Interface nonstandard sensors using standard circuit methods

Try these designs to interface such sensors as photomultiplier tubes and ultrasonic devices to your measurement system.

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Although a transducer might be exotic, its interfacing and signal-conditioning circuitry can be simple, as this first article in a 2-part series shows. The designs presented here, all of which have been built and tested, illustrate several useful interfacing techniques for sophisticated transducers, expanding on the somewhat sketchy data sheets often characterizing the devices.

Use electrons to find photons

The first design uses perhaps the most versatile light detector available—the photomultiplier tube (PMT). In addition to single-photon-detection capability, these sensors provide subnanosecond rise times, bandwidths approaching 1 GHz and response linearity better than 10^7. PMTs furnish low noise, stable performance and long life because they don't employ a filament-heated cathode as the electron source; instead, they employ a photosensitive cathode, a focusing electrode, 10 amplifying dynode stages and an electron-collecting anode.

In operation, a PMT's photocathode emits electrons when struck by a photon. The more positively biased focus electrode (Fig 1) collects and beams these electrons toward the first dynode, where the particles generate additional electrons via impingement-induced

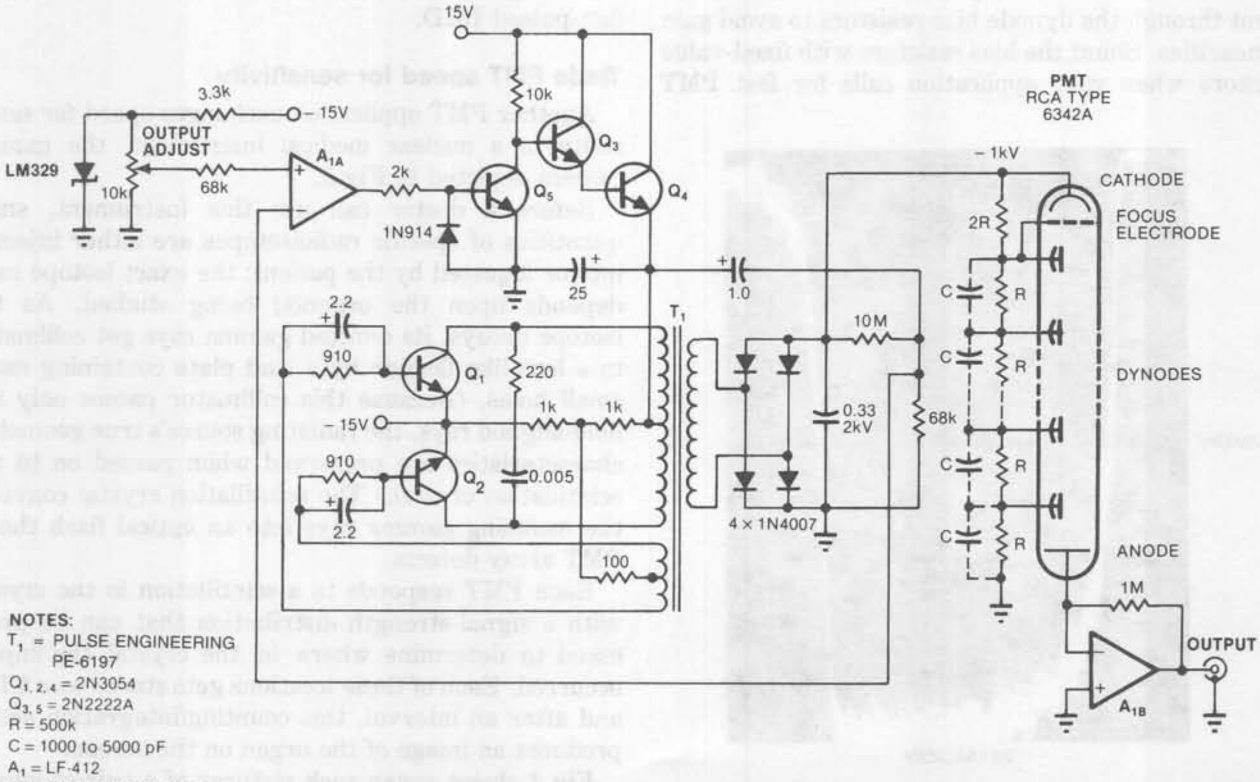


Fig 1—Photomultiplier-tube power-supply designs *must be stable and accurate but not complex. In this scheme, a closed-loop feedback-amplifier network—consisting of A_{1A} and Q_3 through Q_5—compares a portion of the dc/dc converter's output voltage with an adjustable reference level. The error-correcting result appears at Q_4's emitter as a varying converter-supply voltage.*

Phototube-based designs look into you with gamma-ray sources

secondary emission. Then, because the second dynode is even more positively biased, the now-larger electron cloud bombards this dynode's surface and again multiplies in density. In this fashion, several cascaded dynodes (10 in this example) can achieve an overall current gain spanning 10^6 to 10^8. The final dynode's electrons are collected by the anode, which functions as a nearly ideal current source.

To satisfy the PMT's requirements, you must provide both a stable high-voltage bias supply and a low-noise current-to-voltage conversion stage at the anode's output. The design shown in **Fig 1** employs a closed-loop stabilized dc/dc converter to generate the required 1-kV PMT bias supply. An op amp (A_{1A}) compares the LM329-derived reference voltage with a sample of the high-voltage stage's output and sets Q_3 through Q_5's output accordingly. This regulated voltage in turn supplies the converter's drivers (Q_1 and Q_2) and, via T_1's step-up action, the circuit's high-voltage output.

In general, a PMT supply's regulation should be at least 10 times greater than the measurement's required gain stability. (This requirement arises from the PMT's gain-slope vs applied-high-voltage relationship.) Additionally, the supply must be able to source a current at least 10 times that needed by the PMT. This specification stems from the necessity to bleed that much extra current through the dynode bias resistors to avoid gain nonlinearities. Shunt the bias resistors with fixed-value capacitors when your application calls for fast PMT response—they supply the peak transient currents required by a fast-acting PMT.

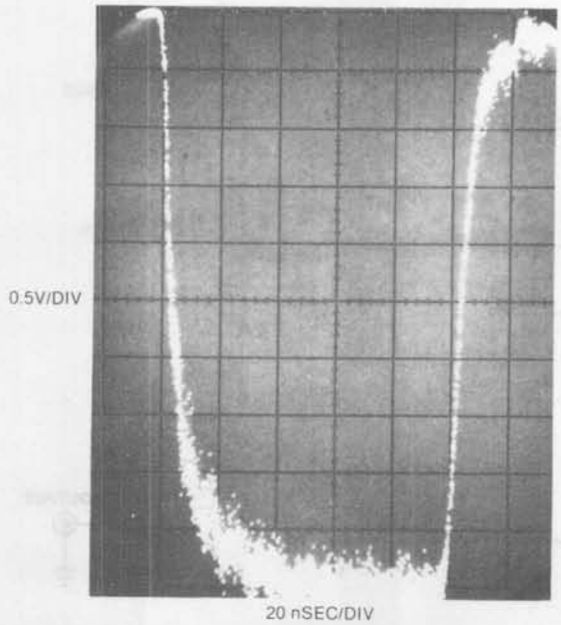


Fig 2—A photomultiplier tube's speed *captures a pulsed LED's optical-output rise and fall times. To realize the PMT's maximum speed capabilities, you might have to incorporate the dynode-shunting capacitors shown in* ***Fig 1.***

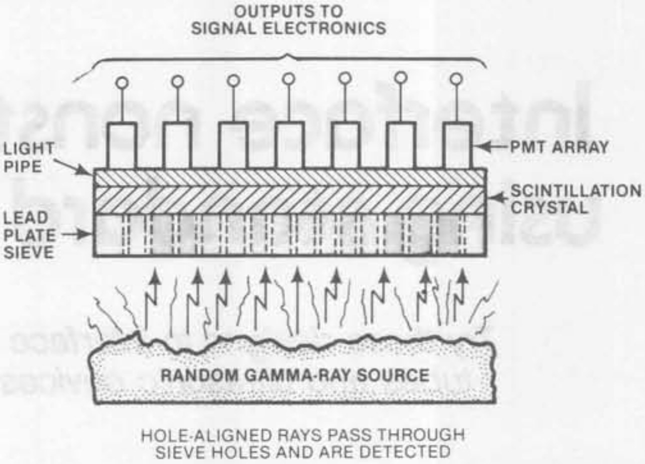


Fig 3—A gamma-ray camera *results when the collimating action of a lead-plate sieve allows only image-related rays to impinge upon a scintillation crystal. A photomultiplier-tube array detects and converts the output into usable signals.*

Although **Fig 1** shows how you can employ op amp A_{1B} as the PMT's current-to-voltage converter, **Fig 2**'s remarkable photo was taken with a high-speed PMT directly feeding the 50Ω input of a 1-GHz-bandwidth sampling scope. This photo demonstrates the PMT's combination of high speed and high sensitivity by capturing the actual (inverted) rise and fall times of a fast-pulsed LED.

Trade PMT speed for sensitivity

Another PMT application exchanges speed for sensitivity in a nuclear medical instrument, the gamma camera depicted in **Fig 3.**

Before a doctor can use this instrument, small quantities of specific radioisotopes are either injected into or ingested by the patient; the exact isotope used depends upon the organ(s) being studied. As the isotope decays, its emitted gamma rays get collimated in a lens-like fashion by a lead plate containing many small holes. (Because this collimator passes only the hole-aligned rays, the radiating source's true geometric characteristics are preserved when passed on to the scintillation crystal.) The scintillation crystal converts the incoming gamma rays into an optical flash that a PMT array detects.

Each PMT responds to a scintillation in the crystal with a signal-strength distribution that can be processed to determine where in the crystal the impact occurred. Each of these locations gets stored on a CRT, and after an interval, this counting/integration action produces an image of the organ on the screen.

Fig 4 shows seven such pictures of a pair of human lungs. In image **A,** the administered isotope is beginning to collect in the lungs, and **B** shows saturation. Images **C** through **G**—taken at 30-sec intervals—depict the isotope's progressive decay. (Healthy lungs are usually clear after 120 sec. This patient, however, shows evidence of an obstructive pulmonary disease; congestion is especially pronounced in the lower part of the right lung.)

The next design uses another type of light detector—a pyroelectric unit. These ceramic-based devices provide extraordinary sensitivity that spans microwatts to watts—with excellent linearity (flat from ultraviolet through the far IR bands). They also achieve subnanosecond response times and don't need cooling—they operate at room temperature.

Why, if they're so good, aren't these devices used more often? Probably because they don't respond to dc inputs and provide signals that are difficult to condition.

For signal-conditioning purposes, you can model a pyroelectric sensor either as a voltage source in series with a capacitor **(Figs 5a, b)** or as a capacitively shunted current source **(Fig 5c)**. And because the unit has no resistive component, no Johnson noise arises.

If you're detecting fast, high-energy light pulses, consider **Fig 5a**'s simple solution. Here, the pyroelectric detector directly feeds a high-speed scope. **Fig 5b** shows how to interface to the device a slower detector for lower speed applications; the 1-MΩ resistor correctly terminates the sensor, and the low-input-bias FET op amp provides the required isolation. When the required response time exceeds several milliseconds, you can employ a light chopper between the signal source and the sensor. When chopped, the output signal appears as an amplitude-modulated carrier

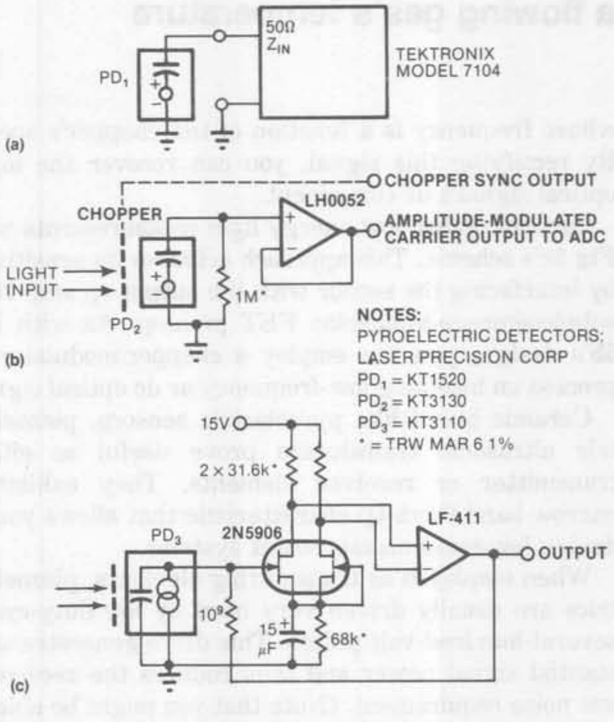
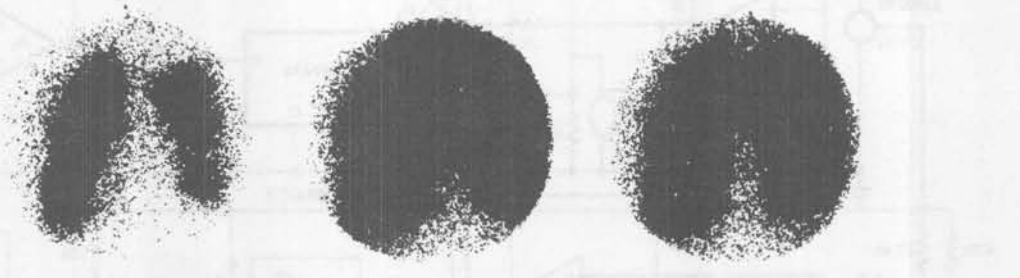


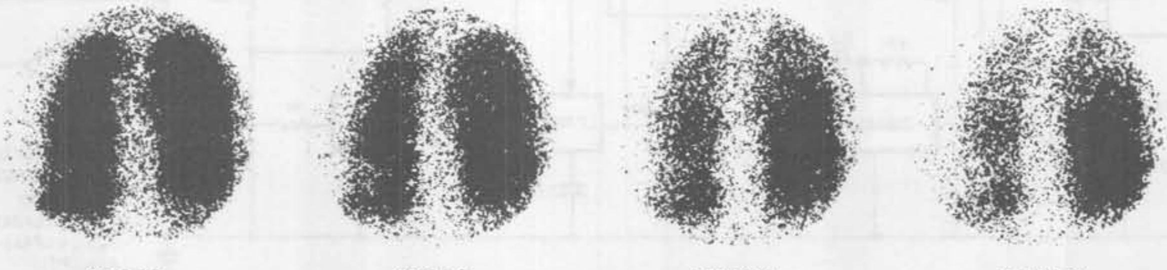
Fig 5—Pyroelectric detectors *can be modeled as series voltage-source/capacitor combinations,* ***((a)*** *and* ***(b))*** *or as a capacitively shunted current source* ***(c)****. But because neither version responds to dc inputs, you need special signal-conditioning circuits. Fast-pulse detection is accomplished in* ***(a)*** *by directly driving a scope's 50Ω input port. Slowly changing optical signals are best handled by the chopper techniques shown in* ***(b)*** *and* ***(c)****.*



INHALATION
A

SATURATION
B

ISOTOPE DECAY
30 SEC C



60 SEC
D

90 SEC
E

120 SEC
F

150 SEC
G

Fig 4—Congestion in human lungs *is revealed by this series of gamma-camera images. Image* ***A*** *depicts how a selective radioisotope starts concentrating in the lungs, with saturation occurring in* ***B****. Images* ***C*** *through* ***G****—taken at 30-sec intervals—disclose how the radioisotope decays with time. Healthy lungs clear within 120 sec (image* ***F****). This patient, however, shows obstructive pulmonary problems in the lower part of his right lung (****G****) even after 150 sec.*

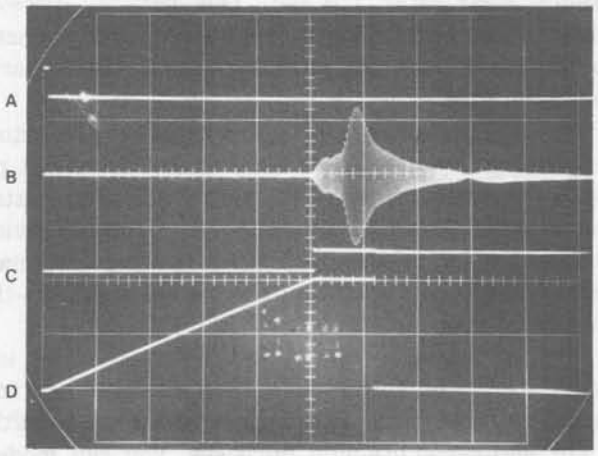
Use ultrasonic signals to find a flowing gas's temperature

whose frequency is a function of the chopper's speed. By rectifying this signal, you can recover the input optical signal's dc component.

You can realize low-energy light measurements with **Fig 5c**'s scheme. This approach achieves its sensitivity by interfacing the sensor with the output op amp via a subpicoampere-input-bias FET preamp. As with **Fig 5b**'s design, you can employ a chopper/modulator to process an incoming low-frequency or dc optical signal.

Ceramic based like pyroelectric sensors, piezoelectric ultrasonic transducers prove useful as either transmitter or receiver elements. They exhibit a narrow-band (high-Q) characteristic that allows you to design low-noise measurement systems.

When employed as transmitting elements, piezoelectrics are usually driven very hard by low-duty-cycle, several-hundred-volt pulses. This drive generates substantial signal power and thus reduces the receiver's low noise requirement. (Note that you might be able to employ the same transducer as both a transmitter and receiver in some applications.)



TRACE	VERTICAL	HORIZONTAL
A	30V/DIV	500 nSEC/DIV
B	10V/DIV	
C	10V/DIV	
D	2V/DIV	

Fig 7—Gas-temperature measurements *commence when* ***Fig*** *6's A_1 pulses the ultrasonic transmitter (trace* ***A****). This action also sets a flip flop's Q output LOW (trace* ***C****) and starts the capacitance charging cycle (trace* ***D****). When the sonic pulse is detected (trace* ***B****), the flip flop resets HIGH and terminates the charge cycle. The capacitor's voltage is then a convertible function of the gas's temperature.*

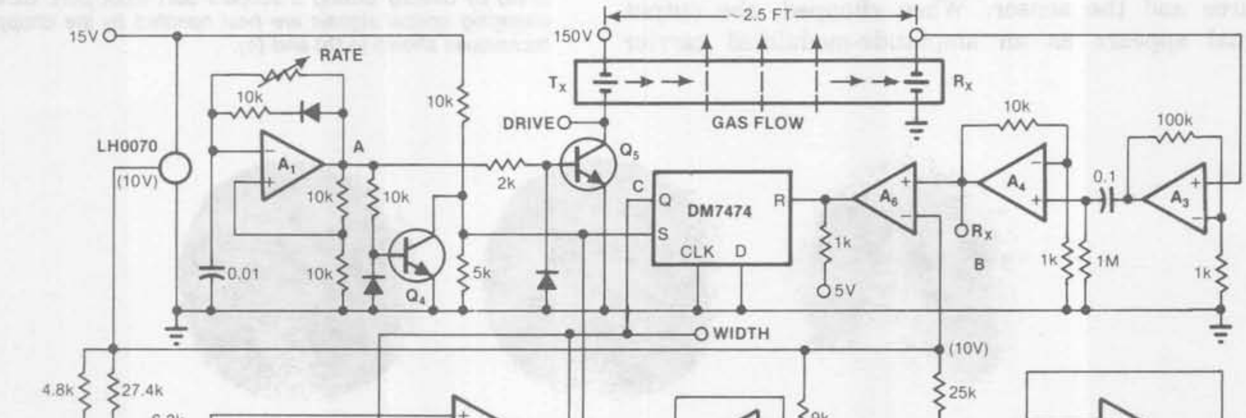


Fig 6—A gas's temperature *is determined by its sonic-propagation characteristics in this design. A_1 pulses an ultrasonic-wave transmitting transducer (T_X) and simultaneously enables the Q_1-based capacitance-charging constant-current source via a flip flop's Q output. At a later, gas-temperature-dependent time, receiver transducer R_X detects the pulse and stops the charging cycle. Because the capacitor's voltage is a function of the sonic travel time (and thus the gas's temperature), it can be sampled, linearized and used to drive a direct-reading temperature indicator. (Points marked with boldface letters correspond to* ***Fig 7****'s traces.)*

In contrast to an ultrasonic transducer's usual camera-focusing, intrusion-alarm or liquid-level-sensing applications, **Fig 6**'s circuit permits its use for difficult thermal measurements. The technique employed resembles one that measures high-speed temperature shifts in a gaseous medium. Unlike most other temperature-measuring schemes, though, it doesn't require that the sensor come into thermal equilibrium with the measured material. Instead, it finds the medium's temperature by determining the medium's ultrasonic-propagation characteristics. Thus, the circuit's response times are very short, and the measurement is noninvasive. As an example of this principle, you can find the absolute temperature (T) of dry air by using the equation

$$T=C^2\times 273/(331.5)^2$$

where C=a sound wave's speed in the medium, measured in metres per second.

Obviously, then, if you can identify the gaseous medium and know its temperature-dependent characteristics, you can determine its temperature using only the ultrasonic signal's propagation time. And by using high-Q transducers, you can achieve a noise-filtering feature that ignores medium-generated noise.

The traces in **Fig 7** (corresponding to the points marked in **Fig 6**'s circuit) illustrate how the scheme operates. Amp A_1 periodically generates a pulse (trace A) that drives a 40-kHz transmitter transducer (T_X) on via Q_5. This same trigger pulse turns on Q_4 and sets a flip flop LOW (trace C). After a time interval

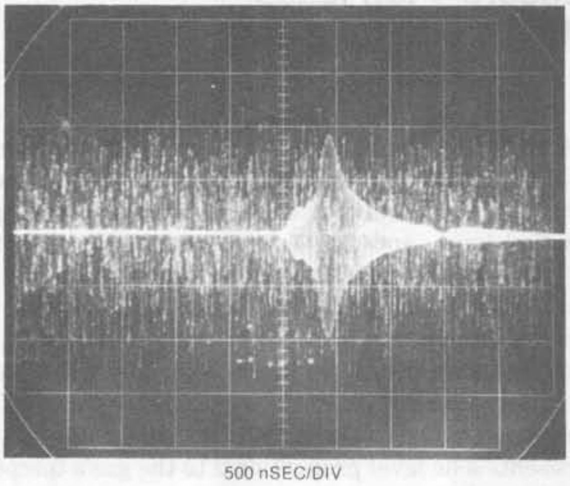
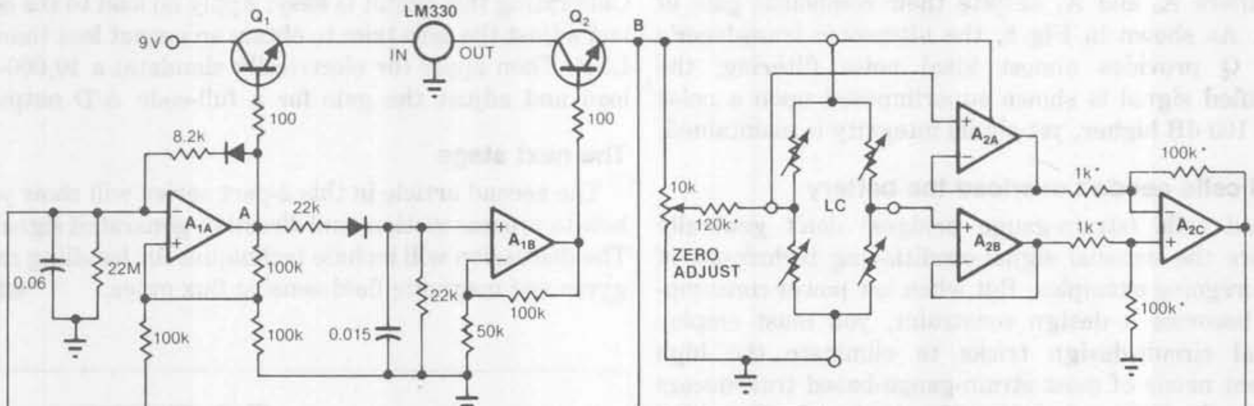


Fig 8—The noise-filtering property *of a high-Q ultrasonic transducer permits amplifying the desired signal (the same as* ***Fig 7****'s trace* ***B****) even though it's buried in an excess noise level of 100 dB.*



NOTES:
LC = LOAD CELL
BLH ELECTRONICS
MODEL U3G1-10,000
A_1, A_2 = LM324
TRANSISTORS = 2N2222A
DIODES = 1N4148
* = 1% METAL FILM

Fig 9—Pulse-powering a load cell (LC) *and its signal-conditioning electronics reduces current requirements from more than 35 mA to 1.8 mA. A_{1A} and A_{1B} gate voltage followers Q_1 and Q_2 to provide the load cell, its amplifiers (A_{2A} through A_{2D}) and an A/D converter with a 5V supply level. A delayed trigger—created by $A_{1C,D}$ and Q_3—operates the converter after the cell's amplified output stabilizes.*

determined by the distance between the transducers and the gas's temperature, the sonic signal pulse arrives at the receiving element, R_X, where it gets amplified by A_3 and A_4. (A_4's output appears as trace **B**.) This amplified signal triggers A_6 and resets the flip flop HIGH. During the flip flop's LOW period, the current source formed by Q_1 charges the 0.01-µF capacitor (trace **D**). Then, when a received pulse resets the flip flop HIGH, Q_2 comes on and in turn shuts off the current source. Voltage follower A_2's output then represents a dc level proportional to the gas's temperature-dependent transit time.

After being triggered by the flip flop's Q transition, a one-shot times out and causes the LF398 S/H stage to sample A_2's output. The S/H's output feeds a pair of multifunction LH0094 nonlinear converters arranged to linearize the sound-speed-vs-temperature relationship. This level, further processed by bridge amplifiers A_7 and A_8, then drives a directly indicating temperature-calibrated voltmeter. When A_1 issues its next pulse, a one-shot times out, Q_3 discharges the capacitor and the cycle repeats.

Note that you need no bandwidth limiting in receiver amplifiers A_3 and A_4 despite their compound gain of 1000. As shown in **Fig 8**, the ultrasonic transducer's high Q provides almost ideal noise filtering; the amplified signal is shown superimposed upon a noise level 100 dB higher, yet signal integrity is maintained.

Load cells needn't overload the battery

Load cells (strain-gauge bridges) don't generally require the unusual signal-conditioning techniques of the foregoing examples. But when low power consumption becomes a design constraint, you must employ special circuit-design tricks to eliminate the high current needs of most strain-gauge-based transducers —these devices can consume 35 mA when driven with a 10V signal.

To circumvent a load cell's high current requirements, consider a pulsed power source like **Fig 9**'s. This technique provides complete signal conditioning but requires only 1.8 mA average current from a 9V battery. (The design's output signal is an A/D-converter-derived 8-bit word.) **Fig 10**'s trace **A** shows how **Fig 9**'s A_{1A}'s stage oscillates at approximately 1 Hz. Every time this signal is HIGH, Q_1 and the 5V regulator turn on, and 5V appears at Q_2's collector. Concurrently, A_{1B} amplifies a pulse-shaping network's output and drives the emitter follower Q_2 into saturation. (This slow-rising waveform (trace **B**) drives the load cell at a limited dV/dt and thus eliminates abrupt step-drive-induced bridge changes over time.)

A differential-input, single-ended output-amplifier network processes the bridge's signal, which it feeds to the A/D converter (trace **C**). An $A_{1C,D}$-generated delay pulse (trace **D**) triggers the conversion when A_{2D}'s output is stable. In this fashion, the circuit realizes considerable power savings—the bridge, its conditioning stages and the A/D converter are all pulsed. Calibrating this circuit is easy: Apply no load to the cell and adjust the zero trim to obtain an output less than 1 LSB. Then apply (or electrically simulate) a 10,000-lb load and adjust the gain for a full-code A/D output.

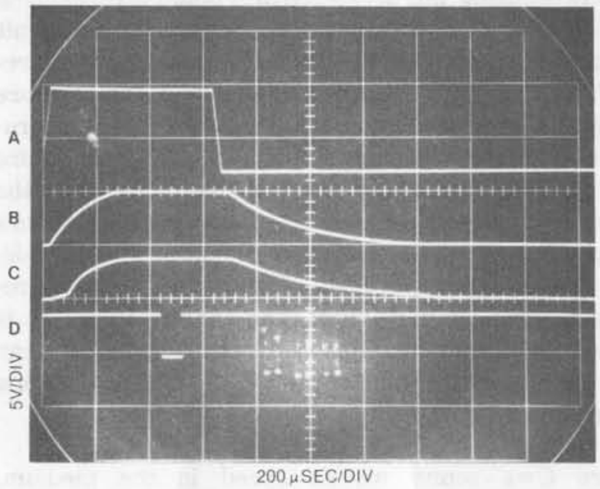


Fig 10—A 650-µsec signal (A) *initiates Fig 9's pulse-powered load-cell-based measurement scheme. This signal, after being shaped by A_{1B} and Q_2 (trace* ***B****), drives the load cell (LC) and its conditioning stages and supplies the A/D converter with power. After the cell output-amplifier's signal stabilizes (trace* ***C****), the $A_{1C,D}$-generated delay pulse (trace* ***D****) triggers the data converter.*

The next stage

The second article in this 2-part series will show you how to process motion- and direction-generated signals. The discussion will include techniques for handling rate gyros and magnetic-field-sensing flux gates. **EDN**

Author's biography

Jim Williams, applications manager with National Semiconductor's Linear Applications Group (Santa Clara, CA), specializes in analog-circuit and instrumentation development. Before joining the firm, he served as a consultant at Arthur D Little Inc and directed the Instrumentation Development Lab at the Massachusetts Institute of Technology. A former student of psychology at Wayne State University, Jim enjoys tennis, art and collecting antique scientific instruments in his spare time.