireless interface data communication speed | 19,200 bps |
| Power batteries | One to two NiCd AA batteries or elements, or a single-cell lithium-ion battery; and one CR2032 lithium battery for real-time counter supply |
| Power consumption (5-V power supply) | 20 to 60 mA depending on the operational mode |
| PC interface type | High-speed RS-232 with automatic shutdown |
| Data flash memory size | 4 Mb with expansion possibility |
| Time of data collection into internal memory | 10–14 h |
| Board dimensions | Autonomous unit: 95 × 90 mm. Data communication unit: 80 × 67 mm. |

**Table 1—***There are several design characteristics that you'll find intriguing, including board size, range, and power.*

## ELECTROCARDIO MEASUREMENT

In Electocardio Measurement mode, the ECG signal is amplified by a low-noise instrumentation amplifier (INA) and reaches the first multiplexer (MUX) input. The integrator (INT) sets the common-node INA signal level and suppresses the AC main's inducted noise at the same time. The multiplexer output signal passes through the high-pass filter (HPF), active transient suppressing system (ATS), and amplifier ($AMP_2$) before reaching the A/D converter ($ADC_1$). The CPU analyzes the $ADC_1$ samples. The low-frequency, 0.05-Hz high-pass filter removes the DC component in the input signal. The ATS provides the short high-pass filter set-up time by detecting $ADC_1$ saturation conditions and increasing the filter's cut-off frequency by several orders.

The $ADC_1$ datastream can be sent via a radio transceiver (RTS). The radio transceiver provides a simple bidirectional data link between the autonomous device and the PC communication unit. At first glance, it may seem somewhat odd that I used the bidirectional data link. But my reason for doing so isn't complicated: the autonomous system's incoming commands allow you to dynamically change the operation mode or measurement settings used to send various commands concerning the dangerous situations to the person being monitored.

Moreover, in the next software release, I plan to add the ability to communicate between devices in Person-to-Person mode. This will be achieved by forming a dedicated network that allows one node to inform others concerning problematic health-related conditions.

Alternatively, the $ADC_1$ samples can be stored in the nonvolatile flash memory for off-line analysis. If flash memory is used, the real-time counter (RTC) provides time stamp information regarding when the measurements started and stopped. The built-in battery back-up RAM is used for flash memory data index storage, which acts as a simple file system. When electrocardiogram collection is finished, you can upload the accumulated data to a PC via an RS-232 interface.

## PULSE MEASUREMENT

In Pulse Measurement mode, the infrared or red LED is powered by the modulation signal generator (GEN) via an output switch (OSW) that's used for switching between two LEDs. The light beam is passed through human tissue and reaches the photodiode (FED). The FED signal is amplified by $AMP_1$ and passes via a band-pass filter (BPF) to a synchronous amplitude demodulator (SAD).

The BPF center frequency is equal to the generator output signal. The SAD output signal reaches the second multiplexer MUX input via a low-pass filter, which suppresses the high-frequency products in the SAD output spectrum. The signal-processing scheme is the same as the electrocardiogram collection mode signal path. The signal-processing scheme is characterized by excellent immunity to light noise from diverse sources such as AC-powered lamps, fluorescent lamps, sunlight, and so on.

## MEASURING PACE RATES

In this case, the accelerometer ACC signal is passed to $ADC_2$ and processed by the CPU. The two independent ADCs allow for the simultaneous transmission of the pulse or ECG waveforms and accelerometer signal, which allows you to discover the correlation between various parameters. For instance, it helps to uncover some abnormalities in the heart rate during an individual's movements.

The switching power supply (SPS) transforms the battery voltage into the required 5- or 3.3-V level. The data communication module is simple and consists of the radio transceiver (the same as for the autonomous unit) and RS-232 level translator.

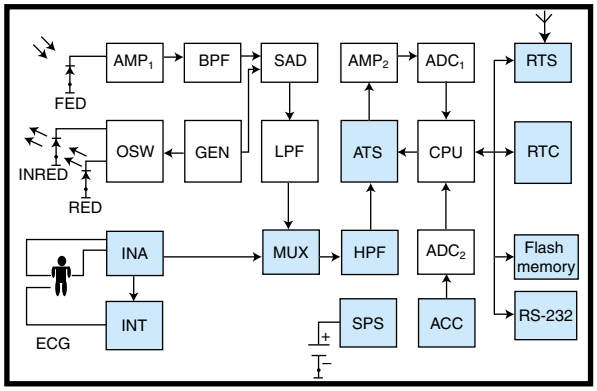



**Figure 1—***The white blocks mark the internal PSoC's units. The blue rectangles correspond to the external components.*

## HARDWARE

The monitor's heart is a reconfigurable Cypress PSoC

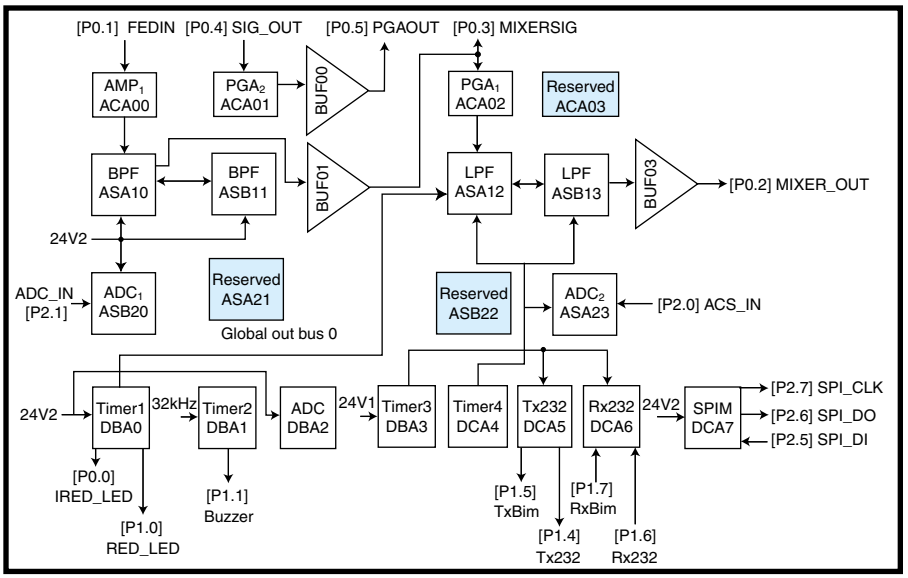



**Figure 2—***The PSoC's internal structure is straightforward. The white blocks are used. The blue blocks are reserved.*

that combines the flash memory-based processor core with a rich set of reconfigurable analog and digital peripherals. These unique peripherals allowed me to simplify the project. You can download the monitor's schematics from the *Circuit Cellar* ftp site. I suggest you first review the monitor schematics and then go on to the processor's configuration.

The modulated light reaches the photodiode ($D_2$) and is routed via a high-pass filter ($C_{10}R_{20}$) to the input amplifier and band-pass filter, which are located in the processor's internal blocks. The filter's output is routed to the TP3 test point for testing and debugging purposes. The amplitude demodulator output signal is passed to the PSoC's internal low-pass filter, and the filter output is connected via the $R_1C_1$ network to the first input of the multiplexer, $U_1$. Note that the $R_1C_1$ discrete low-pass filter suppresses the sampling frequency components and out-of-band noise in the output signal spectrum of the switching capacitor block, and it improves the overall signal-to-noise ratio.

The ECG electrodes are connected to the inputs of the low-noise differential amplifier $U_2$ via a low-pass filter ($R_3R_6C_4$) that cuts the radio-frequency noise signals. The common-mode signal of the instrumentation amplifier is integrated by an operational amplifier, $U_{4A}$, and goes to the right-leg electrode, which sets the differential amplifier input's bias level and suppresses the AC main's inducted noise.

The amplifier's output is connected with the second input of $U_1$. During my experiments, I wanted to use the PSoC dynamic reconfiguration possibility, so I tested the characteristics of the internal PSoC instrumentation amplifier. But, I obtained unsatisfactory INA noise performance and decided to use an external low-cost instrumentation amplifier for better noise characteristics.

The high-pass filter ($R_2C_3C_5$) is connected with a two-stage amplifier. The first stage is implemented on $U_{4B}$. This operational amplifier is characterized by low voltage and current noise. The second stage is implemented on the internal PSoC programmable gain amplifier (PGA). The PGA output is routed via a discrete low-pass filter, $R_{28}C_{25}$, to the input of the 11-bit sigma-delta $ADC_1$. The test point, TP4, can be used for observing $ADC_1$'s input signal.

The gate switch, $U_3$, is used in the active transient suppression circuit; the CPU controls it. The accelerometer, $U_5$, forms the signal proportional to device linear acceleration, and its signal is brought to $ADC_2$.

I used a Radiometrix radio transceiver, $U_{14}$, which is characterized by its low cost, high sensitivity, relatively high data rates, and low supply current. The device operates in an unlicensed 433-MHz band. The radio transceiver is connected to the system serial interface via $U_{15A}$, $U_{15B}$, and $U_{16}$. The $U_{15B}$ gate suppresses the receiver output signal when the carrier isn't detected. The RXS and TXS signals select the receiver or transmitter accordingly.

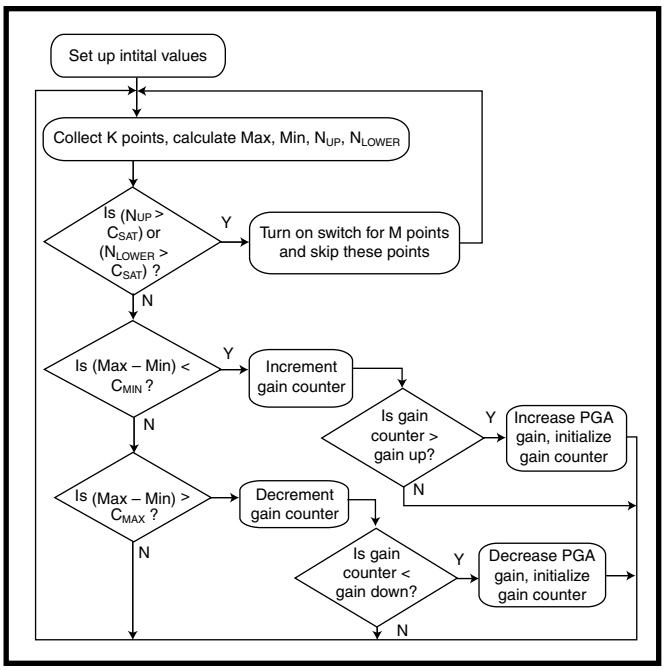


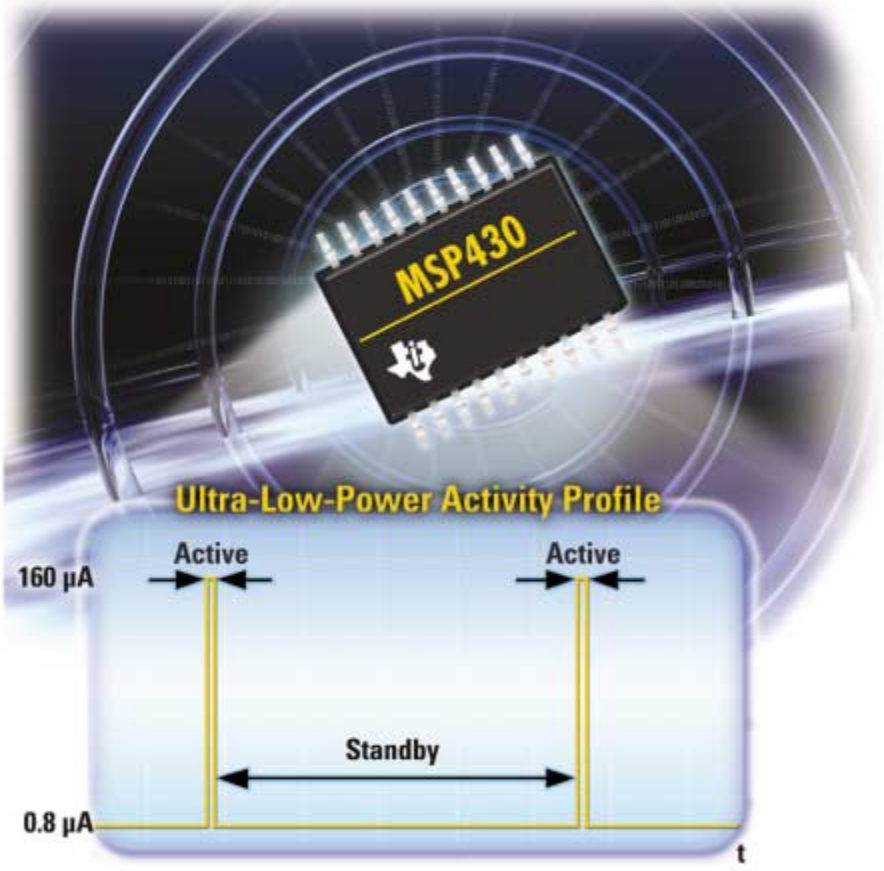

**Figure 3—***Take a look at the automatic gain control and transient suppression algorithm. Max and Min are signal maximums and minimums within* K *sample points. $N_{UP}$ and $N_{LOWER}$ are sample amounts when the sample value is equal to the upper and lower limit in the $ADC_1$ code's range. $C_{SAT}$, $C_{MIN}$, and $C_{MAX}$ are the predefined coefficients.*

## PSoC INTERNALS

The total chip interconnection is presented in Figure 2. The photodiode signal reaches the $AMP_1$ input amplifier, which is placed in the ACA00 block. The amplifier output is connected with the input of the band-pass filter, which is located on the ASA10 and ASB11 switching capacitor blocks.

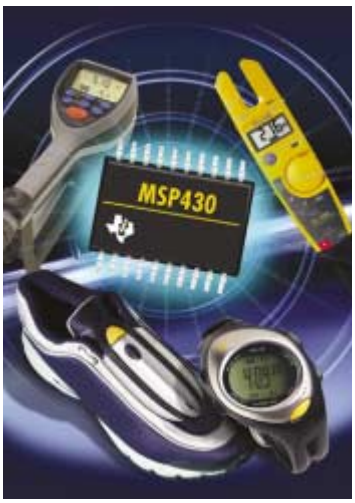
The filter's output is routed to an external pin for testing purposes. By way of a programmable gain amplifier, $PGA_1$, it reaches the signal input of the syn-

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chronous amplitude demodulator. The demodulator is combined with a low-pass filter that suppresses the modulation frequency components and high-frequency noise signals. The filter's cut-off frequency is 50 Hz.

The output of the operational amplifier, $U_{4B}$, is connected via a programmable gain amplifier ($PGA_2$) and low-pass filter ($R_{28}C_{25}$) to the $ADC_1$ input. $ADC_1$ is located in the ASB20 block.

Timer1 is used to generate the modulated signal for pulsometer LEDs. The timer output is connected with the global output bus 0 and used as a reference signal for the synchronous amplitude demodulator. The demodulator's operation is based on the amplitude modulation capability of the ASA12 switching capacitor block. Besides bringing the reference signal to the demodulator, the global output bus 0 is connected to ports P0.0 and P1.0, which drive the infrared and red LEDs, correspondingly. The turning on and off of corresponding LEDs is done by dynamically changing these ports' bit functions. If you want to turn on the corresponding LED, change the port P0.1 or P1.1 function to global output; otherwise, set the port bit as a standard CPU pin. The modulation frequency is 3.75 kHz.

I put the $ADC_1$ counter in the DBA2 block, and fixed the sample rate at 366 Hz. Timer2 is used to generate a variable tone sound and light signals with minimum CPU overhead; it's also used to generate timeout intervals for the communication module.

Timer4 is the clock timer for the amplitude demodulator low-pass filter. Timer3 is used for generating clock signals for the serial interface, which is comprised of a separate serial transmitter, Tx232, and a separate serial receiver, Rx232.

I decided to use two separate modules for building a UART because better API support is suggested by the current version of PSoC Designer. For switching between the RS-232 level translator and radio transceiver, the dynamic multiplexing of transmitter output and receiver input is used by direct modification of the PSoC registers in the firmware. The SPI master module is placed on DCA7 and used for communicating with data flash memory and a real-time clock. Note that the firmware generates the device select signal, SPI_EN.

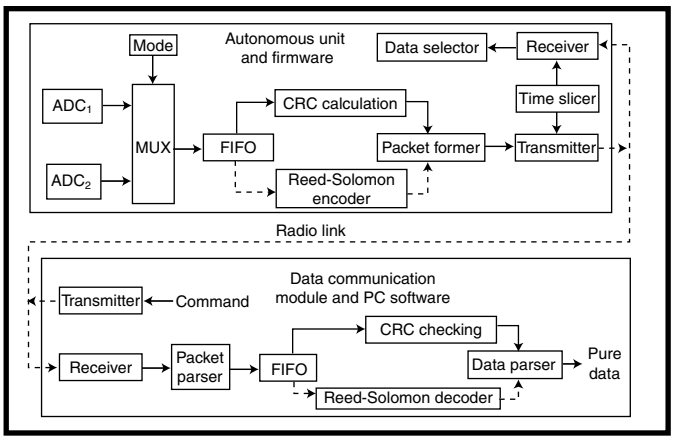



**Figure 4**—*Data flows in this way when it's transmitted by a wireless interface. The $ADC_1$ or $ADC_2$ datastreams are multiplexed, passed through an incoming FIFO, the error-correction coder, packet former, and then transmitted by the transmitter. Or, the time slicer can select the transmitter and receiver. In that case, the received data is passed via a packet parser, incoming FIFO, error-correction decoder, and the data parser—which determines the appropriate data type (cardio, optical pulse signal, or accelerometer).*

## THE MONITOR'S FIRMWARE

The health monitor's software consists of two parts: the autonomous unit firmware and the PC-based software for data analysis, visualization, and documenting. You can download the firmware and software from the *Circuit Cellar* ftp site. The firmware is responsible for the device's general control, data collection, and communication.

The control procedures include the peripheral set initialization, the PSoC on-the-fly dynamic reconfiguration (i.e., changing the port functions and signal rerouting), and the generation of time intervals.

Data collection is performed by the $ADC_1$ interrupt service routine (ISR), which decreases the CPU overhead. This ISR is responsible for the following functions: packing and putting the ADC samples into the intermediate FIFO buffer; performing the automatic digital gain control loop; detecting transient conditions and controlling the active transient-suppression switch; and determining heartbeat pulses and controlling the corresponding LED or buzzer.

The ADC samples are 11 bits wide. They are packaged in a datastream by combining the two adjacent high nibbles into a single byte, and putting that byte together with the FIFO and low samples. During ECG or pulse measurement, the input signal values can be varied in relatively wide bounds. The automatic gain control loop allows you to use the full ADC dynamic range to obtain better measurement accuracy. Changing the high-pass filter DC component input (e.g., during moving sensors positing or even nerve impulses) can raise the ADC saturation within transient time intervals and cause the loss of incoming signal measurements during relatively long periods of time.

I suggest the following reliable algorithm for the automatic digital gain control loop (AGC) together with transient condition detection and suppression: If the signal range is lower than some threshold value, the gain loop counter is incremented. If the gain loop counter reaches the upper predefined value, then setting the next gain level, if possible, increases the gain, and the gain loop counter will be reinitialized. On the other hand, if the signal range is greater than some threshold value, the gain loop counter is decremented. When the gain loop counter reaches a lower limit, the gain is decreased, and the gain loop counter is reinitialized.

When the ADC is saturated on the upper or lower limit longer than the maximum expected signal period, it's considered a transient condition, and the high-pass filter time constant is decreased for a predefined number of the ADC cycles. Note that the difference between the ADC's over-range limits and transient conditions lies in asymmetric saturated points distribution: during over-range there is an equal number of saturated points with lower and upper limits; during transients, the one is much greater than the other.

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Figure 3 illustrates the proposed algorithm, which was implemented in the $ADC_1$ ISR. $PGA_2$ serves the role of the variable gain amplifier.

To detect heartbeat pulses, the software comparator was implemented. The estimated ADC signal swing was used to automatically adjust the comparator threshold and hysteresis. Together with the AGC it guaranties reliable detection of pulse signals and can be used for device self-testing or to adjust the optical sensor location.

The data communication routines are responsible for transmitting the collected data and receiving the control commands from the communication unit. Because the wireless link can introduce errors, error detection/correction must be applied. The firmware incorporates two alternative methods: CRC for error detection only, and the Reed-Solomon encoder to fix multiple errors.

The former method is characterized by low CPU overhead and is preferred when power consumption is critical. The latter is recommended when you want to reach the maximum operational range, because the error rate is large when the receiver's signal is weak. But the CPU must operate at 24 MHz to drive the Reed-Solomon encoder for the desired ADC sample rates. You can select the appropriate coding method when you're ready to compile the firmware.

The health monitor uses packet-based data communication. The collected ADC samples are pushed to the FIFO buffer. When the FIFO is filled, the encoder pops the data from the FIFO and forms the packet. Each packet consists of the preamble to set the receiver gain control and the data bytes mixed with check bytes or CRC. All packet bytes are XORed by AAH for bit dithering. When the packet is ready, the transmitter is activated and transmission starts.

The Radiometrix transceiver operates in Simplex mode, and must be switched to Receiver mode when you want to receive incoming data. Because the pause between adjacent packets is not enough to properly set the Radiometrix receiver's gain level, the firmware periodically stops transmission for several tens of milliseconds, switches the transceiver to Receiver mode, and checks the incoming data. There are no losses in the monitor datastream because the FIFO provides enough buffering.

My current firmware version employs the simple majority rule to analyze the incoming command. To eliminate the UART polling, data transmission and reception has been implemented in the transmitter and receiver ISRs. Figure 4 depicts the overall communication data flow.

## DATA ANALYSIS SOFTWARE

The data analysis software receives the incoming packets, and then decodes, filters, and visualizes it. You can store and load the collected data on a disk and perform the simplest waveform analysis (i.e., cursor measurement, range estimation, etc.). The software displays the autonomous unit carrier detection and packet losses ratio, as well. You can send a command to monitor and switch the monitor's operational mode (e.g., turn the device to collect the ECG instead of the optical pulse signal).

Photo 2 illustrates the received waveform examples. The software is written in Borland's Delphi 7 and runs on Windows.

## DESIGN OPTIMIZATION

I tried to create a multifunctional device that can cover various customer demands, but some design portions are redundant for some applications. Others must be improved to satisfy special demands.

For instance, you can definitely improve the power efficiency. The accelerometer is relatively expensive both in power consumption and price; it can be omitted for most applications. If you want to create an off-line cardio recorder, you can omit the optical pulsometer portion and reduce the overall power consumption. In addition, the firmware doesn't support the dynamic turning off of the unused PSoC peripheral modules. You can add this functionality to the incoming command-processing routine.

My current design uses the single-channel communication module. If you need to collect and process data from multiple users, you must use multipeer communication modules. Many companies produce these modules. The MaxStream frequency-hopping, low-lost, long-range modules are nice for this purpose. If you want to use the device in hospital rooms, you can try Bluetooth. It's pretty easy to find RS-232-to-Bluetooth converters these days.

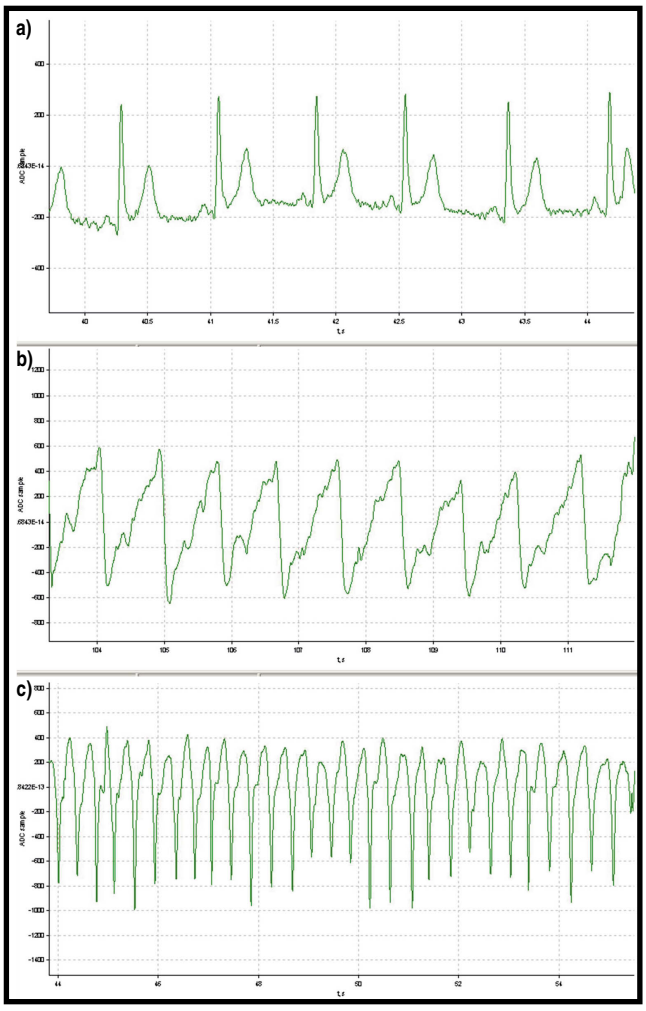



**Photo 2—***With the remote health monitor, you examine the ECG signal (**a**), optical pulse signal (**b**), and accelerometer signal (**c**).*

## OTHER APPLICATIONS

You can use the suggested health monitor structure as a foundation for creating alternative applications. I'll briefly describe four possibilities.

One option is a portable, autonomous electrocardiogram data logger with an acoustic or phone line modem. The PSoC dynamic reconfiguration allows you to combine various functions in one system with minimal cost increases.

Another option is the reliable optical pulsometer. The proposed photodiode signal-processing scheme is characterized by excellent light-noise immunity. For the reliable estimation of a pulse rate, I recommend the robust statistics method. You can exclude the external amplifiers and digital buffers if you only want to measure the pulse rate.

The third possibility is the pace rate meter and counter. Only the accelerometer sensor may be left for this device. Virtually all of the analog parts can be eliminated. To reduce the cost, the MEMS accelerometer can be replaced with a low-cost piezoelectric vibration sensor. The PSoC allows you to process the sensor signal without external components.

Finally, there's the on-line driver health state monitor. Together with dedicated data analysis software, you could use the proposed system for car, truck, or train drivers. The information could be used to detect dangerous situations (e.g., sleep, loss of consciousness, infarct, death, etc. of the driver) and the braking of a car or train.

*Victor Kremin earned a diploma in radio physics in 1996 from Ivan Franko National Lviv University and a Ph.D. in Computer Aided Design Systems in 2000. Currently, he's an associate professor at the National University "Lvivska Polytechnika" in Ukraine. Victor's interests include all aspects of embedded systems design. You may reach him at vkremin@polynet.lviv.ua.*

## PROJECT FILES

To download the code, go to ftp.circuitcellar.com/pub/Circuit_Cellar/2003/155/.

## RESOURCES

J. Bachiochi, "Smart RF Designing," *Circuit Cellar* 149, December 2002.

Cypress MicroSystems, "CY8C25122, CY8C26233, CY8C26443, CY8C26643 Device Data Sheet for Silicon Revision AD," 38-12010 CY Rev. 3.20.

R. Hood, "The PSoC 5-Cent Modem," *Circuit Cellar* 146, September 2002.

## SOURCES

**AD620 Instrumentation amplifier, ADXL105 MEMS accelerometer**
Analog Devices
(781) 329-4700
www.analog.com

**CY8C2*xxxx* Microcontrollers**
Cypress MicroSystems
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# The Altmotor

*Most robotics projects require powerful, high-torque motors. Understanding the need for such a motor but unwilling to spend the cash on one, Chris built his own variable-speed motor. If you think it was a complicated project, think again. All it took was a little imagination and the alternator in his wife's van.*

A powerful motor with high torque is necessary for many robotics applications. For instance, your BattleBot may need to swing a battle-ax at its opponent; or one of your service robots may need both torque and speed to push, lift, and climb. Although industrial 180-VDC motors are available in the 1-hp range, they cost more than $600. In an effort to recycle scrap car parts and save some cash, this article focuses on the transformation of an automotive alternator into a stepper motor (i.e., the Altmotor) and the design aspects of its driver circuits.

First, I'll describe the alternator and the transformation modifications. Then, I'll cover some background material concerning stepper motor driver circuits. I'll close with the details of the final design.

## ALTERNATOR POWER

An automotive alternator converts mechanical energy to electrical energy in the form of direct current (DC). The average output is in the approximate range of 14 V and 50 A, which corresponds to an output of one electrical horsepower. (Note that 1 hp = 746 W.) Therefore, by driving an equivalent amount of electrical energy into an alternator, I would expect to extract that magnitude of mechanical output to make the Altmotor.

One way to achieve this is to remove the rectifier assembly from the alternator and drive the stator coils directly. At the same time, a bias current is fed to the armature via the slip rings to maintain a constant magnetic field around the rotor assembly. When the stator coils are energized and deenergized in sequence, the fixed magnetic field around the rotor assembly is pulled around like a stepper motor.

The rotor's speed (rpm) is determined by the stepping frequency and, ultimately, by a variable clock source. Further-more, the maximum torque is available at 0 rpm and decreases as the speed approaches the Altmotor's speed limit, which is in contrast to induction-type motors in which the maximum torque is obtained only around the operational speed (e.g., 1725 or 3450 rpm). Thus the Altmotor should be an ideal power plant for many robotics applications.

## INSIDE AN ALTERNATOR

Let's begin with a short description of the modifications to the alternator. I'll touch on some of the characteristics of its key components.

Photo 1a shows the alternator—which I borrowed from my wife's van—disassembled and cleaned up. (Note that WD-40 and a toothbrush work great for removing stubborn grease and dirt from the aluminum housing.) As you can see, I've included the major components of the alternator (from left to right): the pulley and fan, front housing, armature, and rear housing. The stator windings and brush assembly are shown in the foreground.

As part of the clean-up process, I polished the slip rings on the rotor with 600-grit emery paper. The extension wires (10-gauge) are soldered to the phase leads and insulated with color-coded heat-shrink tubing. Red is connected to the common of all three phases. Blue, green, and yellow are arbitrarily connected to phases A, B, and C.

The brush assembly has new brushes and springs, which I obtained from a local auto parts store. In preparation for reassembly, the compressed brush-

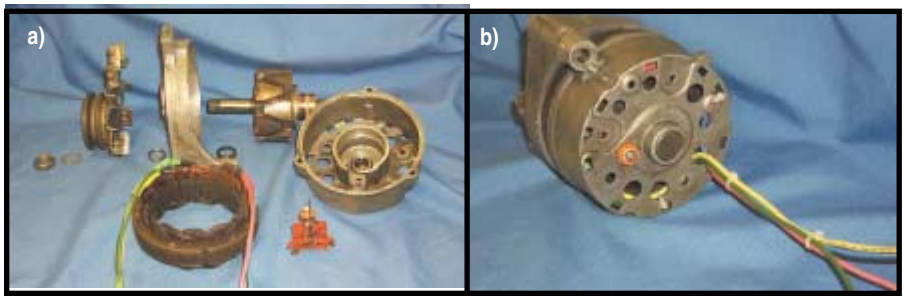



**Photo 1a—***Take a look at the disassembled alternator with the rectifier diodes removed and extension wires attached to the stator windings. From left to right are the fan and pulley, the front housing, the armature assembly, and the rear housing. The new slip-ring brushes and springs are held in place with a small drill bit.* **b—***I reassembled the Altmotor with the extension wires exiting the rear housing through one of the holes where a diode was mounted. Small wire ties secure the 10-AWG wires to each other and to the case.*



**Photo 2—***I tested the static torque of the Altmotor using a 12″ lever arm and adjustable weights. The 50-A supply on the top bench powers a single stator coil. The smaller supply provides 2 A to the armature. Note that 270 ounce-inches of torque were developed at 26 A.*

spring assembly was held in place with a small diameter drill bit. I removed the entire rectifier assembly from the rear housing to make room for the extension wires. With the connections to the diodes severed, the stator windings can be removed as a complete unit.

The stator is wound with magnet wire around a laminated core, which is used to minimize eddy-current losses. The stator's coils are wound around several slots in the core to dimensionally match the lobes of the pole pieces on the armature. The number and placement of the coils determine the step size when the unit is driven as a stepper motor. In this particular case, there are three phases and 12 sets of coils. Thus, there are 36 full steps per revolution with 10° of rotation per step.

The armature assembly consists of the following main parts: a winding, slip rings, and pole pieces. The winding is wound concentrically around the rotor shaft and the slip rings supply DC current to the winding to create an electromagnet. To bend the magnetic field and concentrate it on 12 specific poles, two end plates, or pole pieces, sandwich the coil. Note that the pole pieces of the armature are fabricated from a solid block of steel rather than laminations. Not only is it simpler to manufacture this way, but it also supports a static magnetic field, and eddy currents are not a concern.

As you can see in Photo 1b, the transformed alternator was reassembled with the extension wires exiting the rear housing through one of the holes where a diode was mounted. The assembled unit was ready for testing the inductance and static torque. In both tests, the common (red) was connected to the positive output of a bench supply while one of the phase wires was grounded.

In testing the inductance, several resistors of known value (i.e., 30, 15, 5, and 1 Ω) were connected between the phase being tested and ground. The power supply was set to 10 V, and a switch was used to complete the circuit. An oscilloscope was used to measure the voltage drop across the resistor (and the current) as a function of time. I computed the inductance using the measured data and equations that I'll discuss shortly. The resulting values were in the range of 180 to 250 µH. At the higher currents, the magnetic field extended further into the armature and increased the inductance.

I could have used Maxwell's equations, field theory, and calculus combined with the geometries of the armature and stator to compute the theoretical torque of the motor. Instead, I went to the lab and measured the torque.

Torque is, by definition, a force acting on a lever arm that rotates about an axis. To measure the static torque of the motor, a single phase was connected to the power supply directly. A secondary supply was used to bias the armature with 2 A of current. The pulley was removed, and a 12″ lever arm was bolted down to the fan (see Photo 2).

The current in the stator phase was set in increments of 2 A, and weights were added to the end of the lever arm until the Altmotor cried uncle and was back-driven by the load. The results are plotted in Figure 1.

The idea was to find the system's saturation point—where increasing the current didn't increase the holding torque (a plateau on the curve). But, the weight supply was exhausted at 25 A, so I needed to either obtain additional weights or extend the lever to find the limit.

The electrical diagram in almost any automotive repair manual will show the alternator circuit (see Figure 2). Over the years, the three-phase Y-configuration alternator has proven to be both efficient and compact. Each phase is full-wave rectified, and the current in the armature is adjusted to maintain a relatively constant voltage regardless of engine speed or electrical load on the output.

To better illustrate the interaction between the three phases and the armature, Figure 3 shows that each phase consists of several smaller coils in series. Each phase is staggered around the armature.

## STEPPER DRIVE CIRCUITS

Depending on the particular circuit requirements and motor characteristics, stepper motors and motors in general can be driven by any of the many varieties of power FETs or insulated gate bipolar junction transistors (IGBT). When the supply to the motor is 200 V (or more), IGBT drivers are a good choice because they have higher breakdown voltages. Also, at these voltages, the collector-to-emitter saturation voltage drop is a small percentage of the supply, which

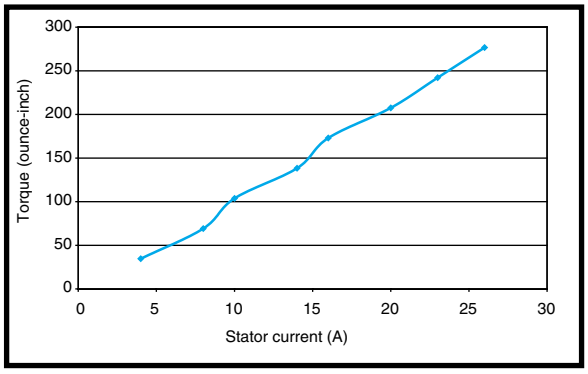



**Figure 1—***I plotted the data taken during the static torque test. Note that the testing stopped when the weight container was full. However, the 60-A rating stamped on the casing gave reason to extrapolate the curve to a maximum of 650 ounce-inches, or 54 pounds-inch at 60 A.*

factors into the efficiency of the system.

For high currents (i.e., 50 A or more), low $R_{DSON}$ FETs offer lower voltage drops than IGBTs; therefore, they make for a more efficient driver. In either case, the proper selection should be made with regard to power dissipation and the safe-operation-area (SOA) curves, as well as breakdown voltages.

Most stepper motors are driven in either Unipolar or Bipolar mode. The choice between the two is often driven by the need for simplicity, lower cost, or higher performance. Unipolar drives are simple, so they're less costly to build. In contrast, bipolar drives provide higher output torque at the expense of complexity and cost.

The unipolar drive circuit (download the diagram from the *Circuit Cellar* ftp site) uses a driver per phase with the common of all phases tied to the positive supply. Thus, the phases are always energized in the same polarity.

The drivers are shown as generic transistors to represent either FET or IGBT. The resistors represent the inherent resistance of the winding itself and any external ballast resistance. External ballast resistors can be added to operate the motor at higher voltages and faster step rates. The drivers are turned on in sequence to pull the permanent magnet rotor around.

The frequency at which the drivers sequence on and off has a practical limit that's dependent on the motor, load, and circuit. In general, when an unloaded motor is stepped at a rate that exceeds the time required for the rated current to build up in the coils,

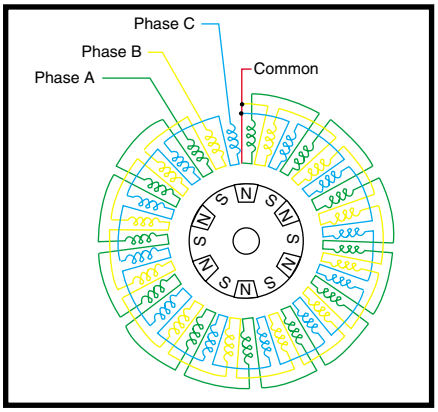



**Figure 3**—*The stator windings illustrate the Y connections and that each phase consists of several coils in series. The poles of the armature show how the rotor aligns with each phase as it's energized.*

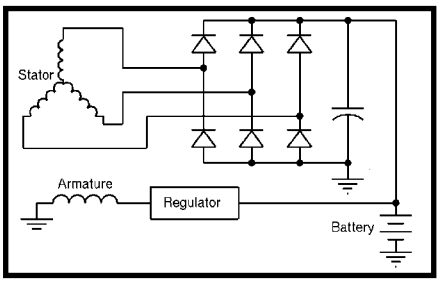



**Figure 2**—*Take a look at the three-phase Y wiring of the stator coils and slip rings to the armature winding. The six diodes provide a full-wave rectification. The regulator adjusts the current in the armature to maintain a constant voltage output regardless of the speed or load.*

the motor loses torque and stalls. After the motor stalls, the stepping speed must be reduced to the point at which the rotor will catch and start turning again. The time required for the rated current to build up in the coils is governed by the LR circuit, which is defined in Equations 1 through 3.

Equation 1 is simply Ohm's Law, which defines the maximum current:

$$I_{MAX} = \frac{V}{R} \quad [1]$$

Equations 2 and 3 define the current as a function of time, resistance, and inductance.

$$I(t) = I_{MAX}\left[1 - e^{\frac{-t}{\tau}}\right] \quad [2]$$

Because Equation 3 defines the time constant, this type of drive is often referred to as an L-over-R drive.

$$\tau = \frac{L}{R} \quad [3]$$

Although unipolar drives are simple and lower in cost, bipolar drives are capable of producing more torque for a given motor. You may download an illustrated comparison between the voltage output of the alternator (with the diodes removed) and the unipolar drive signals from the *Circuit Cellar* ftp site. In the three-phase example, each phase of the alternator swings both positively and negatively, while the unipolar drive only pulls down. Thus, the unipolar driver is similar to a half-wave rectifier and utilizes only half of the available power.

You may download a schematic of a three-phase bipolar drive and motor from the *Circuit Cellar* ftp site. The sequencer provides the step logic, and the buffers turn on and off the power transistors. If you download the schematic, you'll see that the high-side drivers are referenced to the supply to drive the upper transistors, and the low-side drivers are referenced to ground. The circuit can drive each of the three phases both positive and negative using an H-Bridge driver. The common to all three phases is not connected; therefore, to complete the circuit, one of the lower transistors has to be on while an upper transistor of a separate phase is on.

## STEPPER MOTOR SEQUENCING

The sequence of turning on and off the drivers is referred to as the stepping sequence. This can be done in Full-Step, Half-Step, or Micro-Step mode. In this article, I'll focus on the Full-Step and Half-Step modes, and save microstepping for some other time.

In Full-Step mode, only one phase is energized at a time, and the armature rotates to align with the coil, making a full step. Table 1 lists a full-step sequence for a unipolar driver and a three-phase stepper motor (Altmotor). Energizing the phases in the order 1-2-3-1-2-3 rotates the rotor in one direction. Reversing the order, 3-2-1-3-2-1, rotates the rotor in the opposite direction.

The sequence for Half-Step mode is also listed in Table 1. Here, the sequence alternates between having one and two phases on, and the armature rotates to align between the coils, making a half step. Thus, it takes two times as many steps in Half-Step mode

| Step | Phase A | Phase B | Phase C |
|---|---|---|---|
| **Full-step sequence** | | | |
| 1 | 1 | 0 | 0 |
| 2 | 0 | 1 | 0 |
| 3 | 0 | 0 | 1 |
| 1 | 1 | 0 | 0 |
| **Half-step sequence** | | | |
| 1 | 1 | 0 | 0 |
| 2 | 1 | 1 | 0 |
| 3 | 0 | 1 | 0 |
| 4 | 0 | 1 | 1 |
| 5 | 0 | 0 | 1 |
| 6 | 1 | 0 | 1 |
| 1 | 1 | 0 | 0 |

**Table 1**—*The full-step sequence for a unipolar driver and a three-phase stepper motor is straightforward. Note that a one represents that the respective phase is on, and a zero means that it is off. The sequence for Half-Step mode alternates, so it takes twice as many steps to rotate.*

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to make a complete rotation, but the angular resolution of each step is doubled (i.e., 5° in the case of the Altmotor).

To expand the full-step unipolar stepping sequence in Table 1 to a bipolar stepping sequence, you need to add three more columns for the high-side logic. Table 2 was generated by carefully inspecting the alternator three-phase voltage waveforms to see which phases needed to be driven high or low and what the drive sequence should have been.

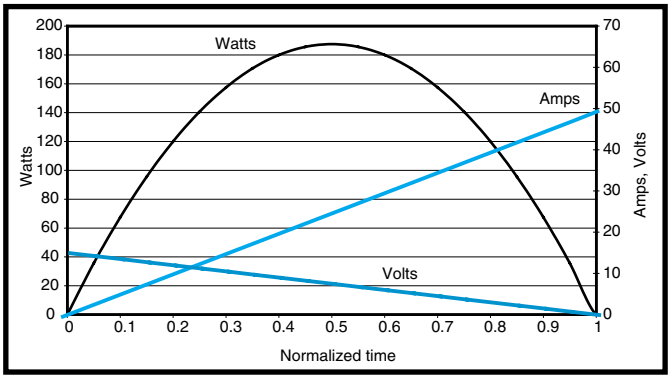



**Figure 4—***You can study how power was dissipated in a single switching event. The current started at 0 A and built to 50 A, while the voltage across the transistor dropped from 15 to 0 V. The area under the watt curve represents the total power; it's averaged by the ratio of turn off or on times to the chopping frequency.*

## INITIAL RESULTS

The initial testing of the hardware and software with the Altmotor was carried out using 1-Ω ballast resistors in Unipolar mode. The drive transistors were surface-mount FETs that had 3.5 mΩ of on-resistance. This indeed proved to some skeptics that energizing the coils could spin an alternator.

However, using a 10-V power supply to power the Altmotor limited the current to 10 A, which also did not produce a lot of torque. One way to increase the current would be to use a higher voltage.

A 100-V supply and 2-Ω ballast resistor would put 50 A into the Altmotor so I could obtain that horsepower; however, it would also consume 5000 W of power. Oh, did I forget to mention that I was building a space heater, as well? This kind of efficiency is simply not green at all, so let's turn our attention to chopper-drive technology.

With a chopper driver, the ballast resistor is replaced with a low-value shunt resistor that monitors the current. When the current exceeds the set point, the driver is turned off. After a delay, the driver is turned on, and the process repeats itself, usually in the 30-kHz frequency range or above. The unipolar driver circuit used for initial testing would have to be modified to handle the additional power dissipated from both the higher current and switching.

## CHOPPER DRIVER

The power that's dissipated in a FET during switching peaks when half the supply voltage is across it and half the maximum current is passing through it. I used a spreadsheet to estimate the power in a switching transient using numerical integration.

The switching transient that's modeled uses a 15-V supply and 50-A load. The results of the ideal integration are plotted in Figure 4. The average power is 125 W for a single switching event. As long as the peak is within the SOA for the particular transistor, no damage should occur.

One reason the integration is ideal is because the voltage curve goes to zero at the right when in fact there will be a small saturation voltage drop. Nevertheless, you can use the following equation to estimate the total power the drive transistor needs to handle:

$$P_{AVG} = 2P_{SW}\left(\frac{t_{SW}}{t_{PER}}\right) + P_{ON}\left(\frac{t_{ON}}{t_{OFF}}\right) \quad [4]$$

In Equation 4, $P_{SW}$ is the switching-transient power, and $P_{ON}$ is the saturation voltage drop times the current. The fraction of switching time is represented by the switching time, $t_{SW}$, divided by the period, $t_{PER}$. A coefficient, *2*, is used to include both the turn on and turn off switching transients. The duty cycle fraction is simply the on time, $t_{ON}$, divided by the off time, $t_{OFF}$.

For clarity, let's use the aforementioned integrated power and a chopping frequency of 100 kHz with a 50% duty cycle. Also, the FETs in this example are turned on in 200 ns and have an on-resistance of 5 mΩ. The computed average power is 11.25 W (i.e., 5 W switching and 6.25 W full on).

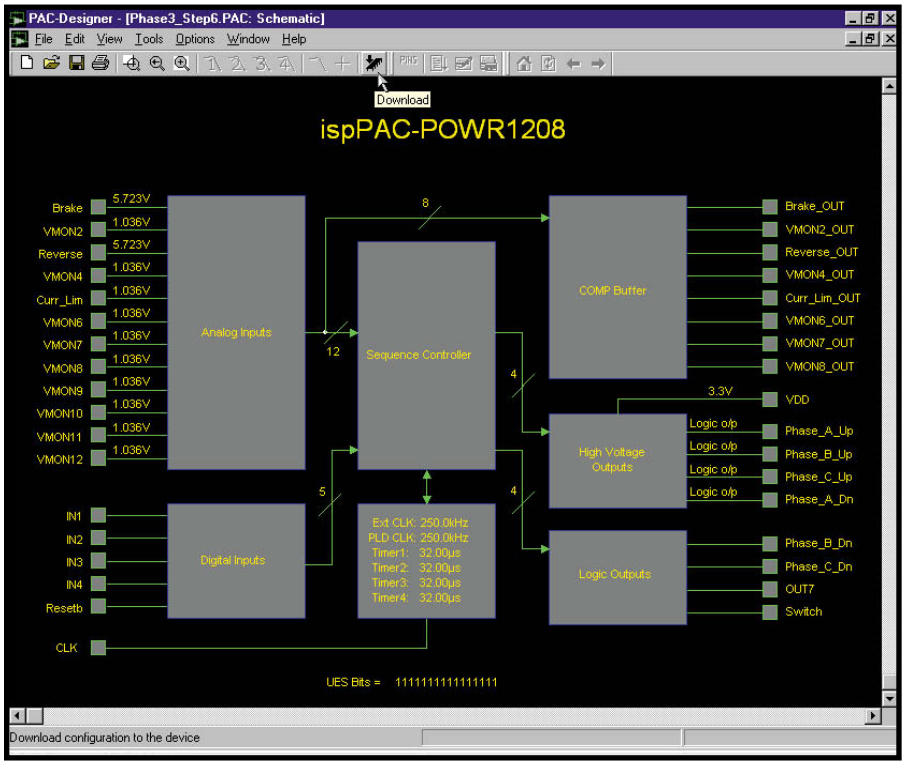



**Photo 3—***The top-level schematic of the PAC-Designer shows the analog and logic inputs are on the left. Comparator buffers, high-voltage and open-drain outputs are on the right. In the center are the clock and timer and the sequence controller. Each block has a dialog box that allows you to adjust the device's programmable features.*

| Step | Phase A down | Phase B down | Phase C down | Phase A up | Phase B up | Phase C up |
|---|---|---|---|---|---|---|
| 1 | 1 | 0 | 0 | 0 | 0 | 1 |
| 2 | 0 | 1 | 0 | 0 | 0 | 1 |
| 3 | 0 | 1 | 0 | 1 | 0 | 0 |
| 4 | 0 | 0 | 1 | 1 | 0 | 0 |
| 5 | 0 | 0 | 1 | 0 | 1 | 0 |
| 6 | 1 | 0 | 0 | 0 | 1 | 0 |
| 1 | 1 | 0 | 0 | 0 | 0 | 1 |

**Table 2—***The bipolar step sequence for a three-phase motor shows the state of both the upper and lower drive transistors. Note that both the upper and lower drivers of the same phase are never turned on during the same step, and have a full step between the on steps to provide ample dead time.*

For the three-phase motor, this power figure is scaled down by a factor of three. Also, the turn-on transient produces less heat than the ideal integration, because the inductance of the phase winding causes the current to lag. Similarly, the turn-off transient will produce more heat than the ideal integration. Nevertheless, this type of calculation indicates that a MOSFET in a $D^2$ package on a square inch of PCB will not last very long.

Using the Tim Allen school of thermal engineering, I went to the garage and dug out the largest heat sink I could find. And, just to be on the safe side, I selected one that was outfitted for water-cooling.

## EXAMINING THE CIRCUIT

Figure 5 is the final block diagram of the system, which drives the Altmotor in Bipolar mode. I chose an International Rectifier H-Bridge driver, IR2106, as the gate driver. This device uses positive logic to match Table 2, and it doesn't have a built-in dead-time delay. The sequence in Table 2 inserts a full step of dead time, so a built-in delay isn't required. The dead-time delay prevents both the upper and lower drivers from being on at the same time and creating a dead short across the supply.

The resulting drive circuit for a single phase is shown in Figure 6. Three gate buffers are paralleled to modulate Q1 to minimize switching times and to

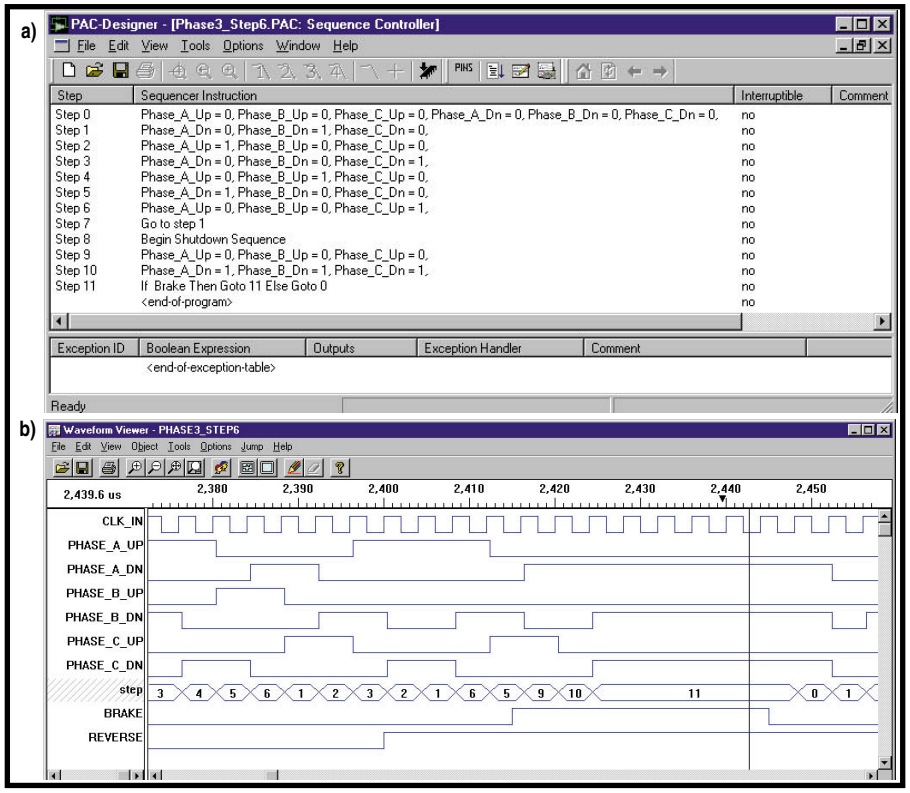



**Photo 4a—***The LogiBuilder interface of the PAC-Designer shows the simple output instructions used to implement the stepping logic.* **b—***The simulation results of the modified ABEL code show the reverse and brake functions as well as the stepping logic.*










handle the gate current at switching speeds. To estimate the gate-drive current, divide the total gate charge of the FET by the switching time (i.e., I = dQ/dt).

The maximum total-gate charge for the IRF1405 is 260 nC—switch that in 200 ns, and you have a surge current of 1.3 A. Thus, the capacitor C4 on U1 is a low-ESR capacitor. The other decoupling capacitors are standard.

Diode D1 charges C1 and C2 via R3 when Q1 is on to bootstrap the $V_B$ and $V_S$ pins of U2. The bootstrap will float up when Q1 turns off so that $V_B$ and the high-side gate driver will be 15 V (less a diode drop) above the source of Q2. The resistor R3 and diode D2 protect U2 from negative-going transients. A single-current limit circuit uses the on-resistance of Q3 as a common shunt to monitor the motor current for all three-phase drivers.

The CHOP signal is also common to all three drivers, and the diode D3 isolates the phase-drive signal from the other phase drivers. The phase drive signals (PHASE_A_Up and PHASE_A_Dn) are generated by the sequencer's open-drain outputs. The CHOP signal also comes from an open-drain output, so the pull-up resistors—R1 and R2—are sized so that no output sees more than 5 mA.

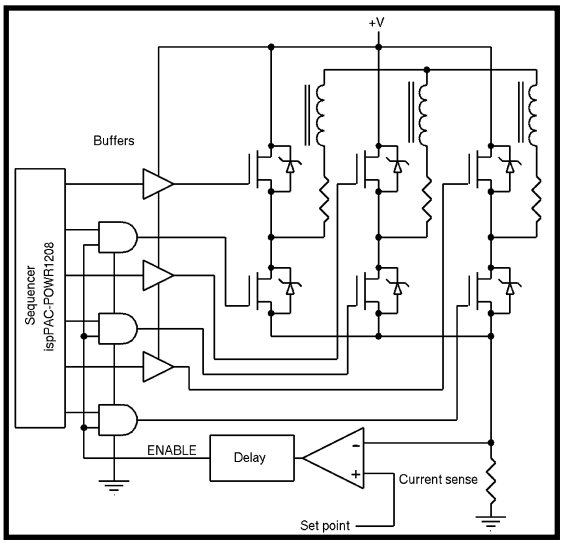



**Figure 5—***In this generic diagram of a three-phase bipolar chopper drive and motor, the low-side transistors are turned off when the current sense exceeds a set point. After a delay, they're turned back on. Note the generic transistor symbols represent either FETs or IGBTs.*

## PROGRAMMING

The sequencer is a Lattice Semiconductor power-manager IC ispPAC-POWR1208 (see Figure 6). It also implements the chopper modulation. This device is designed to sequence multiple power supplies using programmable voltage monitors, programmable logic core (PLD), and programmable gate driver outputs.

On the input side, there are 12 voltage monitors and four logic inputs. On the output side, there are four gate drivers with built-in charge pumps and four logic outputs. The gate drivers (HVOUT pins) are designed to smoothly ramp the gates on power MOSFETs to bring power supplies online. However, in this case, the need was for speed, so the HVOUT pins were configured as open-drain logic outputs and used to control the external gate drivers.

Normally, I would isolate the PLD from the driver circuits and motor with optoisolators, and maintain separate grounds that star at a low-impedance point. However, the PLD inside the ispPAC-POWR1208 is constructed using a special CMOS process that results in an extremely rugged device—so rugged that it can reside on a ground that is bouncing at 30 A and not skip a beat.

I used PAC-Designer software to enter the sequence, simulate it, and program the device. You can download this easy-to-use software from Lattice Semiconductor's web site.

The open-drain outputs were named using the PAC-Designer main schematic to match the six phase-drive signals (see Photo 3). And, one of the VMON inputs was set for the current sense, and the open-drain output was named CHOP. Note that programming

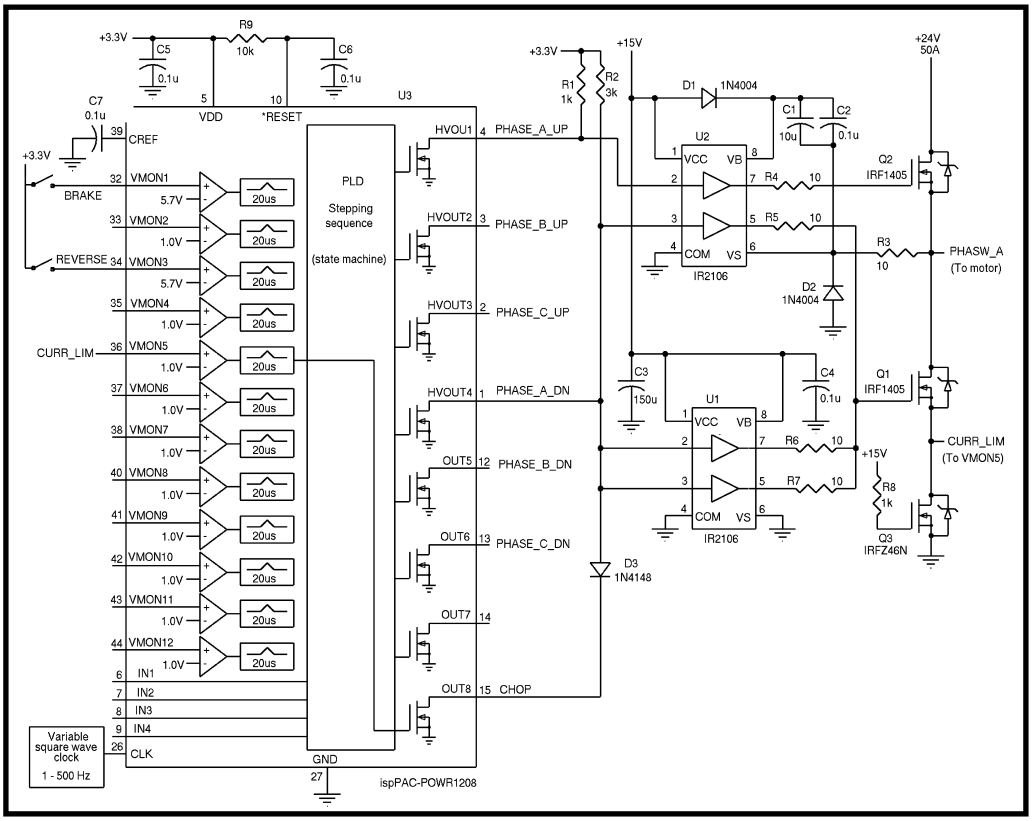



**Figure 6—***When studying this generic schematic of a single H-Bridge phase driver, remember that R8 and Q3 are common to the other two drivers (not shown). The PHASE_A_Up, PHASE_A_Dn, and CHOP signals come from the ispPAC-POWR1208 sequencer. The single wire through the PLD represents the combinatorial logic in addition to the state machine.*

the VMON trip point in combination with the shunt resistor sets the chopper current while the selectable glitch filter establishes the chopping frequency.

In the clock and timer block, the device was configured to use an external clock. After naming the signals, I used the LogiBuilder window to enter the contents of Table 2 as shown in Photo 4a. The additional logic in Step 9 and Step 10 provide support for a dynamic brake. As part of the compilation and fitting process, PAC-Designer generates an ABEL source file from the LogiBuilder window. This source is easily edited using a simple text editor.

The ABEL source was first modified to remove the delay in Step 7 and then to add the reverse and brake functionality. Lastly, the chopper drive signal was implemented using combinatorial logic outside the state machine. The simulation results for the state machine are shown in Photo 4b.

## END RESULTS

Although the resulting drive circuit operated nicely at 24 V (two car batteries wired in series), the dynamic torque was less than I had expected. Simply squeezing the pulley by hand would stall the motor.

The bipolar switch-mode driver did improve the torque at 30 A, but the Altmotor casing became extremely warm. It wasn't hot enough to bake off the enamel coating on the windings, but it was hot enough to out-gas some old engine grease. One possible reason for the lack of torque and excessive heat is that the stator phases were wound overlapping each other in order to concentrate the current generation in Alternator mode. Thus, in Bipolar Stepper mode, they pushed against each other as well as the armature.

Another possible reason for the lack of torque is that the geometry of the pole pieces of the armature doesn't focus the magnetic flux toward stator windings. Although my goal was to end up with a monster robot stepper motor that could swing a battle-ax, the design and testing process provided as much fun as watching robots battle it out.

Well, my wife said something about her van not starting, so I've got to transform the Altmotor back into an alternator. Now, where did I put that diode assembly?

*Christopher Dix earned a B.S. in Engineering Physics and an M.S. in Material Science at the University of Tennessee. Currently, Chris is a Senior Mixed Signal Applications Engineer at Lattice Semiconductor. You may reach him at christopher.dix@latticesemi.com.*

## PROJECT FILES

To download the code and additional diagrams, go to ftp.circuitcellar.com/pub/Circuit_Cellar/2003/155/.

## SOURCES

**IR2106 H-Bridge driver**
International Rectifier Corp.
www.irf.com

**PAC-Designer software, IspPAC-POWR1208**
Lattice Semiconductor Corp.
www.latticesemi.com






# Mad Dash for Flash Cash




## Winners' Announcement

The winners have crossed the finish line in the Mad Dash for Flash Cash. Contestants were challenged to base their designs on the PIC family of microcontrollers from Microchip. The entrants' ingenuity and superior design skills made it a tight race. The results demonstrate why the PIC family is so popular: the versatility and reliability of the PIC12F*xxx*, PIC16F*xxx*, and PIC18F*xxx* have made them effective tools for building dependable embedded applications.

We would like to thank everyone who participated in this contest for making it one of our most successful competitions. The judges based their decisions on technical merit, originality, usefulness, cost-effectiveness, and design optimization. Prizes were awarded for Grand, First, Second, and Third Prize, and Honorable Mention. Congratulations to the winners!

Microchip 2002 Design Contest

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# Grand Prize



## Stealth Telephone Screener

Richard Wotiz, U.S.

Almost everyone has been annoyed at one time or another by an automated telemarketing call in the middle of dinner, to find only silence at the other end of the line. The Stealth Telephone Screener—based on the PIC16F872—answers the phone and determines whether or not the caller is an actual person. If not, it hangs up without disturbing you. Unlike similar commercial products, the caller does not have to know any special code, and is not even aware that they are being screened.

The screener plugs into an ordinary phone line, and has a built-in ringer to alert you when the caller is a person. It works by answering the phone, playing a brief greeting (e.g., “Hello”), and then waiting for a response. If there is no sound for 5 s, or if there is a continuous response that lasts longer than 10 s, then it hangs up. Otherwise, it plays a second greeting (e.g., “Just a minute”), and activates the ringer, while playing a ringing signal to the caller. When you pick up any phone on the same line, the screener stops ringing and releases the line. The ringers on all of the phones are normally kept off, so you would never be aware of a machine-originated call when it comes in.

This technique eliminates both the “predictive dialing” systems (which place multiple calls and only connect to the first person to answer their phone, typically after a delay of more than 5 s, while hanging up on all other calls) as well as automated systems that play a recorded message.

# First Prize



## A USB-CAN-Based Distributed Dual-Axis Motion Controller

Craig Beiferman and Dale Herman, U.S.

During the development of automation equipment, the rapid prototyping of multiaxis designs is often required. You can use centralized controls with PC motion control cards, external amplifiers, and a tangle of wires, or utilize an existing high-cost distributed motion control system with RS-485, Ethernet, or one of the field buses (DeviceNet, CANopen, Profibus, etc.). With a highly integrated microcontroller—the PIC18F258—and power devices like the Allegro A3977/A3959, a small and inexpensive distributed motion control system was developed.

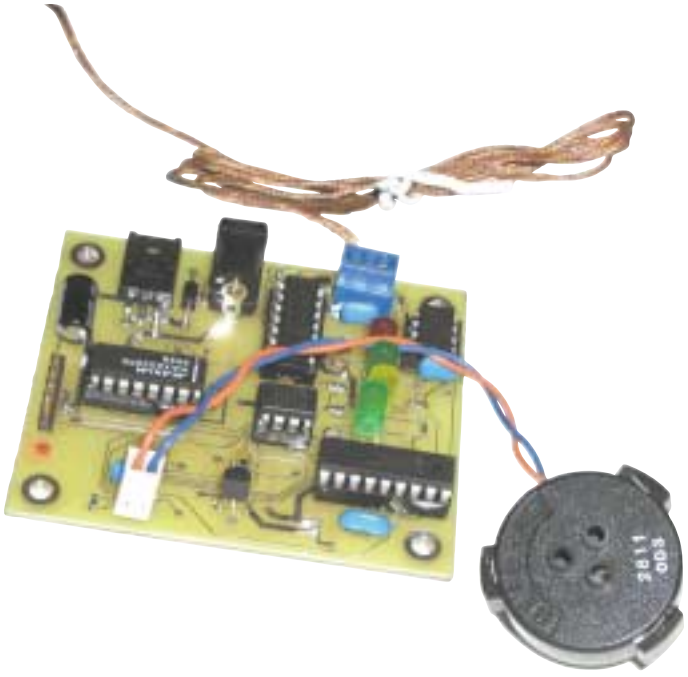


# Second Prize

## Horsepower Monitor

Thomas Dvorak, U.S.

The Horsepower Monitor measures the torque in an automobile's driveshaft and provides an output to a vehicle data recording system or a portable computer via an RS-232 interface. The received data then can be combined with rpm measurements from the data recording system to calculate horsepower. The system consists of the sensor unit, which attaches to the driveshaft, and the receiver unit, which provides the serial output signal. Based on a PIC18F252 microcontroller, the sensor unit is battery powered and communicates with the receiver via a 433-MHz RF data link.



# Third Prize

## Chimney Sentinel

Spehro Pefhany, Canada

The Chimney Sentinel is aimed at preventing fires caused by wood-burning appliances. The device consists of a probe inserted in the chimney and a remote microcontroller-based monitoring unit. When a fire is detected, the Chimney Sentinel sounds an alarm (before smoke has time to reach other detectors within the home). Additionally, it helps prevent fires by monitoring the conditions in the chimney. Creosote tends to build up in chimneys when the temperature in the flue is too low; this build-up can lead to a fire. The Sentinel detects when the flue temperature is in the danger range, and then sounds an alarm if the temperature does not move through the danger zone quickly enough. Even if the heat is such that the sensor is destroyed (the melting point is in excess of 2500°F), the monitor will continue sounding an alarm. The heart of the circuit is an 8-bit PIC16F628 microcontroller with flash memory.

Mad Dash for Flash Cash

# Honorable Mentions

## XY-Plotter

### Robert Lacoste, France

The XY-Plotter is an autonomous analog-like display with two main x and y inputs. It continuously scans the two inputs and displays them on a real-time x-y graph with configurable modes. Both analog and digital auxiliary inputs allow the plotter to display configurable information on the screen. An RS-232 port is provided in order to dump hard copies of the screen to a host computer. A PIC18F252 manages everything in real time, including the LCD pixel generation.

## Zero Pin Loader (ZPL) for the PIC18F Family

### Wouter van Ooijen, Netherlands

The ZPL—a bootloader for the PIC18F*xxx* series—avoids the use of I/O pins by exploiting the *MCLR pin as the only interface between the host PC and the PIC microcontroller. The interface between the PC serial port and the target uses only six components. One of these is the standard *MCLR pull-up resistor. Two others are optional. You could leave out two more resistors, leaving just a single transistor. The interface circuit can be easily put in a DB9 shell, with a DIP clip for the connection to the target. The software runs on Windows and Linux (and other POSIX-compatible systems), and can be easily ported to other operating systems.

## AS7010-STMeter

### Nick Forbes and Junior Powell, U.K.

The AS7010-STMeter is a hand-held installation tool used to set up and configure wireless DSL subscriber terminals operating in a point-to-multipoint configuration. The subscriber terminal (ST) contains both an outdoor antenna unit (radio interface) and an indoor unit with the main processor, voice circuits, Ethernet interface, and maintenance port. To set up a unit, it must be configured with a unique identifier and various radio parameters. Then the outdoor unit must be aligned so that it points toward the central transmitter. Accomplishing this requires expensive equipment, including a laptop computer. The STMeter addresses the problem by providing an inexpensive, easy-to-use installation tool that enables the majority of installations to be carried out without a laptop. Also, you can operate the unit using one hand, to accommodate working on a ladder to reach roof-mounted antennas. The tool is based on a PIC16F877 microcontroller.

## Mechanically Scanned Laser Display

### Benone Radu, Romania

With this simple and inexpensive device, you can display large text messages on a solid or semiopaque surface using a laser beam. The device uses one light source (a laser beam) and mirrors to scan the display surface. The main components include: a laser diode from a keychain pointer, a cassette player motor, a PIC17F877 board with the associated circuitry, a power supply, and an ingenious “head” with mirrors. The head is an octagonal prism, with a small mirror on each lateral face. Each mirror is mounted at a different angle, giving different reflection angles for the laser beam. The mirrors reflect the laser beam, creating a raster. The raster is modulated by turning on/off the laser beam. The microcontroller board receives one pulse per rotation from the rotational speed sensor and calculates precisely the moment for turning on/off the beam.

## Seeker II—An Autonomous Mini-Sumo Robot

### Jon Hylands, Canada

Seeker II is an autonomous mini-sumo robot designed to compete in mini-sumo competitions, which are held in Japan and various cities in North America. It is low, fast, aggressive, and has wide tires that provide a lot of traction. Seeker II’s brain is a PIC16F876, programmed in C. The two-channel PWM provides precise control over the speed of the two motors without using up any processor time. Four ADCs are used to interface to two rangefinders and two edge-detector sensors. One 16-bit hardware timer is used to increment a 32-bit integer millisecond counter, which is used for various timing functions. The UART is used both to program the PIC using the bootloader, and also to run a menu-driven debug system to test and calibrate the motors and sensors. The data EEPROM is used as a log to show the robot’s state transitions.

**The full projects and source code of all winning projects are posted at:**

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# Construct a Hand-Held Radiation Monitor

*If you're a safety-conscious homeowner, then you've probably equipped your house with safety devices like smoke detectors and burglar alarms. But shouldn't you also protect yourself from radiation? If you're interested in doing so but don't want to spend a fortune on a machine, then you can follow Mikhail's instructions and build your own.*

Over the past few decades, almost every household has acquired environmental sensors such as thermostats, fire alarms, and CO sensors. These devices have become standard features in new homes. On the other hand, it's rare to find a household with a radiation sensor. Most people are well aware of the consequences of prolonged exposure to relatively low levels of radiation, but how many of them know the average radiation level in their area?

Background radiation is permanently present. One source is radon gas, which can be found in poorly ventilated basements. Radiation is dangerous because it's odorless, colorless, and lacks any other characteristics that would help us sense it. With this in mind, having some knowledge of the radiation levels around you may offer some peace of mind, especially in this day and age.

Numerous Internet sites sell military surplus radiation counters and similar devices for science projects, but most of them don't fit the purpose I've described. You shouldn't have to rely on a scary and bulky military-like yellow box, but you do need a reliable product with multiple functions rather than a school science-fair project. My hand-held, battery-operated radiation monitor measures the level of radiation on demand. Furthermore, it guards a home by monitoring these levels in Background mode.




**Photo 1—***My radiation monitor is a portable, battery-powered device designed to measure relative levels of radiation. It has a Geiger-Muller tube with a mica window that allows you to detect alpha, beta, and gamma sources of radiation.*

## RADIATION SENSOR

The Geiger-Muller (GM) tube is frequently chosen as a sensor for radiation surveillance. It contains a central electrode surrounded by a mixture of inert gases. High voltage, applied between the center electrode and tube, creates a strong electric field that accelerates any charged particles passing through it. The accelerated particles collide with the atoms of the gas and release additional charged particles. This process produces an avalanche of electrons and can be recorded as a voltage drop between the tube and the central electrode.

According to Tom Dahlin, nuclear radiation exists in the three forms: alpha, beta, and gamma particles ("The (G)Eiger Sanction," *Circuit Cellar* 150). Because a sheet of paper easily stops alpha particles—which cannot travel more than a few inches in air—most detectors count only beta and gamma particle radiation. Including alpha particle radiation may be important in some circumstances, because basement radon mostly releases this type of radiation. To detect it, the GM tube must include a mica window that allows particles to penetrate inside. The radiation level is measured as the number of particles passing through the sensor during a certain period of time. Only a small percentage of the total particles are detected, and this number depends on factors such as operating voltage, the type of tube, and its geometry.

It's common practice to represent radiation levels as the number of voltage impulses counted per minute (CPM). In order to convert this value into a relative unit like a roentgen, you need a conversion chart for each particular type of tube. In my design, I used a commonly available 1504-W GM tube and was able to find the calibration chart displayed in Figure 1.

## OPERATION

The radiation monitor is designed to measure the radiation level in CPM units. It uses a GM tube with a mica window, which allows the sensor to



**Photo 2—***The design consists of an analog board that holds the battery compartment, a Geiger-Muller tube, a high-voltage power supply, and analog circuits that form the count impulse for the digital board. The MCU, LEDs, push buttons, and a buzzer reside on the digital board.*

measure all types of radiation. The device can measure radiation up to 999 CPM, which far exceeds a safe level.

My monitor is designed to work in two different modes—Continuous Measurement and Monitor. In the former, current radiation levels are measured and displayed in CPM units on the LCD. In Monitor mode, the device is on standby and wakes up to make measurements in specified time periods. If provisioned, measurement results are stored in data logs for the current minute, hour average, or day average. Also, if radiation levels cross a certain threshold, an alarm can be activated to produce audio and visual signals.

The device is shown in Photo 1. It has three push buttons and an RS-232 interface for control. A display button is used to power up the LCD. If the display is active, pressing the alarm button activates Monitor mode. In the default configuration, the device conducts measurements every other minute and checks for threshold crossing, even if the display is off.

Independently from the status display and alarm, the measured data is stored in a log and controlled via the Log button. A serial link (2400 bps, 8N1) is used for connecting the device to a host PC and downloading log data for statistical analysis. Also, it allows you to set new values for the alarm threshold and time period between measurements in Monitor mode.

Although the menu is rather primitive, it allows for the display of the current count value, status, and settings on demand. The LCD is used to display the current count, status of the battery, and alarm and log configuration.

The device is powered by two AA batteries, and consumes 16 mA during a measurement. Operation is sustained until the voltage drops below 2.7 V and the low-battery message—LO BAT—is displayed. If this condition occurs while the device is in Monitoring mode, an audio reminder is activated.

## HARDWARE DESIGN

As you can see in Photo 2, the design consists of two pieces. An analog board holds the battery compartment, GM tube, high-voltage power supply, and analog circuits to form the count impulse for the digital board. The MCU, LEDs, push buttons, and buzzer reside on the other board.



**Photo 3—***The MSP430F435, which is located on the digital board, counts the number of impulses per minute and displays the result on the LCD. Also, it maintains the status of the push buttons and LEDs.*

Figure 2 is a schematic of the analog board. A multivibrator built with transistors, Q1 and Q2, generates narrow impulses in a 1-kHz period. They drive the primary side of a step-up transformer. I used a standard audio transformer with primary and secondary sections connected in series to form an autotransformer. Special attention must be paid to the connection between the end and beginning of these sections (noted as a dots on the schematic).

Capacitors C2 to C6 and diodes D2 to D5 form a circuit to triple and rectify the secondary voltage of transformer T1. They are able to withhold 1000 V. A series of Zener diodes, CR1 to CR3, provide output voltage feedback to the multivibrator. The value of the diodes is selected in such a way that it will turn on transistor Q3 if the multiplier voltage exceeds 500 V. Q3 is used as a shunt for generator output; it provides a stable 500-V supply for the sensor.

I used a 1504-W GM tube with mica windows. With a 500-V operating voltage, it detects ionized particles that create a voltage drop of a few hundred millivolts. Passing through blocking capacitor C7, it will trigger the monostable multivibrator build on Q4 and Q5. Capacitor C8 determines the duration of the impulse and its value, which was chosen to provide 2-ms square impulses.

Transistor Q6 is used as a switch to isolate the circuit from the digital board. All common lines on the analog board are connected to the battery through the MOSFET transistor, Q7, which controls power. Note that Q7's gate is pulled to ground to keep the analog board's power off until a logic 1 is present on pin 4 of the interboard connector. It provides power for the digital board, input for impulses, and output for the power-control signal.

I used a Texas Instruments MSP430-F435 microcontroller. Considering that one chip provides an integrated LCD controller along with a UART, keypad interrupt unit, various timer configurations, and unbeatably low power consumption, there isn't much space for alternatives. Despite so many pros, there's one significant con: the part is only available in a small 100-pin PQFP package that makes prototyping difficult.

As you can see in Figure 3, the output of the analog board is connected to port P1.2 of the MSP430. Push buttons are connected to ports 2.2, 2.3, and 2.7. Ports P1.x and P2.x have the ability to generate an interrupt, which is why I used them in the SW design.

P6.4 controls power for the analog board, and P1.5 drives a buzzer using the MOSFET. The buzzer requires a square wave with a 4-kHz frequency; switching between the analog clock output and the port output functions on P1.5 controls it.

Ports P3.6 and P3.4 are used to control the U2 RS-232-level transmitter's Power mode. Normally, MAX3233's Force On and ~Force Off inputs are pulled low. If the device is in Active mode, ~Force Off is pulled up, which activates the transmitters and sets the device into an automatic shutdown mode. It minimizes power consumption by shutting down the transmitters if a transaction isn't detected for 30 s. For more information about this feature, refer to the MAX3233 documentation.

The MCU's LCD module is used to



**Photo 4—***You can use the plug-in adapter and demo program described in TI's application report to program any micro in the MSP430 family.*

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Compact Flash

2 Serial Ports

TS-5400
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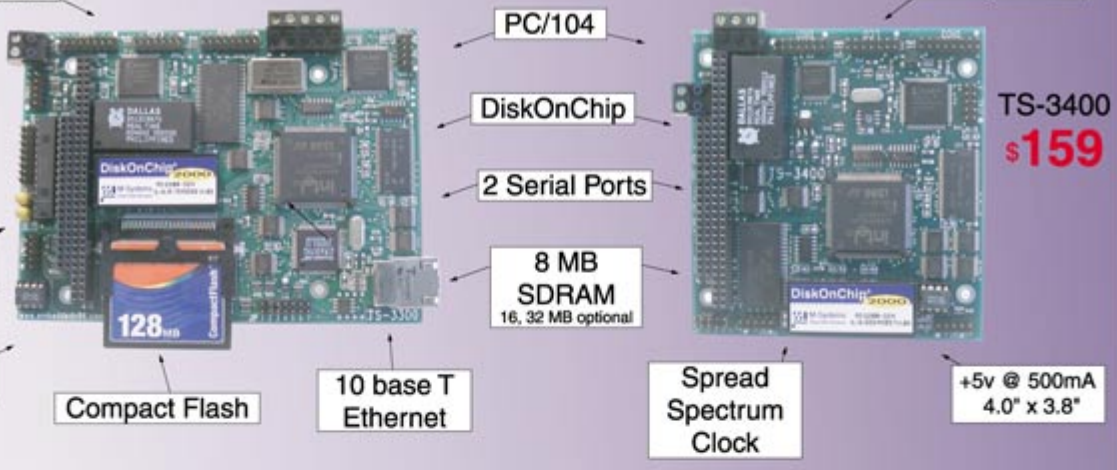
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- Jumper configurable
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* IRQ10-IRQ15 requires 16 bit connector option

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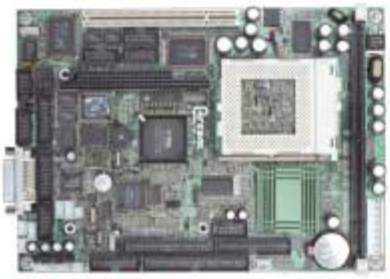
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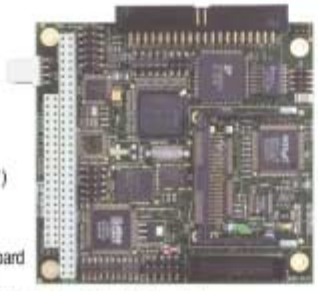


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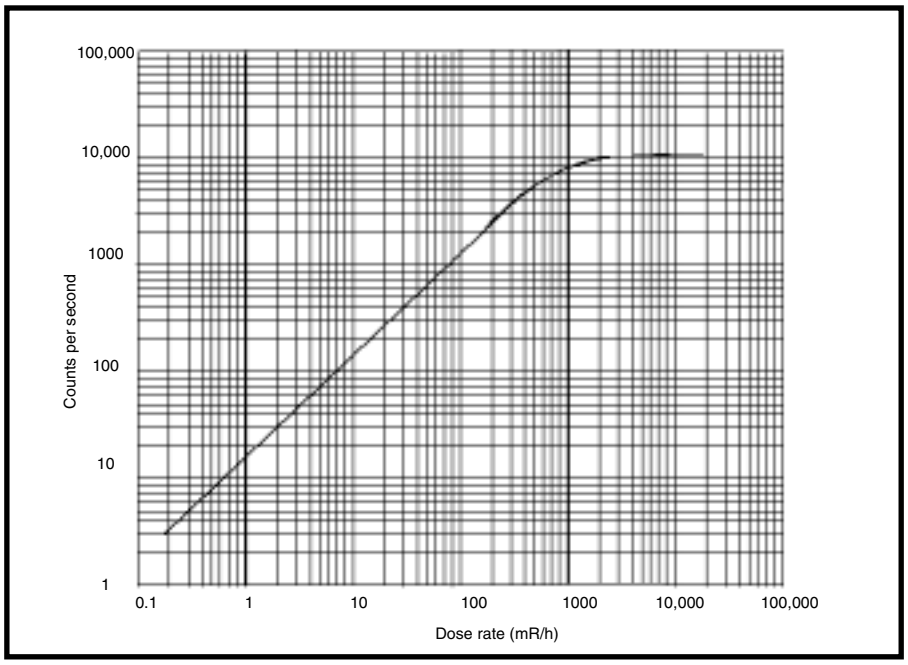



**Figure 1—***It's common practice to represent radiation levels as the number of voltage impulses counted per minute (CPM). To convert this value into a relative unit like a roentgen, a conversion chart for each particular type of tube must be used. This chart is for the commonly available 1504-W GM tube.*

display data and device status. Output pins S0 through S39 are mapped to control the display's segments. They are directly connected to the corresponding LCD's pins. There is an extra connection on a digital board for in-circuit programming (see Photo 3). Most of the parts are surface mounted on the top portion of the digital board. This provides extra insulation from HV power supply circuits.

The MSP430F435 runs a master clock at 1 MHz—a sufficient speed for this type of application. The clock is synchronized with an analog clock using internal circuitry. A 32.768-kHz watch crystal generates the analog clock.

I took my time designing the HV portion of the analog board, because output voltage can leak through parasitic capacitance, which would reduce the efficiency of the converter. Needless to say, 500 V could give you a serious shock, so be cautious.

## SOFTWARE DESIGN

I wrote the software in C with an evaluation version of an IAR compiler. It was limited to 4 Kb of compiled code, which was sufficient for this project.

Regarding the architecture, the software design is driven by interrupts. Figure 4 shows a flow chart that reflects this approach. At power on reset (POR), peripheral blocks are initialized, and the MCU goes into the lowest power mode, LPM4. It enters Active mode (AM) if an interrupt occurs and sets the corresponding mode.

After resuming operation, the UART receiver status is checked. If the command is received, the MSP430 confirms the command and sends a response. Next, the MSP430 checks the battery status, and sets the audio and visual alarm signals if the battery power is lower than 2.7 V.

Also, if the device is in Monitor mode, the MCU will control the power for the analog board. Finally, it returns to LPM4 or LPM3 mode until the next interrupt. During normal operation—as a radiation counter or in Monitor mode—the MCU is set to LPM3 mode. As a result, the MCU's average consumption is minuscule.

The design uses five interrupts: level-change interrupts on ports 1 and 2, basic timer and watchdog timer interrupts, and a UART receiver interrupt. The WDT is used as an interval timer for 1 s; it provides time-keeping functions if the device is in Monitor mode. Also, if the function is provisioned, it

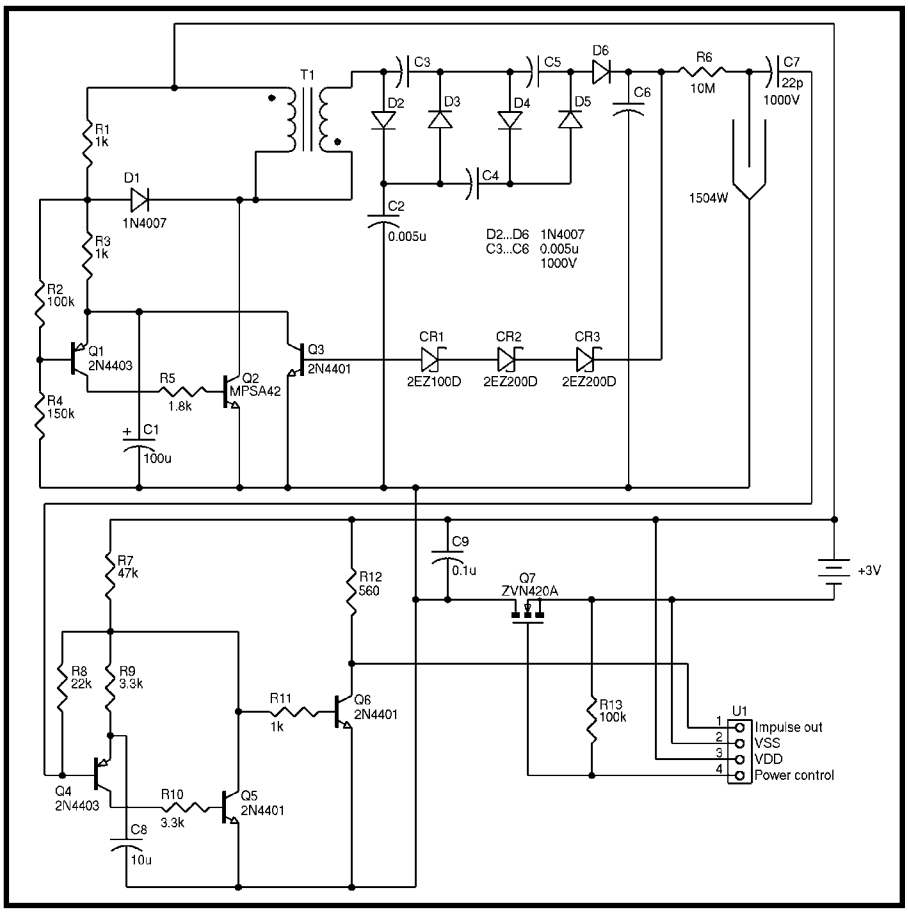



**Figure 2—***The analog board contains a sensor, high-voltage power supply, monostable multivibrator, and power-control circuits.*

will store count data in the logs. In the end, it sets the MCU in Active mode.

A basic timer serves two purposes. First, it supplies the LCD frame frequency rate. (Although it depends on the specific LCD, it's usually about 100 Hz.) Secondly, the timer provides a programmable time delay for the buzzer and LED signals. During the interrupt, all of the signals—as well as the interrupt itself—are disabled. Because the interrupt doesn't require iteration in the main function, the MCU's low-power mode is left unchanged.

The interrupt, triggered by changes in the pins of port 2, is used for push buttons. The ISR determines which button is pushed. If the Alarm or Log buttons are pushed, the MSP430 enables or disables the appropriate functionality by setting the associated flag. If the Display button is pushed and Monitor mode is disabled (alarm and log are off), the sequence to power up or power down will be executed. An impulse from the analog board triggers an interrupt on port 1. After the current-second counter is incremented, the total number of impulses for the last 60 s is calculated, and the value is displayed on the LCD. Also, count values are checked for alarm threshold crossing, and the type of audio singling is set.

A short beep and LED blink means that the impulse was counted, whereas a longer beep means that the threshold was crossed. Because a series of longer beeps is produced under excessive radiation levels, you'll recognize it as a constant sound. The UART interrupt is triggered after the arrival of a new character. It stores the character in the receiver buffer (global, rx_buffer) and checks if the buffer is full, or if a carriage return (CR) is received. Under those conditions, the MSP430 will set a flag (global, rx_flag) for new command parsing. Before returning from an interrupt, it will set the MCU in Active mode, allowing one iteration inside an infinite loop in the main function.

## IN-CIRCUIT PROGRAMMING

The MSP430 supports In-Circuit Programming mode, which is a big help during prototyping and debugging. Texas Instruments has two application notes—SLAA089A and SLAA096B—that describe the MCU bootstrap loader features as well as a demo program. Both documents are posted on the company's web site. [1, 2]

Using this information as a reference, I redesigned the hardware adapter to simplify the programmer design. You can implement the adapter used by the demo program in the application notes to program any MCU from the MSP430 family (see Photo 4). The adapter uses only one chip, the MAX3243, for UART-level conversion. The target board supplies power for the programmer.

Figure 5 is a diagram of the programmer. In order to comply with the original design, the RS-232 transceiver should have inverting and noninverting outputs. Because the MAX3243 has only one noninverting output, transistor Q1 is used as an external inverter. Selecting another RS-232 transceiver (e.g., the MAX3241, which has two noninverting outputs) allows you to reduce the part count even more.

The programmer's software was used without significant changes. In the future, a Windows-based GUI will bring convenience and completion to that design.

## MEASUREMENT RESULTS

It's no secret that the first thing you'll want to do after finishing the project is

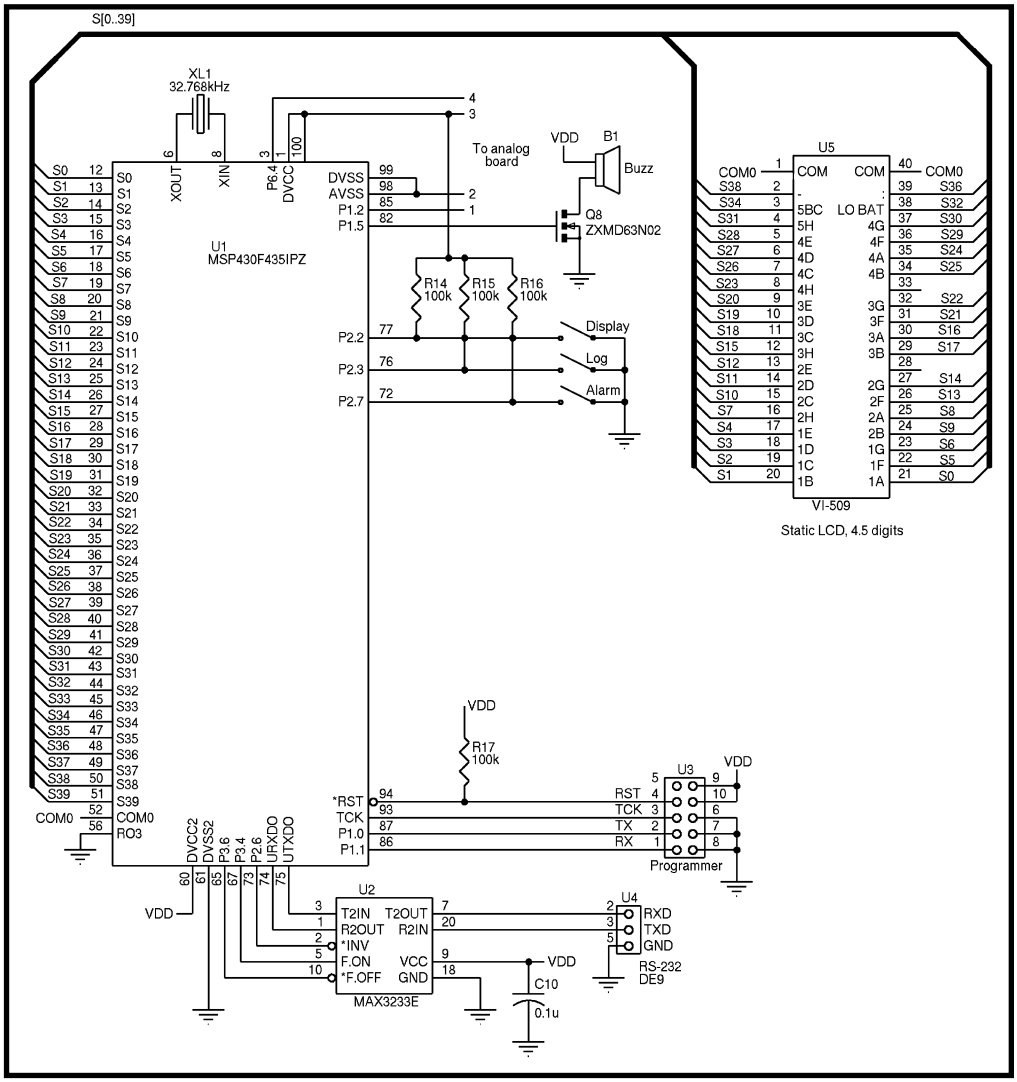



**Figure 3—***The digital board contains an MSP430F435 microcontroller, LCD, keypad, buzzer, and RS-232 interface.*

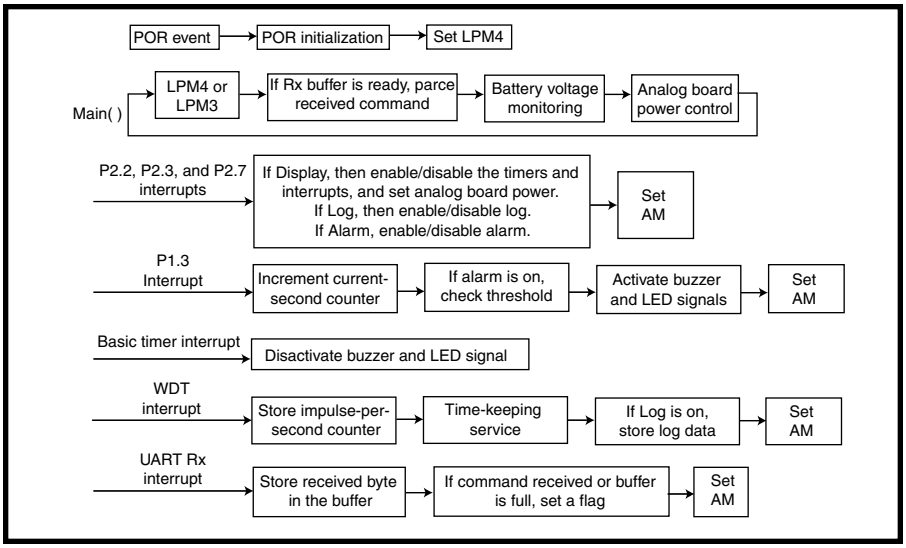



**Figure 4—***Regarding architecture, all software design is driven by five interrupts: level-change interrupts on port 1 and 2, basic timer and WDT interrupts, and a UART receiver interrupt. After power on reset (POR), peripheral blocks are initialized, and the MCU is placed in LPM4, the lowest power mode; it enters Active mode (AM) if an interrupt occurs and sets the corresponding mode.*

test it in a real-world situation. Don't be surprised by fluctuations in the radiation detector's readings! The level of background radiation is a function of the sun's activity, inheriting volatility to some degree. By nature, radiation is a statistical process, and its detection is subject to such laws.

Accuracy is proportional to the duration of the measurement. In other words, if you calculate the number of detected particles over a 1-h period and divide that number by 60 min. to get a radiation level in CPM, the result will have small statistical errors. But such an approach may not be practical in the real world. A compromise was made by continually providing data during measurement.

After the LCD is activated, it displays zeros as an initial count. As particles are detected, the display is updated to reflect the new value. By the time the 60-s timer expires, the LCD displays

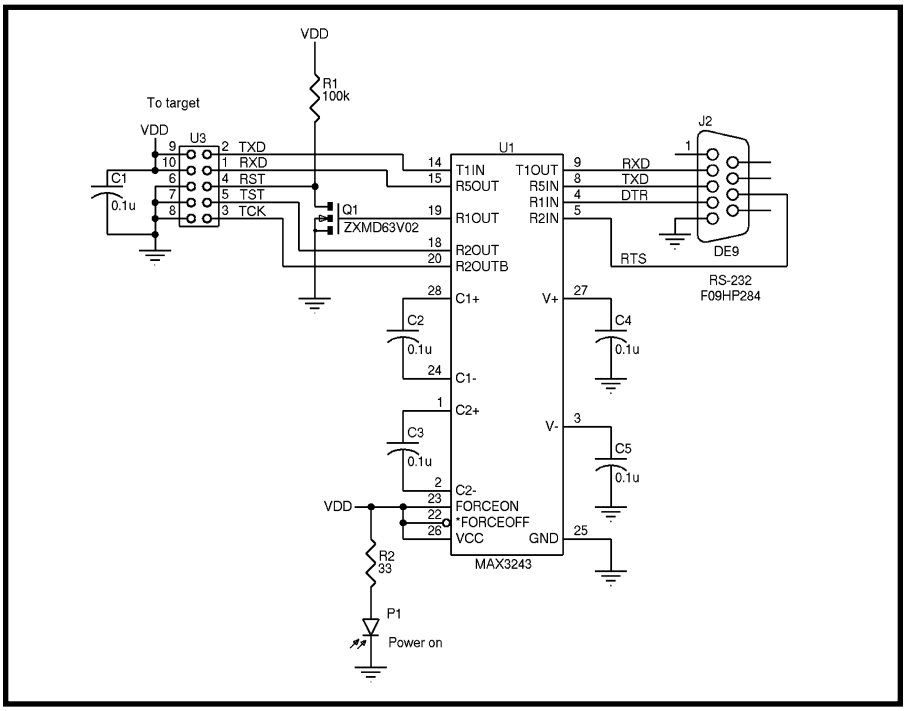



**Figure 5—***The programmer adapter uses the MAX3243 for UART-level conversion. The target board supplies power. Because the MAX3243 has only one noninverting output, transistor Q1 is used as an external inverter.*

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the actual radiation level in CPM units. Because counted data is stored internally at 1-s intervals, the LCD is updated every second to reflect the number of particles detected for the current second (plus the last 59 s). Keep in mind that in Background mode, the device wakes up only in certain time intervals and records results after 1 min. Hence, the error will be bigger.

After polishing my statistical skills, I used two criteria to analyze the variation of measurement results: standard deviation and a histogram chart. [3] The standard deviation of a given set of results is computed in the following way:

$$\sigma = \left[\frac{\Sigma(x_i - \mu)^2}{N}\right]^{\frac{1}{2}}$$

where $\mu$ is the arithmetic mean of the measurement results, $N$ is the number of results in the set, and $x_i$ is a value of the result: i (i = 1 to N).

The histogram is a graphical representation of result distribution. The chart plots the value of results against the number of times this value was recorded. Figure 6 shows the mean, standard deviation, and value distribution for 1 h. You may download additional histograms for different acquisition times from the *Circuit Cellar* ftp site.

The standard deviation is the lowest on continuous measurement and yields a histogram chart with narrow result distribution. If the time between consecutive measurements increases, the standard deviation grows and the histogram chart broadens. At the same time, the arithmetic mean for each set of results remains identical—approximately 18 CPM.

Measurement for the last few months shows that the average radiation level in my area varied between 7 and 30 CPM. I'm not in favor of bringing radioactive materials into my home, so for the field test I went to a nearby granite rock accumulation. Natural stones like granite usually emit a fair amount of radiation. According to my measurements, the level was between 40 and 50 CPM.

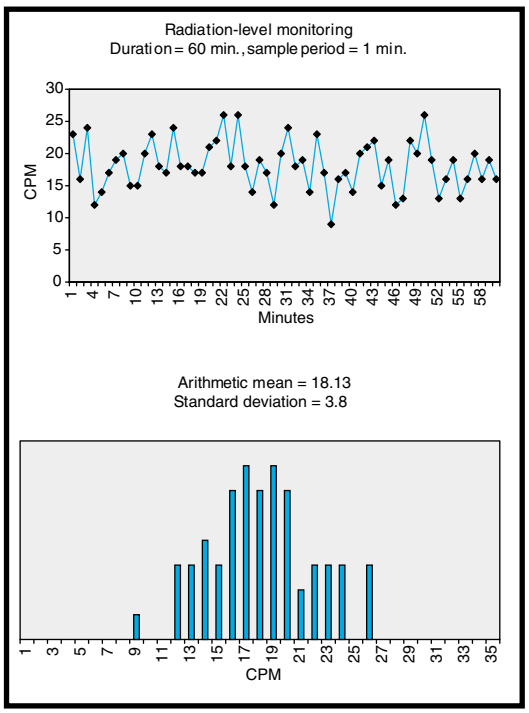



**Figure 6—***The standard deviation is lowest during continuous measurement, and it yields a histogram chart with a narrow result distribution. If the time between consecutive measurements increases, the standard deviation grows. Thus, the histogram chart broadens.*

## FUTURE IMPROVEMENTS

After completing the design, I came up with a few improvements that I plan to implement in the future.

During the measurement process, the high-voltage power supply should run constantly to keep the capacitors fully charged. Excessive voltage (i.e., more than 500 V) is shunted. Because the MCU has an A/D converter, it's possible to monitor the output voltage and activate the power supply if the voltage level falls below 500 V. This will reduce the device's total power consumption. Instead of using a multivibrator that drives the primary side of the transformer, I will use a MOSFET transistor as a switch to create the required oscillation. The PWM signal generated by the MCU will control it. This improvement will reduce discreet element counts, and give me control over the impulse shape and period to optimize the use of the power supply.

In addition, the software can be modified to use flash memory self-programming capabilities to store logged data. This will allow me to log data over a significantly longer period of time. Lastly, it would be nice to have a PC–based program for the collection and a real-time graphical representation of all logged data.

*Mikhail Galeev earned a B.S. in Applied Physics from Rostov State University, Russia and a Master's degree from the University of South Alabama, Mobile. For the last few years, he's been working as a firmware engineer in the telecommunications industry. In his spare time, Mikhail enjoys designing 8-bit MCU-based embedded systems. You may reach him at mgaleev@core.com.*

## PROJECT FILES

To download the code and additional files, go to ftp.circuitcellar.com/pub/Circuit_Cellar/2003/155.

## REFERENCES

[1] F. Graf, *Features of the MSP430 Bootstrap Loader*, rev. A, SLAA89A, Texas Instruments, Inc., November 2001.

[2] V. Rzehak, *Application of Bootstrap Loader in MSP430 with Flash Hardware and Software Proposal*, rev. B, SLAA096B, Texas Instruments, Inc., July 2001.

[3] StatSoft, Inc., *Electronic Statistics Textbook*, StatSoft, Inc., Tulsa, OK, 2002.

## RESOURCE

Texas Instruments, Inc., *MSP430x4xx Family User's Guide*, rev. C, SLAU056C, 2003.

## SOURCES

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www.digikey.com

**C Compiler**
IAR Systems Software, Inc.
www.iar.com

**1504-W Geiger-Muller tube**
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# Build a Graphical User Interface with Tcl/Tk

*So, you want to build a graphical user interface but can't speak a lick of the Tcl/Tk language. What to do? The answer is simple: read on, and let Peter and James teach you everything you need to know to build the perfect GUI.*

The following scenario is fairly common among engineers: You've designed a clever electronic gizmo that does something useful (or entertaining) in the real world. But soon thereafter, you determine that you need a control panel for it.

In the days before microprocessors, you would do this with a multiconductor cable running from the gizmo to a metal panel. The panel would contain switches, lights, and indicators. It would function as the human interface. In the end, the hardware and cabling could be bigger and more expensive than the gizmo's circuitry. And, if the control panel were some distance from the gizmo, the cable and connectors would send the cost through the roof.

These days, you have an alternative: you can build a virtual front panel on a PC screen. The switches, lights, and indicators are a graphical user interface (GUI), which is an arrangement of colored dots on a video display that's manipulated with a mouse.

This ties up a PC to talk to the gizmo. But PCs are cheap these days. This is particularly true for a recycled PC that's sufficient for running the GUI. And the economics look especially attractive when the system is a prototype and the time comes to add another group of controls. This is trivial when the display is a GUI.

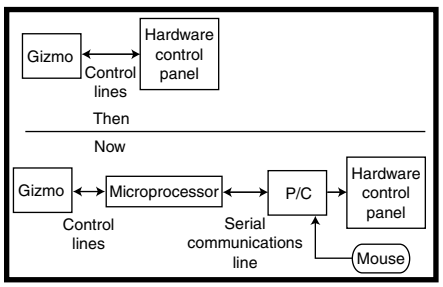



**Figure 1**—*Compare the past and present setups for interfacing to a control panel.*

A common setup (then and now) is shown in Figure 1. The PC-based system looks like a lot of work, and it requires some facility with microprocessors and PC programming.

Each situation has to be evaluated on its own merit, but this arrangement has several advantages. For instance, the gizmo may already have a microprocessor, in which case it's easy to provide serial communications. Furthermore, the serial link can be extended any distance by including a telephone or network connection. Remote debugging is also possible.

Another advantage is the simplified interfacing to the PC. It's a matter of plugging into one of the serial ports. Many programming languages provide built-in access to the serial port. It's relatively easy to add features to the GUI.

Note that the PC isn't locked in. So, provided the GUI software is portable, you can substitute any computer with a serial port. In addition, each computer in the system plays to its strengths. The microprocessor is good at actuating control lines in real time, and it's relatively simple to program. The PC provides the computing power required for a mouse-driven GUI.

On the negative side, the speed of the serial link is somewhat limited—although you can overcome this with careful programming. Numerous examples of the microprocessor end of this system have appeared in the pages of *Circuit Cellar*. In this article, we'll take a closer look at the Tcl/Tk language, which is used for constructing the GUI on the PC.

## THE GUI LANGUAGE

The tool command language, or Tcl, is a scripting language that was developed in the late 1980s by John Ousterhout at the University of California, Berkley. It was originally envisaged as a glue language that would call and be called by C-language routines; however, it has come to be used in many applications as a stand-alone language. The toolkit, or Tk, is a collection of GUI widgets and commands used for constructing a GUI. Perl and Python have adopted its widgets as their graphical toolkits.

Unlike systems languages such as C, Java, and Pascal, there aren't any typed variables in Tcl. Everything is a string. This puts it in the same class as shell programming. It also makes the installation of a Tcl program easy. Simply place the script in a directory, and then direct the interpreter to execute it. No compilation or linking required.

All languages have their strengths and weaknesses, but we like to use Tcl/Tk for GUI development for several reasons. Because it's multiplatform, there are versions that will run on Windows, Linux, Unix, and even the Mac. Many engineering students perform development at home on a




**Photo 1**—*Click on the Hello World button and it's gone.*



**Photo 2—***What do you think of the complete sensor? Are you ready to start on your own?*

Windows machine and then demonstrate their programs in the university labs on a PC running Linux or a Sun workstation running Unix.

In addition, Tcl runs under the control of an interpreter; therefore, the develop-debug cycle is simple and fast. Currently, there are reports (www.scriptics.com/scripting) of programs being developed that are 20 times faster than an equivalent C program. It's exceedingly easy to prototype a user interface. A two-line program to create a labeled button (with its dissection) is shown in Figure 2. To run this program, start the wish windowing shell and type in those two lines. You should get the button image shown in Photo 1. Click it, and it will disappear. Notice that the window comes complete with all the usual window hardware (e.g., resize handles, iconifier, and so on).

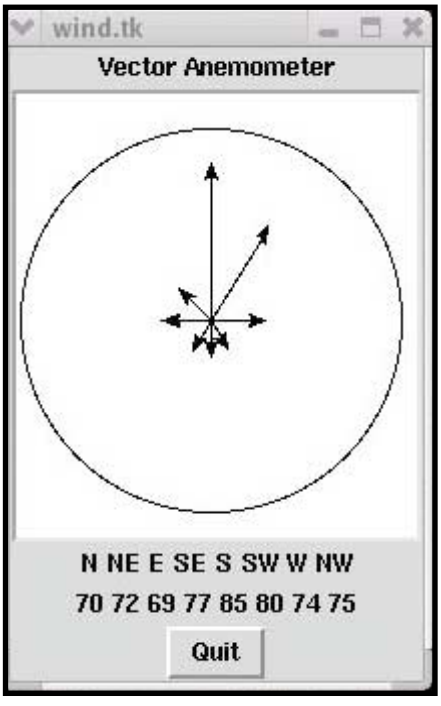



**Photo 3—***It's time to get oriented with your GUI. As the south sensor cools, the north line gets longer.*

There are several other reasons why we like to use Tcl/Tk: there are built-in commands for accessing the serial port, enabling both the transmission and reception of data on an interrupt basis; an active Internet group (comp.lang.tcl) provides discussion and information on the 'Net, and there are several books on the language (see the references at the end); and the source code is open and there are no licensing, installation, or runtime fees.

Furthermore, sockets and an http package are part of the language. Interfacing to other programs is straightforward. For instance, you can construct a Tcl/Tk GUI for an existing Fortran program. Note that the machine resource requirements are modest and Tcl/Tk will run satisfactorily on anything from a 486-66 and up.

Despite the aforementioned strengths, Tcl/Tk has a few limitations. A bytecode compiler is built-in, but it's no speed demon. If you require speed or massive number crunching, you need to interface some C routines.

Interfacing to the serial port is easy, but anything else (e.g., memory mapped I/O, access to the parallel port, or USB) requires driver routines. Finally, it's important to note that it's probably not the appropriate language for a huge systems program. (To find out more about how James learned the language, refer to the sidebar.)

## PROGRAM STRUCTURE

If you're used to programming in a procedural language or assembly, you'll find that a Tcl/Tk program has a completely different structure—it's event-driven. An event can be a mouse click on a widget or the arrival of a character at the serial port. In any case, an event triggers a procedure. When the procedure is complete, the program waits for the next event.

As you can see in Figure 3, a Tcl/Tk program consists of procedure definitions, a listing of constants, descrip-

## LEARNING Tcl/Tk

by James Gaston

When I began working on this project, I knew nothing about Tcl/Tk. I had to learn it as quickly as possible (there were other projects that required my attention), so I borrowed J. A. Zimmer's *Tcl/Tk for Programmers* from the Ryerson University library and browsed the 'Net for example code. The book helped define the various commands and syntax of the language. The code I found on the 'Net showed the structure of a functional program, complete with a graphical user interface. I chose to model the graphic interface for the anemometer after a simple voltmeter program written in Tcl. [1]

I began learning the Tcl/Tk language as I worked my way through the example code, line by line. Each time I came across a command that I didn't understand, I thumbed through my trusty reference book and deciphered its meaning. After I understood the inner workings of the voltmeter program, I began dismantling it, slowly replacing the voltmeter functionality with code that would display the data from the anemometer. I also added serial communication routines to talk to the 68HC11 monitoring the anemometer.

I performed the development and testing for the GUI on a portable computer running the Redhat 8.0 package of the Linux operating system, which includes Tcl/Tk. I also ran an editor, assembler, and terminal emulator to create the 68HC11 code, download it into the MPP board, and debugged the machine code.

Despite the fact that the anemometer GUI program no longer resembles its voltmeter ancestor, using the example code greatly helped with the process of learning Tcl/Tk and producing a functional program. I had a functional GUI with serial interface three days after I had checked out the Tcl/Tk book.

[1] B. Techentin, "A Simple Voltmeter," mini.net/cgi-bin/wikit/877.html.

tions of widgets, and initialization start-up code. After a widget is triggered with an event (e.g., a button clicked with a mouse), the widget command option sends the program to a procedure that's then executed. To see how you use these ideas, let's take look at an example application, the vector anemometer.

## THE VECTOR ANEMOMETER

Traditionally, anemometers have been used to measure wind direction and speed. School children throughout the world have built these devices using common materials such as polystyrene cups and plastic straws. The device spins feverishly in the presence of wind, providing you with an indication of wind speed. So, you may ask: why publish an article about a device that a fourth grader can assemble before recess?

The important difference is that this anemometer doesn't have any moving parts. Most common anemometer designs employ hemispherical cups that are free to rotate around a vertical axis. Mechanical anemometers aren't accurate at low wind speeds, and they have a mechanical inertia that resists tracking wind gusts. [1] This anemometer is based solely on electronic components. [2]



**Photo 4—***We used a wind tunnel for the test. The anemometer was put in the tunnel and connected to the MPP board and a laptop.*

## PRINCIPLE OF OPERATION

The device's principle of operation is simple. A central heat source inside the cylindrical anemometer housing is used to heat metal pads attached to the outside of the casing. The pads are evenly spaced around the diameter of the sensor.

For this particular design, eight sensor pads were placed at 45° intervals around the central housing. Each pad holds a thermistor that's in thermal contact with the pad and acts as a temperature sensor. The central heater warms the pads, and the thermistors attached to them raise their temperature above the ambient temperature of the sensor surroundings.

The thermal resistance between the pads and the central core is large enough so that any wind that comes in contact with the anemometer cools the pads facing the direction of the wind. The copper disc heats the pads and thermistor well above the ambient temperature by allowing heat transfer from the heater resistor. A temperature gradient forms between the heater and


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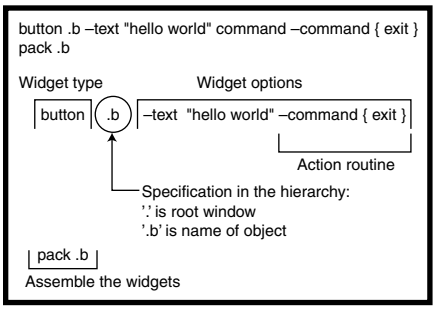



**Figure 2**—*Use this two-lined Tcl/Tk program to create a labeled button.*

the thermistors as the wind cools the outer pads. The resistance of the thermistor increases as the pad is cooled toward the ambient temperature. By monitoring the resistance of the thermistors, it's possible to extract wind direction and magnitude (see Figure 4).

There are three main blocks that make up the vector anemometer: the sensor column, a microcontroller, and a host computer. The sensor column essentially changes wind data into analog voltage levels that are read by the microcontroller. Then, the microcontroller converts these analog signals into digital information, which it sends to the host computer over a serial cable. The PC creates a display for you.

The microcontroller and the PC complement each other. The former carries out the analog-to-digital conversion, which is a weakness of most PCs. The PC processes the converted values and creates a readable display in the form of a GUI, which is a weakness of microcontrollers.

```
Procedure definitions
    proc Transmit_command {message}{
            global port_handle
            puts nonewline "Command Message: "
            puts $message
            puts $port_handle $message
}

Constants
    set logo_color red
    set version_text "Version 0.2"

Description of widgets
    button .power_supply        \
            borderwidth 4       \
            width 20            \
            text {Power Supply } \
            command {source powersupply.tcl}

Initialization
    get_port_settings
    get_spi_addresses
    open_serial_port
```

**Figure 3**—*The structure of a Tcl/Tk program is straightforward. Note that the program consists of procedure definitions, a listing of constants, descriptions of widgets, and initialization/start-up code.*

## THE SENSOR COLUMN

The sensor column is a piece of 3.5″ × 12″ black PVC pipe. We cut the pipe in half at its midpoint to install the thermistor sensor array. The top of the pipe is capped off to prevent moisture and excess wind from damaging the electronics housed at the base (see Figure 5).

The thermistor sensor array is a circular piece of copper from which eight square copper pads protrude. These pads are spread at 45° intervals around the circumference of the disc. Each one holds a thermistor. The disc is the same diameter as the pipe, so the pads stick out past the wall of the pipe. Each pad is bent at a right angle to sit flush against the outside of the pipe. The copper base for the sensor array is made up of the copper disc and sensor pads; it was fabricated from a single piece of copper to ensure the even heating of all eight pads. A 10-Ω, 10-W resistor serves as the heating element for the sensor. It was sheathed in copper and placed vertically through the center of the copper circle.

Holes were drilled in the center of each of the copper pads to accommodate a thermistor lead. For each thermistor, one of the leads was passed through the hole and soldered to the backside of the copper pad. The other lead was insulated and connected by wire to a small PCB contained within the base of the pipe. The PCB contains an SIP resistor pack, power connections, 5-V regulator, and a DE9 connector.

A 1400-mA, 6-V DC wall adapter powers the anemometer. A high-current rating for the adapter is required in order to provide enough power to effectively heat the copper. The adapter was able to supply approximately 6.5 W, which was enough to make the resistor too hot to touch and the pads significantly warmer than the surrounding air.

The thermistors were connected in series with a 10-kΩ resistor, creating a resistor-divider network between the power supply and ground. The 10-kΩ value was chosen to match the thermistor resistance at room temperature. The completed sensor is shown in Photo 2.

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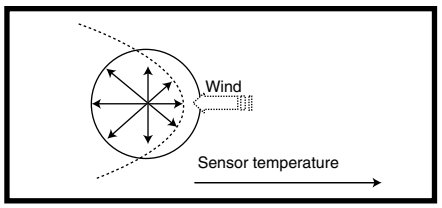



**Figure 4—***The anemometer concept is fairly simple. You can monitor the resistance of the thermistors to extract information concerning the wind direction and magnitude.*

## THE MICROCONTROLLER

A DE9 connector connects the wind sensor to a Motorola 68HC11-based project board (i.e., the MPP board) used at Ryerson University. [1] The 68HC11 has an 8-bit A/D resolution. Software written in 68HC11 assembly language continually reads the A/D ports and sends the information back to the host PC via a serial link. The data is converted from a 1-byte binary format to a two-character ASCII string representing the hexadecimal value of the reading before it's sent to the PC.

Each sensor is individually addressable and numbered from one to eight in a clockwise fashion starting with the north sensor (e.g., the southeast sensor is number four). When an ASCII number from one to eight is received via the serial link from the host computer, the microprocessor sends the corresponding sensor data terminated with a carriage return character.

## THE GUI

The host PC runs software written in Tcl with the Tk toolkit. Software development for the anemometer GUI, including the serial communications, took only three days to complete.

The GUI consists of a circular line graph that displays the relative temperature of each sensor. The program communicates via a serial link with the 68HC11 microcontroller on the MPP board; it continually sends ASCII characters one through eight to the 68HC11 and receives the corresponding sensor data, which it then uses to calculate the length of each corresponding line on the graph.

As the device heats up, the program continually adjusts the reference point for each sensor. The length of each line increases as the thermistor cools and its voltage drop increases. The GUI is set up so that if the south sensor is cooling, the north line on the display increases in length, indicating that the wind is traveling from the south to the north (see Photo 3).

## TESTING

With the kind assistance of Ryerson University's aerospace department, we used a wind tunnel to test the anemometer. The anemometer was placed in the wind tunnel and connected to the MPP board, which was then connected via a serial link to a laptop (see Photo 4).

First, the north sensor was pointed into the wind and the anemometer was tested with wind speeds ranging from 15 to 25 mph. Next, we rotated the anemometer 90° so the east sensor was facing the wind and repeated the test.

We found that the sensor facing directly into the wind was not the coolest. The coolest sensors were adjacent to the sensor bearing the brunt of the wind. Most likely, this was caused by the fact that wind velocity increases



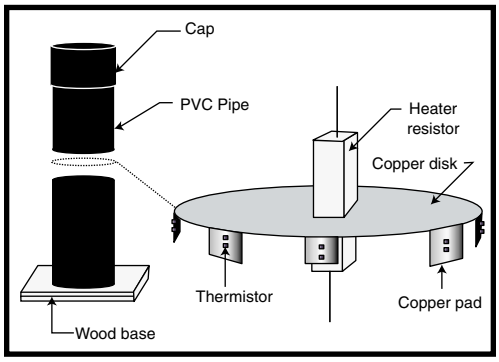



**Figure 5**—*The sensor construction is extremely important, so be sure to follow our instructions carefully.*

as air currents separate and follow the contour of the pipe—much like the airflow around an aircraft wing. For instance, if the north sensor is facing the wind, the wind speed is greatest as it passes the east and west sensors.

After examining the collected data, two conclusions became apparent. First, the anemometer worked: it provided both wind direction and magnitude information without any moving parts. Although the device functioned in the wind tunnel, it performed better in gentler conditions (e.g., the gusts of hot air provided by the hyperventilation of the anemometer designers).

Secondly, it was apparent that several design changes could be implemented to make the anemometer more accurate. The design presented in this article is referred to as a constant power scheme, because the power supplied to the heater resistor is constant, and the temperatures of the metallic pads change with the wind velocity.

An alternate approach would be to use a constant temperature scheme. In that case, the wind sensor pads would be maintained at a constant temperature while the power required to sustain the temperature is measured. Higher wind velocities cause an increase in power as the system attempts to compensate for the cooling.

With few components, the vector anemometer is a low-cost wind sensor solution. It provides wind direction and relative magnitude. With further analysis, testing, and minor design changes, it could provide absolute wind velocity.

*Authors' note: We would like to thank Jerry Karpynczyk for helping with the wind tunnel.*

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## PROJECT FILES

To download the code, go to ftp.circuitcellar.com/pub/Circuit_Cellar/2003/155/.

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J. A. Zimmer, *Tcl/Tk for Programmers: With Solved Exercises that Work with Unix and Windows*, Wiley-IEEE Press, Piscataway, NJ, 1998.

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# Battery Power

## Feeding the Z3801A

*After purchasing a Z3801A GPS receiver, Ed decided that he wanted to play a more proactive role in controlling the device's diet. To do so, he set out to design the perfect battery charger. He ended up with an effective compact power trough for his receiver.*

Sometimes you just can't pass up a good deal, which explains why I recently acquired a surplus HP Z3801A GPS receiver that produces a highly accurate and stable 10-MHz sine wave output. Although it may not be true that every household needs a 10-MHz frequency reference, I'm sure you can sympathize with me.

Frequency standards have a temperature-controlled enclosure, commonly called an oven, which reduces the effect of external temperature changes on their oscillator. The Z3801A snuggles its crystal inside two nested ovens to attain a frequency stability of better than 1 ns per day when it's locked to the GPS constellation and 7 µs per day when it's unlocked. It requires three days to stabilize after power-on, so it's definitely not an instant-on device.

The Z3801A started life as a component of a Qualcomm CDMA wireless telephone base station, which is a situation that leads directly to this month's topic. Telephone gear traditionally runs from a –48-VDC supply—generally two-dozen 2-V lead-acid cells in series. I figured that feeding the Z3801A its familiar diet would make it happy in its new home.

My utility power has relatively few prolonged outages, but blips occur often enough to justify uninterruptible power supplies for my PCs. A crystal oven cannot save its state and shutdown automatically like a PC, so an hour or two of battery runtime makes sense.

Although a battery charger isn't the most advanced topic I've covered, I'll mention some interesting nuances along the way. The fact that the Z3801A runs from a relatively high voltage presents a few challenges, too.

### WHAT THE Z3801A WANTS

The Z3801A's nominal input voltage is –54 V with a range of –60 to –37 V. It dissipates an average of about 25 W with a start-up transient as the nested ovens get up to operating temperature.

The nominal –54-V input seems odd until you realize that it's a float-charged, 48-V, lead-acid battery. The phone company uses a positive-ground system to reduce corrosion on all those metallic doodads hanging outdoors, a consideration that doesn't apply in my shop. The wide range corresponds to what you'd see as those batteries cycle from high charge to deep discharge.

Unlike a NiCd battery, a lead-acid battery can be charged with a constant voltage applied to its terminals, because the input current drops off to nearly zero as it approaches full charge. The charger then supplies the load's operating current at the battery's float-charge voltage. When the AC input power goes away, the battery simply takes over from the charger without any switching.

The exact charging voltage depends on the battery's average temperature and ranges from 2.25 to 2.30 V in room-temperature environments. The familiar 13.8-V level associated with 12-V batteries comes from a 2.30-V charging level that's actually appropriate for somewhat lower temperatures. The technical manual for the batteries I used recommends 2.25 V for temperatures around 70°F, which works out to 54 V for 24 cells and is exactly what the Z3801A expects.

The temperature in my basement office remains fairly constant, which is also the case for most shirtsleeve equipment, and I didn't temperature-compensate the float voltage. A thermistor may be all that you need, though. The application notes should give you ideas.

I've seen many battery-powered projects that compute their runtime by dividing the battery's capacity in ampere-hours (Ah) by the load current.

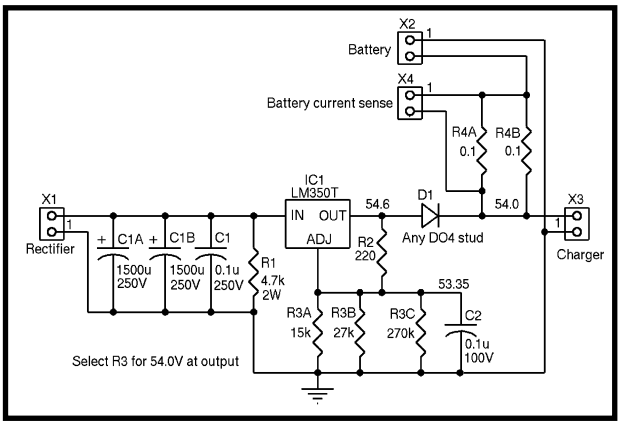



**Figure 1**—*An LM350 regulator floats above ground to deliver 54 VDC to a sealed lead-acid battery. The diode isolates the charger from the battery during power failures. The transformer, bridge rectifier, fuses, and so forth don't appear in these schematics.*

That works for loads much smaller than the battery's capacity, and fails miserably with high currents. For instance, 7-Ah batteries have a capacity of only 4 Ah with a 7-A load and discharge in half an hour. Overall battery life also decreases dramatically with high discharge loads and improves with loads lighter than 5 h. Thus, a 0.5-A load requires at least a 2.5-Ah battery (i.e., 5 h × 0.5 A = 2.5 Ah) and will perhaps run for 2 h.

Both runtime and battery life depend on the depth of discharge: deeper discharge gives a longer runtime and shorter overall life. A higher battery capacity works in your favor by reducing the discharge level for a given runtime or increasing the runtime for a given discharge level.

When I was rummaging around in my parts heap, I discovered an 8″ floppy drive case (I have a big parts heap) that could hold four 7-Ah batteries, the charger circuit boards, transformers, and so forth as arranged in Photo 1. The batteries provide a nominal 14-h runtime at nearly their full rated capacity. They should last for the expected five years.

When you string lead-acid batteries together in a series, you should use matched units and top charge them by applying 2.4 V per cell (57.6 V for four 12-V batteries) for about a day. The spec sheets for your batteries will tell you what's appropriate, but don't apply the topping voltage for longer than the specified time to avoid drying out the electrolyte.

You must install an in-line fuse between two of the series batteries. Do not put the fuse between the battery and the load, because at some point you're going to measure the battery voltage with a multimeter set for current. The ensuing FAP! will—depending on your luck—blow the meter's fuse or current-sensing resistor, metal-plate the inside of the case with vaporized PCB traces, or burn off the probe wire insulation.

The front panel in Photo 2 holds two additional fuses, one for the AC input to protect the transformer and the other on the output to protect the charger. Fuses are cheap insurance against catastrophic faults. You've been warned!

## WHAT IT GETS

Figure 1 shows that a simple linear regulator will float-charge a lead-acid battery. The familiar LM317 adjustable regulator has a 1-A current capability that's a bit too low for this job, so I picked an LM350 with a 3-A limit.



**Photo 1**—*The power supply fits neatly in an old 8″ diskette drive case. Note the in-line fuse atop the rear battery.*

A 50-V power transformer and bridge rectifier supply the input voltage. Transformer output voltages are in RMS at full load, so a 50-V transformer produces 50 × 1.4 = 70 $V_P$ at full load, and somewhat more with a light load. The peak voltage at the input filter capacitors is lower by the bridge rectifier's two diode drops—about 2 × 700 mV. The minimum voltage depends on both the load and filter capacitance.

I've seen many low-end battery chargers without filter capacitors or regulators, even though high ripple currents kill lead-acid batteries. My 7-Ah batteries require less than 700 mA of ripple, which is far less than that caused by charging directly from an unfiltered supply. For a decent first approximation, the ripple voltage for a full-wave rectified 60-Hz supply is calculated by:

$$\frac{A}{120 \times C}$$

A pair of hulking 1.5-mF, 250-V capacitors delivers less than 5 V of ripple at 2 A. My transformer actually produces about 65 $V_P$ under full load and a 58-V minimum to the regulator.

The LM350 drops at least 3 V, and D1—the isolating diode—drops another 700 mV, so the regulator's headroom is almost exactly zero with a 54-V output. Those large capacitors demand R1, a bleeder resistor, to discharge them quickly when the power turns off.

D1, which is an unmarked DO4 stud diode from my collection, isolates the charger from the battery. The LM350—as well as its smaller brother, the LM317—cannot withstand reverse voltage from its output to its input. Normally, you'd use a diode across those terminals to shunt reverse current around the regulator, but such a diode would also discharge the battery.

Because the voltage drop across D1 varies with current, the battery voltage will gradually rise to the regulator's output voltage when the GPS load isn't present. With the GPS plugged in, the diode always carries at least 0.5 A and produces the expected drop. Be careful if you're floating a battery near the upper limit of its permissible range.

The LM350's maximum input-output voltage spec is 35 V—half the 70-V peaks coming from the transformer. A dead battery or an output short imposes more than the rated voltage across the regulator, but I treat this thing with tender loving care, because I know who'll fix it if I blow the regulator.

If your application calls for a more robust design, the LM350 application notes show several techniques that may save the regulator at the cost of considerable additional circuitry. The simplest seems to be a power Zener diode that will blow a fuse at the filter capacitor. Who knows? It may work.

## LOAD CONTROL

Even though the batteries will take care of nearly all outages, after a day without power, I probably won't remember to unplug the UPS. I added a low-voltage comparator to disconnect it when the battery reaches 44 V. Figure 2 shows the handful of parts required to pull this off. The entire circuit derives power from the downstream side of RLY2, requiring a push button Start



**Photo 2**—*The front panel is a sheet of paper protected by laminating film. It's only slightly better looking than Dymo labels on bare aluminum.*

switch to get things rolling.

The LM311 comparator holds RLY2 active as long as the battery voltage is above 44 V, and then it pulls the plug on itself. I considered building a discrete-transistor comparator, deciding that a decent design would require at least as many parts as surround the LM311.

Alas, neither it nor the relays from my heap can run directly from the full battery voltage, which might tempt you to steal 12 V from the lower battery in the 48-V string. That's a bad idea, because all the batteries must see an identical charging current. Drawing a constant current through three of the four batteries would overcharge them and undercharge the fourth.

The circuitry drew about 50 mA—almost exactly 10% of the GPS power requirement. A linear regulator from 54 V down to 12 V dissipates three-fourths of the available power—over 2 W—as heat. A switching regulator would have made more sense, except the box also needed a small fan for thermal control and ventilation to dissipate any hydrogen gas evolving from the batteries. My heap produced a tiny 12-V, 60-mA fan, which I put in series with the regulated load to use some of the otherwise wasted power.

The final circuit regulates the battery voltage to 39 V through Q1. Q2 forms a power Zener diode that maintains 12 V across its collector-emitter terminals. Thus, the fan floats above ground. IC1, which is an LM317 regulator, provides 12 V for the LM311 and the two relays. R4 ensures that the total current from Q1 remains slightly more than the fan's rating, thus maintaining IC1's input voltage at about 25 V.

In normal operation, the fan cools the LM350 and ventilates the case. During power failures, the fan must run from the battery; after the battery is completely flat, it must run even though the output circuit isn't powered. That's what RLY1 does: the fan runs from battery power as long as RLY2 is closed, and then it switches to 12 VDC from a separate transformer. The only time the fan stops is when the battery is dead and the AC power is off, at which time there's no need for cooling or ventilation.

So, although it's tempting to replace Q1 with a switching supply, it wouldn't actually reduce the total power too much. Run the numbers and make your own decision.

## METERING

When I showed the front panel in Photo 2 to a friend, he asked why I used analog meters instead of cheap digital LCD meters. I had two reasons, either of which you may find compelling.

First, cheap LCD meters require a power supply that's isolated from their input terminals. Typically, they run from a 9-V battery and draw enough current that a battery won't last forever, which means I'd need both push-to-measure switches and another battery just for the meters. Second, my parts heap included some surplus meters intended for an FM receiver. The signal meter would serve perfectly for voltage, and the center-zero tuning meter would show both charge and discharge currents without the fancy circuitry. Little needles are more fun to watch than dancing digits, too.

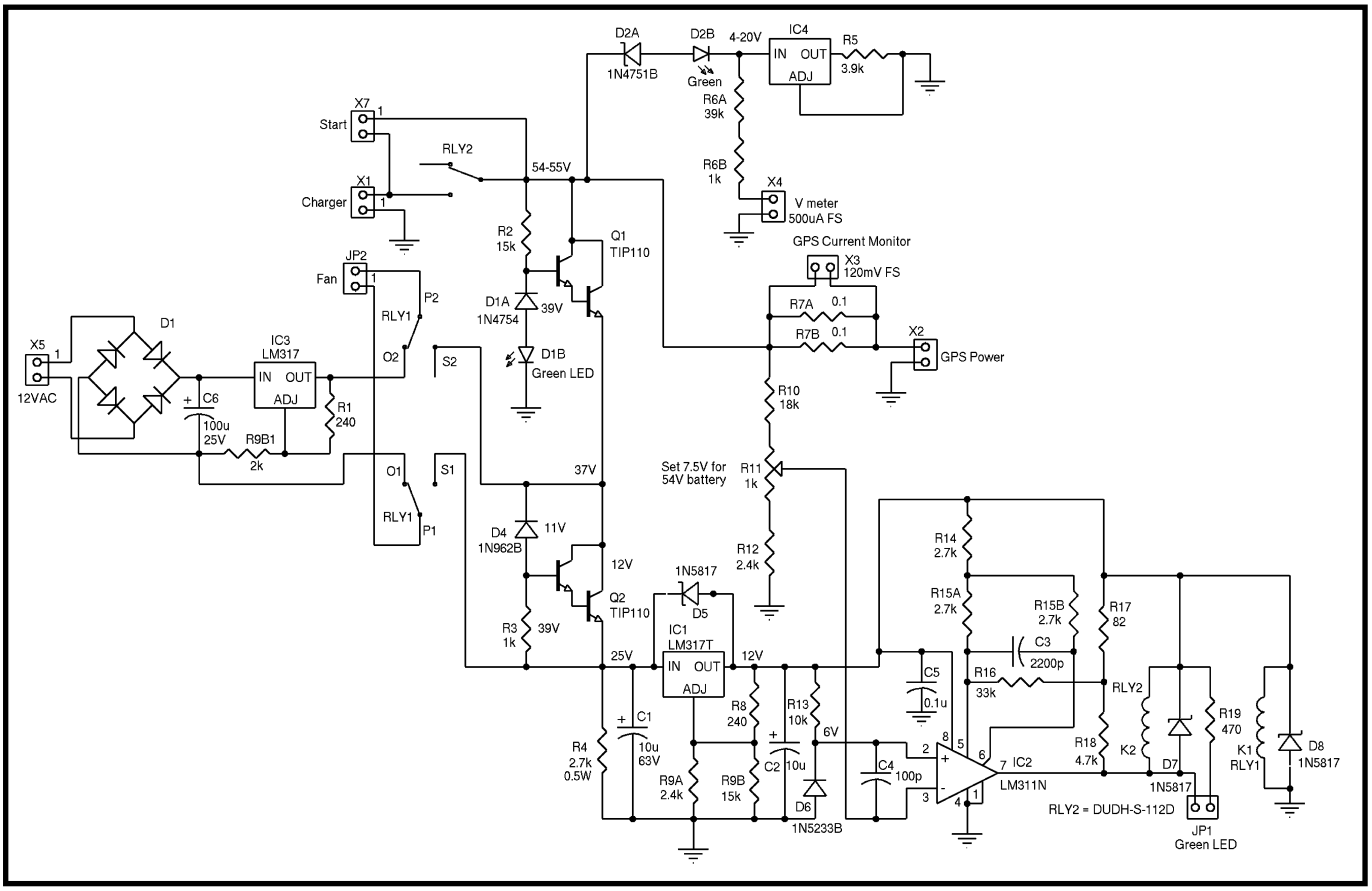



**Figure 2—***A relay disconnects the GPS receiver when the battery discharges to 44 V. The DPDT relay switches the fan between battery and AC power to ensure cooling.*

The batteries self-limit their charging current to about 2 A, and the maximum output current to the GPS receiver is on the order of 1 A. In addition, the tuning meter movement requires 120 mV at full scale, and I have a drawer full of 100-mΩ resistors. Conveniently enough, 2.4 A through 50 mΩ is exactly 120 mV. Bingo!

The signal meter was a bit more difficult, because the battery voltage is always between 40 and 60 V, making a zero-origin, 60-V scale too cramped. D2A and D2B in Figure 2 chop 40 V off the battery voltage, with the LM317 current sink ensuring a constant diode drop. The meter requires 500 µA at full scale, which R6A and R6B provide from the 20-V maximum.

I used WB6BLD's meter.exe program to print new scales. Then, I scanned them back into the PC, applied a dose of Photoshop, and printed the results on heavy photo paper. They look pretty good, although the voltage scale is far more linear than the circuit below about 45 V. I picked R6 for the best match around 54 V and called it finished, although I may go back and bend the scale to match across the entire range.

## CONTACT RELEASE

During a system upgrade, Qualcomm sold thousands of surplus Z3801A receivers for about 5% of their original price. By the time you read this column, most suppliers will be sold out, but a search on Google for "Z3801A" should turn up something roughly equivalent.

My bench now has a precise 10-MHz sine wave locked to UTC within a few nanoseconds. My PCs enjoy stratum-1 timekeeping accuracy, and I know precisely where the birdbath outside my window is in relation to the world at large. (Where would you put a GPS antenna in two feet of snow?) Life is good!

*Ed Nisley, PE, is an electrical engineer and a ham radio geek (call sign KE4ZNU). You may contact him at ed.nisley@ieee.org.*

## PROJECT FILES

To download the schematics, go to ftp.circuitcellar.com/pub/Circuit_Cellar/2003/155/.

## RESOURCES

*QEX* information, www.arrl.org/qex.

Z3801A information, www.realhamradio.com/GPS_Frequency_Standard.htm.

Transformer rectifier voltage calculations, www.atc-frost.com/products/design/va.htm.

*Valve Regulated Lead Acid Battery Manual*, B&B Battery, Inc., Commerce, CA, www.bb-battery.com/table_content.asp.

## SOURCES

**Z3801A GPS receiver**
Hewlett-Packard Co.
(650) 857-1501
www.hp.com

**LM350 Voltage regulator**
National Semiconductor Corp.
(800) 272-9959
www.national.com

**meter.exe**
WB6BLD
www.qsl.net/wb6ld



# Time-Triggered Technology

*Clearly, the older communications protocols used by the aerospace industry are becoming increasingly expensive to implement. But, as George explains, change is on the horizon in the form of TTP technology, which may soon become the inexpensive solution for your future applications.*

In previous articles in *Circuit Cellar Online* and *Circuit Cellar*, I introduced you to the ARINC 429 and MIL-STD-1553B communications protocols, which are widely used in the aerospace industry. [1, 2] Although both protocols are more than 30 years old, they are still alive and well. And, in terms of performance, MIL-STD-1553B remains a serious contender whenever reliable data communication under the most adverse conditions is an undisputable must.

As excellent as those protocols are (especially MIL-STD-1553B), they have a major drawback that prevents them from wider use—the cost of implementation. And so they have been stuck in a vicious cycle of not achieving volume because of the high cost, and not being able to reduce the cost because of low volume.

Current aerospace data bus protocols are getting old—even ARINC 629 has been around for more than a decade. But a change is in the air. The automotive industry is feeling the need for high-performance network protocols to support their "X-by-wire" initiative, and automotive applications mean high volume, which will drive down the cost. But indications show that established aerospace systems won't be dusted and polished for high-volume use. New contenders are vying to become a standard. Nevertheless, the well-documented history of aerospace systems provides us with valuable lessons.

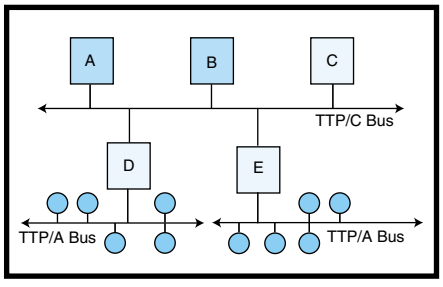



**Figure 1—***The TTP system is similar to time-multiplexed avionic networks such as MIL-STD-1553B. But after you look under the hood, you'll see a much more sophisticated and modern data bus protocol.*

## AUTOMOTIVE DATA BUS

It's been recognized that the majority of the upcoming automotive innovation will occur through electronic systems. The model for the now common X-by-wire phrase is the old "fly by wire" phrase, which originated in the aerospace industry several decades ago. The "X" will be replaced with appropriate functions, such as steering, braking, and so on.

What X-by-wire means is simply that there isn't a direct link between the pilot and the actuator. The control surfaces of an airplane, wheel brakes, engine thrust controls, and so on are all controlled remotely by actuators. Today, a driver turns the front wheels of a car directly through a mechanical linkage, albeit augmented by a hydraulic system, to steer the vehicle. Tomorrow, just like in the cockpit of an airplane, the driver will simply issue position commands through a transducer, which some engineers envision will be a familiar game joystick, and a computer will do the rest through closed-loop control.

Hydraulic, or electric actuators more likely, will be at the working end, turning wheels, applying brakes, or controlling fuel. At the same time, the computer may have to provide a tactile feedback so the driver can feel the automobile on the road.

Currently, there are many electrical automotive systems produced as standalone devices that are ripe for network integration, which the X-by-wire innovation represents. This includes steering, braking, active damping, shifting, and entertainment. Some haven't been introduced yet because their implementation wouldn't be practical without having the electric automobile infrastructure in place. These would be active safety systems, collision avoidance, and so on.

The benefits include safer driving, reduced environmental pollution through the elimination of hydraulic fluids, less noise and vibration, and weight reduction with better fuel economy. And, needless to say, when such a reliable, low-cost, high-volume technology is fully implemented, it will have a positive effect on lowering systems costs in the aerospace industry, too.

Now, consider what this means. First and foremost, you need a network capable of interfacing numerous subsystems and moving fairly large quantities of data in real time, without the possibility of corruption. Can you imagine trying to do the infamous "three-finger salute" to reboot the computer at 70 mph and staying on the road?

Future communications systems must be fault-tolerant, which also means they must support dual redundancy and have extensive error detection and correction. The systems also

must be inexpensive enough to support the high volume, which is the alpha and omega of the automotive industry.

Third, they must be composable and versatile, which will help them to achieve high volume and low cost. Subsystem vendors should be able to manufacture one design, which will ideally interface (the interface cards may be customized) with all cars. And, equally important, car manufacturers should have no problems purchasing subsystems from several potential vendors without having to reintegrate the system. The network needs to be expandable in terms of the number of participants (nodes) and features. Of course, it should also run at a high speed, because more and more data will need to be shared in real time. This is why selecting the right protocol at the beginning of the electrical automobile era is vitally important.

Several new data bus interfaces have gained prominence in recent years. One example is the well-known controller area network (CAN) bus, which is supported by devices such as Motorola's ubiquitous MPC555. The CAN bus has been used successfully in automotive applications for some time, but like many others, it's an event-driven protocol. Therefore, the CAN bus doesn't satisfy the requirements for safety-critical applications.

Currently, there appear to be two serious contenders for the X-by-wire market, FlexRay and the time-triggered protocol (TTP). In this article, I'll introduce you to the TTP, which was developed by Professor Hermann Kopetz of Vienna University. Kopetz founded TTTech Computertechnik, which markets the technology. Some semiconductor manufacturers, namely Austriamicrosystems, NEC, OKI, and Motorola are reportedly working on dedicated controller chips.

By necessity, I will focus only on the highlights of the TTP data bus. TTP is a patented, proprietary protocol; its standards exist in draft version and can be downloaded from the TTTech web site for free.

If you're interested in the details, visit the web sites for TTTech, Austriamicrosystems, and DECOS (www.decos.at). You'll find a wealth of information on those sites. Note that the terminology isn't always consistent, because an official standard is still being worked on. When several names are used for the same subject, they are mentioned.

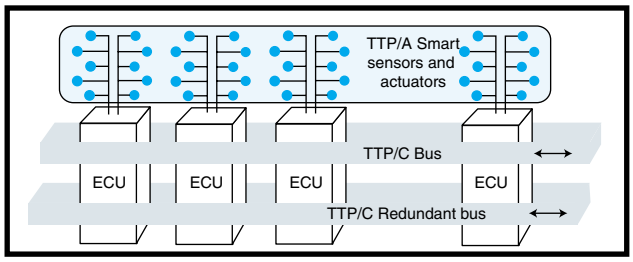



**Figure 2**—*The TTP/C dual-redundant implementation is in a fault-tolerant system.*

## TTP ARCHITECTURE

TTP was developed at the Vienna University of Technology in Austria. It already has 20 years of development and successful testing under its belt, including aerospace applications in Honeywell avionics for general aviation.

On the automotive front, several automobile manufacturers—such as Audi, Peugeot, and Citroen—have reportedly started developing their next-generation vehicles using the TTP data bus. It's expected that new cars with X-by-wire functions and a data bus communications system will be introduced to the market around the middle of the decade.

TTP uses a time-triggered (or time-division) architecture instead of the more common event-driven techniques. The bus controller communicates during predefined time slots with the network participants—bus nodes. Thus, when the controller fails to receive a message from a node during the assigned time slot, it can conclude there is a problem. Assigning a specific time slot to every node also means that multiple events occurring simultaneously will not cause communication overload.

With an event-based architecture, there's always the possibility that a message won't get through; therefore, for safety-critical applications, time-triggered architectures are the only way to go. As time rolls along, there's always a preassigned slot for important messages.

The time-triggered protocols employed in the aerospace industry—such as the MIL-STD-1553B or ARINC 629—have been too costly for practical use in automobiles or even low-end, general-aviation planes. You must expect every node in a MIL-STD-1553B or ARINC 629 network to cost about $1000 in hardware. The TTP/C network target is in a few dollars, whereas the TTP/A is fully software implemented, uses UARTs usually available in microcontrollers, and should cost you nothing in additional circuitry.

Figure 1, which is a typical TTP network diagram, reveals the similarities to its remote grandfather, the MIL-STD-1553B. Both protocols are fault-tolerant, dual-redundant, safety-critical, and time-multiplexed systems, but TTP is far more sophisticated, and it provides additional features. Whereas the fairly high-speed MIL-STD-1553B data bus interconnects individual ECUs (bus nodes) at 1 Mbps, TTP/C is expected to perform safety-critical communications at speeds significantly higher, depending on the physical layer.

TTP comes in two flavors. Version TTP/C satisfies safety-critical criteria as defined by the Society of Automotive Engineers (SAE). It uses a dedicated controller, and it's used in dual-redundant configuration for safety-critical operations. TTP/A is slightly simplified and fully software implemented. As you can see in Figure 1, it's intended to provide the noncritical interface of an individual ECU with a cluster of smart sensors and actuators. The smart sensor interface can be noncritical, because you use two independent sensors for critical functions (see Figure 2).

A detailed comparison of TTP/C and TTP/A is outside the scope of this article, but the main differences will

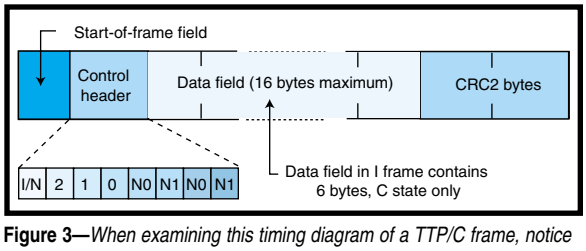



**Figure 3**—*When examining this timing diagram of a TTP/C frame, notice that the data field is only 6 bytes long for the I frame.*

become apparent after you've seen the data structures. Having two protocol flavors makes a lot of sense. I have always been a strong proponent of distributed control, as opposed to central control. Consider that every protocol suffers from latency. This could be somewhat alleviated by event-triggered protocols, but then you'd lose the deterministic nature that's necessary to satisfy safety-critical applications. Most closed-loop control systems need updates every few milliseconds.

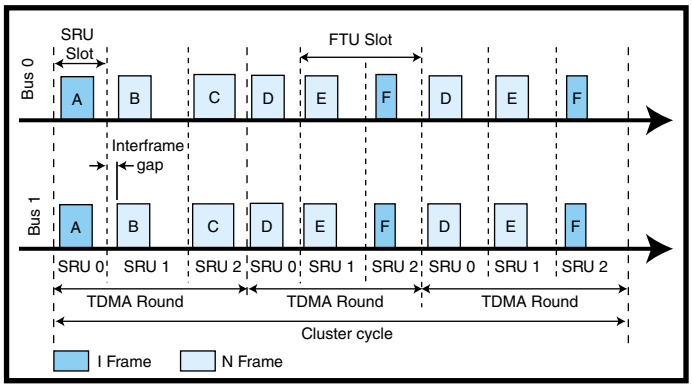



**Figure 4**—*The timing diagram of the TTP/C transmission rounds and cycles is a useful reference. Notice that messages D and E are coupled to form a fault-tolerant slot.*

Now, look at the data structures in Figures 3 and 4, and do the math for yourselves! (TTP is efficient, with relatively low overhead.) How many nodes can you support with the given data bit rate in real time to provide millisecond latency?

A smart sensor (i.e., a micromachined sensor with a microcontroller onboard) can effectively close the loop with a smart actuator. Its communications with the ECU, as shown in Figure 2, don't need the full protocol set. The system-level communications (e.g., fuel delivery control or status reporting) can easily live with tens or even hundreds of milliseconds of latency. That's where the TTP/A comes in handy; it's software running on the already existing microcontroller, which makes it inexpensive. Servicing many nodes, the TTP/C network can be efficient, as well.

## SYSTEM HARDWARE

Deterministic communications protocols such as the TTP don't necessarily have to be tied to a specific transmission medium. TTTech uses this to advantage by giving free choice of what it calls a physical layer to the system designer. Consequently, the TTP protocol was reportedly operated successfully with a multitude of line drivers, receivers, and cables.

Among the tested transceivers, ISO-11898—which was originally designed for CAN bus communications—reportedly achieved a 2-Mbps consistent, problem-free data rate with shielded and unshielded cable terminated with 120 Ω and a length exceeding 20 m (approximately 66'). RS-485 drivers, as well as shielded and unshielded terminated cable, delivered up to 10 Mbps. Similarly encouraging results were achieved with electrical (100BaseTX) and optical (100BaseFX) PHY drivers


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The heart of the TTP/C safety-critical communications system is a TTP/C controller. Austriamicrosystems manufactures several of them, including the AS8202 and AS8204 (see Figure 5). The communications timing, clock recovery, and MFM modulation and demodulation are transparent to the host system and, by the same token, the system designer, as well.

The monolithic controller takes care of the high end of the job. It communicates with the host system via dual-port RAM, which provides effective isolation of the communications subsystem from the system (see Figure 6). Both the AS8202 and AS8204 support up to a 25-Mbps data rate in Synchronous mode and 5 Mbps in Asynchronous mode.

At the low end (i.e., the transmission and reception of the data over a transmission medium), the controller interfaces with hardware of your choice at logic voltage levels. In my opinion, having the freedom to select essentially any transmission medium is a mixed blessing.

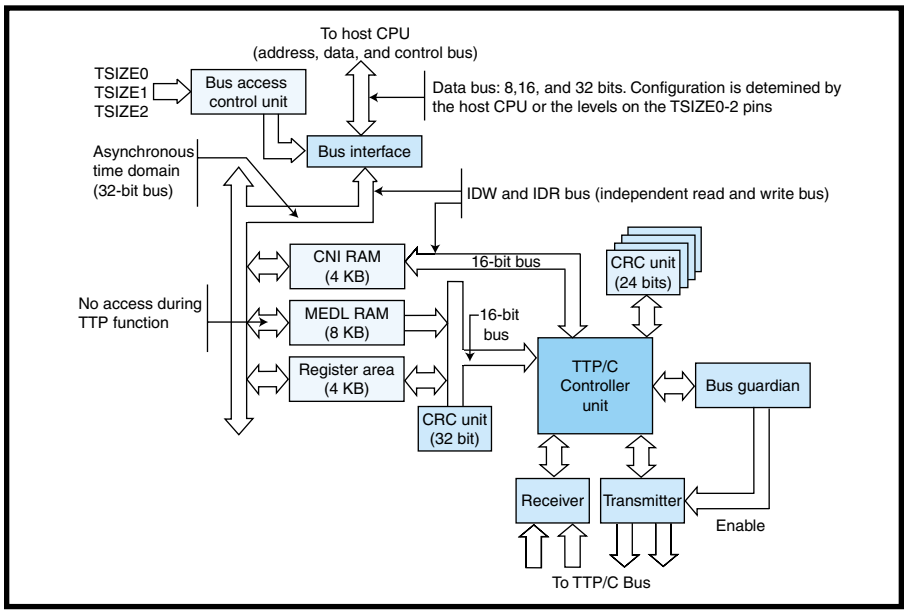



**Figure 5—***The TTP/C controller is responsible for complete communications by exchanging data with a microcontroller system through a dual-port RAM.*

On the positive side, you can draw on existing, proven, and inexpensive technology by selecting from a huge choice of transceivers and cables (i.e., those that satisfy the performance requirements and cost target of the new system). The negative side of this freedom is the apparent lack of standardization. In this respect, my concern is rooted in the years of work I've done in the aerospace industry.

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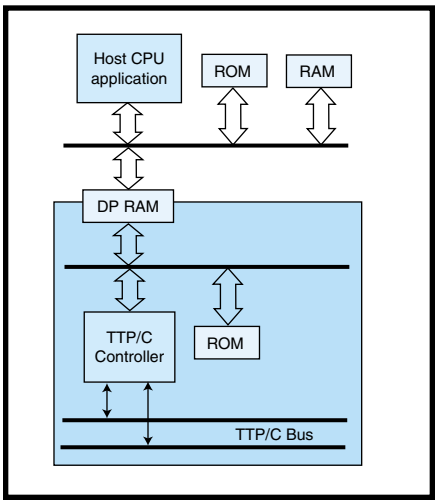



**Figure 6—***The application subsystem (host) and the system with its TTP/C bus are isolated via dual-port RAM.*

ance of a communications bus is significantly affected by the selection of the transmission medium. This selection—and its effect on the achievable data rate, throughput, reliability, expandability, susceptibility to the environment, maximum cable length, and so on—is just as significant as the robustness of the TTP protocol. There will be many different implementations but no hardware standard or large unified installed base for some time to come. This is fine for the majority of noncritical uses, but to certify a new system as safety-critical is a totally different story.

A manufacturer, whether an auto or aircraft maker, must prove the data bus performance without the benefit of a long pedigree of applications, which you can do with MIL-STD-1553B because both hardware and software standards are fully specified. No testing is exhaustive enough to anticipate everything that can happen in the field. And later, every slight change from the originally certified configuration will have to be retested.

Qualification by similarity with previous designs is difficult, because there are always differences, and the similarity quickly becomes a matter of dueling engineering opinions. Having a choice of one or more standard implementations that are fully defined, thoroughly tested, and supported by the industry at large would go a long way toward quick certification.

## UNDER THE HOOD

TTP/C is called a "composable protocol." [3] Thus, after the establishment of a certain property of a subsystem that's communicating via this protocol, system integration will not invalidate or modify this property in any way; instead, it will retain it in full scope. An event-triggered communications system cannot guarantee such a behavior. This characteristic, among other reasons, is necessary to guarantee that in the future a conventional subsystem could be offered as a plug-in kit by a multitude of competing suppliers without the need to reintegrate the system.

A composable network architecture provides clear separation between the system and subsystem issues. This requires the communications protocol to have fully defined interfaces in value and time domains. TTP/C is such a protocol. The "C" indicates that it satisfies SAE Class C requirements for hard, real-time, fault-tolerant communications in automotive applications. The end product of such a system is predictable, hard, real-time message delivery with minimal jitter.

A distributed fault-tolerant clock synchronization with extensive error detection, recovery, and reintegration of nodes is at the heart of the protocol. The protocol, which is patented, was designed for the highest data efficiency and minimal processing overhead.

As its name implies, TTP uses time division multiple access (TDMA) to the bus. All of the activities of a system are driven by a globally synchronized clock at predetermined timeslots. The clock synchronization function is an integral part of the controller (e.g., the AS8202). Every network node is assigned a specific timeslot; therefore, no two nodes can talk at the same time, all nodes know when a certain node sends a message, and the latency of a message is fully predictable by the assignment of the clock ticks.

An important feature of the TTP/C data bus is its ability to guarantee that a single failure of a node doesn't disturb the communication of the remaining nodes in the cluster. In a conventional event-triggered system, a faulty node—sometimes called a "babbling idiot"—is able to monopolize the communications media by permanently sending high-priority messages. Such a failure effectively prevents the correct nodes from exchanging messages. The TTP/C controller features a bus guardian to bring the babbling idiot under control (see Figure 7).

To address criticality, the TTP data bus may send every message two times in addition to having its hardware configured as dual-redundant (see Figure 2). This ensures that no single failure of any part of the communications system will lead to a loss of communications. The two serial communication channels shown in Figure 2 ensure that critical messages arrive even in the presence of a broken channel. The bus redundancy also can be used to double the data bus throughput. This can be done on a per message basis by reconfiguring the controller on the fly.

An important feature of the TTP/C protocol is its replica determinism. This means that a message arrives at all recipients either at exactly the same time with the same contents or it doesn't arrive at all. Therefore, the application software can process a message without having to worry about other nodes receiving the message at a later time, or with a different arrival order, or not at all.

Because the host CPU communicates with the TTP/C controller by reading from and writing to a simple dual-port RAM, the TTP/C communications controller sends and receives all messages autonomously—without the need for the host's involvement (see Figure 6). This gives ideal support to the composability requirement.

The communication pattern, or timing, on the bus is defined precisely for a complete cluster of nodes by the system designer in message descriptor lists (MEDLs), which are loaded into the controllers. This clean separation between communications and application software precludes timing failures leading to communication failures.

Conventional, event-triggered protocols provide error detection on the sender's side, but TTP/C provides error detection at the receivers' side, too. This is possible because TTP is strictly deterministic: all communica-

tion partners in a cluster know the predetermined points in time when a certain message has to be sent. Based on the information about missing messages, the receiver becomes autonomous and can decide on its own how to react to the fact that the sender is no longer providing information. In addition, the membership service gives all correct nodes a consistent and timely view of the status (i.e., OK/fail) of all of the nodes on the bus. Thus, the application software has at all times a view of the system's state and degree of its functionality.

## FRAMES AND ROUNDS

TTP/C steps through the paces fully defined a priori by you in the message descriptor list (MEDL) and precisely executed in accordance with the system-wide clock. Therefore, the success of the protocol depends on its fault-tolerant clock synchronization.

The TTP/C's deterministic nature allows the protocol to take advantage of the previously known, hard-encoded information and reduce the number and size of messages. Because the message timeslot has been assigned to it (once and for all) in the MEDL during system design, identification or background information for a function can be held in the local database, and its retrieval is based on the time of the transmission.

A system using the TTP/C protocol consists of at least one computational cluster. A cluster is a set of ECUs—which are also called nodes or members—that communicate on the bus (see Figures 1 and 2). The data traffic on the bus is made up of frames and cycles. This is depicted in Figure 3, which explains the data architecture of a frame. TTP/C uses two types of frames: initialization (I) and normal (N).

As their name implies, I frames are used for system initialization. They are transmitted by the communications subsystems (ECUs) and broadcast the internal state of their TTP/C controller, which is referred to as the C state. The C state facilitates the nodes' integration in the system at startup or following a fault. It's also transmitted periodically at predefined intervals during normal operation to validate the node status.

The N frames carry the application data. All frames start after the interframe gap with the start-of-frame field (see Figures 3 and 4). The purpose is to facilitate the resynchronization of the transmitters and receivers, and it depends on the bus propagation delay, quality of clock synchronization, and signaling method.

For a transmission speed not exceeding 1 Mbps and a bus cable length not exceeding 20 m (66'), the start-of-frame field is 1 bit, and the interframe gap (IFG) is 3 bits in duration. Note that it's followed by a 1-byte control, or header byte, as it's sometimes called.

In the control byte, the first bit identifies the frame type (I or N frame). The following 3-bit mode-change field is used to request system-wide mode changes. For instance, the system may have several MEDLs, defining different round sequences or switching from Dual Redundant to Dual Capacity modes, and modify its configuration on the fly.


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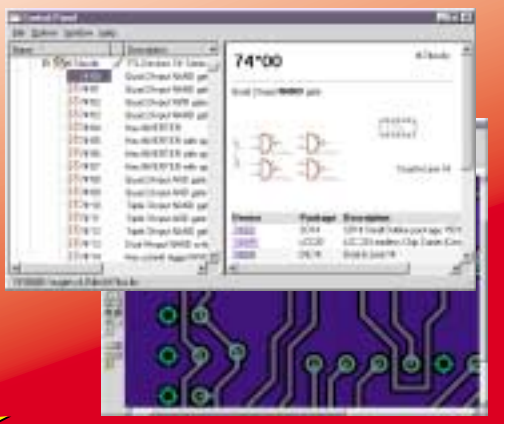
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With 3 bits available, up to seven different configurations can be defined. Note that 000 indicates no change.

The last 4 bits acknowledge that data from the preceding node has been correctly received. In a fault-tolerant system, each node is called a fault-tolerant unit (FTU) and comprises at least two smallest replaceable units (SRUs). These are configured in four different redundancy categories. The 4 bits acknowledge up to four frames sent by a preceding FTU.

The data field is the working part of the transmission; it carries the message, which can be, but doesn't have to be, up to 16 bytes long. Note that the lengths of data fields of frames within the same TDMA round (cycle) can differ. They are defined statically for each mode of operation. Also, note that the frame has no name field, because the receiver can identify the origin of the frame simply by the mode and time of its transmission. The data field is followed by a 2-byte cyclic redundancy check (CRC), which verifies the integrity of the data.

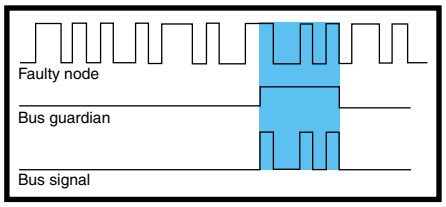



**Figure 7—***The bus guardian, which is a feature of TTP/C, brings the "babbling idiot" mode of a faulty bus node under control.*

## BUS ACCESS

Access to the bus is established by a static time division multiple access (TDMA) scheme. Each node (i.e., member, ECU) transmits in its predetermined timeslot defined in the MEDL and referred to as the TDMA (or SRU) slot. All of the nodes take turns periodically broadcasting their respective frames during the TDMA cycle.

Each node is fail silent, which means that a crash or communications failure results in the node's failure to transmit during its allotted SRU slot. Critical systems recover from such failures because the SRUs are organized in redundant fault-tolerant units (FTUs), which replicate nodes and messages.

There are numerous ways you can configure the TDMA scheme. One example is shown in Figure 4, where a dual-redundant bus services six SRUs—three and three for each bus and identified as 0, 1, and 2. Each pair of SRUs forms an FTU. SRU 0 on bus 0 and SRU 0 on bus 1 form FTU 0. Both SRUs in the FTU transmit simultaneously.

The FTUs are categorized in four groups determined by how their redundancy is achieved. For instance, it's possible to have the FTU, in addition to transmitting simultaneously on two buses, transmit each frame two times. In the timing diagram shown in Figure 4, a pair of two consecutive frames, D and E, would be called an FTU slot.

Although the TDMA round means that every SRU has had a chance to transmit, it doesn't mean that all of the possible messages have been sent. When the SRUs have sent all of the possible messages and executed all of the tasks, the cluster cycle has been completed. What constitutes a cluster cycle is defined in the MEDL.


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## SMART SENSORS AND TTP/A

A smart sensor is a combination of an analog or digital sensor (or an actuator) and a local microcontroller that contains the interface circuitry, a processor, memory, and a network controller in a single unit. [4] The smart sensor transforms its sensor element's signal into a digital form, verifies and calibrates the signal, and transmits it via a data bus to its users. More and more sensor elements are becoming microelectronic mechanical systems (MEMS), which can be integrated on the same silicon die with the associated microcontroller and conditioning circuits.

There are many advantages to smart sensors, but that's another subject altogether. The focus of this article is on the data bus interface used to carry the sensed values to a processing subsystem, as shown in Figures 1 and 2. This task is best performed by a variation of the TTP bus called TTP/A. It's simpler and more economical to implement than TTP/C, because it is implemented entirely in software. A communications-specific interface, such as the UART, is often a standard part of the microcontroller, although an external transceiver, such as RS-485 is needed. Thus, TTP/A can share all the computing resources with the smart sensor, but care must be taken to properly partition the different software functions.

The TTP/A data bus is controlled by an active master, which establishes a common time base within the cluster of smart sensors. If the master fails, a secondary master can take over control.

Let's take a look at the basic characteristics of the TTP/A communications. TTP/A does not differ significantly from TTP/C; its underlying principles are the same. Every node in the TTP/A network has a unique 8-bit personal identification number. The TTP/A controller assigns this ID during the power-up and diagnostic sequence. After it's running, communications within the cluster of nodes are organized into rounds. A round comprises one or more frames, which is a sequence transmitted by a single node. The frames are separated by interframe gaps.

The data architecture of TTP/A is shown in Figure 8. The smallest data unit is a TTP/A slot, which is defined by three timeout windows: send data timeout, or SDT, which is followed by the transmission of a message; await data timeout (ADT), which is followed by data receiving; and data processing timeout (DPT), which is followed by protocol processing.

At SDT, a node starts transmitting a message that has 1 start, 8 data, 1 parity, and 1 stop bit—the most common format supported by just about every UART. Between ADT and DTP, the message is received at each node of the cluster. At DPT, protocol tasks (e.g., data validation and status update) are started, and the new message is assembled for transmission.

Similar to TTP/C, a defined sequence of slots forms a TTP/A round. The dynamically assigned master sends the first slot in every round. It's called the fireworks slot, and the first frame is called the fireworks




frame. This frame identifies the MEDL (each node stores them locally), which defines the protocol sequence that follows. To distinguish a fireworks frame from a normal frame, the protocol execution interval—which is determined by DPT and SDT points in time—is significantly longer, and the parity of the fireworks frame is inverse to that of normal frames. The fireworks frame synchronizes the clock in each node for this specific round; data frames from the smart sensor nodes follow it.

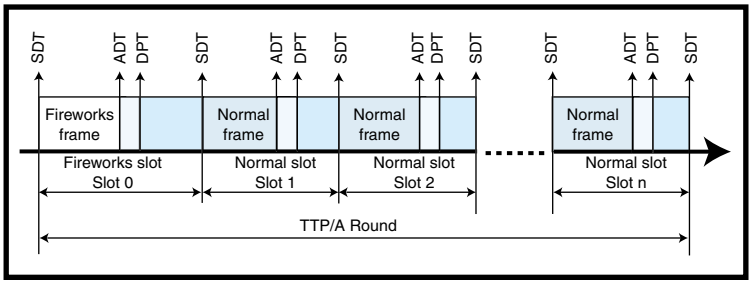



**Figure 8—***The first slot in every round, which is called the fireworks slot, always determines the protocol sequence.*

Each round is independent of the other rounds with any two rounds separated by an interround gap, which is significantly longer than an interframe gap. Each round has a specific name to identify it. The structure and duration of each round, just like the TTP/C, is static. It's known a priori, specified by you, and is common knowledge to every node of a cluster.

The TTP/A protocol uses three types of rounds. A broadcast round consists only of the fireworks frame sent by the active master. The master-slave round consists of two frames: the fireworks frame from the master, which contains the slave address (among other things), and a response frame from the slave. The main purpose of the master-slave round is reading and writing data to a file residing in the slave. The third type is the multipartner round, which starts with the fireworks frame from the master and continues with predefined data (normal) frames from the nodes. Multipartner rounds are periodic, and they're the vehicles for transferring real-time data.

Messages are the data contained in data frames. The protocol distinguishes between three types of messages: restricted messages, unrestricted messages, and free messages.

A restricted message reserves codes 1111 0000 to 1111 1111 of the first byte for in-band error codes. An unrestricted message starts with a special first byte that contains the confidence code in the first half byte and an error code in the second half byte. If an error code is set, the confidence marker in the first half byte must be 1111 (i.e., no confidence). If the confidence marker has any value other than 1111, the error code must be 0000 (i.e., no error). All of the other bytes of unrestricted messages are application-specific. No rules restrict the data coding of free messages.

The TTP/A master contains at least two interfaces. One interface is the TTP/A bus, which communicates with the smart sensors in the cluster. The other typically goes to the system via a dual-port RAM to a TTP/C data bus monolithic controller.

During TTP operation, all nodes must agree on their controller states, or C states. Those states consist of three values. First, all nodes must have their internal pointers set to the same MEDL location, which identifies the current position in the time division multiple bus access slot. The global time each node sees must be identical across the cluster of nodes. And third, the membership field, which identifies the units that have and haven't been active at the last membership point, must also agree across the cluster. The agreement is enforced and validated through a cyclical redundancy check (CRC) of the message.

## THE FUTURE

Advances in communications protocol technology have brought fault-tolerant, inexpensive data buses within your grasp. Out of several potential contenders, TTP seems to be the most promising, but it will take some time before the technology has proven itself in the field. After the volume has risen beyond experimental, the price will drop to a level expected in commercial applications (i.e., a few dollars). What's more, if the developers of TTP are successful in achieving their goal of making it a true commercial, off-the-shelf (COTS) device that's available for all applications—with all the gory communications details transparent to a system designer—the positive effect on the system design process will be tremendous. Let's hope it happens soon.

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[4] H. Kopetz, M. Holzmann, and W. Elmenreich, "A Universal Smart Transducer Interface: TTP/A," Institut für Technische Informatik Technische Universität Wien, Austria.

## SOURCES

**AS8204 TTP/C Controller**
Austriamicrosystems AG
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www.austriamicrosystems.com

**TTP/C Protocol**
TTTech Computertechnik AG
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# E-Field Evaluation Module

*Despite the references to force fields and spaceships, you'll soon learn that building a Z8-based e-field EVM is neither science fiction nor rocket science. In fact, it's a fairly straightforward, uncomplicated process—just how Fred likes it.*

"Motor-rola" is world famous for its embedded automotive electronics. However, some of Motorola's auto-oriented parts serve two masters and find their way into embedded applications that don't burn gas or require regular oil changes. We all know Motorola as a supplier of RF products and the semiconductors behind them. Also, you would have to be isolated in the deepest of jungles or marooned on Gilligan's Island from birth not to know about Motorola's microcontroller and microprocessor product lines.

In the article that follows, I won't be punching any significant holes in the earth's magnetic field or crunching complex numbers on a 32-bit microcontroller. Instead, I'm going to take you into a world that has been restricted to science fiction until now. Remember *Lost in Space*, the television series? The very first thing Will Robinson's father did was set up the "force field" around his family (Robot included) and the Jupiter spacecraft. Likewise, Captains Kirk and Picard deployed "shields" to protect them from hostile environments and unfriendly attacks. Fortunately, I don't expect any extraterrestrials to pounce on the Florida Room, but I do have a "force field" device of my own: the Motorola MC33794 electric field imaging device (EFID).

## MOTOROLA'S EFID

You can't tell from its innocent looks in Photo 1, but it's pretty obvious the MC33794 EFID was originally intended to accompany automobile passengers on road trips. You don't find built-in ISO 9141 interfaces thrown into IC designs just in case. For those of you who don't work in Detroit, ISO 9141 is the core physical interface for that little diagnostic box your mechanic plugs into your ailing ride. Another giveaway as to where this little device lives is the 12-VDC power pin and the 12-VDC indicator lamp interface pins.

The MC33794 also incorporates interface pins that accept and produce standard 5-V logic levels. To that end, the MC33794 contains an internal 5-V regulator capable of supplying 75 mA to an external load as well as tapping some of the incoming voltage to power its own internal circuitry. The presence of a 5-V regulator and TTL-compatible I/O means the EFID has internal circuitry that is capable of establishing communications with and supporting external devices such as microcontrollers. A further indication that the MC33794 is microcontroller-friendly is the inclusion of an active-low reset (RST) output and a watchdog input (WD IN).

The MC33794's internal oscillator, which doesn't require a crystal or resonator, supplies a clock output (CLK) that can be tied to the watchdog input if the watchdog function is not needed. The MC33794's CLK output is a square wave representation of the internal oscillator's sine wave signal. The analog outputs (LEVEL, VDDMON, PWR IN MON, and LAMP MON) suggest that if a microcontroller were added to the system, it would need to be equipped with an analog-to-digital converter subsystem. In case your MC33794 design needs additional external analog circuitry, the device also provides a regulated 8.5-VDC power source. With these obvious analog, TTL, and microcontroller-oriented interfaces, it's easy to see that the MC33794 EFID doesn't have to be restricted for use in automotive applications.

The MC33794 was designed to sense objects in its proximity using a low-level electric field. So, unlike the plasma and electrical fields found around the famous TV spacecraft, the MC33794 won't zap you or produce an electric field that will stop you like a sheet of invisible glass.

The device's electric field is derived from a low-harmonic content, 5-$V_{PP}$, low-frequency RF sine wave that is generated by the oscillator circuitry within the MC33794. A single 39-kΩ resistor is used to tune the internal oscillator's frequency to around 120 kHz. The signal produced by the internal sine wave generator is passed through an internal 22-kΩ resistor. The sine wave signal flows through the 22-kΩ resistor into an internal multiplexer that routes the signal onto one of 11 output pins, which are selected by the ABCD mux select pins. The ABCD mux selector inputs are TTL-compatible and allow only one electrode at a time to be accessed by the internal analog circuitry.

**Listing 1**—*Don't try to run this code: it is a partial listing that should be regarded for example only. You can get the real thing from the* Circuit Cellar *ftp site. This example is intended to show you how little I had to do to get ADC clicks from the Z8-based EVM to the Tera Term Pro terminal session.*

```
// ** Before a line indicates added or changed code in the original
   Z8 example code.
** #define     ISRC   0x00
** #define     E1     0x01
** #define     E2     0x02
** #define     E3     0x03
** #define     E4     0x04
** #define     E5     0x05
** #define     E6     0x06
** #define     E7     0x07
** #define     E8     0x08
** #define     E9     0x09
** #define   REFA     0x0A
** #define   REFB     0x0B
** #define   IOSC     0x0C
** #define     ROSC   0x0D
** #define     IGND   0x0E
** #define     esc    0x1B
** unsigned char p_counter;
** void cls(void);
** void vthome(void);
**********************************************************************
** void vthome(void)
** {
**     printf("%c[f",esc);
** }
**********************************************************************
** void cls(void)
** {
**     printf("%c[2J",esc);
** }
**********************************************************************
void print_data_continuous(void)
{
 ** cls();
 ** vthome();
 ** PFOUT = 1;
 ** p_counter = 0;
 while(1)
  {
   if(data_ready ==0x01)
    {
 **  if(++PFOUT == 0x0C)
 **   PFOUT = E1;
     data_ready=0x00;
     DI();
     DACTL &= 0x0F;
     read_all_channels(no_of_channels);
  ** display_data_new();
     DACTL |= 0xC0;
     EI();
     }
    }
 }
**********************************************************************
void display_data_new(void)
 {
  unsigned int temp;
**  temp=store_adc_value[2];
**  printf ("%4d\r\n", temp);
**  if(++p_counter == 0x0B)
**   {
**    p_counter = 0;
**    PFOUT = 1;
**    vthome();
     }
  }
**********************************************************************
main()
{
**    PFADDR = 0x01;                  //Set port F data direction
**    PFCTL = 0x00;                   //All outputs on Port F
**    ADCCTL |= 0x20;                 //Activate external VREF
**    no_of_channels = 0x02;          //Access ADC channels 0 to 2
init_uart();  //Initialize UART for Tera Term Pro communication
**    DMA_ADC_Test();
**    init_dma_adc(1,no_of_channels);
**    with_intr_start_dmaadc();       //Continues with interrupt
**    print_data_continuous();
}
```

With the exception of the reference inputs, Ref A and Ref B, each unselected electrode is automatically grounded internally by the logic. The current flowing between the active electrode and any other grounded objects within the influence of the active electrode's electric field including the grounded deselected electrodes generates a voltage drop across the internal 22-kΩ resistor that's located at the output of the sine wave generator. Thus, an electric field is set up between the active electrode and any grounded object the generated electric field can envelope. Objects entering or exiting this electric field affect the capacitance of the electric field, thereby changing the current flowing through the 22-kΩ resistor. This results in a voltage drop across the 22-kΩ resistor, which, in turn, results in a voltage change at the LEVEL pin.

A receiver multiplexer that follows the selected electrode is connected to the output pins as well and routes the selected electrode signal into a detector on-board the MC33794. The detector converts the sensed sine wave signal from the active electric field to a DC level. The received DC level is then filtered, multiplied, and offset. All that is needed to enable the MC33794 to process the receiver's DC signal is a single 10-nF filter capacitor tied to the LP CAP pin. The 10-nF value is coupled to an internal resistance; this provides adequate noise filtering while enabling the signal to settle well inside the detector's response-time window. The processed DC signal is then passed out through the LEVEL pin for your processing pleasure.

Let's talk about electrodes as they pertain to the MC33794. An electrode can be anything you desire it to be as long as it can participate in the MC33794's electric field. Electrodes can be attached directly via wire or coax cable. If you have to use coaxial cable to attach your special electrode, the MC33794 is equipped with shield driver circuitry. The MC33794 drives a matching signal on the shield, which allows the shield voltage to closely follow the center conductor voltage. This reduces the effective capacitance of the coax line, which is necessary because the MC33794 recognizes capacitance changes in the electric field as an indicator of an

object's proximity to an electrode. You don't want your coax line introducing a significant capacitance to your electrodes. As an object gets closer to an electrode, the effective capacitance increases, and thus prompts a change in the electric field. By employing multiple electrodes, it is possible to get an idea about the size and shape of an object influencing the MC33794's electric field depending on which electrodes indicate a change in their electric field.

The coax shields are not grounded. Instead, each electrode's coax shield is tied to the MC33794's shield driver pin. In addition to driving the coax shield to minimize cable capacitance, the shield driver also can be used to test the electrical integrity of the coax by toggling the shield disable signal (SHLD DIS) and checking for a change in the LEVEL output. If no change is noted, either the coax shields are compromised or the shield signal isn't being presented to the coax shields.

Voltage at the LEVEL pin is inversely associated with the capacitance between an electrode and other objects in the selected electrode's electric field. As capacitance increases, the associated voltage decreases, and vice versa. The 22-kΩ internal resistor and nominal 120-kHz oscillator frequency provide a close linear relationship between capacitance and voltage over a capacitance range of 10 to 100 pF.

Of course, many factors can affect the value measured at the LEVEL pin. Component values may change over time or be affected by environmental variables such as temperature and humidity. To compensate for this, the MC33794 relies on two reference inputs, Ref A and Ref B, that can be loaded with known capacitances. It is recommended that one reference capacitor be near the minimum capacitance at the electrode and the other fly close to the maximum capacitance to be expected at the electrode. Using these reference capacitances and their corresponding voltages (measured at the LEVEL pin using the ABCD-controlled output mux) provides a set of references that can be used to respond to sensor-system changes caused by time, humidity, and temperature. If your electrodes aren't guaranteed to always have a high DC resistance to ground or a voltage source, then you can insert a 10-nF capacitor in series between the MC33794's electrode pins and your electrode.

The lamp control and monitoring features of the MC33794 are pretty easy to comprehend, so I won't cover them here.

## DANGER, WILL ROBINSON

Now that you know what MC33794 devices do, let's put a couple of them to work. The electronic device sporting an MC33794 in Photo 2 is Motorola's e-field evaluation module (EVM). From left to right, the main players are an MC68HC908GR8CP

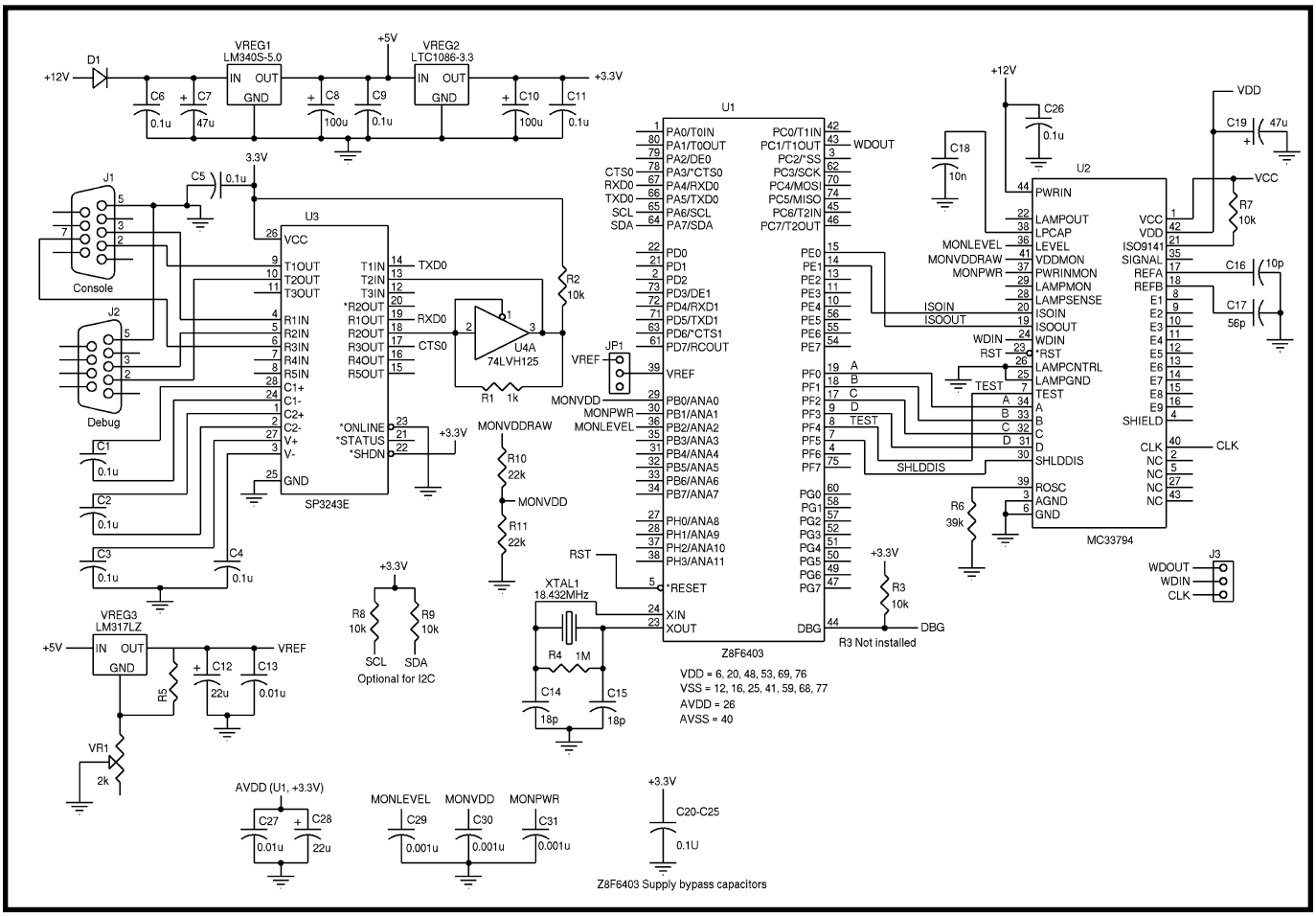



**Figure 1—***The hardware design allows you to purchase the inexpensive Z8 Encore! development kit and use the X-Tools Z8 C compiler and debugger to manipulate the resources on my Z8-based EVM.*



**Photo 1—***The MC33794 electric field imaging device (EFID) is housed in a "heat slug" 44-lead heatsink small outline package (HSOP) package. This is a top and bottom view. If you want to play with a MC33794 without soldering it down, you can get a through-hole test socket from WELLS-CTI.*

microcontroller, and an ever-present Sipex SP232ACP. If you take a closer look, you'll see that some parts seem to be missing. They're actually there but on the opposite side of the board in SMT form. I used the EVM as an EFID trainer and baseline hardware development tool. While I was waiting for my gaggle of MC33794 devices to arrive, I removed the MC33794 from the EVM you see in Photo 2 to verify its footprint against my CAD drawing. In that removal and resolder process, I fried some capacitors and the 32-kHz crystal that clocks the microcontroller. After some minor through hole-to-SMT electronic surgery, I got my EVM back online.

As soon as I had positive confirmation of my MC33794 PCB footprint data and a born-again EVM, I proceeded to place various capacitors on the EVM's Ref A and Ref B pads to get a feel for the voltages produced by different capacitance values. The EVM features a useful software tool that monitors and displays all of the sensor values (thanks to the Sipex SP232ACP) in real time on a serially attached PC. The Motorola e-field program is shown running in Photo 3.

The nice color display you see in Photo 3 is attributed to the resident firmware embedded in the MC68HC-908GR8CP microcontroller. I used my Serial Test Async RS-232 sniffer program to look at the datastream flowing between my PC serial port and the EVM. Using a terminal emulator like Tera Term Pro or HyperTerminal to select an electrode manually, I entered S 1 (i.e., S space 1) for electrode 1 and then entered an "X" to perform the ADC read of the MC33794 LEVEL pin. The resolved voltage of the selected electrode was then displayed in the terminal window. The e-field PC program simply issues the same commands issued in the terminal session to the microcontroller on the EVM and displays the electrode voltages in a graphical format. Some of this trapped command data is shown in the Serial Test Async capture session you see in Photo 4.

## A Z8-BASED E-FIELD EVM

Armed with a hardware reference design and four brand new MC33794 devices, I decided to build my own e-field EVM. Recently, I worked with the Zilog Z8 Encore! development kit and was impressed with the capabilities of the new microcontrollers ("Test-Driving the Z8," *Circuit Cellar* 153). I decided to do an encore (pun intended) performance and bring in a Z8F6403 as the MC33794's companion microcontroller.

My first hurdle to create my Z8 E-Field EVM was to develop a plan to successfully integrate the 5-VDC logic of the MC33794 with the 3.3-VDC logic of the Z8F6403. The Z8's I/O is 5-V tolerant, which alleviates any problems with interfacing to the MC33794's 5-V-based I/O. However, some of the MC33794's analog outputs exceed the Z8's 3-V ceiling for its ADC.

The PWR IN MON-to-PWR IN ratio is a nominal 0.2444 V/V and can range from a minimum of 0.2200 V/V to a maximum of 0.2688 V/V. My Z8-based EVM is powered by the 12-VDC portion of my standard PC power supply. Measuring the 12-VDC leg of my power supply at the input of the Z8-based EVM's LM340 5-V regulator yielded 11.2 VDC. My 10-bit Z8 ADC registered 863 counts (2.53 V) with a 3.000-VDC reference. Using the Z8 ADC as

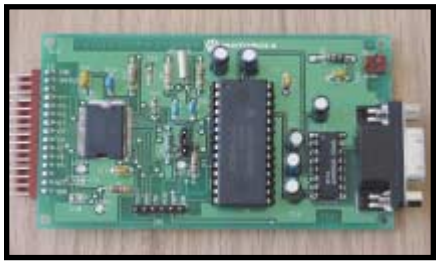


**Photo 2—***Besides some new SMT components and a set of header pins, this is an out-of-the-box Motorola e-field evaluation module. I put this little board through the ringer during the research and development phase of this column. All of the basic building blocks found in the EVM are designed into my Z8-based version, called the Z8 E-Field EVM.*




the absolute reference puts the PWR IN MON-to-PWR IN ratio at 0.2257 V/V, which falls within the MC33794's PWR IN MON-to-PWR IN V/V ratio window. That's all good considering the possibility of error introduced by circuit loading from my bench equipment. The last time I checked my mailbox, I hadn't received a multimillion dollar grant for lab-grade equipment from the National Science Foundation, but my measurements will stand considering I don't use cheap test equipment.

The VDDMON-to-VDD ratio ranges from 0.45 to 0.55 V/V. You already know that the MC33794 supplies 8.5 VDC at the VDD output. With a typical 0.5-V/V ratio, that puts the VDDMON voltage above the 3-V range of the ADC. Because the MC33794's VDD output voltage should remain fairly constant, I added a simple voltage divider to bring the voltage into the Z8 ADC's measurement window. With the voltage divider active, my Z8-based EVM measured the VDDMON voltage at 748 clicks, or 2.19 V. The voltage divider accounted for half the voltage drop. So, 4.38 V should be present at the MC33794's VDDMON pin. Again, without any equipment support from the National Science Foundation, I measured the voltage at the MC33794's VDDMON pin at 4.30 V. A quick calculation put the VDDMON-to-VDD V/V ratio at 0.51, which is in line with the nominal VDDMON V/V measurement.

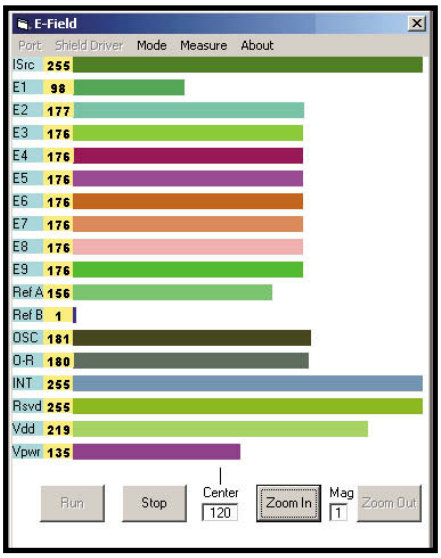


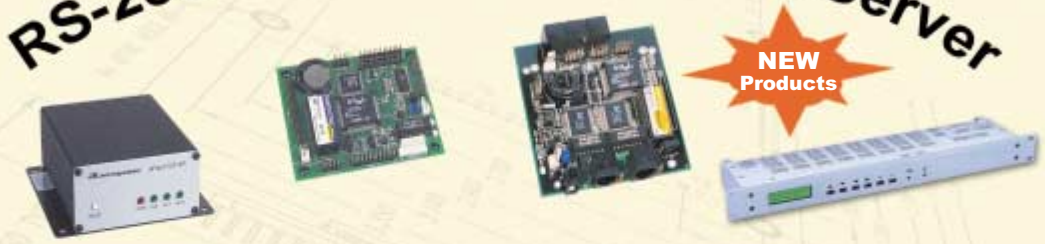

**Photo 3**—*Electrode E1 is attached to one of my aluminum foil sensors and has my HP16C Computer Science calculator in its electrical field. Ref A is loaded with a 10-pF capacitor. The pads of Ref B are supporting a 100-pF capacitor. The numbers are 8-bit ADC clicks from the Motorola MC68HC908GR8CP with a 5-V reference.*

You're probably wondering how I came about that ADC data. The Z8 development kit comes with tons of example code. One of the neat features of the Z8F6403 is its on-IC DMA engine. Using the DMA subsystem allowed me to do a continuous ADC conversion and, under interrupt control, put that ADC data into RAM for later retrieval by the main application. I simply used the DMA-ADC sample code that comes with the development kit as a basis for getting my Z8-based EVM readings out to a Tera Term Pro terminal session. The coding was dead easy because all I had to do was add a few lines of code to define the MC33794's ABCD input-to-electrode mapping. Then, I added some VT-100 terminal commands to manipulate the Tera Term session, which was emulating a VT-100 terminal, and did some minor formatting using printf statements. I made all of my changes in the main.c module (see Listing 1).


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Photo 5 shows the hardware I used to get the Z8's ADC counts to the PC's serial port. The power supply chain on my Z8-based EVM begins with an LM340S 5-V regulator, which feeds a Linear LT1086 3.3-V regulator. The National Semiconductor LM340S also feeds a stock National LM317LZ adjustable regulator circuit that is used to provide the 3.000-V reference for the Z8's ADC subsystem. I opted not to use the MC33794's on-IC 5-V regulator to supply the LT1086 because it can only supply a maximum of 75 mA. The Z8 runs at 18.432 MHz and can possibly draw a bit more than 75 mA by itself. Also, the LT1086's heatsink tab is not connected to ground and is instead coupled to 3.3 VDC. I wanted to have plenty of ground plane area, which does double duty as a heatsink for the voltage regulators and the MC33794. To keep the Z8-based EVM as cool as possible and get as much ground plane area as I could, I decided to include the LM340S ahead of the LT1086.

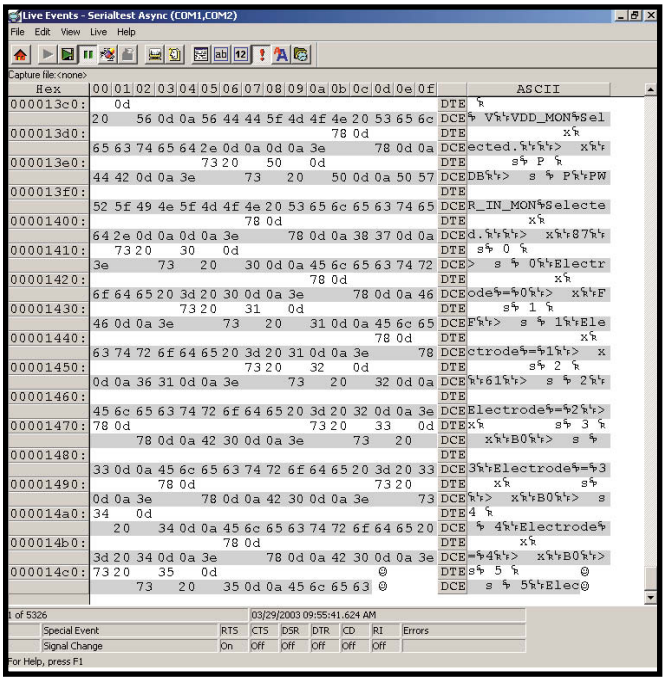



**Photo 4—***The e-field program is issuing commands in the white areas of the capture. The Motorola e-field EVM is prompting and responding in the shaded areas of the capture. $V_{PWR}$ in Photo 3 is associated with PWR_IN_MON in this screen shot. In the fifth from top shaded ASCII area, you can see that the value of hexadecimal 87 was returned for PWR_IN_MON, which equates to the 135 decimal value you see in the Photo 3 graphic for $V_{PWR}$.*

The X-Tools package that comes with the development kit includes a good C compiler and an excellent debugger. Taking advantage of the IDE toolset required the addition of a 74LVTH125 tri-state buffer and a Sipex SP3243ECA RS-232 converter. The 74LVTH125 is used to implement the two-wire to one-wire debug interface between the C compiler/debugger and the Z8-based EVM. The RS-232 component of the debug interface is contained within the SP3243ECA. The SP3243ECA contains enough drivers and receivers to support both the Z8 debug interface and a standard three-wire RS-232 interface, which I used as the console port of the EVM. The inclusion of the debug and console interface hardware allowed me to use the C compiler and debugger without writing a single byte of Z8, debug, or RS-232 interface code. I now have the ability to access the Z8-based EVM hardware from the X-Tools IDE in the exact same manner as I access the Z8 development board. Note that the unused I/O pins are available at standard 0.1″ header points on the EVM.

My finishing touch was adding a MC33794. The EVM schematic (see Figure 1) shows how to connect the MC33794's analog outputs to the Z8's ADC inputs. The necessary filter capacitors have been put into place per the schematic as well. The ground, shield driver, and MC33794 electrode access points are pinned out to a standard 0.1″ header. Photo 5b shows the other side of the Z8-based EVM board and helps to associate the remainder of the physical components with their schematic counterparts.

## CAN'T TOUCH THIS

The first thing I did after completing

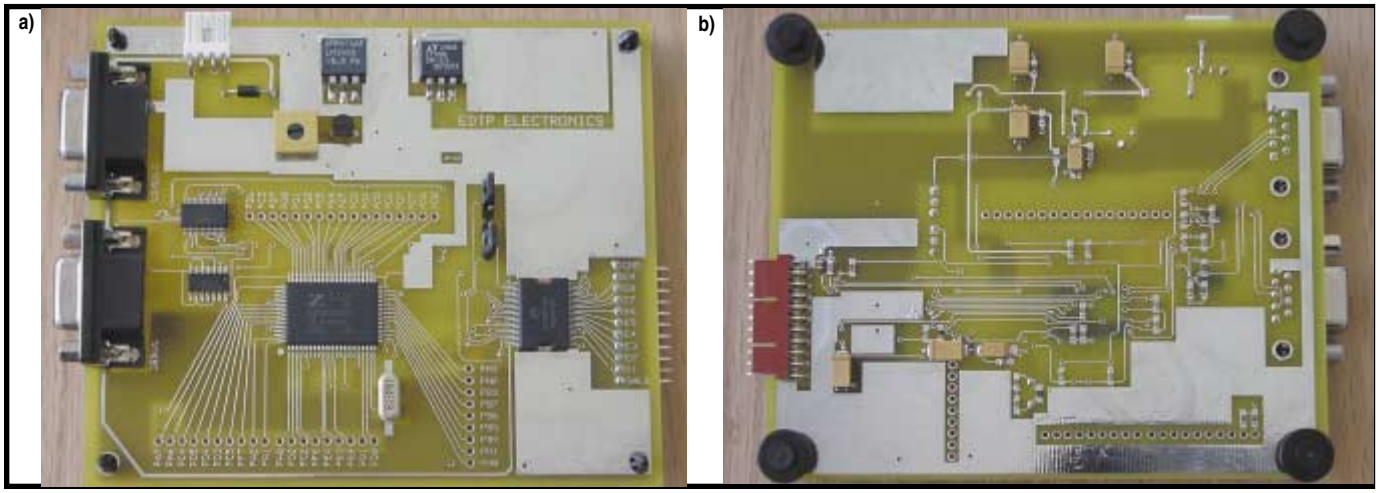



**Photo 5—***As you look at the top of my Z8 E-Field EVM, you can see the top jumper connects the external VREF to the Z8. The watchdog signal select jumper is just below the VREF jumper. Note the floppy drive power connector.* **b—***You'll find nothing unusual in my Z8-based EVM. I decided to mount the support components on this side of the board to free up as much space as possible for extending the Z8's I/O and to provide as much heatsink and ground plane as I could on the other side of the board. Note the Ref A and Ref B capacitor positions are just to the upper right of the header.*

the assembly and verification of my new Z8 E-Field EVM was create a chart of the capacitance versus voltage. I put various capacitance values on the EVM Ref A and Ref B pads and noted the resulting voltage. Thanks to Microsoft Excel, I can show you the fruit of my labor in Figure 2.

Then, I went crazy. I used pieces of copper-clad printed circuit board material as electrodes. In my sensor feeding frenzy, I noticed that my larger PC board electrodes produced a lower ADC count than the smaller boards. So, I went to the kitchen and got a piece of aluminum foil and started making electrodes in a multitude of shapes and sizes.

I found that I could "tune" an aluminum foil electrode to a capacitance that would match a desired arbitrary ADC voltage level by simply folding it into a smaller electrode or expanding the foil into a larger electrode until I got the ADC count I wanted. Because the voltage is not a linear function of capacitance, I was able to use my Excel chart to make an intelligent determination as to the capacitance of the electrode.

I graduated to the aluminum sheeting that is used when drilling printed circuit boards to eliminate burrs in the copper. Because I couldn't solder the aluminum, I cut slots in the aluminum sheets and used some of those push-on automotive quick connects to connect the Z8-based EVM to the aluminum electrode.

I passed everything I had on my bench through my EVM's electric field and noted the changes in the ADC count using my modified Z8 ADC-to-DMA-to-Tera Term Pro sample code. Then, I turned to the fridge and started examining fruits and vegetables and even bottles of water filled at various levels. I thought I had really gotten out of hand until a friend suggested hanging a piece of Life Saver candy on a string to measure body-area electricity. The direction the candy turned (clockwise or counterclockwise) could determine whether or not my body was "stressing" in that area. No way, I said to myself. But, curiosity overcame me, and I tried the candy trick over a foil electrode about the size of a deck of playing cards. The Z8-based EVM picked up the Life Saver's presence, but I won't comment on the direction of rotation versus how my EVM felt.

You would think the candy-on-a-string-rotation thing would have been the ultimate play toy, but I wasn't finished yet. Next, I started placing pieces of Saran Wrap, paper, and plastic between the copper and aluminum electrodes and my fingers. Touching the electrodes directly with my body overloaded the MC33794 electrode inputs and reduced the ADC readings to a point near zero. This scenario was similar to having the electrodes touch grounded or voltage-carrying objects. By placing an insulator between the electrode and my body, I could "touch" the electrode and generate a change in the electric field without overloading the electrode input. I'm sure you're getting the idea now. Are visions of glass or plastic-covered touch panels and keypads without switches coming to your mind, too?

## RAISE YOUR SHIELDS

I had a blast playing with the Motorola e-field EVM, and it's always fun to build a new project using cutting-edge technology. Because this is a hands-on column, I'll be more than happy to supply my Z8 E-Field EVM hardware and code modifications to those of you who want to experiment with this technology. The MC33794 is easy to set up and use, proving yet again that it doesn't have to be complicated to be embedded.

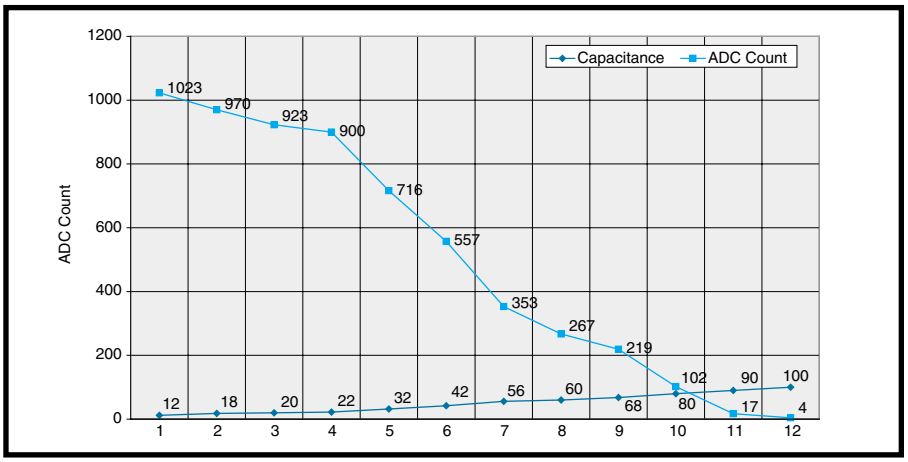



**Figure 2**—*Somewhere under 18 pF is out of bounds for the Z8's ADC. Note the inverse relationship between voltage and capacitance. I used this chart to get an idea of the capacitance values of my aluminum foil electrodes.*

*Fred Eady has more than 20 years of experience as a systems engineer. He has worked with computers and communication systems large and small, simple and complex. His forte is embedded-systems design and communications. Fred may be reached at fred@edtp.com.*

## PROJECT FILES

To download the code, go to ftp.circuitcellar.com/pub/Circuit_Cellar/2003/155/.

## RESOURCES

**Z8 E-field kit**
EDTP Electronics
www.edtp.com

**Through-hole test socket**
WELLS-CTI
www.wellscti.com

## SOURCES

**Serial Test Async**
Frontline Test Systems, Inc.
www.fte.com

**LT1086CW-3.3**
Linear Technology Corp.
www.linear.com

**MC33794 EFID, e-field EVM**
Motorola
www.e-motorola.com

**LM340S-5.0, LM317LZ**
National Semiconductor Corp.
www.national.com

**SP3243ECA RS-232 converter**
Sipex Corp.
www.sipex.com

**Z8F6403 Microcontroller**
Zilog, Inc.
www.zilog.com





# Encore!

## Zilog's Z8 Flash Memory-Based Micro

*Zilog's Encore! has Jeff standing and clapping, and for good reason. In addition to bringing flash memory to its Z8 ensemble, Zilog has delivered a great set of peripherals that have Jeff's imagination working overtime.*

Have you ever been to a really good concert? If so, then you know of the feeling: what starts out as a gentle foot tap, quickly escalates into a full-fledged air guitar solo. I recently attended an outdoor concert that was plagued by rain showers. Fortunately, the warm rain created in me a sense of heightened anticipation, particularly after it was clear that wet was the outfit of the day, and I had made the conscious decision to go with the flow. Although the band stayed dry (for the most part), they fed off the energy of the soaked fans. Thus, after their last set, they returned for multiple encores, performing to the cheers of an aged crowd. (I'm allowed to use that term because the band, like myself, is over the proverbial hill.)

Concerts aren't cheap anymore, so when I put down the bucks, I expect a good show. I'm rarely disappointed, and when it comes down to the end of the show, it's the encore that leaves me with a smile and over-active adrenaline glands.

Can you get pumped in the same way about a microcontroller? Today, the first thing I look for when choosing a microcontroller is whether or not it's flash memory-based. This is because I'm a blow-and-go kind of guy. My debug process advances by executing code and correcting errors based on what actually happens (or doesn't happen). I take full advantage of simulating most of the code; but it really boils down to trying it out for real. The expensive windowed parts require UV-erase time between code changes. Today's flash memory parts reprogram quicker than the time it takes to change the code.

Zilog's Encore! family brings flash memory to their popular Z8 product line. In April, Fred Eady sang the praises Zilog's $49 Z8 Encore! test-drive kit. His column, "Test-Driving the Z8," paid homage to the TRS-80 (Z80), and showed how far Zilog (and manufacturers in general) has come by not only improving their products, but also providing good tools for their support (*Circuit Cellar* 153).

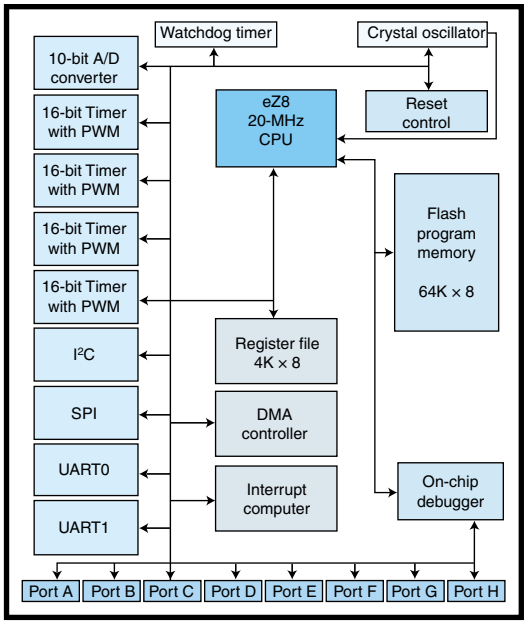



**Figure 1—***The Z8 Encore! family has up to 60 individually programmable I/Os that are available on the 80-pin quad flat pack. The 40-pin DIP version has 31 I/Os.*

### ENCORE!

As a wise elder would say, "flash memory alone does not a successful product make, my young padiwan." Zilog seems to be one with the force, and as such it compliments the flash memory capabilities with plenty of useful peripherals.

Figure 1 shows all of the goodies possible with the Z8 Encore!. This microcontroller revs up the execution of instructions at up to 10 MIPS. With 16 to 64 KB of flash memory, there's plenty of room for your application. Your client's last-minute changes can be handled at any time thanks to the in-circuit programming capability. RAM comes in two sizes—2 and 4 KB—for the larger stack and data-table applications.

All of the peripherals are included in each Z8 Encore! product in the family's portfolio. So, you don't have to wonder which parts contain certain peripherals. Now, because of the I/O limits on the smaller parts, not every product contains the maximum number of each peripheral. But you can be assured that they all contain some of the available peripherals.

For precise analog measurements, all of the parts have at least eight analog inputs to the sigma-delta, 10-bit A/D converter. And, for precision timing, each flavor has a minimum of three 16-bit timers. Each timer is capable of PWM output. In addition, every Z8

Encore! has two 9-bit UARTs, and they support both SPI and I²C interface protocols.

Moving data is of the utmost importance; therefore, three DMA channels support background data shuffling. The interrupt structure supports interrupts from 24 sources, including GPIO pins and internal peripherals. And maybe of most importance (to software designers, at least) is the single-pin debugger. Let's look a little closer at these features.

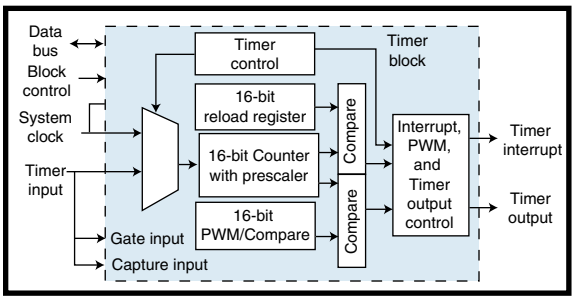



**Figure 2—***All Z8 Encore! family products have at least three 16-bit timer/counters (with prescaler). Each provides an asynchronous PWM output.*

## ADDRESS SPACE

The eZ8 CPU can access three distinct address spaces: the Program memory (flash memory), the register file (RAM), and the data memory (ROM). The program memory contains addresses for all memory locations having executable code and data (i.e., up to 64 KB of flash memory). The register file contains addresses for the general-purpose registers (RAM) and the eZ8 CPU, peripheral, and general-purpose I/O port control registers (i.e., up to 4 KB). The data memory contains addresses for all memory locations that hold only data (i.e., up to 128 bytes).

## PROGRAM SPACE

The eZ8 CPU supports 64 KB of program memory address space. Depending on the device, the Z8 Encore! contains 16 to 64 KB of on-chip flash memory in the program memory address space. Reading from program memory addresses outside the available flash memory addresses returns FFH. Writing to these unimplemented program memory addresses produces no effect. Program memory begins at 0000H with the flash memory option bits, the interrupt vectors depicted in Table 1, and it extends upward to the extent of the individual device's available flash memory. Flash memory option bits configure the watchdog timer and program space read protection.

## REGISTER FILE

The register file address space is 4 KB (4096 bytes). The register file is composed of two sections: control registers and general-purpose registers. When instructions are executed, registers are read from when they're defined as sources, and they're written to when defined as destinations. The architecture of the eZ8 CPU allows all general-purpose registers to function as accumulators, address pointers, index registers, stack areas, or scratch-pad memory.

The upper 256 bytes of the 4-KB register file address space are reserved for controlling the eZ8 CPU, the on-chip peripherals, and the I/O ports. These registers are located at addresses between F00H and FFFH. Some of the addresses within the 256-byte Control register section are reserved (i.e., unavailable). Reading from a reserved register file address returns an undefined value. I don't recommend writing to reserved register file addresses, because it can produce unpredictable results.

The on-chip RAM always begins at address 000H in the register file address space. Depending on the devices, the Z8 Encore! contains 2 to 4 KB of on-chip RAM. Reading from register file addresses outside the available RAM addresses (and not within in the control register address space) returns an undefined value. Writing to these register file addresses produces no effect.

## DATA SPACE

Data space is 128 bytes of read-only memory at the top of the eZ8 CPU's 64-KB data-memory address space. This ROM space contains a 20-character ASCII alphanumeric part number beginning at address FFC0H. (It's left-justified and padded with zeros.)

## GPIO

Four registers for each port provide access to GPIO control, input data, and output data. Table 2 shows lists these registers.

| Priority | Program memory | Vector address interrupt sources | Interrupt assertion type |
|---|---|---|---|
| Highest | 0002h | Reset (not an interrupt) | Not applicable |
| | 0004h | Watchdog timer | Continuous assertion |
| | 0006h | Illegal instruction trap (not an interrupt) | Not applicable |
| | 0008h | Timer2 | Single assertion (pulse) |
| | 000Ah | Timer1 | Single assertion (pulse) |
| | 000Ch | Timer0 | Single assertion (pulse) |
| | 000Eh | UART 0 receiver | Continuous assertion |
| | 0010h | UART 0 transmitter | Continuous assertion |
| | 0012h | I²C | Continuous assertion |
| | 0014h | SPI | Continuous assertion |
| | 0016h | ADC | Single assertion (pulse) |
| | 0018h | Port A7 or port D7, rising or falling input edge | Single assertion (pulse) |
| | 001Ah | Port A6 or port D6, rising or falling input edge | Single assertion (pulse) |
| | 001Ch | Port A5 or port D5, rising or falling input edge | Single assertion (pulse) |
| | 001Eh | Port A4 or port D4, rising or falling input edge | Single assertion (pulse) |
| | 0020h | Port A3 or port D3, rising or falling input edge | Single assertion (pulse) |
| | 0022h | Port A2 or port D2, rising or falling input edge | Single assertion (pulse) |
| | 0024h | Port A1 or port D1, rising or falling input edge | Single assertion (pulse) |
| | 0026h | Port A0 or port D0, rising or falling input edge | Single assertion (pulse) |
| | 0028h | Timer3 (not available in 40/44-pin packages) | Single assertion (pulse) |
| | 002Ah | UART 1 receiver | Continuous assertion |
| | 002Ch | UART 1 transmitter | Continuous assertion |
| | 002Eh | DMA | Single assertion (pulse) |
| | 0030h | Port C3, both input edges | Single assertion (pulse) |
| | 0032h | Port C2, both input edges | Single assertion (pulse) |
| | 0034h | Port C1, both input edges | Single assertion (pulse) |
| Lowest | 0036h | Port C0, both input edges | Single assertion (pulse) |

**Table 1—***Here are the Z8 Encore! interrupt priority levels, vector addresses, and assertion types.*

The port address and control registers provide access to subregisters for port configuration and control. Subregisters control the data direction, alternate function, output control (open-drain), high drive enable, and Stop mode recovery source enable for each pin of the port.

The subregister of choice is selected by writing to the Port Address register. The value for the subregister is written to the subregister by writing it to the Port Control register. The indirect addressing of subregisters helps prevent unauthorized configuration alterations.

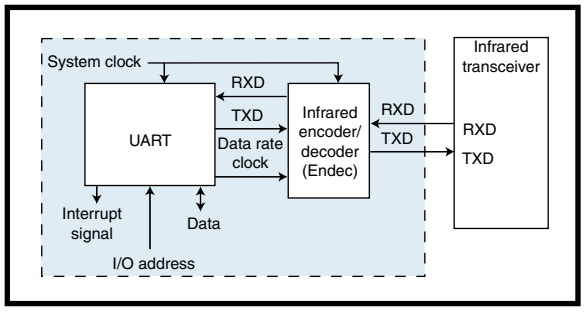



**Figure 3—***Integrated infrared encoder/decoders bridge the gap between the UART and external IR transmitter/receiver components. Few external parts are required for IR communication.*

## ANALOG

Zilog uses the typical three major functional blocks (i.e., converter, analog multiplexer, and voltage reference generator) for the ADC. The ADC converts an analog input signal to a 10-bit digital representation of the input signal. The input analog multiplexer selects one multipurpose input as the conversion source. The reference voltage for the conversion may come from the external VREF pin, or the voltage reference generator generates it internally.

If the ADC is idle (i.e., no conversions in progress) for 160 consecutive system clock cycles, portions of the ADC are automatically powered down. From this power-down state, the ADC requires 40 system clock cycles to power up. The ADC automatically powers up when a conversion is requested using the ADC Control register.

The ADC can be configured for either single or continuous conversions. A single-shot conversion instructs the ADC to perform a single analog-to-digital conversion on the selected analog input channel. After completion of the conversion, the ADC shuts down. Continuous conversion allows the ADC to continuously perform analog-to-digital conversions on the selected analog input. Each new data value overwrites the previous value stored in the ADC Data registers. An interrupt is generated only at the end of the first conversion after enabling.

The direct memory access (DMA) controller controls the operation of the ADC, including analog input selection and conversion enable. You can pick the number of channels to be sampled and where the conversion values are to start in RAM. The ADC_DMA controls the channel selection, conversion, and conversion data storage for each channel in the sequence. This can be a single pass through all selected channels or continuous conversions.

| Port register mnemonic | Port register name |
|---|---|
| PxADDR | Port A–H address register (selects subregisters) |
| PxCTL | Port A–H control register (provides access to subregisters) |
| PxIN | Port A–H input data register |
| PxOUT | Port A–H output data register |
| **Port subregister mnemonic** | **Port register name** |
| PxDD | Data direction |
| PxAF | Alternate function |
| PxOC | Output control (open drain) |
| PxHDE | High drive enable |
| PxSMRE | Stop mode recovery source enable |

**Table 2—***Looking for GPIO control, input data, and output data? Try these port registers.*

## TIMERS

All timers are identical 16-bit up-counter/timers. Each timer has a control register with a 3-bit prescaler value that can be set to divide by 1, 2, 4, 8, 16, 32, 64, or 128. This register also sets the operational mode. One-shot, Continuous, Counter, PWM, Capture, Compare, Gated, and Capture/Compare modes are available. Gate/capture input and clock outputs for each timer complete the flexible timer/counter structure illustrated in Figure 2.

## COMMUNICATION

The Z8 Encore! product family contains two fully independent universal asynchronous receiver/transmitters (UART). The UART is a full-duplex communication channel capable of handling asynchronous data transfers using an 8-bit data mode with selectable parity and 1 or 2 stop bits. It consists of three primary functional blocks: transmitter, receiver, and data rate generator.

The transmitter and receiver function independently. They have separate enables and interrupts but share the same data rate and data format. Error checking provides feedback for framing, parity, overrun errors, and break detection. Each 16-bit data rate generator (BRG) can be used as a general timer if the UART function isn't needed. The UART also supports the 9-bit multiprocessor Addressing mode.

Infrared endecs are integrated with each UART to allow easy communication between the Z8 Encore! and the IrDA physical layer specification, version 1.3-compliant infrared transceivers (see Figure 3). Infrared communication provides secure, reliable, low-cost, point-to-point communication between PCs, PDAs, cell phones, printers, and other infrared-enabled devices.

The serial peripheral interface (SPI) is a synchronous interface that allows several SPI-type devices to be interconnected. SPI-compatible devices include EEPROMs, A/D converters, and ISDN devices. A dedicated data rate generator can supply synchronous clocking for SPI Master mode. The

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**Photo 1—***Measuring roughly 4′ in height with an aligned ankle and hip axis, the hip servos are responsible for tilting the upper platform to counteract the effect of gravity on the inverted pendulum leg.*

full-duplex, synchronous, character-oriented communication uses a four-wire interface to supply data in, data out, clock, and slave (chip) select. You have full control of the polarity of the clock pulse as well as the sampling-edge selection.

The Z8 Encore! also supports I²C Master-Only mode, which consists of two bidirectional bus lines: a serial data signal (SDA) and a serial clock signal (SCL). The I²C controller operates in both 7- and 10-bit address modes at a maximum data rate of 400 kbps.

## DMA

Earlier, I briefly mentioned the direct memory access (DMA). I'll go into more detail now. The DMA controller provides two additional independent DMA channels. These channels—DMA0 and DMA1—transfer data between the on-chip peripherals and the RAM or from the RAM to the on-chip peripheral control registers.

Either DMA controller can be initiated from any of the timers, the UARTs, or the I²C interface. Both byte and word transfers can be handled. Loading the start and end address registers (pointers to RAM) allows multiple transfers to automatically take place (e.g., a serial receive or transmit buffer).

## INTERRUPTS

The interrupt controller on the Z8 Encore! prioritizes the interrupt requests from the on-chip peripherals and GPIO port pins. Twenty-four unique interrupt vectors offer plenty of control over enabled interrupt sources via through levels of individual programmable priority. GPIOs have eight selectable rising- and falling-edge interrupts (i.e., four dual-edge interrupts). The CPU supports both vectored and polled interrupt handling. For polled interrupts, the interrupt controller doesn't affect operation. Table 1 shows interrupt vector addresses and priority ranking within the same interrupt level.

Interrupt priority is set with 2 bits for each interrupt enable. Essentially, a 00 disables the interrupt; a 01, 10, or 11 enables the interrupt and sets the priority low to high (respectively). Continuous assertion interrupts are those that aren't cleared by the CPU upon acknowledgement. Note that these are mostly the communication peripherals. The interrupts must be cleared as part of the interrupt routine.

## RESET

The Z8 Encore! contains a reset controller for Reset and Stop mode recovery operation. In typical operation, the following events cause a reset to occur: power-on reset (POR), voltage brownout (VBO), watchdog timer timeout (when configured to initiate a reset), and an external reset pin assertion. In Stop mode, a Stop mode recovery is initiated either by the watchdog timer timeout or GPIO port input pin transition on an enabled Stop mode recovery source.

Executing the eZ8 CPU's Stop instruction places the Z8 Encore! in Stop mode, during which the primary crystal oscillator and system clock are disabled, and the CPU is idle. In addition, the program counter (PC) stops incrementing, the watchdog timer's internal RC oscillator continues to operate (if enabled, the watchdog timer continues to operate), and all of the other on-chip peripherals are idle.

To minimize current in Stop mode, all GPIO pins that are configured as digital inputs must be driven to one of the supply rails (e.g., $V_{CC}$ or GND). The Z8 Encore! is brought out of Stop mode using the Stop mode recovery.

The watchdog timer is a 24-bit counter based on an internal RC oscillator. The minimum count overflow is ~60 µs, and a maximum count overflow is over 5 min.! The overflow can cause a reset or wakeup.

## DEBUGGER

The integrated on-chip debugger (OCD) is rapidly becoming a standard function in micros. The Z8 Encore!'s OCD provides access to the register file, program, and data memory. Advanced features include the setting of breakpoints and watchpoints, and the immediate execution of eZ8 CPU instructions.

The OCD consists of four primary functional blocks: transmitter, receiver, auto data rate generator, and debug controller. Figure 4 illustrates the architecture of the OCD using the

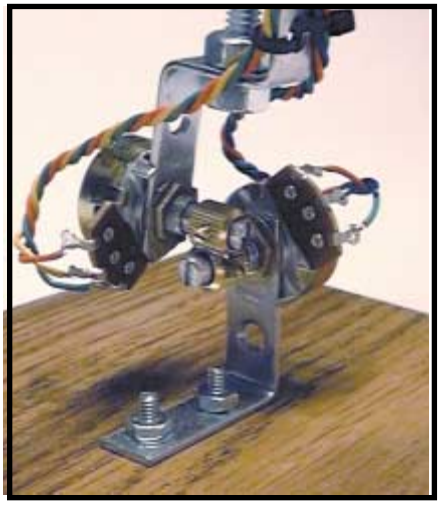


**Photo 2—***The metal bushings pulled from control knobs are soldered at right angles to hold the potentiometer's shafts creating an X-Y mechanism. The Z8F6401's $V_{REF}$ drives the potentiometers, which return voltages indicating the position (movement) of the vertical leg.*

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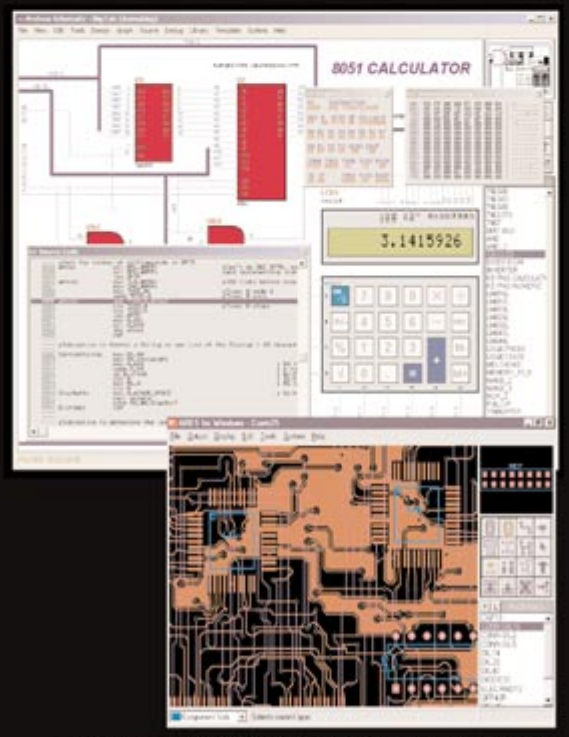
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*E.g. PROTEUS VSM can simulate an 8051 clocked at 12MHz on a 300MHz Pentium II.

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**Photo 3—***The levers attached to the hip gimble allow the servos to tilt the body (platform above the gimble) in a ± X or Y direction referenced to the leg (and ankle axis).*

DBG pin for communication with an external host. This one-pin interface is a bidirectional open-drain interface that transmits and receives data (not simultaneously). The serial data on the DBG pin is sent using the standard asynchronous data format defined in RS-232. This pin can act as an interface from the Z8 Encore! to the serial port of a host PC using minimal external hardware. Figure 5 shows a typical circuit that's necessary to connect the DBG pin to a PC. (This circuit is Zilog's target interface module board.)

If the DBG pin is low when the Z8 Encore! exits Reset mode, the OCD automatically puts the Z8 Encore! into Debug mode. To run over a range of data rates with various system clock frequencies, the OCD has an auto data rate detector/generator. After a reset, the OCD is idle until it receives data. The OCD requires that the first character sent from the host is the character 80H. The character 80H has eight continuous low bits (i.e., one start bit and seven data bits). The auto data rate detector measures this period and sets the OCD data rate generator accordingly. The system clock clocks the auto data rate detector/generator. The minimum data rate is the system clock frequency divided by 512; the maximum recommended data rate is the system clock frequency divided by eight. After the data rate is set, you can communicate directly with the OCD.

The BRK instruction (opcode 00H) signals the OCD. If breakpoints are enabled, the OCD enters Debug mode and idles the eZ8 CPU. If breakpoints are disabled, the OCD ignores the BRK signal, and the BRK instruction operates as an NOP.

A breakpoint is established by writing 00H to the desired address and overwriting the current instruction. To remove a breakpoint, the corresponding page of flash memory must be erased and reprogrammed with the original data.

If you aren't looking to take control of the OCD with a roll-your-own debugging application, then Zilog's Z8 Encore! test-drive kit, complete with its great integrated development environment (IDE), is all you need. Again, refer to Fred's aforementioned column to learn more about the details.

## LOOSEN UP

Before diving into the code for a new micro, it's always good to start with something that already works. You can avoid immediate frustration by running (and reading) the tutorial code included in the development kit. The kit comes with a sample assembly test program on the CD; it prints a message on the four 5 × 7 LEDs.

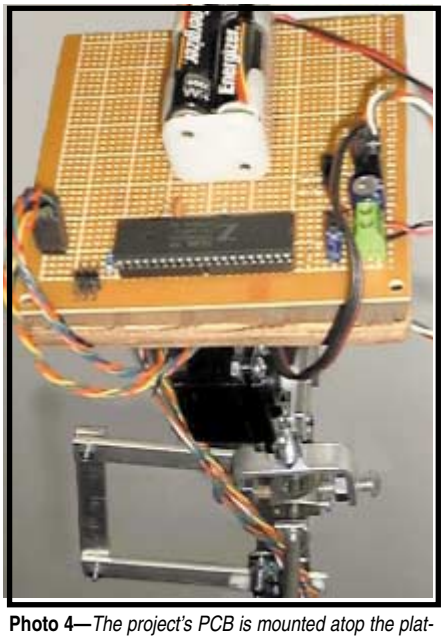


**Photo 4—***The project's PCB is mounted atop the platform along with the four AA batteries. Plenty of space remains on the PCB to accommodate circuitry for future sensors. I've only begun to use the horsepower and application space available on the Z8F6401.*

This application includes four files: encore_main.asm, xtools2_led.asm, scroll2_led.asm, and lights_out.asm. Basically, the main file continuously calls the other three files in endless succession. The xtools2_led.asm file defines a number of macros to write data to the 5 × 7 LEDs and calls these from a number of routines, which set particular character combinations on the displays. The combinations appear as characters jumping from one display position to the next (i.e., "XTOOLS RULES"). The scroll2_led.asm file is similar code with a second message, "PASS." The lights_out.asm file simply turns off all of the LEDs.

The routine used a character-jumping technique, so the scroll wasn't the smoothest. To get warmed up, I chose to rewrite this for a smoother scroll. Although the 5 × 7 LEDs in the PCB kit are separated, the spacing is only 0.1". This happens to be the same as the LED spacing within each display; therefore, as the columns of a character scroll between two displays, the column spacing remains constant as it scrolls through this darkened space. This adds to the smoothness of the scroll.

Certainly, the application could have been written in a single .asm file, but the technique used demonstrates the use of multiple files. Thus, it's part of the learning experience.

I altered the LED routines to accept register data (i.e., R5 to R9), as opposed to the sample's use of constants. This change allows the same routine to be used to write all data. In the original sample, the message is defined by the constants in each routine (i.e., one routine for displaying each set of characters on the four LEDs). Now the message is defined in a table of column data for each character (with a column of 00 data as an empty column between characters). Only the table length limits the message length.

The last piece of the puzzle is a loop (download from the *Circuit Cellar* ftp site) that indexes into the table,

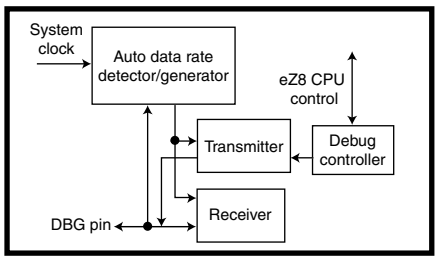



**Figure 4**—*A half-duplex serial channel is created via the Z8 Encore! DBG pin. This single pin gives you access to the CPU via the debug controller.*

transfers the appropriate data into R5-R9, and calls the display routine. Incrementing the table pointer by one each time through the loop allows the character data to scroll one column at a time.

## A QUESTION OF BALANCE

This column is a setup for a project that you can work on yourself. Photo 1 shows the platform I built to experiment with balance. The idea was to monitor the movement (from gravity) of a body fixed atop a single leg and attempt to counteract the movement with a shift of weight.

The foot of the leg is attached using a joystick-type ankle joint. The potentiometers on this joint give the position indication of the leg as X and Y outputs (see Photo 2). The body (platform) is connected to the leg through a hip joint, which can be adjusted by X and Y servos (see Photo 3). A Z8F6401 micro (a 40-pin DIP) is mounted on the platform and takes in the foot's position data through analog inputs 0 and 1 (see Photo 4). The hip servos are controlled via the PWM outputs of Timers 0 and 1 (see Figure 6).

Experimental code initializes the A/D converter for continuous operation; it uses DMA transfers to automatically move the conversion values for channels 0 and 1 into RAM locations (new sample values). The 10-bit conversion values are left justified within their 16-bit word, and they must be shifted to the right by six bits to lower justify them.

The RC servos used in the hip joint must see a positive pulse every 20 ms. The width of this pulse determines the position of the servo. A pulse

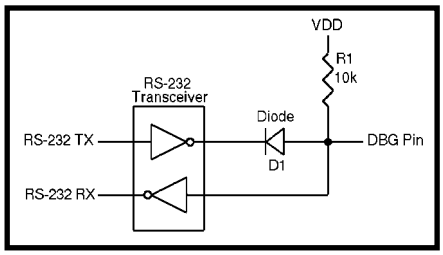



**Figure 5**—*A 2 × 3 square pin connector supplies power, ground, and a single communication line (DBG) from the target PCB to this simple half-duplex serial adapter. The MAX232 converts serial from a host PC to the 3.3-V logic levels used by the DBG interface pin.*

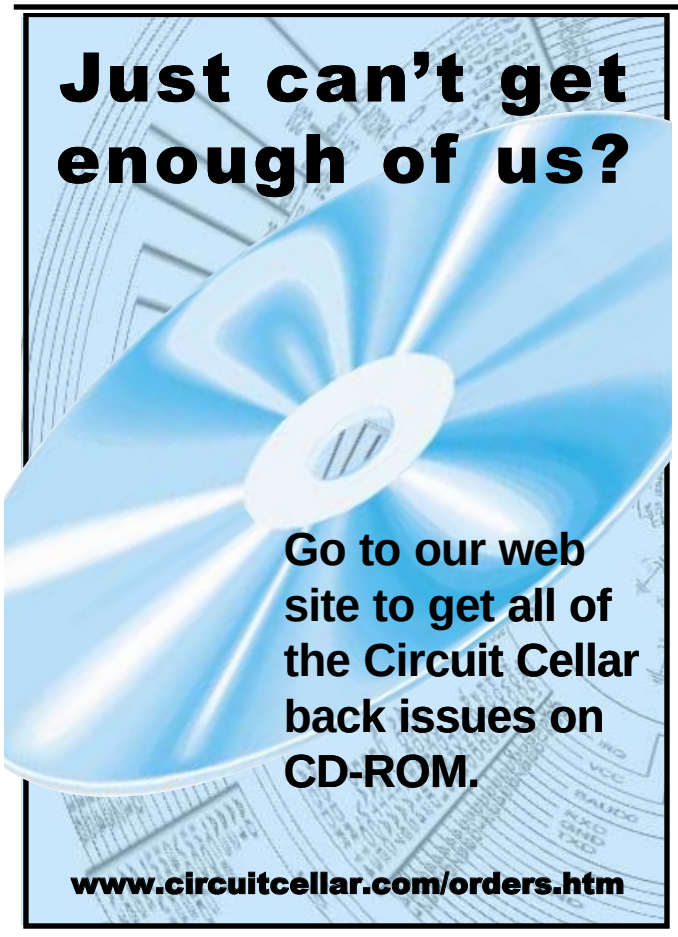
width of 1.5 ms positions the servo at the center of its rotation (neutral). Timers 0 and 1 are initialized for a PWM output of 1.5 ms. This requires the following timer reload value:

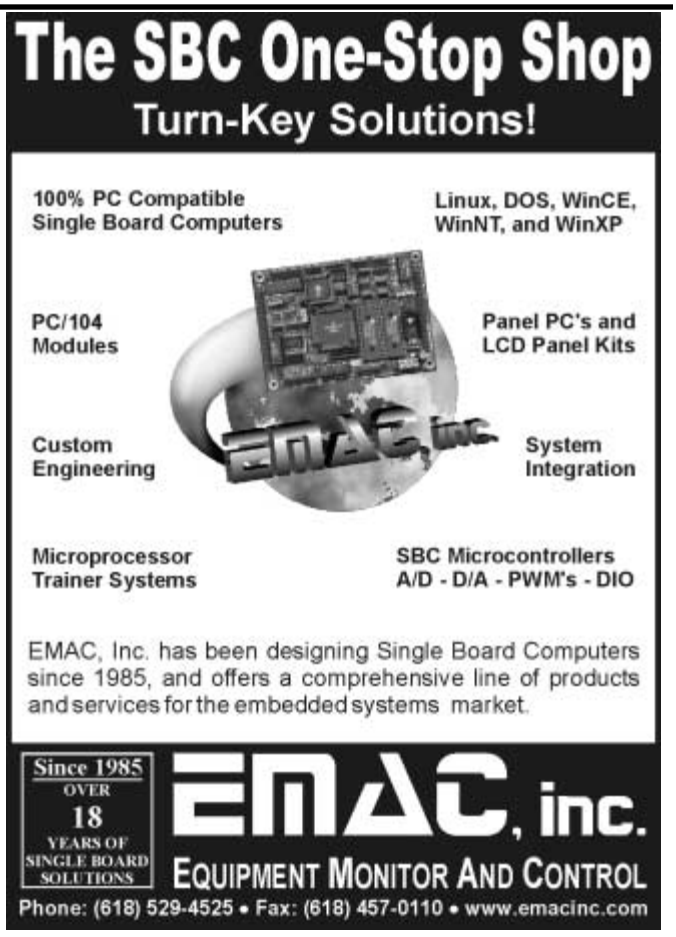
$$\text{PWM period} = \text{reload value} \times \frac{\text{prescaler}}{\text{system clock}}$$

Thus,

$$0.02\ \text{s} = \frac{50{,}000 \times 8}{20{,}000{,}000}$$

where the reload value equals 50,000 (or C350H), and the prescaler equals eight. The PWM value (i.e., high time)

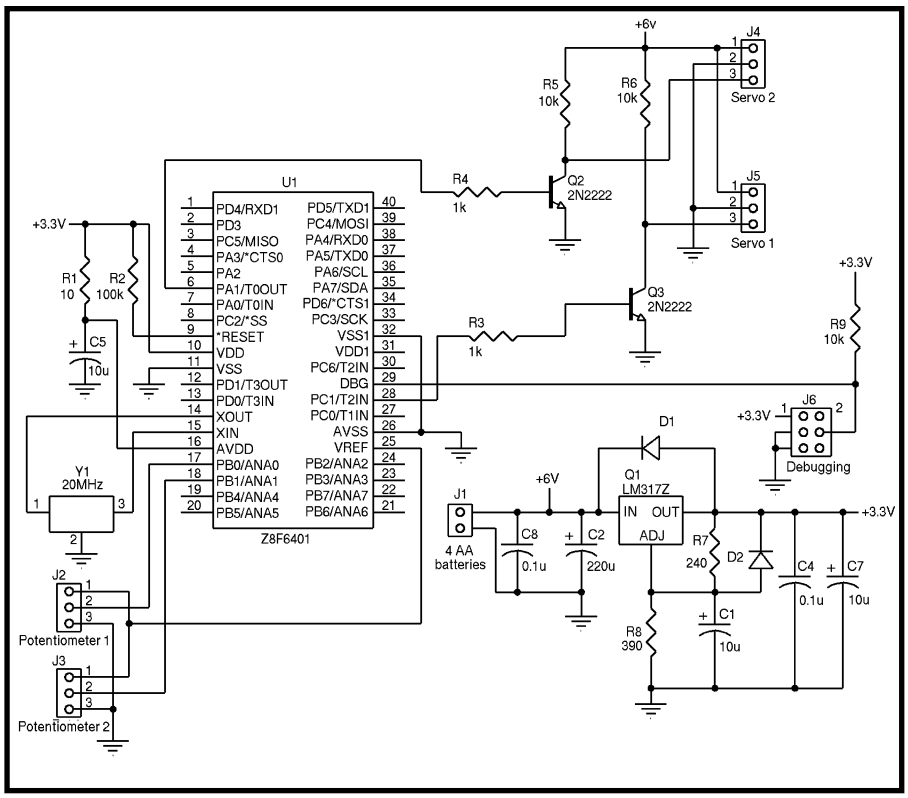



**Figure 6—***The 40-pin DIP version is used to eliminate surface-mount soldering. J6 is the debug connector that allows the debugger interface to be connected for debugging/programming of the Z8F6401. Q2 and Q3 interface the 3.3-V PWM outputs to the 6-V servo inputs. (The inverters require an inverted PWM output.)*

is the percentage of the period. In this case, you want the following:

$$\text{percentage} = \text{high time} \times \frac{100}{\text{period}}$$

or

$$\text{percentage} = \frac{1.5\ \text{ms} \times 100}{20\ \text{ms}} = \frac{150}{20} = 7.5$$

Therefore, you arrive at the following equation for the PWM value:

$$\text{PWM value} = \text{reload value} \times \frac{\text{percentage}}{100}$$

or

$$\text{PWM value} = \frac{50{,}000 \times 7.5}{100} = 3750$$

where the PWM value equals 3750, or 0EA6H.

Maximum and minimum PWM values are also needed, because you can't ask the servos to move more than their design limits. I used 1.25 and 1.75 ms as the lower and upper design limits; they correspond to approximately 6.25% and 8.75%, or values of 3125 and 4375 (or 0C35H and 1117H, respectively).

To sustain a controlled point of balance, there are many factors to consider. The leg's position sensors in the ankle provide movement information concerning the leg. The arc of leg movement must be small per bit of the A/D converter. Using a potentiometer with a full-scale rotation of 300° and a 10-bit A/D converter gives roughly 0.3° per bit. At a leg length of 38″, 0.3° of arc would represent approximately 0.2″ of movement at the arc's circumference.

A weight will fall at 32′ per second. This calculation isn't so simple when the weight is supported from falling. When the weight is perfectly centered on the leg, it will not fall, because the weight's falling vector (0° toward the center of the earth) is canceled by the leg's supporting vector (180° away from the center of the earth). As the weight moves off the center, the leg vector no longer cancels the weight vector, and the weight begins to fall. The farther from the center, the less the leg can slow the weight's acceleration. By this (and through personal experience), it's clear that the faster you respond to an off-balance situation, the more likely you are to correct it.

Servos aren't the quickest positioners. The Cirrus CS-50s that I used are rated for 60° in 0.16 s (i.e., roughly 3 ms per 1°). There are about a 6″ between the platform holding the electronics and batteries and the hip joint. This is the (body) weight that the servos must move to counteract the leg position. When the Z8F sees a change in leg position, it changes a PWM output in an attempt to counter the movement.

## ALGORITHMS ANYONE?

I wish it were all this easy. If it were, then Segway (the person mover) would be a toy you could buy at "Toys Be Us" for about $100. After all, it only deals with balance in one direction. The algorithm that must be employed for the success of this experimental platform needs refinement. And, although the software needs tweaking, I've also been thinking about alternative sensors and joint mechanics. So much to do, so little time.

I hope this project sparks your imagination, because as soon as the fuse is lit, you're going for a ride. And, as luck would have it, knowledge doesn't necessarily come from success, but through the process of striving for it.

*Jeff Bachiochi (pronounced BAH-key-AH-key) has been writing for* Circuit Cellar *since 1988. His background includes product design and manufacturing. He may be reached at jeff.bachiochi@circuitcellar.com.*

## PROJECT FILES

To download the code, go to ftp.circuitcellar.com/pub/Circuit_Cellar/2003/155/.

## SOURCES

**CS-50 Standard servo**
Cirrus Logic, Inc.
www.cirrus.com

**Z8 Encore! kit, Z8F6401 DIP**
Zilog, Inc.
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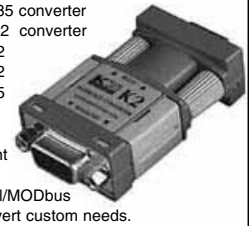
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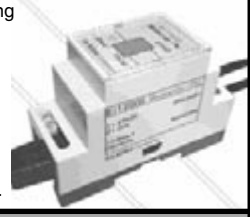
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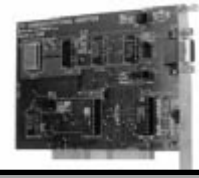
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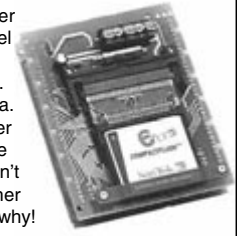
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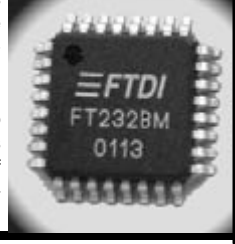
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# Good Vibrations

*What do the Beach Boys, B-movie aliens, and Motorola have in common? They all owe some of their varied successes to the science developed by a KGB bug maker named Leon Theremin. In this column, Tom connects the technological dots by way of an introduction to the MC33794 and e-field technology.*

Have you heard the story of Leon Theremin and the musical instrument named after him that he invented almost a century ago? Actually, to be correct, the story is really about Lev Sergeyevich Termen and his cathode electromusical instrument. (The Russian-born inventor changed his name when he moved to the United States in the early '20s.) Anyway, it's an eminently interesting tale, and the subject of plenty of 'Net hits (start at www.theremin-world.com or just search for "Theremin" on Google) and even recent books and movies (see Photo 1).

The story goes well beyond technology and music, combining depression-era Americana and Cold War intrigue. To this day, there are still questions about the circumstances of his "kidnapping" (or voluntary return?) in 1938. Back in the Soviet Union, Theremin was forced (or chose?) to develop spy gadgets for the KGB. One of his first inventions was the bug planted in a gilded eagle given to the U.S. Ambassador by Soviet "Boy Scouts" in 1945. Meanwhile, on the home front, RCA made about 500 theremins in the '20s, and those that remain are collector's items today.

Well, maybe you haven't heard the Theremin story, but it's almost inconceivable you've never heard the ethereal tones produced by one of the first purely electronic musical instruments, seminal ancestor to the synthesizers and MIDI technology you'll find in today's music studios. Indeed, the well-known synthesizer pioneer Robert Moog got his start by home brewing theremins, and he's still working with them to this day. (You can find his how-to articles on the 'Net.) [1, 2]

The theremin came into its own in the '50s, providing the audio signature for various invaders from outer space, which is all the more ironic given the Cold War backdrop to the age. I've got to laugh at the fact an instrument designed by a KGB guy ended up being a musical calling card for faceless Sputnik-on-steroids evildoers such as robot Gort in *The Day the Earth Stood Still* (1951) and the furious queen in *Queen of Outer Space* (1958).

Subsequently, theremins enjoyed some niche success on the musical front in the '60s and '70s. Although bands like Lothar and the Hand People had arguably limited reach, there are better-known theremin players up to and including Led Zeppelin's Jimmy Page.

The famous "wee-ooh" sound of the Beach Boys's 1966 hit "Good Vibrations" was perhaps the celebrity highpoint for the theremin, at least in spirit if not fact. Actually, the Beach Boys used a so-called electro-theremin, which was an instrument built in the '50s that used a mechanical pitch slider controlling a sine wave oscillator.

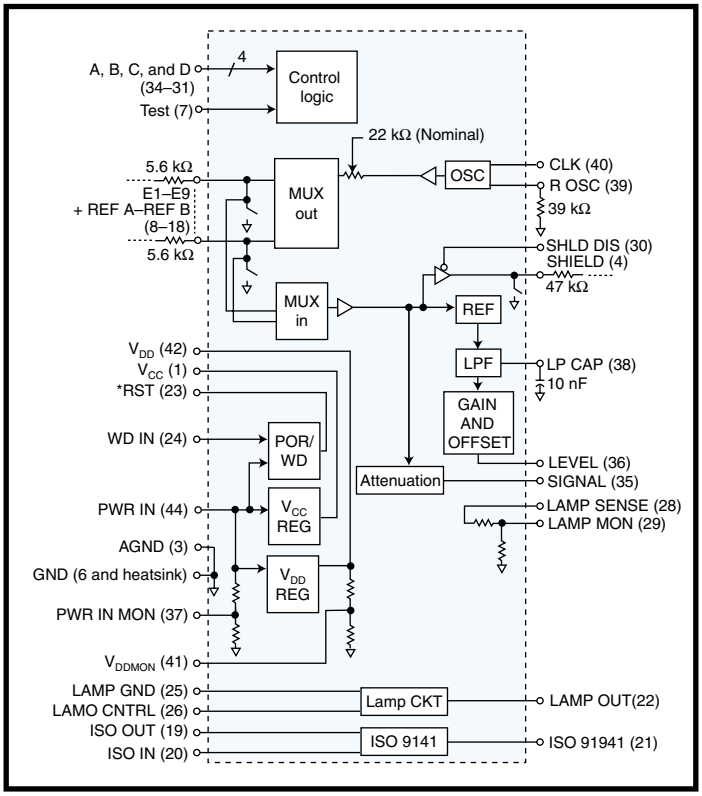



**Figure 1**—*Although the design was prompted by the need for smarter airbags, the MC33794 electric field imaging device raises other intriguing application possibilities.*

## I CAPACITOR

Putting the Beach Boys and B-movies aside, Theremin's invention still resonates today with practical application. The theory of operation represented at the time a breakthrough for the heterodyne concept. You may recall the idea: mixing two sine waves of different frequency will produce a beat frequency equal to the difference between the two.

Of course, the most striking feature of the theremin was its seemingly paranormal operation, in which a player would wave their hands in proximity to two antennas, one for pitch and one for volume. A newspaper article at the time reassured readers that it was all based in science and explained that they needn't worry that the instrument was monitoring their thought waves.

The key to the whole scheme is the fact that humans are capacitors, albeit small ones. Who hasn't had the experience of affecting a piece of electronic gear's operation by proximity, whether fuzzy TV reception or a balky chip?

Theremin exploited so-called hand capacitance to induce a relatively small change in a tuning oscillator relative to a fixed (a.k.a. "local") oscillator. Thanks to the heterodyne principle, even a relatively minor difference between high-frequency oscillators can sweep the audio range (e.g., a 1- to 1.02-MHz difference covers 0 to 20 kHz).

## DOWN TO EARTH

I was prompted to go on the theremin jag by Motorola's introduction of an intriguing-sounding electronic field imaging device. That's because the basic premise behind the new chip and Theremin's instrument is the same: exploit the capacitance of a human (or another electromagnetic object) to detect proximity.

Admittedly more practical than whimsical, the chip was developed to serve a compelling application: occupant detection for smart air bag systems in cars. According to the press release, the chip is already at work doing just that with Honda mentioned as one of the first customers.

Needless to say, the well-reported stories of the early "let 'er rip" (your head off) airbag designs set the stage

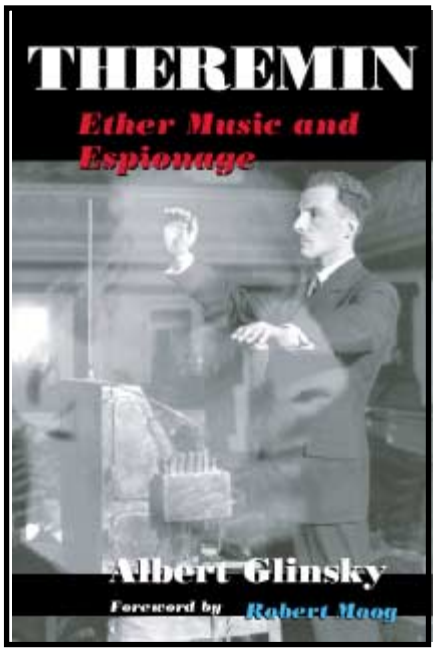



**Photo 1**—*Theremin, who is now the subject of books and movies, exploited the concept of hand capacitance almost 100 years ago. Source: A. Glinsky and R. Moog,* Theremin: Ether Music and Espionage (Music in American Life), *The University of Illinois Press, Champaign, IL, 2000.*

for technology to come to the rescue. I see a future where your car seat is a veritable cocoon of front and side airbags and curtains, all working in concert to soak up as many Gs as possible. But doing the job right requires not only knowing if a seat is occupied, but also identifying the occupant's size, height, seating position, and so on.

Hey, how about an Off-Baby-Kid-Adult switch for the airbag? Oops, that wouldn't be passive enough, not to mention the problem of multiple languages, occupants who can't read or forget their glasses, and so on.

The engineer in me loves to brainstorm the options. How about a scanning ultrasonic dish that maps the interior? Dash cams with image processing? Piezo strain gauge seat covers? But the reality of automotive applications is that the solution has to be reliable and durable without inducing sticker shock. Enter the MC33794 (see Figure 1).

Before getting into the e-field stuff, let's talk about some overall design-in factors. First, just a glance at the chip's pinout highlights its automotive roots. For instance, there's an ISO 9141 transceiver (ISO IN, ISO OUT, and ISO 9141). If you've gone under the hood (literally) of your modern car, then you'll recognize this as the connection to automotive networks such as On-Board Diagnostics (OBD II). It's the wire hooked to the connector under your dash that the mechanic plugs a scanner into in order to diagnose problems and turn off the Check Engine light by clearing trouble codes.

The chip also includes a lamp circuit and related pins (LAMP CNTL, LAMP GND, LAMP SENSE, and LAMP MON), perhaps intended to drive a Check Airbag light. Hook everything up right, and you can not only turn the lamp on and off, but also check whether it's shorted or burned out.

And I'm not talking about a wimpy LED, but something more like a headlight—the built-in current limit is a whopping 1.7-A max! Along with the ISO 9141 interface (120-mA current limit), that explains the need for the fancy heatsink package this chip utilizes. If you aren't planning an automotive application, feel free to hook up a motor or some other high-current device.

One welcome by-product of the MC33794's road-going roots is that automotive stuff is designed to take a licking and keep on ticking. For instance, an extended temperature range (–40° to 85°C) is standard, and this nominally 12-V chip happily runs on anything from 9 to 18 V. It can even tolerate the infamous load dump (40-V spike) and double battery (26.5 V for up to 1 min.) hazards.

It's also obvious that the chip is designed to work in concert with an external MCU as evidenced by a built-in regulator (5 V at 75 mA) with voltage monitoring, power-on reset (POR) circuit, and even a watchdog timer. The good news is that some or all of these may come in handy or allow for the use of a simpler, lower-cost MCU.



**Photo 2**—*The evaluation kit combines the M33794 with an HC908 MCU that's in a DIP package and socketed for easy experimentation.*

However, it's a bit disappointing that none of the characteristics are programmable. For instance, the watchdog timeout is imprecise—anywhere between 50 and 250 ms—and there's no way to adjust it. The same goes for the POR circuit, which may assert the RST output for anywhere from 9 to 50 ms, take it or leave it. The 5-V regulator voltage monitor can trigger anywhere between 4 and 4.72 V on the low side and 5.26 and 5.83 V on the high side—a rather loose spec, and certainly problematic when working with a typical 5-V ±10% part.

One nice touch is that three monitoring pins are provided for PWR (chip power), $V_{DD}$ (output of the 5-V regulator), and the LAMP. These include built-in voltage dividers that scale down the voltage for connection to a 0- to 5-V A/D converter. For instance, the PWR MON pin divide ratio is 1:4, so a 0- to 5-V A/D converter can monitor a range of 0 to 20 V on the PWR pin.

Even if you don't need the '33794's automotive or MCU support features, keep in mind that at $3.09 in quantities of 10,000, you're not really paying much for them anyway.

| Pin/Signal | D | C | B | A |
|---|---|---|---|---|
| Source (internal) | 0 | 0 | 0 | 0 |
| E1 | 0 | 0 | 0 | 1 |
| E2 | 0 | 0 | 1 | 0 |
| E3 | 0 | 0 | 1 | 1 |
| E4 | 0 | 1 | 0 | 0 |
| E5 | 0 | 1 | 0 | 1 |
| E6 | 0 | 1 | 1 | 0 |
| E7 | 0 | 1 | 1 | 1 |
| E8 | 1 | 0 | 0 | 0 |
| E9 | 1 | 0 | 0 | 1 |
| Ref A | 1 | 0 | 1 | 0 |
| Ref B | 1 | 0 | 1 | 1 |
| Internal OSC | 1 | 1 | 0 | 0 |
| Internal OSC after 22 kΩ | 1 | 1 | 0 | 1 |
| Internal ground | 1 | 1 | 1 | 0 |
| Reserved | 1 | 1 | 1 | 1 |

**Table 1—***Four source select pins (A to D) define which of the eight electrodes or other internal sources are selected for measurement.*

## SI(G)NS

With the road-going background (and most of the pins) out of the way, let's take a look at the thereminesque aspects of the '33794. The e-field side of the story boils down to little more than the following: a dozen pins, eight electrode connections (E1 to E9), four electrode select lines (A to D), a shield driver (SHIELD) and associated control pin (SHLD DIS), two references (Ref A, Ref B), and the LEVEL output. Here's how it works.

The four select lines (A to D) control a multiplexer that determines which electrode (or other internal signal as in Table 1) is to be measured. A nominal 120-kHz, 5-V peak-to-peak sine wave is routed to the chosen electrode and to the built-in level check circuit. As an aside, Motorola highlights the purity of the generated sine wave (i.e., –20 dB for second to fourth harmonics, and –60 dB for fifth and beyond), which is no doubt designed that way in order to prevent the chip from interfering with radio reception or the other electronic gadgets found under the hood these days.

Capacitance (i.e., "hand capacitance" in Theremin-speak) between the chosen electrode and ground is detected, amplified, and offset to generate a nominal 0- to 5-V output on the LEVEL pin for connection to your MCU's A/D converter. Absolute capacitance may vary depending on temperature, aging, or the overall ambient electromagnetic environment, for instance. To that end, low (e.g., 10 pF) and high (e.g., 100 pF) reference capacitors are connected to two lines—Ref A and Ref B—to enable relative measurements and calibration.

It's likely that packaging and placement concerns will call for the connecting of electrodes to the chip via a length of coax. The problem is that the cable brings along it's own capacitance between the center conductor and the shield. To solve this problem, connect the SHIELD pin to the coax shield. As a result, the shield is driven to the same level as the electrode pin, in essence making the coax disappear. The shield driver can be turned on and off (SHLD DIS pin), which provides a way to self-test for broken connections or other faults. Toggle the shield driver on and off, and if you don't see a corresponding change on the LEVEL pin, you'll know something is amiss.

## HANDS ON

Motorola offers an HC908 MCU-based evaluation module that serves as a reference design and makes it easy to play around with the '33794 (see Photo 2). It's probably well worth the reasonable $70 price tag just to avoid the hassle of having to homebrew with the fine-pitch, surface-mount package.

As you can see from the schematic in Figure 2, hooking up the '33794 to any MCU should be a snap. In fact, if you ignore the automotive and glue logic extras, all that's really required are four or five digital outputs (electrode select lines A to D and SHLD DIS) and one 0- to 5-V analog input (LEVEL). One trick: if you want to take advantage of the power-on RST output but don't want to be bothered with the watchdog, just connect the WD IN pin to the '33794's CLK output, and the chip itself will

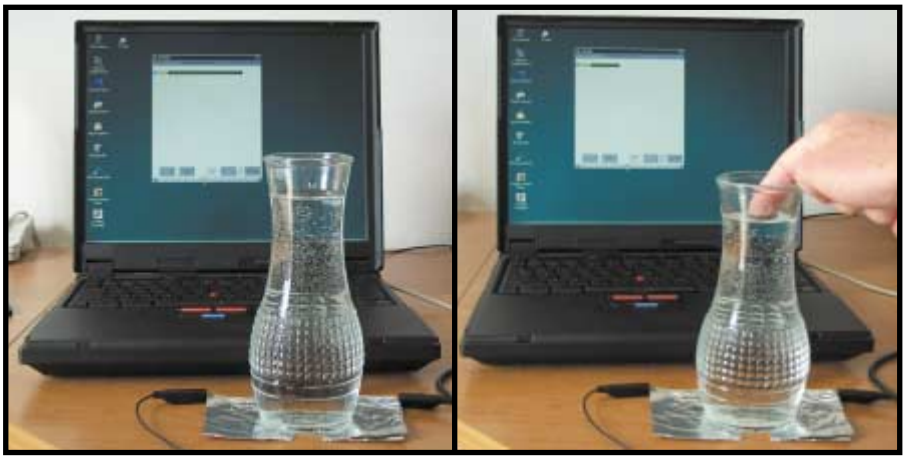


**Photo 3—***Get your feet wet (or my finger in this case). Look closely at the bar on the top of the EFLD.EXE window in the background, and you'll see how the MC33794 detects contact with the water.*

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take care of feeding the watchdog.

The MCU has a small built-in monitor (source code provided) that allows for basic '33794 operations using an RS-232 terminal program. There are commands to select an electrode, reference, or voltage monitor for access and turn the shield driver on or off. The kit also comes with a Windows GUI application that presents a graphical view of the chip's operation (see Photo 3).

Most of the monitor code is command decoding, message display, binary-ASCII hex conversion, and so on. The actual software to drive the chip is as straightforward as you may hope for. Set the A to D select lines to specify an electrode (or other internal source), wait for the output to settle (about 5 ms), and grab the 0- to 5-V analog result from the LEVEL pin.

The first thing I wanted to check was the basic responsiveness of the chip. For an electrode, I used aluminum foil, but other options include conductive foam (i.e., the black stuff chips are shipped in to avoid electrostatic damage), conductive tape (from burglar alarms), and conductive paint (i.e., anything that conducts electricity).

I quickly confirmed, as the documentation notes, that the detection level is directly related to the area of the electrode. Using some good old hand capacitance, I found the threshold for proximity detection using a square piece of foil to be about the length of a side (i.e., 1" for a 1" × 1" electrode, 2" for a 2" × 2", etc.). It is no surprise that a larger electrode increases sensitivity, but there are limits—too large, and it starts to load the output and reduce accuracy and dynamic range.

Within electrode size and range constraints, the MC33794's sensitivity is pretty good. In fact, by slightly raising and lowering my hand, I could see the discrete quantization steps associated with the MCU's 8-bit ADC. My hand-waving experiments would have been better served with a 10- or 12-bit ADC (or an external programmable amp).

I connected my foil electrodes using about 0.5 m of coax. (Note that Motorola recommends limiting the length to 1 m or so.) It was easy to see the virtue of the shield driver feature: when I turned it off (i.e., SHLD DIS pin), the output from the electrode was completely swamped by cable capacitance.

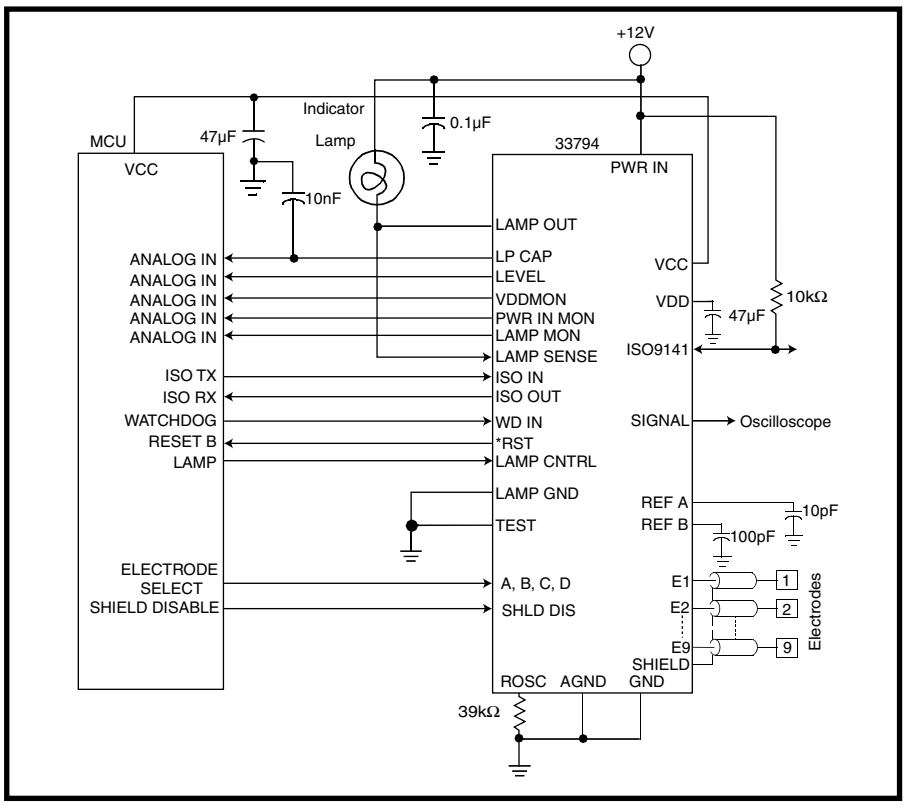



**Figure 2**—*Connection to an MCU is straightforward—all the better if the MCU can take advantage of the support functions (i.e., voltage regulator and monitor, power-on-reset, and watchdog timer) built into the MC33794.*

## BAGS AND BEYOND

Let's face it, the number of *Circuit Cellar* readers who design airbag systems for a living isn't large. For the rest of us, the real interest in the '33794 likely lies with "thinking outside the car" applications. Motorola mentions liquid-level and spill detection (e.g., a stove that automatically shuts off when the pot boils over).

I explored that concept a bit by putting a water glass on top of two electrodes. One was connected to the chip, and the other was connected to ground. Sure enough, putting even a tiny amount of water (less than a teaspoon) in the glass caused a noticeable change—approximately 10% of the full-scale difference between Ref A and Ref B capacitors.

Better yet, I noticed that touching the water with my finger also produced a solid 10% step (see Photo 3). Just brainstorming brings to mind a possible solution to the certainly worthy problem of childproofing pools and hot tubs. Other interesting application ideas include harsh environment no-key keypads that are hermetic without moving parts; or perhaps even a let-your-finger-do-the-walking mouseless pad.

I think creative designers are going to have a lot of fun with this chip. Hey, maybe it can even find its way into a modern-day incarnation of the theremin. *Queen of Outer Space II* anyone? ■

*Tom Cantrell has been working on chip, board, and systems design and marketing for several years. You may reach him by e-mail at tom.cantrell@circuitcellar.com.*

## REFERENCES

[1] R. Moog, "The Theremin," *Radio-Television News*, 1954.

[2] ———"A Transistorized Theremin," *Electronics World*, 1961.

## SOURCE

**MC33794 Electric Field Imaging Device**
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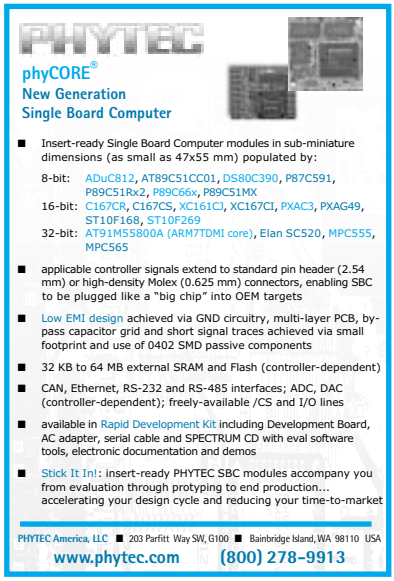
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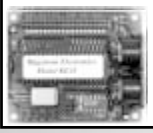
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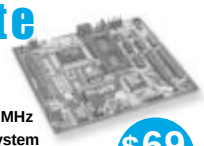
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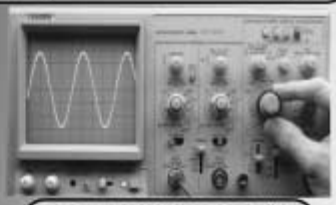
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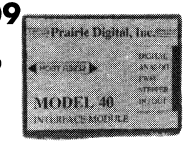


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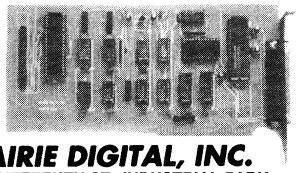
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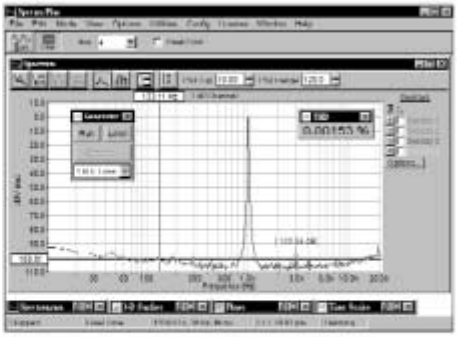


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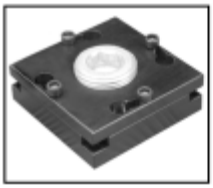


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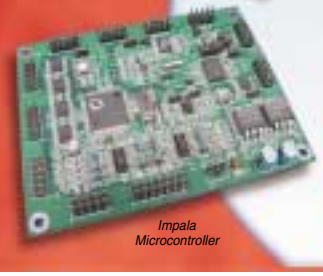
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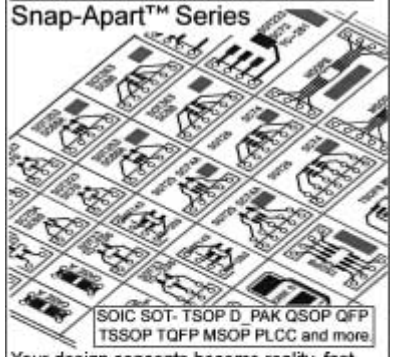
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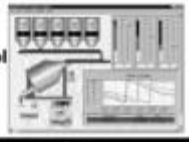
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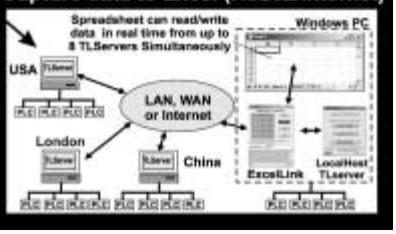


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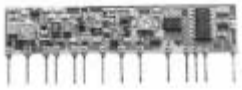

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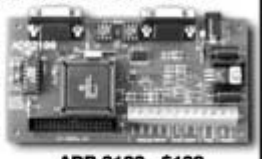
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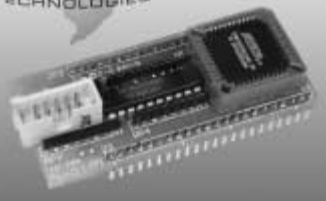
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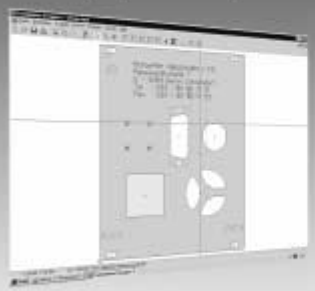
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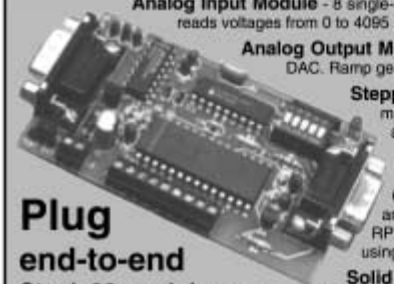
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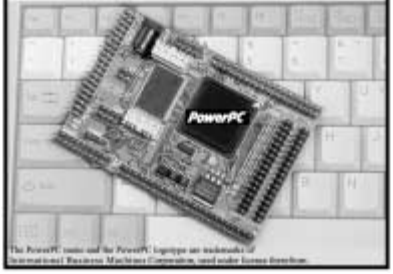
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**The Index of Advertisers with links to their web sites is located at www.circuitcellar.com under the current issue.**


| Page | | Page | | Page | | Page | |
|---|---|---|---|---|---|---|---|
| 91 | Abacom Technologies | 91 | EmbeddedPCI.com | 39 | Motorola E-Field | 88 | Sealevel Systems |
| 85 | ActiveWire, Inc. | 9 | ExpressPCB | 21 | Motorola Contest | 89 | Senix Corp. |
| 43 | All Electronics Corp. | 85 | FDI-Future Designs, Inc. | 82 | MVS | 95 | Sierra Proto Express |
| 90 | Amazon Electronics | 92 | Front Panel Express | 86 | Mylydia Inc. | 84 | Signum Systems |
| 93 | AP Circuits | 85 | Hagstrom Electronics | C2 | NetBurner | 93 | Softools |
| 34 | Arcom | 81 | HI-TECH Software, LLC | 88 | OKW Electronics, Inc. | 93 | Spectrum Engineering |
| 7 | Atmel | 92 | HVW Technologies Inc. | 52 | On Time | 84 | Square 1 Electronics |
| 93 | Avocet Systems, Inc. | 42 | ICOP Technology Inc. | 92 | Ontrak Control Systems | 89 | Starflight Electronics |
| 91 | Bagotronix, Inc. | 89 | IMAGEcraft | 25 | PCB123 | 86 | Syspec, Inc. |
| 63 | Basic Micro | 89,93 | Intec Automation, Inc | 9 | PCBexpress | 85 | TAL Technologies |
| 91 | Bellin Dynamic Systems, Inc. | 85 | Intrepid Control Systems | 87 | PCB Fab Express | 88 | TLData Corp. |
| 55 | CadSoft Computer, Inc. | 91 | Intronics, Inc. | C4 | Parallax, Inc. | C3 | Tech Tools |
| 87 | Carl's Electronics | 86 | Ironwood Electronics | 84 | Phytec America LLC | 32,33 | Technologic Systems |
| 45 | CCS-Custom Computer Services | 65 | Jameco | 87 | Phyton, Inc. | 87 | Technological Arts |
| 56 | Cogent Computer Systems, Inc. | 64, 85 | JK microsystems, Inc. | 93 | Picofab Inc. | 89 | Tern Inc. |
| 92 | Conitec | 23 | JR Kerr Automation & Engineering | 86 | Pioneer Hill Software | 13 | Texas Instruments |
| 53 | Connecticut microComputer, Inc. | 23 | K-Team S.A. / Hemisson | 86 | Prairie Digital, Inc. | 91 | Triangle Research Int'l, Inc. |
| 84 | Cyberpak Co. | 45 | LabJack Corp. | 89 | Pulsar, Inc. | 52 | Trilogy Design |
| 1 | Cypress MicroSystems | 45 | Lakeview Research | 90 | QKITS.COM | 93 | Weeder Technologies |
| 90 | CWAV | 49 | Lemos International | 88 | R2 Controls | 93 | Xeltek |
| 91 | DataRescue | 2 | Link Instruments | 73 | R4 Systems Inc. | 87 | Z-World |
| 85 | Decade Engineering | 44 | Linx Technologies | 15 | Rabbit Semiconductor | 88 | Zanthic Technologies Inc. |
| 90 | Delcom Engineering | 58 | MaxStream | 25 | Remote Processing | 57 | Zilog, Inc |
| 86 | Digital Products Co. | 90 | MCC (Micro Computer Control) | 5 | Renesas Technology Corp. | | |
| 17 | Earth Computer Technologies | 53 | Microchip | 90 | RLC Enterprises, Inc. | | |
| 84 | EE Tools (Electronic Engineering Tools) | 92 | microEngineering Labs, Inc. | 77 | Saelig Company | | |
| 75 | EMAC, Inc. | 86 | Mosaic Industries, Inc. | 88 | Scidyne | | |
| 90 | Embedded Micro Software | 71 | Motorola | 3 | Scott Edwards Electronics Inc. | | |


## Preview of July Issue 156
## Theme: Embedded Programming

**Spread Spectrum:** Theory and Practice

**Stealth Telephone Screener**

**Build a Three-in-One Measurement System**

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# PRIORITY INTERRUPT

by Steve Ciarcia, Founder and Editorial Director

## Opening E-mails From HairyAl

Have you ever had one of those days where you start out in one direction and end up doing something entirely different? It sounds trite, but that's what I'm doing right now. I was all ready to tell you about my experiences at the West Coast Embedded Systems Conference, the great reception *Circuit Cellar* always gets, and the great products I saw. Of course, I'd probably slip in a little about doing all of this in a California monsoon, having to eat six meals a day with PR people, and being virtually strip-searched to get on the plane. In fact, I started writing all about ESC longhand in a notebook at 30,000 feet on the way back.

It wasn't writing it longhand that redirected my thoughts. It was the nagging exasperation of remembering why I don't take my laptop on trips anymore. I used to always take my laptop when I traveled, albeit for business or vacation. Like many of you, 99% of my job these days is done through e-mail. It's a lazy practice for sure, but I'm guilty of even e-mailing editors who are only 50 feet down the hall.

Like many of you, I have to wade through hundreds of useless, distracting, and time-consuming spam messages every time I turn on my e-mail. It's worse when I travel. The whole world might have high-speed Internet but invariably I end up in some remote corner where people still think DSL is an abbreviation for diesel. At one time I could go directly to our server and purge all of the spam before starting my e-mail program. For the two or three good messages left, it didn't make any difference whether I was on a high-speed DSL or dial-up connection. A few kilobytes of text download and I was good to go. Today everything is rich text and HTML and I can't just toss a hundred messages like I used to. Now, I have to open many more e-mails just to determine whether they're real or not. Basically, the spam senders have gotten a whole lot better at disguising their e-mails, and the people who send me real messages have gotten a whole lot dumber about differentiating theirs.

Most of my problems are business related, like contest correspondence from guys in foreign countries with Hotmail addresses, who use nondescript subject lines like, "did you get what I sent yesterday?" Give me a break.

People who don't have a pile of e-mail don't really comprehend the problem. In fact, I have one close friend, Dick, who needed a little help understanding. Like many people who finally get a high-speed connection, they like everyone to share in their surfing experience. All of a sudden I started getting a bunch of e-mails from Dick. He'd stop on some web site, think it was great, and send it to me. I don't mean he sent me the link. I mean he sent me the page! He actually started pasting home pages into e-mails and sending them to me.

I called him and thanked him. I also mentioned that he didn't have to share every new web site with me anymore because I do enough surfing myself. Unfortunately, the subtle approach didn't get through to him. After a few more days of the barrage on my in-box, I decided to send him a few web sites to check out. I forwarded 75 spam messages to his in-box with a note that he could expect this helpful activity every day from now on. A couple hours later I got a telephone call and he said, "So I guess you don't need me to point out any web sites?"

Dick finally got the message about sending a lot of innocuous crap, but I also had to educate him again about making his "real" e-mails not get tossed out with the spam. Obviously, because he isn't spammed everyday, Dick didn't realize how much his e-mails looked like spam. He'd send a dinner invitation from "Dick" (or one of a half dozen other handles) with a subject like, "Want to get together Saturday?" Sound like about a dozen solicitations you get every day too? After not replying to any of his e-mailed invitations, he called and asked if I was mad at him. Now, he puts his full name in the subject line so I don't trash his e-mail.

Unfortunately, with all the junk e-mail I have to delete, I can miss quite a few legitimate e-mails if people don't use some intelligence when they send messages. If you really want me to read your e-mail, I've come up with a few rules to save it from the trash can.

1. Make the subject something that I will recognize. Write "Have the Motorola Design Contest Winners been announced?" and not just "Anybody win yet?" If you are sending me something about a contest project or an article in the magazine, always put the project number or something about the specific issue number in the subject line.

2. Unnecessary attachments are a pain. They keep me from downloading your e-mail until I return from a trip. Besides the ever-present possibility of viruses, it's irksome when the attachment is 50 characters of contact information embellished with a 100-KB company logo.

3. Don't send me our complete communication history with every e-mail. If we've been going back and forth, I like to see the past couple of messages to remind me of the conversation, but I don't need the previous 15 messages and answers.

4. Use a real e-mail address. I'm always suspicious of e-mail from tripleXguy or hairyAl@hotmail.com. Unfortunately, I get lots of real correspondence with address names stranger than that. It almost looks like the spammers are now using more legitimate-looking addresses than the general public. But really, would you open e-mail from hairyAl either?

Certainly there are more dos and don'ts I could add, but these are my hot buttons for today. I'm not sure we'll ever solve the problem as long as it's an open Internet. I don't want spam to be used as the excuse to add restrictions. I guess I'm only complaining because I don't have the luxury of even mediocre defenses. I can't even use keyword filtering or I miss the reader who doesn't take my advice and replies to this editorial with the subject line, "I get all those Viagra messages too." In the meantime, and while I wait for the world to achieve a higher level of e-mail etiquette, I'll relish my present success. Dick isn't junking up my in-box any longer and I haven't missed any of his recent dinner invitations.

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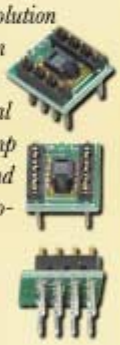



*The TCS230 sensor module set is a complete color detector, including a TAOS RGB sensor chip, white LEDs, collimator lens, adapter board, and connecting cable. It interfaces easily to any BASIC Stamp and can detect/measure a huge range of colors. Applications include color edge-following robots, color sorting, and color matching.* TCS230 color sensor; #30054; $79.00



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