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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 cali-

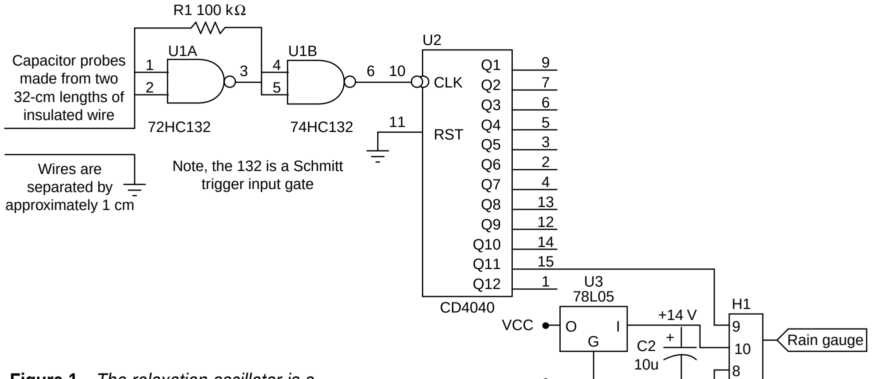


Figure 1—*The relaxation oscillator is a simple RC-based Schmitt trigger in which the capacitance portion is contributed via the probe wires as plates, and the water between them as the dielectric.*

brated 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 intended 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

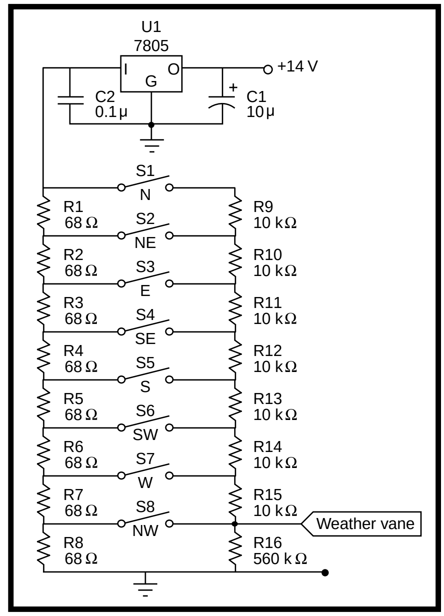


Figure 2—*A novel eight-key encoder circuit does not require a large spread of resistor values. These reed switches were taken from surplus reed relays.*

(the 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°C, 40-kph winter windstorm. Look at the external view in Photo 2.

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

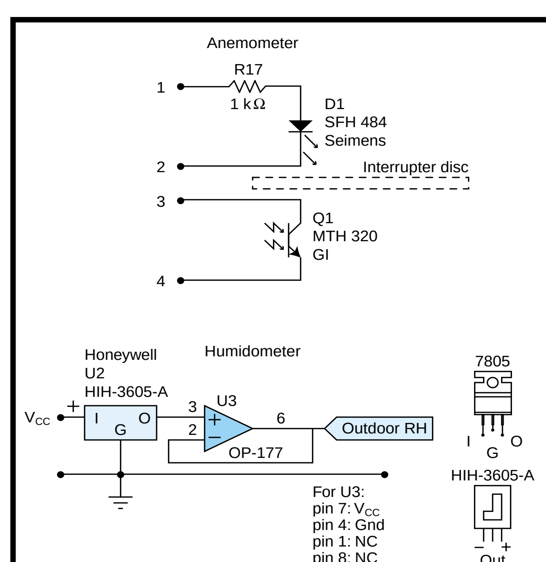


Figure 3—*I added a buffer because of the sensor's high impedance output. Although the OP 177 works, it isn't the best choice in this application.*

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 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

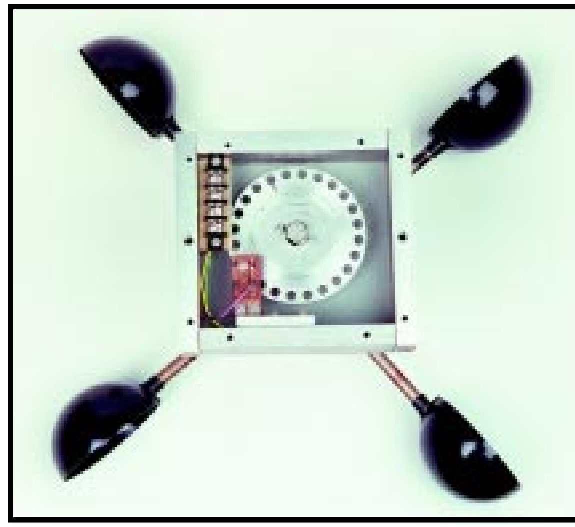
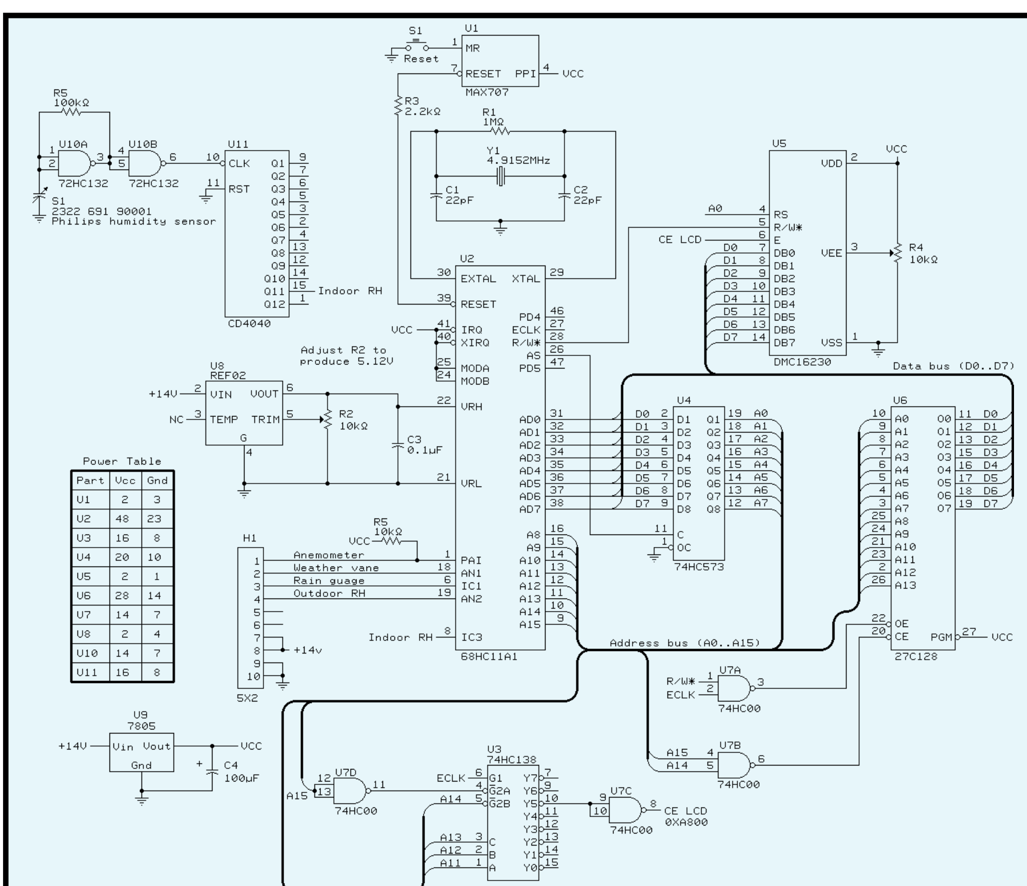


Photo 1—*This is an internal view of the anemometer. The perf board unit near the bottom is the interrupter module. The interrupter-positioning bracket is not clearly visible from this angle.*



Part	Vcc	Gnd
U1	2	3
U2	48	23
U3	16	8
U4	20	10
U5	2	1
U6	28	14
U7	14	7
U8	2	4
U10	14	7
U11	16	8

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.*

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.*

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.

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

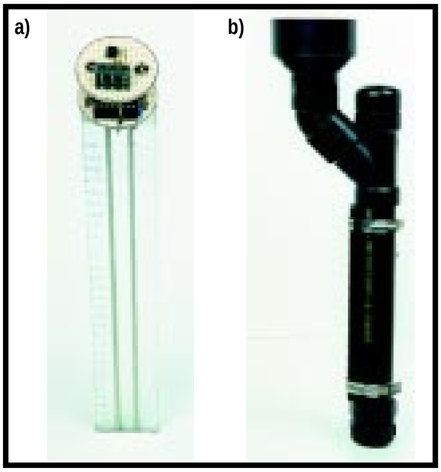


Photo 4—*Here's the liquid level probe and the required circuitry. The oscillator and prescaler are on the bottom level. The 5-V regulator and connector are on the top level. The probe and electronics fit inside a 1.5″ pipe.* **b—***Some black sewer pipe, a few fittings, and presto, a rain gauge vessel.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

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 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.

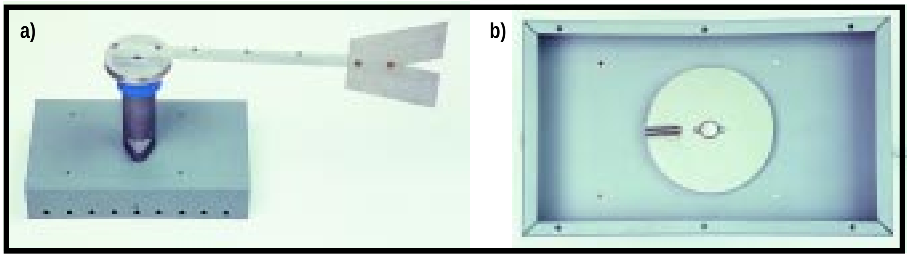


Photo 3—*This is an outside view of the weather vane. The arrow is plain, but is adequate to weather cock in the slightest of wind.* **b—***You can see from this inside view that the weather vane's mechanics are simple. The magnet is attached to the aluminum disk.*

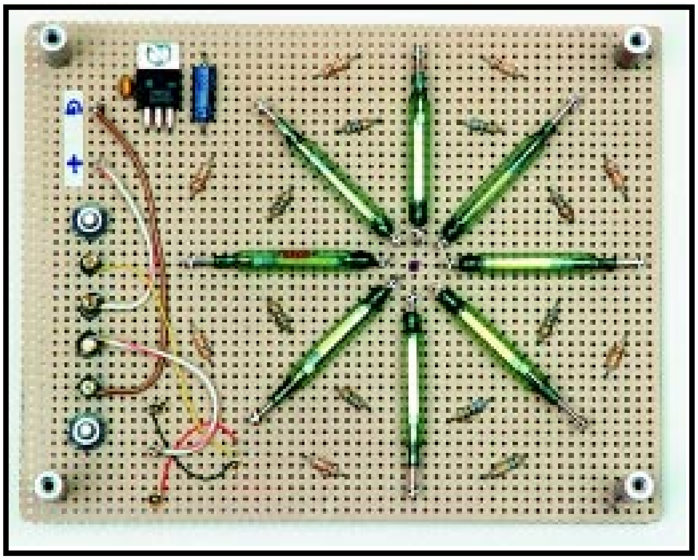


Photo 5—*The reed switch encoding circuit is another part of the weather vane. A barrier terminal strip and the outdoor RH sensor are mounted on the other side of the board.*

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 direction 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 RTI_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 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 possibil-

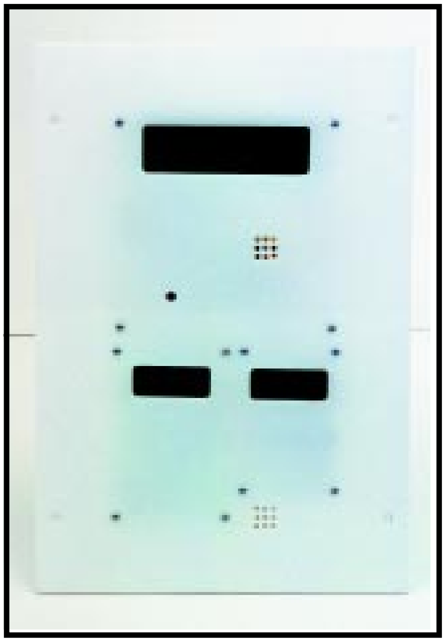


Photo 6—*This is a view of the front panel with everything attached and ready to be installed between the studs of a wall.*

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 HCll 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 occured, 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. ◼

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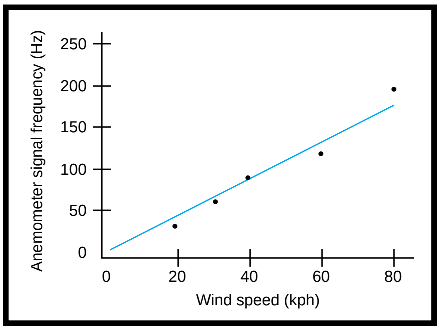

Figure 5—*I discovered a surprising linear relationship between wind speed and anemometer shaft rotational velocity.*

ity 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

SOURCE

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[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)