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Construct An Ultrasonic Snow Depth Sensor

Gerhard used the sonar components from an autofocus camera, a Microchip PIC18F452 microcontroller, and several off-the-shelf parts to construct an ultrasonic snow depth sensor system. The low-power design provides accurate snow depth measurements and is easy to integrate into other weather station systems.

Snowfall and snow depth measurements are important to anybody who receives regular snowfall. Several traditional methods of measuring snow accumulation include snow boards, snow pillows, rulers, and tipping bucket rain gauges. Other methods measure the "water equivalent." One method uses a gauge that contains antifreeze to melt the snow as it collects. The increase in the volume collected indicates the water equivalent of the snow. The water equivalent of snow can vary by as much as 50 to 1, depending on the climate.

Ultrasonic snow depth measurement is commonly used at many automated meteorological measurement sites. The advantages of an ultrasonic snow depth sensor are low-power operation, and low maintenance. It also can be readily integrated into an existing weather station monitoring system. Unfortunately, only a handful of ultrasonic snow depth sensor manufacturers exist worldwide.

Besides being practical, an ultrasonic snow depth sensor is an ideal project for an embedded microcontroller, such as a Microchip Technology PIC. Readily available ultrasonic transducers and driver boards can be purchased or salvaged from Polaroid autofocus film cameras. A working snow depth sensor, based on these components, was built in the fall of 2005. [1] The sensor has also been integrated into a home-based modular weather station that has been in operation since 2002. In this article, I will describe how to construct your own snow depth sensor based on the ultrasonic hardware found in some models of Polaroid cameras or from off-the-shelf parts available from SensComp, see Photo 1, A Microchip PIC18F452 microcontroller measures the time interval for the sonar measurement and provides system control and serial data communication with the host system, see Figure 1,

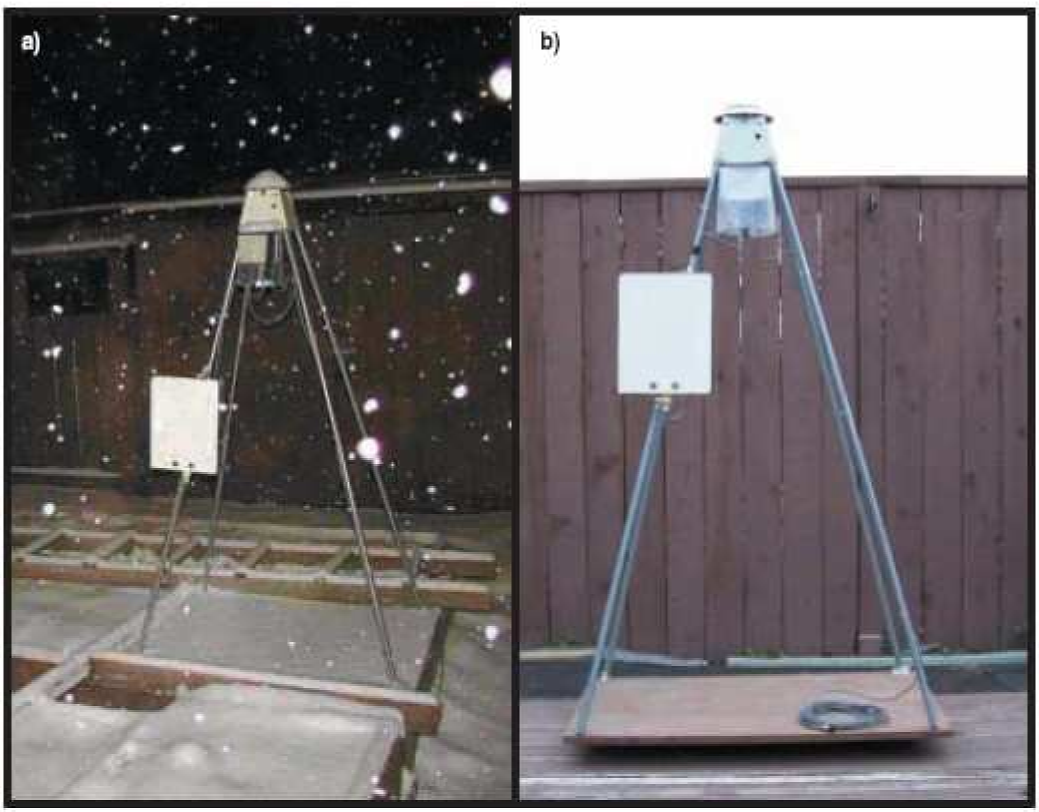

Photo 1a—The snow depth sensor is ready to take on winter. **b**—The four-legged mounting structure provides stability and is not subject to wind vibration. A solar radiation shield is mounted on the left support leg. It is painted bright white to reflect solar radiation.

Figure 1

SNOW DEPTH SENSOR
The snow depth sensor consists of an ultrasonic ranging head, an external ambient temperature sensor protected by a solar radiation shield, a junction box, a snow board, and an arrangement of four poles holding the sensor head rigidly ,about 1.5 m above the snow board ,see Figure 2,

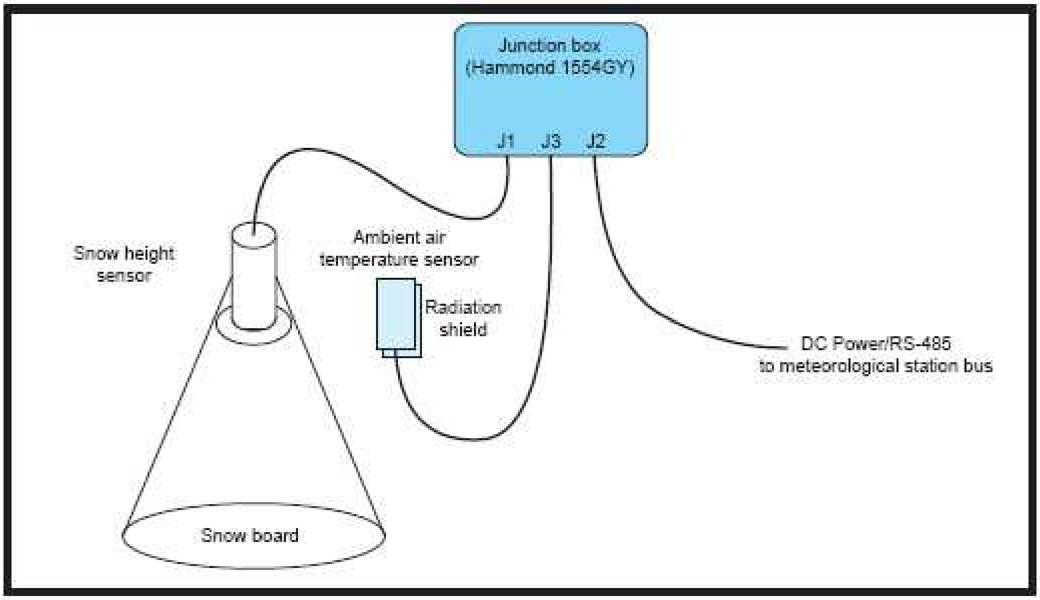

Figure 2—This is how the individual parts of the snow depth sensor are interconnected.

An ultrasonic distance sensor must have a suitable sound transducer, which can be used to transmit and receive. This is the case with the Polaroid ultrasonic transducer. The circuit emits a short burst of short wavelength sound toward the target. The snow depth sensor operates at a frequency of approximately 50 kHz, see Photo 2,

Photo 2—The snow depth sensor's electronic parts are ready for installation on the mounting structure. The temperature sensor will be mounted in a solar radiation shield to prevent excessive heating. The plastic film cans protect the connectors from the elements.

After a built-in default blanking dead time of 2.38 ms to enable the transducer membrane to quiet down, the receiver portion is re-enabled by the digital IC to process the echo signal reflected from the target. When the echo arrives, a logic signal transition indicates the arrival of the pulse. The microcontroller's hardware timer is configured to capture the time difference between the initiation of the transmit burst and the received echo pulse. The microcontroller then calculates the distance traveled with the speed-of-sound equation. [2] The ambient temperature must be measured to compensate for the temperature dependency of the speed-of-sound travel time. The sensor's specifications are listed in Table 1.

Power requirements	8 to 33 VDC, 1 A
Power consumption	100 mA average at 15 VDC with brief 2-A peaks. The current will fall with increasing voltage.
Measurement time	Programmable Burst mode
Output format	Serial ASCII, 1,200 to 57,600 bps
Communications mode	Automatic or polled
Communications interface	Internally terminated RS-485 Half-duplex
Tested distance measurement range	Greater than 0.5 m to a maximum of 10 m
Tested accuracy	±1 cm at close range increasing to ±4 cm at the upper limit of the range. Uses the external LM34 temperature sensor for compensation.
Temperature accuracy of speed of sound compensation (depends on temperature sensor exposure)	±1 cm from –40° to 60°C
Transducer used	SensComp series 600 instrument grade type
Resolution	Less than 1 mm
Cone angle	±15° at –6 dB
Maximum cable length	300 to 1,000 m at 9,600 bps
Suggested cable type	Four conductor shielded dual-twisted pair, 22 AWG
Operating temperature	–40° to (60°C)
Dimensions	Depend on the stainless steel coffee mug enclosure

Table 1—This table lists the snow depth sensor's specifications.

CAMERA SONAR HARDWARE

I am using the 600 series electrostatic instrument transducer from SensComp. The driver electronics are similar to the SensComp 6500 board. It has a beam angle of 15° and enables operation between 6″ and 35′ ,see Photo 3,

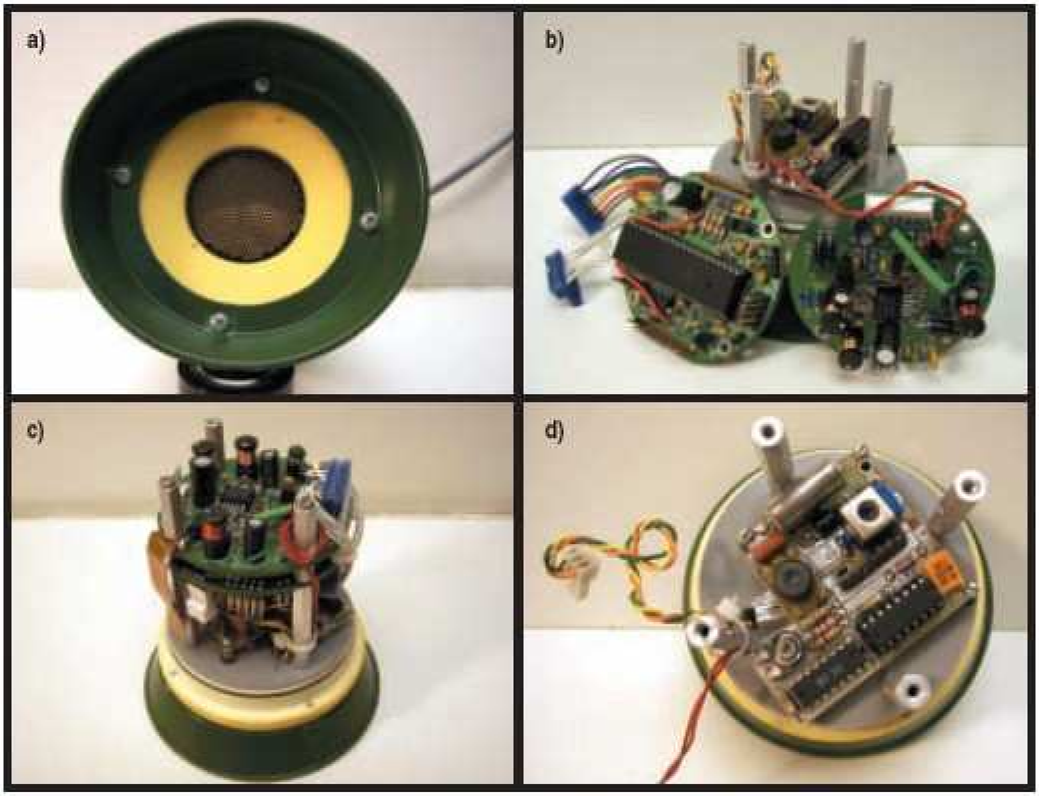

Photo 3a—This is the 'business end' of the snow depth sensor. The tiny transducer pressure equalization hole is near the seven o'clock position. The green shroud protects the transducer from wind-driven moisture to prolong its life. The 5-W heating resistor is located directly behind the transducer body to prevent condensation. **b**—The circuit boards are circular to enable stack-type mounting inside the circular stainless steel enclosure. Insulation displacement connectors complete the interconnections. **c**—All of the boards are mounted with interconnect cables in place. The small four-pin connector hidden behind the left-front mounting stud accepts the sensor cable carrying DC power and RS-485 communications. **d**—The sonar board is mounted directly over the transducer base to enable short connections. A gray plastic disk separates the transducer from the inside compartment to maintain a good seal from the outside world.

The transducer is fundamentally a capacitive microphone and requires a high polarization voltage in Receive mode for the best receive sensitivity. The SensComp driver generates a 400-VPP,49.4-kHz burst of 16 sine wave periods resulting in a burst duration of approximately 320 µs. When finished, a high positive voltage of approximately 200 VDC remains on the transducer during the receive interval to provide the required polarization voltage for the Receive mode of operation. Don't touch the output because the high voltage pulses are sufficient to produce a noticeable tingle depending on your skin resistance. ‚I have personal experience with this phenomenon□‚

The SensComp board uses a Texas Instruments chipset consisting of an analog and a digital custom chipset. There is a difference between OEM SensComp boards and salvaged camera boards. OEM boards allow re-triggering, whereas camera versions require power down between measurements. If you use a board salvaged from a camera, then the digital chip must be replaced with a TL851CN. The chip used in the camera, although almost identical, is designed to power down the electronics briefly before each new measurement. The TL851CN allows continuous operation without power down. You could use the original chip, but it would require the microcontroller and an added transistor switch to power down the board between each measurement. This would require some small changes to the firmware, which I have not tried. However, it is more convenient to use the replacement IC due to the burst mode of operation. Digi- Key carries the replacement IC. For further information, refer to the module schematic in the datasheet for SensComp 6500 series ranging modules.[3]

SPEED OF SOUND

The measured travel time must be corrected for the dependency of the speed of sound with temperature, humidity, and pressure. In

this application, only the ambient air temperature is considered. An external temperature sensor, mounted suitably in a solar radiation shield, provides temperature input to the computer to enable compensation for the change of speed of sound versus temperature. If you refer to Wendy Brazenec's master's thesis "Evaluation of Ultrasonic Snow Depth Sensors for Automated Surface Observation Systems, ASOS,," the speed of sound in meters per second is related to the ambient temperature, T, in degrees Celsius.[2]
The simplified equation is□
Speed(m/s)=331.4+0.6*temperature(c)
The distance can then be calculated with the following equation□
Total travel distance=Speed(m/s)*Total travel time *0.0001
Because this computes the total travel distance, the result must be divided by two to obtain the distance to the target.

TARGET QUALITY
Ultrasonic ranging imposes certain requirements on the orientation of the transducer, field of view, and the characteristics of the reflecting surface. To allow for the quality of the target reflectivity, the controller computes the mean variance based on the sum of differences relative to the mean average. This method avoids the floating- point calculations that traditional standard-deviation calculations require. The lower the result, the more the readings are similar to each other. The controller triggers a consecutive burst of rapid measurements that are stored in memory for averaging and calculation of the variance, which is a measure of the target quality. The controller can be programmed to generate between one and 32 burst measurements. Typically, a variance below four can be achieved on a hard target. Any value greater than 50 is considered a poor target. The target quality is dependent on the snow's consistency

and other factors. For short periods of time, there are instances of total loss of echo signals with certain types of fresh snow.

COMMUNICATIONS
An RS-485 communication link is used as part of a complete modular weather station system using several independent sensors to communicate with a remotely located host computer. Each system component responds to a unique address when polled by the remote host computer.

I used a Microchip Technology PIC18F452 microcontroller, see Figure 3, The 16-bit Timer1 is configured to increment at a rate of 1 µs, derived from the MPU time base crystal. To measure the 1-µs resolution time interval, the capture/compare register is used. The ADC section is used to measure temperature sensors and internal voltages. The UART is connected to an RS-485 transceiver in Half-Duplex mode. A serial LCD interface port is provided for future use in special applications.

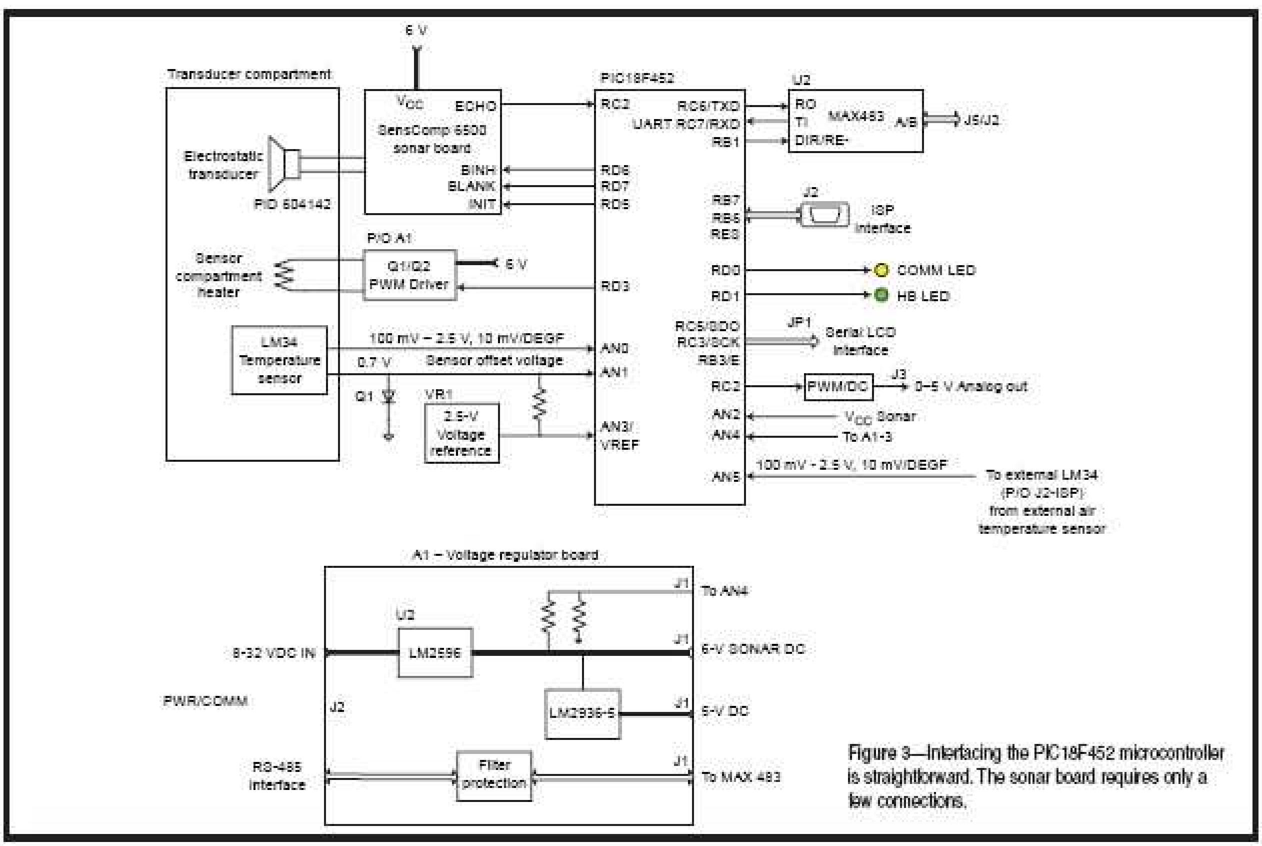

Figure 3—Interfacing the PIC18F452 microcontroller is straightforward. The sonar board requires only a few connections.

For basic operation, the Polaroid board requires only a transmit trigger signal and the use of the ECHO output signal to measure distance. Additional interface I/O lines exist for more sophisticated applications. Please refer to the SensComp 6500 series ranging module's datasheet for more information.[3] Although the digital control IC allows multiple echoes, the PIC firmware does not take advantage of this possibility.

To prevent transducer frost and condensation damage, a small heater resistor is housed behind the transducer inside the transducer compartment. A National Semiconductor LM34 temperature sensor provides feedback for proportional temperature control. A firmware-based control loop is set to maintain the temperature around the freezing point. The 1-ms Timer2 ISR generates a 1-ms resolution PWM drive signal to vary the heater output. The firmware also can be configured to operate in Constant Differential Tracking mode. As long as the transducer temperature is higher than ambient, condensation cannot occur. In two years of use, no visible damage or deterioration of the transducer was detected.

POWER SUPPLY & SAFETY

The sensor's power supply features a National Semiconductor LM2596 simple switcher TO-220-based buck regulator. It produces 6 V at up to 3 A to power the Polaroid board and the heater. A National Semiconductor LM2936 LDO provides a clean, low noise 5 V to the controller.

The circuitry includes protection components to limit overvoltage, over current, and transients. A self resettable fuse, SRF, is used to limit the power supply current in case of internal short circuits or wrong DC polarity. The 1.5KE36CA protects against overvoltage, transients, and the wrong polarity applied. The RS-485 lines are also protected from transients with SRFs.

A MAX483 RS-485 half-duplex balanced transmission line data transceiver interfaces the UART with the weather station communication path. A unique ID enables multiple sensor communications with other sensors sharing the same communications channel. Five 10-bit ADC channels are used to measure the outputs of the following devices in sequence□ an LM34 air temperature sensor, an LM34 sensor DC-offset, a sonar 6-V power supply,an external DC input voltage, and an LM34 external air temperature sensor. The ADC converter sets the interrupt flag when the conversion is complete, triggering a call to the ADC interrupt handler. The ADC interrupt service routine averages the same channel n times. When the average limit is reached, it increments the ADC channel number and the process repeats.

TIME INTERVAL MEASUREMENT

The ECHO output of the Polaroid board connects to the RC2 timer/capture input of the PIC18F452 microcontroller. The 1-MHz time base for Timer1 is derived from the 4-MHz system clock after division by four by the programmable prescaler. To enable measurement of the time interval, the CCP1 interrupt ISR is configured to respond when the ECHO output line goes high.

To measure the time difference between the start of the sonar pulse, the running 16-bit Timer1 count is captured when the Polaroid board starts a new measurement when triggered by the RD5 output signal. When the ECHO signal goes high, the current Timer1 count is captured via input pin RC2 and retrieved by the associated CCP1 interrupt ISR.

SOFTWARE DESIGN

The sensor's firmware is designed to provide control and communications by polling from a remote host. Hardware interrupts are used to enable a real-time response. The firmware provides convenient access to the controller EEPROM to permanently store operational sensor parameters. The communications protocol requires a unique address to enable the sensor to respond to external commands. This enables multiple sensors to share the communications path on the RS-485 cable. For example, in my installation, a weather station and another sensor share the same cable, each responding to its assigned address.

To avoid lengthy pauses in program execution, a state machine is used to control the sonar board operation ,see Figure 4, The state machine is executed at a period of 5 ms from the Timer2 ISR. The state machine can run for either single sonar measurements or a burst mode.

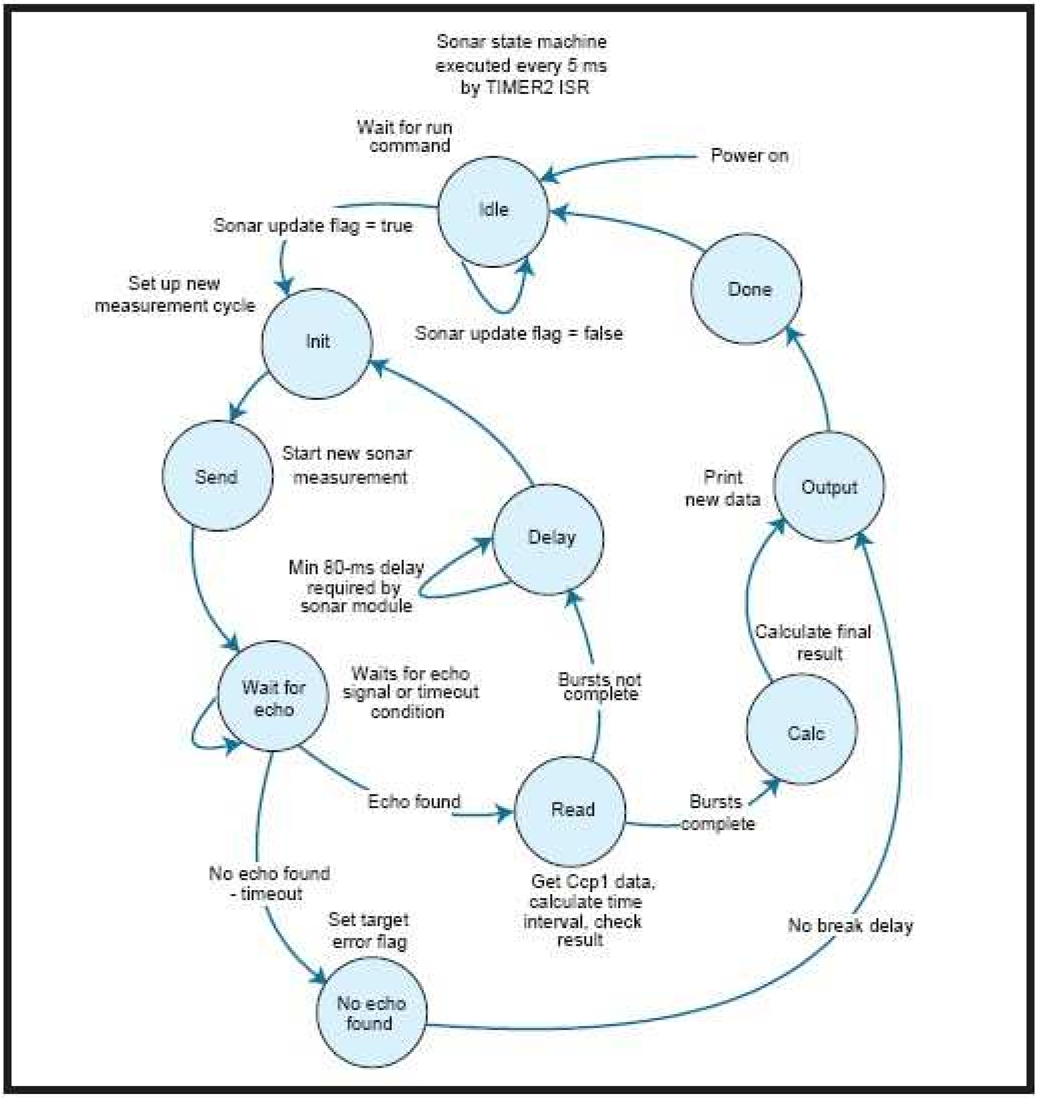

Figure 4—The sonar state machine decouples the fast PIC firmware from the slow sonar board signal timing.

The ADC ISR is configured to use interrupts to signal an end of conversion. A scheduler in the Timer2 ISR controls the update rate. The ADC readings can be averaged if desired. This way, the firmware always has a set of freshly updated analog values available when needed and never needs to wait for ADC conversions to complete.

The RX UART is set up to generate an interrupt whenever a new character is received. The associated receive data interrupt service routine maintains a command buffer for the command processor. No TX ISR is used to buffer outgoing data. The Timer2 ISR provides the master timing for the various tasks of the system.

The Timer2 ,ISR, is configured to execute at a period of 5 ms. The ISR is responsible for scheduling several activities☐ triggering the ADC to start a new measurement, sonar measurement rate, heartbeat timing, temperature control timing, heater resistor PWM, and hardware I/O updates.

COMMAND PROCESSOR
The sensor uses a simple command set to respond to commands from the host system. Please refer to the program Help file, son_cmds.txt on the Circuit Cellar FTP site, for an extensive list of commands and additional information. The command processor responds to simple ASCII commands. Command strings are divided into queries and commands. For example,\nU10V\r\n or \nU10A\r\n are queries, while n\U10K0\r\n or \nU10P5,20\r\n are commands.

Some queries can be used with or without a parameter. They control how the query returns its data. For example, \nU10A\r\n returns all analog fields. Sending \nU10A2\r\n returns only the analog field two. Sending \nU10A2,4\r\n returns analog value fields two to four.

For instance, sending the request firmware version command U10V\r\n to the sensor would return \nURC V2.00,07-JUL-11\r\n. Sending \nU10A2 returns the analog voltage on channel AN2 with \n1023\r\n. The leading \n character is not strictly required when using a terminal program for manual testing, but it is mandatory for reliable stand-alone system operation when you're using another computer for data communications. It functions as a delimiter for the beginning of a new command.

Some commands require parameters. They are sent in the format \nU10cn,m\r\n, where c is the command letter, n is the index, and m is the new value.

To change an EEPROM parameter, send \nU10P5,16\r\n. Note that 5 is the EEPROM register number and 16 is the new data.

The command processor is executed once each time the main loop repeats. If no new commands are received, it returns without further action. If a new command is received, it analyzes the received buffer content until the complete command has arrived. Then, it compares the command prefix and address. If the address matches, the actual command interpreter is called. This parses the command string and executes commands and parameters sequentially until all commands are processed. It is possible to send multiple commands in one transmission. For example, sending \nU10VA3XI3\r\n would be executed in sequence until all command letters are processed. With the above example, the unit would respond with \nURC V2.00, 31-Oct-07 315 13r\n. Concatenation of commands is useful when you want to reduce the communications overhead and improve efficiency.

The firmware maintains a status word to monitor system operation. A variety of information such as temperature sensor malfunctions, loss of target, target too close, temperature controller failure, heater state, and low DC supply voltage,are available. In normal operation, all bits are zero. Any non-zero bit constitutes an abnormal situation. Refer to the Help file for more documentation.

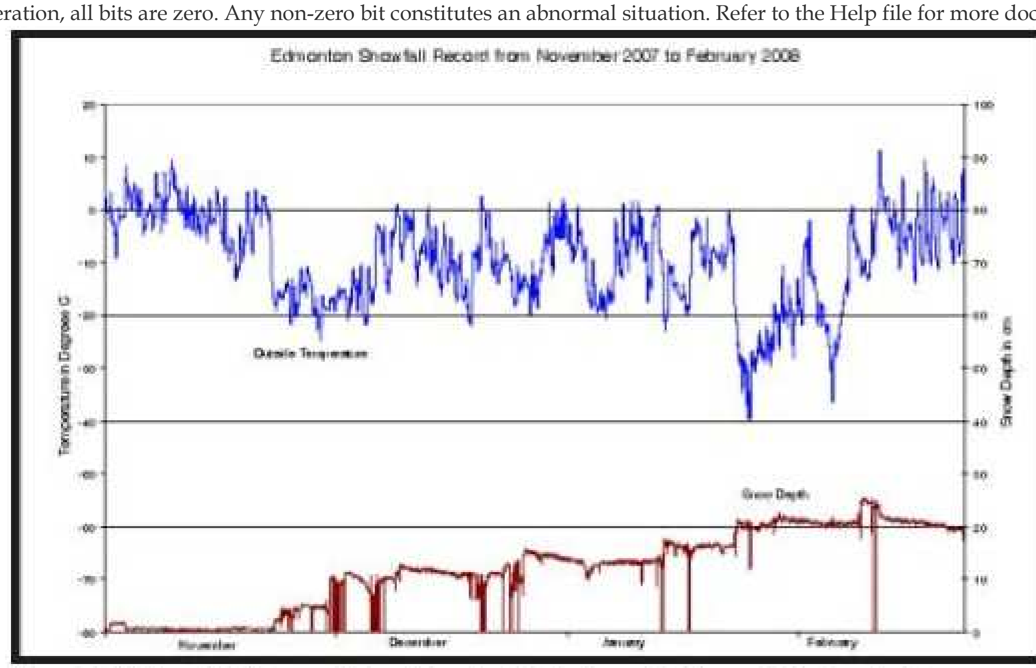

Figure 5—This is a plot of the snowfall from November 2007 to the end of February 2008. Occasional poor snow reflectivity after a fresh snowfall shows up as a sensor failure and zero output at random intervals. Also note the wide temperature swings.

SENSOR CONFIGURATION

The sonar snow depth sensor is housed in a modified insulated stainless steel coffee mug. I chose the mug because it was inexpensive, would provide reliable protection against the elements, and was the perfect size. An externally mounted temperature sensor inside a solar radiation shield provides temperature input to allow compensation of change in the speed of sound versus temperature. The snow sensor electronics assemblies are split up into several sections.

The snow depth sensor is mounted about 4.5′ above a 2′ × 4′ piece of plywood with four legs made of 0.5″ galvanized electrical tubing. Because Edmonton, Canada, seldom receives more than 3′ of snow in the winter, the chosen height was considered adequate. It is important to remember that due to the single transducer method used here, the sonar transmit-to-receive turn-around time imposes a minimum target distance of about 45 cm. Other methods of sensor support can be used. In many installations, the sensor is mounted on metal tubing supported by poles or support towers. The radiation cone of the 600 series transducer can be easily calculated using the equation in the article "Ultrasonic Snow Depth Sensors For Measuring Snow In The U.S." by Wendy Brazenec,

Nolan Doesken, and Steven Fassnacht.[4] The radiation cone size in feet is related to distance☐
Cone [radius] = 0.194(Cone [height])
Therefore, with the snow depth sensor mounted at 4.5′, the cone diameter is 1.75′ and the chosen 2′ × 4′ plywood is large enough to contain the radiation beam.

ENVIRONMENTAL PROTECTION
Because the electronics compartment is hermetically sealed, a desiccant pack is used inside to prevent internal condensation. The desiccant pack is replaced at the beginning of each winter. It reduces internal relative humidity to about 10%. It should be renewed when the RH inside the sensor exceeds 30%. A measurement strip can be left inside the sensor to monitor the RH.

The transducer is housed in a compartment inside a machined Delrin base housing. It is sealed from the electronics compartment. A tiny hole to the outside provides air pressure venting to prevent electrical shorts of the transducer membrane due to air pressure variations. An outside shroud offers some protection of the sensor opening from moisture blown sideways by strong winds. An o-ring provides a hermetic seal for the electronics compartment.

SONAR OPERATION
The snow depth sensor requires a host program that polls the sensor periodically. The weather station uses an old second-hand 25-MHz 386-based low-power laptop computer for low power consumption. The computer uses only 0.5 A at 12 V with the display off. The original hard drive was replaced with a 64-MB flash memory IDE 2.5″ drive to avoid mechanical wear out. The logging and display program was written in compiled Microsoft QuickBasic Version 4.5. The logging program is configured to output the data in a Microsoft Excel-compatible, comma-separated format for easy importing into a spreadsheet program. Cone [radius] = 0.194,Cone [height],

It was not important to pack the data in a more compact format. Data transfer to the Windows 2000/XP computer uses a Windows-based parallel port transfer utility program ,Briggs Soft works Link Maven, It's easy to remotely move the data and delete old data files from the laptop's hard drive.

A National Instruments LabVIEW based program is planned to replace the MS-DOS-based QuickBasic logging program to enable monitoring and control with modern computers. Additionally, a web server interface might enable access from outside the home. Practical guidance for siting and mounting a snow depth sensor is offered in the documents listed at the end of this article.

SNOWFALL RECORDING
An example of the snowfall received in Edmonton in the winter of 2007-2008 is shown in Figure 5. I think this is a good place to point out a couple of distinctions about the recording of snowfall. This is the amount of snow that has fallen since the first flakes have fallen. To obtain the new snowfall, the data should be graphed and then examined for steps in the graph. The difference in reading for each step is the new snowfall amount.

To accurately determine the snow depth, the data file should be graphed in a program such as Excel and examined for the beginning and end of each snowfall event. The difference of each event should be added up to obtain the total snow depth. Due to melting, a loss of snow depth occurs.

IMPROVEMENTS TO COME
The observed signal losses due to wind and low-density snow require investigation. Wind has produced a loss of signals due to the target signals being deflected, preceded by a rapid loss of target quality indications. Wind can also degrade the

distance accuracy somewhat. Also, the sensor occasionally stops working due to an insufficient echo signal after some types of new snowfall. The variability of the snow's composition also seems to affect reflectivity, resulting in poor sensor performance at times. These may be difficult challenges to meet because some research on the Internet has produced evidence that these problems seem typical for sonar-based measurement. Perhaps,diligent further experimentation and research may solve some of the problems.

Monitoring snow height with an ultrasonic sensor proved to be an effective method to record the local snow height over the course of a winter. Designing this instrument was straightforward due to the availability of a suitable ultrasonic transducer and interface chips. The microcontroller provided essential peripheral support to enable accurate measurement of time intervals, whereas using C language allowed speedy development and experimentation. The address-based communications protocol allowed easy integration with an existing weather station.

Although the recorded results were accurate most of the time, more work needs to be done to address the problems caused by wind and poor snow composition. The acoustic reflectivity and absorption of fresh snowfall varies widely and presents challenging problems. Commercially available sensors seem to suffer from the same problem.[1, 2] Perhaps some research will help improve sensor performance.

Integrating the physical design into an insulated stainless steel coffee mug was a good idea. The affordable mug has served well as a durable electronics shelter. Thus far, the system has survived two winters without any sign of transducer deterioration

PROJECT FILES
To download code, go to ftp://ftp.circuit cellar.com/pub/Circuit_Cellar/2008/214.

REFERENCES
[1] Campbell Scientific, Inc., "SR50 Sonic Ranging Sensor Instruction Manual," 2007, www.campbellsci.com/documents/manuals/sr50.pdf.

[2] W. Brazenec, "Evaluation of Ultrasonic Snow Depth Sensors for Automated Surface Observation Systems (ASOS)," M.S. thesis, Colorado State University, 2005, http://ccc.atmos.colostate.edu/pdfs/Brazenec_Thesis_ALL.pdf.

[3] SensComp, Inc., "6500 Series Ranging Modules datasheet," 2004,www.senscomp.com/specs/6500%20module%20spec.pdf.

[4] W. Brazenec, N. Doesken, and S.Fassnacht, "Ultrasonic Snow Depth Sensors for Measuring Snow In The U.S.," Colorado State University,http://ams.confex.com/ams /pdfpapers/101687.pdf.

RESOURCES
Maxim Integrated Products, Inc.,"Low-Power, Slew-Rate-Limited RS-485/RS-422 Transceivers," 19-0122,2003.

Microchip Technology, Inc.,"PIC18F852 Data sheet: High-Performance, Enhanced Flash Microcontrollers with 10-Bit A/D," DS39564C,2006.

National Oceanic and Atmospheric Administration's National Weather Service Forecast Office, "Snowfall Measuring Procedures," www.crh.noaa.gov/jkl/?n=snow_measurement.

National Semiconductor Corp.,"LM2596: LM2596 Simple Switcher Power Converter 150 khz 3a Step-Down Voltage Regulator," DS012583,2002.
---, "LM34: Precision Fahrenheit Temperature Sensors," DS006685,2000.

Philips Semiconductors, "TL431C Datasheet: TL431C, TL431AC,TL431I, TL431AI, LM431AC Adjustable precision shunt regulators,"853-1927 17795, 1997

SOURCES
PIC18F452 Microcontroller Microchip Technology, Inc. www.microchip.com

LM2596 Voltage regulator, LM2936 voltage regulator, and LM34CAZ temperature sensor National Semiconductor Corp.www.national.com

600 Series instrument transducer SensComp, Inc.www.senscomp.com

TL851CN Sonar ranging control Texas Instruments, Inc.www.ti.com