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THE MAGAZINE FOR COMPUTER APPLICATIONS

WIRELESS COMMUNICATIONS

Wireless Tracking Solution

RFID Security System

DSP-Based Vehicle Monitoring

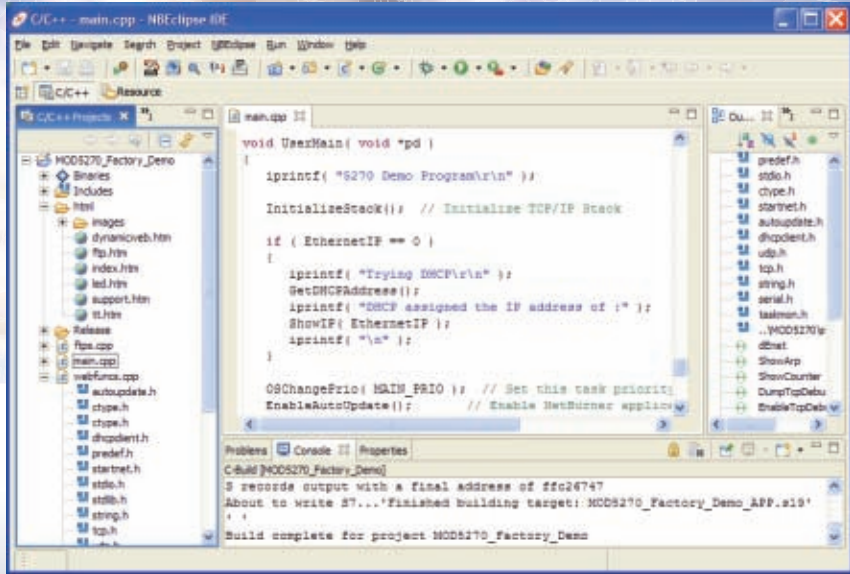
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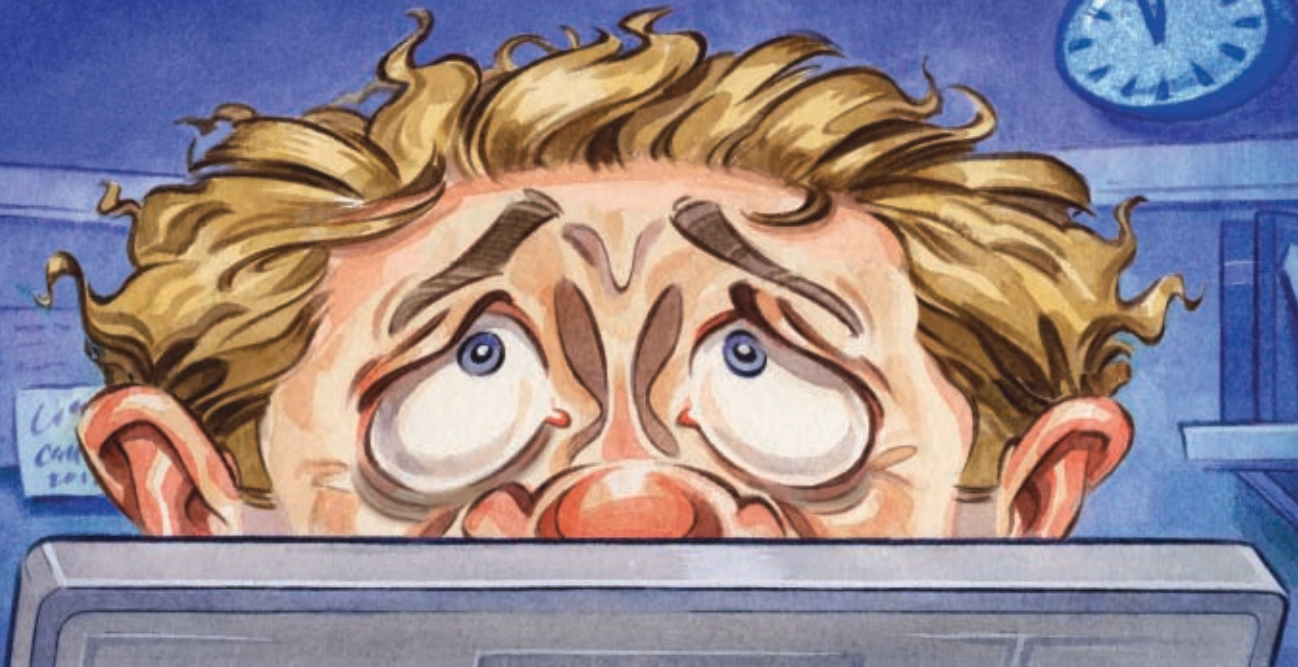
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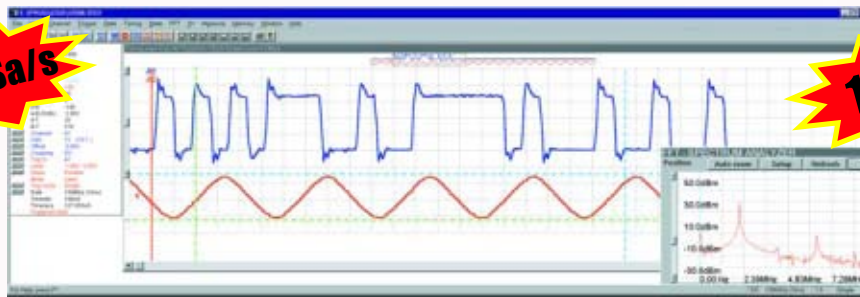
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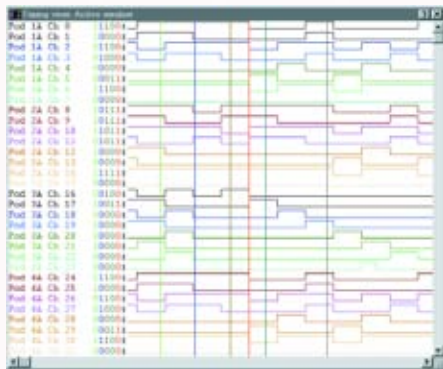
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1Mpts

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TASK MANAGER

What's Your Thing?

The type of engineer who reads *Circuit Cellar* on a monthly basis is the sort of person who has his own *thing*—you know, a certain topic of interest that preoccupies his mind and keeps him surfing the Internet well into the night. Steve Ciarcia is the type of guy who has a few *things*, many of which he has written about over the years: magazine publishing, BMWs, fine wine, haute cuisine, and, of course, his ever-evolving home control system (HCS). As you know, his interest in home control technology dates back to the mid-1980s, when the idea of an HCS was relegated to science fiction novels and movies. The technology has sure come a long way since then.

During the past 20 years, the systems Steve has rigged up have increased in functionality and complexity in direct proportion to the development of the new technologies we cover in this magazine. His current system incorporates the latest generation of web-enabled surveillance and data acquisition technologies. Motion sensors, zoom cameras, and time-logging software: they're all included. As a result, family, friends, neighbors, and even local law enforcement officers here in Connecticut have come to regard Steve as "that guy"—the self-sufficient digerati living in a high-tech house in rural New England.

Stop reading! Turn to Steve's editorial on page 96.

This month we feature articles by engineers who are all about wireless technology. These designers aren't merely riding the wireless bandwagon, they're driving it—remotely, of course. They're the type of people whose ears perk up when they hear words like "ZigBee" and "Bluetooth." They're visionaries who don't consider cell phones to be mere accessories: they see them as potential remote control units for new designs. They're the engineers whose designs will change the ways in which we communicate with each other in the coming decades.

On page 14, a team of designers from Camosun College walks you through the process of designing and building a functional modular wireless tracking system. They designed the system so parents and guardians can monitor the meanderings of the young children under their care, but you can design a similar system to track various other things. Get creative!

Craig Ross and Ricardo Goto's RFID security system (page 24) is a great design for anyone trying to secure a building and keep tabs on entry/exit traffic. I can definitely see someone incorporating this sort of technology in a home control system.

If you've ever wanted to perform remote firmware updates, Alex Deyneko has the project for you (see page 54). Now you don't have to disassemble your devices and their physical connections to CPU boards.

So, what's your thing? Are you a wireless buff like the designers whose projects are featured in this issue? Are you feverishly working on several robotic systems at once? Do you write hundreds of lines of code each day? Whatever your fancy, keep at it—and definitely keep us informed about your progress.

cj@circuitcellar.com



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FOUNDER/EDITORIAL DIRECTOR

Steve Ciarcia

CHIEF FINANCIAL OFFICER

Jeannette Ciarcia

MANAGING EDITOR

C.J. Abate

MEDIA CONSULTANT

Dan Rodrigues

WEST COAST EDITOR

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CUSTOMER SERVICE

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CONTRIBUTING EDITORS

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Ingo Cyliax

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GRAPHIC DESIGNER

Mary Turek

STAFF ENGINEER

John Gorsky

PROJECT EDITORS

Steve Bedford

Ken Davidson

David Tweed

ASSOCIATE EDITOR

Jesse Smolin

ADVERTISING

860.875.2199 • Fax: 860.871.0411 • www.circuitcellar.com/advertise

PUBLISHER

Sean Donnelly

Direct: 860.872.3064, Cell: 860.930.4326, E-mail: sean@circuitcellar.com

ADVERTISING REPRESENTATIVE

Shannon Barraclough

Direct: 860.872.3064, E-mail: shannon@circuitcellar.com

ADVERTISING COORDINATOR

Valerie Luster

E-mail: val.luster@circuitcellar.com

Cover photography by Chris Rakoczy—Rakoczy Photography
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CONTACTS

SUBSCRIPTIONS

Information: www.circuitcellar.com/subscribe, E-mail: subscribe@circuitcellar.com

Subscribe: 800.269.6301, www.circuitcellar.com/subscribe, Circuit Cellar Subscriptions, P.O. Box 5650, Hanover, NH 03755-5650

Address Changes/Problems: E-mail: subscribe@circuitcellar.com

GENERAL INFORMATION

860.875.2199, Fax: 860.871.0411, E-mail: info@circuitcellar.com

Editorial Office: Editor, Circuit Cellar, 4 Park St., Vernon, CT 06066, E-mail: editor@circuitcellar.com

New Products: New Products, Circuit Cellar, 4 Park St., Vernon, CT 06066, E-mail: newproducts@circuitcellar.com

AUTHORIZED REPRINTS INFORMATION

860.875.2199, E-mail: reprints@circuitcellar.com

AUTHORS

Authors' e-mail addresses (when available) are included at the end of each article.

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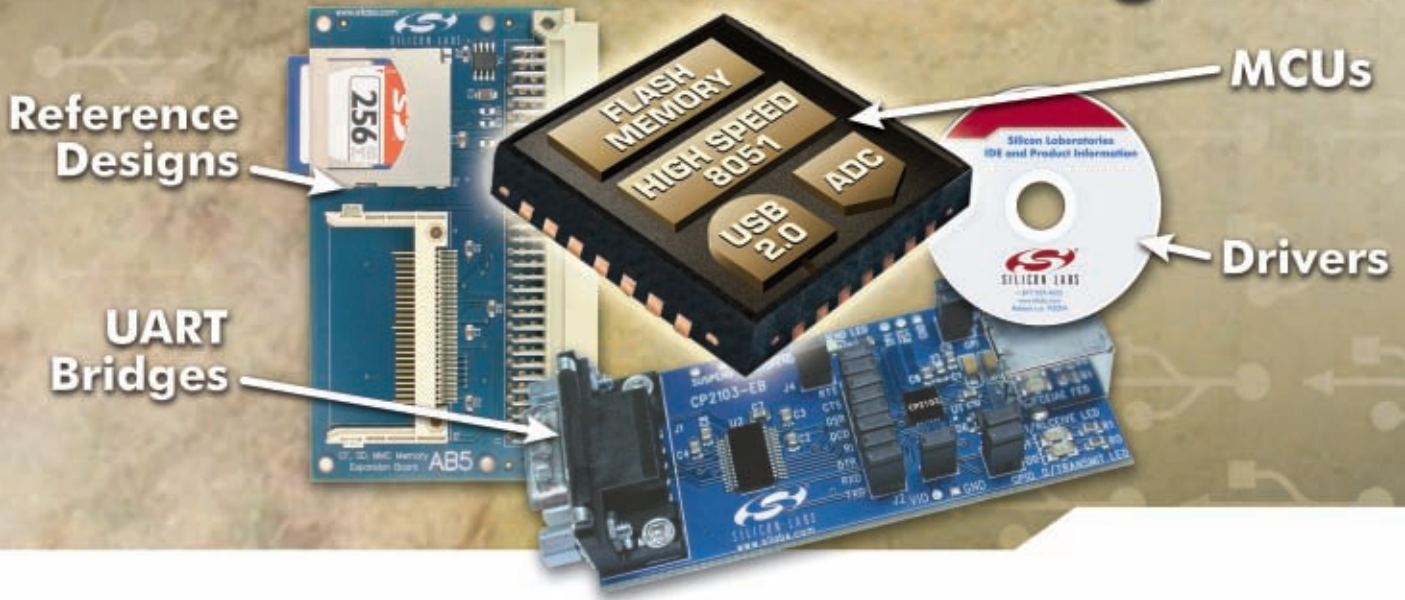
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We Provide Everything to Make USB Designs Easy



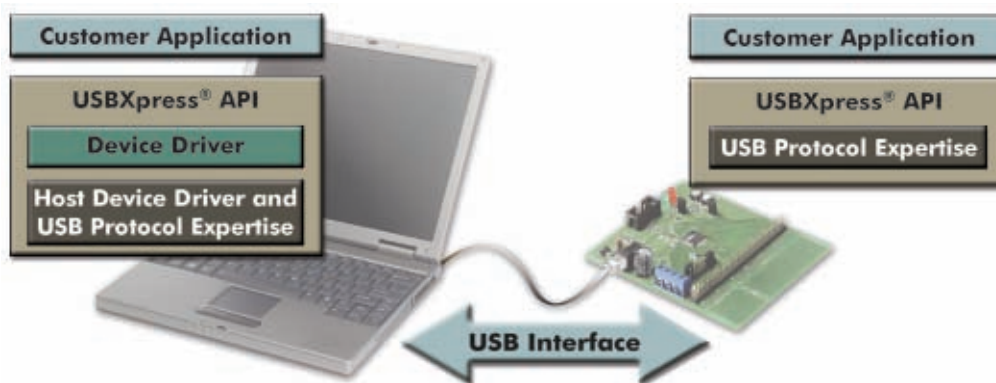
Low-Cost Embedded USB

Silicon Laboratories' extensive portfolio of USB MCUs and USB to UART Bridges include complete, low-cost development tools and drivers to make system design quick and easy. Software examples for real life systems are also available and include a mass storage device, USB audio and human interface device. The USB MCUs feature an on-board USB 2.0 function controller with an integrated transceiver that requires no external oscillator. On-chip resources include a high-speed 8051 CPU (up to 48 MIPS) with up to 64 kB Flash, multi-channel 10-bit ADC, voltage reference, internal oscillator, UARTs, SMBus, SPI, timers, counters and PWM generators.



USB to UART Bridge

- Single Chip (5x5 mm)
- USB 2.0 Controller
- UART Interface
- Update RS-232 Designs



Product details: www.silabs.com/USB

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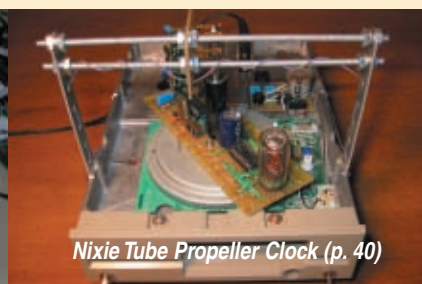
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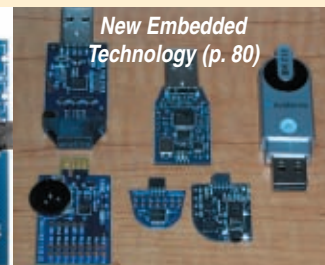
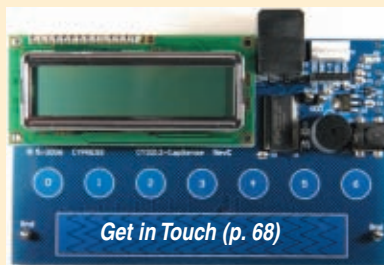
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Steve Ciarcia



AVR picoPower Microcontrollers

To meet the tough requirements to modern microcontrollers Atmel® has now combined ten years of low power research and development into picoPower™ technology for AVR® microcontrollers. picoPower enables AVR to achieve the industry's lowest power consumption with 650 nA with a real time counter running and 100 nA in deep sleep.

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- Sleeping brown-out detector enabling full protection with no power penalty
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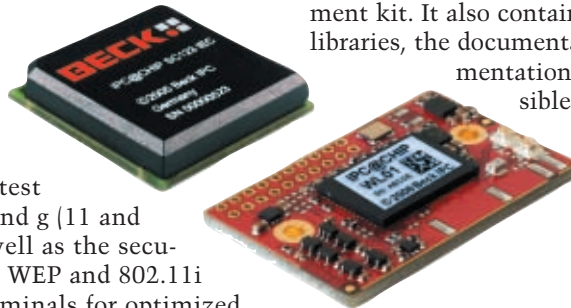
For more information, check out www.atmel.com/ad/picopower



FAST AND AFFORDABLE IMPLEMENTATION OF WIRELESS LAN SOLUTIONS

The new **WL01 Wireless LAN** module provides the IPC@CHIP Controller SC123/SC143 with a fully fledged Wireless LAN interface. The module also enables both infrastructure mode on an existing access point as well as adhoc mode between several WL01 modules.

The connection of the compact $23 \times 36 \times 5$ mm add-on module to the IPC@CHIP is implemented serially, via an SPI interface, with a maximum transfer rate of 48 MHz. The module supports the latest transmission standards -802.11b and g (11 and 54 Mb in the 2.4 GHz range), as well as the security standards in compliance with WEP and 802.11i (WPA), and offers two antenna terminals for optimized



reception and transmission.

An FK61-WL01 development kit will be offered for users to develop their own wireless LAN solutions inexpensively and quickly, as well as the Wireless LAN module and an adapter board for the existing DK61 IPC@CHIP development kit. It also contains all of the required software libraries, the documentation, and a demonstration implementation with a web configurator. It is possible to configure the wireless LAN module directly from the application program via a C-API as well.

The FK61-WL01 costs approximately \$448.

The FK61-WL01 costs approximately \$448.

Beck IPC GmbH
www.beck-ipc.com

READY-TO-GO BLUETOOTH MODULE

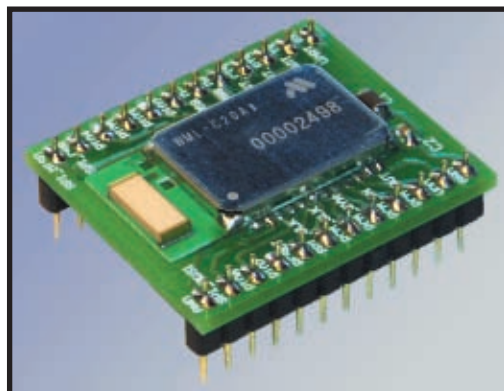
PearlBlue is a Class 1 (up to 100 m range) intelligent Bluetooth module that implements a transparent UART-to-Bluetooth interface bridge in Master or Slave modes, offering a fast, wireless solution for embedded applications. PearlBlue implements a proprietary command-based firmware over the Bluetooth SPP to allow worry-free, point-to-point wireless communications for devices incorporating this profile over Bluetooth. It connects the radio serial port to a physical UART that can be easily interfaced to any embedded microcontroller, PDA, or computer. The module also offers six general-purpose I/O lines.

The tiny $1.25" \times 1.1"$ module can act as a master or slave and implement a wireless RS-232-type link between a piece of equipment and other Bluetooth devices. It may also be used as an RS-232-to-Bluetooth configurable dongle (when used with the RS-232 accessory board) with advanced capabilities such as: the ability to initiate a connection, wait for a connection, search/identify (name and Class of Device), define name and CoD, and security with configurable PIN.

PearlBlue is OS and hardware independent. It is intended to give Bluetooth capability to embedded instruments, industrial controls, ambient monitors, and medical instruments. The radio power is 14 dBm at a carrier frequency of 2.4 GHz. The power requirement for the module is 3.3 V at 100 mA, and it is rated to run over the -40 to 70°C range. An accessory RS-232 board is also available with sockets for the PearlBlue module and a 3.3-V regulator.

emxys's PearlBlue is available in the United States through the Saelig Co. for \$99.

emxys
www.emxys.com



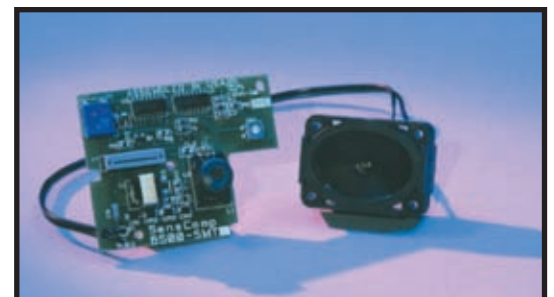
PIEZO ULTRASONIC TRANSDUCER DRIVER

The **9000 Sonar Ranging Module** is a new transducer driver board. It provides engineers and designers with a fast and easy solution to interfacing Piezo ultrasonic transducers, such as the 9000 series transducer, with the external circuitry or a controller for ultrasonic sensing in a variety of applications. It operates on 5 VDC and provides a TTL pulse-width output proportional to distance-to-target. As a matched component pair, the 9000 transducer and ranging module can detect objects or liquid surfaces from 1' to 18' (0.3 to 5.5 m). Common applications include liquid level sensing in tanks, an anti-collision sensor for AGVs, and other industrial environment applications.

Also available is the Series 9000 OEM Kit for prototype and technology feasibility studies, as well as an instructional tool for studies in ultrasonic measurement and proximity experiments in high school and university labs.

The 9000 module costs \$24.70 each in 10-piece quantities. The 9000 OEM Kit costs \$103.

SensComp, Inc.
www.senscomp.com



NEW PRODUCT NEWS

ZigBee PLATFORM WITH TRANSCEIVER AND ANALYZER

The **MRF24J40** is a 2.4-GHz IEEE 802.15.4 transceiver targeted for the ZigBee protocol—and proprietary wireless protocols—in RF applications requiring low power and excellent RF performance.

Due to the fact that the ZigBee protocol has grown too large and complex for many applications, a large percentage of the market for IEEE 802.15.4 wireless Personal Area Networking is likely to use alternative, proprietary protocols, such as the MiWi protocol. The MiWi protocol is a free, small-footprint protocol developed for customers who do not need ZigBee interoperability but want to use IEEE 802.15.4 transceivers in low-cost networks. Additionally, ZigBee protocol certification is costly and cumbersome for many companies. The MiWi protocol provides a simpler, lower-cost solution for customers who do not need interoperability, but still want to use robust IEEE 802.15.4 radios. No certification is required for MiWi protocol systems, and the protocol stack is provided under a free license, when the combination of Microchip's microcontrollers and MRF24J40 transceiver is used.

Also available is the ZENA wireless network analyzer tool that uses a simple graphical interface to configure the protocol stacks. This enables customers to reduce the code size of the stacks by removing optional features; it cuts development time by simplifying the interactions with the stacks. It also allows for customization of the stack to fit a particular need.

In 10,000-unit quantities, the MRF24J40 starts at **\$2.99** each, in 40-pin, 6 × 6 mm QFN packages. The Zena tool is available for **\$129.99**.

Microchip Technology, Inc.
www.microchip.com



VIDEO GAME DEVELOPMENT KIT

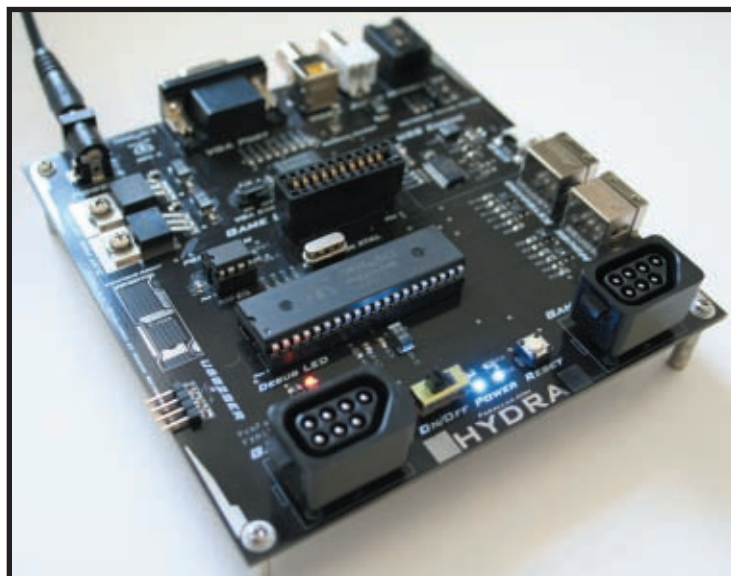
If you have ever thought about becoming a video game developer, now is your chance. The **HYDRA Game Console**, a new Propeller-powered gaming product, allows you to develop games, graphics, and media applications.

For beginner to intermediate coders, you need only basic programming experience in any BASIC or C-like language. All of the hardware and software you need is included. Additionally, the HYDRA hardware is covered in detail with schematics, descriptions, dozens of games, demos, and tips, allowing you to take full advantage of its resources, including its expansion port and 128-KB game card.

The HYDRA kit also comes with *Game Pro-*

gramming for the Propeller Powered HYDRA, Andre LaMothe's latest book. This comprehensive book covers everything you need to know about game programming for the Pro-

PELLER in Spin and assembly language. All aspects of the Propeller chip are introduced, from its architecture, to using the Propeller Tool for programming.



The Propeller chip was designed at the transistor level. It uses a new custom-silicon design for simultaneous multi-processing. The Propeller is a 32-bit architecture consisting of eight processors that run at 3.3 V up to 80 MHz. The Propeller is programmed in both a high-level language, called Spin, and low-level (assembly) language.

The HYDRA Game Development Kit costs **\$249.95**.

Parallax, Inc.
www.parallax.com

NEW PRODUCT NEWS

500 MSa/s PC-BASED OSCILLOSCOPE

The DSO-8502 is a PC-based oscilloscope that samples at 500 MSa/s with a 1-Mpt data buffer. This portable, battery-powered scope connects to a PC via a USB 2.0 connection. The powerful FrontPanel software is easy to use. It runs on Windows XP, 2000, and Vista.

With bandwidth exceeding 100 MHz, the DSO-8502 operates at an impressive single-shot sampling rate of 500 MSa/s in single channel mode and 250 MSa/s in dual-channel mode. A large memory buffer allows users to maintain a high sampling rate for a long recording time, thus capturing otherwise elusive events.

The software provided with the DSO-8502 oscilloscope has a single operating screen that displays the waveforms and all setup controls in easy-to-use menus. The unit also offers advanced



features like automatic measurements, advanced triggering modes, FFT spectrum analysis and pass/fail testing. Advanced trigger modes include pulse width, pulse count, combined pulse width and count, and a new pulse-width window mode that triggers on pulses within a given range.

Included with the DSO-8502 are two 100-MHz bandwidth switchable 1×/10× probes. Another feature of the unit is its small size (7" × 3.5" × 1.5"), which makes it very portable. It can be run with the included power adapter or by four AA batteries. Consequently, it does not drain your laptop battery when wall power is not available.

The DSO-8502 has a list price of \$950. The price includes the DSO-8502 main unit, software, probes, a USB cable, and an AC adapter.

Link Instruments, Inc.
www.linkinstruments.com

SINGLE PORT POWER OVER ETHERNET CONTROLLER

The LTC4263 is an autonomous single-channel Power Sourcing Equipment (PSE) controller with an onboard MOSFET for use in IEEE 802.3af Power Over Ethernet (PoE) compliant systems. Requiring only a few external components, the IC is a complete single-port PSE solution that detects, classifies, and provides isolated 48-V power to Powered Devices (PDs) connected to it. Offering standard-compliant AC or DC methods to sense the removal of a PD and featuring sophisticated onboard control algorithms, the LTC4263 provides autonomous operation through all of the required tasks without processor intervention.

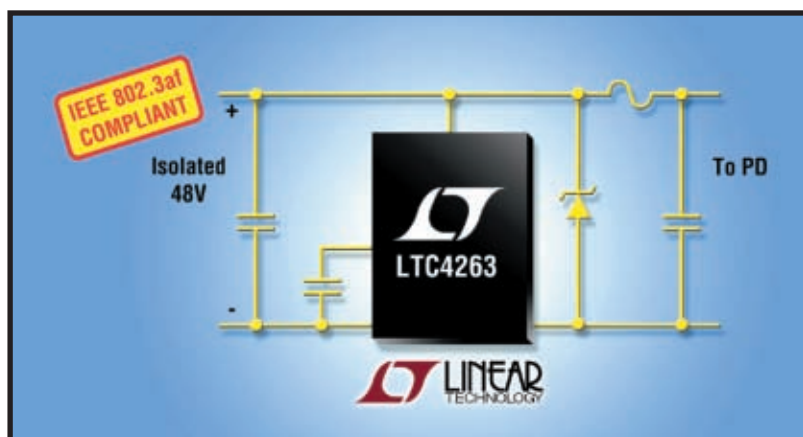
Using an internal sense resistor, the LTC4263 provides precision inrush, current limit, and short circuit control to further ensure IEEE 802.3af compatibility. The port current limit can be configured to automatically adjust to the detected PD class. Advanced detection and power monitoring techniques prevent damage to legacy data-only devices, while still supplying power to newer, Ethernet-powered devices. The LTC4263 also allows for simple implementation of power management across multiple ports, while being driven by a single power supply.

The rich feature set allows the IC to significantly simplify the PSE implementation, requiring only a single 48-V supply and a small number of passive support components. It also

makes the part an ideal choice for IEEE 802.3af-compliant Endpoint/Midspan systems, including low-port-count PSEs or standalone PSEs. Specified over the full commercial and industrial temperature range, the LTC4263 is offered in 14-pin 4 mm × 3 mm DFN and SO-14 packages.

Pricing begins at \$2.95 each in 1,000-piece quantities.

Linear Technology Corp.
www.linear.com



NEW PRODUCT NEWS

Visit www.circuitcellar.com/hpn for more New Product News.

IrDA TRANSCEIVER

The TFDU7100 is a new device integrating a remote control receiver and an IrDA transceiver into a single, three-lens, surface-mount package. Integrated within the TFDU7100's

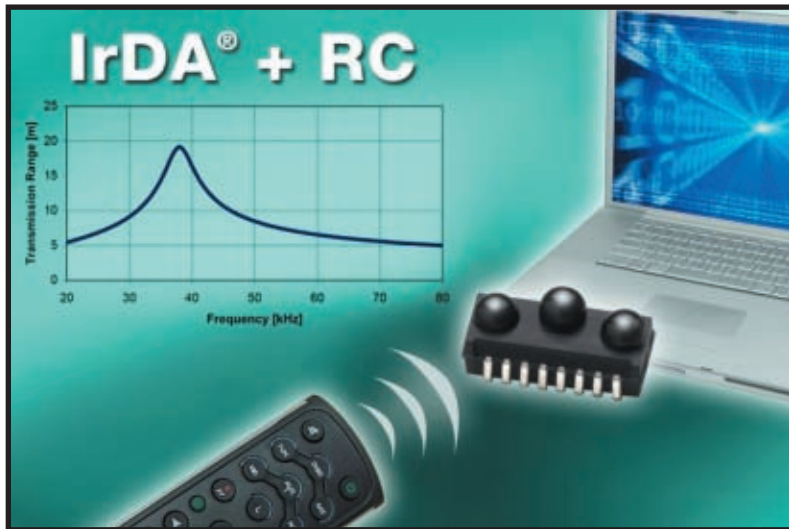
eight-pin package are two high-speed PIN photodiodes, an infrared emitter, an IrDA control IC, and a remote control IC. For remote control, the TFDU7100 meets Microsoft's Media

Center specifications by receiving signals with carrier frequencies from 20 to 60 kHz over a minimum distance of 5 m. Its maximum receiving distance is 18 m in the 36- to 38-kHz range. For IrDA communication, the TFDU7100 supports all IrDA data rates up to 4 Mb over the inherently secure distance of 1 m.

To simplify the transition to the TFDU7100, the package is the same size and pad pitch as the Vishay 4 Mb. Providing added flexibility, the device can be mounted with lenses in side- or top-looking orientation. The TFDU7100 IrDA plus RC transceiver operates from 2.7 to 5.5 V over the full temperature range of -25° to 85°C .

The TFDU7100 IrDA plus RC transceiver is available now. Pricing for U.S. delivery is \$1.50 each for 1 million units per year.

Vishay Intertechnology
www.vishay.com



Reliable ZigBee™ Mesh Networks

ZigBee™ certified

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- Up to eight times the range of typical ZigBee
- Order a development kit today!

	Frequency	Indoor Range	Outdoor Range	Power Output	Mesh Network	Agency Approvals
XBee™	2.4 GHz	30 m	100 m	1 mW	Yes	Global
XBee-PRO™	2.4 GHz	100 m	1.6 km	60 mW	Yes	Global

MaxStream www.maxstream.net 866-765-9885

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Trinity College, Hartford, CT

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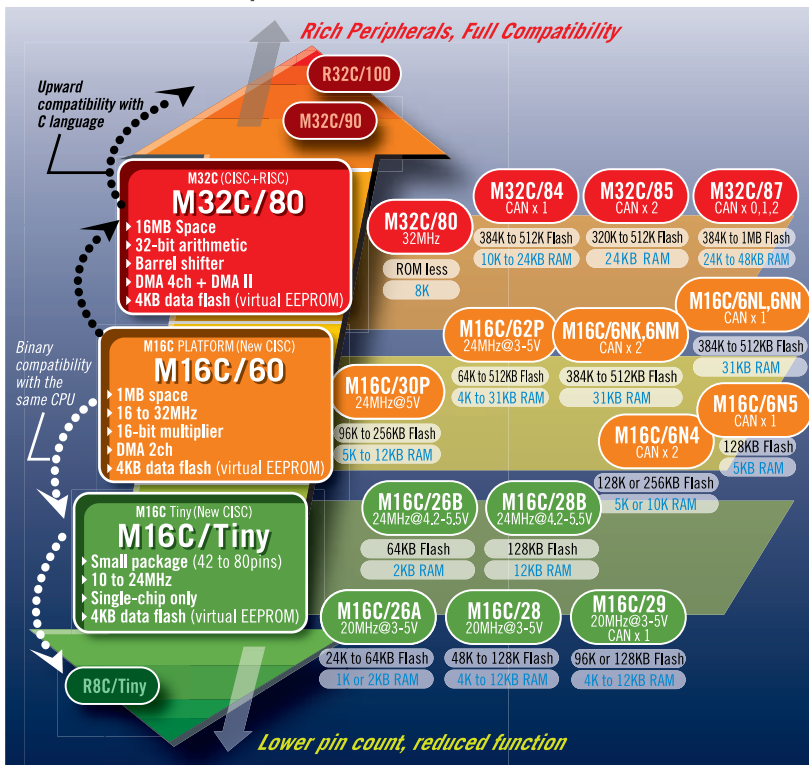
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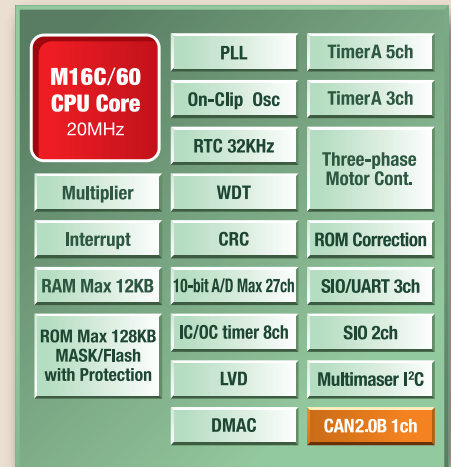
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Modular Wireless Tracking System

Children, vehicles, and animals all have something in common: they are always on the move. With this modular wireless tracking system, you can keep tabs on the moving objects of your choice. The system features a GPS module, a digital compass, and an LCD.

Young children are always on the move. That's why we built an easy-to-use child-tracking unit that enables adults to keep tabs on the youngsters in their care. With an adjustable perimeter for each child (capable of ranges greater than 200 m) and a real-time directional display arrow, a parent or guardian can receive instant alerts and information about their child's location.

In this article, we'll describe how we designed and built our PIC-based system (see Photo 1a and b). If you don't need to monitor the movement of children, you can customize a system to track any number of other mobile objects.

EASE OF OPERATION

The system's primary control setting is simply the maximum distance at which the object you're tracking can be away from you. Distance and direction data are displayed on a graphical LCD. With one press of the Mode button, you can use the Up and Down buttons to change the distance in 5-m increments.

By default, when our system is powered up, the child's range is set to a 25-m radius. A parent can attach the smaller child unit on a child's wrist and send him on his way. The parent module immediately displays the distance (in meters) from the child. One of 16 directional indicators shows the direction of the child with respect to the parent.

SYSTEM OVERVIEW

The tracking system features a parent module (see Figure 1), which is worn by the parent to convey information about a child, and the child module, which passes location and status data to the parent (see Figure 2). An adjustable perimeter for each child can be set to any range from 25 to 200 m (80' to 650' limited by the RF link). A real-time directional indicator (displayed on a large graphical LCD

screen) shows the distance and direction to the child. A piezoelectric alarm alerts the parent if the child strays beyond the set perimeter.

The parent module features a GPS module, PIC controllers, a digital compass, a graphical LCD, and an RF transmitter/receiver. The child model contains most of the same components, but it doesn't have an LCD or a digital compass.

The parent module simply compares its position to that of the child, which it determines using GPS data. It then compares the direction in which the parent module is facing, which it determines from the digital compass, to the child's bearing. An RF link between the parent and the child module is used to send the GPS data.

WIRELESS SYSTEM

The wireless system features a Linx Technologies HP3 receiver and transmitter. Although there are many different RF modules that you can use for this system, consider spending the extra money on a frequency-shift-keying (FSK) module/chipset. We originally used Linx 433-LR modules with on/off shift keying (OOSK), which has been around since the dawn of RF. Although OOSK works, it performs poorly in this day and age because the RF spectrum is polluted with noise. Try the Linx HP3 or ES

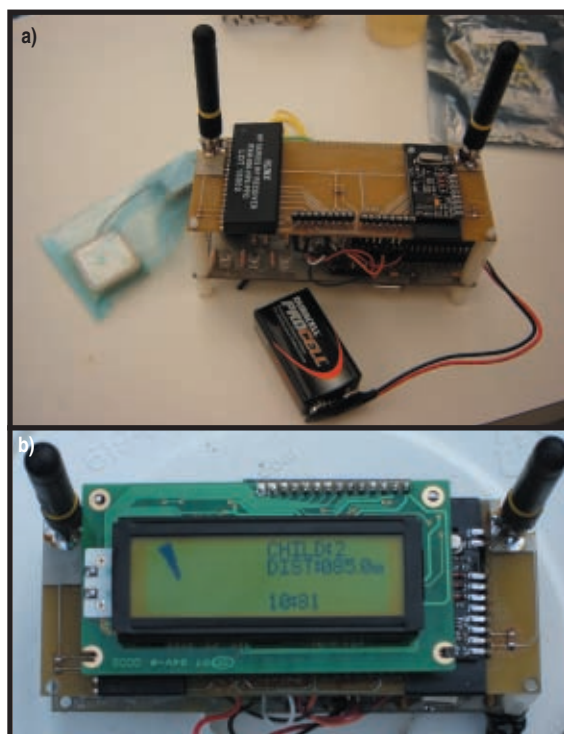


Photo 1a—The child module is a two-board stack. On the top is the RF module and antennas. The lower board is shielded from the RF by a full ground plane. The bottom board has the two PIC microcontrollers. It connects to the GPS in the blue bag. **b**—The parent module is displaying the distance and direction to child 2.

series. Both work with FSK. The ES module is a little cheaper because it doesn't allow for channel selection. We used Linx coiled quarter wave antennas and connected them to a standard SMA antenna connector.

We used a Microchip Technology PIC16F877A to control the RF portion of the project. Although it was overkill for our RF needs, we had plenty of them sitting around. The benefit of using a second processor is that the GPS data can be received at the same time that data from the RF link is received.

TRANSMIT & RECEIVE

We used Manchester encoding for the RF data transmission. Easy to set up, Manchester encoding ensures there is a logical transition for each bit that is sent. These mandatory transitions make it very easy to have the receiver sync with the transmitter.

They allow for a long packet length without the chance of a long string of zeros or ones unsyncing the data.

A simple search on the Internet will provide you with numerous links for information about Manchester encoding and piles of sample code, which is all that is required for this project.

ADDRESSING PROTOCOL

Our system works in the crowded 915-MHz spectrum. The physical device will inevitably be used near other 915-MHz transmitters, so it is important to include noise filtering and addressing to ensure you only transmit and receive from the units associated with your family.

To filter out noise, a specific preamble (start-up code) is transmitted to separate our data from other data. To keep things simple, we used 1 byte (11010110). Therefore, any incoming transmission (at the same data rate)

will be received, but it will only continue the receive routine if the data string has this first noise filter byte. Once the noise filter byte has been checked, another byte is sent. It is the unique address of the device that transmitted the signal. The parent examines this byte to see which child has transmitted. The parent can also use this byte to send messages to specific child units.

After the addressing has been sent out, there is an "info byte" that contains command codes for the different units. These command codes allow the parent to ask the child unit to resend GPS data, pull in new GPS data, turn on the alarm buzzer, or activate various extra features. The following 8 bytes of data are the x and y GPS coordinates, 4 bytes for each axis, and the final byte is a cyclic redundancy check (CRC).

Inside the receiver, a simple loop

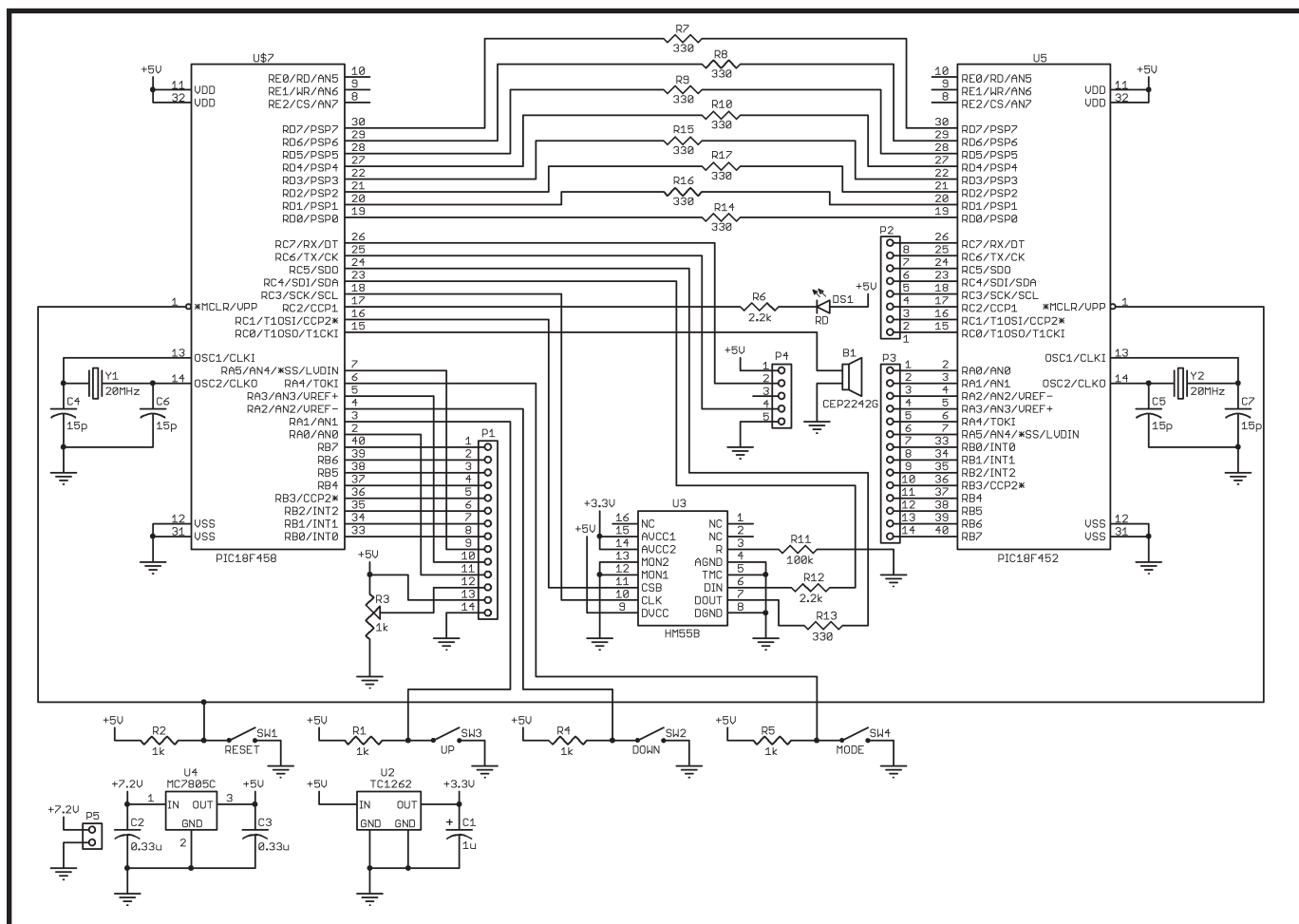


Figure 1—The primary differences between the parent and the child boards have to do with the available interfaces. The LCD screen on the parent module enables you to control a variety of settings. This required a few momentary switches to interface with the microcontrollers.

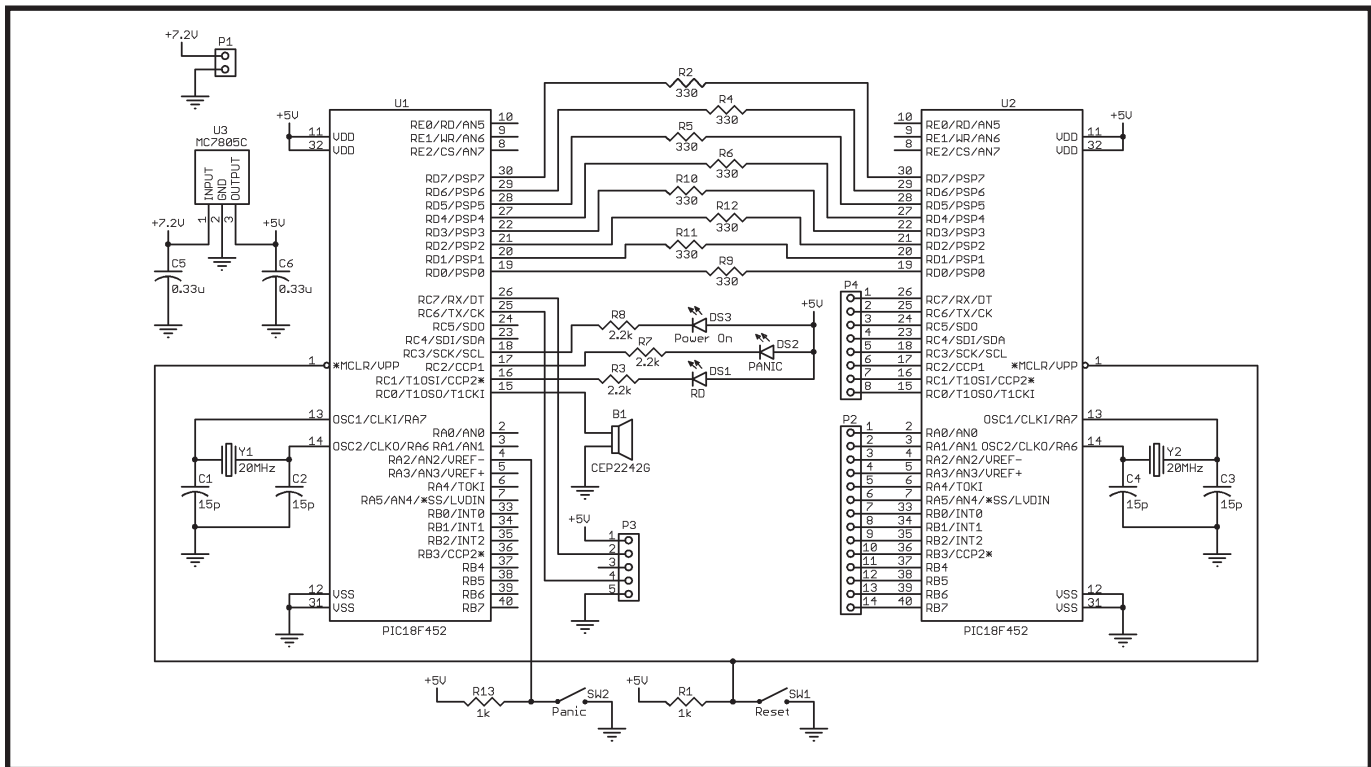


Figure 2—The child board doesn't have an LCD or as many momentary switches, but a few LEDs and a buzzer make for an easy interface that anyone can understand.

takes the most popular values of each set of the three bytes. As a result, 1 in 3 bytes can be completely corrupt and the data will still get through.

When a transmission occurs, the 36-byte packet is transmitted three times in quick succession (see Figure 3). The receiver fills a different array for each transmission, compares all three arrays, and takes the most likely byte value (i.e., 2 out of 3 bytes are the same). In this way, each byte is actually sent and compared nine times making the system very robust in noisy environments.

GPS SYSTEM

GPS is a mature technology. Many GPS choices were available for our project. Some modules can cost as little as \$30, but if you want a performance module, expect to pay more. We used a Globalsat Technology GPS Module in SiRF (EM-402).

The EM-402 is a highly sensitive module that features 12-channel parallel processing, an active antenna package, and a super capacitor to hold up data for faster acquisition times. Interfacing to this module is easy. It supports the NMEA 0183 data

protocol at 4,800 bps.

The EM-402 outputs its data at TTL levels allowing for very easy interfacing to microcontrollers. Hooking up the module so a PIC microcontroller can interpret the data correctly takes a couple of days at most. The GPS string also sends accurate time data that we used to update the system's clock. Remember to factor in the time difference, as GPS outputs only Greenwich Mean Time.

The EM-402 costs around \$70. We would like to thank Globalsat for donating two EM-402 modules for this project.

DIGITAL COMPASS

Digital compasses come in more configurations than we had previously thought. With degrees of resolution ranging from 60 points (6 degrees per point) up to 720 points (0.5 degree per point), some chips also send information on pitch. As with everything, you will get what you pay for. We used a Hitachi HM55B compass module, which has 60 points of reference and does not convey pitch. (We opted for a \$3 bubble level as opposed to a \$100 chip that has pitch.) This compass pro-

vides updated heading data very quickly, which was essential for the product. Any compass placed on a person needs to accommodate the quick hand movements of the person holding the device, most importantly in a panic situation.

The HM55B supports SPI, but we elected to bit bang it, which was also easy. Bit banging the HM55B also kept the SPI free so we could use it for the inter-chip communication.

Using the most current GPS data points, the microcontroller can calculate the relative direction of the child module from the parent module. We simply determined the number of degrees from North, traveling in a clockwise rotation. Our digital compass data is also calculated in this format, which made the relative calculation for the child's direction with respect to the board a simple math calculation.

It is important to note that this digital compass is influenced by metal in the same way as a regular compass. If it is to be placed by a little bit of metal in your design, a simple calibration will ensure accurate results. Note that digital compasses also tend



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to be tiny; this one in particular is a 16-pin J lead that is only 5.3 mm × 4.6 mm, so expect to think small and solder smaller.

The HM55B comes in module form with through-hole leads (T. Cantrell, "Direction Finder," *Circuit Cellar* 183, October 2005). We recommend getting this pinned module to avoid the soldering. (We would like to thank Hitachi Metals America for donating two HM55B modules that

Preamble byte	Device address byte	Information byte	Data (8 bytes)	CRC Byte
---------------	---------------------	------------------	----------------	----------

Figure 3—Each byte in this packet is transmitted three times. The entire packet is sent three times.

we used for this project.)

LCD

The LCD you use is entirely up to you. If you use a graphical LCD, it will be easier to build the arrows that point to your child, but you will have to code or search the Internet to find a

good character set to use for the text on the display. If you use a character LCD, then the characters are already built. Building the

arrows will be a bit challenging and difficult to line up. A good alternative would be a small character LCD surrounded by a simple ring of LEDs that could be used to display the direction of the child. You might want to try using a small LCD because this project is supposed to be wrist mounted.

We used a SunLike SG12232D 32 × 122 dot graphical LCD simply because we had one sitting around. The unintentional benefit of this display was that it has a separate microprocessor for each side. Setting up one side for the arrows and the other for the text was easy. This LCD uses an SED1520 dot-matrix LCD driver.

PIC ACCESS

A problem that we had to resolve was the division of available programming time slots. We have two major wireless communications that each require uninterrupted access to the PIC microcontroller. The GPS module requires approximately 200 ms to receive all of the necessary GPS data. To keep accurate data in the GPS coordinate buffer, the main chip checks for incoming information as fast as possible. For approximately 30% of the time, the main chip is busy pulling in GPS data. The RF transmission takes about 500 ms of uninterrupted processor time. Any RF communication could potentially be a distress call from the child; no RF transmissions can be missed. However, without good GPS data, that distress call could be pointing to a place where your child was, instead of where your child is.

To get around this and keep things simple, we decided to use two chips. A PIC18F458 runs the GPS, digital compass, and LCD. It also acts as the master. A PIC16F877A acts as a dedicated RF chip. Using a dedicated RF chip is very helpful if you are operating in a noisy environment, where an interrupt-based RF routine could potentially get tripped often enough to disrupt other functionality. Since the

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PIC16F877A has to deal with only wireless communications, it can continuously monitor the 915-MHz band, pull in all data that it sees, and send information to the 458 only once it has seen new, correct, and relevant data.

POWER SUPPLY

We used a 5-V power supply because of the LCD. However, if you can get a 3.3-V LCD, you can make the entire project with 3.3 V. While a switching power supply could be used to boost power, switching power supplies and RF devices are generally not the best of friends. So, we used a high-accuracy 5-V linear power regulator that is fed by a 7.2-V lithium ion camera battery with a 1,100-mAh capacity.

The RF receiver and transmitter each draw about 15 mA when operational. Using the power-down function, only one is on at a time. Together they account for a constant 15-mA drain. The LEDs are wired up for a 5-mA drain. Only one LED is typically on.

The real power pig is the GPS, which

averages a little less than 60 mA. In total, the device typically wants about 80 mA if you're working off a 5-s update rate on the GPS. The devices last a minimum of 10 h, but when we set the GPS update interval to 15 s, we can squeeze six more hours out of the modules. The only way to really cut power consumption would be to find a GPS module that uses less power or updates your GPS locations less frequently.

SOFTWARE

The software for this project is very user-dependent and configurable (see Listing 1). You can use it to track children, pets, or anything outside that is within the range of your transmitter and receiver. You can also independently set up any number of things to happen should the target stray too far: alarms for the kids or shocks for the pets. Using the GPS to map locations, you can even hardcode off-limit areas like the swimming pool for your kids or the garden for your dog.

Our devices were designed for chil-

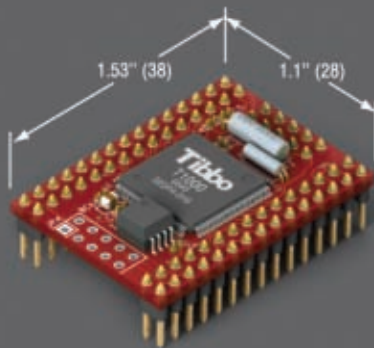
dren, so we worried only about situations in which the child had wandered too far from the parent or when the child had pressed the Panic button. We consider these emergency situations.

The parent module periodically queries each child module for its current or last known GPS location. Each child has a unique child identification number, which is sent to the parent with each GPS update so the parent can distinguish between each child. Once the parent receives an updated GPS location from the child, it then proceeds to calculate the distance between itself and the child, the bearing to the child (using the digital compass onboard), and it checks for out-of-range and panic situations.

LCD screen and digital compass updates occur in between GPS updates. The digital compass provides 22 bits of data consisting of an x and a y coordinate. From this vector (x, y), the angle is calculated relative to 0° (which corresponds to Magnetic North). Using trigonometric identities,

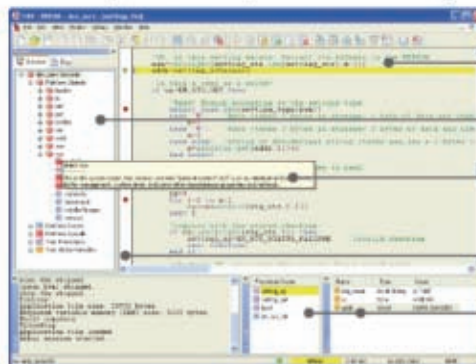
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the bearing between the parent and the child relative to True North was calculated (accounting for the declination discrepancies between Magnetic North). This value is then subtracted from the GPS bearing to provide the actual position of the child.

EMERGENCY SITUATIONS

While the units will happily plod along while the child is within the boundary, what is to be done when the child goes too far? Or what should the child do when placed in a negative situation? If the child wanders too far away, the parent is alerted by the panic LED as well as through a piezoelectric alarm. We also set up the child's device to set off the buzzer and flash the panic LED. The buzzer and flashing LED can be set off in one of three ways: the child wanders too far away; the child presses the Panic button; or the parent selects Panic from the options menu.

It would be nicer to send a voice message to the child, but that would reduce the amount of power your transmitter could legally put out (in accordance with the FCC's standards) with the 915-MHz spectrum. Because the device could be put into a wrist-sized device, a dead man switch is incorporated in the strap. So, if a child tries to take off the watch, or if someone else removes the watch, the panic alarm is automatically sent to the parent.

The only other emergency situation is when a child has strayed beyond the maximum distance that the transmitter can transmit. In this case, the parent module will alert the parent with a panic alarm while displaying the last known distance and position of the child. This allows the parent to quickly move toward the child's last known position to reestablish communication. When the child unit has gone 30 s without hearing a transmission from the parent module, it will begin a calling schedule every 5 s, so that the parent will be given updated information the second it gets within range.

DigiKey carries a good selection of piezoelectric alarms. Alarms with up to 90-dB tones cost a few dollars; how-

Listing 1—These two protocols compare the GPS coordinates of the parent and child modules, returning the relative distance in meters, and the angular direction from North in degrees.

```
// Calculates the distance in meters between two GPS locations
// Takes two GPS coordinates in DD.mmm format (i.e., 48.490975;123.417650)
// Returns signed float in meters
signed float Calc_Distance(signed float lat1, signed float long1,
signed float lat2, signed float long2) {
    signed float dLat, dLong, sideA, sideC;
    unsigned float EarthRadius = 6378100; // in meters
    lat1 *= 57.29577951; // Converts coordinates
    long1 *= 57.29577951; // from
    lat2 *= 57.29577951; // Degrees to Radians
    long2 *= 57.29577951; // 57.29 = 180/pi
    dLat = lat2 - lat1; // get difference in latitudes
    dLong = long2 - long1; // get difference in longitudes
    // trigonometry to calculate the distance between 2 GPS coordinates
    // see http://mathforum.org/library/drmath/sets/select/dm_lat_long.html
    sideA = (sin (dLat/2)) * (sin (dLat/2));
    sideA = sideA + ( (cos(lat1)) * (cos(lat2)) * (sin (dLong/2)) |
    * (sin (dLong/2)) );
    sideC = 2 * atan2( sqrt(sideA), sqrt(1-sideA) );
    return (EarthRadius * sideC); // in meters
}
// Calculates the bearing in degrees between two GPS locations
// Takes two GPS coordinates in DD.mmm format (i.e., 48.490975;123.417650)
// Returns signed int in degrees
signed int Get_Bearing(signed float lat1, signed float long1,
signed float lat2, signed float long2) {
    signed float dLong, x, y;
    signed int GPS_Bearing, temp_Bearing;
    unsigned float Radians_2_Degrees = 57.29577951; // (180/pi)

    lat1 *= Radians_2_Degrees; // Converts coordinates
    long1 *= Radians_2_Degrees; // from
    lat2 *= Radians_2_Degrees; // Degrees to Radians
    long2 *= Radians_2_Degrees;

    // Trigonometry to calculate the bearing between 2 given GPS coor-
    // dinates. See http://mathforum.org/library/drmath/view/55417.html
    dLong = long1 - long2;
    y = sin(dLong)*cos(lat2);
    x = ( cos(lat1)*sin(lat2) - (sin(lat1)*cos(lat2)*cos(dLong) );

    if (y > 0) {
        if (x > 0) GPS_Bearing = (atan(y/x) * Radians_2_Degrees);
        if (x < 0) GPS_Bearing = 180 - (atan(-y/x) * Radians_2_Degrees);
        if (x == 0) GPS_Bearing = 90;
    }
    if (y < 0) {
        if (x > 0) GPS_Bearing = (-atan(-y/x) * Radians_2_Degrees);
        if (x < 0) GPS_Bearing = (atan(y/x) * Radians_2_Degrees) - 180;
        if (x == 0) GPS_Bearing = 270;
    }
    if (y == 0) {
        if (x > 0) GPS_Bearing = 0;
        if (x < 0) GPS_Bearing = 180;
        if (x == 0) return 0xFFFF; // points are the same
    }
    if (GPS_Bearing < 0) {
        GPS_Bearing = 360 + GPS_Bearing;
    }
    temp_Bearing = GPS_Bearing - CompassBearing;
    // if calculated bearing is less than 0, add 360 degrees
    if (temp_Bearing < 0) {
        temp_Bearing = 360 + temp_Bearing;
    }
    return temp_Bearing;
}
}
```

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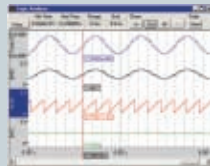
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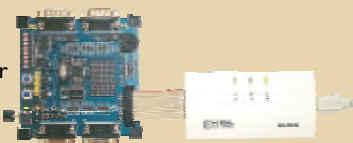
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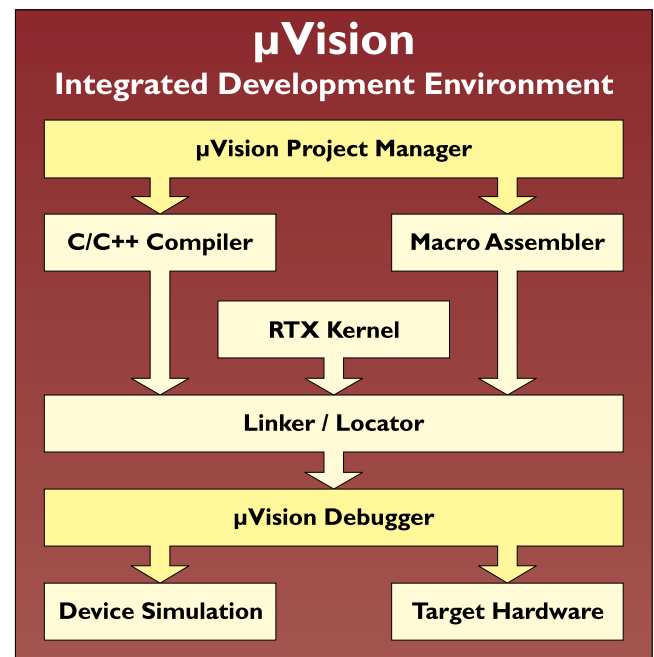


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FEATURES TO COME

Given that our objective was to build a functioning prototype within a short amount of time, we decided to stick to this objective and produce a reliable base model. As we worked on our project, we wrote up wish list of extra features that could be built into the system.

Consider adding a water sensor to determine if a child has fallen into a pool or some other water hazard. An accelerometer can be used to determine if the child has had a rough fall. With a little extra code, various other features could be added.

By simply looking at the changing GPS locations, you can determine an object's velocity. This can give parents warnings if the child is moving fast (e.g., in a car). Velocity data can also give you advanced warning that the child is going to leave the area.

SUCCESSFUL TRACKING

Our tracking unit combines GPS technology, RF technology, a digital compass, and an LCD for tracking objects of all sorts. The two separate modules are easy to use. With the push of a few buttons, you can set a maximum perimeter to be monitored.

We demonstrated the effective use of our prototype. One of our team members walked around with the child module while the rest of us tracked him with the parent module. We were able to determine his distance from the parent as well as the direction in which he was moving.

We built the entire system for approximately \$300. When evaluating the cost of a mass-marketed product, we speculated that we would be able to construct a finished system for about \$200 for one parent module and one child module. Each additional child module would cost around \$80. 📦

John Caruana (johnec@shaw.ca) worked as a network administrator for four years before graduating from Camosun College's electronics engineering technology program in 2006. He is an electronics technician for the

Canadian Coast Guard.

Doug Irvine (irvinedouglas@hotmail.com) earned an electronics engineering technology diploma from Camosun College. He is employed with the city of Campbell River, BC, where he lives with his wife and young son. Doug continues to develop innovative projects such as this child-tracking unit.

Matthew Quenet (matthew_quenet@hotmail.com) underwent communications training at the Canadian Forces School of Communications and Electronics. After his training, he voluntarily served a tour of duty in Syria with the United Nations. Matthew recently graduated with a diploma in electrical engineering technologies.

Christopher Cheng (chrischeng@shaw.ca) graduated from the electronics engineering technology program at Camosun College and is currently working toward a degree in electrical engineering at the University of Victoria. He is interested in wireless communication and circuit design.

PROJECT FILES

To download code, go to ftp://ftp.circuitcellar.com/pub/Circuit_Cellar/2007/199.

RESOURCE

Source code and Protel PCBs, www.elex.camosun.bc.ca/programs/projects.htm.

SOURCES

GPS Module in SiRF Star II (EM-402)
Globalsat Technology Corp.
www.globalsat.com.tw/

HM55B Compass module
Hitachi Metals America
www.hitachimetals.com

HP3 Receiver and transmitter
Linx Technologies, Inc.
<http://linxtechnologies.com>

PIC16F877A Microcontroller
Microchip Technology, Inc.
www.microchip.com

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RFID Security System

Craig and Ricardo designed an RFID-based proximity security system for use with identification cards. The system communicates with an administrator PC via a serial communications link and HyperTerminal.

It all started when the antiquated push-code lock broke on our fraternity house's front door. The mechanics of this primitive device limited the possible codes such that a pass code could have only four distinct numbers and the correct code could not be changed. With simple combinatorics, you can deduce that there were only 120 different combinations for possible codes. This meant even a moderately resourceful burglar could easily crack the code and steal our fraternity's new 50" DLP TV.

At the time the lock failed, we were enrolled in Bruce Land's ECE476 microcontroller design course at Cornell University. Only a week before, we had designed and tested a keypad security system built around an Atmel ATmega32 microcontroller, which was basically a modern version of the lock already on our door. However, this one had limitless four-digit pass codes, data logging, and administrative overriding commands. Because we had to design and build a final project for the course anyway, we thought that developing a home security system to work with our student ID cards was a good idea.

The great thing about Cornell ID cards is that they have been equipped since 2003 with both magnetic stripe and radio frequency identification (RFID) capabilities. For our project, we chose the latter

because we thought it would be a better blend of hardware and software design. And, basically everything from passports, to credit cards, to inventory tracking, has been adopting RFID technology. We figured it would be a little more cutting edge and relevant to modern topics of electrical engineering.

RFID TECHNOLOGY

RFID technology is based on the concept of magnetic coupling, which is the principle that current flowing in one circuit can induce current flow in another circuit through a magnetic field generated in the space between the circuits. In passive RFID, there are two major components: the reader and the mobile tag. The reader has two main functions: the first is to transmit a carrier signal, and the second is to receive a response from any tags in proximity of the reader. A tag needs to receive the carrier signal, modify it in

some way corresponding to the data on the card, and retransmit the modified response back to the reader.

In modern passive RFID devices, the tag consists of a small integrated circuit (that performs the modulation) and an antenna. The benefit of passive RFID is that it requires no internal power source; the circuit on the tag is actually powered by the carrier signal. Thus, the carrier signal transmitted from the reader must be considerably large so that the response can be read even from the card.

Most passive RFID devices operate in one of three frequency bands: low frequency (125 kHz), high frequency (13.56 MHz), and ultra-high frequency (400 to 930 MHz). Within these bands, there are various ways to modulate the signal so the reader can easily decipher the data. After some research, we determined that Cornell uses HID Global's DuoProx II identification cards (see Photo 1).

The datasheets on HID's web site gave us some general information about the cards such as the band of operation. The Cornell ID cards operate at the same frequency as most passive RFID security cards: the low-frequency band at 125 kHz. A Google search revealed that this specific HID card uses frequency-shift-keying (FSK) modulation. In FSK, the modulating signal switches between two different frequencies (12.5 and 15.625 kHz in our case)

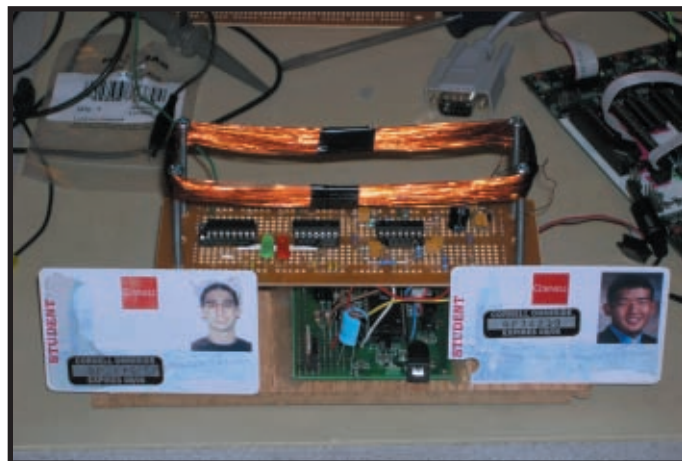


Photo 1—The base is made of wood flooring. The columns and antenna braces are long screws.

that represent either a logical one or zero. This allows an electromagnetic signal to hold data simply as a string of bits. The modulated signal is then multiplied by the carrier signal, overlaying the signal with binary data from the tag and producing an output signal that looks like what you see in Photo 2.

One of the challenges associated with any type of modulation is that there has to be a way to unambiguously extract this binary data from the FSK modulated signal. We decided to implement this part of our reader mostly in hardware.

HIGH-LEVEL OVERVIEW

At the highest level, our reader circuit has to generate and amplify the carrier signal, receive the modulated signal, filter out the original carrier signal, and detect the envelope, turning it into actual data at TTL levels (see Figure 1). This is then passed on to the ATmega32, which interprets the incoming data and tries to match it with the code bank stored in the memory. If the code matches, a green LED illuminates, signifying the “door” unlocking. If it doesn’t match, a red LED illuminates.

The microcontroller also has serial communications via RS-232 to an administrator PC running HyperTerminal, which can perform several functions. We’ll cover this in the Software section of this article. For now, we’ll just break things down into the two major components of design: hardware and software. We’ll describe the specifics of each in a (hopefully) easy-to-understand manner that should give you some insight into how to build your own RFID security system.

HARDWARE

The first stage in our

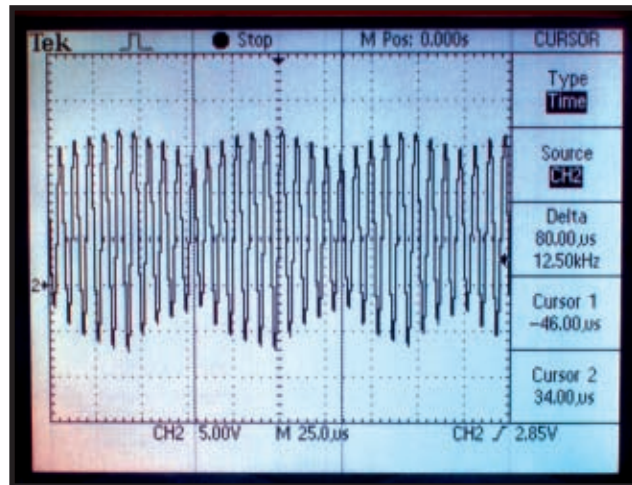


Photo 2—The FSK-modulated carrier signal indicates a response from the tag. Resonance from the LC circuit creates the extremely high peak-to-peak amplitude of the signal. All of the data from this signal is found in the modulating envelope.

circuit is the output stage, where the 125-kHz signal is created, amplified, and transmitted over the antenna (see Figure 2). In order to better understand motivations for the creation and amplification parts of this stage, it is probably best to start with the last (but probably most crucial) part of the stage: the resonant antenna LC circuit.

There are typically two ways to design an LC antenna: putting the inductor and capacitor in series or in parallel. Both serve their purpose well; however, when reading the Microchip’s extremely helpful “microID 125-kHz RFID System Design Guide,” we learned that we should go for the series implementation. With a series-resonant circuit, you get maximum admittance (highest current) at the resonant frequency.

To choose the values for our inductive antenna and capacitor, we used:

$$f_0 = \frac{1}{2\pi\sqrt{LC}}$$

where f_0 is our resonant frequency (125 kHz). For our particular design, we had a lot of 1-nF capacitors around the lab, so we designed around this. Doing so gave us a target inductance of 1.62 mH. We wound the antenna out of lacquered copper wire in a rectangular configuration. This enabled us to incorporate the antenna in our “housing” and still keep it fairly compact.

The loop’s inductance is:

$$L = \frac{0.0276[(x + y + 2h)N]^2}{1.908(x + y + 2h) + 9b + 10h}$$

L is in microhenries. x and y are the width and length of the coil (in centimeters). h is the height of the coil (in centimeters). b is the width across the conducting part of the coil (in centimeters). N is the number of turns. In our case, x was 3.6 cm and y was 13.8 cm. We estimated that h was 1 cm and b was 0.3 cm. Using the equation, we calculated that the coil needed approximately 90 turns. We tuned the coil afterwards to achieve maximum resonance on a 125-kHz signal, which is important for getting higher read distances.

The next big step in the design was actually generating the carrier signal. For this we used one of the three timers found on the ATmega32. We were using a 16-MHz clock, so the 125 kHz is a straight division of that. As a result, all we had to do was initialize the timer with that prescaler and set the

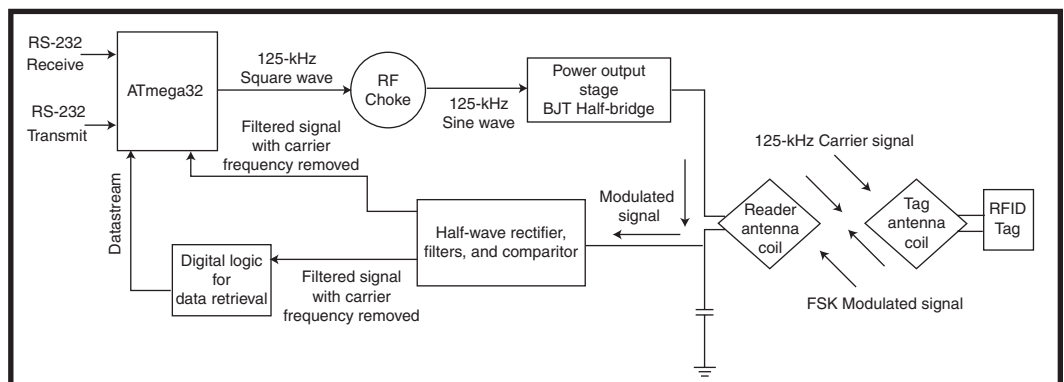


Figure 1—The reader circuit is fairly simple. Notice how the microcontroller uses the outputs from the filter stage and the data retrieval stage.

TIMSK register to output that from its respective output pin. We then put the square wave through an RF choke (basically a beefy low-pass filter) in order to remove all the extra harmonics created by the square wave. This produced a 125-kHz sine wave. Note that at maximum resonance we have extremely high current, so we have to amplify this signal lest we blow out the ATmega32.

For the amplifier we used a PNP emitter-follower stage followed by a BJT Half-bridge power amplifier to give us the necessary power. For this part, we used the 2N3904 and 2N3906 NPN and PNP transistors because they were in our lab and convenient. To get a little more power out of this stage, yielding a better read range, you can use power MOSFETS.

The second stage in our reader circuit is the envelope detection and filtering stage. In order to retrieve data from the tags in our ID cards, it is necessary to separate out the actual modulation envelope from the carrier signal. We started with a simple RC low-pass filter with an RC time constant designed to filter out most of the 125-kHz signal with minima. We also employed a diode to half-wave rectify the signal to make things simpler down the line.

Photo 3 shows the stage's output. As you can see, although there is definitely a visible ripple from the carrier signal, the entire waveform seems to oscillate along the envelope, which is exactly what we were aiming for.

Next, the signal is processed through a cascade of active filters. The aim of these filters is to both completely remove the carrier frequency, as well as give the modulating frequencies adequate gain to saturate the op-amps powering the filters, thereby creating a square wave that can be interpreted as a digital signal. The microID reference circuit provided the design for these. It uses cascading twin-T band-pass filters in order to provide gain to the modulating frequencies relative to all other frequencies.

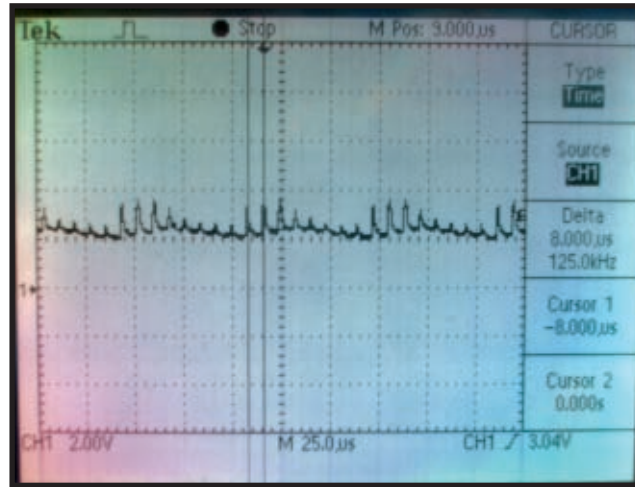


Photo 3—Check out the incoming signal once it passes through the half-wave rectifier and RC filter. There is clearly a 125-kHz ripple. The envelope is now the defining part of the signal.

After this, we put the signal through an active low-pass Butterworth filter to give even more gain to frequencies within the original passband and quash all high frequencies, including the carrier signal. The Bode plot in Figure 3 illustrates the effects of the cascade.

Now we have a square wave signal that oscillates at both of the modulating frequencies when an ID card is placed in the reader antenna's proximity. Lastly, we put the signal through a comparator and voltage divider to generate a nice square wave at TTL levels so that it could be further processed and analyzed.

Technically, from the output of the comparator, we should have been able to read and interpret data from the card using a timer interrupt. We quickly realized, however, that by doing this we would cripple the system's functionality. In order to accurately measure the frequency of the incoming datastream, we would realistically need to sample at 125 kHz, which meant that with a clock rate of 16 MHz, we would have 128 clock cycles to run the rest of our program before the next interrupt. That would have been extremely difficult to implement along with the rest of our system, especially because beyond just general code storing and checking, we planned to implement a communications protocol that could potentially block the interrupt. Additionally, in practice, we found this method for

gathering data somewhat unreliable. Looking for an alternative method to obtain data, we found yet another brilliant design in the Microchip reference guide that made use of flip-flops and a decade (Johnson) counter.

The rationale behind this "data formatting" stage was simple: we needed to slow down the incoming signal so the ATmega32 could analyze it without limiting the functionality of our security program. It also has the added benefit of creating a signal that is only high when a 12.5-

kHz pulse is received and is zero otherwise (as opposed to switching between logic 1 and logic 0 at different frequencies).

Implementing this stage was slightly complicated, but it didn't require too many extra components. The purpose of the first flip-flop is to generate extremely short pulses at its clock frequency, which we made the TTL output from the comparator. The length of these pulses are directly determined by the size of the resistor used to bridge $\sim Q$ and $\sim CLR$, and these are used to reset the decade counter and clock the second flip-flop. Photo 4 illustrates this circuitry a little more clearly.

The decade counter is a 1-hot counter that shifts the ACTIVE pin with each clock cycle. Because our two modulating frequencies are integer divisors of our carrier frequency ($12.5 = 125/10$ and $15.625 = 125/8$), it was convenient to use the 125-kHz signal output from the microcontroller for the carrier signal as this clock cycle. The slower frequency counts as logical 1 and the counter is reset at the modulating frequency, so all we had to do was take the pin corresponding to 10 clock cycles in order to determine if we were dealing with a one or zero. The purpose of the second flip-flop is to lengthen the duration of that one or zero and give us a constant datastream to be ported to the ATmega32 (see Photo 5).

SOFTWARE

Although the hardware portion of

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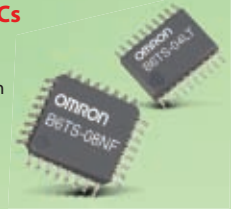
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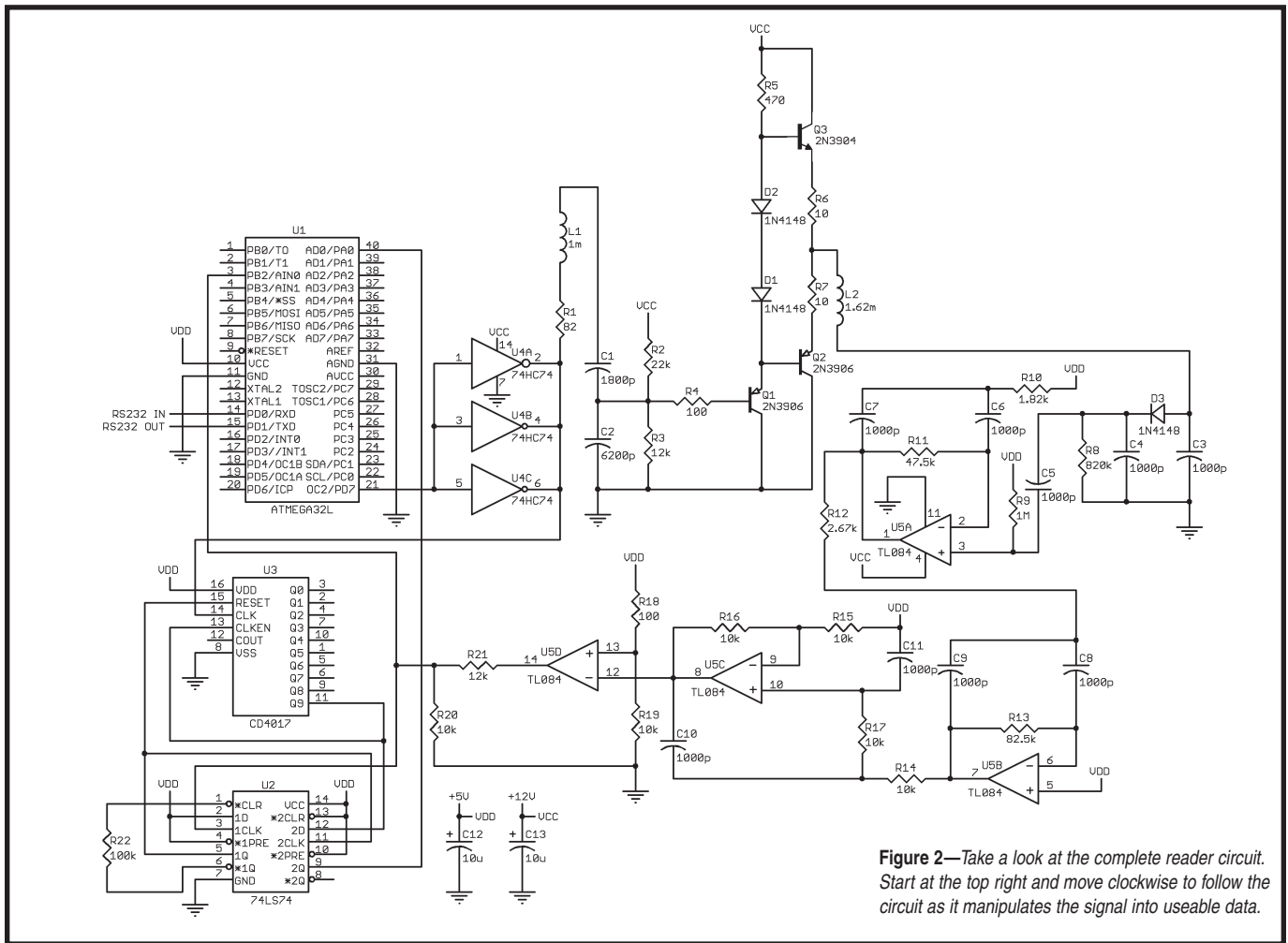


Figure 2—Take a look at the complete reader circuit. Start at the top right and move clockwise to follow the circuit as it manipulates the signal into useable data.

the RFID security system performs many of the critical functions of the reader, it would not be complete without proper software. From the program's perspective, there are two main modes of operation: Security and Administration.

In Security mode, the reader functions as (surprisingly) the actual security system. When idle, the reader is constantly transmitting the carrier signal and waiting for a card to come into the electromagnetic field of the antenna. Once a card is detected, we keep reading until the same code is read three consecutive times. This code is then compared to the code bank stored in EEPROM. If this code matches any of the authorized codes in the code bank, the security system allows access for 3 s and signifies this by lighting a green LED. If the code is not stored in the bank, a red LED is lit for 3 s signifying that access was denied. When a card is read and either access is granted or denied, a message is sent

to the PC that logs the ID number read from the card, the time at which it occurred, and whether or not access was granted. The reader enters this mode of operation on reset.

In Administration mode, the administrator has the ability (using a serial communications program such as HyperTerminal or API) to change the state of the security program, be it adding and deleting codes, unlocking the "door," or putting the program into a state we like to call "Remote Administration mode." The administrator can also query the microcontroller to list all of the codes stored in the code bank.

In Remote Administration mode, the administrator can add codes to the code bank by directly scanning the ID cards into the reader. This method of adding authorized IDs to the code bank is useful because there is no specific correlation between the data stored on the card and the person's

name, identification number, or any other personal information. Thus, it is the only feasible way to add codes to the code bank without having to know what number is stored on the card. To prevent reading errors and possibly storing corrupted codes in the code bank when operating in this mode, the reader will try to read the same code five times, as opposed to the three in regular Security mode.

Remote mode has two submodes: Positional Add and Batch Add. In Positional Add, the administrator specifies the specific code bank slot to add a code to and overwrite prior codes if they are there. In Batch Add mode, the administrator need only specify the number of codes to add to the code bank (up to 20) and the program will add them into whatever empty spaces it can find, stopping and prompting the user when all of the codes are added or there is no space remaining.

Serial communications on the

microcontroller side were handled by a combination of the USART interrupt and functions found in the stdio library in order to send data to the administrator computer, and our own non-blocking function to receive instructions from the administrator. We chose a data rate of 9,600 bps because we didn't really need anything faster. If you want specifics about how the functions work, please refer to our source code posted on the *Circuit Cellar* FTP site. For interpreting data coming from the administrator, we developed a very simple syntax, which was, for the most part, one or two letters to serve as an opcode and up to two arguments. This is detailed in a Help screen when the system boots.

How does the software know when there is a card in the antenna's vicinity? The reader knows there is no card near the reader when the output of the flip-flop/counter circuit is logic low. When a card comes within the antenna's read distance (approximately 3"), the datastream from the data-processing circuit begins to pulse at TTL levels. We know that this input corresponds directly to data from the card in an NRZ format, so all we need to do is sample the data at the proper intervals.

We employed one of the ATmega32's asynchronous external interrupts using the output from the comparator in our filter stage to trigger the interrupt (see Photo 5). Once we noticed that the datastream went high for the first time, we began storing samples in an array until the array was completely filled. Initially, when we were still developing the reader, we had no idea what this response was going to look like. Luckily, careful observation revealed a definite periodicity of 540 bits, which gave us plenty of confidence because it looked like we were on the right track.

To illustrate the basic idea, let's pretend the number of bits received is only 78 bits long. A particular sequence received from the card would look something like:

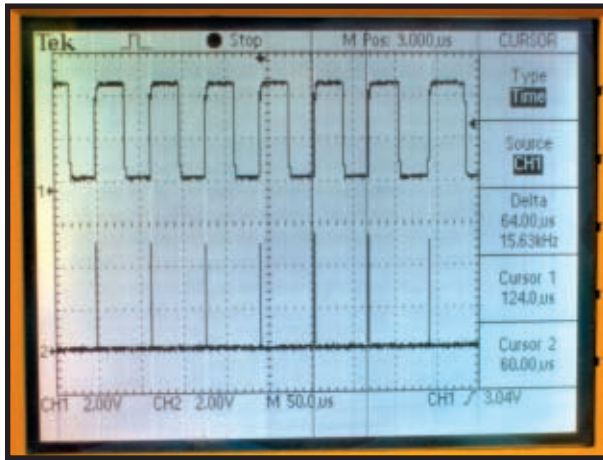


Photo 4—Channel 1 is the TTL-level output of the comparator after the filter stage. The short pulses in Channel 2 are created from the first flip-flop. The pulse widths after the flip-flop are roughly 350 ns.

```
11111111111111111100000111111000001111111
111110000000000111111000000000000000000
```

The long sequence of 16 ones is the start sequence. The last sequence of 18 zeros is the stop sequence. The data in between is grouped in five to six zeros and ones. At first, we had no

```
01011001
```

Although it may not be immediately apparent with an 8-bit sequence of numbers, it was very obvious that the full 90-bit sequence was encoded Manchester code. By splitting the sequence into pairs of bits, there is always a

idea how to interpret the numbers, so we looked at it the simplest way possible. We assumed that a group of five to six zeros or ones condensed down to a single 1 or 0 bit. Afterward, this theory made sense. The circuit on the card probably doesn't modulate precisely enough; thus, it pads a bit with a sequence five to six bits. Analyzing the 78-bit sequence above with what we learned, we removed the start and stop sequence and condensed the groups of five to six bits to single bits to get another sequence:

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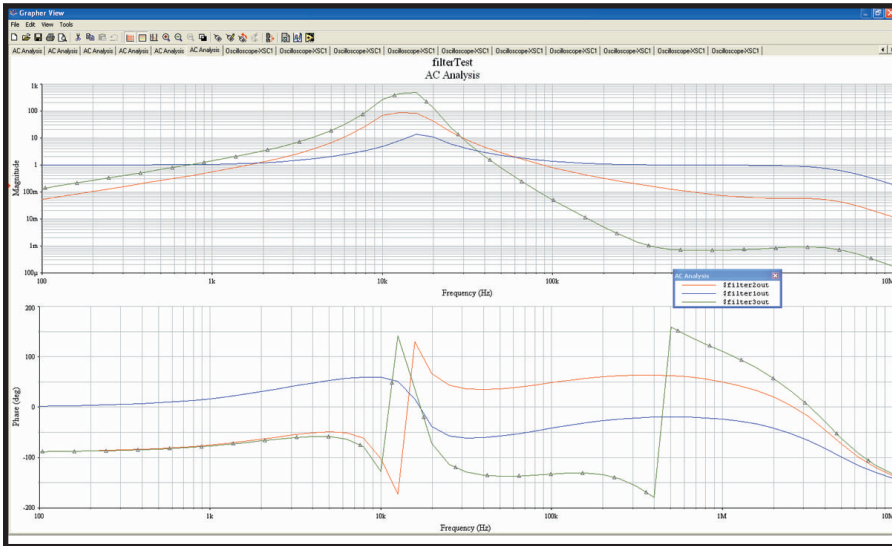


Figure 3—This is a Bode plot of each stage of the cascaded filters. The output of the first Twin-T filter is in blue, the second is in red, and the output of the Butterworth filter is in green. Notice the 1-dB point at roughly 30 kHz. This stage's output should be a square wave at this frequency (idle frequency) when no card is present.

transition, either from low to high or high to low. In Manchester code, the former transition signifies a one and the latter signifies a zero. Applying this to our existing sequence, we got the following sequence:

1101

As you can see, the long 78-bit sequence stored only 4 bits of actual data. For our Cornell ID cards, the 540-bit sequence decoded to a 45-bit code.

DESIGN IMPROVEMENTS

Although we were extremely happy

with our result, this was our first time taking on such a project. Naturally, there is room for improvement. The first of these would have to be the construction process. For this project, we had a limited budget (we were required to spend no more than \$50 or we would be penalized), and we didn't have a lot of time to complete the system.

The system's housing basically comprises a piece of wood tiling, four long screws, a reference PCB prototype board that Professor Land designed for the ATmega32, and our circuit on a piece of solder board. It served its purposes for our demonstration, but it did include a lot of exposed wires and circuits.

Additionally, it probably would have been better to move the actual code bank onto the administrator computer and edit using an administration program with a specialized GUI. This would have enabled us to store infinitely more codes and present a better interface. For the purposes of this project, however, it was more of a proof-of-concept than anything else. By keeping more things on

the microcontroller, it better displayed our microcontroller-programming prowess.

We could have done several things differently in terms of the hardware. We could have used a DSP instead of envelope detection hardware. A simple FFT on the incoming signal from the tag would have told us everything we needed to know about it and made our design more flexible.

There are plenty of other design improvements to be made, but we'll leave them up to you. At the very least, we hope that you have found this article informative. Now it's your turn to start a project based on RFID technology. Good luck! 🍀

Craig Ross (cjr37@cornell.edu) studies computer engineering and architecture at Cornell University. In the summer of 2006, he completed an internship at Keithley Instruments.

Ricardo Goto (rhg22@cornell.edu) studies computer engineering and architecture at Cornell University. In the summer of 2006, he completed an internship at Advanced Micro Devices.

PROJECT FILES

To download code, go to ftp://ftp.circuitcellar.com/pub/Circuit_Cellar/2007/199.

RESOURCES

B. Land, ECE476 Designing with Microcontrollers Course, Cornell University, <http://instruct1.cit.cornell.edu/courses/ee476/>.

J. Westhues, "Proximity Cards," 2003, <http://cq.cx/prox.pl>.

SOURCES

ATmega32 Microcontroller

Atmel Corp.
www.atmel.com

DuoProx II Identification card

HID Global Corp.
www.hidcorp.com

microID RFID System

Microchip Technology, Inc.
www.microchip.com

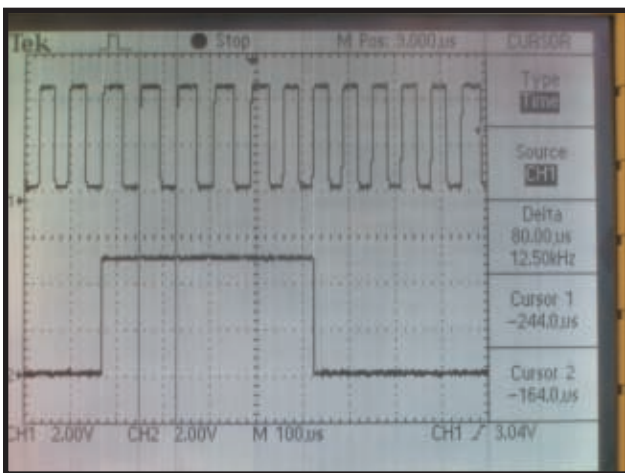


Photo 5—Channel 1 is the TTL-level output of the comparator after the filter stage. Channel 2 is the datastream from the Data Retrieval stage. Notice how Channel 2 is high only after a 12.5-kHz pulse is observed. Both of the signals are used by the ATmega32 to determine the tag data.



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DSP-Based Vehicle Monitoring

Chris's iTrack DSP-based vehicle-monitoring system features remote cellular control. You can use your cell phone to locate your vehicle and control everything from its headlights to its door locks.

The iTrack is an inexpensive yet robust tracking device and cellular remote control designed for automotive applications (see Photo 1). Using any touchtone telephone, you can call the iTrack to determine your vehicle's GPS location, lock and unlock the doors, turn off the headlights, roll down the windows, and control virtually any other function.

In this article, I will describe the system's DSP-centric design and explain how the industry-standard Freescale Semiconductor DSP56300 digital signal processor series can be used to implement normally demanding tasks. Focusing on the inner workings of the system, I'll cover topics such as implementing a simple speech

synthesizer, detecting DTMF tones, rapidly converting floating point to binary coded decimal (BCD), decompressing ADPCM speech in real time, detecting a cell phone ring, and other jobs suited for a DSP. Read on for a practical look into the process of implementing signal processing voodoo trickery.

DEVELOPMENT TOOL SUITE

I have come to believe that a good set of accessible development tools largely determines whether my projects live or die. Although I would be hard pressed to name a DSP manufacturer that does not provide one form of development tool or another, I find



Photo 1—The finished project is housed in protective black Bakelite casing. A cell phone antenna is on the left and a GPS antenna is on the right. Power and serial connectors are in the front.

that as a minimalist, most are either out of my price range or painful to use. Fortunately, Freescale provides a decent development environment for its DSP563xx series.

Freescale's free Suite56 contains an assembler, linker, GUI simulator, and debugger (see Photo 2). The simulator and debugger are available in command-line form for those of you command line lovers out there. I developed my firmware in Microsoft Windows, but the Suite56 tools are also available for Sun Solaris. One of the tool suite's drawbacks is its lack of a C compiler. A costly third-party C compiler is available from Altium. There's also an out-of-date, hard-to-find port of the GNU C compiler, which was supported by Freescale back when it was still Motorola. However, developing in assembly was elegant fun, and it arguably enabled me to better understand the magic of the DSP engine.

To interface iTrack to Suite56's debugger, I used the affordable Amontec ChameleonPOD. For the purposes of this project, the ChameleonPOD is a hardware debugger that connects the parallel port of a PC to the JTAG port of the DSP. But it is so much more.

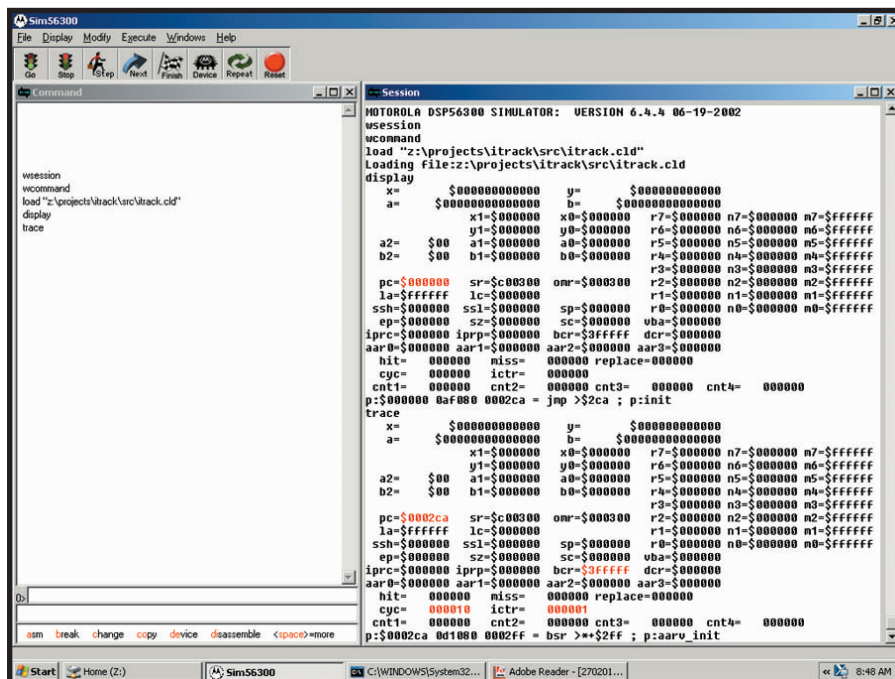


Photo 2—Check out the GUI56300, the Suite56 simulator. The GDS56300 is the Suite56 debugger that looks and operates almost identically.

With a reconfigurable CPLD at the center of its design, the pod can change functionality, as the name suggests. The CPLD can be reprogrammed to have the pod function as an Altera ByteBlaster, Xilinx Parallel Cable III, Atmel AVR STK500, Macraigor Raven, or one of several other specialized and normally costly debuggers.

I could not find a way to have the Suite56 tool suite link voice recordings for the speech synthesizer into the final image while making them accessible from code. To solve this problem, I wrote a small tool (dubbed "bin2asm") that converts a binary file into assembly code. The resulting assembly code then can be referenced within a look-up table or assembled into a relocatable object file. Together with a couple small supporting bash scripts, I used bin2asm to convert all the voice recordings used by iTrack into relocatable object files that could be referenced by the speech synthesizer code.

HARDWARE

Now that we've taken off the hood, let's look at the parts (see Photo 3). The system has three primary components: a GPS module, a cell phone so old that the battery pack is corroded, and a Freescale DSP56303 processor at the helm. The DSP listens for and answers incoming calls. When a call is answered, the DSP voices speech into the cell phone's microphone while detecting incoming tones over the speaker. The keys pressed by the caller on the other end generate the tones. The caller can use a touch-tone keypad to navigate and select options from the speech-based menu (much in the same way callers interface with a phone-banking service).

Originally I planned on implementing an ITU v.21 300-bps FSK modem. However, GSM cell phones compress data by transmitting the resonance frequency every 5 ms, whereas a 300-bps FSK would require a frequency transmission at least once every 3.3 ms. Using the special GSM data channel would solve this, but that usually requires a costly subscription service.

Using the peripheral interfaces provided by the DSP resulted in a simple,

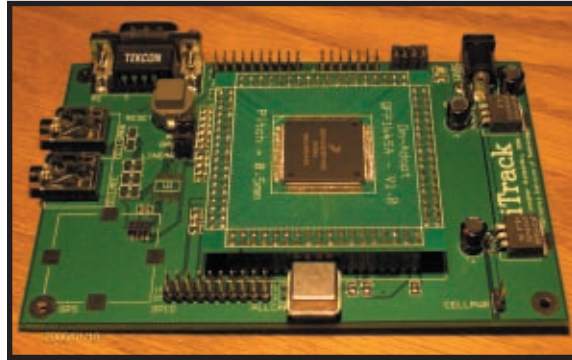


Photo 3—The PCB features a DSP on the adapter board. The GPS and codec are not populated. SRAM and flash memory are hidden beneath the DSP.

elegant circuit without glue logic (see Figure 1). The DSP (U2) communicates with the cell phone microphone and speaker via a Texas Instruments telecom audio codec (U1) that uses a standard serial bus (called McBSP by Texas Instruments and ESSI by Freescale) for the digital DSP interface. The codec also performs signal processing, using digital filters to remove noise. These filters require a 2.048-MHz oscillator, so I made my system clock 32.768 MHz and had the DSP generate the 2.048 MHz to save

myself an oscillator. To be able to run the DSP faster, I made room for a phase-locked loop capacitor (C25). I gave myself a cookie for this when the 16.384-MHz clock speed proved too slow for real time.

For the GPS link, the system uses a Trimble Lassen iQ module (JP4). The stand-alone module is about an inch squared and reports a GPS fix every 1 s to the DSP through the UART. I wanted a console for the debugging, but I had only one UART. I multiplexed

the receiver wire with a jumper (JP6).

One thing that makes this DSP a bit strange is the 24-bit architecture, and there aren't too many 24-bits-wide memory chips out there. To remedy this problem, add three 8-bit SRAMs (U7, U8, and U9) on the same chip select. Finally, add a flash ROM (U10) for code and the iTrack platform will be complete.

Where's the cell phone? You can use any cell phone, so I decided to leave it out of the schematic, although I added a voltage regulator (U11) for power. To

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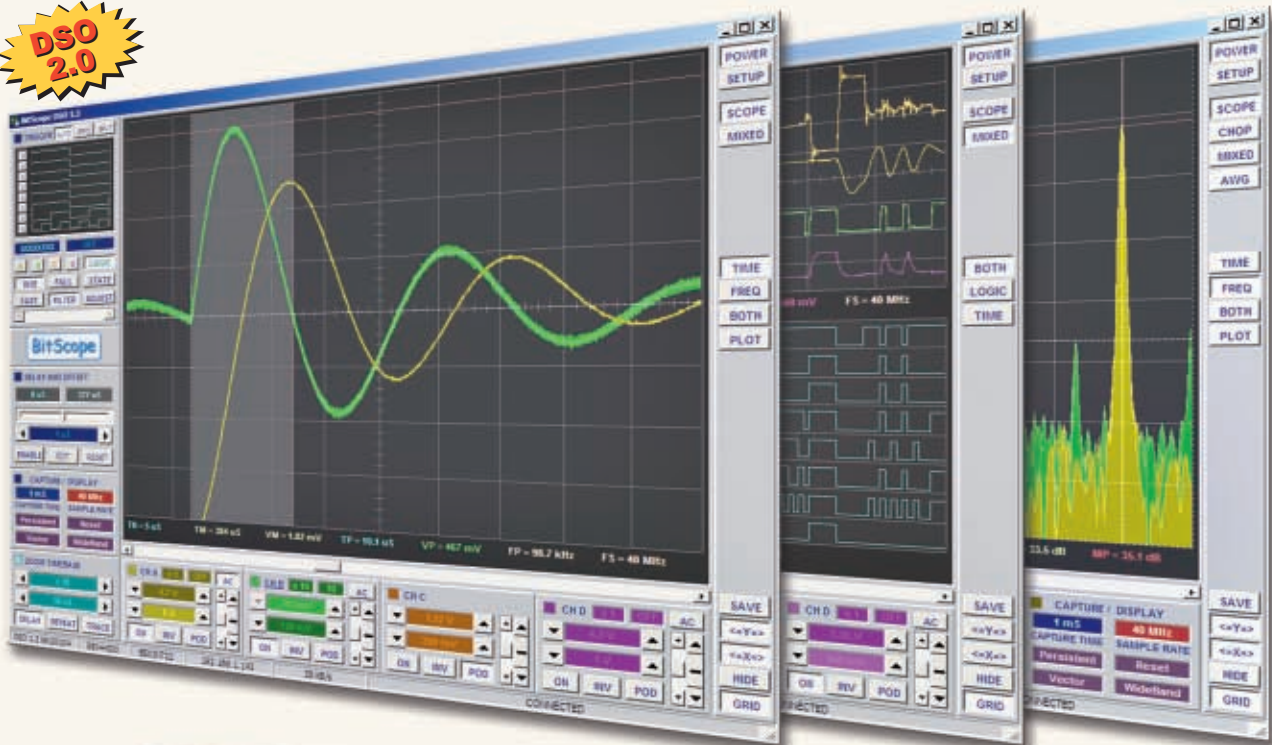
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simulate presses on the Answer and Power keys, I soldered a 2N7000 N-channel JFET across the contacts of each key and wired the gates to GPIO pins (see Figure 2). I also found that a 1-k Ω pull-up resistor across the gate and drain of each JFET was needed to fool the phone. Lastly, I directly connected the codec output and input to the microphone and speaker contacts, although using microfarad coupling capacitors to make the connections is a better idea.

With the hardware designed, let's

look at some code.

SOFTWARE

DSPs are very good at signal processing tasks, but the hardware simply isn't designed for microcontroller code. Although writing a routine to perform some DSP tasks is manageable, orchestrating several tasks into a symphony could result in a cacophony. Fortunately, there are steps that greatly simplify the problem.

The first is a standard procedure call

to adhere to when writing routines. I passed arguments through the X0, X1, Y0, and Y1 registers and returned values through accumulator A. Further, I required that any modified registers be restored in all but a few routines. Although this gave a performance hit, it kept the code structured and uniform.

Next, I set up a simple tasker in `init.asm`. This pseudo-tasker continuously calls six tasks in sequence while `iTrack` is in a call. Each task performs a small chunk of processing per execution

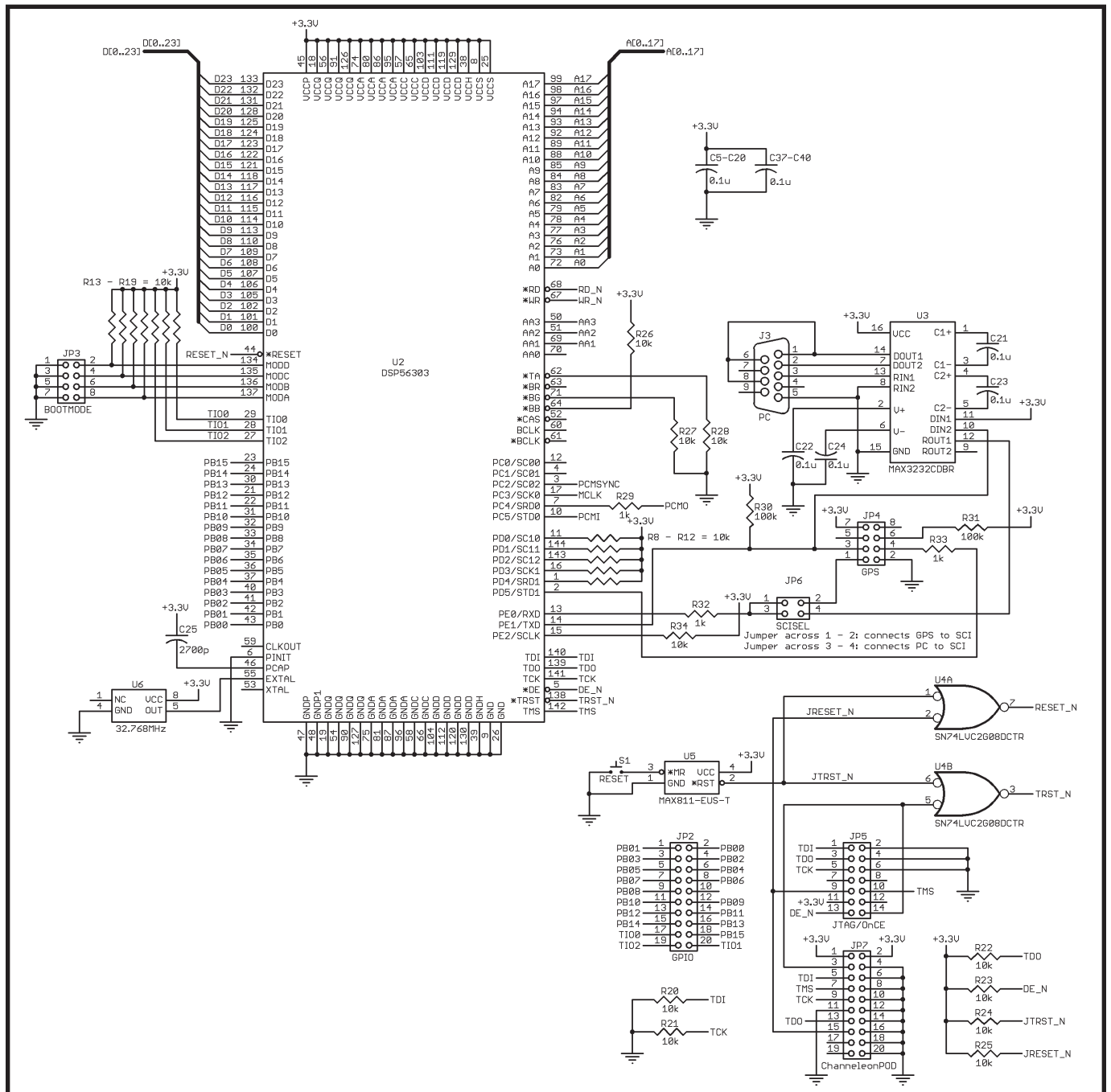


Figure 1—Here you see the DSP and supported peripherals. A full schematic diagram is available on the Circuit Cellar FTP site.

and returns, so it doesn't stall the other tasks. When not in a call, the system saves power by idling with the DSP core off, only turning it on to check if the cell phone is ringing. Although this design is simple, it works very well.

Files for the project are organized hierarchically (see Figure 3). Files directly connected to `init.asm` contain top-level routines for their respective tasks. For example, `menu.asm` contains the `menu_task` routine that processes user menu navigation using the speech synthesizer in `speech.asm`. In the next few sections, I'll talk more about how specific tasks in these files work.

DTMF DEMODULATION

Callers communicate with the iTrack via a touchtone telephone. Touchtone technology uses dual-tone multiple frequency (DTMF) modulation to communicate key presses. With DTMF, two of eight possible tones are transmitted simultaneously for each key, one for the column and one for the row.

The system detects the two DTMF tones using the Goertzel algorithm.^[1] The algorithm uses one infinite impulse response (IIR) filter per tone to be detected. The Z-transforms of each filter are nearly identical. Each has three terms, where the only difference between frequencies is in the coefficient, *c*:

$$z(y) = 1 + cz^{-1} + cz^{-2} \quad [1]$$

What does this mean? Basically, each filter's output equals the codec input plus scaled versions of the filter's output from the previous two samples. The DSP's multiply-accumulate (MAC) instruction makes computations for this equation very lean.

After a couple hundred samples, the squared filter outputs are compared against a fixed threshold. When one row tone and one column tone exceed the threshold, a key is detected. The key is decoded into a key code and queued into the key buffer for processing by other tasks. For a detailed look at the DTMF code, refer to the `dtmfkeys.asm` and `goertzel.asm` files on the *Circuit Cellar* FTP site.

RING DETECTION

Cell phone speakers are designed for clarity, not volume, so a separate

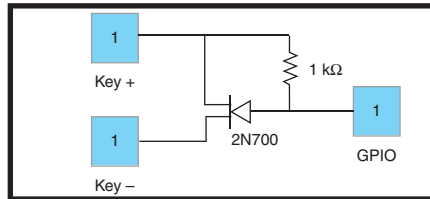


Figure 2—This circuit is used to simulate key presses on a cell phone.

transducer (the Star Microelectronics MUT-03A in my Ericsson CF388) usually produces the ring tone. This is why most ring tones have been monophonic until recently. But these transducers also produce other tones such as new voicemail. Distinguishing a ring tone from other tones can be tricky.

Transducers produce tones based on square wave input. The frequency of the square wave determines the pitch of the tone. You could monitor the frequency input to the transducer and look for the ring-tone pattern, but there's a better way. Most cell phones have an indicator LED for visual event notification. For example, the CF388 has one that blinks at 2.5 Hz during incoming calls. Such an LED can be used for ring tone detection. Unfortunately, the LED also blinks at 2.5 Hz for new voicemail. But examining the LED signal on an oscilloscope reveals a hidden jewel. During an incoming call, the power-hungry antenna circuit turns on and superimposes high-frequency crosstalk pulses. These pulses have no visible effect on the LED, but they provide a reliable way of detecting incoming calls.

The DSP's triple timer module (TTM) can measure the blink rate in hardware. This allows the iTrack to power down the DSP core during measurements to save power. When a measurement has been made, the processor is awoken and compares the blink rate against the incoming call blink rate. Refer to the ring detection code (`phone.asm` and `timer.asm`) posted on the *Circuit Cellar* FTP site.

SPEECH SYNTHESIS

Synthesizing speech can be difficult, but with only a couple hundred words, it's not too bad. The basic idea is to record individual words and string them into sentences during playback. You can do this neatly.

First, focus on recording. Find some-

one with a nice voice. Once the recordings are done, split words with common syllables into two recordings for reuse in other words. For example, split the recording "twenty" into "twen" and "tee." Reuse "tee" in numbers like thirty. Editing software such as NCH Swift Sound Wavepad helps. Save the final recordings into VOX audio files. VOX is an old format that only stores audio data, nothing else.

The speech synthesizer code must also know the recording addresses and sizes. I used my `bin2asm` program that converted binary VOX files into assembler files, complete with label references and recording size prefixes.

Now let's take a look at the synthesizer. Sentences are represented as null-terminated strings of labels corresponding to recording addresses. For example, the sentence, "Welcome to iTrack," is represented as:

```
DC welcome,two,i,track,0
```

The speech generation task reads 3 bytes from the word to voice on each execution and writes the decoded values to the audio queue, drained on codec interrupts. If the task returns indicating that the audio queue is full, the same bytes are read and retried during the next execution.

The DSP provides a couple benefits for the speech synthesizer. First, it has registers dedicated for implementing circular queues, making writing and reading values from the audio queue very fast. Second, it accelerates audio decoding. I'll talk more about this in the next section.

VOICE COMPRESSION

The recordings that the iTrack uses to voice speech are compressed using adaptive differential pulse coded modulation (ADPCM). Using the standard 8-kHz voice-sampling rate, uncompressed voice requires about 64 kbps. ADPCM requires only 32 kbps. This allows for twice as much audio.

The basic idea used is that speech signals usually vary slowly. Thus, ADPCM encodes only differences between samples. One bit is used for the sign; three bits are for the difference. Occasionally, speech changes are

rapid and the difference is larger than three bits. In this case, a multiplier is applied, but it is not encoded in the compressed data. The encoder and decoder both keep track of the multiplier separately, adapting it based on how rapidly the signal is changing.

There are many ADPCM standards with different ways of adapting the multiplier. I used the freely available Dialogic ADPCM algorithm.^[2] The DSP provides a couple of advantages in implementing this algorithm. Two that came in especially handy were conditional execution of the addition instruction based on the value of a specific bit and parallel execution of instructions. For a detailed look at my implementation of the Dialogic ADPCM decoder, refer to the `vox.asm` file.

GPS MODULE

GPS technology is a modern marvel. With a simple hand-held, receive-only device, you can precisely determine its location and velocity. However, the notorious complexity of GPS receivers makes the technology intimidating. Don't stress, it's not that hard.

With only power required, the Trimble Lassen iQ stand-alone GPS module can automatically obtain position and velocity fixes. This small and inexpensive module works very well in the iTrack. Periodically, the module transmits GPS information to the DSP UART.

Three protocols are supported: NMEA 0183, TAIP, and TSIP. NMEA 0183 is an ASCII-based national maritime standard. TAIP is an ASCII-based Trimble standard. TSIP is a binary Trimble standard. Binary data was easier for the DSP to handle, so I decided to use TSIP.

TSIP consists of a delimiter, marking the start of a message, a message ID, the message body, and another delimiter that marks the end of a message. There's one caveat: the delimiter can coincidentally occur within the message, so it must be escaped. I wrote a small state machine to

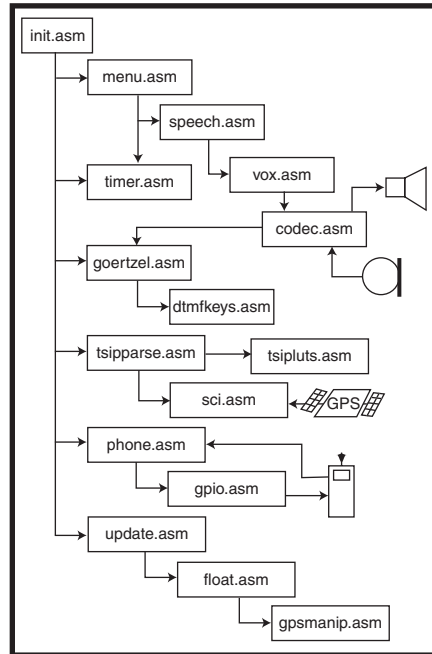


Figure 3—Take a look at the file dependencies and system organization.

parse TSIP. (Refer to `tsipparse.asm`.) The parser removes delimiters from the beginning and end of a TSIP message. It also removes escapes from the message body. GPS information is then extracted from the message body and stored in variables for reporting to the next caller.

Unfortunately, DSPs are not the end-all solutions that they sometimes appear to be. This is one task better suited for a microcontroller than a DSP. Using a jump table for the action to be performed by the parser involved non-intuitive manipulation of the program counter. In addition, the parser stalled the DSP instruction pipeline on several instructions due to restrictions on register usage. For example, at least three instructions must occur between the loading of register `r0` and a branch to the address in `r0`.

I'm not done yet. The GPS data extracted from TSIP packets needs more processing before it becomes useful.

FLOATING POINTS

Every second, the GPS module

transmits TSIP packets containing position and velocity fix information to the DSP. The goal is to convert this information into numbers that the speech synthesizer can voice.

Spoken numbers are pronounced based on context. For example, 312 and 323 are pronounced as "three hundred twelve" and "three hundred twenty-three." The first uses three words. The second uses four. Teen numbers are also pronounced differently. To determine how to voice a number, we need to examine its individual digits. The binary coded decimal (BCD) encoding makes this easy.

It would be convenient if the GPS module reported information in BCD, or even decimal. Instead it reports coordinates in floating-point radians. The GPS module can report either single (32-bit) or double precision (64-bit) float point. We'll look at single precision. So, we have some signal processing to do.

First, a short refresher on floating point. Floating-point numbers consist of a sign bit s , an exponent e , and a significand m .^[3] The most significant bit—set when the number is negative, clear when positive—is the sign bit. The next 8 bits are the exponent for the number two. The last 23 bits are the significand, the part of a real number after the radix point. A floating-point number n is expressed in terms of these three variables as:

$$n = (-1^s)(2^e)(1.m) \quad [2]$$

Here the period between the 1 and m represents the decimal radix point. One caveat: the exponent is biased by 127. For instance, if 28 were stored in the exponent bits of a float, this would mean that e would be one. Manipulating these floats on a fixed-point processor like the DSP56303 can get tricky.

FIXED-POINT FLOATS

To be able to perform operations on floats, you must convert them to a more accessible form for the fixed-point DSP. I should mention that the DSP56303 can operate only on fractional numbers between -1 and 1. But this is not as bad as it seems.

First, you left-shift the float by 1 bit. This separates the exponent and significand into the A1 and A0 registers.

Listing 1—The algorithm is used for converting to degrees, minutes, and seconds.

```
degrees = ipart(degrees)
minutes = ipart(fpart(degrees) × 60)
seconds = ipart(fpart(minutes) × 60)
```

Listing 2—The DSP routine is for converting binary to binary coded decimal.

```
bin2bcd clr      a
move    #0.010001,y0      ; b1 = ipart[bin/100]
mpyuu   x0,y0,b           ; b0 = fpart[bin/100]
move    #>10,y0           ; digit extractor
move    b1,a1             ; a1 = hundreds digit
move    b0,x0             ; x0 = rem

move    #2,n0             ; 2 remaining digits
do      n0,_enddo
mpyuu   x0,y0,b           ; b1 = ipart[(rem)*10]
; b0 = fpart[(rem)*10]
asr     b                 ; corrects multiply
asl     #4,a,a            ; next digit
move    b1,x1
or      x1,a              b0,x0 ; stores bcd digit
_enddo rts
```

You then remove the sign bit, negating A0 if it was set. The significand is still not a number, but it's part of a number. This would make computation tricky, so you divide it by two and add one to the exponent. (Refer to the float.asm file.) You now have a separate integer exponent and signed mantissa. Finally, something you can work with!

DEGREES, MINUTES, SECONDS

Radians are not very useful for determining a point on the globe, so convert to degrees:

$$\begin{aligned} \text{degrees} &= (\text{radians}) \left(\frac{180}{\pi} \right) \\ &= (\text{radians}) (0xE52EE0) \end{aligned} \quad [3]$$

The magic number 0xE52EE0 arises because the DSP multiplies fractional numbers between -1 and 1. In this case, you must multiply by $180/\pi$, which is roughly 57.296. This number is greater than one, so you normalize it (i.e., divide by 2^6). The conversion factor 57.296 hence becomes 0.895, less than one. Written as a 24-bit fractional number, it is:

$$0.895 = (0xE52EE0)(2^{-24}) \quad [4]$$

How is this computation done in floating point? Simple. Six is added to the exponent in A1 and 0xE52EE0 multiplies the mantissa in A0.

Lastly, convert degrees into degrees, minutes, and seconds (see Listing 1). Multiplication by 60 is done the same way as multiplication by $180/\pi$. There's another neat trick. Accumulator A has eight overflow bits (called register A2) for manipulating numbers up to 255. The number of degrees

should never exceed this, so A2 can be conveniently used to extract the integer portion of the product.

TO BCD

Coordinates in terms of degrees, minutes, and seconds are nice, but not yet useful. Each number must be converted to BCD so that its digits can be interpreted and voiced. I used a traditional algorithm for the conversion: divide by 100 to get the hundreds digit, divide the remainder by 10 to get the tens digit, and the remainder is the ones digit. But division is expensive. The DSP has a division instruction, but it computes iteratively, 1 bit per cycle.

Multiplying by $1/100$ is equivalent to dividing by 100. The DSP can do this multiplication in a single clock cycle. Converting to BCD then becomes very similar to the conversions in Equation 3 and Listing 1. The code for the conversion is shown in Listing 2.

This is where the true power of the DSP shines. Perhaps you'll be able to compact this routine even further.

NEW HORIZONS

My hope is that this article has removed some of the mystery surrounding DSPs without taking away their luster. If I've whet your appetite for an iTrack, even better. There's still plenty of room in the sandbox. Perhaps the iTrack can be voice-controlled with speech recognition. Or, perhaps it can analyze GPS data to provide an estimated time of arrival at a coordinate specified by the user. The possibilities offered by DSPs are endless. Sometimes all you need is a challenging project. 📧

Chris Hiszpanski (chiszp@gmail.com) is pursuing an M.S. at Caltech with a specialization in communications and signal processing. He received a B.S. in electrical engineering from Caltech in June 2006. In addition to his interests in electronics, Chris enjoys bicycling, playing card games, and discussing philosophy in the company of friends.

PROJECT FILES

To download code and additional files, go to ftp://ftp.circuitcellar.com/pub/Circuit_Cellar/2007/199.

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- [2] Dialogic Corp., "Dialogic ADPCM Algorithm," 1988.
- [3] IEEE Standards Association, "Std 754-1985: IEEE Standard for Binary Floating-Point Arithmetic," <http://standards.ieee.org>.

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Freescale Semiconductor, "DSP56300 Family Manual Addendum," DSP56300FMAD, rev. 5, 2006.

———, "DSP56303 User's Manual," DSP56303UM, rev. 2, 2005.

SOURCES

ChameleonPOD

Amontec Reconfigurable Computer Systems
www.amontec.com

Swift sound wavepad

NCH Swift Sound Software
www.nch.com.au

DSP56303 DSP and Suite56 for DSP566xx/DSP563xx

Freescale Semiconductor, Inc.
www.freescale.com

TLV320AIC1106 PCM Codec

Texas Instruments, Inc.
www.ti.com

Lassen iQ GPS module

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Nixie Tube Propeller Clock

Peter built his Nixie Tube Propeller Clock (NTPC) around a Microchip PIC16F84A microcontroller. The firmware was developed in assembly language with the MPLAB development suite.

In this article, I'll introduce a propeller clock that features a nixie tube, which I named, quite creatively, the Nixie Tube Propeller Clock (NTPC). The primary purposes of my project were to demonstrate the application of this simple yet capable device and to have a little fun in the process.

The heart of the design is a Microchip Technology PIC16F84A microcontroller. I developed the firmware in its native assembly language using the MPLAB development suite.

NIXIE TUBES

The nixie tube is one of the most ancient electronic display technologies, predating LEDs, LCDs, and other contemporary displays. (It is now an obsolete technology that's seen only in old Cold War video footage as the symbol of the era's state-of-the-art technology.) The tube is a cold cathode discharge tube with a shape resembling that of a vacuum tube, although its cathodes are not heated (hence the name). In principle, nixie tubes are the same as the neon bulbs typically found in the illuminated switches on surge protectors.

Photo 1 shows the Matsushita Electric Industrial Co. (Panasonic) CD72P nixie tube that I used for this project. The glass enclosure contains neon gas at a low pressure. When a sufficiently high voltage is connected between the cathode (negative) and the anode (positive), the neon gas ionizes in a rather complex process. As a result, neon ions and electrons fly to the cathode and anode, respectively. The anode quietly swallows the electrons; how-

ever, the recombination of neon ions and electrons covers the cathode in a beautiful, ethereal orange glow. Refer to G.F. Weston's *Cold Cathode Glow Discharge Tubes* for more information about cold cathode tubes.

The aforementioned phenomenon is used in the nixie tube to display characters (typically numeric). Multiple cathodes etched to the shape of each supported character are stacked on top of each other, standing behind the anode mesh that resembles miniature chicken wire. Energizing one of the cathodes and the anode produces a glow in the shape of the selected character.

This is a delicate and fragile technology that has been extinct from manufacturing for decades. Yet, the sparkling glass case and glowing neon has kept a group of nixie enthusiasts loyal ever since. The community got a great boost in 2002, when artistic inventor Raymond Weisling of Zetalink Technology founded the NEONIXIE-L Yahoo group. Today, the group has more than 1,500 members across the globe, with new members joining every week.

Finding an actual nixie can be tricky because vendors don't always carry them. But there is a plethora of nixie-related information on the Internet. Refer to the web sites listed in the Resources section of this article for more information.

PROPELLER DISPLAYS

The fundamental and truly ingenious idea behind propeller displays is based on the phenomenon of positive after-images, which is also known by

the obsolete term "persistence of vision." It's the principle of producing a wide display perception from a narrower but physically moving display element. (The technology deserves to become a new meaning for the term "spatial multiplexing.")

Bob Blick created the first propeller clock, which spins a single column of LEDs along a horizontal circle to produce the display on a cylindrical surface. (A similar approach is used for "window wiper" clocks like the Fantazein Message Clock.) My project was a fun way to combine an exotic

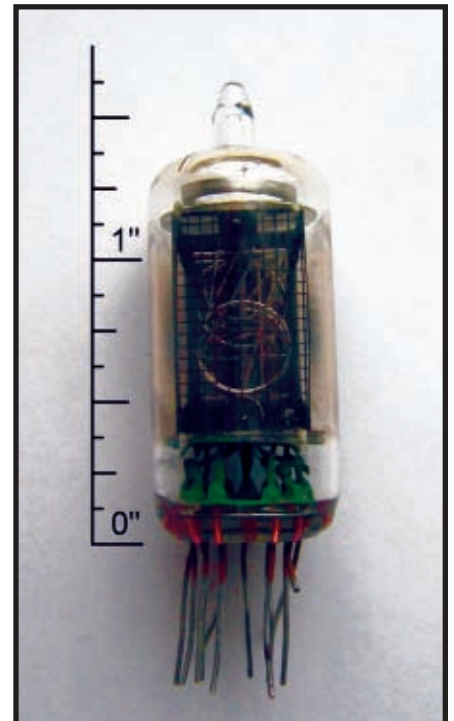


Photo 1—The CD72P nixie tube is relatively small. Its size and wire pins make it optimal for the propeller display application.

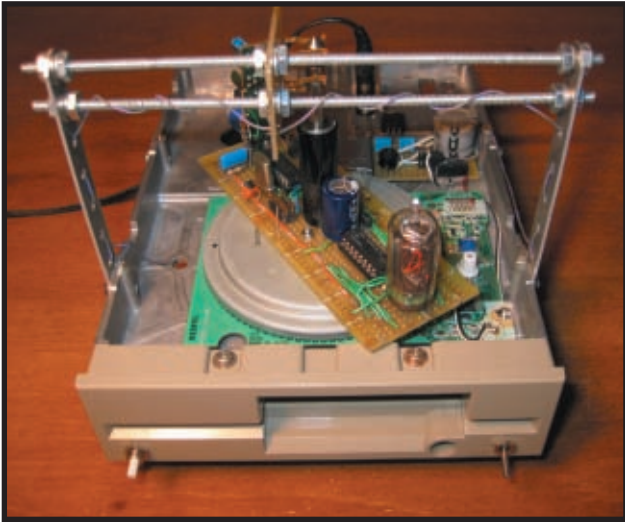


Photo 2—The Nixie Tube Propeller Clock is built on an old 5.25" floppy drive turned upside down. In addition to the speed-controlled motor, an infrared LED (inside the white plastic cylinder) and a photodiode can be used from the drive electronics.

play is the type of arrangement that will provide the rotary motion. The rest of the mechanical design hinges upon this decision.

As an avid collector of computer junk (more precisely, all electronic junk), a little browsing among my musty boxes turned up the solution. The Holy Grail was a long-forgotten 5.25" floppy drive, which I found sitting at the bottom of a box with a few other drives.

The plan immediately became clear. I realized that I could implement the propeller display by attaching a rectangular circuit board to the floppy motor and mounting a side-view nixie tube upright to one end of the board facing outward (see Photo 2). That unit

proved to be an ideal choice.

First, the size of the drive is about right, even if every point of the rotated circuit board remains within the confines of the drive, which is recommended for a simpler and safer mechanical implementation. However, the real boon is the drive's speed-controlled motor, which spins away at 300 or 360 RPM, depending on the state of the SPD input signal received by the motor electronics. A single revolving nixie tube's readout is not completely flicker-free (even at the higher speed), but it's easily legible. (The very first experiment I performed was to verify if this central conjecture was true or false.)

Turning the drive upside down revealed the motor electronics and the magnet-filled metal plate acting as the rotor. After stripping all of the other components from the drive, I mounted the propeller clock's circuit board to this side, as opposed to the original top. The three tiny holes on the plate seemed perfect for holding the mounting screws. With a little effort, I pried

display method with an unusual display device. It replaces the column of LEDs with a nixie tube.

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the plate off of the rotating hub. After that, I put the mounting screws in the holes and tightened them. I then glued the plate (referred to as “carousel” henceforth) back to its original place.

The clock’s electronics were assembled on a 5” x 1.75” prototyping board, but a PCB design could probably achieve a narrower footprint. In any case, it is important that the board is balanced (i.e., its center of gravity falls as close as possible to the point at which the rotation axis intersects the

board). The device’s Achilles heel—and the part that required the most precision—was the array of linkages for the power and signal lines between the stationary world and the rotating clock circuitry. That problem is typically solved using commercially available slip rings. However, an extensive search for a suitable replacement came back empty, so the NTPC received a homegrown “slip ring” assembly. It consists of a 0.25” stereo headphone plug screwed vertically right in the

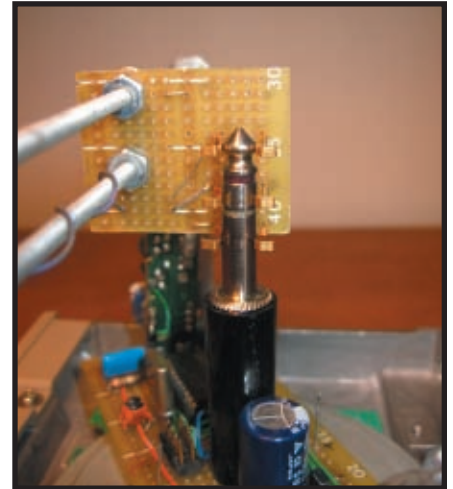


Photo 3—Check out the homemade “slip ring” solution. The 0.25” stereo headphone plug is another off-the-shelf component that turned out to be ideal for its intended purpose in the clock. It is fastened to the board by a screw after dropping a 0.375” diameter #10 washer in its plastic case.

middle of the circuit board (exactly above the rotation axis) and a set of stationary contacts (see Photos 2 and 3). I yanked the contacts out of an old edge connector and soldered on a piece of prototyping board, which was then mounted on the chassis using old Meco pieces and threaded aluminum rods. (If you want to build a similar clock, you’re free to come up with other creative ideas.) With an occasional spray of WD-40 for lubrication, this slip ring has been churning away without a glitch. The contacts can withstand the slight wiggle of the spinning headphone plug, provided that they aren’t pressing against the plug too tightly.

The stereo headphone plug has three connections (two of which are needed for power), so there is only one signal line left for any widgets to control the clock. The NTPC implements one push button. Anything more would complicate matters significantly. Fans of the one-button Apple mouse will certainly appreciate the user interface, which required some extra finesse on the firmware side.

ELECTRONIC DESIGN

The NTPC’s floppy motor electronics demand 5- and 12-V DC power supplies (see Figure 1). These supplies are placed on the stationary power board. The four-way rectified and filtered

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power of the 9-V AC adapter comes out at about 11 V RMS, with a 1-V_{pp} ripple that's a good enough 12 V to run the floppy's motor flawlessly. The 5 V are generated with the classic 7805 voltage regulator. The clock's electronics are powered from this 5-V source as well.

The power board also hosts jumper JP1 to select between the two speeds of the floppy motor (just for fun, 360 RPM is always the recommended speed). In addition, this is where the incoming wire from SW2 is connected. This switch is mounted on the face plastic of the floppy drive. It stops the motor for in-circuit firmware upgrade or test measurement purposes.

The nixie tube, as well as all of the clock electronics driving it, are placed on the spinning board, which is the circuit board mounted on the carousel. Capacitor C7 is responsible for removing slip ring noise from the power signals. The PIC16F84A microcontroller implements all of the clock's functions, including time keeping. The signals from the environment are received by inputs on port B. The firmware turns on the port's internal pull-up resistors. Port A provides the

one-digit BCD signal, plus a bit for driving the nixie's decimal point. The oscillator is formed by the microcontroller's internal circuitry and the external 19.6608-MHz quartz crystal X1.

This device is a clock (albeit quite eccentric, no pun intended), so it's a good idea to replace the crystal by a temperature-compensated crystal oscillator (TCXO), whose frequency tolerance and stability are only a few PPM (10 to 100 times better than naked crystals, but for a heftier price). The TCXO's output is connected to the microcontroller's OSC1/CLKIN input.

The 74141 TTL chip is responsible for converting the BCD-encoded digit information to nixie-edible decoded signals. Functionally, this IC is an ordinary active low BCD-to-10 decoder. However, a closer look at the datasheet reveals that the outputs are open collector (i.e., the inactive outputs are high-impedance), and this is still not the entire story.

What's so special about the 74141 is that its output drivers are able to withstand high voltages appearing on the inactive outputs. That would make ordinary TTL outputs malfunction

or burn out permanently. In fact, the 74141 was specifically designed to drive cold cathode tubes, which rendered the chips obsolete as soon as nixies themselves became obsolete. As a result, this part is no longer available through conventional channels. Fortunately, the special vendors who carry nixies often have inventories for this chip as well, and they also turn up regularly on Internet-based auction sites, especially the IC's Russian equivalent, which is more proof that the Cold War is really over.

The NTPC firmware also uses the nixie's decimal point, but the 74141 does not drive its cathode. But don't even think about connecting it directly to the PIC16F84A's RA4 pin! Coincidentally, this output is also an open collector (more exactly, an open drain); however, it does not possess the 74141's high voltage tolerance. Therefore, the decimal point must be controlled by a suitable transistor, such as the popular MPSA42, or the ZTX458 used in this circuit.

HIGH VOLTAGE SIDE

The price to pay for the warm neon glow that drives nixie enthusiasts crazy is the burden of generating the high voltage that drives the nixie itself. Let's focus on the requirements and possible solutions.

Like most nixies, the CD72P requires a 170-V ionization voltage to turn on the cathodes quickly and reliably. Once ionization has gained full momentum, a smaller voltage called the sustaining voltage is sufficient to keep the nixie lit. The recommended operating current for the CD72P is 2 mA. At that current, the voltage drop on the tube is about 130 V.

High DC voltage generation in a DC-powered circuit

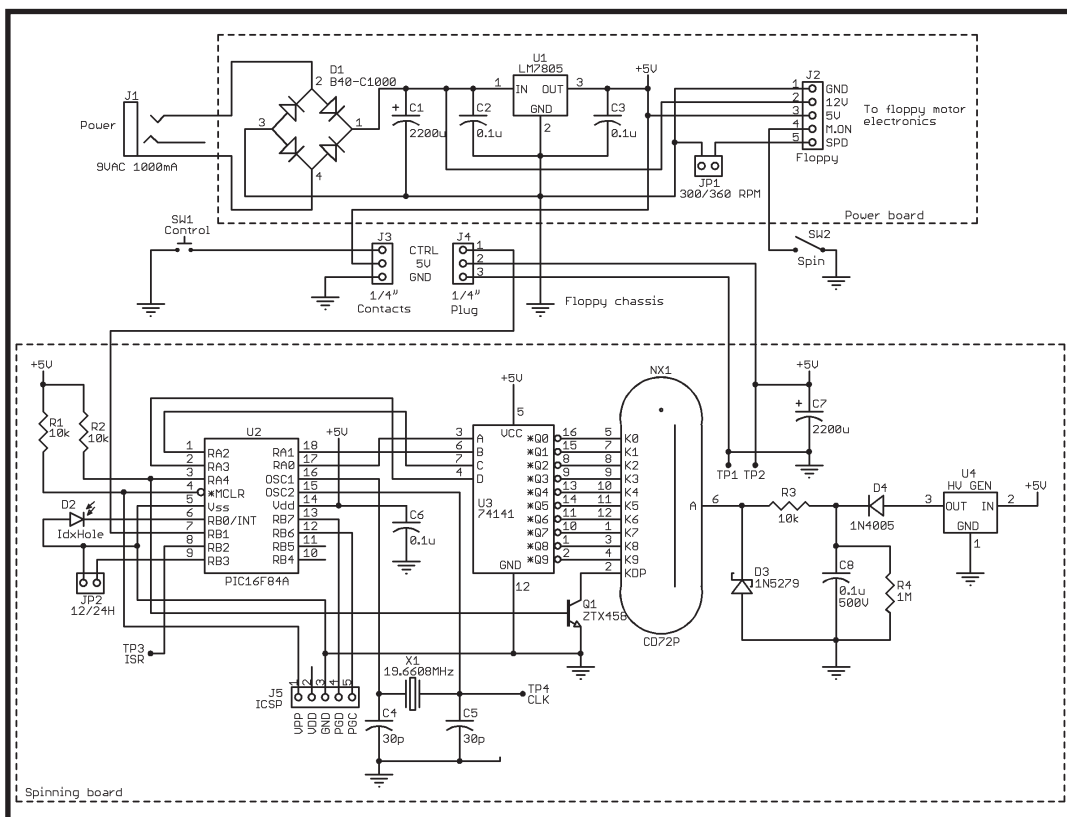


Figure 1—The clock features two circuit boards. The components hosted by the boards are clearly identified.

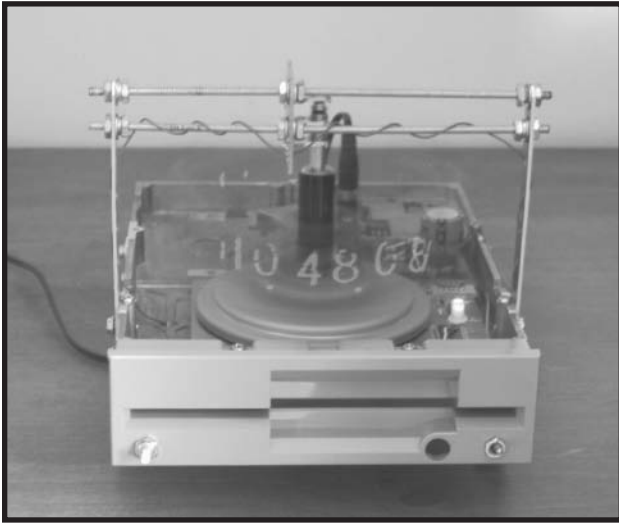


Photo 4—Notice one of the best-kept secrets in the digital camera industry: the near-infrared radiation of the LED shows up as a white glow with a slight bluish hue.

requires a DC/DC converter. A popular genre of circuits is a Switching mode power supply that uses a single coil as the precipitator of high voltages. These are typically based on specialized chips, such as Maxim's MAX771; however, I've read about a similar circuit that uses a plain 555 timer.^[1] Regardless of the details, these circuits often have arcane traps, such as sensitivity to board layout. A search on the Internet for "nixie power supply" reveals kits and circuits that offer an easier alternative.

I followed yet another simple approach for the NTPC. Most small, battery-operated fluorescent lights available in hardware stores contain a simple circuit to produce the high voltage necessary for operation. Luckily, the circuit taken from one of these lamps also turned out to be suitable for squeezing out the juice for one nixie tube.

I didn't include the schematic for the reverse-engineered circuit in this article. Suffice it to say that it implements a relaxation oscillator connected to a transformer. When the relaxation oscillator "pops," a pulse of up to 400 V is induced on the transformer's secondary coil. Let's define this pulse as a positive voltage. In the remainder of the cycle, an almost flat curve occurs between -50 and -100 V. The pulses are caught with D4 and C8, and the desired high voltage is now available. R3 sets the nixie's cur-

rent to 2 mA. (R4 is the so-called bleeder resistor that makes sure that after power-down, the high voltage is removed from the capacitor.) This DC/DC converter is not very efficient (about 40% at a 2-mA output), and it is only capable of producing 2.5 mA before the voltage on its loaded output drops below 130 V. However, it can easily drive multiplexed displays (including the "spatially multiplexed"

propeller display).

The role of D3 (a 180-V Zener diode) may require some explanation. When none of the nixie digits are on, the converter's load-free output voltage jumps to the sky. This alone would not be a problem. However, due to the protective 70-V Zener diodes inside the 74141 between the outputs and ground, there is now a high enough voltage between the nixie's anode and all of the cathodes for ionization currents to start trickling, and the cathodes become immersed in an eerie, smudged orange haze. This phenomenon is referred to as ghosting, which is a consequence of the unregulated high-voltage supply. The 180-V Zener caps the nixie's anode voltage, busting the ghost problem once and for all.

Just a word of caution before carrying on: even though the high voltage converter can only output low currents, all safety precautions must be made to avoid any sort of accident!

FIRMWARE DESIGN

I developed the NTPC's firmware entirely in the microcontroller's assembly language. With the price of microcontrollers constantly dropping, you may wonder why I didn't choose a more powerful device and program it in a high-level language like C. However, you should realize that when mass-producing millions of copies of an item, even cutting the cost of components by a few cents can result in a

great savings. This is an incentive to use parts whose features are the most suitable for a given problem. Assembly also provides an easier grip on execution timing, which is essential for this project. Therefore, the PIC16F84A was an ideal choice in all regards.

The NTPC displays the time and date along the nixie's entire circular path, with two selectable modes. Scrolling mode is used when the printout is scrolling clockwise a couple of times per minute. Stationary mode is used when the time and date are swapped between the front and back of the display every 2 s. The latter requires an "index hole" on the NTPC circuitry, signaling the position where printout needs to begin. (Therefore, this index hole is somewhat related to those found on floppy disks.) The necessary infrared LED and photodiode were reused from the drive. The LED with the white plastic enclosure (now turned up and glued to the top of the motor control IC) can be seen in Photo 2. (Ironically, however, this LED was part of the drive's Write Enable notch detection. The actual index hole LED is still shining away on the bottom of the clock.)

The real challenge in the firmware development arose from the need to properly handle four real-time events: the passing of 1 s, the press of the clock's Control button, the moments when the display needs to change (according to the position of the rotating carousel), and finally, the index hole with the photodiode passing over the LED. These events are mostly independent, but some of them are correlated.

The first two events are handled by periodic interrupt calls, a familiar method present in virtually all embedded systems. In the PIC16F84A, the wrap-around of the 8-bit counter called Timer0 (actually, the only timer module) triggers this interrupt. In the NTPC, the Timer0 module is configured so that its interrupt hits exactly 75 times per second. Therefore, the corresponding interrupt service routine (ISR) has an easy job, determining when 1 s has passed by maintaining a 1-byte count variable. This ISR is also suitable for handling the Control button. Its period is much longer than the

button's sub-millisecond mechanical bounces, but it's much shorter than the minimum human reaction time of about 100 ms. A state machine in the ISR determines the length of button presses and differentiates between two button events (Short and Long) for the purpose of setting the clock.

The background code is responsible for generating the propeller display by tracking the turn of the carousel using carefully crafted code execution delays. This routine must run in the background because the display is being generated "around the clock," no pun intended, so this functionality hogging an ISR would bring everything else to a grinding halt. The implementation uses $\pi/1,000$ (called point) as the atomic unit of angle measurement. Its heart and soul is the `PtDelay` subroutine that provides delays equivalent to the desired points of carousel motion. Values directly related to physical quantities are the angle for which a nixie digit is turned on and the largest angle taken up by a digit. The former (`CDIGLTP`) is an empirical value that's set as the optimum between the digit's appearance being too faint versus too smudged. The latter (`CDIGWP`) was determined from the following formula:

$$\alpha = 2 \arctan \frac{w_{DIG}}{2r_{MIN}} \times \frac{1,000}{\pi}$$

where w_{DIG} is the width of the digits. r_{MIN} is the distance of the nixie's deepest digit from the rotation axis (both measured in the same unit). All other angles specify the propeller display's layout.

The only fly in this ointment is that the background process is constantly being disturbed by the `Timer0` interrupts, threatening to compromise all timing efforts. Fortunately, however, the execution time of the `Timer0` ISR is very short. It is way within the tolerance of delay accuracy, above which humans would perceive the resulting display as distorted or herky-jerky.

The last outstanding event is the passing of the index hole. The first idea that comes to mind is to make the index hole's photodiode trigger an external interrupt (or at least a silent interrupt, where the interrupt itself is

disabled, but its flag is set by the microcontroller's hardware for future polling). However, measurements showed that the LED illuminates the photodiode for about 5 ms, which is two orders of magnitude longer than the ISR's worst-case execution time. Furthermore, a new index hole event never occurs before the current revolution's printout has been completed. Therefore, the index hole can be detected from the background code, simply by sampling the port input directly. (Here I leveraged the correlation between carousel rotation and index hole transit and was rewarded with simple code.)

THE WORLD'S FIRST

Creating my nixie tube propeller clock was a tremendous amount of fun. The display is not quite bright enough to be easily visible in broad daylight; however, in dim areas and at night, it offers a mesmerizing view (see Photo 4). It is also a great conversational topic.

While the firmware's resource requirements are generally well within the PIC16F84A's capabilities, the microcontroller's eight-entry-deep hardware stack was definitely a bottleneck. The length of the deepest subroutine call chain in the background code and in the ISR combined must not exceed seven. (Remember that the ISR itself is also a subroutine call.) Due to this limitation, the ISR code's `DayRoll` subroutine needed to be "de-subrutinized." (Fortunately, it was possible because the routine was called only once and was separated only for clarity.) Stack overflows are terrible bugs because they are random in nature, which makes them very hard to diagnose, and can cause a total system crash. They often remain hidden during testing and wreak total havoc out in the field. For this reason, a careful "call count" before the product release is crucially important.

Implementing the motor itself, the slip ring, and the DC/DC converter with off-the-shelf components can improve the NTPC's design. Taking AC to the spinning board makes high-voltage generation easier. In addition, the high-accuracy 60-Hz timebase of the power grid can be used (although

it may not be trivial, due to slip ring noise). Ultimately, the most elegant (but also most advanced) solution would be to power the spinning board through inductive coupling, thus eliminating all rubbing components from the design. As for the firmware, the time and date format selection could be implemented as EEPROM-stored software options. While the former could be added with little effort, the latter would require significant changes in the code. 📦

Peter Cszaszar (csaszar@ltu.edu) is an assistant professor of electrical engineering at Lawrence Technological University in Southfield, MI. Prior to his academic appointment, he worked for Motorola as a software engineer. His areas of interest include hardware and software design for embedded systems, which he pursues as a consultant in projects with Fortune 500 companies. In academia, Peter's primary goal is to make a new generation of students fall in love with the engineering profession. For more information about Peter's NTPC, visit www.nixiana.com.

PROJECT FILES

To download code, go to ftp://ftp.circuitcellar.com/pub/Circuit_Cellar/2007/199.

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Build a Reflow Oven Controller

If you're having trouble soldering small chips, try reflow soldering. Ko and Kashif explain how to design a reflow soldering oven that won't burn a hole in your wallet.

When we were designing a small microcontroller board for the biorobotics laboratory at Cornell University, the difficulties associated with component population were often brought up in our meetings. Because of the physical size constraints associated with a PCB, we ended up using ball-grid arrays, small-pitch quad flat packs, and small-outline packages that have ground pads on the bottom of the chip. Just how could we solder these chips? With conventional soldering tools, we were able to solder chips that had pitch sizes as small as 1 mm. But a 0.5-mm pitch on the new board's microcontroller gave us a serious scare.

Reflow soldering is a viable soldering method for small-package chips. A precise board stencil is used to lay solder paste precisely on the component lands. The components are carefully placed on the lands with solder paste and then "cooked" in a reflow soldering oven or with a reflow heat gun. Unfortunately, professional reflow ovens cost thousands of dollars, and the university did not own one at the time. There are many online tutorials that explain reflow soldering with a toaster oven (even with a skillet), but a consensus was reached in our lab that we needed something more reliable because all of the components that go on each board cost more than \$200.

We took the final project requirement for the EE476 microcontroller class at Cornell as an opportunity to design a reflow controller for conventional toaster ovens. The project consisted mainly of a solid-state relay controller, an Atmel ATmega32 microcontroller, and a graphical LCD

that provided a GUI.

The system is easy to use. You can program a time-based temperature target profile. The controller uses a modified proportional-derivative control to appropriately change the duty cycle of the 1-Hz PWM signal to the solid state relay's control input. The solution is relatively inexpensive in comparison to buying a professional reflow oven, and the intuitive GUI walks you through the soldering process.

The system, which also fulfills the appropriate safety requirements, can abort the process in the event of a mishap. Photo 1a shows the entire system, which features a toaster, relay box, LCD, and the microcontroller board. Photo 1b shows the graphical LCD and the target temperature profile.

HIGH-LEVEL DESIGN

The system is divided into three parts: an LCD, an oven control, and a temperature sensor inside the oven. Figure 1 shows the system's logical structure.

The ATmega32 microcontroller sends a digital signal to the solid-state relay, which controls the on/off state of the oven for appropriate heating and cooling. The temperature sensor inside the oven makes a voltage divider circuit in series with a resistor, and the analog voltage signal is connected to the ATmega32's ADC. The ADC's output is used as feedback by the program to measure temperature inside the oven and to control the relay state. At the same time, the state of the system is updated in real time on the LCD so you can see the progress.

The keypad is used for input, and

the LCD provides step-by-step instructions for the input process. The oven control hardware, which includes the relay switch, is safely contained inside a metal box. It has three pin plug connections for connecting the oven and the AC voltage supply. It also has female banana plugs for connecting the digital input of the relay to the microcontroller's output pins.

HARDWARE SPECIFICS

We soldered the ATmega32 on the custom prototype board provided for the ECE476 course. We programmed it with an Atmel STK500 board.

The keypad is a standard 16-key, eight-pin model. Connected to port C, it's software debounced. We used a 128 × 64 pixel Crystalfontz CFAG12864B-WGH-N graphical LCD. It has a 20-pin interface with a 5-V requirement for logic and a 9-V requirement for the LCD. The LCD is soldered on a prototype board along with the keypad. It is connected to port B and port D (six pins out of eight) on the ATmega32. Both ports are used as output to provide the necessary signals to the LCD for the control.

The LCD unit, which includes two KS0108B controllers, is divided into two columns of 64 × 64 pixels with a column SELECT pin to switch between the two columns. Each column is further divided into eight pages. Each page consists of eight rows of 64 pixels each. The LCD RAM that corresponds to 128 × 64 pixels or 1 KB is addressed in a way that all eight rows belonging to the same column—the y axis, not to be confused with the two aforementioned columns—in a

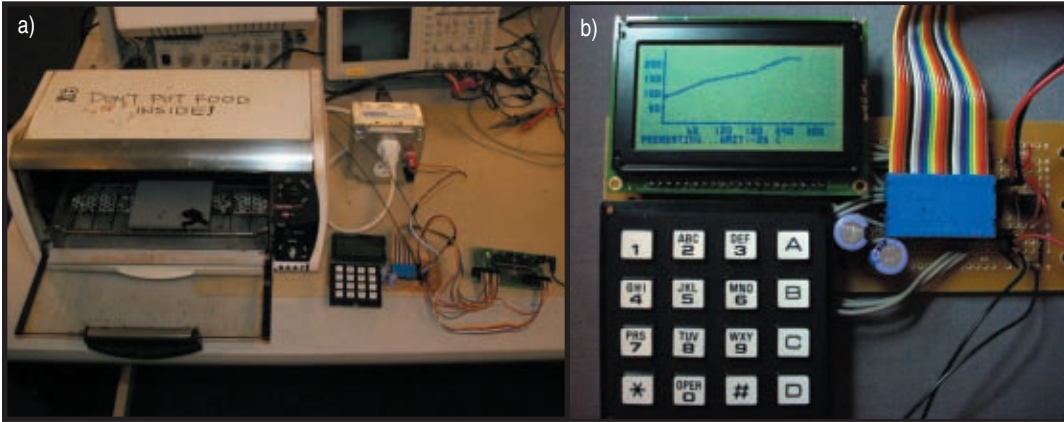


Photo 1a—The reflow oven controller system includes a toaster (left), relay box (top right), LCD (bottom middle), and a microcontroller board (bottom right). **b**—We used a Crystallontz CFAG12864B-WGH-N graphical LCD. Check out the target profile.

into the box. The signal for the solid state relay switch was given through PORTD[5] via the prototype board.

The system includes a BC Components 2322-633-83303 negative temperature coefficient (NTC) thermistor with a temperature range from -40°C to 300°C . The device was placed inside the oven and connected to the voltage-divider circuit on the prototype board.

page can be read or written at a time. The pixels are set on logic high and cleared on low. The entire LCD RAM could be updated on the order of milliseconds, which means that the LCD interaction could be easily done in real time. The LCD was powered through a voltage divider circuit using the Maxim ICL7660CPA reverse-voltage generator, which is also soldered on the prototype board.

Omron Electronics was generous enough to provide a solid-state relay for our project. The relay has the maximum rating of 75 A at 24 to 240 AC, which is more than enough for a normal toaster oven. We placed the relay switch in a heatsink metal box with three pin plug connectors mounted inside to connect the toaster oven and the AC power supply. The digital input was connected via harness plugs drilled

We connected the thermistor in series with a 2-k Ω resistor. This voltage divider circuit was connected on one end to ground and another end to the LM711 op-amp output, which was configured in a voltage-follower on the V_{CC} signal. The variable voltage output between the thermistor and the fixed resistor is fed to the ATmega32 via pin A0 that goes into the ADC on the chip.



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The entire system is shown in Figure 2. Note that the ICL7660 boost chip satisfies the 9-V requirement of the LCD unit from a single 5-V power supply. If you encounter a problem when rewriting the ATmega32's program flash memory, we recommend temporarily disconnecting the LCD unit during the memory rewrite.

SOFTWARE DESIGN

The software design is divided into three main categories: LCD functionali-

ty, system control flow, and PID control. Let's take a look at each category.

LCD functionality is one of the system's most important features because all of the interaction between the user and the soldering system is performed via the LCD. The main function for the LCD is the `setpixelxy()` procedure that takes in three arguments: row, column, and a flag value. The flag determines if the pixel at the specified row (0-63 vertically) and column (0-127 horizontally) is set (with one)

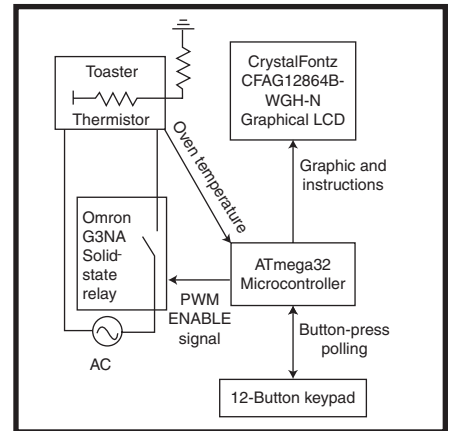


Figure 1—Take a look at the high-level system. It features an LCD, an oven control, and a temperature sensor.

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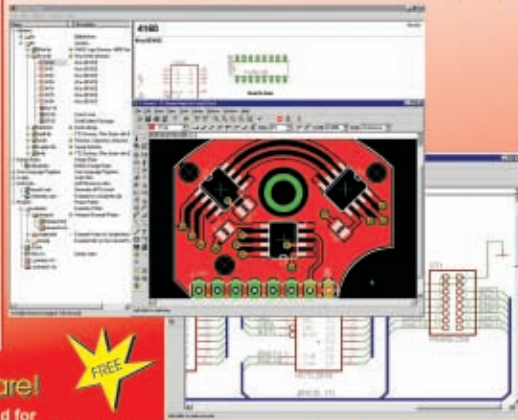
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or cleared (with zero). The driver on the LCD unit doesn't allow a single pixel to be written. It allows only a byte to be written in the corresponding page. For this reason, the LCD RAM has to be read first and the pixel position in that byte has to be updated with the new setting.

To go around the read-and-write issue in manipulating single pixels, an LCD buffer of the same size as the RAM (1 KB) was created in the ATmega32's EEPROM memory. This buffer in the software was used as virtual RAM for the LCD, which was updated and read whenever the display was updated.

The next step was to implement alphanumeric characters for displaying data. Bitmaps were created for characters from 0-Z and for some special characters like space, period, and hyphen. These bitmaps are displayed on the LCD using wrappers like `putbyte()` and `putchars()`, which set the corresponding pixels. Another function was the `drawline()` function, which takes in four parameters (x1, y1, x2, and y2) and draws a line between them.

Figure 3 shows how the display on the LCD is formatted. Much of the available area is dedicated for the graph. The instructions are displayed in the bottom six pixel rows.

The x-axis of the displayed graph is the time axis with a resolution of one pixel per 3 s. The y-axis shows the temperature in Celsius scale with one pixel corresponding to a 5°C change.

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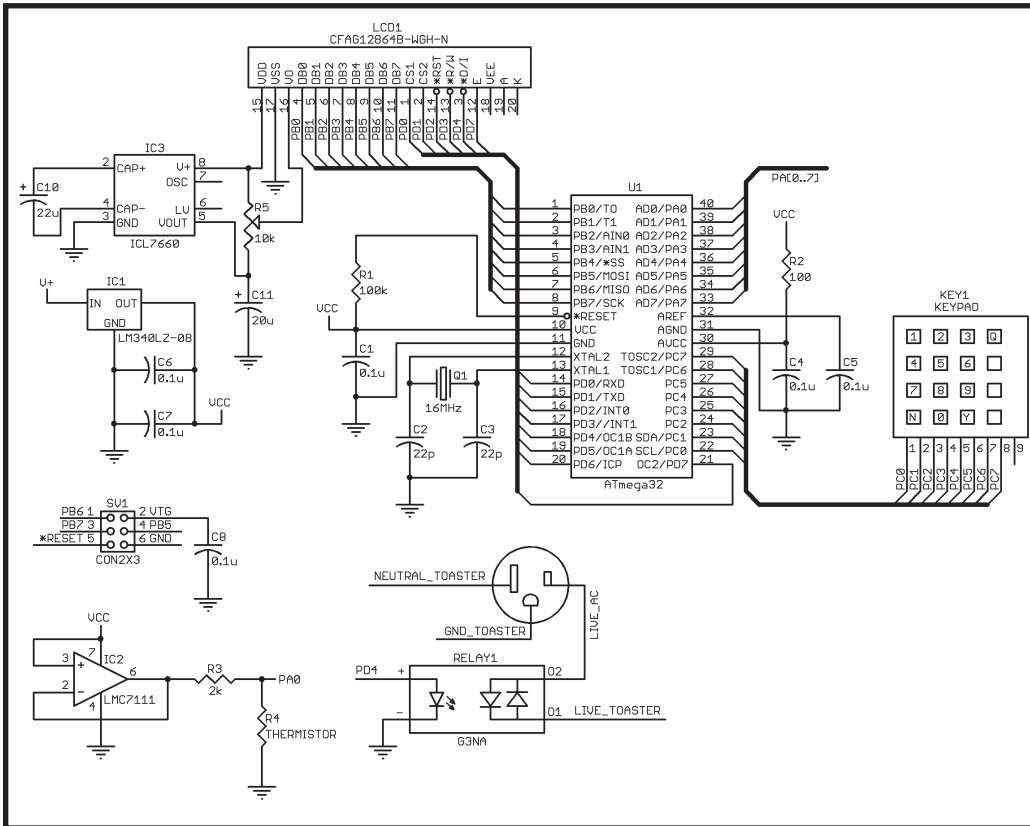


Figure 2—This is the reflow oven system. You could fit all of this into a prototyping board. But note that you should isolate the solid-state relay in a separate grounded box for your safety.

The bottom line is the area where the instruction and feedback is displayed. Each character is 5 × 4 pixels wide and is readable to the naked eye.

The maximum time for our system is set at 340 s, meaning that it can handle 340 temperature points and can run for approximately 3.5 s with a maximum temperature of 250°C. These limits were determined by analyzing a standard reflow curve. The user input is taken in an array of 340 elements, with the index corresponding to the time and the value corresponding to the temperature at that time. An interpolate() function was written that scans the array and linearly interpolates the empty slots between target points.

The LCD has several

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other functions. `clear()` clears the display. `drawgraph()` draws the target curve. `cleargraph()` clears the target curve but marks target points at 30-s intervals for comparison with the actual curve updated every second as reflow continues.

CONTROL FLOW

The main function of the program calls the `initialize()` routine, which sets up the LCD, sets up the various registers for timer interrupts and ADC, sets up the ports, and prompts you for input via the LCD. The main function then loops infinitely, calling the `keyscan()` function every 30 ms for user input on the keypad and the `heat()` function every second. It also tells the reflow soldering system to follow the programmed time-temperature profile.

The program starts in Default mode, which is a preprogrammed mode with a standard target temperature profile programmed from the manufacture-recommended profile (see Figure 4). At this time, a message is printed on the LCD that asks if you want to use the default temperature profile. If you want to use the default curve, you can press the Yes button. At input, the `keyscan` code would call the button handler that implements part of the state machine for the system. The system would go into the Preheat mode and the default curve would be displayed. The `heat` function, which implements the rest of the state machine, would notice the mode set to Preheat and `PORTD[5]` would be set high to trigger the relay which in turn switches on the oven. This routine is called every second and converts the ADC output into temperature, using the calibration table hard-coded in the flash memory. The procedure keeps on polling the temperature until it reaches the desired starting temperature for time input 0.

When preheating is done, `cleargraph()` is called, the mode is set to Ready, and you are prompted to insert the part and press Yes. The mode is then set to reflow and the `heat()` routine calls the `pid()` routine, which implements the feedback control system to control the relay. At

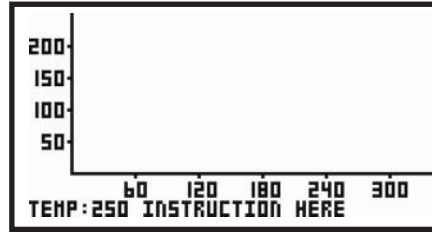


Figure 3—We were able to fit the graph on a rather cramped 128 × 64 pixel LCD.

the same time, the current state of the system is shown on the graph, which is updated every second.

Once the maximum time is reached, the oven control is disabled and the system is put into the cool-down mode. The system is allowed to cool until it reaches a safe temperature, the state is set to done, and you are prompted to remove the part and press Yes. The system is reinitialized in the “done” state and readied for the next task.

If you had chosen not to use the default mode, the system would have entered the `program2` state. This mode is for entering temperature input. It assumes that the first input is for time 0. You would enter the temperature desired and press Yes. This temperature is added to the input array, interpolated, and the target curve is updated.

The next state is `program3`, where you’re asked for further input. If yes, you’re taken into `program1`, where you can enter the time for the next temperature input. From `program1`, you are taken into `program2`, which takes in temperature for the last time and goes into `program3`. This contin-

ues until you press No (the asterisk key) in `program3`. The mode is then changed to preheat to start the reflow mechanism as described above. You can press the Abort key (the A key) to stop the procedure. Abort mode disables the control and takes the system into cool-down mode.

THERMISTOR CALIBRATION

We took the resistance versus temperature data from the BC 2322-633-83303 thermistor datasheet and converted all of the resistance values into corresponding analog voltage when the thermistor was placed in a two-resistor voltage divider circuit with a 2-kΩ resistor. The voltage versus temperature information was curve-fitted in Microsoft Excel by a five-order polynomial fit. The temperature equation was estimated to be:

$$\text{temperature} = -1.33722V^5 + 17.067V^4 - 80.523V^3 + 182.7V^2 + 235.79V + 272$$

Using this equation, the corresponding temperature to analog-to-digital converted count values between 0 and 1,023 were calculated and stored in the ATmega’s flash memory (see Figure 5).

CONTROL ALGORITHM

The bang-bang control in Reflow mode failed to follow the curve accurately, so a sophisticated control algorithm was necessary. To control the toaster oven, we decided to use a modified proportional-derivative control algorithm that we dubbed the “PDF” algorithm. Because the time-based temperature target and the most

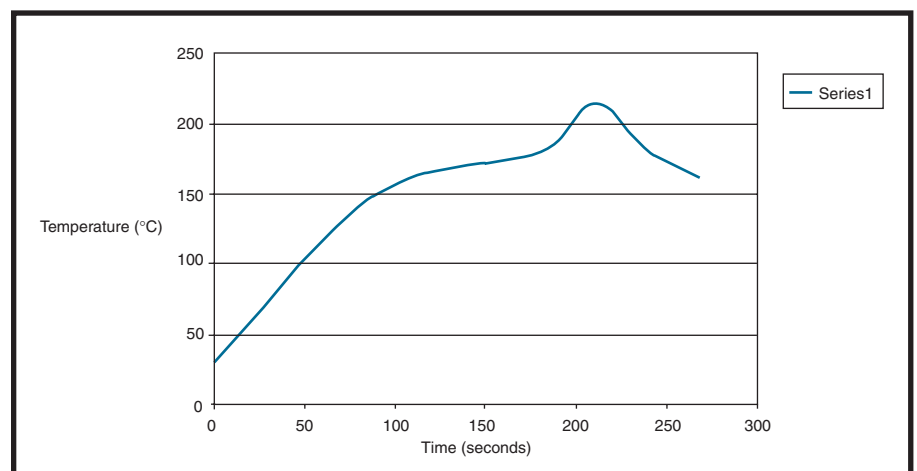


Figure 4—This is the recommended temperature profile for Kester solder paste.

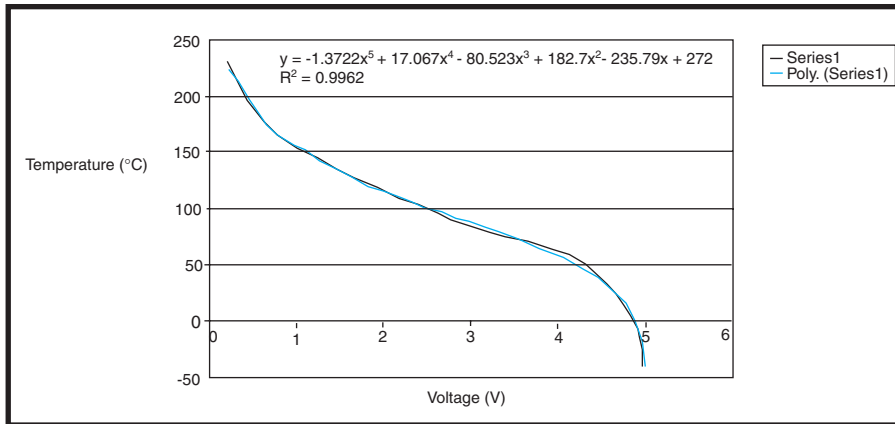


Figure 5—The curve-fitted data is for the NTC thermistor voltage-divider circuit.

recent $\partial(\text{time})/\partial t$ slope is known, we can estimate the future errors by extrapolating the two most recently measured temperatures. Our PWM signal was configured to have a constant period of 1 s, with a variable duty cycle calculated from our PDF algorithm (see Figure 6).

COOLING OFF

We are satisfied with our system's performance, but one of the problems


we faced was cooling the system. If the future target points show a decrease in temperature at a steep gradient, then the actual curve would be slightly off. This is due to the thermal inertia of the oven. The heating coil retains the heat for a while, even though the oven is off. This introduces much natural damping, and causes a slower decay in temperature. Similarly, a steep rise in temperature is also not readily achievable due to the heating

limitation of the toaster oven.

We plan to add a cooling system. We can add fans that are triggered if the current temperature is higher than the target temperature. Another idea is to use a fan to blow hot air in the oven instead of using the heating coil. This way the same blower can be used to heat and cool the system by changing the temperature of the air blown in. ☒

Authors' note: Solder paste is highly toxic and 115/230 VAC can be lethal. Prevent skin contact with solderpaste, and never place any consumables inside a reflow oven. Take all measures to prevent the risk of electrocution.

Ko Ihara (kihara@gmail.com) earned a B.S. in Engineering at Harvey Mudd College and a Master's in Electrical and Computer Engineering at Cornell University. He is now an aspiring ASIC engineer at a chip company in Santa Clara, CA. In his spare time, Ko continues to dabble in random micro-



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$$Duty[n + 1] = K_p \times proportional[n] + K_D \times derivative[n] + K_f \times future\ integral[n],$$

where

$$proportional[n] = target[n] - temp[n]$$

$$derivative[n] = proportional[n] - proportional[n - 1]$$

$$future\ integral[n] = \sum_{i=1}^{SIZE} \frac{SIZE - i}{SIZE} [target[n + i] - (temp[n] + i(temp[n] - temp[n - 1]))]$$

Figure 6—The last (SIZE-i)/SIZE is for the linear deemphasis of the future error estimation. More emphasis is placed on the error estimation in the near future.

controller-based projects.

Kashif Javed (kj49@cornell.edu) earned a Bachelor's degree in Computer Science from Lahore University of Management Sciences (LUMS). Prior to receiving a Fulbright scholarship (U.S.), he worked as a research assistant in the Computer Vision lab at LUMS. He is currently working towards a Master's degree in Computer Science at Cornell University.

PROJECT FILES

To download code, go to ftp://ftp.circuitcellar.com/pub/Circuit_Cellar/2007/199.

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Crystalfontz America, Inc
www.crystalfontz.com

R276 Solder paste
Kester
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For many applications, especially mobile and robotics designs, it would be useful to be able to update the CPU's firmware remotely, without having to disassemble and reassemble the device and its physical connection to the CPU. This would save you a lot of time during the development stage of the design process. Such functionality would also be useful when you are working with an ARM microcontroller operating in a potentially dangerous environment. Finally, note that this kind of functionality can be very useful for field firmware updates, especially when you don't want the end user to have to disassemble your device.

In this article, I'll describe a few simple ways to perform a remote firmware update with an Atmel AT91SAM7S ARM-based microcontroller. I used an AT91SAM7S-EK evaluation board for this project. Atmel offers a free SAM-BA software utility for programming the CPU over a serial channel.

APPLICABLE METHODS

An ARM CPU can decode and run firmware code from flash memory, just like every other microcontroller. In addition, it has the ability to decode and run the code from RAM. This means that you can place your code in the RAM and run it from there. During firmware execution, the flash memory will remain untouchable. If the flash memory is untouchable, it means that you can potentially modify the flash memory on the fly without any collision with firmware that's already running from RAM.

The next logical steps are to create

the firmware utility that is running from RAM in order to control communication with the PC over a regular serial channel, get new data from the PC, and write the data to flash memory. To achieve this functionality and establish communication with the PC, the target ARM CPU has to initiate the loading and running of its own firmware (usually referred to as the bootloader).

In the AT91SAM7, the bootloader is in hidden ROM, where it's invisible under normal conditions. In order to switch the boot sequence to the bootloader, the ARM SAM7 CPU has a special TST pin. "TST" is the abbreviation for TEST SELECT pin. (Refer to the SAM7 CPU's datasheet). When you apply V_{CC} for 10 s to the TST pin, the CPU copies the bootloader firmware from ROM to CPU RAM. Why is it so slow? At that time, the CPU is running on a 32-kHz crystal to ensure the proper timing because the frequency of the external crystal is unknown. The bootloader inside the ARM CPU and the SAM-BA application on the PC must run at the same time and communicate with each other using an x-modem predefined protocol. During this communication, the new data for the flash memory is transferred from the PC to the ARM CPU.

While this idea seems fine, it has a disadvantage. The ARM CPU doesn't know when you've designed a firmware update and if you're running the SAM-BA software utility on your PC.

The Standard RS-232 channel does not have a spare wire to signal the ARM CPU that it is time to initiate the firmware update mode. This means

the PC can't tell the ARM CPU that it is time to run the bootloader. Thus, you must do it manually. You must apply V_{CC} to the TST pin for 10 s. After this, the CPU will copy the bootloader firmware from hidden ROM to RAM and run it from the RAM.

SEQUENCE OF ACTION

Let's consider a typical sequence of actions for updating the firmware on the Atmel ARM CPU, following the traditional method. First, manually apply V_{CC} to the TST pin. Then you must wait 10 s and release V_{CC} from the TST pin. (The first three steps will copy the bootloader to the RAM.) Following this, run SAM-BA on the PC, update firmware, and press the Reset button on the CPU board. Finally, exit and run new code.

As you can see, you can control the entire process for firmware updates from the PC via the serial channel (that means remotely and potentially wirelessly), except for manipulation of the TST and RESET pins on the targeted ARM CPU. In order to resolve this problem, I added a low-cost ATmega88 microcontroller to my AT91SAM7S evaluation board, which has a small prototyping area (see Photo 1). To make this modification, I had to connect three pins (UART Rx, TST, and RESET) from the ATmega88 to the evaluation board (see Figure 1). The ATmega88 also requires power (from the evaluation board) and a crystal (7.37 MHz).

ATmega88 & CODE

Although I used an ATmega88 (I had a few of them on my shelf), you can use any CPU in the AVR family with



Photo 1—I modified the AT91SAM7-EK board. I placed the Xbee radio module and the ATmega88 in the DIP package in the prototyping area.

an on-board UART. The ATmega88 operates in spy mode. It just listens to incoming data traffic and looks for particular data sequences. When particular predefined sequences appear in the seri-

al channel, the ATmega88 sets to logical one or logical zero for the TST and RESET pins on the AT91SAM7.

Listing 1 is a portion of the actual source code for the ATmega88 micro-

controller. I also created my own ComWrite software utility for the PC. It can transmit predefined bytes with predefined pauses between them to assemble the control data sequences and transmit them to the assigned serial channel. For example, you can send a single byte to the serial channel, keep silent for 200 ms, send another byte, keep silent for 300 ms, and so on. In this manner, you can generate unique sequences and avoid the collisions between regular datagrams and control data. The ComWrite software utility has a text format configuration file that enables you to assign any control bytes and define the pause time between them with an accuracy of 10 ms.


In the C source code for the ATmega88, you can assign the sequences that match your ComWrite configuration file sequences. You can then set the ATmega88 to look for pre-assigned sequences of bytes and particular pause lengths between them.

To control the RESET pin on the evaluation board, you must send data to serial

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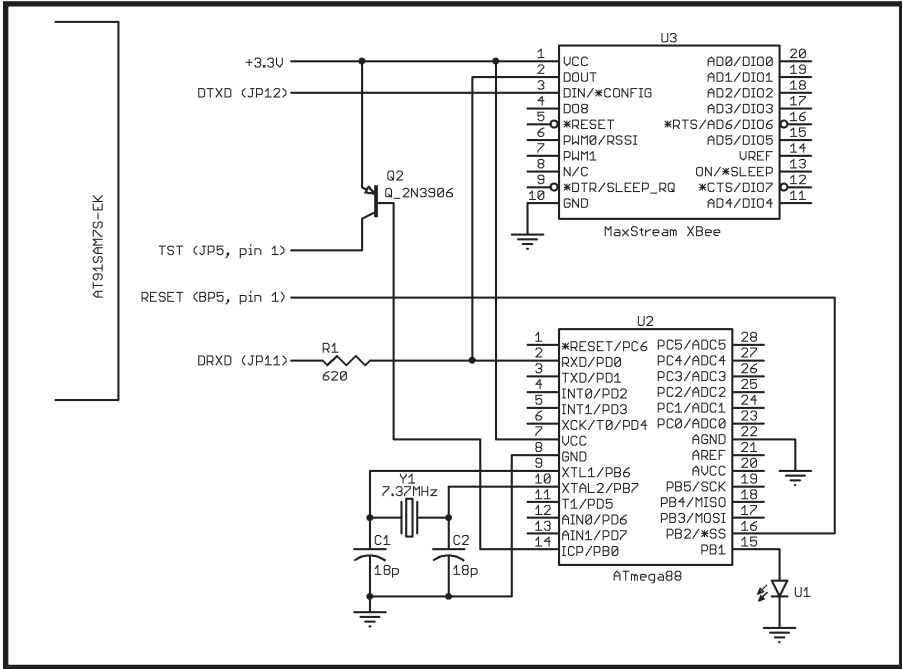


Figure 1—How do you like my modifications? I needed only six wires for the connection: 3.3 V, GND, TST, RESET, DTXD, and DRXD. This modification enables me to use the radio module for the ZigBee application and for a wireless firmware update.

channel 0x01. Do not send any data for 100 ms. Send 0x04. Do not send any data for 100 ms, and then send 0x44. The probability that any random datagram on the serial channel will correlate with such sequences is very low.

The algorithm for cooperation between the ComWrite software utility for the PC and the ATmega88's firmware is really simple (see Figure 2). ComWrite generates data sequences and the ATmega88 decodes it.

You can assign particular sequences for ComWrite over text configuration files. The following is a sample of a configuration file for ComWrite to control the RESET pin:

```
.500
0x01
.100
0x04
.100
0x44
```

As you can see, the sequences on the PC and sequences on the ATmega88 match.

The result of the hardware modifications is that I can now update the firmware on my AT91SAM7S evaluation board without even touching the actual evaluation board. A sequence of

actions enables you to update the firmware for the AT91SAM7. First, run the ComWrite software utility to control TST pin. Next, run SAM-BA on the PC and update the firmware (SAM-BA version 1.9 was tested).

Finally, run the ComWrite software utility to control the RESET pin.

WIRELESS CONNECTION

The next logical step is to organize a wireless connection between the PC and the AT91SAM7S evaluation board. I used MaxStream's ZigBee development kit for the wireless link. One ZigBee module was connected to the PC's USB port through the MaxStream XBIB-U development board. Another XBee-Pro module was mounted on the AT91SAM7S evaluation board's prototyping area.

I tested the XBee-Pro module's firmware (revision 1094). Two modules were configured for Transparent mode. I can now update the firmware on my AT91SAM7S evaluation board wirelessly.

There are two other ways to implement this functionality. The XBee modules are configured with a Freescale microcontroller that controls an on-board radio chip. MaxStream provides the SDK toolkit for its XBee modules (for free) from the module information web page. These modules have some unused pins that can be programmed by the end user. Instead

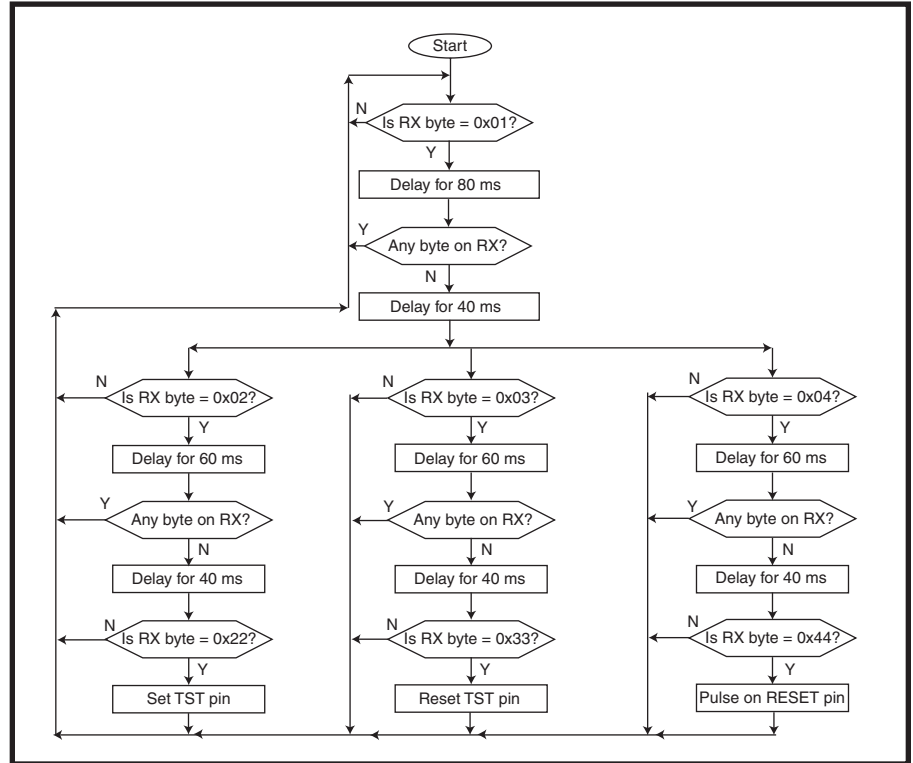
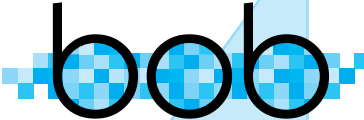


Figure 2—This is the algorithm for the ATmega88 firmware. The CPU is looking for control bytes and calculating the timing between control bytes.




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Listing 1—Take a look at the firmware for the ATmega88. You will need a WINAVR GCC compiler to compile the source code.

```

SIGNAL( SIG_USART_RECV )
{
  nVar = UDRO ;
  RX_INT_flag = 1 ;
}
int main(void)
{
  sei(); // enable global interrupts
  Init();
  On_LED(); Delay_mS (200) ; Off_LED(); Delay_mS (200) ;
  On_LED(); Delay_mS (200) ; Off_LED(); Delay_mS (200) ;
  On_LED(); Delay_mS (200) ; Off_LED(); Delay_mS (200) ;
  for (;;)
  {
    Off_LED(); // indication on LED
    while ( nVar != 0x01 ) ; // awaiting for datastream
    On_LED(); // indication on LED
    RX_INT_flag = 0 ;
    Delay_mS(80);
    if ( RX_INT_flag == 0 ) // to prove the silence in channel
    {
      Delay_mS(40);
      if ( nVar == 0x02 )
      {
        RX_INT_flag = 0 ;
        Delay_mS(60);
        if ( RX_INT_flag == 0 )// to prove the silence in channel
        {
          Delay_mS(40);
          if ( nVar == 0x22 )
          {
            On_LED() ; // indication on LED
            Set_Low_RESET(); Set_High_TST() ;
          }
        }
      }
    }
    else if ( nVar == 0x03 )
    {
      RX_INT_flag = 0 ;
      Delay_mS(60);
      if ( RX_INT_flag == 0 ) // to prove the silence in channel
      {
        Delay_mS(40);
        if ( nVar == 0x33 )
        {
          Off_LED() ; // indication on LED
          Set_Low_TST(); Set_High_RESET();
        }
      }
    }
    else if ( nVar == 0x04 )
    {
      RX_INT_flag = 0 ;
      Delay_mS(60);
      if ( RX_INT_flag == 0 ) // to prove the silence in channel
      {

```

(continued)

Listing 1—continued.

```
Delay_mS(40);
if ( nVar == 0x44)
{
    Set_Low_RESET(); Delay_1mS(); Set_High_RESET();
}
}
}
}
}
}
```

of adding on an AVR microcontroller for controlling the TST and RST pins, you can use the internal Freescale microcontroller on the XBee module. In this way, you can minimize your hardware expenses.

Your other option is to delegate the spy job to the main ARM CPU and implement wireless firmware update functionality without having to invest in an additional CPU. This method is advantageous, primarily because it won't cost you anything and you won't need additional PCB space for a separate CPU. But there are several disadvantages. First, your firmware will handle your main tasks and analyze the incoming serial datastream at the same time in Multitasking mode. This is possible only if you have enough CPU resources to share.

Another disadvantage is based on the assumption that your firmware is debugged and doesn't include any mistakes (which is not always true). For example, if your CPU decodes at address A a command to jump to address B. And if at address B you have a command to jump to address A, you will have an infinite loop. The CPU will be in a condition of an infinite loop and you will not have any tools to exit it. Theoretically, you can avoid this situation with a watchdog timer, but the period of the watchdog timer also needs adjustments. How will you adjust the watchdog timer period if the CPU will not respond?

Another disadvantage associated with this method is that you must create your own bootloader and software utilities for the PC just like SAM-BA. Therefore, I recommend delegating the spy job to another low-cost CPU. In this case, you will be able to repeat the

programming procedure, under any condition of the ARM CPU, because the programming control tool is located on another CPU and was untouched during the ARM firmware update.

REMOTE ACCESS

The ComWrite utility for the PC and its source code, which can generate serial control data sequences, is posted on the *Circuit Cellar* FTP site. You can use the C source code for the ATmega88 in order to decode the sequences.

I hope this article will help you determine which method will work for you. Now it's your turn to update your firmware remotely. ☒

Alex Deyneko (adeyneko@yahoo.com) lives in Vancouver, BC, and provides hardware and software consulting services to many companies in British Columbia and Washington State, primarily in electronics product design and embedded systems. To e-mail Alex, type "Circuit Cellar" in the subject line to get past the spam filter.

PROJECT FILES

To download code, go to ftp://ftp.circuitcellar.com/pub/Circuit_Cellar/2007/199.

SOURCES

ATmega88 and AT91SAM7 Microcontrollers

Atmel Corp.
www.atmel.com

XBIB-R Module

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You can't do much to improve battery design. You can, however, do your best to understand their chemistry, how they work, and how they behave under various loads. Ed focuses on the discharge portion of the battery cycle.

We devote rapt attention to the circuitry and software in electronic devices, because that's the "fun stuff" we enjoy working with. Unfortunately, batteries form the weak link in most gizmos: without batteries, nothing else works! Even with the best batteries inside, the device's run time, performance, and cost may not reach your expectations.

While we can't do much to improve battery design, we can make the best of what's available. That often requires looking beyond the facts that everyone knows to find the truth of the matter, so I'll take a detailed look at the sometimes surprising performance of common batteries. I'll concentrate on the discharge part of the battery cycle in this column and save charging for the April issue.

ALKALINE AA: THE BASICS

Alkaline AA cells are the ones everybody loves to hate, because they're good enough and cheap enough to make everything else look bad. Indeed, a device powered by AA alkaline cells can run on power bought in any open-air, dirt-floor market in the world. Try to find a fancy lithium-ion photo battery in the same place, let alone compatible AC for your recharger, and you'll get the message.

Figure 1 shows the discharge curves for four brand-name alkaline cells from the same lot. The graph shows the relation between the cell voltage (on the vertical axis) and the cumulative energy drawn from it (on the

horizontal axis).

For example, the top curve shows that a 100-mA load will initially see about 1.6 V, which then stabilizes around 1.1 V during the middle of the curve and then drops abruptly after the battery has delivered about 2.2 A·h. The test ended at 0.4 V after 2.5 A·h.

The horizontal axis uses ampere-hour units, rather than time, to simplify energy comparisons. My battery tester applies a constant-current load and records the voltage as a function of the elapsed time in seconds, so the conversion is:

$$\text{A}\cdot\text{h} = \frac{\text{amperes} \times \text{seconds}}{3,600}$$

Converting units in the other direction is equally easy: a cell that delivers 2.5 A·h at 100 mA lasts for:

$$25 \text{ h} = \frac{2.5 \text{ A}\cdot\text{h}}{0.1 \text{ A}}$$

That's 90 kiloseconds, if you prefer hard metric units, and should give some indication why I don't present discharge curves for lower currents.

The lower trace shows that alkaline cells behave poorly in high-current devices: a 1-A load draws about 0.8 A·h from the cell, only a third of the energy delivered during the 100-mA test. An alkaline cell would last only 0.8 h or 48 min. in that application!

The endpoint voltage depends on your gizmo's specifications. I chose 0.4 V to draw the maximum energy from the cells, but a device requiring a higher voltage will draw less energy

from the cell before failing.

A 0.8-V endpoint delivers nearly the same 2.5 A·h at 100 mA, but only 0.3 A·h at 1 A. The unwary designer who assumes a "1.5 V" alkaline cell will be all used up at 1.0 V is in for a rude surprise: at 1 A, the cell fails in 6 min. after delivering just 0.1 A·h!

Fairly obviously, alkaline cells work best in low-current devices that must operate for prolonged periods, particularly at room temperature. As you'll see, they have a surprisingly high capacity compared to more modern technologies.

Incidentally, the obvious glitches in Figure 1's brown 250-mA trace came from a failing alligator clip. I used heavy-duty bulldog clips or crimped-and-soldered connections for the remaining tests and had no further troubles. My West Mountain Radio Computerized Battery Analyzer has excellent, low-resistance Anderson Powerpole connectors, but the battery termination is obviously out of their control.

NiMH: THE CONTENDER

Alkalines have the severe disadvantage that they're primary, non-rechargeable cells. Nickel-metal hydride cells, the next step up, are secondary cells that can be recharged "up to 1,000 times!" At least, that's what the ads claim, anyway. The reality is that NiMH cells have their own set of trade-offs.

Figure 2 shows discharge curves for a single 2 A·h AA cell at the same

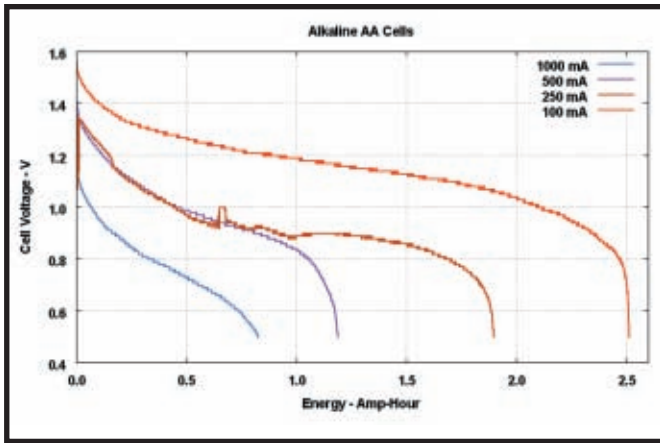


Figure 1—Those familiar AA alkaline cells behave surprisingly well at low discharge rates, but high internal resistance limits their usefulness in high-current gizmos. A bad alligator clip caused the glitches in the 250-mA trace.

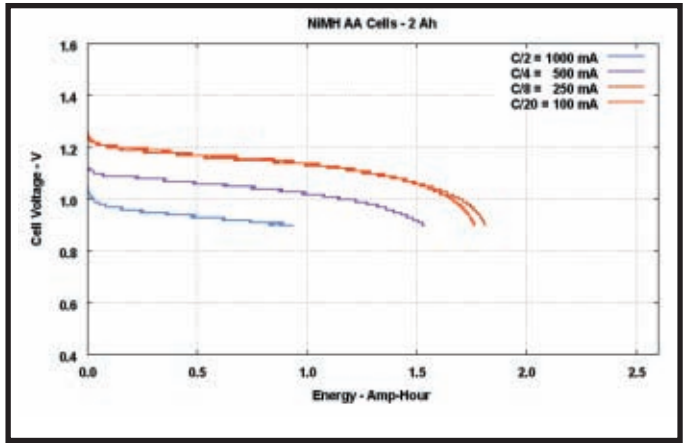


Figure 2—AA Nickel-metal hydride cells have lower voltage and capacity, but much better high-current performance. Yes, the cell discharged at 250 mA barely outlived the one at 100 mA, but that may be due to a different starting charge or sheer perversity.

scale as Figure 1. Two essential facts stand out: lower overall energy capacity and better high-current performance!

Although the cell delivered nearly its total rated capacity at lower discharge rates, it may come as a surprise that even high-capacity NiMH cells deliver less total energy than cheap, disposable alkaline cells. The 100 mA trace in Figure 2 seems low, although that may be a slight variation in the starting charge level. We'll see an example of that with a NiCd cell later on.

I stopped the NiMH tests at 0.9 V, rather than 0.4 V, because that's the recommended per-cell endpoint voltage for multi-cell packs. Although you can discharge single cells to lower voltages, the shape of the curves shows that you don't get that much additional energy. Worse, over-discharging a pack can ruin it, as you'll

also see later in this column.

A cell's high-current performance obviously depends on its internal resistance. That value doesn't appear on the label, but you can get a good approximation to a cell's internal resistance by measuring its terminal voltage at different currents. The internal resistance generally increases as the cell discharges, which means you get lower output voltage for a given current over the life of the cell.

For example, the alkaline cells in Figure 1 have an initial internal resistance of:

$$0.4 \Omega = \left| \frac{1.55 - 1.15 \text{ V}}{0.1 - 1.0 \text{ A}} \right|$$

At the endpoint of the 1.0-A current curve, the resistance has doubled to:

$$0.8 \Omega = \left| \frac{1.2 - 0.5 \text{ V}}{0.1 - 1.0 \text{ A}} \right|$$

The NiMH cell shows internal resistances of 0.2 and 0.3 Ω under similar conditions. Note that the NiMH cell delivers more total energy than the alkaline cell at 1 A, despite the higher endpoint voltage, in contrast to its performance at lower current.

Cells also display an AC impedance that may be much higher than the resistance in applications that deliv-

er AC power. If you're designing RF transmitters, in particular, pay attention to supply decoupling and filtering, because batteries are definitely not perfect voltage sources.

A cell's energy capacity is denoted as "C" (not to be confused with C-size cylindrical cells) and cell currents are generally given as fractions or multiples of that numerical value in amperes. A 1-A discharge current is a "C/2" rate for those NiMH cells and slightly less for the alkalines.

As a rule of thumb, charge or discharge currents exceeding C/2 require careful consideration of temperatures, voltages, and external circuitry to prevent damage. In any event, alkaline and NiMH cells have sufficiently high internal resistance to prevent discharge currents much beyond 2C, at least for non-pulsed applications.

When you're using loose AA cells in a high-power system, you must also consider the current-carrying capacity of the battery contacts and the interconnections, as I discussed back in my June 2002 column ("Invisible Components," *Circuit Cellar* 143).

LITHIUM ION: THE PRETENDER

Figure 3 shows discharge curves for four lithium-ion battery packs that fit my old Sony DSC-F505V camera. The two oldest batteries (with two sub-AA Li-Ion cells in parallel) produced the lowest curves and, because the camera determines the remaining charge by measuring the terminal voltage, they provide only a few minutes of service.

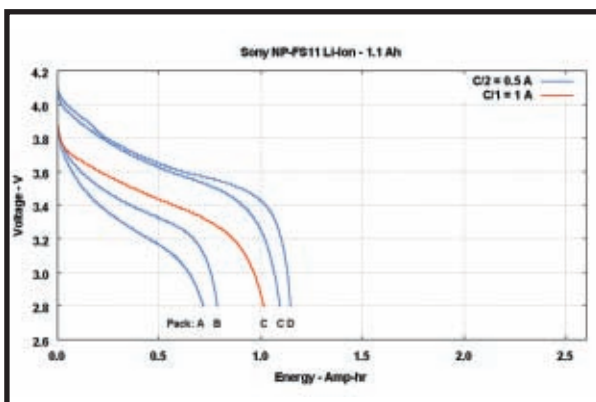


Figure 3—Two older lithium-ion batteries for my Sony DSC-F505V camera produce a "Low Battery" warning almost instantly. Two traces for pack C show the high internal resistance. The voltage axis covers a different range than the other figures, corresponding to Li-Ion's much higher per-cell voltage.

The other two batteries are newer and deliver their rated 1.1 A·h capacity even at a C/2 discharge. In actual use, they last for perhaps 45 min., which simply shows that the camera really needs a higher-capacity battery.

Indeed, my next-generation Sony DSC-717 camera has a much larger battery pack that powers it for 3 h, despite a nearly identical 1.2-A·h rating. The difference is that the 717's battery has two Li-Ion cells in series to provide 7.2 V.

Assuming that the two cameras have roughly equivalent power consumption, the newer pack can supply half the current and, thus, should last more than twice as long.

I'm reluctant to abuse these packs, as genuine Sony NP-FS11 packs cost upwards of \$50, but the middle trace in Figure 3 shows the result of a C/1 =

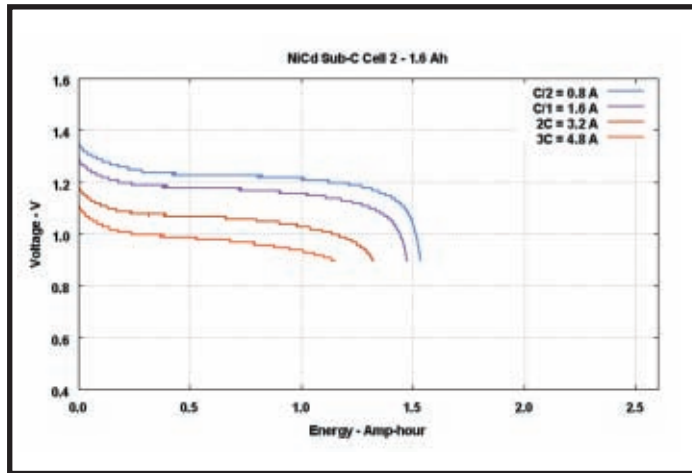


Figure 4—Sub-C nickel-cadmium cells have lower energy storage than AA NiMH cells, despite being physically larger. Their lower internal resistance provides correspondingly higher current capacity, making them valuable for niche applications.

1 A discharge applied to pack C. It delivers nearly its rated capacity, but its internal resistance near the middle of the curves works out to:

$$0.4 \Omega = \frac{3.6 - 3.4 \text{ V}}{0.5 - 1 \text{ A}}$$

Note that the curves aren't particu-

larly flat, showing that the voltage changes dramatically as the battery discharges. I decided not to perform a 2C test, because the C/1 discharge heated the pack more than I expected.

Note that Li-Ion cells provide a third of the energy of alkalines and half that of NiMH, at least for low currents, despite being roughly the same size and shape as two AA cells. Lithium cells have higher energy density on a weight basis, but their key advantage is their ability to be shaped into flat

packs or formed around internal components, a trick that's not feasible with loose cells.

Ni-Cd: THE POWERHOUSE

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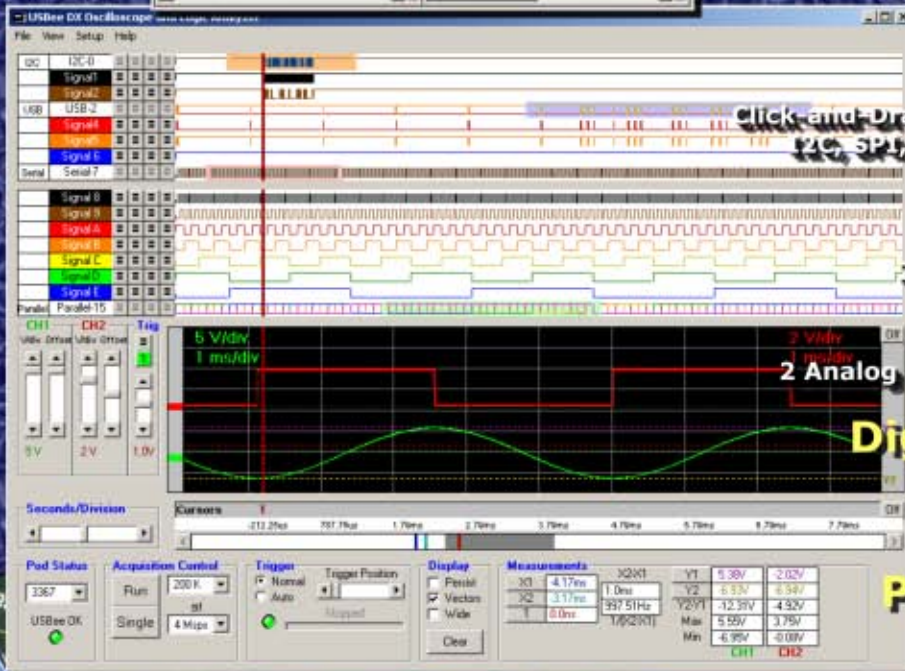
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portable power tools. The reason is simple: the only advantage NiCd cells have over the competition is lower internal resistance. In all other measures, notably energy density and toxicity, they fall short.

Figure 4 shows discharge curves for a single sub-C NiCd cell. I used the same axes as in Figures 1 and 2 to highlight the differences, but with much higher discharge rates.

At 0.5 A-h the internal resistance is about:

$$0.06 \Omega = \frac{1.22 - 0.99 \text{ V}}{0.8 - 4.8 \text{ A}}$$

That's a quarter of the NiMH resistance and nearly an order of magnitude less than alkalines! The resistance increases only slightly during the entire discharge cycle, so the cells can deliver consistently high current.

Because this sub-C cell is physical-

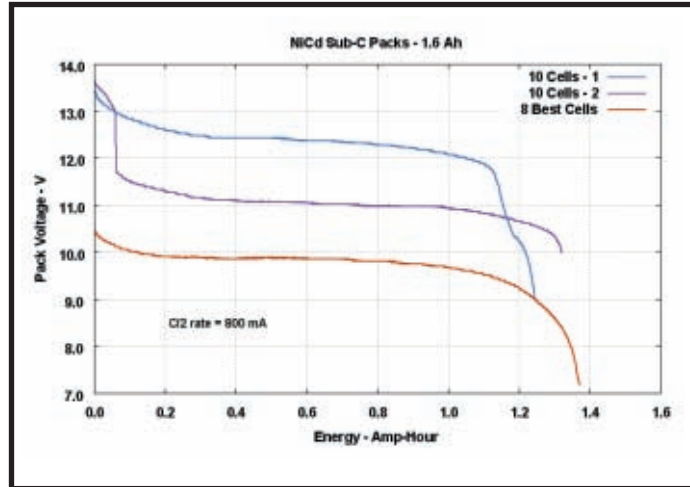


Figure 5—The first decline at the end of the blue trace follows one cell discharging through 0 V. The abrupt drop in the purple trace shows that cell was not fully recharged. The eight best cells worked fine, though, as shown in the brown trace.

ly larger than the AA cells that produced Figures 1 and 2, the lower resistance has two components: a larger electrode area and different chemistry. However, if you're designing a gizmo that must use NiCd cells, you'll probably need larger cells to get enough capacity, which will permit even higher discharge rates.

Because of their low internal resistance, NiCd battery packs can produce staggeringly high short-circuit currents: circuit breakers or fuses aren't just a good idea, they're essential! Pay attention to the cell connections within the battery to reduce the risk of inter-cell shorts.

Outside the pack, ordinary spring-contact battery compartments may not have the low and consistent resistance required to deliver high current to the load. Even at the relatively low 4.8 A I used, two bulldog clips can drop 100 mV: that's 10% of one cell's contribution to the pack's output! High-pressure slip-fit connectors provide low resistance while requiring careful attention to mechanical design.

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inside a battery pack provides higher voltage and delivers more power at the same current. The pack's total energy is the sum of the individual cells, but it has the same A·h rating as each cell because the same current passes through each one.

All of the cells in a pack should be identical, but in real life that does not happen. Figure 5 shows the death of a battery pack when the weakest cell fails.

The pack was a watertight case containing 10 1.6 A·h sub-C NiCd cells with an integral C/2 charger. It was a "New Old Stock" surplus item that had been built for a failed product line and, presumably, never used. I figured out how the charger worked, charged the pack, and then measured the pack's performance.

The blue trace seems normal out to about 1.1 A·h, at which point one of the cells was completely discharged and its voltage dropped to zero. Almost immediately another cell discharged and, with two dead cells, the pack reached 9.0 V and the test ended. The pack delivered somewhat less than its rated 1.6 A·h, but with at least one weak cell, it's in bad shape.

The purple trace shows the result after recharging the pack. The weakest cell evidently did not receive a full charge and dropped to 0 V almost immediately. For the remainder of the test, that cell was "reverse charging" and producing hydrogen gas. NiCd cells can contain a limited amount of hydrogen gas under those conditions and it probably didn't vent the gas into the sealed enclosure, but you shouldn't treat your batteries like that. I terminated the test at 10 V, a more conservative 1 V/cell value, because I wanted to prevent any further damage.

I removed the two weakest cells and the charger, manually charged the remaining eight cells, and the brown trace shows that they work fine with about 1.4 A·h of energy. Because NiCd cells improve after a few charge-discharge cycles, these cells will play nicely together as a 9.6-V pack powering the HT on my bike.

Contrary to what you might think,

the weakest cell isn't dead and, in fact, produced Figure 4. Its first solo charge cycle, though, was a bit of a challenge, but that's a subject for the next column.

CONTACT RELEASE

I produced the discharge curves for this column with a West Mountain Radio Computerized Battery Analyzer (CBA). It's basically a power FET mounted on a fan-cooled heatsink, a voltmeter, and an ammeter, all USB-interfaced to a logging program. I wish it had Kelvin voltage sensing and a Linux driver, but it works well enough.

The CBA records one data point per second, producing huge files that choke spreadsheet programs. I used Gnuplot to produce these graphs, with Bash scripts feeding it the commands for each figure. The details are in this column's downloadable files. ☒

Ed Nisley is an EE and author in Poughkeepsie, NY. You may contact him at ed.nisley@ieee.org with "Circuit Cellar" in the subject to avoid spam filters.

PROJECT FILES

To download the Graphs, Gnuplot scripts, etc., go to ftp://ftp.circuitcellar.com/pub/Circuit_Cellar/2007/199.

RESOURCES

Exhaustive NiCd information, www.rcbatteryclinic.com/seminar.htm.

Excellent battery comparison, www.buchmann.ca/Article4-Page1.asp.

SOURCES

GnuPlot
<http://gnuplot.info/>

Anderson PowerPoles
PowerWerx
www.powerwerx.com

Computerized Battery Analyzer
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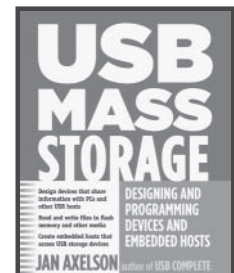
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From the author of USB Complete



Embedded Capacitive Touch Applications

Get ready to build a capacitive touch application. Fred covers the basics and then describes useful capacitive touch sensing techniques for CapSense-enabled PSoC devices.

It's just like riding a bicycle. Once you've learned how to do it, you'll never forget. That's my take on using Cypress Semiconductor's PSoC devices. It didn't take me long to get back into the groove of using PSoC Designer to program and reconfigure the PSoC device on my Cypress CY3212 CapSense training board. The purpose of the board is to get you up to speed on capacitive touch-sensing techniques, using CapSense-enabled Cypress PSoC devices.

If you're a regular *Circuit Cellar* reader, you most likely know what a PSoC is. However, if PSoC is not in your vocabulary, here's a view from 10,000'.

Mixed signal is PSoC's claim to fame. A PSoC device incorporates internal analog and digital building blocks that are connected by firmware. The PSoC building blocks interact in input-to-output fashion using the PSoC's internal multiplexer and bus infrastructure. A PSoC application allows you to string together and interconnect comparators, timers, PWM modules, digital communication blocks (RS-232, IrDA, I²C, SPI, etc.), counters, ADC, digital buffers, and digital inverters. They can generate and process real-world signals according to

the firmware you feed into the PSoC's on-chip microcontroller. The latest addition to the PSoC mixed-signal array is the CapSense capacitive sensor relaxation (CSR) oscillator user module.

Capacitance-based touch sensors are easily realized with mixed-signal PSoC devices. The Cypress PSoC engineers have put together a combination of PSoC hardware, practical

capacitive touch sensor design guidelines, and a capacitive sensor library, complete with API calls that makes putting together a PSoC capacitive-based touch sensor design quick and easy. If you need to jettison the mechanical switches in your design, the CY3212-CapSense board and the theory behind it will give you the knowledge needed to replace those mechanical switches with simple

capacitive touch pads that can be etched directly on your device's PCB. In addition, the PSoC device providing the touch pad service can focus its remaining digital and analog resources on other parts of the application that the touch pads are supporting.

CAPACITIVE SENSING

Sports drink companies bombard you with commercials that make you think you need to drink their products in order to replace the electrolytes your body loses when you sweat. Those very same electrolytes that run out of your pores are the reasons why human fingers and capacitive touch pads work so well together. The electrolytes you carry around every day coupled with your lossy dielectric-like skin allow you to hold an electrical charge.

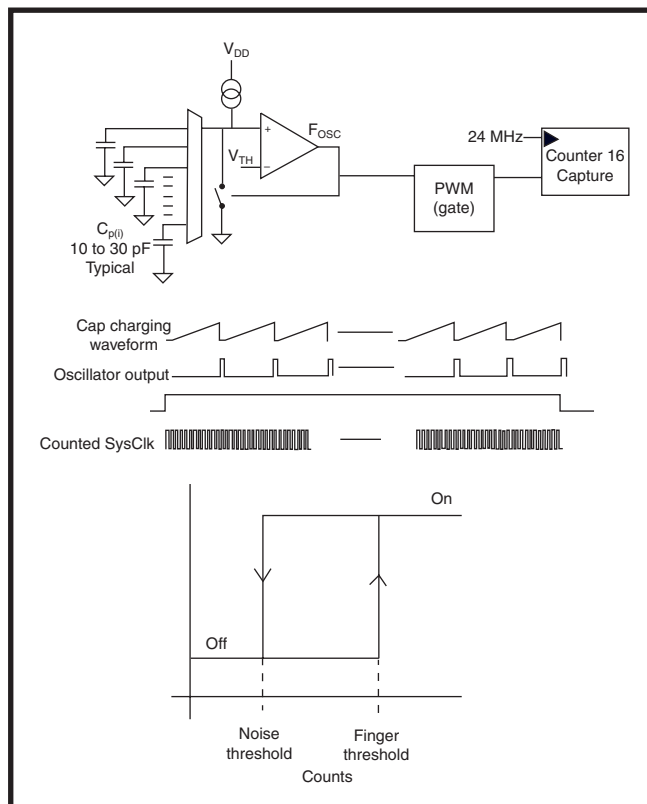


Figure 1—The sensor capacitors in this diagram are actually capacitive sensors that respond to the proximity of a conductive object, such as a finger. The PSoC allows each sensor to be muxed into the capacitive sensor relaxation (CSR) oscillator circuitry.

A typical capacitive touch sensor consists of an electrically isolated printed circuit pad sitting inside a ground plane. Isolation of the printed circuit pad is provided by a 0.040" gap etched around a 0.40" pad. The result of the pad/ground plane arrangement is a simple capacitor. Unlike the enclosed parallel-plate capacitors that you mount on your project boards, the CapSense-oriented capacitor plates are side by side. They expose some of the electrical field bands, which form energy bands between the capacitor's pair of open plates and ground. Because a finger is able to conduct and thus hold a charge, placing a finger in the proximity of our open-face pad/ground plane capacitor increases the conductive surface of our simple open-faced printed circuit capacitor.

The additional conductive surface supplied by the intruding finger adds additional charge storage capacity, which you can see as an increase of capacitance between the capacitive sensor and ground. Interestingly enough, the finger adding the capacitance does not have to be grounded. In fact, the finger's added capacitance can be sensed if the finger is grounded or floating. Sensing the finger's capacitance is accomplished by the finger's charge participating in the electric fields spilling from around the pad/ground plane sensor. This interaction of fields implies that the finger doesn't have to touch the capacitive sensor to be sensed. The ability of the capacitive sensor to sense the finger without physical contact allows a thin nonconductive covering such as glass or lead-free plastic to be placed over the sensor.

CapSense BASICS

All you need now is a way to sense the change in capacitance that occurs when a conductive object nears your open-faced capacitive sensor. If you can sense a capacitance change in one capacitive sensor, there's no reason why you can't do the same for an array of capacitive sensors. However, if you decide to deploy an array of capacitive sensors, you must have a way to interrogate each of the sensors individually and



Photo 1—The CY3212 CapSense training board is very unassuming. There's just enough stuff here to sense your finger on the pads and the slider. The training board includes a CY8C21001 OCD part, which adds a bunch of advanced debugging clout to this unassuming development board.

report the sensor's status. That's where the PSoC comes in.

CapSense is implemented within a PSoC, using a relaxation oscillator circuit consisting of a current source, a sensor capacitor, a comparator, and a discharge switch (see Figure 1). The arrangement of analog and digital building blocks is officially called a CSR user module. The sensor capacitors in Figure 1 are actually an array of capacitive touch sensors.

When selected by the analog mux, the capacitive touch sensor is attached to the CSR user module and begins to be charged by the module's DAC-controlled current source. Meanwhile, the PWM is set to its start value and the oscillator is enabled. The CSR user module's comparator will trip and close the discharge switch when the voltage across the capacitive sensor reaches the comparator's preset threshold voltage. The charging ramp and the discharge cycle create a sawtooth waveform across the capacitive sensor. As the sensor charges toward the comparator threshold voltage, the comparator's output remains low. When the comparator threshold voltage is reached, the comparator output will go high.

By design, the comparator trip time and reset switch add a fixed delay of two system clocks. The comparator's output is synchronized with the system clock to make sure that ample

time is allowed to completely reset the charging voltage on the selected capacitive sensor. Each time the comparator threshold is reached and the comparator output changes state, a high-going pulse appears at the comparator's output. The CSR user module's PWM counts these comparator output pulses. While the PWM is counting comparator output pulses, the 16-bit counter gate is enabled, allowing the 16-bit counter to accumulate clocks from its 24-MHz signal source. The PWM eventually counts down to zero and disables the gate signal to the 16-bit counter. The raw count yielded by the 16-bit counter is then transferred to the CSR_iaSwResult integer array. The counting of pulses by the PWM module is associated with what Cypress calls the "period method of measurement."

If you use your imagination to stretch and compress the sawtooth cycles in Figure 1, you'll come to the conclusion that, the larger the sensor capacitance, the longer the ramp of the sawtooth cycle. That means more time between PWM counts, resulting in a longer 16-bit counter gate time and more counts accumulated by the 16-bit counter.

Determining whether or not a finger is influencing the sensor is based on the difference in baseline counts versus finger counts. Initially, baseline

counts are accumulated at start-up time while there is nothing in the proximity of the capacitive sensors. Each sensor is scanned and then its initial baseline value gets stored in the baseline array. The baseline is historically updated on every user-determined number of scans defined by the update rate parameter. Keeping track of the baseline ensures that changes in the characteristics of the capacitive sensor due to environmental changes are accounted for.

Noise threshold is defined as the number of counts below sensor turnoff. If the sensor's difference value is within the positive and negative limit of the noise threshold, the sensor's baseline value is updated using an IIR filter. The IIR filter adds 75% of the previous baseline and 25% of the current raw data count from the new baseline value. If the sensor's difference value is in "the dirt" as far as noise is concerned, the current raw data count becomes the baseline value. If the sensor isn't in "the dirt" and the difference value is not within the positive and negative limit of the noise threshold, the baseline value is not altered.

The opposite of the noise threshold is the finger threshold, which is defined as the number of counts needed to consider the sensor on. The combination of the noise threshold and finger threshold cut-off points creates a welcomed hysteresis effect.

The baseline count is a 16-bit variable with a maximum value of 0xFFFF. The CSR user module's baseline adjust routine multiplies the raw baseline count by four to maximize resolution. Thus, your raw finger count cannot exceed 0x3FFF counts. The PSoC documentation doesn't mention running the CSR user module at any other system clock frequency except 24 MHz. So, your maximum sensor count

time at 24 MHz is 42 ns (1/24 MHz) multiplied by 16,383 (0x3FFF), which is 682 μ s.

The simple idea behind the CSR user module works very well. If you've been around as long as I have, you've built similar capacitive-controlled circuits using the famous LM555. If you're just a young pup and wouldn't know a 555 if it fell on you, it may interest you to know that you can build up an emulated LM555 using the elements of a PSoC. If you're interested in the LM555 in PSoC clothing, there is a PSoC application note that tells you all about it. However, you are not creating PSoC 555 timers, so let's take a look at the CapSense hardware implementation offered by Cypress.

CapSense HARDWARE

My CY3212 CapSense training board can be seen in Photo 1. As you can see, the board's capacitive sensor array consists of seven etched buttons and a slider, which is made up of 16 capacitive sensor segments. All of the

CapSense work is done by a single CY8C21001 on-chip debugger (OCD). The CY8C21001 stands in place of the CY8C21434 PSoC that it emulates on the board.

Using the CY8C21001 instead of the stock CY8C21434 PSoC allows the PSoC CapSense designer to use more powerful PSoC emulation and debugging tools for CapSense project development. As you can see in Figure 2, most of the glue components are dedicated to interfacing the emulation and programming devices to the CY8C21001.

Speaking of programming PSoC devices, the training board comes with a PSoC MiniProg module, whose likeness has been captured in Photo 2. The PSoC MiniProg is driven by a USB-enabled program called PSoC Programmer. PSoC Programmer has the ability to instruct the PSoC MiniProg to reset and power the CY8C21001 after programming, which is very handy when you're running through quick little code changes. The PSoC MiniProg worked

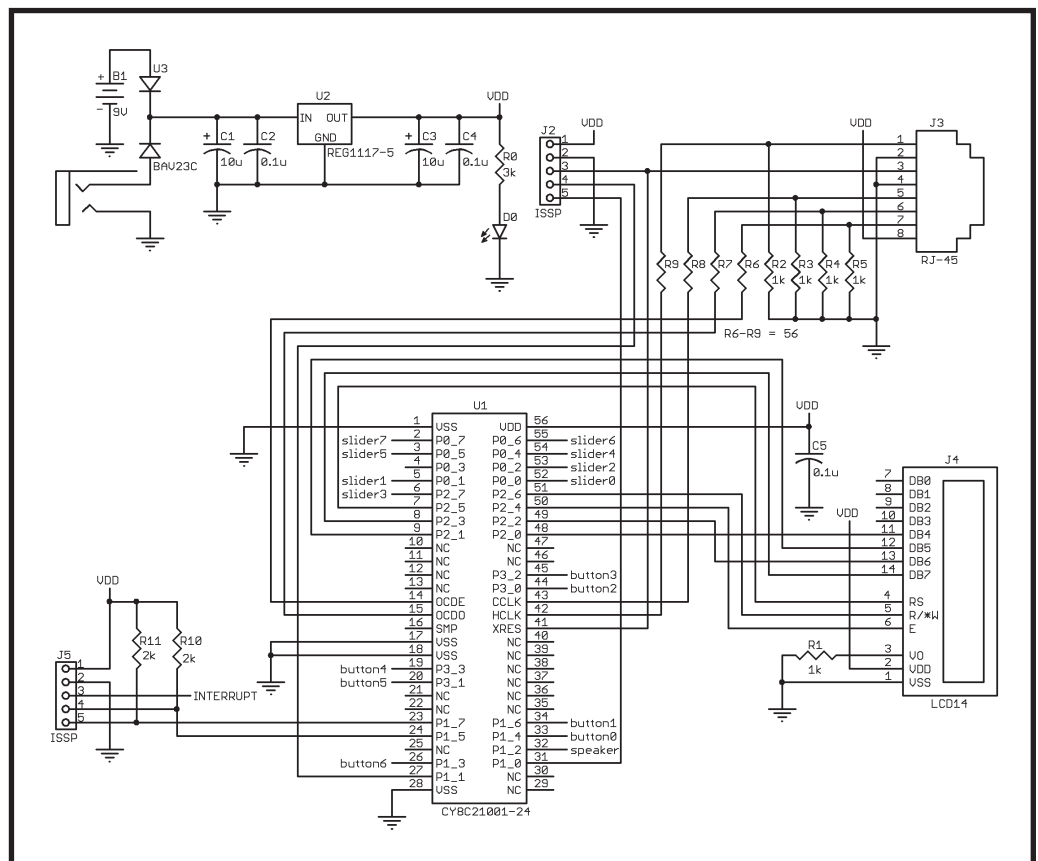


Figure 2—This is a simple layout. All of the power lifting is done within the PSoC.

so well for me that I did not pull out my PSoC emulator.

Another plus is that the PSoC MiniProg module eliminates the need for a wall wart. The CY3212 board doesn't come with a power brick, and I never used one while putting the words together for this column.

The 2 × 16 LCD mounted on the training board is used to visually indicate which capacitive sensor is excited. One of the coolest things you can do is slide your finger across the sensor while checking out the LCD. The default CapSense demo program not only indicates numerically where your finger is on the slider, but it also tells you which direction you're moving it (right or left). For those of you that are musically inclined, a speaker is also part of the board. I zoomed in on the business end of the CY3212-board for you (see Photo 3).

CapSense LOGIC

I'm sure interactive magazine columns are on their way. However, they aren't here yet. So, showing you what happens on the LCD every time I touch a sensor isn't going to happen right now. Instead, I'll physically remove the LCD, make a slight PSoC hardware change, and gain access to the CY8C21001's CapSense results by way of a good old RS-232.

Before I explain how to make modifications, let's look at the PSoC Designer view of the original CSR user module hookup, which appears when you run the LCD demonstration that comes loaded on the CY8C21001. Shift your attention to Figure 3 for a moment. The little tag labeled with a one feeding the ACE00 comparator module's clock input is the CY8C21001's 24-MHz system clock. Although the PSoC Designer view doesn't show it in detail, the comparator's input is actually muxed to the capacitive sensor buttons that are attached to the PSoC's port 1 and port 3 general-purpose I/O pins, using an internal AnalogMuxBus. This internal AnalogMuxBus is also used to connect the CSR user module's DAC current source and Reset switch.



Photo 2—This little bugger kept my PSoC emulator in the box. I was able to program my CapSense code changes into the CY8C21001 and run them without having to remove the PSoC MiniProg module from the CY3212 CapSense training board's ISSP socket.

The comparator's output, which wouldn't be obvious to the casual observer, is routed internally to GlobalOutputOdd4 (GOO4). An interconnect resource takes the GOO4 signal to GlobalInputOdd4 (GIO4), which is connected to RIO[0]. The PSoC PWM module gets its input from RIO[0], whose signal path was traced back to the comparator output.

The PWM module output feeding RO0[3] is passed to the NOT input side of the [~A AND B] gate fed by RO0[3]. The remaining PWM module output takes the RO0[0] rail to the B side of the RO0[3] [~A AND B] gate. The [~A AND B] gate's output feeds GOO7 and interconnects to GIO7, which feeds into RIO[3] and the 16-bit counter module's input.

The hardware shown in Figure 3 uses an associated PSoC C program to put the number of the sensor touched on the LCD. Count values are associated with the sensor activations. The best way to see them is to feed the count values out through a standard serial connection to a terminal emulator running on a PC.

Figure 4 is a PSoC visual of the touchy-feely CSR user module application. The module is laid in concrete

and there are no changes that I could make there. I need to get at the CY8C21001's general-purpose I/O pins that are attached to the LCD. They are the only way I can get signals out of the CY8C21001 without having to micro-solder wire-wrap wire directly to the CY8C21001's pins. (You'll see what I mean when you look back at Photo 3.) Using PSoC Designer, I eliminated the LCD connections on the CY8C21001's port 2 general-purpose I/O pins and pulled the physical LCD from its 14-pin SIP socket on the CY3212 CapSense training board. I can stick some header pins into the LCD SIP socket and use jumpers to get the signals I need out.

The PSoC module library includes separate serial transmitter and serial receiver user modules. I really don't need to receive any data, so the PSoC 8-bit serial transmitter module does just fine. After loading the CSR user module into the configuration, the architecture of the CY8C21434 that is being emulated by the CY8C21001 leaves me with a single digital module (DCB03), which I can put to good use as an 8-bit serial transmitter.

To use the DCB03 as an 8-bit serial transmitter, all I had to do was set the data clock and connect the output of the 8-bit serial transmitter to a CY8C21001 general-purpose I/O pin, left open by the removal of the LCD. Setting the data rate clock was an easy task. The PSoC requires that the 8-bit serial transmitter be clocked at eight times the bit rate. I wanted to run the 8-bit transmitter at 115,200 bps. So, with a 24-MHz system clock, I needed to divide the incoming system clock by 26 to achieve the 8× bit clock.

Performing the system clock-division was an easy task. All I had to do was specify the system-clock source, specify the clock output portal, and dial in a divisor of 26 for the output portal in the PSoC Designer Global Resources window. Once I had the bit rate parameters set, all I did was connect the serial transmitter module's output to one of the CY8C21001's port 2 general-purpose I/O pins.

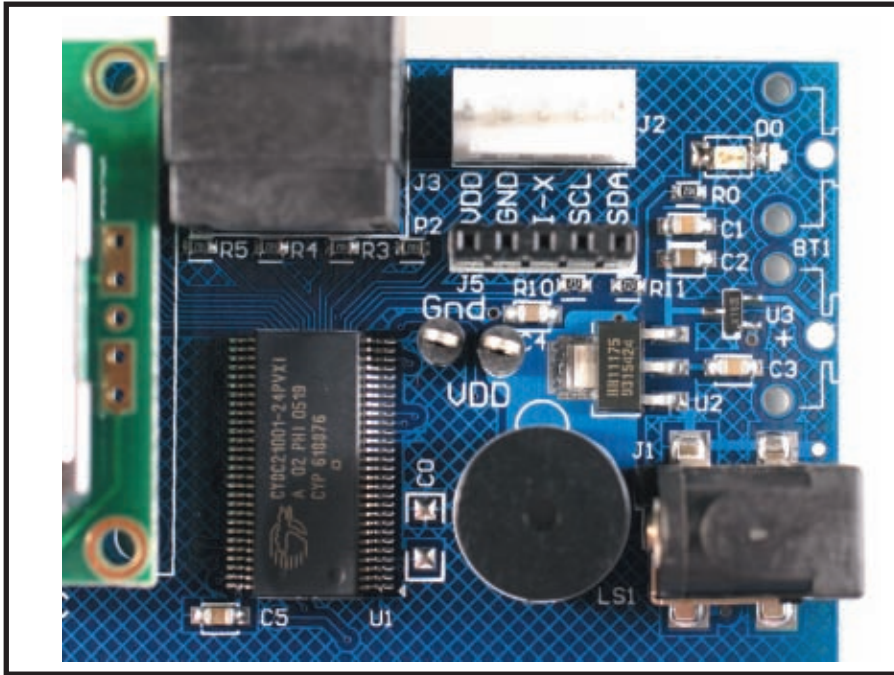


Photo 3—Another advantage when using PSoC devices is the reduced number of popcorn and glue parts needed by the final PSoC hardware. Most of the stuff you see in this picture would be eliminated if this were to become a commercial product. Note the hatch ground plane, which is recommended and specified in the CapSense design documentation.

The PSoC CY8C21001 doesn't have the resources available to do the digital-to-RS-232 voltage level conversion. That's fine. I have literally dozens of prototypes containing the necessary TTL-to-RS-232 conversion circuitry that I can tap the serial transmitter's output into.

MAKING SENSE

The capacitive sensors of the CY3212 CapSense training board are in the open and are not covered with an overlay. The absence of an overlay makes the sensors very sensitive. Thus, the scan speed of the training board's sensors is set at the minimum of three, which scans for a single oscillator period. Three is the minimum for a single oscillator period as two oscillator peri-

ods are added to compensate for the PWM interrupt overhead. The DAC current also has to be adjusted for the conditions because the number of raw counts is inversely proportional to the amount of DAC current supplied to the sensor.

Many application engineers consider capacitive touch sensing an art. With that in mind, the calibration extents of the CY3212 CapSense training board sensors have been determined to lie within a range of 290 to 310 raw counts with no fingers present. A simple loop increments or decrements the DAC-controlled current source value for each of the seven individual sensors, using the `CSR_StartScan` and `CSR_SetDacCurrent` API calls, until each sensor raw count falls into the calibration extents that were specified.

Much of what you have to deal with when designing capacitive touch-sensing applications is left up to experimentation. I'm sure that's where the 290 to 310 numbers came from. There is absolutely no technical or mathematical explanation for how these numbers were chosen. I like to use SWAG design methods every now and then. Right now, the finger threshold is set for 100 and the noise threshold value is set to 40 in PSoC Designer. The aforementioned values were most likely derived from the physics of the CY3212 CapSense training board, so I'll let them be. I'll also let the current `BaselineUpdateRate` value of 40 stand.

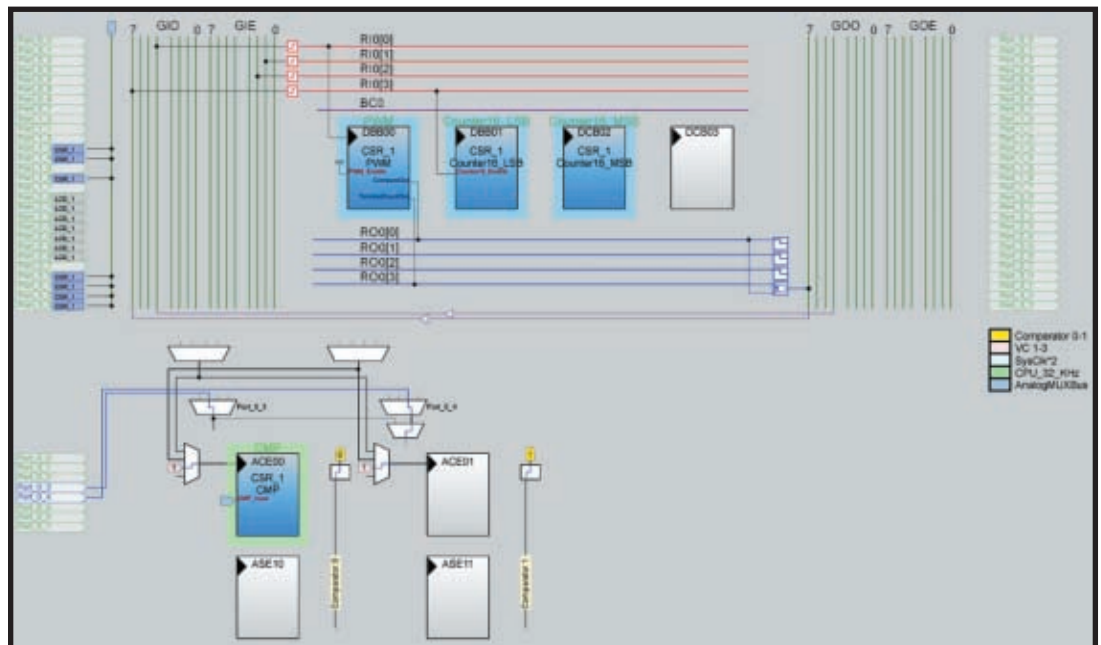


Figure 3—PSoC Designer includes a CSR user module wizard that is used to assign the CSR_1 sensor inputs to their respective PSoC general-purpose I/O pins. Note that the LCD is assigned exclusively to port 2. The CSR user module is cast in stone and will always populate the PSoC resources and make the connections you see in this figure.

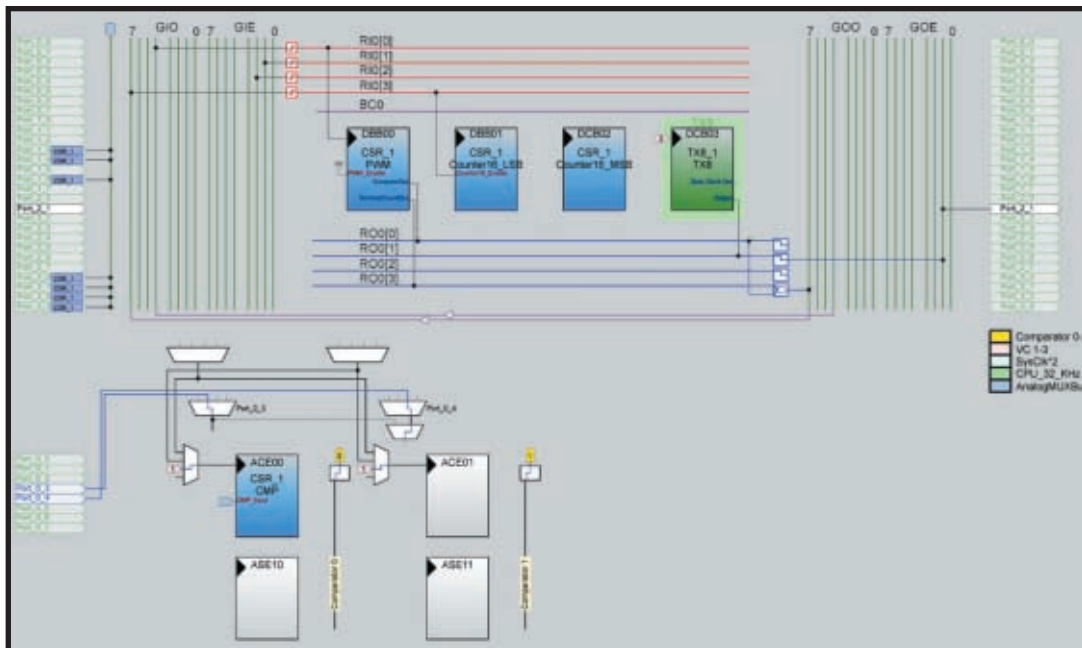


Figure 4—I left the CSR user module alone, scuttled the LCD connections, and added an 8-bit serial transmitter user module. I used the PSoC Designer resources to assign a clock to my new transmitter and make the connection from the transmitter output to a PSoC general-purpose I/O pin.

Once all the sensors were calibrated, I called on the CSR_bUpdate-Baseline API for the interrogation of the sensors one by one. The CSR user module was multiplexing the sensors into a common CSR user module configuration, so the DAC current calibration value for each particular sensor was loaded before the selected sensor was scanned.

Here's what goes on inside of the CSR_bUpdateBaseline API call. The CSR_bUpdateBaseline API call interprets the raw sensor data and is responsible for many of the numbers I generated with a touch of the training board's 0 sensor (see Table 1). A difference value—stored in

waSnsDiff[0] for sensor 0—is calculated by subtracting the previous baseline value (waSnsBaseline/4) from the raw data (waSnsResult) obtained from sensor 0 (zero).

The bBaselineUpdateTimer value begins with 0x28 (see Table 1). Every time the CSR_bUpdateBaseline API call returns a positive result (a sensor is on), the bBaselineUpdateTimer value is decremented. When the bBaselineUpdateTimer value exhausts itself, the CSR_bUpdateBaseline API is eligible to perform an update on the sensor's baseline value depending on the noise threshold value, as I described earlier. The most important thing

Sensor	waSnsResult	baSnsOnMask[0]	waSnsDiff[0]	bBaselineUpdateTimer	waSnsBaseline/4
0	01B4	1	88	28	012C
0	01B4	1	88	27	012C
0	01C2	1	96	26	012C
0	01C1	1	95	25	012C
0	01C7	1	009B	24	012C
0	01C3	1	97	23	012C
0	01C9	1	009D	22	012C
0	01D0	1	00A4	21	012C
0	01CE	1	00A2	20	012C

Table 1—The sensor with a finger on it is indicated by the bit mask in the baSnsOnMask column. Raw counts are tallied in waSnsResult. The baseline counts used in the difference calculation are found in the waSnsBaseline/4 column. The waSnsDiff[0] value is used by the CSR_bUpdateBaseline API call to make an on/off decision.

the CSR_bUpdate-Baseline API call does is determine if the sensor is on or off. The determination of the sensor status is stored in the baSnsOnMask[0] array as a one for on and a zero for off.

TOUCH DOWN!

I know; that's a bad section header. To make up for the bad pun, I provided the code that is posted on the *Circuit Cellar* FTP site. Note that the code generated the numbers you see in Table 1.

It was very refreshing to discover

er that the CapSense application engineers admitted that you'll need more than the math and theory to build up a good CapSense implementation. However, the CapSense documentation and application notes provide more than enough of the engineering stuff you'll need to mix with your experimentation. The PSoC takes most of the behind-the-scenes complication out of putting together an embedded capacitive touch application. ☑

Fred Eady (fred@edtp.com) 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.

PROJECT FILES

To download code, go to ftp://ftp.circuitcellar.com/pub/Circuit_Cellar/2007/199.

SOURCE

CY3212 CapSense training board
Cypress Semiconductor Corp.
www.cypress.com



Electric Movement and Control

Electric power or gas? As the debate over the use and abuse of energy resources rages on, Jeff weighs in with some useful information about electric vehicles. How do they operate, and how can you apply your engineering skills to get a working design on the road? Read on to learn how he mapped the energy consumption for an electric bicycle.

My son-in-law Bryan just made the switch. Yup, he gave up his PT Cruiser and went with a hybrid. The long commute and frequent stops at the pump prompted a move for improved MPGs. I'm jealous. However, I'm not in any financial position to make that kind of investment. I ride my motorcycle on most days, at least until the temperature gets downright uncomfortable. And at 60 MPG, not even Bryan's hybrid can beat it for efficiency.

I've been contemplating building an electric motorcycle for a few years now. In reality, I'd like to end up with an electric vehicle that I could use all year round. That most likely means I'd have to design one with more than two wheels. Recently, I ran across an advertisement in the Sunday paper that looked too good to pass up. A big-box auto parts supplier was clearing out an electric bicycle for \$200. I could hardly buy a DC motor for that. I thought this would be a perfect entry-level platform to experiment with.

An electric vehicle has three major components: a motor, a controller, and a battery. The perfect battery must be capable of charging and discharging quickly. Unfortunately, this deep cycling is tough on many types of storage

cells. To efficiently operate a motor at various speeds, PWM control of the motor is used. The semiconductors must have the ability to control some rather large currents. Although it isn't necessary, many controllers now employ microcontrollers to improve efficiency and provide additional functions. The DC motors used may be brushed or brushless. Although doing away with replaceable brushes eliminates arcing and noise while increasing the motor's efficiency, the required multiphase drive controllers are more expensive.

ELECTRIC BIKE

Dr. Malcolm R. Currie and Richard A. Mayer cofounded Currie Technologies in an effort to use their electric vehicle expertise to address the environmental and economic needs of an

emerging international market.

Presently, they build Electric Scooters and Hybrid Electric Bicycles (the IZIP brand) and outsource their technology to other companies like Schwinn and Mongoose.

The I-Chopper that I purchased is based on a single-speed, chain-driven, BMX-style bicycle (see Photo 1). A handlebar mounted brake lever applies caliper-type brake pads on the oversized rear tire rim. The banana seat placement creates a low center of gravity for the (easy) rider. The frame and fork are made from high-tensile steel and come with the standard Consumer Product Safety Commission front, rear, and side safety reflectors.

This is an electrified bicycle. The motor, controller, and batteries were not just stuck on as an after thought; they seem to have been part of the initial design process. The

batteries and controller are housed in a removable plastic carrier in the shape of a motorcycle's engine (see Photo 2). The motor is well hidden between this case and the rear wheel. This brushed DC motor uses a roller-bearing, one-way clutch to disengage from the rear axle if the axle is rotating faster than the motor (e.g., while pedaling or moving downhill). A twist throttle mounted on



Photo 1—Currie Technologies produced this bicycle in 2005. It's unusual for a bicycle to be electrically powered right from the get go. It uses twin 12-V, 12-A batteries to power a 350-W DC motor.



Photo 2—Cracking open the plastic engine shell reveals two 12-V, 12-A-h gel cells and a solid-state 40-A motor controller. Two external connectors can be seen at the bottom right of the photo. The large high-current connector goes directly to the DC motor and the smaller 1 x 6 plug interfaces to the twist-grip throttle mounted on the right handlebar.

the right handlebar grip is similar to a twist gearshift used on some multiple-speed human-powered bikes.

IT'S THE LAW

According to U.S. federal law H.R. 727, which amended the Consumer Product Safety Act, low-speed electric bicycles are consumer products and not motor vehicles (as defined in section 30102(6) of title 49 of the U.S. code). It further defines a low-speed bicycle as “a two- or three-wheeled vehicle with fully operable pedals and an electric motor of less than 750 W (1 hp), whose maximum speed on a paved level surface is less than 20 mph, when driven solely by the motor and ridden by an operator weighing 170 lbs.” This places low-speed electric vehicles under the regulation of the Consumer Products Code of Federal Regulations section 1500.18(a)(12) and part 1512 of title 16.

In Connecticut, a driver's license is required for an electric vehicle that is greater than 2 hp and can exceed 30 mph. Low-speed electric vehicles are forbidden from use on any limited-access divided highway, as they can't, by definition, maintain a minimum of 40 mph.

BARBIE & G.I. JOE

You may be familiar with the drivable battery-operated play vehicles for tots. Barbie cars and G.I. Joe Jeeps have been popular for years. These are typically powered by a 6-V gel cell and

tiny DC hobby motor (with a gear train to reduce the motor's speed and raise its torque). Speeds are limited to a slow crawl to reduce potential injuries.

As we move upscale to a vehicle that can handle the weight of an adult and conquer hilly roadways, the energy requirement increases. More energy means more watts. Since watts = volts x current, the energy can be increased by increasing the volts, amps, or both. Referring

back to HR727, 750 W seems to be the magic number for an unlicensed vehicle. For this discussion, I'll remain in this range.

Using 6 V for a source of 750 W requires 125 A! Wire size requirements (low single digit) for carrying this level of current becomes unmanageable, so raising the voltage source is a must. Table 1 shows how raising the source voltage reduces the required wire size. Batteries are produced in 6 and 12 V varieties. To increase the voltage beyond 12 V, you must use additional batteries. A trade-off is made between adding extra batteries to the system and reducing the necessary copper wire size.

Mathematically, the physical size of any combination of batteries for a given energy would remain virtually the same independent of the voltage. In practice, you wouldn't necessarily reduce each battery's size (and capacity) just because you added batteries to raise the voltage. Therefore, adding multiple batteries (of the same size) doesn't just give more voltage; it also increases the capacity of the system.

A 48-V, 125-A-h (four 12 V, 125 A-h batteries in series) system has eight times the capacity of a 6-V, 125-A-h battery. Of course, four 12-V batteries also have eight times the volume of a single 6-V battery (you don't get something for nothing). When specifying the size and number of batteries that will be used, you must take into account the weight and physical size

of these batteries. You might easily double the weight of a vehicle by using multiple batteries or ones with high capacity. This generally limits the maximum travel distance of the vehicle because the heavier the vehicle, the more energy that must be expended to travel the same distance.

BATTERY RATING

The lead acid battery (including gel cells) rating is based on a 20-h discharge. That's a total of 144 W (i.e., 12 V x 12 A) over a 20-h life. At this rate, you have:

$$7.2 \text{ Wh} = \frac{144 \text{ W}}{20 \text{ h}}$$

or

$$0.6 \text{ A average current draw} = \frac{7.2 \text{ W}}{12 \text{ V}}$$

You can certainly draw more than 0.6 A, but you will pay a price for it. If you want the full 12-A draw from the 12-V battery, you will lose about 50% of the rated energy. You could draw 12 A for about 30 min.:

$$72 \text{ Wh} = 12 \text{ V} \times \frac{12 \text{ A}}{0.5 \text{ h}}$$

This derating continues with an increasing demand of current draw. The starters on many automobiles draw hundreds of amps for a very short period of time. Very high currents for extended periods of time will damage the battery due to internal heat generation.

A deep cycle battery uses the same construction as a standard battery. The difference is in the material used for the battery plates. The standard lead-acid battery uses a sponge lead, which increases the surface area exposed to the electrolyte (increasing the weight to power ratio). Unfortunately, this is more fragile than a solid lead plate (used in deep cycle batteries),

750 W		
Volts	Amps	Wire size
6	125	2
12	63	6
24	32	10
48	16	16

Table 1—The table shows the recommended wire size based on current in a single copper conductor in free air.

and it's susceptible to crumbing due to deep cycling (discharging to below 90% capacity).

When starting an automobile, the few seconds of starting time do not cause excessive discharge. The engine's alternator returns the charge quickly once the engine starts. On the other hand, an electric vehicle will squeeze as much from the batteries as possible. This repeated deep discharge/charge cycling would reduce the usable lifetime of a standard battery. It is recommended that you use a gel cell or another deep cycle lead-acid battery as a power source in electric vehicles.

The storage system chosen for use with this electric bicycle is made up of two 12-V, 12-A-h batteries. Each 12-V gel cell is approximately 6" x 4" x 4". These add only about 17 lbs. to the bike's overall weight. The 450-W DC permanent magnet motor used on this cycle could look for 18 A from

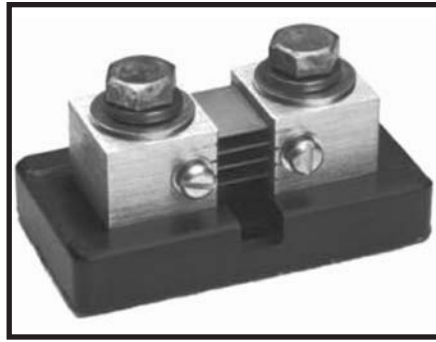


Photo 3—This is a typical high-current sensor. The two larger bolts are used for a connection to the high current path, while the smaller screws are used for measuring the actual voltage drop across the shunt. (Source: www.rc-electronics-usa.com)

the 24-V gel cell source. As I already explained, drawing high currents from these batteries trades off current for capacity.

The advantage of a gel cell (other than being deep cycle) is the gel. This makes the battery spill-proof and maintenance-free. Therefore, you can

mount it in any orientation. Foregoing these advantages will save a little money with less expensive non-gel deep-cycle batteries. A typical gel cell 12-V, 100-A-h battery costs around \$220, while a sealed lead acid (SLA) battery with fiberglass mat separators (instead of gel) costs around \$194. A typical deep-cycle battery used for marine maintenance (of a similar capacity) costs approximately \$144. The gel cell batteries used on this bicycle (12 V, 12 A-h) have a replacement cost of around \$30 each.

MOTOR & CONTROLLER

When 24 V is applied to this permanent magnet motor, it can achieve 2,600 RPM. A planetary gear on the motor reduces shaft speed by a ratio of 19:4. The chain drive (motor pinion to rear wheel) has an additional 3:1 ratio, bringing the maximum rear wheel rotation to around 180 RPM. The rear tire has a radius of approximately 11"

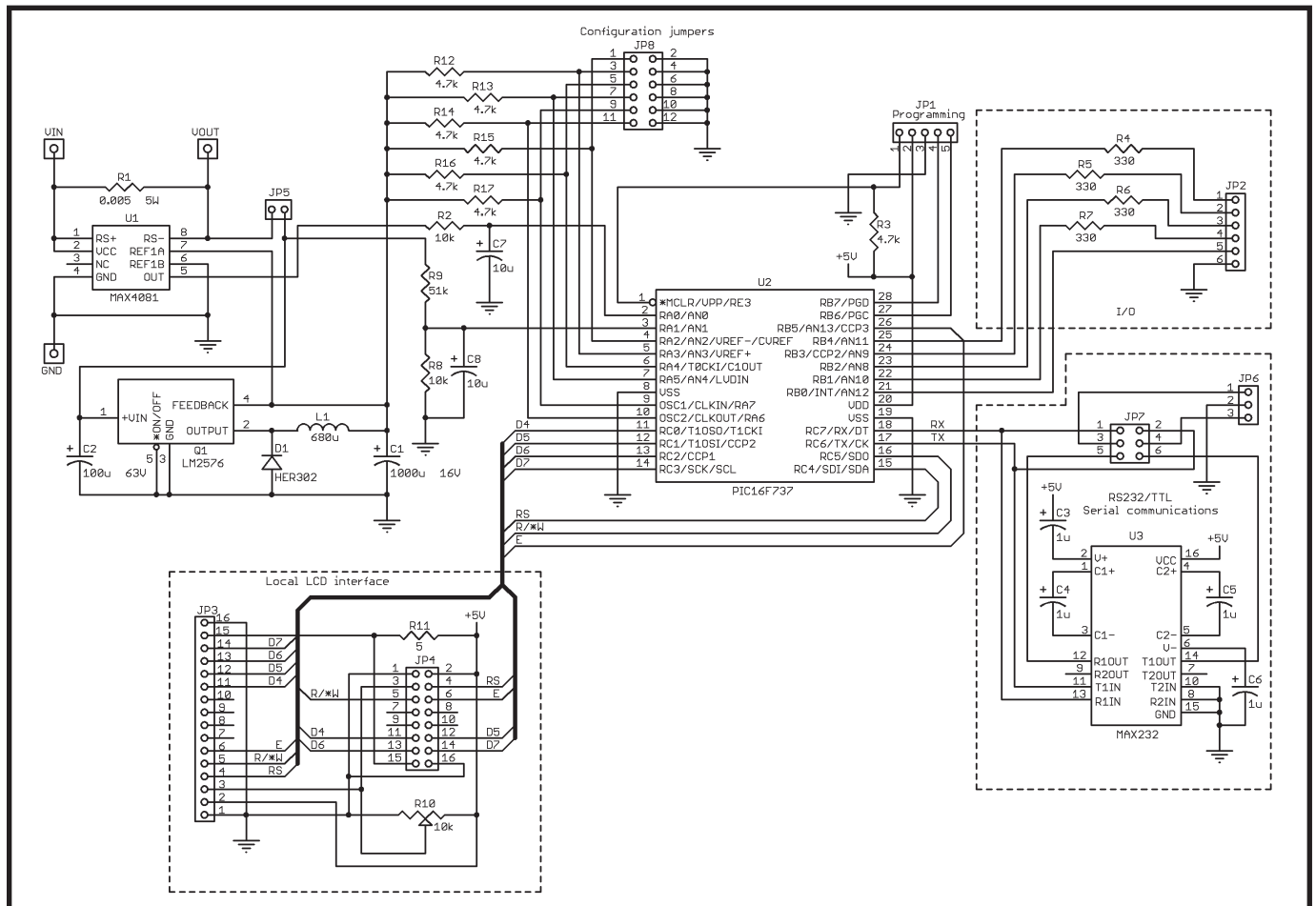


Figure 1—This is a schematic of the design presently used in this project. While a local LCD is used for monitoring and debugging, it may disappear along with the RS-232 if I choose to go with some alternative for connecting additional I/O. I could have the only bicycle in the world with a LIN bus. We'll see.

(circumference = $2\pi r = 69.115''$).

Depending on the driver's weight, this will be reduced somewhat, but I'll use the nice round number of 69' (5.75') for the circumference, or the distance traveled per revolution of the rear wheel. By dividing 1 mile by eight, you know how many revolutions the rear wheel must make to travel 1 mile: 660 revolutions. Therefore, the theoretical maximum speed is:

$$\frac{180 \text{ rev/min} \times 60 \text{ min/h} \times 5.75 \text{ feet/rev}}{5,280 \text{ feet/mile}} = 11.76 \text{ MPH}$$

MEASUREMENT

Crystal Lake, which isn't far from my house in Ellington, CT, is nestled in one quadrant of two intersecting state roads that aren't heavily traveled. My running route circles the lake and requires using these roads for approximately 1 mile. This route's remaining secondary roads are more typical of New England; there are some pretty good hills. This makes a perfect test track for the types of terrain normally encountered here in New England. Driving in this region generally doesn't require any great distance, but there are hills almost everywhere you go.

Although our automobiles have considerable mass, they have been designed to roll fairly well. Wheel bearings help keep friction low. Getting the vehicle moving requires the most work. The supply of energy necessary to keep it going is minimal and therefore produces the best fuel economy. That is until air friction becomes a large part of the equation and reduces the vehicle's MPG. An enormous amount of energy is lost whenever you brake (not so however with the regeneration possible in electric vehicles). This is one reason city driving produces lousy MPG numbers in gas-powered vehicles.

This project was an attempt to map energy use of the electric bicycle so that it could be analyzed easily and compared to a terrain map. To do this, I

had to measure both the voltage output of the storage batteries and the current used by motor at some periodic rate. With this data, I calculated the instantaneous energy (watts) and the average power usage over an hour (watts per hour).

It would be most productive if this design took into account higher voltages and currents such that the hardware would continue to be useful if the project were to expand in the future to a larger vehicle. This might use a 48-V source with currents up to a few hundred amps. An on-board current sense resistor is capable of handling about 25 A. To measure higher currents, an external current sense resistor is necessary because of its physical size. High current sense resistors usually have four terminals associated with them (see Photo 3). At high currents, the leads contribute some drop and generate an erroneous reading. By providing the high current its own path to the sensor, the other pair can more accurately measure directly at the sensing junction.

As you can see in Figure 1, all of the current either going to the battery or being provided by the battery will go through R1, which is a 0.005 Ω 1% 5-W current sense resistor. The MAX4081 in Figure 2 has the special ability to indicate positive and negative currents. It can withstand 4.5 to 76 V, requiring just 75 μA . Although the part has fixed gain, it is available

in three fixed gains 5, 20, and 60. In this application, a reference of 5 V_{CC} is supplied to the REFA input while the REFB input is grounded. This sets a reference voltage of 0.5 V_{CC} on the positive input of the output amplifier.

With no input from the input amplifier (no current flowing in the sense resistor), the MAX4081's output will be 0.5 V_{CC} . The Maxim part used here has a gain of 20, which means that any voltage measured on the sense resistor will be multiplied by 20 and added to the reference (0.5 V_{CC}). Note that 10 A through the 0.005- Ω current-sensing resistor will cause a voltage drop across the resistor of 0.05 V (i.e., $0.005 \Omega \times 10 \text{ A}$). This 50 mV is multiplied by 20 (i.e., $0.05 \text{ V} \times 20 = 1 \text{ V}$) and will add or subtract 1 V from the reference of 0.5 V_{CC} depending on the direction of the current flow. Thus, a 0- to 5-V output for the MAX4081T would represent a -25 to 25 A measurement. Using a 10-bit ADC, that is 512 bits per 25 A, or approximately 48 mA per bit.

A maximum input voltage limits most regulators (i.e., 7805 = maximum 35 V). Designing for 48 V or higher limits your choices. Fortunately, National Semiconductor's LM2576HV regulator can withstand up to 60 V. This buck-switching regulator can provide 3 A of regulated power, but this circuit requires only a fraction of that. Because the battery voltage for this design might be 6, 12, 24, 36, or 48 V, this voltage will always exceed V_{CC} . Therefore, a voltage divider must be used to reduce this to no more than V_{CC} (5 V). In this case, when two 12-V batteries are used, I use a divider of six. A battery reading of 24 V will therefore look like 4 V (i.e., $24 \text{ V}/6$) to the ADC (leaving some headroom to 30 V). A constant in the code can be adjusted if this divider is changed.

CONTROL

The removable replica V-Twin gasoline engine houses the two 12-V gel cell batteries and the DC motor controller. This enables the batteries to be carried

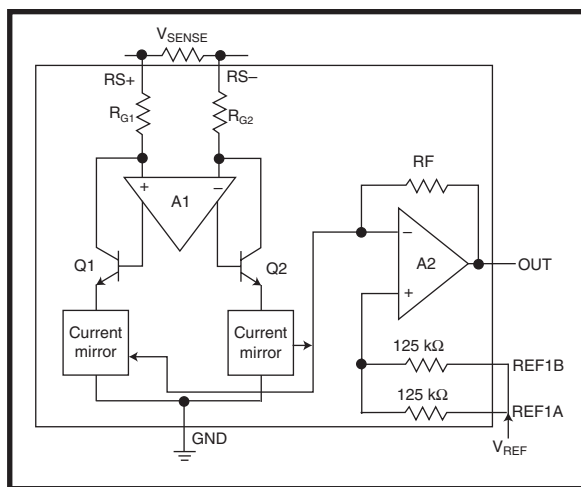


Figure 2—The MAX4081 has the properties to measure both positive and negative current flow. It is available with a fixed gain of 5, 20, or 60. I use a 5-W, 0.005- Ω current-sensing resistor to provide a 0- to 5-V output representing -25 to 25 A.

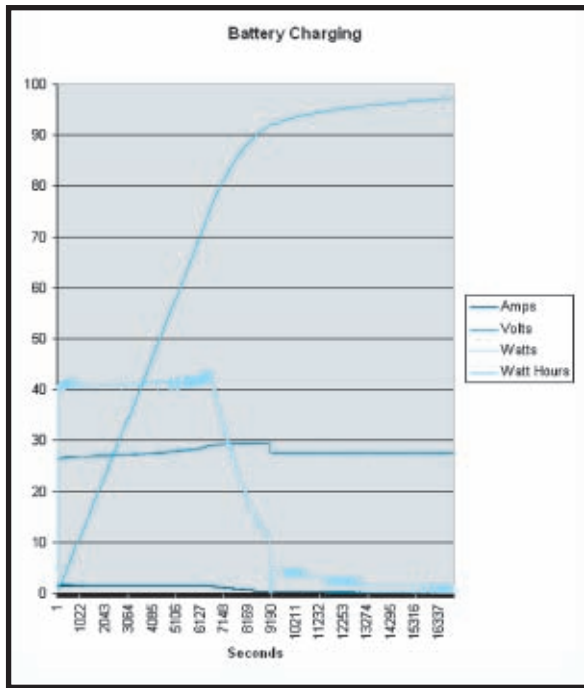


Figure 3—This Excel graph comes from a text file captured by HyperTerminal. The serial data is the result of recharging the gel cells from an external battery charger that came with the I-Chopper. Voltage and current are measured values, while watts and watt-hours are calculated. Can you see where the charger changes charging modes?

indoors for charging (or security) if necessary. Two connections are required from this pack to the bicycle: power and throttle. The twist-grip throttle has two purposes: input and output. As an input device, the throttle supplies a 0- to 5-V control signal to the motor controller. This sets the duty cycle for PWM control of the motor. The controller also uses the throttle as an output device. It pays attention to battery voltage and creates a gas gauge using three LEDs: full, two-thirds, and one-third. These trip points (approximately 21.7 V for two-thirds and 19.5 V for one-third) are reset only when the power has been recycled. A low-battery indication of 18 V (one-third LED blinking) shuts down power to the motor to prevent battery damage due to excessive discharging. Lower battery discharges can reduce the overall life of the batteries. (Don't plan trips that will tax the battery's limits. Recharge the batteries as soon as you can.)

The plan at this time is not to redesign the controller (assuming it is designed well). I will monitor the energy instead. With the present design, I can monitor both the energy

going into the batteries during charging and the energy coming from the batteries to move the vehicle.

You may have noticed a connection in the schematic for a local LCD interface. It is used for debugging and the real-time monitoring of the voltage and current levels. I've programmed a 1-s update rate to display the present voltage and current measurement. Using these values, I can calculate the wattage that these measurements represent. In addition to power, I can calculate the total energy used by summing the wattage calculation into a watt-hour total (based on 3,600 1-s periods.)

The microcontroller's hardware UART enables this (or any) data to be sent out as serial data. The serial output is formatted so that it is ASCII data that can go to a PC (a laptop in this case). It is captured as a text file, which can be imported into Excel so you can graph the data. Figure 3 is an Excel graph produced from captured data during a charging cycle of the gel cells. Notice that charger begins with a constant current mode, followed by a constant voltage mode, and ends with a reduced constant voltage mode to maintain the proper charge. The charger's power LED turns from red to green at the third stage, indicating the charging is complete.

BELLS & WHISTLES

Although this proposed circuitry is sufficient to monitor and capture the data necessary to do some basic analysis, I can't help but take this opportunity to introduce some other aspects that can be associated with electric vehicles. These will include additional input and output devices. I may also try the LIN network used in the auto industry.

Are electric vehicles ahead of their time? Even if every vehicle on the

road today became electric overnight, we'd still be dependent on oil for electricity generation. Although this might reduce pollution and greenhouse gas production, it wouldn't solve our energy crisis. How quickly we forget about the gasoline rationing of the not-too-distant past.

Our civilization needs a long-term energy plan. We need to treat this like we treated the process of going to the moon. We must be willing to invest in the research and development necessary to accomplish the plan within a challenging timeframe. Ultimately, this will have the largest return on investment for our civilization. We could use a good challenge right now. ☐

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.

RESOURCES

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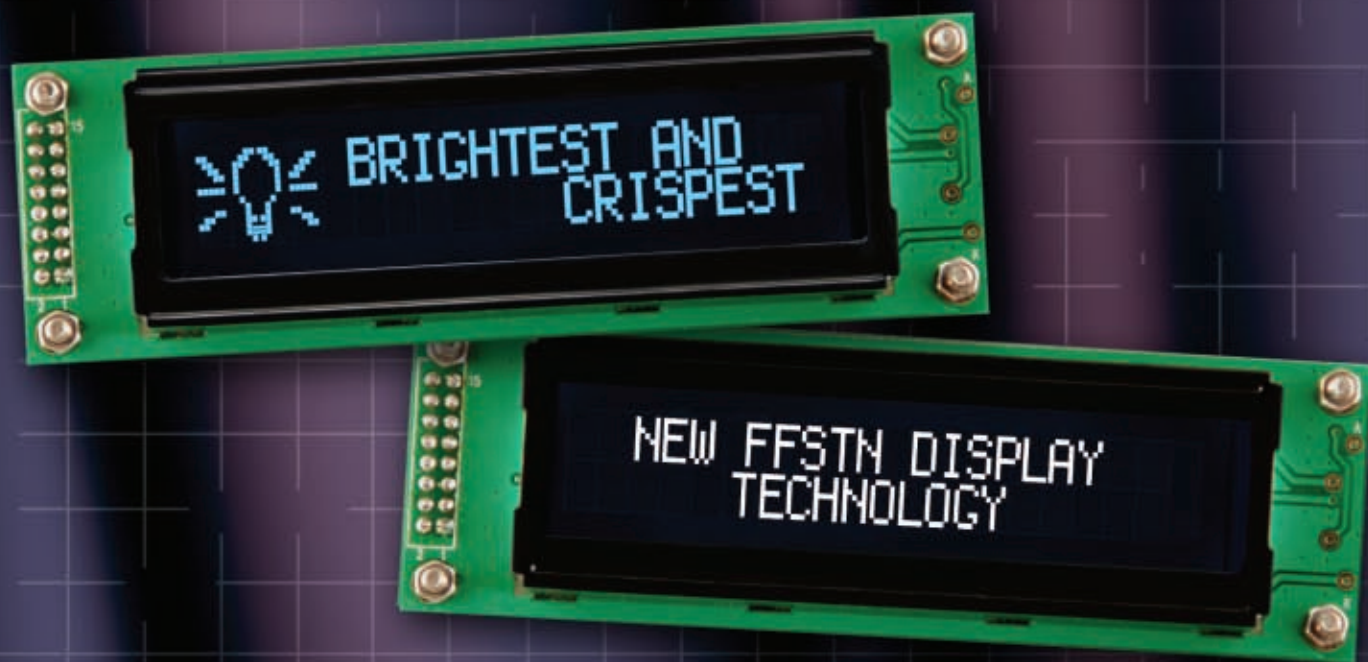
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RC Electronics, Current Shunt Resistor Specifications, www.rc-electronics-usa.com/buy-current-shunt.html#csspecs.

SOURCE

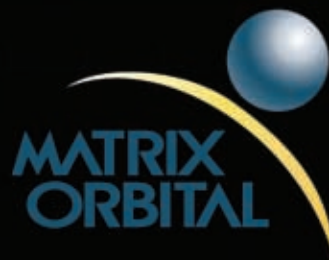
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Traveling Man

Tom recently traveled to the Embedded Systems Conference in Boston and the ARM Developers' Conference in Santa Clara. This month, he introduces many of the new embedded technologies that may soon figure prominently in your designs.

Well, I'm a California man,
my instrument in hand I'm electrified
On a fast flying trip, dirty laundry in my grip,
mostly drip-dry
We got the 17 jewels that dictate the rules
And the time to fly, as we're passing by
We just got the time to say hello,
and then a fast good-bye
I'm a traveling man

—The Association, "Six Man Band," The Association's Greatest Hits, Warner Brothers, 1968.

I'm sure there are good reasons why most of the industry's events are scheduled in the fall and spring, namely that folks have other stuff to do over the summer and winter holidays. Nevertheless, having just attended two shows on two coasts in two weeks, I wish the various event organizers would check each other's calendars. Oh well, it's a tough job, but somebody has got to do it.

The good news is that the Embedded Systems Conference in Boston and the ARM Developers' Conference in Santa Clara both had a lot to offer in the way of new announcements. Judging by the activity level, I'd say that the embedded business remains strong and steady, as it always has. It's the tortoise to the flashier PC and consumer markets here, but I'm putting my money down on the turtle.

My watch doesn't have 17 jewels since, like every other embedded gadget, it's electrified. And right now it

says it's time to shake off the jet lag and get down to the business, and chips, at hand.

MCUs ON THE MARCH

The embedded MCU business may be a tortoise, but parts continue to proliferate like bunnies on Viagra. It's a wonderful time to be a designer, with a dizzying array of more-for-less chips to choose from, as you'll see. But before I get into the announcements, a few prognostications on the overall "micro" market, notably the difference between a "processor" and a "controller."

In the old days, it used to be easy to categorize parts into clearly defined categories: microprocessor (i.e., MPU), microcontroller (i.e., MCU), 8-bit, 32-bit, etc. For example, most MCUs

were 4- or 8-bit, while a 32-bit chip was surely an MPU. If a part had on-chip program memory it was an MCU, while if it required external program memory it was an MPU. But these days, the proliferation of parts that cross boundaries means relying on simple hardware specs (like "bitness") doesn't tell the whole story.

I see the microcontroller market dividing into two segments, which I'll call "computer" and "controller." Naturally, the computer segment includes chips like the 'x86 in your PC, but it also includes other high-end microprocessor chips (notably PowerPC and top-of-the-line ARMs) that drive computer-in-drag applications like video games, cell phones, set-top boxes, and so on.

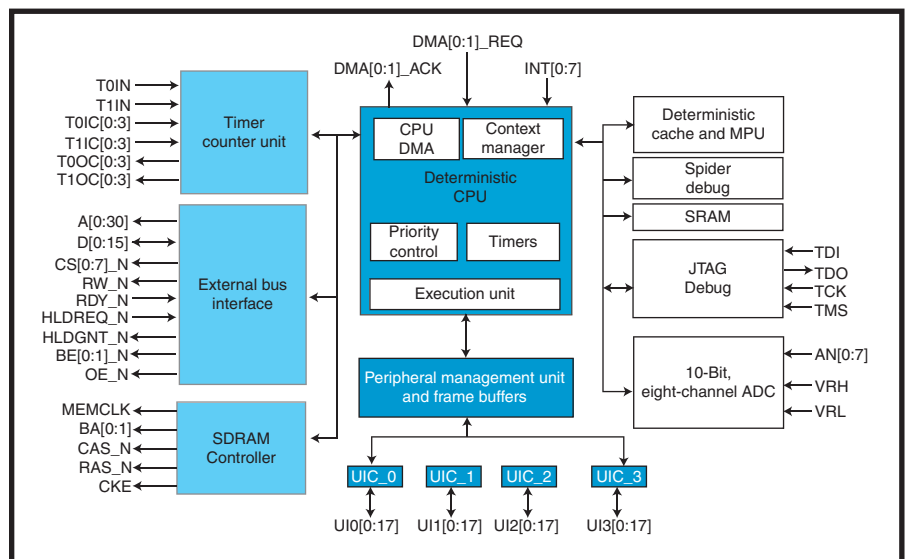


Figure 1—This chip is a real dog and proud of it. The FIDO micro from Innovasic is an interesting combination of old-school CISC architecture and new-age I/O.

Now, I could try to define the various hardware characteristics that differentiate computer and controller chips. But it's simpler just to say that if the chip can run a big-iron OS like Windows, WinCE, or Linux, then it's a computer (MPU). If it can't, it's a controller (MCU).

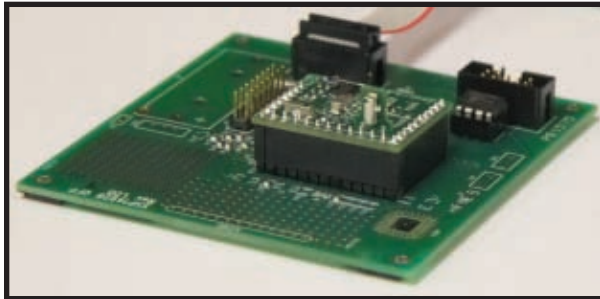


Photo 1—The new Sensor Platforms evaluation kit uses a mezzanine approach to allow plug-and-play connection of various devices to their sensor-centric '51 MCU.

One thing an MCU needs is a long lifetime. In the MPU world, a chip may live just a few years before it is replaced by a later and greater one. That's generally OK because the lifetime of the equipment it's in (e.g., PC and video game) is itself only a few years.

By contrast, the applications that include MCUs (such as cars and appliances) have lifetimes that can be measured in decades. So, let's start with old home week, and the '51s from Tekmos that drop into sockets designed when disco was king and feature the "classic" timing (fast as a turtle) and 5-V supply of the original. If you're willing to cough up a bit of NRE, Tekmos can also custom mix your favorite '51 flavor, including a hopped-up core with stacked die flash memory.

Meanwhile, Sensor Platforms lives up to their name with a new development board for their sensor-centric, mixed-signal '51. The new platform comprises a baseboard containing the MCU and a defined mezzanine con-

necter for adding on specific sensors (see Photo 1). The board comes with an e-compass (i.e., magnetometers) add-on. In addition, they plan to work with sensor providers to offer other standard add-ons and, of course, you're invited to roll your own.

Innovasic is another outfit that relives the past with socket-compatible replacements for old-timey chips like the Intel '186 and '188. Now, they're also branching out with their own chip, the Flexible Input Deterministic Output (Fido) micro with a new CISC architecture that, get this, runs the 68K instruction set. Get past the marketspeak, and you'll find a part with some interesting features (see Figure 1). For instance, the Fido1100 comes with four universal I/O controllers (UICs) that can handle serial I/O variants from 10/100 Ethernet to CAN and everything in between, including UART, SPI, and P_C. The chip also adheres to a real-time philosophy with a so-called

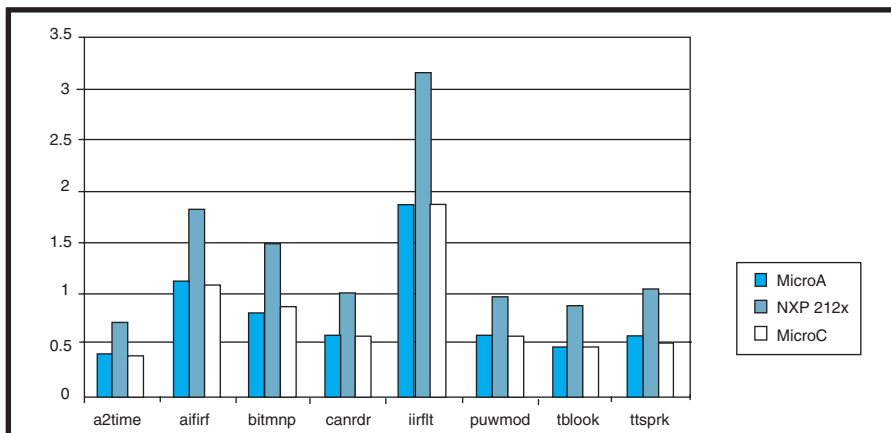


Figure 2—An EEMBC benchmark comparison of three ARM7 MCUs is revealing.^[1] Based on the widely (ab)used "Dhrystone/MHz" metric, these three chips might be expected to deliver similar performance, noting that the same compiler is used for all three. But as you can see, the NXP LPC achieves higher performance by virtue of superior implementation that bypasses the flash memory bottleneck.

+++ NO ROYALTIES +++

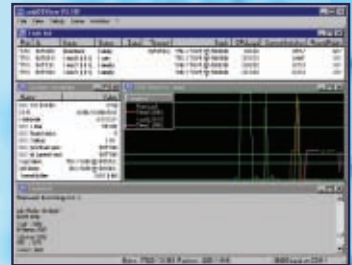
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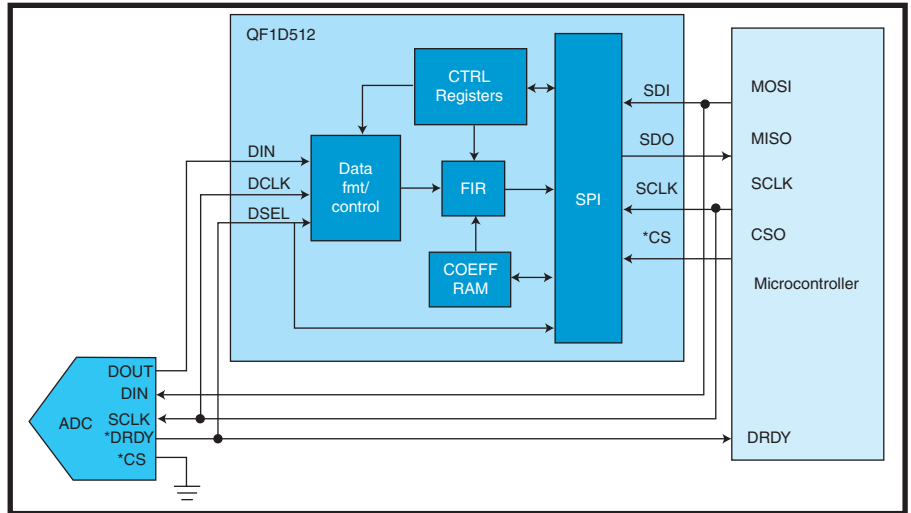


Figure 3—With a 512-tap digital filter, Quickfilter brings a measure of DSP capability to even the lowest MCU design. The new single-channel chips work with typical serial ADCs and can be daisy-chained for multi-stage filtering.

“deterministic cache” and multiple register banks for fast context switching. It may not be purebred, but like a loveable mutt, they say it could be an engineer’s best friend.

The CISC-revival continues with something new from old-timer Zilog. With a 16-bit ALU, 16 × 32-bit registers, and 2-, 4-, and 6-byte instructions, the ZNEO also has a 68K feel. Along with future ARM-based parts

Zilog has on their road map, ZNEO gives them a beyond-64-KB solution for their Z8 customers right now.

Speaking of ARM, the bandwagon continues to gather momentum with announcements from MCU heavyweights Atmel, NXP (Philips), and ST.

The “E” in the new SE versions of Atmel’s ARM7 MCU stands for “expanded,” referring to the addition of a high-speed external bus interface

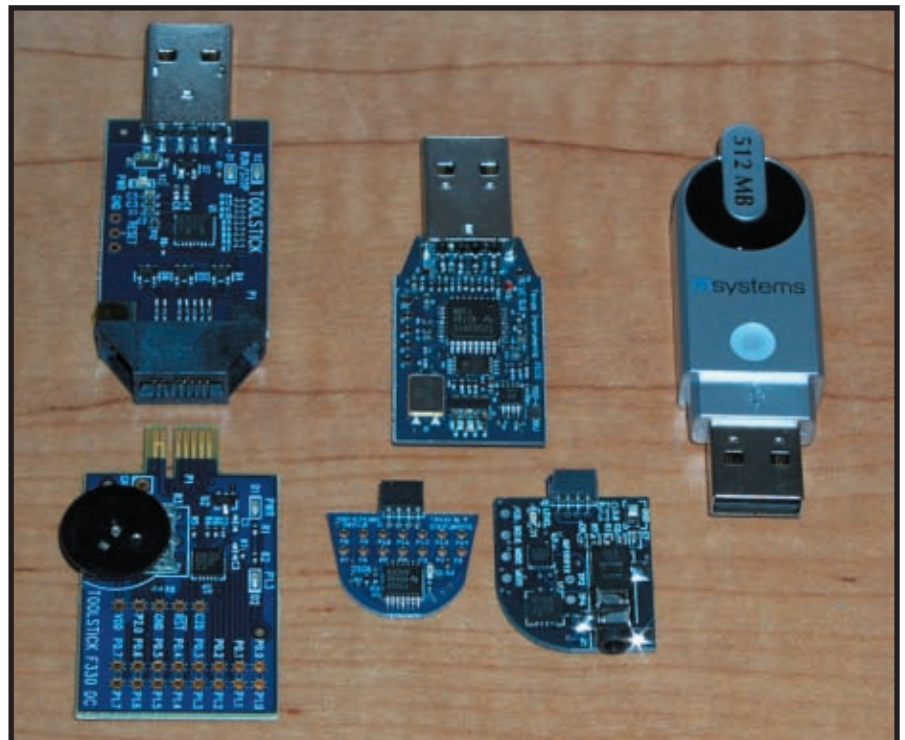


Photo 2—My keychain runneth over thanks to the latest batch of embedded USB gadgets. From left to right, you see MCU evaluation units from Silicon Labs (note the potentiometer), Texas Instruments (including the Quickfilter add-on), and a secured flash memory drive from Msystems.

(EBI) for adding peripherals or humongous amounts of flash memory or DRAM. The SE is a good example of the point I made earlier, namely that just because a chip can connect to gigs of external memory, that doesn't make it an MPU. Rather, it recognizes that sometimes MCU applications need large amounts of storage (e.g., MP3 player) even if they aren't running a fancy OS.

The headlines always focus on CPU megahertz and MIPS, but savvy designers know that the performance of the processor core is only half the battle for I/O-

intensive embedded applications. After all, you can drop a big engine into a little car with skinny tires, but you'll probably just spin the wheels. Getting the bits from here to there calls for rubber-meets-the-road I/O features like DMA and optimized bus arrangements rather than just more MIPS.

There's no better example than Atmel's new ARM9-based AT91SAM9264. DMA controllers for each on-chip peripheral (e.g., Ethernet, USB, and LCD controller/accelerator) talk across a total of 11 (!) on-chip busses capable of an aggregate 40-plus-Gbps bandwidth (yes, that's a capital "B"). Taking the idea even further, the chip includes two external busses, one for memory and I/O as usual and one dedicated to the LCD subsystem.

It's no surprise then that NXP takes the same tack with their newest members of their ARM7-based LPC2300 lineup, in which the processor, USB, and Ethernet all have their own bus and can operate concurrently.

The NXP LPCs have another advantage in the form of their memory accelerator module (MAM). The MAM deals with another truism of no-cache MCUs, namely that the speed of on-chip flash memory, not CPU architecture, is the basic performance limiter. The MAM uses a wide 128-bit prefetching bus to squeeze higher performance from their flash memory and the results can be quite dramatic



Photo 3—Puzzled by ZigBee? Digi has acquired the pieces (i.e., Rabbit and Maxstream) needed to put it all together.

(see Figure 2).

ST joins the chorus with ARM7- and ARM9-based parts that are in the same key. On the ARM7 front, their STR710 features an external bus interface like that of the Atmel SE. And for blue-collar industrial and automotive designs, their STR730 and STR750 offer an extended temperature range (-40° to 105°C) and back-to-the-future 5-V I/O capability.

I remain impressed by the company's STR91X line, which stands as a great example of how to turn an

ARM9 MPU into an MCU by ditching the MMU and cache and adding a bunch of flash memory and SRAM. It may not run Linux or Windows like most ARM9s, but it does offer plenty of object-code-compatible performance and memory headroom for ARM7-based designs.

CHARM SCHOOL

Which brings us to ARM, Inc. and their Cortex initiative. As you may recall, Cortex is a completely new architecture (i.e., new variable length Thumb-2 instruction set) with three versions (A, R, and M) representing

upgrades to today's ARM11, ARM9, and ARM7, respectively.

I suspect the folks in Cambridge may have underestimated the marketing challenge of juggling the old and new architectures. The fact is, there's a bit of angst in the marketplace as both customers and existing ARM licensees try to figure out which way the wind is blowing (and blow it their own way in the meantime).

Just for laughs, try inviting a current ARM7 MCU supplier (e.g., NXP or

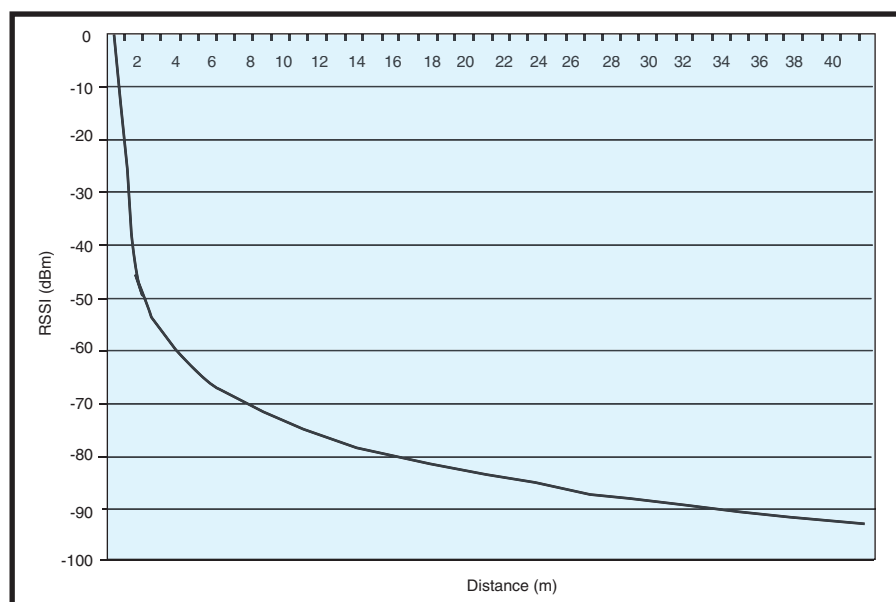


Figure 4—Chipcon, now owned by Texas Instruments, brings a measure of location-finding capability to ZigBee applications. The trick is to use the receive signal strength indicator (RSSI), noting the relationship to distance is nearly linear in the range from 10 to 40 m.



Photo 4—Batteries not included. They aren't needed with this 25-W fuel cell from Ultracell. Actually, future "hybrid" designs may include a battery and power manager to automatically handle intermittent power surges beyond the fuel cell's rated output.

Atmel) into a meeting with CortexM3-based start-up Luminary Micro and see what happens. Can we all get along?

Not to worry. I don't think Cortex will obsolete ARM; nor do I think Cortex is DOA. Both can succeed for the same reasons, which, by the way, have little to do with the technical trinkets. The bottom line is that the popularity and staying power of an architecture is all about sources (the number of suppliers) and seats (a bandwagon of designers).

The ARM architecture already has plenty of sources and seats, and as expected, Cortex is getting them apace. Joining Luminary, ST says they plan to integrate Cortex-M3 into their lineup. And Actel has also licensed the core, giving customers of their intriguing FPGA soft-core solution a choice between ARM7 and Cortex-M3. Have it your way.

SOFTWHAT?

Don't get me started on software. When it comes to both tools and their bloatware tendencies, I'm disappointed in the progress, or rather lack of same, made over the years. Oh well, hand wringing does no good. The fact is that even the best hardware is useless without some software. There may not be a Moore's law for software, but nevertheless there are some software shops that I'm impressed with.

One is Micrium, an outfit that not only produces quality code, but also has a friendly approach to doing business. Notably, they make their code (source included) available for free evaluation, and you have to pay only if you carry it forward into a commercial product. I believe that putting the source on display for all to see naturally imposes discipline that makes for better code. Joining their μ C/OS RTOS, Micrium is now offering a complete TCP/IP stack under the same try-before-you-buy terms.

I stopped by the CodeSourcery booth to get the latest on their GNU-based toolchains. The last time I looked ("ARMed and Dangerous," *Circuit Cellar* 194, 2006), they were still running Linux-based command line versions, something that may appeal to hardcore programmers, but not to me (or IT departments that don't want you messing with the OS). Now I'm pleased to report they have an Eclipse version that runs under Windows and delivers the point-and-click graphics IDE that most users prefer. As an aside, I note they support the Innovasic Fido chip mentioned earlier, along with other popular chips, including ARM and ColdFire.

CMX is another outfit that gets it when it comes to lean-and-mean deeply embedded applications, notably delivering big-iron functionality (e.g., RTOS and TCP/IP) that runs on low-cost MCUs. Now they've expanded their lineup to include USB software and flash file systems that provide another way for your embedded application to make a PC connection. Deal of the month: free USB software for ColdFire chips, presumably courtesy of a subsidy from Freescale.

PLUG FEST

The embedded crowd is hijacking the USB flash memory drive form factor to its own ends (see Photo 2). Outfits like TI and Silicon Labs practically give the gadgets away as mini-me MCU demo units that allow customers to kick the tires or even use them as poor man's development platforms.

Quickfilter has a new variation of their digital filter chip that I covered a while back ("FIR Factor," *Circuit*

Cellar 188, 2006). This time around, they've removed the ADC and downsized to one channel (versus four previously) in order to allow customers to choose their own ADC (speed and resolution) and reduce cost (see Figure 3). Taking the USB craze to the next level, they offer a tiny evaluation board that piggybacks on the aforementioned TI unit.

Msystems gave me a sample of a USB flash memory drive with a difference, namely built-in security utilizing their encryption accelerators. The idea is these things now have enough memory capacity (e.g., 1 GB and beyond) to carry around the personality of your own PC in the form of applications, settings and data. That means you can plug the widget into any public PC, giving it a temporary brain transplant to mimic your personal PC setup. When you're done, ejecting the drive removes all traces of your personal data from the public PC.

Future Technology Devices International (FTDI) is one of the outfits that has enabled the embedded USB takeoff. Their USB-to-serial adapter chips provide a quick-and-easy way to retrofit serial-based designs for USB connection to a PC.

Turning your embedded gadget into a USB device is cool. But turning it into a USB host is another story. First, the USB host-side stack software is much more complex and requires more memory than a device. And even if you get to that point, there's still the matter of software required to complete the PC impersonation.

For example, let's say you want to plug a USB flash memory drive into your embedded design so you can use it to transfer data to/from a PC. Even if you get your design working as a USB host, you still need more software to handle the mass storage device class and PC FAT file system.

FTDI has an easier solution with their new Vinculum (from the Latin *vincere* for the binding of objects together). It integrates the additional resources (including an MCU and memory) needed to function as a host and also a FAT file system driver, all fronted with familiar and easy-to-use commands (e.g., DIR, CD, MKDIR,

REN(ame), etc.).

ZIGBEAT

When it comes to new standards, it's a truism that little heavy-lifting takes place on the software front until there's hardware to play with. And that's where we're at with ZigBee: lot's of hardware solutions just waiting for some clever software to put them to work.

Digi has been pulling the pieces together. First, they bought Rabbit Semiconductor, an outfit known for their networking SBC expertise. Then, just recently, they picked up Maxstream, a popular supplier of ISM-band (e.g., 2.4 GHz) RF modules. Put the two together and you've got an easy-to-use and low-cost platform to crank some code (see Photo 3).

Similarly, TI is bringing recently acquired Chipcon and their ZigBee chip expertise into the fold. They had a cool demo going in their booth, demonstrating a measure of location-finding capability (see Figure 4). It's just the thing for finding lost car keys.

And it's just the thing to inspire this heads-up. The IEEE is looking into a next generation of the IEEE 802.15.4 radio spec at the heart of ZigBee, a revision that targets location finding as a key capability. So far, the 802.15.4 "a" folks are still investigating the basics (e.g., modulation), with alternatives including ultrawideband (UWB) on the table.

POWER TRIPPING

Yes, indeed. There are quite a bunch of cool new chips. Of course, they tend to stay that way until you power them up.

Enpirion makes single-chip switchers that pack a lot of power supply into a tiny package. Real estate, noise, and design hassles are all reduced by integration of the extras that surround a typical switcher chip, notably including the MOSFETs and even the inductor. The only requirements are two external capacitors and a 2.4- to 5.5-V power source and you're in business with seven-pin-selectable output voltage options (0.6 to 3.3 V), which can be changed on the fly or any voltage in between thanks to a resistor-tuning option.

Ultracell says you don't have to wait for Detroit to hop on the fuel cell

bandwagon. Their UC25 25-W power supply is said to deliver twice the energy density (i.e., half the weight) of a Li-on battery equivalent (see Photo 4). The fuel (2/3 methanol, 1/3 water) is reformed into hydrogen inside the unit. Each hot-swappable fuel cartridge is good for 180 Wh. I was looking for a drain plug, but the spec says there are no liquid water emissions.

ON THE ROAD AGAIN

Even trying to keep things short and sweet, I didn't manage to get through all the press kits and datasheets. Nevertheless, I think you can see where I'm coming from when I say there's a lot of neat stuff going on.

Of course, I'm already gearing up for the next round of shows. You can bet there will be even more new goodies to talk about. But right now, I've got a bit of unpacking and laundry to attend to, so it's time to say a fast goodbye. 📧

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.

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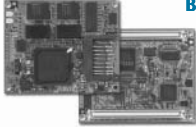
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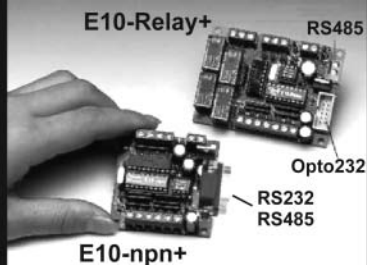


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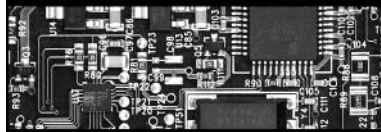
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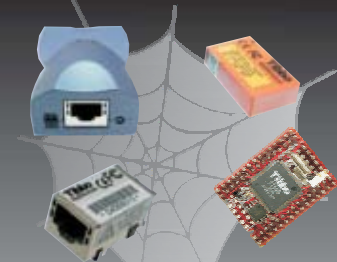
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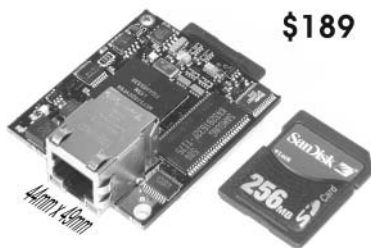


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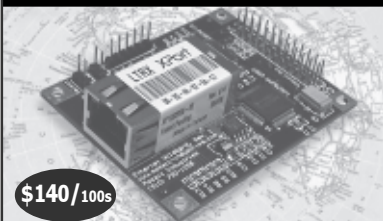
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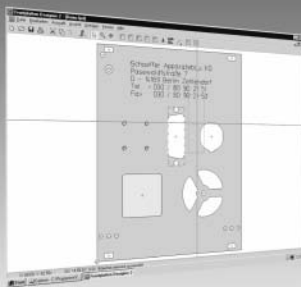
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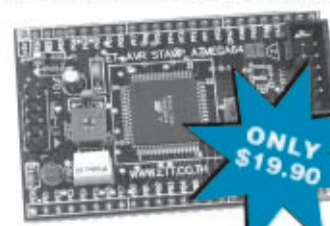
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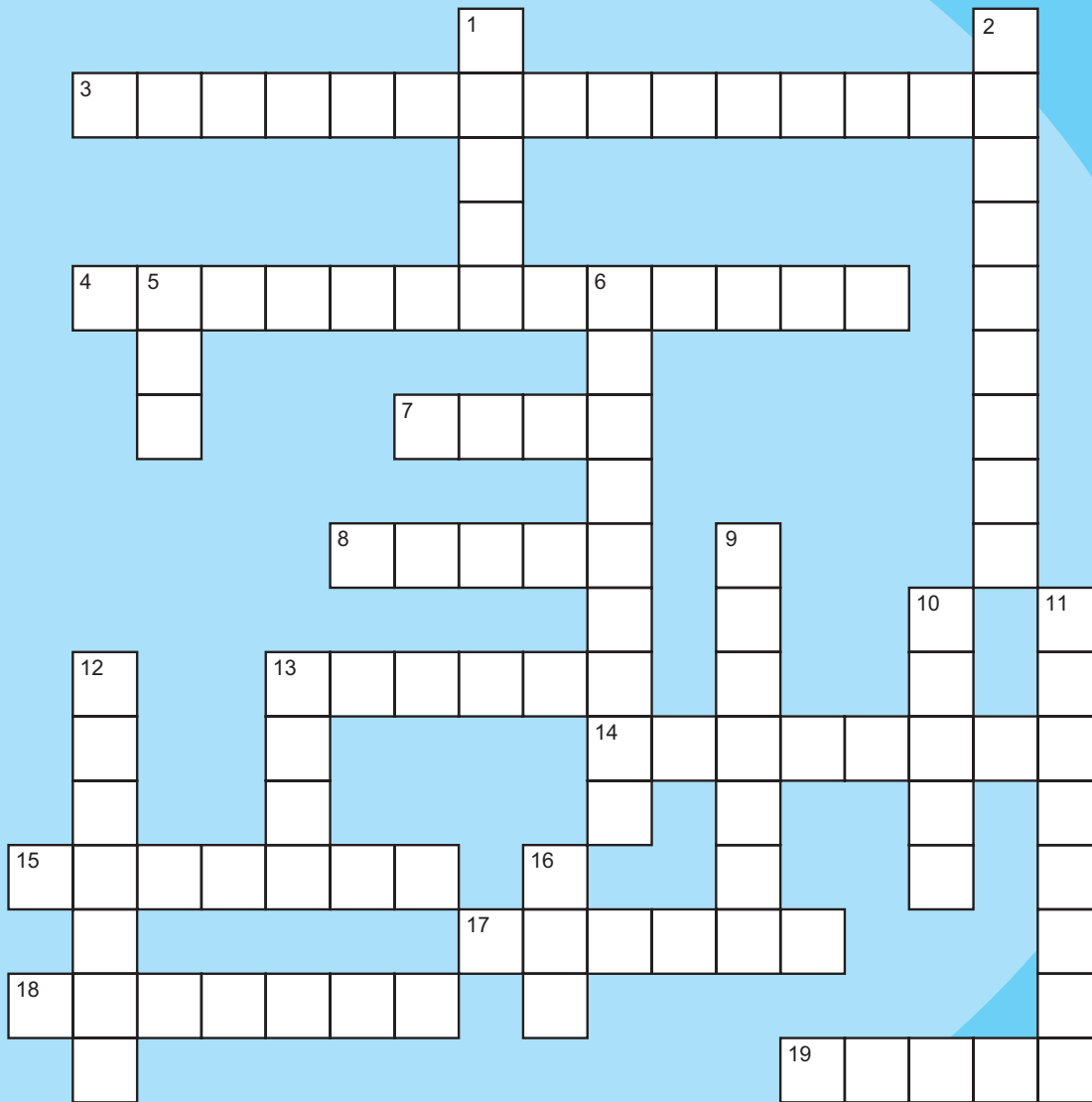
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Across

3. Computer chip used to run electronic devices
4. A circuit board that attaches to a larger circuit board
7. Unscramble the following:
ONSYSTEMCHIPPROGRAMMABLE
8. An "L" word. Not Google, not Yahoo!, not AltaVista.
13. The upper-level of the solar atmosphere known for low densities and high temperatures
14. A group of frequencies higher or lower than the carrier frequency
15. An open-source Internet search browser
17. The lowest points in the range of a function
18. Started in 2005, this free video-sharing site was purchased in 2006 by Google for approximately \$1.65 billion.
19. Causing dissolution of electrical energy

Down

1. His law (1965) regards the number of transistors on the most complex chips.
2. TM
5. Music file extension used by Apple's iPod
6. \
9. An acronym (typically used online) that means to jump around like a common zoo animal
10. To visit numerous web sites (or pubs)
11. The degree to which an electronic system correctly reproduces its input
12. A popular description language for hardware
13. American scientist (1943–present) born in New Haven, CT, who is known for helping develop the 'Net and the TCP/IP protocol. In 2005, Google hired him as a "Chief Internet Evangelist."
16. Bus system used in automotive networks

The answers are available at
www.circuitcellar.com/crossword.

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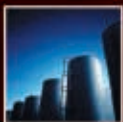
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PRIORITY INTERRUPT

by Steve Ciarcia, Founder and Editorial Director

A Home Control Event Worth Remembering

It's no secret that I'm a home control junkie. I've designed and installed a number of systems over the years and frequently written about the various interfaces I've attached. While some people use home control as sophisticated alarm systems or to enhance elaborate home entertainment installations, my application is primarily coordinated video and sensor monitoring.

Since I like spending more time at the "cottage" these days, my HCS is designed specifically to make sure that my house is still there when I return. Believe me, when you have as many miles of wire and powered devices (dozens) running all the time as I do, the mean time between failure (MTBF) of some device is always ending. Some are more critical than others.

On my first trip away last fall, there was a cold snap and the oil burners were getting their first real winter test. I could see that the guest room thermostat was calling for heat, the oil burner had turned on the circulator pump, there was heated water in the boiler, and that the temperature in the guest room was 55°. The bad news was that after 10 h the circulator was still running and the room was still 55°. Obviously, the heating zone was air-bound or the circulator pump was bad. Returning to a house with cracked or frozen pipes would not have been good. A quick call to John Gorsky at the office and the oil burner service company was at the house replacing a bad circulator pump within a few hours. Of course, I watched the whole replacement procedure via my web cams.

I'm not obsessive about watching all this stuff. My system is designed so that once a day I just have to look at an Excel sheet—which polls my sensors and gives a go/no-go status—and look at the driveway entry/exit log (Priority Interrupt #196) to know everything is OK. An HCS simply adds peace of mind for me. Ironically, however, a recent event demonstrated that my particular HCS configuration might have actually saved someone's life.

A few months ago, I was doing my daily check-in. At 10 A.M., I pulled up the entry/exit log and saw that a car had entered my driveway at 8 P.M. the previous evening. More curiously, the log showed an entry but no exit! Magnetic driveway sensors don't usually miss a whole car!

Next, I pulled up the web cam facing the driveway. It has internal flash memory and records about 30 s of video each time the driveway sensor is tripped. I could clearly see that a silver car came in at 8 P.M. OK, so where did it go after that? Unless you had a four-wheel drive vehicle and an adventurous personality, you were driving back out the same way you came in.

I started flipping on some of the other web cams around the property and, lo and behold, there was a silver Honda sitting at the end of the driveway headed toward the gravel road into the woods. I turned the 21× optical zoom toward the car and wrote down the license plate number. Then, as I panned around a bit more, I saw what looked like movement in the car. Say what?

I switched to another 21× PTZ camera so I could get a closer look at the car and pulled in tight on the driver's side window. Even through all the reflections on the glass I could see that there was a white-haired person sitting in the car. Since no other sensor on the property had been tripped, this person had clearly been sitting in the car since 8 P.M. the night before! It had been 10°F that night.

I called the office and asked John and Sean Donnelly to take a ride over to the house to check it out and call the police if necessary. About 10 min. later, I got a call from the Connecticut State Police asking why someone else was calling the police for my property. I explained that although I was sitting hundreds of miles away, I could see that there was someone in my driveway who shouldn't be there and might be in trouble. I explained that I was doing it via the Internet and web cams.

Of course, you know you live in a small town when it apparently rings a bell loud enough that the state trooper replies, "Are you that guy with all that electronics all over his house and yard?" Over the years, there have been a few times when the fire department and resident state troopers have shown up at my house (like when they were chasing a perpetrator who came ripping up my driveway and over the cliff behind the garage). "Yeah, that's me," I told the trooper.

That event was covered on television and in the newspapers, but to make a long story short, the woman apparently had Alzheimer's disease. Her husband had left the car running while he went into a Wal-Mart and when he came out, the car was gone. The state police instituted a statewide search (using helicopters) while she was driving the considerable distance that led her to my driveway that night. Considering the low temperatures and her apparent objection to exiting the car or otherwise seeking help, the rescue personnel believed she would not have lasted another night.

So, this is one HCS-monitored event that had a very happy ending. From my side of things, it was a media event for the next couple hours as I watched while piles of state and local police cars, rescue personnel, and an ambulance all jammed into my driveway. Needless to say, the entry/exit log on my HCS and the web cams captured everything.

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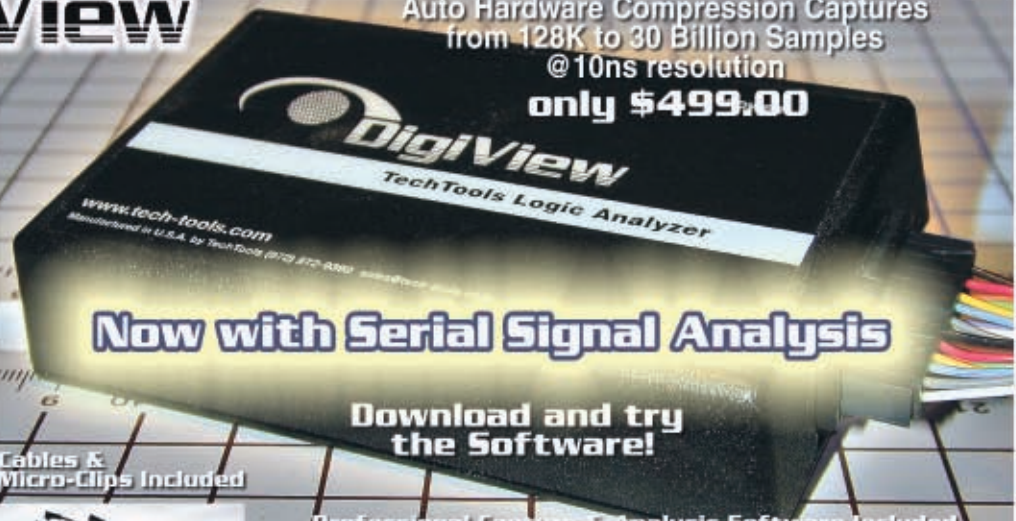
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