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Kit Building

As a young ham radio enthusiast, I assembled my first operating station by tearing down and reassembling broken TVs and radios. After months of saving from several odd jobs, I was able to step up to a 'real' rig — a DIY crystal-controlled CW transmitter from the now defunct Heathkit Corporation. Over the years, I eventually acquired an amplifier, digital multimeter, SWR meter, PLL-based transceiver, and other test and operating equipment kits from the company. The equivalent of paint-by-numbers, the various kits were not only affordable, but easy to repair and modify. Given the well-written documentation and large user community, I was virtually guaranteed of success, and there was no scrounging for hard-to-find, expensive parts.

Heathkit eventually lost the niche for low-end communications and test equipment to less expensive, more compact, and more functional fully-assembled equipment from overseas. Today, it's still the case that pre-assembled, imported equipment is often the most affordable option.

However, for electronics enthusiasts, it's not only the final product, but the process of designing and/or building circuits that counts. Economics still matter, but most of us are willing to pay a reasonable premium for the opportunity to assemble a circuit ourselves. In fact, what makes a kit so attractive these days is the relative cost savings over assembling a circuit piecemeal; $5 for a blank perf-board; $2 for a battery clip; $1.50 for a voltage regulator chip. Pretty soon, the cost of even the most modest circuit can get out of hand. Hence, the renewed popularity of kits.

My latest kit project is a hybrid preamp, the K-270 from Oatley Electronics (www.oatleyelectronics.com). At $20, the kit (see photo) makes an affordable, high-quality guitar amplifier that provides real 'tube sound' that even the best all solid-state preamps can only approximate. As points of comparison, I could have bought a self-contained, solid-state preamp with a nice enclosure for about $35, or copied the K-270's circuit design and ordered the parts from Mouser for about $50. I went with the kit, and used a guitar body for the main enclosure. Go ahead and make your own comparison — the parts list and schematic are available on the Oatley Electronics website.

As you can see in the photo, the hybrid preamp features two JAN6418 sub-miniature pentodes. The pentodes are cascaded in common cathode configuration, each with 1.2V @ 5 mA filaments, followed by a MOSFET buffer. A 5V regular accepts 9 VDC battery input. In addition, an input high-pass and low-pass filter composed...
of switched capacitors enables you to modify the basic 20 Hz - 30 kHz response. Maximum gain is about 100, with a maximum draw of about 11 mA at 9V. The diminutive preamp is just a little larger than a magnetic guitar pickup.

Instead of designing an amplifier from scratch, I invested my time in integrating the amplifier into my electric guitar. After routing my solid-body traveler guitar body with two cavities — one for the amplifier and one for the 9V battery holder — I coated each cavity with conductive paint. Next, I mounted the board and battery holder, and added an on-off switch in series with the 9V supply.

As with most well-designed and documented kits, the preamp lends itself to modification. I couldn't resist modifying the input high- and low-pass filter circuits and adjusting the tube plate voltage to get more of a vintage sound from the preamp.

The take-away is that kits are an affordable, low-risk, fun way to learn about and experience electronics. Several kit companies regularly advertise in Nuts & Volts, and we offer kits from some of our authors in the Nuts & Volts website.

If you're new to kits or simply haven't put one together in a while, this is a great time to try your hand at one.
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March 2009 NUTSIVOLTS 11
HIGH-ALTITUDE, LONG-DURATION INSTRUMENT PLATFORM

Let's say you're a scientist at a university or atmospheric research organization, and you need to make some high-altitude measurements. One option is to strap your instrument cluster to an Atlas or Titan launch vehicle and put it into a geosynchronous orbit. If the package weighs, say, 500 lbs, you're looking at $5-6.5 million to get it there, so you'll need a fat wallet. However, there is a cheaper alternative, as recently demonstrated in a joint venture between the National Science Foundation (NSF, www.nsf.gov) and NASA (www.nasa.gov). Late last year, they conducted a flight test of a new "super pressure balloon" prototype—an improved long duration balloon (LDB) designed to carry large scientific experimental gear to the edge of space for 100 days or more.

The purpose of this flight was to test the durability and functionality of the balloon's unusual pumpkin-shaped design and its novel material—a lightweight co-extruded polyethylene film about the thickness of ordinary plastic food wrap. (In a super pressure balloon, the pressure [rather than the volume] of the lifting gas changes with diurnal heating and cooling, providing constant buoyancy.) According to senior scientist W. Vernon Jones, "While the team has a ways to go in scaling up the pumpkin balloon to be able to lift a one-ton instrument to a float altitude of 110,000 feet, the team has demonstrated they are on the right path.* The prototype has a capacity of seven million ft³, but the full-scale model will be expanded to 22 million ft³.

No cost information was provided, but various sources peg the bill of an LDB at up to $110,000 and enough helium to fill it at $10,000. Adding some overhead for launching and recovering the vehicle, ground transportation, etc., you're probably looking at $250,000 or so.

Several older designs of LDBs are already in operation for things like cosmic and gamma ray studies, infrared astronomy, magnetospherics, etc. If you are interested in tracking their movements, log onto the Columbia Scientific Balloon Facility at www.csbf.nasa.gov/antarctica/ice0809.htm.

MOTOR SETS RPM RECORD

Yeah, it's just an electric motor, but up to now, the fastest one you could get turned about 250,000 RPM. However, the Department of Power Electronics at the Swiss Federal Institute of Technology Zürich (ETH Zürich, www.ethz.ch) has designed a device (prototype built by partner ATE GmbH) that breaks the one million RPM barrier, which is pretty amazing when you think about it.

The breakthrough involved jumping a few hurdles. For one thing, the rotor construction required a special titanium shell to withstand the extreme centrifugal forces involved. The ball bearings (provided by myonic GmbH) had to be optimized for such high speeds. And ETH had to design a special low-loss stator that uses ultra-thin copper wire for the windings, which are inserted in a cylinder made of a specially developed type of iron. Finally, the machine is fed by electronics that had to be specifically designed for such speeds.

The result is a spin-off company—Celeroton (www.celeroton.com)—which has put the motors into production and is "set to become a supplier for manufacturers of, for example, fast-spinning drills or milling machines. The trend towards increasingly smaller cell phones and other electrical appliances means that increasingly smaller holes have to be drilled for the electronics. This is only possible using a drive system that boasts a high rotational speed." Potential applications include microcompressors, micromachining in the semiconductor and PCB industries, fuel cell production, aircraft part manufacturing, etc.

COMPUTERS AND NETWORKING

DUAL-SCREEN LAPTOP INTRODUCED

Those of us who are accustomed to working with dual monitors can enthusiastically recommend the practice, which allows you to use one screen for the main item of interest and the other for toolboxes, IM

By Jeff Eckert
windows, email, and whatever. Until now, this feature has been readily available only with desktop boxes. But in January, Lenovo (www.lenovo.com/us/en/) introduced a dual-screen ThinkPad — the W700ds — which it prefers to call a "mobile workstation."

It is fitted with a 17 in LCD main monitor plus a 10.6 in slide-out secondary one. The latter can be adjusted at an angle of up to 30° for easier viewing. You also get a choice of Intel mobile quad core processors and a NVIDIA® Quadro FX mobile graphics CPU with up to 128 cores, optional dual hard drives with RAID configurations and/or solid-state storage, and up to 8 GB of DDR3 memory. This makes possible a maximum of 960 GB of storage.

As a Lenovo representative noted, "This is the nitro-burning drag racer of ThinkPads."

The main negative features appear to be the machine's price (ranging from $3,069 for the basic unit to well over $8,000 with a heavy helping of the bells, whistles, and extended warranties), and weight (11 lb [5 kg]). The latter may explain why the company doesn't call it a laptop.

**WITH FRIENDS LIKE THIS ...**

**B**urger King — already known for its often bewildering marketing methods — last year instituted the Whopper® Sacrifice website (www.whoppersacrifice.com), aimed at Facebook users. The concept is simple. If you are willing to delete 10 of your Facebook friends, you can download a small application, give them the boot, and subsequently receive a coupon for a free Whopper.

Alas, you are now stuck with your Facemates, as well as the empty stomach. BK decided to shut down the program after people traded away 233,906 of their friends (apparently, at least one applicant couldn't count to 10). The stampede on free burgers isn't too surprising, given that Facebook has something like 150 million users, most of whom are in the fast-food-gobbling age group of 18 to 34 year olds.

But don't be too disappointed. A Whopper with cheese contains 770 calories, 48 g of fat (16 g saturated), 100 mg of cholesterol, and 1,450 mg of salt. At least your no-good friends aren't likely to give you a coronary.

The website is still up and running, and if you have been sacrificed and aren't happy about it, you can still send your ex-friend an Angry-Gram that includes a screaming animated sandwich.

**CIRCUITS AND DEVICES**

**PHONE WATCH AND MORE**

The concept dates back to 1946, when cartoon police detective Dick Tracy and other members of the force were issued two-way wrist radios. Now, 63 years later, LG Electronics (www.lge.com) has taken it a step further with the LG-GD910 Touch Watch Phone. It's the commercial version of a prototype introduced about a year ago, upgraded to include a touchscreen interface, 3G capabilities, and video calling.

According to LG, it's the first watch phone in the world to feature 7.2 Mbps 3G HSDPA compatibility, which enables high-speed data transmission and video phone calls using its built-in camera. It also has voice recognition capabilities (with or without a Bluetooth headset), a text-to-speech feature, and a built-in speaker for playing music files. The device will go on sale in Europe sometime this year but — sorry to inform you — no release date has been revealed for the USA.

**WORSE SPEAKERS/BETTER SOUND**

In the old days, a reliable rule of thumb was that the heavier the magnet, the better a speaker's sound quality. The employment of light, rare earth magnets has more or less smacked that thumb with a hammer, but it remains difficult to get decent sound from the crappy little $2 transducers that come with low-end audio systems. Addressing the problem is the Sound Terminal™ STA339BWS chip.

Recently introduced by STMicroelectronics (www.st.com), it merges the company's audio processing and class-D power amplifier ICs into a single package and includes multiband dynamic range compression (DRC). DRC "uses the latest sound-processing algorithms to enhance the performance of low-cost speakers, and also prevents large bass signals from causing vibrations and damaging small speaker units."

The chip also incorporates a seven-band equalizer and provides continuous audio streaming when changing channels or audio sources. Output is configurable to provide
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DIY World Domination

For a while, it looked like the altercation between Apple and a Mac clone maker was over, but Psystar has filed a revised version of its argument that Apple has abused copyright laws by tying its operating system to Apple hardware. Psystar buys legal copies of OS X and installs them on its Open Computer and OpenPro machines, which it claims is perfectly legal. And while it's true that Apple's end-user license agreement forbids installing the system on anything other than its own hardware, Psystar's view is that the license agreement runs counter to US law and the "first sale" doctrine.

The doctrine — which goes back to a 100 year old Supreme Court decision — allows the purchaser of any copyright work to sell or give it away without the copyright holder's permission. The case is scheduled to hit the trial stage in April, so stay tuned. In the meantime, it looks like you can still buy an Open with OS X (with 2.2 GHz dual core Pentium processor, 2 GB RAM, 320 GB drive) for $554.99 or an OpenPro (3.16 GHz Core2Duo or 2.4 GHz Core2Quad, 2GB RAM, 750 GB drive) for $1,154.99. Go to www.psystar.com if you dare.

NEED A CONVERTER BOX? YOU LOSE!

In other news that will disappoint some owners of now-obsolete TV sets, the National Telecommunications and Information Administration (www.ntia.doc.gov) used up its $1.3 billion of Congressional funding for the TV Converter Box Coupon Program even before analog programming was phased out as of February 17th. As of this writing, US residents applying for a digital TV converter box voucher will be put on a waiting list. It seems that 24 million households had applied for a total of 46 million of the $40 coupons. Only 53 percent have been redeemed, with 13 million having passed the 90-day expiration date. But don't throw away the old Philco box just yet. According to acting NTIA Administrator Meredith Attwell Baker, the NTIA will work with Congress and the administration to "ensure everyone is prepared for the transition and no one is left in the dark."

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INDUSTRY AND THE PROFESSION

THE FEUD CONTINUES

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MOVIES ARE ACTUALLY STILLS

When we go to the theater to see a "motion picture," what we're actually seeing is the projection of 24 still images every second; it is our eyes and brain that blend the images into what seems like smooth motion. It makes sense, then, that we can take any series of images and stitch them together to make a "movie." Of course we can, animators do this day in and day out to make cartoons. Video cameras are not set up (very well, anyway) to take single frame images like film cameras, so we have to take a different path: use a digital still camera.

When John showed me this trick, I actually laughed as it is so elegantly simple. Using a digital still camera to create a time-lapse movie is possible for two reasons: 1) The still camera saves images as numbered files; and 2) Almost every video editing application has the ability to take a group of numbered still images and convert them to a video file. My Sony digital still camera conveniently has frame sizes that match standard and high-def video frame sizes; the only thing I have to do is trigger the camera at the desired interval.

Once I got hooked on this idea, I started doing a bit of research and guess what? I'm not the first to go down the path of creating a time-lapse controller with the SX. In the December 2007 issue, Joe DeMeyer created a very nice, fairly sophisticated intervalometer using the SX48, a DS1302 RTC, and a Parallax serial LCD (which uses an SX28!). Mr. DeMeyer's requirements are greater than mine so the SX48 made sense relative to code space. My goal is to create a basic intervalometer — a microcontroller version of my original 555 device — and try to squeeze the works (control code, LCD...
CAMERA CONTROL

The one thing that my camera doesn't have is a manual control port — not a physical port, anyway. It does, however, have an IR port and a small remote that allows me to take pictures. Using January's project (SIRCS 'sniffer*), I was able to determine the 12-bit SIRCS codes that the remote sends. The chore for this project, then, is to send the command that corresponds to the shutter button at the interval of my choosing. In addition to the SIRCS output, I'm going to add a couple open-collector outputs — just in case I want to control other devices later.

After determining the code and building it into a little test program, I got absolutely bupkis from the camera when transmitting the 12-bit SIRCS code. On the thought that the remote may be sending a sequence of codes, I connected the IR receiver output to a scope and boy was I surprised! The camera remote wasn't sending 12-bit codes at all. It was sending 20-bit codes!

I'd heard about 20-bit SIRCS codes but this is the first time I actually ran into them. In Figure 1, you can see the captured output of my camera remote when pressing the shutter button; it sends the same 20-bit code five consecutive times.

After a half day of Google-ing, I was never able to come up with a specification for the 20-bit SIRCS code but there was the suggestion that the 20-bit code used an eight-bit device code and a 12-bit command code. I updated the SIRCS sniffer code for 20 bits and used a Sony DVD remote to confirm this.

TRANSMITTING SIRCS

Last time, we dealt with receiving the SIRCS stream which was pretty easy because it is simply a matter of accepting pulses from a standard IR detector. Transmitting isn't very complicated, but it's not just a matter of sending out a pulse stream; we also have to modulate the IR LED.

In order to keep everything in one chip, I decided to connect both leads of the LED directly to the SX and use one of them (the cathode) as the modulation source; this needs to be 40 kHz. Keeping with the KISS philosophy, I set the interrupt to run at 80 kHz and then toggle the cathode through each pass to create the proper modulation signal.

The top of the ISR looks like this:

```c
'================================================================================
INTERRUPT NOPRESERVE 80_000
'================================================================================

Marker:
isrFlag = 1

Modulate_LED:
IrLedK = ~IrLedK
```

As with other programs, we set a bit called isrFlag at the top of the ISR; this is used by the foreground code for timing when needed. The modulation signal to the LED is simply a matter of inverting the output signal to the cathode. As this pin gets inverted 80,000 times a second, we end up with a modulation signal of 40 kHz with a duty cycle of 50 percent.

If you look at Figure 2, you'll see that both sides of the IR LED are tied to SX pins. The cathode pin provides the modulation and the anode gates the LED on and off. By making the anode pin high, the LED will be on whenever the cathode side is low. When the anode side is low, the LED will always be off, no matter what is happening on the cathode side.

Now that we can modulate the IR LED, we just have to create a control stream to the anode side to generate the SIRCS output. You'll remember that the SIRCS signal has a 2.4 millisecond start bit, "1" bits are 1.2 milliseconds wide, and "0" bits are 0.6 milliseconds wide — and every bit is spaced by a 0.6 millisecond off-time.

With the ISR running at 80 kHz, we can't use PAUSE or PAUSEUS so we'll need to create a set of custom routines. With the isrFlag, we're able to create sub-millisecond timing; this is done with the DELAY_TIX subroutine:
This routine takes the value passed to it and uses the `isrFlag` bit to decrement this value. You can see that within the loop the flag is first cleared and then the program waits for it to be set again which will happen during the next ISR. When the `isrFlag` is detected, the value in `isrTix` is decremented; once this value is zero, the routine exits.

At 80 kHz, the ISR is called every 12.5 microseconds; this is the timing value of each "tick." This means, then, that an SIRCS start bit will be 192 ticks, a 1 bit will be 96 ticks, and a 0 bit (and bit spacing) will be 48 ticks. The program defines constants called `MS_024, MS_012,` and `MS_006` for these values.

The TX_SIRCS20 subroutine takes care of transmitting the 20-bit SIRCS code:

```
SUB TX_SIRCS20
  BANK irWork
  irDevice = __PARAM1
  irCode = __WPARAM2
  irFrameTmr = MS_450
  ' start bit
  IrLedA = IR_ENABLE
  DELAY_TIX MS_024
  IrLedA = IR_DISABLE
  DELAY_TIX MS_006

  ' send command code
  FOR irBits = 1 TO 12
     IrLedA = IR_ENABLE
     IF irCode.0 = 1 THEN
         DELAY_TIX MS_012
     ELSE
         DELAY_TIX MS_006
     ENDIF
     IrLedA = IR_DISABLE
     DELAY_TIX MS_006
  irCode = irCode >> 1
  NEXT

  ' send device code
  FOR irBits = 1 TO 8
     IrLedA = IR_ENABLE
     IF irDevice.0 = 1 THEN
         DELAY_TIX MS_012
     ELSE
         DELAY_TIX MS_006
     ENDIF
     irDevice = irDevice >> 1
     DELAY_TIX MS_006
  NEXT
  ' complete frame space
  DO WHILE irFrameTmr > 0
     LOOP
  BANK
ENDSUB
```

The routine has to accommodate 20 bits which means we'll be passing three bytes to it; to keep the call easy, I decided to structure it to accept a byte (the device code) and a word (the command code).

Before I get too far, let me point out something new: Inside this subroutine, the code is switching to a bank of variables called `irWork` using the `@` directive. This is a very cool feature in SX/B 2.0 and saves a lot of code space when a subroutine can work within the confines of a single, 16-byte bank. Let's look at the declaration of `irWork`:

```
irWork   VAR  Byte (6) BANK
irFrameTmr VAR  Word @irWork(0)
irCode   VAR  Word @irWork(2)
irDevice  VAR  Byte @irWork(4)
irBits   VAR  Byte @irWork(5)
```

Normally, we can only have bytes inside an array but when using the `@` declaration as we've done here we can also declare words. Now, we do have to be a little careful with this style. Using these declarations, we're actually creating named offsets into the bank that is presently selected, so if we use one of these names while in another bank we will clobber something we don't want to. The advantage, however, is that we can use these elements just like ordinary variables once we switch to the bank; this keeps the amount of code SX/B generates smaller and by moving these variables to an array we preserve general RAM space. Let me just reiterate: We can treat these variables like normal program variables, but only when we're inside the bank — once we switch back to the general RAM bank, we should not use these variables.

I have no official documentation but information from what seems like a reliable source suggests that when a remote key is held down, the code is transmitted inside a 45 millisecond frame — and this was verified by my 'scope display. It stands to reason that we would want to create a 45 millisecond window in which to transmit the SIRCS code; for this we'll use `irFrameTmr`.

Management of this timer is handled inside the interrupt:

```
Update_Frame_Timer:
  ASM
  BANK irWork
  MOV W, irFrameTmr_LSB
  OR W, irFrameTmr_MSB
  JZ FT_Exit
```

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The purpose of this code is to decrement *irFrameTmr* when it's greater than zero. Since *irFrameTmr* is a word (two bytes), the easiest way to check for zero (in Assembly) is to OR the upper and lower bytes together. If the result is zero, the **JZ** instruction will cause the code to jump to **FT_Exit**. If *irFrameTmr* is not zero, then it gets decremented. We have to use two instructions to do this because it's a two byte value.

To enable this timer for the SIRCS window, we set it to 3600 as this is the number of 12.5 microsecond interrupt cycles in 45 milliseconds. This is done inside **TX_SIRCS20** using a constant called **MS_450**.

Once the frame timer is started, we create the start pulse by activating the IR LED (anode high) and waiting 2.4 milliseconds; the **DELAY_TIX** subroutine takes care of the timing in the foreground.

After the start pulse, we drop into a loop that will transmit the 12-bit command code — LSB-first. The IR LED is activated and then the proper delay is inserted: 1.2 milliseconds for a 1 bit or 0.6 milliseconds for a 0 bit. Per the spec, there is a 0.6 millisecond off-time between each bit. The IR code is shifted right after each bit to position the next. A second loop is used to transmit the eight-bit device code, again LSB-first. In all, 20 bits have been transmitted.

Finally, we wait for the 45 millisecond timer to expire before exiting. This allows the **TX_SIRCS20** routine to be called successively without violating the timing requirements of the protocol.

You're probably wondering: **What happens when the interrupt triggers in the middle of TX_SIRCS20 — won't the bank setting be thrown off?**

Good question, and the answer is no. At the start of the interrupt, the SX automatically saves a few key registers — one of them is the FSR (bank pointer) — and this is restored when the interrupt terminates.

**LCD CONTROL**

Suffice it to say that I and others have written a boatload of material on LCD interfacing in the pages of *Nuts & Volts* so I'm not going to go into detail here except to say that I'm using a four-bit interface to minimize I/O requirements (see Figure 3). This means, though, that writing to the LCD requires two nibble writes. This is handled by **LCD_OUT** which also preserves the backlight control pin and the RS line (command or character mode) of the LCD.

One of the choices I made was to forego reading the LCD busy flag. This means that there is standardized timing built into the write cycle and that I have to remember to include a two millisecond or greater delay after using the clear ($01) and home ($02) commands. The initialization code disables window scrolling so the home command should never be needed; remembering a short delay after clearing the LCD won't be a problem.

While I don't anticipate needing the backlight for this project, I've added control from the port and a manual switch — just in case I'm doing some late-night photography.

**ACCEPTING USER INPUT**

My intervalometer has three modes: setup, run, and manual. These modes can be handled with a three-position toggle switch and two I/O bits. For entering information, I'm using the other six bits on the same port.
to create a generic interface: Up, Down, Left, Right, OK, and Escape. Using the SX’s internal pull-ups adding the interface is simple (see Figure 4).

We all know that we should debounce digital inputs; we also know that this takes time. After some thought, I decided to put the debouncing code inside the interrupt. By doing this, a set of flags can be used to indicate that an input is valid. Here’s the code for that:

Debounce:

```
ASM
BANK btnWork
INC tmr1ms
CJNE tmr1ms, #80, DB_Exit
CLR tmr1ms
INC tmrScan

DB_Check:
CJB tmrScan, #50, DB_Port_Scan
CLR tmrScan
MOV btnFlags, btnTemp
MOV btnTemp, #%1111_1111
JMP DB_Exit

DB_Port_Scan:
MOV W, /UserIn
AND W, btnTemp
MOV btnTemp, W

DB_Exit:
BANK __DEFAULT
ENDASM
```

This code uses two timers: one that counts the number of ISR cycles in one millisecond (80), and a second that sets the debounce timing. In this case, I’m using 50 milliseconds.

At the beginning of each 50 millisecond debounce period, a temporary variable (btnTemp) is set to %1111_1111. We start the debounce scan assuming a button is pressed (1 is pressed, 0 is not pressed). On each millisecond tick through the cycle, the temporary variable is ANDed with the button port — any pin that is active will remain 1 in the temporary variable.

Note that as we’re using active-low inputs, we have to invert the port value during the scan.

At the end of the debounce period, the temporary variable is moved to a global variable called btnFlags for use by the foreground program. This cycle runs constantly so the btnFlags variable is updated every 50 milliseconds. In the foreground, we don’t have to do anything except check the bits in btnFlags to see if any inputs are active.

**OPERATION**

I use a toggle switch for the mode selector as my time spent developing sprinkler timers for Toro taught me that users generally don’t like navigating menus for operational modes — just settings. When this switch is in the middle position, we’re in setup mode that allows us to adjust the interval timing for run mode. The program will allow any interval — with one-second resolution — from one second to 24 hours. Time will be displayed on the LCD as 00:00:00 to 24:00:00.

In setup mode, the LCD will appear as in Figure 5 (top). An underlined cursor will denote the field that can be updated: seconds, minutes, or hours. These values are stored in an array and use a BCD format like common RTCs (DS1302, etc.).

Having a single menu item with three fields meant that the code to update the interval was actually quite manageable, and using the Up, Down, Left, Right, OK, and Escape buttons makes it intuitive:

Setup_Interval:

```
LCD_CMD LcdCrsrOff
LCD_CMD LcdCls
DELAY_MS 3
LCD_STR "SETUP"
```

Setup_Reload:

```
iChanged = No
PUT cntDn, iTime(0) TO iTime(2)
```

Setup_Show_Time:

```
LCD_CMD LcdCrsrOff
cmdChar = LcdLine1 + 7
LCD_CMD cmdChar
IF iChanged THEN
LCD_OUT "+"
ELSE
LCD_OUT " "
ENDIF
LCD_HEX2 cdHrs
LCD_OUT ":"
LCD_HEX2 cdMins
LCD_OUT ":"
LCD_HEX2 cdSecs
```

At the start, we clear the screen and display the current interval setting. The interval has been moved into a temporary array called cntDn; we’ll manipulate this array instead of the present user setting.

By using a temporary array for the interval, we actually have a method to "undo" any changes. You’ll notice that right before the time elements are written to the LCD, a
bit flag called iChanged is examined and if this bit is 1 we print an asterisk; otherwise, a space. The iChanged flag lets us know that the temporary array has been changed and may not match the internal setting.

The next section of code positions and displays the underline cursor, then scans the inputs by looking at btnFlags:

```c
Setup_Field:
  LCD_CMD LcdCrsrOff
  LOOKUP iState, 15, 12, 9, cmdChar
  cmdChar = cmdChar + LcdLine1
  LCD_CMD LcdCrsrOn
  DELAY_MS 200

Setup_Wait_Button:
  pgmMode = btnFlags & %0000_0011
  IF pgmMode <> %00 THEN Main
    tmpB1 = btnFlags & %1111_1100
    tmpB1 = BIT_COUNT tmpB1
    IF tmpB1 <> 1 THEN Setup_Wait_Button
    LOOKUP iState, $59, $59, $24, fldMax
    IF btnMnuUp THEN Setup_Inc_Field
    IF btnMnuDn THEN Setup_Dec_Field
    IF btnMnuLf THEN Setup_Next_Field
    IF btnMnuRt THEN Setup_Prev_Field
    IF btnMnuOK THEN Setup_Set_Interval
    IF btnMnuEsc THEN Setup_Reload
```

The input field state (seconds, minutes, hours) is tracked in a variable called iState and this is used with a LOOKUP table to get the cursor position in the time display; as the program increments/decrements in ones, the cursor is displayed under the 1's digit in each field. I added a short delay after the cursor updating so that I can hold a button down and still see changes in the display.

At Setup_Wait_Button, we look at our debounced inputs stored in btnFlags. The first thing to do is make sure we're still in setup mode. If we are, then we can mask out the mode buttons and check to see if any button is pressed. To prevent ambiguities, we check the number of active inputs. If only one button is pressed, we can drop through to the handlers.

Another LOOKUP table is used to set the maximum value for the current field; minutes and seconds have a logical range of $00 to $59 (BCD), and we're going to allow the hour's field to go all the way to $24.

The last step in this section is to jump to the appropriate handler code for each button. Let's start with changing the field values (Up and Down buttons):

```c
Setup_Inc_Field:
  iChanged = Yes
  cntDn(iState) = ADD_BCD cntDn(iState), 1
  IF cntDn(iState) > fldMax THEN
    cntDn(iState) = fldMax
  ENDIF
  IF cdHrs = $24 THEN
    PUT cdSecs, $00, $00
  ENDIF
  GOTO Setup_Show_Time

Setup_Dec_Field:
  iChanged = Yes
  cntDn(iState) = SUB_BCD cntDn(iState), 1
  IF cntDn(iState) > fldMax THEN
    cntDn(iState) = fldMax
  ENDIF
  IF cdHrs = $24 THEN
    PUT cdSecs, $00, $00
  ENDIF
  GOTO Setup_Show_Time
```

As you can see, these routines are nearly identical. The first will increment the current field and if it is bumped beyond its maximum value, it is reset to zero. There is a limit check on the hours field and when the hours is set to $24, the seconds and minutes fields are cleared to $00 — this limits the maximum interval time to 24:00:00.

The decrement routine is a virtual copy except that it handles under-flow by setting the field value to its maximum. As the fields are expressed in BCD, we use the ADD_BCD and DEC_BCD functions; these are SX/B shells around some neat code I found on www.sxlist.com (which is a great resource for SX programmers).

Moving the cursor is trivial — just a matter of incrementing iState and dealing with roll-over or roll-under:

```c
Setup_Next_Field:
  INC iState
  IF iState > 2 THEN
```

As FIGURE 5 shows, Intervalometer displays.
iState = 0
ENDIF
GOTO Setup_Mode

Setup_Prev_Field:
DEC iState
IF iState > 2 THEN
iState = 2
ENDIF
GOTO Setup_Mode

After adjusting the input state, the program is routed back to Setup_Mode where the cursor is re-displayed. Finally, when we press the OK button, we want to transfer the contents to the operation interval array:

Setup_Set_INTERVAL:
PUT iTime, cntDn(0) TO cntDn(2)
iChanged = No
GOTO Setup_Show_Time

SX/B 2.0 has an improved version of PUT which makes moving elements from one array to another very simple. As you can see, we're moving the contents of the temporary buffer (cntDn) into iTime. The next step is to clear the iChanged flag which will remove the asterisk from the display to let us know that the new interval is set.

There is no special handler for the Escape button; if we press it, the program jumps back to Setup_Reload which will move the current interval (iTime) into the temporary buffer (cntDn). This process also clears the iChanged flag as the temporary and user intervals now match.

**LET THE PHOTOS FLY**

When I first started this project, I created a background RTC and was going to compare it to the user interval but after working with the code, I concluded it would be easier just to move the interval into a temporary buffer and count down in one second units. To keep precise, however, means that the one second timing would have to be solid and not deviate — sounds like another routine in the interrupt.

The code is really easy. We count up to 80,000 (the interrupt rate) and when we get there, we set a flag and restart the counter from zero. The foreground is responsible for dealing with and resetting the flag:

```
LET THE PHOTOS FLY

When I first started this project, I created a background RTC and was going to compare it to the user interval but after working with the code, I concluded it would be easier just to move the interval into a temporary buffer and count down in one second units. To keep precise, however, means that the one second timing would have to be solid and not deviate — sounds like another routine in the interrupt.

The code is really easy. We count up to 80,000 (the interrupt rate) and when we get there, we set a flag and restart the counter from zero. The foreground is responsible for dealing with and resetting the flag:

```
```
At the top, we double-check the mode switch and the one second flag. We'll loop right here until the mode changes or the one-second flag goes high. When the flag is detected, we immediately clear it and drop down to Int_Update_Time to decrement the interval.

As in the setup mode, we use the SUB_BCD function to decrement the seconds register and when that underflows we cascade to minutes and hours. As long as there is any time left, the program is routed back to Int_Show_Time which updates the display. Otherwise, we drop through.

Since the camera output takes about 220 milliseconds, I decided to clean up the display by moving the cursor left and printing a 0; this shows 00:00:00 during the time the camera control output is active. A flag called shootNow is used to enable the camera output at the top of the interval loop. This also updates the variable called frames and sends it to line one of the LCD:

```
SUB SHOW_FRAMES
    sfChar  VAR  tmpB3
    sfIdx   VAR  tmpB4

    sfChar = LcdLine1 + 11
    LCD_CMD sfChar
    STR nStr, frames
    FOR sfIdx = 0 TO 4
        LCD_OUT nStr(sfIdx)
    NEXT
ENDSUB
```

There is a new function in SX/B 2.0 called STR that will convert a number to a string. As this generates a fair bit of code, I've wrapped it into the previous subroutine so that it can be called from run and manual modes without using extra code space. The default output is to pad the number with spaces, and it has optional modes that will pad with zeros or extract to decimal digits — a very handy addition to SX/B.

Okay, I know this was a bit of a bear and we couldn't cover everything but I hope you have as much fun with the code as I have — all 900 lines of it! Even if you don't build the intervalometer, you should still be able to find a lot of useable code snippets here that will help in other projects. I always do my best to make code as portable and re-usable as possible as this makes future projects easier to put together.

### TIME-LAPSE MATH

Now that you know how the intervalometer works, let me show you how to work the intervalometer. Let's say we wanted to recreate the Los Angeles to Las Vegas time-lapse movie using a new digital camera. What interval setting would we need to use? To find this setting, we need to know three things:

1) Projected frame rate
2) On-screen time
3) Event duration

The projected frame rate is usually going to be 30 (NTSC) or 25 (PAL, etc.), though you could do a custom frame if your intention is video for the Internet. Let's use 30 for the time-being.

With the projected frame rate and the on-screen time, we can calculate the total number of frames to shoot: 1,800.

\[3 \text{ mins} \times 60 \text{ secs/min} \times 30 \text{ frames/sec} = 5,400 \text{ frames} \]

The next step is to calculate the event time in seconds:

- **Projected frame rate**: 30 frames/second
- **On-screen time**: 3 minutes
- **Event duration**: 60 seconds

\[3 \text{ mins} \times 60 \text{ secs/min} = 180 \text{ secs} \]

\[180 \text{ secs} \times 30 \text{ frames/sec} = 5,400 \text{ frames} \]

### BILL OF MATERIALS

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Optional (Replaces *)

- SX28 Proto Board, Parallax 45302 Power Supply
4 hours x 60 mins/hr x 60 secs/min = 14,400 secs

To get the interval setting, we divide the even duration by the number of frames:

14,400 secs / 5,400 frames = ~3 secs/frame
(the interval is set to 00:00:03)

You'll need to test your camera to find its minimum interval. In auto mode, mine takes about two seconds so the three-second setting should be okay. What I would probably do is set the camera to manual focus and exposure to ensure that I can use short intervals.

**MOVING ON**

I was really happy to be able to fit this project into the SX28 — honestly, I wasn't sure I would be able to in the beginning. As it stands, the program uses about 75% of the code space so there is some room for new features. One of the ideas John suggested was a "pre-light" output. The idea is that we could enable the secondary output (on RA.3) before the shot is taken. This would be used to turn on lighting and allow it to warm up. Those that want to do time-lapse video of plant growth in a controlled environment would use this. I know what the feature is but haven't wrapped my head around implementing it yet so, for now I have left it on my to-do list.

Chances are that my next version will be on an SX48 or even the Propeller; with the code space, a lot of new features — like those in Mr. DeMeyer's project — could be added, and the additional I/O means that the LCD could use an eight-bit bus which simplifies the interface. With more code space and I/O, the thought of adding steppers to move the camera between shots is appealing, as well. Hmmm … I'm going to need to think about that one for a while.

Until next time, Happy Stamping, SX/B style! **NV**
Let your geek shine.

Meet Kristin O’Friel and Che-Wei Wang, inventors of Momo. Momo is a haptic GPS navigational device born out of a physical computing class project at ITP. Kristin and Che-Wei used SparkFun products to develop their Momo prototype.

The tools are out there - from GPS modules to microcontrollers, tutorials to forums. Find the resources you need and let your geek shine too.

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PLL synthesized for drift free operation
Front panel digital control and display of all settings and parameters!
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Both the FM30 and FM35WT operate on 13.8 to 16VDC and include a 15VDC plug-in power supply. The stylish black metal case measures 5.55”W x 6.45”D x 1.5”H. (Note: After assembly of this do-it-yourself hobby kit, the user is responsible for complying with all FCC rules & regulations within the US, or any regulations of the respective governing body. FM35WT is for export use and can only be shipped to locations outside the continental US or valid APO/FPO addresses or valid custom brokers for end delivery outside the continental US.)

Pocket Audio Generator
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around looking for things to bump
into! Sensors below his LED eyes
detect presence and make him turn
ear with flashlights too! Runs on two “AA” batteries.
WEB1 Walking Bug Kit $29.95

Super Snoop Amplifier
Super sensitive amplifier that will
pick up a pin drop at 15 feet! Full 2
watt output drives any speaker for a
great sound. Makes a great “big ear”
microphone to listen to the “static”
both in the field and in the city! Runs on 6-12 VDC.
BN9 Super Snoop Amp Kit $9.95

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Generate 2” sparks to a handheld
screwdriver! Light fluorescent tubes
without wires! This plasma generator
creates up to 25Kv at 200Hz from a
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regular bulbs and more! Runs on 100WAC or 5-24VDC.
PC13 HY Plasma Generator Kit $64.95

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Ultra high gain amp boosts audio 50
times and 24dB it at a listening
input! Generates a loud 5W output, and will drive any spea-
cers as low as 300Hz! Super for
sales and more! Great for home
sound systems.
MK136 Stereo Ear Amplifier Kit $9.95

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ASCII TO BAUDOT CODE CONVERTER

Q
Taking a giant leap backwards, I'm looking for an ASCII to Baudot converter circuit that works at 45 baud. Thank you!
— Craig Edmonds

A
I assume the Baudot code you refer to is the Western Union teletype code in common use. Converting the seven bit ASCII word to the five bit Baudot word is just a program for a microcomputer; but probably more than I can do at my level of learning.

Fortunately, the problem has been solved already. I found a UK paper that described such a system but it would have been too big a job for me. Don't despair, there is a kit available from Gil Smith; check out www.baudot.net/tty-connect.htm. Gil told me that this is a hobby with him. The board is not in production, but you can buy one for $30 and you supply your own components.

SCHOOLS

Q
I read Nuts & Volts all the time even though it's way out of my league; this is why I'm writing to you. Is there any possibility that you might know of a school that teaches electronics? I'm a working adult, so I don't have time to go to a regular college. Perhaps you might know of a private school or courses in the New York City area. This is something I've been interested in for a long time so any help would be greatly appreciated.
— Anthony Polizzi

A
The best school in your area is New York City College of Technology (City Tech); it offers an Associates degree in Electrical Engineering Technology, but it is a day school. I think what you want is an online school like Cleveland Institute of Electronics or Penn Foster Career School. These both offer basic electricity and work up from there. Many schools (such as ITT Tech) offer Information Technology courses but I don't think that is what you are looking for. Request information from these schools, and decide which courses will lead in the direction you want to go.

MEASURING ENERGY USE

Q
I'd like to calculate the energy in mAh consumed over a long period by a system consisting of a microprocessor and an LED. The LED flashes according to a programmed sequence consisting of pulses at a constant frequency and varying pulse width in a repeating pattern. The pattern is complex and lengthy, but averages out reasonably well over about an hour. I can measure the time it takes for batteries to expire, but batteries last for months and a test series would last for years. Is there any other way besides battery tests to predict battery life in this application? I have an oscilloscope, an ammeter, and a precision power supply.
— James Turner

A
Measuring an average over a long period of time would require a microprocessor, but since you already have one, I suggest that you modify the program to add all the on times over a period of an hour, then turn on the LED for the total time. You know the current drawn during the on time and the operating current of the micro. An alternative is to locate an electroplating unit that is designed to measure elapsed time. The plating builds up while the LED is on, so you can measure the thickness after an hour or 10 hours to determine the total on time. I had one of those 40 years ago but don't remember the name or if it is still available.
OSCIllATIONS

Q Could you explain the Barkhausen criteria and conditions for oscillation? I understand the loop gain must be 1.0 but what about the phase conditions? How are these conditions met differently by a Colpitts oscillator and a Wein Bridge oscillator?

A The Barkhausen criteria are that the gain around the positive feedback loop must be at least one and the phase must be zero degrees. According to Wikipedia, these are necessary but insufficient criteria for oscillation. Nyquist further adds that for stability, the real part of all poles must be negative. This implies that there are circuits which have closed loop gain of +1 and zero phase that do not oscillate. I have never run across such a circuit. In my experience, circuits follow Murphy’s Law: If it is possible for anything to go wrong, it will.

The Wein Bridge (Figure 1) is popular in oscillators because there is leading phase due to C1 and lagging phase due to C2; somewhere in the middle, the phases cancel producing zero phase. At the same frequency, the attenuation is minimized. I have chosen C1=C2 and R1=R2 because that makes the computation of frequency of oscillation simple: Fo = 1/(2πRC). The attenuation at the peak is -9.54 dB when I analyze the SPICE plot closely. The amplifier in Figure 2 must have at least 9.54 dB gain to oscillate. In Figure 2, the gain is 3 or 10 dB and the circuit is oscillating. In a real circuit, it would not work so well; you have to have gain control to maintain a sinewave. Otherwise, the output will be clipped. In their first product (the 200CD oscillator), Hewlett Packard used the Wein Bridge and in an elegant design, used a lamp for R3. As the signal increases, the lamp gets hotter and increases in resistance, which reduces the gain.

I should explain the current source at the input: oscillators in the real world start because of noise in the system (even resistance has noise, so any oscillator will start if there is enough gain). The SPICE simulator has no noise, so oscillation will not start unless you give the circuit a poke. The current source is a single pulse that starts the oscillator and then is just an open circuit.

Figure 3 is a frequency sweep of the circuit that shows another reason that the Wein Bridge is popular: The phase change at resonance is so sharp that the frequency cannot deviate without getting far from zero.

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Figure 3 is a frequency sweep of the circuit that shows another reason that the Wein Bridge is popular: The phase change at resonance is so sharp that the frequency cannot deviate without getting far from zero.
phase. Note that the right hand scale is -180 degrees which is also zero degrees. Why the feedback makes the phase change so rapidly is something I have not investigated; I'll leave that to those who have to know.

Figure 4 has R4 reduced to 19K, making the gain less than needed to oscillate. The circuit rings due to the initial pulse but quickly dies out.

The Colpitts oscillator in Figure 5 is different in that it uses an L-C circuit which has a "flywheel effect." Energy oscillates between the magnetic field and the stored charge, and all the circuit needs to do is poke it regularly to keep it going. Oscillators of this type usually operate class C (the transistor is off some of the time). You can operate class A (transistor
conducting all the time) but the waveform will be more distorted and the efficiency lower.

L-C oscillators operate on power gain rather than voltage gain. The feedback must provide enough power to overcome the losses. The ratio of $C_1/C_2$ determines the feedback power; a larger $C_2$ gives less power. In Figure 5, I am using a ratio of 1:70; a real circuit would not work with such a large ratio, but this L-C has no loss. Note that $V(fb)$ is at +10 volts which means that the transistor is mostly off (class C). Actually, a real circuit would not go so high because the base-emitter breakdown voltage is about seven volts.

In Figure 6, I have swapped the values of $C_1$ and $C_2$; that puts the circuit in class A operation. Note that the collector current shows negative spikes; that is due to the base-collector junction being forward-biased because of increased power being fed back. The emitter voltage is following the base because the transistor is conducting all the time.

In Figure 7, I have moved the L-C to the collector circuit. The advantage is that the breakdown voltage of...
the collector is higher, so a larger voltage swing is possible. Note that the emitter voltage $V_{\text{fb}}$ barely gets to $-600 \text{ mV}$ where the transistor is turned on and at the same time the collector voltage is minimum, so the power dissipated in the transistor is minimized.

Since $V_1$ is a virtual ground, separate capacitors could be used for feedback as in Figure 8. The advantage here is that the circuit can be tuned by $C_2$ and not affect the feedback ratio. Since the transistor has internal capacitance from base to emitter, $C_3$ is not needed and Figure 9 is the one normally used.

### INFORMATION ABOUT FLAT PANEL TVS

**Q** Do you know of any literature (principles and trouble-shooting) concerning flat panel (LCD and plasma) TVs? To our surprise we couldn’t find anything on Amazon, Alibris, or other book dealers. Even Google lacks technical information about these topics.


The service manual for a particular TV should have trouble-shooting information.

---

**Mailbag continued ...**

expires before I need another sample so I have to re-establish it.

The dead-time is 1.3 $\mu\text{S}$ out of 5.1 $\mu\text{S}$ on time; that is a long dead time. $R_2$ could be cut in half with no problem. That would increase the frequency, so you should increase $R_1$ by the amount that $R_2$ was decreased. Feedback to pin 5 of the 555 could have been used for regulation but I did not regulate the output because the radio does not care that much about it.

Many of the newer parts are not available as through-hole. In order to stay current, you need to learn how to handle SMD. You can use PNP Blue and a laser printer, or some people laser print onto glossy paper to make the printed circuit board. I have used prepasted wallpaper but have not been able to find any smooth enough lately.
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KA-1119 $18.95 plus postage & packing
Have you ever unsoldered a suspect transistor only to find that it checks OK? Troubleshooting exercises are often hindered by this type of false alarm. You can avoid these hassles with the In-Circuit Transistor, SCR and Diode Tester. The kit does just that, test drives WITHOUT the need to unsolder them from the circuit! Kit includes PCB, case and all specified electronic components. Case, heatsink and battery holder not included.

DIGITAL MULTIMETER KIT

KG-9750 $11.75 plus postage & packing
Learn everything there is to know about component recognition and basic electronics with this comprehensive kit.

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- Meter dimensions: 67(W) x 123(H) x 25(D)mm

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- Operates from 9V DC

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The new WaveAce is available in two channel models with bandwidths of 60 MHz, 100 MHz, 200 MHz, and 300 MHz; all models have color displays and maximum sample rate of 2 GS/s and up to 8 kpts/ch memory. The long memory allows users to capture full sample rate acquisitions that are twice as long as others. The WaveAce has 32 built-in automated parameters including advanced timing parameters for skew, phase, and edge to edge measurements between channels. Additional features such as pass/fail testing, user definable digital filters, and a waveform sequence recorder all simplify and shorten debug time.

The high performance and large feature set of the WaveAce is controlled by an intuitive user interface with 11 different languages and streamlined front panel. All important controls and menus are accessed from the front panel with a single button press. All position and offsets can be reset by simply pressing the knob; pressing the V/Div knob will switch between fixed and variable gain and pressing the T/div knob will toggle between zoom modes. Buttons on the front panel that open and close menus or switch modes are backlit to let the user know exactly what mode the WaveAce is operating in.

Internal storage can hold up to 20 waveforms and 20 setups. Mass storage can be done by connecting a USB memory device directly to the front panel of the oscilloscope. The rear panel USB port allows for direct printer connection or connection to a PC for control with a software utility called EasyScope. EasyScope enables remote control through a virtual front panel and also provides an easy method for saving waveforms and screenshots directly to a PC.

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The inductive sensor is a simple device. At the fundamental level, the sensor is a coil of wire with an AC current passing through it. When a metallic object is brought near the coil, it creates a load and the inductance significantly increases. Most non-metallic objects have a negligible effect when it comes to changing the inductance value because the resulting AC magnetic field doesn’t “couple” to the coil.

While a capacitor opposes a change in voltage, an inductor opposes a change in current. When used together, a capacitor and inductor complement each other to form an LC circuit that has a specific resonant frequency. This frequency is determined by the values of the inductor and capacitor. There are two types of LC circuits. The first is called “series resonant” where the capacitor and inductor are placed in series. The other is “parallel resonant” where the capacitor and inductor are — not surprisingly — placed parallel to one another. Series resonant configurations are generally used to amplify voltage, while parallel resonant configurations are used to amplify current. In this project, we will be using a series resonant circuit built on a Propeller demo board to detect the proximity of a metallic object (Figure 1).

Coil Construction

Materials you will need (Figure 2):
- 48 inches of 30 gauge enameled copper wire (RadioShack sells this as the “red” spool in their three-pack of magnet wire)
- 100 grit sandpaper
- 14.5 mm coil-form that you can easily slide the finished coil off of (I used a rechargeable AA battery with the label removed)

With 48 inches of
Only distinguish the difference between a logic suited for the input of a microprocessor that can one? A sigma-delta ADC is a type of ADC ideally. Question: What the heck is a sigma-delta ADC and why are we using feedback output. The configuration of the second positive edge triggered detector with an inverted while another counter can be configured as a running local oscillator to sweep the frequency, processors has two counter modules.

The Propeller (radio transmitter) must try all possible frequencies in a sweep pattern to determine if its signal is fixed to one frequency. Second, there needs to be a detector of some kind is needed to provide a sweep frequency in order for it to function properly. First, a local oscillator...with the use of a few external passive components. In its simplest form, an ADC requires two pins (P0 and P1 for this demo). One pin is configured as an input (P0), while the other pin is configured as an output (P1). The relationship between these pins can be thought of as a simple inverter. If the input detects a HIGH, then the output is made LOW; likewise, if the input detects a LOW, then the output is made HIGH. The Propeller basically implements this basic inverter function in software through one of its specialized counter configurations. Doing so with a special counter frees the Propeller processor to perform other tasks while the inverter function is allowed to do its thing.

Okay, so how does this ADC work? When you tie the output of an inverter to the input of the same inverter via a resistor (R4), it will tend to migrate the output voltage of the inverter to a voltage level equal to the input threshold voltage. This is because the output pin (P1) constantly creates a signal in the opposite direction from the detected input (P0) value. With the Propeller, this threshold voltage is typically half of the supply voltage. At this point, if we took a measurement by counting the number of 1s vs. the number of 0s, we would see that the ratio would be right at 50% as expected...since the output voltage is half, or 50% of the supply. By adding capacitors (C3 and C4) which are balanced to the power and ground terminals, a unique charge/discharge circuit is set up with the output (R4 through P1) of the “inverter.”

Sigma-delta ADCs offer a high resolution and low cost solution to this all-or-nothing digital dilemma.

The Propeller doesn’t have a built-in ADC, but we can simulate one in software, with the use of a few external passive components. In its simplest form, an ADC requires two pins (P0 and P1 for this demo). One pin is configured as an input (P0), while the other pin is configured as an output (P1). The relationship between these pins can be thought of as a simple inverter. If the input detects a HIGH, then the output is made LOW; likewise, if the input detects a LOW, then the output is made HIGH. The Propeller basically implements this basic inverter function in software through one of its specialized counter configurations. Doing so with a special counter frees the Propeller processor to perform other tasks while the inverter function is allowed to do its thing.

Circuit Description

Operation of this circuit has two basic requirements in order for it to function properly. First, a local oscillator of some kind is needed to provide a sweep frequency that will excite the RLC circuit at or near its resonant frequency. Second, there needs to be a detector of some sort to measure the coupling of the circuit. We’ll use the Propeller in both roles!

It’s helpful to think of this circuit like a radio except that your tuner (the RLC circuit) is fixed to one frequency. The Propeller (radio transmitter) must try all possible frequencies in a sweep pattern to determine if its signal can be “heard” on the nearby radio (the RLC). In order for the Propeller to listen or monitor its own signal, there needs to be a way to detect any changes that happen on the output of the RLC circuit as it is being swept. With a few external passive components (Figure 5), both requirements can easily be fulfilled by using the Propeller chip’s unique internal counter capabilities. Each of the chip’s eight parallel processors has two counter modules.

One counter can be configured as a free running local oscillator to sweep the frequency, while another counter can be configured as a positive edge triggered detector with an inverted feedback output. The configuration of the second counter serves to function as a sigma-delta ADC (analog-to-digital converter). Question: What the heck is a sigma-delta ADC and why are we using one? A sigma-delta ADC is a type of ADC ideally suited for the input of a microprocessor that can only distinguish the difference between a logic HIGH “1” or a logic LOW “0” on an input pin.

### PARTS LIST

<table>
<thead>
<tr>
<th>ITEM</th>
<th>DESCRIPTION</th>
<th>SUPPLIER/PART #</th>
</tr>
</thead>
<tbody>
<tr>
<td>Platform</td>
<td>Propeller demo board</td>
<td>Parallax/32100</td>
</tr>
<tr>
<td>C1</td>
<td>10 pF capacitor</td>
<td>Digi-Key/478-3160-ND</td>
</tr>
<tr>
<td>C2</td>
<td>0.01 μF capacitor</td>
<td>Digi-Key/478-3178-ND</td>
</tr>
<tr>
<td>C3, C4</td>
<td>220 pF capacitor</td>
<td>Digi-Key/478-3166-ND</td>
</tr>
<tr>
<td>D1</td>
<td>1N914 diode</td>
<td>Digi-Key/1N914ACT-ND</td>
</tr>
<tr>
<td>L1</td>
<td>30 gauge enameled copper wire</td>
<td>RadioShack/278-1345</td>
</tr>
<tr>
<td>R1</td>
<td>100kΩ resistor</td>
<td>Digi-Key/OD101JE-ND</td>
</tr>
<tr>
<td>R2, R4</td>
<td>1M resistor</td>
<td>Digi-Key/OD105JE-ND</td>
</tr>
<tr>
<td>R3</td>
<td>220KΩ resistor</td>
<td>Digi-Key/OD224JE-ND</td>
</tr>
</tbody>
</table>
The capacitors help stabilize the result and introduce a charge/discharge delay on the input (P0). It is the mechanism of this charge/discharge delay that allows an external voltage to persuade the charge/discharge ratio to one direction or the other and make its way into the charge/discharge cycle affecting the ratio. The result is a ratio of 1s and 0s that are proportional to the input voltage doing the initial persuading.

Using a series resonant circuit consisting of R1, L1, and C1, the RLC functions as a voltage amplifier when the sweep frequency (provided on P7) is close to the resonant frequency of the RLC circuit. When a metallic object is moved closer in proximity to a coil, the inductance of the coil will increase. This also increases the resonant frequency of the RLC circuit. D1 and C2 form a pseudo “peak detector” for the RLC that will feed a voltage divider. The voltage divider, consisting of R2 and R3, has an approximate ratio of 6.5:1. R4, C3, and C4 make up the sigma-delta ADC hardware.

This application makes use of the indicator LEDs built onto the Propeller demo board. If you are using a different Propeller platform, you will need to connect eight LEDs with 240 ohm series resistors to Propeller I/O pins P16-P23. For an LED wiring diagram, refer to the PropDemoDschem.pdf schematic file on the Parallax website located at www.parallax.com/Portals/0/Downloads/docs/prod/prop/PropDemoDschem.pdf.

Software

The code for this demo “Inductive Proximity Sensor.spin” can be downloaded from the Propeller Object Exchange at www.obex.parallax.com. Here are some excerpts:

In the CON section, this code tells the Propeller what Crystal frequency we are using, and that we want to use the PLL to multiply the Crystal frequency by 16.

```
_XINFREQ = 5_000_000 'Propeller Processor
_CLKMODE = XTAL1 + PLL1X
```

In the CON section, this code configures what pins will be used with our hardware.

```
SensePin = 0 'ADC INPUT pin
DrivePin = 1 'ADC OUTPUT pin
FPin = 7 'Frequency Synthesizer 'OUTPUT pin
```

In the CON section, this code configures the Start Frequency, Stop Frequency, and Sweep Step required for the auto calibration routine.

```
StartFrequency = 8_00_000 'Start Frequency to
StopFrequency = 10_000_000 'Stop Frequency to
SweepStep = 25_000 'Sweep increment used in
```

In the VAR section, we define some variables that we will be using.

```
long Frequency, FMax, ADCmax, Temp, Scan1, Scan2, Blink, n, Sample
```

Auto calibration main loop:

```
cognew(@asm_ADC, @Sample) 'launch Sigma Delta ADC ; uses CTRA
Fmax~ 'Clear Fmax
ADCmax~ 'Clear ADCmax
repeat Frequency from StartFrequency to StopFrequency step SweepStep 'Sweep frequency
  Synth(FPin, Frequency) 'set oscillator ; uses CTRB
  waitcnt(cnt+clkfreq>>10) 'Delay ; Allow ADC to settle
  'approx 1/1000th of a second
  if Sample > ADCmax 'Detect 'peak' voltage value from ADC
    ADCmax := Sample 'this will be the resonant frequency
    Fmax := Frequency 'of the RLC
DEMO program main loop:
```

```
Synth(FPin, Fmax) 'set the oscillator to the resonant frequency of the RLC circuit ; uses CTRB
dira[16..23] ~~ 'Set I/O direction of LED's to output
repeat 'Main Loop
  Temp := Sample 'Read current ADC value
  Scan1 := Temp / 412 'Set COARSE LED scale as Scan1: Maximum ADC value is 3300 (set below) ....so 3300 / 8 Leds = 412
  outa[16..23] := |< Scan1 'Turn on 1 of 8 LED's based on ADC value
  Scan2 := (Temp - (Scan1 * 412))/51 'Set FINE LED scale as Scan2:
  ++ ''Used for blinking LED ; increment n if n > 2500 'if n > 2500 then clear 'n, and toggle
  n := 0 'Blink variable
  Blink := 1 - Blink 'Turn on 1 of 8 LED's based on ADC value
outa[23..16] |= (|< Scan2)* Blink
```

Subroutines to set synthesizer frequency:

```
PUB Synth(_Pin, Freq) | s, d, ctr, frq
  Freq := Freq #> 500_000 <# 128_000_000 'limit frequency range
  ctr := constant(%00010 << 26)'..set PLL mode
  d := >|((Freq - 1) / 1_000_000) 'determine PLLDIV
```
March 2009

What to Do? What to Observe?

There are two modes of operation with this demo. When you connect the circuit and run the code without any metal in proximity to the sense coil, you should see two illuminated yellow LEDs on the Propeller demo board, with the leftmost LED solid and the rightmost LED blinking (assuming the LED side of the board is closest to you). If this is not the case, then re-check your wiring and make sure that all of your connections are secure.

With both modes, the sensing distance is about 5-10 mm from the coil. If you have a metal object such as a quarter, move it slowly towards the coil and you should see the blinking LED move from right to left. This is the “fine movement indicator” (FMI). As you continue to move the metal object even closer to the sense coil, you should notice that the solid LED or the “coarse” movement indicator” (CMI) will start moving from left to right, and the FMI has wrapped back around to the right side to begin the process all over again. Thus, each time that the FMI wraps around from right to left, the CMI advances one position to the right. This LED implementation is a compact way to provide visual feedback representing several different data positions from only eight indicator LEDs.

The second mode of operation involves running the code with metal already in close proximity to the sense coil. The LED indicators should still be the same as mentioned above with two illuminated yellow LEDs on the demo board. This time, by removing the metal object you should see the FMI (the blinking LED) move from right to left. As you continue to remove the metal object even further away from the sense coil, you should notice that the CMI (the solid LED) will start moving from left to right, and the FMI has wrapped back around to the right side to begin the process all over again.

The reason for why there are two different operation modes will be explained in further detail in Part 2, where we will use multiple coils in a differential sensor approach. For now, have fun with this and enjoy trying different coil sizes and shapes to see what you can come up with on your own.
Welcome back! Last time, I described how the user interacts with mistralXG to switch MIDI streams to the synthesizer and to control the various user options. This month, I’ll lift the hood on the design to show you how the hardware and software work together to make mistralXG do its thing.

Guided Tour of the Hardware

First, let’s take another look at the mistralXG block diagram (Figure 1).

Comparing this with the circuit schematic (Figure 2), we can identify the major functional areas of the design. The detail may be too fine to read in the magazine, so I recommend getting the schematic from the Nuts & Volts website (www.nutsvolts.com) and opening it with the free version of Eagle (www.cadsoft.de/freeware.htm) so you can explore it more fully. In the meantime, I’ll give you an overview.

The hardware is relatively simple. As you can see in the schematic, there are only a handful of chips: the PIC18F2550, three 74ALS00s, a couple of dual op-amps, and an opto-isolator for the MIDI input. The WX IN input is for a wind controller; as well as receiving the MIDI data, it provides power to the controller. Make sure anything you attach to this port is suitable and won’t be damaged by the voltage present at the connector. If you don’t need this input, you can replace it with a second standard MIDI IN port by duplicating the other MIDI IN circuit.

Areas 1 and 2 implement Switches 1 and 2 in the block diagram, respectively. Area 3 provides the control to enable and disable MIDI THRU and MIDI OUT. These controls use three 74ALS00 logic chips, selected to give a fast response with low power consumption. Outputs from the MCU control these features.

Area 4 contains the MCU and its oscillator. The PIC18F2550 supports many oscillator configurations. I chose a 4 MHz crystal, running the internal clock at 48 MHz as needed by the USB port. Each MCU instruction takes four CPU clocks, giving a cycle time of about 83 ns. To use a different crystal, you’ll have to modify the MCU’s configuration settings (mxg_config.c). Q1 is a transistor that uses pulse width modulation to control the brightness of the LCD backlight.

The DB50XG daughter card is attached via connector WB1 (Area 5). The pin numbering used on WB1 matches the numbering printed on the DB50XG. The outputs of the DB50XG are protected from an inadvertent short-circuit by a pair of op-amp buffers (IC4A&B). A second pair of op-amps (IC5A&B) provides stereo outputs for headphones; the volume is controlled by a 50K dual-gang pot. These amplifiers are in Area 6 in Figure 2. The DB50XG outputs about 3V peak-to-peak, so I’ve included a way to attenuate the line outputs. If no attenuation is required, R12 and R14 should be replaced with plain wire links. As shown, they are 10K resistors and halve the output voltage (-6 dB). You can select an appropriate value to give the attenuation you need, but I wouldn’t go above about 50K for each of these two resistors — use 1% components to give good stereo matching.
The headphone amps can also be tweaked. As shown, they give a gain of 2 (+6 dB — about 6V peak-to-peak), but I found a gain of 1 (leaving resistors R16 and R18 out of the circuit altogether) sufficient. I don't recommend increasing the gain beyond 2, to minimize the risk of distortion.

Area 7 shows the LCD, the two pushbuttons, and the volume control. Header pins for these are included in the circuit so that they can be connected via flying leads. The USB connector is also here. This, and the MIDI inputs and outputs could be either mounted on the
circuit board or panel-mounted, as you prefer.

**Building the Circuit**

I used a breadboard for the prototype, but techniques such as stripboard, custom PCB (printed circuit board), etc., could also be used. Unfortunately, the free version of Eagle only creates circuit boards up to 80x100 mm (which is too small), so there is no PCB design at present.

Care should be taken when laying out the oscillator circuitry. Keep track lengths short and position the crystal and its capacitors close to the MCU. Also keep the analog (op-amps) area separate from the logic to avoid digital noise on the analog signals.

The capacitors shown to the bottom right of the schematic are for general decoupling. Position a 0.1 μF capacitor as close as possible to each chip. These provide good high frequency decoupling. The larger value polarized capacitors are for bulk decoupling and are not so critical in their placement.

Construction is straightforward. Anyone with basic electronic skills (soldering, reading a schematic, and so on) will be able to put the unit together.

**Power**

The completed circuit needs ground, +5V, +12V, and -12V power supplies; ±12V are only needed if the daughter board is used. If not, the op-amps can also be omitted and only +5V is required.

<table>
<thead>
<tr>
<th>Condition</th>
<th>+5V supply</th>
<th>+12V supply</th>
<th>-12V supply</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>No daughter board, backlight off.</td>
<td>50 mA</td>
<td>Not needed</td>
<td>Not needed</td>
<td></td>
</tr>
<tr>
<td>No daughter board, backlight on max.</td>
<td>250 mA</td>
<td>Not needed</td>
<td>Not needed</td>
<td></td>
</tr>
<tr>
<td>Daughter board playing music, backlight on max.</td>
<td>600 mA</td>
<td>25 mA (see note)</td>
<td>25 mA</td>
<td>My wind controller draws an additional 50 mA from the +12V rail.</td>
</tr>
</tbody>
</table>

Table 1 shows the current drawn under various conditions to allow you to tailor your power supplies depending on what you choose to include in the design.

**Software: The Brains Behind mistralXG**

mistralXG's software is written in C, using the Microchip C18 compiler (student edition). The compiler and MPLAB integrated development environment (IDE) are both available as free Windows downloads from the Microchip website.

The individual modules are listed in Table 2. Each C module is shown with its directory path relative to the main.c module and a brief description of its function. A matching *.h file for each *.c module contains definitions used in the other modules. There are some additional *.h files included with the framework to control things such as how the MCU senses when the USB port is connected to the PC.

**Framework File Changes**

Several sample applications are included with the USB Firmware Framework. mistralXG is based on the Generic Framework. mistralXG is based on the Generic Framework File Changes

The main() routine (Example 1) first initializes application modules. It then loops around servicing the user
routines in ProcessIO() and USBTasks(), which handles USB housekeeping routines such as disconnecting and reconnecting to the PC. The USB code is not interrupt driven. ProcessIO() must execute promptly, otherwise the USB interface will fail. I'll come back to this point later.

**Interrupts Provide the Heartbeat**

The heart of the mistralXG code is the interrupt routine (interrupt.c) which handles three types of events: a timer running every 1 ms; and receive and transmit interrupts from the EUSART, generated by the incoming and outgoing MIDI streams.

The timer interrupt manages a number of things:

- A display refresh timer that updates the display every 100 ms.
- A display timeout timer that returns the display to the Home Screen after a few seconds.
- The Running Status injection timer that ensures a MIDI command/status byte is sent at least every 250 ms.
- Switch debouncing to prevent spurious input from the pushbuttons.

MIDI data to and from mistralXG are handled by the interrupt routine and placed in buffers for transmission to the PC and synth.

**Keeping Everything Going — user.c**

There are three main routines in user.c. UserInit() handles initialization of the various user routines and is responsible for configuring the various peripherals. Next in line is ProcessIO(), discussed later, and finally there is ServiceRequests(), responsible for the user data flowing over the USB.

**ProcessIO() — the scheduler**

If interrupts form mistralXG's heart, ProcessIO() is the brain. This routine keeps everything in sync and on track. A pseudo-code skeleton of its function is shown in Example 2.

If you look at the source code, you'll see that there is a lot of additional fine detail to make sure that everything works as it needs to, but the pseudo-code captures the essence of the routine's function, and I'll take you through this step-by-step:

- It first checks whether a MIDI byte has been received by the EUSART. If so, processNextByte() (mxg_musm.c) handles it by building it into a USB-MIDI packet. A complete MIDI command message of one to three bytes is combined into a single packet, with up to 16 packets being sent in a single USB transfer.
- Changes to the two pushbuttons are checked for and handled in mxg_iface.c.
- If the user has changed an option, its setting is saved in the MCU's EEPROM (mxg_eeprom.c). Writes to the EEPROM take several milliseconds so they are scheduled and processed when the hardware is available.
- If the display timeout timer has expired, the display is switched back to the Home Screen (mxg_iface.c).
- If the display refresh timer has expired, a display refresh is scheduled (mxg_iface.c).
- Some display updates can take well over 1 ms, so these are scheduled to occur when the hardware is available (mxg_iface.c).

If the USB port is connected, ServiceRequests() is then called to handle the application's USB transfers, doing so in two stages:

- It first checks whether any incoming MIDI data has been assembled into packets for the PC and, if so, sends them.
- It then checks for received USB-MIDI packets and, if so, transfers extracted MIDI data to the transmit buffer where the interrupt routine picks them up and sends them out to the synth.

**Timing is Critical**

I've used the word scheduled several times in the
code description. This is important and I’ll use the LCD to illustrate why. Microchip provides a library of routines for driving an LCD display with its C18 compiler, but it quickly became obvious that I couldn’t use it. This is because many of the routines wait for the display to finish executing a command before returning control to the calling routine. As mentioned earlier, if ProcessIO() holds things up for too long, the USB code times out and fails.

To avoid this problem, the application code is written using non-blocking routines — that is, routines that do not wait for an event to complete. I achieved this by setting flags to indicate when actions are pending and waiting until the hardware is idle before executing them. It takes 34 writes to completely update the screen. They are scheduled to start every 100 μs and ProcessIO() performs one write each time it executes and the display isn’t busy. Using this technique, the 34 writes take just a few milliseconds.

Monitoring MIDI Channels

The error flags were originally on the Home Screen. I decided that it would be a better use of the display to monitor MIDI data, but wasn’t sure how to do it with the limited display resources. Figure 3 shows how I solved the problem.

The LCD controller chip supports eight user-defined characters. By defining the four characters shown, a single bit change indicates that a channel has received data. Sixteen characters representing channels 1-16 are held in a buffer. After the character for a particular position is written to the display, it is set to the “no data” state. Then, as each MIDI IN or OUT packet is processed, the appropriate bit is switched on, changing the character code to indicate data traffic IN and/or OUT. This is reflected on the display at the next refresh. The overhead to do this is low as the channel number is easily obtained from the MIDI streams, and the MCU has instructions that flip a single bit. You can see the monitor in action in Figure 4.

Tools for Construction

Construction is straightforward; just make sure you get the chips and polarized capacitors the right way ‘round.

Programming the device requires a suitable device programmer to install the bootloader. Once that is installed, the chip can be programmed with the mistralXG code via the USB port. A quick Google search found many sites from which you can purchase relatively cheap programmers and programmer kits (<$100, some much less). Probably the best solution is one of the programmers/debuggers from Microchip. The PICKit2 is a good value at less than $50 for a starter kit that includes an evaluation board.

Alternatively, I may be able to provide a pre-programmed PIC18F2550 for a nominal charge. Anyone interested should first contact me at pic.projects@grapevyne.com to discuss availability.
Programming mistralXG's MCU

Microchip provides a bootloader for the PIC18F2550 MCU. This sits in the first 2K of program memory and lets you reprogram the chip over the USB interface. I modified this to suit the hardware configuration used by mistralXG. The bootloader hex file (MistralBoot.hex) needs to be burned into the MCU. The pushbutton connectors have been arranged to double-up as the In-Circuit Serial Programming (ICSP) interface, so this could be used if you have a suitable programmer.

With the bootloader installed, holding the Select button down as you switch on puts mistralXG into programming mode. You can then program the device with hex files from the PC using Microchip's PDFSUSB.exe utility (included with the firmware framework). Use the utility to program in mistralXG.hex and then cycle the power (leaving the pushbuttons alone) to see the Splash Screen and start playing with your own mistralXG!

Conclusion

I had great fun developing mistralXG and learned a lot about USB and PIC peripherals. I hope you feel as inspired to experiment as I did and build a mistralXG of your own or put the code to use in some other personal project.

I plan to continue to enhance the project over time. One plan is to add external storage to the design using the SCL and SDA pins on the MCU — these are not used at the moment. I may also update the code to use a later version of the USB Firmware Framework. I'll post any new developments on my website (www.grapevyne.com/pic.projects). NV

Tools for Debug

A multimeter is handy for checking voltages and it is useful to have access to an oscilloscope to check what various signals are doing. As long as you've not made any assembly errors, mistralXG should just burst into life when you apply power. If that doesn't happen, you'll need to be able to check that the oscillator is running and the MCU has reset correctly. The Microchip programmer/debugger tools are invaluable in helping you to do this.
With switch-mode projects, there’s always the problem of where to obtain inductors and/or transformers with the necessary specifications. Parts can be hard to find and expensive. So why not “roll your own?” In this project, we will design and wind a transformer and use it to get +12V and -12V from a 9V battery with the DC-to-DC converter shown in Figure 1.

Magnets: MMF and Flux

Once it was thought that magnetism and electricity were separate things. They're not. Magnetism is caused by quantum electron-spin and by the relativistic effects of current in a conductor. But let's keep it simple.

We start with magneto-motive-force (mmf) and magnetic flux (Φ). Wrap a coil of wire around a steel core and put current through it (Figure 2). You get mmf = N x I where N is the number of turns of wire and I is the current. The mmf causes flux to flow through the core. We can write Ohm’s Law for magnetic circuits: Φ = mmf/R where R is the reluctance.

Resistance depends on three things: the length of the resistive material (l), the area of its cross-section (A), and its resistivity (ρ): R = ρ/l/A. Length and area can change, but the resistivity of a material is constant.

Reluctance has a similar equation: R = υ(l/Ac) where l is the flux path length, Ac is the core’s cross section area, and υ is the material’s reluctivity. The inverse of reluctance is more commonly used: 1/R = μ (Ac/l) where μ = 1/υ is permeability.
**Permeability, Magnetizing Force, and Flux Density**

Like resistivity, permeability is a property of magnetic materials like iron. Unlike resistivity, permeability is not constant; it changes with flux. Actually, it changes with flux density \( B \).

Flux density is \( B = \frac{\Phi}{A} \). Since \( \mu \) changes with \( B \), the B-H graph is non-linear as in Figure 3.

Permeability is the slope of the B-H curve at a specified value of \( B \): \( \mu = \frac{\Delta B}{\Delta H} \). As \( H \) increases beyond a certain point, the curve flattens out. That's saturation: the maximum flux density a given material can have.

**Faraday’s Law**

In 1831, Michael Faraday showed that moving a coil through a magnetic field (or moving a magnetic field through a coil) induces voltage in the coil: \( V = N(\Delta \Phi/\Delta t) \) where:

- \( V \) is the induced voltage.
- \( N \) is the number of turns of wire in the coil.
- \( \Delta \Phi \) is the amount of magnetic flux the coil "cuts."
- \( \Delta t \) is the amount of time the coils cuts through the flux.

In Figure 2, closing the switch applies voltage across the coil. As coil current increases, mmf increases, \( \Phi \) increases, and a voltage is induced in the coil that is equal but opposite to the applied voltage. The induced voltage lasts until the core saturates. Then, the coil becomes a short-circuit across the battery. So, the maximum \( \Delta t \) in the above equation is the time it takes for the flux to go from zero to saturation \( (\Phi_{sat}) \). Saturation causes current spikes so the maximum flux used \( (\Phi_m) \) must be less than \( \Phi_{sat} \).

**Hysteresis, Eddy Currents, and Power Loss**

The B-H curve for magnetic material is more complicated than Figure 3. Apply a magnetizing force to a bar of steel. When you remove the mmf, the bar is magnetized with residual flux. To demagnetize the bar, you have to apply reverse mmf. If the battery in Figure 2 is replaced by an AC source, you get the B-H curve of Figure 4: a hysteresis loop. Every time the core flux cycles around the loop, some electrical energy gets converted into heat. It's a form of core loss.

A changing magnetic field will induce voltage into any conductor it passes through, including the core itself. Voltage in the core causes eddy currents to flow producing I^2R core loss. I^2R in the coils is copper loss.

**Ferrite vs. Steel**

Both hysteresis and eddy current losses increase rapidly with frequency. At audio frequencies, transformer cores are made from insulated steel laminations. Steel has very high permeability, but a lot of loss at switch-mode frequencies where ferrite is used instead.

Ferrite is a ceramic containing iron and other elements. It starts as clay-like material that can be formed into many shapes, then baked hard. It's brittle and can crack or break from too much mechanical stress. It has less permeability than steel, but much less loss at high frequency. Ferrite is conductive and abrasive, so often it's coated with insulation. Figure 5 shows a toroid core like the one we will use. A toroid is the ideal shape for a transformer core.

**Voltage and Flux**

In Figure 6, the switches alternately...
open and close producing square wave voltage on the primary. Starting at \( t = 0 \), flux increases according to \( \Phi = (V/N)t \), producing triangle wave flux in the core as shown in Figure 7 (triangular as long as \( \mu \) doesn't change much with \( \Phi \)). The current in the coil is also triangle wave.

Two points about Figure 7: First, flux goes from \( -\Phi_m \) to \( +\Phi_m \), so \( \Phi = 2\Phi_m \). Second, \( \Delta t \) is half the period, so \( \Delta t = T/2 = 1/2f \).

**Turns per Volt**

Rewrite Faraday's Law:
\[
V = N(\Delta \Phi/\Delta t) = N(2\Phi_m)/(1/2f) = 4N\Phi_m f
\]

Rearranging terms yields an important parameter: the turns-per-volt \( (N/V) \). \( N/V = 1/(4\Phi_m f) \).

**Magnetizing Current (Im)**

The flux linking primary to secondary in a transformer is generated by the primary mmf which is 90° out of phase with primary voltage as seen in Figure 7. Since \( \Phi \propto I \), primary current is also 90° out of phase with primary voltage so, except for losses, no power flows in. The primary looks like an inductor. The current in that inductor is the magnetizing current:
\[
H_m = Bm/\mu \Rightarrow Nlm/le = Bm/\mu \Rightarrow Im = (Bm le)/\mu N
\]

where \( le \) is the effective length of the flux path. High \( Im \) increases copper loss.

Putting a load on the secondary causes primary current to increase, but not flux in the core. The mmf caused by current in the secondary cancels mmf caused by the additional primary current, so there's no net change in flux.

**Terminology and Units**

Table 1 shows the two sets of magnetic units. Table 2 shows how to convert from one to the other. The unit for mmf is actually just amps. The number of turns is a dimensionless multiplier.

**Choosing a Core**

We want a core that is efficient at 100 kHz with an internal diameter big enough so winding turns is easy. To minimize the number of turns, \( N/V \) should be between 1 and 2.

The core chosen for this project is a FERROXCUBE TX16/9.1/4.7 epoxy coated toroid. The part number gives the dimensions: 16 mm OD, 9 mm ID, 5 mm thickness. It's made from their 3C90 ferrite material, designed for power applications up to 200 kHz. From its datasheet, \( Ae = 14.7 \text{ mm}^2 \) and \( le = 37.2 \text{ mm} \). Core loss at 100 kHz and 100 mT is less than 55 mW. Similar cores from other manufacturers like MAGNETICS and Fair-Rite would work also.

Bmax for 3C90 is about 350 milli-Tesla (mT) at 25°C. Using Bmax would lead to higher core loss and the danger of saturation. To be conservative, let \( Bm = 100 \text{ mT} \).

The turns per volt is:
\[
N/V = 1/(4\Phi_m f) = 1/(4 \times 0.1 \times 14.7 \times 10^4 \times 1 \times 10^5) = 1.7
\]

---

**Table 1**

<table>
<thead>
<tr>
<th>PARAMETER</th>
<th>SYMBOL</th>
<th>CGS</th>
<th>SI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Magneto-Motive-Force</td>
<td>mmf</td>
<td>Gilberts (Gb)</td>
<td>Amp-Turns (AT)</td>
</tr>
<tr>
<td>Magnetic Field Strength</td>
<td>H</td>
<td>Oersteds (Oe)</td>
<td>Amp-Turns/meter (AT/m)</td>
</tr>
<tr>
<td>(Magnetizing Force)</td>
<td></td>
<td>(Gb/cm)</td>
<td></td>
</tr>
<tr>
<td>Magnetic Flux</td>
<td>( \Phi )</td>
<td>Maxwells (Mx)</td>
<td>Webers (Wb)</td>
</tr>
<tr>
<td>Flux Density</td>
<td>B</td>
<td>Gauss (G)</td>
<td>Tesla (T)</td>
</tr>
<tr>
<td>(Magnetic Induction)</td>
<td></td>
<td>(Mx/cm²)</td>
<td>(Wh/m²)</td>
</tr>
<tr>
<td>Reluctance</td>
<td>( \mathcal{R} )</td>
<td>Gilberts/Maxwell</td>
<td>AT/Weber</td>
</tr>
<tr>
<td>Permeability</td>
<td>( \mu )</td>
<td>Gauss/Oersted</td>
<td>Tesla (AT/m)</td>
</tr>
</tbody>
</table>

**Table 2**
**Calculate Np and Ns**

Primary turns (Np) depend on primary voltage (Vp). \( Np = \frac{Vp \times (N/V)}{1.7} = 15.3 \), which rounds off to 15.

The 7812 and 7912 regulators need 2.5 volts between input and output. Adding 2.5 to 12 gives 14.5 volts. Adding 0.5 volts for the drop across the Schottky rectifiers gives 15 volts. Another 0.5 volts for loss gives \( V_s = 15.5 \) volts.

Secondary turns \( N_s = \frac{V_s}{V_p} \times N_p = \frac{15.5}{9} \times 15 = 25.8 \) which rounds up to 26. For a few less turns on the secondary, increase \( B_m \) a bit and recalculate N/V.

**Calculate Im**

From the 3C90 specification sheet, \( \mu \approx 4 \times 10^{-3} \) at \( B = 100 \text{ mT} \). So,

\[
Im = \frac{(B_m \cdot le)}{\mu N} \approx \frac{(0.1 \cdot 37.2 \cdot 10^3)}{(4 \cdot 10^{-3} \cdot 15)} = 0.062 \text{ amps}
\]

\( Im = 62 \text{ mA} \) is a reasonable value.

**Winding the Transformer**

This is the fun part. You need:

- Toroid core (1)
- Bifilar wire, 28 Ga., 42 inches
- Nylon screw (1), 10-32 3/4 inch
- Nylon nuts (2), 10-32
- Fiber washers (2), center-hole for #10 screw [optional]

**Wind Primary and Secondary**

We use **bifilar** wire: two strands of magnet wire glued together, with different insulation colors (e.g., red and green). It makes the center-tap very easy, but it’s not available everywhere. Sources will be given in the Parts List.

You need 16 inches of wire for the primary and 26 inches for the secondary. Hold the core with the fingers of one hand. Put the primary wire through the core so that the short end forms a two inch lead; call it Lead 1. Use your thumb to hold the wire to the core.

With your other hand, fold a small loop in the long end close to the core and push it through the center (Figure 8). Grab the loop and pull the wire all the way through. (A small stick helps. The cosmetic department of your local drug store may have a cuticle stick — the perfect tool!). Bend the wire around the side of the toroid and put your thumb on the new turn to keep it from unraveling.

Repeat the process counting the turns. Distribute the turns more or less evenly. Space the turns so the last turn ends up next to the first turn. Leads 1 and 2 form the last turn. For example, Figure 10A shows 19 turns. When you get to the end, cut the remaining wire to make Lead 2 the same length as Lead 1. Lock the leads with three twists close to the core (Figure 9). Lay four inches of plastic electrician’s

<table>
<thead>
<tr>
<th>CGS</th>
<th>( \times 0.796 = )</th>
<th>SI</th>
<th>( \times 1.26 = )</th>
<th>CGS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gilberts</td>
<td></td>
<td>Amp-Turns</td>
<td></td>
<td>Gilberts</td>
</tr>
<tr>
<td>Oersteds</td>
<td>( \times 79.6 = )</td>
<td>AT/meter</td>
<td>( \times 0.0126 = )</td>
<td>Oersteds</td>
</tr>
<tr>
<td>Maxwells</td>
<td>( \times 10^{-8} = )</td>
<td>Webers</td>
<td>( \times 10^{8} = )</td>
<td>Maxwells</td>
</tr>
<tr>
<td>Gauss</td>
<td>( \times 10^{-4} = )</td>
<td>Tesla</td>
<td>( \times 10^{4} = )</td>
<td>Gauss</td>
</tr>
<tr>
<td>Gauss</td>
<td>( \times 0.1 = )</td>
<td>milli-Tesla</td>
<td>( \times 10 = )</td>
<td>Gauss</td>
</tr>
</tbody>
</table>
tape on a cutting surface. Cut the tape lengthwise into strips about 1/4 inch wide. Take a strip and wrap it over the primary turns as shown in Figure 9. To tell the primary from the secondary later on, tie a small piece of thread around the primary leads. Start winding the secondary 180° opposite of the primary leads using the same procedure. When done, tape the secondary as you did the primary.

**Form the Center-Taps**

Use a sharp tool to split the ends of the primary leads. Peel apart the red and green wires (Figure 10A). Take the red wire from one lead and the green wire from the other lead and twist them tightly together to form the center-tap (Figure 10B). Repeat on the secondary leads.

Scrape about 1/4 inch of insulation off the center-tap (CT) and the other wires of the primary. Tin the exposed copper ends. Repeat on the secondary wires. Use an ohmmeter to check continuity between CT and both wires of the primary; likewise for the secondary. Verify there is no continuity between primary and secondary.

**Add the Hardware**

Refer to Figure 9. Insert the nylon screw

---

**PARTS LIST**

<table>
<thead>
<tr>
<th>ITEM</th>
<th>DESCRIPTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>R1, R2, R5, R6</td>
<td>1K trimpot, 4 mm square, Cermet</td>
</tr>
<tr>
<td>R3</td>
<td>1K</td>
</tr>
<tr>
<td>R4</td>
<td>5.1K</td>
</tr>
<tr>
<td>R7</td>
<td>10K</td>
</tr>
<tr>
<td>C1</td>
<td>10 μF, 25V, 20% AVX Tantalum, SMT</td>
</tr>
<tr>
<td>C2</td>
<td>0.1 μF, SMT size 0805</td>
</tr>
<tr>
<td>C3</td>
<td>0.001 μF, SMT size 0805</td>
</tr>
<tr>
<td>C4-C6</td>
<td>1 μF, 50V, Ceramic, 0.2 inch radial</td>
</tr>
<tr>
<td>C7</td>
<td>10 μF, 25V, 20% AVX Tantalum, SMT</td>
</tr>
<tr>
<td>C1</td>
<td>IC1 LM3524DM/NOPB, SOIC-16</td>
</tr>
<tr>
<td>C2</td>
<td>IC2 7812</td>
</tr>
<tr>
<td>C3</td>
<td>IC3 7912</td>
</tr>
<tr>
<td>Q1, Q2</td>
<td>Q1, Q2 MOSFET, SMT, IRFR024NTRPF</td>
</tr>
<tr>
<td>D1-D4</td>
<td>MBR150RLG (or equivalent)</td>
</tr>
<tr>
<td>Terminal block</td>
<td>Two position, 0.2 inch spacing</td>
</tr>
<tr>
<td>Terminal block</td>
<td>Three position, 0.2 inch spacing</td>
</tr>
<tr>
<td>Core, ferrite</td>
<td>Ferroxcube TX16/9.1/4.7</td>
</tr>
<tr>
<td>PC board</td>
<td>10-32 x 3/4 inch</td>
</tr>
<tr>
<td>Screw, Nylon</td>
<td>Nylon, 10-32</td>
</tr>
<tr>
<td>Nuts (2)</td>
<td>Fiber, Keystone #4702</td>
</tr>
<tr>
<td>Washers (2)</td>
<td>42 inches, bifilar, 28 ga.</td>
</tr>
<tr>
<td>Wire</td>
<td></td>
</tr>
</tbody>
</table>

**SOURCES**

- MWS Wire: [www.mwswire.com](http://www.mwswire.com)
- WireTronic: [www.wiretron.com](http://www.wiretron.com)
through a fiber washer. Insert the screw with the washer through the center of the toroid. Put the other washer on the screw and thread on a nut. Hand-tighten until snug. DO NOT OVER TIGHTEN. Figure 9 shows the transformer mounted on the circuit board using the second nut.

The transformer is done. Set it aside until needed.

**Circuit Description**

Figure 11 is the schematic of the converter. IC1 (LM3524) drives power MOSFETs Q1 and Q2 which, in turn, drive the primary of the transformer in a square wave. Switching frequency is set by R4 and C3. The stepped-up voltage at the secondary is rectified and filtered to raw DC which is regulated down by IC2 and IC3. R7 prevents C4 and C5 from charging up to the peak of voltage spikes that can occur with an unloaded secondary. R5 and R6 are pull-downs to speed up the turn-off of Q1 and Q2. Since the MOSFETs turn on faster than they turn off, both transistors would be on for a part of every cycle if they switched simultaneously, causing the transistors to get hot from current spikes. To prevent that, the LM3524 provides dead time between turning off one transistor and turning on the other. Dead time is set by the voltage at pin 2, adjusted by trim-pot R3.

**Construction**

Figure 12 is the board layout. Components on the primary side are surface-mount (SMT) devices. (I’m using SMT since through hole parts are obsolete). The secondary side has mostly through-hole parts; I had a lot of the diodes and regulators, and wanted to use them.

There’s an excellent video on soldering SMT devices on the Nuts & Volts Store page (http://store.nutsvolts.com) under the High Voltage Power Supply Circuit kit. I recommend viewing it before starting this project. Since the video is so thorough, I won’t go into details about soldering here.

Mount IC1 — a 16 pin SOIC device — first. With a magnifier, carefully inspect the solder joints. Then, mount C1, C2, C3, and C7. Check polarity on C1 and C7. Next, mount R1, R2, R4, R5, R6, R7, and trim-pot R3. Then mount Q1 and Q2.

Mount D1, D2, D3, and D4. Next, mount C4, C5, and C6. Then, mount IC2 and IC3. There are lines near the holes for IC2 and IC3 showing the positions of their metal tabs. Mount the two terminal blocks.

Before installing the transformer, connect the board to nine volts. Use an oscilloscope to look at the gates of Q1 and Q2. You should see a square pulse with a
rep-rate of about 100 kHz. Adjust R3 and verify that the pulse width varies. If it’s working properly, set R3 for minimum pulse-width and disconnect power. If it’s not working right, disconnect power and examine the solder joints on IC1. Verify that R4 and C3 are correct.

**Mount the Transformer**

Refer to Figure 8. Mount the transformer with the primary winding facing the P on the circuit board. (Remember that piece of thread you put on the primary?) Install the second plastic nut and hand-tighten it to the board. Clip off excess screw length. Insert the primary leads with the center tap going in the center of the three holes and solder them. Similarly, insert the secondary leads in their three holes and solder. Insulation on some magnet wire allows you to solder through it. If your iron is hot enough and you hold it on the wire long enough, the insulation will dissolve. Otherwise, you need to scrape it off.

**Testing**

Measure input current when you power up the board. If your supply has a current display, use it. If it doesn’t, you can put a 1Ω resistor in series with the supply and get the current by measuring the voltage across it. (I got tired of replacing fuses in my DMM when using its current range.)

Apply nine volts to the board. If current jumps past 0.25 amps, remove power and examine the board again. Double-check polarity on C1 and C7. Verify IC2 and IC3 are installed correctly. Look for solder bridges. If you can’t find the problem by inspection, you can always re-apply the power and see what gets hot or starts to smoke. (I’m not kidding; I’ve had to do that on several occasions.)

If the board passes the smoke test, verify that you have +12V and -12V on the outputs with no load. Then put a 220Ω, 1W resistor from each output to ground and verify that you still have +12V and -12V on the outputs. Use a voltmeter to measure the raw DC with and without a load. You’ll see a drop with load. If the raw DC is too low with full load, you can increase it by adjusting R3.

**Wrap-Up**

The LM3524 requires 8V minimum and has a 40V maximum supply limit. Use the board as a platform to test your own transformer designs. Try making one that uses 12 volts input. Try making a step-down transformer to get +5V and -5V outputs (replace IC2 and IC3 with a 7805 and a 7905). You can eliminate the regulators and install jumpers at IC2 and IC3 to bring the raw DC to the output terminals. Have fun with it! NV
This article highlights my design process and the problems that I encountered during the creation of the DEFCON 16 Badge. Hopefully, you’ll be able to learn from my mistakes or build on my work to enhance your own endeavors.

A Brief History of the DEFCON Badge

The previous years’ electronic badge designs each had their own set of unique challenges, interesting lessons, and frustrating problems. The DEFCON 14 badge was a round PCB with complicated cutouts of graphical elements and consisted of a six pin Microchip PIC10F202, two jumbo blue LEDs, and a single CR2032 Lithium coin cell. The badge had four different LED modes (on, blinking, alternating, random) and a Microchip ICD2 programming interface for attendees to load their own customized firmware onto the badge. We didn’t know what to expect when we started handing them out to conference attendees, but the response was overwhelming, which led to a new badge design for the next year.

I upped the ante and the technical complexity of the DEFCON 15 badge by using a Freescale MC9S08QG8, a 95 LED matrix (five columns by 19 rows) for custom scrolling text messages, capacitive touch sensors, and unpopulated areas for accelerometer and 802.15.4 wireless support. You can read all about the trials and tribulations of the DEFCON 15 badge in the July 2008 issue of Nuts & Volts. Even with the success of the badge, I felt that I had over-engineered it and that it contained too much for attendees to digest over the weekend. So with DEFCON 16, we wanted to have an electronic badge that could still be personalized in some way, but without a lot of “noise” to detract people from the key features and turn them off from hacking their badge.

Design Goals

The primary goal of the DEFCON 16 badge was to incorporate a file transfer feature to allow an attendee to transfer files to another attendee using his or her badge, not unlike the “beaming” capability of PDAs and smartphones. Attendees would load their desired file — be it a business card, picture, poem, or write-up of their latest discovery or research — onto a SecureDigital (SD) card, insert it into the badge, and transfer it to a willing recipient via infrared. Just like last year’s badge in which attendees could display a customized text message onto it, the file transfer functionality of DEFCON 16 would meet this same “personalization” goal, allowing attendees to make their badge unique based on what sort of information they chose to share with others.

Every summer, thousands of hackers and computer security enthusiasts descend into Las Vegas for DEFCON (www.defcon.org) — the largest and oldest continuously running event of its kind. It’s a mix of good guys, bad guys, government officials, and everyone in between, all focused on having fun, sharing technical information, seeing old friends, and learning new things. This is the third year in a row that I’ve had the honor of designing the conference badge for DEFCON. Unlike other conferences where boring plastic or metal badges are used, DEFCON has been setting the trend since 2006 in giving out full-featured, active electronic badges to their attendees and challenging them to do something unique with their new-found technology.
badge to do something interesting right out of the box if the user didn’t insert an SD card into the socket. I decided to incorporate “TV-B-Gone” functionality into the badge and take advantage of the infrared components that would already be in place. The original TV-B-Gone (www.tv-b-gone.com) product was designed by Mitch Altman of Cornfield Electronics. The unit simply transmits all known television remote control power-off codes one after another, allowing you to turn off practically any TV in North America, Asia, or Europe. Depending on how the TV-B-Gone is used, it can be quite mischievous and I thought it would be suitable for a hacker conference where people are used to taking advantage of and pushing the bounds of technology. Above and beyond the engineering design goals, there were some fundamental requirements:

- **Aesthetics.** The badge needed to look nice and be as non-intrusive to the wearer as possible. From the graphics to the routing to the parts placement to the circuit board traces, every aspect of the badge design was considered.
- **Low Cost.** The badges had to be cost-effective. The goal was a $7 total BOM (bill of materials) cost per unit including components, programming, PCB manufacturing, assembly, and testing for 8,500 pieces. Meeting the badge budget has been a major challenge in previous years.
- **Hackable.** The badge should be completely “hackable” in nature by providing source code, schematics, and development resources for those who wanted to modify their badge to do something different and out of the ordinary. Although any product can be hacked without provisions to do so, I wanted to make the badge welcoming to hackers and foster the hacking spirit so prevalent at DEFCON.
- **Continued Use.** The badge should be designed to provide a general-purpose development environment or reference platform that attendees can build on and learn from after the conference.

**Engineering Process**

With the design goals in mind, I first put together a system-level block diagram — basically a high-level conceptual drawing to help me visualize the overall design. The design is based on a Freescale Flexis MC9S08JM60 eight bit microcontroller (www.freescale.com/webapp/sps/site/prod_summary.jsp?code=MC9S08JM60) and has interfaces to the SD card socket, infrared transmission and receiver circuitry, USB port, and debug/programming connector. The JM60 microcontroller has 60KB of Flash, 4KB of RAM, a 12 channel, 12 bit ADC, USB 2.0 full-speed device support, two SPI (Serial Peripheral Interface) modules, two SCI (Serial Communications Interface)/UARTs, two timer/PWM modules, eight keyboard interrupts, real-time clock, internal reference clock, and 51 general-purpose I/Os. It’s a powerful part and has lots of on-chip functionality that I could take advantage of. A set of eight LEDs on the front of the badge is used as status and mode indicators. I had over 68,000 LEDs leftover from last year’s DEFCON 15 badge and wanted to do something with them.

The next step was to start developing with actual hardware. I used Freescale’s off-the-shelf DEMOJM evaluation board (Figure 1; www.freescale.com/webapp/sps/site/prod_summary.jsp?code=DEMOJM) and CodeWarrior Development Studio for Microcontrollers — which is freely available for up to 32K of code (www.freescale.com/webapp/sps/site/prod_summary.jsp?code=CW-MICROCONTROLLERS) — to get the basic firmware and state machine environment set up. Then, I added an SD card socket to the DEMOJM’s expansion header and continued with the firmware development until I was comfortable that the intended functionality of the badge would succeed.

After that, using the block diagram as a rough guide, I built a custom circuit board with only the specific hardware that I wanted to have on the badge. I also designed in provisions for a few elements that I hadn’t yet completely decided on, like how to support the infrared transmission and reception (discrete components or an IrDA-compliant module) and battery selection (AAA or something else). The hardware and firmware designs were finalized on this board before moving to the next step, which was a true-to-form pre-production prototype. Using an intermediary board like this allowed me to not only verify my schematic, but also to easily make changes to component values and take measurements of various signals to aid in troubleshooting and diagnostics. The majority of hardware and firmware development was done on this platform before moving to the “form and function” pre-production prototype.

With the hardware and firmware completed, the final task was to lay out the actual badge circuit board and build a few pre-production prototypes to verify the entire system before kicking off the production run. I ordered a few bare boards with yellow soldermask and red silkscreen, hand-soldered them, and ran through my test procedure to verify that the individual aspects of the badge worked as desired. This step was the last chance for me to correct any mistakes before committing to many thousands of dollars of circuit boards and components. I also used these prototypes as samples for DEFCON to approve.

Using two hand-soldered pre-production prototypes let
me verify that the complete design looked and worked as desired. Each board took about one hour to assemble.

The total BOM cost per unit was $10.72, not including taxes or shipping. The largest line items were the PCB fabrication, manufacturing, assembly, and testing at $3.88 and the microprocessor at $1.95. What I thought would be the hardest part of the project (the engineering) was completed with relatively few mishaps.

**Badge Functionality**

The DEFCON 16 badge packed in lots of functionality using minimal components. A single pushbutton switch serves as the user interface to cycle through the badge's three operating states: Receive file; Transmit file (or TV-B-Gone if no SD card is inserted); and Sleep. Let's take a look at the technical details of the major subsystems of the badge.

**Infrared Remote Control and TV-B-Gone**

For the infrared (IR) subsystem, I decided on using on-off keying — one of the oldest and simplest modulation techniques. I would essentially turn on and off a low frequency carrier (in our case, 38 kHz) in order to modulate data. Then, using an encoding scheme known as Pulse-Width Encoding, I defined a logic 0 and logic 1 by the width of the 'on' pulse, while the pulse distance (the distance in between the pulses) or 'off' pulse remained constant. This no-frills approach is used by just about every infrared remote control receiver module on the market and the only concern, as well, and I was able to implement the discrete IR circuit for $1.48 versus approximately $6 I would have had to pay for a fully IrDA-compliant design.

I used one of the JM60's timer/PWM channels to generate a 38 kHz carrier at a 33% duty cycle and could turn the carrier on or off by simply enabling or disabling the PWM channel. As an initial infrared test, I decided to impersonate a Sony TV power-off code to see if I could turn off my television using my badge development board. The Sony remote control specification is well documented online and defines a logic 1 as a 0.6 ms off pulse followed by a 0.6 ms on pulse, I simply duplicated the entire pulse train for a power-off signal, not caring about what data I was actually transmitting. The test worked perfectly! Now, I could move on to incorporating the TV-B-Gone functionality. I captured this signal from an IR remote control receiver module, so it is inverted.

The TV-B-Gone simply transmits all known television remote control power-off codes at their pre-defined carrier frequency and pulse-width timings, one after another. The open-source version of the TV-B-Gone ([www.ladyada.net/make/tvbgone](http://www.ladyada.net/make/tvbgone)) contains a header file with all of that information. I grabbed the header file and ported the TV-B-Gone functionality to the badge by parsing the data, properly configuring the PWM channel, and turning the carrier on and off at the correct timing. The IR LED (Osram SFH4650-Z, D9) that I selected for the badge is low power and narrow beamwidth (± 20 degrees half angle). The narrow beamwidth is especially important for the file transfer mode to prevent interference between multiple people transferring files within the same area. Because of that, the TV-B-Gone functionality only works with televisions a few feet away. Most attendees who really wanted to take full advantage of the TV-B-Gone mode replaced the stock IR LED with a high brightness, wide beamwidth LED to get the farthest range possible.

**Infrared File Transfer with SecureDigital Card and FAT File System Support**

As opposed to the transmit-only functionality of the TV-B-Gone mode, a file transfer requires one badge to transmit and one badge to receive. The badge uses a Sharp GP1US01XP infrared receiver module for remote controls, which is tuned to 38 kHz (the same as my IR transmit modulation frequency). The receiver will bandpass the incoming signal to help reduce noise caused by the ambient environment (in particular, lighting) and then provide a demodulated signal at logic levels that can easily be interfaced with a microprocessor. The goal of the file transfer feature is to read a file from an SD card, transmit it to a willing recipient, and store the received file onto the recipient's SD card. The physical interface from the SD card socket to the JM60 microprocessor is as simple as it gets. In its most basic configuration, SecureDigital uses an SPI interface, consisting of four lines — Master In Slave Out (MISO), Master Out Slave In (MOSI), Clock (CLK), and Chip Select (CS) — for its MultiMediaCard (MMC) protocol. Two additional switches on the socket — Card Detect (CD) and Write Protect (WP) — are connected to two general-purpose inputs on the processor. It is trivial to read and write data to the SD card using SPI, as it's essentially just an external serial memory device, but the trick is incorporating the FAT file system structure ([http://en.wikipedia.org/wiki/File_Allocation_Table](http://en.wikipedia.org/wiki/File_Allocation_Table)) so you can load and retrieve files from any computer system.

There are lots of available implementations of FAT for embedded systems and it didn't make sense for me to try...
and recreate the file system from scratch. As luck would have it, Freescale was in the midst of creating a small reference design—a data logger with light sensor, USB, SD card, and FAT file system. It wasn’t publicly released, but they were gracious enough to share their source code with me, which gave me a huge head start on getting my implementation working. Freescale’s design only supports SD cards that have been formatted in FAT16, which means it will only work with cards 64 MB or larger. Windows automatically formats cards less than 64 MB as FAT12, which will lead to a corrupted FAT table on the SD card if used in the badge. I learned this the hard way after countless hours of troubleshooting.

With the low-level SD card and FAT file system support complete, I could move on to designing the actual file transfer mechanism. Instead of making use of an existing file transfer protocol like Kermit or XMODEM, I decided to roll my own version, which would be more educational (though much less graceful). I decided to build on the same on-off keying and pulse-width encoding schemes that were used for my initial infrared transfer tests with the Sony protocol, and added a mechanism to send large streams of data instead of short remote control codes. I reduced the pulse width timing in order to increase data transmission speed and added a way to send the filename, file size, and CRC along with the actual file.

USB Debug Console and Bootloader

In previous years’ designs, the only way a badge user could load new firmware onto the badge was through whatever proprietary programming/debugging interface was provided by the selected microprocessor. DEFCON 14 used the Microchip PIC ICD2 interface and DEFCON 15 used Freescale’s BDM (Background Debug Mode) interface, and both required specialized hardware. I think that hindered participation in previous Badge Hacking Contests, as I only brought a few programming units to share.

The USB interface on the DEFCON 16 badge serves two distinct purposes. Most important is the bootloader functionality, described in Freescale’s application note AN3561 (www.freescale.com/files/microcontrollers/doc/app_note/AN3561.pdf), that allows in-circuit reprogramming of the JM60’s Flash memory. With the bootloader enabled (achieved by holding down the mode select button while applying power to the badge), the user simply needs to connect their badge to a PC with the mini-USB connector and load their compiled code onto the badge using a free GUI. The only downside is that no debugging capability exists through the bootloader. If, for some reason, the firmware gets corrupted through a faulty programming operation, a standard six-pin BDM header is also made available on the badge for complete re-programming.

The USB bootloader satisfied our requirement of a hackable badge. Since no specialized development hardware was necessary to modify the firmware of the badge, the pool of potential badge hackers increased tremendously.

When not being used by the bootloader, the USB port serves as a virtual serial port created using the standard USB Communications Device Class (CDC). With the proper driver installed (which was included on the DEFCON CD), you can simply load up your favorite terminal program, and transmit and receive serial data. I used this feature during development to send debug messages and left the capability enabled for attendees to explore and use.

Power/Batteries

The selection of power supply components and batteries was a key challenge of this design. I did not want to repeat the problems of last year’s badge, in which the batteries would be depleted within two days if the badge was heavily used. There were five elements I needed to be concerned with, in order of priority: Battery Life (must last longer than the weekend-long DEFCON); Availability; Cost; Complexity; and Weight. I began by taking current measurements of the major operational states of the badge on my custom development board (all @ 3V):

- Sleep = 0.79 mA
- IR Receive mode = 5.3 mA
- IR Transmit mode (continuous data transmission) = 9.1 mA
- SD Card (continuous read and write) = 25-35 mA
  but can be as high as 200 mA, according to SecureDigital specification

When the USB connection is plugged in, the badge automatically increases the microcontroller’s clock speed from 12 MHz to 48 MHz (required for the JM60’s USB module to function), so current consumption increases across the board by about 20 mA.

My previous DEFCON badges used one or two 3V CR2032 Lithium coin cells, which are lightweight and low profile. However, they aren’t suitable for high-current applications (greater than 3 mA continuous or 10 mA pulse), so they couldn’t be used for this year’s design. The original plan was to try and power the badge from a single AAA battery. After looking into some single-cell boost converters/regulators—such as the Micrel MIC2571, Sipex SP6644, and Sipex SP6641B—to boost the 1.5V nominal battery cell voltage to a higher system voltage, I decided that, although suitable for many consumer electronic devices, the additional external components (such as inductors and specialized capacitors), critical PCB layout, and potential switching noise introduced into the system, would have made this direction too risky to use on the badge with such a short development cycle.

Next, I had narrowed down the selection to either three AAA batteries or a single CR123A Lithium cell. Both were easily available at convenience, photography, and electronics stores, though the AAAs are arguably more common and definitely cheaper. It was now apparent that whatever battery solution we went with would be heavier
and more bulky than we would have liked, but my primary concern was making sure the system would function as designed, and I'd just brace for any negative comments (of which there were very few). I spent hours on the phone with the DEFCON organizers discussing battery chemistry and the pros and cons of each battery type. They chose to move forward with three AAA batteries, which would provide 4.5V at 1,250 mAh that I could bring down to a 3V system voltage with a low-cost linear regulator. But, when I started to look around to purchase 25,500 surface-mount AAA battery holders, there was not enough stock worldwide and the manufacturer's leadtime was past the date of DEFCON, which killed this approach on the spot.

We settled on using the CR123A, which I now know is a better, simpler solution. The battery has built-in PTC (Positive Temperature Coefficient) protection to limit current flow in a short circuit or battery failure condition, and doesn't require any external voltage regulation circuitry in order to be used in our system (thanks to the stiff voltage output the battery has until it's close to end-of-life). The above current measurements show that with a single 3V CR123A rated at 1,400 mAh, the badge can last for hundreds of hours of normal use, satisfying our requirement that the badge remains operational for the length of DEFCON.

Circuit Board

Creating the badge electronics was only one part of the battle, as aesthetics of the badge was also a fundamental design goal. Each year when the folks at DEFCON say "Let's try to make a badge that looks like this," they're saying it purely from an artistic point of view. They're not concerned with any electrical characteristics, manufacturing methods, or PCB related limitations or constraints. That naivety is what pushes me to try PCB design and layout techniques that I wouldn't normally consider in order to meet their proposal. There were a number of major elements to the badge's circuit board design: the physical board outline's subtle curves; the complicated text cut-outs for the conference attendee type; masking certain areas of soldermask to bring out graphics on the copper layer; and parts placement, such as the arc of LEDs along the bottom edge and locating the IR transmitter in the ninja's left eye. I made a conscious decision to leave all parts designators off of the badge. This lends itself to a much cleaner look at the expense of easy parts identification. The assembly drawings were available to people curious about hacking or modifying the badge to make their job easier.

I had added in a few surprise graphical elements, such as a two-dimensional Data Matrix barcode (http://en.wikipedia.org/wiki/Datamatrix) and a secret message used for the Mystery Challenge — a popular hardware hacking/puzzle contest at DEFCON.

Until Next Year ...

All told, the DEFCON 16 badge project took about 220 hours, including the firefighting of supply chain and manufacturing problems after development was completed. The majority of engineering was done on nights and weekends, much to the chagrin of my very pregnant wife, Keely, as I was then spending my days as a co-host of Prototype This (www.discovery.com/prototypethis). Thankfully, most of my time was spent doing what I love to do — engineering.

We've already started to think about designs and features for the DEFCON 17 badge and have had a lot of great input from attendees and badge hacking contest participants. Next year's design will be even simpler and more accessible to electronics hobbyists and beginner hardware hackers, but will also contain some "so new it doesn't even exist yet" technology to impress even the most hardened gadget geek. Even though I'll be keeping the lessons of previous years' badges in the back of my mind, I can all but guarantee there will be unexpected problems this time around. Who ever said engineering was boring?! Complete source code, schematics, audio, video, and other documentation for the DEFCON 16 badge is available at www.grandideastudio.com/portfolio/defcon-16-badge NV

Due to space limitations, the article presented here is a condensed version of the original. To read the complete article, go to www.nutsvolts.com.
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DEMystifying USB to Serial

In the previous installment of Design Cycle, we went to school and studied the Silicon Laboratories CP2103 USB-UART bridge. If you had the opportunity to take a look at last month's Design Cycle, you have enough CP2103 theory under your belt to build up your own USB interface. However, as Gomer Pyle would say, "Surprise! Surprise! Surprise!" If you took the time to be part of our previous discussion, you also have what it takes technically to put a CP2102 to work in your projects, as well.

It's time to stop talking and start soldering. This month, you have your choice of USB projects. One project shows you how to fabricate a microcontroller utility board based on a PIC18LF4620 that is front-ended with a CP2103. The alternate project includes an identical microcontroller layout but substitutes a CP2102 for the CP2103. Let's talk about why you may want to choose the CP2102 over the CP2103 for your USB interface.

CP2102 OR CP2103

Both chips are upgraded versions of the CP2101. And compared to its younger brothers, the CP2101 is vastly less capable in the UART area and is no longer recommended for new designs. If you happen to have some CP2101 parts floating around (who doesn't? -Ed.), you can plug them into our CP2102 project without having to perform any printed circuit board modifications. Two project PCBs are necessary as the CP2103 is not pin-compatible with the CP2102.

The CP2102 and CP2103 transceivers, clocks, and EEPROMs are integrated into the silicon and eliminate the need for any additional external ICs, crystals, or resistors. The internal power subsystems of the transceivers are also identical in physics and operation.

Our CP2102 design is depicted graphically in Schematic 1. If we wanted to take this design down to the bare minimum, we could get away with just the CP2102 and the four capacitors. However, I didn't find an example design in the CP2102 factory data that was without the optional transient voltage suppression (TVS) diodes.

Notes:
1. USB CONNECTOR-MOUSER 806-KUSBX-SMTBS1NB30
2. C1 - DigiKey 511-1471-1-ND
3. C4 - MOUSER 80-C0805C105M4R
4. ALL LEDS 1206 SMT PACKAGE
5. ALL RESISTORS 0805 SMT PACKAGE
6. ALL CAPACITORS 0805 SMT PACKAGE
CP2102 does not include a VIO pin. The CP2103 uses the voltage applied to its VIO pin as a reference for the voltage levels applied at its I/O interface. Voltage levels at the CP2103's I/O pins can range from 1.8 volts to VDD (3.3 volts). The CP2103 also supports open drain connections to certain I/O pins. Pins configured like this can interface with I/O voltage levels between VDD and +5 volts using pull up resistors. As you can see in Schematic 2, we have limited our I/O interface voltages to the VDD level by tying the VIO input directly to the CP2103's 3.3 volt VDD output.

Another look at Schematic 2 tells us that the CP2103 has four I/O lines that don't exist on the CP2102. The quad of CP2103 GPIO_x signals are controlled by Silicon Laboratories-supplied API calls issued over the USB interface. The GPIO_x pins can also be programmed to take on predetermined or device-controlled tasks. When the GPIO_x I/O interface is under the control of the CP2103 hardware, the GPIO_0 and GPIO_1 pins become transmit and receive indicators respectively for converted RS-232 and RS-485 links. When the CP2103 is used in an RS-485 environment, GPIO_2 serves as the RS-485 transmit/receive interface control pin.

The final CP2102/CP2103 differentiator is the CP2103's Dynamic Suspend feature. By default, the latch values of the CP2102 and CP2103 I/O interfaces remain static during the USB suspend state. The Dynamic Suspend feature allows the programmer to set the CP2103 interface pin latch to a predetermined state when the device moves from the USB configured state to the USB suspend state. The previous value of the interface pin latch is restored when the device exits USB suspend state.

So, here's the bottom line. If you need a UART interface with extended voltage level flexibility or if you need to convert an existing RS-485 interface, the CP2103 is a better choice. Otherwise, the CP2102 is sufficient to supplant a standard RS-232 interface in most applications.

**INSTANT GRATIFICATION**

The USB interface circuits we are about to build up are really challenging and exciting. However, just blinking the LEDs attached to the CP2103's GPIO pins is not our goal. The idea is to put the new embedded USB interfaces to work as replacements for legacy embedded RS-232 interfaces.
Schematic 3 represents a simple PIC implementation that is supported by a CP2103. The Microchip hardware behind the CP2102 is shown in Schematic 4. I have chosen to use the PIC18LF4620 as it supports multiple timers, numerous communications protocols, and lots of I/O. The LF in the PIC part number tells us that the PIC18LF4620 can also operate efficiently with a 3.3 volt power rail. Just in case you need to run your PIC and peripherals at 5.0 volts, I’ve designed in a jumper to allow you to use VBUS (+5 volts) or VDD (3.3 volts) to power the PIC. Both the CP2102 and the CP2103 I/O and UART are five volt tolerant.

ASSEMBLING THE UNITS

You can only purchase a CP210x IC in the QFN-28 package. So, in keeping with the intent of the QFN package, at every opportunity we’ll design in SMT components. I realize that many of you have access to SMT soldering and rework equipment. I also realize that most of you probably don’t. I want to be sure that any Nuts & Volts readers with reasonable soldering skills can assemble these projects. So, to prove that manual SMT soldering can be used, I’ll assemble both projects using common sense, SMT soldering techniques that you can easily understand and apply.

The solder sides of a CP2102 and CP2103 are under the lens in Photo 1. If we can get the CP210x on straight, the rest of the assembly process will be a walk in the park. Normally, I would use a stencil to lay down the solder mask for a part like this. Following a highly magnified precision mounting process, I would run the fully stuffed PCB through a batch oven. However, in that you may not have a batch oven and a precision rework station, we’ll mount the CP210x parts the cheap-and-not-as-easy way.

There are many ways we can manually mount and solder the CP2102 and CP2103. No matter which project variant you decide to build up, to make the job easier.

CP2103 CONFIGURATION

NOTES:
1. ALL DISCONNECTED PIC PINS TERMINATE AT HEADER
2. ALL RESISTORS 0805 SMT PACKAGE
3. ALL CAPACITORS 0805 SMT PACKAGE

■ SCHEMATIC 3. Note that the only hard data connections between the CP2103 and the PIC18LF4620 are limited to the TXD and RXD pins. As long as you supply the UART code on the PIC side, you can substitute any PIC that you desire behind the CP2103.
You'll need a magnifier, some solder paste, and a fine pitch soldering tip. The difficulty of successfully soldering in the CP210x can be reduced if you have access to a hot air soldering system. A hot air soldering station also comes in handy when it comes time to remove a fine-pitched SMT component like the CP210x.

Begin the soldering process by applying a small dot of solder on the CP210x's ground pad via as shown in Photo 2. The ground pad via is supplying a ground connection to the PCB pad by way of the ground plane on the solder side of the PCB. The idea is to electrically connect (solder) the CP210x's ground pad to the solder plating of the PCB land pattern by heating the solder-laden via.

The next step involves carefully lining up the CP210x pins to their respective pads. Pay careful attention to the orientation of pin 1 of the CP210x, as the pin 1 position is closest to the U1 silkscreen designator. A small square marks the pin 1 corner of the CP2103. Although the

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**CP2102 CONFIGURATION**

**NOTES:**
1. ALL DISCONNECTED PIC PINS TERMINATE AT HEADER
2. ALL RESISTORS 0805 SMT PACKAGE
3. ALL CAPACITORS 0805 SMT PACKAGE

**PHOTO 1.** The large area in the center of the parts is a grounding pad. Letting the grounding pad float electrically is not an option. To keep the components as compact as possible, I used a via in the printed circuit board ground plane instead of a trace to the CP210x's ground pin. Note the pin 1 square marker on the CP2103 on the right versus the semicircle cutout on the CP2102 to the left.
marker is absent on the CP2102, the CP2102 pin 1 orientation is identical to that of the CP2103. Correct pin 1 orientation for the CP2102 and CP2103 places the package pin 1 designator dot in the position shown in Photo 3.

Once you’re sure about the CP210x’s orientation, tack down the part by soldering a couple of its opposing corner pads. After you have secured it in position, heat the ground pad via from the solder side just enough to flow the solder paste you placed on the ground pad via. If things go as planned, you will bond the solder plating inside and around the ground pad via to the CP210x ground pad. If you use an ExpressPCB PCB, the extra solder plating on the pads will also reflow and provide some additional solder for the joint. If possible, use solder paste exclusively as you can easily place a small dot of solder where you want it with a toothpick or similar pointed instrument.

If you’re using a soldering iron for assembly, here’s something to consider. To utilize the CP210x parts, you only need to solder nine of the CP2102’s 28 pins and 14 of the CP2103’s 28 pins. If you forego the LEDs in the CP2103 design, you only need to solder 10 of the CP2103’s 28 pins.

For those of you with hot air soldering systems, you’re in for a treat. The CP210x parts just seem to grab the PCB pads and align themselves when the solder goes molten. In addition to the dot of solder on the ground pad via, I coated the CP210x pads with a thin film of clear solder paste before mounting and soldering with the hot air machine.

The PIC18LF4620 is a large target compared with the CP210x and is easily soldered into place using a hot air nozzle or a fine pitch soldering iron tip. The 0805-packaged resistors and capacitors are also relatively large components and are not at all difficult to mount and solder down. The same goes for the 1206-packaged LEDs, the SMT USB connector, and the crystal. If SMT soldering is foreign to you, Robert L. Doerr’s SMT soldering “How To” in the January 2009 issue of Nuts & Volts is a good reference for those of you tackling SMT soldering for the first time.

In the midst of celebrating your soldering success with the CP210x and the PIC18LF4620, be sure to solder the USB connector shell tabs to their grounding pads. The SUSPEND, VBUS, VIO, and VDD termination points are intended to allow you to electrically mix these signals and voltages into circuitry you assemble in the breadboard area. If you decide to use the VIO feature, be sure to cut the solder side trace between the VDD and VIO.
As you can see in Photo 3, pin 1 of the SP0503BAHTG is larger than the part's other three pins. Orient it to place the larger and slightly offset pin 1 on the ground pad closest to the silkscreen designator $D1$. As $C1$ is a 4.7 μF polarized tantalum capacitor, make sure you orient the positive terminal as shown in Photo 3.

Just in case you're missing the presence of the Microchip-standard RJ-11 ICSP jack, it's on the dongle. You can find the ExpressPCB file for the programming/debugging dongle in the download package for this set of projects on the Nuts & Volts website (www.nutsvolts.com).

I don't know about you, but I'm ready to test. My fully assembled and yet to be tested CP2102 and CP2103 project boards are saying cheese in Photos 4 and 5, respectively.

**TESTING YOUR CP210X HARDWARE**

This is where I used to punch out. Even when a typical USB interface contained a crystal, an EEPROM, and various glue components, it was relatively easy to put the hardware together. What seemed possible in the hardware became impossible in the firmware and host software. I have a good feeling that we are about to be triumphant. We have promising USB interface hardware and known good host software. There is no USB interface device firmware to write as it's all embedded in the CP210x hardware. With that, go to the Silicon Laboratories website (see Sources) and download the USBXpress Development Kit and the VCP driver.

Everything we will need to bring a CP210x online is contained within the USBXpress code. If you're feeling lucky and want to exercise your C++ and Visual Basic skills, you can use the USBXpress DLL to assemble some custom CP210x interface applications. If you're feeling lucky and can't spell USB, C++, or Visual Basic, use the factory supplied precompiled CP210x interface applications to set up your CP210x.

Much of the work needed to put a CP210x online can be done with the CP210x Set IDs application. For instance, in Screenshot 1 I changed the default CP2103 Serial Number of 0001 to NV090104. I also customized the Product String. Note that the CP210x Set IDs application also allows the CP210x programmer to assign a VID and VID. After making the changes and clicking on the Program Device button, the new values were loaded into the CP2103's internal EEPROM. A moment later, Windows flashed the Found New Hardware bubble displaying the new Product String (NUTS AND VOLTS CP2103 Project). I then closed the CP210x Set IDs application and immediately reopened it. Sure enough, the updated Serial Number and Product String were displayed in the CP210x Set IDs window.

If you opted for the CP2103 project, you can invoke the CP210x Port Read/Write application to exercise the GPIO_x LEDs. I used the write portion of the application to turn on all of the CP2103's GPIO_x LEDs in Screenshot 2.

**FINAL CHECK**

Obviously, if your CP210x hardware responds to the canned USBXpress applications, you've assembled your hardware correctly. The next step we must take is to write some simple code for the PIC18LF4620 that will echo characters across our new USB link.

According to the sales pitch, a CP210x USB circuit can be substituted for a legacy RS-232 serial circuit with no changes to the application code. That means that we should be able to use some time-tested PIC RS-232 code without modification.

Our PIC18LF4620 code will set the PIC18LF4620 EUSART baud rate for 57600 bps. We'll also configure the PIC18LF4620's interrupt subsystem to catch incoming characters and immediately push them back out. Our character generator is an instance of Tera Term Pro running...
on a laptop personal computer.

The PIC18LF4620 code consists of an EUSART interrupt handler that buffers incoming characters and dispatches outgoing characters. The outgoing data is loaded into a transmit buffer under the control of the application code. Characters are retrieved from the receive buffer using a function called `recvchar`. Our PIC18LF4620 echo application uses the `sendchar` function to load characters into the transmit buffer. The presence of characters in the receive buffer is discerned by executing the function `CharInQueue`. So, to echo incoming characters, we code up these statements:

```c
while(!(CharInQueue()));
sendchar(recvchar());
```

Powering up to a blank Tera Term Pro window is not desirable. So, let's force the PIC18LF4620 to transmit a banner message after the EUSART has been initialized:

```c
printf("NUTS AND VOLTS USB ECHO APPLICATION\r\n");
```

Now, let's put it all together. We want to initialize the PIC18LF4620 EUSART, display a banner and run our echo code forever:

```c
Void main(void) {
    unsigned int i,x;
    init(); //init the EUSART
    printf("NUTS AND VOLTS USB ECHO APPLICATION\r\n");
    for(i=0;i<0x3FFF;++i) // kill time ++x;
    do{
        //wait for incoming character
        while(!(CharInQueue()));
        //echo incoming character
        sendchar(recvchar());
    } while(1);
}
```

Don't worry about the code you don't see here as you have access to the entire USB echo application in the download package. I compiled the USB echo application with HI-TECH C PRO for the PIC18 MCU Family. The compiled code was programmed into the PIC18LF4620 using the RJ-11 programming/debugging dongle assembly in the download package and a brand new Microchip ICD3. From the looks of the messages contained in the Tera Term Pro window you see in Screenshot 3, we've added an embedded USB interface to our Design. NV

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**SOURCES**

Silicon Laboratories — [www.silabs.com](http://www.silabs.com)

PCP2102; CP2103; USBXpress

HI-TECH Software — [www.htsoft.com](http://www.htsoft.com)

HI-TECH PICC-18

Microchip — [www.microchip.com](http://www.microchip.com)

PIC18LF4620; MPLAB ICD3

ExpressPCB — [www.expresspcb.com](http://www.expresspcb.com)

CP210x Printed Circuit Boards

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Fred Eady can be contacted via email at fred@edtp.com.
In Part 6, we used the Butterfly joystick with library functions to implement a menu navigation system but didn’t go into any details of how the joystick worked. This month, we will use the joystick as an introduction to AVR interrupts and I/O registers.

The Butterfly Joystick Hardware

The original joystick was an early aircraft control lever that allowed the pilot to maneuver the plane left, right, up, and down. Fighter planes added a center button to fire machine guns. The Butterfly joystick — like many menu navigation devices found on remote controls and cell phones — has five positions: UP, DOWN, LEFT, RIGHT, and PUSH (see Figure 1). Manufacturers, of course can’t know which direction the user will orient their device, so they label them A, B, C, D, and Center (for PUSH) as in Figure 2, which correspond to pins numbered as in Figure 3.

The Butterfly orients these pins and connects them to five of the ATmega169 port pins as in Figure 4.

Now that we’ve got the joystick all wired up, how does the Butterfly know when a joystick event occurs?

Interrupts In General

In microcontrollers, we typically use either polling or interrupts to check to see if an event has occurred. Polling checks periodically to see if an event has happened. For instance, in the loop in main() we might check pin 6 to see if the voltage is +3 or 0 and, depending on the state, do one thing or another. If the microcontroller hardware is designed so that pin 6 can be used to interrupt the program, then we don’t have to poll the pin. We can set the software so that when the pin state changes — say, falling from +3V to 0V — an interrupt function will be called automatically.

Interrupts on microcontrollers are like interrupts in daily life. The telephone interrupts your activities by its insistent ringing. Imagine how it would be if you had to poll the telephone to receive calls. Periodically, you’d pick up the receiver and say ‘Hello, anybody out there?’ and your caller would shriek, ‘I’ve been waiting for an hour! Why don’t you check your phone every five minutes like a normal person?’ The ring of the phone interrupting workflow is annoying, but if someone wants to tell you that your garage is on fire, you want to know about it immediately.

Microcontrollers respond to interrupts much like you would.

Maybe you are reading a book and the phone rings. You use your fingernail to mark the line you were reading and dog-ear the page before closing the book (librarians everywhere groan). Then, you answer the phone, and when the call is finished and you’ve put out the fire in your garage, you can refer to the desecrations to your book and go right back to where you left off.

From the hardware perspective, an interrupt causes the microcontroller to stop what it is doing, store sufficient data so that later it can get back to what it was doing, look to see which interrupt happened, run the interrupt code, and when finished, restore the machine to its state before the interrupt occurred using the previously stored data.

Potential Interrupt Bug 1

Interrupts are great, but they provide an avenue for
some particularly pernicious bugs. For example, your code is reading an integer from memory; an integer is made of two bytes. The code gets the first byte, then is stopped by an interrupt that changes the value of that very same integer before returning control to the part of the code that was reading it, which then gets the second byte of the integer. The integer will be wrong because it is made from half of the pre-interrupt value and half from the post-interrupt value. The crazy-making debugging problem is that the interrupt can happen at any time; maybe only rarely during the integer read. Your system can run like a champ and then lock up for no apparent reason. You don't want this kind of bug in your pacemaker. So you prevent it by disabling interrupts before reading variables that can be changed by interrupts, and then re-enabling them after you've got the correct number.

**Potential Interrupt Bug 2**

Another problem with interrupts changing variables can occur when you have the variable in a section of your code that looks to the compiler optimizer like it is not being used. The optimizer has various rules to search around to see if a variable is used, but it may not have a rule to look at the interrupt service routines to see if the variable is used there. If it doesn't look there, then it may reasonably decide that you made a mistake and aren't really using the variable, and then optimize it away in the code generated from the C source code. This can cause another tricky bug since that variable is in your source code and you may not realize that the optimizer got rid of it. To prevent this error, you should declare all variables that will be changed by an interrupt as 'volatile' which tells the compiler that — with all evidence to the contrary — you actually know what you are doing so don't get rid of this volatile variable.

**C Knows Nothing About Interrupts**

It is important to realize that the C programming language knows nothing about interrupts. C is machine independent — interrupts are machine dependent. Even different versions of the same machine — such as the AVR — may handle interrupts differently. Also, different compilers for the same microcontroller will often have different ways to use interrupts. We are fortunate to have the free WinAVR tool set with the GCC avrlibc to handle some of the more gory details, though it will get pretty gory anyway.

**A Quick Look At Registers**

The AVR is a very flexible device and many of its features have several different ways they can be used. For instance, the ATmega169 I/O pin that we will be using for our UP selection in the joystick can be set up to be used in one of various ways: as either input or output; with or without an internal pull-up; it can be turned off (tri-stated) to remove it from the circuit or work for PWM output compare; or it can be used as an input interrupt. Other pins may be even more complex in their possible uses, but since each can only be used in one of its many possible configurations, the AVR must keep track of how it is supposed to be used. Setting bits in a special set of I/O registers to configure and keep track of various possible states does this.

AVR registers are eight bit memory locations that can be quickly accessed by the CPU. The AVR sets aside 64 I/O and 160 Extended I/O Registers in memory locations that can be used for peripheral configuration and state flags. The ATmega169 uses over 100 of these registers. Each of these registers is named and may have two to eight named bits for each. As usual for microcontrollers, the names may be cryptic and confusing. This provides us with a bewildering excess of riches. You can see the list on page 341 of the ATmega169 data book — pretty scary, isn't it? But, relax because we won't have to memorize any of the details. Over time, we will carefully set up each register only when it is needed for a particular application and once we get...
that AVR feature working properly, we will consign the register and bit states to header files hidden behind some easy to remember names — well documented and carefully locked away in a tested library. The earlier Workshops hid all this in libraries, and there will be many libraries to come. In the meantime, it will help us to understand what is going on if we get an overview of this I/O register/bit concept.

**Setting Up External Interrupts Using The ATmega169 And avrlibc**

To enable the joystick interrupts, we will need to set bits in four registers. We will see how to do this for three progressively simpler ways. The first is the most like a professional C programmer would do it — using the datasheet acronyms and bitwise operators which can be a bit cryptic for a novice. The second is a little simpler and hides the bitwise operations behind a macro. The third and simplest expands the acronyms to spell out the full register and bit names. In this Workshop, we will show the details only for the EIMSK (External Interrupt Mask Register), but the source code shows this for all used interrupts.

### External Interrupt Mask Register

We set the PCIE0 and PCIE1 (Pin Change Interrupt Enable 0 and 1) bits to enable PCINT15..8 which are the upper eight Pin Change Interrupts and are associated with the Port B pins 7..0 in the ATmega169 as shown in Figure 5.

The first way to do this is to use the register and bit acronyms listed in the io.h header file:

```c
// Least verbose - most usual C like
EIMSK = (1<<PCIE0) | (1<<PCIE1);
```

If you remember the bitwise operators from Workshop 4 and know that in the header file that PCIE0 is defined as 7 and PCIE1 is defined as 6, you will see that this sets bit 7 and bit 6 in the EIMSK register. This register is shown on page 78 of the ATmega169 datasheet (see Figure 6).

A slightly easier way would be to define a macro for the bit shift operators to set the bits:

```c
#define setBit(value1,value2) value1 |= (1<<value2)
```

A macro is a preprocessor directive that causes the “compiler to substitute one set of characters with another set. This can help simplify things in that you can substitute a simpler string of text for something more difficult. We can hide the bitwise operators that shift and the OR bits.

```c
#define ExternalInterruptMaskReg EIMSK
#define PinChangeInterruptEnableBit0 PCIE0
#define PinChangeInterruptEnableBit1 PCIE1
```

And using:

```c
// Most verbose
setBit(ExternalInterruptMaskReg, PinChangeInterruptEnableBit0);
setBit(ExternalInterruptMaskReg, PinChangeInterruptEnableBit1);
```

You can see how this is done for all five registers by looking at the initJoystick() function in the source code in the Workshop8.zip (refer to the download link at the end of this column.)

### Enable Global Interrupts

SREG — Status Register

I-bit — Global Interrupt Enable

Setting the I-bit enables all interrupts and clearing it disables them. After a hardware interrupt occurs, the I-bit is cleared so that no further interrupts can occur while the interrupt service routine is running. When the interrupt finishes, the interrupt returns with the RETI instruction that will reset the I-bit, thus enabling further interrupts.

### External Interrupt Flag Register

EIFR — External Interrupt Flag Register

PCIF0 — Pin Change Interrupt Flag 0 Bit

PCIF1 — Pin Change Interrupt Flag 1 Bit

If PCIF0 is set, when any PCINT7..0 pin changes state and if the I-bit is set and the PCIE0 bit is set in EIMSK, then an interrupt request is triggered so that the associated interrupt service routine will be run. The same is true for the PCIF1 bit and the PCINT15..8 pin changes.
Pin Change Mask Registers

PCMSK0 — Pin Change Mask 0 Register
PCMSK1 — Pin Change Mask 1 Register

The PCMSK0 register has PCINT15 to PCINT8 bits, each of which when set to 1 enables the pin change interrupt for the corresponding I/O pin.

Interrupt Service Routines

When the ATmega169 receives an interrupt, it loads the address of an Interrupt Service Routine from the Interrupt Vector Table. A 'vector' is just a fancy way to say address. There are 23 vectors shown on page 47 of the datasheet but we will only be using vectors 3 and 4 for the PCINT0 and PCINT1 interrupt.

// Pin Change Interrupt 0
// Interrupt Service Routine
ISR(SIG_PIN_CHANGE0)
{
    pinChangeInterrupt();
}

// Pin Change Interrupt 1
// Interrupt Service Routine
ISR(SIG_PIN_CHANGE1)
{
    pinChangeInterrupt();
}

So, if any of the joystick pins change then the pinChangeInterrupt() function will be called by ISRs. When an interrupt is triggered, the I-bit is cleared and no further interrupts will be serviced until the ISR exits — so interrupts should to be serviced as rapidly as possible (there are exceptions, but we won't deal with those yet). If the interrupt requires some serious processing to be done, just set a flag, exit the interrupt, then look for the flag in the infinite loop in main() and call a regular function that can be interrupted.

Servicing The Joystick Interrupt

In the pinChangeInterrupt() function, we will not use any simplifying macros. We first load the ports B and E pin pattern into an eight-bit variable:

uint8_t buttons;
buttons = (~PINB) & PINB_MASK;
buttons |= (~PINE) & PINE_MASK;

Note that the pin state is 0 for the pin that got changed. The PINB_MASK makes sure that only valid joystick pins are looked at and PINB contains the state of the pins on port B. Since we are ANDing it with the mask, we use the ~ operator to invert the levels, changing 0 to 1. You may want to review bitwise operators in Workshop 6 and do a little pencil and paper computing if this isn't clear.

After we get the pin states in the button variable, we check for the key:

// Which key was pressed?
if (buttons & (1<<BUTTON_A))
    key = KEY_UP;
else if (buttons & (1<<BUTTON_B))
    key = KEY_DOWN;
else if (buttons & (1<<BUTTON_C))
    key = KEY_LEFT;
else if (buttons & (1<<BUTTON_D))
    key = KEY_RIGHT;
else if (buttons & (1<<BUTTON_O))
    key = KEY_PUSH;
else
    key = KEY_INVALID;

If there is a valid key present, we load it in the global joystickInput variable and set the global joystickChanged to true:

// Is there a valid key?
// Load it in the global variable joystickInput
// And set the global variable joystickChanged
if(key != KEY_INVALID)
{
    joystickChanged = 1;
    joystickInput = key;
}

This works much like the Menu in Workshop 6, but this time we hide the state machine in a library and show the joystick hardware setup and use. You can download the source code and a supplement: C Programming — Out of the Nest for this month's article from www.nutsvolts.com or www.smileymicros.com.
WITH THE RECENT HEADLINES ABOUT bailouts, layoffs, and global recession, it’s pretty obvious there’s going to be some belt-tightening in the average household. For many of us, hobbies are one of the first things to get cut out when there are bills to pay. At the very least, we want to look a bit harder at our purchases and see if we can draw a firm line between our “wants” and our “needs.” Of course, all work and no play can result in the axe-chopping of a hotel door in the wilderness (REDRUM!), so we need to find some way to keep "play" in the game! That means it’s time to go hunting for some low-cost (maybe no cost?) robotic fun!

THE THRILL OF THE CHASE

Most towns have a thrift store or other shops that recycle and resell clothes, toys, household wares, and the like. In many cases, you'll find these stores carry lots of useful electronics that can be picked up for a song. Typically, they are camouflaged as broken electronic toys, answering machines, computers from previous decades, telephones, boom-boxes, and other consumer electronics. It can be fun (and frugal) to go hunting through the shelves for these hidden parts caches. You may be surprised how many parts you can scrounge up with as little as $10 (Figure 1).

For example, many thrift stores have old ink-jet (and sometimes dot matrix) printers. These are a great resource for harvesting parts! Gears, motors, belts, sensors, buttons, LCD displays, and all kinds of electronic components can be extracted with a bit of time, some hand tools, and a soldering iron. The same thing can be said for electronic “action” toys. These have been known to contain sound generators, LEDs, speakers, battery holders, and even infrared transceivers (Figure 2). Also, many of the thrift stores I’ve visited really have no idea how to price the electronics and so you may be able to fill an entire shopping cart for as little as $20!

FIGURES 1A, 1B, and 1C. Examples of some thrift shop finds including switches in an old joypad, a human hand analog that seems to be crying out to be upgraded with a servo, and the “gripper” used in last month’s column on pneumatics.
HARD DRIVE HARVEST

One item that is almost always able to yield some useful parts after being opened up is the venerable computer hard drive. Some older drives (especially older 5-1/4" MFM/ST-506 type drives, and some 5-1/4" floppy drives) contain very nice stepper motors (Figure 3), gear trains (Figure 4), sensors (Figure 5), and other useful bits for the hobbyist. If you can’t find this vintage of hard drive, don’t despair! Similar parts can be found in most CD/DVD ROM drives.

Most all modern 3.5" hard drives (Figure 6) contain recyclable and useful parts including very powerful neodymium magnets, .100" jumpers, precision screws, bearings, and other hardware (Figure 7), as well as the shiny data platters. Disassembly is simple, quick, and fun and the parts yielded are usually useful and worth your time to harvest.

Another item I hunt for at thrift stores is the oft-maligned wall wart (given its name due to its appearance as an unsightly growth on the wall). It always seems I need a specific voltage, amperage, plug type/size, or gender that I don’t have on hand. I’ve been known to walk out of a thrift store with 10 or more of these babies (Figure 8). This way, I can always dig out an acceptable, portable power supply for a small experiment.

In the Austin, TX area, wall warts at thrift stores typically go for between $0.50 and $2.00. You can also often discover orphaned ‘brick style’ power supplies commonly used to power laptop computers. These tend to be higher voltage/amperage and can sometimes produce multiple supply voltages so they have the potential of replacing a couple of wall warts. Keep your eyes peeled (and possibly take a magnifying glass with you) as the writing on these can be very small.

KEEP IT ON THE DOWN-LOW!

In most cases, my idea of "low cost" is below $100. I know this will probably be different for each person, but I stay with this number for two reasons. One: sub $100 purchases are less likely to be picked up on the radar by a "significant other." Two: if you are discovered, it’s easier to recover from because it’s about the same cost as a nice dinner out for two.

So, with $100 as the benchmark, can we really buy much in the way of "new' robotics parts or projects? The answer is a resounding YES!

Compared to a couple decades ago when a useful robotic training system cost thousands of dollars (think HERO-1), today’s robotics offerings are immensely powerful with exceptional price/value ratios. For example, Parallax offers a complete two-wheel robot kit with their ever-popular BASIC Stamp II at its heart that retails for $99.99 (careful online shopping can nab one for $75 or less!).

The "Scribbler" (Figure 9) is a real programmable robot with the ability to move, use sensors, evaluate inputs, make sounds, and even draw pictures (hence the name). It also includes a
free graphical programming interface, as well as a comprehensive teaching curriculum to help newcomers learn robotic principles. Of course, since it is powered by the venerable BASIC Stamp II microprocessor, it’s possible to skip the entry level stuff and program the unit directly using the free IDE.

There are similar offerings from a variety of companies with some more "focused" kits that are in the sub $20 range. These usually explore a facet of basic robotics such as sensors or motors (see Resources for a list of low cost robotics kits). A good example of this is the Light Spider Robot Kit that sells for $12.25 (Figure 10) or the Aqualocator Robot Kit that sells for $24.95 (Figure 11). These "single purpose" robots are a good place to learn and experiment with facets of robotics without breaking the bank.

ULTRA LOW COST MICROCONTROLLERS

Though I am (and continue to be) a big fan of Parallax parts and their incredible support, there are some very interesting offerings from other companies that have been in the microcontroller game for quite a while. For example, the UK company Revolution Education Ltd. markets the PICAXE series of microcontrollers. Their PICAXE-08M is an eight-pin chip that sports five I/Os, three analog inputs, and is programmed in a dialect of Basic. I found this chip being offered on the SparkFun website for $3.95 (Figure 12). In fact, a complete kit that has a socket for the PICAXE-08M microcontroller chip, programming jack, and prototyping area was selling for $4.95 (Figure 13).

A 3.5" stereo (i.e., Tip-Ring-Sleeve) jack is required to connect to the programming port and you can buy the DB-9 to 3.5" cable pre-made from SparkFun for about $7. However, to keep things cheap I was able to make one from a recycled serial mouse (removed the cable with the correct gender DB-9 connector) and a broken pair of portable headphones (I clipped the cable and used the 3.5" stereo plug). So all tolled, that’s a fully functional prototyping kit for a microcontroller chip programmed in Basic for less than $10. To me, it’s astounding that so much power and versatility now resides in the same footprint as a classic 555 timer!

OKAY, SO HOW ABOUT SOME NO-COST IDEAS?

So, the pennies have been pinched, the numbers have been crunched, and it turns out that unless you want to be programming your projects by candlelight, you may sadly have to forgo any more expenditures in the electronics/robotics department for a while. With a budget of effectively zero, is there any way to continue in your hobby?

GET RE-EXCITED!

Quite a few years ago (I shudder to think), I was a typical "starving artist" singer/songwriter with big dreams of rock and roll stardom. At loose ends during the day and between gigs, I would head on down to the local music shops and wander the isles examining the newest breakthroughs in musical equipment. I would often find myself salivating over some hot new MIDI instrument, effect processor, recording system, sound processor, or PA system gadget. It was particularly depressing when I would return home empty-handed as times were tough and I couldn’t afford to buy any of these.
cool toys. It was in those days that I discovered a cure for the "new gear blues" that continues to work for me to this day.

Here's the trick: I would go back and re-read the advertising literature for the equipment that I already owned. Reading through the lists of capabilities, the marketing hype, and the typical configurations of the stuff I already had would in many cases rekindle the excitement I felt when I first opened the box!

Now with the Internet, it's possible to pull up information, specifications, and marketing literature for just about any part or device you have lying around. A good place to start "prospecting" for the gold you may already own (but may have forgotten about) is one of those junk boxes in the closet or even hiding in plain view collecting dust on a shelf (Figure 14). Punch a few model numbers into Google and see if you can remember why you bought these things in the first place. Sometimes we forget the excitement that drove the original purchase, but it can come back to you with a little bit of reading.

NOW, WHY DIDN'T I THINK OF THAT!?

You may find your searches lead to websites with pictures and videos of some new and interesting way to combine or use the very devices you already have. A couple of months back, I was wanting to bring a project to the Robot Group's weekly meeting "Show and Tell" event. I did a few searches on Google and found a cool video blog where the Parallax GPS and a BASIC Stamp II were combined to make a rudimentary GPS system (see Resources). I had purchased a Parallax GPS unit a while back for a Magellan robot I was contemplating, and a quick search through my microprocessor box turned it up in its anti-static bag, never used. A bit more digging turned up a BASIC Stamp II, a Board of Education, and a two line serial LCD display (among other parts) just sitting in a box. Inspired by the video, I combined my pieces in a similar way to recreate this unit. By the next day, I had a simple GPS display sitting on the dashboard of my car as I headed to the meeting. Total equipment cost: zero dollars.

After this success, I remembered watching an episode of "Prototype This!" on The Discovery Channel where Joe Grand from Grand Design Studios used a Stamp to join an RFID reader to a speech synthesizer to create a neat "restricted access" system. After a bit of digging in my junk boxes, I discovered I had all the parts he used in that design. So, I was able to make another complete project using existing parts I already owned, just combined in a way I hadn't done before (Figure 15).

VIRTUAL ROBOTICS

Another idea for zero cost involves virtual robotics projects. I went over this in-depth in the March 2008 issue of Nuts & Volts. It has quite a bit of information about how to experiment with robotic simulations that cost nothing to download and run on your computer. As a subscriber to Nuts & Volts, you are able to use the on-line service to read back issues for Nuts & Volts for free! See the Resources section for a link to the on-line edition of the magazine.
**PLANNING IS FREE!**

While you’re perusing the Internet, I think it’s important to remember that research and planning cost you nothing. All you need to do is bookmark the interesting pages and/or spend some time drawing up your ideas — either in a CAD program or with something as humble as a notebook and pencil. I spend lots of time doodling drawings of devices that sometimes don’t come to fruition (yet) and others that do (check out the December 2007 issue of Nuts & Volts to see how one of my sketches became a 20 foot tall pingpong ball shooting robot). I’ve placed a couple of useful links in Resources that you can use to get inspired to start planning your next project (don’t miss the “Let’s Make Robots” site where members share their latest creations!).

**KEEP YOUR CHIN UP!**

I hope this article helps to inspire you to not let economics defeat your interest in electronics and robotics. As Theodore Roosevelt once said, “Do what you can, with what you have, where you are.” This is good advice for those faced with a sudden drop in funding. Necessity, though normally just famous as the mother of invention, may masquerade as vern@txis.com. NV creativity! Remember, you’re not alone. There are thousands of hobbyists out there that share your interest, your hardships, and your triumphs. Why not take a moment to come by the Nuts & Volts online forum and meet some of them? In the meantime, feel free to let me know what you’re thinking. You can always reach me by email at

**RESOURCES**

- Joe Grand and Bre Pettis weekend project video on GPS: [http://blog.makezine.com/archive/20071031/track_gps_part_i.html](http://blog.makezine.com/archive/20071031/track_gps_part_i.html)
- The show “PrototypeThis!” featuring Joe Grand of Grand Design Studios: [www.discovery.com/prototypethis](http://www.discovery.com/prototypethis)
- For more inspiration check out [Joe Grand and Bre Pettis weekend project video on RFID](http://www.cnet.com/news/joe-grand-and-bre-pettis-weekend-project-video-on-rfid/) and others that do (check out the December 2007 issue of Nuts & Volts to see how one of my sketches became a 20 foot tall pingpong ball shooting robot). I’ve placed a couple of useful links in Resources that you can use to get inspired to start planning your next project (don’t miss the “Let’s Make Robots” site where members share their latest creations!).

**FIGURE 15. The Talking RFID Access Control demonstration system I built for “Show and Tell” at The Robot Group meeting in Austin, TX.**
BALLOONSAT MINIS: ONE SMALL STEP FOR A PICAXE, ONE GIANT LEAP FOR BALLOONSAT DESIGN

A STUDENT'S FIRST INTRODUCTION TO NEAR SPACE normally includes BalloonSats and a neat datalogger like the Hobo by OnSet Computing. If, however, you are ready to try BalloonSat avionics a bit beyond that, I have the perfect solution: BalloonSat Minis. These BalloonSat flight computers don’t contain nearly as much data memory as a Hobo, but the Minis are simple printed circuit board (PCB) kits for a BalloonSat class to assemble and program. BalloonSat Minis are flexible in their ability to log data and they can operate servos, cameras, and experiments — not just record data. They can even monitor cosmic rays with an Aware Electronics RM-60 Geiger counter. BalloonSat Minis are one of three new BalloonSat flight computers designed during my first semester of grad school. You will read about these other BalloonSat avionics in coming months, but let’s start with the Minis.

CAPABILITIES OF THE BALLOONSAT MINIS

At the heart of a BalloonSat Mini is a PICAXE-08M — the closest thing to silicon popcorn that I have found. At less than $4 a pop and programmable to the tune of 256 bytes, these microcontrollers are the ultimate tasty addition to any electronics project. The '08M shares program space with its data storage space, so you’ll want to keep your program small to maximize its data collection ability. The 08M’s limited memory creates a challenge for students as they design the avionics software for their BalloonSat. However, this challenge is not too tough, as even this old dog wrote an acceptable program for a Mini that left around 180 bytes of storage available for data. That’s enough to record two sensor voltages every minute for the BalloonSat’s entire ascent.

Minis operate from a nine volt battery and contain an external power switch, power indicator LED, and commit pin. The battery choice keeps them cheap to operate while the external components (switch, LED, commit pin) allow students to power up and launch their BalloonSat without having to open it up.

The only difference between the two flavors of Minis operate from a nine volt battery and contain an external power switch, power indicator LED, and commit pin. The battery choice keeps them cheap to operate while the external components (switch, LED, commit pin) allow students to power up and launch their BalloonSat without having to open it up.

The only difference between the two flavors of

This BalloonSat Mini 3 is designed to operate a servo with the male header hidden behind the two visible receptacles. Alternatively, the servo header can record data from a third sensor.

This Mini 2 is designed with photography in mind. Its reed relay can easily take on a near space mission to reliably trigger a camera inside the BalloonSat.
Minis is the configuration of the third I/O port. The Mini 3 has three I/O channels, all capable of digitizing sensor voltages at either eight or 10 bits of resolution. I recommend using female receptacles for the first two I/O ports and a three-pin header for the third. That way, a servo can easily connect to the Mini 3. However, even with its three-pin header, a third experiment can still be connected to the Mini 3; it just needs a connector identical to the ones used on servos.

The Mini 2 has two I/O channels since its third I/O port operates a camera via a reed relay. I recommend using female receptacles for both I/O ports, although there isn't any reason one couldn't use a male header instead. A modification like that would make the Mini suitable for one sensor, a servo, and a camera. As you can see by their schematics, the Minis are pretty simple in design and have a low parts count. That's because they make heavy use of the capabilities built into the PICAXE-08M.

**ASSEMBLING A BALLOONSAT MINI**

There's nothing tricky about soldering the BalloonSat Minis together. Since they are single-sided boards, there's one jumper wire to install on both designs. Check out the diagrams for the placement of parts.
**SOLDERING**

Always bend a component’s leads before you insert it into the PCB. Stores like Jameco sell bending jigs that are perfect for getting them bent correctly the first time. It’s usually easier to assemble a PCB if you solder the lowest lying components first. So in this case, begin by soldering the jumper wire. The most convenient jumper wire is a cut resistor lead. If you have one lying around — great. If not, then solder a resistor to the PCB first and then trim its leads to get your jumper wire.

After installing the jumper wire and resistors, then solder the IC socket. If you are good at soldering, then you can bypass the IC socket and solder the PICAXE directly to the PCB. However, I do not recommend this as it is more difficult to replace a damaged IC if it is soldered to the PCB.

Watch the orientation of the IC socket. Although it does not matter electrically, the proper socket orientation keys you to the proper orientation of the PICAXE when you are ready to pop it into its socket. Next, solder the headers and receptacles followed by the LM2940 voltage regulator and 22 μF capacitor. Both are sensitive to their orientation, so match them to the illustrations. Double-check your work at this point to verify there are no shorts from the overflow of solder.

**CABLING**

Note that there are enlarged holes on the left side of the BalloonSat Mini figures. These are for strain relief of the external cabling. External connections to the PCBs pass through these holes before being soldered to the PCB. This prevents the cables from breaking off over time. I thought I was clever

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**BALLOONSAT MINI 3 BILL OF MATERIALS**

- LM2940 five volt regulator (TO-92 case)
- 22 μF radial tantalum electrolytic capacitor (0.1” between leads)
- 1K ohm 5% resistor (1/4 watt)
- 10K ohm 5% resistors (1/4 watt); need two
- 22K ohm 5% resistor (1/4 watt)
- Eight pin DIP socket
- 2 x 3 female receptacle (0.1” between pins)
- PICAXE-08M
- 1 x 3 male header (0.1” between pins); quantity two
- Subminiature SPST switch
- LED
- 9V battery snap
- 1/8 inch mono jack
- 1/8 inch mono jack receptacle
- Stranded wire (#24 AWG is good)

**BALLOONSAT MINI 2 BILL OF MATERIALS**

- LM2940 five volt regulator (TO-92 case)
- 22 μF radial tantalum electrolytic capacitor (0.1” between leads)
- 1K ohm 5% resistor (1/4 watt)
- 10K ohm 5% resistors (1/4 watt); need two
- 22K ohm 5% resistor (1/4 watt)
- Eight pin DIP socket (300 mils wide)
- 3 x 3 female receptacle (0.1” between pins)
- PICAXE-08M
- Mini reed relay
- 1 x 3 male header (0.1” between pins)
- Subminiature SPST switch
- LED
- 9V battery snap
- 1/8 inch mono jack
- 1/8 inch mono jack receptacle
- Stranded wire (#24 AWG is good)
developing this system, but have recently discovered it is used with other PCBs.

Both Minis use a nine-volt battery snap, so pass the stripped ends of the snap through their strain relief holes and then solder the end of each wire to the PCB. Just watch the polarity of the battery snap when you solder it (the diagram of parts placement is color coded, so you can’t mix the wires).

The three remaining wire pairs in the BalloonSat Minis are for the Power Indicator LED, On/Off Switch, and the Commit Pin. Since BalloonSats are usually small in size, the cables can be kept short. Cutting the wires six to eight inches long ought to be good enough. Strip one end of each wire, pass it through its appropriate strain hole, and then solder it to the PCB. I like to color code my wires for the LED so it is easy to identify the correct ones when it comes time to solder the LED to the wires.

After soldering the six wires to the PCB, strip their free ends in preparation for the LED, sub-mini toggle switch, and 1/8 inch phono jack receptacle. The LED cable is stripped back 1/2 inch, twisted tight, and well tinned. Slide thin heat shrink over the tinned leads once the solder has cooled and push them close to the PCB (or else they could prematurely shrink. Now pass two-thirds of a bare wire through one hole in a solder tab in the phono jack receptacle and twist the wire tight around itself. Solder the twisted wire with just enough solder to lightly coat the twisted wires. Verify no blob of solder is bridging the gap between the solder tabs, then slide the heat shrink over the connection and heat. Repeat this for the remaining three wires. The BalloonSat Mini 2 has an additional cable for the camera. I strongly recommend the end of this cable be terminated in a connector rather than permanently attached to a camera. If the camera is permanently attached, then eventually the cable between the Mini 2 and camera will break from the weight of the camera. I use either a small Dean’s connector or a male header. The termination that you use will depend on how you modify your camera. However, I recommend picking a single type of connector and sticking with it.

### TESTING AND PAINTING

At this point, you have a complete BalloonSat Mini. However, before snapping in the PICAXE-08M, take a moment to check your soldering for unintentional shorts (do we ever have intentional shorts?). Make sure solder did not overflow its pad and that no cut leads are sticking to the bottom of the PCB. After a visual check, get out a multimeter and check for continuity between power and ground in the battery snap. Be sure to check with the power switch both turned off and on. If no short is detected, then attach the nine volt battery to the Mini and flip the power switch. You will see the LED light up, indicating power. Now, set your multimeter to measure voltage.

Between pins 1 and 8 of the PICAXE you should measure five volts — give or take 5% — or between 4.75 and 5.25 volts. Then, check the voltage of the I/O ports. To do this, stick cut resistor leads into a +5V and a ground hole of the receptacle to make it accessible to the multimeter. Again, you should measure within 5% of five volts in the receptacle. Of course, if the battery catches fire and sparks fly out of the PCB, disconnect power and look for a short.

Turn off the power before you snap the PICAXE-08M into its socket. A PICAXE-08 will work in the Mini,
but use the M model for its additional memory. Now you can apply power and try programming your Mini. Note that the color diagram of the parts layout is marked with a GND on the ground pin of the PICAXE programmer. If you plug the programming cable in backwards, the PICAXE will not program.

The simplest programming test is to write the command DEBUG and download it. The DEBUG command tests that the PICAXE is good and that two-way communication is possible. The result is that you will see the progress of the download and then the debug window open. There will be one debug statement and the values of the memory displayed (which will be all zeros).

After testing the connections on the PCB, mark your Mini PCB with its power and ground indicators. Place a green dot on the PCB next to the ground row of the receptacles and headers (don’t forget the programming header). Place a red dot next to the +5V row of the receptacles and header. Look at the color parts placement diagram for an example.

**BOTTOM SEALING**

To protect the Mini from loose objects inside the BalloonSat, cover the bottom of the PCB in a layer of Foamcore, the material used to mount posters. It consists of a thin sheet of Styrofoam backed with paper. The material is easily cut with a sharp X-acto knife. Carve small pockets in the Foamcore where the strain relief wires exit the PCB. Use hot glue to attach the Foamcore to the underside of the PCB and fill the remaining gaps along the edges with additional hot glue.

**PANEL**

Now all that remains is managing the LED, power switch, and commit receptacle. I make an instrument panel to do this from a two inch by three inch sheet of 40 mil thick polystyrene. I like the stuff because it is easy to cut and can be drilled by spinning the tip of the X-acto blade. Make the hole for the switch and phono jack receptacle large enough to mount them. They lock into place with nuts, so don’t worry if their hole is a little too large. Make the hole for the LED just smaller than the diameter of the LED so it fits tightly. However, if the hole for the LED is just a little too large, you can use a bit of hot glue to hold the LED in place.

The commit pin is a 1/8 inch phono jack. The jack’s tip and base is shorted together internal to the jack housing. That way, when the jack is inserted into the mono jack receptacle, the PICAXE-08M’s commit pin (which is pulled high) is shorted to ground. Unscrew the jack housing and solder a doubled-over wire across the tip and base connections. Use a 6” length of wire to do this so when the wire is doubled over, it extends outside the housing. Squirt a little hot glue around the soldered connection of the jack, but be careful not to use so much that it covers the holes in the housing.

---

This BalloonSat Mini 2 is ready to rock and roll. It will record the air temperature and cosmic ray flux during a mission while also taking pictures from near space. To keep the cables between the instrument panel and BalloonSat Mini manageable, you might try using some spiral wrap as I did.
much glue that the housing cannot be screwed back on. Pass the folded end of the shorting wire through the back opening of the jack housing and screw it back onto the jack. Finish the commit pin by squirting more hot glue through the opening in the back of the housing to create a solid jack. I like to tie a red ribbon to the wire loop protruding from the commit pin so I won’t forget to pull it before launching the BalloonSat.

You’ll notice there are four small holes in the corners of my instrument panel. I use them to mount the instrument panel to the BalloonSat airframe with 2-56 bolts. The instrument panel mounts to the inside of the airframe and there is a rectangular reinforcement ring on the outside. This ring is the same size as the instrument panel, but it has a rectangular opening with a 1/2 inch border. To mount the instrument panel to the airframe, cut a rectangular hole measuring one inch by two inches in the airframe. The #2 bolts sandwich the Styrofoam airframe between the instrument panel and rectangular reinforcement ring as illustrated here.

You’ll find sample PICAXE code on the Nuts & Volts website (www.nutsvolts.com) along with a negative mask of the PCBs of both BalloonSat Minis, if you’d like to make one for yourself.

NOT QUITE FINISHED

Well, that does it for this month. Next time, I will describe a couple of BalloonSat Mini experiments I have developed along with the next higher level of BalloonSat flight computer. If you would like to order a Mini, please contact me. NearSys LLC is preparing to sell kits of its near space avionics. Kits of every near space flight computer and experiment will eventually be available, but for now, a slightly simpler and more compact version of the BalloonSat Mini is ready. The kit contains a professionally manufactured PCB with top silkscreen and solder mask along with all the necessary electronic components. The price for the BalloonSat Mini Compact is approx. $19.50 and the BalloonSat Mini Compact Plus (with camera relay) is approx. $22.50 (for exact prices check the NearSys website at www.nearsys.com). There is a $6 shipping and handling fee for orders in the US. Be aware that large orders may require a different shipping fee. Contact nearsys@gmail.com for delivery times and availability. Pictures and assembly directions of each NearSys PCB kit will be available on the NearSys website as they are developed. Along with the NearSys PCB kits, a BalloonSat book is in the works.

Onwards and Upwards,
Your near space guide NV

NOTE: All PCB patterns and files are available on the Nuts & Volts website at www.nutsvolts.com.
We were “lucky” enough to get another two inches of snow here in Michigan, so it’s been easy to stay trapped inside at my computer cranking out another project to help you get started programming with Microchip PICs. In my January column, I described the I2C form of serial communication. This month, I am covering its cousin — the Serial Peripheral Interface or SPI communication. I’ll perform the same function and communicate with a serial EEPROM as in my January column, but this could easily be a temperature sensor, an external Analog-to-Digital Converter (ADC), a Digital-to-Analog Converter (DAC), digital potentiometer, programmable gate array, or an eight-bit I/O expander. In fact, all of these items are included on the Serial SPI Demo Board you can get from microchipDIRECT (www.microchipdirect.com; see Figure 1).

Many chips offer SPI capability, including PIC microcontrollers (MCUs). The SPI bus operates in a master-slave arrangement. The master supplies the clock and data to the slave. The master can also have a third line for receiving and then a fourth line for controlling which slave to talk to on the bus. This is why the SPI bus is sometimes referred to as a “four-wire” serial bus. The SPI bus is not really a true standard with a platform agreed to by an international committee like I2C. This leaves the SPI bus open to interpretation by the maker of the slave device. It is critical that you read through the datasheet for the slave device you are using. Some may want the data to clock in on the rising edge while others may want to clock in on the falling edge of the clock signal. The thing you’ll notice most — if you’ve worked with digital chips for years — is that SPI looks a lot like the old-fashioned method of clocking data into a shift register.

SPI BASICS

The master SPI signal is essentially a clock and data output signal, also called the Master Output Slave Input (MOSI) signal. The clock can idle in a low state or a high state. Both are shown in Figure 2. The data output can be sent the Least Significant Bit (LSB) first or the Most Significant Bit (MSB) first (also shown in Figure 2). The data is shifted in on the
rising or falling edge of the clock, per the circuitry inside the slave device. A second data signal is used as the master input signal, also called the Master Input Slave Output (MISO). As the master clocks the data out, it also clocks the data into its own buffer. Therefore, the slave must have its data ready to send when the master starts clocking. The only way the slave can determine that the master is going to start sending is to monitor its Chip Select (CS) or slave select (SS) line to see whether the master has pulled it low. When your setup has only one slave, it is still a good practice to use the CS line.

The CS or SS line is the key to having more slaves connected to a single master. The master will pull the CS line low for the slave it wants to talk to, and when the communication is done, the master pulls that CS high and then pulls the CS line low of the next slave to talk to. This allows multiple slaves to share the same set of clock and data lines. Figure 3 shows a single slave and Figure 4 shows multiple slaves.

**USING SPI WITH THE PICBASIC PRO COMPILER**

The microEngineering Labs PICBASIC PRO compiler simplifies SPI down to a single command. Many PIC MCUs have a hardware SPI peripheral built in, so the communication can happen in the background while the software is doing something else. The PICBASIC PRO method uses a "bit banging" or "firmware" implementation of SPI. This prevents the software from multitasking during SPI communication. The firmware method allows you to use SPI on any PIC MCU. The small eight-pin PIC12F683 MCU doesn't have a SPI peripheral, so the PICBASIC PRO method makes sending SPI from this small chip very easy. However, I went the other direction and used a larger chip than the normal 20 pin PIC16F690 that I have used in previous articles. In this month's project, I use a 28 pin PIC16F870. The reason for this has less to do with the chip than the development board.

**HARDWARE SETUP**

The development board I used is shown in Figure 5. It is a PICkit 2 board that you can purchase separately. You get one fully populated board with a PIC16F886 MCU, and then two blank boards. The PICBASIC PRO sample version doesn't support the PIC16F886, but it does support the PIC16F87X parts. The PIC16F870 is a 28 pin part in this family that works with this board.

The main reason I selected this board over the PIC16F690 is the six pin header on the side labeled "PICkit Serial." This six pin header is designed for serial communication to Microchip's PICkit Serial Analyzer tool. The tool also works as a great connection header to the PICkit Serial SPI Demo Board shown in Figure 1. With a simple six pin cable that I had in my pile of lab extras, I could easily connect the two boards together. The microcontroller connections for this header come from the PORTC pins of the 28 pin socket, per the schematic in Figure 6.

The PIC16F870 doesn't have an internal oscillator option, but the development board has the circuitry included for an external oscillator. I added a three pin socket and then plugged in a three pin resonator with capacitors built in. I ran the project at 4 MHz, which is the

---

**FIGURE 4.** Multiple Slaves.

**FIGURE 5.** PICkit 2 28-pin Development Board.

**FIGURE 6.** Six-Pin Header Connector.
default speed for the PICBASIC PRO compiler. The final schematic is shown in Figure 7.

The demonstration program I wrote initially writes 16 bytes of data to the EEPROM and then reads each byte back one at a time. This is done over and over again in a continuous loop, with each value displayed on an LCD module. Because the sample version of the PICBASIC PRO compiler only supports 31 commands, I needed a simple way to display the data. The problem I found driving a parallel LCD module was that it took too many set-up lines and pushed me beyond 31 commands.

My second choice was a serial LCD module. With a single SEROUT command and three connections — Vdd, ground, and signal — I could easily display the data read from the EEPROM. I used a serial LCD module from microEngineering Labs connected to a 2 x 40 LCD. The LCD is connected to the MCU’s C5 pin through the expansion header on the side of the development board, making this an easy connection. The expansion header has Vdd and ground connections, as well. The final setup is shown in Figure 8. The PICKit 2 supplied enough current to power the whole circuit through the USB connection. No jumper wires, no soldering, and no separate breadboard. You can't get much easier than that.

**SOFTWARE**

I wrote the software in blocks to make it easier to explain the operation. Combine all the blocks together for the complete software routine. I start off with a simple description of the operation and then set up the port settings. The labels SI and SO are from the EEPROM perspective. The LCD is on PORTC.5. I use a VAR or variable directive to establish these labels, even though it may seem like they could be constants. The labels can't be constants though, because the value can contain a zero or one value, thereby requiring a variable definition. As a final step, I preset the input and output states of the pins by writing directly to the TRISC register. A one makes the pin an input and a zero makes the pin an output. The most significant bit is to the left.

```
' Program to read and write to SPI EEPROM
' 25LC020 on PICkit Serial SPI Demo Board
' using PIC16F870.
' Write to the first 16 locations
' of 25LC020 serial EEPROM.
' Then Read first 16 locations back
' and send to LCD repeatedly.

' *** Port Settings ***
CS var PORTC.7 ' Chip select
SCK var PORTC.3 ' Clock pin
SI var PORTC.6 ' MOSI pin
SO var PORTC.4 ' MISO pin
LCX var PORTC.5 ' LCD

' C4 input, C7-C5, C3-C0 outputs TRISC = %00010000

The next section creates two byte variables that I will use throughout the program. One is the "addr" variable that contains the address of the data to be read or written. The other is a general-purpose "B0" variable that I use to hold the data being written to or read from the EEPROM. The 25LC020 EEPROM uses eight bit communication. Check the datasheet of the EEPROM you use in your SPI communications because some require a 16-bit address.

'*** Variable Setup ***
addr var byte ' Address
B0 var byte ' Data

The 'main' label marks the FOR-NEXT routine that loads the initial data into the EEPROM. The addr variable is used as a counter variable, and also as
the address of the location where we will write the data to inside the EEPROM. The data will be the address value plus 100, so the first location address zero will contain the value 100. Address one will contain the value 101. This continues for all 16 locations (0-15). The loop uses a subroutine called "eewrite" to actually write the data. I'll cover this a little later. The pause 10 delay is a 10 millisecond delay between write operations that is required by the EEPROM so it can finish what it's doing.

'*** Load Data in EEPROM ***
main: For addr = 0 To 15 ' Loop 16 times
    B0 = addr + 100     ' Data for EEPROM
    Gosub eewrite      ' Write to EEPROM
    Pause 10        ' Delay 10ms
Next addr

The "loop" label marks the continuous-read loop of the EEPROM data and the display of that data on the serial LCD. The loop uses a FOR-NEXT loop again, with the "addr" variable as the counter and address locator. Another subroutine to read the EEPROM is then called. The SEROUT command line sends a command $FE, $1 to position the data at the first line, first location of the LCD screen. Then, the ASCII representation of the address is displayed, followed by a colon and space; and then the ASCII representation of the data is then read from the EEPROM. The # symbol converts the number into its ASCII characters (i.e., 105 is sent as '1,' '0,' '5'). The value "6" in the SEROUT command line represents a non-inverted 9600 baud rate. This was the communication speed the LCD required. The pause 1000 creates a one second pause, so you can see the data on the LCD; then the next value is retrieved. After all 16 bytes of data are captured and displayed, the whole process starts again. Figure 9 shows one of the results displayed on the serial LCD.

' Continuous Loop to Read and Display Data
loop: For addr = 0 To 15 ' Loop 16 times
    Gosub eeread ' Read from EEPROM
    ' Display data read from EEPROM on LCD
    SEROUT LCD,6,[$FE,$1,*,addr,*: *,#B0]
    Pause 1000
Next addr
Goto loop

The subroutines make up the heart of the code. The SHIFTOUT command is used to send the command value $03 to the EEPROM. This indicates that the master wants to read a value from the EEPROM at a specific address. The second byte contains the address in the "addr" variable. Before this will work, though, the chip-select line must be brought low by setting the CS variable to zero. The SHIFTOUT command line designates the pin connections, and then the value "1" is a PICBASIC PRO value that indicates the most significant bit (MSB) will be sent first with clock idle in the low state.

The data is read back using a SHIFTIN command and stored in the variable B0. The "0" in the command line is the PICBASIC PRO code to command the data to be sent MSB first and read the data, before sending the next clock. The clock will also idle low. The CS line is set high, to end the operation and then the RETURN command sends the control back to the program section that called this subroutine.

' Subr. to read data from addr in serial EEPROM
eread:
    CS = 0 ' Enable serial EEPROM
    ' Send read command and address
    Shiftout SI, SCK, 1, [$03, addr]
    Shiftin SO, SCK, 0, [B0] ' Read data
    CS = 1 ' Disable
    Return

The second subroutine is the write routine that uses two SHIFTOUT commands. First, the CS line is pulled low to enable the EEPROM for communication. Then, the command code $06 is sent to the EEPROM. This tells the EEPROM to allow the data to be modified, also known as the "write enable" mode. The CS line is brought high to end that command and allow the EEPROM to enter the write-enable mode. I added a small delay and then pulled the CS line low again, to send the data byte. The SHIFTOUT command sends the $02 command to indicate write mode, and then the address and byte data values to store. The value "1" indicates MSB. The CS line is brought high again to end the communication; the EEPROM then writes the value to the memory location. Location 14 has the value 114 stored in it, and Figure 9 shows that value displayed. A RETURN command gives control back to the code that called the subroutine.

' Subr. to write data at addr in serial EEPROM
fwrite:
    CS = 0 ' Enable serial EEPROM
    ' Send write enable command
    Shiftout SI, SCK, 1, [$06]
    CS = 1 ' Disable to exec command
    CS = 0 ' Enable
    ' Send address and data
    Shiftout SI, SCK, 1, [$02, addr, B0]
    CS = 1 ' Disable
    Return

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As a final step, I added an END command to mark the end of the program. This is always a safe way to complete a PICBASIC PRO command.

' *** Mark End of Program ***
End

CONCLUSION

The SPI Demo Board has several different SPI chips to talk to. The SHIFTIN/SHIFTOUT commands can be used to talk to any of them. SPI communication is really easy to understand, once you get the basics down. The problem is that it takes up more I/O with all the extra CS pins for each SPI chip you use. This is an advantage to I2C that I covered in my previous column. SPI is typically faster than I2C, though, so it can sometimes offer an advantage. However, if the EEPROM takes 10 milliseconds to complete a write operation, that becomes the limiting time factor.

I like to think about next steps for all my projects so the reader can take what I taught them and prove to themselves that they understand it by going further with the same hardware. This setup lends itself perfectly to that concept. The SPI demo board has multiple chips on which to experiment. Each chip requires you to read the datasheet for any command codes required, but these are all free to download from www.microchip.com. The CS line on the demo board was designed for one-chip communication only, with jumpers to select the chip. Communicating with multiple SPI parts requires you to create jumper wires from the MCU’s extra CS lines to the CS connections on the demo board. This could be an interesting project — I just didn’t have time to try it.

Another source of information regarding serial EEPROMs is the Microchip "Recommended Usage" application note for SPI Serial EEPROMs (AN1040) and the datasheet for the 25LC020. Both are also available for download at www.microchip.com.

Let me hear your feedback on this column or previous columns. I’ve gotten some email from people who are still working on projects from the 2006 articles. If you missed these, they’re compiled together in a book entitled Getting Started with PICs (2006) that you can purchase from the Nuts & Volts webstore (http://store.nutsvolts.com). Just shoot me an email at chuck@elproducts.com, and type Nuts & Volts in the subject line so it doesn’t get lost among the numerous junk emails I receive. See you next time! NV

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Bretthauer Appointed CEO of LPKF Laser & Electronics AG

The Supervisory Board of LPKF Laser & Electronics AG has appointed Dr. Ingo Bretthauer (53) as the new Chief Executive Office of LPKF AG, beginning Feb. 1, 2009. Alongside the current members of the Board of Managing Directors (Bernd Lange, 48 and Kai Bentz, 37), Bretthauer will in particular push ahead the global sales of all LPKF products. Bretthauer has broad experience in sales and marketing of industrial equipment. With a degree in engineering and a PhD in economics, he previously worked seven years in various positions at AEG. He moved from AEG to Deutsche Bahn, where his last position was Chief Marketing Officer at DB Reise & Touristik. He was CEO and sole managing director of Joh. Heinr. Bornemann GmbH in Obernkirchen, Germany from 2001 to 2007. Bretthauer takes responsibility of most areas previously managed by former CEO Bernd Hackmann who left LPKF at the end of 2008. LPKF Laser & Electronics is an ISO-9001 certified equipment manufacturer of equipment for the electronics industries. For more information about LPKF, visit www.lpkfusa.com.

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Plasma Speakers

Does anyone have any schematics and info on building a plasma speaker? I have seen [www.instructables.com/id/Build_A_Plasma_Speaker/](http://www.instructables.com/id/Build_A_Plasma_Speaker/), however, some of the details regarding the driver and other info is not stated.

#3091 Bill Lost via email

Detecting a Fault on a High-Side OMNIFET

I am designing an H-bridge motor driver using two STMicro L6384 drivers, and four VNY35N07 OMNIFETs. Since the OMNIFETs are internally protected, I hope to avoid using sense resistors for fault detection. Please suggest an elegant way to detect faults on the highside. If a highside VNY35N07 has clamped the gate, what is a good way to detect this and produce a 5V logic level signal referenced to ground? Power supply to the H-bridge will usually be 24 VDC, though it could be anywhere from 6V to 30V.

#3092 James Smith Ontario, Canada

Voltage Regulators for Bicycle Lights

I have an electric bicycle that runs on 36 VDC and would like to make a circuit that would power the lights and radio on the bike. There are four items all powered by various quantities of AAA batteries.

There is 1@6V, 1@4.5V, and 2@3V. If someone could provide me with a
Digital Multimeter Input Impedance

I have purchased an inexpensive DMM which appears to work satisfactorily. Is there a method to measure the input impedance of the meter?

David Luther
Los Angeles, CA

#3096

Doug Poray
Jackson, NJ

>>> ANSWERS

[#1099 - January 2009]

Electronic Simulation Software

I see simulations of circuits in many articles. I used to have a copy of Electronic Workbench 12 years ago, but found it to be unreliable in switch mode designs. I would like to know what package you recommend for mixed signal and switch mode design simulation that is easy to use and under $1,000. Also, I have been out of electronics for six years and need a single source for info on SMT packaging.

#1 Surprisingly, there are a couple of free circuit simulation software packages available. I like Linear Technology’s LT SPICE IV (Switcher CADIII), which is a general SPICE program, but uses a specific algorithm to do switch mode simulation extremely well. It excels at start-up and transient events, and rarely fails to find the operating point or hangs. The program updates frequently and other SPICE models are easily added. Almost all of their products are supported. Also, there is TINA-Ti (Texas Instruments) and National Semiconductor has a web-based solution. The best sources for SMT information are the manufacturers themselves, since most of them have extensive tutorials and PDF files available. Other good sources are the PCB manufacturers and many of them have free layout software. I recommend expresspcb.com; they have an excellent, brief (on-line) manual and CAD software to get you going quickly. Other good sources right now are the solder manufacturers, parts, and equipment makers, due to RoHS (Restriction of Hazardous Substances).

Walter Heissenberger
Hancock, NH

#2 You probably sent this SPICE question in a few days before the December 2008 issue of Nuts & Volts was published. The most inexpensive SPICE for the MS Windows OS is described in "A Touch of SPICE" by Peter Stonard in the December 2008 and January 2009 issues. This superb introduction to LT SPICE (Linear Technology SPICE) will get you started on a package with a schematic capture front end. LT SPICE is probably the best answer.

If you have a rich employer to buy Electronic Workbench, the schematic capture is much improved. Back when you were using EW, I used Penzar TopSPICE to good effect when it was half today’s $500 price. If your employer provides OrCAD schematic capture, consider PSPICE. Most of the published SPICE netlists are based on PSPICE. There is a free student version of OrCAD/PSPICE.

I got a lot of mileage out of the PSPICE student edition before it had schematic capture in the early 80s because my "fortune 100" employer wouldn’t buy it. I actually learned SPICE from Intusoft newsletters and books. They sell IsSPICE. They are very good at providing models of exotic devices.

These days, I am Linux OS based using Xcircuit schematic capture and a patched version of Berkeley SPICE 3f5. I don’t recommend this approach for casual users. See Kuphaldt, "Lessons in Electric Circuits" AC, Chapter 6 on the web for examples.

Dennis Crunkilton
Abilene, TX

[#12086 - December 2008]

Power Tool Batteries

Does anyone have information on how to recell/rebuild power tool batteries? Procedures and suppliers of equipment needed to do it properly?

I have rebuilt numerous power-tool batteries, generally upgrading them as far as capacity (ma/hrs) and reliability as I did. I have discovered that about 90% of all common tool batteries are made up of sub C size NiCds or NiMH cells. A few older ones were actually full size D cells (not the Eveready, etc., D cells with a 1/3 D tucked in one end that they sold as rechargeables for home use to replace dry cells). Those D cells were very powerful and heavy. There is also a smattering of AA, AAA, AAAA, and "coin cell" stacks out there now. Then there are lead-acid, lithiums, and nickle-iron Edison cells, and even some alkalines.

The most important thing is that the cells you rebuild with need to be as identical as possible to each other in capacity, internal resistance and charge and discharge rates, as your battery pack can only perform as well as its weakest link.

Another consideration is operating temperature (there are high temp versions) and the temperature tolerance of the insulation around the cells — some of the plastics used on China imports melt and short the cells together — a common failure in "liquidation store," weak, low priced drills and saws. I have found the blue plastic thin insulation on available high capacity cells and the old standby "cardboard" or pasteboard paper-like insulation to perform well. The non-oil or non-plastic soaked pasteboard insulation’s only flaw is that continual repeated exposure to moisture and/or salt water can cause a high resistance short between cells due to either salt or mineral build-up and residual moisture or iron oxide (rust) from the cell’s outer case permeating the material. Use the plastic or soaked "paper" insulated cells for tools, RC toys , etc., used in rain or underwater cameras, for example. I have soaked paper ones in varnish or polyurethane when desperate, and have also seen wax used.

I now go on the Internet Googling NiCds or NiMH or batteries, etc., to find good ones at a good price — 2,250 ma/hr is easy to come up with and close to that in sub C NiCds, but I don’t remember the site. They were cheaper than the 1,250 ma/hr ones. Over 5,000 ma/hr units have been located. There appears to be a

March 2009 NUTS & VOLTS 95
Panelspotter" to accomplish this, but the metal band tightly to the cell.

Electrode back quickly while holding contacting the weld. Pull that spot-welding using Cu as the metal secondary low (2.5 to 35V) to do the primary for a short burst and use the or 250 VAC) into a transformer discharging a high voltage (110 VAC 50,000 mfd capacitor at 6V or a relay use tin/Cu/selenium solder. In rare the original if you can. Now, I tend to Re-install those in the same place as installation of thermal breakers.

Pastboard insulation) with the factory disappeared (along with charred out to .5 ohms. Those occurrences disappeared (along with charred pasteboard insulation) with the factory installation of thermal breakers. Re-install those in the same place as the original if you can. Now, I tend to use tin/Cu/selenium solder. In rare instances, I spot weld using either a 50,000 mfd capacitor at 6V or a relay discharging a high voltage (110 VAC or 250 VAC) into a transformer primary for a short burst and use the secondary low (2.5 to 35V) to do the spot-welding using Cu as the metal contacting the weld. Pull that electrode back quickly while holding the metal band tightly to the cell.

I have used such tools as a "Panelspotter" to accomplish this, but it's not really necessary if you're good at tinning both cell and connecting wire or band, and then heating them together while pressing the connection flat with a tool that solder doesn't stick to — like a popsicle stick. Thick solder joints eat up precious space in the battery shell and may cause a problem closing it up. Thick rubber bands can help bundle cells together for connecting. I generally copy the layout of the original battery.

A small (15, 25, 35 watt) soldering iron will work but I prefer a real chromed brass secondary solder gun like the Weller 8200 (125/150 watt), D-440 (400W), D550 (500W), D-660 (600W), as the higher heat does not have to be applied as long to heat the connection. The longer heat is supplied, the more likely a seal failure or other damage can occur.

Lithium cells can be replaced in the same manner as NiCds and NiMH when all cells are not cast in the same plastic or physically are not a part of the battery housing. A similar problem exists with many lead/acid batteries (gel cells) although some are made up of individual 2V usually steel jacketed cells such as Gates 'Cyclon' cells (often D size) that can be easily soldered together and are usually supplied spot-welded on the solder tabs.

Many NiCds and NiMH also have metal bands already spot-welded to them so you can solder to the next cell in your pack's band; bands are available separately. I like to use thin copper strips from old TV chassis ground straps. Bands supplied on cells are usually so long they have to be trimmed on one cell at least. Battery shells are usually screwed together, sometimes with goofy heads on screws like tri-way, torx, Canadian Phillips, and all common ones with a post sticking up in the middle of it. Some cases are welded and need to be split by controlled violence, or cut and reassembled by thermal or solvent welding or welding in plastic to hold nuts, or be drilled for screw supports. All in all, it's really a fun adventure and with some experimentation, a far superior battery can be created!

Bob Kennet
Everett, WA

Logic Analyzer

I have a LEADER Model 300 DMM/scope with logic analyzer. I need help/info to build an interface circuit that would allow me to use the eight channel logic analyzer.

I recommend against building your own probe, because you may encounter insurmountable obstacles due to parts availability. I do recommend, however, to go out on eBay and either find the probe, or find a repairable one. The service manual for the LEADER Model 300 is available at Manuals Plus for about $40, which is somewhat typical. A logic analyzer probe sells for about $20-200 on eBay. Consider buying a Tektronix 1230 or 1241 logic analyzer instead, which are much better instruments and can be had for as little as $30, since labs are shutting down due to the economy. I also like the HP1631D, which is a 50 MHz, two channel scope mated to a logic analyzer and it has the pods (probes) attached. I've seen the HP1631D sell for as little as $20.

Interestingly, probes tend to be somewhat expensive and harder to get, probably because fewer functional ones have survived.

Walter Heissenberger
Hancock, NH

Humidity Sensor

I am looking for a small humidity sensor circuit powered by 120V that can trigger a relay based on an adjustable humidity level. My ultimate goal is to wire it into a bathroom fan and have the relay trigger an X10 command via an X-10/Insteon I/O module. The X10 command would turn the fan on or off based on the humidity in the room and the humidity trigger level set. It needs to be small and self-contained (no wall wart).

Check out grainger.com and look for “humidity control” or part number 2E574; 2E574 is an adjustable humidistat that will work with your X10 system or as a stand-alone control using 120V.

Bob Lindstrom
Broomfield, CO

[1098 - January 2009]
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CSI-2901 LEAD Free
Soldering Station

Compatible with all lead-free alloy solder and standard solder. Excellent thermal recovery without a large increase in tip temperature. Utilize an integrated ceramic heater, sensor, control circuit and tip for greater efficiency, along with a highly dependable 24V output transformer. The effortless replacement of soldering tips makes for quick changes and the optional shutdown setting turns the unit off after 30 min. of idle time. Various tips are available at our Web Site!

Item #

Price 1-4
Price 5+

CSI3003X-S 0-30V/0-3A $119.00 $112.00

CSI5003X5 0-30V/0-3A $127.00 $119.00

CSI3005X5 0-30V/0-5A $129.00 $122.00

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High stability digital read-out bench power supplies featuring constant voltage & current outputs. Short-circuit & current limiting protection is provided. SMT PCB boards and a built-in cooling fan help ensure reliable performance & long life. All 3 Models have a 1A@5VDC Fixed Output on the rear panel.

Item #

Price 1-4
Price 5+

CSI3003X-S 0-30V/0-3A $119.00 $112.00

CSI5003X5 0-30V/0-3A $127.00 $119.00

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Hot Air with Vacuum I.C. handler & Mechanical Arm
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BK2000
Compact Soldering Station
The BlackJack SolderWerks BK2000 is a compact unit that provides reliable soldering performance with a very low price. Similar units from other manufacturers can cost twice as much. A wide range of replacement tips are available.

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BK4000
Thermostatically controlled desoldering station
The BlackJack SolderWerks BK4000 is a thermostatically controlled desoldering station that provides low cost and solid performance to fit the needs of the hobbyist and light duty user. Comes with a lightweight desoldering gun.

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BK5000
Hot Air System w Soldering Iron & Mechanical Arm
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BK3000LF
Digital Display Solder Station for Lead Free Solder
The BK3000LF is a compact unit designed to be used with lead free solder that provides reliable performance featuring microprocessor control and digital LED temperature display. A wide range of replacement tips are available.

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