HARDWARE HACKER

Electronic Clinometers; Low-Frequency Communications; Fundamentals of A/D Converters . . .

By Don Lancaster

There sure has been a lot of interest in our "neuron" A/D converter from the July 86 *Modern Electronics*. Several comments on all this. First, be sure you are using "buffered" CMOS inverters that consist of three cascaded stages. The unbuffered types just do not have enough gain for sharp switching.

Secondly, many of you seem to want to build a video A/D converter using our simple low-frequency "neuron" circuit. Simply put, the circuit will probably glitch too badly, and will respond too slowly for high-speed video use. I'll try to have more on high-speed A/D converters in a future column.

Thirdly, the resistor values are not nearly as sneaky as they seem. The resistors at the input to any gate form a simple voltage divider. They are adjusted so that a "yes" output occurs for any voltage even slightly under 2.5 volts, while a "no" output occurs for any voltage even slightly over 2.5 volts.

Note that the feedback resistors are always connected either to +5 volts or ground, while the input summing resistor goes from 1 volt (a logical "15") to 4 volts (a logical "0"). Note also that the CMOS inverter itself draws no input current.

We sure are getting lots of response on this. Most of the responses are really well thought out.

Onward and upward . . . .

What makes A/D conversion so messy?

Analog to Digital (A/D) converters are used to change varying voltages or currents into digital logic levels. Important uses of A/D converters include computer game paddles, digital voltmeters, industrial process controls, robotics, video processing, military radar, and digital audio, to name a few.

Some A/D converters are very simple, while others are insanely complex. What causes the big difference?

There are two important things used to spec an A/D converter. One is the resolution, or the number of output bits that will result. A 6-bit A/D converter can resolve only one level in 64, but might be well suited for video uses. An 8-bit version easily interfaces a personal computer, but allows only 256 input levels.

Industrial 10- and 12-bit converters allow 1,024 and 4,096, respectively, levels at added cost. Digital audio needs 14-to-16-bit converters that can handle from 16,384 to 65,536 levels.

Finally, an A/D converter used in a 5½ decade digital voltmeter has to resolve better than one part in 200,000, the binary equivalent of 18 bits.

The second important spec is conversion time. A few conversions per second is all that is needed for a digital voltmeter or tachometer, because anything faster will only blur the display. A millisecond or so is available for personal computer game inputs. An industrial process control or digital audio needs conversion rates in the tens to hundreds of microseconds. Video requires conversion rates of 10 megahertz and higher, while military radar might need 0.5-gigahertz conversion speeds. The higher the resolution or the higher the speed, the greater the cost of the A/D conversion scheme that must be used.

To further complicate things, most real-world A/D converters require four very important accessories. These are an input sample-and-hold, an antialiasing filter, very careful guarding, and an output latch.

If the input is allowed to change during the conversion process, you will get a wrong answer. This means that any higher-resolution A/D converter can accept only ridiculously low input frequencies if it does not have an input sample-and-hold. For instance, a 16 bit A/D converter with a 16 microsecond conversion time can only accurately accept a few hundred Hertz as its maximum input frequency without a sample-and-hold.

Sample-and-hold works by "catching" the input signal and keeping that sample at a constant value during the conversion process. This will dramatically up the maximum permissible conversion rate. You can build a most useful sample-and-hold out of a CMOS 4066 analog switch, an output capacitor, and a decent op amp.

But when you add a sample-and-hold, a new problem results. If you input any frequencies that are anything above one-half the sample rate, you will create all sorts of erroneous artifacts that will totally mask the signal being converted.

These artifacts are called "aliases." To get rid of aliases, you use an antialiasing filter. This is a sharp cutoff low-pass filter that is set to one-half the sampling rate or lower.

Guarding is the process of making sure that no digital output noise gets back on the input lines. This is usually handled by careful circuit layout with separate grounds for the analog inputs and the digital outputs.

As an example, a 16-bit A/D converter with a 0-to-5-volt analog input can resolve one part in 65,536, giving you a resolution of 5/65,536 volts or 76 *microvolts* of input sensitivity.

It is not at all unusual for a digital logic system to generate 300,000 microvolts (0.3 volt) of ground noise. Let so much as a tiny whiff of this show up at the input, and you lose all of the resolution you set out to achieve.

Other tricks can be used for noise reduction. In a digital voltmeter, conversion time is often made an exact multiple of the power line period. This will cancel out any hum that is present, since any ac waveform will always average itself to zero over its period.

Turning to the output side, wildly wrong answers may appear during the conversion process. This is particularly sticky with video, since a glitch or two will totally smear the works, besides ruining your entire day.

An output latch can often be nothing but some flip-flops, but even here you can get into trouble. You must be absolutely sure your computer or whatever accepts the input only during valid data times. At high speeds, even the difference between the "turn-on" and "turn-off" times of the latch can become very important.

There are a wide variety of A/D conversion schemes in use that differ greatly in their resolution and speed tradeoffs.

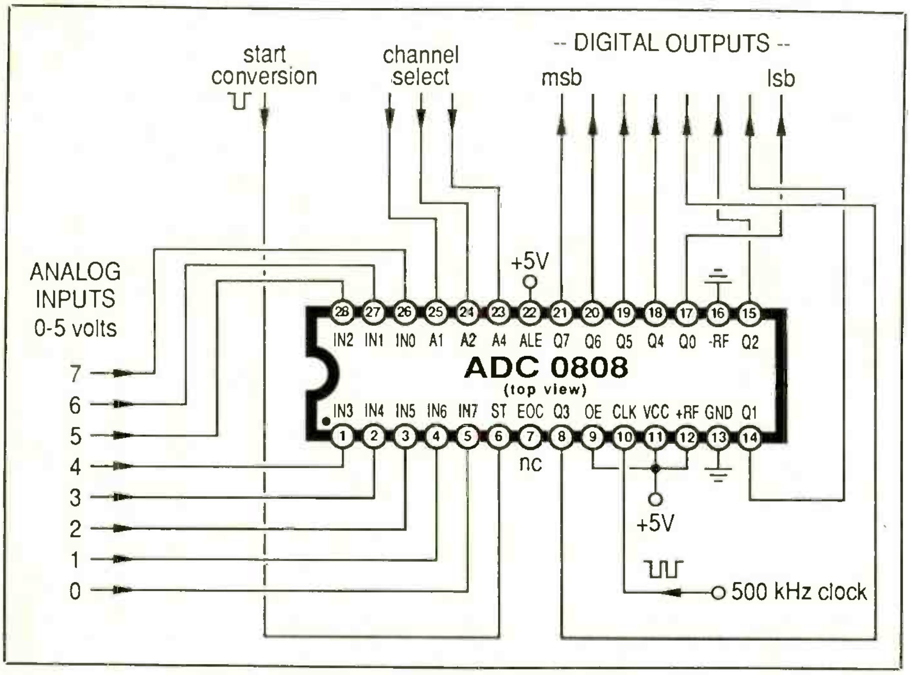

Fig. 1. A medium-speed, 8-channel A/D converter.

These include simple voltage-to-frequency converters used for game paddles, dual-slope integrators intended for digital voltmeters, brute-force circuits used for video and radar, our own "neuron like" experimental converter, older industrial successive approximation converters and their new feedforward converter replacements that are a little slower than brute force circuits but are also quite a bit simpler.

We'll try to have examples of all these different converter types from time to time. More details on many of them appear in my *Micro Cookbook*, Volume II.

Show me a typical A/D converter circuit

Figure 1 shows a great little successive-approximation converter that interfaces beautifully with most microcomputers. This jewel has eight selectable input channels of 0 to 5 volts each and provides an 8-bit output resolution of 1 part in 256. Cost is around $9. This is a *National* part. You can find variations and improvements on this device from both National and *Analog Devices*.

To use it, you first output three bits worth of binary "channel selection" from your computer. Then you output a "start conversion" command, wait for a millisecond or more, and then read your input port. It's that fast and that simple.

How can I get involved in low-frequency communications?

Low frequency, or lf, communications involve radio waves that are lower in frequency than those used on the AM broadcast band, ranging from 30 to 500 kHz. Very low frequency, or vlf, communications are lower still, being under 30 kHz. Important uses of these bands include time standards such as WWVB, navigation aides, submarine communications, cave mapping and communications, beacons, signaling devices, and other unique services.

As we saw last month, there is a great quarterly underground technical publication out named *Speleonics* that covers a lot of this sort of stuff. At $4 per year, Speleonics is a real bargain.

But the "mother lode" of general lf and vlf information seems to be a group called the Longwave Club of America. You may want to check out these people. Their publication is called *The Lowdown*, and costs $10 per year. They also have lots of reference materials available.

One unique vlf device that recently caught my attention was a cave-mapping transmitter. It consists of a loop antenna, a transmitter, and a level, all built into an all-plastic BMX bicycle wheel.

The transmitted frequency is 3,580 Hz. This frequency is a magic number that (1) is low enough to go through lots of rock, (2) is a stock TV crystal frequency divided by 1,000 and (3) is far enough away from both 50- and 60-Hz harmonics that it can be used here or in Canada without any worries about power-line interference. The 3580-Hz is pulse modulated at a 3.58 Hz-rate, which is obtained with another division by 1,000.

Such a device could be used either for mapping or rescue. Either way, the transmitter is hauled somewhere inside a cave, turned on and very carefully leveled. A somewhat similar receiver is then used on the surface to pinpoint the location of the underground transmitter. The exact location and depth can easily be found. The null point at which the signal drops to zero for a level receiver will be directly over the transmitting loop.

A loop antenna has a very precise and mathematically defined field. By moving the receiver around in circles and measuring the null tilt angle, the depth of the transmitter can be found. To do this accurately, the transmitter must be perfectly level.

Some hairy math is involved in the depth calculation. This is easily handled by a BASIC program, run on most any personal computer.

For some strange reason, the calculated depth always ends up a few percent lower than the actual depth. A suitable fudge factor is then used to predict the read depth.

Which way is up?

Electronic level sensors have lots of interesting uses. These have traditionally included aircraft instruments, construction levels, robotics, and percent-of-grade indicators for road machinery.

Thanks to some recent developments,

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low-cost electronic levels are now becoming available and will open up all sorts of new uses. For instance, table saws can now automatically indicate the depth of cut versus table angle, a calculation that is otherwise far from trivial. Better yet, the latest electronic level scheme is easily done as a simple yet challenging hacker project. With some ingenuity, you should be able to build an electronic level for well under \$4.00.

Let's review.

The correct name for an electronic level is a "clinometer." As Fig. 2 shows, you can build a simple clinometer out of a plumb bob, a string, and a protractor. The plumb bob points straight down, and the angle you read tells you the slope of the top of the protractor.

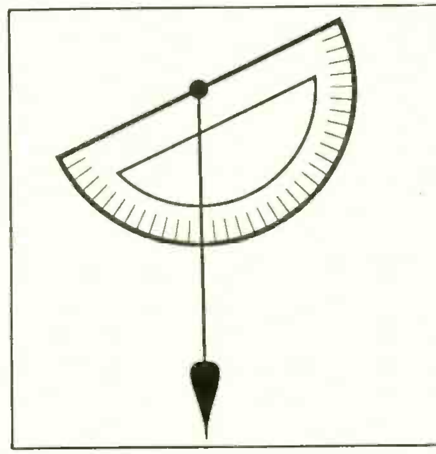

Fig. 2. A mechanical clinometer.

You could use a bubble level instead of a plumb bob. This is how the clinometer on a Brunton compass works. You slide the level arm until the bubble is centered and then read the inclination off a dial.

Electronic levels must instead provide some sort of analog or digital output. You can "electrify" either of these simple clinometers, but you are likely to get into resolution and "stiction" problems.

Some precision aircraft clinometers use a device called a "linear differential transformer" to sense the small angular changes needed for high accuracy. The cost of these is horrendous.

Figure 3 shows another older approach to electronic level sensing. It is called an "electrolytic gravity sensor" and looks suspiciously like a bubble level with three terminals on it. A mildly conductive liquid (often bromine) partially fills the sensor. When level, the same amount of bromine will be in contact with both outside electrodes. The outside-to-center resistance, therefore, will be the same at both ends.

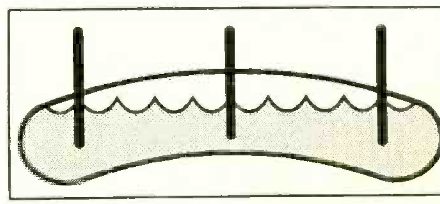

Fig. 3. An electrolytic level.

As the sensor tilts, the bromine moves down to the low end, increasing the high-end resistance and decreasing the low-end resistance. A simple bridge circuit can then give an analog output.

Hamlin is one source of these. Last time I checked, these beasties ran around \$30 each. Besides the high cost, they are fragile, slosh sensitive, and have a strong "wrong axis" cross-sensitivity.

The latest, and potentially the cheapest, type of clinometer is the capacitance level sensor of Fig. 4. What you have here is a very thin metal tank that houses a liquid and two capacitor plates. The liquid should be an insulator with a high dielectric constant. Propylene glycol (antifreeze) with its dielectric constant of 30

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National Semiconductor
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Longwave Club
45 Wildflower Road
Levittown, PA 19057

Speleonics
Box 5283
Bloomington, IN 47402
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Sperry Sensing Systems
Box 21111
Phoenix, AZ 85036
(800) 545-3243

comes to mind as one possibility, although mineral oil with a constant of 3 is probably much better behaved.

At any rate, the portion of the sensor plate that is covered by the liquid will have a much higher capacitance than the part that is not. As the sensor rotates, capacitance to the case of one plate increases, while the other one decreases. The particular shape shown gives a linear sensor output over a $\pm 60°$ range.

The plates are routed to a pair of 555 timers. The difference in time delay created by the liquid coverage is then easily converted into an analog or a digital output.

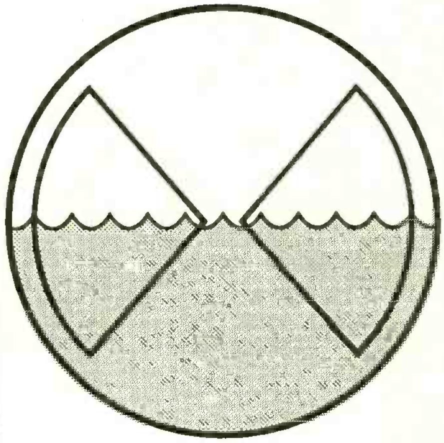

Fig. 4. A capacitive clinometer.

Cross-axis sensitivity is nearly eliminated by putting two sensors back to back in the same case. As you tilt the sensor in the "wrong" direction (towards or away from you), the liquid on one side creeps up on its sensor, while the liquid on the other creeps down. The two will thus nicely cancel out.

The Accustar Electronic Clinometer by *Sperry* is one example of this new technology. Being aerospace people, their $100 single-quantity pricing is totally out of line for something like $4 worth of low-tech parts that anyone could throw together on a kitchen table.

Nonetheless, their data sheet and application notes make very good reading on this new clinometer. More technical info on the capacitance level sensors appeared in the June 16, 1986 issue of *Design News*.

It seems that this product could be dramatically "value engineered," putting the plate sensors on the same circuit board as the rest of the electronics, and using metalized plastic cups for the tanks. There's no reason an outfit in a Hong Kong alley couldn't knock these out for under $2.00 each.

Can you do better? **ME**

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