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Freescale
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Projects

38 MODEL TRAIN SWITCH CONTROL VIA PC OR PIC
Either version of this control system can easily replace your old manual controllers, plus the circuits are versatile enough to use in other applications.
■ By Dan Gravatt

44 AUDIO SPECTRUM ANALYZER
The device described here is a configurable audio spectrum analyzer incorporating FFTs and a graphical LCD. You’ll also be able to view audio signals up to approximately 20 kHz. (And who doesn’t need that?)
■ By Larry Cicchinelli

Be sure to check the Nuts & Volts website for downloads that go along with these projects.
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Memristors — Rethinking the Fundamentals

Every electronics enthusiast and engineer is familiar with the fundamental passive circuit elements — resistors, capacitors, and inductors. With these elements, a source of power, and a few transistors, diodes, or other active elements, it’s possible to create just about every electronics device imaginable. Or perhaps not. What if our perception of what’s possible is limited by the nature of these basic elements? What could you create if you had additional elements to work with? Can you imagine a new element, and how it might be used in communications, computing, robotics, and entertainment?

In 1971, Leon Chau of UC Berkley did more than wishful thinking and postulated a fourth element: the memristor [1]. The theoretical device — which some engineers have termed the ‘missing element’ — could remember the changes in current passing through it by changing its resistance. What’s remarkable about Chau’s mathematical postulate is that this past May, researchers at HP Labs, Palo Alto, announced they had actually developed memristors. And, as expected, several patents assigned to HP dealing with memristors suddenly appeared on the USPTO website.

Apparently, scientists at HP have been working with memristors for some time now.

According to Chau’s publications, press releases from HP, and patent applications, a memristor behaves like a non-linear resistor with memory — a behavior due to hysteresis. Electrical hysteresis is commonly associated with ferromagnetic materials, as depicted by the double-s-shaped hysteresis loop. While hysteresis is often an annoyance in magnetic tape and hard drive circuitry, it has many practical applications in electronics. The use of a Schmitt trigger to eliminate contact bounce in switches is one practical application of hysteresis.

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According to patent applications, HP’s memristor design is based on a sandwich of titanium dioxide films that loosely resembles the construction of a capacitor. However, unlike capacitors, one layer of titanium film is an insulator while the other layer is doped so that it is a conductor. Wires on either side of the sandwich are used to pass a charge through the film. Current through the film lowers the resistance of the film by a factor of 1,000. In this respect, the memristor seems a lot like an active device to me, but it’s nonetheless classified as a passive circuit element.

Some of the first applications of memristors will likely be high-density, energy-efficient memory devices that compete with Flash memory devices. However, as with any new technology, it’s difficult to predict what will come of the memristor. Because the memristor has qualities of both analog and digital circuitry, one application identified by HP is the development of memristor-based neural networks [2]. Perhaps memristors will make it possible to implement affordable, semi-autonomous robots with a semblance of intelligence.

If you’re like me, you probably can’t wait to order an assortment of memristors from Mouser or Jameco. However, we’re not there yet. We’ll probably have to be content with a SPICE simulation or other virtual experience for months, if not a year or more.

One of the unfortunate aspects of memristors — from the perspective of an electronics experimenter eager to create the first ‘must have’ device using memristors — is that just about every imaginable application is patented. Take a look at uspto.gov or www.freepatentsonline.com. One of the most straightforward patent applications — United States Patent 20080090337 — is for an electrically actuated switch. The application provides a good background on the mathematics and physics of a memristor. A second patent application — United States Patent 20080079029, ‘Multi-terminal electrically actuated switch’ — provides additional information, including specifics on materials and doping.

It’s not likely that memristors will make time travel or anti-gravity possible. However, it’s a new building block that will undoubtedly have myriad practical applications in areas ranging from computing and entertainment to automotive electronics. And you can be certain that Nuts & Volts will be featuring projects that illustrate the utility of the memristor — just as soon as I can get my hands on one. NV

REFERENCES
READER FEEDBACK

READY TO DIVE INTO PCB PRODUCTION

Thank you, thank you, thank you!
For some time now, I have been sitting on the fence thinking I need to figure out how to create my own PCBs using expresspcb.com. I have been reluctant to wade into those waters, however, because of my inexperience with this aspect of electronics. Just last week I recall thinking to myself, “I wish someone would write an article that would step me through the process.” The June issue of Nuts & Volts just arrived! So, thank you very much. I think it’s time to go “swimming.”

Greg Lewis

Response: You are welcome, you are welcome!

Thanks for taking time to read the article. I’m glad it was useful to you.

Fred Eady

MORE SWIMMING REVIEWS

I would like to thank you for the well-written article “PCB Basics: From Your Brain to a Finished Board,” appearing in the Nuts & Volts June 2008 issue. This is exactly the sort of basic how-to article I need to advance my own skills.

I have a question. When you click the “Order Boards...” option, is ExpressPCB smart enough to know whether the board needs to be two layer or four layer and default to what the design actually needs?

Bob Cochran
Greenbelt, MD

Response: Thanks for reading!

When you begin your design, you should set the board type to two or four layer. The program is not smart enough to determine the type of board to use versus the design criteria.

There are things you can’t do in two-layer mode that apply only to four-layer boards.

The order program will pick up four-layer things that can’t happen in two-layer boards and post an error for you to correct them.

You’ll sometimes get the four-layer component in two-layer board errors when you reuse components that have been laid out in a four-layer board design. For instance, if you reuse a component from a four-layer board that has been attached to one of the internal four-layer planes, that will flag an error in a two-layer design as the planes don’t exist.

Hope that helps, and again, thanks for reading.

Fred Eady

GIVING THE WRONG SIGNALS

I have enjoyed reading your magazine for a few years now, since all the other electronic magazines have disappeared. But I have also noticed sometimes that answers to some of the readers questions are not always correct and lead me to believe that whoever gave the answer does not know as much as they think. I have emailed in several times with my views, but have not seen any results. Today, I would like to give a simple comment on the digital TV questions.

I have been an electronics technician/broadcast technologist for about 25 years; I think this gives me some insight to comment on this.

As far as the simple explanation on how they can fit three digital TV signals in the same space as one analog channel — it is really simple. THEY SEND LESS INFORMATION!!!! It has been a couple years since I have worked in the broadcast industry, and there are probably many people out there that can give a more in-depth explanation, but here is mine.

In the early 1990s at one place I worked, we were testing coax cable to handle digital TV signals in the studio environment. The analog bandwidth needed was 6 MHz minimum, the equivalent digital signal ran at 270 megabits per second. End result:

You need much more bandwidth to send the same signal in digital format than analog.

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*• Kit supplied with silk screened PCB, electronic components and processed panels.*

**Bridge Mode Adaptor**
KC-5469 $14.50 + post & packing
This excellent kit will let you run a stereo amplifier in 'Bridged Mode' to effectively double the power available to drive a single speaker. There are no modifications required on the amplifier and the signal processing is done by this clever kit. Supplied with silk screened PCB and all specified components.
*• Requires balanced (+/-) power supply.*

**Three Stage FM Transmitter**
KJ-8750 $12.75 + post & packing
This is a Three-Stage radio transmitter that is so stable you could use it as your personal radio station and broadcast all over your house. Great for experiments in audio transmission. Includes a mic, PCB with overlay and all other parts.
*• Requires 9V battery (not included)*

**Three Stage FM Transmitter**
KJ-5465 $46.50 + post & packing
Want to control a really big DC motor? This design will control 12 or 24VDC motors at up to 40A continuous. The speed regulation is maintained under load, so the motor speed is maintained even under heavy load. It also features automatic soft-start, fast switch-off, a 4-digit LED 7-segment display to show settings, an overload warning buzzer and a low battery alarm. All control tasks are monitored by a microcontroller, so the functionality is extensive. Kit contains PCB and all specified electronic components.

**Smart Card Reader & Programmer Kit**
KC-5361 $34.95 + post & packing
Program both the microcontroller and EEPROM in the popular gold, silver and emerald wafer cards. Card used needs to conform to ISO-7816 standards, which includes ones sold by Jaycar. Powered by 9-12VDC wall adaptor or a 9V battery. Instructions outline software requirements that are freely available on the internet. Kit supplied with PCB, wafer card socket and all electronic components.
*PCB measures: 141 x 101mm.*

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*• Forward and reverse control*  
*• Approx 200mm long*

**Solar Eco-House Kit**
KJ-8924 $14.50 + post & packing
The house is fun to build and will introduce your child to the eco-friendly concepts in a deceptively entertaining way. It has it own solar panel and a windmill to supply free power to the lighting & sound circuits, or it can run from ordinary batteries. Simple and safe for ages 8+.
*• Requires 2 x AA batteries for non-solar operation.*

**Deluxe Solar Educational Kit**
KJ-6694 $15.95 + postage & packing
A series of do-it-yourself experiments to acquire the basic knowledge of solar power. Includes solar cell module, musical unit, plastic lamp, motor accessories and plastic adaptors.

Jaycar cannot accept responsibility for the operation of this device, its related software, or its potential to be used in relation to illegal copying of smart cards in cable TV set top boxes.

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FLYING SAUCER: PATENT PENDING

The US Patent Office recently received an application for something that resembles a traditional flying saucer, but the applicant isn’t a Martian — the culprit is Assoc. Prof. Subrata Roy, of the University of Florida’s Dept. of Mechanical & Aerospace Engineering (www.mae.ufl.edu). The design is properly known as a “wingless electromagnetic air vehicle,” or WEAV. The innovative part of the concept is that the vehicle will have no moving parts and the ability to take off vertically, hover, and fly not only in Earth-like atmospheres but also in places like Titan, Saturn’s most inviting moon.

Some pretty substantial hurdles exist, though, so don’t get prematurely excited. For one thing, it remains to be seen if anyone can create a power source capable of generating enough plasma to raise itself against Earth’s gravity. In addition, the plasma creates enough EMI that communicating with the vehicle is highly problematic.

The present design is aimed at a six-inch prototype. But it isn’t going to exist in hardware for a while, so if you see a UFO outside your window, you can still jump to extraterrestrial conclusions. But the Air Force and NASA reportedly have expressed interest in the concept, so you never know.

LASER MAY AID SEARCH FOR PLANETS

Also presenting possibilities for space exploration is a laser device developed by scientists at the National Institute of Standards and Technology (NIST, www.nist.gov) and Germany’s University of Konstanz (www.uni-konstanz.de). We’re talking about an ultrafast laser that offers a record-breaking combination of high speed, short pulses, and high average power: This dime-sized device produces 10 billion pulses per second, each about 40 quadrillionths of a second in duration, with an average of 650 mW power. As it turns out, the laser — when used as a frequency comb (see www.nist.gov/public_affairs/newsfromnist_frequency_comb.htm for a detailed definition) — could provide 100 times the sensitivity of existing astronomical tools used in the search for Earth-like planets orbiting distant stars. In practical terms, this means we should be able to detect starlight “wobbles” created by such planets down to a few centimeters per second rather than the present one meter per second.

Standard frequency combs have “teeth” (see illustration) that are too finely spaced for instruments to read. But the new laser bounces light between sets of mirrors to eliminate some blocks of teeth, thus creating a “gap-toothed” comb that displays only every 10th or 20th tooth. The next step is to incorporate the device in a ground-based telescope or satellite. Other possible applications include remote sensing of gases and precision control of high-speed optical communications.
**Computers and Networking**

Another Box for Bottom-Feeders

The latest discovery in our never-ending search for el-cheapo computers is the K-4500-RS Perfect Cube Mini from the Shuttle Computer Group (us.shuttle.com), US division of the parent company in Taiwan. With a street price starting at $209.99, it looks like a surprisingly formidable little box. The basic unit runs on a Celeron® 430 processor, but a Pentium® dual-core chip is optional. Also standard is 512 MB of RAM (supports up to 2 GB), an Intel® graphics accelerator, high-def audio, four USB 2.0 ports, and an 80 gig hard drive. It comes with Foresight Linux and a one year warranty. And to make it look nice on your desktop, the black front cover has a removable clear panel, behind which you can mount your favorite work of art.

**Step Aside, Pixar**

You can spend a lot of money on 3D imaging software, such as 3ds Max ($3,500), Maya Unlimited ($6,999), and Houdini Master ($7,995). But how about a full-featured package released as Open Source software (i.e., for free) under the GNU General Public License? Enter Blender, downloadable from www.blender.org. It can be used for modeling, animation, game creation, and a range of other things, and it is available for mainframes to PCs and most operating systems: Windows, Linux, MAC OX, Solaris, and FreeBSD. Blender isn’t for the casual user, being complex and reputedly difficult to learn. But for a good example of what can be done if you have enough time on your hands, take a look at “Big Buck Bunny,” a video about a congenial rabbit who has to deal with three rude rodents. The movie, generated using Blender on Sun Microsystems (www.sun.com) hardware, has been released on 35 mm film and Blu-ray. But you can download it for free at www.bigbuckbunny.org. It was given a “special mention” award at Italy’s Cyborg Film Festival and, according to Sun’s David Folk, “demonstrates that the barriers to entry in the 3D animation world can be lowered tremendously using on-demand computing platforms.” If you have dreamed of being the next animation genius, you now have the tools to make the dream come true.

**Computer within a Pen**

Yeah, we’ve all seen digital pens that capture handwritten notes, double as a mouse, and perform other essentially nonessential functions. But an interesting twist is the Pulse smartpen, a product of Livescribe (www.livescribe.com). According to the company, it is “a computer within a pen that captures handwriting and simultaneously records audio and synchronizes it to the writing. Users can simply tap on their notes to replay what was recorded from the exact moment they were writing, so they never miss a word they hear, write, or speak.” It also offers (or will offer) a range of general purpose computer functions including games, language translation, personal organization, ebooks, birdwatching assistance, transcription, and a built-in can opener. (Well, maybe not the latter.) The $149 1 GB model stores 100 hours of audio and 16,000 pages of notes. For $199, you can pick the 2 GB version. And even if you don’t end up using it, the sleek, charcoal blue anodized unit will make a handsome paperweight.
CIRCUITS AND DEVICES
SUPERCONDUCTOR CABLE ENERGIZED

You don’t get to see superconductors in operation every day, but back in April, the Long Island Power Authority (LIPA, www.lipower.org) fired up the first high-temperature superconductor (HTS) power transmission cable system in its commercial power grid. The cables shown entering the ground in the photo can carry as much power as all of the overhead lines shown in the background. The 138 kV system can handle 574 MW of power (enough to run 300,000 homes) via the three individual power cable phases running in parallel (150 times the current handled by copper cables of the same size), and it virtually eliminates the typical seven to 10 percent resistance loss. The 2,000 ft (610 m) cable system is cryogenically cooled using a liquid nitrogen refrigeration system. Return

INDUSTRY AND THE PROFESSION
DIG OR DUMP DIRT

Back in June, glassdoor.com opened its virtual doors with the aim of providing inside information on employers, salaries, and other subjects. So far, it’s concentrating on San Francisco Bay area tech companies, but expansion into other regions and industries is in the works. If you want to find out what it’s really like to work for a prospective employer, or warn others about how you’re treated by yours, all you have to do is sign up (for free) and contribute a review or salary report. In return, you get access to everyone else’s reviews and salaries. Should make interesting reading, although accuracy will be iffy until the site builds up a large enough database to marginalize the statistical effects of disgruntled employees and pathological liars.

US REMAINS COMPETITIVE

Contradicting a common perception that the old red, white, and blue is losing its competitive edge in science and technology, a recent RAND Corporation study revealed that the US still accounts for 40 percent of the world’s total spending on scientific R&D, employs 70 percent of the Nobel Prize winners, and hosts 75 percent of the top 40 universities. Much of the credit belongs to the contributions made by students, scientists, and engineers from other countries.

“Much of the concern about the United States losing its edge as the world’s leader in science and technology appears to be unfounded,” said Titus Galama, co-author of the report and a management scientist at RAND, a nonprofit research organization. “But the United States cannot afford to be complacent. Effort is needed to make sure the nation maintains or even extends its standing.”

The study offers a range of recommendations for maintaining our lead, including making it easier for foreign-born graduates to remain here, facilitating immigration of highly skilled labor, improving K-12 scientific education, and boosting our ability to learn from science centers in Europe, the Far East, and other areas. For a copy of the 188-page report, go to www.rand.org/pubs/monographs/MG674/. It’ll run you $28.80 with the Web discount.

ANOTHER WIN FOR THE GOOD GUYS

Last October, 21-year-old hacker Gregory King was arrested in the FBI’s “Operation Bot Roast.” He was tracked down after launching Valentine’s Day distributed denial-of-service attacks against antiphishing website CastleCops and KillaNet, a forum for gamers and graphic designers. As agents were breaking down his door, King stashed his laptop in the backyard, but the authorities eventually located it and charged him with two counts of “transmitting code to cause damage to a protected computer.” Using a botnet of about 7,000 hacked computers, King had bombarded CastleCops with a 969 Mb/s datastream. If the volunteer-run organization had been charged for the bandwidth, it would have been forced to close down. King is scheduled for sentencing on September 3rd, and the plea agreement calls for him to be put away for two years. A pat on the back goes to US District Judge Lawrence Karlton.
on investment may take a while, as the project cost $58.5 million, about half of which was funded by the Department of Energy. But the mission is to “modernize the electric grid, enhance security and reliability of the energy infrastructure, and facilitate recovery from disruptions to energy supply.” Sounds like a worthy goal.

HEFTY DVR STORAGE

You’re probably familiar with Seagate's line of hard drives aimed at computer data storage, but the company recently announced the Seagate® Showcase™, a series of products that extend the storage capacity of DVRs. Designed for compatibility with Motorola’s eSATA capable high-definition products (but you also can connect via a standard USB 2.0 cable), they are slated for market soon, perhaps by the time you read this. The boxes will initially come with 1 TB of storage, which translates into 200 hr of HD movies or 1,000 hr of standard-def TV. The Showcase family features Seagate’s Pipeline HD™ series of hard drives.

The Pipeline drives are designed specifically for DVRs, providing top-notch high-definition performance and capacity with “bedroom-quiet acoustics,” low-power operation, and the ability to support up to 12 simultaneous HD streams. The drives are Windows Vista certified, making them suitable for home media centers. The list price has not been divulged, but the product does come with a one year warranty and free tech support even after the warranty expires. You can check for price and availability at www.seagate.com.

60-V LED DRIVER

Linear Technology (www.linear.com) recently announced the LT3755 device, a 60V output, high-side current sense DC/DC converter designed to drive high current LEDs. It has a 4.5V to 40V input range, making it useful for such applications as automotive, industrial, and architectural lighting.

Using an external N-channel MOSFET, it can drive as many as 14 1A white LEDs from a 12V input to deliver over 50W. The high-side current sense allows it to be used in boost, buck, buck-boost, or SEPIC and flyback topologies. Frequency can be adjusted between 100 kHz and 1 MHz and, because the device is better than 94 percent efficient in boost mode, no heatsinking is required.

The LT3755 uses True Color PWM™ dimming to deliver constant color with a dimming range of up to 3,000:1. Two versions are available: the standard LT3755, which offers an open LED status pin; and the LT3755-1, which replaces the pin with a frequency synchronization pin; in production quantities, they’ll run you about $2.75 each. For $3.15, you can get an extended-temperature version.

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The PICAXE-28X1 has so many improvements and powerful new features that it's hard to know where to begin. In order to avoid the risk of information overload, I have decided on a two-phase approach. In this installment of the Primer, I'll present a brief overview of most of the new features and then go into more detail on a couple of them that we will be using right away. In future Primer installments, we'll explore each new feature in depth as we have a need to use it in a project.

HARDWARE IMPROVEMENTS

Let's begin by taking a look at the memory and storage capacity of the 28X1. Figure 1 presents a comparison of the relevant features of all the current PICAXE processors; a quick glance will give you some idea of the scope of the 28X1's improvements in this area. Most of the information in Figure 1 is self-explanatory but a couple of points are worth noting.

First of all, the general-purpose byte variables (b0 to b13 in all the previous PICAXE chips) have been doubled to b0 to b27 in the 28X1. If you have ever run out of variables in a program, you will appreciate how significant this improvement is. Also, the 28X1 includes an entirely new 128-byte storage area (the scratchpad) that can be used for additional storage; it's especially useful for tables and arrays as we will see in a future installment of the Primer.

Finally, although it's not included in Figure 1, it's worth mentioning that the maximum system speed has been increased from 8 MHz in the earlier processors to 20 MHz in the 28X1. System speed options have also become much more flexible — we'll get to that in detail later in this installment when we take a look at the new resonator features of the 28X1.

SOFTWARE IMPROVEMENTS

Figure 2 presents the pin-out of the 28X1; in it, some of the major new software functions are highlighted in a larger bold font. We will consider the pins in numerical order, so the first new feature that jumps out is "ULPWU" (pin 2), which is an acronym for the new "Ultra Low-Power Wake-Up" feature. We will explore the ULPWU in some detail in a future installment of the Primer when we begin working on a 28X1 battery-powered data-logging system, but for now all we need to know about it is that ULPWU provides a means for greatly reducing power consumption.

Next, we see the "timer clock" function on pin 11. This feature
accesses a new 16-bit background timer/counter, with a user-accessible timer variable. It can operate in one of two modes: timer mode and counter mode. In timer mode, your program can set up a timer that runs in the background and increments at a frequency you can specify, e.g., once per second. “In the background” means that your program can go about its business and check the timer variable periodically to determine its current value. In other words, it’s possible to include a real-time clock function in your program without needing an external clock chip; we will do exactly that in the near future. In counter mode, your program can count the number of pulses received on input 0 (again, in the background) so it can be carrying out other tasks simultaneously.

Pins 13, 22, 23, and 25 are all used to implement the 28X1’s new hardware PWM command which is used for advanced motor control and is a more powerful alternative to the more traditional “pwmout” command (pins 12 and 13) which we will also implement in an upcoming Primer installment.

Pins 14, 15, and 16 provide the necessary I/O lines to implement the standard three-wire SPI protocol. SPI is a much faster alternative to RS-232 serial communications; many inexpensive peripheral SPI chips are readily available to carry out a variety of communications functions. For example, the Max7219 is a 24-pin chip that can be used to interface with up to eight seven-segment LED displays. An upcoming Primer I/O project will use the MAX7219 to implement a stand-alone, four-digit seven-segment LED display.

I’ve saved the best until last — pins 17 and 18 can now be used in conjunction with the new hardware-based “hserin” and “hserout” commands. These commands support much higher serial baud rates than the older serin and serout commands (which are also still available). More importantly, hserin can operate in the background and automatically save the received data in a special area of memory. This means that your program no longer has to sit and wait for serial input; it can be doing other tasks while serial data is being received and when it’s convenient, it can retrieve the received data for processing.

In addition to the new features whose presence is clearly announced on the 28X1’s pin-out, there are many additional new commands and improvements to older commands that can be discovered by reading the documentation. Don’t forget, you will need to install the latest version of the Programming Editor software (available at www.rev-ed.co.uk/picaxe) to be able to use these new features in your programs. We’ll explore the vast majority of them in detail as we need them in our various I/O projects in the coming months. In the meantime, the following summary list of the major improvements in the 28X1 should whet your appetite:

- **ADC Commands (calibadc, calibadc10):** In the past, ADC readings have been based on the supply voltage. Therefore, in battery-powered systems, changes in the supply voltage produced inaccuracies in the ADC readings. The new commands allow access to a fixed, internal 0.6V supply for increased accuracy.

- **Data Storage Table (table, readable):** Allows for a 256-byte data lookup table in EEPROM; we’ll find it useful for LCD menu text.

- **I2C Commands (hi2cin, hi2cout, hi2csetup):** The 28X1 is able to function as either an I2C master or slave which (among other advantages) allows for the networking of multiple 28X1 processors.

- **IR Commands (irin, irout):** IR communication can now be implemented on any I/O pin. Also, the irin command includes a “timeout” feature so your program won’t hang if data is not received.

- **Keyboard Input (kbin):** Similar to the older “keyin” command, but now also includes a timeout feature.

- **Memory Access (get, put):** Provide access to the 128-byte scratchpad memory area for additional data/variable storage.

- **One-Wire Commands (own, owout, readowsn):** Provides full support for the 1-Wire protocol on any I/O pin.

- **Power-reduction Commands (disablebod, enablebod, hibernate):** Implements the new ULPWU feature. We’ll explore disablebod and enablebod next.

- **Serial Communications**

![FIGURE 2. PICAXE-28X1 pin-out.](image-url)
(disconnect, reconnect, serin, serout, serrx, setrd); The disconnect command stops the 28X1 from looking for a new program download, which enables your program to use the download cable for data communications (using serrx and setrd) with your PC (e.g., via a terminal program). The serin command now includes a timeout feature so your program won’t hang if data is not received. Also, the new hardware serial commands (discussed previously) allow for automatic serial input in the background.

- **Sound Output (play, sound, tune):** Sound and music output can now be implemented on any output pin.

- **SPI Commands (hspiin, hspiout, hspiwrite):** Enables higher communication speeds.

- **Timer Commands (settimer, settimer count):** New 16-bit background timer/counter.

There are also several significant additions in the area of mathematical computations. We don’t have space to list them here, but we’ll get to many of them in upcoming installments of the Primer. All of the new features and commands are covered in the documentation, especially Part 2 of the PICAXE manual — have a read!

### RESONATOR ENHANCEMENTS

The 28X1 isn’t the first PICAXE to support an external resonator; each of the earlier 28-pin chips did so, as well. However, the 28X1 provides more external resonator choices. Also, with a top speed of 20 MHz, the 28X1 is the fastest PICAXE currently available (40 MHz X2 processors are already being developed). Of course, the option of increased speed is in itself a big improvement. However, the 28X1’s resonator flexibility is an even more significant advance.

In addition to the external resonator choices of 20, 16, 10, 8, and 4 MHz, the 28X1 also supports internal oscillator speeds of 8, 4, 2, and 1 MHz, as well as 500, 250, 125, and 31 kHz. What’s so great about that, you might ask, and why would anyone ever want to run a program at 31 kHz, anyway? Well, for any CMOS processor (which includes all the PICAXE chips), power consumption is directly proportional to processor speed — so slower program speed goes hand in hand with lower power requirements. In other words, if your project is battery powered, the more you can slow down the speed of program execution, the longer your batteries will last.

### A LITTLE EXPERIMENT

As you already know, once we have completed a few of our upcoming I/O projects we’re going to develop a battery-powered data-logging system, so the prospect of a significant reduction in power consumption is of special interest. To get some idea of just how much power we might be able to conserve, I carried out a little experiment with a simple 28X1 circuit, but before we get into the details and the results, I need to introduce a term that may be new to some readers. The 28X1 has a feature called “brownout detection” or BOD; its function is to cleanly reset the chip in the event of a power brownout (i.e., a temporary drop in the input voltage). It’s a great feature for line-powered circuits, but not really necessary with battery-power, and it does require a fair amount of power to operate. Fortunately, the 28X1 supports software commands to enable or disable BOD (enablebod and disablebod).

I had three goals in mind when I set up my experiment. The first was to measure the 28X1 supply current at each of its internal resonator speeds. I focused on the internal resonators because the Microchip data sheet for the PIC16F886 (the chip on which the 28X1 is based) contains data that shows that the external resonators consume significantly more power, even at the same speed (i.e., 4 MHz external vs. 4 MHz internal).

The second goal was to determine the magnitude of the supply current reduction obtained by disabling BOD at each internal speed. Finally, since power consumption also decreases with lower supply voltages, I took all my measurements with a five-volt power supply and then repeated the process with a 3.3-volt supply. When I recorded each measurement, I made sure that the 28X1 wasn’t powering any external components (e.g., an LED) because the additional power usage would confound the results.

If you examine the resulting data (presented in Figure 3), you can see that all three variables influenced power consumption exactly as we would expect: For both supply voltages, lower resonator speeds resulted in lower supply currents; compared

<table>
<thead>
<tr>
<th>Speed</th>
<th>5.0-volt Power Supply</th>
<th>3.3-volt Power Supply</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>BOD Enabled</td>
<td>BOD Disabled</td>
</tr>
<tr>
<td>8 MHz</td>
<td>1.82</td>
<td>1.75</td>
</tr>
<tr>
<td>4 MHz</td>
<td>1.07</td>
<td>0.98</td>
</tr>
<tr>
<td>2 MHz</td>
<td>0.68</td>
<td>0.60</td>
</tr>
<tr>
<td>1 MHz</td>
<td>0.49</td>
<td>0.41</td>
</tr>
<tr>
<td>500 kHz</td>
<td>0.39</td>
<td>0.32</td>
</tr>
<tr>
<td>250 kHz</td>
<td>0.35</td>
<td>0.27</td>
</tr>
<tr>
<td>125 kHz</td>
<td>0.32</td>
<td>0.24</td>
</tr>
<tr>
<td>31 kHz</td>
<td>0.11</td>
<td>0.03</td>
</tr>
</tbody>
</table>

Note: See text for important information about the 28X1 Brown-Out Detection feature.
to the 5.0-volt supply, the 3.3-volt supply consistently resulted in lower supply current at each speed; and, disabling BOD further reduced the supply current at every speed. So, when we get to our battery-powered data-logger project, we’ll definitely use the slowest possible speed (but not 31K, unless we can resolve the problem described later in this installment).

If you would like to make your own supply current measurements, a schematic of the circuit I used is presented in Figure 4. A close-up photo of the breadboard is shown in Figure 5 and Figure 6 is a photo of the entire setup including the multimeter I used for the current measurements. In the schematic, I am assuming you are using a separate programming adapter board, so I have not included that portion of the circuitry. Also, note the pull-down resistors on all of the unused input pins. Without them, the inputs would float and possibly change from a high state to a low state due to random static charges.

Whenever a CMOS input changes state, it consumes power, so to avoid any unnecessary power consumption I grounded all the unused inputs. This is a good idea in any circuit (even if you don’t care about the power consumption) because it can also reduce unnecessary noise in the supply lines. The push-button switch on input 3 allowed me to keep the 28X1 at its current speed while I wrote down the supply current measurement; pressing the button advanced the 28X1 to its next speed setting and the next supply current measurement (except at 31K — we’ll get to that problem shortly). The software I used is too long to include in the Primer, but it’s available for download at the N&V website (www.nutsvolts.com); look for “CurrentTest.bas.”

The 28X1’s powerful and flexible resonator features can sometimes result in a minor inconvenience that you should keep in mind. Whenever you initiate a program download to a PICAXE chip, the Programming Editor software requires that the target
PICAXE is running at 4 MHz. This is never a problem at power-up or reset; in those two cases, the 28X automatically defaults to its 4 MHz internal resonator. However, if the 28X1 is currently running software that has changed the speed to anything other than 4 MHz, you may get a “hardware not found” error and the program will fail to download. The solution is to do the following: Hold down the 28X1’s reset button, initiate the download, and then release the reset button — the program should download successfully.

**PROBLEMS, PROBLEMS, PROBLEMS ...**

Actually, my little experiment didn’t proceed nearly as smoothly as the results might suggest. As I carried out the measurements, I encountered two very surprising and perplexing problems. First, every measurement I made with the DisableBOD command in effect was higher than the corresponding measurement with EnableBOD in effect. This, of course, is exactly the opposite of what it should be, and I spent a fair amount of time examining both the hardware and software to see if I could find the source of the problem. Finally, in desperation (I hate to admit I can’t figure something out on my own!) I posted a message on the PICAXE forum ([www.picaxeforum.co.uk](http://www.picaxeforum.co.uk)) detailing the problem. Within a day or so, there were several responses confirming my results, and by the second day a response from “Technical” (the RevEd guru who moderates the forum) indicated that the strange results were due to a bug in the 28X1 software and that the bug would be corrected in the next update to the Programming Editor software. In the meantime, I’ll just use the two commands as if their meanings were reversed, which is what I did to obtain the data presented earlier in Figure 3. Of course, when the bug is corrected, I’ll need to reverse the commands again to straighten things out.

This little saga is one indication of just how helpful the PICAXE forum can be and how responsive RevEd is to input from its user base. If you’re not already a forum member, I would highly recommend joining. The members are very knowledgeable and willing to help. If you have a question, first search the archives because your problem may have already been addressed. If you can’t find what you’re looking for, post a message with a thorough description of your hardware and software setup and the nature of the problem, and you’re very likely to get some helpful feedback.

The second problem I encountered is even more perplexing than the reversed BOD commands. As I mentioned earlier, I used a push-button on input 3 to give myself time to write down the current readings. After each internal resonator speed change, the program idles in a loop until the button is pressed (at least that’s what I intended). The idling works properly at every speed except 31K; in that case, the software seems to reset itself. My deadline for submitting this article to N&V arrived and I still haven’t figured out what’s going on. I haven’t posted the problem on the forum yet, but at some point I may have to give in and ask for help again! In any case, I’m sure we’ll revisit this issue in future installments of the Primer, but even if 31K turns out to be unsuitable for our battery-powered data-logger, it’s great to know that we can reduce our supply current by 90% by simply disabling BOD (with whichever command works!), switching to a 3.3-volt supply, and turning down the internal resonator speed from 8 MHz to 125 kHz. In order to get a rough estimate of how long we might expect a battery-powered 28X1 system to operate, I made a couple of assumptions and calculated what I think is a very conservative estimate of battery life. I chose the Eveready Energizer six-volt lantern battery (#528 or 529) for two reasons: It has a huge capacity (26,000 mAh — see [http://data.energizer.com](http://data.energizer.com)) and six volts should give us more than enough headroom to supply a 3.3-volt low-dropout regulator.

As we saw in Figure 3, at 3.3 volts the 28X1 will draw 0.17 mA at 125 kHz with BOD disabled. Of course, we’ll also want to take various measurements (e.g., temperature) and perform other tasks occasionally, so let’s triple that and assume 0.5 mA current draw on average. A full day of operation will consume 24h x 0.5 mA = 12 mAh, so we can expect 26,000/12 = 2167 days (almost six
years) of full-time operation. In addition, the 26,000 mAh capacity is based on typical current drains that are much higher than our relatively low drain of 0.5 mA, so the actual capacity of the battery should be considerably higher and the theoretical lifespan may be even longer than six years.

On the other hand, temperature fluctuations and other real-world factors will probably decrease the battery’s lifespan, but even four or five years would be more than adequate. We’ll also have for our data logger monitor its own supply voltage, so we’ll be able to determine if our estimate turns out to be reasonably accurate.

Finally, we haven’t even considered how we can use the new “hibernate” command to further reduce the supply current (but, trust me, we will). By the time we’re finished with our project, it will probably outlast the Energizer Bunny!

WHAT’S NEXT?

That’s it for our overview of the major new features of the 28X1. It’s an impressive chip and in future installments, we’ll delve more deeply into the details of many of the features we only touched on this month. If you want to get a head start with any new feature or command, don’t forget that Part 2 of the PICAXE Manual contains the complete documentation — there’s lots of valuable information in there.

In the next installment of the Primer, we’ll develop our first I/O device for use with the 28X1 (or any processor, for that matter) — a multi-function infrared board capable of sending and/or receiving IR signals in the SIRC protocol, as well as functioning as an object detector for robots or home control projects. We will also explore the 28X1’s new hserin command, which can operate automatically in the background while our program is tending to other matters. In the meantime, if you want to review the basics of PICAXE infrared communication, take a look at last February’s column.
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**Q&A**

**RAILROAD CROSSING LIGHT CONTROLLER**

**Q** I am a volunteer worker/helper at a small local history museum located in Tullahoma, TN. We have a two arm RR crossing light that has been modified with small 110V holders and lamps. I would like to buy/build a controller to alternately light the lamps so that when one goes out, the other will come on. Do you happen to have any ideas?

— Greg Klein

**A** This calls for a flip-flop. I have used a 555 oscillator driving an SN74LS74 and two solid-state switches (see Figure 1). The oscillator is designed to run at 2 Hz, but you may want to make the frequency variable by replacing R2 with a rheostat connected 500K pot. The SN74LS74 is a dual D type flip-flop and I have connected them in parallel to give more drive to the solid-state switch. The output is arranged to pull down because TTL does not pull up very well. The switch is an opto triac rated at two amps, so it will operate a 100 watt lamp with no problem. The rocker switch mounts in a rectangular hole; you will have to file it to fit, and the toggle switch mounts in a round hole — just drill it. A five volt power supply is needed and the power is low, under 1/2 watt. If you don’t have a spare kicking around, this $8.70 unit from Mouser will do: 826-DA4-050US.

**AUTOMATIC ON/OFF SWITCH**

**Q** My project is to design and build an automatic on/off circuitry for a remotely located audio amplifier. The

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**FIGURE 1**

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**Q&A@nusvols.com**

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**WHAT’S UP:**

Join us as we delve into the basics of electronics as applied to every day problems, like:

- Fly Zapper
- Vacuum Tube Circuit
- Solar Tracker

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**WITH RUSSELL KINCAID**

In this column, I answer questions about all aspects of electronics, including computer hardware, software, circuits, electronic theory, troubleshooting, and anything else of interest to the hobbyist. Feel free to participate with your questions, comments, or suggestions.

Send all questions and comments to: Q&A@nusvols.com
function is to switch the 120 VAC on and off with a device that is triggered by a three volt audio signal from the preamp. A shielded cable will deliver the signal to the automatic switch. Since a portion of the circuitry is always exposed (AC) and it will be remotely located with the amplifier, I wish to use good quality components. Could you suggest some alternatives. My assumptions include a high impedance input to the triggering device feeding an electronic and/or electromechanical switching device. Surface-mount devices are not a necessity. Thanks in advance for your assistance.

— Paul Lunn

Since the audio is being used to turn the power amp on, and since the signal will vary in amplitude, I have designed a time delay turn off when the signal goes away of about one second (see Figure 2). If it is possible that the audio will have quiet times exceeding one second, you will want to increase C2. The design includes the power supply which provides ±8V volts to the switch circuit. I included L1 and L2 to reduce current spiking and make the supply quieter.

U1 is a dual op-amp; the first stage is a half wave rectifier with a gain of two. With a three volt peak input, the capacitor, C2, will be charged to six volts. The second stage is a unity gain buffer to drive the opto triac switch. The triac is a zero crossing switch, so it should not produce much noise. The opto triac specs are: must turn on at four volts input and must turn off at one volt input. I included specs for a heatsink, although I doubt it will be needed. From an initial charge of six volts, it takes about one second to get down to one volt. The resistor, R1, is for static protection; it has no effect on gain. If the preamp output is ground referenced, C1 and R2 could be eliminated.

A AUDIO LEVEL ADJUST CIRCUIT

I have a whole-house audio system that I’d like to connect to two different TVs as audio sources. The problem is, the TV line level audio out is considerably lower than my other components (CD player, FM radio, etc.) and is not adjustable. So when I switch to the TV source, I have to turn up the room volume. Then when I switch back to the radio or CD player, the audio blares out the speakers if I forget to turn down the room volume.

Can you recommend a circuit for a two channel audio level shifter with (I’m guessing) a unity-to-5x gain adjustment? Something with a frequency response as good as or better than HD TV audio? A single chip amp would be fine since it does not need to have a high power output and my preference would be for thru-hole technology as my eyes are not what they used to be.

— Jon Wilbert

Two channel mixer with adjustable gain ... piece of cake! The signal is undoubtedly stereo, so two pairs of op-amps are needed. Separate volume control for each channel is provided (see Figure 3). Most audio devices nowadays use RCA jacks, so I included those in the parts list. The power supply can be 12 volts (±6V) or use the power supply of Figure 2 (±8V). The parts list is for a 12 volt DC wall wart, but if you have one in your junk box that is between 10 and 16 volts, use that. If you use the power supply in Figure 2, R1 and R2 are not needed. The gain in each channel is...
FLY ZAPPER

Q In the September '07 issue (page 30, Figure 4), I am interested in the fly zapper schematic. I have a raccoon tearing up our trash even though it is heavily secure. The coon is smart, big, and strong. Here’s my thought — I do know a little about auto ignition and for the coil to output a good strong spark, it needs the correct ignition cap. Cap needs to be around 0.06 µF, but that depends on coil make. I have two coils for old VW Beatles without the caps and the local auto supply store (Pep Boys) wants an arm and a leg for the caps.

Also, for me to use your circuit I would need it to fire about 2X per second. I’ll call it RussKin’s Critter Getter. Any ideas on that? I’ll bet that arm and leg that many people have the same problem with critters!

— Bob Jay (long-time subscriber)

A I can help you with the cap: 0.068 µF from Mouser, 72 cents, part number 5989-1KV.068-F. You can connect the cap across the coil primary and eliminate R1 and D1. To make the 555 run at 2 Hz, change R2 to 1.2K and R3 to 3.3 meg. Use C2 = 0.1 µF, Mouser part number 5989-250V.1-F.

VACUUM TUBE EQUIVALENT CIRCUIT

Q I have a circuit that I got from a magazine (transistor), but I wonder if I could convert it to tubes. I know tubes are old technology, but I like them. My endeavor was the circuit in Figure 4 — an OTL tube circuit. I had to make some compromises but I wonder if this scheme would work? The first tube is a pentode and a triode in one. The other tubes are power pentodes. I’m not sure if the biasing is right. I do know the transistor circuit says that the 680K R2 is adjusted to bring Q4, Q5 emitters to half the supply voltage. Is this tube circuit practical?

— Craig Kendrick Sellen

A DC coupled tube circuits are difficult. Tektronix used to do it using NE-2 neon bulbs for level shifting. But let me list the problems with the tube circuit:

1) There is no tube equivalent for a PNP transistor. The cascode circuit will have low impedance pulling up and high impedance pulling down. That will not be a problem if the speaker impedance is high enough; but high impedance implies low power, and I don’t know where you would find such a speaker.

2) With the cathodes at different potentials, you can’t connect the screens together.

3) With V5 cathode near ground and V7 cathode at -V, V7 will be saturated. R8 should return to -V and V7 needs a resistor in series with the cathode to limit the current.

4) The connection between V4 plate and V5 grid is the place to put the NE-2 neon to bring the grid down close to -V.

Enough of the critique; vacuum tube
tubes should be operated push-pull, class AB, for reasonable power output and low distortion. I have modified your design in Figure 5. The final stage is AC coupled because there is no point in maintaining DC coupling, and it would be difficult. The first stage gain is about 60 (6.8K/110), but the second stage is just a phase splitter — it has no gain. You will need a preamp to get the maximum power output of seven watts. The bias current in the final stage is arbitrary; I chose 10 mA, so you would adjust the negative bias to obtain one volt DC at each cathode. Matched 6V6 tubes will be necessary. According to my tube manual, the output transformer should be 10KCT: eight ohms. I have labeled the schematic with the expected voltages and currents. If you build it, let me know how it works!

800 MHZ BUSINESS BAND COMMUNICATION

Can you tell me where I might get a book on FM communication decoding and encoding? Or, maybe at least a schematic? If it matters, it’s for the 800 MHz business band FM. I have been monitoring the band for 4+ years now — just a hobby.
So, if you know where I might buy such a book, I would appreciate it.
— George Gunter USN (Ret.)

I know nothing about this but if the signal is not clear voice, it may be frequency hopping spread spectrum. I don’t think a schematic is applicable in this case. I found a few books at Barnes & Noble that may be of interest:
- Principles of Spread Spectrum Communication, ISBN-13:9780201633740; and

Another possibility is that the signal you are trying to receive may be digital voice. Cell phones operate in this band and I believe most, if not all, are now digital voice. If that is the case, this book may be helpful:

So, if you know where I might buy such a book, I would appreciate it.
— George Gunter USN (Ret.)

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TOOL SETTER REVISITED

I require a little more help with the Tool Setter circuit you designed for my milling machine (May ‘08, page 25). I had to reverse the contact logic in the milling machine so that my touch probe would work correctly. Because of this change, your original schematic for the Tool Setter will no longer work. Do you think you could take a second look at this circuit for me? Here are the new criteria for the Tool Setter:

1) The circuit is now normally closed (NC) and must open when a tool touches the top plate.
2) The secondary part of the circuit needs to be isolated from the frame of the milling machine.
3) We can still use a battery to power the primary circuit.
4) I still would like an LED to come on when a tool touches the top plate.
— Bill Blackburn

The solution is simple: just replace the HSR312 solid-state relay with the normally closed G3VM-353A, Mouser part number 653-G3VM-353A.

SOLAR TRACKER

I have three questions:
1) I am in need of a simple solar tracker schematic. Some years ago, T. J. Byers sent me one that for some reason, I can’t get to work (Figure 6). I have changed components many times. I wired the two pin photo transistors both ways (no pin info); maybe you can supply that info for me — which is the collector, the longer lead or the shorter one? I’ve been working with the schematic over the years and like it for its simplicity but can’t seem to make it work. What do I do to get this circuit to work? In theory, it sounds good. Could there be an error in this circuit? I recently used a Darlington transistor in place of the 2N2222 transistor; same results, it still doesn’t work. What do I try next? I won’t give up after so many years of trying.
2) Figure 7 is an automatic solar charger that turns on my solar lights all around my house. While experimenting with different MOSFETs, I find that the lights go on when it is still reasonably light outside due to the internal resistance of the MOSFET. I have not tried changing the voltage divider resistors, especially the 1K resistor, R2. Normally, it would be a simple task to just try changing the value of the resistor but unfortunately, the control box housing for the circuit is mounted in a difficult place. That is why I am asking your opinion on this particular circuit.
3) Do you have any simple solar circuits that charge a battery during the day then at night switch on the outside lights? I am now using some super bright 39 cluster LEDs which operate on 12 volts DC.
— Antonio J. Anzevino

1) There are no specs for the RadioShack photo transistor, so there is no way to know if it should work or not. I suspect that if you buy enough of them, you will find a pair that work. BTW, the shorter lead of the photo transistor is the collector.

Instead of a photo transistor, try using a CdS photo resistor, RadioShack No. 276-1657. There are five in the package so you should find two that will work. It may work without modification, but if you make
R1 a 500K pot (rheostat), you can adjust it such that the motor starts running when Q1 is partially shaded.

The way the circuit works is this: Q3 is the daylight/dark detector. In daylight, the photo transistor (and CdS cell) is low resistance, which allows the motor to run. Q1 is shaded by an east-west wall for the elevation servo and by a north-south wall for the azimuth servo. When Q1 is shaded, the base of Q2 is raised which closes the relay and starts the motor running.

When sunlight falls on Q1, the base is pulled down and the motor stops. You will want a way to return the servos to the starting position, ready for the next day.

An alarm clock could be used for that or, another CdS cell as in Figure 8. When it is dark, the transistor is energized, causing the motor to run backwards until the tracker hits the normally closed limit switch, which opens the circuit.

2) It is not the MOSFET resistance that determines when the lights come on, it is the voltage output of the solar panel. The turn-on voltage of the FET and the value of R2 has a minor effect on when the lights come on, but when the 12 volt solar panel output gets down to 0.6 volts, it should be quite dark. You can gain some by removing R1 but that is only 50 millivolts difference, again minor. Bottom line, there is not much that can be done to vary the light level that determines when the lights come on.

3) Changing Q1 to a comparator as in Figure 9 will provide the variability that you want. The threshold can be adjusted all the way to zero; in which case, the lights may never come on.

**NIMH BATTERY CHARGER**

In the N&V July ’07 Q&A column, you provided a PIC-based charger circuit for NiMH batteries consisting of up to 10 cells.

What limits the charger to this maximum number of cells? If I use a power supply with more than 20 volts, can I use this to charge greater numbers of cells? Per your description, I would change the charge current by a bit because new cell capacities are always being introduced and, of course, the sense voltage divider (R4, R5) would also need adjusting.

— Dave Carpenter
The schematic (Figure 10) is modified to charge 20 cells. I added R9 and D5 because 33 volts exceeds the input rating of the 78L05. I also added R10 to reduce the input to ground (ADJ) voltage. R10 is not strictly needed because the 317 is rated 40 volts input, but it shows what needs to be done if the voltage goes much higher. I changed the voltage divider, R4 and R5, to provide three volts max to the A/D. The A/D voltage only has to stay between 1V and 4V as the batteries charge.

---

MAILBAG

Dear Russell,

In your answer to Geff Waite, I was glad to see your comment about the capacitor ripple current. Too often it is ignored. Unfortunately, it isn’t quite as simple as you said. Different manufacturers, different series from the same manufacturer, and different cap values have different ripple current ratings. A few of the caps in the Mouser and Digi-Key catalogs have ripple current ratings. Most manufacturers’ capacitor datasheets give the ripple current ratings. The quickest way to get the datasheets is to do an Internet search of the manufacturer’s name and the capacitor series ID.

A quick look at the Mouser catalog gives some examples. For Xicon snap-mount, series LS, a 25 volt, 4,700 µF cap is rated at 2.31 amps ripple current, while a 63 volt, 4,700 µF cap is rated at 3.49 amps, and a 200 volt, 2,200 µF is rated at 5 amps! For nearly every cap series of every manufacturer, the ripple current goes up (and the ESR goes down) as the voltage rating is increased. Because of this, I try to stay away from low voltage caps, even in low voltage circuits. (This difference may be primarily from the can size; a larger can has better heat dissipation.)

For the 10 amp DC output of Mr. Waites’ power supply, the ripple current would be 13 to 15 amps, depending on the resistance of the transformer windings and other factors (including the effective series resistance of the AC power line). For any power supply, if the caps seem to run warm, the ripple current may be too high. The easiest cure is to parallel more caps. The actual ripple current can be measured fairly easily. Connect a 0.1 ohm or smaller, 1%, three watt resistor (available from Mouser) in series with the cap, measure the voltage across the resistor with a true RMS meter, and calculate the current.

We might also mention the current rating of the transformer. There has been some discussion of this recently. For a bridge rectifier and 10 amps DC output, the transformer should be rated at 16 to 18 amps RMS (depending on which transformer manufacturer’s guidelines you follow). And there’s always the question, build or buy? Marlin P. Jones and Assoc. (www.mpga.com) sells a 24 volt 12.5 amp switching power supply (no. 16489-PS) for $97.

— Bill Stiles

Thanks for the feedback, Bill. I had not noticed that current rating goes up with voltage rating. Good info.

Dear Russell,

In response to your statement that “There is no quality of sound advantage in hybrid digital; analog FM stations already transmit more bandwidth than most people can hear and with low distortion,” I should like to invite you to my home in a northern suburb of New York City where I, a classical musician, can find virtually the only listenable FM by pointing my 14-element beam at lower Connecticut. There I will demonstrate what happens when I tune WSHU at 91.1 and wait for my Sangean HDT-1 tuner to recognize the signal as digital, at which point the background noise drops out, the separation increases, and all I hear is music.

I am now waiting for the one “classical” station from New York City to go digital so I can receive it without the multipath distortion which makes it virtually unusable.

— Robert Voss

Not having had the experience of multipath distortion with FM radio, I was not aware that it was a problem. I get excellent reception of classical music from WCRB, Boston at 99.5, 50 miles away. I believe WCRB is hybrid digital also; you should be able to receive it.

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www.microchip.com/usb
B&K Precision Corporation’s new Model 2534 dual channel Digital Storage Oscilloscope (DSO) delivers a combination of performance and value. This versatile bench top unit is a high-performance 60 MHz digital oscilloscope with analog-style knobs and controls. The Auto measurement function makes this oscilloscope easy to use. Advanced triggering, digital filtering, waveform recorder, delayed sweep/zoom, mask testing, and waveform recorder/replay mode provide the user with many options to debug circuits.

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Measuring 12.2” wide by 10.6” deep by 5.8” high, the Model 2534 weighs eight pounds and comes complete with operating manual, 10:1 probe set (two pieces), power cord, USB interface cable, and PC software installation disk. It is priced at $799 (quantity one) and is available for immediate delivery.

For the name and location of an authorized distributor near you, contact B&K Precision Corporation.

For more information, contact:
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IT professionals can now save money using the new DLP Design Data Center System to remotely monitor temperature and humidity at locations housing sensitive electronic equipment such as data centers and computer, server, and equipment rooms. Operating 24/7/365, the DLP Design Data Center will immediately send an alert email to the designated recipient(s) when readings fall outside the customer’s predetermined limits. At no additional charge, Data Center users can view or download temperature and humidity data from any computer with Internet access. The DLP Design Center can also be utilized for other industry applications including food service, warehouse, and long-term storage.

Distributed by Mouser Electronics, the new DLP-UT1 sensor and DLP-UTH8 hub are low-cost temperature and humidity acquisition products which can be purchased for $29.95 for the sensor and $79.95 for the hub. With operating temperatures of 0-70°C (32-158°F), the DLP-UT1...
sensor measures temperature on a single channel, while the DLP-UTH8 is a data-collection hub with eight channels that can be connected to temperature only or temperature and humidity modules via standard Intranet cables. The sensors can be located up to 250 feet away from the UTH8 hub and are purchased separately.

Designed to work with the above hub and sensors, the new DLP Design Data Center monitors data continuously and allows for remote access and alerts. Service routine software that communicates with the DLP-UT1 and DLP-UTH8 continuously sends temperature/humidity readings to a secure server. For privacy, customers log in to the Data Center with an ID and password. They can then remotely monitor, set, or change temperature alert points, specify email addresses for alert mail recipients, view data from the previous 24 hours in either chart or graph format, or download data from the previous 30 days. Customers may try the DLP Design Data Center for the first month at no charge. The Data Center service may then be purchased for $35/six months or $60/year through www.dlpdc.com via credit card.

“For this level of performance, what sets us apart from our competitors is our pricing,” comments Don Powrie, President of DLP Design, Inc. “Our products are the best choice when you’re trying to watch your bottom line but need to know that your equipment is protected.” Datasheets are available upon request.

Parallax, Inc., introduces the new Propeller Proto Board with USB.

The Propeller Proto Board USB has all the features of the Propeller Proto Board but utilizes the USB programming interface on the board for those projects which need the USB interface in the application. The Proto Board provides a low cost prototyping platform for projects or industrial applications. The new Propeller Proto Board USB houses the incredible P8X32A-Q44 Propeller chip. The Propeller chip makes it easy to rapidly develop embedded applications. Its eight processors (cogs) can operate simultaneously — either independently or cooperatively — sharing common resources through a central hub. The developer has full control over how and when each cog is employed; there is no compiler-driven or operating system-driven splitting of tasks among multiple cogs. A shared system clock keeps each cog on the same time reference, allowing for true deterministic timing and synchronization. Two programming languages are available: the easy-to-learn high-level Spin; and Propeller Assembly which can execute at up to 160 MIPS (20 MIPS per cog).

For more information, contact: Parallax, Inc.
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August 2008 NUTS & VOLTS 35
FULL FEATURED FUNCTION GENERATORS

A high stability Direct Digital Synthesis, dual output function generator, with less than -54 dBc (sine wave) harmonic distortion and a keyboard for rapid entry of waveform parameters, are among the advanced, cost-effective features of the new Protek Model B8040FD, 1 µHz-40 MHz DDS function generator.

This latest entry delivers 40 ppm long term and 1 ppm short term stability, generates waveforms including sine, square, pulse, triangle, ramp, sine (x) x, exponential up, and exponential down, plus noise; provides AM, FM, PM, FSK, ASK, and PSK modulation and bursts of up to 65,535 of all internal waveforms. Frequency range is 1 µHz to 40 MHz for sine wave; to 5 MHz square wave; and 1 MHz for all other waveforms.
waveforms. In addition, it has a built-in 100 MHz frequency counter and an RS-232 interface. All these features are available at a cost-saving user price of $778.

This instrument heads the firm’s Series B8000FD series of dual output DDS function generators which also include three (3) “lower frequency” models: the B8003FD, with a 1 µHz to 3 MHz frequency range at $387; the B8010FC, with a 1 µHz to 10 MHz frequency range at $484; and the B8020FD, with a 1 µHz to 20 MHz range at $599. All units have the same features and functions as the “flagship” model, except for frequency ranges.

For more information, contact: Protek Test and Measurement Web: www.protektest.com
Both designs work on the same basic principles. The PC-based system has many possibilities for displaying track switch status, at the expense of needing a dedicated computer at your model railroad control station. The PIC-based system is a stand-alone direct replacement for the manual electrical controllers and has a simple three-button user interface.

There are other control systems commercially available for track switch control, mostly based on the Digital Command and Control (DCC) standard. DCC was originally designed to control model locomotives by sending power and data through the tracks, allowing multiple DCC-enabled locomotives on the same track to do different things. Add-on modules for DCC are available to control track switches, but they are fairly expensive and won’t work without a master DCC system. My control system will work just fine on either DCC or non-DCC model railroads as it does not depend on any other hardware.

**Anatomy of a Track Switch**

The most common model railroad track switches — often called snap switches — are electromagnetically actuated by two solenoid coils: one moving the track to the “straight ahead” position and the other for the “turn” position (Figure 1). Reversing the polarity

![Track switch solenoid. When attached to the railroad track, the lever on the end of the solenoid moves the track section back and forth.](image-url)
of the voltage on a coil does not change the track switch’s position and, in fact, the manual electrical controllers that come with the track switches use low-voltage AC. A momentary current pulse is applied to one or the other of the coils to make the track switch change position. Unlike an electromechanical relay, no current is required to hold the track switch in position; continuously energizing either coil will cause it to burn out.

A second type of track switch — known as a slow-motion or “tortoise” switch — uses a small DC motor and reduction gears to gradually move the track switch from one position to the other. This type of switch is favored by modeler railroaders who want to more realistically simulate the movement of a real railroad switch mechanism. Tortoise track switches also contain electrical limit switches to provide feedback on the track position without having to look at it — a good thing when your model railroad is large.

The control system I describe here is designed to operate snap-type track switches. However, most of the circuitry and code could also be applied to operating tortoise switches, with some modifications to the power output driver stages.

**PC-Based Control System**

The PC-based control system takes advantage of the ubiquitous eight-bit parallel port, which is easily interfaced to external TTL circuitry to operate the track switches. Any laptop or desktop PC will suffice for this application, as long as its operating system will allow you to directly access the printer port LPT1. Since I am not much of a programmer, the user interface is strictly bare-bones, but it could be replaced by any custom graphical interface you would care to write, as long as it follows the underlying principles for interfacing with the external circuitry.

**PC Software Development**

The software for this project (Listing 1, also available on the Nuts & Volts website at www.nutsvolts.com) is written in QuickBASIC, mostly because I never learned any other PC programming languages. You may have a copy of QuickBASIC on CD and don’t even know it; it can be found on the Windows 98SE installation disk in the directory D:\tools\oldmsdos. Running QuickBASIC in a DOS window under Windows 98SE, I had no problem writing data to the printer port LPT1 using the command “OUT &h378” where “378” is the hexadecimal address of LPT1. If you use other programming environments or operating systems, make sure they allow you to write data directly to LPT1 without interference.

The software performs three tasks. First, after prompting you to power-up the circuit, all track switches are reset to a known position — I arbitrarily chose “straight ahead.” This is done one at a time to avoid overloading the power supply for the track switches. After this is finished, a table showing the track switch positions is displayed along with a prompt to select a track switch to be moved. Any time a track switch is selected, one byte of data is sent through LPT1 to the external decoder/driver circuit to energize the selected coil, followed by a second byte of data to de-energize that coil. The table of track switch positions is then updated, and the software is ready to move another track switch.

**Listing 1**

REM toggles model railroad switches using two 74HC4514 4-to-16 decoders on LPT1

```basic
DIM switch(1 to 15) AS INTEGER
CLS: INPUT "Power up the switch controller, then press enter", null
PRINT: PRINT "Resetting switches, please wait..."
FOR x = 1 to 15
OUT &H378, x
SLEEP 1
OUT &H378, 0
switch(x) = 0
NEXT x

Main:
CLS: PRINT "Model Train Switch Control v1.0"
PRINT
PRINT "Switch Position Status:"
PRINT
FOR x = 1 to 15
PRINT "Switch "; x; "; is ";
IF switch(x) = 0 THEN PRINT "Straight" ELSE PRINT "Turning"
NEXT x
PRINT
INPUT "Select switch (1 through 15) to move: ", move

IF switch(move) = 0 THEN
OUT &H378, move
switch(move) = 1
ELSE
OUT &H378, move * 16
switch(move) = 0
END IF
SLEEP 1
OUT &H378, 0
GOTO Main
```

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PC Circuit Theory

The decoder/driver circuit for the track switches is very straightforward, consisting primarily of two 74HC4514 4 to 16 decoders and 30 TIP120 NPN Darlington power transistors (Figure 2). There are two nearly identical halves of the circuit: one for driving all the “straight ahead” coils in the track switches; and one for driving all the “turn” coils. (Note that only one of the 15 track switch driver circuits is shown in Figure 2 for clarity.) The four low bits of the parallel port feed one decoder’s inputs, and the four high bits feed the other’s. The “0” output of the decoders is not used since — for programming simplicity — the decoder’s Inhibit input is not controlled by the parallel port. Thus, one of the decoder outputs must be active at all times and, as stated before, the coils will burn out if continuously energized.

The software’s “ready state” causes the “0” decoder outputs to go high, and they are used to drive LEDs indicating the circuit status — green for ready and off when active. Current limiting resistors are used between the parallel port and the decoder inputs to help isolate the parallel port from the external circuitry. I found that the current needed to drive the power transistors was less than one milliamp — well within the output drive specification for HC TTL devices, so I omitted any current limiting resistors between the decoders and power transistors.

Model railroads often include track switches at both ends of a track segment (such as a siding) that are operated in parallel to allow a train to access that track segment. The current rating of the TIP120 is more than adequate to drive a pair of track switches in parallel, as each coil typically draws around 1A at 12 volts DC (although this varies by manufacturer; I tested the circuit using an Atlas-brand track switch). The TIP120 has a built-in reverse-protection diode to absorb the voltage spikes generated as the coils de-energize, protecting the transistors and decoders from damage.

The power supply portion of the circuit is designed to be operated from the 20 VAC accessory supply available on most model railroad power packs. Thus, no separate power supply is necessary, and the DC voltage available from the bridge rectifier (around 28 VDC) is more than sufficient to operate the track switch solenoids. Current draw from the 7805 voltage regulator is minimal, so no heatsink is required. The low duty cycle of the TIP120 transistors means they do not need heatsinks either.

Circuit layout and construction is not critical, though I would not recommend using point-to-point wiring. One word of caution is in order on the circuit’s operation: Make sure the circuit is connected to the PC’s parallel port and the software is running before applying power to the circuit. This ensures
that the "0" outputs of the 74HC4514s will be active, and there will be no unpredictable track switch movements. If you apply power without connecting to the parallel port, the decoder inputs will assume random states, leading to randomly selected outputs. If you apply power while your computer is booting up or running other software, the states of the parallel port data lines are unknown and most likely incompatible with proper circuit operation. Just for fun, try connecting some LEDs to the parallel port's data lines (use current limiting resistors) and watch what they do while your computer boots — you'll see what I mean.

**PIC-Based Control System**

Although the PC-based system was easy to
design and offers a lot of flexibility in the user interface, it wasn’t really true to my original intent to create a drop-in replacement for the multitude of electrical switch boxes typically used to control track switches. I decided to take the decoder-driver circuit from the PC-based system and add a PIC microcontroller and liquid crystal display (LCD) to make a self-contained controller (Figure 3). The controller described here operates eight track switches and can easily be expanded to control 16 using the same basic operating principles.

**PIC Software Development**

The popular Microchip PIC16F8761 forms the heart of this project, and flowing through that heart is the code in Listing 2 (file available on the Nuts & Volts website). This code performs the same three main tasks that the PC-based software performs and, in addition, monitors three switch inputs and drives the two-line by 24-character parallel-mode LCD.

The three pushbutton switches making up the user interface include an up button to increment the track switch number, a down button to decrement it, and an enter button to move the selected track switch. All three buttons have a repeat action when held down, to scroll through the track switches or cause one switch to move repeatedly (not very useful, but fun to watch for a few seconds). The code determines which switch is pressed by checking the value of PORTB, which represents the state of all eight Port B I/O lines as one value. Pins PortB.5 through PortB.7 are unused and always high, while PortB.3 (the enable output for the LCD) is
low and PortB.4 (the inhibit output for the 74HC4514 decoder) is high when the state of PORTB is being read.

Valid values of PORTB for the SELECT CASE command correspond to PortB.3 and either PortB.0, PortB.1, or PortB.2 being pulled low. Pressing more than one button at a time — which might lead to unpredictable track switch movements — yields an invalid value of PORTB which is ignored. To minimize the parts count, the internal Port B weak pull-ups are enabled, so no external pull-up resistors are needed for the three pushbutton switches.

The position status of each track switch is stored in an eight-bit array variable which is updated each time the enter button is pressed. The position status and/or selected switch number is updated on the display with each pass through the main program loop. The LCDOUT command from PICBASIC PRO is used to drive the LCD, which uses a standard HD44780 controller chip. All of PICBASIC PRO’s default parameters and pin assignments for the LCDOUT command are used.

### PIC Circuit Theory

The main difference between the decoder-driver portions of the PC-based and PIC-based circuits is the use of the Inhibit pin on the 74HC4514 in the PIC-based circuit (Figure 4). This allows all 16 outputs to be low at once, and thus they can all be used to control the track switch coils. Rather than have separate decoders for the straight and turn coils, outputs 0-7 drive the straight coils and outputs 8-15 drive the turn coils. When the enter button is pressed, the binary value of the track switch coil to be activated is placed on PortC.0-PortC.3, and a PULSOUT command on PortB.4 sends a 400 millisecond negative pulse to the 74HC4514’s Inhibit pin which briefly enables the selected output. Adding a second 74HC4514 decoder with its inputs driven by PortC.4–PortC.7 and its Inhibit pin driven by PortB.5 allows up to 16 track switches to be controlled, with some minor changes to the code.

### Wrap-Up

I hope that one of the approaches described here will inspire you to replace your old manual controllers with something more user-friendly. Or, for those not into model railroads, I encourage you to come up with other uses for the circuits and code described here. Send your results to Nuts & Volts. I’m sure the readers would enjoy them! NV

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**PARTS LIST**

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<tr>
<th>ITEM</th>
<th>DIGI-KEY P/N (except for LCD)</th>
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<tr>
<td>❑ 74HC4514 four to 16 decoders</td>
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<tr>
<td>❑ TIP120 NPN Darlington power transistors</td>
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<td>❑ KBL04 four amp diode bridge</td>
<td>KBL04-E4/51GI-ND</td>
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<td>❑ 10 µF 50 volt electrolytic capacitor</td>
<td>P5178-ND</td>
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<td>F2705-ND with 3520K-ND clips</td>
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<td>❑ 1K resistors</td>
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<tr>
<td>❑ Green LEDs</td>
<td>511-1195-ND</td>
<td>2</td>
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**PIC-Based Control System:**

<table>
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<th>ITEM</th>
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<tr>
<td>❑ TIP120 NPN Darlington power transistors</td>
<td>TIP120-ND</td>
<td>16</td>
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<tr>
<td>❑ SPST PCB-mounted momentary switches</td>
<td>P12223SC-TND</td>
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<td>❑ 7805 Linear voltage regulator, TO-220 package</td>
<td>MC7805CT-BPMS-ND</td>
<td>1</td>
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<tr>
<td>❑ KBL04 four amp diode bridge</td>
<td>KBL04-E4/51GI-ND</td>
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<tr>
<td>❑ 1000 µF 50 volt electrolytic capacitor</td>
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<tr>
<td>❑ 10 µF 50 volt electrolytic capacitor</td>
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<tr>
<td>❑ Two amp fuse</td>
<td>F2705-ND with 3520K-ND clips</td>
<td>1</td>
</tr>
</tbody>
</table>

**FOOTNOTE 1:**

Programmed PIC16F876s are available from the author.
When I first thought about this project, I simply wanted to see if I could do it. I had never worked with Fast Fourier Transforms (FFTs) before or developed an interface and software for a graphics LCD. It was a very interesting and rewarding experience! One of my primary uses for this device will be to monitor the output of a public address (PA) system I am responsible for. It lets me see if any frequencies are being over or under emphasized. I can also see the frequency of any feedback and then adjust the equalizer accordingly. Used in conjunction with my DDS (N&V, November '06), it can be used to determine the acoustic characteristics of a room or PA/recording system.

This unit has been designed to view audio signals up to about 20 kHz. The data is displayed on a graphics LCD with a pixel matrix of 64 x 128. It uses a microprocessor-based module with a clock speed of either 29.5 MHz or 59 MHz that enables a maximum display update rate of about 5 or 10 Hz. The audio processing circuit allows you to select one attenuation value or any combination of three gain values.

The program uses several separate — but coordinating — files to complete the software for the system: the main program, a library for the LCD, and a library specifically for the menu functions. Provision has been made to allow the user to store up to 10 custom configurations. Since the source code is available, you can customize the program to meet your specific needs. To do this, you will need access to a development system for the microprocessor. If you do not want to incur the expense of a development system, I will be happy to program the microprocessor module for you if you send it to me with a SASE. (Contact me at k3pto@arrl.net)

Although the program uses the FFT, I will not be going into any details on how this works. There are good descriptions of this algorithm available on the web, as well.

NOTE: Circuit board artwork is available on the Nuts & Volts website at www.nutsvolts.com.
as others that transform between the time domain and the frequency domain. There is a good primer of the DFT in the October ‘07 issue of Nuts & Volts.

This device is relatively small, fitting into an enclosure of about 6.8” x 4.8” x 2.5”, and is powered by a DC wall wart between 9V and 15V. Someone who is better at packaging than I am could probably fit it into a smaller enclosure. I tried a 4.5” square box but could not quite make it work.

The main thrust of this article is to describe each of the circuits, some of the software, and the construction of the system. Complete construction information, including the bill of materials (BOM), schematics, and printed circuit board (PCB) details can be found on my website at www.qsl.net/k3pto under the heading “Audio FFT display.” The source code for the main program and the libraries are also on my website, as well as at www.nutsvolts.com.

The three circuit boards embody of the following: power supply and processor; analog circuits; and the interface for the graphics LCD. I could have put the LCD interface on the same board as the processor but I decided to make it a separate board for two reasons: (1) it allows the LCD to be ported to other projects more easily; and (2) the board has very fine and closely spaced traces (.020” pitch). I felt it would be advantageous to have a separate board just in case the first assembly attempt fails. Then only this board would be affected — see the Construction Notes elsewhere in this article.

Figure 1 is a block diagram of the system. Note that the controlpath to the display and the ADC are over SPI (Synchronous Peripheral Interface). This is a serial communications protocol designed by Motorola in the 1960s. It is a popular method of enabling a microprocessor to communicate with peripheral devices, usually on the same circuit board. With SPI, you can control several devices connected to the controller via a serial bus that has the following signals: Clock, Data In, and Data Out. Each controlled device also requires a separate Chip Select signal.

When implementing an SPI system with multiple devices, you need to make sure that the proper phase relationship (there are four possibilities) between the clock and the data is maintained for each device. In this system, both devices use the same clock to data phasing. One project I built (see N&V November ‘06) used two devices from the same manufacturer that had different clock to data phasing so I had to adjust the phase each time I initiated communications with one of them and then put it back when done.

The power supply (Figure 2) contains two series regulators: 5V and 3.3V. The 5V is used by the analog circuits and the 3.3V by the microprocessor and LCD. The output of the 5V regulator is also the source for the 3.3V regulator. The series resistor, R1, reduces the power dissipation of the 5V regulator. If you want to optimize the circuit a little, you can change the resistor based on the wall wart you use. The analog circuit current is about 20 mA (mostly due to the relay) and the 3.3V current is either 70 mA or 140 mA, depending on the processor board you are using. You have to have at least 7V on the input of the 5V regulator for proper operation. With a 10 ohm resistor, the voltage drop with 200 mA will be about 2V. So, a 9V wall wart is sufficient to power the unit that uses the faster processor. If you choose to use the slower processor, then a 20 ohm resistor will be a better choice. Be sure to get a resistor with the appropriate power rating.

There are two main functions the Input Amplifier/
Attenuator circuit (Figure 3) must perform: (1) give the input signal a fixed 2.5V offset; and (2) present an approximately 1 VRMS signal to the input of the ADC. The 2.5V offset is required because the op-amps and ADC are powered by a single supply (+5V) and will operate properly only with positive input signal voltages. This circuit allows the input voltage to be symmetrical around ground. Resistors R1 and R2 form a voltage divider that allows you to measure voltages greater than what can be sent through the op-amp circuits. The voltage applied to the input side of R5 needs to be symmetrical about ground and no larger than about 1 VRMS.

The circuit of IC1.1 gives the input signal the required 2.5V offset by configuring the op-amp as a “follower with gain.” The gain is two and is set by the formula: \((R4/R3) + 1\). The reason for the gain of two is that R5 and R6 essentially form a divide-by-two circuit. The resistors in this circuit (R3-R6) should not be modified. Neither should the voltage divider formed by R7 and R8 that develops the 2.5V offset. The loading of R5 and R6 on the 2.5V is negligible.

The circuits of IC1.2 and both halves of IC2 perform a programmable amplification function. The three circuits are essentially identical except for the gain values. This description references the circuit of IC1.2. The values of the feedback resistors (R10 and R11) need to be determined based on your specific requirements. The gain of the circuit is \(R_{FB}/R_9\) (\(R_{FB}\) is the feedback resistor). You can calculate the resistor values based on the signals you want to measure and the gain required to get 1 VRMS. IC3 is an analog switch that allows you to select between two gain values for the stage by switching R11 in or shorting it. With the switch closed, the gain is 1 (0 db); with the switch open, the gain is 10 (20 db). The reason the switch for R11 (IC3) looks backwards as compared to IC4 and IC5 is that the board was easier to lay out with pins 1 and 2 reversed.

These resistor values and the relay allow for the following attenuation/gain values: attenuation = 28:1 (about -30 db); gain = 0 db, 10 db, 20 db, 30 db, 40 db, and 50 db. You can also get attenuation values of -10 db and -20 db by using the attenuator and the appropriate gain values. I have elected to use 1% resistor values since...
they are the same cost as 5% values (as SMD resistors). Also, an error of 1% is equivalent to only 0.09 db.

There are two procedures that must be used to calibrate the ADC and the FFT processing:

1) Measure the no-signal DC offset voltage. You can do this by simply not activating K1 and not applying an input signal. Also, each of the analog switches must be turned on so that the gain of each of the three stages is one. The voltage will be very close to 2.5V and is subtracted from all the readings in order to present the FFT algorithm with a series of values centered on 0 volts — a requirement of the algorithm. This ADC value — that should be close to 2048 — is stored into the configuration memory area.

Note that there is an adjustment potentiometer for each of the gain circuits. These are required due to the offset voltages and currents of the op-amps. There is a menu option that allows you to activate and deactivate the analog switches so that you can use the potentiometers to “balance” the output voltage to the same value whether or not the switch is activated. When done, the voltage should be very close to +2.5V, independent of the selected gain.

2) Measure the processed signal amplitude of a single
frequency sine wave input. This procedure allows you to adjust the input signal amplitude and will store both the processed and unprocessed amplitudes. I suggest 0 dBm or 1 VRMS — see the discussion that follows. The calibration function displays the value of the input signal you are using for calibration so that you can monitor it while adjusting it. This yields the best calibration for the system.

Note: The “processed” amplitude is the output value of the FFT algorithm.

The maximum signal presented to the ADC must be less than 5V peak-to-peak, about 1.7 VRMS. I suggest that you use 0.7 VRMS as a standard because it is equivalent to 2.0V peak-to-peak, as well as 0 dBm into 500Ω and makes a nice reference value. You could also use 1 VRMS since this would be 2.828V peak-to-peak. Both leave a little “headroom,” but not a whole lot. The resistor values I show on the schematic are based on the following two examples.

1) Suppose you want to monitor the output of a 100W power amplifier that is driving an eight ohm speaker. The output voltage at full power is therefore: \( V = \sqrt{100*8} = 28.3 \) VRMS. In order to measure this signal, you need to divide it by 28. A set of “reasonable” resistors is then: \( R1 = 2.7K \) and \( R2 = 100 \) ohms. I have designed the circuit board so that \( R2 \) is an SMD and \( R1 \) is a thru-hole part so it can be 1/2 watt. By not activating \( K1 \), the attenuator will be used giving the overall circuit a “gain” of 1/28. There is a disadvantage to this circuit — it gives the audio circuit an input resistance of 2.8K. If this is not acceptable, you can increase the resistor values — but not too much or the ratio will be affected by \( R5 \) and \( R6 \).

2) Now, suppose you want to monitor a signal that is 100 mVRMS. All you have to do is multiply it by 10. Using the values shown in the schematic: With IC3 turned off, the gain is \((1K+9K)/1K\) that is a voltage gain of 10 (20 db); with IC3 turned on, \( R11 \) is shorted out that would yield a gain of 1 (0 db).

The program has a feature that causes it to read calibration values from its Flash memory when it first starts. I have set up the program so that if it detects that no calibration values have been previously stored, it will use default values that should be very close — assuming the circuit is built with the values in the schematics.

The circuit has enough gain for a typical microphone if you use the suggested transformer. Most mics have an output voltage of about -60 dbm (0.7 mV into 500Ω). The transformer has a gain of about 12 db, so with the available gain of 50 db that should be adequate for most mics. Note that there is also voltage available for mics that need phantom power. This should be applied to the primary of the transformer as shown in Figure 7.

One of the requirements of the FFT is that you must sample the input signal at least twice as...
fast as the highest frequency being analyzed. This
sampling frequency is called the Nyquist limit after
an early developer of sampling theory. One of the
anomalies of the FFT is that input frequencies
above one half the sampling frequency will be
“mirrored” into the lower frequency range of the
results. For instance, if the sampling frequency is
40 kHz, the highest input frequency that should
be applied is 20 kHz. However, if a signal of 21
kHz is applied, it will be displayed as if it were 19
kHz. This is one of the limitations of this system.
There are two ways of getting around this: (1)
insert a low pass filter with a sharp cutoff at the
highest frequency of interest; or (2) sample at a
higher rate than necessary. The disadvantage of the
low pass filter is that it should be programmable.
The disadvantage of the high sampling rate is
lower resolution. The resolution of the system can be
calculated as follows: Resolution = Sample
Frequency/(2*Sample Size). The factor of 2 is due to the
FFT algorithm that I am using.

I have decided to include an active low pass filter
(Figure 4) with a cutoff frequency of 22 kHz. The filter is a
four pole Sallen-Key design and can easily be bypassed if
you do not want to include it. The design I used was
found at http://beis.de/Elektronik/Filter/ActiveLPFilter.
html. This site allows you to modify the characteristics of
the filter on-line and calculates new values for you. I have
no idea how sensitive the filter characteristics are relative
to the component values. However, I did measure the
response of the filter in the circuit and it is quite good:
at 20 kHz it has about 1.2 db loss; at 24 kHz it is about
4 db. I suggest that you use a sampling frequency of
about 45 kHz if you are going to analyze signals with
frequency components up to 20 kHz. This should allow
the filter to remove most — if not all — of the higher
frequency artifacts. Another limitation of the system is the
display frequency resolution; 100 columns are used for
the FFT display. Based on the formula above for resolution,
at a sample frequency of 45 kHz and a sample size of
512, the resolution is 43.9 Hz. Since the data is displayed
in 100 columns, that essentially means that the total span
of frequencies displayed must be a multiple of 100 *43.9
or 4390 Hz. In practical terms, this says that if you tell the
system that you want an upper frequency of 10 kHz
displayed, you will actually get 4390*3 or 13.2 kHz.

My original design had the analog circuits on the
same board as the processor. I decided to move them to a
separate board for two reasons: (1) to keep digital noise
### Parts List

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<tr>
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<tr>
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<tr>
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<tr>
<td>163-2325-E</td>
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<td>1770-2532</td>
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<tr>
<td>16PJ080</td>
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</tr>
</tbody>
</table>

* 160882 Headers are cut to size and require 100766 pins and housing
** 100766 socket pins requires 103158 housing cut to size

The system needs about 55 total pins — this is equivalent to two pieces each of 103158 and 160882

NOTE: All items are from Mouser unless stated otherwise. A more detailed parts list is available at www.nutsvolts.com.

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Some Construction Notes

A few comments about the BOM. Although the BOM shows mostly Mouser part numbers, many of them are available from other sources, including Digi-Key and Jameco. If you want to save some money, I suggest you search the sites for the best prices on the higher cost items. Bear in mind that these companies may have a minimum dollar value for orders. For instance, the gain resistors in the analog circuit may be customized for your application. The transistor type used for K1 on the analog board and the backlight on the digital board can be any small signal PNP or even an FET (2N7000). The PCBs (three) can be purchased from FAR Circuits as a set.

I recommend that you purchase two of the LCD boards, as well as two of the LCD connectors.
Soldering the LCD connector to the board is the most difficult part of this project. I highly recommend using a 3X, lighted magnifying lens (5X would be better). I also used a 10X eye loupe to make sure of the connections and that there were no shorts. Soldering with a very fine tip is required — I use a .030” tip. One suggestion for soldering is to tin the leads of the connector using fine solder, align the connector, solder the tab near pin 1 to keep it in place, then heat the pins with a clean soldering iron tip. This method takes advantage of the tinned circuit board and prevents the application of too much solder that could create shorts between pins. I highly recommend that you use .015” solder; using thicker solder will probably cause you to create shorts between adjacent pins. You should also have some solder wick on hand.

I like to use single row pin headers for my I/O connections. Their cost is about $.15 per point if you buy enough to do 100 points. I like this method because it allows me to disconnect all the sub-systems. If you do not want to use these connectors, you can easily just solder wires into the header location points. If you do use the connectors, I suggest that if you are hand crimping, you keep the socket pins on the strip while crimping with a small pair of needle-nose pliers. A better solution is to have a crimp tool available — but these are somewhat expensive. Whatever method you use, you should strip 1/8” of insulation off each end to make a good connection.

You need mount only the input sockets you need for your application instead of all the ones I have shown in the enclosure schematic (Figure 7). The schematic does not show any connections to the high level input (H2). You can mount and connect any appropriate sockets your application requires. Another possibility is to use a switch to connect J3 to either H1 or H2 of the analog board.

You may use whatever switches you like for the power and pushbutton switches. I selected ones from the Mouser catalog based primarily on cost.

My website has a number of JPEG files to aid you in assembling the circuit boards. There are three files for the analog and digital boards and two for the LCD board. These files include: top side silk screen, bottom side silk screen, and vias. The silk screen files show parts placement and the via files show the locations of the vias. The via locations are needed because my vendor for the boards does not do plated-thru holes. You will have to insert wire jumpers in all the via locations. This also means that a number of components need to be soldered on both sides of the boards in order to complete the circuits.

The wiring between the subsystems should be done with fairly flexible wire. I happen to have a supply of eight conductor telephone cable. This is an advantage because it is multi-color that makes tracing signals easier. I was able to use this effectively by first cutting the cable to the required length, then removing the wires from the outer sheath. Let me know how your build goes. NV
This article will introduce you to the Greyhill 62P22-L4 pushbutton rotary encoder. I will describe what it is, how it works, and how to integrate it into your project. A demonstration will be presented using a PIC16F84A, along with the project code written in C.

The Greyhill 62P22-L4

I chose this device more or less at random, because it was in stock from my favorite supplier. The shaft rotates with soft detents, and can be pressed in as a pushbutton. Each detent is at 22° of rotation. There are no stops and no reason why it cannot be rotated endlessly either clockwise or counterclockwise. This model comes in two different rotational torque and two different pushbutton forces; the L4 model is the lower torque and lower force model. (Other types with a variety of features such as integrated joystick are also available.)

This rotary encoder requires a +5 VDC supply at 30 mA. It uses an internal LED and optical detector to produce its output. The pushbutton is a mechanical contact type and requires a few milliseconds to debounce (four at make and 10 at break). The rotary encoder outputs a two bit binary code on its Output A and Output B pins. This gives four unique values, after which the code repeats itself. Once you know the previous and current output values and the code sequence, you can determine which way the shaft has been rotated.

If you assume that Output A is the low order bit and Output B is the high order bit, when rotated clockwise the encoder outputs 0, 1, 3, 2. When rotated counterclockwise, the output is 0, 2, 3, 1. (There is,
of course, no reason why the bit order could not be reversed and the output sequence changed correspondingly.)

To produce a number in the sequence shown, place Outputs A and B in a byte in working storage like this:

<table>
<thead>
<tr>
<th>bit 7</th>
<th>bit 6</th>
<th>bit 5</th>
<th>bit 4</th>
<th>bit 3</th>
<th>bit 2</th>
<th>bit 1</th>
<th>bit 0</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>B</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td>A</td>
</tr>
</tbody>
</table>

At startup, the program must read the encoder value, since it could output any of its four values. The value is saved in memory as the previous value. The encoder is then polled until the value changes. Comparing the previous value and current value to the sequence 0, 1, 3, 2, you can tell which way the shaft has been rotated and act accordingly. Then the current value is saved as the previous value and polling continues.

Note that the encoder outputs require pullup resistors. In my demonstration example, I use the internal pullups available at port B of the PIC16F84A for the encoder and the pushbutton. Otherwise, 10K resistors to the +5V supply are recommended.

The pushbutton is debounced and read like any pushbutton. According to the specifications, the longest settle time is 10 milliseconds — which is pretty fast — so your code can be responsive to button presses.

Finally, the encoder supply pin requires a 150 ohm resistor between it and the +5V supply. The encoder’s pinouts are shown in Table 1.

### Table 1

<table>
<thead>
<tr>
<th>Pin</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Supply (+5 VDC through a 150 ohm resistor)</td>
</tr>
<tr>
<td>2</td>
<td>Ground</td>
</tr>
<tr>
<td>3</td>
<td>Output B</td>
</tr>
<tr>
<td>4</td>
<td>Output A</td>
</tr>
<tr>
<td>5</td>
<td>Pushbutton</td>
</tr>
<tr>
<td>6</td>
<td>Pushbutton</td>
</tr>
</tbody>
</table>

### What Can I Do With It?

The obvious use of the encoder is for the clockwise rotation to signal an “up” type event, the counter-clockwise rotation “down,” and the pushbutton to signal some kind of request or mode selection. For example, let’s say you are designing a programmable thermostat with an LCD readout. You want it to control either a furnace or air conditioner, so it has three states: cool, heat, and off. You could use up and down buttons for the temperature, and a three position switch for the state. Or, you could use an encoder. Rotating the shaft raises or lowers the temperature setting. Pressing the button changes the mode, activating a menu which allows you to select heat, cool, or off (by rotating the shaft). Pressing the button...
again returns the unit to run mode.

This is a very simple thermostat, but it is now easy to extend the design with more features, taking advantage of the flexibility of the encoder and LCD display. You can add a clock and time of day programs; you can set the clock; you can add a fan on/off function; and so on, without having to add any more hardware to your design.

Another application is a power controller, possibly to control the temperature of a soldering iron. The pulse width modulation feature of many microcontrollers is ideal for power control of a resistive load, with the help of a power MOSFET. The device could have a one or two digit LED display showing the power level, and a rotary encoder to turn the heat up or down. The encoder’s pushbutton could be used as an on/off switch. (In fact, the power would always be on to the microcontroller, but turning the unit off instructs the processor to set the output power level to zero and disable the LED display.)

If you add hardware debouncing to the pushbutton and connect it to an external interrupt pin, a press of the button can be used to put the microcontroller into sleep mode and the interrupt caused by another press used to wake it up. Battery operated applications would benefit from the decreased power consumption when the unit was off.

The Demonstration Project

This simple project uses a PIC16F84A to manage a rotary encoder as input and a single digit LED display and buzzer as output. On power up, ‘0’ is displayed. Rotate the encoder clockwise, and the number is incremented to 9, then back to zero again. Rotate counter-clockwise and the display becomes ‘9’ and decrements down to 0. Pressing the encoder pushbutton makes the buzzer sound.

The rotary encoder S1 is interfaced to U1 with three I/O pins configured as inputs. The port B internal pullups are used for each PORTB input port, so external pullup resistors are not needed. The PIC uses a 3.58 MHz crystal oscillator, but any crystal up to the maximum frequency supported by the PIC is okay, as long as the timer0 interval parameters are adjusted accordingly. J1 is used for in-circuit Flash programming (I use a Pickit24) and is not required for operation. The buzzer and the LED display are connected to the remaining I/O pins configured as outputs. (If you don’t want to bother with a buzzer, just replace it with an LED and 470 ohm limiting resistor.) U2 provides regulated five volts so that a battery or wall wart can be used to power the project.

The Software

The hardware design of microcontroller projects is deceptively simple, because so much of the work is done in the software. Polling for input events is a major task, which must be carefully coordinated with the other work being done by the processor. Improper or poor design may result in input events being missed or responded to sluggishly. The way I manage this problem is to use the PIC’s timer to do all the input polling and switch debouncing. It then posts event flags to the foreground code, which is free to respond to events as they occur.

This architecture works well when an event signals an action that can be processed quickly. I do this for my encoder inputs, where I am incrementing or decrementing the display. Other kinds of events that require time to perform can be more difficult to handle. For my button press, I want to sound the buzzer for a period of time, but I do not want to tie up the main code with a long delay. In this case, the solution is to sound the buzzer in response to the button press, and then schedule an event to turn the buzzer off later (conveniently done in our timer interrupt routine). The benefit is no time-wasting delay loops at all in the program.

To see how the rotary encoder is managed in the software, have a look at encoder_demo.c and encoder_demo.h in the downloads available on the Nuts & Volts website at www.nutsvolts.com.

1) In function InitCPU, the option register is loaded to assign the prescaler to timer0 and set the prescaler to 16:1. The timer0 counter TMR0 is initialized to the value in define TIMER0_INIT. Note also that PORTB pull-ups are not needed. Then timer0 and global interrupts are enabled.

2) An interrupt handling function isr (PICC) or interrupt (BoostC) is provided to handle timer0 interrupts. The choice of
prescaler and timer0 counter initialization value, along with the crystal frequency, determine the interrupt interval, chosen to be four milliseconds (but not particularly critical for this application). Comments in the code further explain how these values have been derived.

The main activity is to call `debounce_switch`, the function that polls each input pin and performs the input debouncing. There are no parameters, since global variables in memory are used to manage the debouncing states. If any input level changes, an event flag is set for the main code to deal with.

The secondary activity is to look for the beeper being on, and count down to zero and turn the beeper off.

3) Function `debounce_switch` polls each input (two encoder and one pushbutton) and keeps track of the state, returning the current state in global variable `ucDebouncedState`.

4) Function `analyze_switch` is called by the main code in response to an input changed event. This function determines if the button was pressed or the encoder shaft turned clockwise or counter-clockwise. A corresponding event bit is turned on for the mainline to process.

For the encoder, the method used is to isolate Output A and Output B as the lowest two bits in a byte as described above and see how it compares to the previous value.

Button presses are detected but not button releases. An event for button release could be added if necessary, or a global variable set to 1 when the button was down.

5) The main function looks for the various event flags and performs the required processing.

References

Conclusion
I hope you found the rotary encoder as interesting as I have. It is easier to design a project to use one in place of a number of other input devices. It is also easier to build a project with one input device instead of many, and the project may be simpler for the user to operate, as well.
I first converted a car to purely electric operation in 1999 and after several improvements — particularly to the battery pack — the car was moderately successful. I was generally able to travel about 50 miles on a charge and considerably more if care was taken. The car completed the London to Brighton Electric Vehicle (EV) Run in 2005 and 2006.

Unfortunately, the achilles heel of the EV is still the battery pack. With low cost, traditionally lead-acid batteries the range is severely limited and a long, cross-country run must be planned like a military campaign. There must be charging points every 50 miles or so, and you need to stop for a couple of hours at each to restore some charge.

In 2005, I started looking at the hybrid cars that were available and the Toyota Prius in particular. The interesting thing about the Prius was that it could run for a limited period as an EV, however with the NiMH battery pack the electric motor can take the car only about one mile at less than 31 mph. I wanted to reduce the fuel consumption of the Prius from 60 mpg to 100 mpg — a massive cost savings — by the addition of a large Li-Ion pack. This article described how I achieved this using E-blocks and Flowcode from Matrix Multimedia as a control system.

How It Works

Figure 1 shows how the Toyota Prius works. Essentially, it is a normal car with the addition of an electric motor/generator in the drive train. When the driver needs to slow down, the brake pedal puts the ‘motor’ into generator mode which charges the battery up. Conversely, at low speeds the motor is used to assist the conventional petrol engine which decreases fuel consumption.

When I started the project, a few groups in the US were experimenting with supplementary battery packs to increase the range of the Prius. The Toyota — along with most modern cars — has a very complex electronic control system. The part that deals with drive and battery management uses CANbus for communication. The operation of the drive among...
other things is based on the State Of Charge (SOC) of the battery pack. If the SOC is low, the management system will recharge when descending a hill, braking, or use any surplus energy from the engine. If the SOC is high, then the battery pack will be used to drive the car at low speed or to supplement the engine when driving, climbing hills, or overtaking. In practice, the SOC is moving about the entire time, dependent upon traffic and driving patterns.

I saw two main problems in adding a large battery pack in parallel with the existing battery. The first was what would the reaction be from the Toyota management system if — out of the blue — the existing battery started receiving charge from an outside source — the second battery! The second problem was how to control this external charging source.

The control system needed to be such that the existing batteries’ SOC could be manipulated so that the Toyota management system saw a high SOC and used the battery instead of the engine wherever possible.

The first problem was simple. I connected my EV charger across the Toyota battery pack and charged the pack. The SOC increased up to fully charged (about 80% SOC). The battery manager took into account the pack temperature and voltage, and computed the SOC quite happily. Solving the second problem — transferring energy to the Toyota’s battery — was the main area of work.

**Circuit Details**

I was lucky enough to have acquired a set of 56 Thunder Sky Li-Ion cells which I could use as a second battery. These are connected in series to give a resulting DC voltage of around 210V and more than 50 Ah. The Toyota’s NiMh battery produces around 240V DC, so I knew that I would need an inverter to allow the additional battery pack to charge the Toyota’s own battery. I also wanted to be able to recharge the Li-Ion batteries overnight, so I needed a recharge circuit. I needed a circuit to control the flow of charge into the Prius’ own battery, as well. You can see the circuit in Figure 2.

![Figure 2. Block schematic of the system.](image)
Hacking the Prius

The means of connecting the extra battery pack to the existing pack was by using four single pole, high voltage power contactors and a high power DC-DC converter.

The converter is actually a battery charger which has a bridge rectifier as the first component to convert the normal AC mains input to DC. Of course, you can just feed it with DC. The DC-DC onboard converter is used to charge the Li-Ions if required, but that's another story.

The converter had a two-stage, selectable output. In high, the converter would try to lift the existing pack to a high voltage and thus a high SOC. In low, this voltage was lower and allowed the existing pack to lose charge letting the SOC% to fall back. The output of the DC-DC converter is controlled by switching in one of two sets of points. When the battery is being charged overnight, it is isolated from the Toyota circuit by a second set of points.

Controlling this system meant hacking into the Toyota CANbus system. The car has many devices on the CANbus network and fortunately they all broadcast their data onto the bus. The devices that need the data read it and react accordingly. As far as I am aware, no device solicits information from another device (CANbus is arranged as one master and N slaves -Ed). What was needed was a custom CANbus device that could read parameters on the system and move charge into the existing battery pack at the right time.

At this point, I read an article in Elektor on Flowcode (February ’06); this referred to a CANbus system consisting of two nodes of a network. From past experience with other bus systems, it can take a long time to get a system up and running. I have a bit of experience with Microchip PIC devices and there is a wealth of information on their website on CAN networking. The datasheet on the CAN interface chip (MCP2515) runs to 81 pages.

I ordered the Flowcode CAN system and saw immediately all the hard work of using the CANbus had been done already. Setting up the parameters for the bus and reading specific messages is carried out by prewritten macro commands. Getting the communication between two points was very straightforward.

In order to read the messages emitted containing data on the SOC, a Kvaser Light CAN to USB unit was used to look at the bus traffic. There is a convenient OBD-II connector with 12V power located just under the steering wheel in the Prius. There is some documentation regarding the messages on the bus on the Internet. The format of the data varies and a bit of manipulation is needed to convert the data to a form which can be displayed on an LCD.

With some idea of what I wanted initially from the bus, I set up a system in the workshop mimicking the function of the CAN bus in the Prius. One of the E-block systems continuously transmitted an SOC message in the same format as the Toyota message; the other system was set up as a display unit which showed the system parameters on an LCD display. This was used in the development and commissioning phases of the project on the bench, and fitted into the radio compartment of the car as shown in Figure 5. The display shows the Battery Current, Battery Voltage (charging/discharging), State of
Charge %, Charge Current Limit, Discharge Current Limit, Max Battery Temperature, and Min Battery Temperature. In this way, the whole system could be built up and tested away from the car.

The second stage of the program used only one of the items (SOC%) and gave out one of two outputs — high or low — depending on the value of SOC. In order to maintain the existing battery SOC at around 70%, a simple pair of decision instructions in Flowcode are put on the low output if SOC% > 70 (and disconnected the Li-Ion cells from the charge circuit) and put on the high output if SOC% < 65 (which switched the Li-Ion cells into the circuit and charged the NiMh Prius battery). In each case, the opposite output would be turned off.

One additional output was used to drive a relay which, in turn, energized the four main contactors. This output would come on five seconds after the system powered up and would go off in response to the additional battery pack becoming discharged.

There was no need for a display on the final controller and this now lives in an enclosure in the boot (or trunk for us Yanks — Ed) next to the extra batteries and power contactors.

The additional battery pack is a set of 56 Thunder Sky Li-Ion cells. These cells are about two years old and vary in capacity; the worst being about 50 Ah at 20 degrees C when discharged at 25 amps. The worst cell defines the pack capacity, so with the current limit set to 25 amps the car will run for two to three hours in assist mode until the battery pack switches off. The car then runs in normal hybrid mode as before.

One drawback of the system is these batteries are still very expensive and physically quite large. Another is that the batteries take up some of the boot space as you can see in Figure 6.

Figure 8 shows the Flowcode program. Flowcode allows users to develop a program by dragging standard flow chart icons onto the workspace and then clicking on them to enter the properties. Users can simulate this on screen, and when the program is debugged can compile the flow chart to machine code which can be downloaded to a PIC microcontroller. Flowcode includes built-in routines and dialogs for CANbus communication which allows you to easily transmit and receive packets of CAN data.

**Conclusion**

In summer, the car will return
about 60 mpg in normal hybrid mode and about 100 mpg in battery boost mode. Unfortunately, the Prius’ read-out only goes to 99.9 mpg so you are a bit blind as to how well it’s really doing. In Figure 9 you can see a photograph of the Toyota's display and pulsing a relay when the speed drops below 30 mph to force the car into EV mode. The relay would be pulsed again on the speed rising to 30 mph to take the car out of EV mode — another job for Flowcode.

References

Elektor February 2006 Easy CAN
Microchip www.microchip.com
Plug-in Prius Wiki group at: www.eaa-phev.org/wiki/Main_Page
Follow links to plug-in hybrids, then Prius.

The E-blocks Easy CAN bus pack includes a copy of Flowcode, two PICmicro multiprogrammers, two CAN bus boards, an LCD display, switch board, LED boards, and accessories.

Matrix Multimedia www.matrixmultimedia.com
C programming and microcontrollers are two big topics, practically continental in size, and like continents, are easy to get lost in. Combining the two is a little like traipsing from Alaska to Tierra del Fuego. Chances are you'll get totally lost and if the natives don't eat you, your infected blisters will make you want to sit and pout. I've been down this road so many times that I probably have my own personal rut etched in the metaphorical soil, and I can point to the sharp rocks I've stepped on, the branches that have whacked me in the face, and the bushes from which the predators leapt. If you get the image of a raggedy bum stumbling through the jungle, you've got me right. Consider these workshops a combination roadmap, guidebook, and emergency first aid kit for your journey into this fascinating, but sometimes dangerous world.

I highly recommend that you get the book *The C Programming Language — Second Edition* by Kernighan and Ritchie, here after referred to as K&R. Dennis Ritchie (Figure 1) wrote C, and his book is the definitive source on all things C.

In Figure 1, Ritchie (inventor of the C programming language) stands next to Ken Thompson, original inventor of Unix, designing the original Unix operating system at Bell Labs on a PDP-11.

I have chosen to follow that book's organization structure in this series of workshops. The main difference is that their book is machine independent and gives lots of examples based on manipulating text, while these workshops are machine dependent, specifically based on the AVR microcontroller, and the examples are as microcontroller oriented as I can make them.

**Why C?**

Back in the dark ages of microprocessors, software development was done exclusively in the specific assembly language of the specific device. These assembly languages were character based ‘mnemonic’ substitutions for the numerical machine language codes. Instead of writing something like: 0x12 0x07 0xA4 0x8F to get the device to load a value into a memory location, you could write something like: MOV 22, MYBUFFER+7. The assembler would translate that statement into the machine language for you.

I've written code in machine language (as a learning experiment) and believe me when I tell you that assembly language is a major step up in productivity. But a device’s assembly language is tied to the device and the way the device works. Assembly languages are hard to master and become obsolete for you the moment you change microcontroller families.

They are specific-purpose languages that work only on specific microprocessors. C is a general-purpose programming language that can work on any microprocessor that has a C compiler written for it.

C abstracts the concepts of what a computer does and provides a text based logical and readable way to get computers to do what computers do. Once you learn C, you can move easily between microcontroller families, write software much faster, and create code that is much easier to understand and maintain.

**Why AVR?**

There are many excellent microcontroller families out there, but I chose the AVR because — among many reasons — it was designed with the C programming language in mind, has Flash memory that can be configured with a bootloader (more on all this later), and has the best user forum I've ever used: [www.avrfreaks.net](http://www.avrfreaks.net).

The AVR is fast, cheap, in-circuit
programmable, and development software can be had for FREE (really free, not crippled or limited in any way). I’ve paid thousands of dollars for development boards, programming devices, and C compilers for the other micros, but never again — I like free. The hardware used in these workshops — the Atmel AVR Butterfly — can be modified with a few components to turn it into a decent learning system and the needed components can be had for less than $40. You can’t get a better learning system for 10 times this price and you can pay 100 times this and not get as good.

You will often stumble across arguments on the Internet as to which microcontroller or programming language is the ‘best.’ People take sides and soon a religious war breaks out. I don’t want to enter that fray, so I’ll just say that the AVR is the best microcontroller and C is the best programming language and if you don’t believe me, you are bound for perdition — hallelujah and amen. (Agreed! -Ed.)

Workshop Goals

What I hope to accomplish with this series is to help you learn SOME C programming on A SPECIFIC microcontroller and provide you with enough foundation knowledge that you can go on your own somewhat prepared to tackle the many kinds of microcontrollers and C programming systems that infest the planet.

Both C programming and microcontrollers are best learned while doing projects. I’ve tried to provide projects that enhance the learning process, but I’ve got to admit that some of the projects are pretty lame and are put in mainly to help you learn C syntax and methods.

I know how easy it is to get bogged down in all the detail and lose momentum on this journey, so we’ll begin with a quick start guide and learn just enough to get our learning platform tools working — kind of a jet plane ride over the territory.

Quick Start Guide for the AVR Learning Platform

Software

AVR Studio — FREE and darn well worth it.

AVR Studio is provided free by the good folks at Atmel Corporation, who seem to understand that the more helpful free stuff they give developers, the more they will sell their microcontrollers. Actually, this software could cost hundreds and still be darn well worth it, but unless you just really like Norway, don’t send them any money; they’ll get theirs on the backend when you start buying thousands of AVRs for your next great invention. The workshop is based on version 4.14 and if you use a newer version you may find differences in it and our discussions. You can find AVRStudio at www.atmel.com under the AVR Tools & Software section: http://atmel.com/dyn/products/tools_card.asp?tool_id=2725.

WinAVR — Oh, Whenever ...

WinAVR is a GCC compiler toolset for Windows that we will use in AVR Studio. We will use this package under the AVR Studio IDE that has a GCC plug-in that finds the WinAVR installation and adapts it to the IDE. You can find WinAVR at: http://sourceforge.net/projects/winavr/.

Developer Terminal

Figure 2 shows the PC terminal we will use to communicate with the AVR in our workshop. You can get the terminal installer and related documents from www.smileymicros.com. The source code in C# and Visual Basic .NET for this terminal is discussed in detail in the book Virtual Serial Port Cookbook (by me) and is available from www.smileymicros.com and Nuts & Volts (www.nutsvolts.com).
Hardware

It is simply amazing what the Butterfly has built in:

• 100 segment LCD display
• 4 Mbit (that’s 512,000 bytes!) data Flash memory
• Real time clock 32.768 kHz oscillator
• Four-way joystick, with center push button
• Light sensor
• Temperature sensor
• ADC voltage reading, 0-5V
• Piezo speaker for sound generation
• Header connector pads for access to peripherals
• RS-232 level converter for PC communications
• Bootloader for PC based programming without special hardware
• Pre-programmed demos with source code
• Built-in safety pin for hanging from your shirt (GEEK POWER!)
• Kitchen sink

I mean this thing has everything (except a kitchen sink ... sorry). If anyone can find a learning platform with anywhere near this much for this price, I want to hear about it. If I seem to be raving a bit, get used to it. I do that a lot.

The AVR Butterfly box has instructions to show you how to use the built-in functions. Play with it now before you risk destroying it in the next step. I shudder to think how many of these things will get burned up, blown up, stepped on, and drenched in coffee. (And that’s just me this morning.) After you’ve seen how it works out of the box, remove the battery and prepare to add components for our learning platform.

Butterfly++ Mini-Kit Construction

The Butterfly provides an excellent learning platform, but it can be even better with a few extra parts that Smiley Micros supplies in the Butterfly++ Mini-Kit. This kit includes a CdS light sensor, a DB-9 female connector and wires, and a two AA battery holder with power on LED and resistor.

Adding a CdS Light Sensor

Atmel’s AVR Butterfly no longer has a light sensor due to European RoHS compliancy considerations (don’t get me started ...). The mini-kit...
provides a suitable substitute component that the user must solder to the Butterfly to use the light sensor function. This sensor works with the existing Butterfly software.

The CdS light sensor is a device that has resistance proportional to the incident light. As a resistor, the device has no polarity so either leg can be inserted in the pads shown circled in red (see Figure 5). Seat the sensor snug to the top of the Butterfly, then solder the legs to the bottom and trim them just above the solder meniscus.

**DB9 Female Connector and Wire**

In order to communicate with a PC, the Butterfly must connect to a serial cable. The mini-kit provides the connector and wire to make the connection to a serial cable.

The Butterfly has built-in RS-232 converters for serial communication with a PC. Most serial cables will have a DB-9 male connector on the device side that will mate with the provided DB-9 female connector (calm down – it’s technical).

Strip about 1/8 inch from the ends of each wire and then carefully solder them to the Butterfly and the DB-9 connector as shown in Figure 6. Notice that the upper wires in the picture cross. Be very careful to get this exactly according to Figure 6; about half the emails I get for problems turn out to be related to either incorrect wiring or poor soldering of this component.

**Female Headers**

Refer to Figure 7 to see the location of the ADC, USI, PORTB, and PORTD pads. Solder the two-pin header to the ADC pads; the four-pin header to the USI pads; and 2x5 headers to the PORTB and PORTD pads. Notice that Figure 7 shows a male header on the ISP pad; this is not included in the kit and won’t be used for our work (maybe later).

**AVR Learning Base Board**

The AVR Workshop Learning Platform is built on a foamcore board that lives in a protective foamcore box. (Details for this construction can be found in Smiley’s Workshop 1 Supplement: AVR Learning Platform Foamcore Base and Box at www.nutsvolts.com.)

You will need to carefully twist the ends of the battery box wires until they are straight, then soak them with solder so that it runs up under the insulation to make these wires strong enough to insert into the breadboard power bus. The red wire goes to the + red bus and the black wire goes to the – blue bus. Connect the two power busses with red and green wire and then put an LED with a 2.2K resistor on the breadboard. The resistor goes to the + power; the LED short leg goes to the – power. The LED and resistor are then connected on a breadboard strip.

The Butterfly receives power from the bus as shown, the + red wire goes to the rightmost top of the header, and the – green wire goes to the rightmost bottom of the header.

**Test Your Connection Using Developer Terminal**

Hook your Butterfly DB-9 connection to an RS-232 cable from a PC. If you use a USB-to-serial converter cable, you may have problems if the voltage levels are not robust. I’ve used several and have not had a problem.

Open Developer Terminal. You can read the user manual (I recommend: RTFM) by clicking the ‘Help/Manual.’ Click the ‘Settings/Port’ menu item to open the settings window. Select the RS-232 COM port that the Butterfly is connected to. Set the baud rate to 19200, data bits to 8, parity to None, stop bits to 1, and handshaking to none. You can test that your learning platform is
working okay by two methods. A simple test is to turn the power off on the Butterfly and then WITH THE JOYSTICK BUTTON PRESSED TO THE CENTER, turn the power back on. Now each time you press the joystick button to the center, you should see a series of question marks (???????) in the Simple Terminal receive window. This is the Butterfly bootloader wondering what the heck is going on.

Another test is to turn the Butterfly on and click the joystick up to get the LCD scrolling. Move the joystick straight down three times till you see ‘Name,’ then move the joystick to the right twice till you see ‘Enter name.’ Move the joystick straight down once and you will see ‘Download name,’ then push down the joystick center for a moment until you see ‘Waiting for input.’

In Developer Terminal, make sure the ‘Send Text: Immediate’ radio button is checked. Type in your name, then in the ‘Send HEX Immediate’ dropdown box, select and click on 0x0D that tells the Butterfly you are finished sending characters. Your name should appear on the LCD.

This isn’t easy and there are many opportunities to mess up along the way. Many folks get this going right away, but others seem to have fits getting over this hurdle, so I’ve provided a Workshop 1 Supplement: Problems Communicating with the Butterfly on www.nutsvolts.com to help you get past this point. Trust me, if you see the ??? or get your name scrolling on the LCD, you are over a major hump and subsequent workshops will be easier to get going than this step.

Well, that was a lot and we haven’t really gotten started yet. Next month, we will look at the software side of the AVR Learning Platform and learn about the AVRStudio IDE and the WinAVR C compiler toolset. We’ll write our first C program and create a set of Cylon Eyes in hardware.

---

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PS: Although you’ll probably get a whole lot more attention for mounting a gyro, Photodetectors/Solarforms add a lot of value.

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Bill of Materials

<table>
<thead>
<tr>
<th>ITEM</th>
<th>Supplier/PN</th>
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<tr>
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<td>Digi-Key/PDV-P9005-1</td>
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<td>Jameco/690742CG</td>
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<td>Circuit Specialists/DE-09S</td>
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<tr>
<td>Green LED</td>
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<td>Green LED</td>
<td>Circuit Specialists/BAG-GREEN3MM</td>
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</tbody>
</table>
75W HALOGEN FLOOD LAMP
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18 Volt 1.4 Amp transformer. Removed from new equipment. Wire leads (primary) are 2" long. Secondary solder terminals have solder on them. 2" x 2.45" x 2.10" high. Mounting holes on 2.9" centers. 
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August 2008 NUTS & VOLTS 67
SO, YOU’VE BEEN WORKING ON YOUR electronic masterpiece for a few weeks (months?) and it’s finally finished, so ... now what? Where can you go to show off your little beauty, the child of your imagination, the fruits of your labor? How about Dorkbot?

Dorkbot’s motto is “People doing strange things with electricity” and from what I’ve seen, I’d say that’s a very accurate description. Founded by Douglas Repetto of Columbia’s Computer Music Center in the fall of 2000, Dorkbot has spread across the world providing a framework for display, collaboration, and celebration of all things tech (Figure 1).

On a sultry, summer evening in June 2006, David Nunez, Rodney Gibbs, and Rich LeGrand pulled off the first Dorkbot Austin “Cafe Mundi” — a cute and quirky East Austin restaurant and hangout. When I arrived, there was a video projector pointed at a big screen on one side of the parking lot and a small PA system for the presenters to use. In a matter of moments, I got a general impression of what Dorkbot Austin was all about. There were projects and people, devices and drinks, music and madness. It was a contagious carnival atmosphere with artists, electricians, programmers, musicians, the curious, and the chaotic all coming together to show and tell about their creations while networking with other self-confessed “dorks” (Figure 2).

At the time of this writing, there have been 15 such events in Austin since that first summer night, averaging a little over one every other month. Most of the events have been at Cafe Mundi; the exceptions being the South By Southwest (SXSW) festival events that were held in downtown Austin and one special event held at the Austin Children’s Museum. Though most of the events...
have been privately organized and funded, some have been sponsored by such big names as South by Southwest (SXSW), Make Magazine, Amaze Entertainment, and the International Game Developers Association (IGDA) (Figure 3).

Due to the nature of a Dorkbot event, the main facilitators have changed as new folks become interested and some of the early movers and shakers have moved on to other projects. Though David Nunez and Rich LeGrand are no longer working with Dorkbot Austin, the current Dorkbot Austin crew of Rodney Gibbs, Luke Iseman, Chase Hammock, and Nick Pietraniec have stepped in to make sure the event lives on.

I did get a moment to chat with

![FIGURE 2. Dorkbot Austin at Cafe Mund](image)

![FIGURE 3. Dorkbot poster by Noel Waggren](image)

**FIGURE 2.** Dorkbot Austin at Cafe Mundii.

**FIGURE 3.** Dorkbot poster by Noel Waggren; subculturepress.com.

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**THERE’S NO DORKBOT IN YOUR CITY? MAYBE YOU SHOULD START ONE!**

**Some things to consider:**

What is Dorkbot, exactly? Each Dorkbot event is different and is driven by the needs and interests of people in the local community. But generally, the main goals of Dorkbot are: to create an informal, friendly environment in which people can talk about the work they’re doing and to foster discussion about that work; to help bring together people from different backgrounds who are interested in similar things; and to give us all an opportunity to see the strange things our neighbors are doing with electricity. Dorkbot isn’t really a forum for formal artist talks or lectures, but rather a chance for diverse people to have friendly conversations about interesting ideas. The organizers of Pixelache 2008 asked Douglas to talk about Dorkbot’s “organizational strategy.” Here’s what he had to say:

**Frequency:** How often will you hold meetings? Some Dorkbots have meetings every month, others just a few times a year. It’s a lot of work putting the meetings together, and in smaller cities it can be difficult to schedule enough speakers. You don’t want to burn out!

**Locale:** If you are in a smaller city or town, you might want to consider collaborating with people in other nearby cities/towns. Maybe the Dorkbot meeting can travel to a different location each month, or maybe you can pool your resources for a couple long-form meetings each season.

**Venue:** Is there a place to hold the meetings? It can be very convenient to have the meetings in the same place each time. Often, an art gallery or performance space will be willing to donate their facilities for the occasional meeting. If you know someone connected to a university, you may be able to get a space through them. It doesn’t have to be a fancy space!

**Equipment:** Do you have access to presentation equipment? At the least, you’ll probably need a video projector, a small sound system, and a network connection. A laptop computer can also make things easier on the presenters. As with the venue, it’s best if you can use the same equipment at each meeting. It can be very stressful trying to track down a video projector the day of a Dorkbot meeting! Often, the venue you use will have A/V equipment you can borrow.

**$$$:** Dorkbot is a non-$-oriented organization. Dorkbot meetings are generally free events, so you need to be careful about spending lots of money to produce them! Several Dorkbots sell beer and/or food at the meetings to help cover their costs. Make sure you talk to the venue before selling anything. Dorkbot.org donates web space, email lists, etc., to the local Dorkbots, so there is no administrative cost associated with setting up a new Dorkbot.

**Meeting Format:** Dorkbot meetings are rather informal. There are usually two or three presentations (about 20-30 minutes each) per meeting and sometimes very short “lightning” presentations from audience members. The specific format is up to each organizer to decide. You’ll probably have to play with your format for a few meetings until you find something that works well in your context. One thing to keep in mind is that the Dorkbot format works best for informal, conversational presentations on a particular work or topic, rather than formal artist talks or lectures on a body of work. Thirty minutes isn’t much time, so focused presentations work best.

**What happens next?**

If you think you’d like to start a Dorkbot in your city, contact Douglas at douglas@dorkbot.org for more information.
Nick Pietraniec about Dorkbot to get his take on things. Nick comented, “I think fundamentally our goal is to provide a forum for our community to meet, collaborate, socialize, brainstorm, and show off their work — this is probably a common mantra for most Dorkbot communities, but there’s no central organization or mission. If you go to an event in London, Montreal, South Africa, or Dallas — it might look completely different.”

When I asked him what it was like running a Dorkbot event, he responded, “Actually, ‘running’ probably isn’t really the proper term. We’re more ‘facilitators’ in that we simply solicit for presenters, coordinate the venues. When we reach a critical mass of folks interested in showing off their work, we send out the announcements, get the gear, and head for the site.”

Though I haven’t had the pleasure of attending a Dorkbot outside of Austin, the ones here have been a LOT of fun and are both very well attended and received. At the SXSW Dorkbot Austin, there was a huge crowd of people who came together to talk about tech, show off their electronic feats, and let their inner dork shine (Figure 4). Attendees are encouraged to bring finished items, parts and pieces, or even just plans or sketches. It’s a good place to hang out and to network with other folks that have similar interests.

Experimental music, strange contraptions, and prototype systems breaking down on stage accompanied by small gouts of blue smoke make for an exciting day. Even the projects that flame out are enthusiastically applauded!

So, what is attending a Dorkbot like? To me, it felt something like a trade show — rock concert — nerd party — ham fest — science fair all at the same time. There’s usually adult...
beverages being consumed (which certainly adds to the festive nature of the event!) and kids running around having fun and beeping/zapping/blinking things everywhere (Figure 5). At the Austin shows I’ve attended, the “master of chaos” David Nunez was usually scampering about trying to make sure the next presenter was ready to go, introducing each new segment, and generally making sure everyone has what they need and has a good time.

In addition to being just a heck of a lot of fun to attend, Dorkbot has been a wonderful venue for The Robot Group to test out and demonstrate some of our newest designs. It has provided a sympathetic and knowledgeable audience for some of our more notable projects such as the RoboSpinArt machine (Nuts & Volts, January ’08) and the Power Flowers (Nuts & Volts, July ’08). The first time I presented a concept project, all I had to show

Q&A ABOUT SELF-ORGANIZATION: DORKBOT 
AN INTERVIEW WITH DOUGLAS REPETTO

“*I generally try to stress that each Dorkbot is autonomous and some of them are quite different in form and spirit from one another. So, it’s difficult to make very general, overriding statements. Of course, journalists live for general, overriding statements, so sometimes it’s a hopeless cause …*” —Douglas Repetto, Dorkbot creator

What are the aims of the project you are involved in?
Dorkbot has only a motto: “People doing strange things with electricity.” Different groups have interpreted the motto in different ways. When I thought of the motto, I purposely made it broad and inclusive so that it would interest many different kinds of people doing different kinds of things. Artists, inventors, scientists, engineers. The exciting thing to me is to learn about strange things that creative people are doing around the world, with no regard for genre, style, school of thought, area of expertise, etc.

How is the project organized?
It is mostly dis-organized. We have a server at the Computer Music Center at Columbia University (where I work). That hosts many of the Dorkbot websites (but not all). We also run many (but not all) of the mailing lists from the server. Other than that shared web resource, each Dorkbot is more or less completely autonomous. Very early on when there were just three or four Dorkbots, I decided that the best thing to do would be to give up any control I might have over the other organizations. At first, I was worried about other people using the name in ways I didn’t like, or organizing meetings in ways I didn’t agree with, but I quickly realized that if I really wanted to be inclusive I would have to let go and let other people find their own way. We have a Dorkbot-overlords mailing list, and we exchange occasional messages between the various people who run all the different Dorkbots around the world. But even that is very low volume. I think that the main thing that has given Dorkbot an identity of sorts is the website and the motto. People see that it is not super self-serious. That it is informal and friendly. That it is about creativity. I think that is enough.

The above interview excerpt courtesy of “Pixelache 2008 Helsinki.” To read the rest of the interview, point your web browser to ttp://tinyurl.com/3sewrg.
was a bunch of sketches and a development board (Figure 6) for the RoboSpinArt machine that was hastily glued back together moments before I was scheduled to talk (Figure 7). When I was done speaking, I got a hearty round of applause and was then peppered with questions about the demo board and how I envisioned the final project taking shape. When we brought the finished machine back for a later show (Figure 8), the crowd was very enthusiastic and many folks came up to ask about details of the mechanisms and how we had solved some of the problems mentioned in the first presentation.

The fact that the folks behind Dorkbot don’t really run Dorkbot so much as set the stage for it to happen makes for an interesting dynamic since there are none of the typical trappings of a managed event. The folks who show up are the ones who get up and talk. The presenters swap places with the audience and there is plenty of opportunity for interaction and collaboration. In order to be featured at Dorkbot, all you have to do is sign up via email and tell the Dorkbot folks what you’d like to do — kinda like a grown-up

RESOURCES

- Dorkbot: http://dorkbot.org
- Dorkbot Austin: www.dorkbotAustin.org
- Cafe Mundi, Austin, TX: www.cafemundi.com
- The Robot Group: www.therobotgroup.org
- The Thereping: www.thethereping.com
- The RoboSpinArt Machine: www.robospinart.com
- PingPongPrinter: www.youtube.com/watch?v=8Ep5Oc3Eo2I
- Poster artwork by Noel Waggener: www.subculturepress.com

PHOTO 5. “Professor Conrad” (a.k.a., Marvin Niebuhr) adjusts one of the instruments from his Screaming Babyhead Band. (Photo by James Delaney.)

PHOTO 6. The SanDraw kinetic sculpture by Rick Abbot and Paul Atkinson. (Photo by James Delaney.)

PHOTO 7. A ceramic, wood, and light bulb sculpture by Denise Scioli.

PHOTO 8. “Gator Girl” animatronic sculpture in aluminum by Brooks Coleman. (Photo by James Delaney.)

PHOTO 9. Paul Atkinson checks out the POV display at Dorkbot SXSW.
version of “show and tell.” You would think this free-form method of (non? dis?) organization would lead to chaos, but every Dorkbot I’ve attended has run surprisingly smooth.

If this sounds like something you’d like to do, but there isn’t a Dorkbot scheduled in your city, you can start your own Dorkbot. All you need to do is send an email to Douglas Repetto (his email address is on the main Dorkbot.org website). He’ll set you up with a mailing list and a link on the main site, and you’re off! If there is a Dorkbot near you, you should make a point of at least attending if not signing up to present something. What better way to meet folks than to stand up before a small crowd of other tech geeks just like yourself and talk about your project?

I’d like to close this month by thanking everyone who has sent in an entry for the Workbench Design Challenge (see the Resources section for a link to the contest details on the Nuts & Volts web forum). I look forward to handing out the prizes! And, if you happen to find yourself at Dorkbot Austin, look around for me there.

Otherwise, you can always reach me via email at vern@txis.com if you have any questions or comments. NV

I’d like to say a special thank you and goodbye to one of the founders of Dorkbot Austin, David Nunez. A good friend and long time collaborator with The Robot Group, we wish him Favorable Chance and Deity Velocity in his endeavors out east!

Dorkbot Austin, look around for me there.

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BLUETOOTH IS 10 YEARS OLD

I am not kidding. It was back in 1998 that this wireless method was conceived by European telecommunications giant Ericsson. Ericsson along with four other companies selected the name Bluetooth and formed the Bluetooth Special Interest Group (SIG) to develop the technology. Now it is the most widely used short-range wireless technology.

BILLIONS SOLD! THERE ARE MORE BLUETOOTH RADIOS ON THE PLANET THAN ANY OTHER

Cambridge Silicon Radio — the leading Bluetooth chip supplier — shipped over 600 million chips in 2007 and is expected to ship about a billion more this year. That’s just one supplier. The total number of chips buried in other products is well over several billion. The reason for such high volume is that the number one use of Bluetooth is to implement the wireless headset in cell phones. That means two Bluetooth chips for each: one in the handset and the other in the ear piece. Most cell phones have this feature today. And since cell phones sell in the one billion per year range, you can see how Bluetooth got to be number one. There are dozens of other uses, as well. ABI Research — a market information company — predicts that about 2.4 billion Bluetooth-enabled products will ship in 2013.

THE BLUETOOTH SIG MANAGES THE STANDARD

The Bluetooth SIG is the organization that develops the technology, establishes the standard, tests for interoperability and certification, and promotes the brand. It is a consortium of over 10,000 companies. And their work is on-going. For more details on this wireless success story, go to www.bluetooth.com or www.bluetooth.org.

BLUETOOTH SPECIFICATIONS AND FEATURES ARE CONTINUOUSLY UPDATED

Bluetooth is a short range technology that operates in the unlicensed 2.4 GHz industrial-scientific-medical (ISM) band. It has to co-exist with Wi-Fi LANs, cordless phones, and microwave ovens, to mention just a few services that also use this band. But it does pretty well with a range up to about 30 feet. The basic output power is 1 mW (0 dBm) but you can use two other power levels for longer ranges: 2.5 mW (4 dBm) and 100 mW (20 dBm).

Bluetooth uses a very robust radio technology called frequency hopping spread spectrum. It chops up the data being sent and transmits chunks of it on up to 75 different frequencies. In its basic mode, the modulation is Gaussian frequency shift keying (GFSK). It can achieve a gross data rate of 1 Mb/s. A more recent upgrade called Enhanced Data Rate (EDR) uses π/4-DQPSK that gives a data rate to 2 Mb/s and 8DPSK that will deliver up to 3 Mb/s.

BLUETOOTH IS A VERY FAMILIAR NAME THESE DAYS if you have a cell phone or laptop. It is a wireless technology that has been around a while and probably can be credited as the start of a whole boat load of short-range wireless technologies. But even if you have heard the name, you may not really know all about it. Here are 10 facts that will update your knowledge of this hot wireless method.
BLUETOOTH PROFILES DEFINE THE APPLICATIONS

The Bluetooth standard defines not only the radio interface just described but also a comprehensive data transmission protocol. The protocol spells out how the data is packaged into packets, transmitted, and received. It is a flexible protocol that can be adapted to almost any type of data. The protocol is implemented in a software stack that defines the sequence of operations. While designers are free to create their own application on top of the Bluetooth protocol, it is a difficult process.

To make Bluetooth more attractive to a wider range of applications, the SIG has developed a wide range of Profiles. These are special software packages designed to implement the most popular applications. The Profiles define the applications. Among the Profiles available are one for cell phone headset, wireless headphones, wireless printer to PC connections, human interface devices (keyboards, mouse, etc.), automotive hands-free kits, cordless phones, fax machine links, video streaming, and a whole bunch of others. The Profiles speed up and simplify the application development and help ensure compatibility of similar products. One popular application is the use of Bluetooth in the hand controllers for the Nintendo Wii game console.

LOW POWER VERSION OF BLUETOOTH NOW AVAILABLE

A couple of years ago, Nokia — the leading cell phone maker — developed a low power wireless technology similar to Bluetooth. Nokia joined with several other companies to develop this technology into a standard. It was called WiBree and a consortium was founded. Last year, the WiBree group merged with the Bluetooth SIG to further develop this method. It uses a simpler version of Bluetooth to significantly cut operating power so that wireless devices can be operated from coin batteries like those in wrist watches.

The goal is to create wearable wireless devices in watches, running shoes, and medical monitoring devices. Many of the newer Bluetooth chips contain the standard Bluetooth transceiver in addition to a low power (LP) transceiver.

HIGHER SPEED VERSION OF BLUETOOTH WILL USE ULTRA WIDEBAND (UWB)

The fastest version of Bluetooth is called EDR and can transmit at a rate up to 3 Mb/s. That is fast enough for most audio and low speed applications and that rate has certainly not limited Bluetooth’s adoption. But for faster data transfers like downloading photos from a digital camera or transmitting video, a faster radio technology is needed.

Recently, the Bluetooth SIG adopted the WiMedia ultra wideband (UWB) radio technology. This wireless standard developed by the WiMedia Alliance can transmit data at a rate to 480 Mb/s over several meters. It uses orthogonal frequency division multiplexing (OFDM) in the 3.1 to 4.7 GHz range. Its main use so far has been a very successful wireless USB cable replacement. The Bluetooth SIG is developing a version of this standard that will carry the Bluetooth protocol and profiles but with the ability to transmit at rates up to the 480 Mb/s range over short distances. The Bluetooth version will operate above 6 GHz and is expected to be available in 2009.

BLUETOOTH TEAMS UP WITH WI-FI TO BOOST DATA RATES

The Bluetooth UWB effort is on-going but in the meantime, the Bluetooth SIG has adopted another way to speed up some transmissions. Specifically, it has created a way to let the Bluetooth protocol and profiles operate over a Wi-Fi radio if present. Wi-Fi is the wireless local area network (WLAN) standard of the IEEE, also known as 802.11. It is available in several versions: a, b, g, and n. Bluetooth radios will incorporate what is called a generic alternate MAC/PHY. MAC means media access control and PHY means physical layer interface. The MAC part of the radio defines how the data is packaged and transmitted while the PHY defines the radio interface like RF and modulation. This alternate MAC/PHY will be able to...
dynamically select either the Bluetooth radio or the Wi-Fi radio based on the need for faster transmission, or not.

**BLUETOOTH IS SUCCESSFUL DESPITE THE COMPETITION**

If you follow the wireless field at all, you know that there are many other wireless standards and methods out there. Most of the short-range technologies are competitive with one another in some way. Yet even with the competition, Bluetooth has carved out a healthy niche, if you can call billions of units sold a niche. Bluetooth had a head start on most of the other technologies and that is partially the reason Bluetooth is so well entrenched. While Bluetooth applications may overlap a bit with Wi-Fi and UWB, the SIG was smart to adopt these technologies to support Bluetooth in some applications. So you can almost write off Wi-Fi and UWB as competition. That leaves ZigBee as the only clear competitor.

ZigBee is that technology developed around the IEEE 802.15.4 standard that targets industrial control, building monitoring and control, remote meter reading, and other applications where sensor outputs are observed and used to initiate controls or record the data. It uses very low power so a ZigBee transceiver can operate for months or even years on a coin battery. ZigBee’s big claim to fame is its ability to form mesh networks among hundreds of radio nodes. While Bluetooth has some limited networking capability, it was not designed for mesh networks. So, while the two technologies may butt heads in a few applications, for the most part each has its own sphere of uses.

The only other short-range technology that may come close to Bluetooth in volume is ISM band radios that operate in the 315, 433, and 915 MHz range. These are used in garage door openers, remote keyless entry devices for vehicles, tire pressure monitoring, remote thermometers, and toys. These devices are usually much simpler so do not need the sophisticated protocol of Bluetooth.

**WHO MAKES BLUETOOTH CHIPS?**

As I mentioned earlier, the leading Bluetooth chip company is Cambridge Silicon Radio (CSR). They were one of the first vendors and they still maintain a wide lead over the others. Other Bluetooth chip companies are Broadcom and Texas Instruments. Figure 1 shows CSR’s latest transceiver chip which incorporates the latest Bluetooth EDR radio, a low power transceiver, a GPS satellite navigation receiver, and a standard FM radio all in one. It is expected that this chip will save lots of space and power when built into cell phones.
My guitar amp and stereo projects became transistorized. I even started to wonder about what was inside of those “magical” calculators. As I transitioned from teen to adult, building stereo equipment and guitar amps gave way to transistor and IC-based logic projects. The transition was complete. Well, not quite.

These days, my guitar amplifiers are all tube-based. However, I’m still “solid-state” when it comes to logic. In past Design Cycle columns, we’ve explored the nuances of many a microcontroller. We have also recently delved into the world of CPLDs. It’s time to move up another step on the logic food chain. In this installment of Design Cycle, we are going to tackle the FPGA.

FPGA 101

FPGA is short for Field Programmable Gate Array. In reality, an FPGA is actually a programmable solderless breadboard populated with interconnectable logic blocks. An FPGA differs from a CPLD (Complex Programmable Logic Device) in that the FPGA contains considerably more logic gates. Also, an FPGA may contain memory and high-level embedded building blocks such as adders and multipliers.

CPLD logic is based on sum-of-product logic arrays that interconnect and feed clocked registers. FPGA logic is rooted in LUTs (Look-Up Tables) such as the one you see in Figure 1. Basically, we can configure the LUT to be any type of logic gate with up to four inputs. The clock signal in Figure 1 would normally be provided by the FPGA’s internal clock routing system. Depending on our desired logical function, the LUT infrastructure allows us to pass our logic output through the D flip-flop for registered operation or bypass the D flip-flop for an unregistered output operation.

The power of the LUT comes in numbers. The FPGA fabric allows for interconnection of a large number of LUTs. Using the FPGA’s internal interconnection fabric allows us to combine the logic contained within a large number of LUTs to generate complex logical operations.

In this spin of Design Cycle, we will be basing our FPGA designs on Xilinx FPGAs. Thus, the generic concept of a LUT is similar to what Xilinx calls a CLB (Configurable Logic Block). A CLB is made up of function generators, registers, and reprogrammable routing controls. Equating a

![Figure 1](image-url)
CLB to Figure 1 illustrates the CLB concept. Translating the Xilinx speak to Figure 1 graphics, the Xilinx “function generators” are actually the look-up table. In terms of an FPGA, a register is synonymous with a latch or a flip-flop. In the case of Figure 1, the Xilinx register is our LUT’s D flip-flop. Reprogrammable routing control is a fancy way of saying multiplexer. Our LUT’s reprogrammable routing control is represented in Figure 1 by the two-input multiplexer at the LUT output.

CLBs are the physical foundation that all Xilinx FPGA designs are built upon. All of the software-generated logical functions are implemented by CLBs. In the Xilinx FPGA we will be working with, a CLB is a wee bit more complex than our simple LUT in Figure 1. A CLB is made up of four interconnected slices. Each slice consists of a pair of LUTs and two dedicated storage elements that can act as flip-flops or latches. One pair of LUTs supports logic and memory functions within the slice. The remaining LUTs in the slice service logic only. This logical arrangement of slices allows the LUTs to be used as 16x1 memory or as 16-bit shift registers.

We will be working with two Xilinx Spartan-3A FPGAs: the XC3S700A and the XC3S50A. The plan is to cut our FPGA teeth with the larger 700A and design our own FPGA hardware with the smaller 50A. To give you a feel for the FPGA size difference, the BGA-packaged 700A contains 1,472 CLBs and 700,000 system gates while the much smaller 144-pin 50A has but 176 CLBs and 50,000 system gates. We’re going with the smaller Spartan-3A FPGA for our hardware design because it is housed in a solder-friendly 144-pin TQFP package.

The whole idea of using an FPGA in an electronic circuit of our design would be null and void if we were unable to access the internal logic of the FPGA. The physical I/O pins of our Xilinx FPGAs are all tied internally to IOBs (Input/Output Blocks). Think of an IOB as a programmable unidirectional or bidirectional I/O interface to the FPGA’s logic blocks. A typical Xilinx IOB has three data paths. On the input path, the logic signal presented at the FPGA pin is routed through an internal buffer that feeds a programmable delay mechanism. The output of the programmable delay block can be routed directly to the FPGA logic or through a latch and then out to the FPGA logic. A simplified block diagram of the FPGA input path is shown in Figure 2.

The second and third data paths work cooperatively to form a programmable output path, which has the ability to be coaxed into high impedance or tri-state mode. Figure 3 gives us an

---

**FIGURE 2.** From a user/programmer standpoint, these FPGAs aren’t as complicated as one might think. Buffers, clocks, multiplexers, and latches are common logic building blocks that I’m sure all of you understand. What you don’t see here are the pull-up/pull-down and ESD components at the input buffer input.

**FIGURE 3.** This graphic is greatly simplified as you really only need to understand the concept. There are actually two storage blocks available in each output path. In addition, the same pull-up/pull-down and ESD circuitry that is made available to the input path is also available to the output path.
executive view of the Xilinx programmable output block. The direct output path looks very similar to our LUT output path. The output signal can be driven by a storage block or simply routed directly to the FPGA output pin via the multiplexer and the three-state output driver. The tri-state output path is used to drive the three-state output driver’s output into high impedance mode. Note that programmable storage elements are present in both of the output paths. To complete the feature set offered by the Xilinx IOB, every signal path that enters an IOB has an associated programmable inverter option.

There’s one more basic thing you need to understand about FPGAs. When the lights go out, so does the FPGA program. Therefore, if we want our LEDs to blink every time we power up our FPGA hardware, we need to include some program storage for the FPGA to boot from. The FPGA program storage can be in the form of serially-interfaced (SPI) or parallel-interfaced memory. We can also get fancy and use a microcontroller to load an FPGA. We’ll be using the official Xilinx Platform Cable USB on the FPGA’s JTAG interface to download our FPGA designs. Using the FPGA JTAG interface for programming the FPGA also opens up the use of Xilinx’s JTAG-accessible Platform Flash as our FPGA boot memory element.

If you had the opportunity to participate in our past Design Cycle CPLD discussions, you’ll see that we are using the very same CPLD support equipment (platform cable USB programmer and ISE WebPACK software) to load our design logic into Xilinx FPGAs. The only thing we’re going to change is our programming language. Instead of using ABEL, we’re going to lay down our FPGA logic with Verilog. Before we start our Verilog coding, let’s take a quick look at the hardware target we’ll be working with.

**THE XILINX SPARTAN-3A FPGA**

Our goal is to build up some home-brew FPGA hardware using a Xilinx XC3S50A like the one you see in Photo 1. Since all of the members of the Spartan-3A family of FPGAs have identical basic characteristics, we can do our preliminary FPGA firmware and hardware design work on a prefabricated Spartan-3A-equipped demo board. The Xilinx Spartan-3A Starter Kit you see in Photo 2 has way more stuff on it than we’re going to need right now. However, the simple and necessary things we’re going to need here (like LEDs, pushbuttons, RS-232 interface circuitry, and an LCD) are included as subsystems in the kit. All we have to do is use the starter kit’s resources to map them into our FPGA application. The mapping is done within ISE WebPACK with the User Constraints Floorplan I/O utility.

As we progress through our FPGA projects, I am going to pull selected items from the Spartan-3A kit and associate them schematically with our Verilog code. If you want to see what the starter kit looks like as a whole from a schematic point of view, you can download the Spartan-3A Starter Kit schematic from the Xilinx.
website. Let’s begin by directing our attention to the bank of LEDs on the starter kit printed circuit board (PCB). We’ll write a bit of Verilog code to instruct the FPGA to do something constructive with the LEDs and slide switches I’ve captured in Photo 3.

**TURNING ON THE LIGHTS WITH VERILOG**

Most of you already know how to program microcontrollers and personal computers in Basic or C. For you C and Basic programmers, picking up Verilog will be effortless. However, since making assumptions turns me into a donkey, I will approach Verilog as if all of you know little to nothing about C, Basic, or Verilog.

I’ve pulled the LED and slide switch area from the schematic and transplanted them into Schematic 1. The 700A is packaged in a BGA (ball grid array) package, which explains the alphanumeric FPGA pin identifiers (W21, Y22, etc.). Since we’re taking hardware pointers from the Spartan-3A starter kit, I’ll point out that all of the LED FPGA I/O pins are located in Bank 1 of the 700A. The reason for this is that Spartan-3A FPGAs allow up to 24 mA of drive current from I/O pins located in Bank 1 and Bank 3.

Banks 0 and 2 are only able to supply a maximum of 16 mA of drive current. The slide switches are also strategically pinned to the 700A. All of the slide switches are pinned to dedicated FPGA input pins located in Bank 2. From the perspective of our targeted 50A, here’s how the FPGA bank pins fall out:

- **Bank 0 = pins 109 – 144**
- **Bank 1 = pins 73 – 108**
- **Bank 2 = pins 37 – 72**
- **Bank 3 = pins 1 – 36**

That works out to a bank being a complete side of the square FPGA package you see in Photo 1. If you orient pin 1 of the 50A in the upper left corner (looking down onto the legend side of the FPGA IC), Bank 0 consists of the pins along the top pin row of the FPGA. The successive FPGA banks flow in a clockwise direction with Bank 1 being made up of the right-hand pin column of the 50A. Bank 2 runs along the bottom row of the FPGA and Bank 3 is positioned in the left-hand column of pins opposite to Bank 1. Believe it or not, the same banking scheme is applied to the 700A BGA package with ball A1 oriented in the upper left corner and ball AB22 in the bottom right corner.

One must understand the basic I/O principles of a microcontroller before being able to code more complex I/O-oriented tasks. The same holds true for FPGAs. So, let’s write some Verilog code that will mirror the slide switch positions in the LED bank. A slide switch is in the “ON” position when the slide switch common terminal presents a logical high to the FPGA. Conversely, the slide switch “OFF” state is represented by a logical low at the FPGA input pin. We’ll illuminate the corresponding LED when a slide switch is “ON.”

Verilog is based on modules. Verilog modules use ports as I/O mechanisms. The arguments associated with a module are contained in the port list, which follows the name of the module in the module declaration. Consider this Verilog code snippet:

```verilog
module slide_to_led(
    input sw0_in,
    input sw1_in,
    input sw2_in,
    input sw3_in,
    output led0_out,
    output led1_out,
    output led2_out,
    output led3_out
);

endmodule
```

Our first Verilog module is called slide_to_led. The module ports (arguments) consist of our slide switch inputs and four of the LEDs which are defined as outputs. Note the use of commas, parentheses, and a semicolon to bracket the port list. That looks a
lot like C to me. As we add more Verilog source, you’ll notice the minimal use of braces ({}). Verilog likes to replace braces we use so often in C with begin and end statements. Braces do have a place in the Verilog scheme of things as Verilog employs braces to concatenate and replicate.

Our slide_to_led code won’t do much in its current state. Since we want to control the LEDs with the slide switches, the most logical Verilog code would look like this:

```
module slide_to_led(
    input sw0_in,
    input sw1_in,
    input sw2_in,
    input sw3_in,
    output led0_out,
    output led1_out,
    output led2_out,
    output led3_out
);
always @(sw0_in,sw1_in,sw2_in,sw3_in)
begin
    if(sw0_in)
        led0_out = 1;
    else
        led0_out = 0;
    // if/else code for rest of switches goes here
end
endmodule
```

Naturally, we would include the appropriate if/else statements to cover all of the rest of the LEDs and slide switches. The Verilog if/else statements are just like their C counterparts with the exception of the C braces, which are replaced by Verilog begin and end operators when the need arises. The good old do/while(1) loop-forever C code has been replaced here by the Verilog always @ loop code. Everything between begin and end inside of the always loop is executed every time one of the slide switch logic levels is changed. In other words, a Verilog always loop runs freely and triggers on the arguments in the sensitivity list. In our case, the logic levels of the slide switches make up our always @ sensitivity list. There are times when you can run a Verilog always loop without a sensitivity list. Doing a plain vanilla always loop is just like running a never-ending while(1) C loop.

After all of that typing, we would find that this code doesn’t work. The key to writing some working code lies behind understanding what Verilog is doing to us here. Here’s what the code really looks like under the Verilog covers:

```
module slide_to_led(
    input wire sw0_in,  // added wire for clarity
    input wire sw1_in,  // added wire for clarity
    input wire sw2_in,  // added wire for clarity
    input wire sw3_in,  // added wire for clarity
    output wire led0_out,
    output wire led1_out,  // added wire for clarity
    output wire led2_out,
    output wire led3_out  // added wire for clarity
);
always @(sw0_in,sw1_in,sw2_in,sw3_in)
begin
    if(sw0_in)
        led0_out = 1;
    else
        led0_out = 0;
    // if/else code for rest of switches goes here
end
endmodule
```

Verilog uses the data type wire to connect modules and gates. Think of a Verilog wire just as you would a piece of wire in one of your electronic projects. I added the Verilog wire data type into our Verilog module manually for illustrative purposes as Verilog defaults all of the module arguments to the data type of wire. Verilog wires can only be read/driven by a continuous assignment statement or tied to an input or output of a module or gate. Thus, we can’t write a logical “1” or logical “0” directly to led0_out as we attempted to do in our Verilog module code because led0_out is a Verilog wire.

The fix for our faulty Verilog module is simple:

```
module slide_to_led(
    input wire sw0_in,  // added wire for clarity
    input wire sw1_in,  // added wire for clarity
    input wire sw2_in,  // added wire for clarity
    input wire sw3_in,  // added wire for clarity
    output reg led0_out,  // added reg data type for clarity
    output reg led1_out,  // added reg data type for clarity
    output reg led2_out,  // added reg data type for clarity
    output reg led3_out  // added reg data type for clarity
);
always @(sw0_in,sw1_in,sw2_in,sw3_in)
begin
    if(sw0_in)
        led0_out = 1;
    else
        led0_out = 0;
    // if/else code for rest of switches goes here
end
endmodule
```

The Verilog data type reg is short for register. Verilog registers are able to hold their values from procedure to procedure. We can also read them and write them. Don’t get too cozy with the concept of a Verilog register being a piece of silicon as reg is a Verilog data type just like a Verilog wire. All we really care about is how, when, and where to use regs and wires best.

Now would be a good time to show you how continuous assignment works. Let’s use our original default-to-wire module code and add some Verilog assignment code to handle getting the slide switch states out to the LEDs:

```
module slide_to_led(
    input wire sw0_in,  // added wire for clarity
    input wire sw1_in,  // added wire for clarity
    input wire sw2_in,  // added wire for clarity
    input wire sw3_in,  // added wire for clarity
    output wire led0_out,
    output wire led1_out,  // added wire for clarity
    output wire led2_out,  // added wire for clarity
    output wire led3_out  // added wire for clarity
);
always @(sw0_in,sw1_in,sw2_in,sw3_in)
begin
    if(sw0_in)
        led0_out = 1;
    else
        led0_out = 0;
    // if/else code for rest of switches goes here
end
endmodule
```

The fix for our faulty Verilog module is simple:
module slide_to_led(
  input sw0_in,
  input sw1_in,
  input sw2_in,
  input sw3_in,
  output led0_out,
  output led1_out,
  output led2_out,
  output led3_out
);

reg led0;
reg led1;
reg led2;
reg led3;

assign led0_out = led0;
assign led1_out = led1;
assign led2_out = led2;
assign led3_out = led3;

always @(sw0_in,sw1_in,sw2_in,sw3_in)
begin
  if(sw0_in)
    led0 = 1;
  else
    led0 = 0;
  if(sw1_in)
    led1 = 1;
  else
    led1 = 0;
  if(sw2_in)
    led2 = 1;
  else
    led2 = 0;
  if(sw3_in)
    led3 = 1;
  else
    led3 = 0;
end
endmodule

Note that I removed all of the explicit data type definitions. Doing that allows all of our port arguments (inputs and outputs) to default to wire. We have already proven that we can’t directly drive a Verilog wire with code alone. So, we have to add something to our Verilog code to drive the ledx_out wires. That “something” is a quartet of Verilog registers: led0, led1, led2, and led3. To have the newly added Verilog regs drive the Verilog LED output wires, we assign each of the ledx registers to its logically associated ledx_out wire. The rest of the if/else Verilog code remains the same, sorta. Note that now we must write to our newly added ledx registers as our ledx_out entries are now Verilog wires.

FPGAs are natural born counters. Now that we have a grasp on FPGA I/O operations, let’s build on our Verilog knowledge and code up an eight-bit counter that reveals itself via the LEDs.

SOURCES
Xilinx — www.xilinx.com
XC3S50A; XC3S700A; ISE WebPACK;
Spartan-3A Starter Kit; Platform Cable USB
Saelig — www.saelig.com
CleverScope

BLINKING THE LIGHTS WITH VERILOG

The Spartan-3A starter kit is equipped with an on-board 50 MHz oscillator. There’s no way we humans can see a 50 MHz scan rate in the LED bank. So, we must divide the incoming 50 MHz clock to produce a scan rate that we can see in the LED bank. To keep things simple, we’ll craft our clock divider to run on powers of 2.

Let’s shoot for a scan rate of around 10 Hz. That means that we must divide our 50 MHz clock by 5,000,000. The divisor value in hexadecimal is 0x4C4B40. The idea is to key our clock divider on an overflow of the most significant bit. We can’t do that accurately with 0x4C4B40. So, let’s use 0x3FFFFF as our clock divisor. We’ll count from 0 to 0x3FFFFF and reset our divisor when it rolls over to 0x400000. Let’s do the math to see what scan rate that will give us:

\[
\text{Scan rate} = \frac{50,000,000 \text{ Hz}}{0x3FFFFF} = \frac{50,000,000}{4,194,303} \text{ Hz} = 11.92 \text{ Hz}
\]

To double-check our scan rate math, let’s compute the period of 11.92 Hz and take a snapshot of the scan rate with a CleverScope:

\[
\text{Period of } 11.92 \text{ Hz} = \frac{1}{11.92} = 0.084 \text{ seconds or 84 ms}
\]

Screenshot 1 confirms our scan rate. Here’s the Verilog code that produced the waveform you see in Screenshot 1:

module led_cntr_code(
  input clk,
  output reg [7:0] led_out
);

reg [22:0] clk_divider;
always @posedge clk
begin
  clk_divider <= clk_divider + 1;
  if(clk_divider[22])
    begin
      clk_divider[22] <= 0;
      led_out <= led_out + 1;
    end
end
endmodule

There’s some new stuff in the LED counter code. However, I don’t think you’ll have any problems figuring out what our Verilog code is doing. Our 50 MHz clock is fed into the FPGA via the clk input, which is assigned to an FPGA clock input pin (E12). The LED output is defined as an eight-bit (bits 7 through 0) register with each of its led_out LED pins tied to an FPGA output pin as specified in Schematic 1. Our 23-bit clock divider register collects the 50 MHz ticks and is reset every time the most significant bit (bit 23) is equal to 1. At every clock divider reset, the led_out register is incremented and the LEDs reflect the value of the led_out register.

Note that our “always” sensitivity list is focused on the rising edge of every clock cycle of the incoming 50 MHz clock. Thus, this always loop’s contents are executed on
every rising edge of the 50 MHz clock. Note also that the "=" operator we used in our slide switch code has been replaced with "<=" in our counter code. The "=" operator is called a procedural blocking assignment, which means that statements that use it will execute in the order of their appearance. When blocking is employed, the next statement will not execute until the current statement execution has completed. The "<=" operator is non-blocking. All non-blocking statements execute in parallel. As the non-blocking operator infers, the non-blocking statements are evaluated right to left. Non-blocking operation closely models a physical flip-flop and should be used in clocked always loops. Blocking statements are best suited for combinatorial logic like our slide switch code.

DUST OFF YOUR SOLDERING IRON

... because next time we’re going to build up our own homebrewed XC3S50A FPGA hardware. All of the Verilog code in this installment of Design Cycle was written using Xilinx ISE WebPACK version 10.1.01, which is a free download from the Xilinx website. I’ve stuffed all of the projects into a download package on the Nuts & Volts website (www.nutsvolts.com) so you can run the FPGA projects just as we ran them here. You don’t need any FPGA hardware to compile the project code. I’ve included the entire project file set for both projects so that you can look at all of the ISE WebPACK options and settings. For instance, if you’re wondering how I assigned FPGA pins to the LEDs and slide switches, you can see how I did it by looking at the User Constraints Floorplan I/O utility entries, which are available from the ISE WebPACK Processes window. With our FPGA projects verified on the Spartan-3A starter kit, we now have some known-good test code we can run on the XC3S50A hardware we’ll build up in the next edition of Design Cycle. 

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less bandwidth, don’t send all the sync info. H/V sync in the analog signal takes up about 20% of the bandwidth. In the digital world, all that can take up one byte. Saved a bunch of space there!!! Do some creative compression, data processing, error correction, remove parts of the image people won’t notice, and before you know it you have squeezed that digital signal into less space than the analog one.

I get tired of everyone saying that the digital signal is better — it’s not all the time. I would tell people if they thought that, then they haven’t seen a really good analog signal! If you take a good look at a digital TV picture, you will see lots of picture faults. Most people don’t notice these faults and the broadcast companies can get away with it. If, in the past, a broadcast company broadcast a picture with as many impairments as in the digital picture, their phones would be ringing off the hook. Thank you for your time.

Donovan Stenger
Broadcast Technologist

TRYING TO TUNE IN

Apparently I always have things backwards! If the advertisers are to be believed, the whole world wants to watch video on their iPod, iPhone, or laptop. Apple even comes out with iTV figuring people’s monitors to be smaller than the wide screen TVs they are sure to own. Not me!

I have an Apple 30” Cinema Display connected to a 2 GHz dual G5 running Mac OSX 10.4.x Thanks to iDVD, I can watch DVDs on this, but the problem came with trying to watch cable TV.

When I upgraded from analog to digital cable service from Time/Warner, I insisted on a set top box E/W a Firewire® output. After connecting everything together, the G5 reports seeing the Scientific Atlanta “Explorer” 3250HD STB at the Firewire input, but refuses to T anything with it.

In the interim, I have opted to use a MIGLIA TVMini HD (now discontinued) digital over-the-air tuner. The FCC in its infinite wisdom has edicted (if the news readers on TV can make “impact” a verb, why not “edict”?) all broadcast TV stations to have digital over-the-air programming. These are on other frequencies from their VHF/UHF programming. The MIGLIA tuner outputs on USB 2.0 and came with a driver package called eyeTV2. Unfortunately, the password issued for the tuner restricts the driver to only access the USB port, even though there are other drivers provided which may have made the Firewire port available for input, and thus the STB viewable.

There are channels from my STB that I cannot get from local broadcasters that I wish to view with my setup. I can only assume that the STB must utilize a standard protocol if it is to be compatible with any TV set that has a Firewire input. There are discussions on line about recording from STBs, my only interest is to view. Please, do you have any advice?

Thanks in advance for your most kind consideration.

Tall Henning

Response: You have quite a nice setup there. While Firewire has been around for a while, it’s not in common use to connect home theater equipment. The Scientific Atlanta “Explorer” 3250HD you have specifies the Firewire connectors as “reserved for future use.” Depending upon which of the two main software OS your box is running, these connectors may someday be active. Until then, I think you will have to find another way to hook up your STB.

I assume you are using your Mac as the hub, probably hoping to let it perform DVR functions. If not, I would suggest replacing the STB with a unit that has DVI or HDMI output. You could use a DVI switch (perhaps w/remote control) to toggle between the computer and STB. And you could have a DVR in the STB as well (for a fee, of course).

Probably not what you wanted to hear, but unless you want to go shopping for a new STB (cable companies are now required by law to let you buy your own), there’s nothing else you can do.

Jeff Mazur
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*** QUESTIONS ***

I’m looking for information on power line communication systems. Does the US power grid broadcast any information that can be read from the power lines coming into my home? Are there any projects that can tap that information?

Steven Van Epps via email

I need info on refurbishing or building custom solar yard lights. I currently have a Lighthouse lawn ornament that has a solar light that doesn’t recharge the replaceable rechargeable battery. Information on troubleshooting would be helpful for what I assume to be a fairly common circuit. I would also like to illuminate the lantern of a Lawn Jockey and a Pagoda. Adding multiple LEDs with changing colors and blinking patterns could also be a take off. Anyone have a circuit?

Mike Hoffert via email

#8084 - May 2008

I’m looking for an affordable (US) PCB MFG who specializes in prototype quantities (<100) of COB (chip on board) from DIE that I provide. I need a company who can lead-attach the DIE and epoxy-seal it, forming a COB PCB.

#1 I found these companies online. They offer prototype services among others.

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www.idaxlabs.com/services.asp

Quik-Pak
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Daryl via internet

#2 I have had prototype and full production PCBs made with the company listed below, with excellent personal service, board quality, and pricing without any problems for over 25 years. They are directly associated with several companies that will provide your requests with great satisfaction.

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John F. Mastromoro
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#3 Hybrid Design Associates www.hda-smc.com/ in Tempe, AZ may be

Daryl via internet
able to help you. They are not inexpensive, but they are capable of doing almost any COB assembly.

Robert Zusman
Scottsdale, AZ

[#6081 - May 2008]
Has anyone adapted surplus computer parts for other uses? For example: adapting on old sound card for use as an amplifier. If so, please tell what you did and how. Also, can someone explain the similarities and differences between audio CDs and DVDs?

#1 The power supply in the PC can be used, with just a small modification. There are a number of write-ups telling you how on the web — here's one: http://web2.murraystate.edu/andy.batts/ps/powersupply.htm

You can find many uses for parts scavenged from old PCs.

Figure 1 is a zener tester circuit built exclusively from parts out of a defective CRT monitor. Attach a volt meter and the zener to be tested across the DUT terminals. The meter measures the zener voltage on zeners up to about 100 volts. The oscillator and transformer produce the high (about 100) voltage; the Q2-Q3 circuit limits the current to about 12 mA. The meter and the zener to be tested are established every time the PC boots. It's better to view these surplus cards as a source for components, and/or as practice for soldering rather than for adaptation to other projects.

All compact discs (CDs) operate on the same principle that was invented by Philips and Sony in 1980 and presented as the “Red Book” Standard further defined a WORM (Write Once Read Many) disk that can be recorded by an end user drive — called CD-R — and a fully read-erase-write disk called CD-RW, by “burning” the inner disk surface with a higher power laser.

Various speed enhancements have been made; the 1X disk spins at approximately 200-500 RPM, and records in real time (80 mins audio or 700 MB data for a complete disk), currently 52X drives record the same 700 MB of data in about 90 seconds!

The DVD uses a 650 nm (visible red, same as a laser pointer) reading laser, and is also available as a WORM disk and erasable disk media. There are three standards in common use causing confusion. The “plus” standard (DVD+R) can only be recorded once, unlike the “minus” standard (DVD-R, DVD-RW) and DVD-RAM standard. DVD-RAM is popular with camcorders and personal video recorders since 1998, and stores data in concentric tracks (like a hard drive or floppy) while CD, DVD+R, and DVD-R use a spiral track.

The DVD disks can have data on both sides, and are further enhanced by “dual-layer” technology that allows data to be stored on a second internal layer.

The latest addition to optical media is the Blu-Ray disk which uses a 405 nm wavelength laser — allowing a six fold increase in data storage compared to DVD. Blu-Ray (BR) technology became the winner of the recent high definition disk format wars.
when Toshiba abandoned the competing DVD HD format is February 2008.

Peter Stonard
Campbell, CA

[#6083 - May 2008]

How can I configure a small LCD display as a voltmeter and/or amp meter?

#1 The raw LCD component is a glass screen with the LCD liquid sandwiched inside and transparent terminals that usually connect to a socket, ribbon cable, or other PCB-friendly contacts, such as this one http://tinyurl.com/4hxuv6. An LCD module is similar but has the driver electronics embedded on the glass. The raw display needs the electronics to be added, and both voltage levels and timing are critical to operate the LCD – so an LCD module with interface electronics is preferred.

Starting with an LCD module, such as http://tinyurl.com/4enbco would still require additional circuits to scale the analog input voltage, rectify it for AC ranges, and convert it to a digital data stream that is decoded to drive the LCD display. There are custom and Application Specific Integrated Circuits (ASIC) to do this, and these are built into commercial LCD voltmeter modules – which can be had for little money on auction sites.

To build an LCD voltmeter from scratch would be uneconomical but fun for a hobbyist. A good place to start is with an Application Specific Standard Product (ASSP) like http://tinyurl.com/4rbvjs. Another approach would involve a uC (microcontroller) – many of which have ADC converters and I/O for driving an LCD module on a single chip.

Peter Stonard
Campbell, CA

#2 There are basically two ways this can be done, depending upon the type of LCD display you want to use. The easiest way is to use a digital panel meter (available from quite a few N&V advertisers), LCD, or LED, with a voltage divider for the voltmeter application or a shunt for the ammeter. (Figure 2) The other way is to use a microcontroller with an A/D converter driving a HD44780-based LCD panel. There are several books which cover this subject quite well: Programming the PIC Microcontroller with MBasic by Jack Smith is an excellent starting point using Basic as the programming language and Advanced PIC Microcontroller Projects in C by Dogan Ibrahim if you want to use C. PIC in Practice by D.W. Smith covers this subject quite well.

Walter Heissenberger
Hancock, NH

Figure 2

[7083 - July 2008]

How can I interface data collecting hardware (data loggers and real-time hardware) with Microsoft Excel through serial or USB ports?

#1 There are two parts to solving this job. Communication between the PC and data loggers, and converting the data to a format that MS Excel understands. If the data loggers/real time hardware store the data, then send it on command; a serial terminal program (like Hyperterminal) with "capture to file" turned on may be used to collect the data. On the other hand, if the data loggers send the data as it happens, then a specialized communication program is needed. This is because Hyperterminal isn't designed to have capture to file left on for long periods. For a format that MS Excel understands, I suggest CSV (Comma Separated Values) files. This would be done with a program or script that parses the raw data and creates the CSV file. A USB-to-serial converter looks like a serial port, allowing terminal programs to work over USB connections. A data logger that has a USB port — instead of a serial port — should come with an interface program for the PC.

Dale Yarker
via email

#2 There are several low cost Shareware utilities that can read data from your COM port and populate a MS Excel spreadsheet, for example: COMxL RS232C from Lye-tech, http://tinyurl.com/4ac7xr

Peter Stonard
Campbell, CA

#3 I am assuming that you already have the serial signal, therefore you need a software fix. Windmill Software Ltd. has a free RS-232 instrument driver with their Windmill 4.3 software suite. For the free data acquisition software, go to www.windmill.co.uk/jsarrdms.htm. They also have a newsletter that is worth subscribing to.

Steve Lueck
Bisbee, AZ
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August 2008 Nuts & Volts 97
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**Mini RF Transmitter, Receiver & Transceivers**

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C Compiler for the Propeller Chip

ImageCraft’s ICC for Propeller Software is an ANSI C development tool for the Parallax Propeller chip. The IDE features project-based design and supports C86 dialect source and C-based Propeller objects. The Propellent library is directly supported by the IDE for ease in build-to-run development cycles. ICC for Propeller comes in a non-commercial or STD version.

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- Optimizations
- Assembler / linker
- Libraries
- Documentation
- Technical support
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- Access Propeller multiprocessing and other Propeller-specific features in C
- Write native assembly code and launch it in another Cog for high performance driver
  - Built-in terminal
  - Integrated Parallax Propellent Library for program downloading
  - Includes libraries such as ASynclO, VGA Text, etc.
- Non-Commercial edition supports programs up to 16 K

Note: There is currently no C source level debugger.

ICCV7 for Propeller Product Editions:

Non-Commerical (#32380; $99.00): ANSI C compiler for Propeller LMM code generation. IDE with editor, project manager and code browser. Supports programs as large as 16K.

Standard (#32385; $249.00): ANSI C compiler for Propeller LMM code generation. IDE with editor, project manager and code browser. Supports programs as large as Hub RAM.

For more information or to order ImageCraft’s ICC for Propeller Software online visit www.parallax.com. Or call our Sales Department toll-free 888-512-1024 (Mon-Fri 7:00 a.m. - 5:00 p.m., PDT).

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