#203 June 2007

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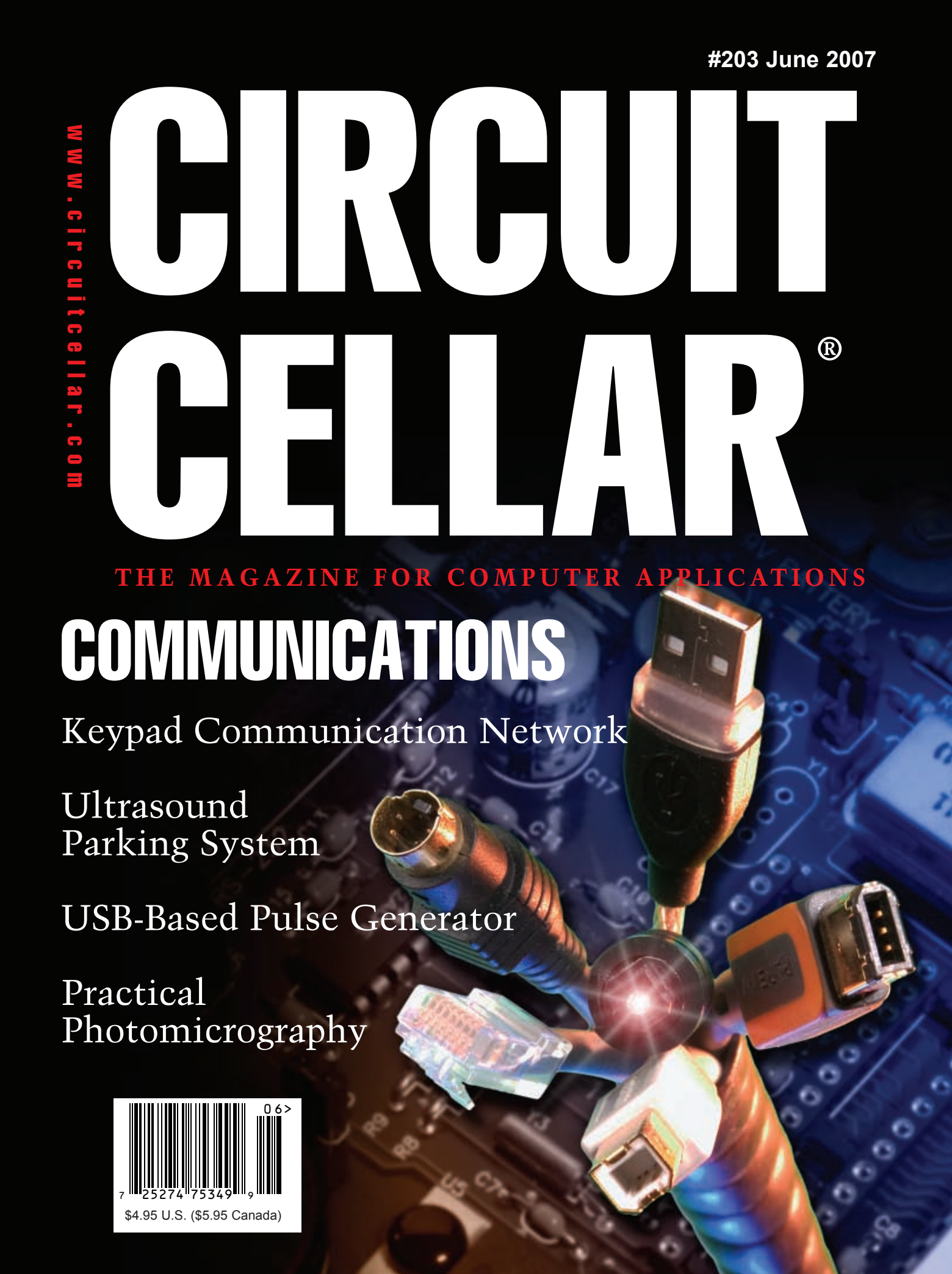
COMMUNICATIONS

Keypad Communication Network

Ultrasound Parking System

USB-Based Pulse Generator

Practical Photomicrography

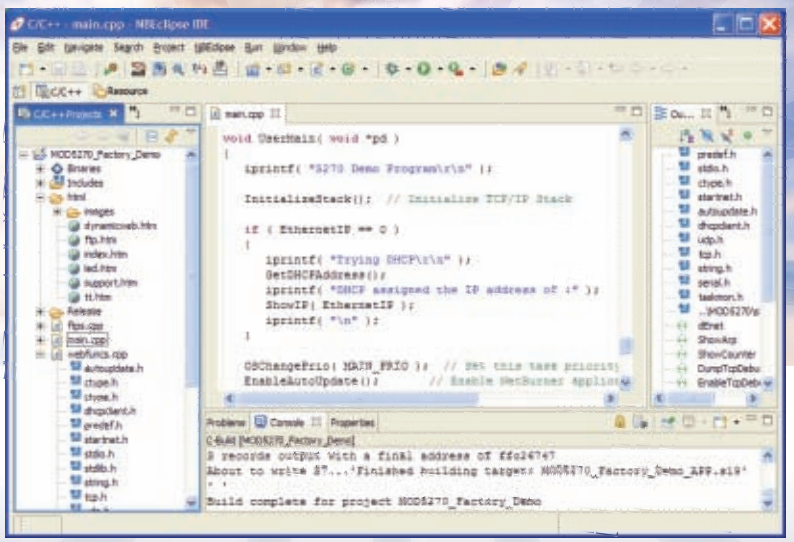


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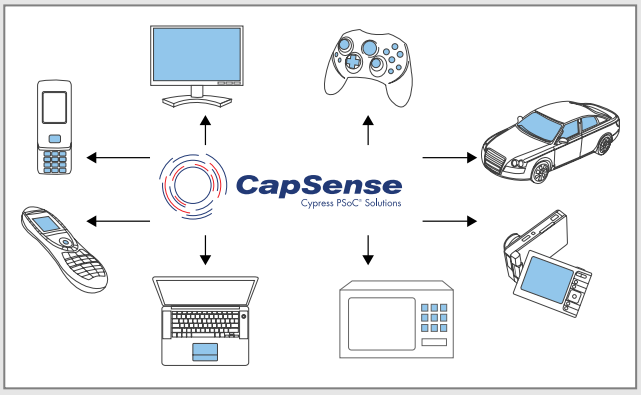
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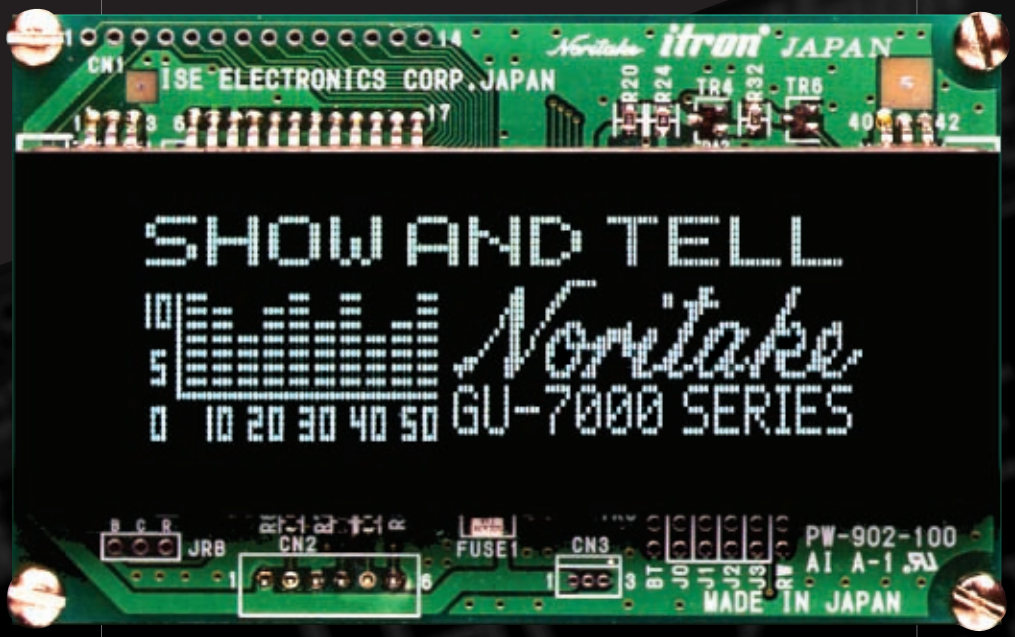
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TASK MANAGER

Projects, Projects, and More Projects

When I was at the Embedded Systems Conference in San Jose last April, I spent a lot of time studying the MCU-based systems on display. At one booth, I watched well-designed mobile robots track lines drawn on the floor of a small "robo arena." At another booth, I observed a mechanical arm quickly ordering and transferring DVDs in a compact shelving system. At the Luminary Micro booth, I took a close look at some of the projects that placed in the DesignStellaris contest. It was a lot of fun.

During the flight back to Connecticut, it struck me that all of the projects had something in common: similar designs have appeared in the pages of *Circuit Cellar*. I'm not suggesting that *Circuit Cellar* articles were the starting points for all of the interesting systems that I saw at the conference, but ask yourself, which other periodical has been running articles about such designs for the past two decades?

Over the years, we've published a number of articles about mobile systems and line-following robots. An example is the interesting system described by Peter Hiscocks and Jim Koch in "Electrical Engineering Robot" (*Circuit Cellar* 153, 2003). Looking for an article about an MCU-controlled mechanical arm that can pick up DVDs or any other small object? As recently as last March, we ran an article about a handy robotic arm controller (M. Hall, A. Patten, and E. Simpson, "Robotic Arm Control System," *Circuit Cellar* 200, 2007). And what about oscilloscopes? Jingxi Zhang and Yang Zhang won First Prize in the DesignStellaris contest for their LM3S811-based multifunctional oscilloscope. If you're a long-time subscriber, you've seen versions of similar systems described in *Circuit Cellar* as far back as 1988. The first was Russell Lindgren's article "10-MHz/8-bit Digitizing Board for the IBM PC: An Affordable Digital Oscilloscope on a Plug-in Board" (*Circuit Cellar* 5, 1988).

This month, we feature a variety of articles that will inspire you to start working on a project of your own. Perhaps the system you design will place in a *Circuit Cellar* design contest, end up on display at a major conference, or both.

If communication systems are your thing, start with the article "Network of Keypads" (p. 16). This system was designed by a team of engineers led by Dhananjay Gadre after their interest was piqued by a keypad system that they saw on a game show. After watching a few episodes of the international hit "Who Wants to Be a Millionaire?," this enthusiastic design team built a working keypad network of their own.

Want to know what it takes to place at the top of a major international design contest? Check out Naubert Aparicio's article about his video-based motion sensor (p. 24). The project won Third Prize in the 2006 Atmel AVR Design Contest.

If you pay close attention to the bylines when you read our articles, you're probably familiar with the name Peter Gibbs. This month, Peter and Ramon Sargeant describe an easy-to-use dew point monitor that they designed and built at the University of the West Indies (p. 32). The simple system cools a mirror and records the temperature when moisture forms on it.

As you read through the rest of the feature articles, keep in mind that we have a special treat for you this month. Ed Nisley decided to break from his regular analog and RF themes to cover another interesting topic: photomicrography (p. 71). An offbeat topic and cool pics: it doesn't get much better than this!

Please enjoy, and let me know what you think.

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C. Abate

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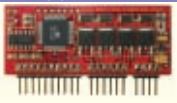


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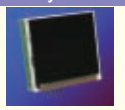
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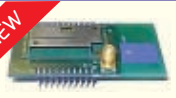


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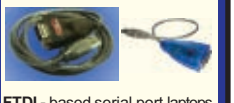
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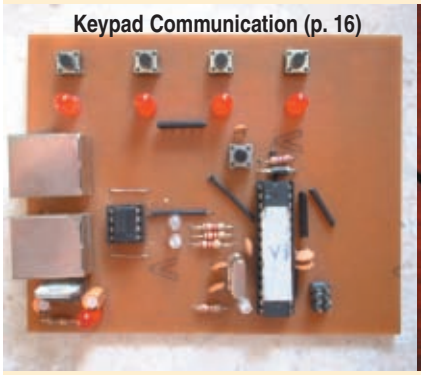
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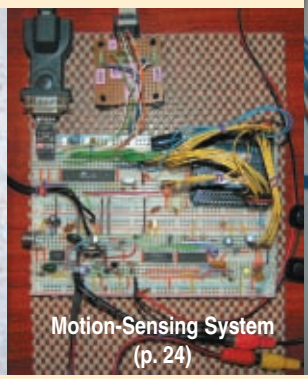
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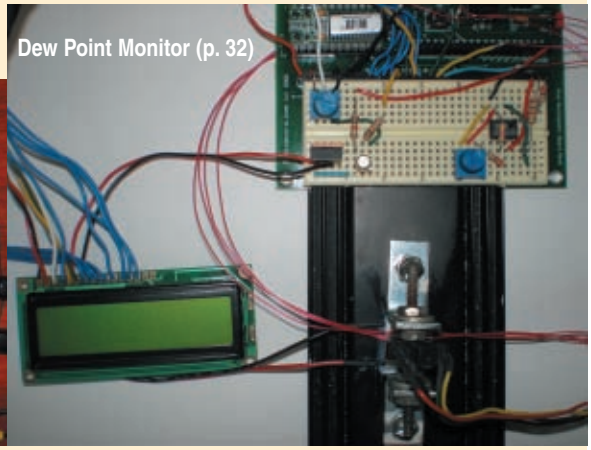
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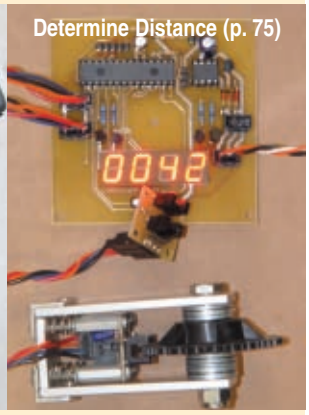
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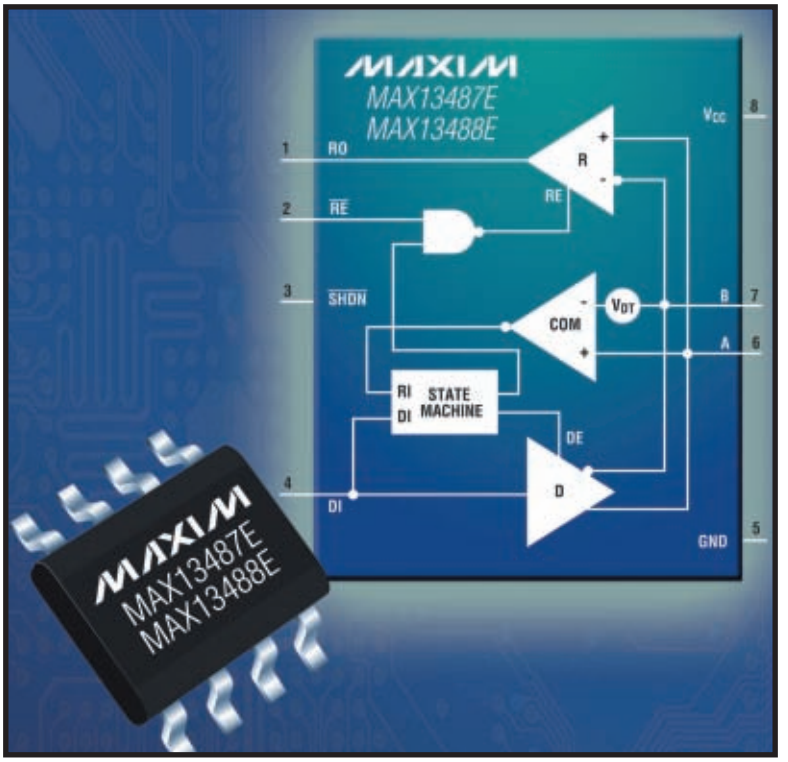
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The **MAX13487E** and **MAX13488E** are new half-duplex, RS-485 transceivers featuring autodirection, which automatically enables the driver when transmitting data. This feature eliminates the driver-enabled control signal, saving space and reducing component count in isolated metering, automotive, and industrial applications.

The MAX13487E offers ±15-kV ESD protection using the IEC 61000-4-2 air-gap discharge method. Both transceivers provide ±15-kV ESD protection using the human body model. The MAX13487E's slew rate-limited drivers provide reduced EMI and operation in environments with high levels of radiated noise for error-free transmission up to 500 kbps. The MAX13488E allows data rates up to 16 Mbps. Additionally, these devices feature a 0.25-unit load receiver input impedance, allowing up to 128 transceivers on the bus.

The MAX13487E and MAX13488E operate over the extended –40° to 85°C temperature range and are available in an industry standard, eight-pin SO package. The transceivers start at **$1.25** in 1,000-piece quantities.



Maxim Integrated Products, Inc.
www.maxim-ic.com

RUGGED ETHERNET SWITCHES

The **ESW series switches** are rugged, industrial Ethernet switches that shrug off ambient temperatures from –22° to 167°F. The DIN-mount switches handle both 10Base-T and 100Base-T speeds. They accept incoming data at its native speed, store it, and forward it at the native speed of the receiving device.



The ESW 205 (five ports) and ESW 208 (eight ports) switches are built to work in harsh industrial environments. They handle both high and low temperatures with ease and accept unregulated DC power from 10 to 30 V. That makes them ideal for both industrial control systems and vehicular applications.

Both models mount to standard DIN rails and have removable screw terminal strips for easy maintenance of DC connections. No crossover cables are needed and the ESW series switches automatically match the speeds of 10Base-T and 100Base-T simultaneously.

Both switches have LEDs that display the network and power status, and both are protected against 8-kV contact ESD and 15-kV air-gap ESD.

The ESW series Ethernet switches are now shipping from stock. They start at **$125**.

CyberResearch, Inc.
www.cyberresearch.com

NEW PRODUCT NEWS

HIGH-SPEED USB PROTOCOL ANALYZER

The **Beagle USB 480 is** a new USB 2.0 protocol analyzer. The analyzer features packet-level timing of 16.67-ns resolution with real-time data display and filtering.

With the ubiquitous presence of USB 2.0 in devices from consumer electronics to industrial controls, the powerful and affordable Beagle USB 480 protocol analyzer will satisfy the feature and budget requirements demanded by USB system developers.

It is not uncommon for the development of a USB device to be constrained by the availability of a USB analyzer. By offering a price that is significantly less than the competition, it is possible for companies to realistically consider putting a USB analyzer on the desk of every USB hardware or software developer, thus removing a significant productivity bottleneck.

The Beagle USB 480 protocol analyzer will be available this summer at the special introductory price of **$1,200**.

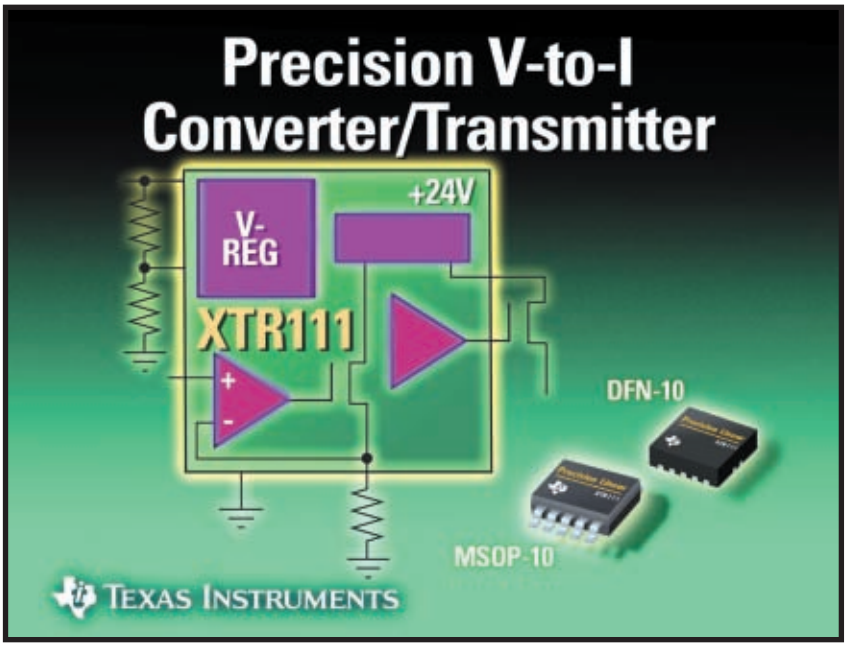
The analyzer comes complete with analysis software and royalty-free API. Discounts are offered for volume purchases.

Total Phase
www.totalphase.com



VERSATILE INDUSTRIAL-VOLTAGE/CURRENT-OUTPUT DRIVER

The **XTR111** is a precision voltage-to-current converter/transmitter designed for standard 0- to 20-mA and 4- to 20-mA analog signals, as well as 5- to 25-mA signals and voltage outputs. The XTR111 can deliver current up to 36 mA, and it boasts output error detection and output disable. This new device features low supply current of 500 µA, a low drift span of 5 ppm/C, and a wide 7- to 44-V supply range. The XTR111 is easy to use and adaptable to many applications, such as analog current output for industrial process control and three-wire sensor systems.



The XTR111 features an external resistor that sets the ratio between the input voltage and output current. The circuit can be modified for voltage output as well. With an accuracy of 0.015% and a low cost, it is ideally suited for current-mode sensor excitation and can be used as a voltage-controlled current source.

When combined with an external MOSFET, the XTR111 ensures large voltage compliance, extending below ground as well as easy power dissipation. Output disable control can be used for conditions where the output should present zero current.

The device costs **$1.45** each in 1,000-piece quantities.

Texas Instruments, Inc.
www.ti.com

NEW PRODUCT NEWS

TINY DAA MODULE

The **XE0402LCC** is a new telephone interface module. The module is barely half the size of the previous generation's product.

The XE0402LCC telephone interface module includes a solid-state hook-switch, a caller-ID pass through, and a ring detector while providing a full 3,000-VAC isolation barrier.

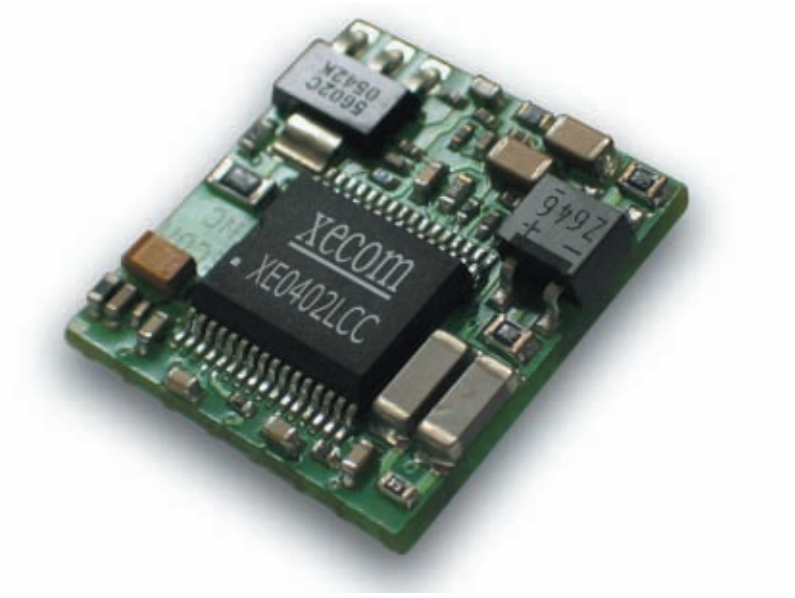
A smaller telephone interface not only permits the smaller systems to be created, it also increases design flexibility. The smaller telephone interface gives the system designer more flexibility in placing it in the system. The DAA is a leadless surface-mount module measuring just 0.8″ × 0.78″, and it is RoHS compliant.

The new XE0402LCC telephone interface module has a lower total cost than equivalent telephone interface solutions. Other telephone interface modules on the market are more expensive.

When compared with the cost of qualifying and sourcing the different components, the XE0402LCC telephone interface module also costs less than a discrete telephone interface design.

The price of the new XE0402LCC telephone interface module in 5,000-piece quantities is **$6.30** each.

Xecom, Inc.
www.xecom.com



MODBUS TCP COMPATIBLE I/O CUBES

The **UEIModbus Cube** functions as a Modbus slave, and it is easily accessed by any software client acting as a Modbus master. The UEIModbus is a compact, rugged, Ethernet-based data acquisition and control interface that communicates with a host computer or PLC over the Modbus TCP. Most popular HMI software supports the Modbus protocol.

The UEIModbus 600 cube is 4″ × 4″ × 5.8″ and supports up to 150 analog inputs or 288 digital I/O. The UEIModbus 300 is 4″ × 4″ × 4″ and offers 75 analog or 144 digital I/O channels. Offering over 60 million different configurations of analog I/O, digital I/O, counter/timer, and a quadrature encoder system, this is sure to be one that's a perfect fit for almost any application.

The UEIModbus is ideally suited for a wide variety of industrial monitoring and control applications. With an operating temperature range of –40° to 85°C and being capable of withstanding 50 g of shock and 5 g of steady vibration, the UEIModbus is rugged enough to handle the most demanding environments.

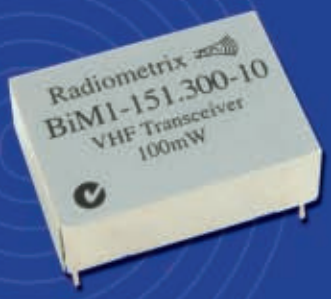
The UEIModbus 600 costs **$1,795**. The UEIModbus 300 costs **$1,495**.

United Electronic Industries
www.ueidaq.com



VHF/UHF FM
WIDEBAND & NARROWBAND RADIO MODULES

BIM 1



VHF Transceiver module that offers 100mW output power, giving a usable range of up to 10 km.

BIM 2A



VHF Transceiver module that offers 100mW output power, giving a usable range of up to 10 km.

NiM2



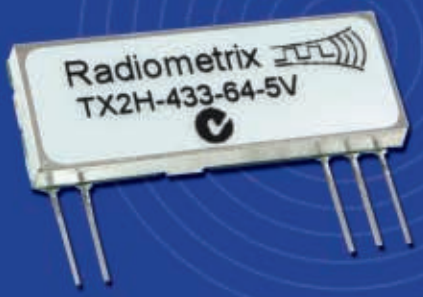
UHF Narrowband transceiver operating 433 MHz offering ranges up to 500m.

TX1H/NRX1/CVR1



TX1H, VHF Transmitter 100 mW output power, when used with either the NRX1 or CVR1 VHF receivers, they offer a low cost reliable VHF link.

TX 2H



Low cost UHF transmitter with 25 mW output power, offering ranges up to 500 m. Also available is a 100 mW version: the TX2EH.

www.lemosint.com

1-866-345-3667
sales@lemosint.com

NEW PRODUCT NEWS

NEW 8-BIT FLASH MCU WITH ON-CHIP LCD CONTROLLER/DRIVER

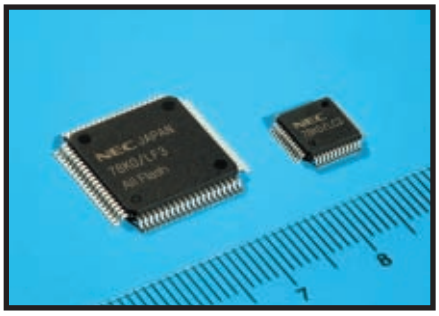
The new **78K0/Lx3** line of 8-bit all flash microcontrollers comes with on-chip LCD controllers/drivers and extremely low power-consumption levels. The 78K0/Lx3 family features 46 devices and 76 product configurations. The MCUs are ideal for consumer electronics-type products that have LCD panels and strict power-consumption requirements. The new devices can be used in home healthcare equipment, such as scales, blood pressure monitors, and blood glucose meters, as well as utility meters in HVAC and industrial systems and household appliances, including coffee makers.

All of the new MCUs have integrated LCD drivers/controllers that help designers reduce the number of system components and increase system reliability. An optimized circuit design reduces standby power consumption by approximately 50%, to just 2.3 µA, compared to the previous generation 78K0/Lx2 MCUs, while an on-chip 16-bit ADC offers a 64-fold improvement in resolution. Additionally, by having eight rather than four common signal ports, the 78K0/Lx3 devices support up to 288 display segments compared to the previous generation's 160. These improvements enable designers to create products with higher LCD resolutions or products with the same LCD resolutions but fewer display segments.

The new MCUs are available in configurations with embedded flash memory capacities ranging from 8 to 60 KB and pin counts ranging from 48 to 80.

Pricing varies according to the device's specifications. For example, the 80-pin 78K0/LF3 MCU with 60 KB of flash memory costs **$5** per unit for quantities of 1,000.

NEC Electronics Corp.
www.am.necel.com



SERIAL FLASH DATA CARRIER READER/WRITER

The new **KeyLink III** and **SlimLink III** reader/writers were designed specifically to optimize throughput speeds when used with SPI-flash memory keys and tokens. In addition to serial flash products, the readers also support interchangeable use of the manufacture's standard serial EEPROM products including those that use Microwire, I²C, and SPI protocols.

These new reader/writers are ideal for developing and programming high-capacity SPI-flash keys and tokens (SFK/SFT/SFX). These 1- to 32-Mb keys and tokens have become increasingly popular for data-transfer applications, such as in-field firmware updates, data logging, and "recipe" uploading. The KeyLink III and SlimLink III have a USB interface and offer typical write speeds of 1.2 Mbps—allowing the user to write the entire contents of a 1-MB data carrier in under 7 s—over 100 times faster than the prior generation.



The KeyLink III and SlimLink III also have the capability to read/write unique identifier keys and tokens. These products allow OEM designers to implement copy-proof data carrier applications.

While the most common application for these devices is product development, the products are entirely suitable for field deployment (resale) by OEM users. They have also been designed to yield better price flexibility at high volumes than earlier models. They can also be provided in panel-mount configurations. Development kits are available.

The KeyLink III costs **$140**. The SlimLink III costs **$130**.

Datakey Electronics, Inc.
www.datakey.com

NEW PRODUCT NEWS

AVR ISP PROGRAMMING FROM AN SD CARD

The **CableAVR-SD** is a stand-alone programmer designed for the in-system programming of Atmel AVR microcontrollers. It's a very handy little tool for production programming and field software updates.



Fuse settings and other programming process information is configured using the included Windows application and saved on the SD card. The programmer also uses BIN, HEX, and EEP files for programming the flash and EEPROM areas of the target device. The programmer derives its power from the target system and will operate from 3.3 to 5 VDC.

The CableAVR-SD comes complete with a programming unit, an installation CD, and set up instructions.

The programmer costs **$99** and quantity discounts are available.

Priio
www.priio.com





NEW PRODUCT NEWS

WIRELESS SENSOR NETWORKS

The **Primer Pack/IP** is an out-of-the-box solution that lets users create pilot wireless sensor networks (WSNs) in manufacturing, office, and retail environments. With a service-oriented architecture (SOA), it is the first sensor network to run native IP end-to-end, taking the IP protocols beyond their current boundaries at the WSN gateway and out to the individual sensor nodes.

Because of IP's pervasiveness as a global communication standard across industries, Primer Pack/IP sensor nodes will be able to communicate directly with other IP devices whether they are wired or wireless, local, across the Internet, on Ethernet, Wi-Fi, 6LoWPAN, or other types of networks regardless of the vendor. Network managers will gain direct, real-time access to sensor nodes and the ability to apply a broad range of Internet management and security tools, while end users will get applications that accommodate their demands for increased mobility and flexibility.

Primer Pack/IP incorporates work recently completed by the IETF 6LoWPAN working group, whose charter is to enable standard IP communication over low-power wireless IEEE 802.15.4 personal-area networks. 6LoWPAN, a proposed standard approved by the IETF, incorporates IPv6, the latest and most scalable version of the ubiquitous IP protocol.

Primer Pack/IP includes: the Arch Rock Gateway Server, which connects via the Ethernet to the enterprise LAN and provides a web-based console for set up, diagnostics, and management of the WSN; the Arch Rock Bridge Node, which provides IEEE 802.15.4 wireless radio communication between the gateway and sensor nodes; six battery-powered sensor nodes with TelosB-compatible industry-standard motes; expansion ports and preinstalled drivers for external sensors; a complete set of web services and gateway server APIs; and link-level AES-128 encryption and authentication.

The Arch Rock Primer Pack/IP costs **$4,995**. It is available as a free upgrade to existing Primer Pack customers.

Arch Rock Corp.
www.archrock.com



BENCH-TOP POWER SUPPLIES

The **PS-1** is a new concept in bench-top power supplies. By incorporating rechargeable batteries, the PS-1 opens new areas of usefulness for the power supplies.

With them, you will no longer be tied to your tech bench when testing, debugging, and developing your products. The PS-1 offers "true" isolation from the power mains. While connected to the charger, it can operate seamlessly through power outages—a critical feature for long-duration testing. The units can also be stacked for higher voltages or multiple voltages.



Depending on the load, the PS-1 will operate for hours to days on a full charge. The power supplies provide an output of 1.2 to 15 VDC at 0 to 1 A, with a settable current limit of 0.01 to 1 A. The supply measures a compact 5.1″ × 2.3″ × 6″ and optional interfaces for a remote control are available.

The PS-1 costs **$179**. RS-232 or USB interfaces are available for an additional **$40**.

R&R Technologies, Inc.
www.rnrtech.com

NEW PRODUCT NEWS

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

NEW STACKABLE USB SPECIFICATION FOR I/O EXPANSION

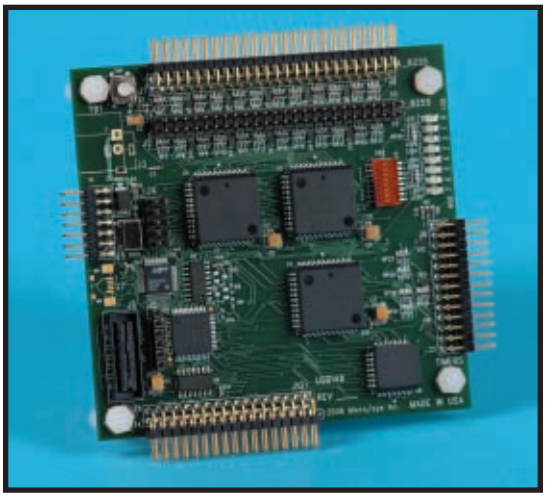
The new **StackableUSB specification** defines a standard for stacking I/O boards onto a single-board computer using the popular USB 2.0 interface. A single-board computer, operating as a host, can communicate to multiple USB peripheral cards directly by mating USB 2.0 connectors on the CPU and I/O cards.

Satisfying the growing demand for faster communication between I/O channels and CPUs in embedded applications, the StackableUSB format eliminates cables, reduces pin count, and requires a smaller connector footprint than traditional interconnect architectures. Securely bolting together to increase reliability and mobility in rugged or harsh environments, the StackableUSB format features a USB point-to-point architecture where connections are routed up a stack to the next peripheral in the stack.

Each StackableUSB connector supports up to eight USB peripheral devices in the stack without a hub. There are several features (USB and I/O supports) that have not been available in the past when using traditional stacking architectures, such as PC/104 and PC/104-Plus. USB supports automatic enumeration that allows the host to detect devices plugged into the stack and to install the drivers necessary for the system to operate with minimal human intervention. USB also supports power management so that USB peripherals or devices can be placed in a low power mode to conserve power, an issue that is paramount in embedded systems relying on battery-backed power or environments where heat generation is of key concern. USB 2.0 also offers increased data bandwidth to support today's high-speed A/D and DAC data rates.

Several processors and I/O expansion boards incorporating the StackableUSB specification are now available. Processor boards start at **$385** and I/O boards start at **$125**.

Micro/sys, Inc.
www.embeddedsys.com





by Dhananjay Gadre, Anurag Chugh, Parag Shah, & Sneha Lele

Network of Keypads

This integrated voting system includes several keypads that feature an ATmega8, a MAX485, a few LEDs, and push buttons. The keypads communicate over the RS-485 bus. A Java application runs on a PC that generates a bar graph similar to the one seen on TV game shows.

Those of us who have seen one of the many versions of the TV game show "Who Wants to Be a Millionaire?" know that one of the "lifelines" available to contestants in the "hot seat" involves asking the audience for help. Basically, a contestant can ask the studio audience to indicate which answer (A, B, C, or D) they believe is correct. Audience members indicate their choices by pressing a key on a keypad that corresponds to an answer. The audience's vote is then displayed on the screens for the contestant and the host.

Our system features similar voting pads, each consisting of an Atmel ATmega8 microcontroller, a Maxim Integrated Products MAX485, a few LEDs, and push buttons (see Photo 1). The keypads communicate over the RS-485 bus, which is a pair of twisted cables, similar to those in a Cat 5 Ethernet cable.

The front end of our system features a Java application running on a PC, which generates a bar graph similar to the one shown on the TV show. A separate circuit, which we call an "RS-232-to-RS-485 bridge," connects the network to the PC via its serial port.

Being the lazy bums that we are, we chose to write the program for the microcontrollers in C language, using the freely available avr-gcc compiler, which is distributed as a part of WinAVR. For the front end, we used the Eclipse Editor to help code the Java application.

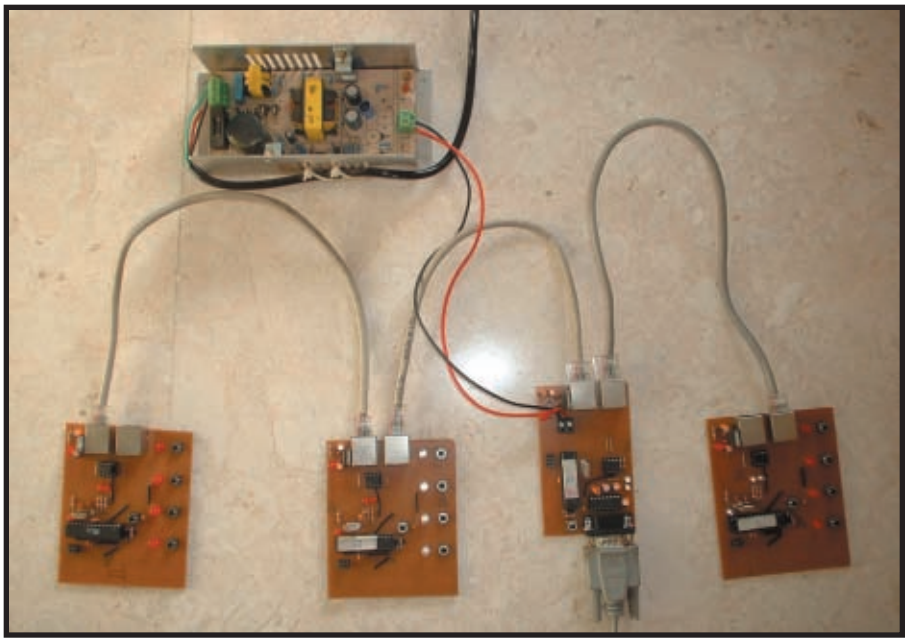


Photo 1—This replica of our entire voting pad network features three voting pads, an RS-232-to-RS-485 bridge, and a power supply.

THE RS-485 BUS

How do you communicate with all of the the voting pads? RS-485 to the rescue! RS-485 has been around for several years now. It has become an industry standard from which more and more sophisticated standards have evolved. The RS-485 specifies a differential signaling technique, which is used to implement a multidrop network. Differential signaling involves using twisted pair cables as the bus.

Like many of you, we now have our own horror stories about getting the RS-485 standard to work for us. After three full makeovers and several agonizing hours of testing, we were able to create a highly reliable network for our voting pads. A reliable, high-speed RS-485 network requires the right combination of connectors, wires, PCB layout designs, and terminations. Many permutations and combinations later, we were able to operate the network at speeds up to 115,200 bps and distances up to 50 m, with an almost

zero error rate.

Before plunging into an RS-485 project, you should thoroughly study the standard. "Designing RS-485 Circuits" (J. Axelson, *Circuit Cellar* 107, 1999) and "The Art and Science of RS-485" (B. Perrin, *Circuit Cellar Online* 108, 1999) are good articles that will acquaint you with the RS-485 standard.

For our project, we used a single pair of twisted wires to implement a half-duplex RS-485 network. We used the Cat 5 cable along with RJ-45 connectors as the main components of the bus. Cat 5 cables, which consist of four twisted pairs, are used to link computers to an Ethernet network. We used one pair to carry the actual data signals (signals A and B of the RS-485 bus) and another pair to distribute power to the nodes. The other two pairs remain unused and simply grounded. You can also use cables with only two twisted pairs, along with RJ-11 connectors (used in telephones) to eliminate the two unused pairs.

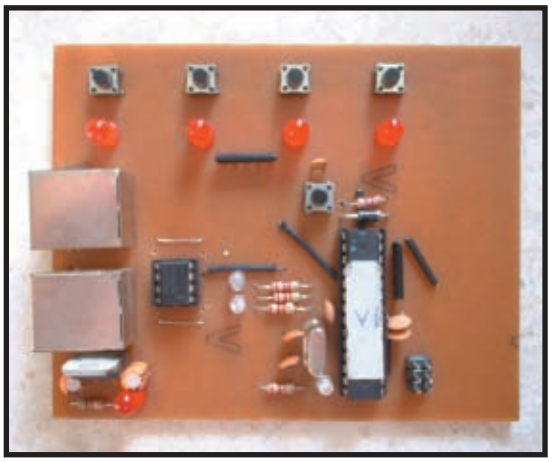


Photo 2—Each voting pad sports an ATmega8 microcontroller. The two metallic components on the left-hand side are the RJ-45 female sockets.

VOTING PADS

Each voting pad sports an ATmega8 microcontroller (see Photo 2 and Figure 1). The microcontroller takes care of reading the status of the push buttons, lighting the corresponding LED, and communicating with the host computer. The MAX485 driver IC is used to convert between TTL and RS-485 signals. The MAX485 is a half-duplex RS-485 driver that can be operated at speeds up to 2.5 Mbps. If you are operating in a noisy environment and spikes are common on the bus, we recommend that you replace the MAX485 with a MAX483. The MAX483 is slew-rate limited and can be operated up to 250,000 bps, which is fine since we are operating at only 115,200 bps.

Serial communications at such high speeds require precise timing. Thus, we used an external 3.6864-MHz crystal to generate the clock for the ATmega8. Another crystal would have worked if it was a multiple of the data rate we used. One thing to keep in mind is that the ATmega8L, which is a low-voltage version, can only be operated at up to 8 MHz, unlike the non-"L" version, which can be operated at up to 16 MHz. If you want to decrease the component count, then an 8-MHz RC oscillator combined with the ATmega8 can be used for speeds up to 38,400 bps.

The MAX485 transceiver consists of a separate transmitter and receiver, which must be enabled mutually and exclusively to either transmit to or receive data from the bus. One of ATmega8's pins is assigned to take care of switching between transmission and reception. A pull-down resistor on that pin ensures that the MAX485 is in Receiving mode at all times. Two LEDs on the ATmega8's

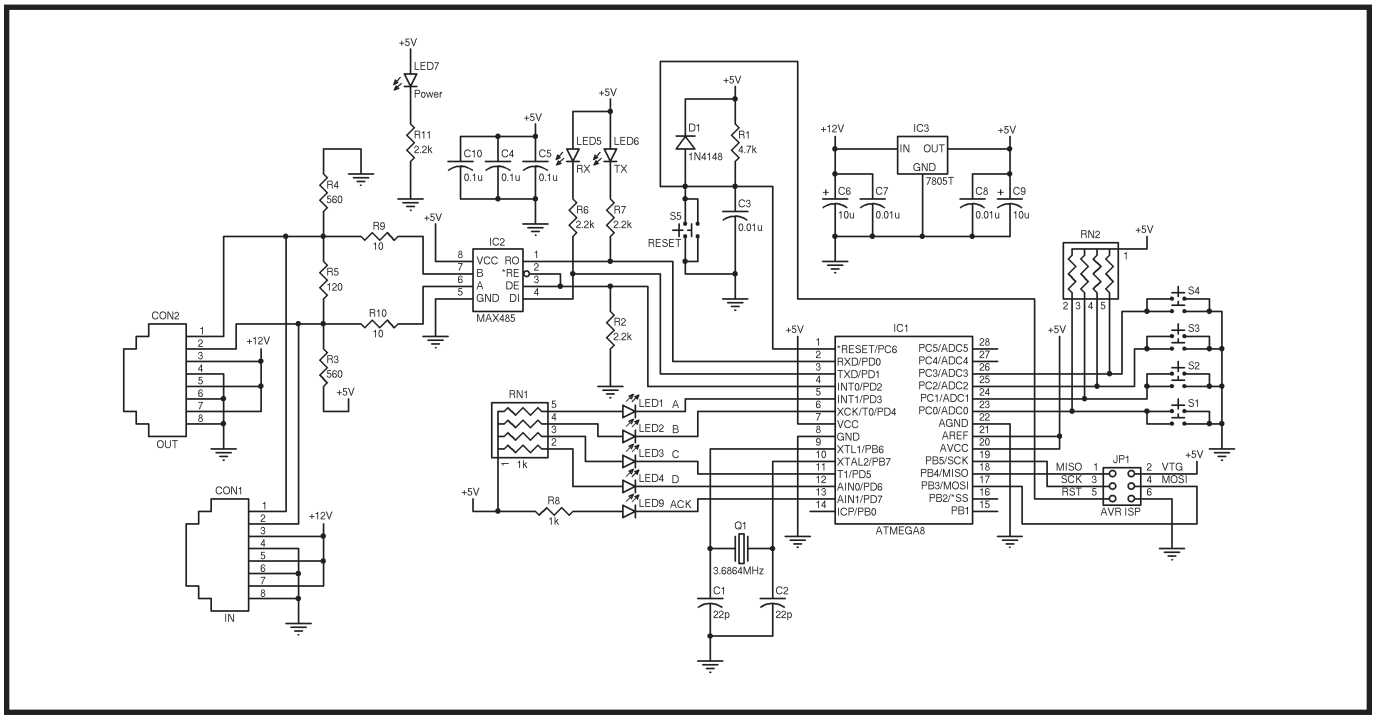


Figure 1—Since 3.6864 MHz is a precise multiple of most of the standard UART data rates, we used one on each keypad to generate the system clock. The termination resistor R5 should only be mounted on the nodes present on the extreme ends of the network. Biasing resistors R3 and R4 would only be mounted on one of the extreme keypads.

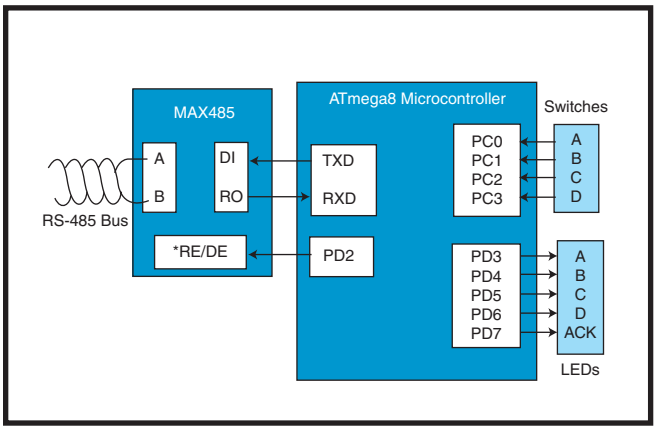


Figure 2—This is a block diagram of a voting pad. Note that the A and B wires must be twisted to achieve high data rates with minimal errors. We used the twisted pairs of Cat 5 cable with RJ-45 sockets and connectors to set up the RS-485 network.

TXD and RXD lines indicate the flow of data in and out of the voting pad. This allows for the easy debugging of the network.

Figure 2 shows the voting pads with only the essential components and connections. The ATmega8 microcontroller is programmed to listen for key presses and store them in a variable in its RAM. The LED corresponding to the selected option lights up accordingly. When queried by the host computer, the ATmega8 microcontroller responds with the option selected and the acknowledge (ACK) LED lights up to indicate that the vote was registered successfully.

COMMUNICATIONS TECHNIQUE

To communicate over the RS-485 bus, we used the standard serial format with 8 data bits, no parity bits, and 1 stop bit. The bit rate was set to 115,200 bps. We used a simple packet-based method to transfer data across the bus. Since we have a multidrop network, we required an addressing scheme. We assigned addresses to each voting pad and stored the addresses in the EEPROM memories of the ATmega8 on each of the pads.

The packet format is quite simple. The first byte in the packet consists of a synchronizing character, which marks the beginning of a packet. This character is "a" in our case. The second byte is the sender's address. The host computer was assigned the address 0. The voting pads were assigned addresses from 1 onwards. The third byte is the address of the node on the bus for which the packet is meant. The fourth byte indicates the number of data bytes to follow in the packet. The bytes following the fourth byte are the actual data bytes meant for the destination.

During development, we used only nine voting pads in the network and used the ASCII values of the addresses instead of their true hexadecimal values. For example, if a voting pad's address was "3," we stored it as 0x33 rather than 0x03 in its EEPROM. This was done to make our jobs easier while debugging the system using terminal software on the host computer. On terminal software, 0x03 would be displayed as a special character, which would make it very difficult to understand what's going on. On the other hand, 0x33 would actually show up as "3" on terminal software.

To understand this packet format further, consider the string "a072KQ." Here, "a" is the synchronizing character, "0" is the address of the host computer, and "7" is the address of the voting pad being queried. Note that "2" specifies the number of bytes to follow. The character string "KQ" represents the 2 bytes of data to be transferred to the destination voting pad. "KQ" is the command for querying the voting pad for the option selected. When the host computer sends such a packet, the corresponding voting pad sends another packet in reply with the option selected on it by the audience member. So, a typical response to the packet would be "a702KB," which means that the person who has voting pad 7 has selected option "B."

Byte	Description
1	Synchronizing character "a"
2	Source address
3	Destination address
4	Number of data bytes to follow "k"
5	First data byte
6	Second data byte
–	–
–	–
–	–
n	k^{th} Data byte

Table 1—This is the packet format. We used a master-slave strategy for communications between the host PC and the keypads.

As you can see, we used the ASCII values (instead of the hex values) to ease the debugging process, as stated earlier. "KR" is the command to reset the voting pad. Table 1 shows the packet format. Note that there is no form of error checking implemented in our packet format. The system worked so well without any errors that we didn't care to add any error-checking bytes (lazy, lazy, lazy). The bit errors were negligible even for speeds of 115,200 bps at lengths of up to 50 m.

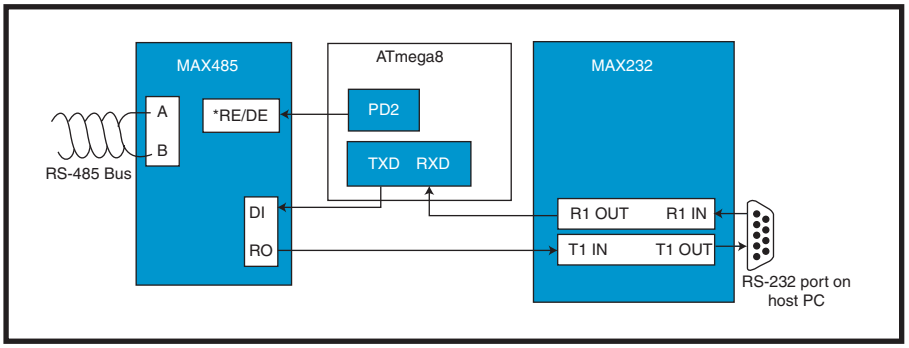
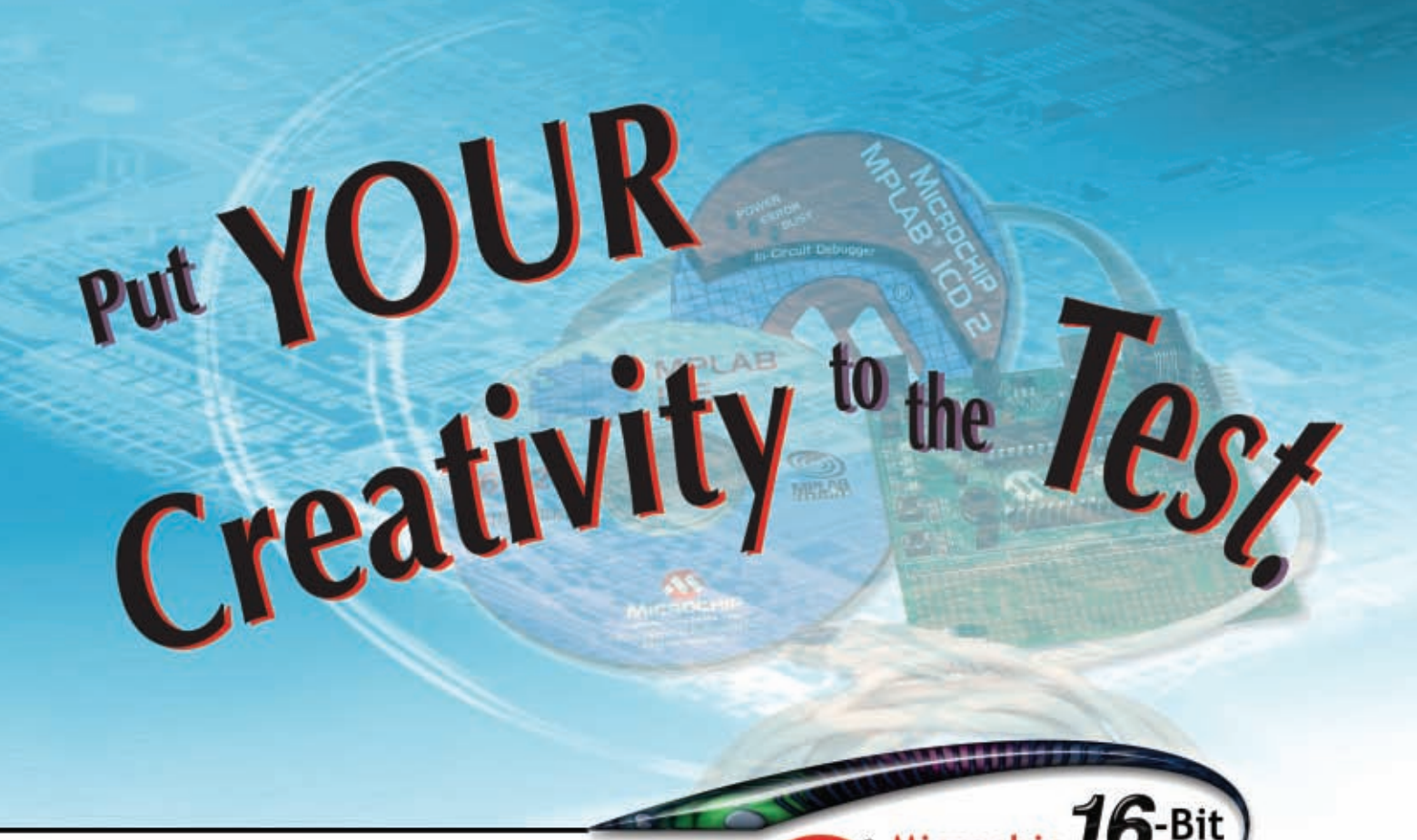


Figure 3—Take a look at the layout for the RS-232-to-RS-485 bridge. The ATmega8 microcontroller acts as a buffer in this case and switches the MAX485 transceiver from Receiving to Transmission modes and back, depending on the direction of the flow of data.

BRIDGE & POWER

Since our computers do not have an RS-485 interface, we needed to con-



Microchip 16-Bit Embedded Control Design Contest

Circuit Cellar magazine and Microchip are pleased to bring you the Microchip 16-bit Embedded Control Design Contest.

This is the perfect opportunity to learn about Microchip's 16-bit Microcontroller and Digital Signal Controller (DSC) families. These powerful workhorses offer a broad range of products while preserving the compatibility that helps save you time and money on subsequent designs. Put your creativity to the test. Your project could win you a share of $15,000 in cash prizes and give you the international recognition you deserve.

Learn about unique contest sample opportunities, special offers from Microchip, and how you can be the next Circuit Cellar design contest success story.

For details, visit www.circuitcellar.com/microchip2007

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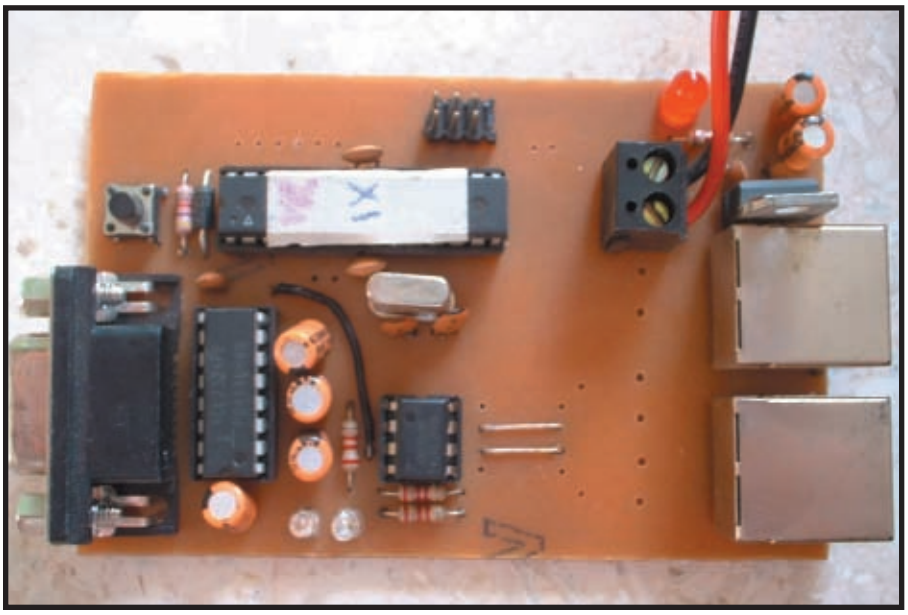


Photo 3—The RS-232-to-RS-485 bridge acts as the interface between the network and the PC, essentially to convert between the RS-232 signals and the RS-485 signals. We achieve multipoint communication through this bridge.

vert the RS-485 signals to RS-232 signals, which are used with the standard serial ports available on most PCs. To do this, we connected a MAX232 and MAX485 back to back. The MAX232 converted the RS-232 signals from the PC's serial port to TTL levels. The levels were given to the MAX485, which converted them to RS-485 signals that could be sent over the bus. All of this sounds quite simple, but in reality, there is a catch—the MAX485 must be switched between the Transmitting and Receiving modes, depending on the direction the data is flowing. One could use the RTS signal available on the PC's serial port to trigger the MAX485 between these modes, but it so happens that Microsoft Windows is very poor at timing while controlling the RTS signal. We encountered problems while using the setup, so we looked for a better way to achieve our goal.

The ubiquitous ATmega8 came to our rescue again. Figure 3 shows the RS-232-to-RS-485 bridge (see Photo 3). As with the voting pads, we used a pull-down resistor to put the MAX485 in Receiving mode by default. Any data on the bus transmitted by any of the voting pads was received by the MAX485, converted to TTL, and passed on to the MAX232 to be sent directly to the host computer in RS-232 format. Whenever the computer transmitted any data, the MAX232 converted it to TTL and passed it on to the ATmega8. Upon sensing that its UART received a byte, the ATmega8 retransmitted the same byte out to the MAX485, while simultaneously triggering it into Transmitting mode. This allowed us to easily switch between the two signaling levels.

We connected the RS-232-to-RS-485 bridge somewhere in the middle of the bus. We added 120-Ω terminating resistors on the two extreme voting pads connected to the bus. One of the voting pads also carried two 560-Ω biasing resistors to hold the A and B signals in their default states whenever there was no data flowing on the bus. One of the twisted pairs in the Cat 5 cable carried our A and B signals.

If you are using a laptop that doesn't have a standard serial port, you can use a USB-to-RS-232 dongle to connect to the network. We tested our system with these converters and found them to be just as good as the actual RS-232 ports available on older PCs.

We used one of the three remaining twisted pairs in the Cat 5 to distribute DC power to the nodes. We used an SMPS working off the AC mains to deliver 12 V to the nodes. The power supply was rated at 2 A and was enough for 10 nodes.

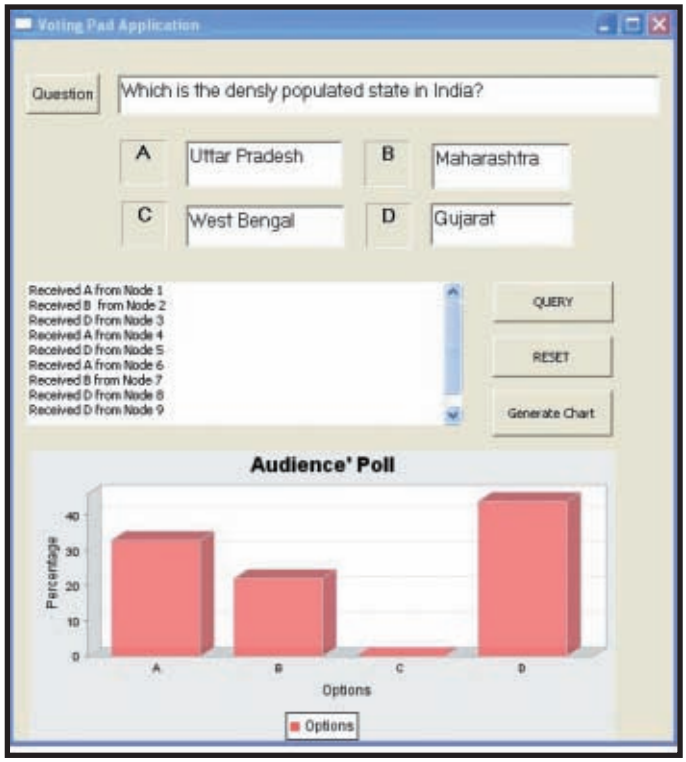


Photo 4—This is a screenshot of the Java application. We used the Eclipse IDE to develop the Java application for the voting pad network.

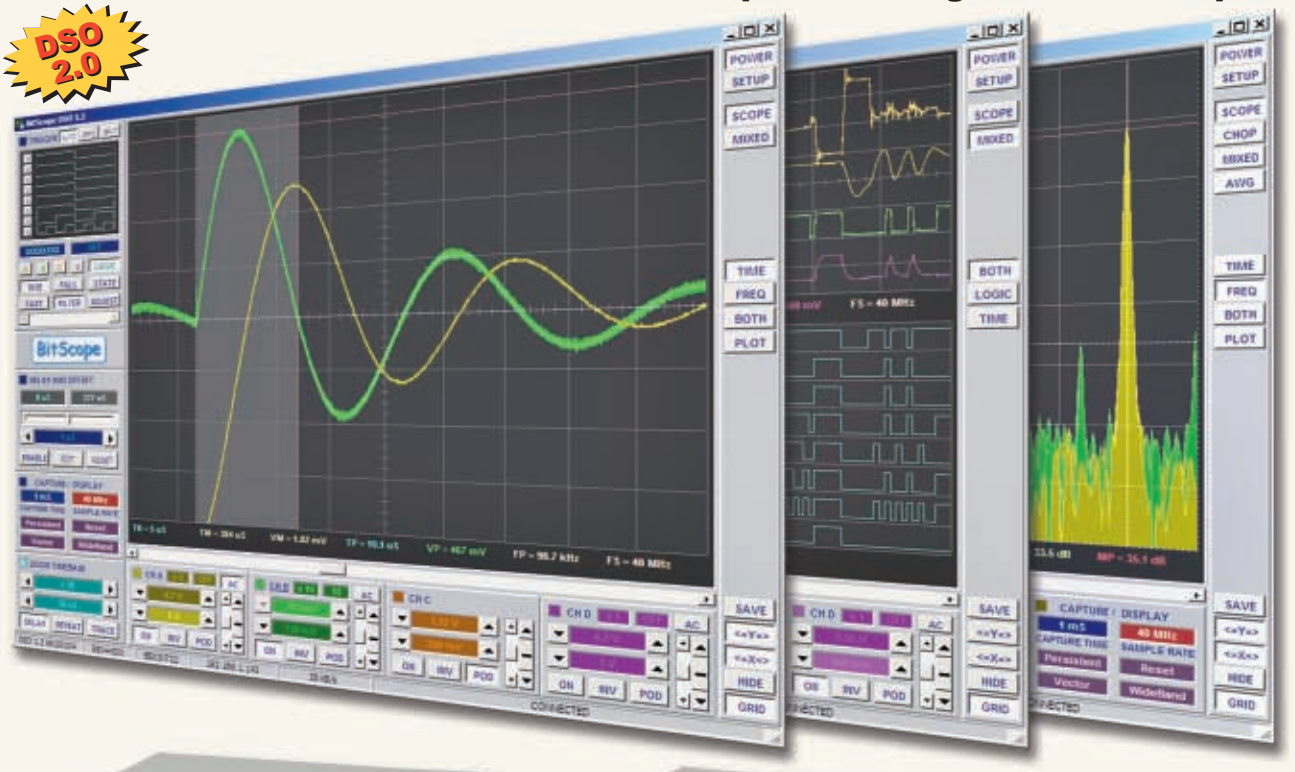
THE FRONT END

We wrote the front end in Java (JDK 1.5.0.60) and used the Eclipse Editor (3.1.1) (see Photo 4).[1] Eclipse is an open-source community with projects designed to provide a platform for building software. It makes developing Java applications a cinch, and its plug-in architecture makes it easier to integrate any library into your application. The Visual Editor plug-in enables you to develop Java applications using a simple Visual Basic-like GUI. Eclipse is

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available as a free download (www.eclipse.org).

To implement serial communications in Java, we were confronted with two choices of libraries: Java Communications API 3.0 (published by Sun Microsystems) and RXTX 2.1 (open-source). Since support for Windows was under development in the latest Java COM API, we resorted to the GNU RXTX 2.1 library for serial communications. To use the RXTX library with Eclipse, the RXTXcomm.jar file and dll files must be copied to the library directory of the project, and the JAR file must be used in the build path of the project.

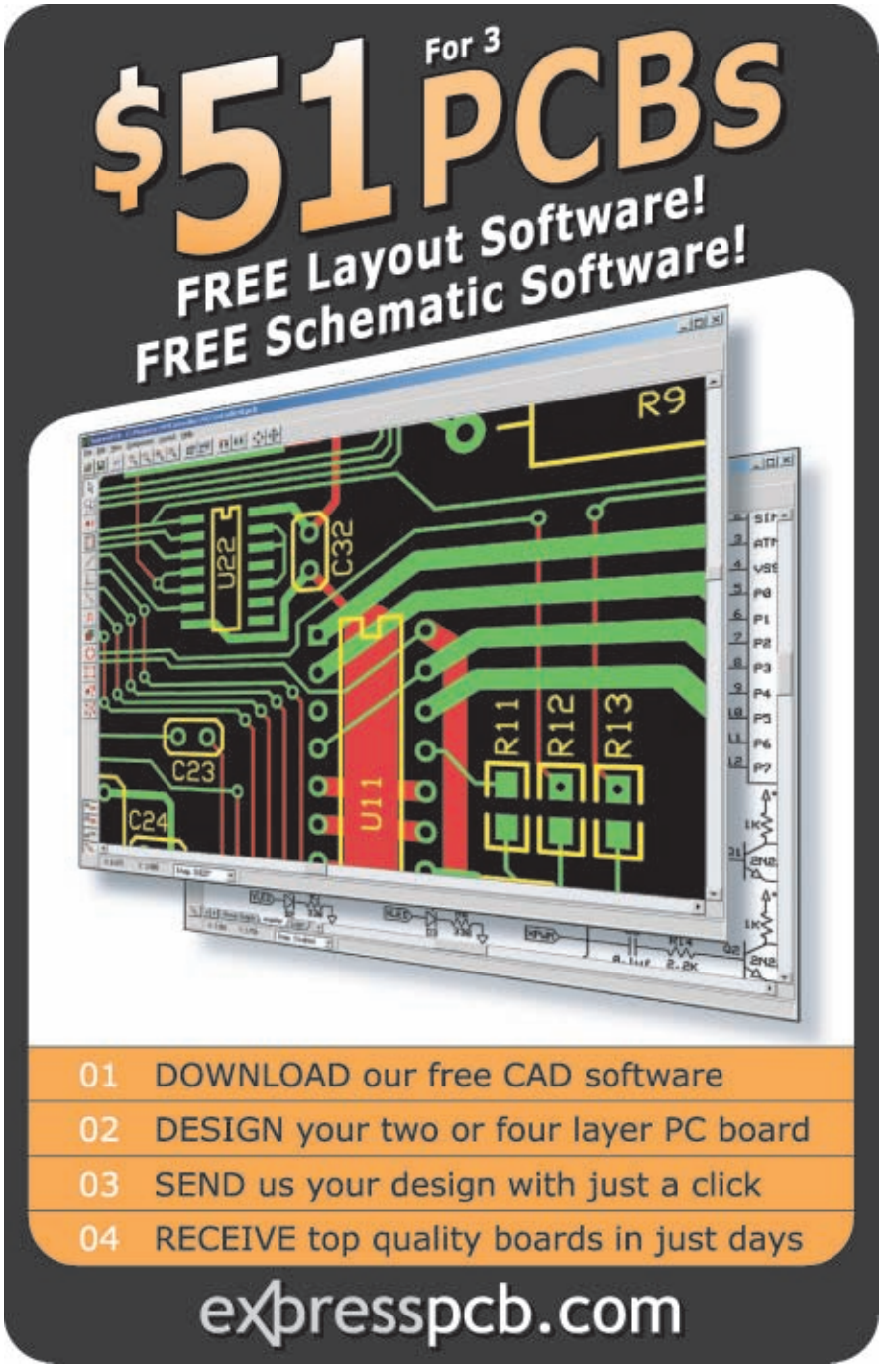
IMPROVEMENTS

We took care to add the AVRISP six-pin header to the voting pad boards so that we could program them easily without having to remove the microcontroller from its socket. A bootloader, capable of programming the microcontroller on which it resides by receiving the new program codes over the RS-485 network, would have been nice. But, adding a bootloader during the initial development phase of the project would have made debugging a nightmare. There would have been much more code to debug, in addition to the already buggy hardware.

Now that we have the hardware fully operational and functioning, we can think of adding features so that newer programs with newer features are easier to download over the network itself. Logging the time that a user takes to make a decision would be a great feature. One of the timers on the ATmega8 could be used for this purpose. When the voter presses any one of the switches, the time it takes to do so would be logged and sent back to the host computer when queried, along with the option selected. A broadcast packet to start the counter may be sent initially to start the counters in all the voting pads simultaneously. Such an arrangement could be used to implement the pads for a "Fastest Finger First" round on a TV game show.

In most scenarios, an excess of 200 voting pads would be required. The MAX485 transceivers we used can only support up to 32 drivers per segment. Therefore, only 31 voting pads (one of the drivers will be the MAX485 on the RS-232-to-RS-485 bridge) can be connected to a given segment of the bus wire. This means that multiple segments would be needed to implement a network for a decent sized audience. These segments would have to be connected to each other with repeaters, which would complicate things and introduce delays. The repeaters would have to be designed separately, and since they would increase the number of devices used in the system, the mean time between failures (MTBF) of the system would decrease. A better solution would be to use a MAX487 instead of a MAX485. A MAX487 can support up to 128 drivers per segment at speeds up to 250 kbps.

Connecting so many devices to the bus would imply that the bus wire would have to be very long, and therefore more prone to bit errors caused by



noise. In such a case, a newer packet format with CRC would help alleviate the problem. Since the system would be used by numerous people, it should be able to withstand at least some number of faults caused by negligence on the part of its users. One of the most common faults would be a break in the bus wire, which would cause some part of the network to be disconnected from the host computer. That would prove disastrous. To prevent such mishaps, more sturdy connectors like the subminiature DE-9 connector could be used with the twisted-pair bus wires instead of the RJ-45 or RJ-11 connectors.

Another enhancement to this effect would be to use not one but two bridge circuits with the system. A host computer with two serial ports would interface with the network via two bridges connected at the two extreme ends of the network. This way, if there is a break in a wire, the entire network would be divided into two segments, each of which would be connected to the host computer via either one of the bridges.

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PROJECT FILES

To download code, go to ftp://ftp.circuitcellar.com/pub/circuit_cellar/2007/203.

REFERENCE

[1] The Eclipse Foundation, 2006, www.eclipse.org.

RESOURCES

J. Axelson, *Serial Port Complete: Programming and Circuits for RS-232 and RS-485 Links and Networks*, Lakeview Research, Madison, WI, 1998.

B. Burd, *Eclipse For Dummies*, Wiley Publishing, 2004.

K. Jarvi, "RXTX Library," 2006, www.rxtx.org.

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www.atmel.com

RS-485 and RS-232 Transceivers
Maxim Integrated Products, Inc.
www.maxim-ic.com





Video-Based Motion Sensor

A mixed-signal design and a lot of creativity helped Naubert build a handy video-based motion sensor. With just an analog front end and an Atmel ATmega88, this system is able to detect movement in real time.

Divide and conquer is a well-known strategy that you can use when designing your systems. In vision sensing, the strategy is normally used to simplify algorithms separating the sensing process from the signal-interpretation process. More sophisticated smart sensors can be developed to manipulate the raw data and provide more elaborate information to a higher-level system. My mOtiOn system is one of these smart sensors. Featuring just one Atmel ATmega88 microcontroller, it can interpret a video signal and report movement in real time at the sensor level.

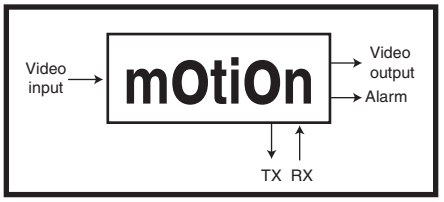


Figure 1—The motion controller's interface is simple: a video input port, a video output with the generated highlighted video signal, an alarm signal, and a serial port for commands.

Several past projects have demonstrated that AVR microcontrollers can be used for image processing. In some of the projects, a digital camera generated a video signal, and a stream of digital information was sent to a microcontroller for processing. I decided to follow a different route. I eliminated the digital camera and the video-encoder chip and manipulated an analog video signal directly to significantly reduce the cost of the sensor. You can purchase a small, analog CCTV camera for less than $20. Real-time analog video conversion to digital frames of 320 × 240 pixels with 8-bit resolution requires a sampling rate of about 6 MHz and a memory subsystem able to sustain a bandwidth of 2 MBps. Although Atmel AVR microcontrollers are fast (about 20 MIPS), processing the signal directly at that speed would exceed the available CPU power required to perform the motion-detection algorithms. I also didn't want to increase the cost by adding external memory, which would be needed to store the frames at a rate of 2 MBps.

To be able to process the video in real time and stay under budget, the system com-

Command	Description
?	Help
M	Run motion detection continuously until interrupted with any character through the serial port. This is the default mode at start-up.
M1	Run motion detection until any valid motion is detected.
D	Dump current frame.
D1	Dump base frame.
H0	Disable highlighting.
H1	Enable highlighting.
I0	Disable the ignore bitmask.
I1	Enable the ignore bitmask.
IC	Clear the ignore bitmask.
IF	Completely fill the ignore bitmask so all movement is ignored.
I:se:vvvv	Set the ignore bitmask from line start to the line end with the value "vvvv".
IS	Show the ignore bitmask.
Wnn:xx	Write to register nn the value xx. These parameters change different limits to adjust the detection sensitivity.
Rnn	Read parameter nn.
EC	Clear the EEPROM.
ER	Set the parameters from the EEPROM values.
EW	Write the value of current parameters to the EEPROM area.
ZZ	Reset the device. Parameters are read from EEPROM if they were saved with EW.

Table 1—This table shows the different commands available in the motion controller. The sensor starts in Continuous Detection mode. Sending any character through the serial port will stop the motion detection function enabling the Command mode.

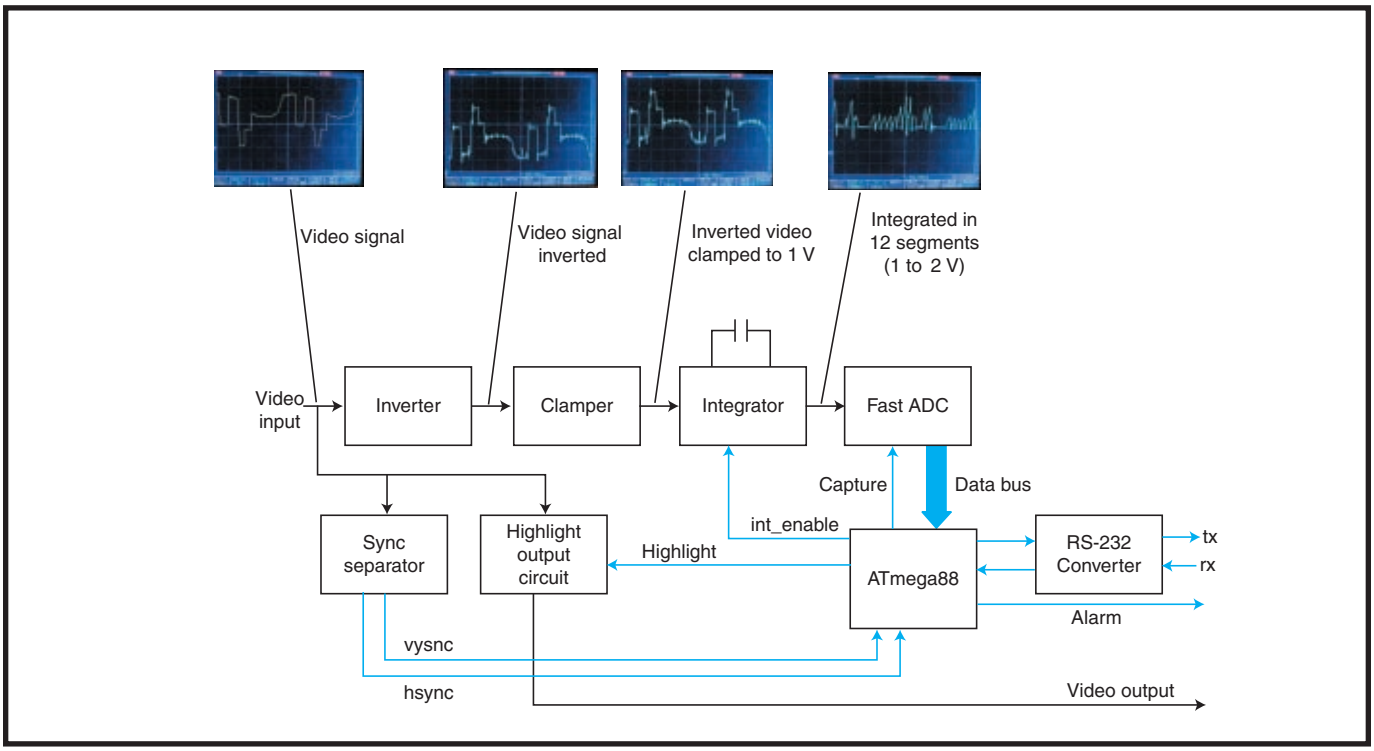


Figure 2—This block diagram shows the major components of the sensor and analog video signal processing. An inverter and clamper are used to fix the signal. After the integrator, every one of the 12 averaged line segments are in the 1- to 2-V range of the ADC.

presses the frames first before sending them to the CPU. I bet you have seen the "matrix block" effect, which is used when a TV producer doesn't want you to see part of a scene (i.e., the face of a person being interviewed). When you see the effect, you can clearly see when the protected scene is moving because the blocks adjust their color and intensity according to the covered object's movement. The motion sensor applies the same effect on the incoming video signal before processing it. It compresses the analog frames and converts them to 12 × 15 averaged brightness block matrices, which are very easy to process and demand fewer CPU resources. Because the compression has to occur before the video signal enters the CPU, I used a mixed-signal design with an analog video preprocessing block to achieve it.

SYSTEM OVERVIEW

Before I explain how I built the motion sensor, it is important to understand what the sensor can do. It is a complete motion sensor with video input, video output, an SPI, and a digital alarm output (see Figure 1). It processes black and white or color NTSC analog-composite video signals, detects movement, and outputs a copy of the incoming video and highlights the blocks where movement has been detected in the 12 × 15 block matrix. It does all of this in real time. If the sensor detects valid motion, it triggers the alarm signal.

The sensor has two modes: Detection mode and Command mode. After starting in Detection mode, it constantly detects motion until it is stopped by the serial port. Then, Command mode is enabled and several commands are available (see Table 1). One of the functions allows you to define an ignore bit mask, masking the blocks in the 12 × 15 frame matrix, where movement should be ignored. Other commands enable you to define several parameters that control how the alarm is triggered, including the number of contiguous frames that must have motion or the number of blocks that have to be reported to activate the alarm. Photo 1 shows how the motion sensor detects movement and highlights the blocks where motion has been detected. The center

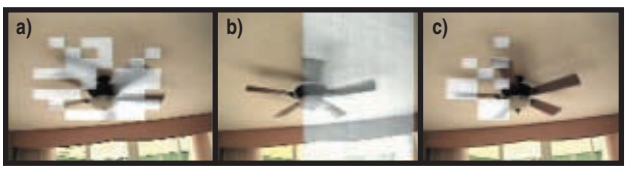


Photo 1—These shots are kind of blurry, but you get the idea. The motion controller is detecting movement in a 12 × 15 block matrix **(a)**. The full motion sensitivity was enabled. Notice that the shadow movement is also reported. **b**—Here the video output has the bit mask defined with the I: command (I:0E:0FF0). **c**—The motion controller detects motion afterwards. Only the nonignored blocks are reported.

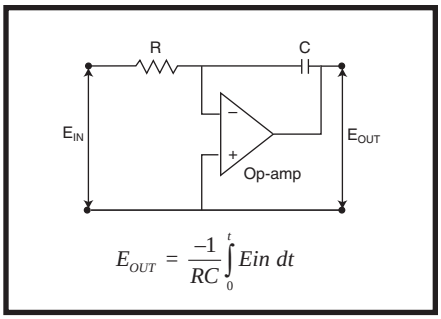


Figure 3—Check out the ideal op-amp integrator. Note that the resulting voltage is negative. To maximize the digitizing range, the integrator's value was inverted and translated to the ADC's input range of 1 to 2 V.

and right pictures show the sensor's ignore mask in action.

SYSTEM DESIGN

The motion-detection algorithm is based on the difference in brightness between the corresponding blocks of two consecutive, compressed frames. If the difference exceeds your defined threshold, then motion is reported at the block and it is flagged in the 12 × 15 matrix. Most of the motion sensor's major components are involved in compressing the video signal (see Figure 2). To compress the video into 12 × 15 blocks, every video line must be divided into twelve 4.3-µs segments. The luminance of the video signal is then averaged into each of the segments through an analog integrator. The integrator sums the voltage of the video signals in each 4.3-µs period, creating a value that is proportional to the average of the segment's brightness. Analog voltage is converted to digital with a fast ADC. Before integrating the signal, the inverter and clamper circuits prepare it to fit in the ADC's range. After the signal has been converted to digital, the firmware vertically averages each of the 12 segment values into 15 groups to form a 12 × 15 block frame. Because this averaging process uses most of the available CPU, it is only performed while the video even fields are analyzed. During the odd fields, the software performs the motion-detection algorithm. It will still follow the video signal in the even fields because the video highlighting requires output in both fields.

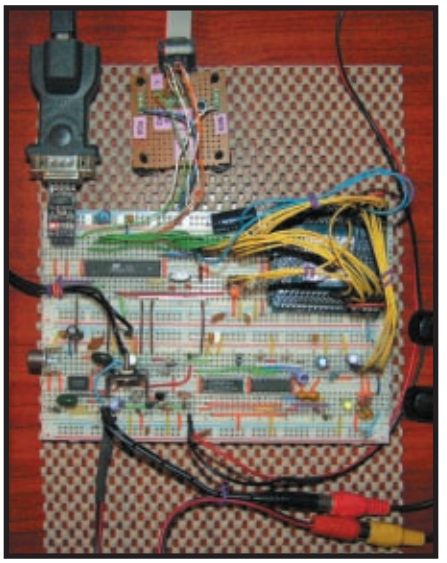


Photo 2—This is a prototype of the motion sensor. The breadboard contains the ATmega88 at the top left. The AD9280 ADC is at the top right. The chips from left to right are the LM1881, the 74HC4066, and the LM6134.

HARDWARE DESIGN

The design is primarily based on an analog integrator circuit. The circuit integrates (i.e., sums) the input-voltage signal over a defined period of time. Based on an op-amp, the ideal circuit is shown in Figure 3. The factor

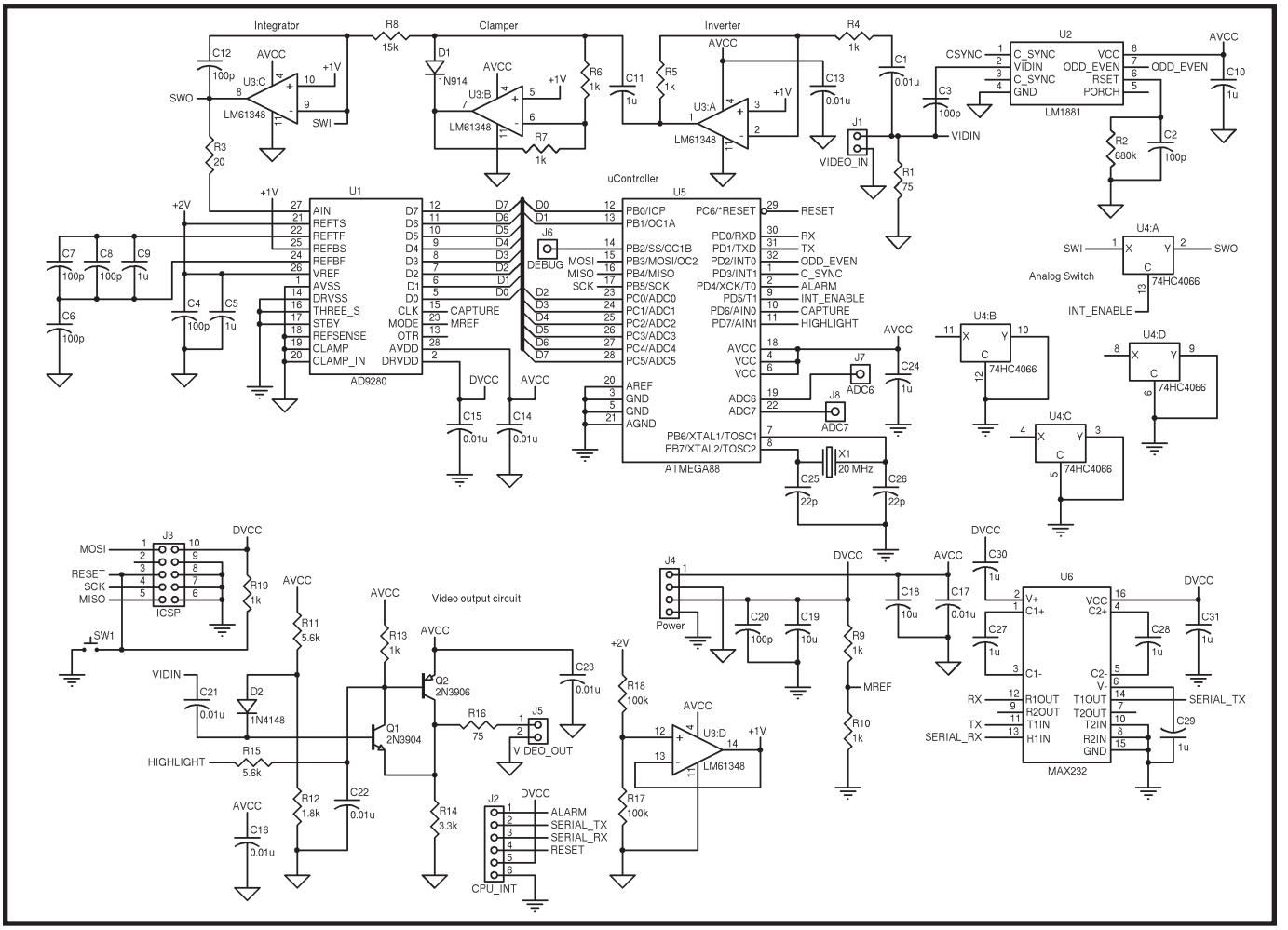


Figure 4—With only six chips costing less than $16 in small quantities, I developed a full-featured analog video motion sensor. The chips include an ATmega88 as the main controller, an AD9280 ADC, an LM6134 high-speed quad op-amp, an LM1881 video sync separator, a 74HC4066 as a simple analog switch, and an RS-232-level converter.

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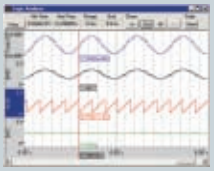
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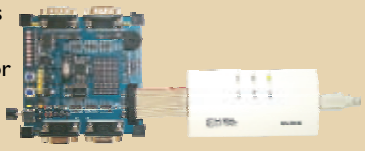
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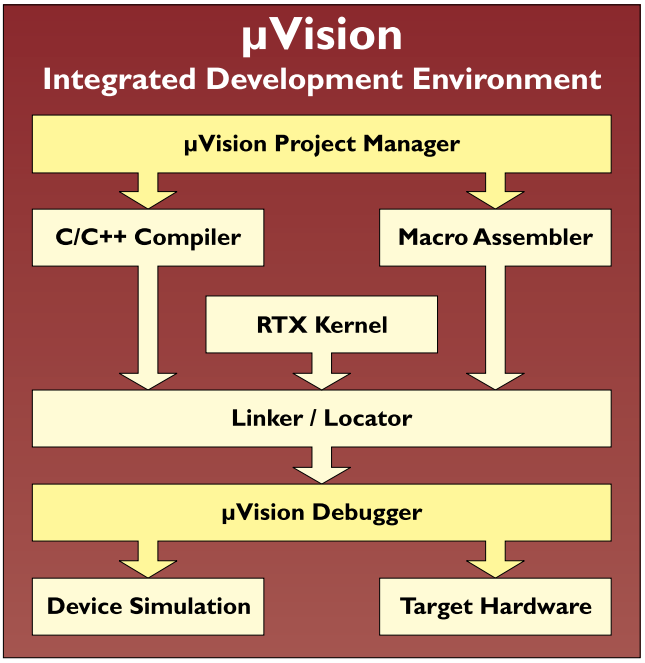


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–(1/*RC*) is constant, so the resulting output is inverted and proportional to the sum of the integrated values (i.e., proportional to the average of the signal in the integrated period of time). This is all it takes to "compress" the analog video signal.

Although it seems complicated at first sight, it should be fairly simple by now (see Figure 4). The integrator is implemented by a National Semiconductor LM6134B, a fast, rail-to-rail, single-power supply op-amp (U3). The output should then be quickly converted to digital because the input changes very fast. Analog Devices's AD9280 ADC (U1) with 32 Msps was selected so a 50-ns capture could be performed. The AD9280 was configured for 1 to 2 V of input to use the internal 2-V reference. A 1-V reference was obtained with U3:D. To prepare the input for this range, the signal was inverted with the op-amp U3:A and clamped just less than 1 V with U3:B (see Figure 2). Just before the integration, the video was inverted under 1 V. The integrator was designed to output a 1-V signal when a ground-referenced, fully saturated video signal was input in 4.3-µs intervals. Note that the integrator is offset at 1 V. So, after signal integration, the ADC will receive a signal that is from 1 to 2 V as required. The integration capacitor C12 is a low-leakage metalized polyester film type. R8 is a metal film resistor, also a 1% part. To reset the integrator, a 74HC4066 analog switch (U4) is used. It is controlled by the ATmega88 through the INT_ENABLE signal.

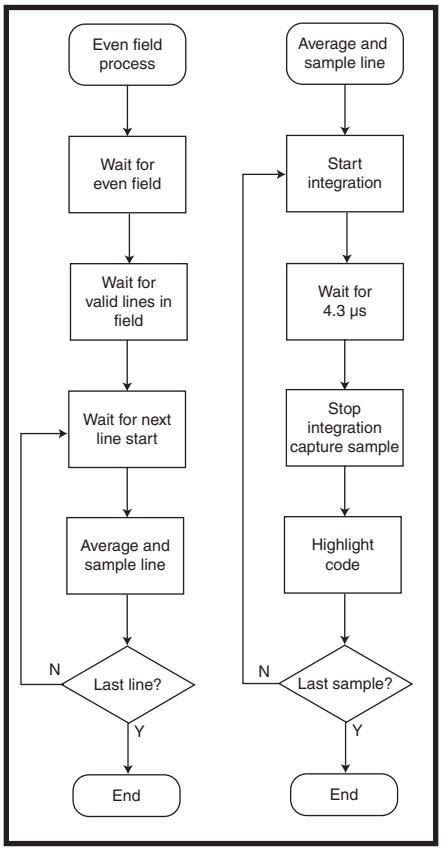


Figure 5—This flowchart shows the logic of the sampling process. Only the even fields are processed to leave time to run the motion algorithm during the odd frames.

The video frame start is detected through the INT0 interrupt when the odd/even output of U2 changes. By using the odd/even output instead of the vertical synchronization output, the same pin can be used to determine if it is an even or odd frame. The video-line start is detected using the composite synchronization output of U2, which is connected to the AVR's INT1 input.

The video output block performs the video highlighting. It is a transistor-based video amplifier that increases the gain when its enable signal is asserted low. Highlighting is used to show where a movement has occurred in the previous frame. It also gives you feedback on the blocks that will be ignored while executing the masking commands.

The only digital components in the design are the ATmega88 (U5), which has 8 KB of flash memory and 1 KB of RAM, a 20-MHz clock, and an RS-232-level converter (U6). The ATmega88, with its versatile instruction set, was key to developing this project. The generous 32 registers, bit-manipulation instructions, and word-pointer registers allowed the integration algorithm to fit in 4.7 µs, where the next sample should be captured. The software was developed in assembler to achieve the large optimizations required. I used AVR Studio 4 as the developing and testing environment.

The circuit requires a regulated 5-V power supply for the analog and digital circuits. A single regulator can be used for both the analog and digital parts, provided that the signals are well filtered, and there is a single point of contact between the ground rails. Take a look at the motion-sensor prototype in Photo 2.

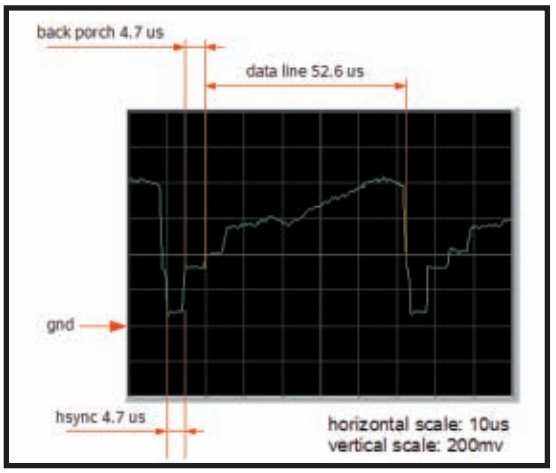


Photo 3—This is an oscilloscope capture of an NTSC video line. Line luminance data starts 4.7 µs after the end of the horizontal synchronization signal.

SOFTWARE DESIGN

The motion sensor's software was designed in functional sections to minimize its complexity. When the software starts, motion sensing begins immediately. The algorithm first enables the interrupt service routines (ISRs), where the video sampling and averaging process is performed. Once the required frames are captured, the motion-detection algorithm processes them. This cycle repeats until it is interrupted by the user. When the motion algorithm is stopped, the user interface code is enabled.

The most important part of the code is the video sampling and averaging process, which produces the 12 × 15 frame matrices (see Figure 5). The process runs in real time through interrupts generated by the video-synchronization signals that come from U2. The ISRs change the state of the finite state machine (FSM) that is used to determine which step of the video-capture process the system is in. The possible states are waiting for frame (ST_WAIT_FRAME), waiting for video line data start, (ST_SEEK_DATA) and integration

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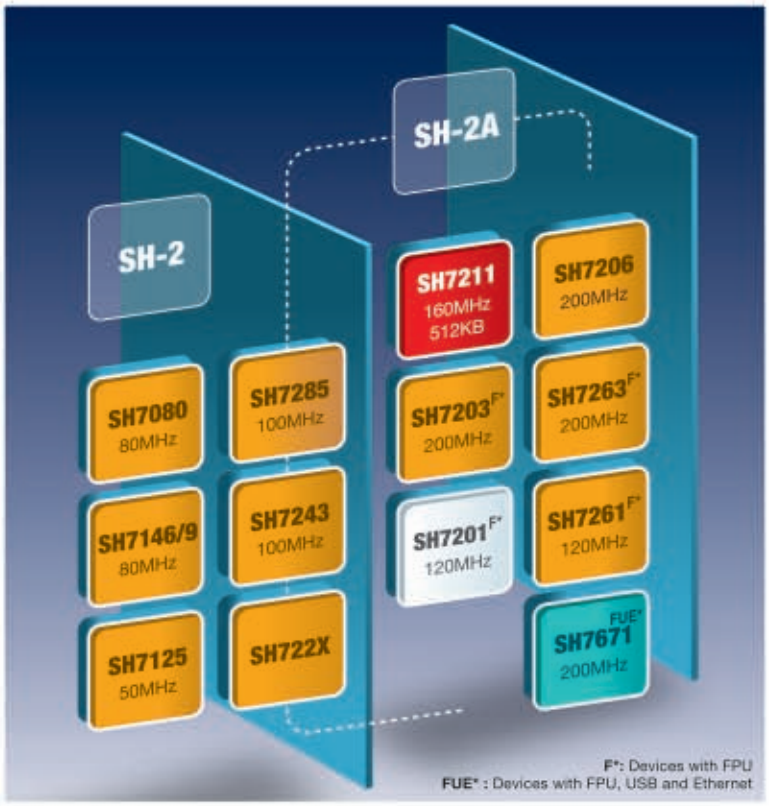
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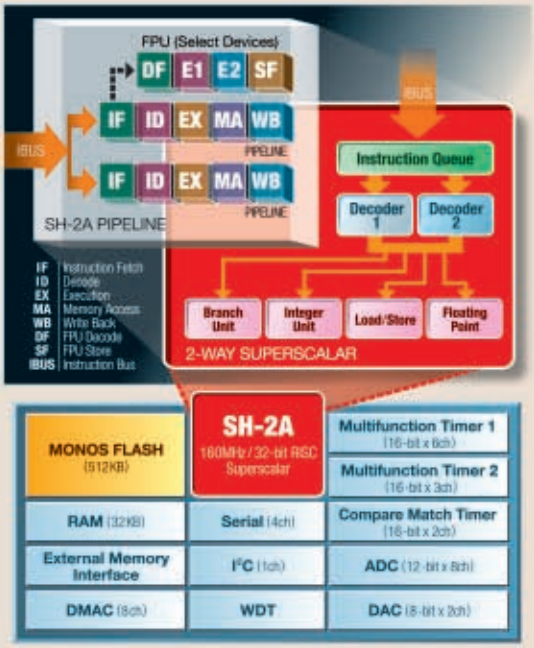
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(R5F72115D160FPV)



MONOS FLASH (512KB)	SH-2A 160MHz / 32-bit RISC Superscalar	Multifunction Timer 1 (16-bit x 8ch)
		Multifunction Timer 2 (16-bit x 3ch)
RAM (32KB)	Serial (4ch)	Compare Match Timer (16-bit x 2ch)
External Memory Interface	I²C (1ch)	ADC (12-bit x 8ch)
DMAC (8ch)	WDT	DAC (8-bit x 2ch)

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  - Register-Banks enable 37.5nsec (6 cycles) interrupt latency time.
- **High Integration**
  - Large on-chip flash and on-chip RAM
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start/capture (ST_INTEGRATE). Three ISRs are defined in the interrupt vector table: frame_start ISR for the INT0 signal, line_start ISR for the INT1 signal, and capture_task for the timer 0 compare A ISR.

When the system starts, the FSM is initialized to the waiting-for-frame state. In this state, only the INT0 interrupt is enabled. When a new frame arrives, the LM1881 senses the odd/even field change and asserts the INT0 signal, which starts the frame_start interrupt handler. This ISR checks if the frame has to be averaged. If it has to (i.e., it is even), the accumulators are initialized. These will store the 16 horizontal segments luminance sums. The line and step counters are also initialized and the FSM is set to count lines (change state to ST_SEEK_DATA). The INT1 is enabled so that the next horizontal-synchronization signal will call the line_start ISR. The X pointer is set to the current frame storage (FRAME0 or FRAME1) where the captured data is going to be stored.

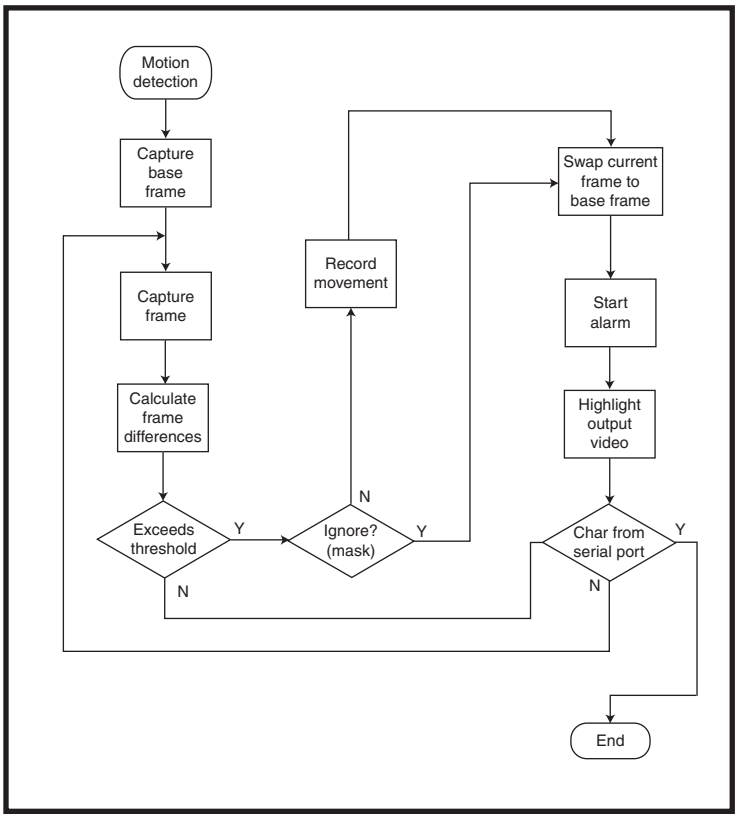


Figure 6—This flowchart shows the logic of the motion-detection algorithm. A base frame is captured and then compared with the following frame as a matrix subtraction. Motion is detected if any element in the resulting matrix exceeds a threshold.

Next comes the INT1 interrupt service handler. Every time a horizontal synchronization signal is detected, the line_start ISR is called. The routine is responsible for skipping the first nonvisible video lines (until line 15) and starting the capture process by changing the FSM state to ST_INTEGRATE. The ISR also counts the lines until the end of the visible frame, where the end of the frame capture is signaled. When the state is ST_INTEGRATE, the line counter is reset to count from 0 to 239, or 240 valid video lines. This offset to zero is useful to simplify the vertical grouping. By dividing the LINE counter by 16, the result will give the vertical group number from 0 to 14 directly. When counting lines in the valid range, the line_start ISR also enables the TMR0 interrupt, which is set to interrupt at T_START cycles from the beginning of the line_start interrupt. This happens to be exactly the start of the video line data (see Photo 3). After line 240, a couple of additional lines are sampled to fill the missing values in the circular buffer, due to the ADC pipeline. After line 241 is processed, the routine stops the sampling process and disables the INT1 interrupt. The resulting captured and compressed frame is stored in the FRAME0 or FRAME1 buffer, which is indicated by the F_FRAME1 flag.

The TMR0 interrupt runs the capture_task, the most important segment of code. This ISR is responsible for sampling the video signal, its vertical averaging, and the video-output highlighting. This task runs 13 times for each line. This ISR is first called at the beginning of the video line. At this point, it starts the integrator and then sets the TMR0 to interrupt about every 4 µs to sample the resulting integrated values from the ADC. In the second to thirteenth interrupts, the previous started integration is sampled by toggling the capture output. It is then averaged into the accumulators (pointed by Y). In the last line of the 16-line group, the accumulator is moved into the frame buffer pointed by the X register. Using this schema, a circular buffer as the accumulator array, and ignoring the first four ADC samples, the four-level pipeline of the ADC is effectively handled and the samples are synchronized with the frame buffers. This part of the code is very time-sensitive, and its length is limited by the horizontal-average resolution of the sensor to 12 segments. A large number of optimizations were performed here, like using dedicated registers as variables and moving some calculations to the line_start ISR.

The motion-detection algorithm roughly follows the logic in Figure 6. The algorithm is performed in the motion_detect subroutine. This subroutine captures a base frame first and then compares it to the following frames. The comparison is just a matrix subtraction. If the absolute value of any element in the resulting matrix exceeds your defined threshold, the corresponding block is flagged to indicate motion at its position in the frame. Only the nonignored blocks are flagged. Once the number of flagged blocks repeatedly exceeds a minimum value for a number of consecutive frames, an alarm is generated and the output signal is asserted. You can define both of those parameters through the serial command interface (SCI). Other parameters can be modified to make the system ignore frames when the number of flagged blocks exceeds a certain threshold. This is useful to avoid false alarms when the illumination changes abruptly. The user can also set a number of frames

to be ignored after these events so that automatic exposure cameras have time to stabilize.

The serial port is configured for data with 19,200 bps, 8 data bits, no parity bits, and 1 stop bit. When you send a character through the port, the motion-sensor function is interrupted and the sensor enters Command mode. This part of the source code interprets and executes the available commands sent to the interface. Backspace support was implemented for user interaction, although the interface can also be used by a controlling computer. Output messages begin with codes that facilitate its interpretation for this effect. A special Movement Detection-mode command (M1) that will detect motion until a movement is detected was implemented. After it stops, frame dump commands can be used to let higher-level systems further analyze the data. The code for this part is very simple. After a line is read, a command comparison is performed and the corresponding segment of code is run. During the execution of the user interface, the motion-detection algorithm is stopped. It will resume after an M or an M1 command.

The project was difficult. Fitting everything in such a relatively low-processing microcontroller was challenging. A good software design was key, but the fast ATmega88, with its versatile instruction set, made this project a reality. I am very proud of the end result. It is robust, it has a lot of functionality, and it has a lot of room for improvement. Of the ATmega88's 8 KB of the flash memory capacity, only about 40% was used. Just 56% of the RAM was used.

After developing the video motion sensor, I am now more open to considering mixed-signal designs for future applications. By creatively using analog components in the design, I significantly reduced the system's complexity and built an interesting application that couldn't have been built digitally at such a low cost. So, thinking outside the "digital box" may reward your design and your wallet.

Naubert Aparicio (naubert.aparicio@usa.net) is the technology director at Quantum Business Engineering in Puerto Rico. Since graduating from Simon Bolivar University in Venezuela, he has gained more than 20 years of experience in computer science engineering. In his free time, Naubert enjoys learning about robotics and advanced digital design, as well as flying radio-controlled indoor helicopters. He is now having fun designing microprocessors in VHDL and designing and building automation devices for his home.

PROJECT FILES

To download code, go to ftp://ftp.circuitcellar.com/pub/circuit_cellar/2007/203.

RESOURCES

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www.analog.com

ATmega88 Microcontroller
Atmel Corp.
www.atmel.com

LM1881 Video sync separator and LM6134B op-amp
National Semiconductor Corp.
www.national.com



Dew Point Monitor

Peter and Ramon built an accurate dew point monitoring system. The system cools a mirror and records the temperature the moment moisture forms on it.

In 1821, Thomas Johann Seebeck discovered that when two different metal conductors were joined together in a loop and a temperature difference was established between the two junctions, a current flowed around the loop. Twelve years later, J.C. Peltier proved the inverse effect. By cutting one of the conductors in the loop and forcing a current through the loop with a battery, a temperature difference was created between the two junctions. That was the birth of the thermoelectric cooler (TEC).

What do a TEC module, a thermometer, a mirror, some optics, and a microcontroller give you? A dew point instrument of course, and although many of you are familiar with "dew," not too many of you know how it forms and why there is interest in the temperature at which it forms (i.e., the dew point).

By definition, the dew point is the temperature at which air (or any gas) must be cooled, at constant pressure, so that it will be saturated with respect to water. In layman's terms, it's the temperature at which moisture condenses from the atmosphere. Below 0°C, dew point hygrometers actually measure the frost point, but in our neck of the woods, we will always measure the dew point because temperatures seldom dip below 75°F.

Some of you may remember seeing a strange-looking pair of thermometers arranged close to each other in the science lab during your high school days (see Figure 1). If you were inquisitive, you may have asked the teacher about them and were told they were wet-dry bulb thermometers. These devices, with the help of charts and formulae, allow us to determine the relative humidity and dew point of the atmosphere.

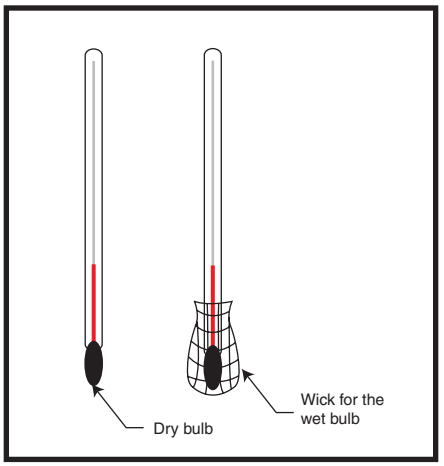


Figure 1—Check out the wet-dry thermometer. The system measures relative humidity by comparing readings of wet-bulb and dry-bulb thermometers. It usually comes with relative humidity tables and consulting charts.

However, one of the easiest self-calibrating ways to measure the dew point is to cool a mirrored surface and record the temperature the instant moisture forms on the surface of the mirror. By definition, this would be the dew point. Other methods are used, but this "chilled mirror" system is relatively accurate and reliable.

The chilled mirror method has been around for years and many manufacturers offer devices with varying levels of accuracy and cost. For example, to minimize the effects of dust, pollutants, and other contamination build-up on the mirror's surface, the complete system is sometimes enclosed with particulate filters. Some have even experimented with elaborate self-cleaning mirrors, where a tiny "windshield type" of apparatus squirts a cleaning liquid when optical reflectance begins to decrease.

WHO IS INTERESTED?

Besides meteorologists, weather fanatics, and orange farmers in Florida worrying about the frost point, who else is interested in the dew point? In industry, there are numerous plants that require this information for their manufacturing processes, including manufacturers of steel and wire products, spray paint, lumber, pharmaceuticals, and photographic film. The information is also useful to workers

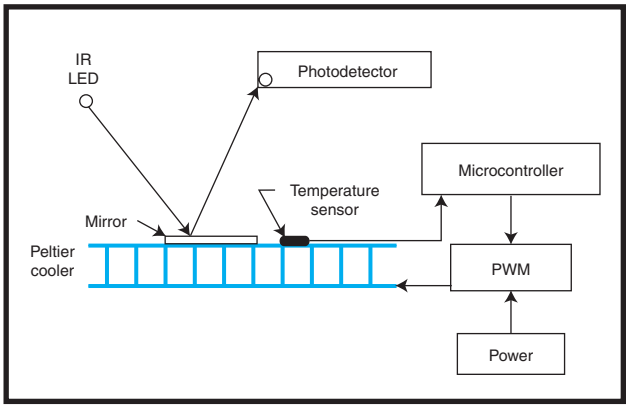
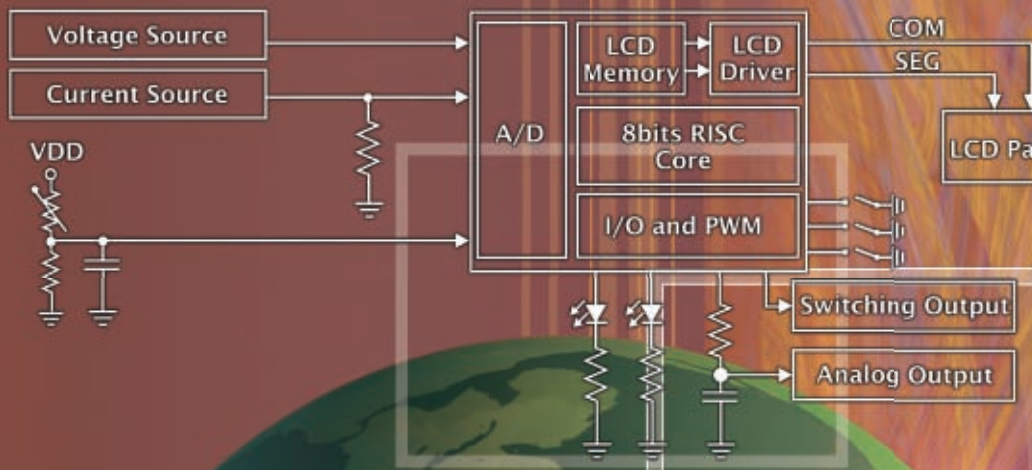


Figure 2—Feedback from the photodetector allows the microcontroller to regulate the Peltier cooler. A small sensor measures the dew point.

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Part No.	Program	Data	I/O	LCD	Timer	A/D	PWM	UART	Package
HT46R62	2Kx14	88x8	20	19x4	8-bitx1	9-bitx6	8-bitx3	--	52QFP, 56SSOP
HT46R63	4Kx15	208x8	32	19x4	16-bitx1	8-bitx8	8-bitx4	--	56SSOP, 100QFP
HT46R64	4Kx15	192x8	24	32x4	8-bitx1, 16-bitx1	10-bitx8	8-bitx4	--	52QFP, 56SSOP, 100QFP
HT46R65	8Kx16	384x8	24	40x4	16-bitx2	10-bitx8	8-bitx4	--	52QFP, 56SSOP, 100QFP
HT46RU66	16Kx16	576x8	32	46x4	8-bitx1, 16-bitx2	12-bitx8	8-bitx4	v	52QFP, 56SSOP, 100QFP

Part No.	Program	Date	I/O	LCD	Timer	UART	Package
HT49R30A-1	2Kx14	96x8	14	18x4	8-bitx1	--	48SSOP
HT49R50A-1	4Kx15	160x8	20	32x4	8-bitx2	--	48SSOP, 100QFP
HT49R70A-1	8Kx16	224x8	24	40x4	8-bitx1, 16-bitx1	--	100QFP
HT49RU80	16Kx16	576x8	31	47x4	8-bitx1, 16-bitx2	v	100QFP

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in museums, storage vaults, poultry facilities, greenhouses, and nurseries. The list is long. Athletes are also interested. Golfers and others who compete on natural turf would like this information because dew usually works its way up from the ground and affects how a ball moves off the grass.

Like any other physical weather parameter, however, your need may very well be in some area we may never imagine. Fortunately, this simple, sensitive sensor can be built at the right price.

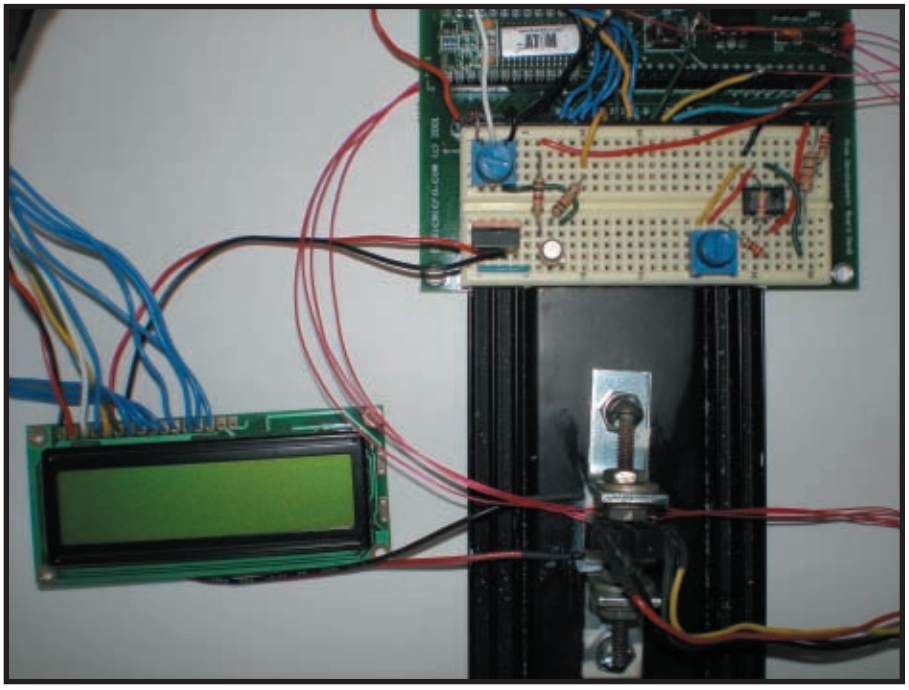


Photo 1—Take a look at the dew point system prototype. It includes an ATOM microcontroller and breadboard (upper right), a sensor assembly mounted on a heatsink (lower right), and an LCD (lower left).

PRINCIPLE OF OPERATION

A number of processes are involved in the design (see Figure 2). Essentially, a mirror is chilled until dew just begins to appear. Meanwhile a beam of IR light from an LED is aimed at the mirror's surface and a photodetector monitors the amplitude of the reflected light. As air flows over the mirror, dew droplets form on the mirror's surface and the reflected light is scattered. As the amount of reflected light decreases, the photodetector's output also decreases.

This, in turn, controls the thermoelectric heat pump (TEC) via a microcontroller system that maintains the mirror's temperature at the dew point. If continuous operation is not required, the system is switched off once the dew point is recorded and restarted from room temperature each time a reading is required. A temperature sensor, properly embedded in the mirror, monitors mirror temperature at the established dew point.

Systems can be as simple as we just described, or they can become more elaborate and accurate if each section is improved. In this article, we will describe our basic system with suggestions on where and how others can improve the design.

HARDWARE

It's temperature we are after, so a sensor (preferably a small one) is required to minimize the thermal load on the solid-state Peltier cooler. Common sense indicates a tiny bead-type thermistor, but this would necessitate an ADC to transform the resistance values to temperature readings. Additionally, since a typical thermistor response is nonlinear (usually exponential), floating-point arithmetic or a large look-up table would be required in the microcontroller to transform



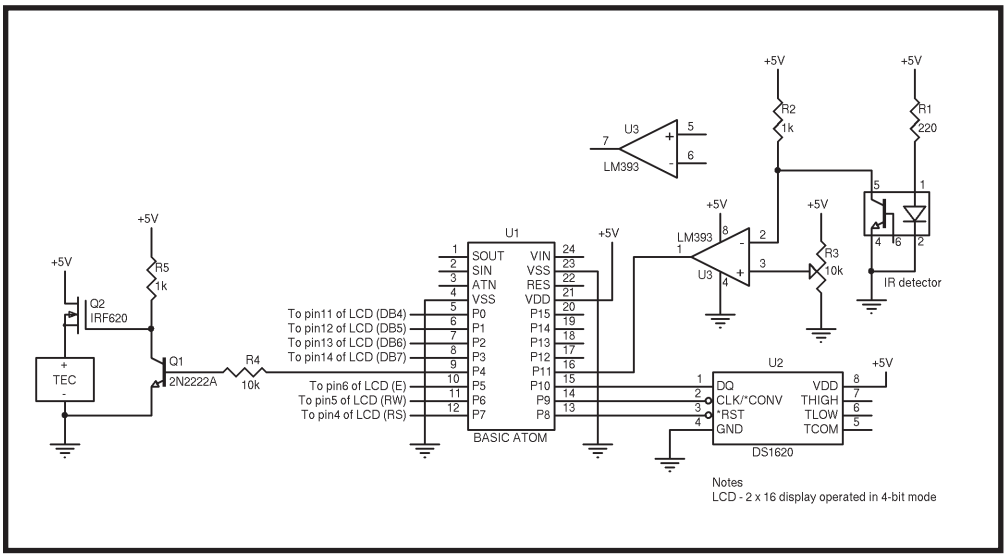


Figure 3—The schematic is quite simple. The system uses very few of the ATOM's capabilities and power. Any small LCD can be added.

the resistance reading into an accurate temperature value.

Alternatively, a Maxim Integrated Products DS1620 IC semiconductor can measure the temperature and deliver it in a convenient digital format. The only disadvantage is the size of the DS1620 compared to the bead thermistor. However, the IC unexpectedly offers a bonus, which we will mention later. After much deliberation, we decided to go with the DS1620 in its small footprint, the SOIC 208-mil package.

The IR LED detector pair used is similar to the standard reflective type available from numerous manufacturers. It has a slotted section that allows it to be mounted as an adjustable component.

The thermoelectric Peltier cooler is from Melcor. We chose the CP1.0-31-08L, which measures 15 mm square with a height of only 4 mm. This module can pump heat away at a rate of 5.3 W, using 2.5 A at 3.75 VDC, and it has a theoretical maximum temperature difference of 67°C below ambient. Smaller modules are available with less heat extraction capability, and they would consume correspondingly less electrical power.

For the microcontroller, we selected the BasicATOM24-M from Basic Micro. This Stamp-like cousin packs quite a bit more punch than the BASIC Stamp 2. Its MBasic language supports 32-bit floating-point math, and it comes with three channels of 10-bit ADC, two hardware PWMs, and a host of other features. The 24-pin version of the ATOM is built around the Microchip Technology PIC16F876 microcontroller (see Photo 1).

The LCD module is a 2 × 16 parallel interface type used in 4-bit mode while the power supply is a standard DC type, variable from 0 to 12 V at 5 A.

THE SYSTEM

Figure 3 shows the DS1620-based system we used. Bit 4 applies software PWM control to the gate of the power MOSFET (IRF620), which regulates the amount of current flowing through the TEC.

Alternatively, we also tried controlling power to the TEC using the hardware PWM, channel 0 on pin 9. This regulated the gate signal on the power MOSFET with full power corresponding to a 100% duty cycle. This is set by the statement `HPWM 0, 16383, 16383`, where the latter value of `16383` sets the duty cycle and the middle value sets the period of the pulse width in clock cycles. The beauty of hardware PWM is that it can be left running while your program is performing other tasks. Both PWM hardware channels and the software PWM channel on the ATOM can be used at the same time if you desire.

In our test setup, the amount of PWM is determined in the software control program. When first started, full cooling is applied to the TEC and the temperature falls quickly towards the dew point. The instant moisture forms, the photodetector's output drops significantly. This is the temperature of interest. At this stage, you have many options for how you wish the instrument to operate.

You can allow the TEC to warm back up to ambient temperature until mist on the mirror disappears and then repeat the process immediately or after a delay. This basic method is the simplest approach and easiest to program. Or, you may jump into a more "controlled" approach back down to the dew point again. This slower or "softer" approach allows the system to settle on the dew point and supply a more accurate reading. Essentially, as mist forms and the photosensor's voltage begins to drop, the TEC current is progressively reduced, thus you are actually tracking the dew point. This continuous tracking method constantly keeps the system at the dew temperature. Thus, it may be read from the LCD instantaneously (without any delay) when required. The mirror, however, tends to collect contaminants quicker in this mode and would require more regular cleaning and maintenance.

Reading the temperature is a breeze with the DS1620, because the IC continuously performs this function and stores the value internally. You simply read out the temperature when required. The bonus of the DS1620 alluded to earlier is that we can reflect the IR beam directly off the IC itself. (The DS1620 is our thermometer and mirror!) The IC is thermally bonded to the TEC and a thin silvered "spot" mirror glued on its top surface. This essentially guarantees that the temperature recorded is the mirror's temperature. We simply used a thin sheet of silvered foil as our mirror.

However, readers may have to modify this arrangement depending on the

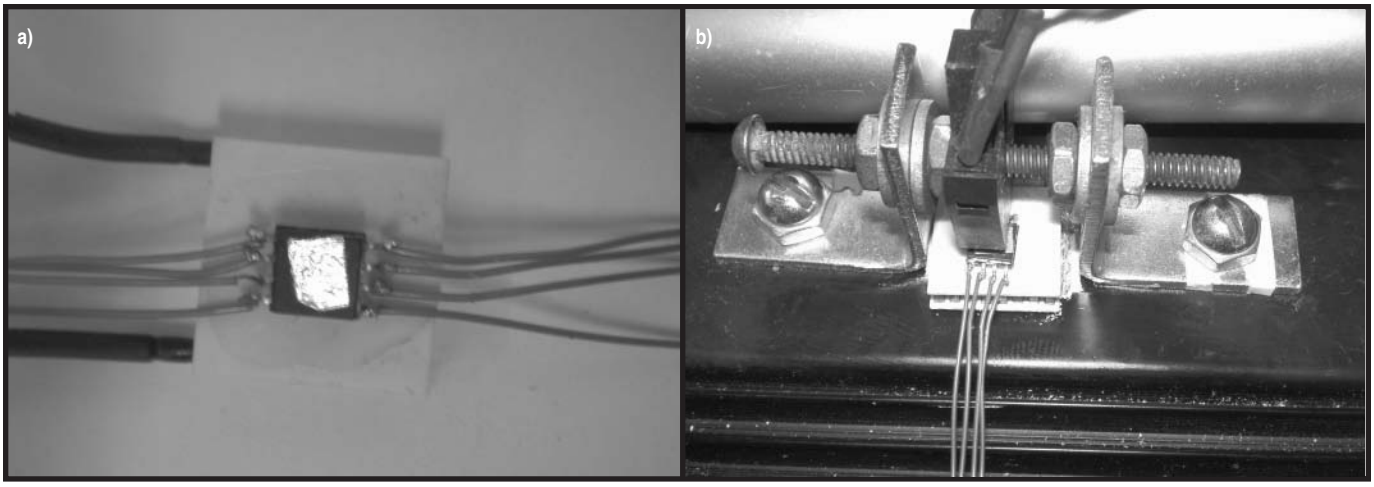


Photo 2a—A small mirror is mounted on the DS1620 sensor and TEC. The sensor is bonded to the cold surface of the TEC. **b—**The optical system has been rotated out of view for this photo.

dew temperatures. In the tropics, where we live, it's only a few degrees below ambient. In colder areas, the DS1620 may be too big a thermal load to cool if the dew temperature is relatively far below the ambient temperature. In that case, you can mount the mirror directly on the cold TEC surface and position the DS1620 off to the side.

If you do not want to poll the photosensor response via software, a simple hardware solution can be implemented. The intensity of the reflected IR beam detected by the phototransistor is fed to the inverting input of a common comparator. The other input to the comparator is set by the trimmer, R3. The comparator output is polled by the ATOM via Bit 11 to signal when it is time to take the dew temperature reading from the DS1620 (or the thermistor). Even this external comparator could be eliminated if one chooses to use the ATOM's internal comparator, or it could be used to trigger an interrupt, thus changing the design into an interrupt-driven system.

Dew temperature is displayed on the LCD, interfaced to the ATOM in 4-bit mode, and easily driven using the built-in LCD commands of MBasic.

CONSTRUCTION

The system is built on a piece of finned heatsink. It is extremely important that heat generated on the hot side of the TEC is removed as fast and efficiently as possible, or else the temperature difference between the hot and cold sides of the TEC will be seriously reduced.

The TEC is bonded to the heatsink using thermal epoxy or heatsink paste. The epoxy was also used to bond the small mirror and the DS1620 to the TEC cold surface. The easier we can dissipate heat from the system, the easier the TEC will operate. Thus, it is important to use an ample heatsink. Photo 2 shows the DS1620 and mirror arrangement on the TEC. The optical system was moved out of view for this shot.

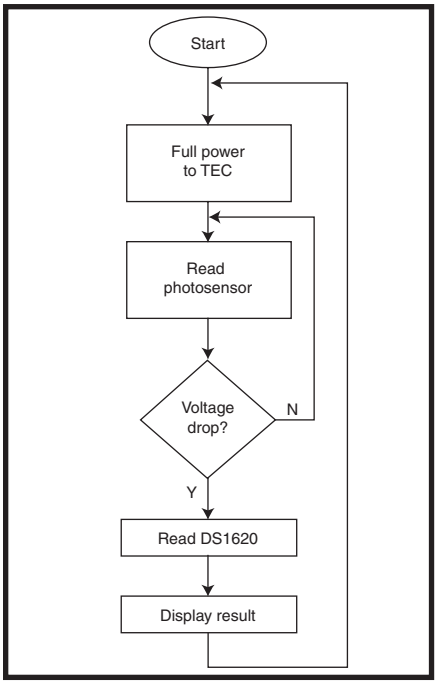


Figure 4—The TEC cools the mirror to the dew point. As soon as the photosensor detects dew, the temperature is displayed.

The photodetector module is held over the mirror using a simple arrangement of two 90° angle brackets, a bolt, and some spacers from any hardware store. Since the module has a slot for mounting, you can fine-adjust its height above the TEC surface for maximum sensitivity, (1 mm according to the manufacturer).

SOFTWARE

Depending on the control approach you desire, the software can be short and simple or more elaborate. Listing 1 illustrates the short and simple method. At the ambient temperature, full cooling is applied to the TEC. As soon as the optical signal drops below the preset value, the dew point is recorded, power is removed from the TEC, and the system is allowed to return to ambient temperature before another reading is taken. Figure 4 shows a flow chart of the polling method.

RESULTS

The device is quite sensitive and accurate. It can maintain the dew temperature to within ±0.5°C in Continuous mode. Surprisingly, if it is not protected from open air, it easily detects people's movement in the room, due to the normal airflow disturbance being created.

The optical system usually detects moisture formation before the naked eye. Unless screened from dust and contaminates, it will require cleaning after a few months. This can be

Listing 1—This Basic ATOM program is compatible with the more popular BASIC Stamp 2. After initialization, the program applies power to the TEC and checks for dew on the mirror. When dew is detected, the temperature of the DS1620 is displayed on the small LCD. The system is then maintained at the dew temperature using a basic on-off control scheme. The LCDWRITE command is the only command not available on the BASIC Stamp.

```
;CPU = 16F876  MHZ = 10            CONFIG 16254
;***********************************************
; Title : DewPoint.bas
; Author   : Ramon Sargeant
; Date  : 26/09/2006
;***********************************************
'DIRS = %0000000000000000
CEcon      4
RST  con    8
CLK  con    9
DAT  con    10
TRIG    con    11
Temp    var    Word
  Pause 500    ;Allows the LCD to initialize
  LCDWRITE 7\5\6, OUTA, [INITLCD1, INITLCD2, TWOLINE, CLEAR, HOME, SCR]
  gosub InitDS1620
  low RST
  pause 50
  high RST
  SHIFTOUT DAT, CLK, LSBPRE, [$EE\8]        'Start conversion
  low RST
Main:
  LCDWRITE 7\5\6, OUTA, [CLEAR, HOME]
  pause 20
  high CE                                   'Enable TEC cooler
main_loop:
  gosub ReadDS1620Temp
  if in11 = 1 then main_loop
  low CE
  pause 500
  Goto Main
InitDS1620:
  low CLK
  low RST
  pause 30
  high RST
  SHIFTOUT DAT, CLK, LSBPRE, [$0C\8, 2\8] '12 - write config reg
  low RST
  pause 30                                  'Pause 20 ms
  low CLK
  high RST     'check config register
 SHIFTOUT DAT, CLK, LSBPRE, [$AC\8] 'ACh - read config reg
 SHIFTIN  DAT, CLK, LSBPRE, [Temp\8] 'x - data store variable
  low RST
  DEBUG [" ", HEX Temp]
  return
ReadDS1620Temp:
  low CLK
  high RST     'check config register
 SHIFTOUT DAT, CLK, LSBPRE, [$AC\8]  'ACh - read config reg
 SHIFTIN  DAT, CLK, LSBPRE, [Temp\8] 'x - data store variable
  low RST
  low CLK
  high RST
  SHIFTOUT DAT, CLK, LSBPRE, [$AA\8]
  SHIFTIN  DAT, CLK, LSBPRE, [Temp\9]       'Read temperature
  low RST
     Temp = Temp & $1FF
  if Temp.HighByte = 0 then
    LCDWRITE 7\5\6, OUTA, ["Temp: ", DEC (Temp.LowByte>>1)]
  endif
  if Temp.HighByte = 1 then
    LCDWRITE 7\5\6, OUTA, ["Temp: -", DEC (127-(Temp.LowByte>>1))]
  endif
  if Temp.BIT0 = 1 then
    LCDWRITE 7\5\6, OUTA, [".5"]
  endif
    LCDWRITE 7\5\6, OUTA, [" C"]
  return
END
```

extended to once a year with proper filtering. As we indicated earlier, you can modify the system to your heart's content. Lots of improvements can be dreamt up to maximize performance and miniaturization.

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Slave Flash Trigger

Aleksander wanted a more powerful camera flash that could reach longer distances and reduce red eye. He built his ATtiny13-based external slave flash trigger to do that and more.

After I purchased my first box camera, I had problems taking photos in poorly lit places because I did not have a portable light source. Nowadays, things have changed. Virtually every contemporary camera, including disposables, has its own light source, which is of course a built-in flash. So, it may seem that my problems have been solved. I wish that were true!

The problem with built-in flashes is that they tend to be weak. For example, the effective range of the built-in flash in my Fuji FinePix S5600 digital camera does not exceed 4 m. The second problem is that the built-in flash fires straight into the face of the subject. This causes the well known "red-eye effect" and creates big shadows behind the photographed object.

The solution to these problems is a more powerful external flash. It is strange, but digital cameras so rich in different connectors, including audio and video outputs, are seldom equipped with an external flash connector or a hot shoe, which used to be standard camera equipment a few years ago. Cameras with these components usually work only with dedicated (rather expensive) external flashes. Please, don't be fooled by the external appearance of this connector. It may look exactly the same as it did in the old analog cameras, but connecting it to an old yet powerful flash (which can now be obtained at virtually no cost) may be dangerous due to the high voltage (up to 350 V) present in the flash plug. This voltage was no problem for preelectronic analog cameras, but it can easily fry a digital camera. Fortunately, the remote triggering of the external flash can solve your problems.

REMOTE FLASH TRIGGER

Devices that remotely synchronize an external flash with the camera's built-in flash can be purchased in some photo stores. You may have noticed them under their common name "photocells." Unfortunately, these triggers do not work correctly with digital cameras because a digital camera does not emit one flash but at least two, one by one. The first one, a so-called "pre-flash," is used by the camera's software to set up the automatic exposure. The second flash is the main flash, which draws the picture. In more sophisticated modes, such as Red-eye Reduction mode, the number of preflashes increases. Simple remote flash triggers do not work correctly, because they trigger the slave flash on every detected light pulse. They cannot discriminate between the preflash or the main flash that is triggered. The external flash can fire only once, and it usually fires simultaneously with the preflash, so it cheats the camera's exposure-control software. The result is a completely dark photo, which looks even worse than a picture taken with only a built-in flash.

I was not able to buy a smart flash trigger. So, after reading negative opinions in an online forum (www.cyberfoto.pl) about a do-it-yourself smart flash trigger, I had no option but to roll up my sleeves and go to work on my slave flash trigger design (see Figure 1 and Photo 1).[1] I designed my system around Atmel's ATtiny13 AVR microcontroller. The external flash trigger counts camera flashes and on this principle determines the main camera flash.

Using a 20-MIPS microcontroller as a simple counter would have been overkill. The ATtiny13 is the right part because it also performs additional tasks, such as servicing the user interface and monitoring the battery voltage. With immunity to high volt-

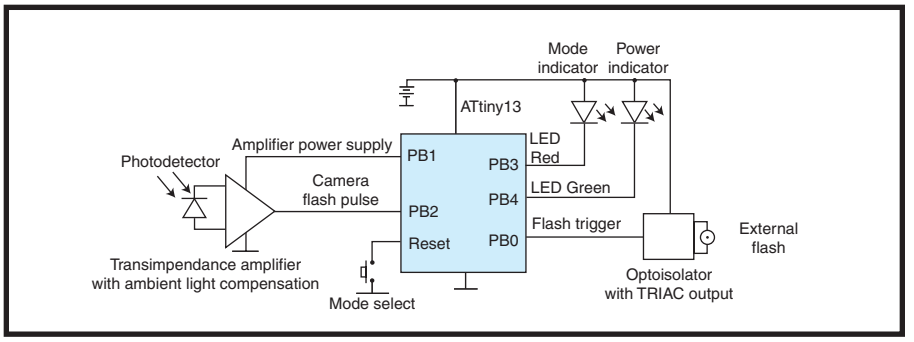


Figure 1—The slave flash trigger has to detect camera flashes, find the main flash, and synchronize it with the external flash.

ages up to 400 V, my slave flash trigger can work with new flashes and old ones that were designed for analog cameras.

HARDWARE DESIGN

As you can see in Figure 1, the design consists of only four blocks: the light sensor, the amplifier, the ATtiny13 microcontroller, and the output switch. For the light sensor, I used a Vishay BPW21 silicon PN photodiode. I chose this photodetector for three reasons: its short-circuit photocurrent is linear over seven decades of illumination levels; its spectral sensitivity is adjusted to the same sensitivity as the human eye; and it is a widely available part that is frequently used as a sensor in exposure and color-measuring applications. The only problem is that the BPW21 is a bit pricey. It costs about as much as all of the slave flash trigger's components put together.

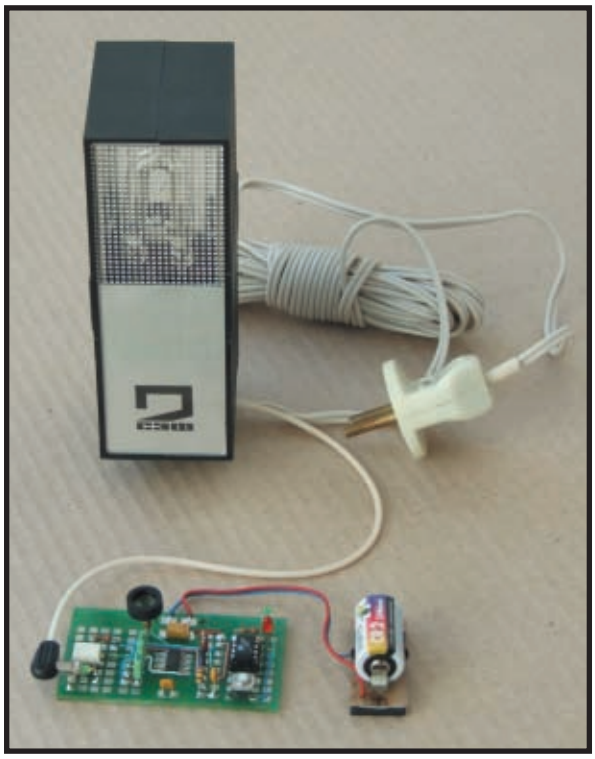


Photo 1—This external main-powered flash from the 1980s is ready to fire. Once plugged in, the flash capacitor stays charged for more than 8 min., so the flash can be unplugged if its cord is too short to take pictures.

Here's how the BPW21 operates. It works in Photoconductive mode, which means that the photodiode is reverse-biased and the reverse current is its output signal. You can see a simplified schematic of an analog signal-processing path in Figure 2. The photodiode D1 is connected to an op-amp U1.3 that works as a transimpendance amplifier or, as some say, a current-to-voltage converter. Its output voltage equals:

$$U_{OUT} = R_1 \times (I_{D1} - I_{R2}) \quad [1]$$

Because the BPW21's current I_{D1} is proportional with coefficient S (9 nA per lux) to changes in the illumination level E_A,[2] the amplifier U1.3 output voltage U_{OUT} can be expressed as:

$$U_{OUT} = R_1 \times S \times E_A + R_1 \times I_{R0} - R_1 \times I_{R2} \quad [2]$$

where I_{RO} is the photodiode dark current. The transimpendance amplifier's output voltage U_{OUT} is integrated by the noninverting integrator formed by op-amp U1.4. When time constants R4C4 and R3C1 are the same and equal to RC, the output voltage U_{INT} of the integrator is:

$$U_{INT} = \frac{1}{RC} \times \int U_{OUT}(t)\,dt \quad [3]$$

The output voltage U_{INT} of the integrator is proportional to the mean ambient illumination level E_A and the photodiode dark current I_{RO}, while fast changes of illumination level E_A are attenuated. Resistor R2 converts integrator output voltage to current I_{R2}. Because the voltage across the photodiode equals zero, the integrator output current I_{R2} can be expressed as:

$$I_{R2} = \frac{U_{INT}}{R_2} \quad [4]$$

This current compensates diode D1 current I_{D1} components, which come from ambient light and dark current, respectively. As the result, the transimpendance amplifier output voltage U_{OUT} is proportional to fast changes of the illumination level ΔE_A:

$$U_{OUT} = R_1 \times S \times \Delta E_A \quad [5]$$

The real circuit is a bit more complicated. Virtual ground is needed because op-amps are powered from a single supply. Its source is op-amp U1.1 (see Figure 3). Since a measured signal is asymmetric (i.e., flash only increases the illumination level), virtual ground has been shifted from 0.5 to 0.09 V_{CC}. First, this increases the circuit's dynamic range. Second, the transimpendance amplifier output voltage U_{OUT} complies with microcontroller input logic levels (i.e., U_{OUT} is LOW when there is no flash and HIGH when there is a flash). Note that output voltage U_{OUT} is 0.09 V_{CC} when ambient light is compensated. Since there is no dedicated pin in the circuit for battery control, I used this feature for battery-voltage measurement.

In the circuit, any 3-V battery-powered op-amp with rail-to-rail input and output features can be used. I decided on Texas Instruments's OPA4340 microamplifier. Since it contains four op-amps, one of them (U1.2) is free in the design. I wired it as a voltage follower to avoid floating inputs, which might increase current consumption (see Figure 3). Owing to the OPA4340's low-current consumption and compatibility with the microcontroller's power supply-voltage range, op-amps U1.x are powered directly from the microcontroller's I/O pin (i.e., PB1), which is programmed as a high-current output. This solution is very comfortable,

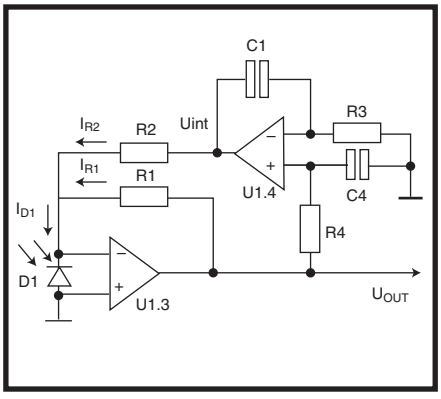


Figure 2—The analog signal-processing tract is built around two op-amps (U1.3 and U1.4) wired as a current-to-voltage converter and a noninverting integrator respectively. The integrator works in an op-amp (U1.3) negative feedback loop and compensates photodiode D1 current components that come from ambient light and dark current.

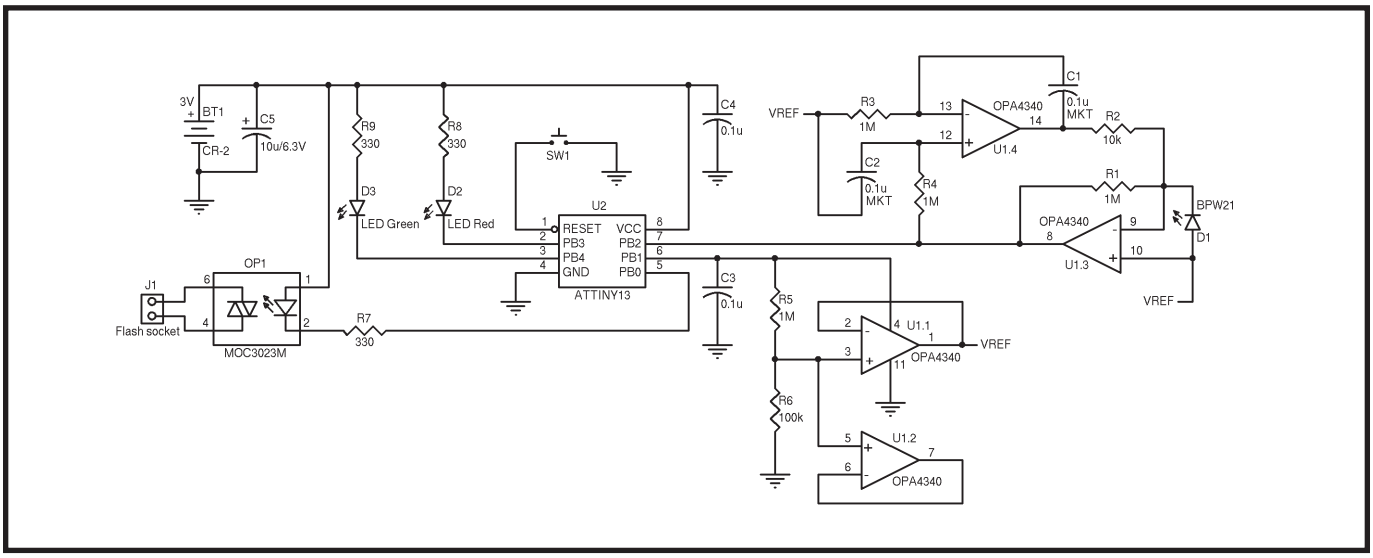


Figure 3—Since all op-amps are part of the same chip, the circuit consists of fewer components than you might expect. LEDs D2 and D3 and switch SW1 form the user interface. Push button SW1 is used for switching to Operating mode. LEDs D2 and D3 indicate the current operating mode and the state of the power supply, respectively.

because turning the op-amp's power supply on and off (via the microcontroller) requires no additional hardware.

Detected by the photodiode D1, flashes are counted and processed by the ATtiny13 microcontroller. This task needs no exceptional processing power, so the ATtiny13 works well. It has only six I/O pins; nevertheless, it turned out to be enough. I used two pins (PB3 and PB4) to control the LEDs. The PB2 pin turns the optoisolated switch (OP1) on and off. Two other pins (PB2 and PB1) are used as the signal input and the op-amp power supply, respectively. I wired the last pin, PB5/RESET, as the mode switch input. By programming the RSTDISBL fuse, it is possible to configure this pin as a general-purpose I/O port.[3] Unfortunately, having the ability of ISP pro-





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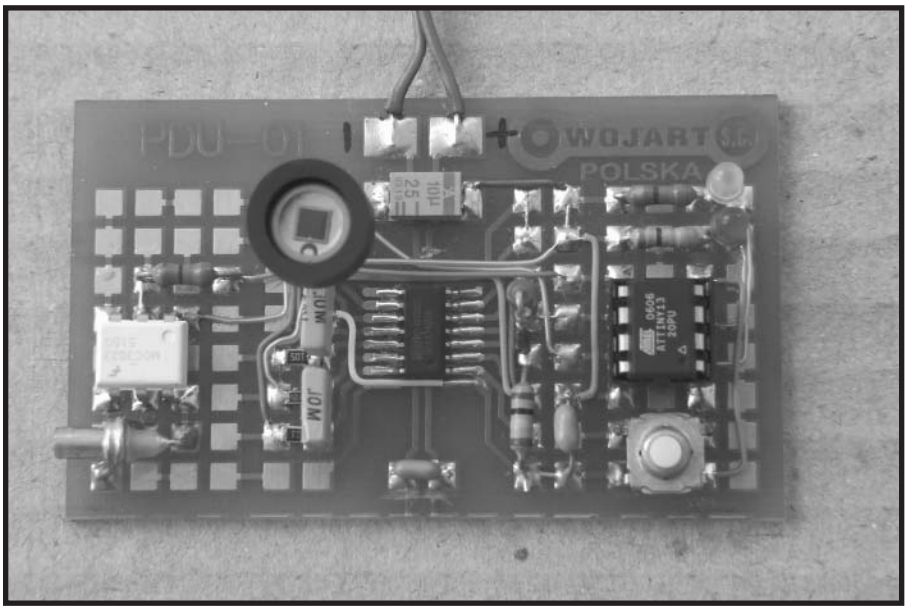


Photo 2—The coaxial socket soldered in the bottom-left corner works with the majority of older flashes. The new ones have different connectors. They are usually equipped with a hot shoe and sometimes with a mini-jack socket.

gramming with the use of an Atmel STK200 dongle is lost in this case. A special high-voltage serial programmer is needed. To avoid this problem, I left the PB5/RESET pin as the RESET input. Because it is possible to determine the reset source in AVR microcontrollers, every press of the SW1 switch is detected in the program as if it were a general-purpose I/O pin change.

The microcontroller is powered directly from a 3-V lithium battery, which is widely used in photo gear and can be easily acquired in photo stores. To achieve long battery life, I put special stress on the minimization of power consumption in both Active and Power-Down modes. I began by switching the microcontroller's internal RC oscillator to 4.8 MHz. Apart from disabling all unused peripherals, I switched off the used ones as soon as they were not needed. Finally, I disabled the brownout-detection circuit. It turned out to be a must-have, because the brownout detector, once enabled by BODLEVEL1/0 fuses, works in all CPU modes, including Power-Down mode. It continuously draws 22 µA at 3 V, which is nothing to sneeze at.[3] Unfortunately, the ATtiny13 microcontroller lacks the function to switch off the brownout detector upon entering Power-Down mode, which so far has only been implemented in the picoPower AVR family. I also widely use all of the microcontroller's power-saving modes. As a result, the entire circuit draws an average of 6.5 mA in Active mode and less than 0.1 µA in Power-Down mode. Therefore, there is no need for a power switch.

The output switch (OP1) is isolated from the microcontroller. Optoisolation protects the circuit against high voltage, which may be present in an external flash connector. I used a Fairchild Semiconductor MOC3023M optoisolator. It withstands voltages up to 7.5 kV, and it can switch voltages of up to 400 V with trigger currents of less than 5 mA.[4] Thanks to the triode for alternating current's (TRIAC) output, the optoisolator switches both positive and negative voltages. Thus, the flash connector's polarity is not important. But, do not forget that the TRIAC is not exactly equivalent to a mechanical switch! Once switched on, it cannot be switched off, unless the TRIAC current decreases below the holding-current level, which is 100 µA for the MOC30*xx* family. Therefore, if a constant current flows out from the plug of your flash in the ON state (in some flash models this current is produced by external trigger input biasing inside the flash), you may need to substitute the MOC3023M optoisolator with a relay, or you will have to switch off your external flash after every camera shot.

I assembled the circuit on a piece of Wojart universal PDU-01 board. The board was designed for prototyping circuits with surface-mount device (SMD) components. I was initially going to use only SMD devices, but problems with obtaining low volumes of SMD resistors and capacitors forced me to use through-hole components. Luckily, soldering parts in classical cases was not a problem because of the large pads on the PDU-01 board (see Photo 2). Note that the photodiode has a rubber ring installed on the top. The ring protects the photodiode's window and filter from scratches and fingerprints, which are unavoidable when you fiddle about with the circuit.

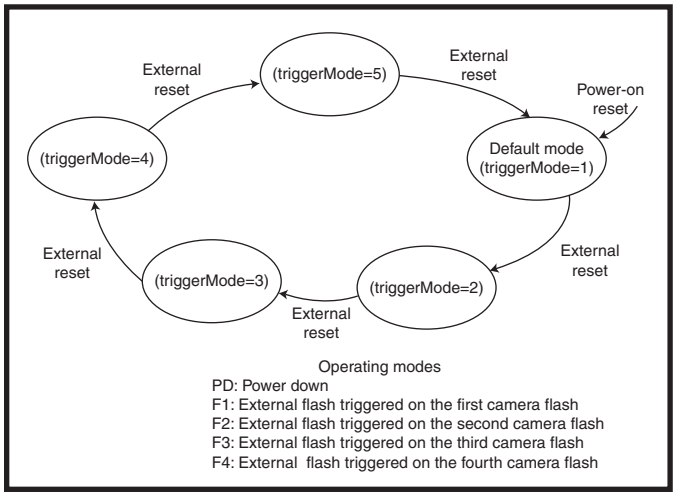


Figure 4—The state machine is organized as a five-state Johnson counter. With every press of the push button, SW1 moves the counter forward.

SOFTWARE DESIGN

The program was written in assembly and compiled in AVR Studio 3.53 IDE. Since I use the RESET input as general input, the RESET handler starts by

checking the MCUSR register. If the EXTRF bit is set, it means that the push button has been pressed, and the program is switched to the next operating mode in sequence (see Figure 4). Otherwise, Default mode (i.e., the trigger slave flash on the first camera flash) is activated. Because the microcontroller is powered all the time, the `triggerMode` variable—which defines Current Operating mode—is stored in SRAM, not in EEPROM, which is what usually happens to system configuration. After loading the Current-Operating mode, the program performs routine tasks such as variable and hardware initialization. Finally, it enters the main loop, where the CPU is switched to Idle mode and waits for interrupts.

LED state	Function
Green LED: Power state	
LED on	Power on, battery OK
LED blinks	Power on, battery discharged
LED off	Power off
Red LED: Active operating mode	
One blink every 3.2 s	Slave flash triggered on the first camera flash
Two blinks every 3.2 s	Slave flash triggered on the second camera flash
Three blinks every 3.2 s	Slave flash triggered on the third camera flash
Four blinks every 3.2 s	Slave flash triggered on the fourth camera flash

Table 1—It may look complicated, but the blinking LED gives accurate information on device operation.

There are two interrupts active in the system: the pin PB2 change interrupt and the timer 0 compare A interrupt. I use the first interrupt for counting rising edges of photodiode pulses on pin PB2. If the counter reaches zero, the optoisolator connected to pin PB0 is switched on, and thus the external flash is triggered. After 1 s, the optoisolator is switched off and the program reenters its initial state. It then waits for a new series of camera flashes. When the delay between camera flashes exceeds 1 s and there hasn't been enough preflashes to trigger the external flash, counted flashes are discarded, the counter is reset, and the program resumes waiting for camera flashes.

The second interrupt works as a system clock interrupt. It services system timers and triggers time-dependent tasks in the main loop. In fact, there are only two tasks: LEDs refreshing and switching off the device after 30 min. of idle time. LEDs D2 and D3 indicate Current Operating mode and the power state, respectively. You can find their detailed description in Table 1.

SLAVE FLASH TRIGGER MANUAL

The slave flash trigger needs no special preparation to work. You just need to connect an external flash and choose your desired operating mode (see Photo 1). If you do not know the number of preflashes emitted by your camera, do not worry, but perform some experiments. The best way to find the proper operating mode is to start from mode F4 and go down after every camera flash. The mode number where the external flash fires will be the searched one. While experimenting, remember that the number of preflashes may be different in different camera operating modes, so you should test all flash modes in your camera and find the corresponding slave flash trigger modes. As a rule of thumb, digital cameras emit two flashes (i.e., the preflash and the main flash) in Auto mode and one flash (i.e., only the main flash) in Manual mode.

When you know which mode to select, it is time to set the flash detector. Since the slave flash trigger is both sensitive to camera flashes and immune to ambient light, there is no need to point its photodiode in any special direction. The device detects flashes reflected from walls as well as from the ceiling. Even if the sun directly lights the photodiode, the slave flash trigger still correctly detects camera flashes. Nevertheless, I would advise you to always direct your photodetector towards the photographed scene, because in spacious places, where the distance to walls and the ceiling is big, or in rooms with very dark walls, light reflections may be too weak to be properly detected.

A problem may appear with quickly flickering light sources (e.g., incandescent high-power bulbs) that are close to the photodiode. When it is pointed directly at such a light source, the slave flash trigger may take light flickers that are invisible to the human eye for camera flashes and incorrectly trigger the external flash. In this case, you may want to use one of two solutions. You can increase the distance between the bulb and the photodiode, or you can point the photodiode in another direction. Since the viewing angle for the BPW21's photodiode equals ±50°, there should be no problem in finding an area where the photodetector is not directly lit by the bulb.

FLASH PHOTOGRAPHY HINTS

Taking photographs with two flashes is a bit more difficult than one-flash photography. The main problem is that the camera's exposure-control circuit does not know anything about additional light sources. Therefore, forget about the automatic modes and switch your camera to Manual mode. Which aperture should be set? Some hints are given in Pawel Wojcik's book, *Flash in Amateur Photography*. For a set of two flashes, when their guidance numbers (GN_1 and GN_2) at a set ISO speed do not differ more than 50%, its equivalent guidance number is:

$$GN_E = 0.707(GN_1 + GN_2) \quad [6]$$

Having calculated an equivalent guidance number, GN_E, everything becomes easy because the searched aperture value A equals to:

$$A = \frac{GN_E}{D} \quad [7]$$

where D is the distance (in meters) to a photographed object. Equations 6 and 7 are for ideal conditions. In real situations, calculated aperture values may need corrections, especially when the external flash lights a photographed scene indirectly (e.g., through reflections from the ceiling). Nevertheless, it is a very good starting point for experiments. After all, photography is an art. Do not expect that everything

there will be described by formulas.

PROSPECTS

A slave flash trigger is very useful for adding a second flash to a camera. If equipped with four working modes, it can be easily adjusted to virtually any camera and built-in flash mode to always synchronize the external flash with the main camera flash. Because the number of external flashes triggered by the single-camera built-in flash is not limited, multiple sets of slave flash triggers and external flashes can be used in a photo studio as the main light source. This is a nice alternative to heat-producing bulbs.

Since the current program consumes only about 30% of the ATtiny13's program memory, the slave flash trigger can be modified. First, I suggest that you implement a learning function so the microcontroller can analyze the camera's flash pattern and automatically set the proper working mode. Another idea is to implement Stroboscope mode, in which the external flash would be triggered several times after the main camera flash. Such a mode would open stroboscope photography to everyone. So far, stroboscope photography has been mainly used in movement analysis, but it can be used for artistic purposes as well. It gives very interesting results. When I was working on this system, I planned to make some tests. Unfortunately, I didn't have a flash that could be triggered a few times per second (the flash you see in Photo 1 can be triggered only once per 20 s). I will return to this project when I get one.

Aleksander Borysiuk (alex_priv@wp.pl) holds an M.S.E.E. in Electronic Equipment from the Warsaw University of Technology. He has also completed post-graduate studies in Physical and Technical Security at the Military Technical Academy in Warsaw. He now designs components for alarm-detection and alarm-monitoring systems. Aleksander is interested in applications for embedded microcontrollers.

PROJECT FILES

To download code, go to ftp://ftp.circuitcellar.com/pub/circuit_cellar/2007/203.

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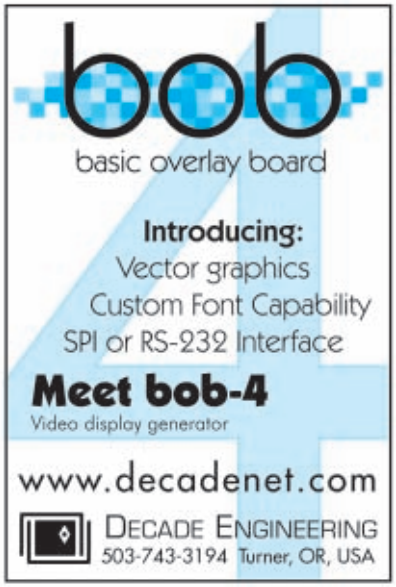
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OPA4340 Single-supply amplifier
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USB-Controlled Pulse Generator

With a field-programmable gate array and a low-cost PC, Alun designed a system for USB-interfaced test equipment. The pulse generator doesn't require much external circuitry. All the hard work is done inside the FPGA.

I always thought that a low-cost PC with additional hardware would be ideal for many test and measurement solutions. The visual toolsets available for PCs enable the man-machine interface to be implemented quickly, and the additional gear can perform tasks quickly and consistently. Until recently, there were many significant obstacles, including writing PC drivers, which is close to a black art. Since I am a hardware engineer, this wasn't an option.

A number of companies now offer USB-based solutions that provide low-level drivers for the major operating systems, real plug-and-play. This makes PC add-ons possible for almost anyone. If you add a large chunk of programmable logic—configurable by the PC—the combination is difficult to beat.

Field programmable gate arrays (FPGAs) are popular because they are easy to use and effective in many applications. In this article, I will outline a simple FPGA project that will make your first steps in FPGA design a cinch. As a bonus, all the tools are free and easily available.

This project was developed to build a system for USB-interfaced, FPGA-based test equipment. I wanted a set of software and firmware routines for interfacing with a PC that could be reused in future projects. I chose the pulse generator because the external circuitry required is minimal. All the hard work is done inside the FPGA.

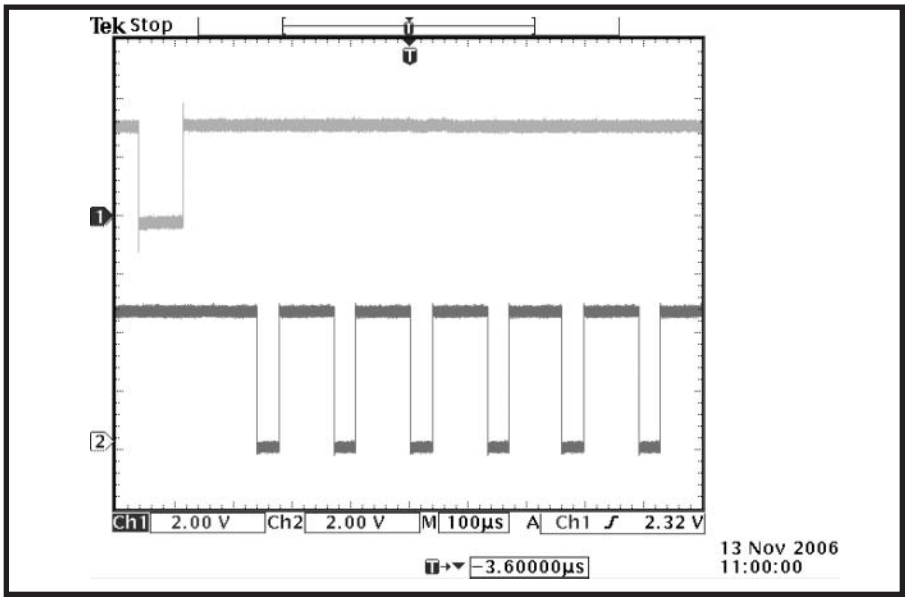


Photo 1—The scope trace shows the generator used in Linked mode. Channel 1 is set to Astable mode, and Channel 2 is in Burst mode with an offset of 150 µs.

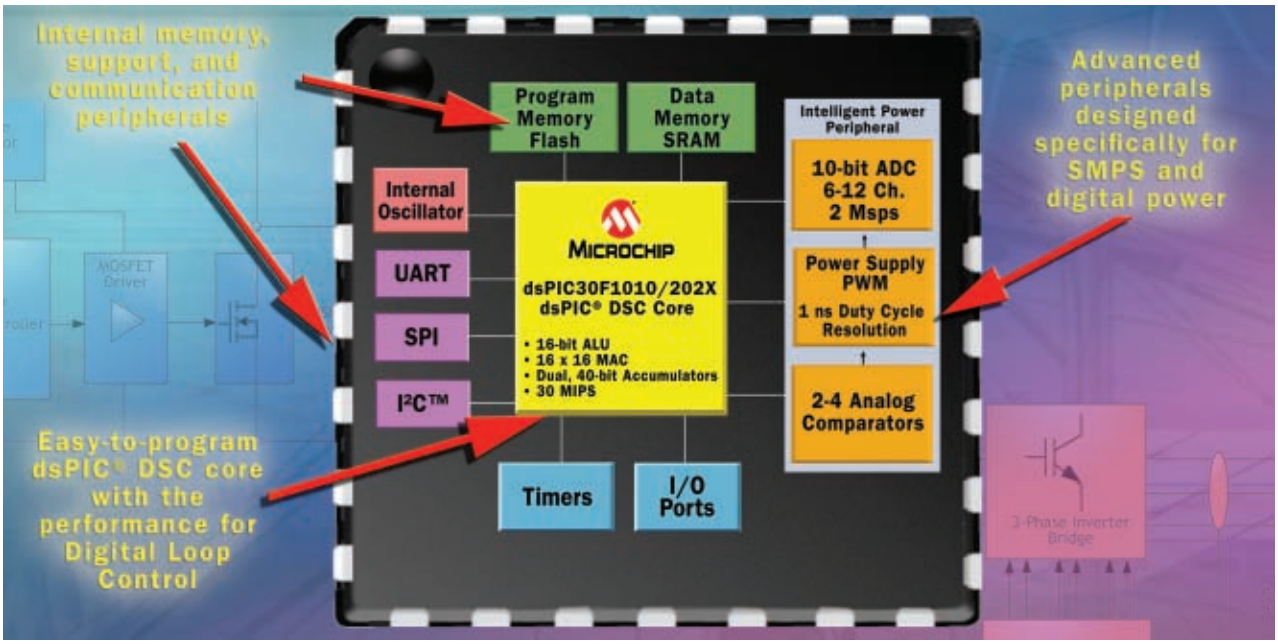
FPGA

An FPGA is a lump of uncommitted logic: think of a small sea of flip flops with some islands of glue logic, add a smidgen of SRAM, and then top it off with some programmable connectivity. The FPGA is an Altera ACEX EP1K50TC144 programmable logic device (PLD). It contains roughly 50,000 gates, which equates to approximately 2,880 logic elements plus 40 Kb of SRAM in a 22-mm

Mode	Min pulse	Max Pulse	Resolution	Min freq	Max freq	True/inverted gate	True/inverted output	True/inverted trigger	Re-Trigger	Burst mode	Jitter
Astable	110 ns	50 s	21 ns	0.02 Hz	10 MHz	Yes	Yes	No	No	To 255 pulses	From 20 ns to 1 ms
Monostable	110 ns	50 s	21 ns	0.02 Hz	10 MHz	No	Yes	Yes	Yes	To 255 pulses	From 21 ns to 1 ms

Table 1—The capabilities and operating modes available from the pulse generator.

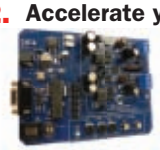
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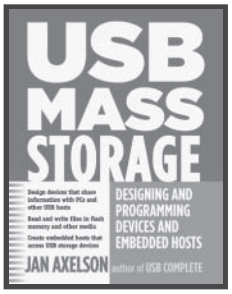
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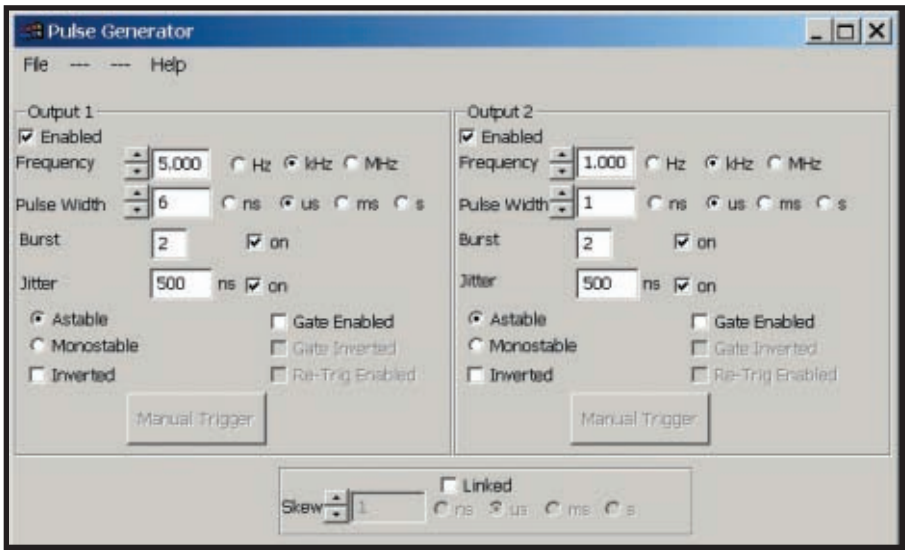


Photo 2—This is a screen capture of the PC-software interface presented to the user. It shows both channels in Astable mode with Jitter and Burst modes enabled.

square lump of silicon. To compare this to discrete logic, think of around 400 20-pin 74-series, TTL devices plus some SRAM and you'll get an idea of the scale for these devices. Then try clocking it at over 200 MHz. If that sounds impressive (and it is), this is a small device (gate counts in excess of 1 million and pin counts in the thousands are not uncommon).

FPGAs are split into three family types: AntiFuse based, flash memory based, and SRAM based. AntiFuse-based FPGAs are one-time programmable; they get programmed only once in a specialized programmer. Bug fixes and upgrades require a new chip to be fitted. They are now a specialty product used primarily in systems like satellites.

Flash memory-based FPGAs are reprogrammable while on the PCB. They can be easily updated and they are nonvolatile. But, due to the bigger size of the flash memory cell, they tend to have fewer gates and take up more space than the two other technologies.

SRAM FPGAs are volatile; they need to be configured every time they power on. They are also faster, cheaper, and have a higher density than the other technologies.

The FPGA market is dominated by three big companies: Altera, Lattice Semiconductor, and Xilinx. All of these companies offer quality products in a highly competitive market.

CAPABILITIES

The pulse generator has two pulse outputs and one input, which is used as a gate or trigger. Both outputs are connected to an independent pulse generator capable of outputting pulses from 105 ns to 50 s with a 21-ns resolution. The pulse generator can operate as a monostable single-shot or as a free-running astable oscillator. In addition, the two outputs can be linked together with Output 1 triggering Channel 2 (see Photo 1).

The input is used as a gate signal for a channel in Astable mode or as a pulse trigger for a channel in Monostable mode. PC software can also generate a software-based trigger.

In addition to the basic modes, there are a couple of additional features. First, each output can generate a burst of pulses up to 255 pulses long. In this case, the pulses are output with a 1:1 mark-space ratio. Second, there is an Edge Jitter mode. Using this mode, a programmable amount of jitter is added to each edge of the output pulses. Jitter can range from 21 ns to 1 ms (see Table 1). The pulse generator is controlled via a PC interface (see Photo 2).

CIRCUITRY

Because of the integration available from the USB interface and the FPGA,

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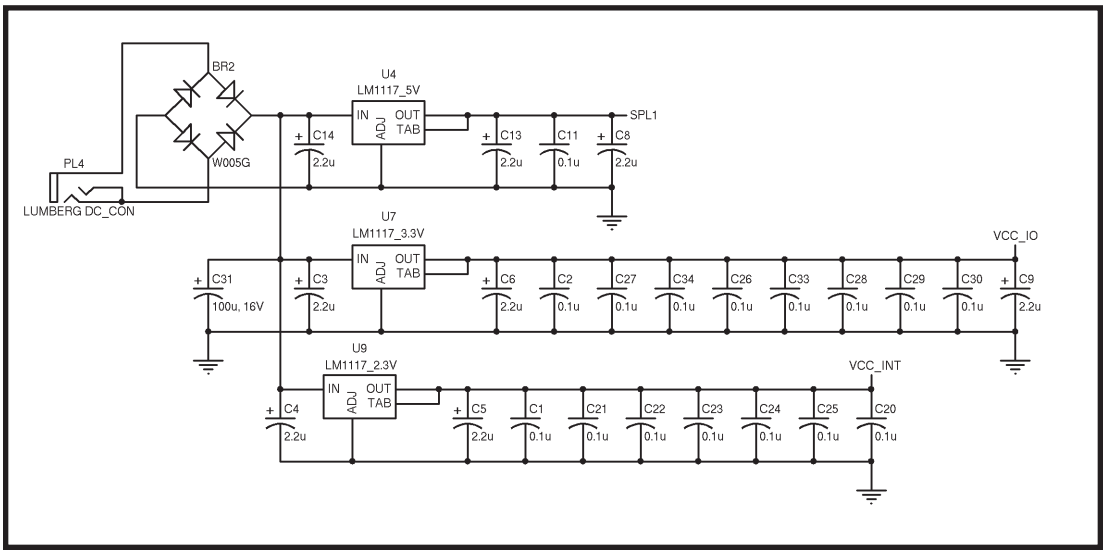


Figure 1—Check out the schematic of the PSU section of the project. It includes the bridge rectifier on the input, which protects against incorrect polarity, power supplies, and lots of decoupling for the FPGA.

the schematics are relatively simple. The project boils down to three ICs, three regulators, and a handful of diodes, resistors, and capacitors (see Figures 1, 2, 3, and 4).

Although the USB specification allows the USB bus to provide power to a USB device, I run USB designs off an external PSU (see Figure 1). I do this for a couple of reasons. First, I can further isolate my unknown development from the PC by using a USB hub. Second, I want to be able to connect multiple USB devices to a laptop, but I don't want to overextend the laptop's power supply. The PSU design expects an external DC input of 6.5 to 9 V at 500 mA or so. When running, the pulse generator requires about 150 mA plus the current required to drive the load impedance. The bridge rectifier takes care of any input-polarity issues.

The rest of the circuit is a set of three simple linear-voltage regulators. The 5 V is used to provide power to the output stage. The 3.3 V is used to power the FPGA I/O pins (more on that later), and the 2.5 V is used to drive the FPGA core logic (see Figure 3).

The USB interface shown in Figure 2 is designed around the Future Technology Devices FT232R, a USB UART IC that provides a complete USB-to-TTL converter. The chip provides an eight-line modem interface plus five user-configurable I/O lines. FTDI supplies a complete set of Windows, MAC, and LINUX drivers for the IC, which are controlled via a DLL-based API.

The FT232R contains regulators, oscillators, and EEPROM plus the core USB interface engine. A fully functional USB interface requires only this chip, a couple of resistors, and three decoupling capacitors.

The PC DLL gives it full software control over bit rates, start bits, parity, data length, and flow-control options. For this design, the FT232R is configured as a four-wire interface using RTS/CTS flow control. The remaining four RS-232 pins are used to configure and reset the FPGA. The five I/O lines are used to provide a 48-MHz clock to the FPGA and the FPGA-configuration pins.

The RS-232 interface is run at 187,500 bps. This is a binary divide of the 48-MHz USB clock, which simplifies the FPGA data-rate generator to a binary divider. Before using the FT232R, it needs several internal EEPROM registers to be set. The FTDI provides a handy PC-based utility for that. It allows the Operating mode, the function of the I/O pins, and the identity of the USB device to be set.

The FPGA used in this design is a relatively mature chip from the Altera ACEX family. I chose the ACEX family of devices because of its familiarity, 5-V tolerance, and availability. I made the decision after asking myself, "What's the largest gate count I can get without using BGA technology?"

The 144-pin TQFP package means I can still hand assemble the prototype builds. So, the 50,000-gate EP1K50TC144 was the choice. The 144-pin package provides plenty of I/O and is still small enough to enable the PCB to fit inside a dinky little case (90 × 60 × 25 mm) as

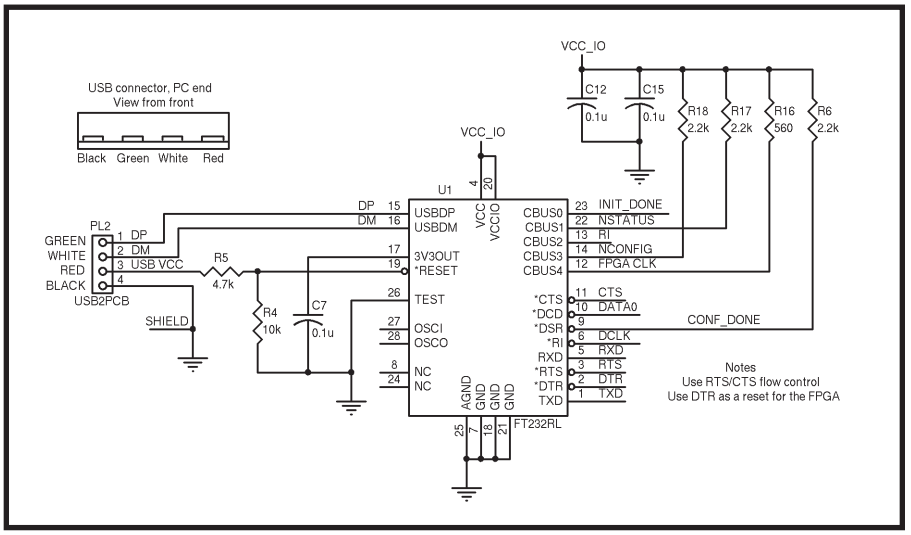


Figure 2—The schematic of the PC interface shows the USB-to-FPGA interface.

you can see in Photo 3. Roughly speaking, the device is half empty, allowing for plenty of space for future development.

The design provides a header; some spare I/O lines, and three status LEDs that have proved invaluable during the debug process. The ACEX family of FPGAs requires two power supplies, one for the logic core, which must be 2.5 V, and another for the I/O blocks, which can be 2.5 or 3.3 V. By using 3.3 V as the I/O voltage, the FPGA I/O stages are compatible with 5-V-TTL logic, which makes interfacing with the real world easier. The FPGA is clocked from the FT232R at 48 MHz.

A three-way 50-Ω BNC connector provides the connections to the real world (see Figure 4). The outputs are 5-V TTL compatible, with 50-Ω source resistance. A Fairchild Semiconductor 74ACT245 octal bidirectional transceiver provides up to 24 mA of drive per output, so combining three will give sufficient current drive to cope with a 50-Ω termination.

There is a single input, which is used as either a gate or a trigger input, depending on the operating mode of the pulse generator. The input is protected by a 100-Ω resistor and a diode clipped between 0 and 5 V. It is then pushed through a TTL bus receiver to protect the FPGA. The protection is not hugely robust, so don't expect it to work if you put 115 VAC onto it. It will save you if it gets only about 15 V.

FPGA FIRMWARE

The VHDL code was written in a modular fashion. This has two significant benefits: each module can be written and tested on its own and new functionality can be easily added. The code was designed so it is easy to replace the pulse-generator module with another function. There are several modules in the FPGA, including system housekeeping, the PC interface, and the pulse generator (see Figure 5).

There are a number of different clocks within the FPGA that are derived from the 48-MHz USB input clock. All the lower-speed stuff, like the RS-232 interface, runs from a 12-MHz clock. The actual pulse-generating logic runs off 48 MHz. This gives a minimum resolution of 21 ns.

PC INTERFACE

The PC interface attempts to convert packets of data on the USB/RS-232 interface into an internal register set, which is used to control and monitor the pulse generators. The PC interface logic runs from the same 12-MHz clock from which the RS-232 data rate clock is derived. The RS-232 interface is run at 187,500 (12 MHz/64). This was chosen so the decoder logic doesn't run much faster than the RS-232 link. Each byte takes 11 bit periods to transmit, so the decoder logic gets 64 × 11 clocks to decide what to do with each byte. That means the RS-232 link should never have to wait for the decoder logic to sort itself out.

The PC interface divides into several distinct blocks. The RS-232 transmit block is driven by a fixed data rate clock. Parallel data is clocked into the transmit-shift register and it is shifted out to the transmit pin by the data-rate clock. Completion of transmission is then acknowledged so the next byte can be sent.

The RS-232 receiver block is slightly more complicated, but not much. A state machine looks at the RS-232 RXD pin waiting for a low transition. The state machine then waits for half a bit before it starts to sample the incoming bit stream at the data-clock rate. When all 8 bits are gathered, the byte is passed onto the packet's decoder logic. To keep things simple, no filtering, parity, or framing-error detection has been included. A higher-level packet checksum filters out data-transmission errors. Since the transmitting device is only 1 cm away from the receiver, there shouldn't be noise issues.

PACKET DECODER

A counter is used to spot synchronization sequences in the packet decoder. This indicates the beginning of a data transfer. This may be overkill for this sort of data link, but the code is being reused from an existing design, so it's more work to take it out than to leave it in. (The great goal of design reuse promotes collecting baggage along the way, so maybe next time I won't get so hot under the collar about software code bloat.) It also makes spotting valid data easy. Given the very low data rates, synchronization using this method isn't going to upset anybody.

Once the synchronization sequence is spotted, the packet decoder knows that the next 64 bytes contain valid data for the pulse generator. As each byte arrives, it is put into internal memory and the running checksum is updated. If a checksum error is found,

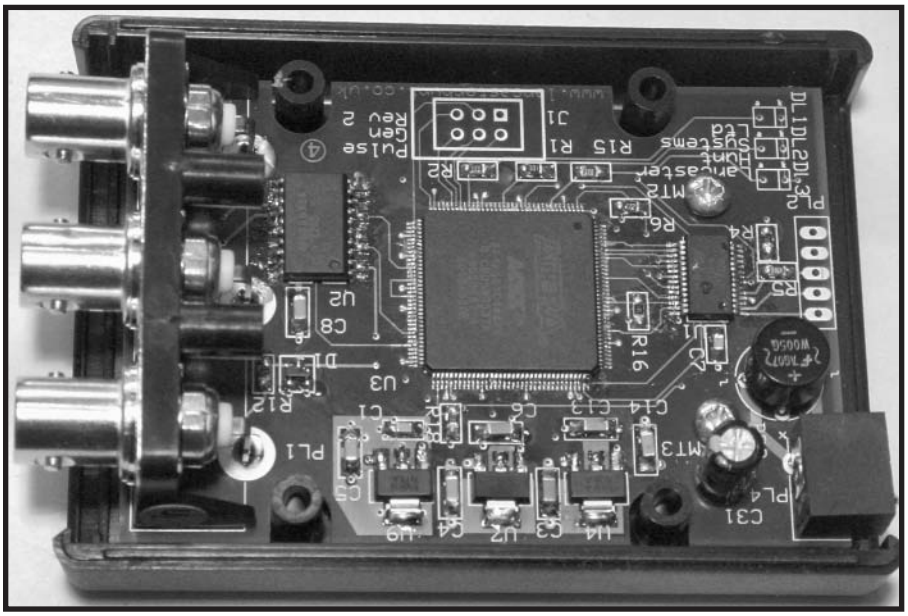


Photo 3—A nearly assembled PCB shows how compact the finished item is.

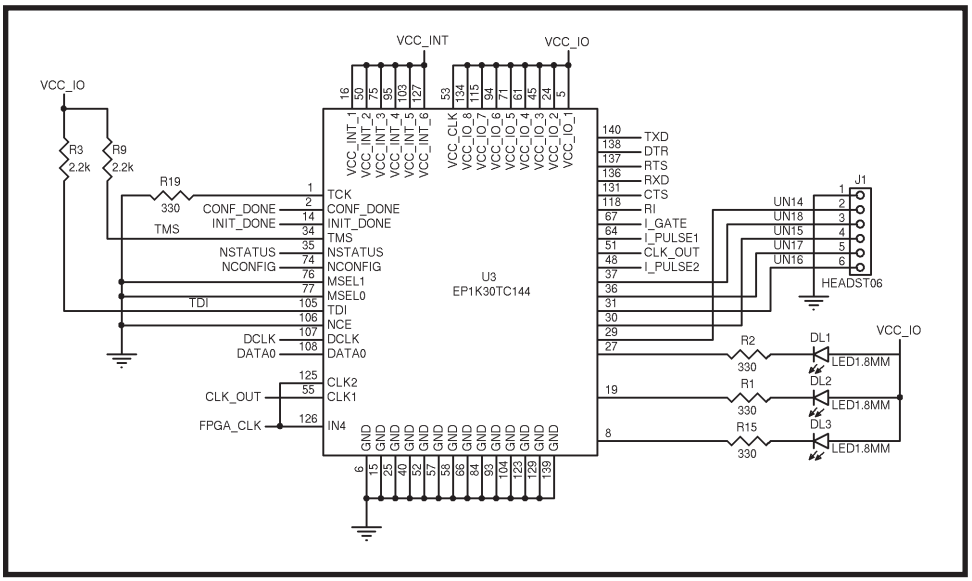


Figure 3—The FPGA is the guts of the project.

the packet is dumped. When a complete packet is received, a state machine is let loose on the data. The data packet contains 2 control bytes that tell the state machine what to do. There are two instructions in this design: update the pulse generators and send status. If it is an update packet, the `packet_decoder` sends each byte with its location in the packet to the address decoder. Once the packet has been processed, the state machine sends an acknowledge packet back to the PC. The acknowledge packet includes the state-of-the-gate pin and the version number of the FPGA firmware.

The data packet from the PC is 80 bytes long. It consists of 16 synchronization bytes (0xAA) followed by a 64-byte data packet. The data packet format is AddressHi, AddressLo, Control1, Control2, Data(0)…Data(n), Checksum, where the Address is a 16-bit identifier to allow multiple functions on the same card. Control1 and Control2 are used to indicate the action of the incoming packet. Control1(0) is equal to a status request, it returns status to the PC. Control1(1) is equal to write data to control registers. Data(0..n) is the data the PC is sending. Checksum is a simple 8-bit checksum of the packet.

The acknowledge packet format is a synchronizing header of 16 bytes of 0x55 followed by a variable-length data packet. The packet format is Bytecount, Status(0)…Status(Bytecount-1), Checksum, where Bytecount is the number of bytes in the packet. The packet byte count is fixed to 16 for this design. Status (0..Bytecount-1) is the return-status information. Checksum is a simple 8-bit checksum of the packet.

DECODER & GENERATOR

The address decoder takes data and updates the register using the data's location within the packet as a pointer. This design has four control registers, one for both of the individual pulse-generator channels, one for functions common to both the channels, and one for the LEDs.

This looks much more complex than it really is. The whole design hangs around two counters. One counter is used to control the ON time and the other is for the OFF time of the pulse output. The enabling and loading of the two counters is controlled via a state machine, which uses the control information from the PC to control which operating mode to use. The state machine loads a counter with a number the PC has sent, then the counter counts down to zero. This tells the state machine to go to the next state, and that's it.

TOOLSETS

The FPGA code has been developed in VHDL (very high-speed integrated circuit hardware description language). VHDL is a language that describes the behavior of the FPGA. The VHDL is synthesized into a programming file, using the Altera Quartus web edition toolset, a free and excellent toolset for FPGA development. Its only weakness is a lack of a VHDL simulator.

FPGA CONFIGURATION

The FPGA is configured using a set of I/O pins on the FT232R. The minimum requirement is a four-wire interface, but I prefer to use a six-wire interface (detailed below). The CONFIGn signal to the FPGA initiates the download process. The STATUSn signal from the FPGA acknowledges that the download may continue. The rising edge of the signal CLK clocks the level on the DATA line into the FPGA. The CONF_DONE line from the FPGA indicates that the FPGA is successfully configured. Finally, INIT_DONE from the FPGA shows the FPGA is up and running and ready to play.

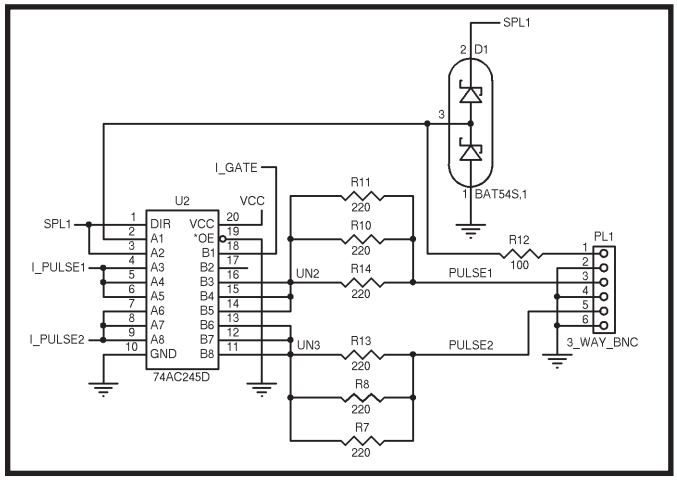


Figure 4—The diagram of the pulse-generator output stage shows the triple-way BNC connector and the TTL-based output driver.

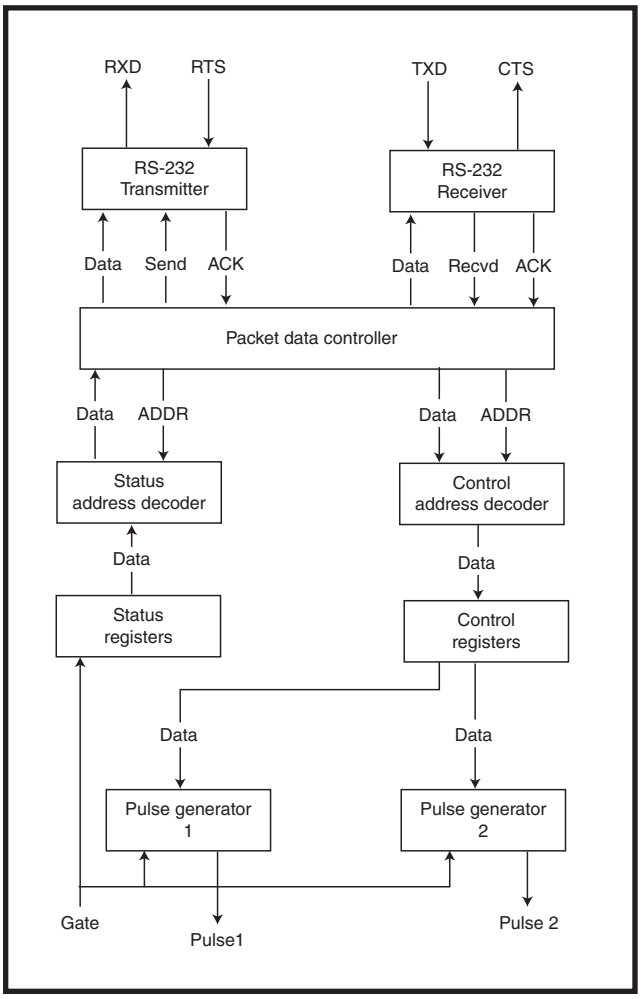


Figure 5—The block diagram of the FPGA's internals shows the major blocks inside the FPGA and how they connect together.

The FPGA is configured every time the PC software application is started. To configure the FPGA, the FT232R is put into a Bit Bang mode. This allows all of the device's RS-232 and I/O pins to be used as general-purpose I/O pins. The pins can be controlled by reading and writing the USB device. If a sequence of bytes is sent to the FT232R, the pins are updated at the current data rate for the chip. It is possible to send clock and data information to the FPGA by sending a sequence of bytes to the FT232R. To speed up the download, the programming file is preprocessed. This allows the configuration software to load a 32-KB chunk of files and send it straight to the USB port.

PC SOFTWARE

The main software is split into four sections, including man machine interface (MMI) bits, data validation, USB packet assembly, and the low-level USB interface. There is also a set of routines to control the FPGA configuration process and an associated off-line FPGA file converter, which takes an Altera programming file and converts it into something more palatable for the USB configuration routines.

Starting at the bottom is a set of routines that interface to the FTDI DLL. The FPGA configuration routines are in here as well because they are closely coupled to the DLL.

Next up the tree are the routines for formatting the USB packet data. The pulse-generator channels have a data structure that contains all of the operating parameters for the device. The code provides a set of routines for writing and reading data into the data structures and then sending the data down the USB port. The routines assume that all of the data has been checked for errors, which leads into the data-validation routines.

The data-validation routines do what it says on the can. The FPGA does not check any of the data sent to it. It will try to do stupid things if you ask it to, typically with unpredictable results. Setting a pulse width longer than the operating frequency or setting the pulse width too small is weeded out at this point.

The top-level software provides a simple panel-based GUI that operates in typical PC fashion (see Photo 2). The PC's software for this project has been developed using open-source products. I used the wxwidgets visual library to develop the user interface. It is a cross-platform visual library that I hope will allow the design to be ported to Linux at some point. The open-source community has developed a nice IDE and compiler set that can use the wxwidgets library called wxDev-C++, which uses the Bloodshed Dev-C++ IDE.

Alun Hunt is a self-employed electronics consultant for Lancaster Hunt Systems Ltd in the U.K. His main areas of expertise are in high-speed digital design, FPGAs, and embedded systems design. He has worked with electronics for over 20 years and still enjoys the challenge. You can e-mail him about this project at pulse@lancasterhunt.co.uk or contact him via the Lancaster Hunt Systems web site (www.lhs-electronics.co.uk).

PROJECT FILES

To download code, go to ftp://ftp.circuitcellar.com/pub/circuit_cellar/2007/203.

RESOURCES

Altera Corp., "Quartus II web edition (v6.1)," www.altera.com/support/software/download/sof-download_center.html.

BloodshedSoftware, "Bloodshed Dev-C++ IDE," www.bloodshed.net/devcpp.html.

wxDev-C++, http://wxdsgn.sourceforge.net/

SOURCES

ACEX EP1K50TC144 PLD
Altera Corp.
www.altera.com

74ACT245 Bidirectional transceiver
Fairchild Semiconductor Corp.
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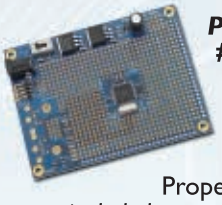
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by Victor Kremin & Valeriy Kyrynyuk

LIN-Based Ultrasound Parking Assistant

This simple system takes the guesswork out of parking in crowded cities. Ultrasonic sensors detect possible obstacles. When an object gets too close, an alarm is activated. If you can't see what's in your way, an OLED indicates its location relative to your vehicle.

Parking in a European city can be a big problem for drivers. In Lviv, Ukraine—an ancient city with narrow, overcrowded streets—we recently experienced such a problem. Parking in those conditions really is a true art, and to master it you need the best instruments. Some expensive cars are equipped with tools to assist you with parking, including cameras. But, how do you safely park less expensive cars that don't have those high-end accessories? There are three ways: Refuse to buy a cheaper car, buy and install parking tools yourself, or become an inventor and build your own parking system. We chose the last option. Although it is the most complex and probably not the cheapest option, it is the most fun.

Our parking system is based on ultrasonic sensors because of their reliability, durability, and low cost. It consists of three modules: distance-measurement modules on the front and rear sides of the car and a graphics display module on the driver's side. The modules are connected by a local interconnect network (LIN), which reduces the total amount of wires.

LIN interfaces are now commonly used in vehicles to communicate between low-speed, noncritical devices, such as points on an indicator panel, seat controls, mirrors, and more. The rise in popularity of the LIN may be due to its low cost, which is important to thrifty people like us. Our parking system also includes a graphical OLED display for obstacle indication and a speaker for the alarm. The measurement board and an example of our obstacle indicator are shown in Photo 1.

The distance-measurement board contains eight channels to connect ultrasonic sensors. We used about four channels for each board, enough to cover a compact car. Figure 1 shows the allocation of the boards and the LIN-bus structure. It also shows the scope of the ultrasonic sensors.

As you can see, we placed four Murata Manufacturing MA40FF14-1CN piezoelectric sensors each on the front- and back- sides of the car. Since the sensors are intended for parking systems, they have optimal angles for scanning environmental or ambient conditions. Before we go into more detail, we will describe the system's characteristics (see Table 1).



Photo 1—This photo of the distance-measuring board and indication screens shows the central elements of the parking-assistant board, which measures the distance to obstacles. Four channels were assembled. You can see the screens while parking with the OLED.

PRINCIPLES OF OPERATION

Although the system's main purpose is to detect obstacles near the car during parking, you are still the main detector. You must be even more vigilant with the addition of ultrasonic sensors. Before parking systems, you just had to look in front of the car and in the rearview mirror. Now, you must also look at the system's display. Despite the small drawback, the system gives you a big advantage: the built-in speakers enable you to park blind! The system beeps if the driver is about to hit an object (another car, pedestrians, a building wall, etc.). Drivers with good reflexes will even have time to stop before they crash. We are joking of course. In fact, parking with the system is a simple, automatic process.

The ultrasonic sensors, which are the eyes of the parking system, operate like bats. Like the nocturnal

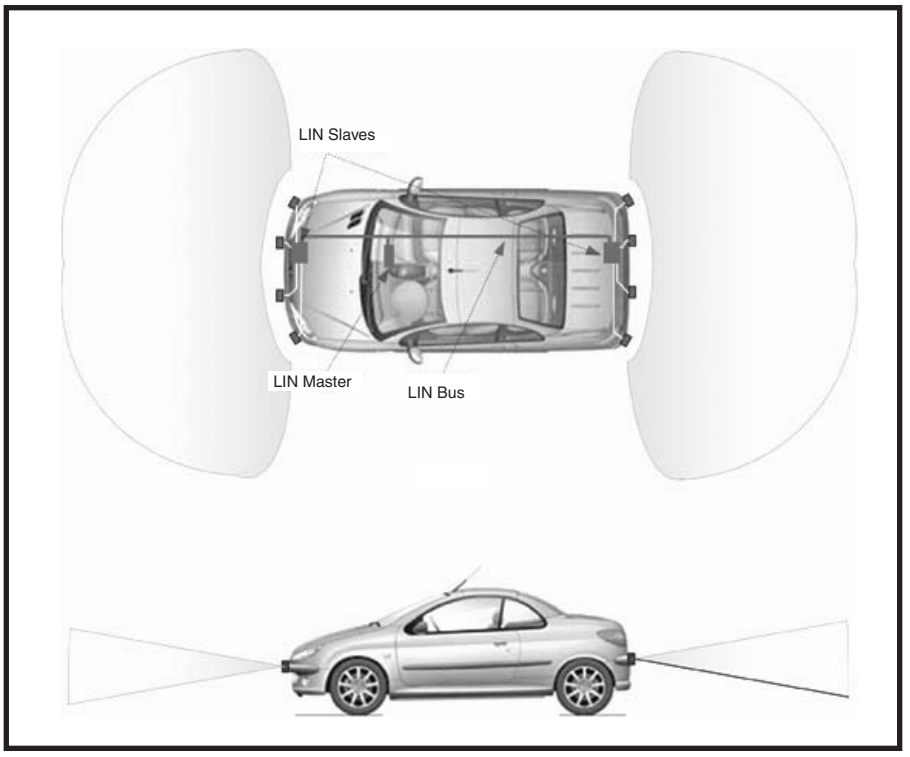


Figure 1—This figure shows the location of the distance-measuring modules, the display module, the ultrasonic sensors on the front and rear sides of the car, and the LIN-bus structure. It also shows the area of the sensor's operation scope.

animals, the sensors detect reflected ultrasonic signals and then measure the period between the emitted and received signal. The method is also used in range finders, level meters, and flow meters because the sensors can be used to generate ultrasonic pulses and detect reflected signals. The resonator emits short ultrasonic pulses (0.4 ms) and receives the reflected signal. The transient period of resonator fading is 1.5 to 1.8 ms. Resonator fading time is a primary factor in minimum-detection distance limitations. The electronics control pulse generation, excite the resonator, and perform signal processing. The time between pulse emission and detection of the reflected signal is used to calculate the distance between the car and the obstacle:

Parameter	Value
Sensors on the front side of the car	4 (maximum 8)
Sensors on the rear side of the car	4 (maximum 8)
Interface	LIN 2.0
Minimum distance to detecting the obstacle	1′
Maximum distance to detecting the obstacle	8′
Accuracy of the distance to obstacle definition	5%
Scanning rate of all sensors	8 Hz
Operation frequency of ultrasonic sensors	40,000 Hz
Maximum voltage of sensor (VPP)	160 V
Sound beam pattern into horizontal plane	110°
Sound beam pattern into vertical plane	45°
Supply current of distance measurement board (V_{CC} = 12 V, depends on quantity of sensors)	50 to 100 mA
Power supply from vehicle on-board battery	9 to 16 V

Table 1—This contains the basic characteristics of the parking assistant, such as the quantity of ultrasonic sensors, the sensors' scope, interface, and the power supply.

$$l = \frac{v \times t}{2} \quad [1]$$

where l is the distance to the obstacle. v is the speed of the sound wave. t is the time between the emission of the pulse and detection of the reflected signal. The sound wave speed depends on several factors, such as temperature, density, and air composition. The sound-wave speed is described by the Laplace formula:

$$V = \sqrt{\gamma \frac{R \times T}{\mu}} \quad [2]$$

where γ is the adiabatic constant (approximately 1.4). R is the absolute gas constant (8.314 Joule/mol Kelvin). T is the air temperature in Kelvins. μ is the molecular gas weight (approximately 28.95 grams/mol.). Typically, Equation 2 is simplified to Equation 3, which takes only the air temperature into account:

$$V \approx 20.046 \times \sqrt{T} \quad [3]$$

The nominal wave speed at 10°C (283.15 K) is near 335 mps. In this design, the influence of temperature on the sound wave's speed is not taken into account. But, this influence can easily be included in calculations within the design. The distance determination accuracy of this project is currently 5% (given the air temperature within a 20° to 40°C range). Such precision is good for parking-assistant devices. Figure 2 is a timing diagram of the poll process. The resonator issues a short pulse and catches the reflected signal.

Remember that after the signal generating is finished, the damping of the resonator lasts for a long time. Damping of the resonator applies restrictions to the minimal obstacle-detection distance. The device can't detect obstacles that are closer than 1′ from the sensor. However, it is possible to decrease the damping time in order to increase the minimal-detection distance. To decrease damping time, decrease the length of the drive pulse, shorten the windings of the swinging transformer, feed the anti-phase drive signal, or use frequency modulation by adding the appropriate mathematical processing. Now, you can examine the device, which uses all of the processes

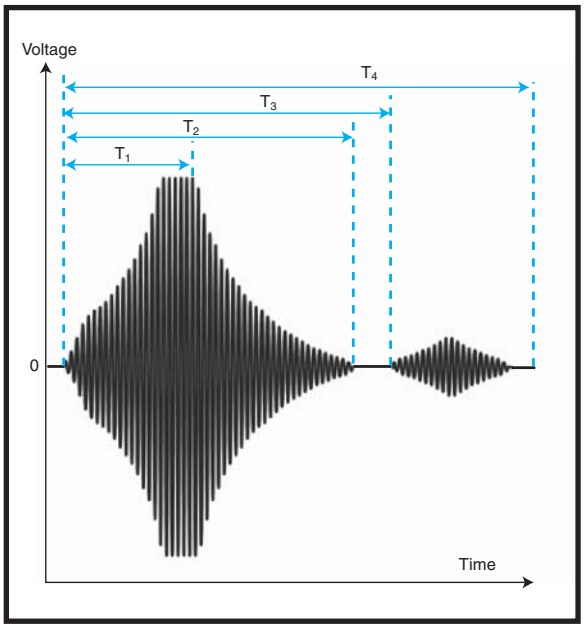


Figure 2—T_1 is the time of the exciting pulse (0.4 ms). T_2 is the time of the resonator's radiation (1.5 to 1.8 ms). T_3 is the time between the start of sampling and receiving of the reflected signal. T_4 is the timeout period (16 ms). This timing diagram should help you understand the measurement poll of the ultrasonic sensor.

described above to detect obstacles when parking a car.

DISTANCE MEASUREMENT

The distance-measurement module includes a microcontroller (with a 16-bit counter and comparator), at least one eight-channel analog switch, eight resonator-excitation blocks, an op-amp, and a band-pass filter (BPF).

If we had implemented this module with standard microcontrollers, we would have needed at least four ICs (microcontrollers, multiplexers, filters, and op-amps) and numerous additional passive components. This results in an increased system cost and reduced device-operation reliability. We built our system around Cypress Semiconductor's CY8C27443 microcontroller. The PSoC can process input and output signals for all eight sensors, internal op-amps, BPFs, and comparators with an adjustable threshold level. This solution provides a sharply reduced system cost.

Examine how the device works (see Figure 3). First, the program picks a current-measurement channel by selecting inputs and outputs from the analog switches. Then, a 16-bit counter is started and the 40-kHz generator emits 0.4-ms pulses. The pulses come to the eight-channel analog switch and enter the signal-processing circuits, namely to the resonator-excitation section shown in Figure 4. The resonator-excitation circuit amplifies the pulses from 5 V (generator output) to 160 V_{PP} (peak to peak). The amplified pulses are sent directly to the sensor and excite the resonator. A reflected signal is then processed by the signal-preconditioning circuit before sending it to the PSoC. There, it is processed by an internal amplifier and a BPF inside the PSoC. Finally, the filter-output signal is fed to the comparator. Receiver sensitivity is varied as the detection range increases. This is accomplished by dynamically changing the comparator's threshold level. As time passes, the threshold level is decreased (see Table 2). As the comparator's threshold level decreases, the obstacle distance increases and sensitivity for the reflected signal rises. The high threshold level on the small distance eliminates any false detection of obstacles (e.g., from small stones on the road). When the comparator stops the 16-bit counter, it contains a value proportional to the period between the emitted and the reflected signals, and the program computes the distances to obstacles using the period value.

The board is powered by an on-board voltage regulator. The schematic in Figure 4 includes a PSoC chip as the main controller, a LIN communication part based on a Melexis Microelectronic Systems TH8080 chip, a 5-V power supply regulator, an ISSP connector for programming, and eight signal-processing circuits that connect directly to the ultrasonic sensor. There is no quartz oscillator in the schematic, because I decided to use synchronization to the LIN bus for precision clocks with 40-kHz generators and 16-bit counters.

Resonator excitation is accomplished using transistor Q1 and transformer U4. Transistor Q1 works as a switch, controlling the 12-V supply to the primary winding. A 160-V_{PP} signal appears on the secondary winding. It is important to select the appropriate

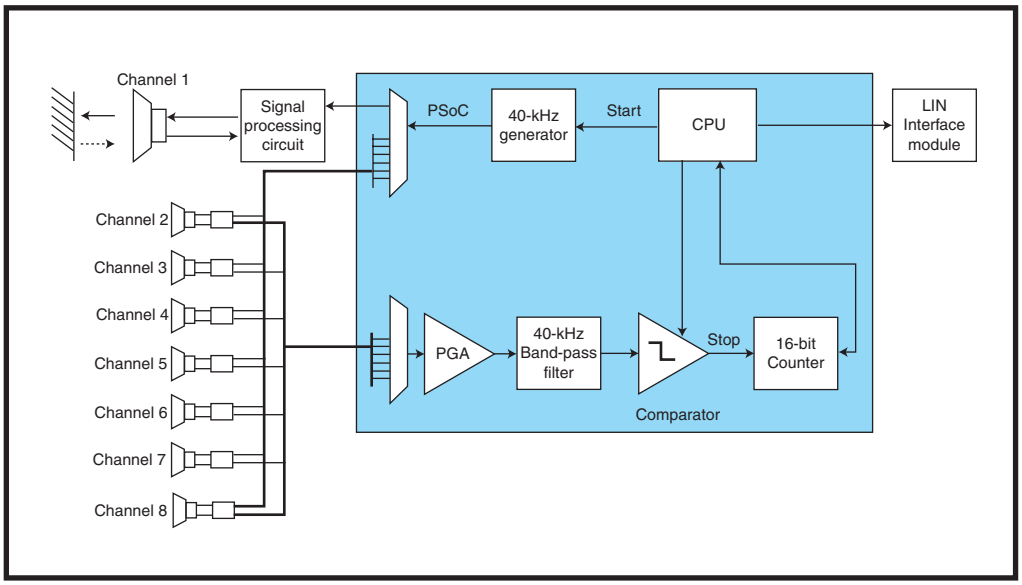


Figure 3—Take a look at the distance-measurement board based on a PSoC. You can see which blocks are built into the PSoC, how connections of the ultrasonic sensors occur, and the allocation of other functionality modules.

Time	Distance	Comparator threshold level
1.6 ms	0.268 m	1.250 V
2.4 ms	0.402 m	1.094 V
3.2 ms	0.536 m	0.938 V
4 ms	0.670 m	0.781 V
4.8 ms	0.804 m	0.625 V
5.6 ms	0.938 m	0.469 V
6.4 ms	1.072 m	0.313 V
8.8 ms	1.474 m	0.156 V
16 ms	2.680 m	0.156 V

Table 2—This table shows the dependence of the comparator-threshold level according to the response time.

winding inductance to get a 40-kHz resonant frequency from the LC circuit (C in this case is the piezoelectric sensor capacitance). By using a movable ferrite core, resonance frequency is tuned in the circuit by changing the secondary winding inductance. The reflected signal from the obstacle is preamplified by transistor Q2, capacitor C12, resistor R8. The high-pass filter centers signals around $V_{CC}/2$ (AGND) and feeds them to the PSoC input.

FIRMWARE FOR MEASUREMENTS

Take a look at some settings from the distance-measurement firmware project, which is posted on *Circuit Cellar's* FTP site. The timeout value defines the period of reflected-signal waiting. If the reflected signal does not return, the program decides there are no obstacles present. In fact, the value defines the maximum distance of obstacle detection. To change this parameter, open the counter8_1int.asm file and find the `PHASE_END` constant definition. The default value is A8h, which means 10′. Decreasing this constant decreases the period of reflected-signal waiting.

There are several parameters of the LIN slave that can be changed. The `bLinNAD` is in the main.c file. This value is the number of LIN slaves and it is used only during the configuration of the LIN cluster. In the LIN cluster, each message must have its own 16-bit number. In this constant array table, users can define or change this number at their discretion. The table named `MESSAGES_TABLE` is in the signaltable.asm file. Message IDs are responsible for transmitting measurement results that are 0x1002 for front and 0x1012 for rear modules. The message configuration record, named Frame1 and Frame2, is also located in the signaltable.asm file. Its content includes the message's direction, size, and the RAM-buffer pointer.

Also, remember that the project is optimized for a LIN speed of 9,600 bps. The proposed design uses only one crystal oscillator (Y1 in Figure 5) as a time reference. It clocks the LIN master device. The slave devices (measurement boards) are synchronized by LIN bus timestamps. The `wBase` 40-kHz variable is responsible for this synchronization.

DISPLAY MODULE

The display module is located in the

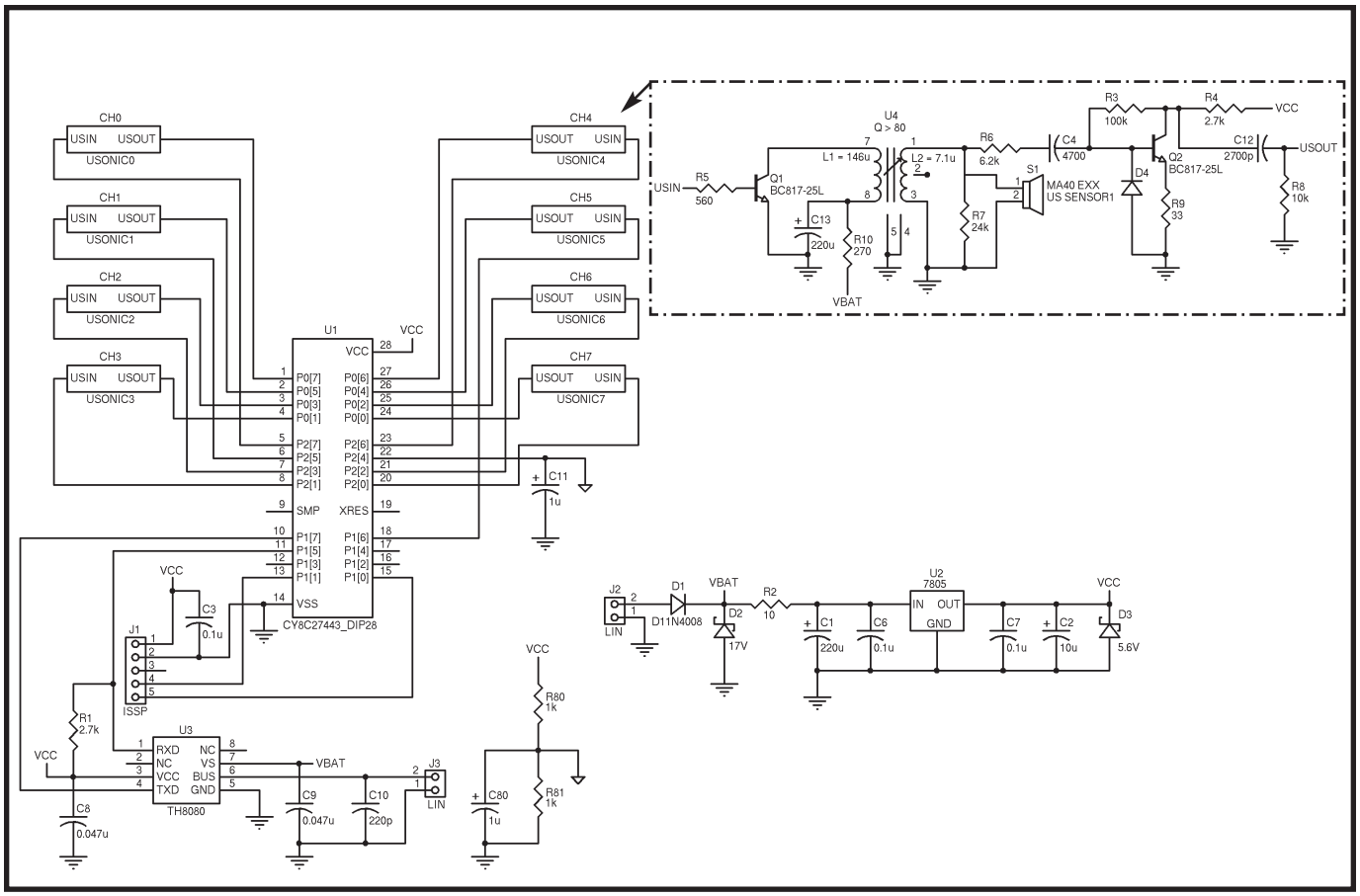


Figure 4—This is a schematic of a distance-measurement board and a resonator-excitation and signal-preconditioning circuit. Eight copies of the latter are built into the distance-measurement board. The resonator-excitation circuit amplifies the measurement pulse up to 160 V for exciting the membrane of the ultrasonic sensor. The signal-preconditioning circuit amplifies and prepares the reflected signal before it gets injected into the PSoC.

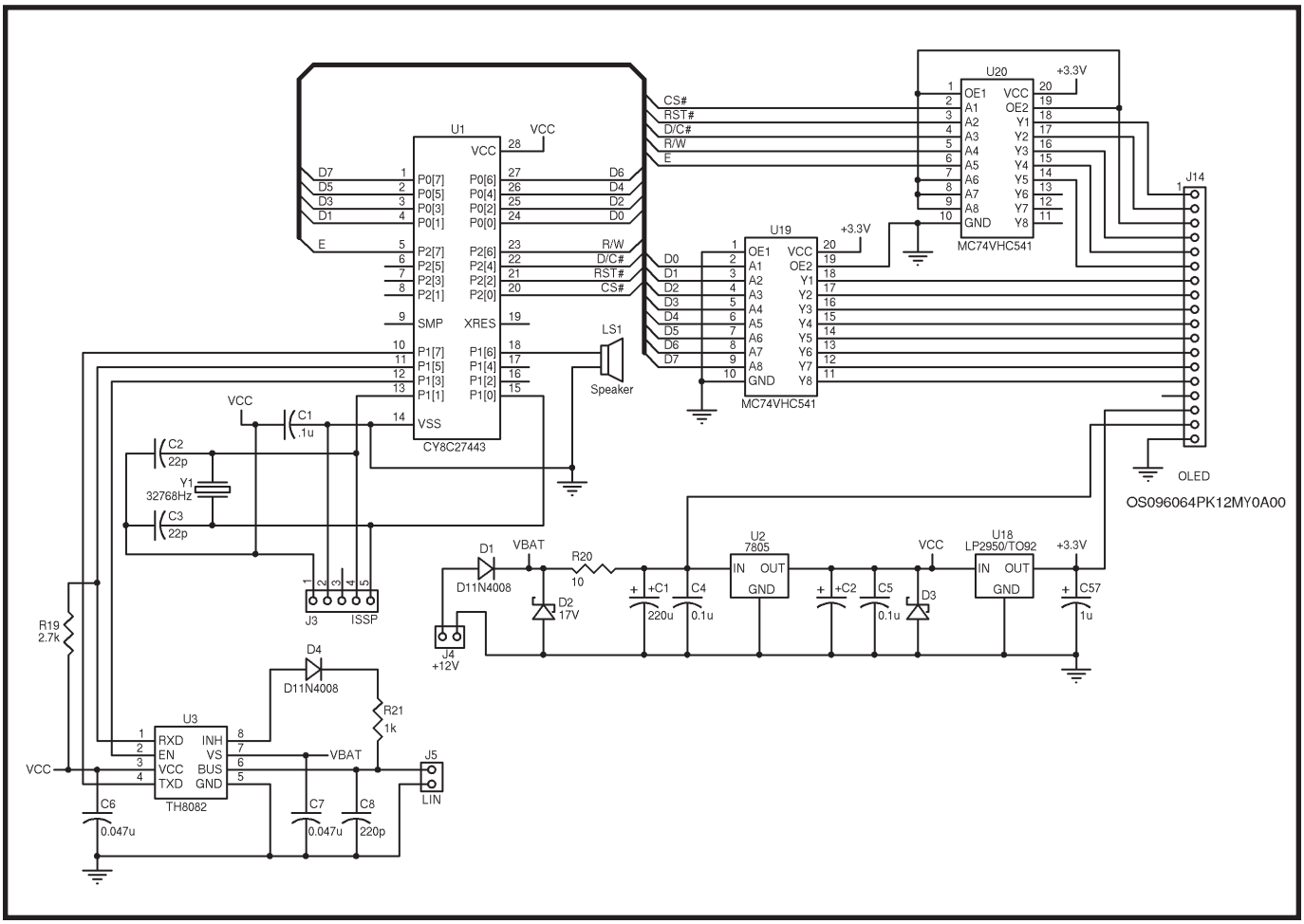


Figure 5—The schematic of the display board shows interfacing between the PSoC and the OLED display, the LIN interface, power control, and the speaker connections.

passenger/driver compartment. It communicates with the front- and rear-distance-measurement modules. The measured distance values from each sensor are transmitted to the display board via a LIN bus and they are shown on the OLED display (see Photo 1). When the distance between the sensor and the obstacle is less than 90 cm (3′), the alarm is activated. The alarm has four signal levels, which differ by varied signal/pause relations (see Table 3).

Distance	Alarm signal
Less than 35 cm	Continued, no pause
35 to 50 cm	50% pause
50 to 70 cm	75% pause
70 to 90 cm	87% pause
Greater than 90 cm (3′)	No signal

Table 3—This table describes how alarm signal faltering depends on the distance to the obstacle. When the distance increases, the silent pause in the alarm signal also rises.

The alarm allows you to park "blind," without looking at the display. In this case, the display is only used for obstacle-location adjustment. The schematic of the display board with the OLED can be seen in Figure 5.

As you can see, the display module is much simpler than the previous module. The CY8C27443 PSoC chip is the main controller and it drives the OLED. The LIN communication part is based on Melexis's TH8082 transceiver. There are two supply-voltage regulators for the 5-V PSoC: a LIN transceiver and a 3-V OLED. The level translators, U19 and U20, are used to match the 3-V OLED interface with the 5-V PSoC supply.

FIRMWARE SETTINGS

An OLED indicates the location of obstacles relative to the vehicle. There are eight variations of obstacle position that are proportional to distance. The step is about 1′ (30 cm). You can take the source code in the program algorithm of the indication module software source code located in the "WriteMarker" function and modify it to your liking.

There are four levels of the alarm. The alarm signal is controlled in the `SleepTimer` interrupt routine, which is called eight times per second. We used a self-excited speaker, which is simple to control and has only one fixed audio signal frequency. It is possible to connect simple "membrane" speakers instead of a self-excited speaker. For this, a free digital block must be configured for PWM, and pin P1.6 should be connected to the PWM. This allows you to change the frequency of the alarm depending on the location of the obstacle. For example, different tones can be produced when the closest obstacle is in front of you or on your side. Those improvements will enable you to park your car using

Listing 1—Check out the Schedule1 constant table located in the project's display module (the scheduletable.asm file). Users can change the speed rate of reading data with the display module. The default value is 16, which is equal to the (16/128 ms) period between messages transferred from the sensor's module to the display module.

```
Schedule1:
      Schedule1:

          dw Frame2, 16        //front board
          dw Frame3, 16        //rear board
          dw 0xFFFF            //no more frames, go to start
```

just the audio signals.

A bitmap of the car is in the park.asm file (see Photo 1). You can change the image at your own discretion by loading a picture of your car into the appropriate format and adding it to your project. The Cypress application note, "User Interface: Graphics Library for OSRAM's OLDED Displays," contains instructions for doing that.

The display board is a master device in the LIN cluster of our parking assistant. The project contains information about node configuration: the NAD addresses connect slave devices and numbers of ID messages, which the master will use. The signaltable.asm file is full of information about configuring the LIN node. Users can change values, which are located in this file, for tuning their own LIN communication frames for addressing messages. The number will be dynamically set during configuration by the LIN master. When the program is started, the master looks for front and rear distance-measurement modules and configures its LIN nodes by calling a ConfigureNode function at the beginning of the project. When the nodes are configured, the master device continuously polls the distance-measurement modules. A schedule of the polling and the configuration of LIN slaves, and a period of polling is located in the scheduletable.asm file. Below that are several code lines, which describe the order and the period of polling (see Listing 1).

If the period of polling is 16, that means 128 ms. Frame 2 and Frame 3 are constant structures and are located in the signaltable.asm file. This structure describes messages, which are used by parking-assistant boards for communication.

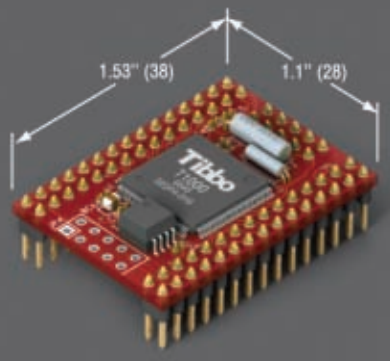
POSSIBLE IMPROVEMENTS

The parking assistant has a lot of room for improvement. The OLED display could be replaced by an LED bar graph, which would sharply reduce the cost.

To protect drivers from accidents, our parking assistant could be integrated in a more robust system to automatically start braking when an obstacle is detected. A CAN con-

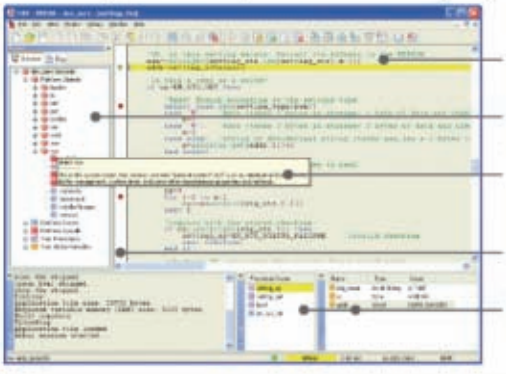
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troller could be introduced to the display board to integrate the parking assistant into the existing CAN. It would also be possible to use the built-in PSoC temperature sensor to increase the distance-measurement accuracy. In this case, no changes to the detector schematic are needed, only changes to the configuration and firmware of the PSoC. PSoC chips on the distance-measurement boards and display board have a lot of free analog blocks as well as digital blocks and memory for improvement and room for the implementation of additional functions. The temperature-sensing option could be used as an outdoor temperature sensor at a minimum cost, making your car more feature-rich.

Finally, we wish good luck to anyone who decides to follow in our footsteps and sacrifice his time and perhaps his car.

Victor Kremin has a Radio Physics diploma from Ivan Franko National University of Lviv and a P.h.D. in Computer-Aided Design Systems. He is an associate professor at National University "Lvivska Polytechnika" in Lviv. His interests include the full cycle of embedded systems design together with various processors, operation systems, and target applications. You can e-mail him at vkremin@lviv.farlep.net.

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PROJECT FILES

To download code, go to ftp://ftp.circuitcellar.com/pub/Circuit_Cellar/2007/203.

RESOURCES

LIN specification, Version 2.0, 2003, www.lin-subbus.org/.

Ramtex International, Graphic Grey Scale Dot Matrix OLED Driver Library, www.ramtex.dk/gclcd/goled0323.htm.

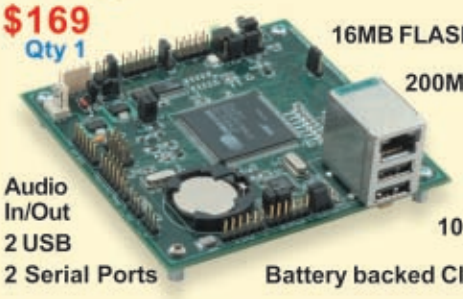
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TH8080 Chip
Melexis Microelectronic Systems
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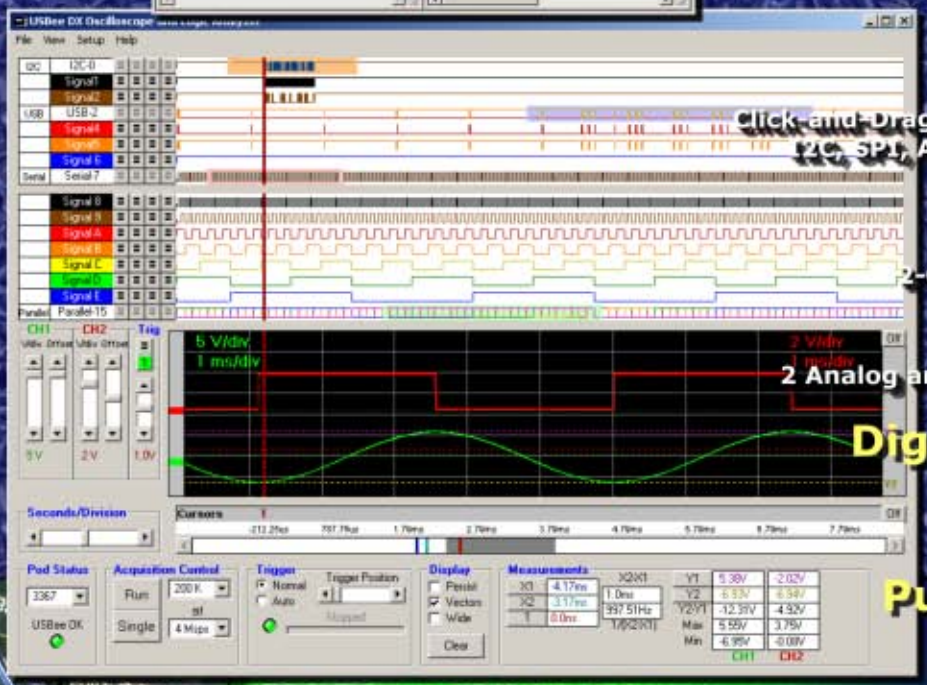
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CYPRESS PERFORM

Power Supply Design

A PID-Based SMPS

Fred reminisces about his first attempt to build a switching power supply. Learn from his experience as he shows you an SMPS development board that will help you learn about and develop power supplies.

I have never paid much attention to power supplies. I just grab a 7805 linear regulator if a project needs 5 VDC. I use an LM317, a precision resistor, and a potentiometer for analog projects that require weird voltages because I rarely need more than 500 mA from a power supply. When the current demand exceeds the capabilities of an off-the-shelf linear regulator, I reach in my bag of tricks and pull out a regulated wall wart or a power brick. I've even used personal computer power supplies to run my creations.

Once upon a time, I got this wild hair and decided that I needed to build a programmer for every PIC microcontroller that Microchip Technology produced. To do that, I had to get a better grip on power supply design and switching techniques because the typical PIC required a switchable V_{PP} (programming voltage) of no more than 13.5 VDC. I fried more PICs than I want to admit because I didn't wrangle the programming voltage into the specified limits or I misplaced the programming voltage-switching window. I finally got a handle on the programming voltage and eliminated the voltage overshoot and switching problems that were killing the target PICs, but that wasn't good enough. I had to generate a system voltage that was greater than the programming voltage, in order to use a simple-to-deploy linear regulator to source the programming voltage. I used a pair of linear regulators: one for the 5-VDC powered rail and another to regulate the programming voltage. I then had to come up with a power supply design that tapped into and boosted the system's power-rail voltage to 13.5 VDC to provide enough programming voltage without adding another linear regulator.

BOOST REGULATOR

There were lots of problems with my first boost converter. Everything was done by trial and error. Figure 1 is a schematic of my first (and last) attempt at generating PIC programming voltages with a boost regulator. Even though I used a standard 2N2222A switching transistor instead of an N-channel MOSFET, I used the host PIC to generate a PWM signal to drive my little boost converter (see Figure 1).

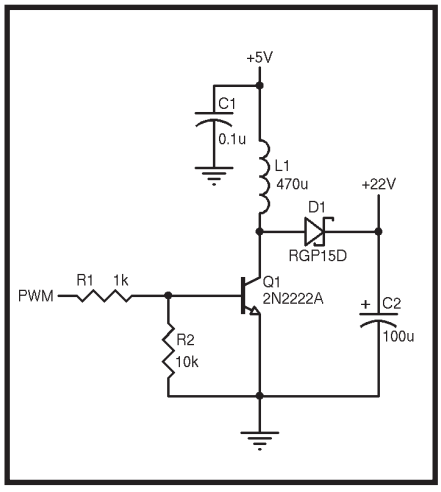


Figure 1—This design can't supply a significant amount of load current. But it didn't need to because the PIC programming voltage inputs required a voltage level and drew very little current. However, I encountered certain PIC devices that would load this puppy down.

Examine how the circuit works. Assume the boost cycle begins with the 2N2222A in an "ON" state. The diode (D1) is reverse-biased at this time. The voltage across the boost inductor (L1) is equal to the input voltage (5 VDC). The boost inductor is allowed to "charge" and current ramps up within the boost inductor. Meanwhile, the output capacitor (C2) is working hard because it is responsible for supplying the load. The PWM signal transitions and the 2N2222A switching transistor are placed in an "OFF" state and D1 becomes forward biased. Energy from the boost inductor (L1) and the input source is transferred to the load and the output capacitor (C2) is simultaneously replenished. The output voltage across the output capacitor is larger than the input voltage because both the input voltage and the energy contained within the boost inductor (L1) are pushed to the load during this phase of the boost cycle.

There are a lot of mathematical operations that can be performed to model and design a good boost converter. My design in Figure 1 made about 22 VDC with no load, but I still had to hang an LM117 circuit on the boost converter's output to prevent the target PIC devices from being

destroyed. Although the boost converter did not accomplish all of my goals, I had fun playing with it.

ONCE UPON A LUNCH

It never fails. Every year that I've presented at the Microchip MASTERS Conference somebody at the lunch table pulls a "rabbit" out of their hat. Last year's luncheon produced the blue board (see Photo 1). The board is a Microchip Technology dsPICDEM buck switch mode power supply (SMPS) development board. The lead engineer told me it was a major breakthrough because the dsPIC could sample and measure any point within the PWM cycle. This means the SMPS designer can look at the average and peak currents and voltages depending on where the samples are taken within the PWM period. Before I could pick my jaw off the table, the engineer told me that the voltage and current readings could be taken simultaneously. I had to respectfully disagree (after all, this guy designed the stupid thing). I asked how that was possible. The answer was simple. Some of the dsPIC's ADC inputs have their very own sample and the hold and ADC modules work in pairs. To make the scheme even slicker, the dsPIC's ADC module operates at a maximum of 2,000 Ksps. It was apparent that they weren't talking about motor control samples and PWM speeds because the engineer told me that the associated dsPIC PWM module has a 1-ns resolution.

By the time we finished lunch, I had met a new dsPIC family that could single-handedly control and monitor a number of SMPS topologies. In addition, nothing external is needed to make all of this happen. The dsPIC incorporates its own PWM, ADC, crystal less PLL-based system clock, power-management capability, power factor correction capability, and communications subsystems (I^2C, SPI, RS-232, etc.). In addition, the dsPIC contains a DSP engine to aid in the speedy calculation of error and correction parameters that can be used in a PID-based SMPS implementation.

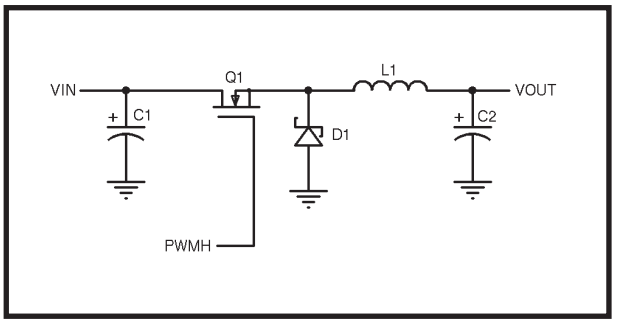


Figure 2—This may seem elementary, but it is essential to know if you want to grow up to design SMPS systems.

BUCK CONVERTERS

All of the high technology in the dsPIC and on the SMPS development board means nothing if you don't understand the basics behind the buck converter. Figure 2 is a very simple buck step-down converter circuit. Assume the cycle begins with the PWM signal in a state that turns the MOSFET (Q1) off. When the PWM signal transitions, the MOSFET is turned on and current begins to flow through the MOSFET from the voltage input. This allows current to flow through the inductor (L1), into the output capacitor, and out to the load. If you've ever taken the time to read the basic component stuff in the American Radio Relay League (ARRL) Handbook (I highly recommend it), you know that the current across the inductor (L1) will increase linearly with time, as long as the MOSFET allows current to flow from the input. The result is a steady increase in voltage across the output capacitor. What you don't see in Figure 2 is the control circuitry that is responsible for turning off the MOSFET when the desired output voltage is measured across the output capacitor.

Assume the control circuitry has read the output voltage and determined it to be within its specifications. The PWM signal is now positioned to place the MOSFET in an "OFF" state and the source voltage is denied the rest of our circuitry. Again, just as the ARRL handbook states, the energy stored in the inductor (L1) has to go somewhere. The reversal of voltage on the inductor allows the diode (D1) to be used as a current path and the energy stored in the inductor begins to decrease in a linear manner. The trick is to time the PWM signal so it doesn't allow the inductor to lose all of its energy before the charge cycle can restart. This is really simple stuff if you chuck the advanced math

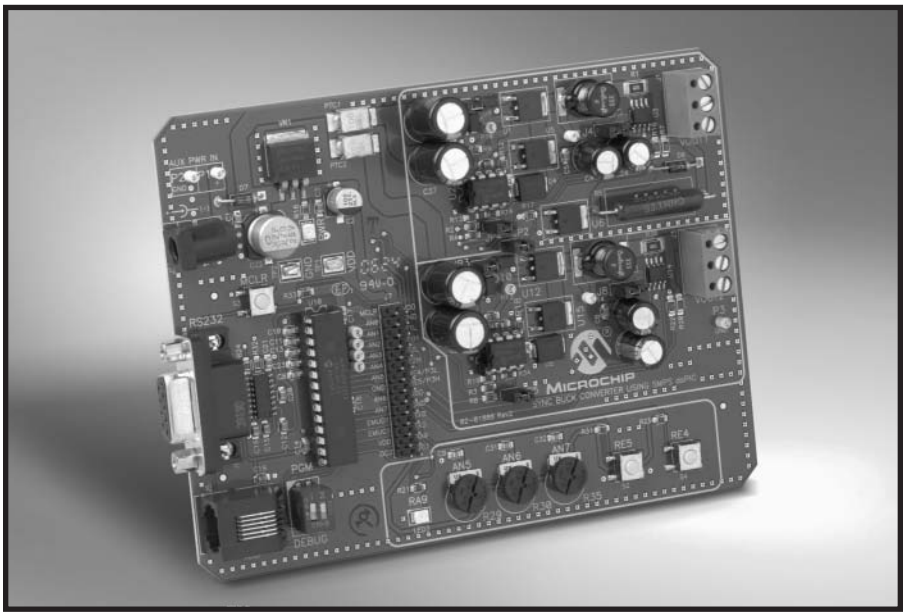


Photo 1—This board is based on a pair of synchronous buck converter modules that are controlled and monitored by a single dsPIC30F2020.

that you can apply to this circuit. The PWM duty cycle is:

$$D = \frac{T_{ON}}{(T_{ON} + T_{OFF})} \quad [1]$$

where D is the duty cycle. T_{ON} is the time the PWM signal is in the "ON" state. T_{OFF} is the time the PWM signal is in the "OFF" state.

It's pretty obvious that if the MOSFET is off long enough, the output voltage will fall to zero. Conversely, leave the MOSFET on, and you'll get the source voltage across the output capacitor. So, with that, the output voltage for Figure 2 is:

$$V_{OUT} = V_{IN} \quad D \quad [2]$$

where the duty cycle is greater than or equal to 0 and the duty cycle is less than or equal to 1.

Throw in another MOSFET (Q2) and make it parallel to D1 (see Figure 3). We never hung a technical name on our Figure 2 circuit so, let's do that now. Figure 2 is a classic asynchronous buck converter. The addition of the complementary MOSFET (Q2) in Figure 3 turns the asynchronous buck converter into a synchronous buck converter. The name of the Figure 3 circuit is drawn from the way the MOSFETs are driven.

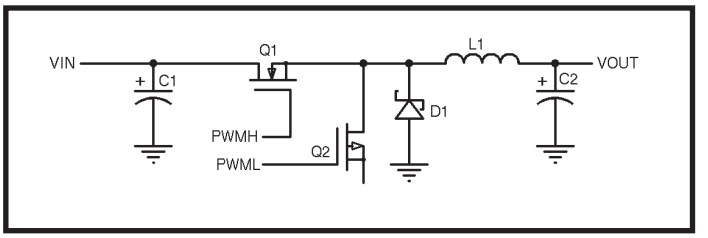
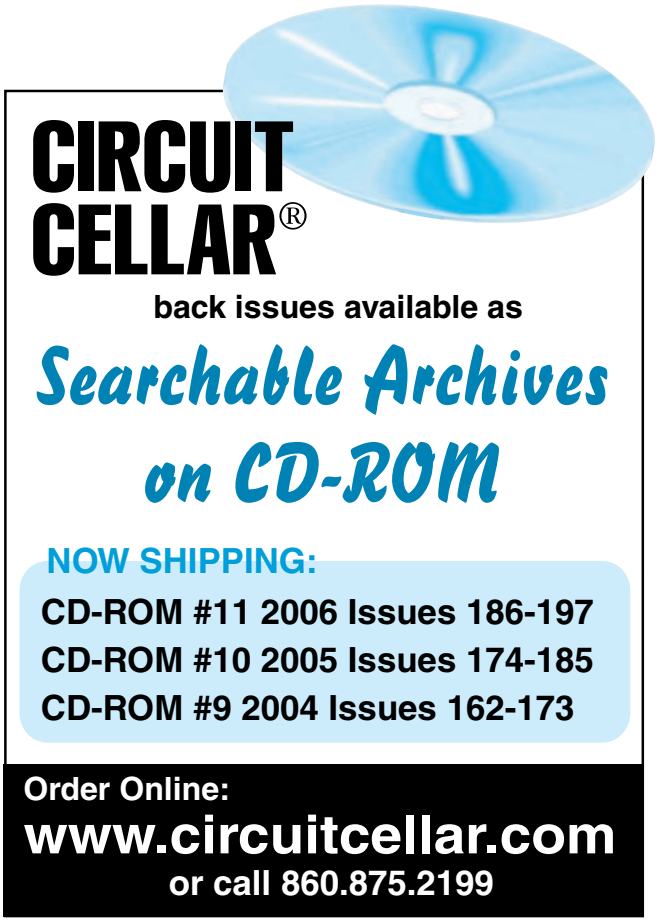


Figure 3—I told you this power supply stuff was fun. Increase the efficiency of your asynchronous buck converter in Figure 2 by adding an additional complementary MOSFET. You will end up with a synchronous buck converter.

MOSFET (Q1) is always off when MOSFET (Q2) is on, and vice versa. That synchronous operation is provided by a complementary pair of PWM signals. The second MOSFET is parallel with the diode and provides a lower-forward voltage drop, which increases the efficiency of the synchronous buck converter.

Everything is good so far; however, the circuit's tap points can't be accessed to monitor and control the buck converter. You can fix that. All you need are a couple of precision resistors at the input to help capture the input voltage. I've enhanced Figure 3 to produce the circuit you see in Figure 4 to accommodate the input voltage monitoring by adding R1 and R2 configured as a precision voltage divider. The voltage-divider ratio of the R1/R2 precision resistor pair depends on the magnitude of the input voltage. The VSENSE_IN voltage monitor tap is routed to one of the controller's ADC inputs. You will definitely need to monitor the output voltage. So, another precision-voltage divider consisting of R3 and R4 is laid across the output capacitor. Like the VSENSE_IN voltage monitor tap, the VSENSE_OUT voltage monitor tap is





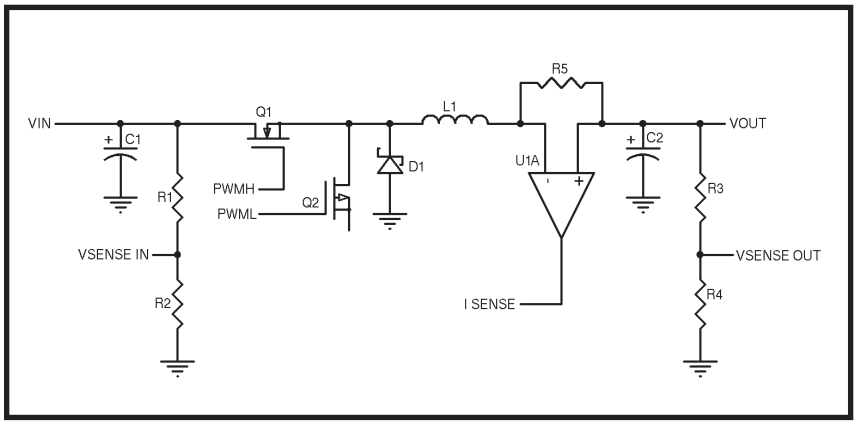


Figure 4—All of the basic SMPS stuff is already here. All you have to do is add taps that allow the SMPS controller to access and monitor key points on the buck converter circuitry.

routed to one of the controller's ADC inputs. There are many ways to measure the buck converter's output current. I've taken the liberty of using a super low-value current-sense resistor and a dedicated current-sensing module to provide the scaled voltage value to another one of the controller's ADC inputs. We already established the fact that the controller can supply the complementary PWM signals. So, in Figure 4 you have a very simplified model of a synchronous buck converter that is under the command of an SMPS controller.

NOT FAR FROM THE TREE

I won't waste paper and space reprinting a two-page schematic diagram that you can get from the Microchip web site. Download the user guide and code package associated with the SMPS development board. My simple figures are the stuff that make up the board's circuitry.

Once you get your package from the Microchip site, you'll see that the development board houses a pair of buck converters. It also allows you to monitor key tap points and configure the buck converters in different ways. For instance, you can disable the complementary MOSFET and run the buck converters in Asynchronous mode. There is also a configuration that allows you to monitor the load current or the current flowing through the inductor. If you want to pull a heavy load and you don't have anything on the bench to assist you, one of the buck converters allows you to kick in a heavy-duty load resistor.

WHO'S ZOOMING WHOM?

The essential physical hardware operations aren't rocket science. The real work is done in the firmware. You need to define the operational parameters before anything else can happen. The maximum and minimum input and output voltages need to be specified and the maximum-current output value has to be nailed down. Once all of the operational parameters are chosen, the human-readable volts and amps are converted to ADC bits that the controller can use.

Even though the development board is driven by a specialized SMPS dsPIC, the basic housekeeping chores still need to be done. A dsPIC is fast and powerful, but it can't configure its own general-purpose I/O lines or configure PWM and ADC to interact at the precise moment within a PWM period. You must make sure that the controller is properly configured and clocked.

You don't have to worry. All of that has been done for you. The code package that is included with the development board download package shows you how to set up one of the buck converters for a 5-VDC output and the other buck converter for 3.3-VDC operation. You don't have to take just what is given to you. As you study the SMPS firmware, you can easily change the factory-supplied operational parameters to get other voltages and output currents.

You won't be PID-challenged if you follow the simple PID algorithms in the SMPS source code. (The SMPS source code is written in assembler.) The PID algorithms make heavy use of the dsPIC's MAC and accumulator shift operations. The source code for these operations is laid out in detail for you.

The SMPS firmware is designed to allow operational parameters in the source code framework. Once the operational parameters are established, the SMPS firmware configures the general-purpose I/O, the PWM modules, the timers associated with the PWM modules, the ADC inputs, and any other peripherals that need attention before the application is allowed to run. Once the SMPS application code executes, the SMPS firmware checks for fault conditions on the input and output. If a fault is detected, the board's buck converters are shut down.

If no faults are detected, the SMPS firmware slowly ramps up the output voltage until the PID firmware engine can take control. Most of the SMPS application time is taken by the ADC interrupt-service routines. All of the PID calculations are performed within the ADC converter ISR. An idle loop is always executing. When everybody is happy, fault checking and other mundane tasks are executed.

JUST LIKE THE OLD DAYS

I'm having just as much fun twiddling with the SMPS code as I did trying to match the right PWM frequency and inductor value when I was toying with the boost converter. I guess I'll have to stop taking power supplies for granted.

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.

SOURCE

SMPS Buck converter development board and dsPICDEM power supply
Microchip Technology, Inc.
www.microchip.com



by Ed Nisley

Practical Photomicrography

This month, Ed digresses from analog and RF topics to describe techniques for taking good pictures of small objects. The next time you modify a part, take a few pictures to improve your memory, your reports, and your documentation.

While I'm building an electronic or mechanical gadget, I document what I'm doing with plenty of pictures. Even when I'm not planning an article or column, pictures remind me of what's inside, how it works, and, alas, how to fix it. Examining an old picture is often easier than dismantling the gadget.

Similarly, I take pictures of repair projects to show how they look before, during, and after my ministrations. The "before" images record which screws go where, how to route the wires, and where the broken parts fit. The "after" images demonstrate that I actually accomplished something!

Photographing small objects no longer requires elaborate optical adapters and chemical processing. This month I'll digress from my usual analog and RF topics to describe how to take good pictures of small objects. The results may not appear in coffee-table books, but they can certainly improve your memory, not to mention your reports and documentation.

OPTICAL ESSENTIALS

Cameras and eyeballs operate on the same principle: light from a scene passes through a lens to form an image on a sensor. Microscopes and telescopes change the image size or the amount of light delivered to the sensor, but the laws of physics govern what's possible: you can't always get what you want.

The retinas in your eyeballs and the image sensor in a camera record light intensity at specific locations, whether they are nerve cells or silicon sites. The sensor's efficiency at converting photons to electrons (or holes or ions or whatever) sets the lowest usable light intensity. Eyes have an astonishingly wide dynamic range and can "see" single-photon events, far outstripping what you'll find in consumer-grade cameras.

The minimum intensity combines with the scene's illumination to set the smallest lens aperture: the larger the opening, the more light reaches the sensor. A larger aperture allows lower scene illuminations for a given sensor, which explains why telescopes have such gargantuan mirrors and lenses. Usually though, the sensitivity and aperture determine the required scene illumination, which explains why cameras have flash tubes.

The number of active elements, usually known as pixels, in the sensor limits the ultimate image resolution and each pixel's size limits its sensitivity. For a given overall sensor area and technology, larger pixels produce both lower resolution and higher sensitivity. That explains why older digital cameras had better dark-scene performance: their larger pixels captured more photons.

Lenses in cameras and eyeballs do not, contrary to popular impression, magnify the incoming image, simply because the sensor is smaller than the external scene. The focal length of the lens does affect the image size, however, with larger focal lengths enlarging the image. A zoom lens changes the image size by varying the lens's focal length at the cost of greater lens complexity and size.

The amount of light reaching the sensor depends on both the focal length of a lens and its aperture. A longer focal length positions the lens farther from the image, which reduces



Photo 1—Compact digital cameras can peer through optical instruments designed for the human eye. My hulking Sony DSC-F717 has much better picture quality, but the Casio EX-Z850 goes where the Sony just doesn't fit.



Photo 2—Check out my compact EX-Z850 mounted on one eyepiece of a stereo-zoom microscope. It works equally well on telescopes and inspection loupes. The wrist strap, which I slip on whenever I pick up the camera, has prevented some truly ugly incidents.

the solid angle subtended by the lens, reducing the amount of light reaching the sensor. Think of the limiting case: the sensor sees a very long focal-length lens as a tiny disk.

Increasing both the focal length and the aperture maintains the same light intensity at the sensor, which is why long telephoto lenses sport huge glass disks out in front. The ratio of the focal length and aperture diameter defines the lens's "f/ number" or "f/ stop." Two lenses with an equal f/ number put the same amount of light on the image sensor, if you ignore any losses in the lens's elements.

In the days before digital sensors, mid-grade consumer cameras produced 36 × 24 mm images on 35-mm film, using a general-purpose lens with a focal length near 50 mm and an aperture near f/2.8. The fastest such lens I ever owned was a hulking f/1.2. A smaller sensor requires a shorter focal length to "see" the same image and a correspondingly smaller aperture for a given f/stop (see Photo 1).

Again, contrary to popular opinion, the diameter of the front piece of glass need not determine the f/ number. The "entrance pupil" is buried deep inside the multiple glass layers of a typical camera lens, typically at the overlapping leaves of the iris diaphragm.

Photo 1 shows how this works out in practice. The Casio EX-Z850 on the left has a 7.9–23.7 mm f/2.8–5.1 zoom lens that's about 12 mm in diameter, where the formula predicts either 7.9/2.8 = 2.8 mm or 23.7/5.1 = 4.6 mm. The Sony DSC-F717 on the right has a 9.7–48.5 mm f/2.0–2.4 zoom lens, which should be 4.8 or 20 mm, but is 36 mm.

The front lens's diameter is actually the projection of the entrance pupil through the lens system, which you can verify by taking a picture of yourself peering into the lens so that the edge of the front element lines up with the edge of the iris. Your eyeball will appear near the edge of the image.

Incidentally, the rectangular mask in front of the Z850's lens is a projection of the image sensor through the lens. It reduces scattered light in the lens system without clipping the image.

DOWN THE TUBES

The human eye's iris opens to about f/2 in dim light, with an entrance pupil of 6 to 7 mm. That's roughly comparable to my Z850, so it can "see" through an optical device designed for a human eye. Photo 2 shows it mounted on the stereo zoom microscope I use for some of my surface-mount circuit work.

Holding the camera in place is the only tricky part, although compact digital cameras weigh so little that the microscope can easily support them. Unlike larger cameras, however, you cannot simply attach the lens to the microscope, because the lens turret deflects under radial loads, rotates while zooming, and retracts into the camera.

Photo 3 shows the simple mount I built from my parts heap. The brown metal tube slip-fits over a layer of electrical tape protecting the microscope's eyepiece. It's a few millimeters longer than the eyepiece and it is slightly larger in diameter than the end of the camera lens turret.

The white PVC tube surrounds the camera lens and seats on the camera's front surface. A thin plastic ring provides a tight slip fit between the two tubes and allows adjustments along the optical axis. I lathe-turned the plastic tubes, but some rummaging in the plumbing aisle of your local hardware store should produce similar results.



Photo 3—Three bumps on the camera's bottom position the aluminum plate, which attaches to the tripod mount. The brown tube fits over the microscope eyepiece and the white tube butts against the camera body. Epoxy putty aligns the camera on the microscope's optical axis. I added black nonslip tape to reduce the camera's slipperiness.

The T-shaped aluminum plate accurately locates against three small feet on the bottom of the camera body and screws to the tripod mount, which isn't directly below the lens axis. I lathe-turned the screw from a surplus 1/4-20 knob, which was easier than creating a screw from scratch.

The camera lens axis must be coaxial with the microscope eyepiece axis, but, faced with the prospect of machining a

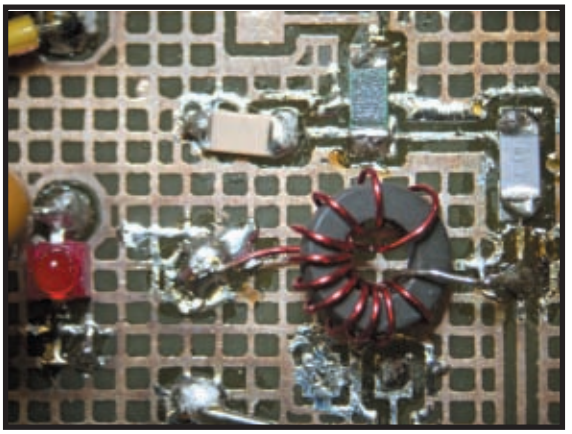


Photo 4—The camera and the microscope's optical zooms can vary the image width from about 2 to 20 mm. The depth of field varies accordingly, but it is never quite enough!

precise concave-surfaced adapter between the aluminum plate and the PVC tube, I decided to cheat.

The rear surface of the PVC tube is perpendicular to its axis, so all I had to do was align it radially on the camera. I attached the base plate to the camera, laid it lens-up on a towel to protect the LCD, mixed up a blob of epoxy putty, and stuck it to the plate. Then, I squashed the PVC tube against the blob, aligned it with the circular rim around the lens turret, mushed the epoxy into a pleasing shape, rechecked the alignment, and walked off.

Fifteen minutes later the epoxy was cured and a quick check showed excellent optical alignment: with the camera zoomed out all the way the image circle was just slightly off-center on the LCD. In fact, the error was less than the wiggle room of the eyepiece tube. That's almost certainly better than I could do on a milling machine.

I drilled 4-40 clearance holes through the aluminum and epoxy, then tapped the PVC tubing for a pair of screws. I don't trust the blob to support a nice camera!

The microscope's eyepieces have a generous 20-mm eye relief which, being a chronic eyeglass wearer, I really appreciate. That also means that the camera need not be mashed against the eyepiece.

An eyepiece's eye relief indicates the distance from the lens where its exit-pupil diameter matches your eye's entrance pupil. If your eye is closer to the eyepiece, you'll see a small, fuzzy-edged, bright image that tracks your eye motion. If your eye is farther away, the bright circle moves in the opposite direction. Exactly at the eye-relief point, the image fills the eyepiece's entire field of view and has a crisp edge defined



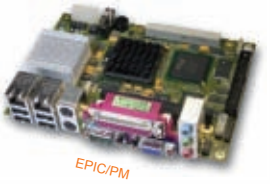
Photo 5—A white LED gooseneck lamp provides direct illumination, albeit with dubious color fidelity. I rewired this lamp to equalize the LED currents, replaced its three AAA cells (!) with a wall wart, and ballasted the plastic base with lead strips.

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by the lens's exit pupil.

To find that sweet spot, set the camera's focus to infinity and choose the largest lens aperture. As you slide the camera along the lens axis, the fuzzy-edged circle on the camera's LCD will become a larger, hard-edged disk. Center the camera in the range in which that's true. You will never have to adjust the camera mount again.

Now for some pictures!

PUSHING THE BUTTON

My microscope presents a field of view that fills about 45° of the visual angle. The Z850's FOV is about 50° horizontally at its 7.9-mm setting, so the crisp image circle very nearly fills the width of the screen. However, I usually want rectangular photographs, so I zoomed the camera lens until the image fills the corners (see Photo 4).

All four corners are slightly darker than the center of the picture: vignetting is an unavoidable part of any optical system I can afford. Let's split 'em entirely, as aligning the camera exactly in the middle of the eye-relief range helps considerably, if you're more fussy than I, vignette compensation applied to the final image works well.

The combined camera and microscope zoom ranges span about 2 to 20 mm across the width of the image. Printed at the size you see in Photo 4, the overall magnification ranges from 3 to 30. I generally set the Z850 to 6 MP (2,816 × 2,112 pixels), which can produce a 300 dpi, an 8 × 10-inch image at a magnification of 125. You can use the same technique on a standard microscope to achieve much higher magnification.

I set the camera to infinity-focus mode and adjust the microscope for best focus. Unfortunately, microscopes have a very narrow depth of field that makes camera images seem blurry compared to the naked-eye view. For example, the SMD resistors in Photo 4 are well focused, but the top of the inductor winding and the LED are both slightly fuzzy. A smaller camera aperture slightly increases the focus range, but the best subjects are the flattest.

I use fully manual aperture and shutter settings, paying attention to the intensity histogram display shown on the left side of the LCD in Photo 2. I've found that specular reflections, such as the solder joints in Photo 4, tend to confuse the auto-exposure logic, so a manual setting that slightly overexposes the highlights produces the best overall image. There's rarely enough dynamic range to cover both specular-solder highlights and dark shadows on epoxy packages.

The camera's delay timer gives vibrations time to damp out before the shutter clicks. Fortunately, my subjects never get bored and fidgety while I set up the shot.

The Electronic Goldmine 14-white-LED gooseneck lamp in Photo 5 provides enough illumination for exposures around 1/15 sec at f/5 with ISO 100 sensitivity. Unfortunately, the phosphor in "white" LEDs produces relatively little red or green energy, so the color balance often seems cold. I set the manual white balance on a sheet of paper seen through the microscope, then I apply color correction to the image. The gray ferrite core in Photo 4 was a convenient reference in this image and, because I'm not producing portrait photos or color-matched product advertisements, the result is close enough.

MACRO SCENES

Most of the pictures in my columns present desktop-scale scenes rather than microscopic objects. For those, I used the Sony DSC-F717, a tripod, and overhead lighting (see Photo 1). Oh, yes, and a towel or a sheet.

Most digital cameras have a macro-focus setting and some cameras can focus on an object, only millimeters from the front lens's surface. I sometimes use a two- or four-diopter close-up adapter to trade-off distance and focal length.

The camera's depth of field, while better than that of a microscope, still leaves much to be desired. I focus on a detail in the most critical part of the scene, set the aperture to f/8, adjust the shutter speed to whatever suits the lighting, and use the delay timer. That works out well enough for my purposes.

When you look at my pictures, you may conclude that I have an unnaturally tidy workbench. The fact of the matter is that I simply drape a white cloth over the junk and arrange it to minimize any visible folds. I left a fold in the background of Photo 5, just below the microscope head, so you can see what's usually missing.

As a good rule of thumb, if your picture has good focus, decent exposure, and a neutral background, it'll look pretty good. Try it out and see for yourself!

CONTACT RELEASE

Take a macro photo of your business card and write-protect the image file in your camera. Then when you leave your camera somewhere, an honest person can find you.

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

RESOURCES

Digital Photography Review, http://dpreview.com/.

P. Gibbs, "Can a Human See a Single Photon?", http://math.ucr.edu/home/baez/physics/Quantum/see_a_photon.html.

R. Kinch, "Making Digital Camera Microscope Adapters," www.truetex.com/micad.htm.

Melles Griot, Inc., "Machine Vision Guide: Pupil Diagrams," www.mellesgriot.com/products/machinevision/lef_4.htm.

SOURCES

EX-Z850 Digital camera
Casio Computer Co.
www.casio.com

DSC-F717 Digital camera
Sony Electronics, Inc.
www.sony.com

G15867 14 White LED lamp
The Electronic Goldmine
www.goldmine-elec-products.com/prodinfo.asp?number=G15867



by Jeff Bachiochi

Gearing Up to Go the Distance

Slotted Optical Switches

This is not your father's odometer. With some modifications, including slotted optical switches, Jeff's odometer measures the speed and distance traveled on his electric bicycle. The information is displayed on an LED.

It's a toss up! Parents have heard the complaints over and over. Many contend the most used phrase by their children is "Not me." But, there is another phrase that sounds like a broken record. "Are we there yet?" can be heard whenever travel to a destination exceeds 5 min. That phrase is used interchangeably with "How much farther?", but the meaning is the same: boredom.

I grew up with three sisters. Whenever we went on a family trip we played one of two games: alphabetical signs or state license plates. The first to go sequentially through the alphabet by finding a word on a passing sign that used the corresponding letter won. Longer trips were filled with locating license plates from every state in the nation. Although we had an AM radio in the old Ford, CDs and cassette tapes hadn't been invented yet, so we used those games to attack boredom.

Growing up in the northeast meant most trips were relatively short (100 miles was a long trip) when compared to other parts of the country. In Connecticut, you can reach every part of the state and still not exceed that limit. As a kid, I walked to the store if we needed something. The grocery store, the hardware store, and the library were close by. The doctor came to our house when we were sick. My dad took the Ford to work each day, and even though my mom knew how to drive, there was no second car. If I wanted to go somewhere, I rode my bicycle. After all, my bike was my ticket to freedom. I'll bet I put more miles on that one-speed hulk than my dad put on our Ford!

I was always saving up for some doodad to customize my bicycle. I even wore through some valuable rookie baseball cards by clothes-pinning them on my wheels in order to create that cool motor sound. My first purchase was a generator light; unfortunately, it lit up only when I pedaled. (Today's bicycle generators charge the batteries to give you light even while standing still.) But, the coolest accessory was the speedometer/odometer. Up until that point, I could only guess how fast I was going down hills.

The mechanical measurement of speed and distance on a bicycle is linked directly to the front wheel. To be accurate, an odometer must be calibrated for the diameter of the wheel that it is attached to.

SPEEDOMETER/ODOMETER

Most noted for his unit of atmospheric pressure and the computer language honoring him, Blaise Pascal invented a numerical wheel calculator called the Pascaline (1642) by the time he was 18. That device helped his father, a French tax collector, calculate taxes. The Pascaline had eight movable dials that added up to eight figured long sums using base 10. When the first dial (the ones column) moved 10 notches, the second dial moved one notch to represent the tens column reading of 10. When the tens dial moved 10 notches, the third dial (the hundreds column) moved one notch to represent 100, and so on. Photo 1 shows how this calculator influenced the modern mechanical odometer. By adding the correct gear reduction, the bicycle's front wheel turns the calculator, displaying an accumulation of distance traveled. The device used to measure distance is an odometer.

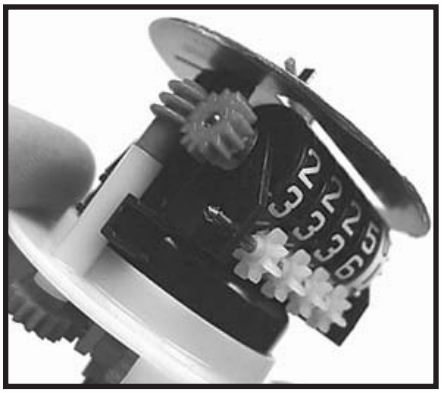


Photo 1—This mechanical odometer uses Pascal's mechanical calculator to display distance. A bicycle wheel supplies the driving force to rotate the digits of the Pascaline. Calibrating the gears to the bike's front wheel provides the proper RPM input. You can see the black aluminum cup that connects directly to the speedometer's pointer (above the top faceplate) located at the base of the white frame.

If you bought a bicycle odometer today, it would most likely use a magnetic sensor to count the wheel rotations of a magnet attached to a wheel's spokes. A computer would then count the magnetic-sensor pulses and display the distance on an LCD.

In this project, I need to measure more than the number of wheel rotations. As you may remember, the rear wheel of the electric bike that I am using for this project travels 8′ (96″) per each revolution of the wheel.

The electric motor's chain on the rider's left side uses 1/4″ links. The chain is directly connected to the rear wheel and always moves with the wheel. The electric motor has a roller-bearing clutch that keeps it disconnected from the chain when it is not

applying a force to it. The chain wraps around a 60-tooth rear-wheel gear. So, for each revolution of the rear wheel, the chain moves 60 links (that's a 96″ circumference, 60 links, or 1.6″ of forward travel for each link).

A chain with 1/2″ links connecting the pedals to a 20-tooth rear gear is on the opposite side of the rear wheel. The chain moves only when the pedals are pushed (that's a 96″ circumference, 20 links, or 4.8″ of forward travel for each link). Based on the 1/4″ chain, you can calculate how far the bike goes. And, based on the 1/2″ chain, you know the distance over which you are applying muscle power. By monitoring the throttle (or motor current) you know when the battery is supplying energy. This information determines energy usage (muscle versus electrical versus gravity).

Because a speedometer measures how fast you cover a certain distance, you must also measure the time related to the distance covered. A mechanical odometer measures distance via a flexible cable to bring wheel rotations up to its gears. It can also indicate speed with a spring-loaded pointer, which is mounted on an aluminum cup. A magnet attached to the odometer cable spins within the cup. As the magnet rotates, its magnetic field creates an eddy current in the aluminum cup (and a secondary magnetic field). As the rotating magnet increases speed, the magnetic attraction in the direction of the rotation drags along the cup. This movement opposes the force of the pointer's spring. The faster the rotation, the more the pointer moves. Because pointer movement is calibrated to indicate speed, the mechanical speedometer is easily susceptible to a loss of calibration due to physical damage. Today's speedometers, like their odometer counterparts, are no longer mechanical. The computer calculates speed (distance/time).

DETERMINE DISTANCE

This project will count the links to determine distance. I first wanted to use a rotary shaft encoder and count the encoder transitions. Rotary encoders can be mounted to a gear and selected with the proper pitch based on the chain's link length. I don't expect speeds faster than 20 MPH on flat ground, but the bike could easily exceed that cruising down hill. This means that the chains could move faster than 500 links per second. With a gear of a reasonable diameter (no more than a few inches), the rotational gear speed could exceed 40 RPS (2,400 RPM). While shaftless rotary optoencoders (in the $200 range) might survive, encoders with shafts that have rotational limits of approximately 2 RPS (100 RPM) cost about $25.

Since the project already includes buying gears to fit the chains, I'll make my own optoencoders using the available slotted optical switches. Slotted optical switches consist of an IR emitting diode (transmitter) and at least one photodiode (receiver) built into a single package. The Optek Technology OPB625 slotted switch includes an amplifier and a Schmitt trigger to reduce noise (multiple triggers on an edge). Photo 2 shows my prototype using two OPB625s. You'll notice that each device is "U" shaped. The slot separates the transmitter and the receiver. Whenever the receiver sees IR from the transmitter, it drives its open-collector (OC) output. (The device is available with an inverter, so either polarity output is possible.) When an object enters the slot and blocks the optical path across the slot, the receiver sees no IR (assuming no external light sneaks in) and thus has no drive for the OC output.

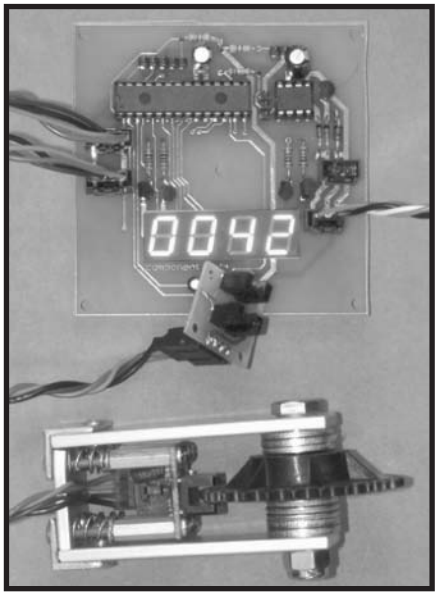


Photo 2—The LIN-slave PCB uses a four-digit, seven-segment LED to show accumulated counts 0000-FFFF. The optical-encoder PCBs connect via separate four-wire cables to the LIN-slave PCB. The LIN bus uses a three-wire cable.

With a single device, you can tell its output whenever an object passes through the slot. By counting output pulses you can determine how many times an object has passed through the slot. If the object passing through the slot is the tooth of a gear (assuming the teeth are large enough to totally obscure the optical path), then distance can be determined by counting the teeth. The relationship between a tooth and the optical path is critical. The tooth must present a completely blocked optical path when it is centered in the path. Yet, the optical path between teeth must be free and clear. In this case, the chain's link size of 1/4″ and 1/2″ (along with the teeth on the rear axle gears and the circumference of the tire) will allow you to convert count to distance. Note that this distance is a total of the movement, independent of the direction. With a single sensor, you cannot determine direction. In many cases this is not a problem if the device, by design, moves in only one direction (i.e., an automobile's engine rotation).

If you need to determine the direction, then two devices are used. Again, position is critical. Not only does the second device have to be positioned correctly in relationship to the object (tooth), but its optical path must be the correct distance from the optical path of the first device. The intra-optical path distance is based on the distance between the objects being counted. The distance must be an odd multiple of one-quarter of the distance between the objects. The gear teeth used for the 1/4″ chain (links) are 0.25″ apart. So, the arc distance between the two optical paths must be 0.0625″ (or 0.1875″, or 0.3125″, etc.). Naturally, the smaller the teeth, the more accurately the positioning must be made.

When spaced correctly, the two devices have a distinct reference to one another depending on the direction of the movement. If the device outputs are viewed over time (Figures 1a and b), you'll notice that one device leads or lags the other depending on

the rotational direction. A change-of-state (rising or falling edge) on device 1 triggers a sample of the other device's state. As long as the rotation stays the same, the logic states will alternate. If the rotational direction changes, the next sample will be the same as the last logic state, indicating a change in direction. This works equally well based on either device. If samples are taken of device 2, only on the rising edges of device 1's output, then the samples directly indicate rotational direction. Device 2 samples will always be logic "0" in one direction and logic "1" in the opposite direction. Again, this works equally well based on either device.

Discrete quadrature decoder chips take the output produced by two optical switches and produce a pulse (count) output and a direction. You can write code to perform this task in software and execute it in a microcontroller if you have the resources. If you have other time-critical functions, this might not be an option. Microcontrollers that contain this hardware will maintain a pulse count based on direction without the need for a single line of code. Often you will find this function in a microcontroller that also has motorcontrol functions.

This project will be watching two pairs of optical switches. The microcontroller I am using (Microchip Technology's PIC18F2420 enhanced flash microcontroller) does not have this hardware function (most support only one optical pair anyways), but it does offer two levels of interrupts. By using a high-level interrupt to keep track of the optical switches, I will not miss an edge even if a lower-level interrupt has taken over program execution. I chose to use external timer inputs (set up to flag a high-level interrupt on every rising edge) instead of external-interrupt inputs. The length of the interrupt routine will depend on the maximum size of the count you need to keep. The basic count uses a signed byte representing –128 to 127. The code for this is minimum. The code size will naturally increase for larger counts, because you need to keep track of byte over/underflows for multiple bytes. Figure 2 shows the flow chart for this project. The area within the dashed box is added for each additional byte required for the needed maximum count.

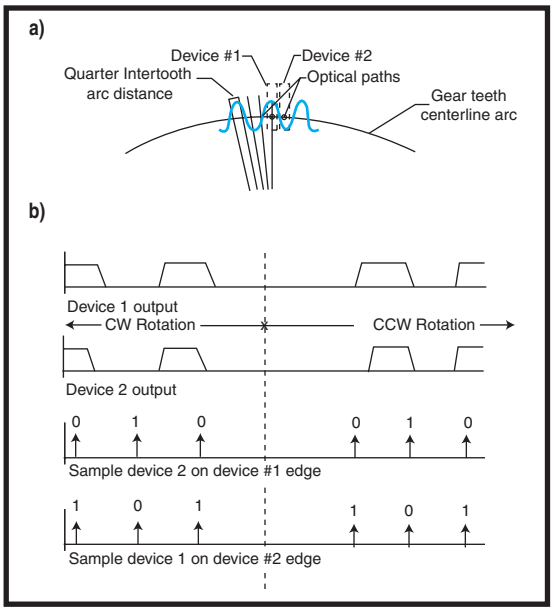


Figure 1a—The slotted optical switches should be positioned on the centerline of the gear teeth and separated by odd multiples of 0.25. **b**—This creates output waveforms that lead or lag based on the rotational direction.

As stated earlier, this project is based on a maximum chain rate of approximately 500 links per second (approximately 2 ms per link). With an execution time of 1 µs, the interrupt routine could keep up with rates of 100 times that, so you have plenty of processor power remaining for the other functions. The project includes the slope circuitry discussed last month, creating input for the master-LAN module. Since the master will be asking for information periodically, there is no reason to keep track of more counts than what can be accumulated in 1 s. Therefore, it won't be necessary to use more than 2 bytes for the accumulated counts of each optical encoder. The count will be zeroed-out each time the module reports the count.

MECHANICALS

Aluminum stock is accessible from most hardware stores. I chose a 1/8″ strap for the U-shaped frame (see Photo 2). Two side plates are fastened to a bottom plate using pop-rivets through 1/2″ aluminum angle to give the frame the required stiffness. Four #4 threaded hexagonal spacers are mounted to the optical encoder's PCB. Long 4-40 screws come up through the bottom plate and thread into the spacers. A compression spring is added between the spacer and the bottom plate at each of the four corners. This gives the optical-encoder PCB a height adjustment. The long screws move the PCB up and down. This adjusts the position of the optical paths in relation to the gear teeth.

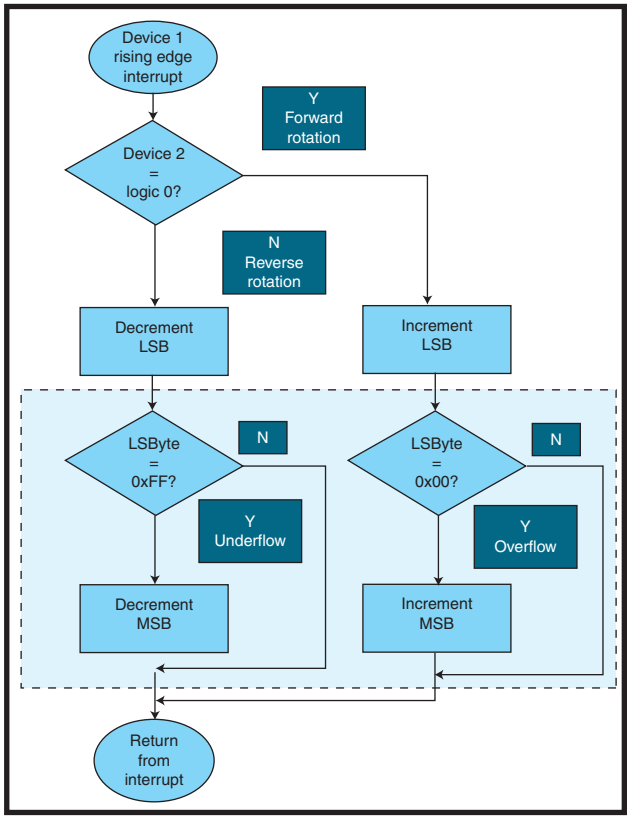


Figure 2—This flowchart shows how pulse accumulation is corrected by determining the rotational direction from a pair of optical switches. Code within the dotted box is duplicated to further expand the multibyte count.

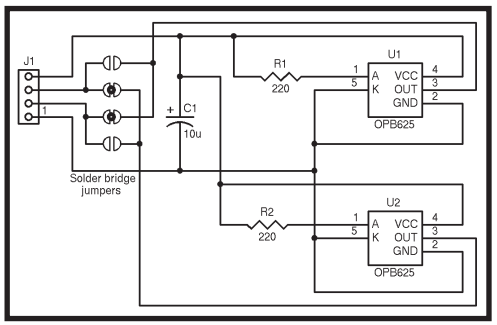


Figure 3—A pair of optical switches creates an inexpensive optical encoder. Spacing between the devices is based on the tooth-to-tooth spacing of the gears used in this project. The PCB in Photo 2 is less than 1 square inch.

To keep the assembly as clean as possible, the optical encoder frame is mounted inside a small plastic case so just the far end of the gear is exposed. The enclosure must be attached to the bike's frame (just above or below the chain) so it will rotate as the chain moves past. Each of the optical-encoder PCBs attaches to the slave PCB with identical four-wire cables (see Figure 3). Each cable carries power and ground to the encoders and returns optical switch outputs (see Figure 4). The LED used to display last month's slope output has been increased to four digits so that it can be used to display (16-bit signed) odometer counts as well as the slope (jumper selected).

The module will strictly be used for data collection. However, you could add routines here to accumulate counts and convert the counts to distance. As a stand-alone module, it might make more sense to display distance in inches, feet, meters, or other increments, rather than counts. Other than supplying a level of comfort (that the module is operating), the display is not necessary. Thus far, I have concentrated on producing and collecting data. In the first installment of this project, data was collected and analyzed externally. Next time, the project will move into a new phase. I will focus on a display that can process and display data in real time.

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

PROJECT FILES

To download code, go to ftp://ftp.circuitcellar.com/pub/circuit_cellar/2007/203.

SOURCES

PIC18F2420 Microcontroller
Microchip Technology, Inc.
www.microchip.com

OPB625 Slotted optical switch
Optek Technology, Inc.
www.optekinc.com

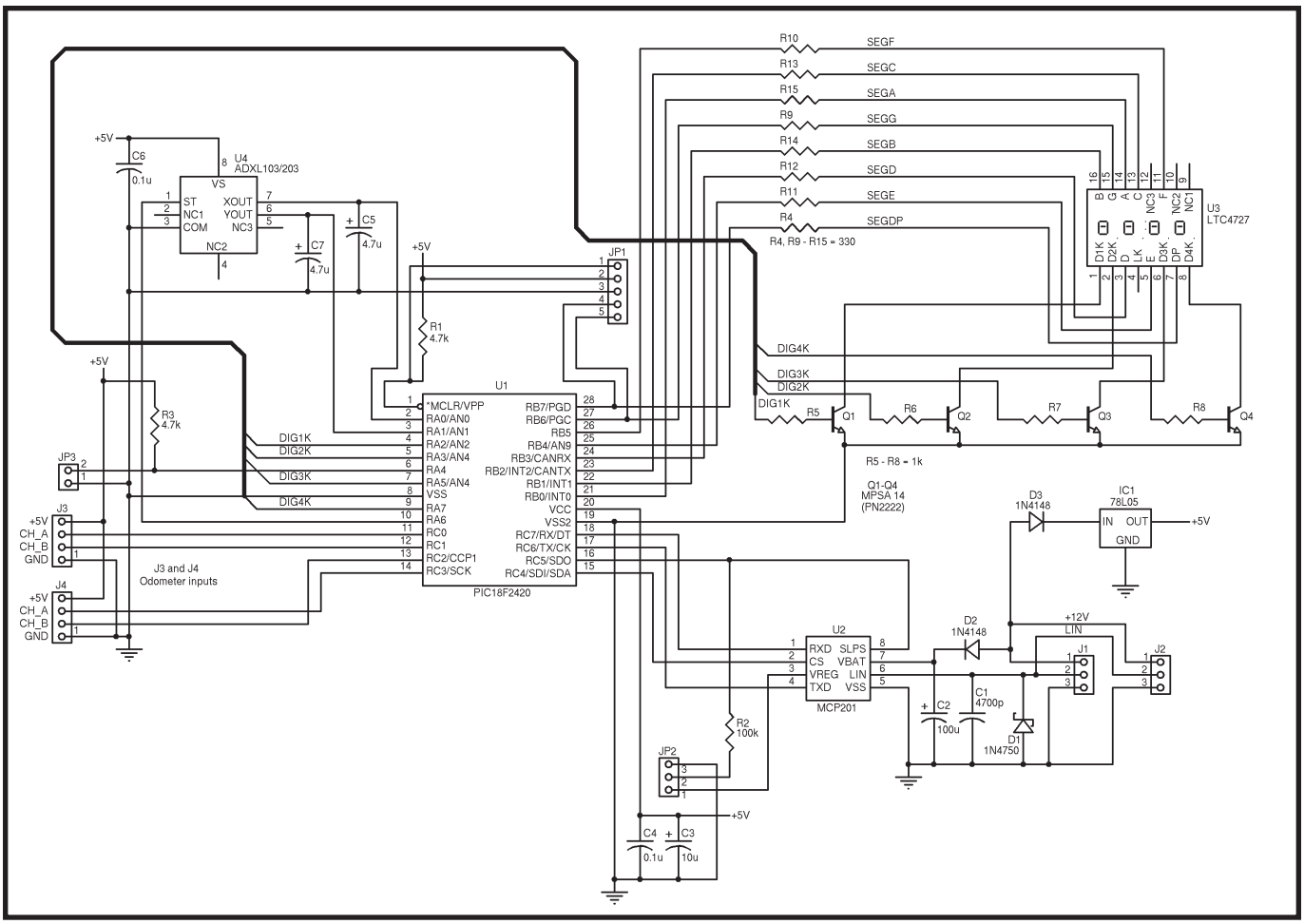


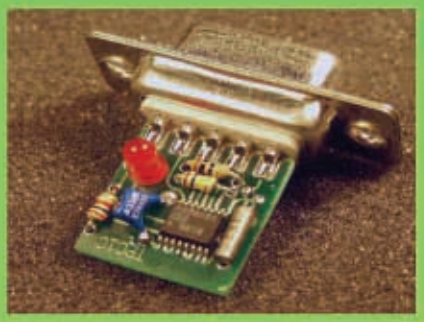
Figure 4—The slave PCB accepts two optical encoders. It also incorporates the slope and LIN circuitry (from last month). Display data is selected via a hardware jumper.

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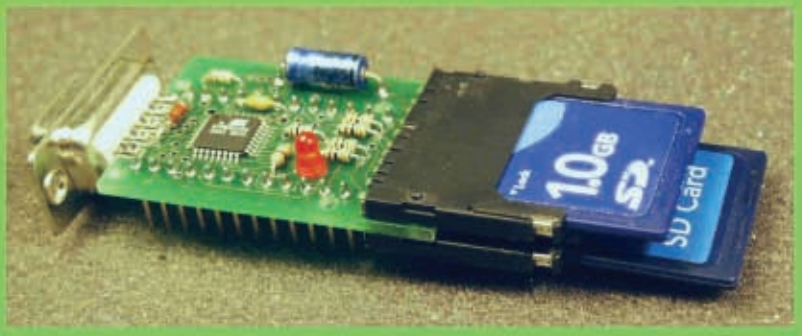


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Rock 'Em, Clock 'Em

Electronics have marched to the beat of quartz crystals for almost 100 years, but times they are a changin'. This month Tom takes a look at technologies that change the way crystals are used, replace them, or even eliminate the need for a clock altogether.

In a way, it's funny that even the highest-tech modern gadgets continue to rely on turn-of-the-century technology. I mean the previous century (i.e., early 1900s). Look at any circuit board and right alongside the fancy silicon doodads you'll still find components fundamentally unchanged in 100 years.

Along with resistors, capacitors, and so on, one of the most important of these old-school standbys is the quartz crystal. The piezoelectric (i.e., electromechanical) effect on which it's based was discovered many centuries ago, but it wasn't until the early 1900s that researchers at Bell Laboratories came up with a way of exploiting the phenomenon to generate an accurate time base.

This was a big deal, bringing an end to centuries of rather remarkable refinement of mechanical timepieces. The Dutch scientist Christiaan Huygens is widely credited as the inventor of the mechanical pendulum clock in 1656, which he later refined to achieve accuracy on the order of 10 s per day. By the early 1700s, clock designers found ways to reduce friction and compensate for temperature changes to improve accuracy to 1 s per day.[1]

In 1761, self-taught British clockmaker John Harrison won a Royal Navy prize with his marine chronometer that approached 0.1-s/day accuracy, all the more remarkable considering the harsh ship-borne environment (see Photo 1).

Now the challenge was getting more difficult, frustrating even the most masterful craftsman. It took nearly 100 years to boost the accuracy by another factor of 10 from 0.1 to 0.01 s/day. Finally, the last hoorah for the grand age of mechanical timepieces came in the 1920s with the W.H. Shortt clock. By using a master and slave pendulum arrangement, Shortt was able to achieve accuracy of nearly 0.001 s/day. But, to no avail, because almost overnight quartz-crystal clocks upped the ante by a factor of 10 (i.e., to 0.0001 s/day), and they never looked back.

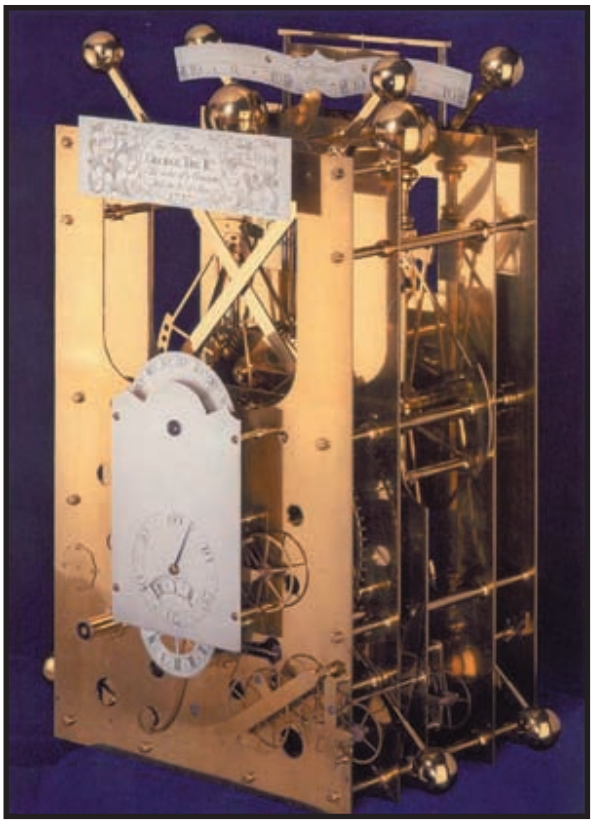


Photo 1—Think your job is tough? John Harrison's against-all-odds-saga, "fifty years of self-denial, unremitting toil, and ceaseless concentration," surely ranks as one of the heroic engineering achievements of all time.[2]

The death of mechanical clocks was inevitable, but lingering. The good old spring-wound wristwatch was probably the last to go, Dr. Jacked by the emergence of quartz versions in the '60s and '70s. Younger readers may not even recall a time when a watch's mechanical heartbeat could lull a baby to sleep, that is if you remembered to wind it up.

In the electronics age, quartz crystals and silicon chips have been a match made in heaven. Lift the hood of any electronic gizmo and if you find one you're almost certain to find the other. However, slowly but surely, new technologies are nibbling at the edges of clocking-convention, technologies that will change the way crystals are used, replace them, or even eliminate the need for a clock altogether.

CRYSTAL POWER

No, I'm not talking about the

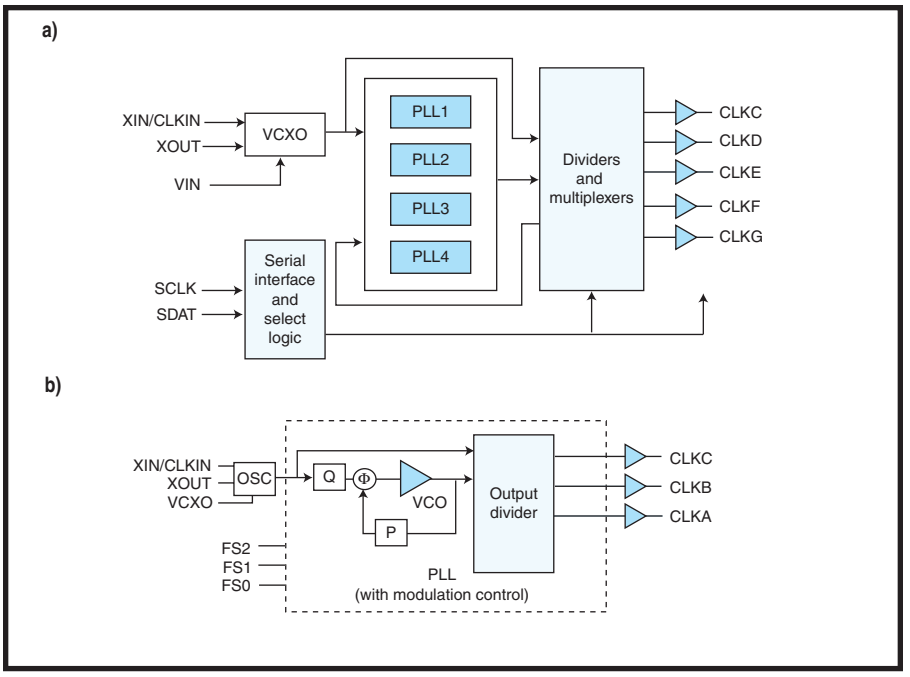


Figure 1—Here are two of more than a dozen different programmable oscillator chips offered by Cypress Semiconductor. The CY24488 **(a)** is ideal for PC and multimedia designs, while the CY22800 **(b)** offers a range of input and output frequencies supporting a variety of general-purpose applications.

latest touchy-feely craze here on the Left Coast. But, there are some mystical chips that bring magical powers to your crystal-based design.

When it comes to clock generation, the trend towards more complex, higher-performance applications poses two problems for designers, namely the need for faster clocks and more of them.

So-called "Fundamental" mode crystals are the easiest to make and use when you're talking double-digit clock rates. But, making fundamental crystals go faster requires shrinking the quartz element. This increases the manufacturing cost, not only by the extra processing (e.g., etching, lapping), but also the loss of yield. Like microchips, making a crystal smaller costs more. Furthermore, as you shave the crystal down, it becomes more fragile and prone to break if (make that when) the gadget it's in gets

Output clock	Application	Frequencies (MHz)
CLKC	Audio	6.144, 8.192, 11.2896, 12.288, 16.384, 16.9344, 18.432, 22.5792, 24.576, 33.8688, 36.864
	iLink	24.576
	HDMI	25.175, 28.322
CLKD	Video	27, 27.027, 54, 54.054, 81
	USB	12, 24, 48
	Video-pixel freq.	74.25/1.001, 74.25, 148.5/1.001, 148.5
	Modem	4.9152, 11.0592
	iLink	24.576
CLKE	Video	13.5, 27, 54, 81, 108
	Ethernet	25
	PCI	33.3333, 66.6666
	Processor	20, 30, 40, 50, 60, 80, 100
CLKF	see CLKC/D/E	REFOUT or copy of CLKC, CLKD, or CLKE
CLKG	see CLKC/D/E	REFOUT or copy of CLKC, CLKD, or CLKE

Table 1—A CY24488 and a low-cost 27-MHz crystal is all it takes to serve up the smorgasbord of clocks required by PC and multimedia applications.



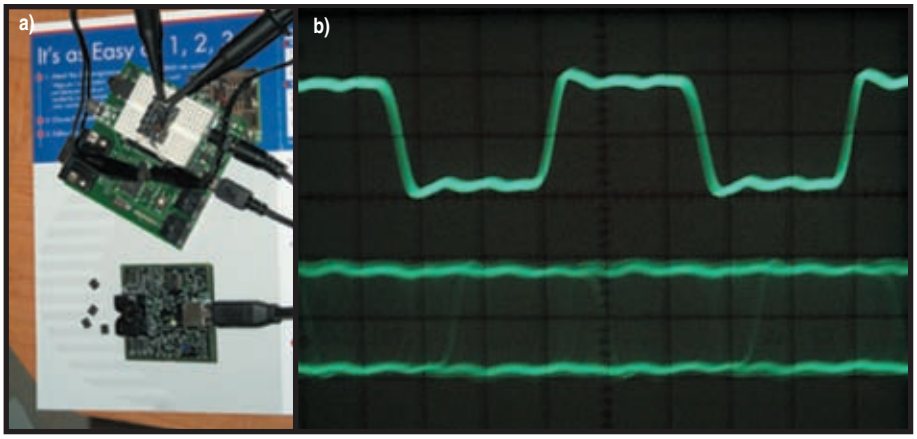


Photo 2—They forgot step four: get some tweezers and a magnifying glass. Here **(a)** is the Cypress InstaClock programmer and some very small CY22800 chips. You can also see my test lash-up using an extra socket and a Parallax Propeller board as a virtual crystal. The scope photo **(b)** shows the effect of the spread-spectrum feature. Look closely and you can see vestiges of the reference frequency peeking through the noise in the spread version.

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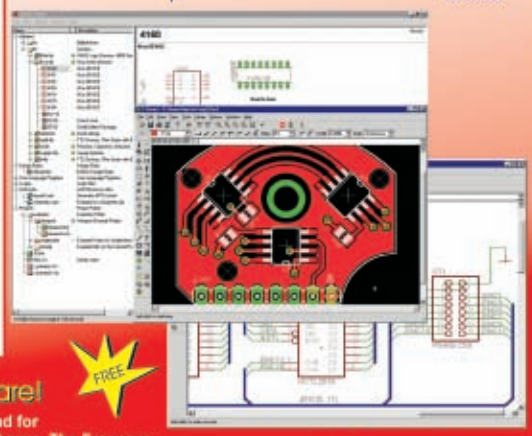
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dropped, hits a pothole, etc.

Look through the catalogs and you'll see lots of triple-digit (i.e., greater than 100 MHz) crystals listed. But, the dirty little secret is that these invariably utilize "Overtone" mode operation, relying on the fact that the crystal generates odd-integer harmonics. So, for example, a 150-MHz crystal is a 50-MHz crystal operating in Third-Overtone mode.

The bad news is that using Overtone mode requires adding an external-filter circuit (e.g., LC) tuned properly to suppress the fundamental frequency and encourage the proper overtone. Worse, said "tuning" can get finicky since it depends on the specific characteristics of the particular crystal and design. Switch crystal suppliers and maybe there's a problem. Switch frequencies and maybe there's a problem. Try to use a design that works for one board and chip combo with a different one; maybe there's a problem. Hang a scope on it (changing the filter characteristics) and maybe there's a problem.

If faster clocks are a problem, the fact that you need ever more of them only makes matters worse. Did you know that the Napoleonic-era French calendar had 10-day weeks?[3] It didn't last long, once the populace realized one day of rest every 10 days was a raw deal, compared to the one every seven that most folks got. Just as different cultures evolved their own calendars, every chip and application arena has its own preferred way of measuring time.

How many different "calendars" (i.e., clocks) do you find in something like a PC? There's the CPU, audio,

Discera MOS1 S4 series MEMS oscillator	
Frequency range	80 to 125 MHz (S2 and S3 series available for 10 to 80 MHz)
Supply voltage	2.7 to 3.3 V
Operating current	Less than 9.5 mA
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Frequency stability	± 20, 50, 100 PPM versions
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Aging	Less than or equal to 5 PPM per year
Shock resistance	5,000 G
Package	Plastic or ceramic (3.2 × 5 × 1 mm)

Table 2—These specs for a Discera MEMS oscillator compare quite favorably with those of mainstream quartz units.

video, LAN, USB/UART, hard disk, CD/DVD, keyboard, mouse, and on it goes. Kilohertz, megahertz, gigahertz—it all hurts. More clocks, faster clocks, what's a designer to do?

Never fear, Cypress Semiconductor is here with the CY24488, the latest in their long line of crystal-helper ICs (see Figure 1a). It provides a simple way to get more (up to five) and faster (up to 148.5 MHz) clocks from a single, reliable, and cheap (i.e., low-frequency Fundamental mode) 27-MHz crystal. There's also a VCO feature for applications that need the ability to fine-tune the clock, typically to synchronize it with another clock source. Best of all, the particular configuration (output frequency, enable and disable, VCO) is dynamically in-system reprogrammable via a built-in I^2C interface.

Two of the clock outputs (CLKF and CLKG) are relatively fixed function as copies of one of the other outputs or the 27-MHz reference input (see Table 1). The other three (CLKC, CLKD, and CLKE) are programmable to serve a variety of applications. According to Cypress, the part can generate additional frequencies. So, if what you need isn't on the list, give them a call, and they'll try to come up with it.

This is a 3.3-V chip, but outputs run off their own supply supporting a 2.5-V option. Specifically, CLKC has its own supply pin, with CLKD, E, F, and G sharing another. Whether 3.3 or 2.5 V, the outputs have more than enough oomph (12 mA) to handle plenty of add-ons. Of course, a fast high-power clock raises the prospects of EMI, so the part also has a four-level programmable drive that lets you quiet things down.

The CY22800 is a part with the same more-and-faster-clocks philosophy, but a slightly different mix of features. It contains only a single PLL, but a post-divider option delivers a total of three clock outputs (see Figure 1b). With only eight pins, it's a smaller part at a mere 4 × 6 mm. There's no separate output-supply pin, so the chip power and output levels are both fixed at 3.3 V. Another major difference is that the '2800 has nonvolatile memory (i.e., EEPROM) for configuration and it is intended for "factory" or "field" programming versus the "in-system" programmability of the RAM-based '4488.

Both parts have the VCO capability, but the '2800 takes a different approach to EMI control in the form of a spread-spectrum feature. Though usually considered a bad thing, in this case the judicious addition of a little (0.25% to 2.0%) "clock jitter" helps soften the spectral edge and spread the noise around.

Another difference is that the '2800 is much more versatile in terms of the clock frequencies that can be generated. That's mainly because it can be programmed to accommodate a wide range of input clock frequencies (8- to 30-MHz crystal, 0.5- to 100-MHz CLKIN) instead of the fixed 27 MHz of the '4488.

While it can be set up to generate the "usual suspect" clocks (e.g., PCI, MPEG, audio), the '2800 can also deliver pretty much anything from 1 to 200 MHz, with a few caveats related to the way the three frequency select (FS) and CLK pins are used. In some configurations, they actually deliver three separate clocks, while in others one or two of the pins may be used to dynamically change the frequency, a feature that partially compensates for the lack of in-system programmability.

And speaking of programming, Cypress offers a cool low-cost

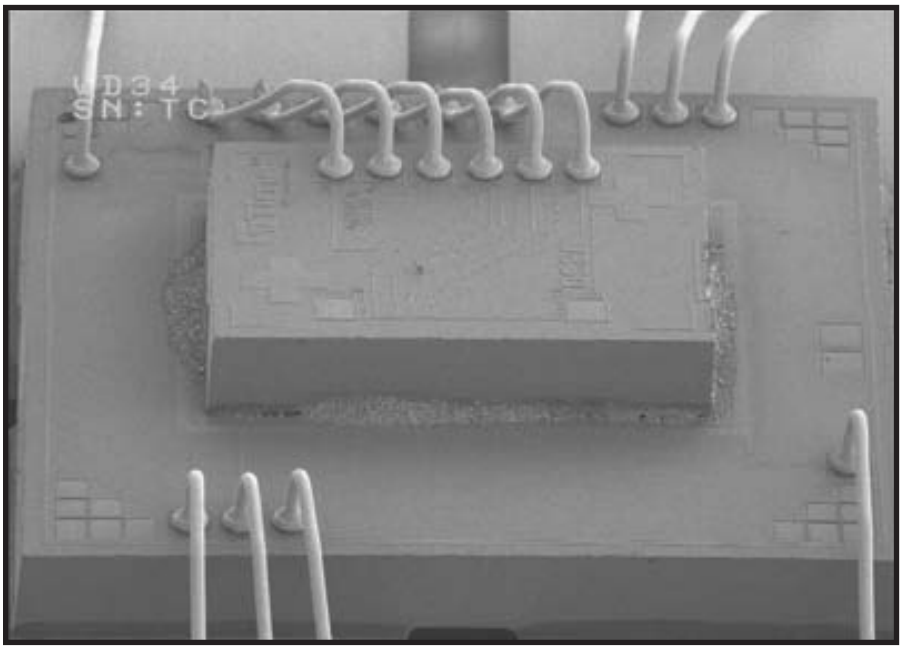


Photo 3—We don't need no stinkin' quartz. All-silicon oscillators from Discera and SiTime (shown here) combine a MEMS resonator and a CMOS PLL in a single package.

InstaClock kit for the ′2800. Of course, for volume orders, you can get your chips preprogrammed by Cypress distributors. But the kit is still handy to determine the proper configuration and make a few samples for testing.

The InstaClock software that comes with the kit is a fast and easy point-and-click affair. First, you select the basic parameters, namely whether the input clock is a crystal or CLKIN and whether or not the VCO and spread-spectrum features are used. Note that the VCO option only works with a crystal, one with certain specs that make it "pullable."

Next, choose your desired input and output frequencies, either specific or a range. Here, the software gives you an option to start with a known input and see what outputs are possible or alternatively, start with the desired output and see what input is required.

The software chews on all of that for a moment and then spits out a configuration and datasheet. Now you can see the particulars of the pin functions and exactly what frequencies are supported. That's helpful since the "generic" (i.e., nonconfiguration specific) datasheet doesn't make it real clear what combination of features and frequencies can be mixed and matched. With the InstaClock software, it takes only a few seconds to try a different configuration and see the exact specs of the resulting part. Once you're satisfied, a test chip (the kit includes five) is only a mouse click away using the USB-connected programmer that comes with the kit.

It's so easy that the trickiest part of the entire process turned out to be ham fisting the teensy parts. I could barely see the little devils, much less consider hand-wiring something. Cypress kindly sent me an extra socket with real pins so I could play around (see Photo 2).

TIME MICROMACHINE

As we've seen, for almost a century, quartz crystals have reigned supreme. It's a bit ironic that the entire silicon revolution has marched to the beat of a quartz drummer from day one. But, that's an irony that outfits like SiTime and Discera aim to put an end to. There's no mystery here. Their MEMS oscillators are much like crystals in principle, simply substituting silicon for quartz as the vibratory element (see Photo 3). However, unlike quartz, rather than individually tuning the vibrating element, the final output frequency is derived using a PLL. Sounds easy, but the challenge of beating quartz at its own game is tougher than it seems. And after all, if it were easy, it would have already happened.

Yes, the idea of making oscillators using a modern chip recipe rather than cracking a rock into little pieces is a no-brainer. Ultimately, MEMS offers the promise of integrating the oscillator, even many of them, on the same chip as everything else.

But, MEMS oscillators have to stick to the basics today and prove themselves worthy in the marketplace. Ph.D. dissertations, technical conferences, white papers, and so on are all well and good, but as Thomas J. Watson of IBM said, "Nothing happens until someone sells something." The answer to the question of whether MEMS oscillators are "real" will be found inside a wristwatch or a cell phone, not in a press release.

My take is that they're getting pretty darn close and this is not "blue sky" at all. That's actually a remarkable achievement considering the technical hurdles involved to get this far, not to mention the competitive barrier posed by the historical dominance and astronomical production volumes of quartz.

The first challenge is to at least meet, and preferably exceed, the basic specs (accuracy, aging, jitter, shock, reliability, etc.) offered by crystals. While MEMS specs don't quite match the best "premium" quartz parts (e.g., "low-jitter" and "high-stability") can offer, they have improved enough to meet the needs of the vast majority of mainstream applications (see Table 2).

Then there's the small matter of price. Well, make that the big matter. Indeed, for many applications price is practically the only thing that matters. Right now, like virtually every "breakthrough" technology, MEMS oscillators are at the starting line of the learning curve, where they have to compete price-wise, even though they lack economies of scale and are still subsidizing R&D. Eventually, growing production volume will allow MEMS price reductions, thereby increasing volume, and then it's off to the races.

With all the attention on quartz and now silicon oscillators, is there anything else on the horizon we might be overlooking? Just for laughs, I punched "atomic clock chip" into Google and I was surprised to see it isn't science fiction by any means. In fact, proto-

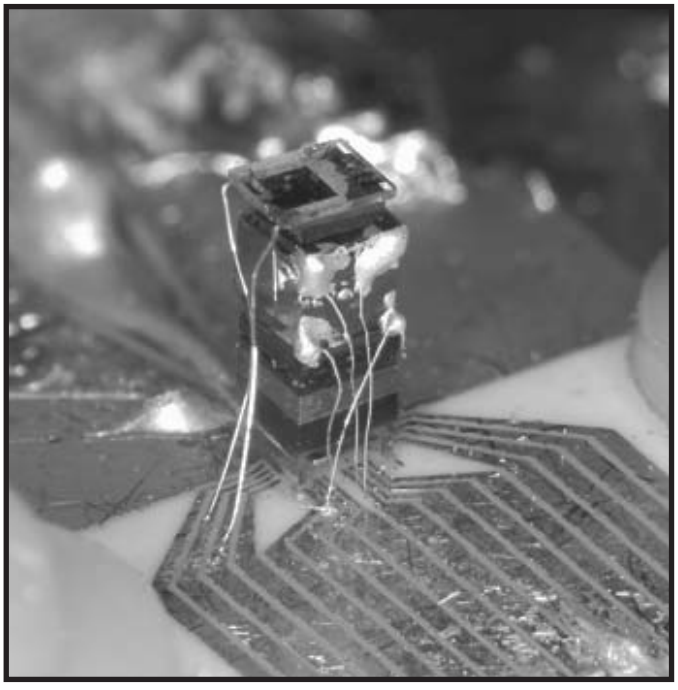


Photo 4—Honey, I shrunk the atomic clock. Just like the big boys, this mini-me atomic clock chip developed by researchers at NIST uses a laser and cesium gas to deliver the ultimate in accurate timekeeping.

	Area	Performance[1]		Power consumption	
	Gate eqv.[4]	MIPS	MHz	pJ/instruction	µW/MHz
HT80C51	5500	9.2	88[2]	89	9.3
Clocked 80C51[3]	5600	4.8	46	500	52
[1] The average execution time of an 80C51 instruction is 1.6 machine cycles (9.6) clock cycles					
[2] Equivalent performance assuming six clock cycles per machine cycle					
[3] Synchronous implementation of an 80C51 with five clock cycles per machine cycle					
[4] Gate equivalents (area in terms of basic two-input NAND gates)					

Table 3—Asynchronous designs, such as the 8051 core from Handshake Solutions, cut power by eliminating the clock and consuming only the minimum power required to accomplish the instantaneous task at hand.

types are already ticking away in various research labs (see Photo 4). Just the thing if your application needs a clock that will stay accurate to the second for 10,000 years.

BORROWED TIME

Quartz, MEMS, and atomic. Is there any clock option we've overlooked? Oh yeah, how about "none of the above"?

On-chip oscillators (e.g., RC) started appearing on mainstream chips more than a few years ago. However, these were wildly inaccurate, both out of the box (initial frequency) and in operation (temperature and voltage drift). I'm talking specs off by a factor of 10%, 20%, 30%, and more, essentially unusable for anything remotely resembling a "real-time" application.

Slowly but surely, chip designers have refined on-chip oscillator design and production techniques (e.g., laser trimming and temperature compensation) to achieve remarkable improvements. Now, you can find chips with built-in factory calibrated clocks that are accurate to within a few percent and stay that way across the entire range of voltages and temperatures.

The "few percent" threshold is an important milestone. It expands the no-crystal opportunity to many "almost real-time" applications and brings more I/O devices into the fold. For instance, you no longer need a crystal to generate the bit rates for a UART or even a full-speed (12 Mbps) USB interface.

And don't forget that even a sloppy clock can be "disciplined" with a variety of clock-correction techniques. The question designers should ask themselves is whether there's an accurate clock somewhere nearby that they can beg, borrow, or steal.

For instance, if you've got access to your design's mains-power section, you can tap into the power-line frequency, which itself is synchronized with atomic clocks. Another option is a radio chip tuned to pick up the timing standards broadcast by a number of stations around the world (WWV in the United States). For you home brewers on a budget, one such option is gutting a low-cost (e.g., $20) "self-setting" wall clock for its WWV radio.[4]

Building Internet access into your embedded design? If so, atomic clock accuracy is only a click away. Similarly, the explosive growth of GPS into everyday products (e.g., cars and cell phones) brings not only location awareness, but also access to the GPS satellite's atomic clocks.

PUNCHING OUT

As you can see, there are more and better clock options than ever before. But, there's one more that I haven't covered, namely getting rid of the clock altogether. Asynchronous chip pioneer Handshake Solutions has just introduced the IP for an asynchronous version of the venerable 8051, joining their initial ARM-based parts.

As their company name implies, instead of a clock calling the shots, asynchronous parts work at their own pace based on a request/acknowledge-type handshake. For instance, the CPU may request an I/O operation at which point the I/O logic wakes up to do its thing while the CPU snoozes. When the operation is complete, the I/O device wakes up the CPU to hand back the data and then the I/O goes back to sleep. The point is only circuits that are doing something at a given moment are active, reducing overall power consumption towards its theoretical minimum (see Table 3). Of course, everybody working at their own pace raises questions about real-time capability. But remember, you can always add a clock to an asynchronous design to use when, and only when, necessary to get in sync.

Keep on rocking, and clocking!

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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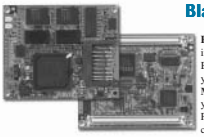
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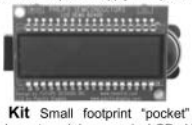
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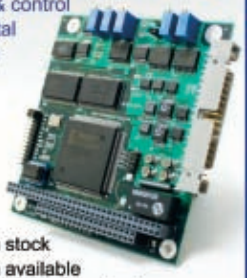
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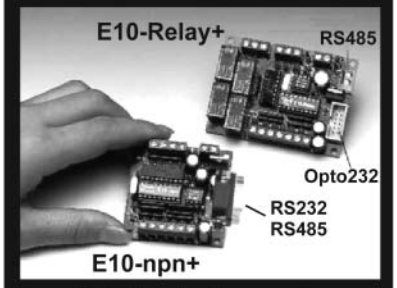


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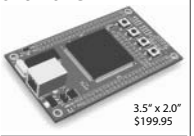


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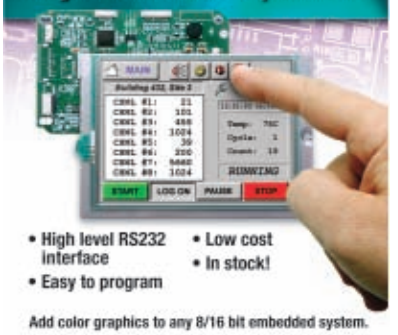
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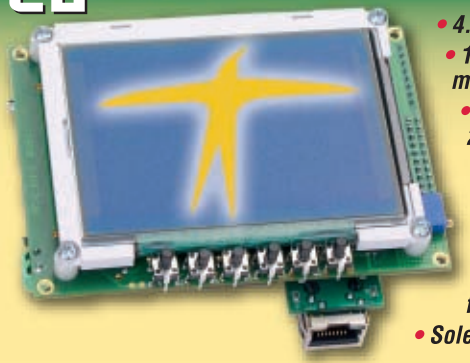
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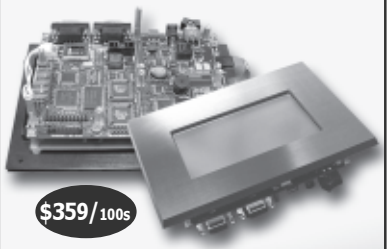
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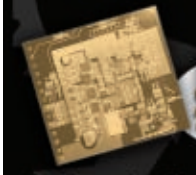


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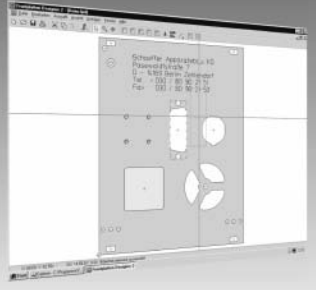
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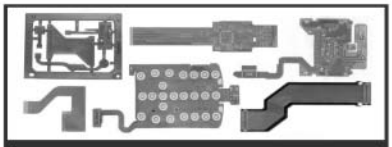
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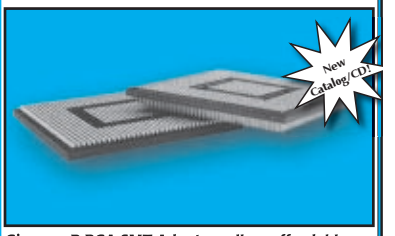
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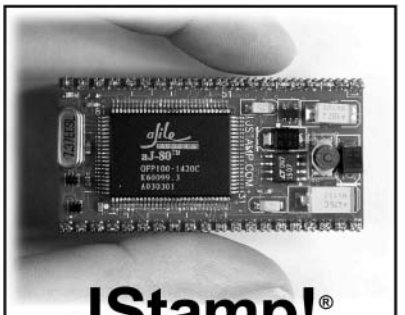


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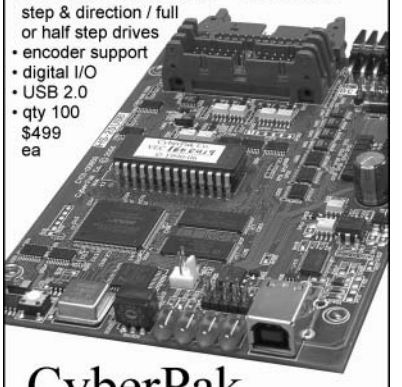
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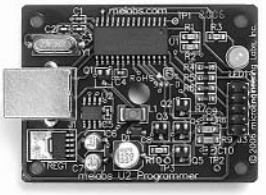
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4. Binary digits attached to the end of a block of data. The value of the attached digits is taken from the sum of the data in the block.
8. The path in space followed by a body
9. Code based on the English alphabet that represents text
14. A repeated process in a computer program
17. To convert into a digital image that represents a rectangular grid of pixels
18. The name given to two or more integrated circuits that work together
19. A device that transfers energy from one electric circuit to another without requiring motion between its parts
20. A network node that links two networks, which use different protocols, and allows them to share information.
21. This (an acronym) is used to measure a computer's performance, especially in floating-point calculations.

Down

1. A passive electrical device used in currents for its ability to make a magnetic field form around a current-carrying conductor
3. Relating to stars, constellations, or their positions in the sky
5. The Scottish mathematician (1831–1879) who contributed to modern physics by creating four equations that express the relationship between electrical and magnetic fields. He also deduced that light is electromagnetic in nature.
6. A code or signal triggered by a processor's internal hardware that is designed to capture errors and reveal their locations
7. Home of NASA's Johnson Space Center
10. The part of the upper atmosphere that has charged particles
11. The ratio of voltage to electric current
12. A collection of information stored in a computer so a program can quickly consult it
13. A resistor used to measure temperature changes
15. The first physical version of a new chip or board
16. A newer version of firmware

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

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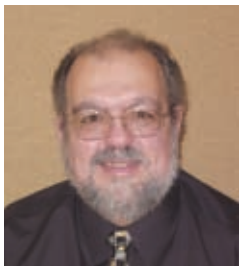
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by Steve Ciarcia, Founder and Editorial Director

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It's no secret that *Circuit Cellar* is the place to go for design contests. We've hosted at least 20 big-name design contests in the last six years. Ever wonder why they come to us? It's because all of you are so smart. Seriously, the concentration of active design talent at *Circuit Cellar* exists in very few other places. Combine a sharp readership with a magazine culture already tailored to showcase exceptional talent and it is an unbeatable recipe for success. That's what we are all about and the sponsors know it.

Because these contests are frequently the launching pads for careers and products, they prompt a lot of queries. Typical questions include: who owns the design once you submit it (you always do), and can you use third-party commercial software in your design? (yes, as long as you document what you use). For the most part, simply referring to the Frequently Asked Questions (FAQ) page of any current contest addresses the majority of issues.

One question I've been seeing more frequently will perhaps be added to the next FAQ. It concerns the judging criteria and specifically, "What type of factors do judges look at when they are determining 'technical merit' and 'originality'"?

My first response is always to suggest that entrants look at the prize winners and the Distinctive Excellence designees posted on our web site from previous contests. The purpose isn't to suggest they look at them to pick similar topics, but, instead, for them to note that it is the accuracy and clarity of the documentation that makes it easy for the judging team to better understand merit and originality.

The important thing to remember is that regardless of which company is sponsoring the contest and the specific technology required to qualify, the contest is truly about demonstrating good design engineering technique and that you have the expertise to incorporate that technology into product-quality examples. This is what the magazine is all about, and that's what the sponsor looks for from our readership.

A contest write-up should, among other things, be an amalgamation of a functional spec and an implementation guide. The functional specification describes the product in terms of what it does, its external interfaces (including user interface), and performance levels. When you're working in industry, this document becomes a kind of "contract" between you (the implementer) and the people describing to you what they want (marketing and/or upper management). The implementation guide describes the product in terms of how it's implemented—the technologies used, the internal interfaces (including the hardware-software interface), and higher-level (more abstract) concepts about how the product works internally. This might include things like dataflow and state machine diagrams, pseudocode for the software, etc. This document is important when you (or anyone else) have to come back and support or enhance the product later. So again, put all the details in here that don't appear in other places like the schematics and the source code.

By necessity a contest entry won't include all of these things as separate documents, but it should touch on the relevant topics in order to rank higher in the judging. Also, a contest entry is usually in the form of a proof-of-concept, using evaluation boards and other items that would not be part of a real, salable product, so some of the topics will be necessarily incomplete. Still, becoming a top winner depends on your ability to convey a clear vision of how they would be accomplished to the judges. An extremely important part of this is having definite goals for the project and confirming whether or not you have met those goals.

The bottom line is this: we don't care whether your project entry is a simple robotic device with two motors and a photocell, or a complete robotic vehicle for the Darpa Grand Challenge—if the documentation is good, it will be ranked higher by the judging team than the same project with poor documentation. Choosing a less grandiose application that can be completed and adequately documented is better than a pie-in-the-sky project idea that never gets finished.

Also, keep in mind that regardless of the number of prizes in any contest, and win or lose, all good project write-ups are also candidates for *Circuit Cellar* Distinctive Excellence awards (posted alongside the contest winners) and becoming feature articles in the magazine. Contest management at *Circuit Cellar* is all about rewarding good engineering technique, not just running a contest.

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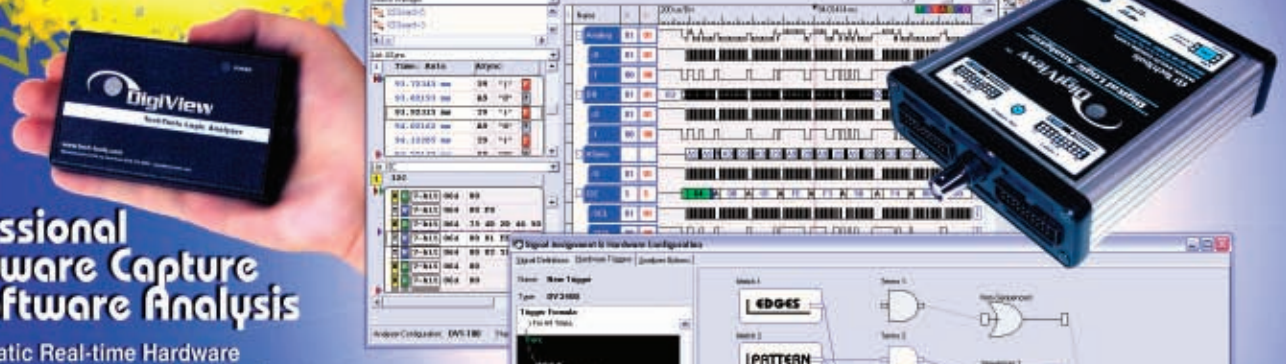
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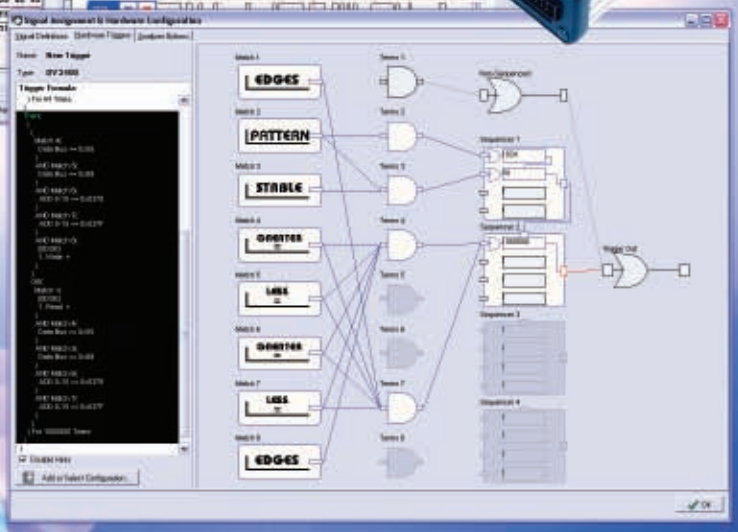
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