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Recommended with this kit:
• Hand Controller Cat. KC-5536 $39.50
• RS232 Cable Cat. WC-7502 $7.00

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Starting Out

One of the most common topics of my email discussions with young readers is how to get started in electronics. To someone new to the hobby, it can be a bewildering first encounter — there’s the vocabulary, the physics, the components, the tools, and (of course) the cost. My advice to novices is to start simple, establish a good work environment and habits, use the appropriate tools and instruments, and, above all, find a mentor.

If you’re just starting your adventure in electronics, keep it simple and affordable. You don’t need a room full of test gear or a $1,000 parts library to get going. I’d start with teardowns. Take apart and analyze whatever you can get your hands on — from kitchen appliances to discarded computers. You really shouldn’t try building something before you’ve studied how electrical and electronic devices are put together. Stick with low voltage devices. There’s no need to get knocked to the floor while disassembling an old TV set that hasn’t been fully discharged. Establishing a good work environment and work habits is essential — especially when you start dealing with live components and devices. Your work area should be well lit, adequately ventilated, and immune to flying pieces of wire and the spray of molten solder. A Formica countertop or kitchen table will do; just protect the surface from dings, scratches, and the heat from your soldering iron. You can move up to a butcher-block workbench with a vise or third-hand tool later.

As far as work habits go, definitely get in the habit of wearing safety glasses. It’s amazing how far a resistor lead can travel once it’s clipped from a circuit board. Or, how far solder can splash. Protect your vision. You should also develop the habit of washing your hands. Even if you use leadless solder, components and circuit boards invariably carry traces of heavy metals and other noxious substances that you shouldn’t ingest. From a safety perspective, use the tools most appropriate for the job. Assuming your tool kit includes the basics — a soldering iron, needle-nose pliers, crescent wrench, diagonal cutters, and a few screwdrivers — this means using the crescent wrench to remove a nut. If you use the needle-nose pliers, they’ll likely slip and either pinch your hand or impale your foot. Not a good outcome for you or your tools.

As you gain experience, you’ll want to increase your arsenal of tools to include tweezers, a hex driver set, drill, and illuminated magnifying glass. A lightweight, desktop vise will enable you to work with small devices and rework circuit boards. Your interests will dictate the types of tools you’ll eventually need. For example, if you’re into appliances, you’ll want tough tools made for heavy gauge work. Conversely, if you’re working with surface-mount...
components, you’ll appreciate delicate, finely crafted tools. Learn the operating range of your tools—most cutters and pliers are rated for wire type and gauge. The only instrument you really need on your workbench is a digital multimeter. You’ll find the resistance function useful for tracing circuits, verifying component values, and the voltage function indispensable for verifying that high voltage capacitors are discharged. You may be dreaming of an oscilloscope, but you really don’t need one until you start designing and debugging complex digital circuits. In the meantime, you can keep an eye out for bargains on eBay and local flea markets for deals on used but functional equipment. As you progress to designing and building your own circuits, you can gradually add the tools and instruments that suit your particular interests and budget. The most important prescription for success is to find a mentor—preferably someone who has worked professionally in the field of electronics. The ideal mentor will be able to teach you diagnostic and construction techniques while keeping you motivated when you hit the inevitable speed bumps. Who knows, your mentor might even steer you into a career in electronics engineering. **NV**

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ADVANCED TECHNOLOGY

WIPING OUT WIRING, PART 1

With the development of wireless routers, Bluetooth devices, wireless keyboards, et al., we've made pretty good progress in the quest to eliminate all those pesky wire interconnects in the office. But some Purdue University (www.purdue.edu) researchers are working on a technology that could cut the communications copper for all of the devices in your home or office, including HD TV, radio, projectors, and whatever. The idea is to transmit all communications from a single base station which would consist of a dedicated computer or perhaps just a card inserted into an expansion slot in an existing one.

"The central computer would take charge of all the information processing, a single point of contact that interacts with the external world in receiving and sending information," according to Prof. Minghao Qi. "We're not talking about conventional RF technology, however. Rather than operating in the noisy 2.4 GHz band, the Purdue system transmits at 60 GHz. This is accomplished by converting ultrafast laser pulses into RF signals using newly developed "microring resonators" that sidestep the limitations of standard digital-to-analog converters, and eliminate the need for large "bulk optics" systems that use optical components to achieve the same thing. By combining a series of microrings into a programmable "spectral shaper," the system can be set to transmit only certain frequencies. Because no one — including the FCC — regulates signals in the range of 57 to 64 GHz, the system could be implemented on a worldwide basis with universal compatibility. Purdue filed for a provisional patent last January, but Qi noted that the technology is still at least five years away from commercialization.

WIPING OUT WIRING, PART 2

Taking a more direct approach to converting light into broadband is a concept recently demonstrated by Jelena Vucic and associates, of the Fraunhofer Institute for Telecommunications, Heinrich Hertz Institute (www.hhi.fraunhofer.de). The idea here is to harness things like simple desk lamps to transmit visible-frequency wireless data. You simply impose high frequency flicker on all of the lights in a room in unison. A minor snag is that incandescent and fluorescent lights aren't capable of flickering fast enough, so the lights have to be LED based. Although present commercial LEDs have a limited bandwidth, the Fraunhofer researchers have achieved a tenfold bandwidth increase by filtering out the blue part of the spectrum. Their first wireless system achieved data rates of 100 Mb/s in the lab, and the latest upgraded system has hit 230 Mb/s. This still isn't earth-shattering speed, but Vucic says a more sophisticated modulation signal should allow the rate to be doubled again. An interesting consideration is that — unlike RF signals — visible-light transmissions cannot pass through walls or other opaque barriers. That's both a limitation and an advantage, though, as securing your facility against eavesdroppers would be pretty much just a matter of closing your curtains.

MAXWELL’S DEMON DISCOVERED?

A team at Massachusetts Institute of Technology (www.mit.edu) has figured out a way to transform polyethylene — usually a great electrical insulator but poor heat conductor — into a material that can dissipate heat as well as most metals. This has obvious potential in applications ranging from heatsinks in electronics to solar collectors and heat exchangers. The interesting facet is that (according to MIT) the material will "conduct heat very efficiently in just one direction unlike metals which conduct equally well in all directions." This sounds eerily similar to James Clerk Maxwell's hypothetical concept of a two-chambered box in which a gatekeeper (the demon) would allow only high velocity molecules to pass from chamber A to B and low velocity ones from B to A, thus increasing the temperature in B and lowering it in A. This would provide an exception to the second law of thermodynamics. Can the MIT material qualify as the demon? Well, not likely. But it should make one heck of a thermos bottle.
COMPUTERS AND NETWORKING

BUTTERFLIES ARE NOT FREE

You know things are slow in the PC business when the most newsworthy item is based on a fashion statement, but here it is. Back in March, Hewlett Packard and "world-renowned" designer Vivienne Tam (whot) brought forth the concept of "digital clutch chic" in the form of an HP Mini 210 netbook incorporating Tam's "Butterfly Lovers" design motif. Said Tam, "To me, butterflies symbolize love, freedom, independence, and transformation. Together we bring life, color, and personality to the computer world, creating fashionable technology for modern women."

Billed as the next must-have accessory, the unit includes a built-in webcam that turns it into an instant digital mirror, allowing the user to discreetly admire her botox or wipe caviar off her chin. It incorporates a special butterfly start menu, custom Tam icons, and three wallpapers that coordinate with the design. In addition, it comes with a matching microfiber (i.e., fake) suede sleeve and (optionally) a Butterfly Lovers wireless mouse and a set of in-ear headphones to take advantage of the Beats Audio feature. "Fashion-forward women around the globe can reserve theirs now at www.hp.com/vivienmetam."

Note, however, that the Tam Edition netbook starts at $599 ($804.98 with the recommended options), as opposed to the $279 list on the standard model. You can always get really nice butterfly decals for a buck or two at your local Walmart instead.

ALL-IN-ONE FOR HOME OFFICE

Kodak's latest offering for the home office market is the ESP Office 6150 all-in-one printer, with "all" meaning inkjet printing, copying, scanning, and fax capabilities in one unit. The 6150 continues Kodak's marketing focus on the price of its ink cartridge which it says is the lowest in the industry. The company claims that its products save consumers an average of $110 per year on ink based on as few as four pages per day. In addition to the basic four functions, the 6150 offers Wi-Fi and Ethernet connectivity with a range of devices, including Blackberry smart phones, iPhones, and the iPod Touch. You get print rates of up to 32/30 ppm and copy rates of 27/26 cpm (black/color), a 200-page paper tray, two-sided printing, and scan resolution up to 1,200 dpi. Faxing is done at 33.6 kbps, and the machine includes a 30-page document feeder. The list price is $229.

INDUSTRY AND THE PROFESSION

WIND FARM ANNIVERSARY

Wind farms still seem a bit futuristic but, in fact, 2010 marks the 30th anniversary of the world's first installation. It was created by US Windpower and employed 20 turbines rated at 30 kW each, perched atop New Hampshire's Crotch Mountain. Unfortunately, the company underestimated how much wind would be available, and the turbines experienced repeated mechanical failure, so the Crotch Mountain facility itself was a failure. The company later changed its name to Kenetech, improved its designs, and built some wind farms in California. At one point, it was the world's number one turbine manufacturer and wind farm developer. However, continuing design problems, overly optimistic development plans, and a weak market eventually contributed to its downfall, and it filed for bankruptcy in 1996. Enron Wind acquired its turbine designs and other assets, which in 2002 finally were bought by GE for about $358 million in a court-supervised bankruptcy auction.

May 2010 NUTS & VOLTS 11
CIRCUITS AND DEVICES

NEW ‘SCOPES INTRODUCED

If you're shopping for a new oscilloscope, Agilent has a bunch of new choices for you. It recently added 14 new models to the InfiniVision 7000 series mixed-signal and digital-storage oscilloscope lineup, offering bandwidths from 100 MHz to 1 GHz. In addition to the standard analog representations, they provide digital signal capture and serial bus triggering and decode. Custom ICs provide accelerated operation and display up to 100,000 waveforms per second to capture signal detail and intermittent events. It offers a range of features including a 12.1 inch display of up to 20 simultaneous channels; rapid core-assisted debug of designs with Xilinx or Altera FPGAs; segmented memory for analysis of laser pulses, radar bursts, and serial packets; offline PC viewing and sharing of previously acquired scope data; and RF contextual viewing of scope data using vector signal analysis software. Details are available at www.agilent.com/find/7000B. Prices range from $4,995 for the base 100 MHz unit and top off at $19,500.

AFFORDABLE NIGHT VISION

Many of us have kicked around the idea of buying a night vision system but have been put off by the price. But Bushnell (www.bushnell.com) may have a deal for you within its StealthView product lineup. If you can live with a monocular unit and don't need military-level technology, the Nightwatch unit might be the way to go. It uses active rather than passive infrared illumination, so a human subject could conceivably figure out what you're up to. If your objective is general security and surveillance, cave exploration, night fishing and boating, wildlife observation, or just fooling around, that shouldn't be a problem either. The units use CMOS chips to convert light into an image that is displayed on an LCD flat panel screen in black and white, plus a video output port allows you to record images on a camcorder or laptop. All Stealthviews have dual IR illumination diodes; one is on at all times for short-range scenes, and the other is an IR spotlight that allows viewing of objects up to 200 ft (61 m) away. A waterproof model is available. The price is a bit difficult to tack down, as the Bushnell website offers the Nightwatch model for $326.95. Amazon and other sites list it for as little as $139, so it pays to shop around.

LIGHT TUBES IN NEW SIZES

If you're designing or building lighting for electronics, architecture, edge illumination, alarm systems, indirect illumination, etc., you might note Elma Electronic's expanded line of LED light tubes with new five and 10 mm options supplementing the existing six and eight mm ones. The tubes' modular design allows a range of lengths (up to 2 m) and shapes, and the housings come in double-ended or optional single-ended configurations. Cited features include a variety of light direction, brightness, and color options; high ESD resistance and mechanical strength; suitability for use on all infrared and vapor-phase soldering systems; and low current, long life operation. Pricing depends on volume, length, and configuration, so you'll need to visit www.elma.com for more information.
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SPINNING UP FUN WITH ENCODERS

In my dual life that crosses between the technical and entertainment worlds, I have the incredible good fortune to meet some really great people. Case in point: I was contacted by a cool cat named Wayne (dubbed “the Brain” by his friends) who (like me) is an electronics enthusiast and embedded programmer, who also works in show biz. Wayne’s entertainment gig is in music, engineering, and mixing songs for some amazing A-List Pop, R&B, and Hip-Hop artists. Wayne needed a little help with an encoder for a personal project. Coincidentally, one of my customers had asked about adding a local user interface to a product. So, while working with Wayne, I solved my own problem and will show you what I came up with so you can put it to use, too. And while we’re on the topic of expanding inputs with just a few I/O pins, I’m also going to show you how to apply an old trick to this new processor.

GRAY CODE IS BLACK AND WHITE

The encoder Wayne selected is called a Gray code encoder; in his particular case, it is a two-bit encoder. Gray code is different from regular binary code in that two successive values differ by only one bit — like this for the two-bit encoder we’ll be using:

%11 → %01 → %00 → %10 → %11

Note that as we move through the sequence in either direction, only one bit changes. This is, in fact, different from a two-bit binary sequence where we would go from %11 to %00 and two bits would change. Why is all this so important? Well, despite best efforts in manufacturing, having two bits change at precisely the same time is darned near impossible, and a processor as fast as the Propeller could easily catch one changing before the other — resulting in a bad input. Gray code solves this with the single bit change between steps.

Dealing with a Gray code encoder is quite simple: scan the inputs; check for a change; and on a change, determine direction. Adding to the mix, Wayne’s encoder — and the one I went with for my own project board — has a pushbutton and detents. That is, it “clicks” when you turn the shaft. The button is no problem. We know how to debounce buttons and we can add that to the object code. The detents create an extra bit of work but once we understand how the encoder behaves, you’ll see it’s also pretty simple.

Figure 1 shows the output of the encoder using normally-open pins that are pulled up to Vdd — this comes right out of the datasheet so I matched it (see Figure 2 for the schematic). Note the location of the detents (when both outputs are off) — we’ll adjust the object for this so that one piece of code will work with “detented” encoders, as well as those that freely spin and can stop at any output pattern.

Let’s jump in. My main goal with this object was to be able to initialize it, and then ask for the position value and button status — everything else is handled behind-the-scenes in the encoder cog. To keep things really flexible, we’ll allow the ability to reset the current position value; this will be
validated (and corrected if necessary) by the object.

Here's the method we'll call to initialize the encoder object:

```c
pub init(base, btn, detent, lo, hi, preset)
{
    finalize

    enctiming := (clkfreq / 1_000) >> 2
    basepin := base
    btnmask := |< btn

    if detent
        hasdetent := true
        lolimit := lo << 2
        hilimit := hi << 2
        encoder := preset << 2
    else
        hasdetent := false
        lolimit := lo
        hilimit := hi
        encoder := preset

    cog := cognew(grayenc, encoder) + 1

    return cog
}
```

The first parameter is the base pin, which is the A pin of the encoder. To keep the code simple, we expect the next higher pin to be the encoder’s B pin. The second parameter is the encoder’s button input. Note that all three pins are active low, that is, they are pulled up to Vdd through 10K and will go low when active.

Next up is the true (non-zero) or false (zero) value that specifies whether the encoder has detents or not. Finally, we'll pass the low, high, and initial (preset) values for the driver. If, for example, we had an encoder with a base pin of 3, a switch pin of 5, is detented, will span from -100 to +100, and starts at zero, we would initialize it like this:

```c
encoder.init(3, 5, true, -100, 100, 0)
```

When a detented encoder is used, the limits and preset values are shifted left by two, which is the same as multiplying by four. We have to do this to account for the steps in between each detent. Shifting negative values left for the range we would typically use is not a problem. I tested this theory on values down to minus 10 million — a value we'd never use in an actual project — just to make sure.

The range limits take priority over the preset value; if the preset is outside the specified range, the object will fix it. Let's have a look at that.

```c
greatenc

    rdlng tmpl, par
    mns tmpl, lolimit
    mxs tmpl, hilimit
    wrlgn tmpl, par
```

At `par` is the address of the encoder value. After reading the preset value into `tmp1`, we use signed versions of `min` and `max` to ensure that it is within the stated bounds. Yes, we could have done this in Spin in the `init()` method, but it's easy and fast so it seemed like this was the best place to handle it.

Next up is basic initialization of the button debounce workspace, the previous scan result (stored in `oldscan`), and creating a timer. We don't need the timer for the encoder, but it does come into play for debouncing the button input.

```c
setup

    mov btnwork, #0
    mov tmpl, par
    add tmpl, #4
    wrlgn btnwork, tmpl

    mov oldscan, ina
    shr oldscan, basepin
    and oldscan, #11

    mov timer, cnt
    add timer, enctiming
```

And now we get to the guts of it.

```c
encloop

    waitcnt timer, enctiming

    scan

        mov newscan, ina
        mov tmpl, newscan

    chkbutton

        test btnmask, tmpl wc

        if_c mov btnwork, #0
        if_nc add btnwork, #1

        max btnwork, BTN_TM wc

        if_c mov tmpl, #0
        if_nc mov tmpl, IS_PRESSED

        mov tmpl, par
        add tmpl, #4
        wrlgn tmpl, tmpl2

As always, delays are a breeze in PASM with the `waitcnt` instruction. I've set the encoder to run on a 250 microsecond loop. That way, if we get really zippy with
```
the encoder knob the program can still keep up.

The present state of the input pins is copied into newscan, and that is copied into tmp1 where we'll use it to check on the button. To check the button input, we AND (using test) the button mask with tmp1 and save the result in the Carry flag. We're using an active-low circuit, so a set Carry flag means that the button is not pressed. If that's the case, the value of btnwork is cleared. Otherwise, it's incremented.

The next step — using max — actually does two things for us: 1) It keeps the value of btnwork at the debounce timing limit to prevent a roll-over on a stuck switch; and 2) The Carry flag indicates whether btnwork is less than BTN_TM (set for 25 ms). If the Carry flag is set, the button is not fully debounced and we move zero to tmp1. Otherwise, we move IS_PRESSED (true) to tmp1, then write it to the hub at the address for the button status. Again, the encoder value address is stored in par, so four (for a long value) is added to this value to get the correct address of the button status variable.

With the button debounced (or not), we can check to see if the encoder moved. We'll start by isolating the encoder inputs and comparing them to the last scan.

```
chkencoder     shr    newscan, basepin
               and    newscan, #111
               cmp    newscan, oldscan
               wz
               if_e   jmp    #encloop
```

Now you can see why we want the A and B pins in contiguous, ascending order on the inputs; we're simply shifting the scan value right by the base (A) pin number and masking off the other bits. This is compared to oldscan and if they're equal (i.e., no change), we jump right back to the top.

Okay, I know there's more than one of you hardcore types that might want to go willy-nilly on input mapping: maybe a PCB routing problem prevents keeping the pins contiguous and in ascending order. Here's what to do: Create pin masks for the A and B pins (just like we did for the button input) and then change the code like this:

```
chkencoder     mov    tmp1, #0
               test   amask, newscan  wz
               test   bmask, newscan  wz
               muxc   tmp1, #01
               muxc   tmp1, #10
               mov    newscan, tmp1
               cmp    newscan, oldscan
               wz
               if_e   jmp    #encloop
```

As you can see, this version tests each input and moves them through the Carry flag, into the correct locations in newscan. I really like the muxc operator; this code snippet shows how useful it is, allowing us to move what's in C to any bit position of a variable. Remember, if you update the PASM code to handle non-contiguous encoder pins you'll need to update the initialization of oldscan and add a B pin parameter to the init() method. Actually, I've done the work for you. (See jm_grayenc2btnx.spin in the download package at www.nutsvolts.com. This version allows us to disable the button pin, as well.)

Okay, let's say we have a change. What I use is an assembly version of a case structure, using the previous scan and comparing it to the value for a positive (clockwise) change.

```
case11     cmp    oldscan, #111
           if_ne  jmp    #case01
           cmp    newscan, #01
           jmp    #update

case01     cmp    oldscan, #01
           if_ne  jmp    #case00
           cmp    newscan, #00
           jmp    #update

case00     cmp    oldscan, #00
           if_ne  jmp    #case10
           jmp    #encloop

case10     cmp    oldscan, #10
           if_ne  jmp    #encloop
```

You'll see that each section is identically constructed. If the new scan represents a clockwise move, the Z flag will be set. Otherwise, the Z flag will be cleared. The program then jumps to update which does the final routing.

```
update     rdlong  tmp2, par
           if_nz   jmp    #decvalue

incvalue    adds  tmp2, #1
            maxs  tmp2, hilimit
            wrlong  tmp2, par
            mov    oldscan, newscan
            jmp    #encloop

decvalue    subs  tmp2, #1
            mins  tmp2, lolimit
            wrlong  tmp2, par
            mov    oldscan, newscan
            jmp    #encloop
```

At update, we retrieve the encoder value from the hub (because it could have been changed by the top-level program) and then increment or decrement it (based on the state of the Z flag) using the previously defined limits. The updated value is written back to the hub and we're done.

Well, almost — we need a method to read the current
encoder value in our top-level program.

```python
pub read
    if hasdetent
        return (encoder -> 2)
    else
        return encoder
```

Remember that situation with the detented encoders and the 4x multiplier? We multiplied the limits and preset value by four to accommodate the changes between clicks. Well, if we’re using a detented encoder we can’t simply shift the value right and return it to the intended range. Doing this on a negative number would cause it to go positive (because a 0 would be shifted into bit 31 — the sign bit). No worries. Spin has a really cool operator call Shift Arithmetic Right (→). This operator does a right shift while maintaining the sign of the value, allowing the use of positive and negative numbers with no muss or fuss.

**MORE EASY INPUT EXPANSION**

The product I mentioned in the opening is a 16-channel DMX controller that my business partner [and former Parallax engineer John Barrowman] and I designed. Since control of the outputs is paramount, we use P0..P15 for the output channels. With the RS-485 circuitry, a two-position mode switch, and other I/O requirements, we just didn’t have enough pins on the Propeller to accommodate the nine-bit DMX address (like I did in my small DMX project last November).

The solution? Dirt easy! Use a 74x165 input shift register. With three pins, we get eight inputs; for the DMX address we simply connected bit 8 of the address switch directly to the Propeller. For my Propeller platform add-on, I used an eight-bit switch and a 2x8 header (to allow off-board switches); see Figure 3 for the schematic.

If you’ve used the 74x165 with PBASIC or SX/B, you probably used SHIFTIN to read it. We can’t do that with the Propeller directly anyway, as there is no built-in SHIFTIN instruction. You might be wondering why. For all its power, the Propeller has to squeeze the Spin interpreter into a single cog and that’s tough work — so some niceties from PBASIC are not included.

No problem! We’ll just write our own method, and no assembly (PASM) is required. The code that follows is very similar to PBASIC’s SHIFTIN, reading a single byte in MSBFIRST mode — though it is set up to accommodate the Shift/Load line of the 74x165.

```python
pub in165(ld, do, clk) | tmp165
    outa(ld)~
    dira(ld)~
    outa(clk)~
    dira(clk)~
    return tmp165
```

As with PBASIC and SX/B SHIFTIN, this method takes care of setting the I/O pins used to achieve the required states. We start by making the Shift/Load pin an output and high; the Clock pin an output and low; and the Data Out (from the x165) an input.

The Shift/Load line is blipped low, then back high; this latches the present state of the eight inputs to an internal register. With the data latched, it can be shifted into the Propeller using a repeat loop.

The first line of the repeat loop does all the hard work; it prepens the work value by shifting it left one bit and then OR’ing the state of the DO pin to the value (in bit 0). After the bit is moved into the work variable,

---

**BILL OF MATERIALS**

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<tr>
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<td>Mouser 858-EN11-HSB1AF20</td>
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<tr>
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<td>Mouser 81-RGLD8X103J</td>
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<td>SW1</td>
<td>DIPx8</td>
<td>Mouser 611-BD08</td>
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<td>U1</td>
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<td><a href="http://www.expresspcb.com">www.expresspcb.com</a></td>
</tr>
</tbody>
</table>

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the Clock line is blipped high, then back low to get the next bit.

One of the things that Spin does not have is dot notation for bits like we’ve used in PBASIC and SX/B. For example, what if we wanted to convert the previous routine to shift the bits in LSB first? Here’s the change that makes that happen:

```plaintext
repeat 8
  tmpl165 := (tmpl165 >> 1) | (ina[do] << 7)
```

In this case, we shift the work variable one bit right and then OR the DO value into bit 7. Note that we had to shift the DO bit before the OR operation. There’s one more trick we could use: the reverse (\texttt{<>}) operator. For example, we could create a global constant called LSBFIRST that would be applied after the value is shifted in like this:

```plaintext
repeat 8
```

While I haven’t personally needed to use more than one 74x165 with a Propeller project, it’s certainly a possibility. Here, then, is a final version of the routine that accommodates the number of bits to shift, as well as the shift mode. With this version of the routine, we could read up to four daisy-chained ‘165s into a single, 32-bit long one.

```plaintext
pub in165x(ld, do, clk, bits, mode) | tmpl165
  outa[ld]~~
  dira[ld]~~
  outa[clk]~~
  dira[clk]~~
  dira[do]~~
  outa[ld]~
  outa[ld]~~
  tmpl165~
  bits <#= 32
  repeat bits
    tmpl165 := (tmpl165 << 1) | ina[do]
    outa[clk]~~
    outa[clk]~
  if (mode == LSBFIRST)
    tmpl165 >>= bits
  return tmpl165
```

The changes should be apparent. We’ll limit the bit count to 32 for obvious reasons, update the \texttt{repeat} loop to use the \texttt{bits} parameter, then use the \texttt{mode} parameter with \texttt{bits} to adjust if LSBFIRST (\texttt{mode = 0}) is desired.

Since I’ve already made use of the 74x165 in two Propeller designs and I anticipate using Gray code encoders in a couple more, I created a little prototyping...
add-on for the Propeller platform that includes the ‘165 and two encoders. These components don't take much space so I filled the rest with pads to place other components. Figure 4 shows the board attached to my original Propeller platform. Figure 5 shows the output of a simple demo using the Parallax Serial Terminal through the programming connection.

**PROP BASIC FOLLOW-UP**

Wow, the response to PropBASIC was really amazing. To be honest, I was a little surprised, but then I really shouldn't be, should I? Those of us with Parallax experience have a lot of time with BASIC and this new tool made moving to the Propeller easier for some PBASIC and SX/B users.

Of course, things got even better when Brad Campbell (an Australian Propeller programmer and very nice guy), integrated the PropBASIC compiler into his BST (Brad's Spin Tool) IDE. What does this mean? Well, if you looked past the Propeller to something like, say, the Arduino because of the availability of a cross-platform development tool, well ... time to drop the single-core processor and move on up to the multi-core Propeller. With BST, you can program the Propeller in Spin, PASM, or PropBASIC, on nearly any Windows, Mac, or Linux PC. Now, that's cool!

The easiest way to get the BST IDE and PropBASIC compiler files you need is through links at [www.propbasic.com](http://www.propbasic.com).

Before I close, let me correct a small error in my last column. When an IDE like the Propeller Tool or BST is downloading to the Propeller, it is the Propeller – not the IDE as I misstated – that makes the adjustment for baud rate. This makes better sense; typically, the receiver does the “auto baud” detection and configuration. I apologize for any confusion.

Okay, then. Until next time – on a PC, a Mac, or Linux box – have fun and keep spinning and winning with the Propeller.
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- Front panel digital control and display of all settings and parameters
- Professional metal case for noise-free operation
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- Super audio fidelity, rivals commercial broadcasts
- Available in domestic kit or factory assembled export versions

For nearly a decade we've been the leader in hobbyist FM radio transmitters. To our engineers we wanted a new technology transmitter that would provide FM100 series quality without the advanced mixer features. They took it as a challenge and designed not one, but TWO transmitters!

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**FM30B Digital FM Stereo Transmitter Kit, 0-25mW, Black**
**FM358WT Digital FM Stereo Transmitter, Assembled, 0-1W, Black (Export Only)**

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<th>FM358WT</th>
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<tbody>
<tr>
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</tbody>
</table>

**Pocket Audio Generator**
A perfect test source for stereo lines on inputs to any amplifier or receiver. Provides 50kHz, 1kHz, 10kHz, and 20kHz tones, plus 32 bit digital pink noise. Great to help you identify cables or left/right reversals. Stereo RCA line level outputs. Uses 2xCR2025, not included.

| K8065 Pocket Audio Generator Kit | $3.25 |

**Mini LED Light Chaser**
This little kit flashes six high intensity LEDs sequentially in order. Just like the k8030n to the right, but with incandescent lights. Makes a great mini attention getter for signs, model trains, and even RC cars. Runs on a single 9V battery.

| MK175 Mini LED Light Chaser Kit | $15.95 |

**Steam Engine & Whistle**
Simulates the sound of a vintage steam engine locomotive and whistle. Also provides variable "engine speed" as well as variable volume. Can be used as a thermometer or a timer. Requires a 12-24VDC power source.

| MK134 Steam Engine & Whistle Kit | $11.95 |

**Grill Light Controller**
Controls and powers 4 incandescent lights so they appear to "travel" back and forth across the grill. Great for the dance floor or promotional material attention getters. Includes enclosure. Runs on 12-24VDC.

| KB402 4-Channel Running Light Kit | $38.95 |

**Pocket Vu Meter**
Hand held audio level meter that fits in your pocket! Built-in mic picks up music and audio and displays it on an LED bargraph. Includes enclosure shown. Runs on 1.5V Lithium battery. No need to look everywhere for level display, easy to use.

| MK146 Pocket Vu Meter Kit | $8.95 |

**High Power LED Driver**
High power LED's have finally found their way into the hobbyist world. This little board provides the correct power and current required to drive these LED's. Runs on 2-8VDC. A constant current output.

| K8071 High Power LED Driver Kit | $14.95 |

**Electronic Watch Dog**
A barking dog on a PC board! And you don't need to feed it! Generates 2 different selectable barking dog sounds. Plus a built-in mic to detect an intruder! This preamp has low noise and can be set to bark when it hears it! Adjustability is the key. Unlike the Saint, this 2-8VDC input will work.

| K2655 Electronic Watch Dog Kit | $39.95 |

**Stereo Ear Super Amplifier**
Ultra high gain amp boosts audio 50 times in stereo or 100 times in 4 channel stereo. DIT at the speaker output. Also can be used as a relay driver. Incredible gain and perfect stereo separation!

| MK136 Stereo Ear Amp Kit | $9.95 |

**Digital Voice Changer**
This voice changer kit is a riot! Just like the k8030n but with incandescent lights. Makes a great mini attention getter for signs, model trains, and even RC cars. Runs on a single 9V battery.

| MK171 Voice Changer Kit | $14.95 |

**Laser Trip Sensor Alarm**
True laser protects over 500 yards. At last within the reach of the hobbyist, this neat kit uses a standard laser pointer (included) to provide audible and visual alerts at a distance. You can even use it to set an alarm! Breakaway board to separate sections.

| LTS1 Laser Trip Sensor Alarm Kit | $29.95 |

**Liquid Level Controller**
Not just an alarm, but gives you a clear visual display of low, middle, or high levels! You can also set it to sound an alarm at the low or high. Use it to monitor the water level in a fish tank relay output. Runs on 12-14VAC or 14VDC.

| K2639 Liquid Level Controller Kit | $23.95 |

**Electrol Condenser Mic**
This extremely sensitive 3/8" mic has a built-in preamp! It's a great replacement mic, or a perfect answer to add a mic to your project. Powered by 3-5VDC, and when not in use, can be used as a current limiting resistor! Extremely popular!

| MC1 Mini Electrol Condenser Mic Kit | $3.95 |

**Broadband RF Preamp**
Need to "plug-up" your counter or other equipment to read weak signals? This preamp has low noise and yet provides 25dB gain from 1MHz to well over 1GHz. Output can reach 100mW! Runs on 12 volts AC or DC or the included 110VAC PS. Assemb.

| PR2 Broadband RF Preamp | $69.95 |
Q: I would like to develop or buy a device/circuit that would apply voltage gradually to a string of Christmas tree lights so when a switch is turned on, the lights would light slowly and when turned off they would go off slowly. In model trains, I believe it is called a 'momentum throttle.' An ability to vary the rate would be good.

Thank you in advance for any help you can provide.

— Bob Rymer

A: Christmas tree lights can vary from tiny milliwatt bulbs to up to two or three watts per bulb, so I will design for up to 70 watts of power.

In the circuit (Figure 1), the diode bridge allows the control circuit to operate at DC while AC flows through the load. When SW1 is open, the full 168 peak volts are across Q1 and there is no current in the load. When SW1 closes, C1 charges to 168 volts; this puts a spike of current in the load (probably not noticeable). C2 gradually charges through R1 and R2, slowly turning on Q1. The AAA battery, G1, puts an initial charge on C2 so you don’t have to wait until it charges up to the Vbe of the transistors. C2 is a super cap; values up to one farad are available if you want an even longer delay. The turn-on time is adjustable from less than one second to about five seconds via R2. The turn-off time is determined by the current draw of Q2 and is not easily varied. The turn-off time is expected to be about five seconds, according to my simulation. Figure 2 is the parts list.

---

**Q&A**

**WHAT'S UP:** Join us as we delve into the basics of electronics as applied to every day problems, like:

- Christmas Tree Lights
- Clock Oscillator Schematic
- Noisy Audio

---

**CHRISTMAS TREE LIGHTS**

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@nutsvolts.com

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**TURN ON/TURN OFF DIMMER PARTS LIST**

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<td>D2</td>
<td>1 amp, 400V diode</td>
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<td>Q1</td>
<td>3 amp, 273V NPN</td>
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<td>Q2</td>
<td>Darlington</td>
<td>512-KSC2258ASTU</td>
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<td>140-XR5250V100-RC</td>
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<td>1.5V AAA cell **</td>
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</tr>
<tr>
<td>R2</td>
<td>100k potentiometer</td>
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</table>

**FIGURE 2**

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**PHASE LOCK LOOP**

Could you explain the basics of phase locked loops? The example that interests me most is the FM demodulator, such as the LM565. I have seen basic circuits like that before on the web or in books, but could you explain where the equations come from? Is it common to treat these chips as black boxes and just use the equations from the datasheet? Is it simple or are the equations fairly complex to derive?

---

**A**: I believe Z transforms are needed to really analyze a PLL but I know nothing about that, so I use standard linear analysis which only goes so far. The following is from an article that I wrote which has not previously been published.

There are two types of phase lock loops (PLL). Type 1 uses a passive filter and type 2 uses an operational integrator as a filter.

The type 2 PLL consists of: mixer or demodulator; integrator, and oscillator, as shown in Figure 3. This type has zero phase error in the steady state and is useful for recovering a pilot tone or carrier frequency.

The type 1 PLL consists of: mixer or demodulator, low pass filter, and oscillator, also shown in Figure 3. This
type has phase error that is proportional to the frequency difference and is useful as a frequency discriminator. The LM565 is an example of a type 1 PLL and is covered in detail in National Semiconductor Application Note #46. The application note is heavy on math, so I will try to boil it down to the essentials.

A logic XOR can be a phase detector (mixer). When both inputs are in phase, the output is low; when both inputs are 180 degrees out of phase, the output is high. The DC output after filtering is proportional to the phase angle, being 50% at 90 degrees. Although it is not obvious, the voltage-controlled oscillator (VCO) is a phase integrator. When there is a frequency difference between the input signal and the VCO, the phase difference just keeps accumulating. Since the filter at the phase detector output has 90 degrees phase shift above the cutoff frequency, and since the VCO is an integrator which has 90 degrees phase shift, the closed loop will oscillate if there is positive gain at frequencies above the low pass filter cutoff. One solution is to reduce the open loop gain, but that impacts the ability of the loop to follow frequency changes.

For a high performance loop, it will be necessary to put in a phase lead at F2 which is accomplished by a resistor in series with the filter capacitor; F2 = 1/(2πR2*C1) — see Figure 3. The low pass filter rolls off at 6 dB per octave and the VCO rolls off at 6 dB per octave for a total of 12 dB per octave at frequencies above the filter cutoff. The filter cutoff (F1) is: F1 = 1/(2πR1*C1).

An American engineer, Hendrik Bode, discovered that the closed loop can be stable if the open loop is rolling off at 6 dB per octave as it goes through 0 dB. Stability is not guaranteed but improves with a wider frequency range of 6 dB rolloff. The closed loop bandwidth of the PLL is determined by the 0 dB intercept of the open loop gain. This frequency is designated F0.

The gain of the phase detector can be calculated from its maximum output (V) in volts per radian (there are 2π radians in a cycle), therefore Kd = V/π. The gain of the low pass filter is one up to the cutoff frequency and -20 dB per decade (= 6 dB per octave) thereafter. The gain of the VCO is in units of radians per second per volt, but the gain is usually measured as: OS = Hz per volt. So, converting Hz to radians per second, Ko = OS*2*π and its gain rolls off at -20 dB per decade.

You can solve the problem with a straight edge and semi-log graph paper using a Bode plot. The vertical axis is dB and the horizontal is frequency. Multiplying the gains: Kol = V/OS*2. This is the gain at 0.159 Hz (one radian per second) This establishes a point on the graph at 20*log(Kol) dB and 0.159 Hz. If this is off the paper, just remember it is 20 dB lower at 1.59 Hz and 40 dB lower at 15.9 Hz, etc. Draw a line at -20 dB per decade through one of those points and note where it goes through 0 dB (call it F0). This frequency is the closed loop bandwidth and the low pass filter cutoff frequency (F1) should be above it in order for the loop to be stable. See Figure 4. If the closed loop bandwidth is more than you want or need and/or the cutoff frequency (F1) of the low pass filter is too close to the oscillator frequency for effective filtering, then move F1 to a lower frequency (much lower) so you can install a phase lead at F2 that is below the new F0 such that the plot passes through 0 dB at 20 dB per decade. See the dashed line in Figure 4.

By following these rules, you should be able to design a PLL with the stability and bandwidth you want.

**CLOCK OSCILLATOR SCHEMATIC**

I have an old sound chip that needs a clock source. Unlike a modern chip that I'm used to, it doesn't have two pins I can straddle a crystal across — rather it has only a single pin. How can I generate a (roughly) 2 MHz clock signal to drive this chip?

— John Calhoun
Figure 5 (A) is a crystal oscillator. I used a CD4011 quad two-input NAND but any CMOS inverting gate or buffer should work. R1 limits the crystal current; too much drive could damage it. R2 provides DC bias to keep the gate input in the linear range. I breadboarded the circuit and find that it works okay at nine volts VCC and above, but the frequency is way low at five volts. Perhaps HCMOS would be better at five volts. If you don’t need crystal accuracy, the hysteresis oscillator using a Schmitt-trigger gate will be cheaper; see Figure 5 (B). The hysteresis is not well controlled so you will have to tweak it to get the frequency right. Also, the frequency varies with supply voltage. I breadboarded the circuit and got 2 MHz with 4.7K and 47 pF.

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**NOISY AUDIO**

I am a new reader to *Nuts & Volts* and thought of a question that you might be able to help with. My wife and I recently moved into a new home, and I purchased a floor-model Samsung DLP. However, one thing in particular bothers me. It seems to inject a low frequency “noise” into the AC line, which my 10" powered sub dutifully picks up and broadcasts to the annoyance of both myself and my visitors. This hum or drone (depending on your opinion) is very noticeable, and only goes away when the TV is turned off or the sub is unplugged — neither of which enhances the full theatrical effect.

My Rotel pre-amp and amplifier seem to be completely immune to the noise. I can’t hear it at all from my bookshelf speakers. This leads me to believe that either a) my inexpensive powered sub wasn’t really worth getting; or b) the sub (or TV) could use a power-line filter.

Do you think such a thing would be worthwhile? I enjoy working with electronics and would be willing to try making a circuit to provide “conditioning” if practical. However, I haven’t got much experience in dealing with mains voltage or designing notch filters. For that matter, I’m not even sure if I would know how to go about identifying the specific frequencies being injected by the TV. Any advice or guidance you would be willing to share is certainly appreciated!

— David Passarelli

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I suspect the problem is caused by the fact that your equipment is plugged into different AC outlets and the safety grounds are at different AC potential. Try plugging the TV and sub into the same outlet. If you’re already doing that, then you have a ground loop formed probably by the coax cables that connect the system. Make sure the grounds don’t close on themselves and make a loop. If you’re still having issues, send me a diagram of the system.
# Electronics Components Catalog

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ESP LAMP CIRCUIT

Images SI, Inc.'s new ESP lamp circuit provides several fertile areas of cutting edge research for users to dabble in, such as influencing quantum probability of decaying radioactive particles and detecting the particles on the machines. The ESP lamp can be used for entertainment/testing various aspects of ESP/PSI, precognition, telepathy, and psychokinesis (PK).

The ESP lamp contains a miniature Geiger counter to generate true random numbers that light one of four different color LEDs so it functions as a truly random mood lamp with a very high coolness factor. The ESP lamp is offered in a round or cube version, and as a kit or assembled and tested. Price for the ESP lamp kit is $149.95; assembled is $199.95.

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WHAT A POTENTIOMETER DOES

This potentiometer is being used as a rheostat or variable resistor. Its function is to vary the resistance in electronic circuits and devices. For example, they are used in radios and TVs to control the volume of the audio in the speaker. A “pot” can also be used as a voltage divider. By doing this experiment, you will see that a potentiometer can vary the resistance in a circuit and, in this case, the brightness of the LED.

1. Build the Circuit.

Using the schematic along with the pictorial diagram, place the components on a solderless breadboard as shown. Verify that your wiring is correct.

2. Do the Experiment.

Theory: This electronic circuit consists of an LED, a 100 ohm resistor (to keep the LEDs from burning out from too much current when the potentiometer is adjusted to zero ohms), a nine-volt battery, and a potentiometer. The electrons flow from the battery through the resistor, through the LED, through the potentiometer, and back to the battery. The higher the resistance in the circuit, the fewer the electrons that will flow.

Procedure: Connect a nine-volt battery to the battery snap and observe the brightness of the LED. Now, turn the shaft fully clockwise and then fully counter-clockwise. As you turn the shaft, the resistance varies through the potentiometer and this will cause the LED to get brighter and dimmer.
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May 2010 NUTSVOLTS 29
BUILD THIS INDOOR SHOOTING RANGE THAT USES PHOTON BULLETS WITH YOUR OWN HAND GUN

BY RON NEWTON

With ammunition in seemingly short supply and the need to keep my shooting skills proficient, dry firing helps control, but does not improve your accuracy. I decided to build an indoor shooting range using my own weapon. There are setups available for about $500 which was a little too much for my budget. I built my shooting range for about $100.

This laser system can be built for use with any pistol 9 mm and above. A plastic tube is used to house the laser, sensing board, switch, and batteries. The tube slides down the barrel of the gun. When it detects the click of the hammer, it fires the laser. Although it is 3” in length, it can be used in guns with 1” barrels.

The target runs off of four AA batteries (or a battery eliminator). It keeps score and lights up where the photon bullets hit.

I consider this an advanced project. It will take about four to six hours to build.
By the time you finish, you will definitely know how to solder surface-mount components. There are 196 small photodiodes and 49 small LEDs. I would build the target first, then prepare the small laser printed circuit board (PCB).

**On Target**

The target measures 3.5” x 3.5” and uses photodiodes to detect the laser. The laser has a 6 mm spot at 40 meters. In a nutshell, a 1/2” square uses four photodiodes which are placed apart and electrically connected in parallel. An LED is located in the center. A grid is set up using seven rows x seven columns, or 49 sets of diodes. The 3/16” clear red plastic allows the red laser to penetrate and blocks most of the ambient light. The .01 mm thick white translucent piece of plastic causes the laser to diffuse and trigger the photodiodes (see Figure 1).

A Microchip PIC16F917 is a 40-pin microcontroller. It has 25 inputs and output ports. Sixteen of these ports are used to detect the laser pulse by multiplexing the photodiodes. Once the hit is determined, they turn on an LED indicating where the hit was. Eight of the other ports are used to multiplex a three-digit display. The seven-segment display shows the accumulated points.

When light strikes a photodiode, it conducts electricity. The collectors are biased to Vcc using a 3.3K SIP (Single Inline Package). The 3.3K SIP used in this project has eight pins and seven 3.3 resistors (bussed), all connected to a single source. There are seven rows and seven columns as mentioned previously. The outputs of the rows are multiplexed using port B and the collectors are multiplexed to ground using port A. In the center of each square is an LED whose polarity is reversed across the photodiodes. The microcontroller runs at 20 MHz and scans the 49 squares in 68 microseconds. When a hit is detected, the microcontroller stops the scanning. It turns on the LED in the square where the hit was detected by reversing the polarity of the column and row. It determines the points in the area of the hit and adds them to the score. The hit and score stay lit for five seconds and then the unit starts scanning again. The score can be reset by pushing a reset button. This is connected to the MCLR (master reset) of the microcontroller.

It can be powered by four AA, C, or D batteries, or a five volt power supply can be used. A jack is provided for the power input.

The three seven-segment displays are common anode and are multiplexed using three PNP transistors. The grounding of the cathodes is performed via eight 470 ohm resistors going to port D. The 470 ohm resistors are in a network which is similar to a SIP; however, they are contained in a DIP (Dual Inline Pin) and are not connected to each other. There is a DIP switch which can change the display for testing, slow fire, rapid fire, or your own program. (Up to eight programs are available that will be discussed later.)

**Building the Target**

Because of the small surface-mount photodiodes and LEDs, use a small tip soldering iron and magnifier (see Figure 2). Place the four feet on the bottom side of the board next to the mounting holes. This will prevent scratching the traces and keep the board from sliding when soldering.

Solder the photodiodes and the LEDs to the board. The photodiode’s marker dots (collector) face to the left; the LED cathodes all face down and are also marked with
small soldering iron. I recommend soldering one pad on each diode and then inspecting it with a magnifier to make sure the dots are correct. It's easy to remove one if reversed. However, if both sides are soldered you almost need a surface-mount removal soldering iron. Perform the same procedure using the LEDs.

Solder the power jack and the .01 μF cap to the board. If you want to use batteries, there is a mounting hole for the wire and pads for soldering. Solder in the DIP switch.

Next, solder the microcontroller, two 470 ohm networks, and the SIP. The SIP sets the sensitivity of the target for ambient light. I found 3.3K worked best. The higher the resistance, the more sensitive the target becomes to light. Please note that the square pads indicate pin 1 (watch the SIP position). Solder the three PNP transistors (flat side points to the top), the three 10K 1/8 watt resistors, and the reset switch. Solder the six headers. The microcontroller can be programmed on the board using the six-pin header and a Microchip PICKIT 2 available in the Nuts & Volts webstore at www.nutsvolts.com.

The programming files are also located on the Nuts & Volts website, along with all the necessary files to complete this project.

**Testing the Target**

To test the board, I use a laser pointer. Connect the power and turn on the target. A bar should be displayed indicating that the power is on. Set the DIP switch on test. Press the reset switch. Using a laser, light one of the four diodes in column one, row one. Each hit on the diode will flash the LED in the center. Perform this procedure in each of the 49 squares, testing all 196 photodiodes. This test is to make sure all the photodiodes and LEDs have been properly installed.

**Final Assembly**

The target can be printed on styrene using a laser printer. (The target diagram is in a Word document on the Nuts & Volts website.) Make another copy on
paper for a drill template. Drill the holes into the red Plexiglas® using a 5/16” drill. Punch the screw holes into the styrene target. Tap the four corner holes of the board using a 6-32 tap. Place the styrene on top of the Plexiglas. Using four white nylon screws, mount both to the board. Place the Plexiglas directly on the photodiodes; do not overtighten the screws.

**Machining the Photon Emitter (Laser)**

You will need a lathe or find a friend that has one. Use a soft plastic such as Acetyl or Deldrin, or even oak. Do not use Lucite. A 5/8” rod is milled to the dimension of the bore of the gun. The tube has a total length of 3”. The end is knurled so you can grasp it to remove it. (For 2” barrels, see Hints and Tips on the NV website.)

**Follow this Method:**

1. Knurl 3/8” of one of the ends of the 3” plastic. This will be the end where the laser will go.
2. Center drill both ends.
3. Chuck the tube’s knurled end and use a center on the tailstock on the other end.
4. Turn the tube to the diameter of your gun barrel leaving 3/8” of the knurl. The tube should be a snug fit into the barrel.
5. Drill halfway through the tube using a 15/64” drill. Reverse the tube and drill from the other side to complete the hole.
6. Chuck the body of the tube with the knurled end flush with the chuck pointing toward the tail stock. Using an “L” drill, drill for two inches.
7. Tap the other end using a 1/4”-20 for 3/8” for the set screw.
8. Using a 1/16” mill or Moto tool, cut a slot from the battery end for 1.5”. This will be a slot for the
positive wire going to the last battery and to access the switch.

9. Drill three #43 holes at 120 degrees 1/8” from the end of the knurled end and tap with a 4-40 tap. Place three 1/8” 4-40 set screws into the tapped holes.

10. Using electrical tape, wrap the last 1/8” to 1/16” of the proximal end of the laser. This will act as a pivot. It can also act as a shim by cutting part of the tape off.

One of the problems I encountered was that if I either bored or drilled the hole for the laser, it was still off from the sights. I discovered that this was due to the laser manufacturing alignment itself. I decided to add an adjustment.

**Laser Electronics**

The photon emitter uses an inexpensive laser diode (<$10) which is powered by five #10 hearing aid batteries. The detection circuit uses a sub-miniature microphone. When the trigger is pulled, the firing pin causes a click that the microphone picks up. Its output feeds into a PIC12F508 which then pulses the laser for 50 milliseconds. R3 limits the laser’s output. This prevents lock-up. The whole detection system is soldered to a 1” x .225” board (see Figure 4).

Solder the microcontroller to the board noting pin 1, the two 10K resistors, and the .01 capacitor. The microphone is soldered from the top of the board to the square pin with pin 1. Cut the speaker leads short and file or sand so that you can mount the switch to the back of the board. R3 is soldered to the back of the board along with the micro-switch. Using a piece of 1/4” solder braid, fill with solder and bend at a 90 degree angle. Solder this braid to the top and bottom square pads next to the microphone. This will act as the negative contact for the batteries. Carefully cut the wires from the laser to about 3/8” and strip. Solder the red wire from the laser to the square pad next to the chip. Solder the black wire to the round hole. Using a 1” piece of red wire wrap, solder it to the pad next to the solder braid. With the slot and the switch up, thread the wire, board, and the laser from the knurled end. The laser should be flush to the end of the tube. Tighten the Allen screws. The red wire runs along the slot. Trim the red wire to the end of the tube and solder the small brass washer to it (see Figure 5). The switch should be visible.

Use a spring from a ball point pen and cut to a length of 1/4”. Place five batteries into the tube with their negative ends toward the board. Put the washer on the last battery, add the spring, and screw the set screw into the tube. Turn on the switch and tap the tube on the table. The LED should pulse on and off.

The microcontroller goes to sleep and wakes up when it detects the click. However, the two 10K resistors will pull 250 uA. The batteries produce 75 mAh. However, when the laser fires it pulls about 25 mAh for 50 milliseconds.

**Testing the Laser Alignment**

Insert the laser tube into the barrel of the gun. The knurled end should be flush.
with the end of the barrel (see Figure 6). Cock the weapon and fire at a blank white wall. Twist the tube for the best alignment. Using an Allen wrench, adjust the three screws until the beam aligns with the sight. Put a drop of white paint or nail polish on top of the tube for relocation the next time.

**Using the Laser Sight and Target**

There are four programs available:

1. **Test.** (DIP switch one on, two and three off).
2. **Normal.** Displays a hit and the score for five seconds (DIP switch one and two are on three is off).
3. **Rapid fire.** Turns on the LED, and keeps them on (DIP switch one, two and three on).
4. **Design your own programs.** (Five more DIP switch settings are available).

Turn on the switch and load the photon tube into your barrel.

Work in a semi-lighted room. If it is too bright, it can lock up the target. Place the target on the wall about 25 feet and turn it on. Set the program you are going to use and press reset. With an automatic weapon, you will need to recycle the breach each time. In the normal mode, the hit will display for the five seconds and the score will accumulate with each shot. Press the reset button to clear.

The Rapid Fire mode will display the number of shots. At the end of six shots, the LEDs will light and the score will display. Again, press the reset button to clear. (Note: If two shots hit the same location, only one will be displayed, but the score will be correct.)

**Think Safety First!!**

Remember these tips:

- Don’t dry fire with children around.
- Remove all ammunition and place it away from the practice area.
- Double-check the chamber!! After checking that your weapon is clear of all ammunition, dry fire into a safe back-stop, for example a brick fireplace.
- Always check to see that the laser is removed from the barrel before live firing!!

I hope you enjoy this project and always stay on target! 

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BY DAVID WILLIAMS

BUILD A JUMBO LED DIGITAL THERMOMETER

Anyone with a tropical fish tank knows that the water temperature must be maintained within a relatively narrow temperature band – typically around 25°C (or 77°F), depending on the type of fish. In most home aquariums, this is achieved using a thermostatic heater. When the temperature drops below a preset level the heater switches on, and when it rises above a higher preset, it switches off.

Many aquariums are also equipped with a thermometer, but it can often be difficult to see or read accurately. This project was born from the need to easily check the water temperature at a glance. It features three 2.2" large LED digits that are easy to read from across the room and a precision DS1822 temperature sensor. Temperatures can be selected to display in Centigrade, as well as Fahrenheit.

The DS1822 is a direct-to-digital temperature sensor with ±2°C accuracy over a -10°C to +85°C range. It is presented in a compact TO-92 package and transmits digital temperature readings using only three wires. It is easy to encapsulate the DS1822 in silicon or epoxy for a robust and waterproof sensor that makes it perfect for this project.

Of course, a digital thermometer with a large LED readout and a remote temperature probe is not just limited to aquarium owners. This project will appeal to anyone that wants accurate digital temperature measurements.

Home beer brewers, hydroponic gardeners, amateur weather watchers, or folks just interested in energy management will all find this to be a very useful device.

Circuit Description

At the heart of the jumbo LED thermometer is an ATMEL AT89C2051 microcontroller. It has been programmed to handle a variety of functions, including display multiplexing, temperature conversion, and seven-segment encoding. The AT89C2051 has 2K of Flash program memory, 128 bytes of RAM, 15 I/O lines, one 16-bit timer, an analog comparator, and three interrupt sources. It is fully compatible with the Intel MCS-51 architecture and instruction set.

Even though the microcontroller is handling most of the functions of the thermometer, some additional circuitry is required. Refer to the schematic shown in Figure 1. The circuit receives power from a 9-12V DC or AC wall-mount transformer. The full-wave bridge DB1 ignores the incoming voltage polarity if it is DC or else rectifies it to DC if it is AC. The voltage is filtered by capacitors C7 and C4, and then regulated to five volts DC by U1. Capacitors C6 and C3 provide additional filtering for the five volts.

Capacitor C5 and resistor R10 provide a RESET signal to U5 at power-on. The three LED displays (DISP1-3) do not require a regulated DC voltage, so they are driven by
the unregulated voltage from DB1. Jumper JP1 allows the user to configure the thermometer to display either Centigrade or Fahrenheit temperatures.

The jumbo thermometer uses three large seven-segment LED displays. In this circuit, the seven segments of all three displays are bussed together. Each display digit can be selected by an output from the CD4017 decade counter U3. This configuration allows any digit to be addressed by the microprocessor using a technique called multiplexing.
Multiplexing

Multiplexing involves lighting each of the three LED digits one at a time. Even though only one digit is on at any single moment, the scanning is done so quickly that all three digits appear to be lit simultaneously. The seven segments of each digit are controlled by seven data lines from the ATMEL AT89C2051 microcontroller U5. During multiplexing, it is necessary to drive the LED’s with a more current than the pins of the AT89C1051 can provide, so the PNP darlington drivers in U4 are used to provide the additional LED source current capacity. U4 also does voltage level shifting, allowing the displays to be driven from the unregulated input voltage. The CMOS decade counter U3 provides a way to turn on each of the three digits in sequence. U3 cannot drive the digits directly, so six TIP122 NPN darlington transistors (Q1-3) are used for LED current sinking.

Two output lines go from the microcontroller to U3. One is used to reset the counter, so the data presented to the seven-segment outputs can be synchronized with the proper digit. The other is connected to the clock input of the CD4017 and is used to increment the counter. Each

---

PARTS LIST

<table>
<thead>
<tr>
<th>REF</th>
<th>DESCRIPTION</th>
<th>SUPPLIER PART #</th>
</tr>
</thead>
<tbody>
<tr>
<td>C1,C2</td>
<td>Capacitor, 22 pF, 50V Monolithic</td>
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<tr>
<td>C3,C4</td>
<td>Capacitor, 0.1 mfd, 50V Ceramic</td>
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<tr>
<td>C5</td>
<td>Capacitor, 10 mfd, 16V Electrolytic</td>
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<td>C6</td>
<td>Capacitor, 100 mfd, 16V Electrolytic</td>
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<td>C7</td>
<td>Capacitor, 1,000 mfd, 25V Electrolytic</td>
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<tr>
<td>DB1</td>
<td>Diode Bridge, 1.5A, 100V, W01</td>
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<td>R10</td>
<td>Resistor, 10K ohm, 1/4W, 5%</td>
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<td>U1</td>
<td>IC, LM78L05, 5V Regulator, 100 mA</td>
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</tr>
<tr>
<td>U2</td>
<td>IC, DS1822 one-WireTemperature Sensor</td>
<td></td>
</tr>
<tr>
<td>U3</td>
<td>IC, CD4017 Decade Counter</td>
<td></td>
</tr>
<tr>
<td>U5</td>
<td>IC, AT89C2051 Programmed with software</td>
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</tr>
<tr>
<td>U4</td>
<td>IC, TD62783AP, 8 CH Source Driver</td>
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<td>CY1</td>
<td>Crystal, 11.0592 MHz, HC49US</td>
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<tr>
<td>TXFR</td>
<td>Transformer, Wal, 12 VDC, 700 mA</td>
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<tr>
<td>DISP1-3</td>
<td>Display, LED seven-Seg CC, 2.3 in, LSD23255</td>
<td></td>
</tr>
</tbody>
</table>

MISCELLANEOUS

Jumper post and shorting block; IC sockets; Hex spacers - 3/4 inch length; Acrylic plastic front panel; #4-40 screws; three-conductor wire.

Thanks to the amazing DS1822 digital sensor from Maxim Integrated Products, no temperature calibration is required for this thermometer. The DS1822 digital sensor provides 9- to 12-bit Centigrade temperature measurements. It has an operating temperature range of −55°C to +125°C, and is accurate to ±2.0°C over the range of −10°C to +85°C.

The DS1822 communicates over a 1-Wire™ serial data bus. The bus was originally designed by Dallas Semiconductor to provide low-speed data, signaling, and power over a single signal wire. Of course in real applications, the bus requires at least one more wire for a ground connection. Even though most 1-Wire devices can take their power directly from the same wire used for data communications (parasitic supply), projects can be more robust if an additional wire is used for powering the device.

So in this application, the DS1822 actually uses three wires. Perhaps naming it the 3-Wire bus would not have sounded as interesting.

1-Wire is currently a registered trademark of Maxim Integrated Products, Inc.
time the counter is incremented, the next digit is enabled. The multiplexing works as follows: First, the microcontroller resets the decade counter to enable digit DISP1. Then, data is output to the seven-segment lines to turn on the appropriate LED segments in the first display. The LED segments in DISP1 are left on for only two milliseconds. Next, a clock pulse is generated to increment U3. As the counter increments, DISP1 is turned OFF and DISP2 is enabled. At the same time, the seven-segment data is changed to turn on the appropriate LED segments of the second display. The sequence continues for each of the three digits before the entire process is repeated. This gives the display a 1/3 duty cycle and a refresh rate of 166 times per second. At that speed, the human eye cannot perceive the multiplexing and the digits appear to be lit continuously.

**Construction Hints**

The **Parts List** shows all of the individual components needed for this project. The HEX program file for the microcontroller and the PCB Gerber files are available for download on the **Nuts & Volts** website (www.nutsvolts.com). Alternatively, the pre-programmed microcontroller, printed circuit board, or an entire kit of parts is available for purchase (ordering details shown in the **Parts List**).

**Figure 2** shows the component placement locations on the printed circuit board (PCB). Double-check the solder connections as you go along. Mount the resistors and crystal to the PCB first. Then, solder in the NPN transistors and the diode bridge, followed by the three IC sockets. Next, solder in the resistor pack RP1 and the mono/ceramic capacitors C1-C5.

Move on to the voltage regulator and the three seven-segment LED displays. Make sure the displays are oriented so the decimal points match what’s shown in **Figure 2**. Next, mount the jumper post and the electrolytic capacitors. Note that capacitor C7 has to be mounted differently from capacitors C5 and C6 in order to clear the red front panel. C7 lies on its side against the PCB. Lastly, connect the power supply wires from the wall transformer and the DS1822 sensor.

Use approximately 12 inches of three-conductor wire to remotely connect the DS1822 to the PCB as shown in **Figure 3**. Since the DS1822 sensor will be in water for aquarium use, seal U2 and the wire connections using waterproof epoxy or silicon. A transparent red acrylic front panel will give an attractive finished look to your thermometer. **Figure 4** shows the final assembly details for mounting the plastic panel to the PCB using four standoffs and eight screws.

**Operation**

Operation of the jumbo LED thermometer should be straightforward. If jumper JP1 is shorted, the display will be in Fahrenheit. If JP1 is left open, the display will be in Centigrade. Plug the wall transformer power supply into an AC outlet and within two seconds, the display should show the digital temperature. If the display flashes “EEE” the DS1822 sensor was not detected. Re-check the wire connections to U2 if you encounter this situation.
Reading and Writing an EEPROM
Using the Arduino

My brother-in-law has five out-of-production CNC machines he uses in his business, three of which had stopped working. By process of elimination, he found the culprit to be a Xicor X88C64 EEPROM that translated user commands to servo controls. Unable to buy programmed replacement chips and finding commercial programmers to duplicate one of his remaining working EEPROM chips prohibitively expensive, he asked me if I could help find a solution. I had gotten an Arduino Duemilanove for Christmas and had experimented with it enough to think it might provide a solution to his problem.

My first task was to Google the X88C64 EEPROM to locate the datasheet for the part (see Links). I looked for any operation that required completion faster than would be possible for the Arduino. The only instance I found was that every write during a Page Write operation must be completed in less than 100 μs. Since the Arduino runs at 16 MHz, it has a clock period of 62.5 ns (1/16 x 10^6) which would allow plenty of instructions to meet the timing requirements.

In looking at the chip specification, I noted that I would need 13 digital pins for the address/data bus plus several control leads. This would be a problem for my existing Arduino, however, since it only supports 13 digital pins (and two of those are needed for serial I/O). Not wanting to add external circuitry, I decided on an Arduino Mega which has 54 digital pins. (I’ll use any excuse to get some new gear!)

Another interesting aspect of the X88C64 was that the eight data bits and the lower eight address bits shared the same pins using the Address Latch Enable (ALE) control to designate when the pins are addresses. Since the Mega pins can be easily changed from input to output, I didn’t think this would be much of a problem.

Another issue I would need to address was that the X88C64 had 8K bytes of EEPROM. My original thought was to load the contents of a working EEPROM into an array, and then replace the chip with a blank EEPROM and write the array contents into the new chip. However, since the Mega only has 8K bytes of RAM that wouldn’t

<table>
<thead>
<tr>
<th>Signal</th>
<th>Register</th>
<th>Register Bit</th>
<th>Arduino Mega Pin</th>
</tr>
</thead>
<tbody>
<tr>
<td>Address 12</td>
<td>C</td>
<td>4</td>
<td>33</td>
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<tr>
<td>Address 11</td>
<td>C</td>
<td>3</td>
<td>34</td>
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<tr>
<td>Address 10</td>
<td>C</td>
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<tr>
<td>Address 9</td>
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<td>Address 8</td>
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<tr>
<td>Address/Data 7</td>
<td>A</td>
<td>7</td>
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<td>Address/Data 6</td>
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</tr>
<tr>
<td>CE Master</td>
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<td>3</td>
<td>46</td>
</tr>
<tr>
<td>CE Slave</td>
<td>L</td>
<td>4</td>
<td>45</td>
</tr>
<tr>
<td>WC</td>
<td>L</td>
<td>5</td>
<td>44</td>
</tr>
</tbody>
</table>
I then considered reading 4K into an array and swapping the chips twice to complete the copy. Since we only had two good EEPROMs remaining, I didn’t want to take a chance of accidentally overwriting a working chip. I settled on a design that had two ZIF sockets: one for the working EEPROM (Master) and one for the blank EEPROM (Slave). I could then read and write on a byte-by-byte basis and not require RAM storage in the Mega. This also would allow me to scale up to any size EEPROM. The downside was more involved wiring on the breadboard.

**Direct Port I/O**

The digitalWrite Arduino command is actually setting one bit in an eight-bit register. The ATmega1280 CPU used in the Mega has 11 registers designated PORTA through PORTL (PORTI is not defined) of which 54 digital bits are brought out to connectors on the Mega board. [See the ATmega 1280 datasheet section 13 (in Links) for more details.] For my programmer, I need to control all 13 address bits and read or write eight data bits, so setting bits one at a time would be quite inefficient. Also, it takes much less time to control the ports directly, even though (in my case) performance was not an issue. Each port pin actually consists of three register bits — DDRxn, PORTxn, and PINxn — where x designates the port (A through L) and n specifies the bit (0 through 7). The DDRxn bit specifies the direction of the pin. If DDRxn is set to a logic one, the pin is an output. If DDRxn is set to a logic zero, the pin is an input. PORTxn is used to set output data and

---

**Code from the main program calling the function:**

```c
edata = read_eeprom(eaddr, ce_master);
```

**Read Function:**

```c
byte read_eeprom (int address, byte ce)
{
    byte fdata;
    // Code to address chip and request a read omitted for simplicity
    fdata = PINA;
    return fdata;
}
```

**Function name**

**Parameters passed from calling program — EEPROM address and chip to read from (Master or Slave)**

**Type of data returned by function. “Void” if no data returned**

**Read data from Port A into the fdata variable**

**Value returned to the calling program**
Figure 5.
Using the Arduino to control X88C64 EEPROM write timing signals.

PORTL = PORTL & ~(1 << rd); //RD LOW

I’ll explain this starting from the right side of the statement.

1. rd is a constant with a value of one, indicating the position of the RD bit in the register.
2. 1<<rd means to shift a 1 bit in position 0, one bit to the left = 0 0 0 0 0 0 0 1 0.
3. ~ means a bitwise NOT operation which reverses the state of each bit = 1 1 1 1 1 1 1 0 1.
4. PORTL at this point in the program is 1 1 1 0 1 1 0 (CE Master, ALE = 0; other bits = 1. See Figure 1 for port bit definitions.)
   This results in:
   a. Value from step 3: 1 1 1 1 1 1 1 0 1
   b. Initial PORTL: 1 1 1 0 1 1 0 0 (final value of PORTL - note only bit 1 changed.)

For more information on bitwise logical operations, see the Links sidebar.
To determine which Mega pin the register bit connects to, refer to the Mega schematic (see Links). For example, my read pin is bit 1, register L. On the ATMega1280 chip (on the schematic), this is designated as PL1 and is chip pin 36. This signal connects to header JP2 which is pin 48 on the board. See Figure 1 for the registers and pins used for the EEPROM programmer.

Functions Simplify the Program

Any time you find blocks of code that are repeated in
your program, you might have a good candidate for using a function. Figure 2 illustrates the function concept using the read EEPROM function. (The timing and port register controls have been removed to focus on the function parameters. Complete details of the function timing are shown in Figure 5.)

The end result of calling this function is that the edata variable contains the data at address eaddr in the Master EEPROM. In my write_eeprom function, no data is returned so the first word in the function statement is “void.”

Design

My first step was to build a quick prototype to prove the concept that I could actually read and write the EEPROM. I used a breadboard, a ZIF socket, and some pre-cut jumper wires to connect to the Arduino Mega. My first program just turned on each of the address, data, and control bits in turn, so I could verify the wiring using my logic analyzer. Without a logic analyzer, it would be extremely difficult to troubleshoot problems with a digital circuit like this. I use a Rigol DS1052D but there are many less expensive alternatives including an open source hardware/software logic analyzer that is around $45. (See Links.)

By the time I had completed the wiring the blank EEPROMs had arrived and I was ready for my first big test. I wrote a program to read all 8k bytes and display them on my PC. After tweaking a few programming errors, I had my first big success and a bit of a surprise. Instead of being blank, the new EEPROMs started at address 0 with 0xAA (hex) and then alternated 0x00 0xFF for 32 bytes, then changed to 0xFF 0x00 for 32 bytes, and repeated this for the remaining data.

Now I was ready for the ultimate test of writing data to the chip. However, the write operation was more complicated than the read because the chip used Software Data Protection (SDP) to protect against inadvertent writes as shown in Figure 3.

I wrote a program to write one byte of 0xBB at address 5 and read it back, but the output showed the write had failed. I checked the timing signals with the ones on the datasheet and everything looked correct. After much pointless troubleshooting, I decided to put the circuit away and reread the EEPROM datasheet from cover to cover. I discovered that there is one important control signal that is not included in the timing diagrams: Write Control—which I had failed to connect to the chip. This signal must be low for all write operations so I just connected it to ground and finally the write routine worked. Next, I modified the write routine to write a fixed pattern to the entire 8K bytes so I would have something to use to test my final copy program (initial value of 0xFF and decrement by one for every subsequent write).

Feeling satisfied that my design concept was sound, I wired up my final version connecting the Mega to the two

![Figure 6.](https://example.com/figure6.png)

Logic analyzer trace when troubleshooting the failure to write the EEPROM. Can you spot the problem?
ZIF sockets. Not wanting to take any chances of damaging a working EEPROM, the Master socket had both the Write Control and Write signals tied high. My final design is shown in Figure 4 with the address and data signal bus in green and the control signals in red.

## Troubleshooting

Troubleshooting my final design mirrored the problems I had on my prototype — reads worked right away but I couldn’t get the writes to work. Of course, one of the first things I examined was the Write Control that had been the cause of my prototype problems. In my final design, I had decided to control the signal from the Mega and make it active at the start of my raw_write function, then turn it off at the end as shown in Figure 6.

After going down many deadends, I reverted back to reading the EEPROM spec cover to cover which finally revealed my error. The X88C64 specification states that “If the Write Control input is driven HIGH (before t_{\text{BLC Max}}), after Write goes HIGH, the write cycle will be aborted. The t_{\text{BLC max}} is 100 \mu s and if you look, my write timing Write Control was going HIGH less than 1 \mu s after Write went HIGH, causing every write to be aborted. In retrospect, I would have saved a lot of debugging time by just grounding Write Control. To correct the problem, I moved the Write Control to the main program and left it active for the entire time the chip was being written.

## Success

My brother-in-law brought me a working EEPROM and I was able to duplicate it and get all his CNC machines working again. I also got an excuse to buy some new gear, and learn a lot about Arduino programming and troubleshooting along the way. Since this was a one-time project, there were several areas of possible improvement that I didn’t pursue. For example, I made no attempt to optimize timing. (Read time was under one second, and write and compare was about one minute.) The chip specifies a worst case time between write cycles (t_{\text{WC}}) of 5 ms which is what I used in my program. However, by monitoring data bit 6 after the write the EEPROM indicates when the internal write has actually completed, which would typically be less than 5 ms.

While I’m probably the only person interested in programming an X88C64, this project illustrates how capable and cost-effective the Arduino platform is in providing an interface to control digital devices. The main consideration is to determine if the ATmega processor it uses is fast enough to generate the controls and process the data. There are many other special-purpose digital capabilities built in, such as 1C and USARTs — not to mention considerable power to process analog signals. All perhaps good topics for another article! NV

**What is an EEPROM?**

Did you ever wonder how a computer knows what to do when you first turn on the power? Whether the computer is in your PC, your car, the microwave oven, or a mainframe they all need some type of permanent program that is present even when the power is off. To put EEPROMs in perspective, it helps to know a bit of history about non-volatile memory (in roughly chronological order).

**ROM - Read Only Memory**

The information in ROM is permanently generated during the manufacturing process and can’t be changed.

**PROM - Programmable Read Only Memory**

Also known as Field Programmable ROM (FPRM) or One Time Programmable Non-Volatile Memory (OTP NVM). These circuits can be programmed (burned) in the field by special-purpose programming machines. They can only be programmed once.

**EPROM - Erasable Programmable Read Only Memory**

Similar to a PROM except that it can be erased by a strong ultraviolet light. It’s easy to recognize because the chip has a transparent quartz window on top of the package.

**EEPROM - Electrically Erasable Programmable Read Only Memory**

Permanent memory that can be changed under program control on a byte-by-byte basis. In the case of the EEPROM used in my project, the manufacturer does not publish information about the function of the chip. However, judging by its location in the circuit it is used to translate the manufacturing program in the PC into servo commands for a computer controlled milling machine.

**Flash**

Flash can also be changed under program control, and can be manufactured in higher densities and speed than EEPROM. However, the write operation can only occur on large blocks of data at a time.

If you examine the specification for the ATmega 1280 used in the Arduino Mega, you will see that is has both 128 KB Flash and 4 KB of EEPROM. The Flash is typically used for programs such as the power-up boot loader while the EEPROM can be used for storing program parameters and data that need to be permanently saved.

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**Links**

- Xicor X88C64 Datasheet: [www.datasheetcatalog.org/datasheet/xicor/mX88C64.pdf](http://www.datasheetcatalog.org/datasheet/xicor/mX88C64.pdf)
- Atmega 1280 Port Register to Arduino Mega Connector References: [http://t3.via42.org/j/Arduino_Mega_QuetschReferenz_v0_23.pdf](http://t3.via42.org/j/Arduino_Mega_QuetschReferenz_v0_23.pdf)
An exciting component in the field of alternative energy is the fuel cell. If powered by hydrogen, its fuel source can be extracted directly from water by electrolyzing (splitting) it into hydrogen and oxygen. Besides heat, the only byproduct a hydrogen fuel cell produces is water; when the two gasses are recombined internally, electricity is generated. Thus, the hydrogen fuel cell can be pollution-free and usually has more energy output as compared with a battery of the same size and weight. As such, fuel cells are beginning to draw the attention of many commercial applications including auxiliary power generators, powering your electric car, and replacing your cell phone battery to mention a few. Large stationary fuel cells already power homes and commercial buildings, and more are being added daily to supplement grid power (see the Sidebar on Types of Fuel Cells).

With all these advantages, why aren’t fuel cells more popular and widespread? There are two main reasons: one is high cost and the other is the lack of a safe, pollution-free fuel source in a form that is suitable for direct energy conversion to electricity. For example, a hydrogen fuel cell uses platinum for its MEA (Membrane Electrode Assembly — see the Sidebar on MEA) which is one of the most expensive and rare metals on earth. Plus, hydrogen is not naturally available in free form since it is chemically bonded to other elements like oxygen in water and in natural gas where a great deal of energy is required to extract it in pure form. There are other fuel cell types like methanol, alkaline, and solid oxide, and each have their own advantages and drawbacks including again cost, as well as toxicity and safety issues. Things are beginning to change, however, in favor of fuel cell technologies to make them more affordable with greater fuel availability along with safer operating and storage conditions. With that in mind, let me introduce you to this technology by doing some interesting experiments with one of them.

**The PEM “Reversible” Fuel Cell**

There are many types of fuel cells out there to choose from but the one that can demonstrate most of a fuel cell’s characteristics, as well as be affordable, easy to use, and safe is the PEM reversible fuel cell. PEM can mean Proton Exchange Membrane or Polymer Electrolyte Membrane. Take your pick — both refer to the part that separates the hydrogen protons and electrons to produce electricity (Figure 1). The reversible part means that it serves as both an electrolyzer for water to create hydrogen and oxygen, as well as a fuel cell. You get the best of both worlds with this device as it mimics a rechargeable battery. The main difference is that the electrolyte is external and does not get used up in the process of generating [DC] electricity. It can continue to generate electricity as long as hydrogen and oxygen are available.

A reversible PEM fuel cell operates in two distinct modes:
Types of Fuel Cells

**PEMFC - Polymer exchange membrane fuel cell**

The Department of Energy (DOE) is focusing on the PEMFC as the most likely candidate for transportation applications. The PEMFC has a high power density and a relatively low operating temperature (ranging from 80 to 90 degrees Celsius, or 140 to 176 degrees Fahrenheit). The low operating temperature means that it doesn’t take very long for the fuel cell to warm up and begin generating electricity.

**SOFC - Solid oxide fuel cell**

These fuel cells are best suited for large-scale stationary power generators that could provide electricity for factories or towns. This type of fuel cell operates at very high temperatures (between 700 and 1,000 degrees Celsius) which makes reliability a problem because parts of the fuel cell can break down after cycling on and off repeatedly. However, solid oxide fuel cells are very stable when in continuous use. In fact, the SOFC has demonstrated the longest operating life of any fuel cell under certain operating conditions. The high temperature also has an advantage in that the steam produced by the fuel cell can be channeled into turbines to generate more electricity. This process is called co-generation of heat and power (CHP) and it improves the overall efficiency of the system. The Bloom Box is one type of SOFC.

**AFC - Alkaline fuel cell**

This is one of the oldest designs for fuel cells; the United States space program has used them since the 1960s. The AFC is very susceptible to contamination, thus it requires pure hydrogen and oxygen. It is also very expensive, so this type of fuel cell is unlikely to be commercialized anytime soon but some companies are still trying.

**MCFC - Molten-carbonate fuel cell**

Like the SOFC, these fuel cells are also best suited for large stationary power generators. They operate at 600 degrees Celsius, so they can generate steam that can be used to generate more power. They have a lower operating temperature than solid oxide fuel cells which means they don’t need such exotic materials. This makes the design a little less expensive.

**PACF - Phosphoric-acid fuel cell**

The phosphoric-acid fuel cell has potential for use in small stationary power-generation systems. It operates at a higher temperature than polymer exchange membrane fuel cells, so it has a longer warm-up time. This makes it unsuitable for use in most vehicles.

**DMFC - Direct-methanol fuel cell**

Methanol fuel cells are comparable to a PEMFC in regards to operating temperature, but are not as efficient. Also, the DMFC requires a relatively large amount of platinum to act as a catalyst which makes these fuel cells very expensive.

Source: [www1.eere.energy.gov/hydrogenandfuelcells/fuells/tec_types.html](http://www1.eere.energy.gov/hydrogenandfuelcells/fuells/tec_types.html)

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**MEA - Membrane Electrode Assembly**

The membrane electrode assembly — or MEA — is the heart of a hydrogen fuel cell. It consists of the ion-exchange membrane, platinum anode and cathode electrodes, and gas diffusion and catalyst layers. Here’s basically how it works with hydrogen and oxygen to create electricity:

**The Anode** — the negative side of the fuel cell — conducts the electrons that are freed from the hydrogen molecules so they can be used in an external circuit. Channels etched into the anode disperse the hydrogen gas equally over the surface of the catalyst.

**The Cathode** — the positive side of the fuel cell — also contains channels that distribute the oxygen to the surface of the catalyst. It conducts the electrons back from the external circuit to the catalyst where they can recombine with the hydrogen ions and oxygen to form water.

**The Polymer Electrolyte Membrane** or PEM — is a specially treated material that looks something like ordinary kitchen plastic wrap that conducts only positively charged ions and blocks the negatively charged electrons. The PEM is the key to fuel cell technology as it permits only the necessary ions (molecules stripped of their electrons) to pass between the anode and cathode. The thickness of the membrane varies, depending on the catalyst and the amount of platinum (Pt) that is used in each electrode.

Image Credit: [Wikipedia](https://en.wikipedia.org)

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Electrolysis Mode and Fuel Cell Mode. There are also two chemical processes involved: oxidation and reduction.

In the Electrolysis Mode (Figure 2), water is introduced to both sides of the MEA where it is split into hydrogen at the cathode (negative) and oxygen at the anode (positive) by a small voltage level less than 1.5 volts DC called the water decomposition voltage that you’ll learn more about later. Hydrogen collects at the cathode and oxygen is created at the anode. Electrolysis of pure water requires excess energy in the form of overpotential to overcome various activation barriers. Without the excess energy, the electrolysis of pure water occurs very slowly if at all. This is, in part, due to the limited self-ionization of water.

Pure water has an electrical conductivity about one millionth that of seawater. Nevertheless, electrolysis can be accomplished. If you’re a chemistry buff, here are the chemical reactions:

**Electrolysis Mode Reactions**

- Anode reaction: $$2H_2O \rightarrow 4H^+ + 4e^- + O_2$$
- Cathode reaction: $$4H^+ + 4e^- \rightarrow 2H_2$$
• Total reaction: $2H_2O \rightarrow 2H_2 + O_2$
  (twice $H_2$ versus $O_2$)

In Fuel Cell Mode (Figure 3),
the process is reversed along with the polarities of the anode and cathode.
As hydrogen flows into the fuel cell on the anode (negative) side of the MEA,
the platinum catalyst facilitates the separation of the hydrogen gas into
hydrogen ions and protons (hydrogen ions). The hydrogen ions pass through
the membrane and combine with oxygen and electrons on the cathode
(positive) side producing water. The electrons—which cannot pass
through the membrane—flow from the anode to the cathode through an
external load which consumes the power generated by the cell. The
overall electrochemical process of a fuel cell is called “reverse electrolysis,”
or the opposite of electrolyzing water to form hydrogen and oxygen.
Once again, here are the chemical reactions:

**Fuel Cell Mode Reactions**
- Anode reaction: $2H_2 \rightarrow 4H^+ + 4e$
- Cathode reaction: $4H^+ + 4e + O_2 \rightarrow 2H_2O$
- Total reaction: $2H_2 + O_2 \rightarrow 2H_2O$
  (back to water again)

**Experiment Setup**

There’s obviously a lot more to say about fuel cell technology, but
the best way to learn about it is through experimenting with it. For
our reversible fuel cell, I’ve chosen one manufactured by Horizon Fuel
Cell Technologies that comes in a neat little package called the
Hydrocar (Figure 4). It has everything you’ll need to do all of the
experiments, plus it’s a car and is one of the least expensive and most
versatile ones on the market without sacrificing quality by any means.
We’ll use it for this and the following two fuel cell articles in this series.
If you have another kind of hydrogen reversible fuel cell you’re
of course free to use it.

To measure everything, we will use our familiar Parallax BS2 or
PICAXE 28X2 circuits (Figure 5 and Figure 6, respectively). You can find
the complete materials required and experiments for both circuits on my
website at [www.learnonline.com](http://www.learnonline.com) →
Experimenter Kits → BS2 or 28X2 → Hydrogen Experiments.

Before we get started with the experiments, however, you should
first “hydrate” your fuel cell so that it is ready to produce maximum
voltage and current. You’ll find these instructions in your fuel cell User
Manual. Also, please adhere to the safety precautions that are always
important for proper use; these are in the fuel cell’s manual, as well.

**Electrolysis Mode**

We’ll start the experiment by
A Little Fuel Cell History

The first known fuel cell can trace its roots back to the 1830s when a Welsh born, Oxford educated barrister named Sir William Robert Grove (1811–1896) who practiced patent law and also studied chemistry (or “natural science” as it was known at the time,) realized that if electrolysis — using electricity — could split water into hydrogen and oxygen, then the opposite should also be true. That is, combining hydrogen and oxygen with the correct method would produce electricity. Sir William was right and the first fuel cell was born. It never went much beyond the laboratory stage for over a hundred years, however.

Fast-forwarding to the early 1960s, a new government agency was about to undertake the next step in maturing fuel cell technology. NASA was developing mission-critical systems for the first prolonged manned flight into space; once in space, the orbiter needed a source of electricity. Batteries were ruled out due to their size, weight, and toxicity necessary to support a mission of eight days in space. Solar panels were also not practical at the time due to their size, weight, and low energy output (about 4% efficiency). The once obscure fuel cell thus became the technological solution to NASA’s dilemma of how to provide reliable “always on” power for extended missions into space. The PEM fuel cell was invented in the early 1960s by two General Electric scientists and was used in the Gemini series of spacecraft. It was replaced by alkaline fuel cells for the Apollo program, as well as the Space Shuttle. On the early missions — especially Apollo 13 — there were problems with fuel cells, but on subsequent missions fuel cells became increasingly more reliable.

Image Credits - Wikipedia

Electrolysis: the electrolyzing voltage, current, and power level off.

Notice it takes about 1.4 volts for the electrolysis process to work; this voltage is important for a later experiment. Also, don’t use a voltage much over three volts. Otherwise, it
may damage the fuel cell. Allow the process to continue until 20 ml of hydrogen are produced. Then, remove the battery or other power source from the setup. If you’re using another fuel cell and you need to clamp off the hydrogen from escaping, do so now. Notice that the level of hydrogen in its cylinder is twice that of oxygen, which confirms the 2-to-1 ratio in the familiar H₂O symbol.

**Fuel Cell Mode**

Now we need to reconfigure our microprocessor setup to remove the battery or solar panel and replace it with the fuel cell as the power source (but don’t attach the fuel cell just yet). We also want to add a 10 ohm load resistor where the fuel cell used to be. Again, don’t connect the motor to the fuel cell as a load. Refer to **Figure 10** and **Figure 11** for these new schematic hookups. Once again with the REEL Power software running, attach the fuel cell to the circuit and witness a plot similar to **Figure 12**. This is the transition from Electrolysis to Fuel Cell Mode. Notice the voltage, current, and power drops as the fuel cell now begins to deliver its stored energy into the 10 ohm load.

**Figure 13** illustrates just how well the fuel cell performs over an extended period of time delivering a constant voltage and current into the load. This is important in that as long as hydrogen fuel is available, the voltage and current outputs remain constant. This is quite similar to the modern lithium and nickel metal hydride batteries we studied in Part 3. Also notice that the average voltage output from the fuel cell is about 0.6 volts; this is the norm for hydrogen PEM fuel cells.

Allow the entire amount of hydrogen to be consumed as we want to be able to start fresh with our next experiment.

**Determining the Water Decomposition Voltage**

I mentioned earlier that there was a minimum voltage necessary to separate hydrogen and oxygen called the Water Decomposition Voltage. The theoretical voltage is 1.23 volts DC; however, it’s higher in actual practice due to impurities in the electrolysis process. The difference between the theoretical decomposition voltage and the measured voltage is called “overpotential.”

Overpotential is a function of the
fuel cell’s inability to expel the hydrogen and oxygen gasses that form on the metal electrodes below a certain voltage; in this case, about 1.47 volts as compared with 1.23 volts. Many other factors are involved in this difference of decomposition voltage; however, the reasons for these differences are beyond the scope of this experiment. So let’s do the experiment to find out for ourselves.

First, set up the equipment as shown in Figure 14. I’ll only show the Parallax setup for sake of space, but the PICAXE setup is basically the same. In effect, we’re attaching the solar panel to the fuel cell through a one ohm current sense resistor to see how much voltage and current are required to begin electrolysis. Also, purge any excess hydrogen that may be left in the cylinder. Next, slowly rotate the solar panel into the light and watch the voltage increase until it “jumps” and current begins to flow (Figure 15). This is when electrolysis begins and the voltage jump is indicative of the internal resistance of the electrolyzer going from a near short circuit to something higher, thus allowing current to flow. You learned about this in the Electrolysis Mode experiment.

Now tilt the solar panel away from the light to stop the electrolysis momentarily. Then “very slowly” adjust it back into the light until you find the exact

What is a fuel cell?

A fuel cell is a device that converts the chemical energy of a fuel (hydrogen, natural gas, methanol, gasoline, etc.) and an oxidant (air or oxygen) into electricity. Fuel cells are classified by their electrolyte material. In principle, a fuel cell operates like a battery as both batteries and fuel cells are electrochemical devices. Unlike a battery, however, a fuel cell does not run down or require recharging. It will produce electricity and heat as long as fuel and an oxidizer are supplied. As such, both have a positively charged anode, a negatively charged cathode, and an ion-conducting material called an electrolyte.

Electrochemical devices generate electricity without combustion of the fuel and oxidizer, as opposed to what occurs with traditional methods of electricity generation. Fuel cell construction generally consists of a fuel electrode (anode) and an oxidant electrode (cathode) separated by an ion-conducting membrane. Oxygen passes over one electrode and hydrogen over the other, generating electricity, water, and heat. Fuel cells chemically combine the molecules of a fuel and oxidizer without burning or having to dispense with the inefficiencies and pollution of traditional combustion (i.e., the Carnot Cycle).

Source - The U.S. Department of Defense (DoD) Fuel Cell Test and Evaluation Center (FCTec) www.fctec.com/fctec basics.asp
minimum voltage where electrolysis begins.

Figure 16 illustrates that our minimum voltage is 1.47 volts where a minimum current of 24 milliamps is flowing. More voltage will result in a lower internal resistance that allows for more current to flow as shown in Figure 17.

Summary

In this first article, you were introduced to some of the fuel cell’s basic operational characteristics like the dual modes of operation and minimum water decomposition voltage. Future articles will address more of its inner workings, as well as applications for portable electronics and for powering vehicles. If recent history is any guide, the fuel cell will most likely gain greater prominence in the coming years. For example, the first decade of the 21st century lead the way to the expansion of the Internet and the “always connected generation” with Internet-enabled portable computers and cell phones.

The second decade will most likely lead to independent, portable power sources that run off grid and produce little or no pollution – plus be economically competitive and ready to use 24/7. Fuel cells will be a big part of this. If that sounds impractical or a bit too optimistic, then just look back 10 years to see what’s happened then.

Figure 17. Adding More Voltage For Greater Electrolysis.

to computer and communications technologies in that short amount of time. We shall see. In the meantime conserve energy and “stay green.” NV

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BY FRED EADY

SHUFFLING THE TCP/IP STACK

Just a few minutes after finishing up last month’s ZeroG column, I realized that the seemingly simple 16-bit PIC24FJ128GA006 microcontroller design contains a ton of potential. I’ve been doing some really deep thinking about how to tap that potential. So this month, in addition to shuffling bits in the Microchip TCP/IP stack, we’re going to perform some soldering iron surgery.

WALKING THE MICROCHIP TCP/IP STACK

The Microchip TCP/IP Stack is designed to accommodate all of the currently available Microchip Ethernet products. However, the Microchip TCP/IP Stack architects also realized that when it comes down to hardware designs, not everyone would be following Microchip’s yellow brick road. So, they left some really obvious back doors and windows open for those of us skipping around in ruby red slippers behind a little yip-yip dog.

Although the PIC18, PIC24, and PIC32 families of microcontrollers are supported by the TCP/IP Stack, the 16-bit PIC24FJ128GA006 we used in the ZG2100M support role is not directly supported in any of the Stack templates. Recall that during the design of the ZeroG support hardware, we attempted to address the ZeroG module in a similar manner to other 16-bit microcontrollers supported by the TCP/IP Stack. So, when we could, we used the same microcontroller I/O pin-to-ZG2100M scheme as laid out in the Stack’s configuration files.

Regardless of our copy cat ways, one of the very first things we need to do is inform the TCP/IP Stack that we are “different.” We can identify ourselves to the stack components by way of the Stack’s HardwareProfile.h file. Here’s how the Stack architects have allowed us to introduce ourselves:

```
// Choose which hardware profile to compile for
// here. See the hardware profiles below for
// meaning of various options.
#define PICDEMNET2
#define PIC18_EXPLORER
#define HPC_EXPLORER
#define PIC24FJ128GA004_PIM
#define EXPLORER_16
#define DSPICDEM11
#define PIC32_STARTER_KIT
#define PIC32_ETH_STARTER_KIT
#define YOUR_BOARD
#define ZeroG_PIC24FJ128GA006_TRAINER
```

Choosing a hardware profile entails removing the comment prefix (//). Naturally — to avoid compiler apocalypse — we should only select a single profile from the list. The PIC24FJ64GA004 PIM is designed to mount in the Explorer 16 Development Board’s PIM socket. However, due to the PIC24FJ64GA004 PIM module’s significantly different pin mappings, this particular PIM has its own set of stack definitions. Most of the other Explorer 16 Development Board PIMs are supported by the TCP/IP Stack under the EXPLORER_16 definition. These devices include the PIC24FJ128GA010, the PIC24HJ256GP7110, the dsPIC33FJ256GP7110, the PIC32MX360F512L, the PIC32MX460F512L, and the PIC32MX795F512L PIMs.

The Microchip 32-bit microcontroller starter kits are also supported by the TCP/IP Stack. The PIC32MX starter kits supported under the PIC32 STARTER KIT definition include the PIC32MX360F512L Starter Kit, the PIC32MX460F512L USB Starter Board, and the PIC32MX795F512L USB Starter Kit II. There’s even specialized stack support for the PIC32MX795F512L Ethernet Starter Kit board.

YOUR_BOARD is really our board, which is the ZeroG PIC24FJ128GA006 Trainer we constructed last month. If we had not defined a chunk of target hardware, the Stack will get up on its donkey and start making assumptions while looking for clues as to what microcontroller it will be compiled to drive. The most obvious place to begin looking is in the area of MPLAB IDE that specifies the microcontroller type to the IDE. Obviously, our life with the Stack is much easier if we don’t allow it to go donkey walk-about.

According to Schematic 1 and the ExpressPCB layout in Figure 1, the ZeroG - PIC24FJ128GA006 Trainer has a couple of user-accessible LEDs hanging out there on I/O pins RC13 and RC14. As my mom would say, “That’s nice.” However, our stack application doesn’t know about them unless we tell it that they are available. The same Stack ignorance holds true for the clock frequency that is driving the Trainer’s PIC24FJ128GA006 microcontroller. When we defined our Trainer to the Stack earlier, we were also given
the privilege to carve out some configuration definition space of our own within the confines of HardwareProfile.h:

```c
#elf defined(ZeroG_PIC24FJ128GA006_TRAINER) // Define your own board hardware profile here
// PIC24F processor
#define GetSystemClock() (32000000ul) // Hz
#define GetInstructionClock()
  (GetSystemClock()/2)
#define GetPeripheralClock()
  GetInstructionClock()
#define LED0_TRIS  (TRISCbits.TRISC13)
#define LED0_IO  (LATCbits.LATC13)
#define LED1_TRIS  (TRISCbits.TRISC14)
#define LED1_IO  (LATCbits.LATC14)
// no other LED's
#define LED2_TRIS  LED1_TRIS
#define LED2_IO  LED1_IO
#define LED3_TRIS  LED1_TRIS
#define LED3_IO  LED1_IO
#define LED4_TRIS  LED1_TRIS
#define LED4_IO  LED1_IO
#define LED5_TRIS  LED1_TRIS
#define LED5_IO  LED1_IO
#define LED6_TRIS  LED1_TRIS
#define LED6_IO  LED1_IO
#define LED7_TRIS  LED1_TRIS
#define LED7_IO  LED1_IO
#define LED_GET() (volatile unsigned int*)(&LATC))
#define LED_PUT(a)
  (*((volatile unsigned int*)(&LATC)) = (a))
```

The pair of user LEDs and the clocking scheme are exposed to the rest of the stack components in our ZeroG Trainer HardwareProfile.h definition space. Note that since we only have a pair of LEDs and the Stack is expecting to see a few more, we must dummy up on nonexistent LEDs that may be expected to be there by other modules that comprise the TCP/IP Stack. Our definition coding references any calls to nonexistent LEDs to our LED1. Any LED beyond LED1 that is referenced in the Stack will resolve to LED1. The absence of the LEDs beyond LED1 won't keep the Stack from functioning. However, trust me. You will grow weary of fixing the undefined LED compile errors. Our MainDemo.c application file wants to blink LED0 to let us humans know that the Stack code is running:

```c
  // Blink LED0 (right most one) every second.
  if (TickGet() - t >= TICK_SECOND/2ul) {
    t = TickGet();
    LED0_IO ^= 1;
  }
```

The Stack creators have thrown us a bone here with the gift of the LED_GET and LED_PUT macros.

**FIGURE 1.** This is a graphic depiction of the ZeroG - PIC24FJ128GA006 Trainer ExpressPCB layout file. You can get the actual ExpressPCB file from within this month's download package at www.nutsvolts.com.
Some of the TCP/IP Stack example applications like to have their buttons pushed. Our Trainer hardware is button free, but our Trainer TCP/IP Stack definitions are not:

```
#define BUTTON0_TRIS (TRISBbits.TRISB12) // Ref S4
#define BUTTON0_IO (PORTBbits.RB12)
```

The buttons on the Explorer 16 Development Board are mapped to PORTD. It doesn’t matter where we map our button (or buttons) just as long as the buttons follow the TCP/IP Stack naming convention. For instance, BUTTON0 is BUTTON0 no matter if it is mapped to RB12 or RF0.

The ZG2100M module feeds from a SPI port. To keep things as simple as possible and to follow the predetermined flow of the TCP/IP Stack, we must map the PIC24FJ128GA006’s SPI portal to the ZG2100M’s SPI portal exactly like the TCP/IP Stack does. In that the PIC24FJ128GA006’s or any other SPI-equipped PIC’s hardware SPI portal is represented by a standard set of PIC microcontroller pins, we can easily map the PIC24FJ128GA006’s SPI portal to the ZG2100M’s SPI pin set in our section of the HardwareProfile.h file:

```
// ZeroG ZG2100M WiFi I/O pins

#define ZG_CS_TRIS (TRISBbits.TRISB2)
#define ZG_CS_IO (LATBbits.LATB2)
#define ZG_SDI_TRIS (TRISBbits.TRISB6)
#define ZG_SCK_TRIS (TRISBbits.TRISB5)
#define ZG_SDOUT_TRIS (TRISBbits.TRISB3)
#define ZG_RST_TRIS (TRISBbits.TRISB0)
#define ZG_RST_IO (LATBbits.LATB0)
#define ZG_EINT_TRIS (TRISBbits.TRISB8) // INT1
#define ZG_EINT_IO (PORTBbits.RB8)
#define XCN331_TRIS (PORTBbits.TRISF1)
#define XCN331_IO (PORTBbits.RF1)
```

You can check the HardwareProfile.h SPI portal entries against the actual circuit routes in Schematic 1. What you can’t see in Schematic 1 are the ZG2100M interrupt definitions which are also part of our HardwareProfile.h definitions:

```
#if defined( __C30__ )
#define ZG_INT_EDGE (INTCON2bits.INT1E)
#define ZG_INT_IE (IECbits.INT1IE)
#define ZG_INT_IF (IFS1bits.INT1F)
#endif
```

The __C30__ definition tells us that the interrupt bits that follow will be used if the MPLAB C Compiler for PIC24 MCUs is being used to compile our TCP/IP Stack application. In our case, the #if will return a Boolean true.

We’ve had quite a few TCP/IP discussions and the Stack has been at the center of many of them. If you’ve been privy to those discussions, you already know that we don’t have to do a bunch of coding to utilize the built-in features of the Stack. Many of the routines that would normally be written in the Stack application are already functions that are permanent, pre-coded members. So, in addition to coding our Stack application, all we really need to do to put it to work is twiddle a few bits in the HardwareProfile.h and TCPIPConfig.h files. Our Trainer design takes advantage of the Stack’s ZG2100M drivers and support functions. We’re about to see just how easy it is to add an LCD and RS-232 interface to our ZeroG Trainer design.

**ADDING A REGULATION RS-232 HARDWARE INTERFACE**

The TCP/IP Stack can talk to us via the Trainer’s RS-232 port. However, as you can see in Schematic 1, there is no Trainer RS-232 port. That’s partly because the PIC24FJ128GA006’s SPI1 portal is being used instead of assigning the SPI SDI1 and SDO1 pins as UART I/O pins U1RX and U1TX. Fred’s First Rule of Embedded Computing states that in the world of embedded design, nothing is free. Not to worry. The Stack is also capable of utilizing the PIC24FJ128GA006’s second UART on I/O pins RF4 and RF5. Before we can pass RS-232 traffic through the second UART, we have some soldering to do.

The header pads surrounding the PIC24FJ128GA006 in Figure 1 are all placed on 0.1 inch centers. Doing this allows us to mate the Trainer’s PCB (printed circuit board) to an auxiliary PCB or breadboarding using inexpensive 0.1 inch pitch SIP (Single Inline Package) header pins and header sockets. As you can see in Photo 1, I’ve chosen to equip the Trainer’s PCB with the 0.1 inch center header pins. The female socket pins are mounted on a Twin Industries 8100-45-LF prototyping board lying under the CANON in Photo 2. The 8100-45-LF is a 4.0 inch x 5.0 inch gold-plated, FR4-based prototyping board with 0.37 inch plated holes. I mounted the Trainer PCB in the upper left corner of the 8100-45-LF prototyping board to meet the RF radiation clearance requirements of the ZG2100M Ethernet module that is integral to this PCB.

The PIC24FJ128GA006’s digital input I/O pins are all five-volt tolerant. However – if we can – it would be nice not to have to worry about that when we construct our UART interface circuitry. So, to keep things simple, we’ll design our UART interface around the STMicroelectronics ST3232 RS-232 Driver/Receiver IC. The ST3232 is capable of operating with power supply rails as low as 3.0 volts and as high as 5.5 volts. Drawing between 0.3 mA and 1.0 mA of current during normal operation, the ST3232 can be easily accommodated by the ZeroG Trainer’s onboard TC1262-3.3 voltage regulator. With that, I’ve added a couple of 3.30 volt electrical paths between the Trainer and the Twin Industries prototyping board.

The Trainer’s RS-232 interface consists of an STMicroelectronics ST3232, five 0.1 µF ceramic capacitors, a 10-pin header, a 10-pin IDC plug, a ribbon cable, and a nine-pin female D-shell connector. I connected all of the aforementioned items together as you can see in Schematic 2.

The RS-232 interface design is identical to the RS-232 hardware used by the EDTP Ethernet MINI NIC. If you orient and assemble your RS-232 interface cable exactly like you see in Photo 3, you won’t have to scratch your head or pull out that ohmmeter. My version of the RS-232

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*NUTS*VOLTS  May 2010
DRIVING THE NEW RS-232 HARDWARE

As I mentioned earlier, the TCP/IP Stack has many built-in functions that we can take advantage of with one of those being a PIC24FJ128GA006 UART driver. We must dip into the TCP/IPConfig.h file to use the built-in UART driver code:

```c
#define STACK_USE_UART // Application demo
// using UART for IP
// address display
// and stack
// configuration
```

The stack UART code is revealed by simply removing the comment slashes shielding the #define STACK_USE_UART statement. Since we aren't using a standard PIC platform expected by the TCP/IP Stack, we must balance the UART equation in our HardwareProfile.h definitions. This involves identifying the PIC24FJ128GA006's UART2 I/O pins to the Stack:

```c
#define UARTTX_TRIS (TRISBbits.TRISF5)
#define UARTTX_IO (PORTB.bits.RF5)
#define UARTRX_TRIS (TRISBbits.TRISF4)
#define UARTRX_IO (PORTB.bits.RF4)
```

Up to this point, we've been performing some serious configuration coding. However, thus far, we haven't handled any executable UART2 code and that's a good thing because the TCP/IPConfig.h and HardwareProfile.h files are configuration files. The actual UART2 code lies in a Stack file called UART.c which is included in our compilation process. The code within the UART.c file is encapsulated with this conditional compilation statement:

```c
#if defined(STACK_USE_UART)
    #ifdef UART2
    //UART.c driver code located here
#endif
#endif
```

To be able to use any of the stack's free UART

PHOTO 1. The ZeroG - PIC24FJ128GA006 Trainer printed circuit board was designed from the ground up to allow external boards and circuitry easy access to the I/O subsystem.

PHOTO 2. Standard perfboard will work just fine here, as well. The ground plane and plated holes make this high-quality prototyping board a top candidate for just about any breadboarding project.

SOURCES
EDTP Electronics, Inc.
ZeroG - PIC24FJ128GA006 Trainer
www.edtp.com

Microchip
PIC24FJ128GA006
TCP/IP Stack
ZeroG ZG2100M Wi-Fi Module
www.microchip.com

code, all of the UART2 functions inside of UART.c must be exposed in our Trainer section of the HardwareProfile.h file:

```c
#define UARTTX_TRIS (TRISBbits.TRISF5)
#define UARTRX_TRIS (TRISBbits.TRISF4)
#define UARTTX_IO (PORTB.bits.RF5)
#define UARTRX_IO (PORTB.bits.RF4)
```

Now that you see what was exposed by our entries in the ZeroG - PIC24FJ128GA006 Trainer area of the HardwareProfile.h file, the UART2 function names provide a good idea of how the functions within the UART.c file manipulate the PIC24FJ128GA006's UART2 hardware.

I don't want that soldering iron to go idle and cool down just yet. So, before we reap the benefits of our new RS-232 capabilities, let's perform the other engineering change.

ADDING AN LCD

I'm sure you know the drill. To integrate an LCD into our Trainer design we must first define the LCD I/O pinout in the sector of the Stack's HardwareProfile.h file. The trick
here is to choose free I/O pins on our PIC24FJ128GA006 that are suitable to be used as LCD I/O pins. Here’s my take:

```c
#define LCD_DATA_TRIS (*(volatile BYTE*) &TRISB))
#define LCD_DATA_IO (*(volatile BYTE*) &LATE))
#define LCD_RD_WR_TRIS (TRISBbits.TRISB5)
#define LCD_RD_WR_IO (LATBbits.LATB5)
#define LCD_RS_TRIS (TRISBbits.TRISB15)
#define LCD_RS_IO (LATBbits.LATB15)
#define LCD_E_TRIS (TRISDbits.TRISD4)
#define LCD_E_IO (LATDbits.LATD4)
```

Beating my LCD I/O pin definitions against Schematic 1 assigns a totally unused PORTE to the LCD data bus; I/O pin RD5 is available for the LCD RD/WR I/O interface pin. It looks like RB15 is also free for duty and so are I/O pins RD4 and RD5. I can’t take all of the credit for this LCD pin map as it is identical to the Explorer 16.

This situation spawns Fred’s Second Rule of Embedded Computing: Never assume anything. In the case of the LCD, the enabler definition is found in the TCP/IP Stack’s TCPIPConf.h file which should never be modified by the programmer:

```c
// Enable the LCD if configured in the
// hardware profile
#if defined(LCD_DATA_IO) && defined(LCD_DATA0_IO)
#define USE_LCD
#endif
```

It seems that we have unwittingly enabled the TCP/IP Stack’s LCD driver functions by simply defining the LCD’s data I/O map to the Stack in the HardwareProfile.h file. As I just mentioned, performing code changes to the TCP/IP Stack’s native files is a NO NO. As we have just seen, the flow of the stack has been well thought out for us. If a Stack feature or function can’t be controlled by editing the HardwareProfile.h or TCPIPConf.h file, you don’t need to control it.

I like to keep things as simple as possible. I also like to include things in my designs that I’ve seen work well in other places. If you’ve ever done anything with a PIC development tool, it’s almost a given that you’ve seen the LCD posing under the White Lightning Photographic Flash Units in Photo 5. The Lumex LCM-S01602DR/M you see there is the LCD of choice for the Explorer 16 Development Board. Now, it’s the LCD of choice for our ZeroG - PIC24FJ128GA006 Trainer.

Well, what the heck are we waiting for? Let’s wire it up! We already have the PIC24FJ128GA006 LCD I/O pin layout and the LCM-S01602DR/M adheres to the industry standard LCD pinout. If you’re LCD challenged, you can use Schematic 3 as your LCD integration guide.

### MAGIC SMOKE RETENTION TEST

As you can see in Photo 5, I’ve wired in the LCM-
S01602DTR/M LCD module to keep our new RS-232 interface company. The LCM-S01602DTR/M LCD module is a five-volt device. That won't present any problems for the PIC24FJ128GA006 as this LCD module's digital inputs will see the PIC24FJ128GA006's signals as valid TTL levels.

It appears everything is working as designed. When our newly updated Trainer is powered up, we are immediately presented with a banner message and default IP address in the LCD pixels. In our case, the IP address shown is a DHCP-assigned IP address that was leased to the ZeroG - PIC24FJ128GA006 Trainer by the EDTP shop network. The serial port reported the connection in Screenshot 1. The text displayed by the serial port and LCD can be altered in the application file which is called MainDemo.c:

```c
#if defined(USE_LCD)
// Initialize and display the stack version
// on the LCD
LCDInit();
DelayMs(100);
strupgm2ram((char*)LCDText, "NUTS AND VOLTS "
          "TCPStack V5.20 ");
LCDUpdate();
#endif
#endif
```

You now possess a commanding knowledge of the TCP/IP Stack and the hardware it supports. You're ready to pull some of that potential I talked about earlier into your own 16-bit projects. I'm going to share this knowledge that comprises Photo 6 with the folks over at SERVO in their native tongue. So, post the TCP/IP Stack and the PIC24FJ128GA006 in your Design Cycle cache and hop over to SERVO and see how we’re going to modify this technology for robotic control purposes. NV

Fred Eady can be contacted via email at fred@edtp.com.

PHOTO 6. Up and operational under the camera.
Photocells are used to vary the amount of resistance in many types of electronic devices. For example, they are used to automatically turn on lights when it gets dark. By doing this experiment, you’ll see that the photocell varies the brightness of the LED, depending on how much light is hitting its surface.

1. Build the Circuit.
   Using the schematic along with the pictorial diagram, place the components on a solderless breadboard as shown. Verify that your wiring is correct.

2. Do the Experiment.
   **Theory:** In this circuit, the electronics flow from the negative side of the battery through the LED, through the photocell, and back to the positive side of the battery. The more light hitting the photocell, the brighter the LED.

   **Procedure:** Connect a nine-volt battery to the battery snap and observe the brightness of the LED. Now, cover the photocell with your finger to keep light from getting to it. Notice that the LED gets dimmer when you cover the photocell.

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As seen on the December 2009 cover

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NUTSVOLTS 65
TESTING THE COMPLETE NEARSYS SUN SENSOR

Last time, this column described the construction of a Sun Sensor — a device that gives the near spacecraft the ability to determine the sun’s position relative to onboard experiments using cameras. This month, we’ll wrap up with my concept test of the sun sensor. Then, I’ll add some comments about the new ultraviolet source I installed into my environmental test chamber.

The sun sensor described last time determines the solar quadrant by reporting which photocell has the highest voltage reading. I wondered though, what is the possibility that the sun sensor could report the sun’s position within the solar quadrant? If possible, the sensor could report the sun’s position much more accurately.

The code used in this test digitized the voltage from a single photocell every five seconds using the READADC command. The reading was then displayed on a laptop with the DEBUG command. Using a protractor, I rotated the sun sensor (in relationship to the sun) in ten-degree increments and recorded the ADC value each time. The test ran twice; the first time without a ping pong ball diffuser over the photocell and a second time with it in place. The ADC readings and the sun angles were then loaded into a spreadsheet. In a third column, I calculated the sun’s intensity on the photocell assuming it would be proportional to the cosine of the angle between the photocell’s normal reading and the sun. I then created two charts to display the results you see here.

My conclusion from these two charts is that the photocell’s small magnitude of voltage change makes it too difficult to determine the sun’s position with respect to a single photocell. However, we can probably determine the sun’s position within an octant (45 degrees) by sorting the voltages of the photocells. The sun’s position would be located between the two brightest quadrants. That is, as long as the voltage of the third highest quadrant is significantly lower than the second quadrant. If the second and third highest photocell values are similar, then the sun is located squarely with the quadrant of the highest voltage photocell.

A ROBOTIC APPLICATION FOR THE SUN SENSOR

Not only is the sun sensor useful for near space missions, it’s also useful in robotics. A robotic simulator of

In this chart, the red curve is the sun’s expected intensity over the face of the photocell. It’s a cosine function. The other two curves are readings with and without the ping pong ball diffusers in place over the photocells.
A near space flight can climb to over 30 km, so it can experience a significant increase in UV-B but still not receive much UV-A. This graphic is from the Geophysical Institute at the University of Alaska, Fairbanks.

A lunar or Martian rover can use a sun sensor to determine directions in lieu of a compass (this is an issue for these two locations since neither the moon or Mars have global magnetic fields). A robot can also use a sun sensor to determine when the sun has risen or set — very important to a solar powered rover. If calibrated properly, a robotic rover might also use the sun sensor to determine the intensity of the sunlight. If you plan to use the sun sensor in robotics, I recommend drilling out the large mounting holes in the PCB (see January’s issue). Bolt two-inch long #4-40 machine screws to the PCB so the sun sensor can attach to the robot. Raise the sun sensor on a mast that keeps it above any other structure on the robot (to avoid shadows). (In the near future, I plan to write an article for SERVO Magazine about an articulated robot that uses the sun sensor in this way. So keep your eyes open.)

NearSys is in the process of producing a sun sensor kit for those who do not want to make their own PCB or gather the needed components. Go to NearSys.com/catalog for more information.

**ADDING UVC TO THE ENVIRONMENTAL TEST CHAMBER**

In my Nov ’09 column, I discussed how I incorporated ultraviolet into the simulator. However, I’m not totally happy with this UV source (UV LEDs) because its ultraviolet light is too close to the violet part of the visible spectrum. As many Nuts & Volts readers know, scientists divide the UV spectrum into three ranges: A, B, and C. Ultraviolet A, or UV-A, spans a wavelength range from 400 to 315 nm — this is the band of UV

fortunately, it’s blocked high in the stratosphere. Ozone in the stratosphere strongly attenuates UV-B, but some still reaches the surface. The small amount that does make it to the ground promotes the healthy production of vitamin D and is responsible for the sunburns we get each summer.

To improve the quality of my near space simulator, it needs to have a source of UV-B. LEDs capable of emitting this frequency are commercially available, but are too costly at this time. UV-C, however, is used as a germicide and is readily available in items like water purifiers for backyard ponds. Since I can’t get an inexpensive source of UV-B yet, I decided I’d settle for mixing some UV-A and UV-C (am I right in thinking that mixing UV-A and UV-C averages out to UV-B?). Actually, I initially thought I had found a good UV-B source when I ran across the UV source described this month. It wasn’t until after I had installed the lamps into my environmental chamber that I discovered they were really UV-C. Therefore, here’s my experience with adding another ultraviolet source to my environmental test chamber. Readers may find other uses for this inexpensive UV-C source.

The DenTek toothbrush sanitizer is a plastic case containing batteries, an ultraviolet lamp, drive circuit, and power switch. The drive circuit boosts the voltage of its two AAA batteries to the 470 volts peak-to-peak it takes to operate the UV lamp (which is an uncoated mercury vapor lamp). So, let’s violate another warranty by bashing this commercially available product into something more useful.

To gain control of the UV lamp, you have to open the...
The top of the lamp driver printed circuit board. The eight-pin IC produces a sine wave at 44.4 kHz to drive a small transformer that produces the 470 Vpp needed to power the tiny mercury lamp.

case by removing three screws from the back and pop the case open. Once opened, take out the three screws holding the PCB to the case. Once free, the printed circuit board looks like what you see in the photos.

There’s no ON-OFF switch on the DenTek toothbrush sanitizer. Instead, there’s a momentary pushbutton switch that’s activated by a small tooth in the lid of the case. There are six contacts on the switch with three on each side of it. The switch leads are soldered to two PCB copper pads (two leads on the first pad and the other four on the second pad). The red wire (+3V) must be moved to the other pad to electrically bypass the switch. The photo shows the PCB pads I’m talking about.

I spliced a two-cell AAA battery pack to the PCB’s red and black wires. I chose not to incorporate a switch since I’ll be the only person turning the UV lamp on and off. This means to power the UV lamp on and off, I either put the batteries into their holder or remove them. You may opt to add a switch. In that case, you can either solder a toggle switch between the battery holder and the PCB or use a AAA cell holder with built-in switch.

Avoid exposure to the UV lamp. When energized, the lamp produces UV-C at a wavelength of 254 nm, which is harmful to DNA in cells (this includes bacteria, fungi, and viruses). The direct damage from UV-C occurs when UV photons convert the hydrogen bonds (weak bonds formed by electrostatic attraction) between some nucleotides in a DNA strand into covalent bonds (stronger bonds where electrons are shared between atoms). Since the covalent bond is stronger, the DNA is unable to unzip itself for gene expression and DNA replication. Basically, covalent bonds foul the operation of the DNA machine and so the cell dies.

I mounted two UV-C lamp circuits alongside the LED UV-A bank inside my near space environmental chamber. The new and improved UV Bank sits at the top of the chamber where it shines light on the victim below. Experiments inside the chamber get exposed to intense cold, bright UV, increased ionizing radiation, and a vacuum (which feels like home in near space). In future experiments, I’ll expose cell cultures to these conditions to see which can still multiply afterwards. Experiments like this can identify microorganisms that could potentially survive a trip from Earth to Mars after being blasted off the Earth by a meteorite impact.

The next stage for the near space environmental chamber is to find a better radiation source (that includes adding betas and gammas) and an affordable UV-B source. Once I locate these, you can count on me to write about it in N&V.

Onwards and Upwards,
Your near space guide NV

With the lamps off, this UV bank looks harmless.
But apply power and it’s a DNA nightmare. Apparently, my digital camera has a problem adjusting exposure time and focus in UV light.

Move the red wire to this pad
Busy As A BeAVR
by Joe Pardue

Recap

Last month, we finished busting up the Arduino and began reassembling the resulting ruins as the Breadboardino. We learned to use it with the regular free Atmel tools AVRStudio/WInAVR and a helper tool that I provided: AVRUp to ease the use of AVRDUDE. Now we can move on to more capable software and hardware (okay, IMHO) without forever trying to explain the word Arduino. Keep in mind that I love the Arduino for beginners, and wrote the book, An Arduino Workshop that along with the Arduino Projects Kit (both available from Nuts & Volts) are, in my totally unbiased opinion, the absolute all-time best possible starting point for beginners. But enough of my public display of humility. This month, I introduce the BeAVR (Breadboard enabled AVR). The hardware version shown in Figure 1 looks suspiciously like the Breadboardino on steroids. That’s because the Breadboardino uses the 28-pin ATmega328 and the BeAVR uses the 40-pin ATmega644. That’s twice the memory and 12 more I/O pins! You can’t be too rich, too thin, have too much memory, or too many I/O pins. And, yes, we are going to be as busy as a BeAVR.

So Why a BeAVR?

BeAVR is an open source design concept for AVR hardware and software. The hardware schematics can be implemented on a breadboard (as we will see first) or on a PCB which we will introduce next month. We’ve seen most of the software in earlier workshops; the main addition will be to use a bootloader for the ATmega644. So, what’s a bootloader?

Baron Munchhausen and the Bootloader

In the early part of the 18th century, the exact date is unknown; Baron Munchhausen saved himself from drowning in a shipwreck by pulling himself out of the sea by his own bootstraps. A particularly miraculous feat since (as you may have noticed from his bust shown in Figure 2) he had no arms. In homage to this great man, computer folk have used the term ‘bootstrapping’ to mean the emergence of a complex system by starting with simple components and progressively developing greater complexity on top of them. In our case, a bootstrapper (a.k.a., bootloader) is a small simple program that can be used to load and run a large complex program.

I like to brag about how many years ago, I wrote an 81 byte machine code bootstrap program for the 8051 that I input by hand (my hand, to be exact) using DIP switches into an SRAM chip powered by a lantern battery. Note that SRAM is volatile memory and forgets everything the moment power is removed. This tiny program allowed me to download a hex file to the 8051 from an original IBM PC over an RS-232 connection. I learned a lot — mainly how difficult it was to input a lousy 81 bytes using DIP switches — and I tended to do things the hard way for some (yet to be explained) reason. I also invented several new words when I knocked the alligator clips off the battery in the midst of one of my test runs causing the SRAM to immediately forget everything I’d told it. After finding where I had thrown all the pieces, I joined the rest of the world and started using non-volatile memory in the form of an EPROM (Erasable Programmable Read Only Memory) which has memory that will remember what you told it if the power has been removed. The EPROMs I used were kind of cool because the IC had a transparent window in the top showing you the silicon chip memory inside. This wasn’t for your personal voyeuristic entertainment though. It was so you
could shine a UV lamp onto the memory and erase it.

This operation took a while, the software test procedure generally went like this: fail, pull out the EPROM, stick it in a UV eraser, go get a cup of coffee and watch a soap opera, load the next iteration of the code using an EPROM programmer, fail, pull out the EPROM ... it was actually even more boring than it sounds. Then, some genius figured out a way to erase the EPROM with electricity thereby creating the EEPROM (the additional E stands for Electrical).

EEPROM is a kind of memory that won't go brain dead if you pull the alligator clip off the lantern battery, and you don't need a special eraser to erase it. The next innovation was Flash EEPROM, more commonly known as Flash memory. This memory was much cheaper than regular EEPROM because it erased memory in large blocks rather than a byte at a time. It's the kind of memory you usually find on memory cards and USB Flash drives. This innovation is one of the reasons that we have AVR's. The guys who designed the AVR wanted program memory that could be both non-volatile and easily erasable, so they got with the folks at Atmel (who were making cash on Flash). So, what does this have to do with Baron Munchhausen? Well, the AVR architecture has some special features that allow us to use Flash memory as a bootloader.

All right, that was strange, but the points were: A bootloader allows you to program a microcontroller without an external programmer; and Flash memory is great for a bootloader because it is non-volatile so you can use lantern batteries and alligator clips without cursing and throwing things.

**Chicken or Egg**

A bootloader is a program that allows you to upload a program without having an external programmer. However, the bootloader IS a program, so how do you program it onto a micro? Well, you use an external programmer. But — you ask — if the reason for a bootloader is so you don’t need an external programmer ... but you need one to put the bootloader on the micro ... Wait a minute! This is confusing! The answer is that if you have an external programmer, then you don’t need a bootloader — but if somebody is kind enough to program the chip with a bootloader for you, then you don’t need an external programmer.

Last month, we relied on SparkFun ([www.sparkfun.com](http://www.sparkfun.com)) to put a bootloader on an ATmega328 for our BreadboArduino. This month, we are going to look at how to put a bootloader on an ATmega644. Atmel has several really good programmers that would fit our needs: the AVRISP mkII; the Dragon; and the STK-500 — in order of cost and capability. Since we will be using ISP (In System Programming), any of the three would suffice. I’ll go with the mid-priced (~$50) option to save space.

**Building the BeAVR on a Breadboard**

To make this truly open source, I thought it best to build this first on a breadboard — which is about as open as you can get — then next month, take the design to a PCB. I had all sorts of fun building the prototype on a breadboard. (And by fun I mean real pain and suffering.) Since this is open source, you too get to share in the fun.

**BeAVR Schematic**

The BeAVR schematic shown in Figure 3 is much like the BreadboArduino from last month with the ATmega328 swapped out for an ATmega644.
Is a Programmer a Person or a Machine?

When I’m sitting at my laptop writing code in either the Arduino IDE or AVRStudio editors, I’m a programmer and I’m programming. After I compile the code and upload it to the AVR, I use a programmer for programming the IC. So, yes, there is a bit of confusion with the words programmer and programming. From one view, it is a human activity and from another it is a machine activity. We will see how to use an Atmel AVR Dragon as our hardware programmer. If you can get your hands on an AVRISP or an STK-500, there is no need to get a Dragon since both will do ISP programming just as well.

AVR Dragon

I’ve got to admit that the AVR Dragon provides the best out-of-box experience I’ve ever had with a programmer — mainly because the box is so darn cool (Figures 4 and 5). The cover has a Norwegian and a Chinese Dragon biting each other’s tail. (There just has to be an interesting story behind that.) Unfortunately, once you get it out of the box, the trouble starts. Don’t get me wrong, this is a great little board and very economical, but you’ve got to do some serious homework to use all its features. Plus, you need to purchase additional parts to make it do anything. Neither the jumpers nor the socket shown in Figure 6 come with the Dragon. That shouldn’t be considered a fault since these items would raise the cost and frankly, anyone using the Dragon should already know how to acquire and use the extras. One warning: Do not touch this board when it is powered. Some earlier Dragons failed when touched, and while the problem is supposed to be fixed, why on earth would you want to touch a powered-up board, anyway? Just keep your hands to yourself mister!

Dragon Rider

Frankly, the Dragon — while economical — is a bear for the novice to set up. You will need various jumper wires, cables, and sockets that don’t come with the board. One really good solution to this problem is to get the Dragon Rider kit from www.ecrotech.com as shown in Figure 7. This solution more or less turns the Dragon into an STK-500 but with USB and an LCD, so it is well worth considering.

Dragons, Medusas, and BeAVRs?

We will use the Dragon to put the bootloader on the
BeAVR then we will use that bootloader for future programming efforts. We are going to go the cheapo route and directly wire the Dragon ISP port to the BeAVR SPI port. [BTW, SPI is not a typo. The ISP (In System Programming) goes through the SPI (Serial Peripheral Interface).]

I happened to have a six-wire IDC cable lying around and a six-pin male header, so I chose the method shown. Before getting started on this, I suggest you open the AVRStudio Help/AVR Tools (Figure 8), find the section on the Dragon, and read it. I summarize some of the more relevant stuff for our venture. In Workshop 21, we were introduced to AVRStudio and WinAVR. You can get them at www.atmel.com/dyn/products/tools_card.asp?tool_id=2725 and http://winavr.sourceforge.net/download.html.

Medusa?

Talk about a bad hair day ... how would you like to have to comb out that curly top? Our Medusa isn’t quite as bad, but let me tell you up front, it will get ugly before it gets pretty, and it might just turn you into stone in the process. You will need to solder six 4” AWG 22 solid core wires to the base of a 2 x 3 0.1” male header (without short-circuiting them — and that is a trick!) as shown in Figure 9. Then, you will want to add “Scotch” tape (actually, any nationality tape will do) flags to each wire and mark them with the SPI signal names as shown in Figure 10. I suggest you get a multimeter and check continuity for each wire. Make sure it conforms to the signal as it starts at the Dragon, passes through the Medusa, then arrives at the BeAVR. Figure 11 shows the finished rat’s nest. Let’s be honest, I didn’t wire this correctly the first time I tried, but eventually got it right. Cheap has a price.

Using AVRStudio to Upload the Bootloader

The AVRStudio Programming Front-End — as AVRStudio calls it — allows you to use several hardware programmers, including the Dragon. Let’s do this cookbook style. Click on the ‘Display the ‘Connect’ Dialog’ as shown in Figure 12.

In the resulting ‘Select AVR Programmer’ window shown in Figure 13, highlight the AVR Dragon and USB.

Open the ‘Main’ tab as shown in Figure 14 and push the ‘Read Signature’ button. If you see the three hex numbers shown in the window and it says ‘Signature matches selected device’, then you are in business. If not ... something’s probably not right about your hardware setup.

Open the ‘Fuse’ tab as shown in Figure 15. Click the boxes and set the settings EXACTLY as shown in the picture. This is where you get the opportunity to turn your ATmega644 into a brick if you get it wrong. (Bricked AVRs can be unbrickied with high voltage programming which is — as they say — a whole ‘nuther topic.)

Finally, open the ‘Program’ tab as shown in Figure 16 and browse to find the input hex file (which should be the Smiley bootloader 644). hex you got from the
Workshop22.zip file). The text box at the bottom should tell you that you succeeded.

Talking BeAVR

Notice in Figure 1 in the lower left corner there is a connector with six wires heading out of the photo. That device is the FTDI TTL-232R-5V USB to Serial cable that you can get from www.ftdichip.com/Products/EvaluationKits/TTL-

232R.htm or from www.adafruit.com. Or, you can substitute the SparkFun FTDI Basic Breakout — 5V DEV-09115 (you will have to move a couple of wires on the breadboard for this one, so pay attention). Either of these options will allow you to talk to the BeAVR serial port using the PC USB.

Our first use for this will be to upload YouSent.hex (located in Workshop22.zip) using AVRUP-V1 (Figure 18), as was discussed last month. Please check the www.smileymicros.com website because I am working on an upgrade for AVRUP and may have further instructions for the BeAVR by the time you read this.

Using YouSent

Open the device in Simple Terminal (available from www.smileymicros.com) and send a character. The Receive box should show ‘You sent: x’ (where ‘x’ is the character you sent). Well, I told you how busy we’d be this month. Next month, we will continue with the BeAVR and introduce a version of the design for a PCB — and this BeAVR will have fangs! NV
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generating signals up to 125 MHz with high sample rate, long memory, and high resolution, as well as a variety of operating modes, modulation capabilities, and a digital pattern generator. The software interface that controls the hardware is designed to simplify waveform creation with an intuitive navigation tree which allows easy access to all channels along with special views for controlling basic function generator outputs, as well as pulse width modulation (PWM) capabilities. The ability to have two and four channel units in a single, compact form factor can save bench space and help provide a lower price per channel. Additionally, the four channel ArbStudio models have an expansion port that allows up to eight units to be connected, providing up to 32 synchronous analog waveforms.

Four ArbStudio models are available, which offer a combination of analog waveform and digital pattern generation capabilities. All models have a bandwidth of 125 MHz, maximum sample rate of 1 GS/s, long memory of 2 Mpts/ch, and high 16-bit resolution.

The ArbStudio software runs on an external PC freeing the user from the small displays and readouts found on a typical AWG. A simple function generator window is available for basic waveform creation while a unique, streamlined control panel dedicated for PWM signals is also available. The main software mode features a start page that provides tutorials on creating a wide range of both simple and complex waveforms, as well as shortcuts to recent projects and an intuitive navigation tree to get started quickly. Once waveform creation has begun, graphical displays show the waveforms that have been created or sequenced, and the views can be customized to only show the windows that are of most interest to the user.

Arbitrary waveform generators are typically available with one of two technologies: either True Arbitrary or Direct Digital Synthesis (DDS). Each of these modes comes with advantages and disadvantages however, the ArbStudio does not have this limitation; it provides both modes and allows the user to choose which mode is needed for their waveforms. Additionally, ArbStudio channels can be set to any mode independently of each other for flexibility. The two channel ArbStudio 1102 price starts at $2,490, with the entire product line ranging from $2,490 to $4,990.

For more information, contact:
LeCroy Corporation
Tel: 800-553-2769
Web: www.lecroy.com
Wireless Networkable Digital Picture Frame
I want to send digital pictures and/or video remotely to a digital picture frame located at my Grandma’s house. The picture frame should have a wireless network ability so I can connect to it and update the video/picture content. What circuits or networking devices do this?

Michael Jimenez
Los Angeles, CA

Anti-theft Alarm
I would like to make a simple/inexpensive anti-theft alarm like you see in the doorways of shops. Some form of oscillator circuit that is interrupted (disturbed) by a small passive antenna-like circuit passing through the field would be good.

The active range should be about 1-1.5 meters.

Claes Kamborn
Stockholm, SWEDEN

Load Controller, Micro Hydro
I built a 3,000W, 220V, micro hydro machine and installed it for a family of five living near a stream. I need a load controller to offset the extra power whenever something is turned off. When the real load goes down, the frequency and voltage go up. The design should monitor the frequency (50 Hz) and dump some load to resistors whenever the frequency starts going up, and dump less of that load when the frequency goes down. If there is a better idea please let me know. Is PWM a good option?

Joseph K.
La Jolla, CA

Alternator Output
It is my understanding that a standard automotive alternator produces three phase AC before the rectifier plus (three diodes). If this is the case, what would the voltage and amperage output of each phase be, as well as across two phases (tapped directly off the windings)? I would base measurements preferably using a 130 amp AC Delco CS130 alternator, but any info will help. At this point, I don’t need any regulation, as I’m just trying to find out average values.

Also, what RPM would best suit the alternator for longevity, as well as best output (they don’t put out full power until a set RPM minimum is reached)? Is there a set math formula to figure this out? At this time, I don’t have access to the Internet.

Geoffrey Mayberry
a.k.a., "The Mad Scientist"

Fuses
I have a machine that calls for a 3.15A 125V slow blow fuse. Will a 3.15A 250V slow blow fuse be wrong? I can’t find a 125V SB fuse. Do they still make them?

You can use the 250V fuse.

To make it simple, fuses have three parameters: max current before it blows, rated in amps; response time (fast blow vs. slow blow); and voltage rating. The element inside the fuse will heat up as current increases through it, until it reaches its maximum rating. Then, it will literally melt or "burn open," stopping current flow — in your case, 3.15 amps. Your fuse being a slow blow type, the element has a built-in time delay to allow for current inrush when you first turn on the machine. Your machine may pull four or five amps for a few milliseconds until it settles down to its normal operating current. If you had a quick blow fuse in place instead, it would blow most every time you turned on the machine — which would be a nuisance.

Voltage ratings on the fuse indicate the maximum voltage source the fuse will clear. Cartridge fuses are typically rated at 32, 125, 250, and 600 volts. When the element burns in two, there is a gap. If the fuse voltage rating is lower than the applied voltage, current may arc across the gap and continue to flow. Higher voltage fuses blow larger gaps in the element. So, if you used a 32 volt fuse in your 120 volt application, it may not clear and stop current flow when it blows. However, the 250 volt fuse will clear a large enough gap to interrupt the 120 volt circuit.

Finally, some small cartridge fuses have a glass body, others ceramic. In a lot of instances, they are interchangeable (assuming electrical ratings are the same). However, ceramic body fuses are intended for installations with higher heat and/or more mechanical vibration. It’s best to replace the ceramic with ceramic, but if not available — and the need is great — you can get by on the glass until the proper replacement is found.

Occasionally, a fuse will fail without an electrical overcurrent being present. Heat or vibration can cause the element to open, sometimes under the endcaps where you can’t see it. If the fuseholder has dirty or corroded contacts, they can generate enough heat to fail the fuse. If you keep blowing fuses and a bad fuseholder isn’t present, there is probably a problem elsewhere.

All questions AND answers are submitted by Nuts & Volts readers and are intended to promote the exchange of ideas and provide assistance for solving technical problems. Questions are subject to editing and will be published on a space available basis if deemed suitable by the publisher. Answers are submitted by readers and NO GUARANTEES WHATSOEVER are made by the publisher. The implementation of any answer printed in this column may require varying degrees of technical experience and should only be attempted by qualified individuals.

Always use common sense and good judgment!
fault in your machine. NEVER substitute a higher ampererated fuse! This is a fire/safety hazard!

Phil Shewmaker
Louisville, KY

[#1101 - January 2010]
Stuttering Discs

I have CD and DVD players which, when playing certain discs, will stutter, skip, cut in and out, and sometimes abort the playing altogether. It only does it on some discs, and at the same place on these discs. However, these same discs will work on other players just fine. On at least one player, the problem got progressively worse, and had trouble with discs it played without errors in the past. Is there a way to repair this? Cleaning the lens and disc sometimes helps, but not always. I am playing only commercially made CDs and DVDs, not home burned ones.

It sounds as if you have either some sort of build-up, lack of lubrication due to hardened or missing lubricant, or a combination of the two. The reading assembly on CD and DVD players consists of a sled on guides (usually two rods) moved by a rack and pinion (or screw). This functions as the coarse movement. The fine tracking is done through a voice coil assembly on springs holding the laser and detector. A third movement in perpendicular direction takes care of the focus. Cleaning the rods, gears, and guides, as well as providing fresh lubricant will usually take care of these issues.

Be sure that there is no dust or lubricant in areas where it does not belong.

Walter Heissenberger
Hancock, NH

[#1102 - January 2010]
Tunable Sine Wave Generator

I am working on a project to provide 100 inexpensive, disposable electronic devices for a church. Each device requires a cheap, low-distortion, parts-stingy sine wave generator, easily tunable using only one pot from 1 kHz to 1 MHz, preferably using one common and cheap IC like an op-amp or a few transistors. To be compact, the parts count should be under about a dozen. I have plenty of XR8038 and XR2206 function generator ICs, but they are far too costly for this project. My experiments have produced only square waves or triangular waves, but meet all my other criteria. What is the best sine wave design?

Simple oscillator circuits capable of 1,000:1 tuning range and exhibiting pure sine wave output with good amplitude stability probably do not exist. However, one of the following techniques should be acceptable in your application:

1. Generate a square wave or pulse at a multiple of the intended output frequency, then convert to sine with a simple counter and resistor network. Don Lancaster discusses cheap digital sine wave generators at length in his CMOS Cookbook on pages 379-385 (second edition). The primary disadvantage is high distortion when the oscillator frequency is a low multiple of output frequency.

2. Use a tracking bandpass filter based on switched-capacitor IC technology to convert square or triangle waves to sine. The oscillator runs at a high multiple — such as 64X or 128X — to clock the switched-capacitor filter chip. I suspect this technique is too costly for the intended application.

3. Generate a triangle wave, then convert to sine by shaping it with a transistor differential amplifier or diode network. This technique is standard in function generators, and it's capable of 2% distortion or better if optimized. See Figure 1 for additional details on a couple of circuit concepts. Your triangle wave must be attenuated to about 85 mVpp at the input base of the differential transistor pair (A). The actual value is critical for minimum distortion. Base bias resistors should be low and equal in value. Reduced emitter coupling can yield further improvement, but I suspect this refinement is unnecessary. The bonehead-simple diode network (B) might be entirely sufficient if resistor values are well selected. Output from that circuit will be about 1.2 Vpp with common silicon diodes. Try LEDs or multiple series diodes for higher output.

4. Build a heterodyne generator with two nearly identical square wave oscillators running at a frequency much higher than your intended output, say 10 MHz. Make one of them variable from 10.001000 MHz to 11.000000 MHz. Combine both outputs in a non-linear mixer such as a logic gate, analog switch, or diodes. Mixer output includes sum and difference frequencies, but the sum is easily removable with an R/C low-pass filter. The remaining difference frequency is a beautiful sine wave! Unbalanced mixers also pass raw input signals to the output, but the LPF (or notch filter) solves this problem, as well. Beware the dreaded lockup phenomenon: The slightest stray coupling between two oscillators snaps them into synchronization when the variable one is tuned too.
not indicate what brand they were. If they are the no-name generics, they would be more prone to external noise.

**Ralph J. Kurtz**
Old Forge, PA

[#1105 - January 2010]
Automotive Speed Sensor

I recently replaced the trans in my Ford van. Somewhere between 00 and 02 model years, Ford changed the speed sensor output to the PCM, but I have an analog gear driven sensor. The newer sensor is digital (variable reluctance). I need to change the signal back to analog so the speedometer, ABS, and cruise will work. Is there a device to do it, or is it even possible?

Walter Heissenberger
Hancock, NH

[#1106 - January 2010]
Design/Test Software

I’ve had electronic engineering schooling back in the ‘80s and have tinkered a little since then. I’ve never had a computer until now and would like to know some free or reasonable circuit design/test software download sites to tinker with.

Circuit Simulators: LTspice IV (free, no limitations, excellent; Linear Technology) and Tina-TI (free scaled-down version; Texas Instruments).

CAD/Layout: ExpressPCB (free) and ExpressSCH (free) are PCB layout and schematic software. Very consistent and easy to use. QuickCAD mechanical CAD software is from Autodesk.

Miscellaneous: AppCAD (free; Agilent) calculates transmission lines, S-parameters, microwave designs, amplifiers, biasing, reflections, noise, etc. MPLAB (free; Microchip Technology, but needs a plug-in for C or MBasic, and a programmer) software is used to program PIC microcontrollers. There’s Microsoft Office which includes Word, Excel, PowerPoint, and Access for general office type applications such as documents, spreadsheets, presentations, and databases. FilterPro (free, Texas Instruments) software is used to design active filters. Last but not least is SpectrumLab (free; uses sound card to digitize and analyze spectrum).

**Walter Heissenberger**
Hancock, NH
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<td>XGameStation</td>
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</table>
2.4GHz 2 Camera Wireless System

- **NEW ITEM**
- **Channel scan for multi-camera monitoring**
- **Night vision effective up to 70 ft**
- **Shell, Weather proof structure for outdoor installation**
- **Built-in microphones for audio monitoring**
- **Up to 100m (328ft) range in open space**
- **Includes 2 camera w/power supplies & 1 receiver w/power supply and remote control**

Item # **DUAL CAM SYSTEM**

**$98.50**

LED Flashlight with On Board 4GB DVR

- **Ideal for:**
  - Law Enforcement
  - Post Fire Inspection
  - Facilities Maintenance
  - Security Companies & Many Other Uses!

- **Monitoring & Recording concealed in a rechargeable flashlight**

This unit will function both as a flashlight AND a Digital Video Recorder and has a multitude of uses. It is equipped with a convenient USB interface for video data file transfer. You can record color video and then transfer it to a personal computer for viewing. Includes one high intensity LED for close up or long distance recording. Also includes a AC adapter for charging the integral Li battery.

Item # **FLASHLIGHT DVR**

**SALE**

**$69.00**

Regular Price **$189.00**

USB Digital Storage Oscilloscopes

**Specifications**

<table>
<thead>
<tr>
<th>Model</th>
<th>Channels</th>
<th>Bandwidth (MHz)</th>
<th>Sample Rate (MS/s)</th>
<th>Resolution (bits)</th>
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<td>20MHz</td>
<td>50MS/s</td>
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<td>50MS/s</td>
<td>8 bit</td>
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- **Probes Included**
- **High performance**
- **USB connected**
- **Versatile data formats**

Item # **DSO-2900**

**$169.00**

Item # **DSO-2910**

**$194.00**

Item # **DSO-2920**

**$289.00**

600Hz Hand Held Scopemeter with Oscilloscope & DMM Functions

Who Says you can’t take it with you?
With the DSO1060 YOU CAN!

You get both a 60 MHz Oscilloscope and a multi function digital multimeter all in one convenient lightweight rechargeable battery powered package. This power packed package comes complete with scopemeter, test leads, two scope probes, chart, PC software, USB cable and a convenient nylon carrying case.

**Item # DSO1060**

**$569.00**
Your Power Supply Headquarters!!

We carry a LARGE selection of power supplies from bench top to variacs to single, dual and triple output to wall plug AC adapters to large and ultra large regulated power supplies.

Adjustable DC Power Supplies with Adjustable Current Limiting

Regulated linear power supplies with adjustable current limiting. The LED display shows both Volts & Amps. The current output can be preset by the user via a front panel screwdriver adjustment screw while the voltage is adjustable by a front panel multi-turn knob for precise voltage settings. Output is by front panel banana jacks and there is also a covered terminal strip for remote voltmeter sensing at the load.

* Utilizes SMD technology
* Pre-Settable Voltage & Current levels
* Front Panel On/Off Switch
* Large LED readout for Voltage & Current
* S+ & S- Sampling terminals

0-30 Volt / 0-10 Amp Adj. (CSI3010X) $198.00
0-30 Volt / 0-20 Amp Adj. (CSI4010X) $239.00
0-40 Volt / 0-10 Amp Adj. (CSI6010X) $299.00
0-60 Volt / 0-10 Amp Adj. (CSI6010X) $319.00
0-120 Volt / 0-3 Amp Adj. (CSI12003X) $265.95

www.circuitspecialists.com/dcpower

HengFu Switching Power Supplies

Circuit Specialists carries a wide selection of HengFu switching power supplies. All models have overload, over voltage, over temperature & short circuit protection.

Hi-Power Enclosed Single Output

<table>
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<tr>
<th>Item #</th>
<th>Price 1</th>
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<td>700W 48V/15A (HF700W-S-48)</td>
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Open Frame Single Output

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<td>15W 5V/3A (HF15W-SPL-5)</td>
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<td>15W 48V/0.32A (HF15W-SPL-48)</td>
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Enclosed Dual Output

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www.circuitspecialists.com/hengfu

Programmable DC Electronic Loads

These devices can be used with supplies up to 360VDC and 30A. It features a rotary selection switch and a numeric keypad used to input the maximum voltage, current and power settings. These electronic DC loads are perfect for use in laboratory environments and schools, or for testing DC power supplies or high-capacity batteries. It also features memory, and can also be connected to a PC, to implement remote control and supervision.

360V/150W (CSI3710A) $349.00
360V/300W (CSI3711A) $499.00

www.circuitspecialists.com/csi3710a
www.circuitspecialists.com/csi3711a

Dual Output DC Bench Power Supplies

High stability digital read-out bench power supplies featuring constant voltage & current output. Short-circuit & current limiting protection is provided. SMT PC boards and a built-in cooling fan help ensure reliable performance & long life. 2 Modules have a 10/100VDC Flexi Output on the rear panel.

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Triple Output DC Bench Power Supplies

* Output: 0-30VDC x 2 @ 3 or 5 Amps & 1 fixed output @ 5VDC @3A
* Stepped Current: 30mA / +/ 1mA

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<th>Item #</th>
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<td>CSI300S1 0-30Vx2@5</td>
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0-30V / 0-5A DC Power Supply

The CSI30S is a regulated DC power supply which you can adjust the current and the voltage continuously. An LED display is used to show the current and voltage values. The output terminals are safe 4mm banana jacks. This power supply can be used in electronic circuits such as operational amplifiers, digital logic circuit, and so on. Users include researchers, technicians, teachers and electronics enthusiasts. A 3 1/2 digit LED is used to display the voltage and current values.

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<th>Item #</th>
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<td>$79.00</td>
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www.circuitspecialists.com/csi30s

Programmable DC Power Supplies

* Up to 10 settings stored in memory
* Optional RS-232, USB, RS-485 adapters
* May be used in series or parallel modes with additional supplies
* Low output ripple & noise
* LCD display with backlight
* High resolution at 1mV

The Boss says we gotta “Reduce inventory!”

Check out the special deals on our great selection of top quality BlackJack, SoldierWerks equipment

www.CircuitSpecialists.com/BlackJack

www.journal-plaza.net & www.freedowns.net
Ready to get off the grid! Parallax's 30 Watt Solar Panel Kit is a do-it-yourself system that can produce up to a maximum of 30 watts of clean, green electrical energy. Not a solar demonstration toy! It is a true kit, once assembled you will have a solar panel that produces a substantial amount (6 volts) of electrical power. In fact, the energy produced per square foot is comparable to many commercially available solar panels. Once you permanently seal the panel, it can withstand the outside elements as well. Daisy-chain multiple units together for higher voltage/current/power output! Dimensions: 23.8 x 15.8 x 0.375 in (60.45 x 40.12 x 0.95 cm). Assemble your panel with confidence! Online demonstration videos show you how to properly handle and solder the delicate cells and their wiring interconnections.

30 Watt Solar Panel Kit (#33000; $149.99)

Order the 30 Watt Solar Panel Kit at www.parallax.com or call our Sales Department toll-free: 888-512-1024 (Mon- Fri, 7am-5pm, PDT).

Friendly microcontrollers, legendary resources.

www.parallax.com

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