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# CIRCUIT CELLAR®

**Electronic Edition**

**THIS IS A SAMPLE ISSUE**

THE MAGAZINE FOR COMPUTER APPLICATIONS

#122 SEPTEMBER 2000

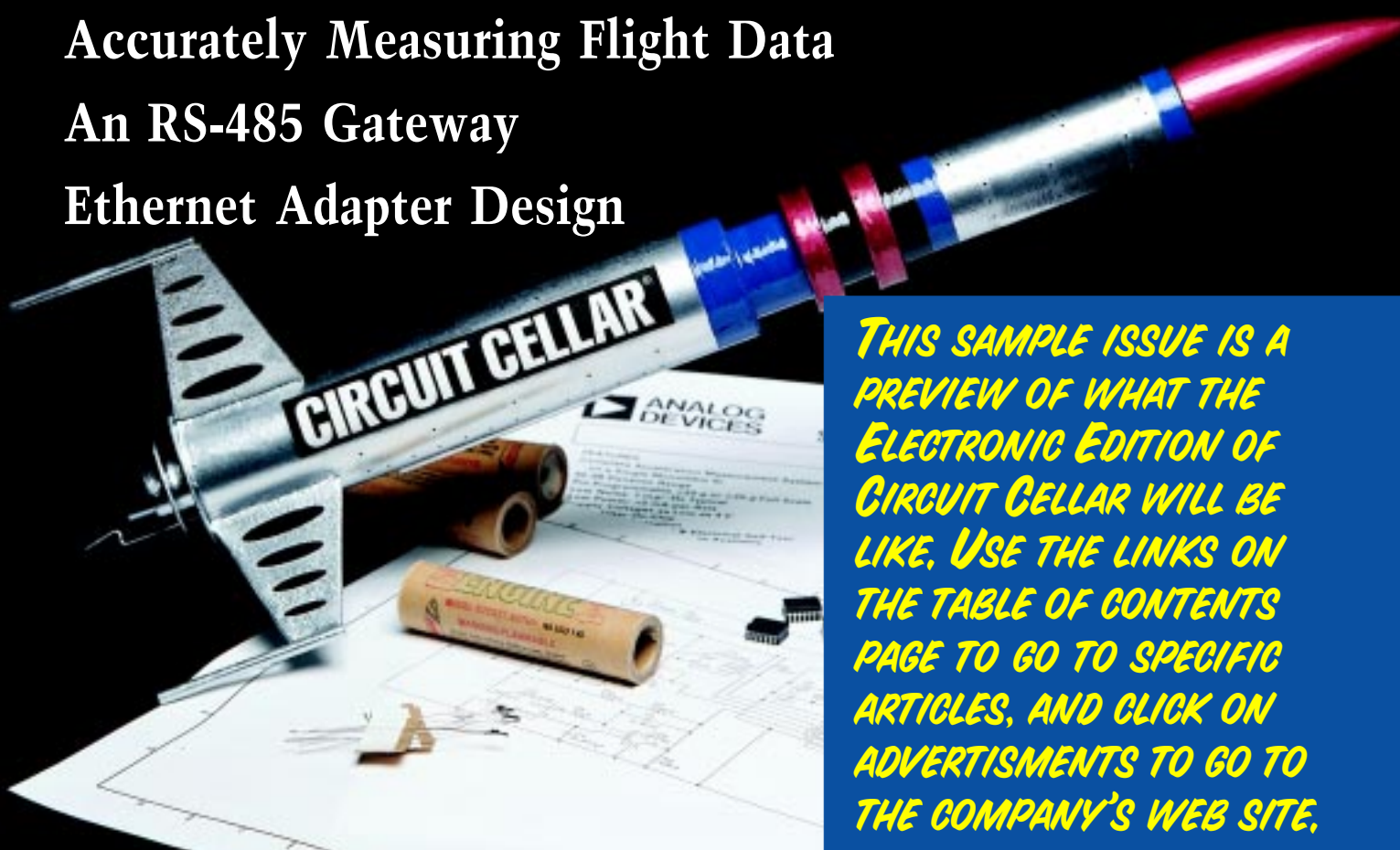
## MEASUREMENT AND SENSORS

Home-Scoping with X-10

Accurately Measuring Flight Data

An RS-485 Gateway

Ethernet Adapter Design



*THIS SAMPLE ISSUE IS A PREVIEW OF WHAT THE ELECTRONIC EDITION OF CIRCUIT CELLAR WILL BE LIKE. USE THE LINKS ON THE TABLE OF CONTENTS PAGE TO GO TO SPECIFIC ARTICLES, AND CLICK ON ADVERTISEMENTS TO GO TO THE COMPANY'S WEB SITE.*

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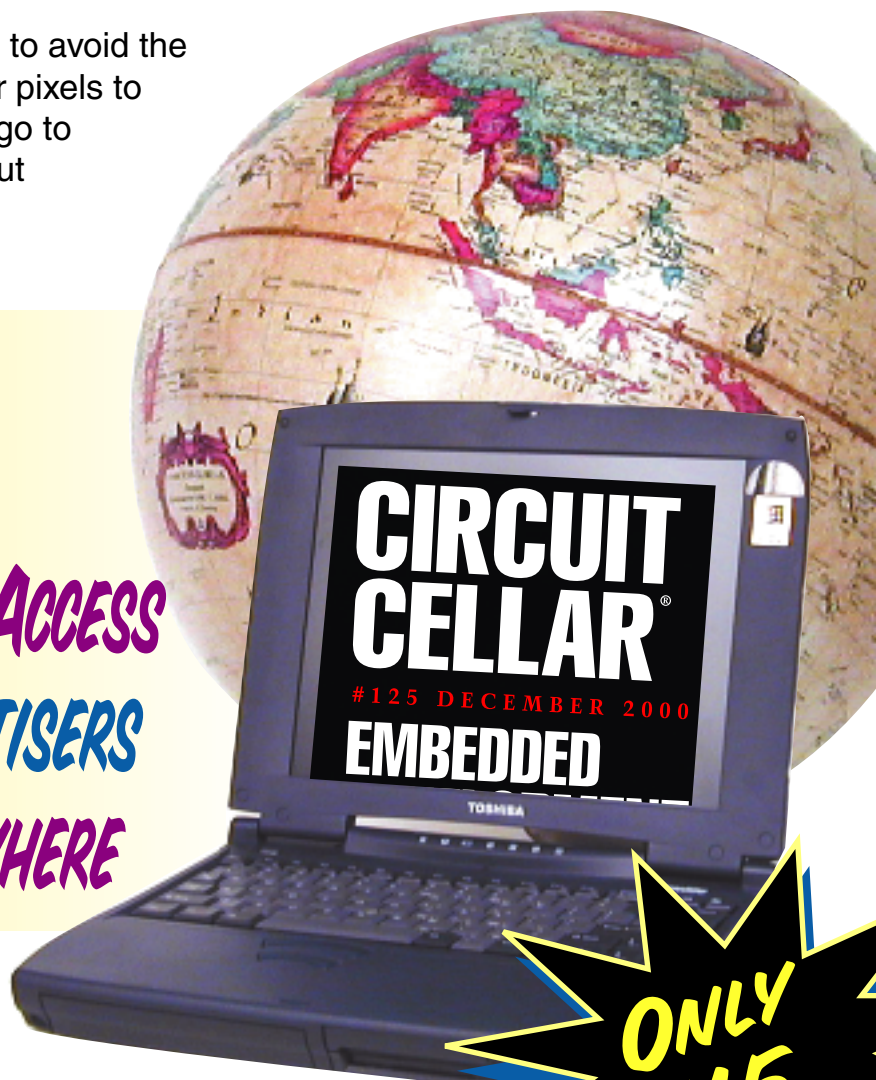
## Electronic Edition

Once again, the readers have spoken! Now all of the same great editorial, advertising, and information you get in the Circuit Cellar print magazine is available in a digital format each month. With the Circuit Cellar electronic edition, the latest issue is available worldwide in a matter of minutes.

For those of you who still enjoy reclining in your favorite chair while you flip through the latest issue—don't worry, the print magazine isn't going away. And, we're not "going digital" just because the latest trends in publishing tend to sway in that direction. The Circuit Cellar electronic edition was created as a service to our international subscribers, most of whom have to wait 3-5 weeks for their issues to arrive.



So, whether you're living abroad and want to avoid the shipping delays, or whether you just prefer pixels to paper when it comes to reading material, go to [www.circuitcellar.com](http://www.circuitcellar.com) to find out more about the Circuit Cellar electronic edition.

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# INSIDE ISSUE 122

Thank you for downloading the sample issue of Circuit Cellar's electronic edition. This sample issue will give you a feeling for the content and quality of our publication. Please note that this is not a full issue so not all of the articles listed in the table of contents are available for viewing.

Because we want to bring you the highest quality product possible, we will be providing the full issues in two formats. For subscribers that have access to a high-speed Internet connection, we will be providing the issues in one large file. For subscribers that do not have access to a high-speed connection, we will also be breaking the issues into several smaller, more manageable files. Subscribers will be able to choose whichever method is most appropriate for them and switch between the methods as their needs change.

# TASK MANAGER

## The Year In Preview



Every journey begins with the first step. As an amateur photographer, I'm more of a fanatic planner than a random wanderer when it comes to travelling. I find out the exact times of sunset, moonrise, low tide, and such so I can be in the right places at the best times. Getting there can be half the fun, but for me, it's all about the destination. Unfortunately, this journey through the new millennium is a rather open ended thing, so I can't exactly plan out what I want to see and where I need to be at what times. I guess I'd better enjoy it one step at a time. As readers, you get to enjoy *Circuit Cellar* one issue at a time. Because about five months of preparation goes into each issue, I can honestly say that I've seen the future and although I don't know what kind of projects *Circuit Cellar* readers will be designing 1000 years from now, the events of the next 12 months are a bit less fuzzy.

- January: This month we're introducing the electronic edition of *Circuit Cellar* (pg 31, 96) and ending the Driven to Design (D2D) contest (pg 10).
- February: Get ready for the kickoff of the Atmel Design Logic 2001 contest and some great articles on Signal Processing.
- March: Robotics fans can look forward to information on a variety of robotics competitions and projects from them.
- April: Stop by our booth at the Embedded Systems Conference in San Francisco or our web site to see the results of the D2D contest.
- May: See how some of the Design2K winners incorporated Measurement and Sensors into their projects.
- June: Read the project abstracts for the D2D winning projects and finish your entry to the Design Logic 2001 contest.
- July: Take a closer look at the challenges of Embedded Programming and visit us at the Embedded Systems Conference in Chicago.
- August: See what kind of Internet & Connectivity projects are out there and find out about *Circuit Cellar's* 16th design contest.
- September: Join us at the Embedded Systems Conference in Boston for the announcement of the Design Logic 2001 winners.
- October: Not everyone has "gone digital" so we'll discuss some Analog Techniques that can get the job done.
- November: If you think Wireless Communications is a hot topic now, wait and see what kind of projects *Circuit Cellar* authors are working on!
- December: In the last issue of the year, we'll show you some of the Design Logic 2001 winning projects and reintroduce the Graphics & Video theme.

There, just a little planning and I already feel better about the journey into this new millennium. So, whether you hit the ground running or are content to mosey along and take the new millennium as it comes, I wish you well on your journey.

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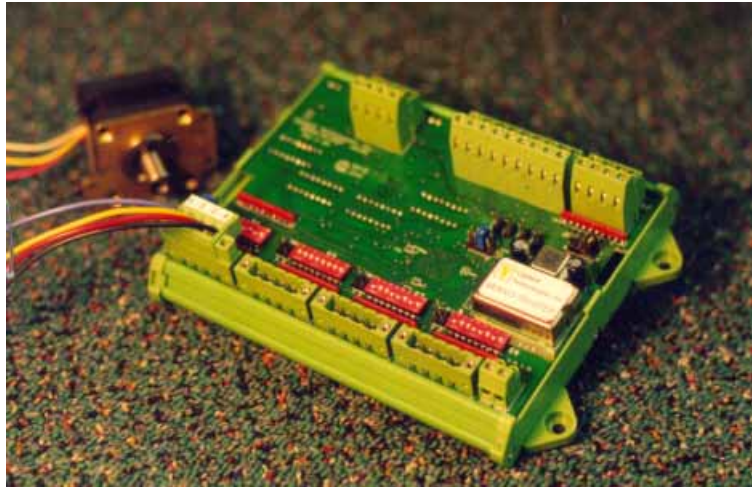
## SERVO-TO-STEP CONVERSION

The **Servo-to-Step Conversion Module** converts servo motor control signals to stepper motor control signals.

Although most industrial motion control software drives servo motors with a velocity control signal, often machines have one or more stepper motors. Instead of changing the software or redesigning or replacing the stepper motor, you may convert the servo motor to stepper motor control signals. The Servo-to-Step module can control four independent stepper motors.

The terminal panel converts a  $\pm 10$ -V signal to the stepper CW/CCW (direction) and step (clock) signals. If the stepper motor does not have an encoder for position feedback, the board can be configured to synthesize quadrature signals. The maximum stepping rate is user-selectable from 7.6 to 31.25 Hz via a DIP switch.

Motor direction and enable are configurable. The module works with servo motor control software that uses analog voltage for velocity and incremental encoder pulses for position feedback.



The module can be ordered with panel mount legs or DIN rail mounting. Cost is \$750.

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## DATA ACQUISITION MODULES

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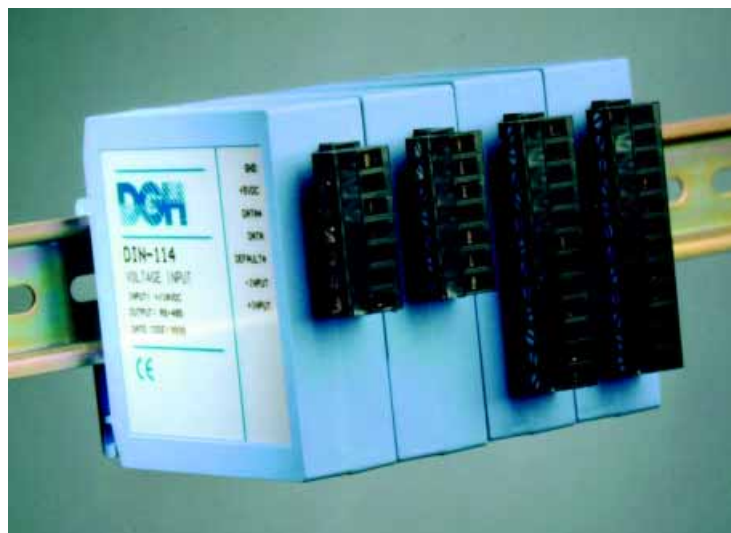
The DGH modules

provide wide-range analog input signal conditioning and A/D conversion, and communicate via RS-485 using Modbus RTU protocol.

Each module is packaged in a DIN rail mount case with a plug-in screw terminal connector. Modules require a 5-VDC unregulated supply at 0.5 W. Performance is specified from  $-20$  to  $+70^{\circ}\text{C}$ . Up to 246 modules can be strung on a pair of wires.

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# FEATURE ARTICLE

Gordon Dick

## A Low-Cost Weather Station

This project was a long time coming, but all it took was a set of anemometer cups to convince Gordon to finish up this micro-based weather station. Actually, some anemometer cups, the spindles from a film-editing machine, #12 power cable....



I had the idea to build a micro-based weather station in the back of my mind for a long time. But I needed a nudge to get going. Then, a colleague gave me the cups for the anemometer; I couldn't let those cups go to waste!

First, I checked my inventory of used parts. There are spindles from a film editing machine for the anemometer and weather vane. And there's a leftover instrument cable from piping the phone and the intercom into my woodworking shop. And there's that long length of #12 power cable that's too leaky for GFIs but will work fine

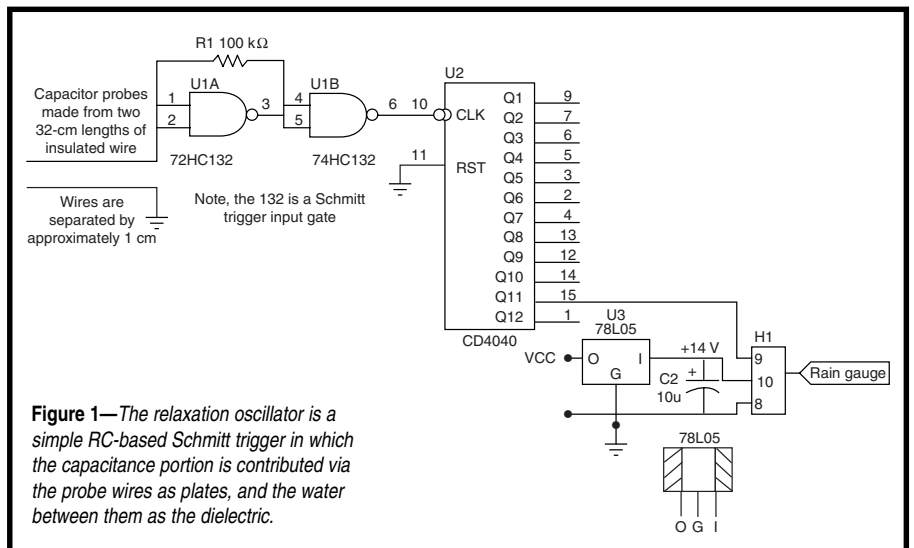
for my low-voltage power feed. Yes indeed, this weather station would come together on a shoestring budget.

What measurements will be done by this weather station? I knew it had to have a rain gauge, my Plexiglas rain gauge is difficult to see from the house. The anemometer and weather vane are essential. I already had an electronic thermometer measuring outdoor temperature, so that was covered. I had an evaluation board for pressure measurement and a transducer for atmospheric pressure, so the barometric pressure measurement was also covered.

The last item to be measured would be relative humidity, if the cost was reasonable. There would be two quantities that are not micro-based in my weather station. My outdoor thermometer has an LCD and was calibrated with ice and boiling water. After modifying the pressure sensor evaluation board, I had an electronic barometer with its own LCD.

### THE QUEST FOR A HUMIDITY SENSOR

Because I'm not familiar with humidity sensors, I researched on the 'Net. Honeywell sells a \$32 (CAN) sensor, which is a complete system that produces an output voltage proportional to relative humidity and operates at subzero temperatures. Although expensive, I went ahead and used it. The other option was a Philips device for \$12 (CAN). The capacitance varies with humidity, but it isn't in-



tended for subzero operation. Because this price is reasonable, I used it as an indoor relative humidity sensor.

The weather gets dry in the winter, so displaying indoor and outdoor RH (relative humidity) would be useful. This meant a minor addition to the conceptual design.

## ANEMOMETER AND WEATHER VANE CONSTRUCTION

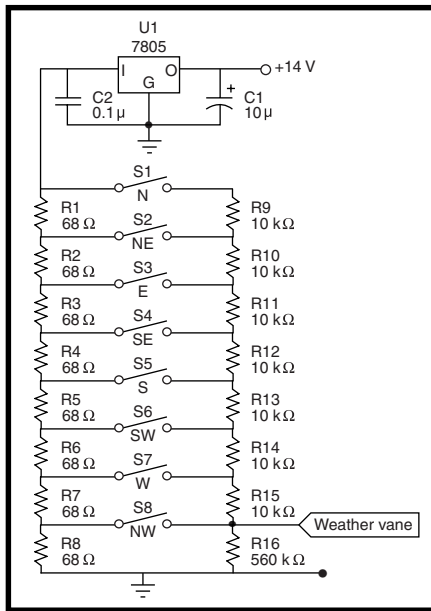
The mechanical component of a weather station project can be significant. Where is the apparatus going to be located? On a roof? On a pole? How will it attach? What about wire routing? And then there's building the apparatus. If you're like me, you would rather spend 20 hours building something than part with \$100. And anyway, I have all these saved parts.

I had a steel pole waiting. It used to have a purple martin house on it, but the martins never liked the house I made for them. Because it was empty, I had an ongoing battle with house sparrows. Eventually I took down the birdhouse. The pole is in the open and about 50' from the house.

First, I constructed the anemometer and built the box (see Photo 1). I had spare optical interrupter modules that worked fine. I also had an interrupter wheel. Some additional bracketry was required so I could adjust the interrupter module position. Then I needed a bracket on which to mount a terminal strip. That completes the internals.

The anemometer cups are epoxied to short lengths of aluminum tubing (the tubing used in bow-hunting arrows is the correct size). The tubing is epoxied into the pulley that was originally with the spindle I had saved for this project. To keep water from gathering on the bearing recess of the spindle body, a plug for a cardboard tube is siliconed over it on a spacer. This is the blue item under the pulley hub in Photo 2.

Before final assembly, the bearing shields were removed and the grease was washed out (removing the shields is difficult without destroying them). I didn't want the anemometer to be too stiff to turn during a  $-40^{\circ}\text{C}$ , 40-kph winter windstorm. Look at the external view in Photo 2.



**Figure 2**—A novel eight-key encoder circuit does not require a large spread of resistor values. These reed switches were taken from surplus reed relays.

The weather vane was constructed next, however, not before its circuitry was designed and tested (more about the circuitry later). This time when I had the urge to build, I already had a suitable box.

The weather vane is mechanically simple. On the outside is a shaft that rotates with an arm and a paddle attached to help the arm weather cock. On the inside, on the other end of the shaft is a disk with a magnet epoxied to it, so that the magnet can rotate just above the circuit board with the reed switches. These details are shown in Photos 3a and 3b, respectively.

The bearings on this spindle also were washed free of grease, and another cardboard tube plug was used to keep water away from the top bearing, similarly to the anemometer. The fixtures that allow these boxes to be mounted to the horizontal pipes on the pole are not pictured.

## THE MUNDANE STUFF

It seems every project has some aspects that are plain work and not much fun. This project had more work than usual. There were the cables to bury, because above ground cables look tacky and

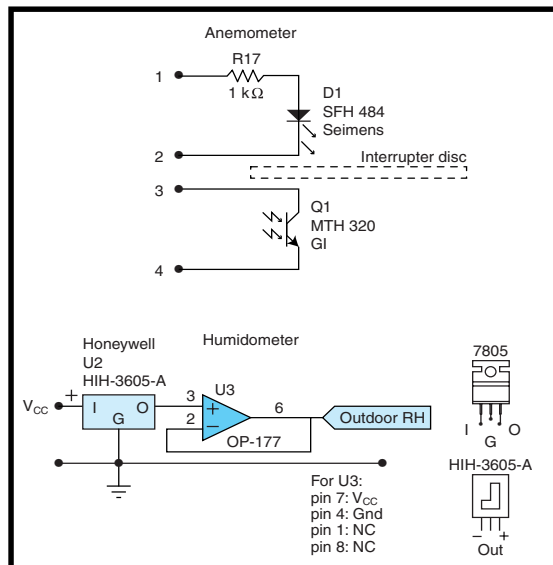
could be pulled down by a vehicle. So I buried them the depth of my sod cutter, about 4". Cables carrying 120 VAC are supposed to be buried 18" here, but this one only carried 14 VDC, so I didn't think deep burial was necessary. Even so, this task took the better part of one morning.

While I was putting cable in the ground, I installed extra wire to provide for some as yet undefined expansions. And, I have another weather-related project in mind that would require power and signal wires.

The cable needs to be terminated at each end in a way so that other wiring can connect to it. A junction box was placed at the pole end with several barrier terminal strips in it. Now there's a connection place for equipment to be mounted on the pole. Inside the house, I had to be able to get signals to the micro, so I used salvaged adapters that are a barrier terminal strip combined with a ribbon cable header. After attaching one small barrier strip for interconnecting the salvaged modular power supply, the cable termination was complete.

## THE INTERESTING STUFF

Designing and building the circuits was the most fun. I pondered for a long time about how to measure the level of water in a vessel. I wanted a method that wouldn't require fiddling and was simple, yet reliable. I wasn't in the



**Figure 3**—I added a buffer because of the sensor's high impedance output. Although the OP 177 works, it isn't the best choice in this application.



mood to break new ground, I wanted something that had been used and worked. At this time, a colleague passed me an article from a British publication that showed me the perfect circuit [1].

A tank level gauge was built using a variable capacitance probe in conjunction with a relaxation oscillator. With some modifications, this became my rain gauge. The probe construction I used was different from the publication's plan, and easier to build and maintain.

Photo 4a shows the probe with the circuitry attached. The probe I made uses insulated wire siliconed into grooves cut into a Plexiglas support. The insulated wire goes from top to bottom and back to the top on the other side of the Plexiglas. In this way, the water is never allowed to touch the wire in the probe. Because water has a high dielectric constant but significant leakage resistance, it's important not to involve the leakage resistance in the oscillator circuit. Hence, you need insulated wire in the probe (of course, I found this out the hard way).

A prescaler is part of the micro timer used in [1], but is not part of the HC11 timer, so it was included externally. Otherwise, my rain gauge circuit (see Figure 1) differs little from that used in [1].

Black sewer pipe was used to make the vessel for the rain gauge (see Photo 4b). The dome-shaped cap at the top of the straight section is not cemented so that the probe can be removed if it needs repair. The cable entry hole (not visible) will also be the overflow, so the body never fills to the point of flooding the circuitry. A screw cap on the bottom allows the body to be drained.

Water enters the body below the circuitry via the funnel and the Y fitting.

The funnel was included to increase sensitivity. Because its inside diameter is 3.5", and the body's diameter is 1.5", the water level in the body is greater, as determined by the ratio of the squares of the diameters (5.44 in this case). Radiator clamps hold the whole unit to a small section of U channel, and the U channel is attached to a post near the pole carrying the weather vane and anemometer.

I tried to be innovative with the weather vane. Often a rotational pot is used on the end of the rotating vane shaft to provide a DC signal proportional to angular position. However, I wanted to avoid the mechanical wear associated with a pot. For a time I toyed with the idea of building a 4-bit absolute optical encoder and using a DAC to produce a DC signal proportional to angular position. But, building the absolute encoder would have taken too long, because of having to make the code wheel and mount the light emitters and detectors.

When I was reading another publication [2], I found a keypad encoder circuit that would do exactly what I needed. Using this approach, up to 15 keys can be encoded into a single 8-bit ADC input. Instead of keypad keys, I used reed switches. A reed switch is positioned at the eight compass points, and the circuit output was fed to the HC11 ADC input. The weather vane circuit is shown in Figure 2. The publication doesn't provide an extensive design guideline, but soon I had a working design after some trial and error on paper. My design makes optimum use of the 8-bit resolution available. Photo 5 presents the component side of the weather vane board.

Creating the code that decides where the weather vane is pointing is simpler if the possibility of multiple switches being closed simultaneously is eliminated. I accomplished this by placing a spacer under the perf board standoffs to adjust the distance between the reed switches and magnet.

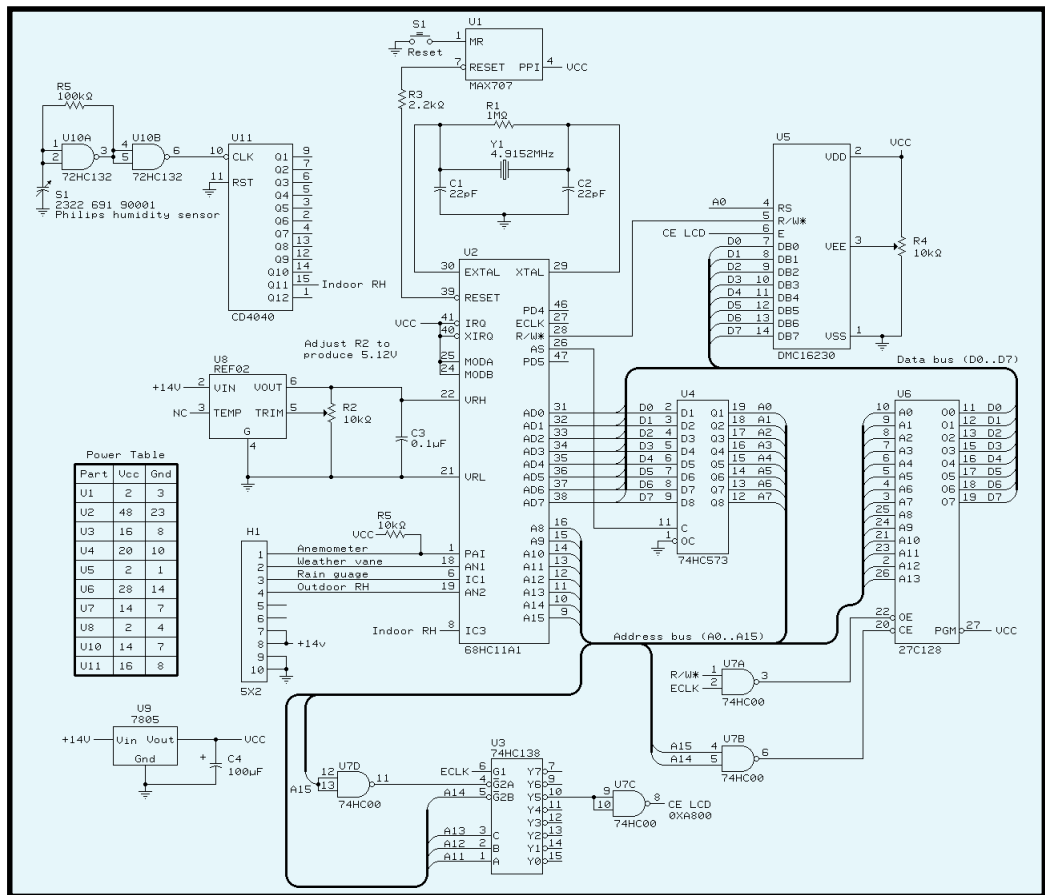


Figure 4—An HC11 operating in expanded mode is the heart of the weather station. There's nothing out of the ordinary here, except the external ADC reference supply.

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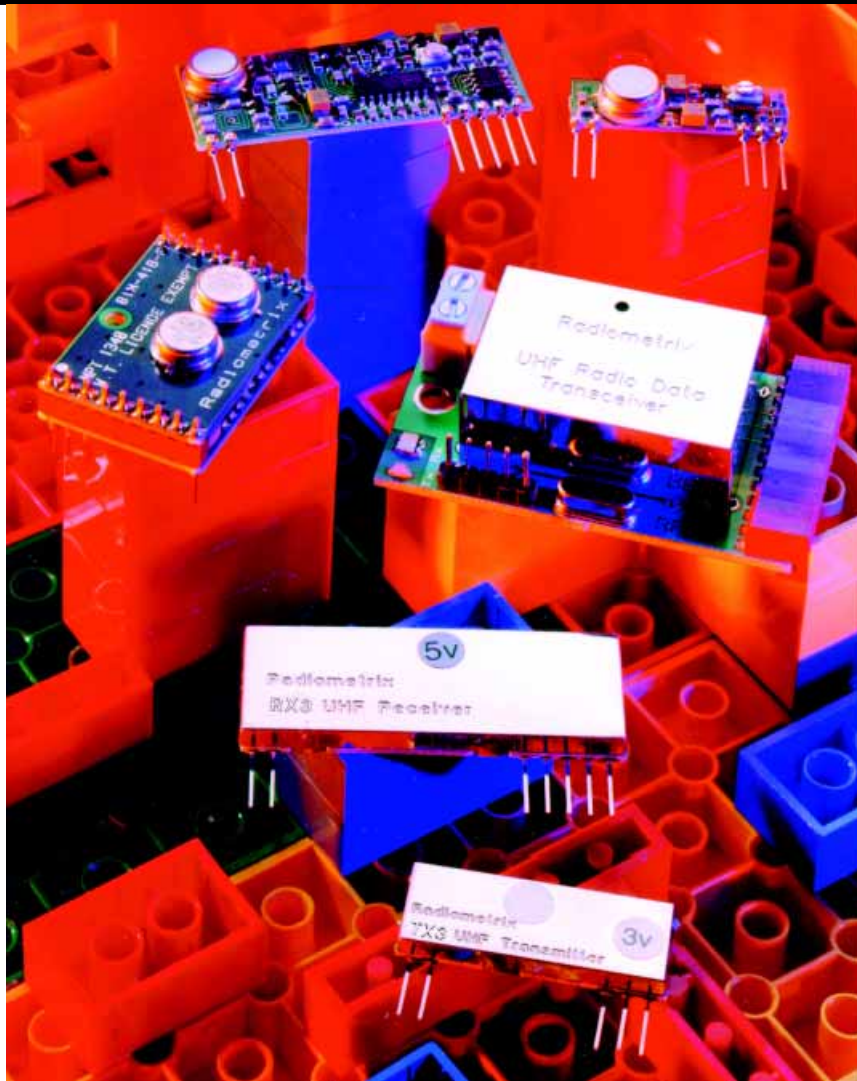
The BiM module integrates a low-power UHF FM transmitter and matching superhet receiver together with data recovery and TX/RX change over circuits to provide a low-cost solution to implementing a bi-directional short-range radio data link.

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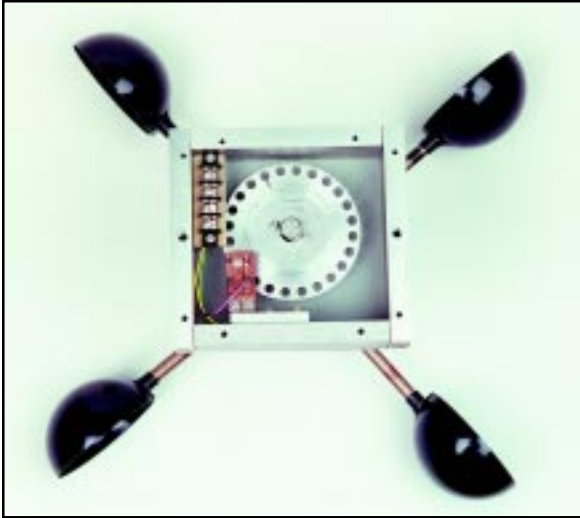
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**Photo 1**—This is an internal view of the anemometer. The perf board unit near the bottom is the interrupter module. The interrupter-positioning bracket is not clearly visible from this angle.

I had tested the Honeywell RH unit, and it seemed to work as advertised. However, I don't have means to do any formal testing on such things. How many of you can place a sensor in an atmosphere with a known water content? All I could do was verify that the percent of RH that the sensor was

giving was reasonably close to that given in the weather report.

Later, the RH sensor was mounted on the weather vane board. But, it didn't work. Should I have been more cautious about static? Regardless, it didn't seem like I had any choice but to buy another sensor, so I did. However, it didn't work either.

This was strange. In brief, the household cement I was using to hold the sensor in position on the board was providing a leakage path sufficient enough to interfere with

sensor operation. When I didn't use any glue, both sensors worked fine. So now I have a spare.

After that experience, I assumed the sensor wouldn't like driving a long cable (potential leakage), so I added a buffer amplifier. A rail-to-rail op-amp would have been a better choice than

the OP 177, but I didn't have one. I verified the OP 177 operated correctly over the range of signals it would have to process. It could get just close enough to ground to work well. The Honeywell datasheet didn't mention the sensor output being high impedance. The sensor and buffer amplifier schematic is shown in Figure 3.

The HC11 microboard was running first. Because it's similar to other projects I've written about for *Circuit Cellar*, it doesn't need much coverage. An LCD with large characters—nearly 1 cm—was used this time. To get the best performance from the ADC system, a separate reference is used instead of  $V_{CC}$ . By trimming the reference output to 5.12 V, the ADC converts to a nice round 20 mV/count. No additional RAM is included, the 256 bytes of internal RAM to the HC11 is adequate.

However, the code won't fit into the 512 bytes of internal EEPROM, so an external EPROM is used. The '128 is larger than needed, but that's what I had, and this weather station isn't

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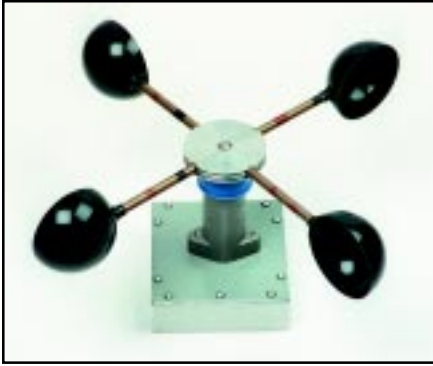
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**Photo 2**—In this finished anemometer photo, you can see the camo paint on the arrow tubing and the blue cardboard tubing plug used as a rain skirt.

going to be mass-produced. Figure 4 shows the complete schematic of the HC11 board.

### CREATING THE CODE

This project required the most code I've ever created for one application. Although I'm not a formally trained software engineer, I approach tasks in a systematic fashion. I break a large task into many smaller modules, and test each module before combining it with other code. There's too much

code to go through in detail, but some general discussion is appropriate. (The complete listing is available for downloading on the *Circuit Cellar* web site.)

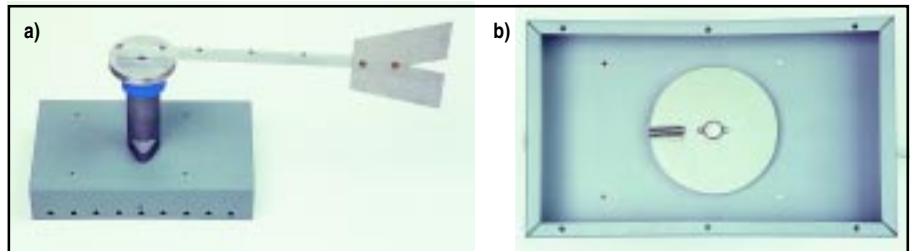
Because the HC11 needs to appear to do several things simultaneously, this project is interrupt-based. The main program is a loop that does nothing other than constantly wait for interrupts. There are five ISRs—RTI\_ISR, Overflow\_ISR, IC1\_ISR, IC2\_ISR, and IC3\_ISR.

RTI\_ISR is the real-time interrupt feature of the HC11. Rapid servicing of this routine is not required and can be irritating if it results in LCD flickers.

This routine is called every 53.3 ms, which is the slowest setting possible using a 4.9152-MHz crystal.

I plan to do extensive data filtering, but that's not present now. And updating the LCD every 53.3 ms is not pleasing to the eye. So this routine only acts every sixteenth time it's called, which produces about a 1-s update rate for the LCD.

When RTI\_ISR runs, it calls several other routines, which all execute without waiting for data. The other routines calculate and display the wind speed from a previously accumulated anemometer pulses, the wind direc-



**Photo 3**—This is an outside view of the weather vane. The arrow is plain, but is adequate to weather cock in the slightest of wind. **b**—You can see from this inside view that the weather vane's mechanics are simple. The magnet is attached to the aluminum disk.

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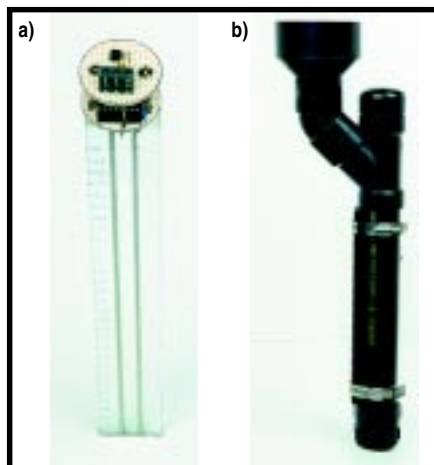
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**Photo 4**—Here's the liquid level probe and the required circuitry. The oscillator and prescaler are on the bottom level. The 5-V regulator and connector are on the top level. The probe and electronics fit inside a 1.5" pipe. **b**—Some black sewer pipe, a few fittings, and presto, a rain gauge vessel. The funnel-shaped piece is a 3" to 1.5" adapter that allows more water to be collected, increasing sensitivity.

tion and indoor and outdoor RH from continuously available data, and the water level in the rain gauge.

As a service to other ISRs, the `overflow_ISR` routine keeps track of the number of times the main timer has overflowed. Currently, all period calculations are based on no more than one timer overflow. This keeps arithmetic to 16 bits, which makes things simple. I may modify things to more than 16 bits in the future.

The rain gauge oscillator output is connected to Input Capture 1. During `IC1_ISR`, the period of the signal is measured and stored for later use by `RTL_ISR`. A new period is calculated if there has been only one main timer overflow. More than one overflow is signaled by a zero being loaded into the period variable for this routine.

During `IC2_ISR`, the anemometer pulse train is fed to Input Capture 2. This routine is similar to `IC1_ISR`. The

difference is that more than one main timer overflow is signaled as a period of `0xFFFF`.

The `IC3_ISR` routine also is similar to `IC1_ISR`. The indoor RH oscillator output is fed to Input Capture 3.

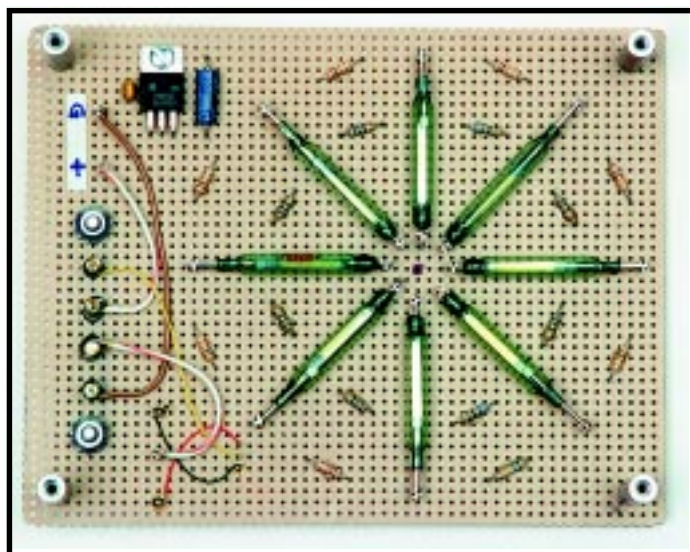
## SOFTWARE TESTING

It's been said that you can't test software too much. The anemometer routine proved that to me.

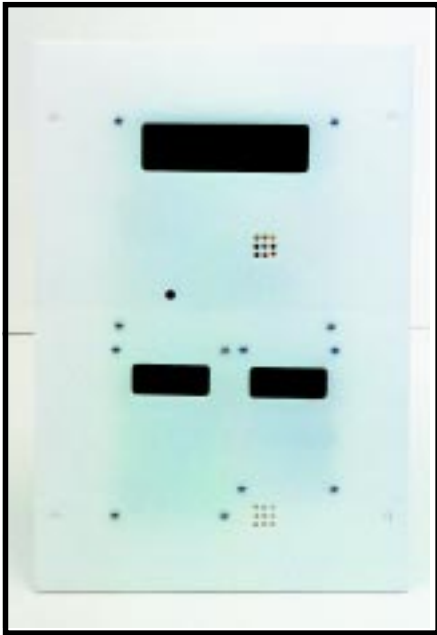
For `IC1_ISR` and `IC3_ISR`, the relationship between measured period and physical quantities were already known. However, this wasn't the case for `IC2_ISR` and the anemometer. But for the moment, it was OK to assume some linear relationship because making sure all the ISRs were working together was the current concern.

To test, I needed three variable frequency signal generators. I considered building three oscillators using 555s, but realized I could use the HC11 to generate three signals (five if needed) using the output compare feature. In fact, the same HC11 could produce the signals that were running the code to measure the periods. I had a second prototyping board, so one micro would generate the test signals for the other. Thus, I can separate the tester from the test.

To produce the variable frequency test signals, three pots were connected to separate ADC inputs. Then, with three simple routines to read the pot voltages and produce output signals



**Photo 5**—The reed switch encoding circuit is another part of the weather vane. A barrier terminal strip and the outdoor RH sensor are mounted on the other side of the board.



**Photo 6**—This is a view of the front panel with everything attached and ready to be installed between the studs of a wall.

whose frequencies were related to the pot voltages, I had my test signals. Now, this is a useful testing tool.

## CALIBRATING THE ANEMOMETER

Before completing the code to calculate wind speed, I had to know how the anemometer shaft's rotational speed is related to wind speed. Without a wind tunnel I pondered how to do this calibration, but never thought of a better choice than calibrating against an automotive speedometer.

This isn't as easy as it sounds. The anemometer has to be mounted to the vehicle, preferably out of the way of turbulence. The unfortunate possibility of damaging the anemometer was looming as well; I really didn't want to build another one!

The anemometer needed power and had to be connected to an HC11 in my truck. I was able to clamp a 2 × 4 to the front bumper that extended 4' beyond the edge of the body. Because this was in the front, I assumed no turbulence would exist there, but didn't test the theory. After connecting the power/signal cables, I was ready for a calibration run.

By picking a straight road with no traffic, no turns, and no hills, the job was accomplished with no danger to other people. Several runs were done in both directions to average out wind,

and to gather lots of data to average. I expected highly nonlinear behavior, however, check out the anemometer calibration plot in Figure 5.

## A TEST NOT DONE

For a final test of the whole system, I planned to connect everything on the bench and rotate the anemometer by blowing it with my shop vac. If I had done that, a later problem would have been uncovered early. But, it was already November and I wanted to get things on the pole before I was knee deep in snow. This came back to haunt me.

## FINALLY, COMPLETION

The last step was adding the Plexiglas panel to fabricate, and it was done! I also added some openings for displays and holes for mounting boards. The openings were difficult to make by hand, so I used my router. That meant I needed to make two templates—one for the larger display and one for the two smaller displays. This took time, but the result is a good-looking front panel (see Photo 6).

And yes, it works when installed in the wall, because I carefully wired the signals and power. The RH values, both indoor and outdoor, need trimming, but that's easy.

But, as I watched the anemometer, everything was not correct. When the wind was steady, it produced sensible results, but when slowing or speeding up, the numbers were erratic. After further reading in the HC11 Reference Manual [3], I understood what was happening. Until then, I thought the Input Capture would capture and hold until it was read. But, because RTI\_ISR

has a lot to do, there were times when IC2\_ISR would like to be serviced but had to wait for RTI\_ISR to finish. While that happened, a second capture event occurred, which caused an erroneous period to be calculated.

Before changing code, I discussed possible solutions with a colleague. He suggested the sensible solution: use the pulse accumulator system rather than measuring period. This incorporates data filtering, and it happens behind the scenes without the need for an ISR. I can accumulate pulses for 1 s and not overflow the 8-bit counter for any wind less than 100 kph.

So I removed IC2\_ISR, and the routine that calculates wind speed only reads accumulated pulses and does a simple calculation. And, a minor wiring change was needed; the anemometer input was moved from IC2 to PA7, which is the pulse accumulator input.

The system works fine now. I plan to add filtering some day. For now, I'm anxious for spring so I can put up the rain gauge and watch it work. ☒

*Gordon Dick (P. Eng.) is an instructor in electronic technology at Northern Alberta Institute of Technology, Edmonton, AB, Canada. He consults for intelligent motion control and is an avid bird and big game hunter. You may reach him at gordond@nait.ab.ca.*

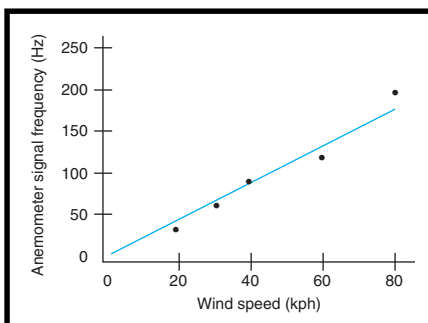
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## REFERENCES

- [1] M. Vacher, "Liquid Level Gauge—an Original Application for the ST62T20", *Elektor*, June 1998
- [2] V. Amorim and J. Simoes, "ADC Circuit Optimizes Key Encoding", *Design Ideas*, EDN, February 4, 1999, p.101
- [3] *M68HC11 Reference Manual*, Revision 3, Motorola, 1991 (Motorola #M68HC11RM/AD)



**Figure 5**—I discovered a surprising linear relationship between wind speed and anemometer shaft rotational velocity.



# FEATURE ARTICLE

Dan Cross-Cole

## Digital Filters Made Easy Part 1: Implementing with a DSP

After years of working on active audio filters and ADC circuits, Dan decided to get to know a real DSP. He found what he was looking for with an eval board from Analog Devices, but it still took some effort to get his application up and running.



After spending many years working on active audio filters and analog-to-digital conversion circuits and software routines, I needed to acquaint myself with a real digital signal processor (DSP). It was difficult to construct narrow active audio filters with steep (brick wall) edges, and the routines used for digital conversions were too slow for the calculations required for signal processing. So, I began searching for an inexpensive DSP chip. It didn't take me long to find the 21xx chip series manufactured by Analog Devices, Inc.

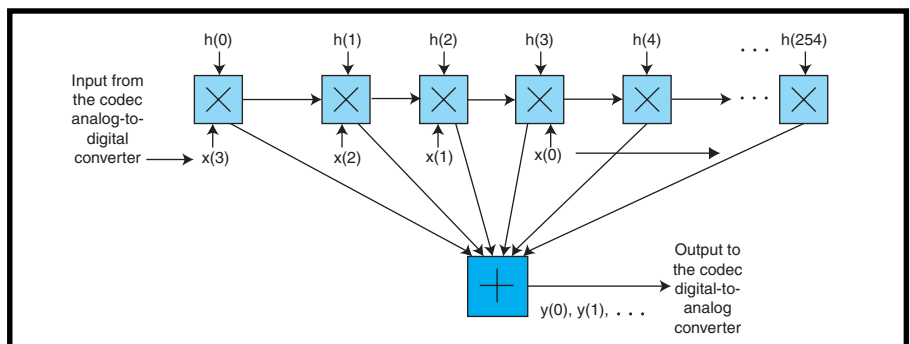
I was elated to see the chips but was disappointed that the instruction sheet did not give even the pinout

diagram for them. It did, however, give an Internet address for Analog Devices. The web site revealed that Analog Devices offers a prototype evaluation board. The nominal cost of \$80 was a small price to pay considering the work required to support the chip with homebrew electronics. Analog Devices doesn't sell the eval board directly, so I ordered it from Allied Electronics.

The board comes in an EZ-KIT Lite kit collection of application notes with an instruction book. Also included are several demonstration programs that run immediately, a Windows program that downloads programs to the DSP board through the RS-232 port, and a connecting cable. The eval board uses the ADSP-2181 DSP chip. The '2181 contains 16 KB of program memory and 16 KB of data memory. The board also contains a codec for fast analog-to-digital and digital-to-analog coding and decoding.

Despite all this capability, I wasn't satisfied because I had a special application for this board. My ham radio has a center audio frequency of 700 Hz. I wanted digital filters of various widths centered around this frequency, but the demonstration programs did not provide these filters.

Specifically, I needed four filters that would only pass frequencies between 500 and 1500 Hz, 500 and 900 Hz, 600 and 800 Hz, and 650 and 750 Hz. These are called bandpass filters because they only pass a band of frequencies between two limiting frequencies. I wanted to cycle from the widest to the narrowest filters, but the ability to go from the narrow-



**Figure 1**—Here's a block diagram of a DSP calculation. The output is the sum of 255 numbers. Each of the numbers is a multiplication sum of the audio input digital value and a filter coefficient. Note that the data shifts from cell to cell as new input data arrives from the codec.



**Listing 1**—The listing of the `filtercoef`.BAS program calculates the 255 filter coefficients used by the DSP program. Inputs are upper and lower frequencies, number of taps, and file name for the output file.

```

200 INPUT "LOWER FREQUENCY?", LF
210 INPUT "UPPER FREQUENCY?", UF
230 INPUT "NUMBER OF TAPS?", T
240 INPUT "FILENAME?", F$
250 OPEN F$ FOR OUTPUT AS #1

300 DIM H(T-1):DIM M(T-1)
303 LU=UF*2*3.14159/8000
305 LL=LF*2*3.14159/8000

310 FOR N=0 TO T-1
320 M=N-((T-1)/2)
330 IF M=0 THEN 350
340 H(N)=1/(M*3.14159)*(SIN(M*LU)-SIN(M*LL))
350 NEXT N
360 H((T-1)/2)=(LU-LL)/3.14159
370 GOTO 500

400 LOCATE 1,1
410 FOR N=0 TO 20
420 PRINT N,H(N)
430 NEXT N

500 FOR N=0 TO T-1
510 A=H(N)
520 IF A<0 THEN 800
530 B=A
540 M(0)=0
550 FOR J=1 TO 15
560 K=2^(-J)
570 IF K>B THEN 610
580 B=B-K

590 M(J)=1
600 GOTO 620
610 M(J)=0
620 NEXT J
630 GOTO 900

700 LOCATE 1,1
710 FOR J=1 TO 15
715 PRINT J,M(J)
720 NEXT J

800 B=1+A
810 M(0)=1
820 FOR J=1 TO 15
830 K=2^(-J)
840 IF K>B THEN 880
850 B=B-K

860 M(J)=1
870 GOTO 890
880 M(J)=0
890 NEXT J

900 C=M(0):D=M(1):E=M(2):F=M(3)
910 GOSUB 1000
915 A1$=A$
920 C=M(4):D=M(5):E=M(6):F=M(7)
930 GOSUB 1000
935 A2$=A$
940 C=M(8):D=M(9):E=M(10):F=M(11)

```

(continued)

est immediately to the widest is useful. When listening to a faint signal, the noise of a wideband receiver can be louder than the signal. The audio filters block this noise, making the faint signal audible.

On the other hand, you don't know what signals are nearby when you are using a narrow filter. Having the ability to switch multiple precise filters easily is a convenience that is difficult to build with analog circuits. Therefore, I had to learn enough theory and programming to develop programs that would meet my requirements. This article will provide only the necessary basic theory of digital filters to understand the program I developed.

The program allows you to switch to one of four different filters. The approach is general enough for bandpass filters in the audio range, and simple enough to modify the filter constants without recompiling. This means you won't have to go through the tortuous process of programming with an unfamiliar language, but you need to know how to calculate the filter constants.

## DIGITAL THEORY

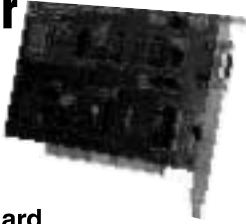
What I need is a Finite Impulse Response (FIR) filter. Britton Rorabaugh's *Digital Filter Designer's Handbook* is a good reference tool. The book states a method for performing the calculations for a bandpass FIR filter, C.

The DSP chip has registers to store the digital values of the incoming signals (see Figure 1). Because I'm using a 255 tap filter (i.e., using 255 samples), I'll call the memory registers M0, M1, M2...M254. These are the multiplication boxes shown in Figure 1. Each register M holds the digital value of the analog input. These values are  $x(0)$  (which is the most recently received digital audio sample),  $x(-1)$  (the previous sample),  $x(-2)$ ... $x(-254)$ .

When the first sample comes in, it is placed in M0. When the second sample comes in, the first sample is transferred from M0 to M1. When the third sample is received, the first sample is transferred from M1 to M2,

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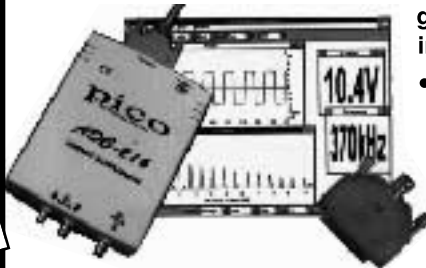
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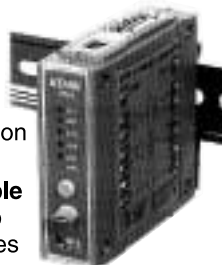
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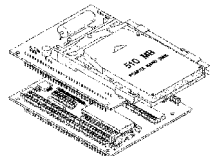
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the second sample is transferred from M0 to M1, and the third sample goes into M0. The first meaningful output appears after the 254th sample is taken. For each output,  $y(0)$ ,  $y(1)$ ,  $y(3)$ ..., the DSP unit multiplies each of the input samples by a filter coefficient (I'll show how to calculate this number later), called  $h(1)$ ,  $h(2)$ ,  $h(3)$ ....

For the 255 tap filter, the first output value is:

$$y(0) = h(0)x(0) + h(1)x(-1) + h(2)x(-2) + \dots h(254)x(-254).$$

The second output value is:

$$y(1) = h(0)x(1) + h(1)x(0) + h(2)x(-1) + \dots h(254)x(-253)$$

The program runs in a continuous loop, placing a sample in the M register, multiplying the samples by the coefficients  $h()$ , calculating the sums, outputting to the codec, and repeating the process. Rorabaugh states an equation to describe the process:

$$y(k) = \sum_{n=0}^{N-1} h(n)x(k-n)$$

$N$  is the number of samples used in the filter computation ( $N = 255$  for this filter). The summation sign indicates that each  $y(k)$  (output byte) is the sum of multiplications of the coefficients with the digital data samples.

This is the basic method of computing the digital filter. All you need to do is calculate the coefficients for  $h(0)$ ,  $h(1)$ .... These coefficients are stored in the DSP program. They define the characteristics of the digital filter. The important characteristics are the lower and upper frequencies of the bandpass filter. You want the filter to pass only those frequencies that are between the lower and upper frequencies.

Take a look at Figure 2 (also by Rorabaugh), which shows the impulse response coefficients for a bandpass filter. Now all you need to do is calculate the 255 coefficients. The QuickBASIC program `filtcoef.bas` eases this process.

**Listing 1—Continued**

```

950 GOSUB 1000
955 A3$=A$
960 C=M(12):D=M(13):E=M(14):F=M(15)
970 GOSUB 1000
975 A4$=A$
980 GOTO 2000

1000 G=(8*C)+(4*D)+(2*E)+(F)
1010 A$=HEX$(G)
1020 RETURN

2000 WRITE#1,A1$;A2$;A3$;A4$;"0";"0"
2010 NEXT N
2015 CLOSE #1
2020 END

```

The program accepts the upper and lower frequencies as inputs and calculates the required coefficients, placing them in a data file for later use. The program calculates the coefficients for filters with different numbers of taps. For this article's filters, use 255 as the number of taps. You will be prompted for a file name for the data file. The `filtcoef.bas` file is available on the *Circuit Cellar* web site.

Listing 1 lists the `filtcoef` program. `filtcoef` calculates the filter coefficients based on the number of filter taps and the upper and lower frequency limits. Enter the frequency in Hertz (cycles per second). The program then converts the decimal numbers to a hexadecimal 1.15 format, which means that the hexadecimal number represents one sign bit and 15 fractional bits. The program then places the data into a text file.

**Listing 2—There are four filter locations in `4filter.txt`. The next 255 lines after 0100 are the filter coefficients for one filter. Each line is a decimal number in 1.15 format.**

```

(previous code)
#123000000004
@PA
0100 (Start of 1000 Hz Filter)
FFD300
000000
006D00
00A800
006E00
FFFF00
FFD100
000000
002F00
FFFF00
FF8B00
FF4C00
FF8900
000000
003100
FFFF00
FFCD00
000000
007D00
00C100
007F00
(continuing code)

```

The coefficients for a bandpass FIR filter are given by:

$$h(n) = \frac{\lambda_U - \lambda_L}{\pi} \quad \text{for } m = 0.$$

$$h(n) = \frac{\sin(m\lambda_U) - \sin(m\lambda_L)}{m\pi} \quad \text{for } m < > 0.$$

$$\lambda_U = 2\pi f_U T \quad T = \frac{1}{\text{sample rate}} = \frac{1}{8000} \text{ (seconds)}$$

$$\lambda_L = 2\pi f_L T \quad f_U = \text{upper frequency of bandpass filter (Hertz)}$$

$$f_L = \text{lower frequency of bandpass filter (Hertz)}$$

$$m = n - 127 \quad n \text{ goes from } 0 \text{ to } 254$$

**Figure 2**—The filter coefficients are taken from Britton Rorabaugh's Digital Filter Designer's Handbook.

Notice that the coefficients are surrounded by double quotes and comma delimiters; run this file through "Search and Replace" to eliminate them.

Then, you can replace the coefficients in the executable file (4filter.exe) with the set of coefficients from the data file produced by filtcoef. No programming! All you need to purchase is the DSP board. Download the files from the *Circuit Cellar* web site and soon you can produce bandpass filters for audio use. Because this program samples at 8000 samples per second, the useful range is

limited to 4000 Hz. This narrow range is actually well matched for my ham radio.

Note that, as the name suggests, 4filter.exe contains the data for four different filters. The filtcoef program produces the coefficients for one filter at a time. Name each file differently as you run filtcoef. You also should copy and rename the 4filter.exe file to your own choice as you begin making a new filter program. After you have the four separate data files from the filtcoef program, put them into your new filter program file at the places marked on the 4filter.txt file. This

**Listing 3**—This is a loop that continuously processes the incoming digitized audio data and sends output to the codec.

```
(Previous code)

        /* This is where we put our filter routines */

voice_input:
    ena sec_reg;
    sr1 = dm (rx_buf + 2); { get new sample from SPORT0
    (from codec) }

process_sample:
    dm(i2,m2)=sr1;      { store sample in data buffer (de
    lay line) }
    jump fir;

output:
    dm (tx_buf + 1) = mr1;      { filtered output to SPORT
    (to spkr) }
    dm (tx_buf + 2) = mr1;      { filtered output to SPORT
    (to spkr) }
    rti;

fir:    cntr=taps-1;
        mr=0, mx0=dm(i2,m2), my0=pm(i4,m4);
        do fir1loop until ce;
fir1loop:  mr=mr+mx0*my0(ss), mx0=dm(i2,m2), my0=pm(i4,m4);
        { if not ce jump fir1loop;}
        mr=mr+mx0*my0(rnd);
        if mv sat mr;
        jump output;
```



is accomplished by cutting the old coefficients and replacing them with the new coefficients from the four data files using a word processor. These are all text files. Don't convert them to anything else.

Listing 2 shows a partial list of the `4filter.txt` file. This file is the same as the executable file (`4filter.exe`), except that it contains comments showing the beginning location of each set of filter coefficients. `4filter.exe` is the same file without the comments and is sent to the DSP when you select "Download file and go" in the Windows Monitor Program furnished with the EZ-KIT Lite.

You can substitute different sets of coefficients for your applications. The coefficients are written in the aforementioned 1.15 (one dot 15) format. The good thing about `4filter.exe` is that you can replace the coefficients using a word processor instead of recompiling the program. Both files are available for downloading.

Listing 3 is a portion of the source code used to produce the `4filter.exe` executable file. This is the code for the main routine of the program. The complete source code is listed as `4filter.dsp` and is available for downloading. Note that this has borrowed heavily, as suggested by the EZ-KIT Lite instruction books, from the sample programs provided with the kit. The code was a combination of the Talk-Thru program, which causes the output to reproduce the input and the filter demonstration.

For my own use, the fact that changing filters required the monitor program was a significant limitation. I wanted to be able to change filters without using the computer. It turns out that, because I didn't need communications with the PC, the code was smaller, and I could use the Talk-Thru program as the basic model and solve this problem.

The EZ-KIT Lite comes with the monitor software, the software required to compile the source code into executable files, and many demo programs. You should install the Windows Monitor program on your PC. Connect the output of the DSP to a suitable audio amplifier and speaker

system, and power up the board. The DSP board gives an audio message to assure that it is running. The cable connecting the board to the PC's RS-232 port should be connected before the Windows Monitor program is activated.

When the monitor is operating, you can download the `4filter.exe` file to the DSP board. You can then disconnect the RS-232 cable and shut off the PC. The DSP is now running the `4filter` program.

Connect a suitable signal, such as the audio output of a radio, to the DSP audio input. One of the push buttons on the DSP board cycles through the filters from widest to narrowest. The other push button resets the whole system and requires you to reload the filter program. Don't push that one. ☒

*Dan Cross-Cole has served as a civilian electronics engineer for the U.S. Navy for twenty years. His interests range from electronics to programming to dobro. He still enjoys soldering. You may reach him at [crosscol@erols.com](mailto:crosscol@erols.com).*

## SOFTWARE

The filter coefficient code is available for downloading at the *Circuit Cellar* web site.

## REFERENCE

C. Britton Rorabrough, *Digital Filter Designer's Handbook with C++ Algorithms*, McGraw-Hill, New York, NY, 1997.

## SOURCES

### ADSP-2181

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**Part 2 of this article ran in the September 2000 issue of Circuit Cellar Online. Click here to read the article in the Circuit Cellar Online archive.**

# FEATURE ARTICLE

Tom Napier

## One Small Step

### Part 1: Measuring Flight Data in Model Rockets

You might think that measuring flight data in a 15" model rocket would be easier than trying to record data from a 30' solid-fuel rocket that's going to splash down in the Mediterranean Sea. According to Tom, both missions have their challenges.



I occasionally describe myself as a former rocket scientist because at one time I integrated scientific experiments into payloads and launched them into space on 30' solid-fuel rockets. I still design and fly model rockets and I've always been curious about what goes on inside—what accelerations they undergo, how fast they spin, how high they go.

My professional rockets had to transmit data by radio, they ended their flights in the Mediterranean Sea. Flying a telemetry transmitter in a model rocket is feasible but cumbersome; I tried it once. It requires a receiver and tape recorder on the ground, and transmitting the data may be frowned on by the FCC. And, model rockets don't have to transmit data. Because they are generally recovered intact they can record it. But what recording device is small and light enough to fit in a rocket that might be 1" in diameter and 15" long? "Ah!" I thought, "Picaro!"

The Picaro model control computer (see *Circuit Cellar* 93) has a PIC microcontroller, serial port, parallel port, and 2-KB serial EEPROM. The processor interprets the user program stored in the EEPROM. I foresaw it recording data, but that was not its

primary function. But, if the controller ran a dedicated data acquisition program, the entire EEPROM would be free to record flight data. The hardware would be similar but repackaged to fit in a long narrow tube.

A trivial modification to the launch stand can start data recording at lift-off using the same snatch-plug technique used in real rockets. Recording at a rate of, say, 200 bytes per second allows for more than 10 s of data, which is enough time to capture the apogee and the most interesting part of the ascent. When the rocket is recovered, the data in the EEPROM can be downloaded via the serial port for computer analysis and display. Then the whole package is ready to fly again.

#### INSTRUMENTATION

What is worth measuring in a model rocket? Well, if you are comfortable putting a \$25 chip in a rocket that you may lose, fly an accelerometer. It gives a complete readout of the acceleration, which, by integration, gives the velocity profile of the flight. This is useful information if you want to try improvements in rocket design. A second integration will give the rocket's peak altitude, though only approximately because of calibration and quantization errors.

You could install a pressure sensor to measure altitude directly. However, model rockets typically reach only 500' to 1500'. The pressure change is insignificant and would be difficult to measure because of the ram and venturi effects associated with openings in the instrument package. An ambitious modeler may couple a pressure sensor chip to a pitot tube and sense velocity directly. Unfortunately, calibration would be tricky because model rockets can reach 200 mph. Measuring the air temperature is also feasible but probably not worth the effort.

One of the easiest things to measure is the rocket's spin rate. Kit rockets generally don't spin, because spin tangles the parachute cords. Real sounding rockets, and most of my home-designed ones, have canted fins. The resulting spin makes them more

stable during flight. If the sun is low in the sky, a simple photo-diode or even an LED makes a good spin sensor.

Just as with real rockets, it's useful to record events onboard. A simple switch connected to a port bit can indicate exactly when the nose-cone of the rocket is ejected. It's even possible to measure how fast the nose-cone is moving relative to the rocket by attaching a thread to a snatch plug. Dividing the length of the thread by the time since the ejection gives the ejection speed.

A friend once suggested using a mercury switch to flag the moment when the rocket reaches its apogee and turns over for the trip down. But he overlooked that when the engine burns out, a rocket has no accelerating forces acting on it other than air resistance. It has no clearly defined sense of up and down or of direction of flight. A mercury switch does respond to G-forces, which are below the resolution of the accelerometer, but then flying mercury-in-glass switches in rockets is probably not environmentally responsible.

## THE PROCESSOR

For this project, I used the PIC16C71 (see Figure 1). It's small, has enough memory, and contains an 8-bit analog-to-digital converter that can be multiplexed to any of four input pins. It has a 5-bit I/O Port A and an 8-bit I/O Port B. In the rocket logger, two Port A bits are programmed as analog inputs. Two more interface with the EEPROM. The remaining one, which doubles as an event counter input, is unused. One Port B bit has an interrupt function, so I used it for the serial input. Plugging in a computer generates an interrupt and starts the readout and control program. Another Port B pin drives a Picaro-style serial data output.

A different Port B pin switches power to the peripheral components such as the EEPROM. This allows the

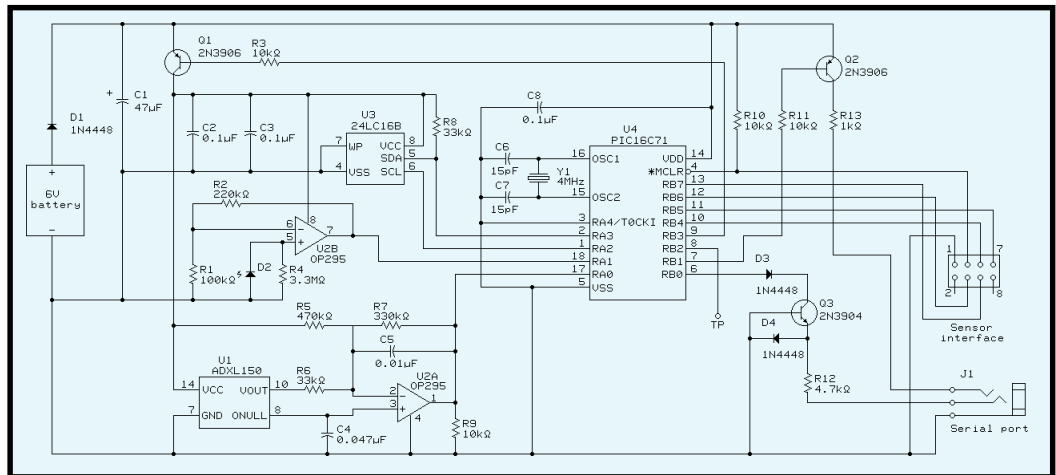


Figure 1—The data logger contains sensors, a signal conditioning amplifier, a microcontroller with an ADC, and an EEPROM to store data. The serial port is used for preflight calibration and downloading the flight data.

PIC to shut them down and go into sleep mode after the flight. One pin is a test point, it generates a 1- $\mu$ s pulse every time the data is sampled.

This leaves four pins for monitoring flight events. One is hard-wired to sense when the instrument package is ejected from the rocket's body. The rest are available for other events. The PIC's reset pin is connected to the "launch detect" snatch plug to start data recording. The clock crystal has a low-profile case that I glued into a cutout in the PC board. I resisted the urge to ask the manufacturer if the crystals were rated for 12-G acceleration. Its 4-MHz frequency gives a processing rate of 1  $\mu$ s per instruction, thus the recording timebase is exact to the microsecond. The serial port runs at 9615 bps, only 0.16% high.

## THE POWER SUPPLY

Power comes from a 6-V alkaline battery, for example, the Duracell PX28AB. This is 1" long, fits in a cut-down AA battery holder, and weighs less than 10 g. The operating current is less than 5 mA for tens of seconds at a time, so one battery should last for many flights. For added reliability, and to save space and weight, there is no on/off switch. The standby battery drain is microamps so you need only remove the battery when you finish launching for the day.

## THE FLIGHT SEQUENCE

Figure 2 shows the master flow-chart for the program. When the battery is inserted, the PIC initializes

some registers and turns off the peripherals. Then, unless the serial port is connected, it goes into sleep mode. If you want to, you can use the preprogrammed recording rate. Put it on the launcher and connect the snatch plug. This plug pulls off at the moment of launch, generating a reset and waking up the PIC. Luckily the 16C71 has a status bit that distinguishes between a power-on reset and a wake-up reset; if this bit is zero, the PIC starts recording data in the EEPROM at the user set rate.

When the EEPROM is full, the PIC shuts off the peripherals and returns to sleep mode. Even if weeks pass before you find the rocket (One of mine hung 150' up in a tree for three months!), the data in the EEPROM is preserved.

Plugging in a stereo mini-jack connected to a laptop's serial port also wakes the PIC. Now it will respond to your commands. The most important is the read-out command. This dumps the recorded data as a text file for subsequent analysis. Other commands cause the accelerometer output and roll sensor output to be transmitted continuously to check that things are working. Preflight commands store calibration information in memory and select the data sampling rate. Unplugging the serial port puts the PIC back into sleep mode.

## RECORDING FORMAT

How information is recorded or transmitted is a compromise between the source and data capacity. I used



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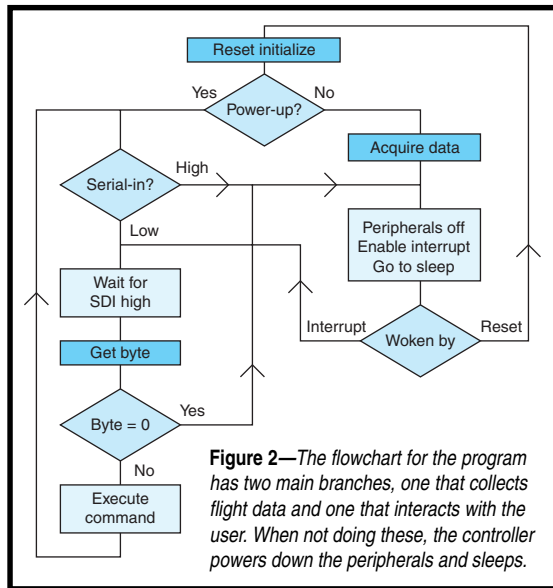
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the same 24LC16B 2-KB EEPROM used in Picaro, so 2048 bytes of nonvolatile memory are available for the entire flight. Suppose that each sample is encoded as two bytes, for example, an 8-bit analog measurement, a 4-bit analog measurement, and four switch positions.

Writing anything to the EEPROM takes 10 ms—slow for a flight recorder. However, the EEPROM can store up to 16 bytes and write them simultaneously. If you buffer samples in the PIC's RAM, then dump them to the EEPROM in gobs, it increases the effective recording rate.

Let's call 16 bytes a block. The EEPROM can store 128 blocks, but reserve one for setup and calibration information, leaving a total recording capacity of 1016 two-byte samples. You only need to transfer a block every eight samples. After a block is transferred to the EEPROM, the internal memory write cycle starts. Let's look at the timing.



**Figure 2**—The flowchart for the program has two main branches, one that collects flight data and one that interacts with the user. When not doing these, the controller powers down the peripherals and sleeps.

At the conservative 100-kbps data rate, it takes the PIC less than 1.8 ms to transfer a block to the EEPROM. You can read the sensors in less than 200  $\mu$ s, so you can do a block write between any two successive samples at up to 500 samples per second. After each transfer, seven sample times (at least 14 ms) occur before you need to

write again. That's plenty of time for the EEPROM to finish writing. Whenever there is no block transfer between samples, do a dummy one to maintain the time delay. To generate a sampling rate less than 500 per second, an extra delay is added between samples. I should mention that getting all the software delays exact was a tough job!

The default recording rate is 100 frames per second, giving a record length of 10.16 s. I incorporated preflight programmability so you can trade resolution against record length. At the maximum recording rate of 500 frames per second, you get a 2-s

high-resolution picture of the acceleration during the motor burn. The slowest rate is 20 frames per second, giving 50 s of recording—enough time to show the bump when the payload hits the ground.

## MEASURING ACCELERATION

The accelerometer, ADXL150AQC, is a high-tech surface-mount chip made by Analog Devices. It costs about \$25. This chip has a nominal full-scale range of  $\pm 50$  G and an output of 38 mV per G (1 G is the acceleration due to earth's gravity, around  $32\frac{1}{8}$  ft/s<sup>2</sup>). Model rocket motors have initial thrusts measured in pounds, but a complete rocket may weigh only a few ounces, so take-off accelerations of 10 G or more are common.

The chip contains a spring-mounted chunk of silicon with movements that are monitored by capacitive position sensors. All measurement and conditioning circuitry is contained on the same chip; what comes out is an analog signal that can vary from about 0 to 5 V over the chip's 100-G effective range. (For more information about the accelerometers, read Tom Cantrell's article in *Circuit Cellar* 107.)

The maker warns that the chip can be damaged by accelerations greater than 2000 G, as can arise if the chip is dropped on a hard surface. After it's mounted in a rocket, it's cushioned against even a severe impact. I glued mine to the circuit board with sili-

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cone rubber and connected its pins with individual wires, also embedded in rubber. This gives a firm mounting while protecting the chip against the board falling on the bench.

An op-amp scales and offsets the accelerometer voltage to give a full-scale range of -1 G to 12 G, giving an 8-bit resolution of 0.05 G. And because this scale is defined relative to true 0 G, the accelerometer will indicate 1 G when the rocket is stationary and nose-up. You must subtract 1 G from all readings when integrating the acceleration to get the velocity.

## THE ROLL SENSOR

I used an ordinary rectangular yellow LED as a sun sensor. This outputs several microamps in sunlight. If connected to a voltage buffer and a large load resistor, its output voltage varies from near 0 to about 1.2 V as the diode faces away from or towards the sun. The output voltage is digitized by the PIC and its four most significant bits are recorded.

Real sounding rockets measure the spin and orientation of the payload with three-axis magnetometers. You can build a flux-gate magnetometer from small ferrite cores, but the power consumption would be the limiting factor.

## ON THE WAY DOWN

When the rocket is on its way down, an expulsion charge in the motor fires to separate the section containing the electronic package from the lower body tube. They remain connected by a 15" strip of elastic. I ran this down the outside of the lower tube to a point near the fins, tucking the slack inside the tube at launch time. This configuration places the lower tube side-on to the air flow, creating sufficient drag for the combination to land unharmed.

Most kit parachutes are undesirable. First, your aim is to recover the rocket quickly, not to admire it flying away in the breeze. Second, the electronics package is supported by a ring glued inside the lower tube; a parachute might get wedged there. Third, if the rocket is spinning, the parachute may not open fully.

From the engineering point of view, the ideal flight would be ballistic to within 100' of the ground. Unfortunately, the timing provided by the rocket engine is not accurate enough. An ultrasonic ground detector would work, but it may be possible after a test flight or two, to use the PIC as an accurate timer to trigger the deployment of a parachute.

By the way, rockets with an ounce of electronics in their noses are more stable than those with weight mostly in the tail. Thus, you can use smaller fins than normal practice would dictate. If you don't want to design a rocket, hobby stores sell many kits that have the correct length and body tube for this project.

That's all there's room for this month. I'll continue in the next issue with details of the circuit board and rocket construction, an outline of the calibration system, and flight results showing speed of model rockets. ☒

*Tom Napier is a physicist and engineer who parlayed his design experience into an electronics con-*

*sulting business. His compulsion to share his knowledge drives him to write magazine articles, and he regrets that he cannot offer free design assistance to individual readers. He will start using e-mail once the bugs have been worked out.*

## SOFTWARE

The firmware is available for download on the *Circuit Cellar* web site.

## SOURCES

### Microcontroller and EEPROM

Microchip Technology, Inc.  
(888) 628-6247  
(480) 786-7200  
Fax: (480) 899-9210  
www.microchip.com

### ADXL150AQC

Analog Devices, Inc.  
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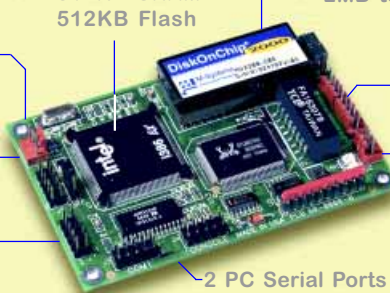
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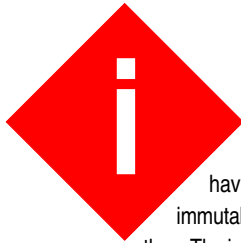
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# PRIORITY INTERRUPT

## Electronic Evolution



wish that everything could stay the same, but we all know it can't. When I look at my picture on this page I have to admit that my hair is a whole lot grayer now than when that picture was taken seven years ago. The other immutable fact is that a copy of *Circuit Cellar* costs about 2½ times more to produce and ship today than it did back then. The increased costs aren't just paper and postage. We have a larger staff these days, pay a lot more to our authors, and have to deal with a lot more of the competitive realities of being a leader in what we do.

Normally, when a company experiences increased costs the remedy is to either reduce services or raise prices. There was a period of time this fall when we recognized the inevitability of the situation and caved in to business reality. The domestic price of a *Circuit Cellar* subscription, originally set at \$21.95 in 1993, was scheduled to go up to \$24.95 with this issue. Foreign rates, already a wallet-killing \$50 per year, would have gone up as well. Shortly before it was to be cast in print, however, I decided to poll the readers about a change in magazine delivery that might solve everyone's problem.

A couple of months ago we posted a poll on the *Circuit Cellar* web site about offering the magazine in PDF format. Let me clarify that further by saying that this PDF magazine would be 100% equivalent to the print magazine. It would be in color, contain all the advertising, and be printable. Basically, all I was asking was if you would subscribe to a PDF version of *Circuit Cellar*.

About 500 people answered the poll in the short time it was posted. The results demonstrated an intense desire among the web-connected, Internet-savvy *Circuit Cellar* audience. 70% of the respondents answered that they would be interested. 71% of foreign non-subscribers would go for it right away and finally, a phenomenal 90% of our present foreign subscribers were interested, too. About the only concerns expressed were that the print magazine continued to be available and that the PDF subscription should cost less than print.

Well, I wish all my publishing decisions were this easy. Starting this month, *Circuit Cellar* magazine is available in PDF format. Of course, easily said isn't necessarily easily or inexpensively done. For everyone who thinks everything posted on the Internet should be free, forget it. You get what you pay for. We are publishing our new Electronic Edition to reduce the cost burden on the print magazine and maintain both our circulation and quality. A magazine has considerable overhead besides paper and postage. These expenses remain regardless of whatever delivery means we use. To reduce the cost-burden being solely on the print magazine, I've determined to spread these costs across our entire circulation base. It keeps the print subscription at \$21.95, offers a reduced price (\$15 per year) to Electronic Edition subscribers, and gives foreign readers an option that is less than \$50 per year.

The infrastructure for doing an Electronic Edition properly is also costly. If our projections are anywhere near correct, we will be dealing with tens of thousands of downloads very quickly. Systems quickly crash when dozens of readers around the world attempt to download a 6-MB file at the same time. This concern is even more acute if they are all DSL or cable modem users. Rather than limiting ourselves to a modest connection like a T1 line (1.5 Mbps), for the actual downloads *Circuit Cellar* is contracting for a high-bandwidth OC-3 connection through two different Tier-1 backbone service providers. At 155 Mbps, this OC-3 is equivalent to one hundred T1 lines! We trust that this will be enough bandwidth for even peak times.

Finally, I want to assure everyone that the print magazine is not going away and we aren't just moving online. The Electronic Edition is the most effective way for us to regulate costs and expand *Circuit Cellar* into the ever-increasing global marketplace. This is merely part and parcel to the continuing evolution of *Circuit Cellar*. I invite you all to check it out at [www.circuitcellar.com/electronic-edition](http://www.circuitcellar.com/electronic-edition).

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