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#132 JULY 2001

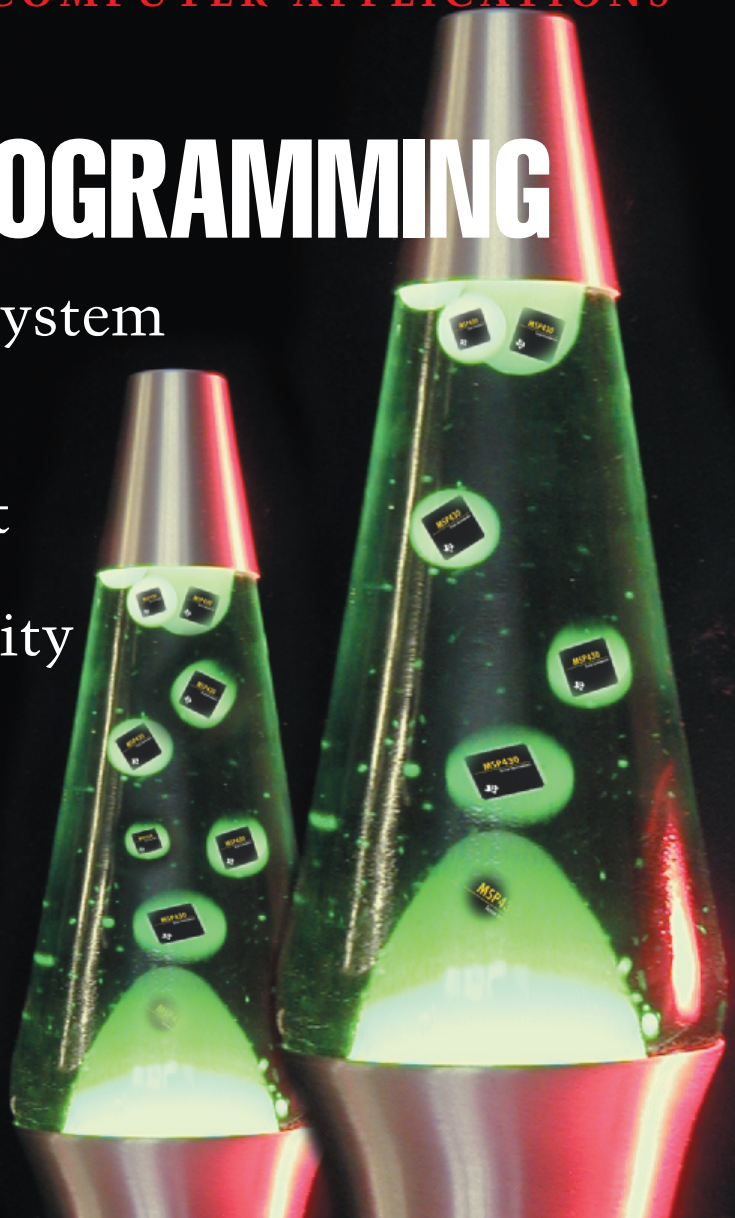
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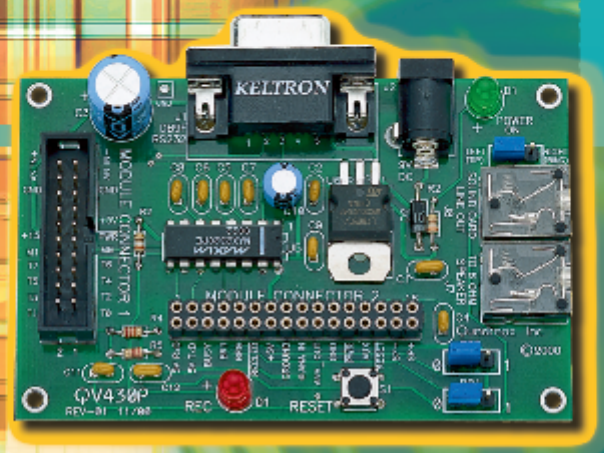
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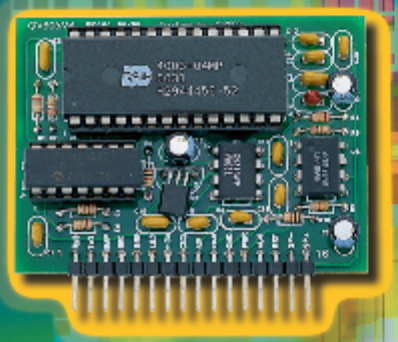


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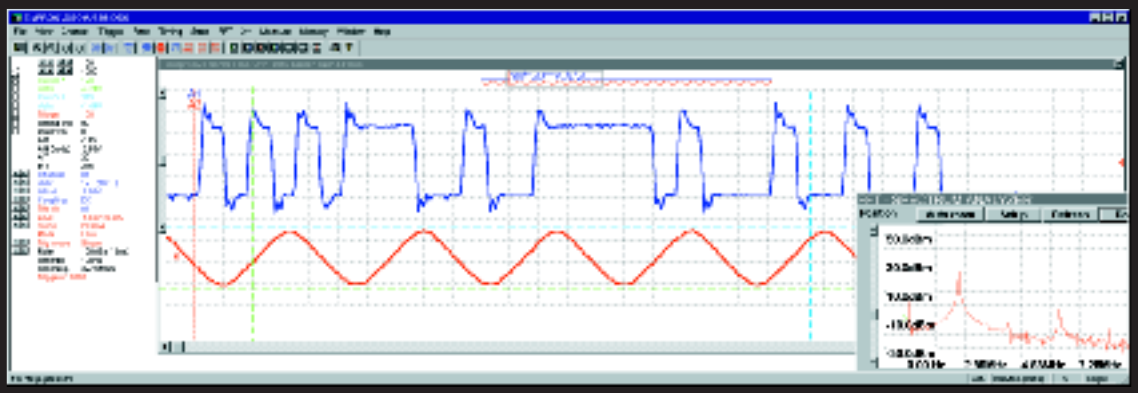
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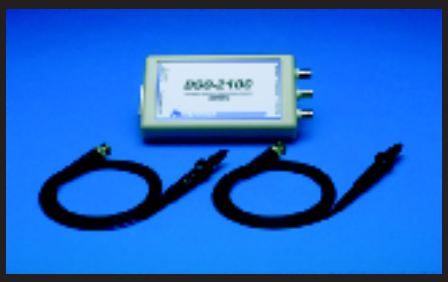
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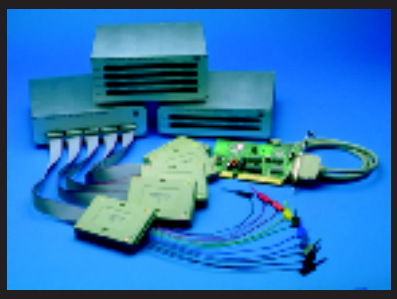


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ALL ABOARD THE CLEAN ENGINE

Automotive Emissions and Onboard Diagnostics
by John West
As efforts are made to keep our environment pollution-free, automobiles are being put to the test with even stricter standards. To meet these emissions requirements, manufacturers have turned to more electronically controlled systems using sensors. Strategies are getting more complicated and require more control code. John sees a future where automotive microcontrollers will start to look more like desktop systems in terms of bandwidth, "evolving faster than you can step on the gas." June 2001

PORTING MICROC/OS-II TO THE TS-2800 EMBEDDED PC

by Robert Bowen
As his designs started getting more complicated, and he found they were not reusable from system to system, Robert began to turn his focus to new development programs. Demonstrating the advantages of using an embedded PC and real-time kernel, he took advantage of open source programming tools and searched for a real-time executive. It all makes for more capability, complex I/O, and high-speed data acquisition. June 2001

USING A WELL-DESIGNED BOOT MONITOR IN EMBEDDED SYSTEMS

Part 2: Building on the Basics
by Ed Sutter
Last month, Ed got us started with the exception handlers in place and basic flash interfaces initialized. Picking up where he left off last month, this time around he starts the process of breaking away from just being a simple boot monitor. Moving forward, you can now overlay a format on the section of flash memory to be allocated to the tiny flash file system. The design goal is to provide a good amount of flexibility without overdoing it. June 2001

AND THE LIST GOES ON...

Putting Together Parts Lists
Lessons from the Trenches—*by George Martin*
With promises of fame, George tries to entice you into submitting an entry to Trinity's Fire Fighting Home Robot Contest. But before you build that bot, you're going to have to buy the parts. It may seem like a daunting task at times, but whatever you do, you need the parts to do it. The simplest way to go about it is to create a list and a purchase order. From there, you can start cashing those winning checks. June 2001

ESCAPE TO SF

Silicon Update Online—*by Tom Cantrell*
The Embedded System Conference always provides a lot of food for thought, and Tom shows us that this year's event was no exception. Having outgrown San Jose, San Fran is now home to ESC, with a whole new wave of applications opening up. Voice recognition gear was probably the hottest item on the scene, along with web-enabling and listening chips. Will the spoken word replace keyboards? Watch and listen for the answer. June 2001

AN ELECTRIC LITESHOW DISPLAY

Part 1: The Electronics Behind the Lights
Technically Speaking—*by James Antonakos*
James has a fascination with electronics, mainly flashing lights on and off. His LiteShow display of 384 lamps makes for an interesting article this month. By putting groups of lamps together, you can create letters, words, and graphics, all individually controlled by only three signals from the PC printer port. Working with some students, he shows them how to design their own version of a printed circuit board. June 2001

RETRO HUMOR CIARCIA STYLE

Part 3—*by Steve Ciarcia*
Way back at the dawn of the microcomputer age, Steve Ciarcia was blazing a trail (sometimes literally) through the hardware and software issues of the era. At the request of many of our readers, we've brought back a series of articles, written by Steve, chronicling the design adventures of those early days in the Circuit Cellar. This month, it's chapter one from *Take My Computer, Please!* June 2001

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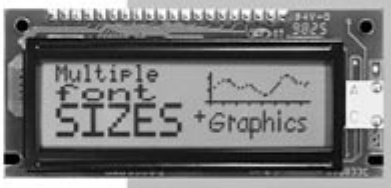
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TASK MANAGER

Are We There Yet?

Not only are those some of the most well-known words of summer, but these days, you don't hear them coming only from the kids who are sick of riding in the backseat. Just listen to yourself the next time you're waiting for your dial-up connection to download new software or e-mail attachments. We've become extremely "connected" via wireless devices and other technology that allows us to save valuable time. Interestingly enough, one of the most common complaints about our digitally-enhanced lifestyles is not having enough time to get things done and relax.

Soccer moms and financial analysts have a host of gadgets that allow them to stay connected to the people and events that are important to them, but those gadgets didn't evolve from a pile of components in someone's part drawer. Every new feature on every new gadget is the result of around-the-clock efforts by engineers and design teams who have been given the task of making sure that the latest and greatest has their company's logo on the gadget or inside the box. No pressure, especially because the current downturn of the economy means that not hitting that mark could mean the difference between having a job and having to find one.

So, if you're feeling the pressure, we understand, after all, *Circuit Cellar* has to keep up with the people (engineers) who have to keep up with the people (soccer moms and financial analysts) who claim to never have time to keep up with people (friends and family). I can't promise that this issue will relieve stress, lower blood pressure, or help make time to unwind, but I hope you'll find the projects in this month's issue refreshing and enjoyable.

You can probably find some information in Marty Vona's article (p. 12) that will help you at your day job, but once you start reading, I'm pretty sure that your day job will fade to black. After all we're talking about programming an off-the-shelf animatronic fish to say anything you want! A project like that is 99% pure fun. If you're looking for bigger fish to fry, Robert Lacoste (p. 32) introduces us to his Scan 3-D device that functions as a 3-D telemeter when connected to a PC. Robotics enthusiasts take note because this project would make a great addition to your latest mobile robot. And last but not least, what could be more relaxing than performing scientific experimentation on your family, friends, or neighbors? Tom Napier's telepathy test system (p. 44) is another off-the-beaten-path project that could help you figure out whether someone you know (e.g., spouse, mother-in-law, boss…) is telepathic or just coincidentally prone to bothering you every time you try to relax. (Wired copper helmet and tie-down hospital bed sold separately.)

For those of you looking for hands-on R&R opportunities, this month we kick off the Texas Instruments Ultra-Low Power Flash MCU MSP430 Design Contest (p. 17). Get started on your MSP430 gadget and you could be on your way to claiming your share of thousands in cash prizes! And everyone knows how relaxing it can be to claim cash prizes.



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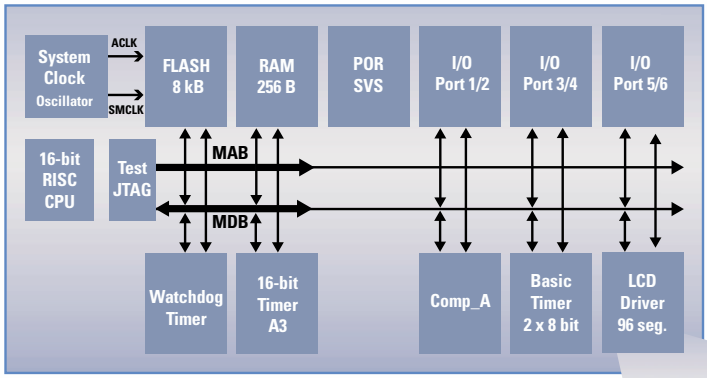
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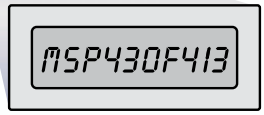
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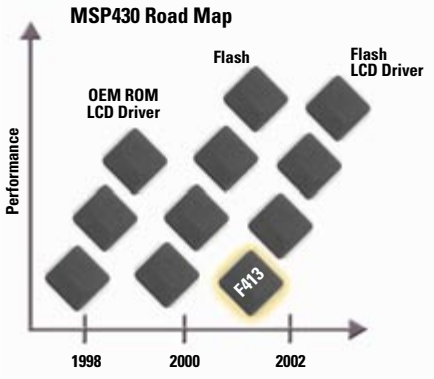
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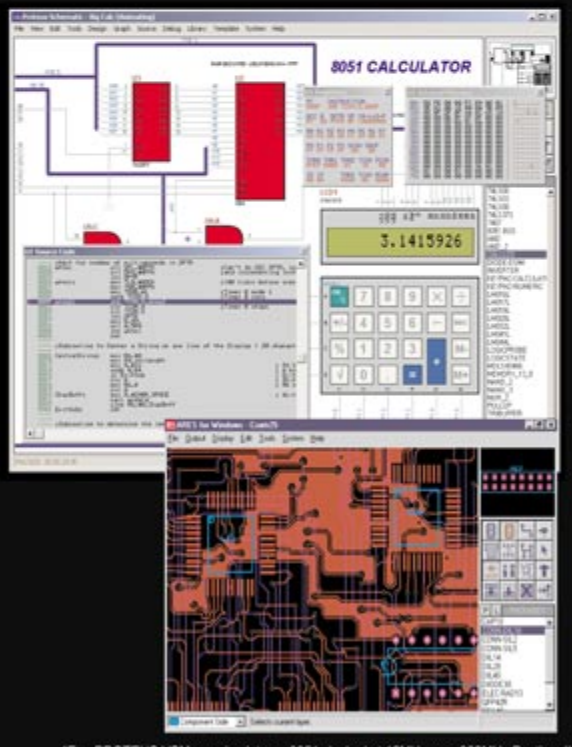
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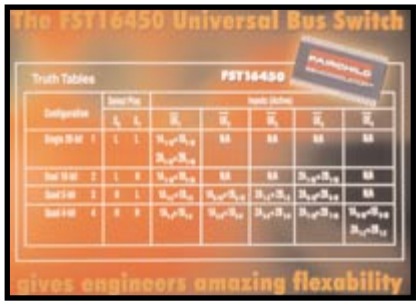
NEW PRODUCT NEWS

Edited by Rick Prescott

20-BIT CONFIGURABLE BUS SWITCH

The **FST16450** is a 20-bit configurable bus switch with selectable level shifting and the **FSTUD16450** is a 20-bit configurable bus switch with undershoot protection and selectable level shifting. Both devices can be configured as 4-, 5-, 8-, 10-, 16-, or 20-bit switches. These devices offer significant space savings, design flexibility, and part count reduction. Additionally, you can replace several devices while maintaining the board's current communications protocol.

The bus switches both include selectable voltage level shifting to allow designers to translate 5-V inputs to 3-V outputs using a select pin. These bus switches also include all standard features such as 4 Ω between ports, zero bounce in flow-through mode, propagation of only 0.25 ns, and 3-µA ICC. The FSTDl6450 and FSTUD16450 are available in TSSOP packaging. Pricing in volumes of 1000 is **$2.10** and **$2.25**, respectively.



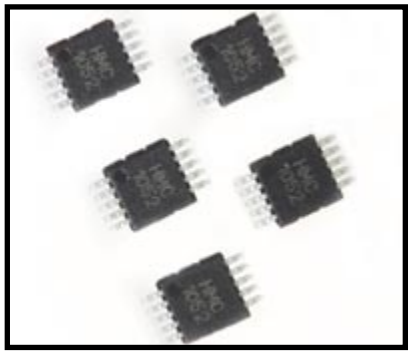
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TWO-AXIS MAGNETIC SENSOR

The **HMC1052** is a two-axis sensor on one chip for compassing and position-sensing applications requiring ultra small size, low power, and high performance. These include handheld wireless appliance applications such as mobile phones, personal digital assistants, walkie-talkies, watches, and GPS receivers. Advantages of this new patented design include nearly perfect orthogonal two-axis sensing in a 3 × 3 × 1 mm 10-pin miniature surface-mount package (MSOP).

The sensor has a sensitivity of 1 mV/V/Gauss, a wide field range up to ±6 Gauss, and can operate on a supply voltage as low as 1.8 V. Nearly perfect orthogonal two-axis sensing and matched sensitivity on both axes improve the performance and accuracy of this sensor. Patented on-chip set and reset straps eliminate the effects of temperature drift and stray magnetic fields.

Sensors are available in packages of five starting at **$100**.



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The **Kilo**, **Mega,** and **Giga series** of half-brick units offers designers a fully-scalable range of DC/DC converters covering a wide output current range of 20 to 60 A. The lines include output voltages from 1.5 to 15 V. All units draw power from a 48-V nominal input (35- to 75-V range) and deliver 20 to 40 A of output current or 75 to 150 W of output power.

An important benefit for designers is the scalability afforded by the full line of half-brick modules. Because all the converters use the same topology, circuitry, pin-out, and footprint, you can be assured of complete plug-and-play compatibility when moving among different power levels within the industry-standard, half-brick format.

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The standard modules in 1000-unit quantities cost **$82** for Kilo, **$99** for Mega, and **$129** for Giga.



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NEW PRODUCT NEWS

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The new **DUO-TOUCH SG** two-hand control system combines two ergonomic self-checking touch buttons (STB) with a 22.5-mm (0.9″) wide DIN-mount controller. The system is designed to provide safe machine cycle initiation and help eliminate the repetitive stress injuries common among machine operators.

The touch buttons incorporate diverse-redundant microcontrollers that continuously check their internal safety-critical functions. If a fault is detected in an STB, its microcontrollers will hold the outputs in the OFF state and flash a fault LED to alert an operator. The STB outputs (one normally open and one normally closed) are monitored by the device's controller.



The system controller also incorporates diverse-redundant microcontrollers, in this case to monitor the STB outputs to determine when they change state, if both STBs change simultaneously, and if there are any controller or machine feedback faults. The system meets safety category four requirements of EN 574 Safety of Machinery. The system also meets Type III C requirements of EN 574 Safety of Machinery.

The DUO-TOUCH SG kit is priced at **$437**.

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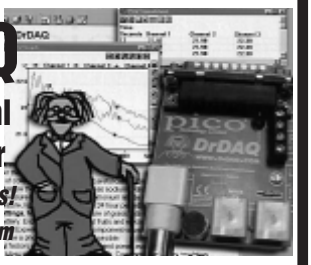
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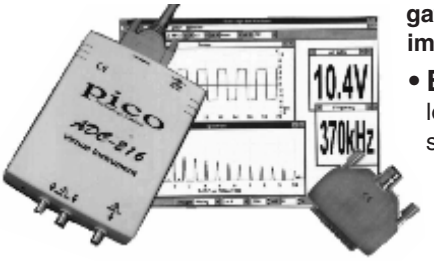
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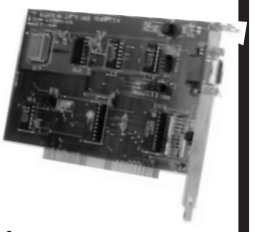
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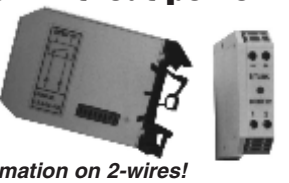
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FEATURE ARTICLE

Marsette Vona

The Lighter Side of Programming

How to Improve a Singing Fish

What's the best part about being an engineer? Playing with all the gadgets! And, we see a potential project in almost anything, right? Well, Marty's here to share his vision for an embedded application inspired by a singing fish and a love for practical jokes.

During the summer of 1999, I was living in Hanover, New Hampshire with my roommate Ben Guaraldi. One quiet, sunny morning I woke up late and walked into the living room to find Ben dozing on the couch. At the sound of my entrance, he opened one eye and we looked at each other for a moment, each of us still experiencing a post-sleep stupor. In an uncommon epiphany it was clear to me that I could communicate to Ben the entire contents of my just-barely-awake mind with one single word: pork!

Yes, indeed, the other white meat. Try it, even if you don't dig swine. You might find that a whole world of human experience can be expressed with this one simple word. Even if you don't agree, Ben did. So, on that quiet, sunny morning in Hanover, New Hampshire, we had an entire conversation using only the word "pork."

As time passed, we became more impressed with the dynamic range of the p-word. And, we got creative about how we communicated it. While shopping at the local drugstore, I stumbled upon a talking bass. For those of you who don't know what I'm talking about, the Bass is one of several "talking fish" toys that have cropped up during the last few years. It looks like a life-size stuffed fish, complete with wall-hanging plaque. When you press the small, red button on the front, the fish comes to life and talks to you. I am serious. In this article, I'll discuss the Big Mouth Billy Bass (see Photo 1), made by Gemmy Industries, because it seems to be the most widely available toy of this type.

These Bass are nothing short of little animatronic wonders. Now who's put two and two together? Pork. Bass. Talking Bass. Christmas was fast approaching and I didn't have a gift for Ben yet.

TEACH A FISH A NEW TRICK

In case you haven't gotten it yet, these three ingredients should complete the picture:

- WECA's ISD 1420P solid-state ChipCorder voice record/playback chip [1, 2]
- Atmel's AT89S8252 microcontroller [3–7]
- Motorola's MC34119 audio amplifier [8]

The recorder chip stores 20 s of telephone-quality voice. It has non-volatile RAM, in-system recording capability, and comes in a 28-pin DIP. The microcontroller has 8 KB of flash memory, 2 KB of EEPROM, and comes in a 40-pin DIP.

After removing the screws that hold the back of the Bass's plaque, I discovered that there's plenty of room for adding special circuitry. Clearly, I didn't want to destroy the existing circuit. I wanted to hijack its power drivers for the motors. And besides,

Special sub-mode	SW1	SW2	SW3
Record Voice	Short	Short	Short
Record Mouth	Open	Open	Short
Record Head	Open	Short	Open
Record Tail	Short	Open	Open
Play (button only)	Open	Open	Open
Play (button or motion)	Open	Short	Short

Table 1—*There are six sub-modes to choose from when the Bass is in Special mode. Set switches one, two, and three according to this table to pick the one to use.*

the messages it comes with are hilarious, especially after you've heard them a hundred times.

An investigation with an oscilloscope revealed that control of the Bass's head, tail, and mouth is extremely simple. Energize the corresponding motor, and the head turns out and the tail extends or the mouth opens. De-energize the motor, and the corresponding body part returns (by a spring) to its rest state. We have binary actuators here, folks. And, it was clear that I could tie into the gate inputs of the motor drivers with simple diode OR circuitry (see Photo 2).

After I got the circuits built and debugged, it took only a few minutes to record my message. First, there's 5 s of silence during which the tail flops around, the head moves out and pauses for 0.5 s, and then the Bass says "Pork!" Then, the head moves back in, followed by 5 s more of silence with its tail flopping.

I wrapped the fish in its original packaging, with the mode switch left at "special" and the batteries inserted. Ben's reaction when he pressed that button was nothing short of priceless.

DESIGN DETAILS

If you envy Ben and want your own hacked Bass, you're in luck, because I'm going to tell you exactly how I did it. The hack adds a 20-s re-recordable special message to the Bass. The movements of the head, tail, and mouth are also re-recordable (stored in EEPROM in the '8252), and the original factory messages are still available.

Figures 1 and 2 show the circuit that I added. Figure 2 is based on a Windbond datasheet and application brief. [1, 2] Photos 3 and 4 show the top and bottom sides of the main added circuit board.

As you see, I added four switches. SW4 toggles the Bass between Normal and Special mode. In Normal mode, the Bass should behave as it always has. In Special modes, operation depends on the settings of SW1…3, which set the current sub-mode. Currently there are six sub-modes: Record Voice, Record Mouth, Record Head, Record Tail, Play (button only), and Play (button or motion).

The Record Voice mode records a new message up to 20-s long. Only one special message is supported at a time. When the button on the front is pushed and held in, any sound will be recorded until the button is let out or 20 s passes. New special messages can be recorded as often as you like; doing so will erase the existing special message and reset all head, tail, and mouth movements.

You can record mouth movements with Record Mouth mode. Press and release the button on the front to start playback of the special message along with any existing recorded tail and head movements. While the message is playing, press and hold the button to open the mouth. Release

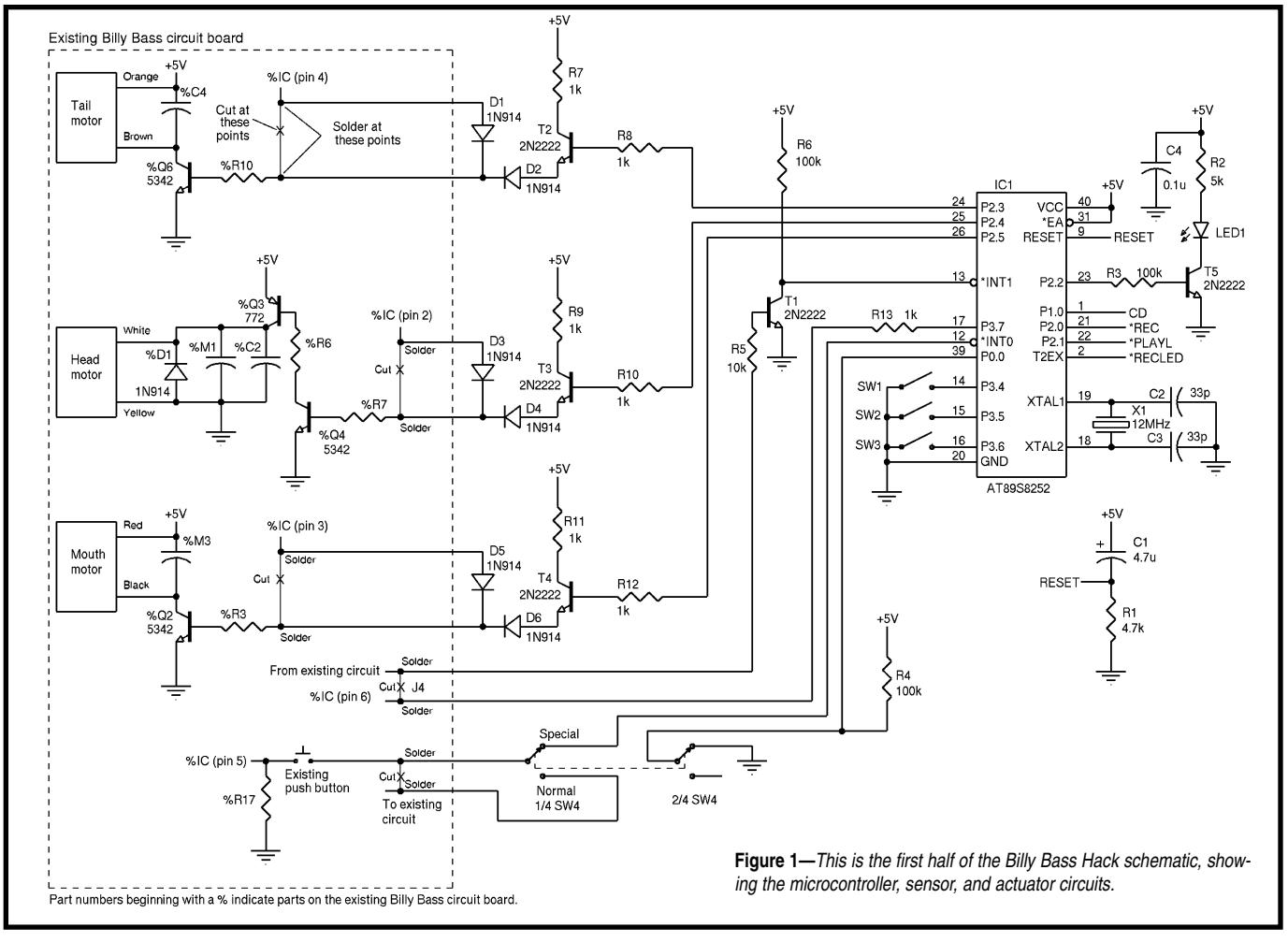


Figure 1—*This is the first half of the Billy Bass Hack schematic, showing the microcontroller, sensor, and actuator circuits.*

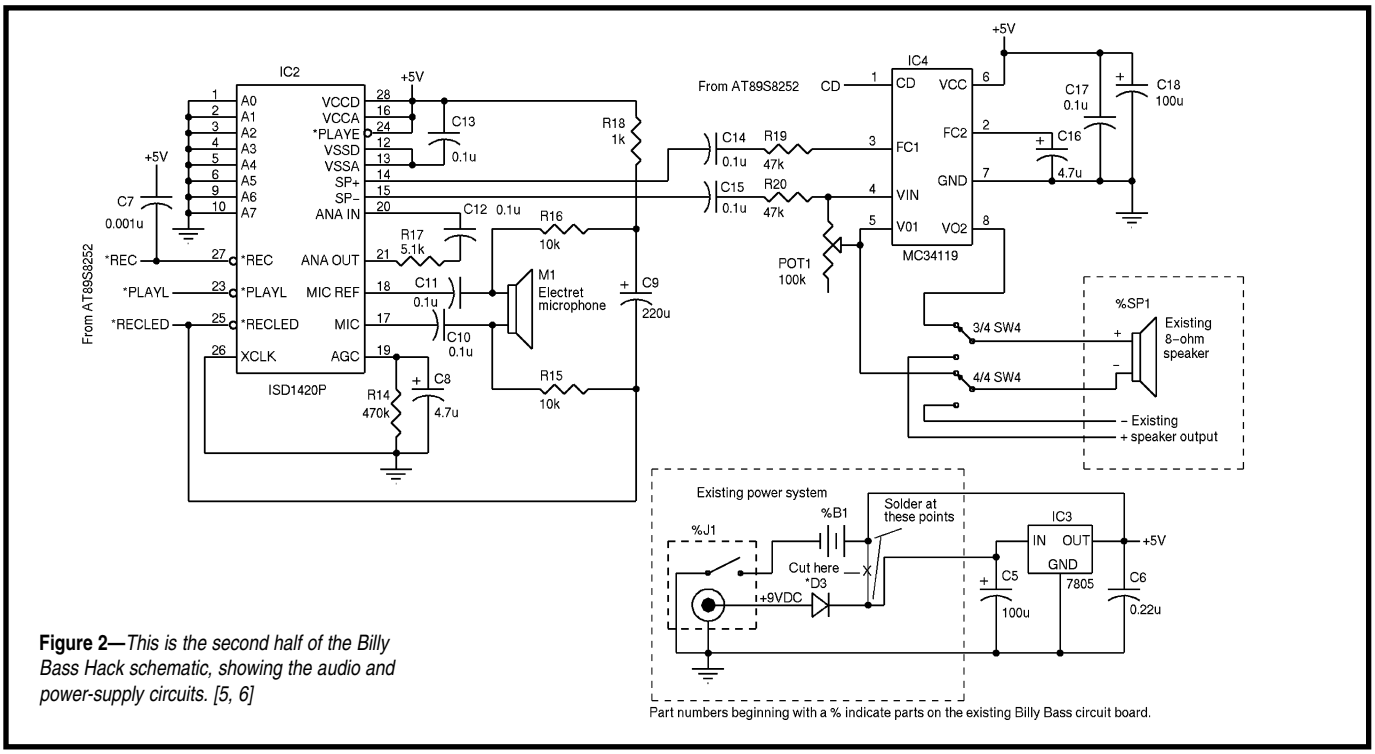


Figure 2—*This is the second half of the Billy Bass Hack schematic, showing the audio and power-supply circuits. [5, 6]*

the button to close it. The mouth movements recorded will be played back subsequently whenever the message is played in Play, Record Head, or Record Tail modes.

It can be difficult to get the timing right, so it helps to have a digital stopwatch on hand. And, you can, of course, rerecord the movements as many times as you like. Rerecording the movement does not erase the current audio or movements of the other body parts.

Record Head mode allows you to program movement of the head (either flat against the plaque or turned to face you). Operation is similar to Record Mouth mode.

Record Tail mode records tail movements. And again, operation is similar to Record Mouth mode.

When the button is pushed and released during Play (button only) mode, the currently stored message is played back along with any recorded head, tail, or mouth movements.

The last sub-mode, Play (button or motion), is the same as the button-only mode except the motion sensor will now also trigger playback. For this to work, the original Big Mouth Billy Bass motion sensor enable switch must be on.

If you build the circuit according to Figures 1 and 2, the Special mode switches work as shown in Table 1.

There is also a knob for adjusting the volume in Special mode (visible just above the '34119 in Photo 3) and an LED (useful during software development). It's possible to use the speaker as a microphone, but to keep things simple I added a separate microphone to the Bass to support recording sound.

POWER SUPPLY

The Bass is designed so that it can be either powered from four onboard C cells or a wall wart power transformer. The Bass actually comes with batteries and a female coaxial power jack for the wall wart.

I originally planned to use a 7805 regulator to supply power to my added circuit from either the batteries or wall supply. But, I quickly discovered that the 6 V from the batteries does not leave enough voltage headroom for a regular 7805, especially when the motors are energized (because the high current drain causes the battery voltage to dip significantly). It may be possible to circumvent this issue by using a (low dropout) LDO regulator, but I didn't have one.

It turns out that a regulator is unnecessary for this circuit when powered by the batteries. Be careful though because the specified maximum oper-

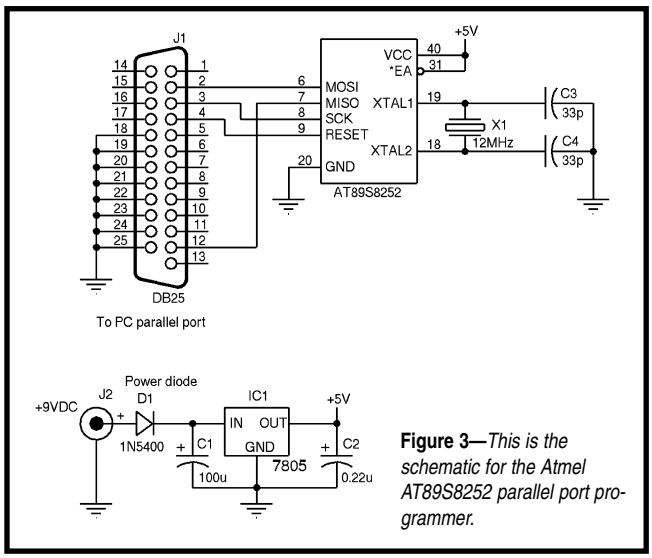


Figure 3—*This is the schematic for the Atmel AT89S8252 parallel port programmer.*



Photo 1—*The Big Mouth Billy Bass from Gemmy Industries provides the basis for a fun project.*

ating voltage of the '8252 is 6.6 V, and some freshly charged cells may surpass this. However, unless you get a regulated wall wart (which is less common than the unregulated variety), regulation is necessary when using the wall wart.

So, I moved the 7805 to the wall wart jack. This way when the wall wart is connected, the Bass is supplied through the regulator. But when the wall wart isn't present, the juice comes directly from the batteries. I found a 9-VDC, 500-mA wall wart from JDR (part TR09-DC) that works well. Polarity isn't standardized for all wall warts. Be careful to use one that agrees with the Bass (center positive).

Internally, the coaxial jack has three terminals. One carries positive voltage in from the wall wart, one is system ground, and the remaining one is battery ground. The terminal with the lone black wire going to the negative side of the battery pack should be battery ground. The one that connects to the outer conductor on the coaxial jack should be system ground. And the remaining terminal should be $+V_{IN}$ (it had a pink wire attached in my Bass).

The jack has a switch that automatically connects auxiliary ground to system ground when the wall supply plug isn't inserted and disconnects it when the supply is inserted. This effectively isolates the batteries when the wall supply is connected. Be careful not to mangle this switch; doing so could inadvertently cause the wall supply to drive current through the batteries, which would be a bad thing. Before and after you finish your work, verify the proper operation of the switch with a continuity tester: When the wall wart is inserted, there should

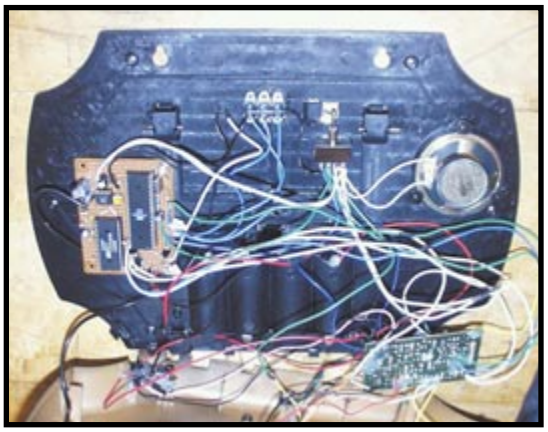


Photo 2—*The innards of the Big Mouth Billy Bass look like this after the addition of Special mode.*



be no continuity from the negative terminal of the battery pack to system ground.

Of course, as in any mixed signal circuit, keep separate power and ground nets for the analog and digital portions. Keep them separate until as close to the supply points as possible. If you have audio noise problems, especially if they occur only when the motors are energized, check your supply voltages.

The special circuit draws about 13 mA when powered. However, the '8252 is programmed to shut down everything after about 25 s of inactivity. In this Low-Power mode, the special circuit draws only about 0.3 mA. C cell batteries typically have capacities around 5000 mAH, so the Bass should be able to sit idle for months before it drains its batteries. And, when you do need to change the batteries, you'll be happy to know that both the memory of the '1420 and EEPROM of the '8252 are nonvolatile. So, you'll lose neither the audio nor motions of your carefully recorded message.

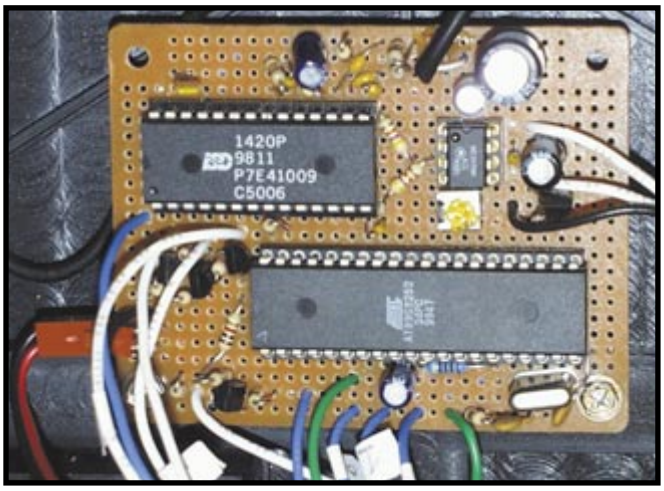


Photo 3—*With a top view of special circuit board, you can see the chips. The large chip is the '8252, the medium-sized chip is the '1420, and the small chip is the '34119.*

PROGRAMMING THE '8252

The AT89S8252 is mostly backward-compatible with the original '8052 microcontroller. All of the code that runs on the '8252 is contained in the assembly language file `bass.asm` (available online).

I used the freely available assembler as31 to produce an Intel format hex file (`bass.hex`) from the assembly code. [6] Well, sort of. Actually, before I ran `bass.asm` through as31, I passed it through the C preprocessor. One reason I did it this way is because it allowed me to define bit addresses as named symbolic constants (which as31 does not handle well). Another reason is that it allows for conditional assembly, although I'm not using this yet.

However, the C preprocessor is not an ideal solution. Unmatched single or double quotes anywhere in `bass.asm` will make the C preprocessor choke (except if enclosed in C style: `/* code comments */`). Comments on the same line after

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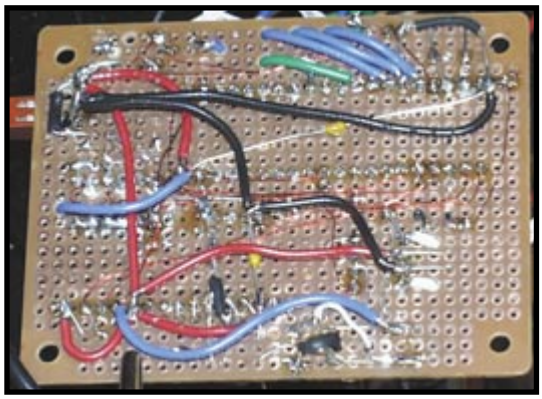


Photo 4—*Here's a bottom view of the special circuit board.*

#define statements will misbehave. And when you get an assembler error, the line number reported actually refers to the post-C preprocessed file (`bass.p.asm`). And, take a look at the last few lines of `bass.asm` for a laugh. A more generic preprocessor like M4 probably would be a better choice.

The good news is that I provide a make file with the design documents, so if you're on a Linux system, all you need to do to build `bass.hex` (after installing as31) is type:

```
> make bass.hex
```

It also should be possible to build `bass.hex` from `bass.asm` on any system in which both the C preprocessor and as31 run, however I've tried it only on Linux. You can probably get the code to build with a different assembler if you make some syntax adjustments.

Of course, if you're not interested in playing with the code, you should be able to use just the Intel hex file, which you can send directly to a programmer. Don't have a programmer? No problem. It's easy to build one that connects to a PC parallel port. That's the major reason I chose the AT89S8252 for this project (I didn't have a programmer either). Get yourself a 40-pin ZIF socket for the '8252 and connect it as shown in Figure 3.

Now, you need a program to run on your PC that twiddles the bits on the parallel port so that the contents of your Intel hex file get transferred to the '8252. A few searches on the Internet turned up a guy named Rob Melby who wrote such a program, called 89prog, for Linux. I added some improvements. For example, now the timing is independent of the machine you run it on, and it runs under DOS as well as Linux. For Linux, you need Linux kernel or higher 2.0. The DOS version runs under most versions of Windows, but not NT.

Source code (`89prog.c`) and compiled executables (89prog for Linux and `89prog.exe` for DOS) are provided with the design documents on *Circuit Cellar*'s web site. Hook up your programmer to the parallel port, insert your '8252, and power up the programmer. Run 89prog, feeding it your Intel hex file like this:

```
> 89prog bass.hex
```

If your parallel port is not at the common address of 0x378 you need to specify the address explicitly on the command line. Run 89prog without arguments to get a usage message that explains how to do this.

Sometimes my programmer fails with an "invalid checksum" error message. Reinserting the '8252 a few times often fixes the problem, trying 89prog each time. (I haven't gotten to the bottom of this yet, so please let me know if you have any ideas.)

CONSTRUCTION NOTES

It's tricky to mount the toggle switch, mode switches, LED, and microphone. You need to get creative here. I recommend trying to mount everything on the rear surface of the Bass's plaque, so that from the front

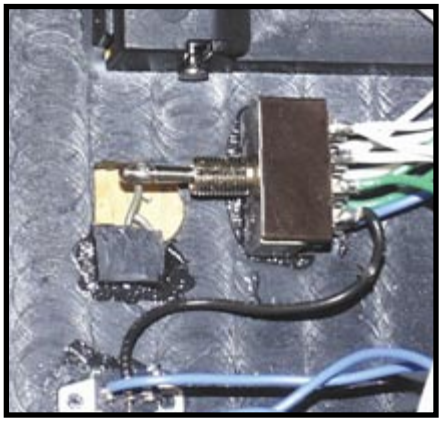


Photo 5—*Use this mounting technique for SW4.*

the Bass doesn't appear to be modified. Be sure to have some gap-filling superglue and hot-melt glue on hand.

When attaching things that stick out the back of the plaque, keep in mind that if you want to be able to mount the Bass on a wall, whatever you attach needs to protrude less than the mounting feet do. This can complicate things. For example, in order to mount SW4, I ended up soldering a stiff wire loop to its knob so I could mount the switch parallel to the back plate of the plaque (see Photo 5).

As shown in Photos 2 and 3, I used a JALPC-3 perfboard that can be soldered from Hosfelt Electronics to build most of the circuit. Point-to-point wiring is used throughout. Use sockets for each of the ICs, and complete all soldering and check everything twice before you insert them. If you plan to modify the code, you may want to get an additional 40-pin ZIF socket to install in the Bass. Just plug it into the regular 40-pin socket that you have for the '8252. This way it's easier to move the '8252 between the programmer and Bass while doing the assemble-burn-test dance.

You'll find that there are many wires to connect the circuit boards and other parts together. Use stranded hook-up wire, and be careful about strain-relieving it at each end. For example, when attaching a wire to the added board, you may want to slightly enlarge one of the holes, pass the wire with insulation through the enlarged hole (from the component side to the solder side), and then solder the wire. When connecting the head, tail, and mouth control wires to the original board, use plenty of hot-melt glue for strain relief. In fact, you should also put big blobs of hot-melt glue around the solder points of the original wires.

It's likely you'll do a lot of rearranging and it would be annoying if during all this you overstress and break off some wires. It's also annoying if you accidentally allow superglue to wick its way to the inside of your switches.

FUTURE WORK

I hope you find that your hacked Bass has all the functionality you need. However, if you're looking for a challenge, consider trying to implement one or more of the following features: in-system programming, serial interface, or multiple messages.

An Atmel application note contains useful information for people who want to make their projects in-system programmable. [7] This note also is a good read for general information about serial programming the '8252. For ISP, the main issue is that you may need to externally latch the outputs of the '8252 that connect to the Bass and '1420 during programming.

Currently, the '8252 has a UART that you aren't using. So, you can hook up a MAX232 level converter and a connector to communicate directly with the Bass from a PC.

As it is, only a single 20-s or less special message is supported. Because the '1420 is addressable, it should be able to support multiple messages that add up to 20 s or less.

Please let me know if you complete any of these modifications or if you think of any other fun ones to tackle. Good luck and happy hacking!

Marsette "Marty" Vona is a graduate student in Electrical Engineering and Computer Science at Massachusetts Institute of Technology. His research is in the field of precision metrology for mechatronic systems. You may find him on the Internet at www.ai.mit.edu/~vona.

SOFTWARE

The design documents, a parts list, and code files are available on the *Circuit Cellar* web site.

REFERENCES

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[8] Motorola, Inc., "Low Power Audio Amplifier," rev. 1, MC34119/D, 1996, e-www.motorola.com/collateral/MC34119.pdf.

SOURCES

AT89S8252
Atmel Corp.
(408) 436-4270
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FEATURE ARTICLE

Steve Hsiung

Keyless Entry Control System

A simple magnetic stripe can tell a lot about a person. It also can serve to keep your loved ones, personal belongings, or office equipment safe. Steve talks shop about a keyless approach to security that's inexpensive and appropiate for just about anywhere.

Providing safety and security for a home or business probably is a major concern for many of you. Replacing standard locks and keys, keyless entry systems have changed the security market. In this article, I'm going to tell you about an entry control system design that's based on Motorola's MC68HC11 microcontroller.

This system covers all of the bases. People are identified by their names and personal access codes, which are read by a magnetic stripe on a 4 × 4 keypad. If the access code and name are correct, the relay will be energized to open the door. Otherwise, a warning signal will be displayed on an interactive LCD. A real-time clock chip tracks the history of date and time. An external 8-KB serial EEPROM records the history of all activities with a time stamp on the security entry system. And, a DB-25 connector interface to a PC parallel port gains access to the recorded history.

MC68HC11

Two circuits on two separate boards comprise the system. The first circuit is the RS-232 loader (see Figure 1a). This uses MC145407 (marked as U2), an EIA-232 transmitter and receiver that downloads the application code from a PC to the microcontroller system board through Motorola freeware called PCBUG11 V.3.42. PCBUG11 runs under DOS and WIN NT but not Windows95/98. It programs the application code to the internal EEPROM or EPROM of the '68HC11. The loader circuit uses the '68HC11's SCI through a DB-25-to-DE-9 cable to the PC serial COM port.

The second circuit is the '68HC11, marked as U1 in Figure 1b. This section has different jumper settings for different applications (see Table 1).

The normal procedure to load application code to the microcontroller's internal EEPROM or EPROM has five steps. First, power the system's board with 5 V and connect the loader circuit to the system board with a four-pin connector cable. Connect the loader circuit to the PC COM port using a DB-25-to-DE-9 cable. Second, at the DOS prompt type:

```
PCBUG11 -E
CONTROL BASE HEX
```

Third, enable Write mode to the internal EEPROM by setting J5 to pins 1 and 2 and J6 is ON. To use EEPROM, set J4 to pins 1 and 2 and type `EEPROM B600 B7FF`. To use EPROM, set J4 to pins 2 and 3 and type `EPROM D000 FFBF`. You also need to apply 12.25 V to C3 for EPROM programming. (You can download a list of the various EEPROM maps of '68HC11s from *Circuit Cellar*'s web site).

Then, for step four, manually disable the EEPROM protection at BPROT ($1035) address by typing `MM 1035 10`. And, fifth, load the application code to the designated EEPROM or EPROM area by typing `LOADS filename.S19`.

The loaded application code can be executed by PCBUG11 by typing "GO starting address" or simply disconnecting the loader circuit, changing J5 jumper to pins 2 and 3, J6 jumper to OFF, and pressing the reset switch. You can download PCBUG11 and a detailed description of available commands from Motorola's web site.

Listing 1—*The regular initialization steps for the LCD module usually are used once at the beginning of the LCD module implementation. The display format can be changed by writing to the instruction register with the proper code, RS = 0.*

```
Enable LCD Display                  ;PB0 = 1
  Set RS=0                          ;PB1 = 0
  Send $38 to Instruction Register  ;Set for 8 bit data transfer & dual line display
  Pulse E Line                      ;PB2 = 1 then PB2 = 0
  Time Delay                        ;CPU Delays for m Sec
  Send $0C to Instruction Register  ;Set display on, no cursor, no blinking
  Pulse E Line                      ;PB2 = 1 then PB2 = 0
  Time Delay                        ;CPU Delays for m Sec
  Send $06 to Instruction Register  ;Address counter increment after each display
  Pulse E Line                      ;PB2 = 1 then PB2 = 0
  Time Delay                        ;CPU Delays for m Sec
  Set RS=1                          ;PB1 = 1
  Send ASCII Byte to Data Register to Display
                                    ;Display the letter in ASCII form
  Pulse E Line                      ;PB2 = 1 then PB2 = 0
  Time Delay                        ;CPU Delays for m Sec
```

INTERFACING

Interfacing the ′68HC11 with an LCD is accomplished with an SPI via a 74164 shift register. Serial data from the SPI is converted to parallel format, which is needed to connect to the LCD's data port in 8-bit interface form (see Figure 2). Because the software is implemented in one-way communication (write) and reading of the LCD status register isn't necessary, the R/W line is always grounded.

Listing 2—*This pseudo-code describes the 4 × 4 keypad scanning, decoding, and debouncing.*

```
Set PC0-3 as Input, PC4-7 as Output
Set Index Pointer to Beginning of Table   ;Table has all 16 keys key codes
AGAIN
  Send $EF to Port C         ;Scan 1st column on PC4
  CALL CHECK_KEY
  Send $DF to Port C         ;Scan 2nd column on PC5
  CALL CHECK_KEY
  Send $BF to Port C         ;Scan 3rd column on PC6
  CALL CHECK_KEY
  Send $7F to Port C         ;Scan 4th column on PC7
  CALL CHECK_KEY
  GOTO AGAIN

CHECK_KEY                    ;Check any row = 0
   Set Counter = 4           ;Use counter for 4 rows
  SEE_COL
   If Column Bit = 0         ;If any row = 0, take data from pointer

Take Data from Table via Index Pointer and save to Memory
DEBOUNCE
Read Port C                  ;De-bounce all 4 rows till no zero read
If PC0 = 0                   ;Check row 0 at PC0
GOTO     ADJ_STACK
Else If PC1 = 0              ;Check row 1 at PC1
GOTO     ADJ_STACK
Else If PC2 = 0              ;Check row2 at PC2
GOTO     ADJ_STACK
Else If PC3 = 0              ;Check row3 at PC3
GOTO     ADJ_STACK
Else     GOTO     DEBOUNCE
ADJ_STACK
SP =+ 2                      ;Adjust Stack  Pointer due to subroutine call
GOTO     MAIN_PROG           ;Exit the keypad scanning routine
Else     Counter =- 1        ;Reduce counter ready for next row
Index =+ 1                   ;Move index pointer along in the table
If Counter = 0               ;If no zero found in row go back to scanning routine
RTS
Else     GOTO     SEE_COL    ;Check for next row
MAIN_PROG                    ;The main program that will use the key pressed
```

PB0 = 1 enables the display of ASCII code on the LCD module. The PB1 to RS line selects the LCD module's instruction or data register. The PB2 to E line provides the enable signal for the LCD module's internal registers. You can download the LCD module's instruction register settings for various display functions and formats from *Circuit Cellar*'s web site.

Take a look at Listing 1, which presents the algorithm used to initialize the LCD module. You may repeat the three steps shown if necessary for any message display. To alter the display format, write to the instruction register with the proper code (RS = 0).

A 16-key keypad is connected to Port C of the MC68HC11. Port pins 0 through 3 are configured as inputs for reading any keystroke. And, pins 4 through 7 are configured as outputs for scanning any key action. All pins on Port C are pulled up through 10-kΩ resistors to eliminate floating noise, as shown in Figure 2. Listing 2 states the algorithm that performs the software scanning and debouncing.

REAL-TIME CLOCK CHIP

Motorola's MC68HC68T1 real-time clock chip keeps track of the entry control system's date and time passed. The chip uses an SPI interface to the ′68HC11 for both direction communications (see Figure 2). PB3 = 1 is used to activate the SPI interface logic of the ′68HC68, otherwise the chip would be in a high-impedance state. The date and time information is displayed on the LCD in a format of year, month, day, hour, and minute and is updated each minute.

To write to the MC68HC68T1 (RTC), first provide the address of the byte to be written, then follow with a write to the data byte. To read from the MC68HC68T1 (RTC), first provide the address of the byte to be read, then follow with a dummy write of $FF. The desired data bits are clocked out at the same time as the dummy bits, but on the different clock edge.

There is only one routine needed for both reads from and writes to this real-time clock chip. The routine is presented in Listing 3.

MAGNETIC STRIPE READER

Mag-Tek's MT-211 magnetic stripe reader is connected in the bit banging method on Port E (PE0 = Data and PE1 = Strobe) for reading user personal identification. An interrupt connection from the CARD PRESENT signal to the '68HC11's IRQ extracts the information from the magnetic stripe card. And then, the magnetic stripe reader reads Track1 card data, which has 6 bits and 1 odd parity bit for each character.

Track1's serial data format is shown in Listing 4. Note that only the Name field characters are used in this application.

All of the information received after the IRQ interrupt, which includes the user's name and personal identification number and time stamp, is recorded in the external serial EEPROM.

All three signals, CARD PRESENT, DATA, and STROBE, are negative true logic. So, the 6-bit data read from the magnetic stripe reader has to be inverted to become the user's name in ASCII code format. I included some sample code of bit banging and reading the serial data, which is available to download from *Circuit Cellar*'s web site.

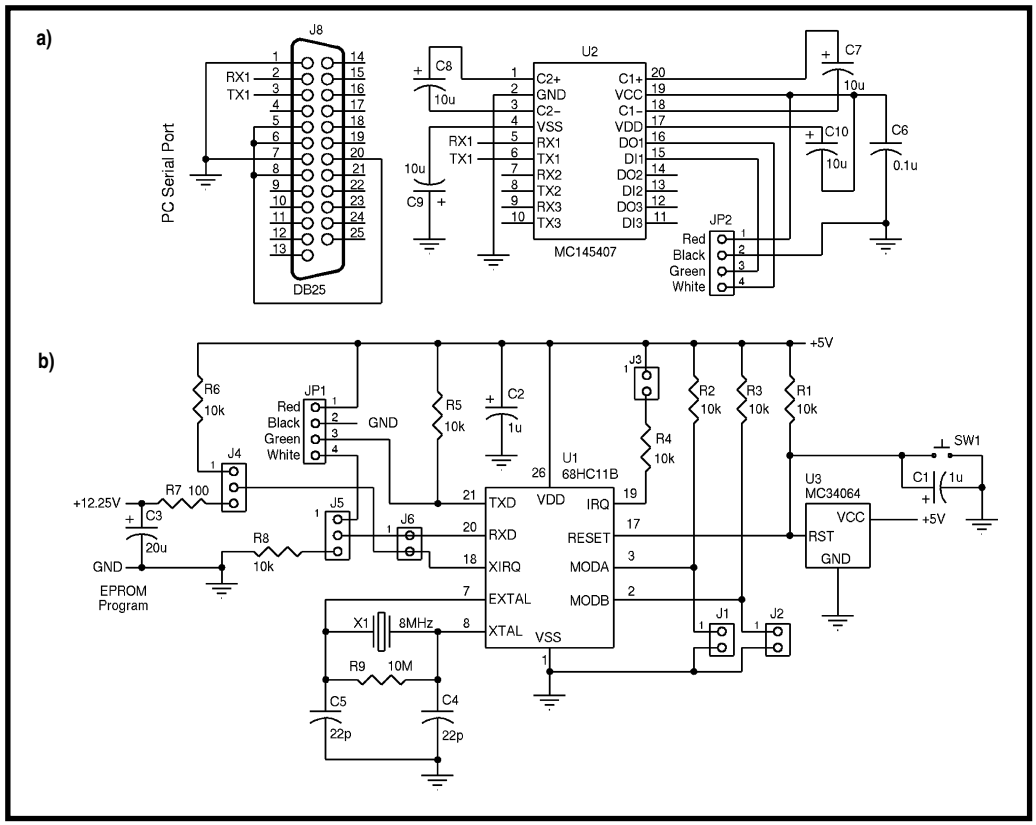


Figure 1a—*The loader circuit has an MC145407 or MAX233 that uses an RS-232 to interface with the PC serial port.* **b**—*This low-cost system board design can be used for various HC11 family members.*

SERIAL EEPROM TO '68HC11

Xicor's X25650 8K × 8 serial EEPROM records the security system's history. Figure 2 shows that the X25650 provides the SPI port interfaces to the '68HC11 and a PC parallel port. This nonvolatile memory can save the user's name, ID code, and time stamp, which are provided by the control code of the '68HC11. The time stamp of any IRQ interrupt from the magnetic stripe reader and all following data sequences are recorded in this 8-KB EEPROM.

The other interface to the parallel port has a 2N7002 and 74HC14 buffer circuit. This interface provides the option of having a PC download the information from the EEPROM to a file or print out a hard copy. The control codes and different functions of the X25650 are available to download.

In addition to the bit banging code, the algorithm and sample code for the '68HC11 to write to and read from the X25650 are available on *Circuit Cellar*'s web site.

The algorithm for a PC to read from or write to the EEPROM of the X25650 can be done in a similar manner by bit banging the PC's parallel port on pins 4, 6, and 7 (data bits are output and pin 13 selects bits as inputs). A high-level language such as C can be used to communicate in SPI format with the X25650.

Jumper	Setting	Function
J1 (MODA)	On	Bootstrap
	On	Single chip
	Off	Expanded
	Off	Special test
J2 (MODB)	On	Bootstrap
	Off	Single chip
	On	Expanded
	Off	Special test
J3 (IRQ)	On	10k Pull-up
	Off	No pull-up
J4 (EPROM)	Pins 1 and 2	Normal operation
	Pins 2 and 3	68HC11 Internal EPROM programming
J5 (EEPROM)	Pins 1 and 2	68HC11 Internal EEPROM programming
	Pins 2 and 3	Normal operation
J6 (XIRQ)	On	Loading E^2 code
	Off	10k Pull-up

Table 1—*The HC11 system board uses these jumper settings.*

OPERATION

The security system control uses an LCD module to interact with users. If there is no interrupt from the magnet-

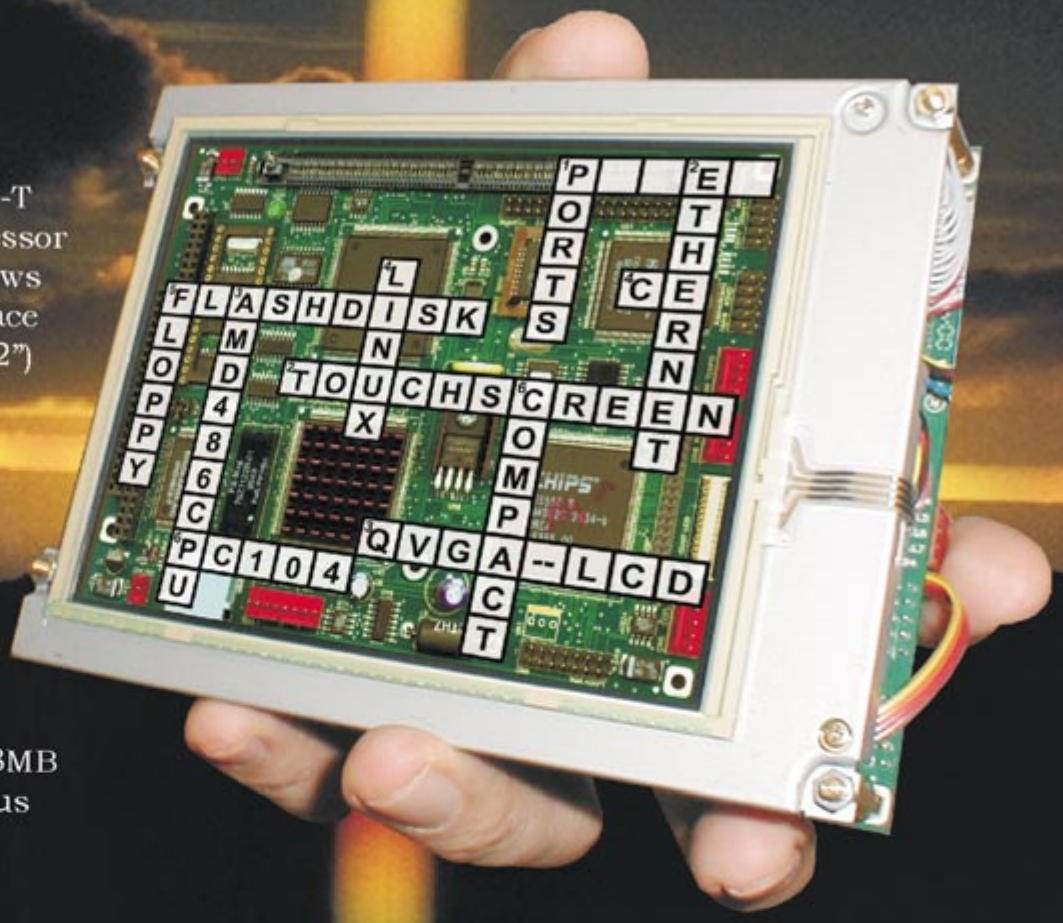
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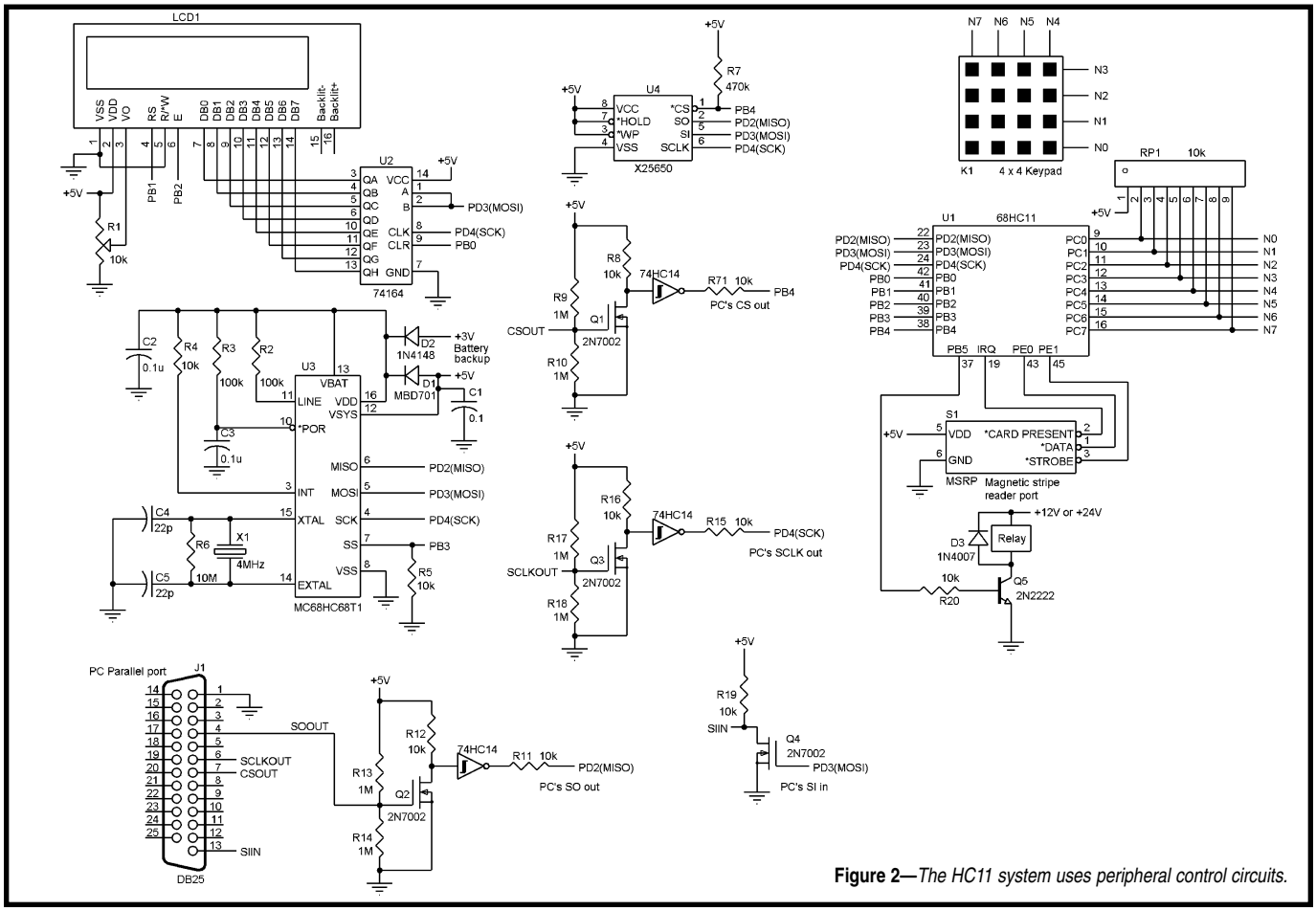


Figure 2—*The HC11 system uses peripheral control circuits.*

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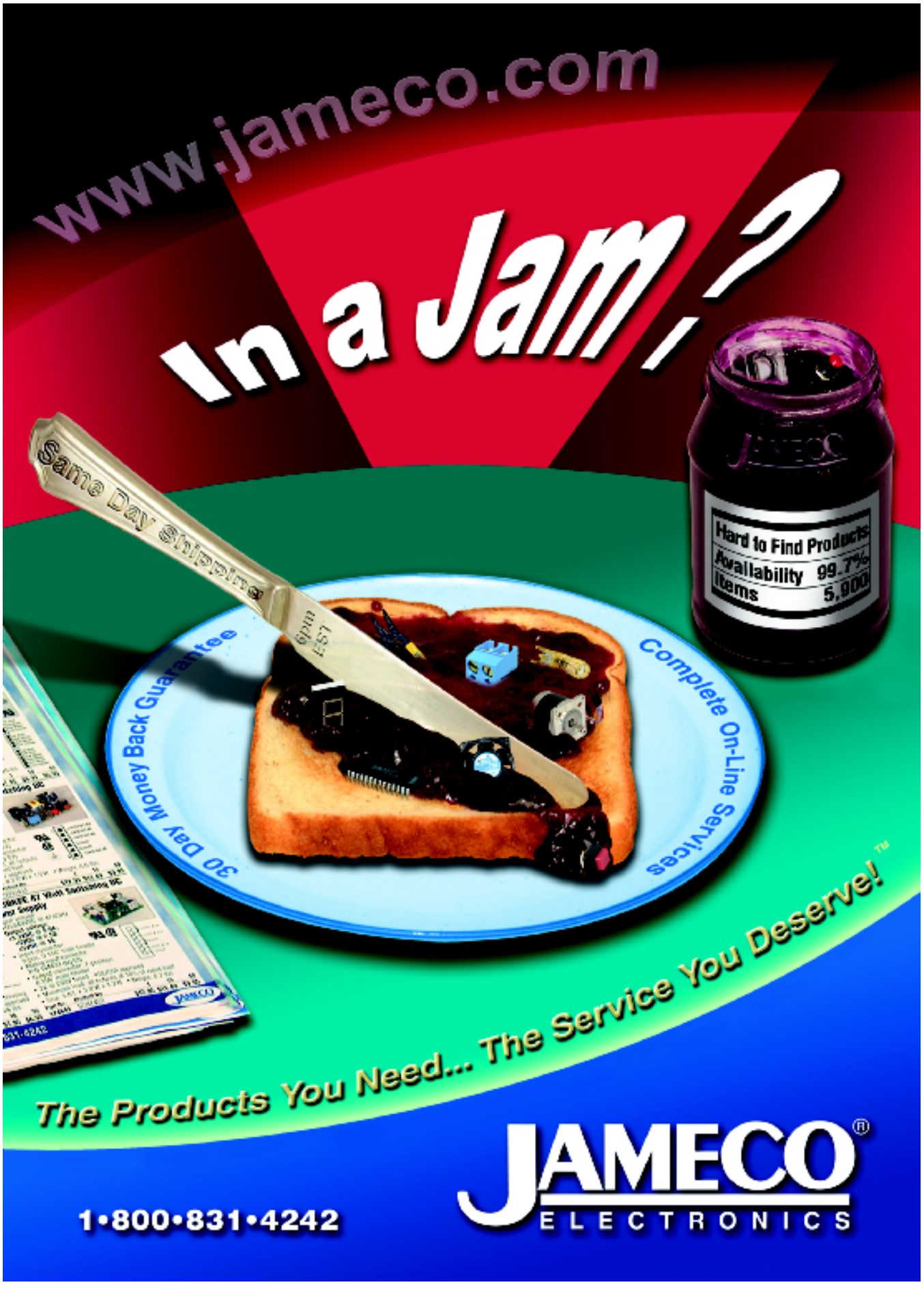
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Technologic SYSTEMS

ic stripe reader, the security system prints a greeting message, updates the date and time information on the LCD module, and instructs potential users to start with a qualified magnetic stripe card. This repeats over and over again until there is a CARD PRESENT interrupt. The desirable setup information is loaded into the system from a PC during initialization and stored in the external X25650 serial EEPROM.

After a card is slid through the magnetic stripe reader, the system prompts to enter the user's security code. After the code has been entered, the system checks the card information and security codes against the pre-stored data. If all of the data matches, the system will energize a relay to open the door through an electric latch. If the information isn't correct, the user will be given two more chances. And, if the third attempt fails, the security system will ignore any further activity by the user for 10 min.


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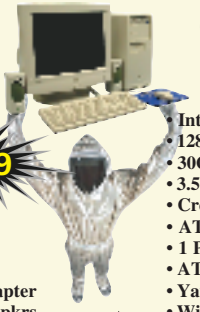
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Listing 3—*The first four lines are used to write to the SPI port by simply loading the data in A_{CC}, and then calling XFER_SPI. The next four lines are used to read the SPI port by loading dummy data $FF in A_{CC}, and then calling XFER_SPI again. INIT_SPI initializes the SPI port and needs to be done only once.*

```
      LDAA     Address
      JSR      XFER_SPI
      LDAA     Byte
      JSR      XFER_SPI
      LDAA     Address
      JSR      XFER_SPI
      LDAA     #$FF
      JSR      XFER_SPI
      STAA     Memory
INIT_SPI
      PSHX
      LDX      #$1000
      BSET     DDRD,X %00111000        ;SS, SCK, & MOSI output
      LDAA     #%01010100              ;Enable SPI, master     mode, bit
                                        rate 1MHz, CPOL=0, CPHA=1
      STAA     SPCR,X
      BSET     PORTB,X %00001000       ;Activate SPI interface
      PULX
      RTS
XFER_SPI
      PSHX
      LDX      #$1000                  ;Set register base
      STAA     SPDR,X                  ;Write to SPI port
WAIT  BRCLR    SPSR,X $80      WAIT    ;Wait till SPI transfer complete
                                        flag (SPIF) set
      LDAA     SPDR,X                  ;Read back SPI port, also serve
                                        as dummyto clear SPIF
                                       ; flag
      PULX
```

Listing 4—*Track 1 has this serial data format.*

```
<Start Sentinel = %><Format Code><Primary Account Number>
<Field Separator = ^><Country Code><Name = 26 Alphanumeric
Characters><Field Separator =  ^>….<End Sentinel = ?>
```

All information input after the magnetic stripe is read is recorded in the external serial EEPROM. If the information stored there overflows, the new data will overwrite the old data in the first in, first out format. To prevent system lockup or program run away, the watchdog timer should be enabled. A parallel port of the PC interfaces with the serial EEPROM of the X25650 to retrieve all recorded information for emergency or security checkout purposes.

You can download a figure showing the system control. If you're in the market for a new keyless entry system, try this application. It works well and is inexpensive.

Steve Hsiung is an associate professor at Utah State University. Prior to teaching, he worked for Maxim Integrated Products, Inc. You may reach him at shsiung@cc.usu.edu.

SOFTWARE

Code and other examples are available on *Circuit Cellar*'s web site.

SOURCES

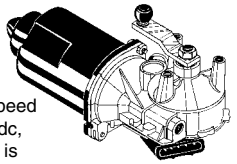
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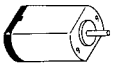
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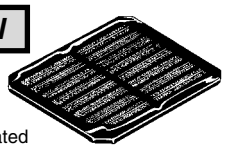
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FEATURE ARTICLE

Jeff Pollard

USB, FTDI Style

Before transferring large amounts of data, you often face difficult choices. But, the answer was obvious to Jeff. He discovered that USB connectivity doesn't have to be a dire task, not when you find the right part and the right company to set the course.

There came a time when I needed to be able to transfer large amounts of data from my Windows98-based PC, where I was compiling code into an embedded target device based on the PC/104 platform running good-old DOS. I figured I had three basic alternatives.

The first alternative was to use a parallel port. Although fast enough for my needs, I didn't want deal with the bulk of wires necessary to take full advantage of the port's speed. The port also has a distance limitation of about 10', but this was not a deciding factor. This port was available on my PC/104 stack and Windows PC.

The next choice was a serial port. This method, in its simplest configuration, is a three-wire solution and therefore solves the problem with the parallel port choice, but it is too slow. This port was also available on my PC/104 stack and Windows PC.

The third choice was USB, which is fast (about 1 MBps on the USB 1.1 version), but has a complex protocol and requires special drivers on the PC. On the other hand, the cable from the device to the PC is only four wires. Although available on my PC, this port wasn't on my PC/104 stack.

And so I was faced with a choice. Although I had worked with the hardware and software means of transferring information using both parallel and serial port systems, they each rated a seven on my score card. USB would be great, but rated a negative number as a result of USB hardware and software protocols and Windows drivers required (all of which I had little knowledge and no experience).

That was until I came across a company called Future Technology Devices International (FTDI) and the FT8U245AM USB chip. FTDI is based in England and its products are distributed in the U.S. by Saelig. The chip handles the USB protocol, electrical issues, and leaves you with a nice 8-bit wide (i.e., 74xx245 chips) port with transmit and receive FIFOs and associated status lines. FTDI also solved the problem of Windows drivers by providing special ones that make its chip look like a standard COM port to the Windows OS (data rate settings are ignored, communications are as fast as the USB allows).

It looked like USB might go from a negative rating to a full 10! After glancing at the web site, it looked as if you could add parts for the onboard oscillator, resistors and capacitors, and the FT8U245AM, and get a complete USB interface. If you want to use more than one FTDI part on the same USB bus, simply add a 93C46 serial EPROM (and more resistors) to the design, and have Windows98 program the EPROM through the USB with a supplied driver. As I mentioned earlier, my design was to be for the PC/104 bus (see Photo 1), so I would need to add address decode logic for that side as well.

I started my quest for developing my own USB-to-PC/104 adapter by downloading and looking at the datasheets and schematics on FTDI's web site. The information was straightforward. If you visit the site, be sure to download all the pertinent documentation including datasheets, app notes, and schematics. The app notes provide insight into why things are done a certain way, so be sure to look at them. I've broken the project down into five main issues.

USB SIDE HARDWARE

The chip is encased in a 32-pin thin quad flat package (TQFP) and operates on 5 V. With a fine-tipped soldering iron, a steady hand, and plenty of light, this chip is easily soldered onto a PCB. With only 32 pins, the job isn't tedious. The chip has eight pins per side, so there are three ways to mount it wrong. (Check twice, solder once!)

The necessary power to drive the USB chip (V_{CC}, AV_{CC}, Gnd, and AV_{GND}) and other chips on the PCB can be taken straight from the USB port or externally supplied. If you choose an external source, be sure not to tie the USB 5 V to the external source. The power from the built-in 3.3-V ($3V3_{OUT}$) LDO regulator (drives the USB buffers), the 5-V digital, and 5-V analog supplies should be decoupled well. The amount of power you can draw from the USB is limited. Visit the USB site (www.usb.org/developers) to get more information.

No level shifters and associated voltages are needed to connect to the USB (USBDP and USBDM). A couple of impedance matching resistors and pull-up/down resistors are all that's needed to get from the chip to the USB connector.

The onboard oscillator (i.e., X_{IN} and X_{OUT}), originally designed to run with a 6-MHz crystal, but later specified to run at 48 MHz, is in a typical parallel resonance configuration, with an LC tank appended to the X_{OUT} pin to ensure proper startup at 48 MHz. This was the first time I had to add an LC tank to a chip with an onboard oscillator, but adding two caps and a small inductor was no big deal.

I chose to drive the reset (*RESET) pin by inverting the RESETDRV signal from the PC/104 bus. I later added the ability to choose reset using Microchip's TCM809 reset chip if the device was to be used in a stand-alone configuration (see Figure 1). FTDI's original schematic used a simple RC reset (FTDI later found this solution inadequate in some situations).

The serial EPROM interface consists of three lines: chip select, clock, and data (EECS, EESK, and EEDATA). The EPROM, Microchip's 93C46, is needed if you want to use more than one FTDI device on the USB. At powerup, the FT8U245AM looks to

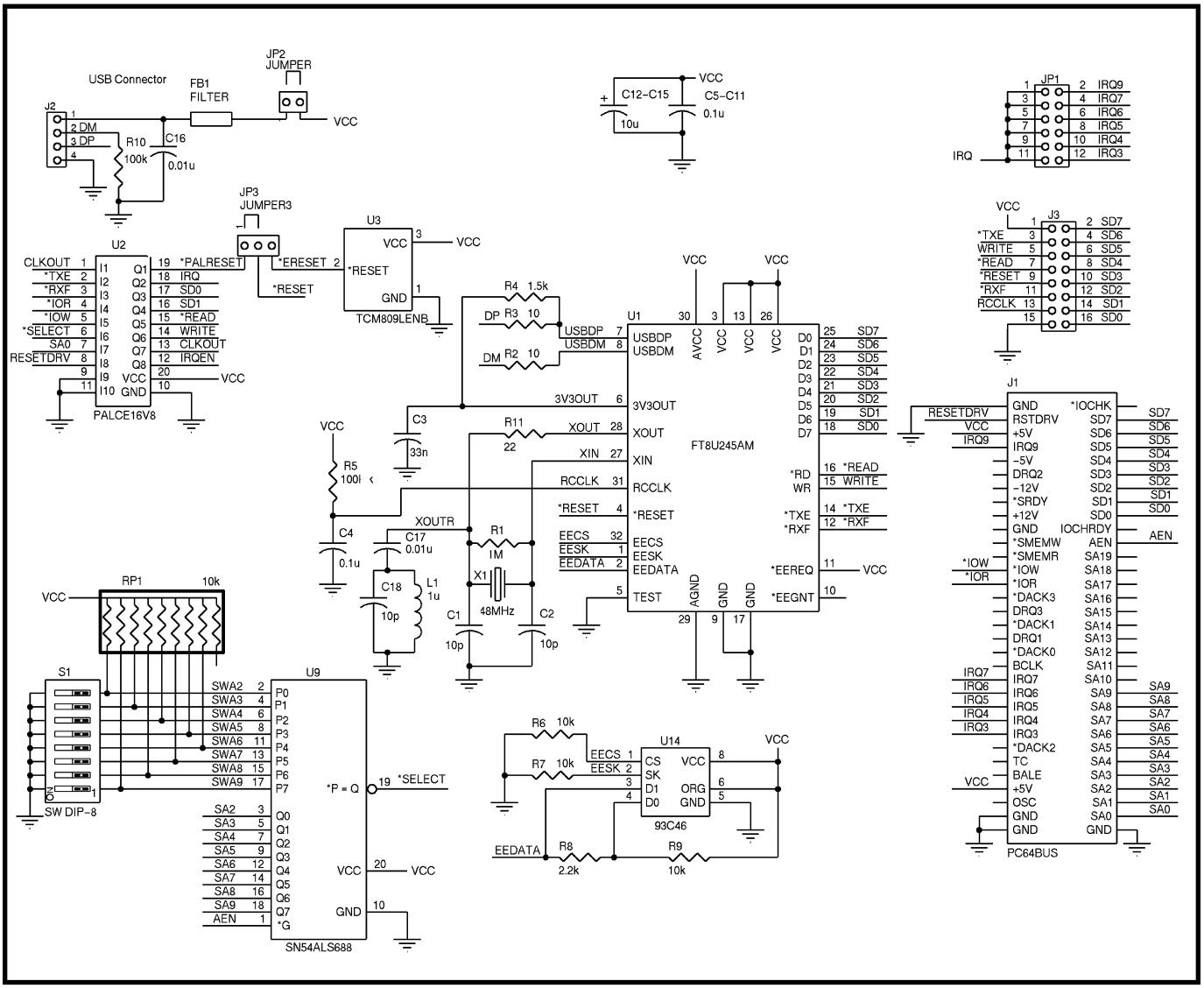


Figure 1—*The schematic shows how simple it is to integrate the FTDI chip into a system, including this PC/104 design. The FT8U245AM, EEPROM, decoding logic, and a handful of passives are all it takes.*

the serial EPROM for vendor identification (VID), product identification (PID), manufacturer strings, and serial number information. If it doesn't find valid information in the EPROM (or if the EPROM is missing), it uses a default setting. So, two devices without EPROMs will default and look like the same device to USB drivers on the PC. The EPROM data is read through a single I/O pin so the EPROM's D_{IN} and D_{OUT} pins are connected through a 2.2-kΩ resistor. I didn't use the pins (*EEREQ and *EEGNT) that allow the EPROM contents to be accessed through the data bus.

The processor interface has eight bidirectional data pins (D0–D7), two status lines (*TXE and *RXF), and two control lines (WR and *RD). The data lines allow access to the 384-byte transmit FIFO and 128-byte receive FIFO. By pulling *RD low, the processor can read the current data byte from the receive buffer. As the line goes high, the next byte in the FIFO (if any) is advanced for future reading. Data is strobed into the transmit FIFO on the falling edge of an active high data strobe of WR. When low, the *TXE line indicates that the transmit buffer can be written to.

Usually *TXE means that the transmit buffer is empty, but in this case it means there is room in the buffer. When the *RXF line is low, it signals that data is available in the receive buffer. Similarly, *RXF normally indicates that the receive buffer is full, but here it means data is available.

I designed a PC/104-compatible PCB to mount the parts on, and after soldering the resistors, capacitors, and FTDI chips necessary to get the USB working (no PC/104 parts at this point), I hot-plugged it into my PC. Windows98 detected the board immediately and I was witness to a miracle, there were no hardware problems! Not finding any drivers present for the new USB board, Windows started the USB installation procedure.

USB SIDE SOFTWARE

A hardware or embedded software person might balk at the prospect of having to deal with the Windows drivers necessary to complete a USB link. Again, FTDI has made the issue easy by providing all of the necessary drivers. Like I said, these drivers make the FTDI USB chip appear like a regular COM port. I had previously copied the drivers supplied by FTDI to my hard disk, and after telling Windows in which directory to find them, the installation was seamless. No shutdown and reboot required. When it was done initializing, I was able to go to the Windows Control Panel, System, Device Manager, Ports (COM and LPT), and see USB serial port (COM4) in the listing. I was connected. Then, most of the complicated parts of the job were done, and all I had left to do was make a few simple connections to the PC/104.

PC/104 SIDE HARDWARE

The PC/104 bus (J1 label PC64BUS) is simple to work with. Because it is really a version of the old ISA bus, data rates and signal transitions are slow by today's standards, and easy to work with. Being an 8-bit chip, the FT8U245AM didn't require the full PC/104 16-bit bus, so I designed for the 64-pin connector only. SD0–SD7 on the PC/104 connect directly to D0–D7 on the FT8U245AM.

I wanted to be able to relocate the USB device anywhere in the ISA I/O space, so I used a 74HCT688 magnitude comparator along with the AEN line as an active low enable to decode address lines A1 through A9 for a select signal. This was fed into a PAL along with address line A0 and *IOR and *IOW to further select the FTDI status lines and data ports.

In a straightforward manner, the aforementioned lines are used to generate the *RD and WR signals for the FT8U245AM. The status lines from the FT8U245AM, *TXE and *RXF, are buffered through the PAL to create a status port and are read as data on the PC/104 data lines D0 and D1. Thus, the main processor can poll the status of the chip.

Both status lines are also combined to generate the interrupt IRQ line for the PC/104 bus. In most cases, the PC will want to know when a character has been received, so the *RXF line is not qualified in the PAL. If you want no interrupt from the USB-PC/104 board, you must set the PC's 8259 mask register appropriately. However, it isn't necessary to always get an interrupt to declare that the transmit buffer has space available, so this line has been qualified in the PAL.

To allow interrupts from the *TXE line, a logic 1 is written to the status port on D0 and to disable them, a logic 0 is written. Use header JP1 to select IRQ 3, 4, 5, 6, 7, or 9. Getting the equations right for the IRQ line and the programmable masking took a couple of tries, but otherwise it was relatively easy. When this was finished, there was only one main issue left…software.

PC/104 SIDE SOFTWARE

This is where most of your time could be spent depending on the required application. All that is necessary to get a simple communications terminal running through the USB is a small program running on the PC/104 side and a COM program running on the Windows side. The PC/104 side could poll the status lines of the FT8U245AM chip, get any available character from the receive buffer, and display it on the screen. It would also get any character you type with the keyboard and put it in the FT8U245AM transmit buffer. The source code available on the *Circuit Cellar* web site goes a little further and adds interrupt capabilities and transmit and receive data queues.

One note to anyone writing your own code with interrupt capabilities, be sure to clear any characters in the receive buffer before enabling the interrupts. From the basic code provided, you could branch off to develop many different methods of throughput. The final software design would depend on the type of information being transferred. For example, different protocols could be used: Xmodem, Zmodem, or Kermit. For more extensive and interactive designs, you could write a program for the Windows side in Visual Basic to open the USB-COM port and exchange information with the PC/104-USB in a proprietary manner as long as both sides follow the same protocol.

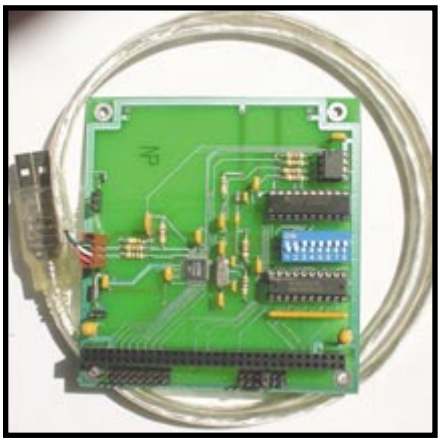


Photo 1—*The working prototype PC/104 USB board only works as the top board in a 16-bit system as a result of my ill-conceived placement of the stand-alone and IRQ headers.*

STAND-ALONE SYSTEM

I decided to add a port for the stand-alone system after I had finished the original PC/104 design. This port is just an extension of most of the lines coming from and going to the FT8U245AM. The 16-pin connector (Header J3) allows access to the control and data lines of the USB chip. A microprocessor development system port similar to what's on PIC or Scenix development boards is easily connected. In the standalone case, the PAL (U2) and 74HCT688 (U9) should be removed, and *RESET selected to come from the Microchip reset device (JP3). Power may come from either the USB port (installing JP2) or the microprocessor development system.

Remember, the serial EPROM is not required if only one FT8U245AM device is attached to the local USB bus. Running a Windows program supplied by FTDI, the EPROM gets properly initialized and programmed with the correct PID, VID, manufacturer strings, and serial number information. The serial number is generated on the fly using time and date information. The EPROM is cheap, easy to program, and differentiates different USB devices, therefore it should be considered for all designs.

FINAL ANALYSIS

The FT8U245AM is easier to use than serial and parallel ports, and as a Windows Drivers novice, I was satisfied with the ease of installing and using the supplied Windows drivers. According to the FTDI web site, drivers for the following platforms are also available: Windows ME, Windows 2000, iMAC, and Linux. I recommend this chip if you need a generic way to gain USB connectivity.

An assembled version of the USB PC/104 board (with stand-alone port) costs $60. A double-shielded USB-A-to-molex cable is included. Contact Jeff at sales@xylotex.com or visit www.xylotex.com for more information. Also, saelig.com offers FTDI's demo board for the FT8U245AM for $85. FTDI's board is not what's described in this article. It just goes to show that if the right company comes along to point you in the right direction, whether or not you have the experience is irrelevant.

Jeff graduated with a BS in Computer Science from California State University, Northridge. He has been working with digital systems design for almost 20 years. His main focus is embedded systems (industrial controls), including both hardware and software design and development.

SOFTWARE

The code for this project is available on the *Circuit Cellar* web site.

RESOURCES

PC/104 Embedded PC Modules
www.pc104.org

USB Implementers Forum, Inc.
(503) 296-9892
www.usb.org/developers

SOURCES

FT8U245AM
Future Technology Devices International (Saelig Co, Inc., distributor)
(716) 425-3753
www.ftdi.co.uk, www.saelig.com

TCM809, 93C46
Microchip Technology Inc.
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FEATURE ARTICLE

Robert Lacoste

A New View

An Award-Winning 3-D Telemeter Project

It's a simple theory and isn't new, in fact, working with 3-D technology is old hat. But, with an innovative approach, Robert determined a unique way to use 3-D. And, you too can build this clever project. Afterward, you may look at the world in a whole new way.

Ultrasonic distance measurement is not a new technology, and its principles are well-known: transmit a short ultrasonic pulse, wait for the reception of an echo, and measure the time to get it. Divide this time by the speed of sound in air (roughly 340 mps) and by two (to target and back) and you get the distance. The theory is simple.

But how do you use this principle to get a three-dimensional image of a given scene in order, for example, to drive a robot in a complex environment? What could such a captor "see" in our real world? Is it possible to build such a device with low-cost parts? I pondered these questions for a long time, and then finally decided to transform these ideas into an experimental prototype. The SCAN 3-D project was born (see Photo 1)!

In order to be able to reuse it after I bore of 3-D images, the SCAN 3-D needed to be usable in two different configurations, as stand-alone and connected. As a stand-alone device, SCAN 3-D is a general-purpose ultrasonic telemeter with an onboard LCD to display the distance to the first echo. A set of four push buttons allows you to memorize distances and calculate sums of distances and even surfaces (useful when visiting a possible new house). And, if connected to a PC through a serial link, SCAN 3-D becomes a 3-D telemeter. The PC acts as a master, scanning a defined region and constructing the corresponding virtual 3-D image.

MECHANICS...

The mechanics are not the easiest part of a project like this one, especially for guys trained to write software rather than use caliper rules and files. The scanning head is built using two standard RC servomotors. These motors are inexpensive, provide excellent precision, and are blazing fast. Moreover, they can be interfaced to a microcontroller with only a TTL-compatible PWM signal. The first servomotor (vertical scanning) is fixed on the enclosing box, the second (horizontal scanning) is directly glued on the axle of the first.

I decided to use standard ultrasonic transceivers (MA40B8S/B8R, often used in ultrasonic remote controls). I put them in a small plastic tube to maximize their directional selectivity. These tubes should be long enough for improved selectivity yet small enough for long distance detection.

I ended with a 1-cm compromise, which gives a 4- to 5-m maximum detection distance but a limited angular resolution (I evaluated it at 5° to 10°). As usual with ultrasonic transceivers, take great care to fix the transceivers; in particular, ultrasonic pulses mechanically transferred



Photo 1—*Two servomotors allow you to rotate the ultrasonic transducers in two directions. And, a minimalist user interface makes it possible to use SCAN 3-D as a stand-alone device.*

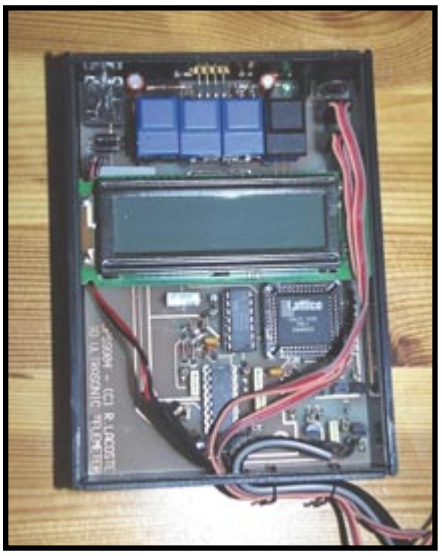


Photo 2—*The SCAN 3-D prototype was built on a small double-sided PCB. The COP is under the LCD. A header near the EPLD allows in-circuit programming, a useful provision during the test phase.*

between them should be minimized using isolation materials. On the prototype, I used some elastic rubber to trap the transceivers in the tubes.

...AND ELECTRONICS

Now it's time to build some electronics to control the SCAN 3-D. Of course, you build with a microcontroller. However, in order to reuse the ultrasonic distance measurement subsystem from design to design, I offloaded a large part of the time-critical functions to an external EPLD, even though the microcontroller can handle everything directly.

Figure 1 shows the final product wired on a small homemade PCB (see Photo 2). The circuit can be divided into five sections, the power supply, microcontroller, transmitter, receiver, and EPLD.

SCAN 3-D can be powered by a 9-V battery or DC power supply. The DC supply is regulated to 9.4 V through a 78L08 and is biased to 9.4 V with an LED on the ground line. The 9.4 V is merged with the battery output through a pair of 1N4001 diodes, and is used directly for the transmitter section. A 7805 gives a clean 5 V for the rest of the circuit.

I used a National Semiconductor COP8 series microcontroller, COP87L88GGN. [1] The COP is clocked by an external 8-MHz oscillator, which also is used by the EPLD section. It is directly connected to a 2 × 16 character LCD and three push buttons (enter, add, and multiply). The TDX/RDX UART lines are dedicated to the PC serial link via an external MAX232 converter (built into the serial cable). T2A and T3A timer outputs drive the servomotors, and three lines (START, ONGOING, ECHOFILT) link the microcontroller to the EPLD section.

The transmitter section is very simple. The ultrasonic burst (16 periods at 40 kHz) is generated by the ELPD as soon as ordered by the microcontroller. A push-pull discrete amplifier built around T1 to T6 amplifies these TTL signals up to an 18-V peak-to-peak signal to get a maximum transmission level from the 9-V power supply. This signal directly drives the MA40B8 transmitter (see Figure 2).

The receiver section is the trickiest part. Because the level of an echo received by the receiver is significantly smaller for a long distance echo than for a close one, a classic design must find a compromise between false short-distance echoes and maximum detection distance. Otherwise, the result is poor performance.

I used a trick I first read about in an article written by Steve Ciarcia (thanks!). [2] The gain of the reception chain is progressively increased (with a log scale) while waiting for progressively long distance echoes. This setup allows for maximizing both performances! To do that, I used a digital potentiometer (DS1666) to control the gain of the reception chain driven by the EPLD. This chip is a 128-taps potentiometer controlled by a clock signal and an up/down input.

The amplifier is built around a couple of TS925, low-noise, rail-to-rail amplifiers, the last one used as a comparator. The result is satisfactory (see Figure 3). I managed a maximum detection distance of up to 5 m during good conditions, and didn't miss any echo up to 3 m.

As stated earlier, I used an EPLD (a Lattice ISPLSI1016) to manage all real-time and timing issues, except the time measurement done directly by the COP (see Figure 4). This EPLD



Photo 3—*The onboard user interface shows a detected echo at 4.7 m. The three blue push buttons allow local arithmetic operations, with the top two values on the stack displayed on the bottom line of the LCD.*

does many things. It generates the ultrasonic burst as soon as the START line is asserted by the microcontroller. The EPLD also inhibits reception of an echo during a 1.5-ms window after the transmit pulse in order to filter direct cross talk between the transmitter and receiver.

It progressively increments the gain of the reception chain while waiting

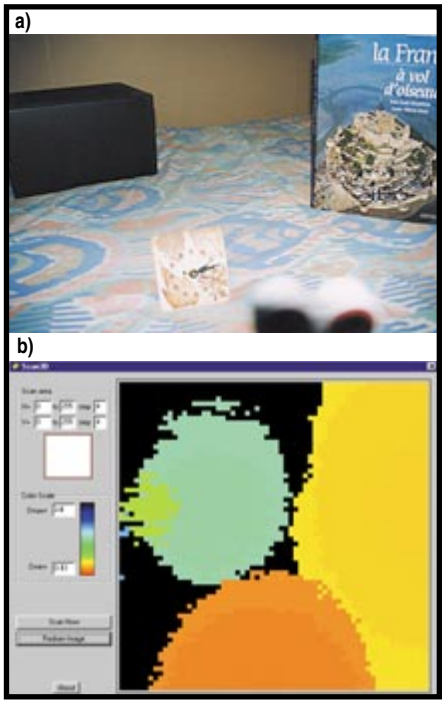


Photo 4a—*This example shows three main obstacles, a book, the black box, and a small clock. The distance of the objects is 30 cm to 3 m. (**b**) shows the vision through SCAN 3-D. The clock, a reflective object, produces a red spot at the bottom, far larger than the object itself because of diffraction. The book produces the yellow spot, and the black box gives the light green spot at the extreme left. The larger green/blue spot is the background wall (depicted as a circle, because only portions perpendicular to the transceiver reflect an echo well).*

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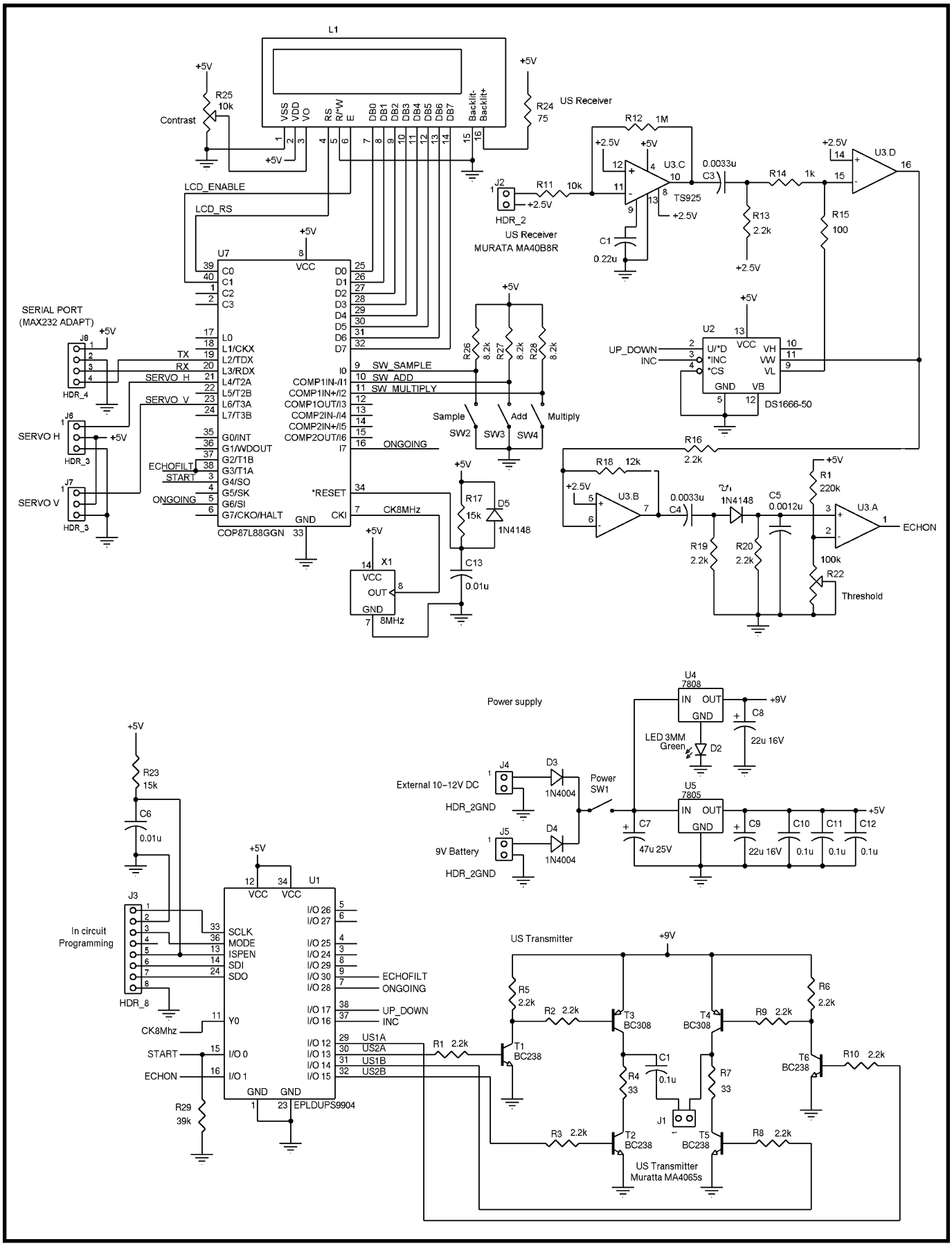


Figure 1—*The four sections of the SCAN 3-D can be clearly identified as the power supply, microcontroller and its peripherals, EPLD glue, and transmitter and receiver drivers.*

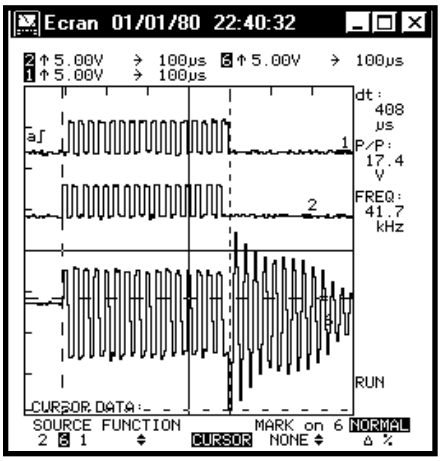


Figure 2—*The first two traces are the outputs of the EPLD. The last trace is the signal between the two pins of the transmitter. The transmit pulse is 16 periods, 40 kHz, and amplified to a 17.4-V_{PP} signal. The ultrasonic transmitter and coupling capacitor generate oscillations after the sixteenth pulse.*

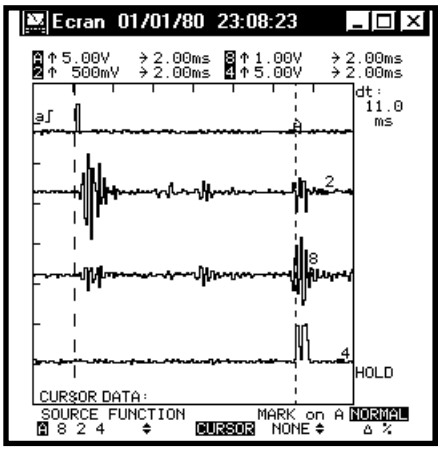


Figure 3—*The receiver section demonstrates why a progressive gain is needed. The first trace is the transmit pulse, the second is the received signal without amplification, the third is after progressive amplification, and the last one is the detected echoes (output of the comparator). In this case, even if a strong signal was present 1 to 2 ms after transmission, the real echo is the one 11 ms after transmission. This is impossible to detect without a different gain over time.*

for long distance echoes, sending pulses to the DS1666 digital potentiometer. The EPLD filters and signals reception of the first echo (ECHOFILT). And, it resets the gain to its minimal value (with a set of quick rewind pulses to the DS1666), waits for a 30-ms security period to eliminate double echoes, and signals the end of the measurement to the microcontroller (ONGOING back to 0).

WHY A COP8 MICROCONTROLLER?

The major constraint for this project was the need for a microcontroller fully loaded with onboard timers. More specifically, I needed one timer that can be configured in Pulse Measurement mode to get a precise time-to-echo measurement independently from other CPU activities and two timers that can be configured in PWM Generation mode to drive the two servo-motors. I also needed a serial port to the PC. Low power consumption (SCAN 3-D can be battery-powered) and low cost were essential.

Not many microcontrollers on the market satisfy all of these requirements, but National Semiconductor's COP87L88GGN fit the list exactly. It isn't a usual chip for hobbyists, but the COP8 series is indeed a classic 8-bit choice particularly in automotive applications. The COP87L88GGN includes 512 bytes of RAM, 16 KB of OTP ROM, along with a full-duplex UART, three 16-bits timers, wake-up interrupts, on-chip watchdog, two analog comparators, and full static CMOS design.

Moreover, National Semiconductor offers an inexpensive programmer and in-circuit simulator (IceMaster EPU). With this EPU, the code execution is simulated on a PC, so it's far from real-time emulation (around 20 KHz equivalent CPU speed), but the I/O is redirected on the target board. That's better than a simple software simulator and cheaper than a real ICE. So let's go with it!

EMBEDDED SOFTWARE

The software embedded in the COP8 microcontroller was written in assembler and is available on *Circuit Cellar*'s web site (`scan3-D.asm`). It uses approximately 1.5 KB of the onboard EPROM memory. After initialization, a main loop is executed with the following main steps:

- Check if an "I" is received on the UART interface
- If so, enter Remote Control mode. If not, get the echo distance, manage the user keys, and update the display
- Loop

In Local mode, a simple local user interface is implemented with the LCD and three push buttons acting as enter, add, and multiply (see Photo 3). The software emulates a reverse Polish calculator and enables quick calculations of sums of distances and area calculations.

In Remote Control mode, a simple protocol allows the host (a PC or master microcontroller) to orient the transceivers and measure a distance (see Table 1). Three measurement modes are supported, a single burst, repeated burst up to the reception of an echo, and an arithmetic average of four successive measurements to improve the precision.

A large part of the software consists of utility routines like UART management, LCD screen management, and fixed-point number crunching, and can be reused for other applications.

PC-BASED SOFTWARE

In order to control and drive the SCAN 3-D module, I developed the accompanying PC side software. This

Host	SCAN 3-D	Comment
I		Switch to Remote mode
	SCAN 3-D V1.0	Confirm Remote mode
H*xx*		Define horizontal position
V*xx*		Define vertical position
M		Get a distance measurement
	*nn.nn*M	Return measured distance
R		Get a distance with retry
	*nn.nn*M	Return measured distance
A		Get an average distance
	*nn.nn*M	Return measured distance
L		Go back to Local mode

Table 1—*An ASCII-based protocol is implemented between the host PC and SCAN 3-D microcontroller. The SCAN 3-D switches to Remote mode when it receives an "I," and goes back to Local mode when it gets an "L."*

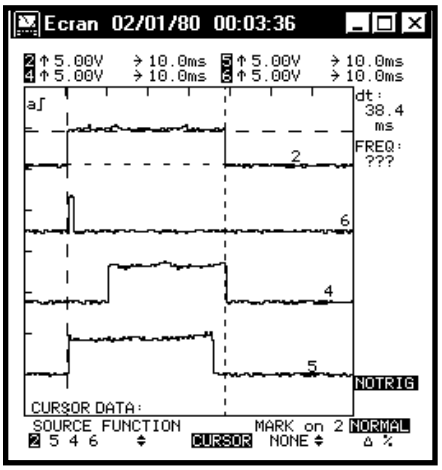


Figure 4—*The first trace of the EPLD is the ONGOING signal, which is active for 38 ms. The second trace is the inhibition signal, which blocks reception for 1.5 ms after transmission. The third trace is the ECHOFILT signal. In this case, the first echo was received 10 ms after transmission, giving a distance of 0.036 × 340/2 = 1.7 m. UP/DOWN is the last signal shown, driving the DS1666 potentiometer. This signal is up during the reception phase, but switches to 0 to reset the DS1666 to its minimal value just before finishing the cycle. During this time, the EPLD switches the DS1666 clock from 4 to 500 kHz.*

Windows-compatible software, developed with Bill's Visual C++ and MFC framework, allows you to define the horizontal and vertical scan range and drive the SCAN 3-D module through the COM2 serial port.

It then displays the corresponding 3-D image in false colors, the hottest colors indicating the closest distances. The color scale can be dynamically changed in order to optimize the display depending on the scene.

SCAN 3-D AT WORK

Enough theory, let's look at what SCAN 3-D can do!

As shown in Photo 4, the directional resolution that the ultrasonic beam is around is important (5°–10° depending on distance), so every obstacle is enlarged and rounded to the same angle. Nevertheless, the resulting image clearly allows detection of obstacles and possibly helps you find a way between the two obstacles.

You should note that ultrasonic detection doesn't detect all objects. Some exceptions are absorbing materials that don't give echo and reflective surfaces with large angles of incidence (the echo isn't reflected in the direction of the receiver).

This is why ultrasonic detection is often used in conjunction with other kinds of captures (like cameras), to construct a coherent and complete representation of the environment by merging the information coming from the different sensors, a task usually called "multi-sensorial fusion"… and not an easy one!

Regarding acquisition time, well, it depends on the resolution you require. The motor speed is never the limiting factor, but each pixel needs 38 ms to capture the required time between each ultrasonic pulse to prevent crossovers between measurements (i.e., the pulse of a previous shot being received after transmission of the next one). For a low-resolution picture (say 10 × 10 pixels), that translates to around 10 s with overheads. But for a high-resolution picture like Photo 4, be prepared to wait for a good 5 min.

WRAP UP

The SCAN 3-D is an interesting piece of equipment. It gives a sometimes surprising vision of the world, but understandable when you keep in mind the physics of ultrasonic waves. Designing and testing this device was a pleasure, mainly thanks to the good development tools supplied by National Semiconductor and Lattice.

Of course, a project like this one is never finished. My next goal is to use it on a robotic platform. For example, a second microcontroller may act as a master and control the SCAN 3-D. In order to quickly detect an obstacle, only the horizontal servo would be used (distance scanning on a horizontal line), and complete pictures can be taken from time to time. Well, that's work for the next couple of years!

Author's note: This project won the second international prize of the COP8 contest organized in 1999 by National Semiconductor and Elektor.

Robert Lacoste lives near Paris, France. He has 10 years of experience in real-time software, embedded system developments, and projects and operations management. He still loves building innovative microcontroller-based devices after-hours. He is currently working for Nortel Networks. You can reach him at robert_lacoste@yahoo.fr.

SOFTWARE

The code, EPLD design file, and C++ sources of this software are available to download from the *Circuit Cellar* web site.

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[1] National Semiconductor Corp., "COP87L88GG: 8-bit One Time Programmable (OTP) Microcontroller with UART and Three Multi-Function Timers," www.national.com/pf/CO/COP87L88GG.

[2] S. Ciarcia, "Home in on the Range! An Ultrasonic Ranging System Using Polaroid's Designer's Kit," *BYTE*, November 1980.

SOURCES

DS1666
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www.dalsemi.com

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FEATURE ARTICLE

George Novacek

Inductive Sensors

The rapid pace of change in technology constantly calls for upgrades and more variety of products. This month, George focuses on the next big thing for position sensors. So, read on to get the skinny on the newest development before it makes it to the mass market.

Accurate, reliable position sensing is the backbone of many closed-loop control systems in robotics, automotive, and industrial process industries, to name a few. In May 1999, I introduced you to the principles behind the popular variable differential transformer sensors, the LVDT (linear variable differential transformer) and its close relative RVDT (rotary variable differential transformer), the reigning family of position sensors. [1] These devices have changed little in their 100-plus years, so the question is: Are there any new devices more in line with today's technology that could lay claim to being the next dominant generation of position sensors?

The answer is a qualified yes. When it comes to operation in extremely hostile environments, such as the cryogenic temperatures encountered in space, or the mere –65°C in the arctic and at high flying altitudes, or the hundreds of degrees heat inside engines, it is hard to beat the variable differential transformer. Not much can happen to a stationary, wire-wound bobbin, which is all the LVDT is. I'm not aware of any new sensor technology that could successfully challenge the LVDT's position in these extreme environment applications any time soon.

In the friendlier environment between –40°C and 125°C, however, several contenders already exist. Optical encoders, Hall effect, and magneto-resistance (MR) sensors for example, have been around for some time. New developments such as piezoresistive beam have been introduced, but they still have to prove their capabilities.

LVDT REVISITED

In this article, I want to introduce you to another technology, the integrated inductive sensor developed by the Swiss company CSEM. What makes this sensor interesting is that in principle it is similar to the variable differential transformer, with the coils micro-machined on a chip. Photo 1 shows the sensor with its driver and decoder electronics encapsulated for protection. Photo 2 is a microscopic detail of the business end of the sensor.

Variable differential transformers and their cousins' resolvers are robust and, when their output signals are digitized, can consistently provide 16-bit resolution. But the coil windings are large and heavy, and the required precision manufacturing is costly.

The size and weight are concerns for many reasons. In the transportation industry, the long-standing maxim is that the cheapest way to improve efficiency and performance is by reducing weight. Lower weight and

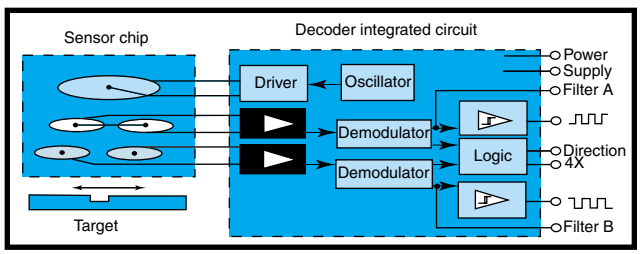


Figure 1—*The CSEM sensor diagram is simple. An oscillator drives the excitation coil while the position signal is picked up and decoded by four series-parallel sensor coils.*

smaller size make it possible to install sensors in previously impossible locations and make their mounting less demanding. Their mechanical characteristics, such as response time and ability to sustain vibrations are greatly improved. Small size also improves EMI characteristics, both emission and susceptibility, resulting in reduced shielding requirements and further size and weight reduction. [1–5]

On the manufacturing side, unlike the old-fashioned coil winding, precision, repeatability, and low cost (with high volume) are inherent to the micro-machining process, and hardly achievable by traditional manufacturing methods (just as the miniature size and weight).

THE WORKS

The CSEM sensor, shown in Figure 1, is deceptively simple. Packaged on a small PCB, the sensor module is merely 0.35″ × 1.18″ (9 mm × 30 mm) and weighs approximately 0.7 grams (0.025 oz). The sensor, which is encapsulated for protection, consists of two individual silicon chips on a single carrier (see Photos 1 and 2).

One chip holds the micro-machined coil assembly with five coils and the other holds the interface electronics. An AC current excites the large octagonal coil. The excitation frequency isn't externally adjustable and, therefore, isn't specified. Judging by the overall operation of the sensor, I estimate it to be in the 200- to 500-kHz range. Its purpose is to generate a magnetic field, which is amplitude-modulated by the movement of a structured metallic target,

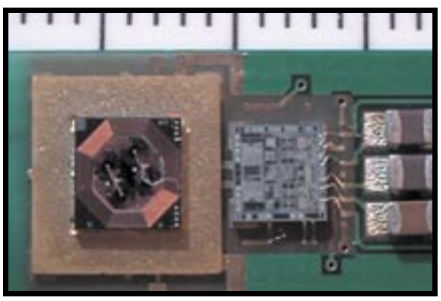


Photo 2—*This is a microscopic detail of the sensor part. You can see the large octagonal excitation coil, which is about 0.15″ (3.8 mm) across. The four smaller sensing coils below it are faintly visible.*

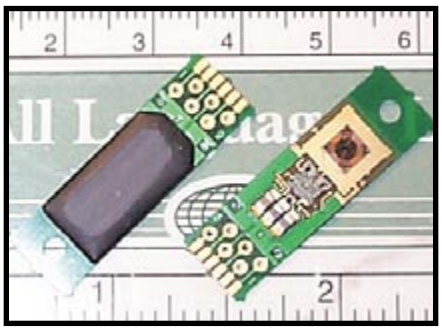


Photo 1—*The sensor module with its driver and decoder electronics is merely 0.35″ × 1.18″ and weighs approximately 0.7 grams.*

typically a gear or slot. Four sensing coils are connected in differential pairs to pick up the modulated field and feed the resulting signal to a set of amplifiers and amplitude demodulators in the second chip.

Because of the use of differential signal pickup and processing, the sensor is nearly independent of temperature and target distance shifts. The amplitude demodulators, followed by low-pass filters to attenuate the excitation frequency remaining in the signal, produce sine and cosine outputs representing the target's teeth movement. The sinusoidal signals are squared in the following voltage comparators to generate two trains of pulses; the pulses are 90° phase shifted because of the positioning of the pickup coils. Their duty cycle is affected by the geometry of the target teeth, but is usually kept to 50% by the teeth design. Although the sensor does not achieve the admirable resolution and precision of its variable differential transformer cousin, it consistently delivers a respectable 12 bits, adequate in most applications.

ELECTRICAL INTERFACES

There are several interface modules available from CSEM; choose based on the type of signal you need. The functions and processing are simple for a microprocessor, however you also can use optimized processing modules. It's a matter of economics. The cost of development may not be justifiable for small volume usage.

Figure 2 is a timing diagram of the output from the decoder shown in Figure 1. Two external capacitors set the low-pass filters' critical frequency. Typically a 3-kHz bandwidth is used, but that can be extended up to 40 kHz. Frequency in this case is determined by the number of teeth the sensor will see per second and, obviously, is an engineering trade-off. The more teeth, the better resolution, but speed decreases. The sensor signals calculate the relative position by counting teeth, determine direction by the quadrature offset of the outputs, and measure velocity. The interpolation signal used in velocity measurement is usually four pulses between teeth, but up to 256 pulses are available.

A more complicated interface will enable you to measure absolute position. Figure 3 shows the timing of the signals. In this mode, the sensor can be used in place of a variable differential transformer, digital resolver, or three-wire analog interface.

In addition to its small size and light weight, the CSEM sensor isn't a power hog, as some resolvers and 'VDTs are. Working off a standard 5-VDC, TTL-compatible supply, the CSEM sensor draws about 20-mA current from it. The output in the low state can sink up to 1 mA. In the high state it can source 200 µA while guaranteeing minimum 2.4-V output.

MECHANICAL INTERFACES

The pickup coils need to see moving teeth or slots to detect motion and determine position and speed. The coils' geometry is optimized for 0.040″ (1 mm) teeth or slot width and 1-mm pitch between them. This will provide a 50% pulse duty cycle. The sensor does not need to touch the target and will work well with a 0.020″ to 0.035″ (0.5 to 0.9 mm) gap.

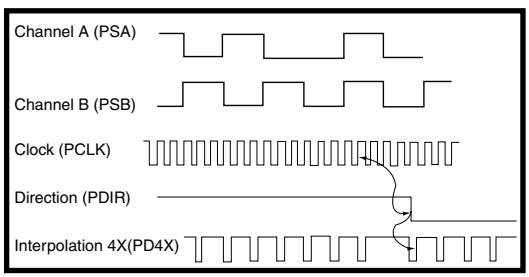


Figure 2—*The timing diagram of the circuit in Figure 1 provides digital indication of relative target position.*

As you expect, sensing a wheel's teeth isn't the only way to use the sensor. You can, for example, use it to detect presence (or absence) of a metallic target or movement of a slot into a predetermined position. In such applications, the CSEM sensor wouldn't be much different from proximity sensors. And proximity sensors are widely used as limit switches or position detectors. Such switches detect position of the thrust reverser transcowls in jet engines or down-and-locked position of a landing gear, where even the best sealed mechanical switch has a limited life.

Another interesting way of detecting position is shown in Photo 3, which is a demonstrator kit available from CSEM. Instead of having teeth on the circumference of the wheel, the wheel has been threaded. So, in effect the sensor sees only one tooth moving across its sensing window as the wheel turns and makes one revolution. This provides you with absolute position measurement of the rotational angle. The interpolation

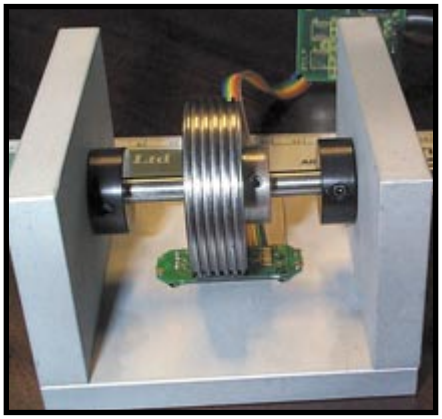


Photo 3—*The CSEM demonstrator kit has a thread instead of teeth.*

breaks up the 360° of rotation to 256 chunks of 1.4° of angular movement. With standard bandwidth the sensor will work up to 9,000 rpm.

THE FUTURE

This is still a new technology, so you'll have to wait a while before it matures enough and high production volume brings down the price. It's still expensive, depending on quantity and special requirements, but it's in line with the competing technologies.

Nothing is perfect, so let's be constructively critical and see what's wrong with this device. Like everything else, it has limitations. The first one is temperature, although I hasten to add it is specified for a respectable –40°C to 125°C. But it may not be good enough for some commercial and automotive applications. The second limitation is its relative complexity, which affects reliability.

These two characteristics don't allow it to be a contender for work in the environments in which the simple coil in 'VDTs and proximity sensors reigns supreme. Consequently, the sensor competes in a crowded field against numerous other technologies, such as optical encoding and Hall effect, primarily by price because it doesn't have a major feature that sets it apart from the pack.

No less important today is the BIT ability, the ability of a built-in test to run diagnostics on the sensor to determine whether or not it's operating properly. In safety-critical applications, it's imperative that the elec-

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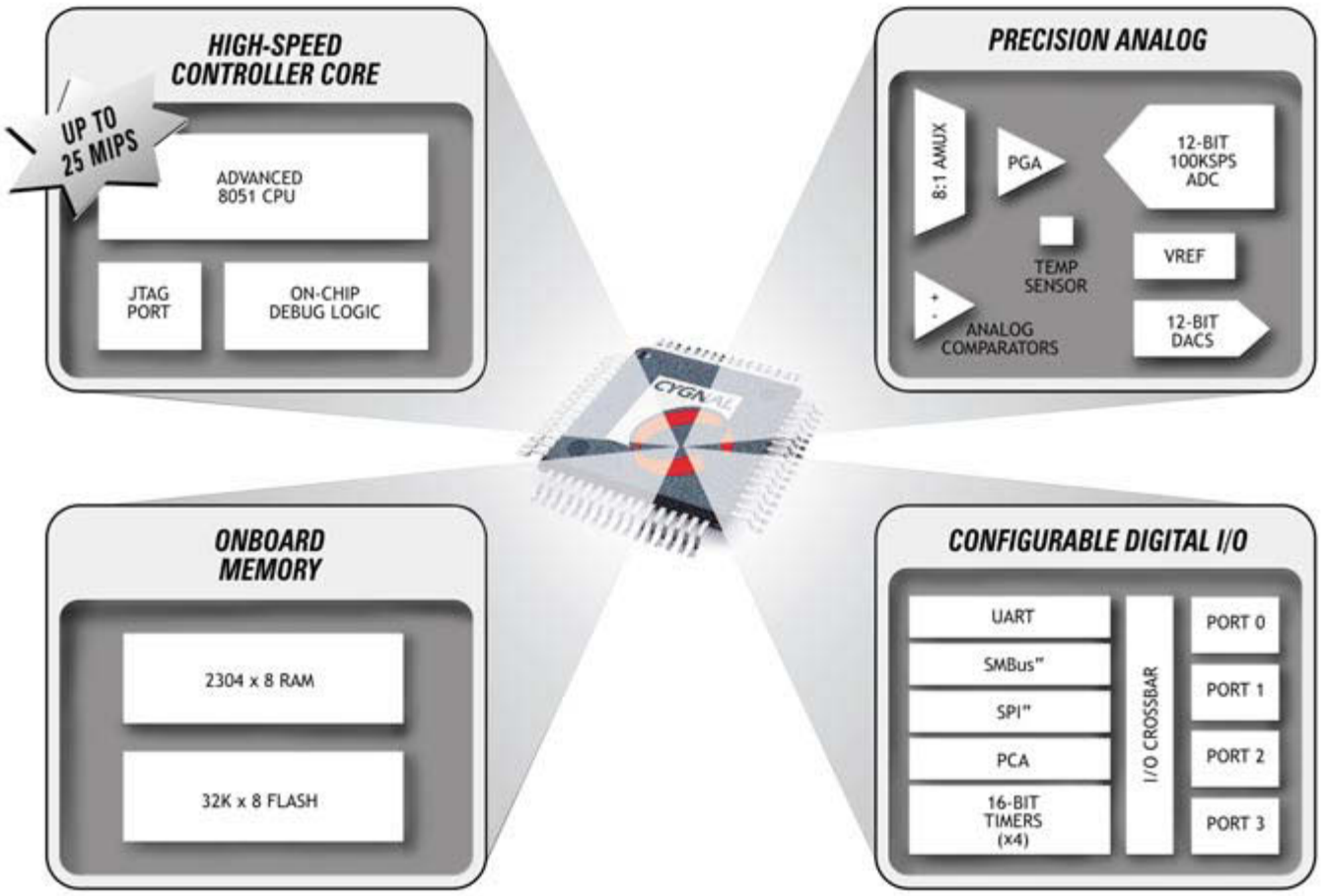
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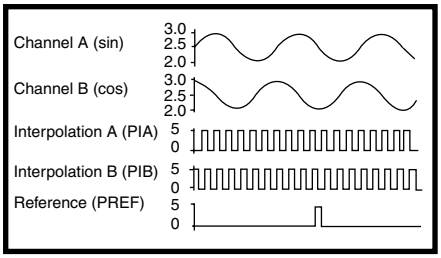


Figure 3—*As the timing diagram of the linear position interface shows, an absolute position signal is available to replace variable differential transformer or resolver-type sensors.*

tronic controller can determine whether or not the signal received from the position (or any other) sensor is valid. With a detection coil, for instance, you can monitor its voltage and current. Unfortunately, CSEM doesn't appear to address this issue in its literature. I haven't found sufficient detail to infer what happens if a part of the sensor fails.

The traditional way to verify a signal is through dual redundancy (i.e., by using two sensors and comparing their outputs). This isn't cost-effective, and therefore isn't desirable in modern systems. Even with two such sensors, you could conclude only that the output is invalid, but you couldn't say which one. For that you would need three sensors and the cost would be hard to justify.

As we continue to automate our lives, we need more and a wider spectrum of sophisticated sensors. In this article, I looked at one method of position sensing. Check out the Resource section if you want to look for more methods.

George Novacek has 30 years of experience in circuit design and embedded controllers. He is currently the general manager of Messier-Dowty Electronics, a division of Messier-Dowty International, the world's largest manufacturer of landing-gear systems. You may reach him at gnovacek@nexicom.net.

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AD #101

FEATURE ARTICLE

Tom Napier

Put Telepathy to the Test

As proved monthly in this magazine, there's pretty much no limit to the capabilities of embedded applications. How about designing a test to evaluate people who claim to be telepathic? Is parapsychology fictive? Even a skeptic can find intrigue in this project.

This is another project that has its roots in my diverse past. During the 1970s, I worked at CERN, the accelerator lab in Switzerland. In Geneva, I met a UN employee who was adamant that he is telepathic. Because I knew of the pitfalls associated with testing such claims, I designed a telepathy tester that would circumvent the problems encountered by earlier experimenters.

This tester was AC-powered, used TTL parts, and had electromechanical counters that recorded results. The modern equivalent described here is more portable. A 9-V battery powers its PIC16C55, LED targets, and LCD.

Both testers present the telepathic sender with one of four randomly chosen colored lights. The telepathic receiver then presses one of four colored buttons. If this matches the color displayed, a hit is recorded. In the long run and in the absence of telepathic ability, 25% of the keystrokes will match the target. A significantly higher score, especially if reproducible, hints at some unusual ability to communicate.

Neither my UN friend nor anyone else I've tested has scored better than chance. However, many people are convinced they have telepathic powers. A simple device to test such claims makes for an interesting if unusual construction project and lets you do some real science, too.

THE TEST PROTOCOL

The aim is to discover whether or not a person in one room can tell, without sensory clues, what color light a person in another room is looking at. Thus, the telepathy tester has two parts, a sender's box and a receiver's box, linked by a cable 50 or so long. A panel in the sender's box is illuminated part of the time by one of four LEDs—red, yellow, green, and blue. The rest of the time the panel is dark. The rate at which the panel cycles between light and dark can be adjusted to suit the subjects. Typically it would be once every few seconds; an experiment of, say, 80 trials lasts only a few minutes.

The receiver's box has four push buttons. Their colored tops match the colors and positions of the four LEDs in the sender's unit. As soon as the sender's panel is illuminated, the receiver's box beeps. This indicates that the sender is looking at a colored panel. The receiver then pushes the button that he or she believes corresponds to the target. (Let's hope telepathic ability isn't associated with color blindness!)

Each keystroke counts as a trial. If the correct button has been pressed, a hit is counted. If any of the three incorrect buttons is pressed, no hit is counted. The test ends when a predetermined number of trials (20, 40, or 80) have finished. If the receiver fails to press a button, that trial is not counted as part of the test.

The number of hits is then evaluated to see if an abnormal event has taken place. A significant deviation from 25% hits, the chance expectation, could indicate that the sender and receiver have been able to communicate in some manner.

As with any scientific experiment, a result can be caused by the effect being sought. Or a result can be an artifact of the experimental design or a chance fluctuation. Table 1 shows the likelihood of various outcomes.

LESSONS FROM THE PAST

Regrettably, telepathy testing has a long history of positive results being achieved, consciously or unconsciously, by improper means. Thus your first concern is to minimize the possibility of deception. Occam's razor tells you not to attribute a positive result to telepathy until all other conceivable (more likely) causes have been eliminated.

The two participants should be in different rooms with a closed door between them. A referee should be present at the sending end to control the test and verify that no tampering with the device has taken place. A witness in the same room as the receiver ensures that nothing untoward (e.g., listening at the door) takes place. Other people should be excluded from the test area in case any of them are confederates who might signal the target to the receiver.

This testing device contains several features to avoid the flaws that have been found in published telepathy experiments. The targets are chosen by a mechanism that is equally likely to pick any of the four colors. There is no list of targets that may not be random, altered after the experiment, or been seen by the receiver.

There is no list of the receiver's choices, which might be recorded incorrectly or altered by the person checking the results. Believe me, it's been done. Both hits and total attempts are recorded automatically when a button is pressed. Pushing more than one button, pushing a button twice, or holding a button down does not result in an extra hit being registered.

The timing of the trials is controlled electronically. This prevents the sender and receiver communicating by code. And yes, that's been tried too. No person needs to communicate between the two parties, possibly giving clues to the correct color.

I was even reluctant to use a microcontroller for this job because it could be reprogrammed to give misleading results. Please don't alter the published firmware. My credibility is at stake every time you use this tester.

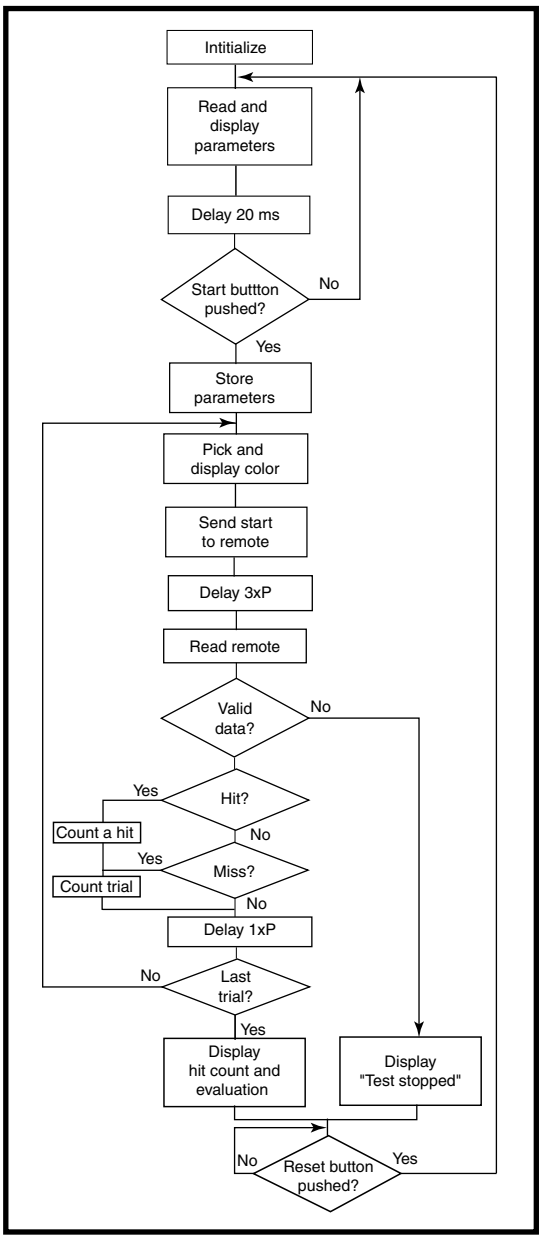


Figure 1—*The firmware allows the test parameters to be set before a test is started. It counts hits and displays the results after the selected number of trials have occurred.*

THE SENDER'S UNIT

The PIC in the main unit is connected to the noise pulse generator, LCD display, target LEDs, control switches, and interface to the remote unit. It illuminates the random targets, checks the receiver's response, records, and displays the results.

To select one of a number of events completely at random is an interesting technical problem which not all experimenters have succeeded in solving; one well-known laboratory built a machine that rarely presented the same target twice in succession. (Computer-generated random numbers are too predictable for serious testing.)

The random pulse generator uses a 9.1-V zener diode as a cheap substitute for a noise diode. When passing around 25 µA it avalanches at irregular intervals. Connecting it to a self-biased comparator chip generates about half a million random pulses per second. These are fed to the RTCC pin of the '16C55 and increase its timer register. Two bits of this register select one of the four LEDs for each trial.

The trial length is adjustable from 2 to 15 s to suit the test subjects. It can't be changed once a test has begun. A four-way Test Length Selector switch can be set to 20, 40, or 80 trials. It also has a Check position. Moving this switch during a test has no effect.

Pressing the Start button begins the trials. A random LED is lit at the start of each trial period. At the same time, a pulse is sent to the receiver's unit. This generates a beep and enables recording of the receiver's response. The beep indicates that the sender is looking at a colored lamp and that it's time to divine it.

At the end of the display period, the receiver's unit is interrogated to see which, if any, button has been pressed. This is compared to the target, and a hit is counted if it matches. A short pause occurs before the next trial starts.

During a test, the LCD indicates the current number of trials and the predetermined total trial number. At the end of the test, the display shows the number of hits and an indication of how likely this result is. The result then can be recorded.

Pressing the Reset button returns the device to Standby mode. If Reset is pressed, the test is aborted and no result is displayed; disconnecting the cable has the same effect. Figure 1 shows the flowchart of the firmware.







Number of trials	Hits	Probability
20	6	3.828×10^{-1}
	7	2.142×10^{-1}
	8	1.018×10^{-1}
	9	4.093×10^{-2}
	10	1.386×10^{-2}
	11	3.942×10^{-3}
	12	9.354×10^{-4}
	13	1.837×10^{-4}
	14	2.951×10^{-5}
	15	3.813×10^{-6}
	16	3.865×10^{-7}
	17	2.960×10^{-8}
	18	1.611×10^{-9}
	19	5.548×10^{-11}
	20	9.095×10^{-13}
40	11	4.161×10^{-1}
	12	2.849×10^{-1}
	13	1.791×10^{-1}
	14	1.032×10^{-1}
	15	5.444×10^{-2}
	16	2.624×10^{-2}
	17	1.156×10^{-2}
	18	4.651×10^{-3}
	19	1.708×10^{-3}
	20	5.724×10^{-4}
	21	1.749×10^{-4}
	22	4.864×10^{-5}
	23	1.230×10^{-5}
	24	2.826×10^{-6}
	25	5.880×10^{-7}
	26	1.105×10^{-7}
	27	1.871×10^{-8}
	28	2.841×10^{-9}
	29	3.851×10^{-10}
	30	4.631×10^{-11}
	31	4.906×10^{-12}
	32	4.536×10^{-13}
	33	3.618×10^{-14}
	34	2.253×10^{-15}
80	21	4.403×10^{-1}
	22	3.426×10^{-1}
	23	2.553×10^{-1}
	24	1.819×10^{-1}
	25	1.239×10^{-1}
	26	8.047×10^{-2}
	27	4.989×10^{-2}
	28	2.950×10^{-2}
	29	1.663×10^{-2}
	30	8.940×10^{-3}
	31	4.582×10^{-3}
	32	2.239×10^{-3}
	33	1.043×10^{-3}
	34	4.635×10^{-4}
	35	1.964×10^{-4}
	36	7.932×10^{-5}
	37	3.055×10^{-5}
	38	1.122×10^{-5}
	39	3.929×10^{-6}
	40	1.312×10^{-6}
	41	4.174×10^{-7}
	42	1.266×10^{-7}
	43	3.659×10^{-8}
	44	1.007×10^{-8}
	45	2.641×10^{-9}
	46	6.593×10^{-10}
	47	1.566×10^{-10}
	48	3.538×10^{-11}
	49	7.597×10^{-12}
	50	1.550×10^{-12}
	51	3.002×10^{-13}
	52	5.516×10^{-14}
	53	9.606×10^{-15}
	54	1.584×10^{-15}

Table 1—*The probabilities of getting N or more hits by guessing are listed for the three test lengths. Probabilities less than 10^{-15} are omitted to save space.*

When you switch to the check position, the random color cycling continues indefinitely and the result of each trial (hit, miss, or pass) is displayed. This allows operation of the box to be demonstrated and the trial period to be selected.

Pressing Reset stops this test. A check should be done before a test to confirm that all four lamp/button combinations show the correct hits and misses (omitted in Figure 1).

The tester runs from a 9-V battery, which has a life of about six hours. A low-power, 5-V linear regulator powers the microcontroller. I added a 7660 inverter to get a high enough voltage for the noise diode; lower voltage zener diodes don't exhibit the avalanche effect. The –8-V output of the inverter can supply a negative bias to the LCD if it needs it. VR3 is the LCD contrast control and should be adjusted for the best display.

I added a crude battery voltage check. This compares a fraction of the battery voltage with the input threshold of a PIC port bit. Because the latter is not well specified, you should run the unit from a variable power supply and adjust VR2 until the "Batt low" message appears around 7.5 V.

AT THE RECEIVING END

I was tempted to put a microcontroller into the receiver's unit, but an all-hardware solution is better. The higher speed and asynchronous nature of logic make it easier to exclude simultaneous keystrokes.

The remote unit uses a 74HCT165 shift register to latch whichever button is pressed first. An enable latch is set to put the '165 in Load mode at the start of each trial. Pressing any button clears the latch and switches the '165 to Shift mode. This latches the current state of the buttons some tens of nanoseconds after the first button makes contact. A button

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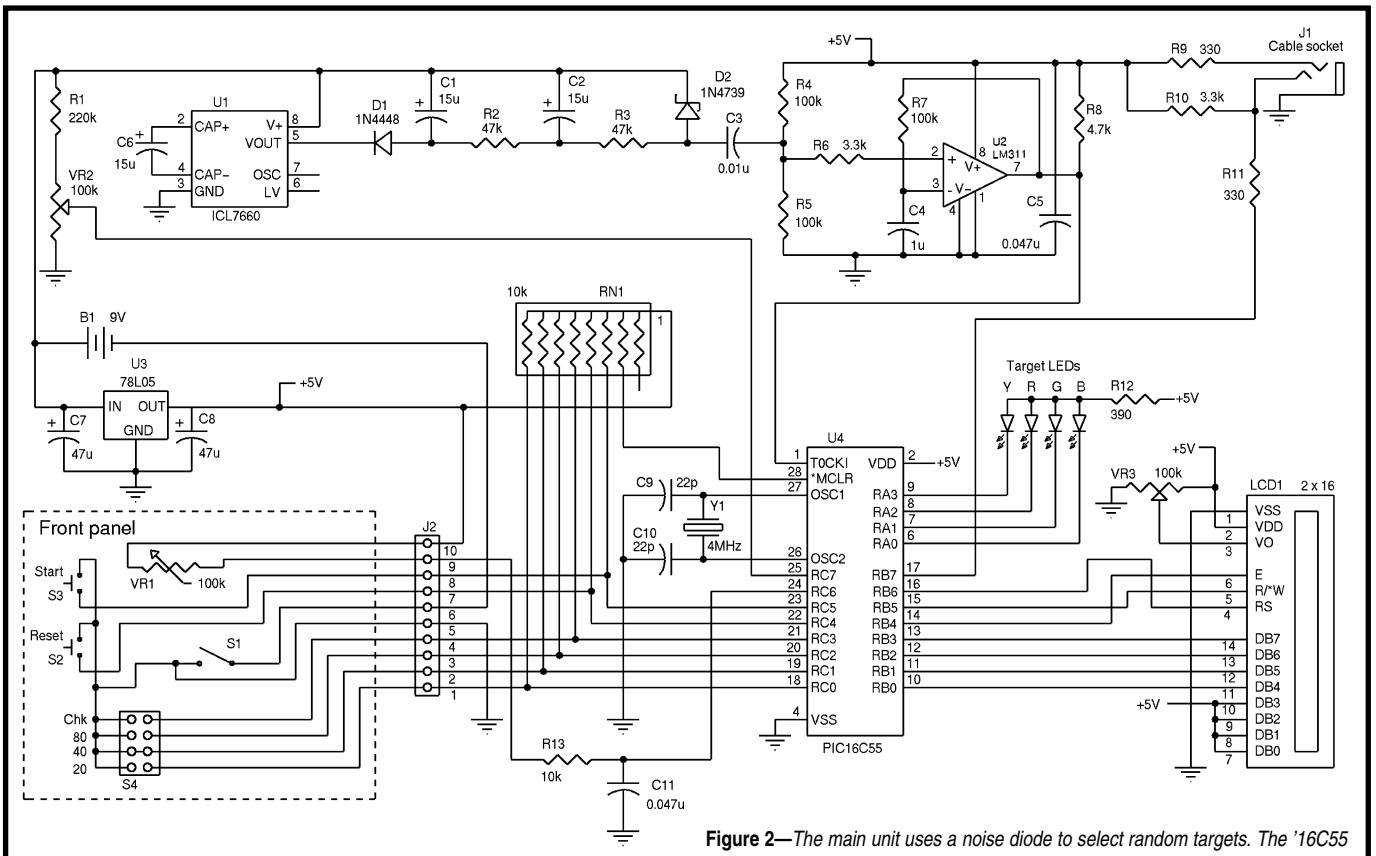


Figure 2—*The main unit uses a noise diode to select random targets. The '16C55 reads and checks the subject's responses, and then displays its conclusions.*

STEP 1

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After you build this telepathy tester and check someone's abilities, the question arises: What do the results mean?

If your subjects are not telepathic, then in 20 trials, the most likely number of successes is simply 20 × 0.25, or five. Carry out thousands of tests and you will get five hits more often than any other number, but, as Figure s1 shows, the probabilities of three, four, five, six, or seven hits are not very different. In 80% of tests, the number of hits will lie within the range of three to seven, unless something other than chance is operating.

That is, small deviations from five hits are not significant. The probability of getting larger numbers of hits purely by guessing drops precipitously. The vertical scale in Figure s1 is logarithmic. The probability of 10 hits is about 1%, but the probability of 15 hits, three times the expected number, is about 3.4 in one million.

Because the aim of the telepathy experiment is not to get a specific number of hits but to do better than guess, it's more meaningful to ask, what is the probability of N or more hits? Table 1 lists these probabilities for the three trial numbers. If you did a trial every second for eight hours of every day for four years, you would stand a less than even chance of getting more than 40 hits out of 80 trials.

On the other hand, an exceptional score can crop up. You may be tempted to crow about that score and ignore all of the others, but that's bad science. Positive telepathy test results are often published; no one knows how many unsuccessful results are buried in desk drawers. If the effect is real you should get a similar result every time you repeat the test.

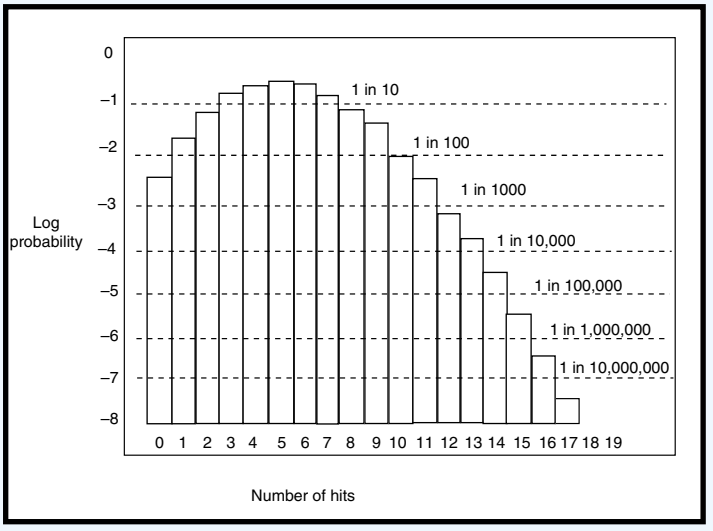


Figure s1—*In the absence of communication, the expected number of hits has this distribution in a 20-trial test. Even large numbers of hits sometimes occur by chance.*

would have to bounce open or a second button close within this period for an incorrect state to be latched. Nothing further happens until the end of the display period when the contents of the '165 are shifted out and sent to the main unit.

The interconnecting cable has three cores. I used intercom wire (part 278-0871) purchased at Radio Shack. One wire supplies 5-V power, one carries two-way communication, and one is common. The data wire is connected to a pull-up resistor in the main unit so either unit can transmit data by shorting the wire to ground. Static protection is provided at both ends of the cable.

A 400-µs active-low pulse from the main unit marks the start of a display period. It triggers one half of a dual monostable, generating a 50-ms pulse that gates a transistor-driven piezoelectric beeper to make the trial synchronizing signal. This also sets the enable flip-flop.

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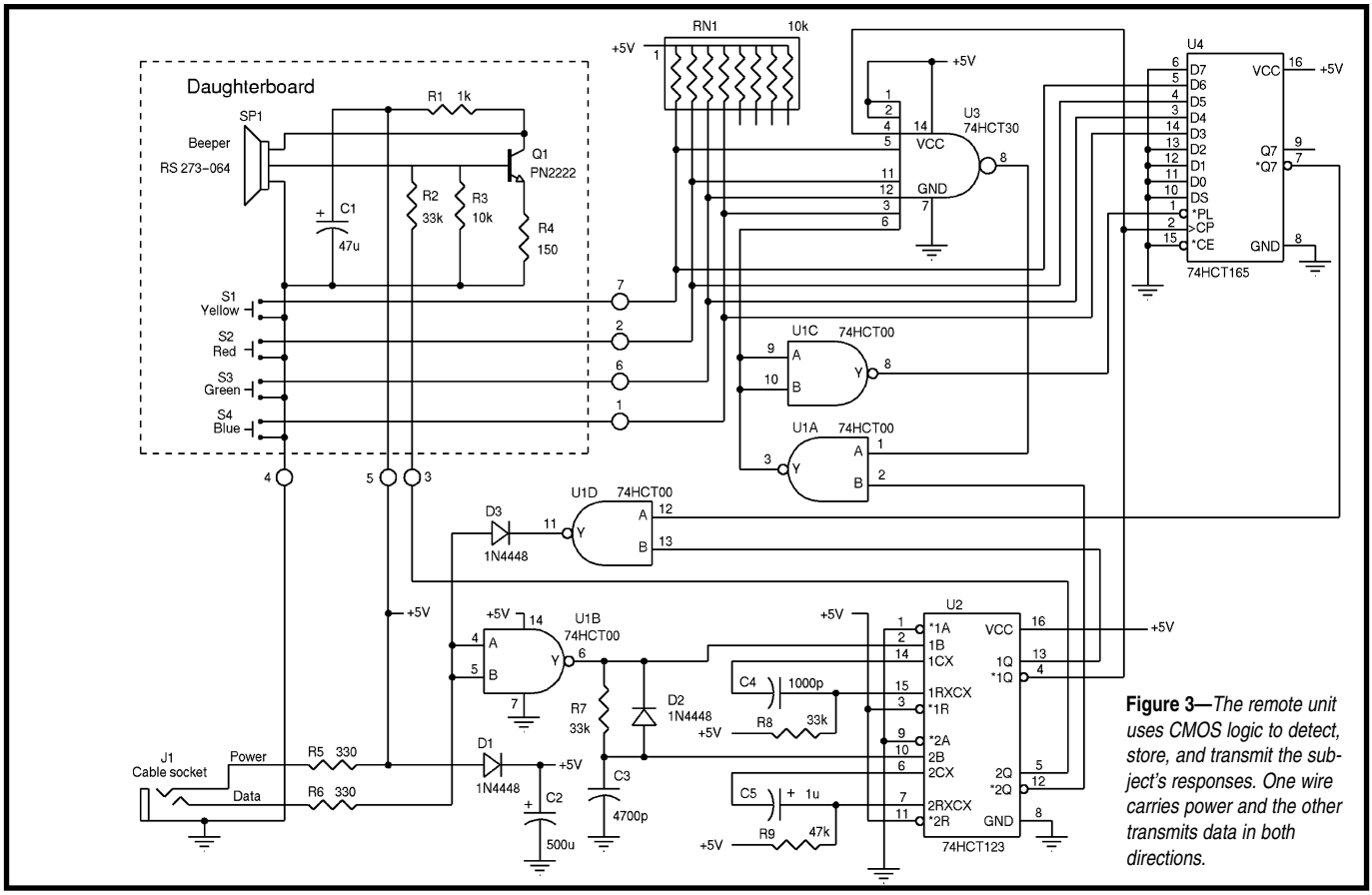


Figure 3—*The remote unit uses CMOS logic to detect, store, and transmit the subject's responses. One wire carries power and the other transmits data in both directions.*

At the end of the display period, the main unit puts six 10-µs active-low pulses on the connecting line some 75 µs apart. These pulses are too short to affect the enable flip-flop but do fire the other half of the monostable, which has a 35-µs period. Its output is gated by the shift register data output and ORed onto the line. A zero data bit has no effect, whereas a 1 bit triples the length of the pulse on the line. After sending a clock pulse, the controller samples the line to see if it is still low and records a 1 bit if it is.

The back edge of the monostable pulse shifts the next data bit to the output of the shift register. The first and last bits are hardwired as ones and the four middle bits indicate which button was pressed. If no button was pressed, the first clock pulse clears the enable flip-flop and switches the shift register from load to shift, so it's ready to be read.

THE MECHANICAL STUFF

The main unit (see Figure 2) is contained in a 3.5 × 5.5 × 1.2 molded plastic box with a built-in battery container. The 16-character, two-line LCD is mounted across the top of the front panel. Both the box and display were relics from an abandoned project. (Surplus dealers sell suitable displays for about $10.)

The target panel is mounted in the center of the box. I used a 2 diameter translucent polyethylene plug cover. This is illuminated from below by one of four high-brightness LEDs. Above and to its left is a potentiometer (VR1) that sets the trial rate. Below that are the Start and Reset buttons and the on/off switch. The four-way slide switch, which selects the trial count, is at the bottom right.

Most of the parts fit on a PC board mounted on the bottom of the box. Connectors on the board link to the display and the panel controls; connection to the remote unit is made with a 0.12 stereo jack socket on the far end of the unit.

The remote unit (see Figure 3) fits a black plastic box that measures 4 × 2 × 1 . Its only visible features are four colored push buttons on one face; each is about 0.5 square (520 series from E-Switch, available from Digi-Key). One PC board carries the push buttons and the beeper. A second board carries the four ICs and the jack socket for the cable. The two boards are linked by a 7-in-line connector.

INTERPRETING THE RESULTS

At the end of each test, the display indicates the number of hits registered and a one-word evaluation. The latter is based on the probability of the result if telepathy isn't acting. "Normal" indicates a score you would expect to get in 19 out of 20 tests. "Unusual" means a less than one in 20 chance and "Amazing" indicates a less than one in 1000 chance. If you get a score that would happen by chance less than once in 100,000 tests, the display shows "Incredible." For a more accurate evaluation, you can look up the score in Table 1.

Even extremely high scores may be purely random (see the "What is Random?" sidebar). However, when a score that should occur perhaps once in a million experiments occurs, you should suspect that something odd is

going on. The best thing to do is carry out another test. If this also shows an unusual result, it probably indicates person-to-person communication. Unfortunately, it does not confirm the existence of telepathy unless you can prove there is no conceivable alternative method of communication. This device, like all telepathy testers, is better at demonstrating the absence of communication than the presence of telepathy.

THE MILLION DOLLAR QUESTION

Is anyone telepathic? I don't know but there is a cash award waiting for anyone who can prove it. The James Randi Educational Foundation (www.randi.org) has a standing offer of $1 million for a demonstration of paranormal ability. So far nobody has been able to demonstrate the powers they claim under proper test conditions. You might just uncover someone who can really do it with this telepathy tester. Just be sure to get your finder's fee up front!

TO LEARN MORE

For a comprehensive discussion of telepathy testing I recommend reading *A Skeptic's Handbook of Parapsychology*, edited by Paul Kurtz, Ph.D. This book contains articles by both skeptics and believers.

For an insider's view of the world of telepathy testing read *In Search of the Light*, by Susan Blackmore, Ph.D. This book describes Blackmore's experiences as a parapsychologist and portrays her gradual conversion from a committed believer whose experiments wouldn't give positive results to a skeptic who uncovered the flaws in other people's experiments.

Tom Napier has been interested in telepathy since he was a physics student. He helped found an educational group, Philadelphia Association for Critical Thinking (www.phact.org), which studies fringe science and paranormal claims.

SOFTWARE

The object code is available on *Circuit Cellar*'s web site.

RESOURCES

S. Blackmore, *In Search of the Light*, Prometheus Books, Amherst, NY, May 1996.

P. Kurtz, ed., *A Skeptic's Handbook of Parapsychology*, Prometheus Books, Amherst, NY, September 1985.

SOURCES

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Fred Eady

Tuning the Data Radio

Wireless Data Communication

The best way to know where you're going is to know where you've been. Radios may now take a back seat to pagers and Palms, but they forged the humble beginnings for wireless technology. So, take a look at the data radio when trying to solve your data transfer problem.

Recently I received an e-mail note from Caleb, a regular *Circuit Cellar* reader, who posed a question concerning my repeated use of the term "Florida room." He noted that the members of Steely Dan had written a song entitled "The Florida Room" and he wondered if there was a hidden message behind my choice of words. I assured him that there is no subliminal intent or backwards-playing strategy on my part. In fact, the band members frequent the Florida room. One of my favorite Steely Dan songs, "FM," has a lot to do with this month's article. So, without further delay (nor static), let's take a look at wireless data communication, local area style.

NO STATIC AT ALL

Everything communications-oriented is taken for granted today. Worldwide, there are wireless Palm devices, Ethernet LAN devices, pagers, and cell phones. A sometimes forgotten fact is that this technology began long ago with the invention of wireless, or as we know it today, radio.

For embedded designers, there are many ways to implement wireless technology. If your product can support the expense, you can use digital pager or cell phone sites and services to route your wireless data from place to place. On the other hand, if you just want to move data in a small centralized area within a radius of a couple hundred yards, the pager and cell method is not a viable alternative.

Campus wireless technology would be a good choice for the small area network I described, but you'd need a pocketful of money to implement it. If your embedded application requires wireless data packet transfer and doesn't entail moving spreadsheets between Palm devices in Singapore and London or over the 10-acre corporate campus, the wireless data movers distributed by Lemos International are your ticket to inexpensive, successful data transfer using wireless networking technology.

Before I get into the details of data radios, I'd like to show you the hardware and software tools I used to put together a wireless data packet network in the Florida room. Photo 1 is a look into a padded cell that contains the Radiometrix Universal Evaluation Kit. Let's investigate the individual parts of the kit beginning with the main data radio evaluation platform, which is shown in Photo 2.

RADIO GA GA

That's what Queen's Freddie Mercury (F. M.) would have said upon opening the Radiometrix black box. The Radiometrix data radio evaluation board in Photo 2 is designed to assist the embedded wireless designer in selecting the right data radio for a given wireless task. The data radio evaluation board consists of an area that is pinned for four types of data radio modules. The supported data radio modules are:

- TX1/RX1
- TX2/RX2
- TX3A/RX3
- BiM2/BiM3

In addition to the modules, the data radio evaluation board is fully loaded with blinking lights that, at a glance, relay information status concerning signals received and transmitted by



Photo 1—*This black box comes equipped with a couple of full-blown data radio support platforms. Each data radio platform can be rigged to use 433- or 173-MHz wireless modules. The longer antennas are quarter wave.*

the attached data radio modules. Transmitter enabled, receiver enabled, carrier detect, preamble detected, and valid packet received are all denoted with LEDs and represented by physical lines that can be monitored by an external microprocessor. The data radio evaluation board can be battery-powered (see Photo 2) or externally powered using the onboard screw terminal block.

Battery operation allows portable operation and permits on-site range testing, antenna evaluation, and noise and interference identification. I completely drained the original set of batteries while putting together this article, and it was nice to just screw in a 9-V wall wart to run the evaluation board while it was on the bench.

The white row of male header pins in the upper right corner support the use of the Received Signal Strength Indicator module (RSSI) you see mounted to the evaluation main board in Photo 3. The RSSI also adds analog transmission and reception capability to the Radiometrix wireless evaluation kit as well as signal strength readings.

The row of male headers along the bottom edge of the data radio evaluation board mate with a female header that couples a DB-25 male shell connector to the parallel port of your embedded or desktop computer. The pinout of this parallel interface between the Radiometrix evaluation board and an embedded or desktop parallel port is shown in Figure 1. There is also a jumper link on the parallel port interface headers that allows the wireless designer to access the built-in data radio evaluation board diagnostic routines.

The presence of a Reset button indicates that there must be intelligence in the form of a microprocessor close by. In the case of the Radiometrix evaluation board, the smarts are provided by a modified version of the RPC-000-DIL (radio packet controller-000-DIL). The Eval-RPC is really a Microchip PIC16F84A-20I/P that is chock-full of radio control diagnostic routines. A portion of the Eval-RPC pins are directly connected to the parallel port interface that attaches to the DB-25 male shell connector and ultimately to the parallel interface of an embedded or desktop computer. When there's no device hanging on the data radio evaluation board's parallel interface, a hexadecimal-coded debug switch is used to select canned test routines within the Eval-RPC's ROM. A rundown of the diagnostic modes is shown in Table 1. The other end of the Eval-RPC manages the communications link to the data radio modules that can be attached to the Radiometrix evaluation system.

Four jumper links on the evaluation board from Radiometrix select the data rate, mode of operation, and isolate external analog data input from the transmit data line (TXD) in Analog mode. The data rate is determined by the crystal frequency. The equation to determine the data rate in bits per second is:

$$\text{data rate} = \frac{\text{crystal frequency}}{256} \qquad [1]$$

Standard crystal frequencies included on the evaluation board are 2.4576 and 10.24 MHz. Using these frequencies with jumper link 2 (LK2) provides data rates of 9600 and 40,000 bps, respectively. A pair of 16.384-MHz crystals is also provided with the Radiometrix Universal Evaluation Kit to allow 64-kbps operation with the TX3A/RX3 and BiM2/3 data radios.

ROCK OR COUNTRY?

Being from Tennessee has its benefits. Not only do I get to mingle with the London rockers, but Faith Hill and Tim McGraw fly down from Nashville to drop into the Florida room from time to time, too.

The Stones one weekend and Faith and Tim the next makes it hard to determine which type of music I prefer over all else. In a parallel situation, I received two sets of radios with the Radiometrix Universal Evaluation Kit, a quartet of TX3A/RX3 modules and a pair of BiM2 transceivers. Both sets of radios have unique attributes. I'll begin by examining the TX3A/RX3 data radio combination.

The TX3A/RX3 data radio set comes in two flavors depending on what continent you're standing on. In Europe, the TX3A/RX3 data radios operate at 868–870 MHz. If you're in the U.S., the frequency range is 902–928 MHz and the wireless U.S. puppies already have an FCC Part 15 pedigree. The UK models are also screened for certification there under EN 300-220-1 and EN 300-683. Caveat emptor! Just because these modules are screened and certified doesn't mean you won't need to have the final equipment they play in certified too. Outside distances of up to 120 m (393.7' or 0.5965 furlongs) and an inside maximum distance of 30 m (98.43' or 0.1491 furlongs) can be achieved with data rates approaching 64 kbps using the TX3A/RX3 radios.

The TX3A/RX3 data radio set (see Photo 4) is FM-modulated with the transmitter (TX3) employing a crystal locked PLL (phase locked loop) for fre-



Photo 2—*This data radio platform is equipped with the 433-MHz BiM2 transceiver. There are female headers underneath it that allow other data radio modules to be plugged in and evaluated.*

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quency stability. The data is demodulated at the receiver end (RX3) by a single conversion FM SAW-filtered (surface acoustic wave-filtered) superhet front-end. The RX3 receiver is capable of providing RSSI output via an RSSI pin. A built-in 2.85-V regulator allows both the receiver and transmitter to operate over a voltage range spanning 2.2 to 12 VDC. Current consumption is a measly 7.5 mA for the transmitter and 9.5 mA for the receiver. An enable function can be employed to reduce current consumption to less than 1 µA. At 3 VDC the TX3 delivers 1 mW of RF power to the antenna.

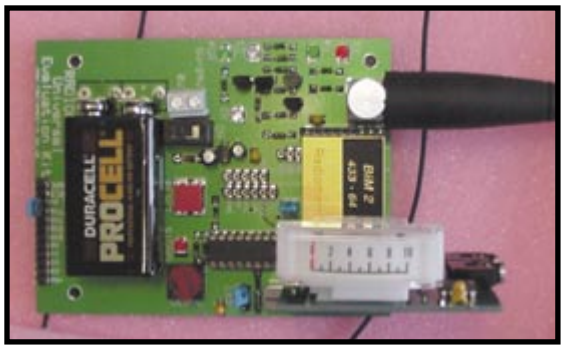


Photo 3—*This configuration allows the newly dubbed embedded wireless engineer to quickly survey the terrain for dead spots and interference without the use of expensive spectrum analysis equipment.*

If you're wondering how the modules can operate below the built-in voltage regulator's threshold, the trick is that there is no regulation taking place below 2.9 VDC. The catch is that the 2.2-VDC power supply must be very clean, as the voltage regulator circuitry isn't helping to filter the ripple. Any applied supply voltage below 2.2 VDC will disable the RF circuitry of the module.

The black and gold module dead center on top of the data radio evaluation board shown in Photo 2 is the BiM2 transceiver. Just like the TX3A/RX3 radio set, the BiM2 is compliant with European low-power radio standards. However, the BiM2 isn't ready to go up against the FCC right out of the box. The usable outdoor range is 200 m (656.2' or 1969 hands). Indoor range extends to a maximum of 50 m (164' or 492.1 hands). BiM2 operates on the European license exempt frequency of 433.92 MHz. I took a look at the FCC Part 15 document that covers the BiM2. I didn't see any exemptions for 433.92 MHz. Better put some puppy paper down on the living room carpet before you turn this one loose in the U.S. Also, there is no resident RSSI output pin on the BiM2.

The rest of the BiM2 specs read much like the TX3A/RX3. The data rate ceiling is 64 kbps, but the BiM2 receiver is a double conversion SAW-filtered superhet and the BiM2 transmitter also uses SAW-stabilized technology to deliver 10 mW of FM power to the antenna. The BiM2 also draws a bit more current, a little less than 20 mA, from a higher minimum supply voltage that spans 3 to 5 VDC. Like the TX3A/RX3, the BiM2 can be powered down to the sub 1-µA level.

IT ALL SOUNDS THE SAME

Musicians are really tonality mathematicians. Their work is with octaves, sharps, and flats timed at specific intervals. Embedded programmers and hardware designers are binary mathematicians who work with bits timed at specific intervals. For the embedded programmer, musical octaves are powers of 2, with sharps and flats being all of the bits in-between. Both musicians and embedded programmers use the same set of notes and bits to write totally different sounding music and totally different types of programs.

The point is that both the BiM2 and TX3A/RX3 data radios have a lot in common. They both have the ability to transfer data over a reasonable distance and both are capable of operation anywhere using battery power. A common interface using the RPC-000-DIL allows almost any microprocessor to interface with the data radio modules. The problem I am faced with right now is determining which data radio I should use.

In applications that don't require a transceiver, the TX3A/RX3 data radio set could be deployed as a single receiver or transmitter. For instance, if I wanted to monitor the movement of alligators in my backyard, I could

simply construct a transmitting station using only the TX3A module. Taking that idea one step further, suppose I needed to monitor the neighbor's backyard, too. I could put another TX3A transmitting station there and set it to report in at a different time than my backyard monitor. Another factor in favor of the TX3A/RX3 is that it is almost FCC-approved right out of the box. Although I would still have to pursue FCC certification for my alligator monitor, the TX3A/RX3 puts me a bit closer than the BiM2.

On the downside, if the parts count and space are at a premium and I really need a transceiver, the BiM2 is a much smaller footprint in a single easily mountable package. The BiM2 is a bit zesty for the U.S. FCC agents, but there is a way to tame the savage beast. The effective radiated power (ERP) output of the BiM2 can be regulated using a short impedance matched antenna, or by impeding the actual power delivered to the antenna using a passive attenuation network.

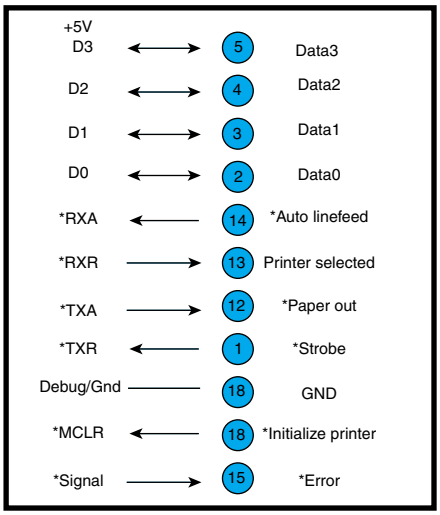


Figure 1—*Although this picture depicts a standard PC-compatible parallel port connection, any parallel port configuration that can handle the I/O configuration and adhere to the signal timings will suffice.*

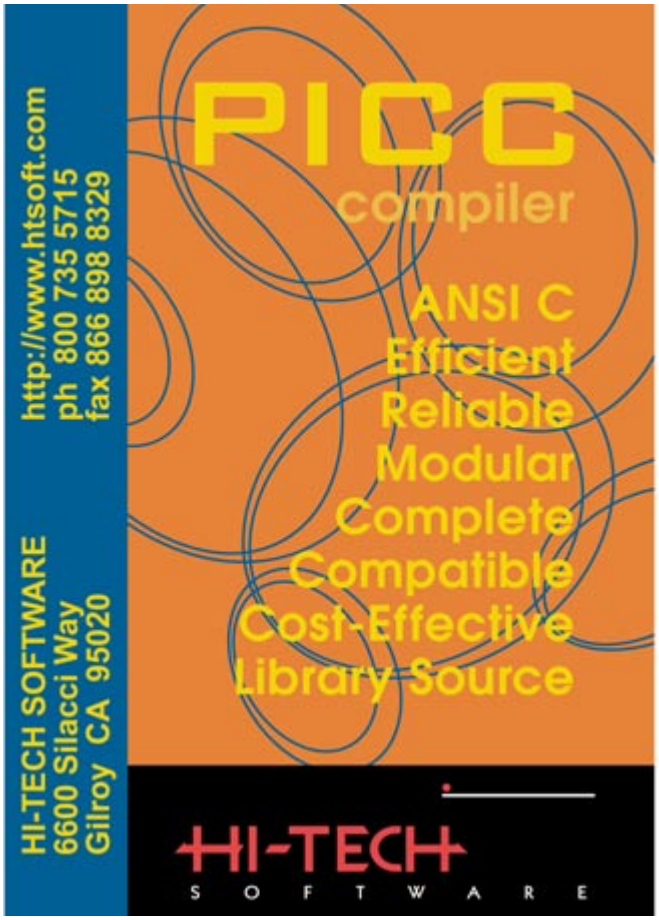
The bottom line is that both data radios will do the job in an equal manner when tuned to the FCC restrictions. As far as my decision process goes, power consumption is of little importance in that both data radios are power-stingy. There is little difference in the receiver sensitivity at 5 VDC and the same antenna gotchas apply to both data radios. Audio is a no-brainer, as it will not be used. I only need a data rate of 9600 bps because I'll only be transmitting very small packets of sensor data on demand to a centrally located embedded system well within either data radio's range.

My application definitely requires a transceiver and I personally like the smaller footprint the BiM2 provides. (I happen to know that the BiM3 is scheduled to come out in September. From what I hear, it has the same footprint as the BiM2). As you see in Photo 2, Lemos has a snazzy little stubby antenna that fits the bill, and the Pi-Network is a piece of cake to implement using surface-mount resistors. I'm going to commit to the BiM2 data radio model for the rest of this article and application.

MAGNETIC PICKUPS

The BiM2 I have selected as the RF component of my sensor station is fully capable of emitting a radio signal





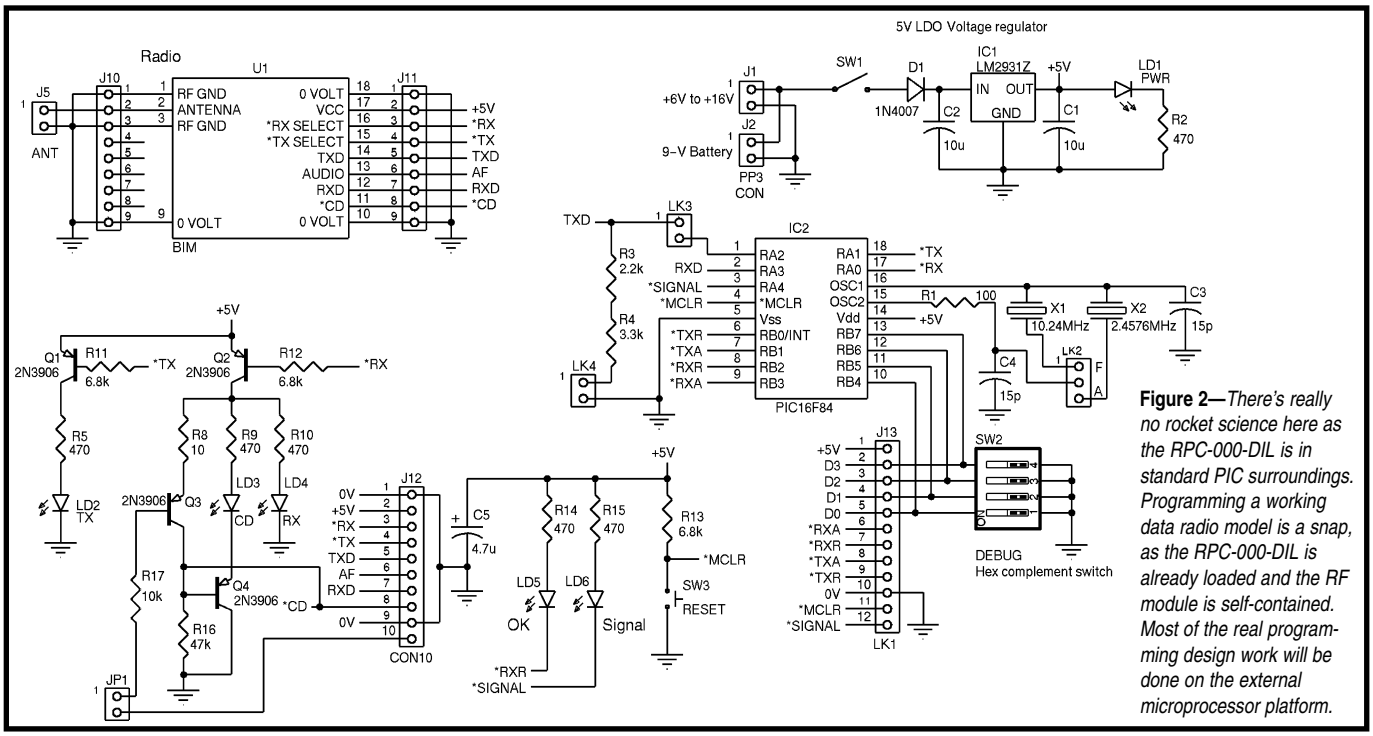


Figure 2—*There's really no rocket science here as the RPC-000-DIL is in standard PIC surroundings. Programming a working data radio model is a snap, as the RPC-000-DIL is already loaded and the RF module is self-contained. Most of the real programming design work will be done on the external microprocessor platform.*

that can be sensed by other BiM2 units in its range. It would be nice if those transmissions made some sense. That's where the Eval-RPC comes in. The Eval-RPC is based on the original RPC-000-DIL.

I needed a network of smart wireless modules. The Eval-RPC and the RPC-000-DIL both provide low-level packet formatting and packet recovery functions, so I had to inter-connect a number of data radio-equipped, alligator-watching microprocessors in a wireless network. I also obtained some RPC-000-DIL parts from Lemos and verified that the Eval-RPC and the RPC-000-DIL are logically identical and can communicate with each other when installed in the data radio evaluation boards. So, from now on I'll call them both by the same name, RPC-000-DIL.

The RPC-000-DIL handles almost everything related to wireless data transmission using the TX3A/RX3 or BiM2 data radios. Using a 4-bit data port and four handshaking signals, an external embedded processor assembles and loads a data packet of 1 to 27 bytes into the RPC-000-DIL. When transmitted, the receiving RPC-000-DIL signals the external embedded processor that received data is available. The received data is moved out to the external embedded processor using the 4-bit data port and the four handshake signals.

To provide reliable wireless data transfer, some precautions must be taken. First, the transmitter must allow the receiver to synchronize with the incoming datastream. In the case of the BiM2 data radio module, it may be sleeping and waiting for the wakeup signal. To accomplish synchronization, the RPC-000-DIL places a preamble and start byte at the beginning of each data packet it will send out. The packet is then appended with an error check code. The packet is then mark:space balanced and transmitted. In your case, the transmission is via a BiM2 but the data radio could be a TX1/RX1 or a TX3A/RX3. The basic packetizing is similar to what's done with Ethernet.

Somewhat like Ethernet, the RPC-000-DIL provides collision avoidance methods. These include fixed delay transmit with no channel check, immediate transmit if channel is clear, random delay transmit if channel is clear, and immediate transmit no-channel check. Fixed delay transmit with no-channel check is ideal for larger wireless networks (approaching 255 data radios) that require polling for data transfer. The random delay transmit if the channel is clear is most similar to today's Ethernet collision avoidance method. The four methods are mutually exclusive and are chosen by the embedded wireless engineer.

On the receive side, the RPC continuously searches the ether for a valid preamble. The preamble allows the receiving RPC to synchronize with the incoming datastream. The data is

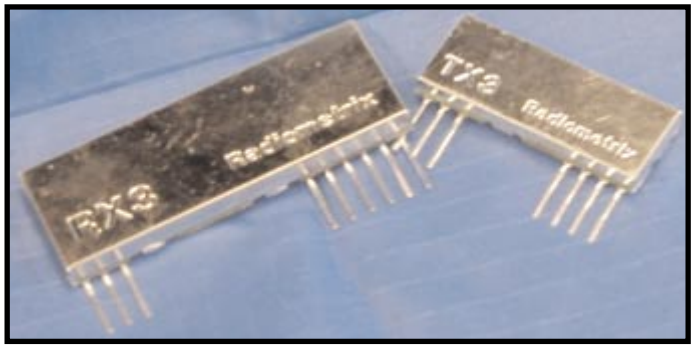


Photo 4—*The division of transmitter and receiver enables the inexpensive assembly of transmit- or receive-only data radio equipment.*

clocked in, decoded, and validated using a checksum. The external microprocessor is alerted that a valid packet has been received by the RPC and is waiting to be transferred.

The actual data format of the packet is up to the embedded engineer. Only the first byte is fixed. The first byte, or control byte, tells the receiving RPC which type of packet it has (control or data) and how many bytes it contains. The contents of the packet could contain routing information or packet sequence information. After the first byte is configured, the rest of the packet payload is at the designer's discretion.

Mode	Name	Function
0	RX-On	Preamble detector on (RXR LED = preamble detected)
1	RX-Pulse	10 ms on, 10 ms off, preamble detector on, RXR LED
2	TX-On-Pre	Preamble modulation, send continuous preamble
3	TX-On-Sq	100-Hz Square Wave mode, TX testing on spec analyzer
4	TX-On-255	Random 40 kb/s data for eye diagram tests, in sync with RXR
5	TX-Pulse	10 ms on, 10 ms off, preamble bursts, RX lock in tests
6	Echo	Transponder mode, retransmit any valid packets received
7	Radar	Send ASCII test packet, Radiometrix, and listen for echo
8	Self-test	Loop test, TX > RX (OK on RXR)

Table 1—*Some of the diagnostic routines, like TX-On-255, are intended to be used in conjunction with a four-channel storage oscilloscope for technical evaluation purposes, and Echo and Radar are focused on a human walking the intended radio range perimeter.*

The data transfer process is a lockstep method using request and accept lines. To transmit a byte via the RPC-000-DIL and a data radio module, the external microprocessor takes the TXR (transmit request) line low. The RPC-000-DIL then pulls the TXA (transmit accept) low. At this point, the external microprocessor enables the 4-bit data bus and places the least significant nibble of data on the bus. After that, the external microprocessor takes the TXR line high to indicate that the bus holds valid data. The RPC-000-DIL reads the data bus and raises the TXA line to signal that the data has been read from the data bus. This entire process is repeated for the most significant nibble of the byte to be transferred.

After the control byte and payload are placed in magnetic space and received by other data radios, the receive process begins with a signal from the RPC-000-DIL (taking RXR low), telling the external microprocessor that "there's data in them buffers." (I'm paraphrasing.) The external microprocessor seeing receive request low, pulls RXA (receive accept) low. The RPC-000-DIL then enables the 4-bit data bus and places the least significant nibble of the first received byte on the bus. Next, the RPC-000-DIL sets the RXR line high. The external microprocessor sees this and knows that the incoming data is valid and ready to be read. After reading the data bus, the external microprocessor takes the RXA line high.

This receive process is repeated for the most significant nibble of the incoming byte. The entire message reception process is determined by the programming in the external microprocessor and should be regulated by the length of the message as defined in the control byte.

The most significant bit in the control byte determines if the packet is a data or control packet. A zero in bit 7 of the control byte makes the packet a data packet, and the last five bits of the control byte are the number of bytes in the packet including the control byte. You know that the RPC-000-DIL is really a PIC16F84A and these flash memory parts contain a small amount of user EEPROM. Some of this EEPROM is allocated to the RPC-000-DIL internal affairs. The rest is there for public consumption. To access the EEPROM, the most significant bit of the control bytes is set. An EEPROM read operation is performed when control byte bit 6 is cleared. The EEPROM write operation is executed when bit 6 is set. In either case, read or write, the remaining six bits of the control byte are the operation's target EEPROM address.

The very first location of RPC-000-DIL EEPROM (0x00) contains the switches that determine such things as which mode to run in (Continuous or Power Save), the collision avoidance method, and whether or not to enable the EEPROM for a write operation. The rest of RPC-000-DIL reserved EEPROM memory holds the number of preamble cycles to generate or how long to sleep in Power Save mode. This restricted EEPROM memory area extends from 0x00 to 0x09. EEPROM locations 0x10 through 0x3F can be used as you see fit. Now that you have a logical knowledge of how the data radio evaluation board works, take a look at the physics of the data radio module in Figure 2.

SIGN OFF

In my days of AM radio, I actually had to turn off the transmitter at night and sign off the station. These days, radio runs 24 hours a day, AM and FM. I've got to turn off my *Circuit Cellar* transmitter now, but next time when I sign on again, I'll explore attaching the data radio equipment to a Linux embedded system. Stay tuned as it becomes increasingly clear that it doesn't have to be complicated to be embedded.

Fred Eady has more than 20 years of experience as a systems engineer. He has worked with computers and communication systems large and small, simple and complex. His forte is embedded-systems design and communications. Fred may be reached at fred@edtp.com.

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(508) 798-5004
www.lemosint.com

PIC16F84A-201/P
Microchip Technology Inc.
(480) 792-7200
www.microchip.com

Radiometrix Universal Evaluation Kit, TX3A/RX3, BiM2/3, RPC-000-DIL
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FEATURE ARTICLE

Don Lancaster

Steplocked Magic Sine Waves

This month, Don tackles an issue facing scores of designers. Who isn't looking for an efficient way to synthesize power sine waves? Although he won't pull a rabbit out of a hat, Don will use a little magic together with Chebyshev polynomials to get the job done.

What is the most efficient method to synthesize precision low-distortion power sine waves? The answer to this big bucks question is a concern for designers of systems like electric autos, industrial AC motor controls, and telephone ringer circuitry and their associated power quality conditioners.

Recently, I've been exploring what I call "steplocked" magic sine waves, which apply Chebyshev polynomials and a few other arcane math tricks to synthesize ultralow-distortion sine waves. These sine waves have precisely defined amplitudes and frequencies and are created by a small number of low-energy switching events for exceptional efficiency.

The key feature of steplocking is that, in theory, any number of low harmonics can be forced to zero. Often n pulses per quadrant can be chosen to force an astonishing 4n low-order harmonics to zero!

Compared to current PWM schemes, steplocking offers compelling advantages. Fewer switching events mean dramatic efficiency improvement. There is low-energy, single-side switching for further efficiency gains. And, significantly less high-frequency energy is involved. Carrier energy is rarely stronger than the fundamental, even at low amplitudes. Any number of low harmonics can be forced to or near zero.

Steplocking offers nearly unlimited choice of precision amplitude increments. Switching pulses are locked to the chosen fundamental. The carrier phase reverses every half cycle to aid harmonic reduction.

This process works well with low-end microcomputers. And, nothing is analog. It requires typically 26 bytes per amplitude. You can safely make steplocking three-phase delta friendly. The final advantage is that per-cycle switching events are often independent of speed or frequency.

And, of course, on the dark side, there are limitations. First, the initial pair of uncontrolled odd harmonics often is strong, possibly comparable in strength to the fundamental. Second, some low-pass filtering is needed; filtering is provided by motor inductance and load inertia.

The third disadvantage is that highly precise timing is required to one part in 30,000 or better. Fourth, speed or frequency may have to be set by a second PLL circuit. Fifth, steplocking is best suited for power and lower audio frequencies. And finally, a reasonably wide speed/frequency range does not go down to DC.

A FIRST LOOK

Figure 1 shows some steplocked sine wave variations. A few exactly spaced pulses thicken nearing the sine wave crests. Thickening and repositioning achieves higher amplitudes.

Often you will work in the first quadrant only. This is mirrored for the second. The pair then can get flipped for the remaining bottom half of the waveform. Using one quadrant guarantees no DC term, no even harmonics, and no Fourier cosine terms for any odd harmonics. It also requires only one-fourth the storage for your table look-up listing of pulse start and pulse width values.

Each pulse is output to connect a DC power supply to your load. Two half-bridge drivers often are used for single-phase applications. Unlike

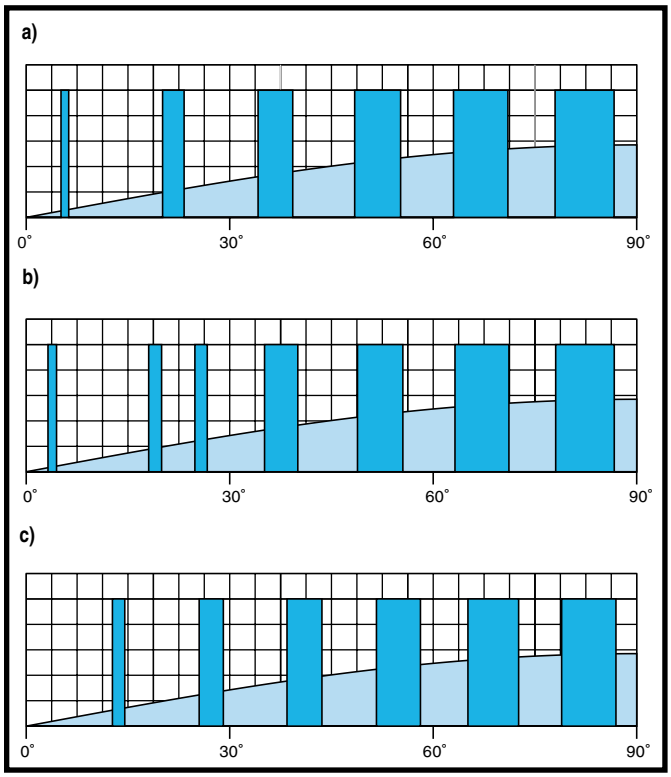


Figure 1—*Here are three examples of variations on steplocked magic sine waves.* **a**—*The normal magic sine wave cancels out harmonics 2 through 22.* **b**—*The delta-friendly magic sine wave handles three phase loads.* **c**—*The best-efficiency magic sine wave cancels out harmonics 2 through 24.*

PWM, only one driver is normally switched at a time, which may improve efficiency.

The spectrum for any steplocked magic sine wave typically consists of zero even harmonics and no DC term. A chosen number of low odd harmonics are also forced to or near zero.

The higher the number of pulses, the more odd harmonics you are able to force to zero. But, the efficiency is worse because of the increase in switching events. The lowest two odd harmonics that aren't suppressed often are strong and may approach (but rarely exceed) the fundamental amplitude. Low-pass filtering can minimize these harmonics.

To have deep harmonic nulls, the pulse positions and widths must be exactly specified. A 1-µs timing accuracy is neither excessive nor unreasonable at 60 Hz.

Numbering sequences by the total pulses is convenient. A seven-pulse-per-quadrant solution can be called a steplock-28 and have 56 half-bridge switching events.

STEPLOCK SYNTHESIS

Figure 2 shows how to synthesize a steplocked magic sine wave with efficiently controlled amplitude. The waveform has no low harmonics through the sixteenth. Similar techniques can be used on other sequences to force any number of low harmonics to zero. Some knowledge of Fourier series would be helpful. For more information, check out the tutorial on my web site.

The secret behind a steplock synthesis is that each pulse edge controls something. Typically it controls an odd harmonic, but it may set your fundamental amplitude or force some useful sequence property.

You should work in the first quadrant to eliminate even harmonics and pick up some other benefits. You'll need one pulse edge to set the fundamental amplitude, one edge to cancel out the third harmonic, and six more to cancel out harmonics 5, 7, 9, 11, 13, and 15. Eight edges for four pulses per quadrant are needed.

This gives you eight messy equations with eight unknowns that can be solved for the precise pulse positions and widths. During previous forceful testing, I learned that at least one useful and unique solution often can be found.

A simple Calculus 101 lesson tells you that any first quadrant unity height pulse adds to the fundamental amplitude using:

$$\text{amplitude} = \left(\frac{4}{\pi}\right)[\cos(\alpha) - \cos(\beta)]$$

where α is the start angle in degrees and β is the end angle in degrees. The first equation should then simply sum the four pulses to give the fundamental amplitude. There are similar four-pulse start and end equations easily written and set to zero for each harmonic to get controlled. Use terms such as cos (3α) for your third harmonic, cos (5α) for the fifth, and so on as needed.

These eight equations are ugly. You may want to play with them to make them friendlier. First you'll want to get rid of those nasty multiple angles. You probably suspect that useful identities are buried in a trigonometry book somewhere:

$$\cos(3\theta) = 4\cos(\theta)^3 - 3\cos(\theta)$$

$$\cos(5\theta) = 16\cos(\theta)^5 - 20\cos(\theta)^3 + 5\cos(\theta)$$

After using these identities, all that's left are zeros, constants, or powers of primary angle cosines. Now you can substitute x = cos (θ) and similar terms to get rid of the nasty trig and have eight plain algebraic equations and eight unknowns remaining. Before solving these though, let's get a bit fancy by driving the…

CHEBY TO THE LEVEE

Those multiple angle substitutions are polynomials or just summed powers of a variable. This particular sequence of polynomials is called first kind Chebyshev polynomials. You can verify this by digging deep enough into any thick math textbook to find this rare gem:

$$T_n \cos(\theta) = \cos(n\theta)$$

where T_n is the appropriate Chebyshev polynomial of the order you need. As you may already know, these polynomials have all sorts of other uses, including filters and curve fitting. More details can be found on my web site and in *Active Filter Cookbook*. [1]

A curious Chebyshev property is that when it is good at something, it may end up being the best possible you can do. So, until proven otherwise, I claim that the steplock synthesis shown here is the best you can do

in terms of the maximum harmonic cancellation for minimum pulse edges and switching events. Hence, it's the most efficient.

You need to know little about Chebyshev polynomials. T_0 is defined as 1 and T_1 is defined as x. The rest of the terms can be found by using this cute recursive formula:

(next term) = 2x (current term) – (previous term)

In steplock magic sine waves, you are usually interested only in odd Chebyshev terms, because you are seeking odd harmonic control. Substituting Chebyshev for the angle reductions gives the superbly compact first equation in Figure 2.

Many fancy PC math packages provide Chebyshev capabilities and work directly with equations of this type. But, you can further reduce the equations to an astoundingly and elegantly simple format. Any time you have a pile of equations, you can add or subtract multiples of the individual equation lines to each other without changing their validity. Doing so leads to the simple power expressions of the second equation in Figure 2.

Often, equations like this are best solved by starting with a good guess and then incrementally "shaking the box" to get a closer answer. Because a fundamental amplitude error is a different animal than a harmonic zero error, it's best to minimize harmonics first and then try again.

For instance, suppose you're trying to get a 0.4000 amplitude and end up with a harmonically zeroed 0.4004 amplitude. You would then ask for a 0.3996 and retry. Note that this ploy rapidly converges.

VARIATIONS ON A THEME

Because real sine waves don't have a hole near their crests, you can also force an odd number of edges per quadrant. The two leftover edges can form a (usually) wider pulse bridging 90° or 270°. To do so, end your final pulse at 90° and let the adjacent quadrant pulse abut.

You also could skip selected harmonics or force them to nonzero values, possibly for channel distortion or to handle an oddball resonance problem. I guess you could even play musical chords!

Table 1 shows a normalized 0.57-amplitude example for a steplocked magic sine wave. Other examples of different kinds of steplocked magic sine waves are available on my web site. A steplock-24 solution of Figure 2 for six pulses per quadrant results in the best efficiency.

You may also create steplocked magic sine waves whose pulses end up more evenly spaced. This costs you control of one odd harmonic, but is more like the PWM signal, has a more obvious carrier, and can help you develop your upcoming three-phase, delta-friendly solutions.

Useful choices for your amplitude increments are 100 or 256 steps, but keep in mind that nearly any amplitude set can be used. In addition, you can work in constant power increments by selecting the square root of your forced amplitude.

Desired amplitude	0.57	
Actual amplitude	0.569999	
Actual power	0.324899	
Distortion 2H-22H	0.00096016%	
First strong harmonics	23 and 25	
Pulses per sine cycle	24	
Total switching events	48	
Delta-friendly	No	
P1 Start: 5.1278	End: 6.2655	Delta: 1.1377
P2 Start: 20.1049	End: 23.2776	Delta: 3.1727
P3 Start: 34.1831	End: 39.2932	Delta: 5.1101
P4 Start: 48.423	End: 55.1945	Delta: 6.7715
P5 Start: 62.9925	End: 71.0116	Delta: 8.0191
P6 Start: 77.9668	End: 86.6674	Delta: 8.7006
H3: -7.10092×10^7	H21: -3.80407×10^6	H21F: -1.81146×10^7
H5: -3.6481×10^6	H23: 0.803194	H23f: 0.0349215
H7: -5.7061×10^8	H25: -0.440767	H25f: -0.0176307
H9: 4.65998×10^6	H27: -0.169326	H27f: -0.00627134
H11: 4.11531×10^7	H29: -0.0100077	H29f: -0.000345094
H13: 5.11062×10^6	H31: 0.0125276	H31f: 0.000404115
H15: -2.63622×10^6	H33: 0.0149846	H33f: 0.00045408
H17: 2.2086×10^6	H35: 0.0162002	H35f: 0.000462862
H19: 2.01816×10^6	H37: 0.0174321	H37f: 0.000471138

Table 1—*This steplock-24 normal magic sine wave is not delta-friendly. Harmonics 2 through 22 are almost 0. The first major harmonics are the twenty-third and twenty-fifth. Harmonic amplitudes are relative to the fundamental. Filtered f harmonics assume a filter of an integrating, or 1/H or 1/f response. A 0.001° or better timing accuracy is required.*

BECOMING DELTA-FRIENDLY

The real world may place another limit on steplocked magic sine waves. Most large industrial motors are three-phase; you wouldn't want to rewire existing motors or use six power half-bridge drivers if you need only three.

I define a delta-friendly magic sine wave as one that lets you control unmodified, three-phase motors. Most steplock sequences are not delta-friendly! Becoming delta-friendly involves some off-the-wall concepts, but it can be done using a few carefully selected steplock sequences. The price is your ability to control a few less harmonics than optimal. Plus there are fewer sequence choices.

Before continuing, let's briefly review delta friendliness. When you connect a three-phase motor to three SPDT switches, you have only eight switch states. For a given winding, the possible combinations can only result in your forcing the individual (ABC) winding currents of (000), (0+–), (0–+), (+0–), (+–0), (–0+), (–+0), or (000) again.

Now, phases A, B, and C will be 120° apart. But B is also where A should end up in time 120° later. And C is now where A will be in time 240° later. So, you can conclude that the third harmonic of any narrow sample of a delta-friendly waveform always must be zero.

Note that this rule is more restrictive than simply generating a waveform whose third harmonic averages to zero over a cycle. You can't rob Peter to pay Paul. Reflecting this need in the first quadrant should give you these two wondrously obtuse rules:

- If there is zero energy in any narrow sample x in the 60° to 90° range, there also must be zero energy in samples (x – 60) and (120 – x).
- If there is one energy in any narrow sample x in the 60° to 90° range, there must be one energy in one but not both samples (x – 60) and (120 – x).


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The reasoning behind these rules is obvious when you draw the first quadrant of a waveform's third harmonic. If there is no negative 3H energy present, there should be no positive energy. On the other hand, if there is something negative, it must be canceled by an equal positive that can lie in either but not both of the two positions on either side of the first 3H crest.

One way to gain delta friendliness is to start with a normal or equally spaced pulse sequence. Then, you can carefully shift and sometimes split the narrowest and middle pulses so you obey the above rule. To visualize this, you can copy Figure 1b and fold it forward at 60° and back again at 30°. Then, hold it up to a strong light and look through it.

Problem:
Create a minimal pulse steplock sequence that generates a fundamental sine wave of 0.53 amplitude but has zero harmonics through the sixteenth.

Solution:
By working in quadrants, all even harmonics will automatically be forced to zero. Eight pulse edges are needed to control the fundamental and first seven odd harmonics (3, 5, 7, 9, 11, 13, 15) for eight equations and eight unknowns.

Write the eight harmonic equations using Chebyshev polynomials:

$$\begin{aligned} T_1(P1S) - T_1(P1E) + \ldots + T_1(P4S) - T_1(P4E) &= 0.53 \times \frac{\pi}{4} \\ T_3(P1S) - T_3(P1E) + \ldots + T_3(P4S) - T_3(P4E) &= 0 \\ T_5(P1S) - T_5(P1E) + \ldots + T_5(P4S) - T_5(P4E) &= 0 \\ \ldots \quad \ldots \quad \ldots & \\ T_{15}(P1S) - T_{15}(P1E) + \ldots + T_{15}(P4S) - T_{15}(P4E) &= 0 \end{aligned} \qquad [1]$$

Where P1S is the cosine of the first pulse start angle, P1E is the cosine of the first pulse end angle, T_1 is a first-order Chebyshev polynomial (used to define the fundamental), T_3 is a third-order Chebyshev polynomial (used to define the third harmonic), and so on. $\pi/4$ is a Fourier series amplitude scaling factor.
By adding or subtracting previous line multiples, the equations can be reduced to this elegantly simple form:

$$\begin{aligned} (P1S)^1 - (P1E)^1 + \ldots + (P4S) - (P4E)^1 &= 0.53 \times \frac{\pi}{4} \\ (P1S)^3 - (P1E)^3 + \ldots + (P4S) - (P4E)^3 &= 0.53 \times \frac{3\pi}{16} \\ (P1S)^5 - (P1E)^5 + \ldots + (P4S) - (P4E)^5 &= 0.53 \times \frac{5\pi}{32} \\ \ldots \quad \ldots \quad \ldots \quad \ldots & \end{aligned} \qquad [2]$$

The solution of these equations using my fast and simple PostScript iterative approximation procedures gives you degree values:

P1 start: 17.9125 P1 end: 21.4007
P2 start: 36.1121 P2 end: 42.7902
P3 start: 54.8818 P3 end: 64.1028
P4 start: 74.4503 P4 end: 85.1345

Figure 2—*Check out the math involved in steplock synthesis.*

Note how the pulses on the first and second folds sum to match the pulses on the third fold. Again, if you have energy on fold three, you must have energy on only one of the first two folds.

From this visualization, you can easily derive which edges will have to track each other to pick up delta friendliness. Note that your first fold pulses should track in the same direction as the third, and your second fold pulses track in the opposite direction.

Mathematically, to create a delta-friendly steplock-28, you could start by using 14 edges. You then lock seven of those edges so that your tracking pulses automatically force the rules. For instance, the start of your first pulse would get locked to the start of the sixth pulse minus 60°.

To force delta friendliness, apparently you have to waste seven of your available edges and seven of your equation variables. But these same seven edges also conveniently cancel out all triad harmonics 3, 9, 15, 21,

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27, 33…. In the steplock-28 example, this leaves seven edges. You use one edge to set your fundamental and six to cancel out the remaining odd harmonics 5, 7, 11, 13, 17, and 19. You still have 14 equations and 14 unknowns, and the usual "shake the box" solution approach still applies. Half of the equations are now simpler.

Certain delta-friendly solutions can introduce other problems such as triad suppression, which interferes with one of your carrier harmonics. The best catalogs I've found demand an odd number of pulses per quadrant.

SOME MORE HELP

A PIC microcomputer seems ideal for steplock magic synthesis. You store the start and length of each pulse in an internal table. The table can be modest; a steplock-24 might require 26 bytes per amplitude. One quadrant worth of pulses might get generated by suitable switching and time delay routines. That quadrant is mirrored for the second, and the pair is flipped for the third and fourth.

For single-phase uses, you would output to a pair of half-bridge power drivers. Making the left driver high and your right one low should force positive current into the load for all pulses in the first 180°. Making the right driver high and the left low forces negative current into the load for the other half cycle.

You can set both drivers high or low to get a zero current. Your choice depends on what will happen. Pick the one that gives the fewest total switching events. The timing needed to cancel out harmonics has to be precise; I recommend an accuracy of at least one part in 30,000. Your range of deep harmonic cancellations ends up being infuriatingly narrow. You can jitter your timing during analysis to pin down the suppression limits.

Frequency or speed is set by overall delay times. To allow sane clock frequencies, magic sine waves are restricted primarily to power and low audio frequencies.

I also recommend setting any variable speed or frequency external to your generating PIC, perhaps by phase-locking the clock.

Author's Note: Many thanks to mathematician Jim Fitzsimmons for his valuable contributions to the steplocked magic sine wave concept.

Microcomputer pioneer Don Lancaster is now the author of 35 books and countless articles. Don maintains a technical help line, (520) 428-4073, and provides consulting services. He is the webmaster of his Guru's Lair at www.tinaja.com. You may reach him at don@ tinaja.com.

SOFTWARE

Steplocked magic sine wave catalogs and calculators are available at www.tinaja.com/magsn01.html. Send an e-mail to request additional support, software, source code, and consulting services.

REFERENCE

D. Lancaster, *Active Filter Cookbook*, Synergetics Press, Thatcher, AZ, September 1996.

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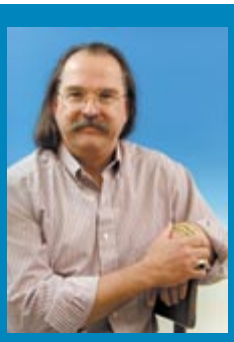
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The Missing (Wireless) Link



Sending data via wireless link can be tricky. Although there are no guarantees with an RF connection, Jeff says the keys to success are asking the right questions and knowing your system.

Every time I need to cheaply send data via wireless link, I forget that most manufacturers of low-end RF transmitters and receivers can't be bothered with circuitry that will actually get data transferred. Isn't that what they're supposed to do? Of course it is. But, you can't cut a hardwired communication link, stick in any old RF transmitter and receiver pair, and expect to resume the same virgin transmission.

Perhaps I'm being harsh, but low-end RF pairs play around in the analog domain. For these, the modulation of choice is OOK or OOSK (on or off shift keying). Although sensitivity for OOK is high (the greatest difference between no modulation (0) and full modulation (1)), just when is a received carrier sufficient?

In other modulation techniques the carrier remains on whenever data is being sent. The data is embedded as a frequency, phase, or amplitude change as opposed to OOK. And, the receiver sensitivity is significantly less, which makes these differences more difficult to detect. But I digress.

Digital signals are considered to be gray if they are not at V_{CC} or Gnd. In this gray area, you can't be sure whether a logic device will see the data as a 1 or 0. Hysteresis can be used in circuitry to force or hold data output high or low as its input transitions through the area. This is accomplished by assigning different switching points to the rising and falling data signals. A couple of comparators can be used to give a signal hysteresis by forming a window comparator. The further apart these switching points are, the wider the hysteresis band becomes. A changing input signal won't affect the output unless it has risen above or fallen below the designed values (see Figure 1).

With analog circuitry, such as that used in RF transmitters and receivers, the signals don't necessarily play fair. The maximum signal excursion may not be 5 V. To be able to assign digital data values to these analog signals, you must sometimes use dynamic means. Translation: Find the average signal value on the fly. Then you must compare this dynamic value to the live analog signal to determine an arbitrary logic state. The point here is that, because this is dynamic, you can't know when an input is giving you a bad signal (noise) or a good signal (data). (Unless, of course, you force the dynamic level to a known state and look for specific data.)

If you force the transmitter to send a 50% duty cycle transmission (preamble data), and the receiver's averag-



Photo 1—*Here's the prototype transmitter and receiver interfaces I built for a one-way transmission path. The Ming modules can handle ~2400 bps.*

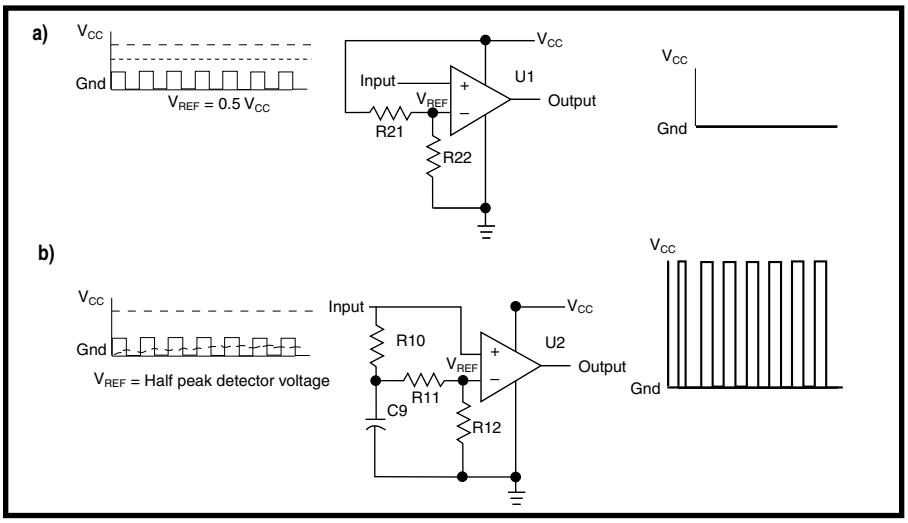


Figure 1—*Without a dynamic level control circuit,* ***(a)*** *will miss levels below the threshold set by the resistor divider (0.5 V_{REF}). Using a dynamic level control circuit,* ***(b)*** *will adjust the V_{REF} level based on the input.*

ing circuit is designed with a capacitor sized to hold its charge for at least *x* cycles, the dynamic level will remain constant. Based on this level, it's easy to compare against the received signal and determine appropriate logic output.

What happens with bad signals? The dynamic level will adjust to noise and the output will again change but will be based on the noise. At this point, squelch circuitry might be used to disable any output when dynamic levels are too high or low. This is not the case with many low-end receivers, so it will cause havoc because it is normally connected to some kind of decoder or UART. Although a good design will reject all of this data (not formatted correctly), the random noise can occasionally create a good data byte. So, how can you make sure you handle only the really good data?

PACKETIZING

When sending snail mail or e-mail, the delivery service doesn't necessarily know what's in the envelope or packet. The envelope accomplishes one thing, it protects your data and provides a delivery scheme. When you're designing a delivery system for data, you can use packetizing to help move the data. I've previously mentioned a preamble. This is the first part of the packet you will define.

To send out an alternating pattern of ones and zeros, a string of Us can be sent. The U character has a bit pattern of 01010101. A UART transmission of a start bit, the U character (LSB first), and stop bit have a pattern of 0101010101. This pattern will continue uninterrupted with additional Us being sent (assuming one stop bit). Assuming that the receiver requires *x* time to get its hysteresis set correctly, the receiver's UART may or may not be in sync with the transmitter's start bit (first 0 bit) of its U character transmission. In fact, it's more likely that one of the other 0 bits in the transmission will be seen as a start bit to the receiver's UART. So, although the receiver will eventually receive the U character, most likely it will not be in sync with the transmitter. How can you get the transmitter in sync with the receiver?

Well, a synchronization character needs to be sent by the transmitter. This is the second part of packetization. The only character you can send that will guarantee synchronization is the character with all ones. The FFh character contains a start bit (0) along with eight 1 bits (plus a 1 stop bit). Independent of which zero the receiver has used as a start bit, after it begins receiving the ones of the FFh character, it will not start a new character until the next start bit. After the character that's not in sync finishes, the remaining ones of the transmitted FFh character will look like additional stop bits and the receiver will wait for the next start bit. Now the receiver is in sync with the transmitter.

Data received by the receiver's UART can now be considered good. I chose to require a null character (00h) to follow as a signal that this is actually the beginning of a packet. This character helps to balance the previous FFh character and also acts as a check to make sure you didn't get to this point by accident (via random noise). The null character is not part of the data message being transferred, just part of the wrapping to ensure delivery. Now you can be sure that the receiver is listening to good data, is in sync with the transmitter, and ready for the message data to be sent. It's important to note that the actual message transmitted should maintain this 50/50 balance between ones and zeros to retain a constant dynamic value. However, most data will not naturally have a 50/50 balance.

BALANCED TRANSMISSION

There are some fancy ways to translate characters into data with a balance of ones and zeros. The simplest way might be to count the ones and zeros of a message and pad the end of the message with bogus data to even out the bits. This has potential problems because the data may contain long groups of consecutive ones or zeros (run length). Although averaged over a message to a 50/50 balance, the dynamic level will wander and potentially create inaccurate decoding.

To reduce run lengths, treat the message on a byte-by-byte basis. With this in mind, a simple approach would be to complement each byte sent. Using this approach the longest run length would be nine. Here you trade off doubling the data sent to ensure both a 50/50 bit balance and a maximum run length of nine. To improve this idea even further, treat the message on a bit-by-bit basis by complementing each bit as opposed to each byte. This improves the run length to a maximum of two.

In addition to the ability of the receiver's code to reject malformed packets, it can also reject bad message data. Because each message byte consists of two transmitted bytes of complemented bits, the receiver's code can reject any packets that contain

message data not conforming to the complement rule. This can be used as error checking on the received message data. You should also note that it is the responsibility of the receiving equipment to handle error checking on the received message as a whole. I believe no data is better than potentially bad data, so I chose to implement this algorithm and dump packets with bad complement data.

Listing 1—*The use of conditional assembly statements allows your code to be assembled with different parameters based on a constant's value preset at the beginning of your code. At the time of assembly, the conditional statements grouped under the matching constant are substituted automatically and alternate conditional statements are overlooked.*

```
IF INV==0
  BCF GPIO, SOUT; clear the serial output bit
ELSE
  BSF GPIO, SOUT  ; set the serial output bit
ENDIF
```

And the bit test (in the receive PIN)

```
IF INV==0

  BTFSC GPIO, SIN; test the serial input bit and skip the next
instruction if cleared
ELSE
  BTFSS GPIO, SIN; test the serial input bit and skip next
instruction if set
ENDIF
```

MESSAGE LENGTH

Very few transfer protocols allow infinite length messages. When multiple transmitters share the same medium, you shouldn't hog that medium. Therefore, messages are usually limited in size. This may, in fact, be limited by the hardware used. Small systems may be limited to a few kilobytes of RAM and micros may have only a handful of RAM. This RAM must be shared between the system variables and the transmit and receive buffers. In an ideal world, the packet message being transmitted would keep up with the message being inputted. Because the number of packetized message bytes actually transmitted can be more than two times the number of message bytes inputted, something's got to give or else the output clogs up quickly.

One way to prevent this is to be able to transmit at a faster transfer rate than the input receives bytes. A second way is to use flow control of the message input. The easiest way is with hardware flow control. When the input buffer is about to be filled, signal the sender to cease sending data. When the buffer is empty, signal the sender that it may continue. This control is built into most serial ports and, when enabled, is automatic. The serial port monitors its CTS input and halts further transmissions when it's disabled. When messages are guaranteed to be shorter than the buffer size, flow control can be disregarded.

DUPLEXING

Most message transmission systems are half-duplex (i.e., data is transferred in only one direction at a time). This system is simplified further by designating a single node as the master while all other nodes become slaves. No slave is allowed to initiate a message. The master node must request a message from a slave for it to respond. This system allows for many slaves to be part of the system without increasing the possibility of unwanted interference. Because each node must be able to receive and transmit, the node cost is also high.

When a system requires transmitting data to or from a single node (data only needs to be sent in one direction), the node cost is cut in half. This design can also work for multiple data senders if you can keep all of them silent while a single node is sending.

Sounds easy, doesn't it? The problem is getting the senders to stay in sync so they

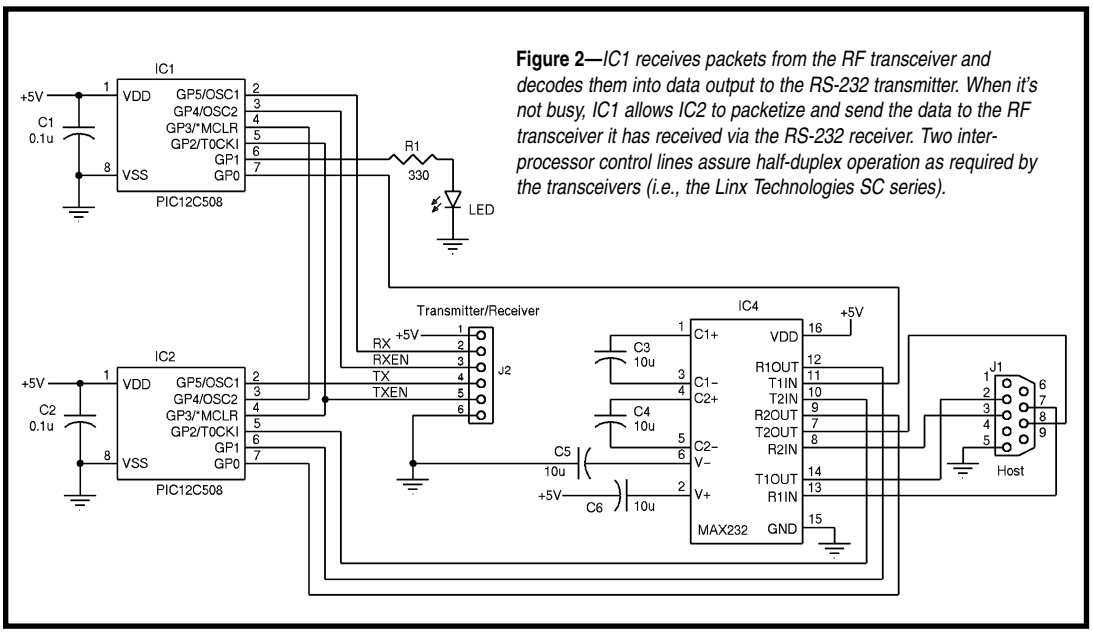


Figure 2—*IC1 receives packets from the RF transceiver and decodes them into data output to the RS-232 transmitter. When it's not busy, IC1 allows IC2 to packetize and send the data to the RF transceiver it has received via the RS-232 receiver. Two interprocessor control lines assure half-duplex operation as required by the transceivers (i.e., the Linx Technologies SC series).*

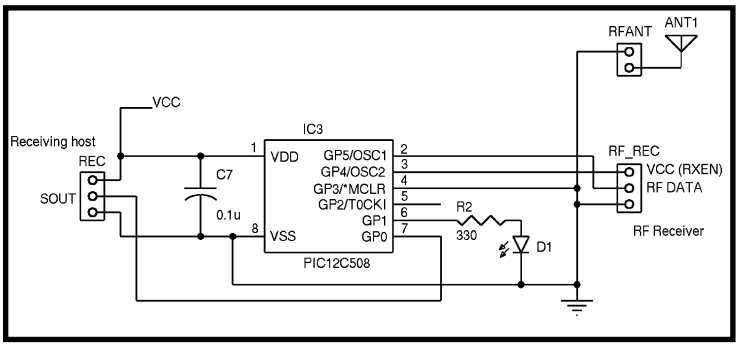


Figure 3—*Here the PIC12C508 handles the packet data from the Ming RX-66 receiver module. While idle, the transmitter may output noise. The PIC's software must be able to strain the data packet out of the noise soup.*

can share the ether. No matter how quickly each node sends its data, if the nodes transmit randomly or at fixed intervals, they will eventually transmit at the same time and trample one another's signal. If you think about this a bit, you will see how this possibility goes up dramatically as there are more and more senders. You can live with missing a message now and then, you say? Just remember, you won't be able to predict when this will happen.

HOW LOW CAN YOU GO?

Is there a way to keep cost down and still handle both two- and one-way transmissions? This project attempts to handle both situations while keeping cost to a minimum. I chose to design with Microchip's PIC12C508 because it's inexpensive. Its 8-pin package can have up to six I/Os as a result of its optional internal RC oscillator. Keep in mind that the internal oscillator is factory-trimmed via an OSCCAL value preprogrammed into the device. This value has been adjusted for 4-MHz operation with V_{CC} equal to 5 V at 25°C, and is voltage- and temperature-dependant. This value can be adjusted slightly to compensate for operation at other voltages and temperatures. Actual operating frequency is only critical for time-dependant operations (i.e., as a software UART). This device contains no hardware UART nor interrupt on timer overflow, so creating a software UART is not easily achieved, especially at higher transfer rates.

Figure 2 shows how I used two 12C508s as separate transmitter and receiver protocol interface nodes (PIN). To assure half-duplex operation, I gave each node an interprocessor communications channel. Essentially this prevents a message from being transmitted while a message is being received (preventing full-duplex operation). Full-duplex operations would be allowed only if the transmission and reception paths were different. In a wired network, this means separate wires for each path. In an RF link, this means different frequencies or channels for each path.

In this design, the transmit PIN requests permission to transmit via the TXREQ line. The receiver interface acknowledges this via the TXEN line if it's not busy with a data reception. When the transmitter interface is used alone where data needs to go in only one direction, its TXREQ output must be tied to its TXEN input. This signal also can be used as an RF transmit enable when necessary. Hardware handshaking is provided to the source of the transmit message when long messages must be sent. A transmission is requested when the PIN's buffer is full or isn't empty and a character hasn't been received for two character times. The timeout sends a partial buffer without requiring a special character (i.e., <cr>).

This design uses the same transfer rate for the data in and data out sides of the PIN. This should be matched to the ability of the RF transmitter. However, there is no rule that says the data inputs and outputs need to be identical rates. In this design, these rates cannot be a user option (except at code assembly time) because all of the I/Os are used. Remember to pay attention during powerup to the transmit to transmit times and transmit enable to transmit times of your particular RF transmitter. These delays must be met before beginning

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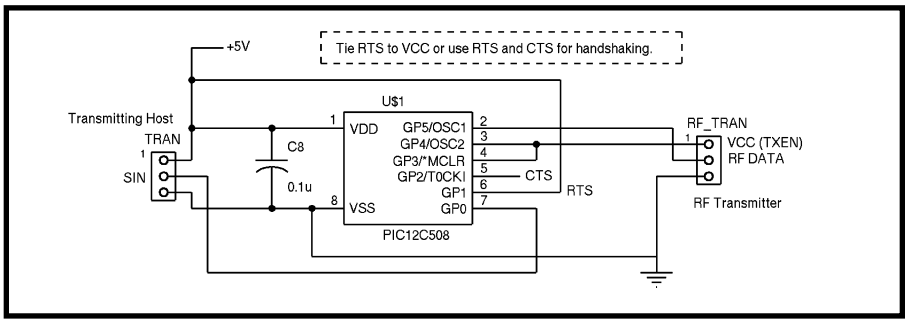


Figure 4—*In this configuration, the PIC12C508 handles a Ming TX-66 transmitter module for a simple one-way transmission. Hardware handshaking can be used on the transmitter interface when you need to have flow control to prevent data overruns.*

any transmissions or you'll end up transmitting only a partial packet.

The receive PIN constantly listens for RF receptions and polls the TXREQ line to learn if it must relinquish control to the transmit PIN. If it's not busy receiving an RF transmission and the transmit PIN is requesting control, the RXEN output is disabled and control is granted to the transmit PIN via TXEN. When the transmission is complete, the transmit PIN gives up control by disabling the TXREQ line. The receive PIN acknowledges this by disabling TXEN and enabling RXEN.

Another reminder: Pay attention during powerup to the receive to receive times and receive enable to receive times of your particular RF receiver. This is important for the transmitting node because this is the minimum time between messages or the minimum delay before the receiver will be ready.

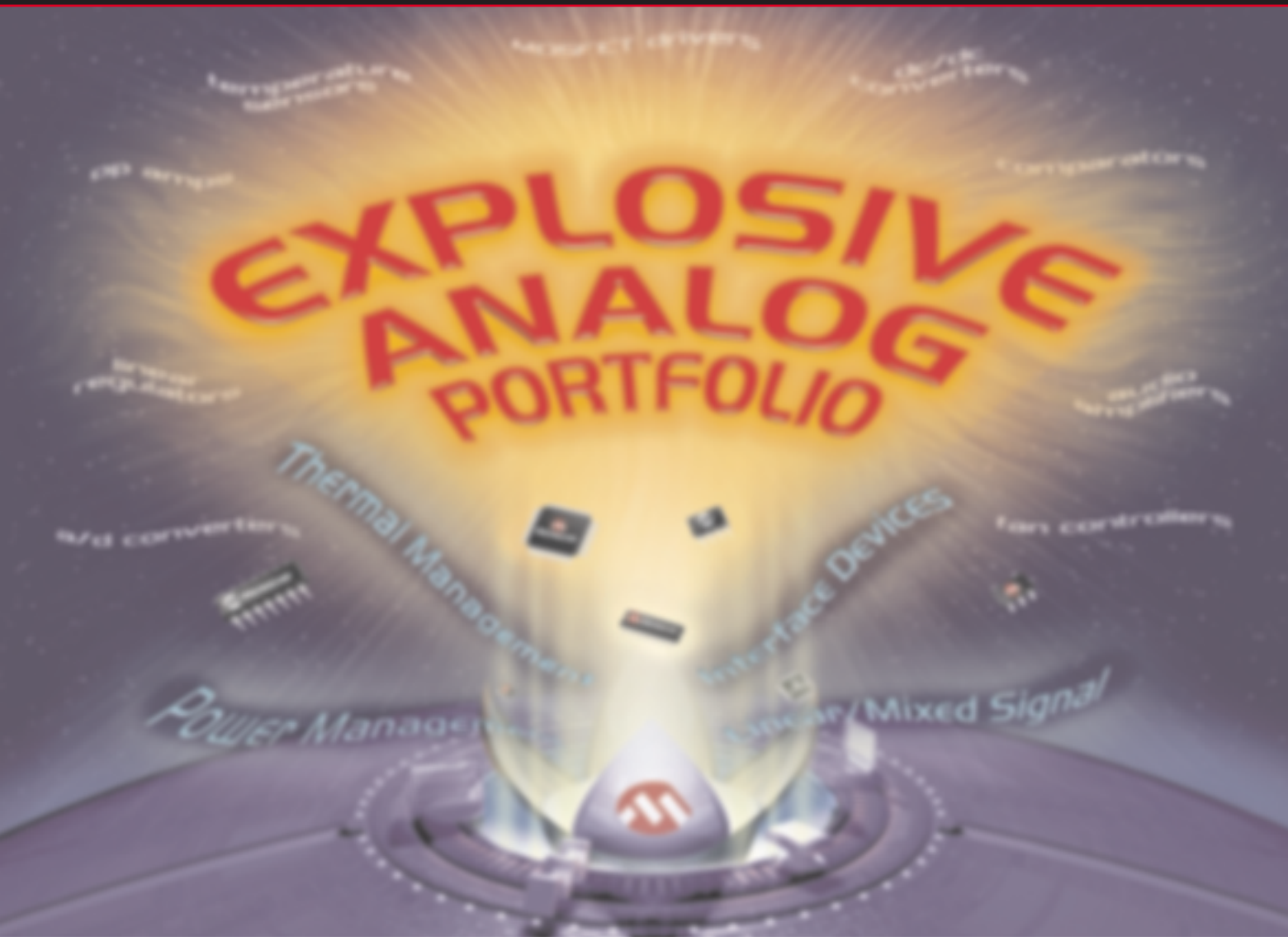
Because the receive and transmit buffers are of identical size, there's no way for a transmit PIN buffer to send too much data to a receive PIN buffer. However, because you're dealing with two software UART routines in each PIN, each device will do tasks sequentially. Each will receive a message from a host and then send a packet to the RF transmitter, or receive a packet from an RF receiver and then send a message to a host. If a transmitting node must send multiple messages back-to-back, it must be aware of the receiver's ability to get rid of the last message and prepare for the next packet. Although data manipulation is similar at each end, to be safe, a short delay is recommended between transmission packets. Hardware handshaking can automatically add a delay to ensure that the receiver has had adequate time for full reception of the packet and retransmission of the message data to its host device.

CODE BITS

Without a timer interrupt, you must pay close attention to the timer value to keep timing as accurate as possible. The minimum loop to read the timer, test for zero, and jump back is four execution cycles. If the timer changes with each execution cycle, you may never see a timer value of zero with the read timer0 instruction (MOVF TMR0,W) because it may occur during one of the other instructions. If the timer0 prescaler is divided by four, the timer value will not change for four instruction cycles. This assures that when it's read, it will remain at zero for each instruction cycle of the loop.

This creates a potential problem with the resolution. You can be sure of timing accuracy only within plus or minus three cycles. At 9600 bps, the bit time is 104 µs. Assuming an instruction cycle time of 1 µs (4-MHz internal RC), you might be anywhere from 101 to 107 µs (9901 to 9346 bps), or ±~ 3%. This may not be enough to be out of specs with UART tolerances alone, but with the addition of the system clock tolerances, it could be of concern. With faster rates it becomes more of a potential problem. Although with slower rates, because the error is a smaller percentage of the rate, it is less of an issue.

Using conditional assembly instructions within your code can be of help



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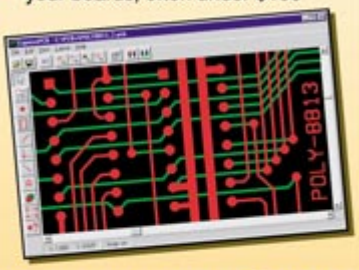
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when programming for options at the time of assembly. In this application, I defined the polarity of the two serial interfaces such that I could have either normal serial levels for interfacing directly to a micro's serial port (or through a pair of RS-232 level shifters), or inverted levels for interfacing directly to a PC that will support TTL signals (eliminating the RS-232 interface chip). A program variable, INV, is set to 0 for normal serial and 1 for inverted serial. Throughout the remainder of the program, IF INV==0, ELSE, and ENDIF statement blocks are used, which define the state of an I/O pin in the transmit PIN (see Listing 1).

When assembled, these blocks produce only one instruction depending on the state of the defined variable, INV. The other instruction is thrown out, but the source code retains the options should you decide to change INV and reassemble the code. The RF serial interface uses the same kind of option, meaning it can be easily matched to the needs of the RF transmitter or receiver.

ONE-WAY STREET

When used with low-cost transmitters and receivers like the TX-66 and RX-66 from Ming Microsystems, the current draw is so low that the RF devices can be powered directly by the '508's output pins (see Figures 3 and 4 and Photo 1). The frequency of your RF devices governs the duration of the transmissions. For these devices (300 MHz), the FCC says that, in addition to radiated power limits, manual transmissions can't exceed 5- s. Periodic transmissions are not permitted, however, when used for integrity checking of security or safety systems. Alarm conditions are allowed during a life-threatening emergency and transmissions are allowed when limited to 1 s/h.

It is interesting to note that the FCC excludes the requirement for product testing for compliance of any circuit built (not from a kit) by a hobbyist for personal use (provided that good engineering practices are used). I'm talking about a respect for personal freedom here, however, you can depend on them to uphold the personal freedom of others if you cause interference outside of the home.

ONE LAST THOUGHT

I've presented some of the things you'll need to think about when designing in an RF connection. When the wire is cut, RF communication brings with it a multitude of problems. The medium is no longer under your direct control. You may have little or no control over how the environment will affect your precious data. You need to spend a good deal of your time investigating how your system responds to data, or the lack of it. How will range and noise affect the data you are trying to pass from point A to point B? What techniques will you employ to ensure data integrity?

It is fairly clear that the RF spectrum is only going to get more crowded in the future. At least manufacturers are beginning to talk about compatibility and interference issues. This can only help bring access to more user-friendly solutions. And with increased use, there's sure to be low-cost, powerful solutions.

Jeff Bachiochi (pronounced BAH-key-AH-key) is an electrical engineer on Circuit Cellar*'s engineering staff. His background includes product design and manufacturing. He may be reached at jeff.bachiochi@circuitcellar.com.*

SOURCES

SC series RF transceiver
Linx Technologies, Inc.
(800) 736-6677
Fax: (541) 471-6251
www.linxtechnologies.com

PIC12C508 8-pin microcontroller
Microchip Technology Inc.
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SILICON UPDATE

Tom Cantrell

Liquid Crystal Delight



You have to love a product that has "easy" built right into the title. Aptly named Easy GUI, from Amulet Technologies, may be the answer to your prayers for a simple solution for middle-of-the-road LCDs.

Last summer I moved into a new house. It's been quite an adventure, a combination of *The Grapes of Wrath* and "The Money Pit." It's great to own a brand-new house as opposed to a fixer-upper, but that doesn't mean there won't be issues, just different ones.

Case in point, as summer came to an end, I concluded that the builders had managed to connect a toilet to the hot water line. With a fall chill in the air, I found myself wondering if this was a new feature, kind of like heated seats in luxury cars.

As a former pool owner, I had seen the unfavorable effects of tepid water with all the hazards of a breeding ground for who knows what. So I presumed that after centuries of using a tried-and-true design, if connecting hot water was a great idea, it would've been done already. Well, a few more cold nights yielded complaints from the kids that the upstairs furnace wasn't working.

Hauling out a ladder, I ventured up to my attic. There's the furnace, but what's this? It's blinking at me. There was a lamp peeking out the side of the furnace repeating a two-digit, blink-pause-blink code of some kind.

Grabbing for the furnace manual (thoughtfully stuck in a rafter), I quickly found the translation: "Open the gas valve, you dummy!" After peering into the dark recess behind the unit and tugging aside some insulation, that's just what I did.

Inevitably I would've checked the gas connection (i.e., whether or not it was plugged in), although I'll bet your average furnace repair person has gone out on just such a call. Nevertheless, it was reassuring to have the furnace confirm the diagnosis, enough so that I felt confident reinstalling the attic access door as I climbed down.

A number of the furnace trouble codes deal with more significant problems and the manual offered some possible solutions to try (e.g., cycling power). Even more useful, some of the trouble codes are so explicit, they help you decide immediately if you'll fix it yourself, call a repair service, or buy a new furnace before nightfall. I appreciated this relatively high-tech feature and suggest that the least you can do is consider designing in a single LED for even your most deeply embedded designs.

Moving up the pecking order of displays, you find the one- to many-digit vacuum fluorescent and LED displays. These can range from relatively cheap single-digit, seven-segment units to larger, fancier dot matrix displays. However, as you move up the size and features scale, the price and power consumption can quickly become problematic.



Photo 1—*The Amulet Easy GUI Starter Kit ($399) includes everything you need to craft your own 1/4 VGA touchscreen display.*

Listing 1—*My example user interface boils down to little more than a page of HTML, which the Amulet compiler crunches down to proprietary uHTML for storing in the onboard serial EEPROM.*

```
<HTML>
<HEAD>
<META HTTP-EQUIV="Content-Type" CONTENT="text/html;CHARSET=iso8859-1">
<META NAME="Amulet" Content="baud=115200">
<TITLE>untitled</TITLE>
</HEAD>
<BODY>
<P>
<TABLE BORDER="0" CELLPADDING="0" CELLSPACING="0" WIDTH="320" HEIGHT="240">
<TR>
<TD WIDTH="320" HEIGHT="240">
<P><body bgcolor="white" text="black" link="blue" vlink="purple"
alink="red">
<p>   <applet code="Field.class" width="137" height="32"
align="middle">
<param name="fontsize" value="5">
<param name="fontstyle" value="bold">
<param name="href" value="1">
<param name="max" value="250">
<param name="maxfld" value="5000">
<param name="min" value="0">
<param name="minfld" value="000">
<param name="printf" value="RPM - %4i">
<param name="updaterate" value="1.0,.1">
</applet>
</p>
<p>0 <applet code="BarGraph.class" width="195" height="39" align="middle">
<param name="fillpattern" value="1">
<param name="href" value="1">
<param name="max" value="250">
<param name="min" value="0">
<param name="name" value="Tach">
<param name="sweepfrom" value="left">
<param name="updaterate" value="1.0,.1">
</applet>
  5000</p>
<p>     <applet code="LinePlot.class" width="178"
height="84"
 align="bottom">
<param name="href" value="1">
<param name="lineweight" value="2">
<param name="updaterate" value="1.0,.1">
<param name="xsamples" value="100">
<param name="ymax" value="250">
<param name="ymin" value="0">
</applet>
</p>
<p> <applet code="FunctionButton.class" width="56" height="25"
align="bottom">
<param name="fontsize" value="3"><param name="fontstyle" value="plain">
<param name="href" value="Amulet:function(1)">
<param name="name" value="Tach">
</applet>
  <applet code="FunctionButton.class" width="56" height="25"
align="bottom">
<param name="fontsize" value="3"><param name="fontstyle" value="plain">
<param name="href" value="Amulet:function(2)">
<param name="name" value="H20">
</applet>
  <applet code="FunctionButton.class" width="56" height="25"
align="bottom">
<param name="fontsize" value="3"><param name="fontstyle" value="plain">
<param name="href" value="Amulet:function(3)">
<param name="name" value="Trans">
</applet>
  <applet code="FunctionButton.class" width="56" height="25"
align="bottom">
<param name="fontsize" value="3"><param name="fontstyle" value="plain">
<param name="href" value="Amulet:function(4)">
<param name="name" value="Load">
</applet>
</p>
</TD></TR>
</TABLE>
</BODY>
</HTML>
```

WORKING GLASS HERO

This brings us to the LCD.

At the low end, enjoying near commodity status, are 1 × 16 (one line of 16 characters) to 4 × 40 alphanumeric units that go back several years, based on a controller chip originally designed by Hitachi. The fact that Hitachi was once a second source for Motorola micros is seen in the 6800-type interface (E, RS, R/*W, etc.) these modules employ.

Meanwhile, high-end embedded PC apps can take advantage of the wonderful VGA-and-beyond LCDs found in laptop computers. The beauty of this approach is that you can use your favorite desktop software development tools without having to write any specialized display drivers. Because both the target and desktop systems are PCs, it's the ultimate WYSIWYG approach.

However, there are a ton of applications that need more than a few lines of text, but don't need (and can't afford) the overkill of a full-blown embedded PC.

If you're a big-shot customer, I suppose you could buy a truckload of raw glass and hack together a bunch of driver chips and low-level software to make it do something useful. Another idea is to draft some consumer electronic gadget such as a PDA, GameBoy, or even a hand-held TV into double-duty as a display.

QUARTER HORSE

What the world really needs is a fully integrated, easy-to-use solution for middle-of-the-road LCD display applications. That's exactly what Amulet Technologies aims to deliver with its aptly-named Easy GUI package of chips, boards, modules, and software tools (see Photo 1). Configurable to support a variety of panels and resolutions, Easy GUI targets the so-called 1/4 VGA (320 × 240) sweet spot, fitting squarely between the resolution offered by the old war horses (e.g., 256 × 64 for the venerable Hitachi LM213B) and the full-blown megapixels of an embedded PC.

Easy GUI technology starts with a chip of Amulet's own design (see Figure 1). Packaged in an 80-pin PQFP,

the AGB64LV01 integrates an 8-bit microcontroller with LCD interface logic including a line buffer and programmable timing generator. External interfaces include an 8-bit data bus for an SRAM, 8-channel SPI port for serial EEPROM and other peripherals, UART for host connection, and the LCD panel interface.

The latter consists of a pixel data bus and a half dozen video-like timing and control signals. Various characteristics are programmable, such as pixel bus width (1, 2, 4, or 8 bits) and pixel and frame clock polarity, to accommodate a variety of manufacturers' panels. At this point, Amulet supports only monochrome panels, but it's not hard to imagine a color follow-on.

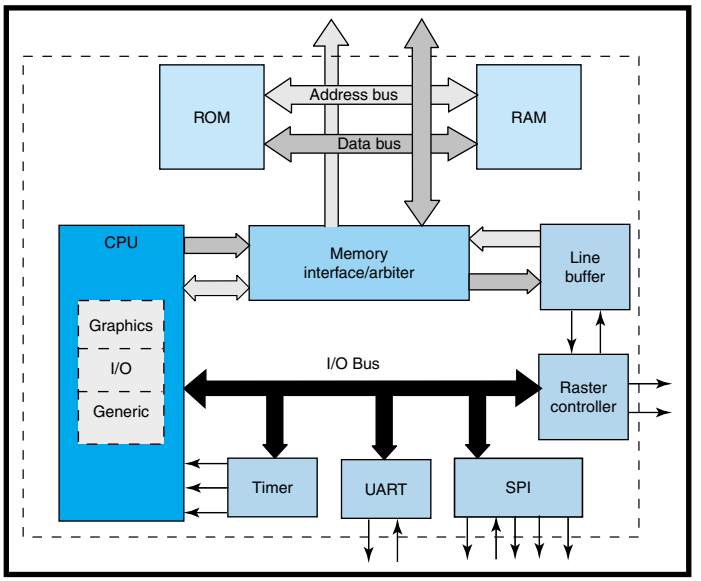


Figure 1—*The Amulet Easy GUI chip ($17.50 in 10k units) combines a micro with custom graphics extensions, a 256-byte line buffer, and an LCD interface with programmable timing to accommodate a variety of displays.*

Figure 2 is the schematic for a typical board design, much like the one that comes with the starter kit (see Photo 2). The Amulet Technologies chip is hooked to a serial EEPROM that stores the user-defined screens and a byte-wide SRAM used for both the display frame buffer and working storage. An RS-232 level shifter and the usual 9-pin connector complete UART connection to the host.

Also shown on the schematic is a Burr-Brown (now part of Texas Instruments) ADS7486 touchscreen controller. This little puppy handles all the details of connecting a resistive touchsceen overlay for "Look ma, no mouse" embedded apps. That's a nice touch.

SOFTWARE TO BOOT

It's great that Amulet offers an easy integration (i.e., connects to anything with a UART) solution for mid-range display apps. However, hooking up the hardware is only part (arguably, the easiest) of the story. No matter whose chip you use, there's still the small matter of software to make it do something useful. It isn't hard to cobble together some low-level drivers

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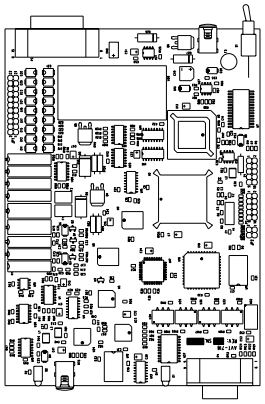
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such as BitBLT (bit block transfer) or a line algorithm, but it's a long journey from these primitives to a pleasing user interface. Worse, the more cycles your host controller has to spend babysitting the display, the fewer cycles it has available to handle the embedded application.

Wouldn't it be nice to be able to take advantage of powerful desktop software tools to craft your user interface, but without having to burden your application with the full baggage of an embedded PC? Well, hang on to your logic probe, folks, because that's just what Easy GUI purports to do. The trick can be described in four letters, HTML. Here's how it works.

Start with your favorite web page editor and craft your user interface, including touchscreen hyperlinks, right on screen. Of course, you can evaluate, share, or otherwise fool around with your user interface design using a standard web browser. When you've got it just right, run the desktop HTML through Amulet's HTML compiler.

The HTML compiler munches on your pages and outputs a condensed version Amulet Technologies calls uHTML. The uHTML gets downloaded to the serial EEPROM on the module where it's interpreted by the Amulet chip at runtime using a built-in uHTML browser.

WIDGET WARRIOR

The concept of using a standard web page editor to build an embedded user interface is intriguing, but Amulet goes even further.

As handy as it sounds, there are many things an embedded system needs to do that aren't really in the domain of HTML or conventional web page development tools.

Although the RS-232 port provides the hardware connection between the display and application, there also needs to be a software scheme for communication. For example, pressing the touchscreen should update a variable or invoke action by the host controller. Likewise, an application should be able to overlay the static uHTML pages in flash memory with dynamic application data.

No doubt there are a lot of embedded apps that could take advantage of canned functions (e.g., a bar graph or line plot), which HTML knows nothing about. Java? Well, you're close.

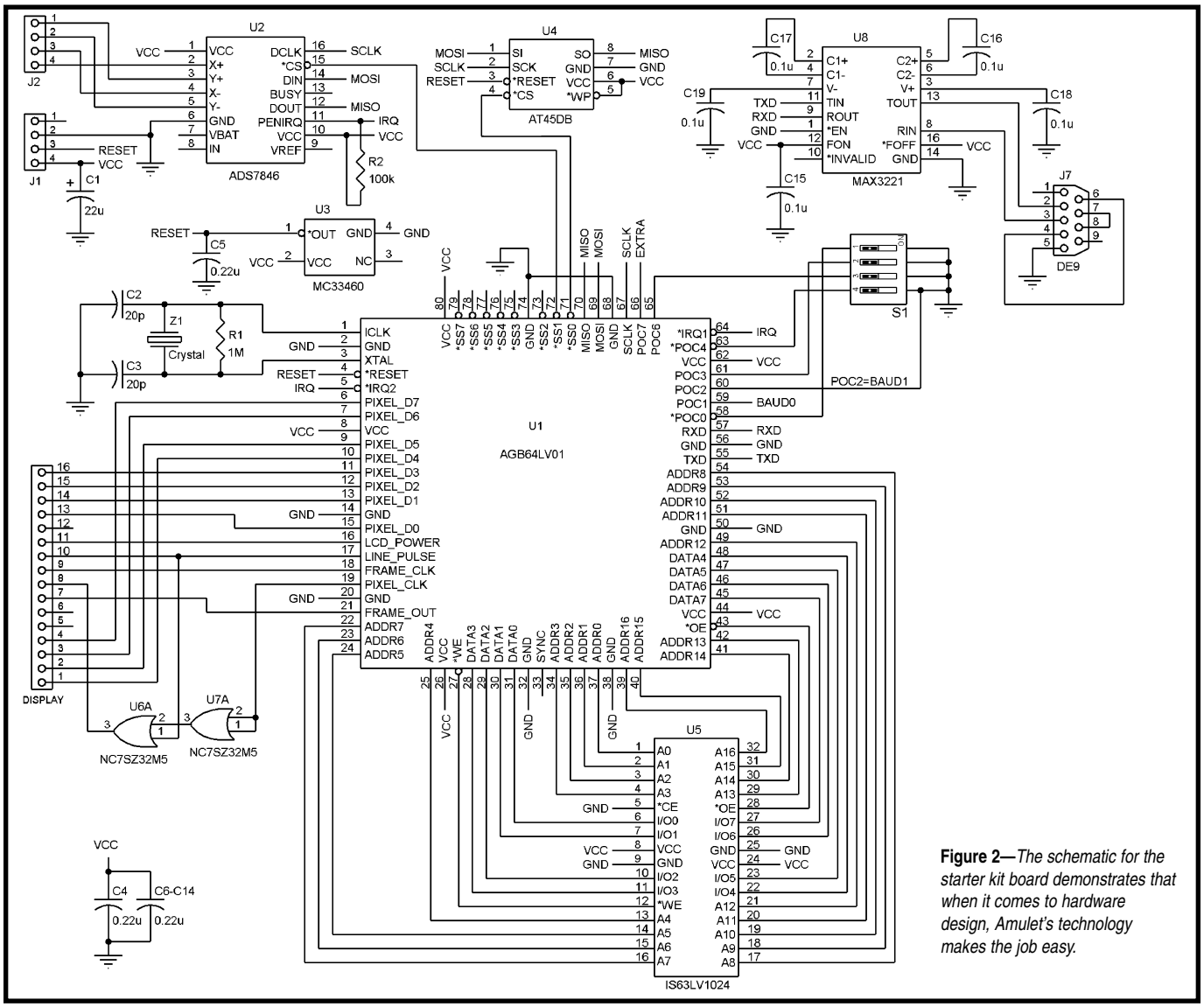


Figure 2—*The schematic for the starter kit board demonstrates that when it comes to hardware design, Amulet's technology makes the job easy.*

In the desktop world, Java applets are indeed the means by which web page functionality is extended in an open-ended manner beyond the confines of HTML.

No, the Amulet chip does not include a full-blown JVM. Instead, Amulet supplies a library of what it calls widgets to handle a variety of user-interface tasks.

At this point, astute readers are anticipating the gotchas for widgets, namely that they break the clever use-a-web-page-editor (which knows nothing about widgets) strategy. Fortunately, Amulet supplies Java applet versions of the widgets, preserving the ability to develop on the desktop with standard Java-capable web page editors and browsers.

HIGHWAY STAR

Let's give the starter kit a whirl around the block. I'm a novice when it comes to web page editors and HTML, so it's all the better that I needed to fill the gap in my quiver of display options. I figured I would be a good test case to see whether or not the Easy GUI concept truly lives up to its name.

I decided to prototype a simple automotive display. Judging by the amount of e-mails I receive, the articles I've written about combining computers and cars strike a chord with a lot of you. Someday, I hope to update my last mobile project ("On the Road Again" *Circuit Cellar* 118 and 119), which put an SBC into my van's J1850 network, and a mid-range bitmap display would be the ticket.

My sample interface (see Photo 3a) consists of various widgets including numeric field, bar graph, and line plot representations of a variable (rpm), and four touch-sensitive function buttons. The rpm is updated from the host via RS-232. Pushing any of the buttons causes a unique code signifying the event to be sent to the host.

To make a long story short, I was indeed able to get my sample interface working in relatively short order, as you can see in Photo 3b. Referring to the HTML source (see Listing 1) is a good way to see what's going on. It starts with some preamble stuff, including the "Amulet" META statement, which conveys hardware-specific information (in this case, the baud rate) to the chip without upsetting the web page editor or browser. As this is a monochrome unit, all color designators are simply ignored.

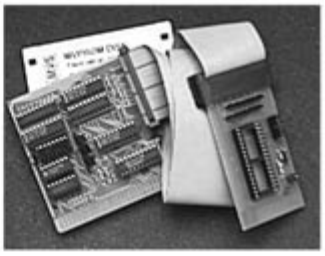
Next, you see the definition of a 320 × 240 table (corresponding to the resolution of the LCD) that's required to set the stage for your interface.

Following are seven applet code sections, one each for the (numeric) `Field`, `BarGraph`, `LinePlot`, and four `FunctionButtons`. Each incorporates a list of parameter names and corresponding values that define the appearance and behavior of the widget. Let's go through them one by one for the `Field.class`, the first numeric field showing rpm.

The `fontsize` and `fontstyle` parameters are self-explanatory. Note that currently Amulet supports only a single sans serif font, and size choice is limited to 8, 10, 12, 14, and 18 points.

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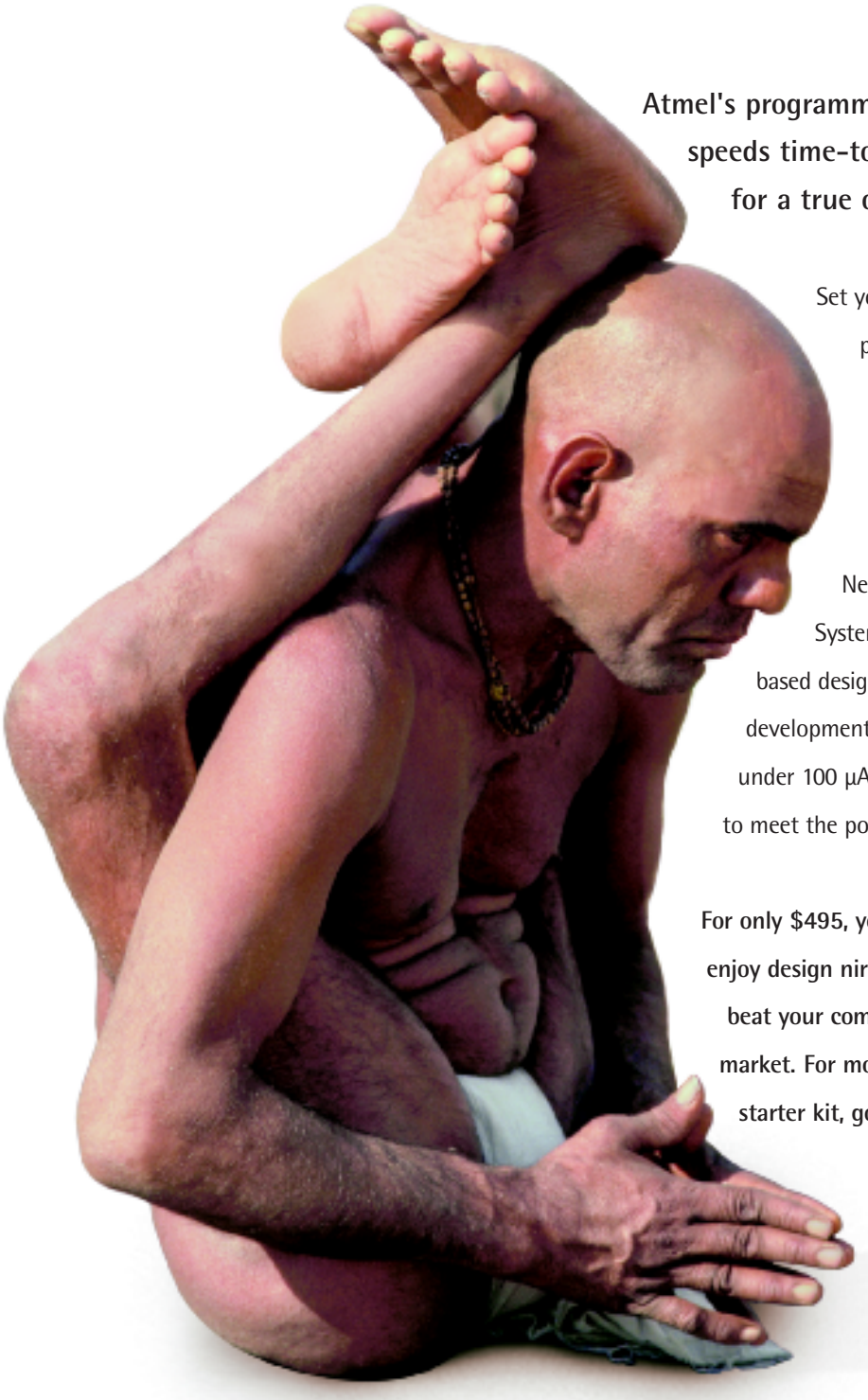
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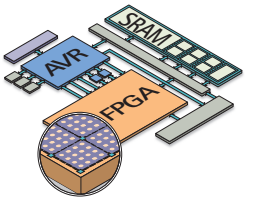
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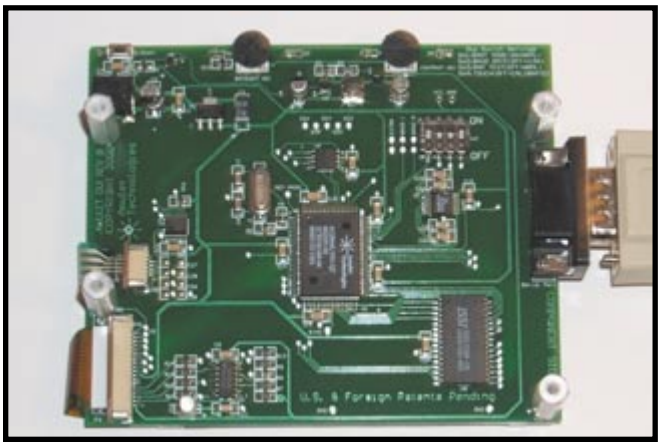


Photo 2—*As this photo shows, a complete Amulet-based solution calls for the addition of just about a half dozen memory and I/O chips.*

`Href` defines the data interchange with the host, with "1" identifying variable 1 as the source of the rpm value. Skipping down to the last entry, you can see that the desired update rate is 1.0 (allowed range is 0.01 to 655.35 s). So, once per second the Amulet board will send a request to the host for the value of variable 1.

One limitation is that variables are only 8-bits wide, so I decided to have the host send rpm divided by 20. On the other hand, a nice touch is that the widget incorporates scaling as defined by the `min`, `max`, `minfld`, and `maxfld` parameters. The variable value between `min` and `max` (i.e., 0–250) is automatically scaled to the corresponding value between `minfld` and `maxfld` (i.e., rpm multiplied by 20). Finally, the `printf` parameter defines the way the field is displayed using, as the name implies, C-like format options and syntax.

Similarly, the `BarGraph` and `LinePlot` parameters define the data source (also variable 1, rpm) appearance, update rate, and so forth.

Skip down to the function button widgets. What happens when they are pressed is defined by the `href` parameter. In this case, the value is `Amulet:function(1)` for the first button, `Amulet:function(2)` for the second, and so on.

This means that when the first button is pressed (Tach), the Amulet board will send a command to the host to invoke function 1 for the first button, function 2 for the second button, and so forth. Other options for handling a button press include switching to a specific page or returning to the previous page.

BETA SITE

I remain impressed with the mid-range positioning and overall web-in-drag concept of Amulet's Easy GUI, although I have to admit that there are some issues, not to mention a few rough edges.

One such issue is that switching between EEPROM programming and normal operation requires toggling a DIP switch, which is mounted on the bottom of the board. It doesn't sound especially unreasonable, but actually runs counter to the easy blow-and-go approach the technology encourages. The good news is that it takes only a few seconds to edit and recompile your project. The bad news is that it also takes a few seconds each time to turn over the board and fuss with the DIP to switch to Programming mode and flip it again to check the result. If it must have a switch to differentiate modes, I suggest something like a dedicated toggle switch that's easily accessible from the top.

A nagging concern lies in the possible complications as a result of ever more bloaty tendencies for desktop web tools and HTML feature creep. This is reflected in Amulet's recommendation that it's better to use a simple web page editor rather than the latest and greatest version.

In truth, after I had roughed out my interface with the web page editor, it wasn't long before I found myself editing the raw HTML directly rather than going through the web editor. For instance, with the web page editor, tweaking the parameters for a widget required navigating a sequence of menus, lists, and dialog boxes versus a few seconds to edit the HTML with Notepad.

Another reason I drifted away from the web page editor was based on the observation that it was not quite as WYSIWYG as I had hoped, with slight differences in the formatting of the desktop and LCD versions of my interface. Perhaps more experience with any or all of the tools would enable reconciling the difference, but I'd rather spend time getting the LCD display to be the way I want it than figuring out how to coerce the tools.

Ironically, I recently wrote a column opining that the PC market is weak because our beloved boxes now have so much horsepower relative to typical users' needs, leaving little reason to upgrade.

But I must say that by the time I had everything running—web editor, browser, Amulet compiler, and proto-

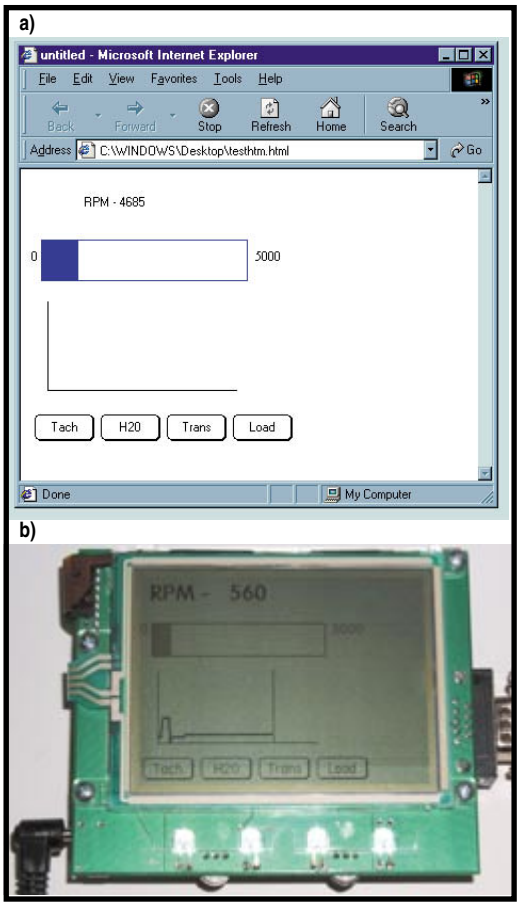


Photo 3—*The example interface runs in a web browser* ***(a)*** *and live on the LCD* ***(b)****. Notice the minor difference in appearance, and the fact that the browser version doesn't use real data (rpm).*

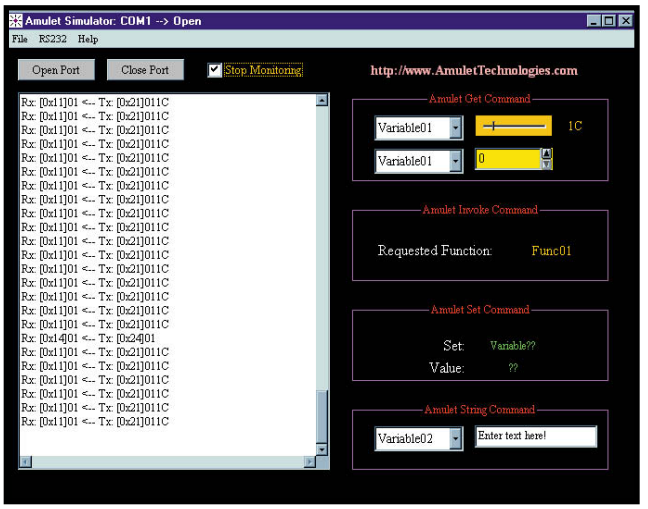


Photo 4—*A recently added serial port simulator allows the PC to stand in for the host. In the RS-232 monitoring window, you can see the periodic rpm message exchange and, near the end, the message that was sent when the Tach (function 1) button was pressed.*

col simulator—things started getting noticeably pokey. Hard to place blame, but it seemed as if emulating the Amulet widgets in the web browser imposed a fair amount of stress.

TAKE IT EASY

It's a work in progress, but even as I finish this article, progress is being made. The latest version of the tools includes a serial protocol simulator (see Photo 4) and the compiler, for example, now allows a single function button press to perform multiple actions (e.g., switching pages locally and invoking a remote procedure on the host). I even hear they're doing away with the dastardly DIP switch.

Judging by the rate of progress, by the time you read this, many of the glitches should be history. In any case, warts and all, Amulet is on to something. It was quicker and easier to get going than the alternative of rolling my own display from scratch.

Whether it's a single LED, full-blown VGA, or, in Amulet's case, something in-between, just remember that embedded systems, even ones in the attic, need a way to tell you what's going on.

Tom Cantrell has been working on chip, board, and systems design and marketing for several years. You may reach him by e-mail at tom.cantrell@circuitcellar.com.

SOURCES

Easy GUI Starter Kit, AGB64LV01
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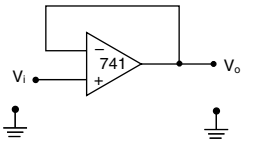
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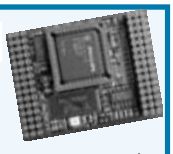
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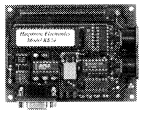


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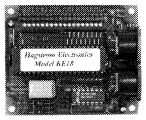
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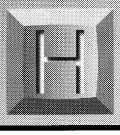
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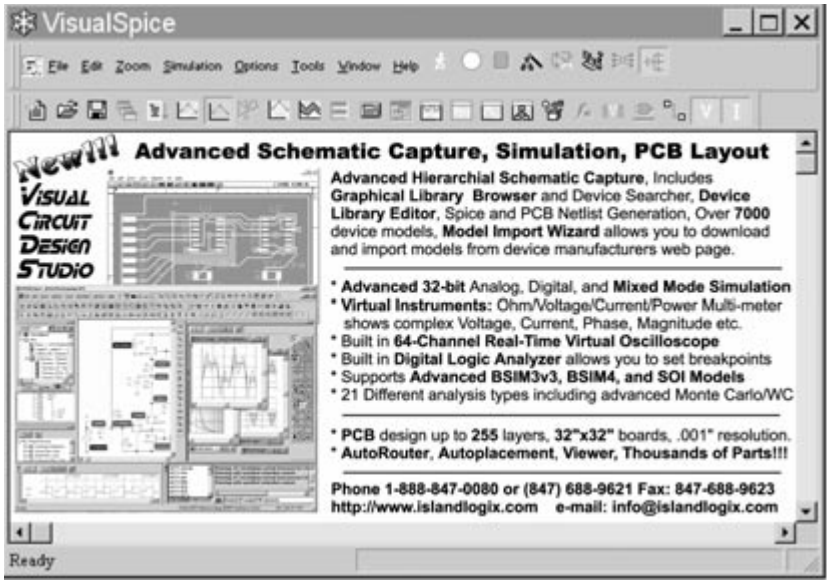
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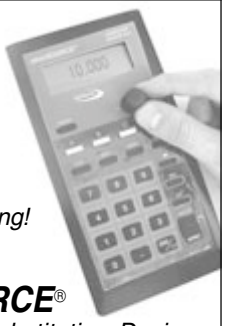
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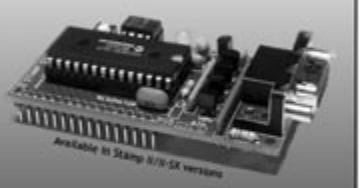
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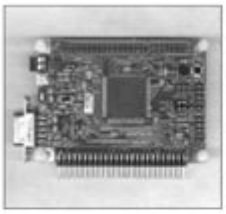
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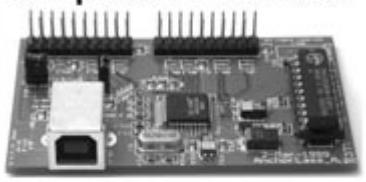
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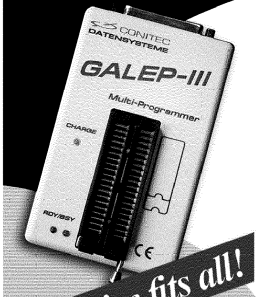
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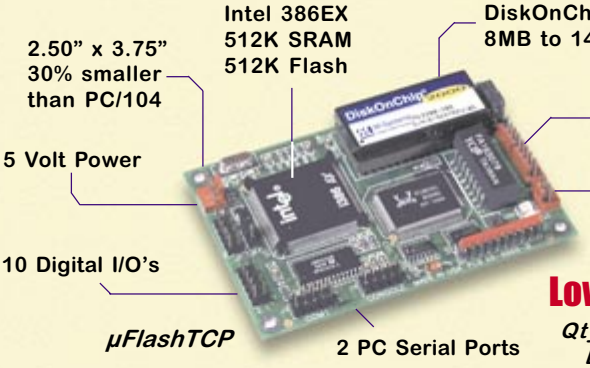
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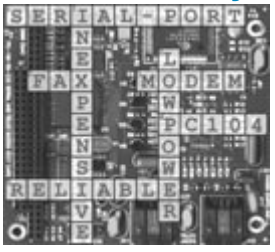
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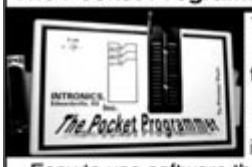
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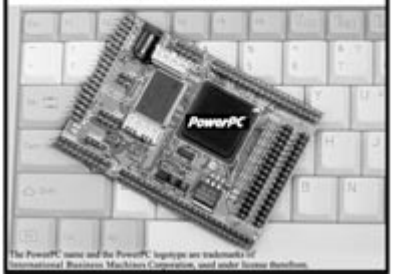
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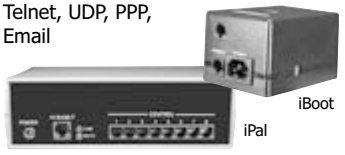
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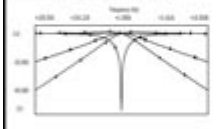
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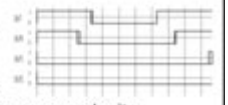
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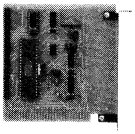


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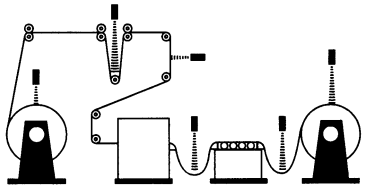
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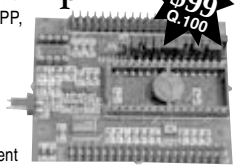
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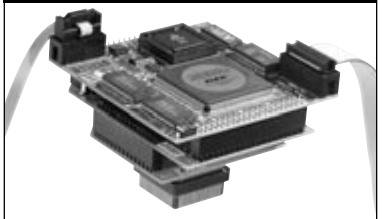
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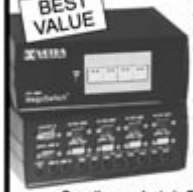


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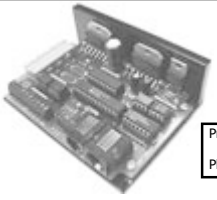
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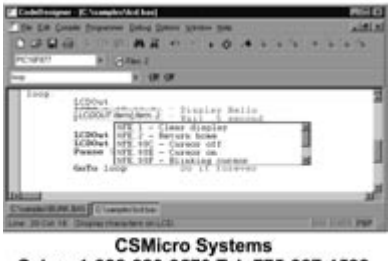
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PREVIEW 133

PRIORITY INTERRUPT

Trade Show Paradigms



How much gloom and doom there is in the economy right now depends on whom you ask. Certainly the people on the West Coast who are experiencing dot-com-downsizing and sitting in the dark are somewhat bitter and warped. At the same time if you ask a builder in New England when you can schedule an addition to your house, he smiles and says, "Take a number." If anything it's a mixed bag. Certain segments of the economy see no tomorrow while others feel that the high-tech blip is just that, a blip. For others, it's the handwriting on the wall.

One sector of the high-tech community that may not recover with the same vigor is the trade show. *Circuit Cellar* usually attends three or four shows each year with the editorial staff and a booth. In addition, we send editors or distribute magazines to a bunch more. In fact, we had just shipped boxes of magazines to the Convergence University show when we were informed that it was "postponed until a more favorable climate." Anyone in Santa Clara need some extra magazines?

They are not alone. Despite joining together, the Internet Device Builder and Applied Computer Conference recently had a lackluster result. Trade shows are in trouble and *Circuit Cellar* is not alone in having to decide how to support or attend future events. For example, we would normally attend the July Embedded Systems Conference in Chicago, but as I write this it appears that it will only have about one quarter the exhibitors of the most recent West Coast ESC. That is hardly the incentive I need to spend the $10k–$15k to staff a booth. More importantly, there is yet another Embedded Systems Conference in Boston only two months later!

Businesses seem to run in cycles. Maybe it's just the nature of the business that more often than not, the higher the boom, the bigger the bust. For years the Internet and everything connected to it has grown at a breakneck speed. The NASDAQ blowout and all the dot-bombs put a real damper on the economy. In true fiscal reality, however, with the exception of the stock speculators and vulture capitalists, we haven't lost trillions of physical dollars in our economy. We just didn't realize the gain we would have had. The disparity in opinions about our current economic shape has a lot to do with how we view financial assets. The portion of the population that used the $100k worth of Priceline.com in their portfolio to justify overspending had an instant attitude adjustment when it became $50.

The trade-show glut is similar and could be expected. Trade shows produce easy money in a boom economy and don't require a lot of "product development" expense. Every publisher and promoter got on the bandwagon to meet the demand. The more shows there were, the more people attended. The more successful they appeared, the more trade shows they created. Transient success doesn't eliminate basic business principles, however. The result was a classic case of supply overshoot.

The real issue is the relative importance of this overshoot on our business mentality and the transient versus long-term fundamental consequences for all of us. Everyone crows about productivity gains from tech, but maybe the fact is that everyone may be just working harder to meet "Internet Time" deadlines. There is also the paradigm shift that the Internet represents for trade show organizers. Trade shows are a low-tech affair with everything from labor, show space, energy, travel, transportation, hotels, and such becoming more expensive and more hassle than ever. What engineer has the time or budget to go to a show every month? Certain traditional roles of the trade shows, like distribution of presentations and establishing contact with relevant personnel, can be precluded to a degree by the Internet. The inevitable conclusion is that some shows need to disappear or be merged. Basically, it's adapt or die.

In terms of conventional trade shows, I think the few biggest ones will survive, but the concept of a small trade show will become an oxymoron. The vacuum may be filled to some degree by non-exhibitor-based conferences, workshops, and training sessions. The more successfully attended ones will be highlighted as "learning vacations." Call it a vacuum or call it sucking wind, either way the trade show business is getting ready for a change.



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