HARDWARE HACKER

Understanding strain gauges; video art A/D conversion; transducer information; robotics parts

By Don Lancaster

If you want to start your own hi-tech venture, check into my *Incredible Secret Money Machine* book that's chock full of ideas for your own technical or craft venture. I just happen to have several autographed copies on hand here that I'll be happy to lay on you.

Uh, it seems there were some problems with last month's *Omnicrom* phone numbers. Try using (617) 881-4100 or (800) 447-2326 instead.

And now, onward with this month's goodies.

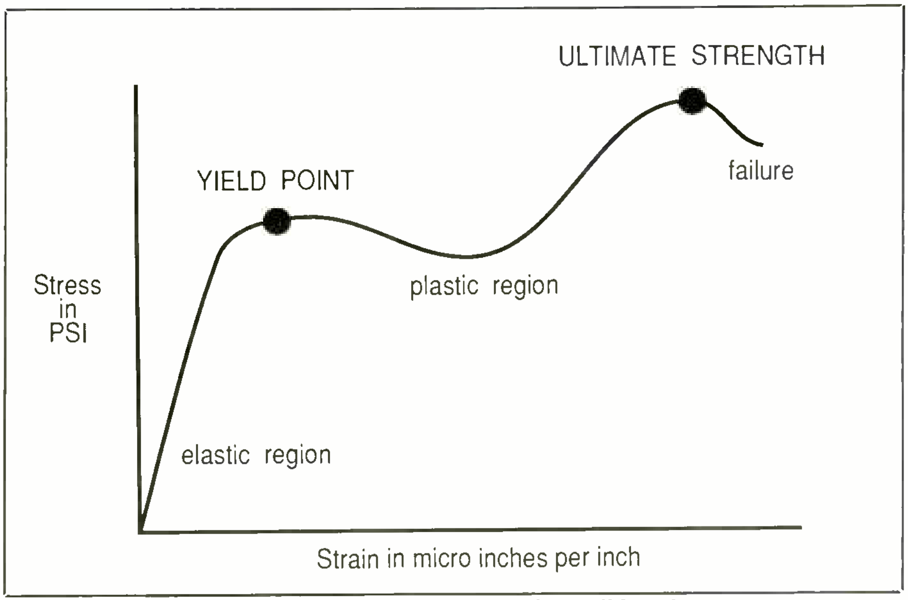

Fig. 1. Stress-versus-strain curve plot for mild steel.

What is a strain gauge?

A strain gauge is a sensor that can measure very small changes in physical size. Strain gauges are extremely useful for electronic weighing and scales; load cells; materials testing; accelerometers; electronic-music keyboards; pressure and force measurement; stress analysis; robotics, traffic sensors; unique game input devices; and much more.

Despite costs starting at $4 and their simple use, strain gauges remain virtually unknown as hacker components. Yet the opportunities here are mind-boggling.

Let's start at the beginning. Say you had a piece of steel and started pulling on it. If you try this, you will generate the classic stress-strain curve shown in Fig. 1. If you pull on the steel only moderately, it will spring back to its original shape. If you pull harder, it will stretch like taffy. Pull too hard, and the steel will fail by snaping in two.

The stress you apply to the steel will be determined by the force you use and the cross-sectional area over which that force is applied. Stress is often measured in psi, or pounds per square inch. If you are pulling on the steel, you place it in tension, much the same as the cables of a suspension bridge. If you are pushing on the steel instead, you put it in compression, similar to the loading on the concrete pylons of a highway bridge.

As the steel is stressed, it will get longer. This lengthening is called strain, and is normally measured in microinches per inch. Under normal loading, strain values usually range from a few hundredths to a few tenths of a percent. This, of course, varies widely with the material and the applied load.

For fairly low stress values, the steel will stretch linearly with the applied load. It will also return completely back to its original size when the stress is released. This is called "elasticity." By this definition, steel is much more elastic than rubber, and ceramic materials are even more elastic than steel.

You could build an electronic scale by measuring the linear elastic strain on a piece of steel as you add weight to it.

As you increase the stress further, you stay elastic, but you are no longer linear, picking up added strain with added load. But, you will still return to the original size when the stress is released.

Eventually you will get to the yield point. The stress here is so high that the steel cannot return to its original state. Instead a process of plastic deformation occurs. Release the stress, and the steel ends up longer than it was originally.

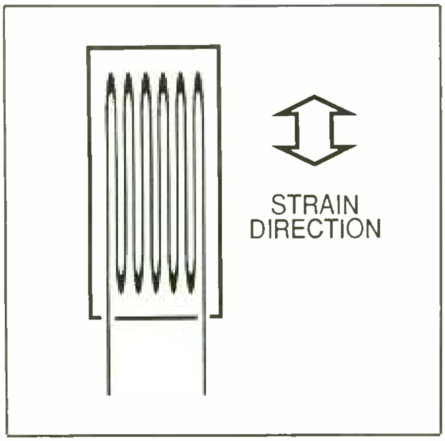

Fig. 2. A resistive strain gauge.

Many metal forming processes, particularly deep drawing and bending, work by forcing the material into its elastic deformation state.

The reason that the curve tends downward past the ultimate strength point is that the cross-sectional area is getting progressively reduced, through a process called "necking down."

Other materials have different stress-strain curves. Ceramics are almost entire-

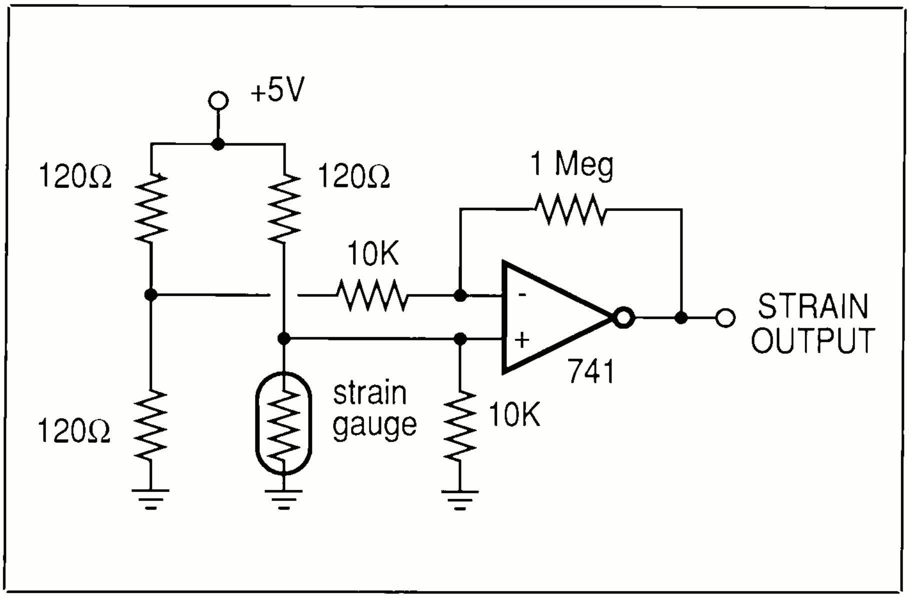

Fig. 3. A typical strain gauge bridge and amplifier.

ly linear, with no plastic deformation at all. Such materials are said to be brittle. A brittle material is elastic up to its ultimate strength, and then fails without much in the way of deformation.

More details on all of this appear in most any college-level text on strength of materials.

What we are interested in here is how to measure strain. While there are many types of strain gauges, the typical resistive type is shown in Fig. 2. What you have here is a foil pattern on an insulating carrier. As you slightly stretch the pattern, the resistance of the foil changes.

In use, the strain gauge is carefully cemented to the material to be stressed. The strain gauge, the material, and the adhesive to be used must be carefully matched to each other, particularly if temperature effects are to be compensated.

As you stress the material, the strain gauge will slightly change its resistance. Nominal resistance values range from 120 ohms upwards. Such low values are used to minimize noise pickup.

The "gauge factor" of a strain gauge is a ratio of how much the resistance changes when length changes. A gauge factor of 2 is typical. Thus, the resistance change will be double the length change.

Figure 3 shows a typical strain gauge circuit. Because of the small changes in resistance involved, you normally use a bridge circuit followed by an operational amplifier. While you can use a 741 op amp for experiments, premium devices with lower offsets and lower temperature coefficients are often better.

You would normally bond the strain gauge to some material that will change its length under stress, using a recommended adhesive. You then use the output of the op amp to measure the resultant strain. The circuit shown has a gain of 200, since the gauge factor is 2 and op amp gain has been set externally to 100. This means that output voltage will change 200 times more than input strain movement.

A zero control can be added by placing a small potentiometer in the middle of the left bridge arm. The actual materials used and the op amp's gain will depend on your particular application.

The *Omega* HBM 6/120 LY 13 is a good choice of strain gauge for hacking. Details on this device and many others appear in the company's free *Pressure, Strain, and Force Measuring Handbook*, along with much more technical details and applications information.

How are strain gauges related to the pressure transducers we looked at in earlier columns? Well, pressure transducers are really nothing but strain gauges that have been factory built on a silicon diaphram. By measuring the strain on the diaphram, you can, in turn, measure gauge, absolute, or differential pressures. You normally would use a pressure transducer to measure pressure in a liquid or a gas, while you would typically use a strain gauge to measure deformation in a solid.

Where can I get robotics parts?

Try *Small Parts*. These people stock all sorts of metals, plastics, hardware, fasteners, and whatever—all reasonably priced. Very small quantities are a specialty here.

They will also custom cut small pieces of steel, stainless, plastic, brass, copper, or aluminum to size. Most importantly, they have the parts the average hardware store never heard of—timing belts, hitch pins, plastic balls, spring assortments, wire clips, perforated metal, and bunches more. Check them out.

How can I find more out about transducers and sensors?

First, check into the excellent free handbook series available from *Omega Engineering* that covers many types of temperature, flow, humidity, pressure, strain, force, and pH measurement.

Second, look into the many specialized magazines that cover this field. Important examples are *Measurements and Data, Control Engineering, Instruments and Apparatus News*, and *Pollution Control News*.

Third, contact the individual companies that specialize in interface electronics, such as *Motorola* and *Microswitch* for pressure transducers, and various application notes from *Analog Devices* and *Burr Brown* on transducer interfacing.

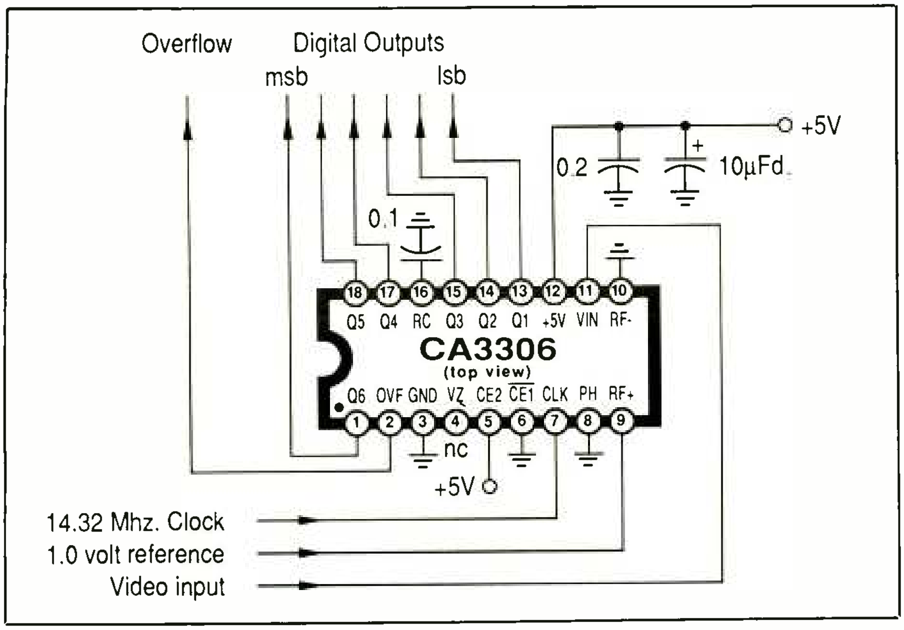

Fig. 4. A 6-bit, 64-level RCA video A/D converter.

There are lots of opportunities out there for new and creative use of sensors, particularly strain gauges, pressure transducers, humidity sensors, and such. Let us know what hacker projects or applications you come up with.

Show me a video A/D converter.

Analog-to-digital (A/D) conversion at video speeds has traditionally been a real hassle. Yet, there is lots of hacker potential here, particularly for such things as capturing images for personal computers, in desktop publishing, and for doing digital TV signal processing.

Video-rate A/D conversion has to be done much faster than can be handled by most traditional circuits. Instead a brute force method has to be used, in which the input analog video is simultaneously routed to 64 or 256 individual comparators. The result of each comparison is then converted into a 6-bit (64 level) or 8-bit (256 level) digital code.

One very popular sampling frequency for video conversion is 14.32 MHz, which is four times the standard NTSC color subcarrier frequency of 3.58 MHz.

Capturing and storing digital data at this rate is not trivial, since you get a new word every 70 nanoseconds or so, and since there will be almost a quarter of a million bytes per frame. If you are planning on processing this image with a personal computer, some sort of a high-speed buffer will be needed between the computer and your A/D converter.

If you are interested only in digitizing to 256 by 256, then a smaller buffer of 64K can be used, combined with a lower clock frequency. There are some exciting new fast memory chips available called dual-port RAMs that are particularly attractive for this sort of thing. Fortunately, single integrated circuits are now available that will do most of the brute force conversion for you. Let's look at two examples.

Figure 4 is a 6-bit, 64-level converter that uses the *RCA* CA3306. As you can see, there is a video input and a reference input. The reference input is usually a precise and fairly high-current source of 1.0 volt. This reference sets the full-scale value of the input video.

You also have to input on pin 7 a reference clock equal to the sampling rate you want. It is extremely important that the highest video frequency you are sampling is less than one-half this value. Thus, some sort of input low-pass filtering or other bandwidth limiting must be done before doing the actual A/D conversion.

Sometimes, you may want to vary the clock rate. In many applications, there is no point in sampling the sync and blanking times.

Finally, you have six data outputs, one for each bit of the 6-bit digitized video, and a seventh overflow line. While we have shown the chip-select on pin 6 grounded here, for most uses, you will want to use this to tri-state control the digital outputs.

A newer *Motorola* 8-bit video A/D converter circuit is shown in Fig. 5. Unfortunately, this chip is larger and needs a negative 5-volt supply besides the usual positive 5-volt supply. It is also faster, which means that it may be noisier for most hacker uses. Cost of these chips is

NAMES AND NUMBERS

Analog Devices
2 Technology Way
Norwood, MA 02062
(617) 329-4700

Burr-Brown
Box 11400
Tucson, AZ 85734
(602) 746-1111

Motorola Semiconductor
Box 20912
Phoenix, AZ 85036
(602) 244-6900

Omega Engineering
Box 4047
Stamford, CT 06907
(203) 359-1660

RCA Solid State
Route 202
Somerville, NJ 08876
(201) 685-6000

Small Parts
6901 NE Third Avenue
Miami, FL 33238
(305) 751-0856

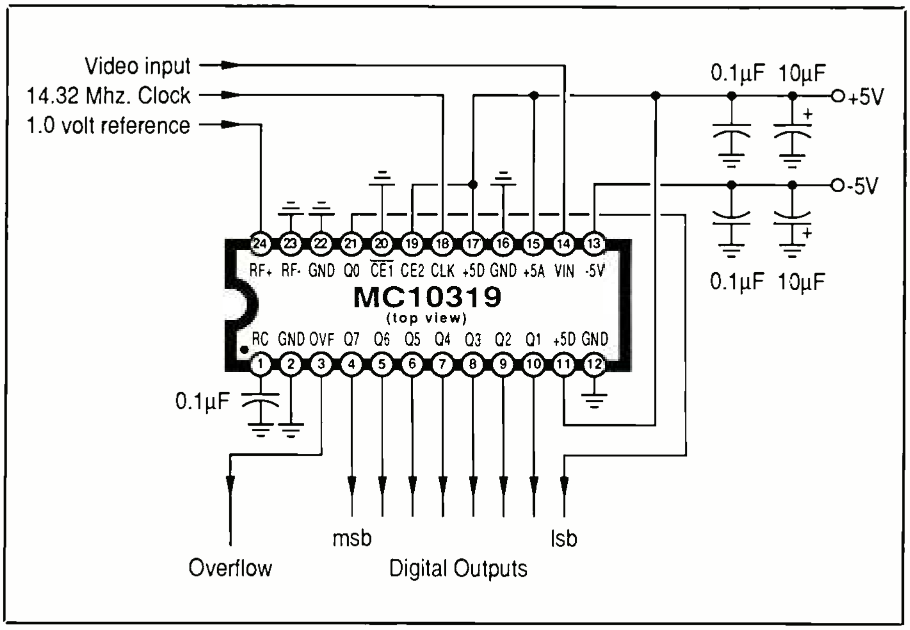

Fig. 5. An 8-bit, 256-level Motorola video A/D converter.

currently in the $20 to $35 range, but lower-priced plastic versions should shortly be available.

Before you throw these two circuits together, note that these are strictly advanced hacker components. A decent oscilloscope is almost essential, as is a very carefully done printed-circuit board layout. It is extremely important to use low-noise power supplies, possibly even to the point of using a separate regulator for the converter itself.

The supply lines must be thoroughly bypassed directly at the converter pins using very-high-quality capacitors. Tantalum capacitors are almost essential, since many electrolytics have uselessly high impedances at video frequencies.

The input video must come from a low-impedance source, preferably from an on-bolard input buffer. The RCA CA3450 is a good choice for this.

There are really two reference voltages needed, one for the top and one for the bottom of a resistor chain that forms the reference for each of the 64 or 256 comparators. While I've shown the bottom end grounded, you can move this up or down a volt or so as needed. One use would be for automatically stripping sync.

It is very important that your reference voltages be low-noise and low-impedance. In a real circuit, you will probably want to drive these from the output of an op-amp setup as a unity gain voltage buffer, driven from a suitable stable source.

Careful control of grounds is also important. The input analog ground return must be direct and must not share any common-mode digital ground noise.

If you digitize a 1-volt video waveform to 255 levels, that is something like 4 millivolts per level. It is trivially easy to get digital ground noise that is hundreds of times higher. **ME**

NEED HELP?

Phone or write your **Hardware Hacker** questions directly to:

Don Lancaster
Synergetics
Box 809
Thatcher, AZ 85552
(602) 428-4073