Piezoceramics plus fiber optics boost isolation voltages

Overcoming traditional magnetic-transformer drawbacks, a novel isolation-amplifier design hikes voltage-breakdown limits more than tenfold by incorporating a piezoceramic-based acoustic transformer and a fiber-optic link.

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When standard parametric or isolation amplifiers don't adequately isolate or protect your analog measurement systems, the circuit design described in this article can help. Although typical isolation amplifiers achieve about a 2.5-kV max isolation voltage, this one can handle 20- to 100-kV breakdown limits. It incorporates a piezoceramic material structured as an acoustic transformer and a fiber-optic lightpipe.

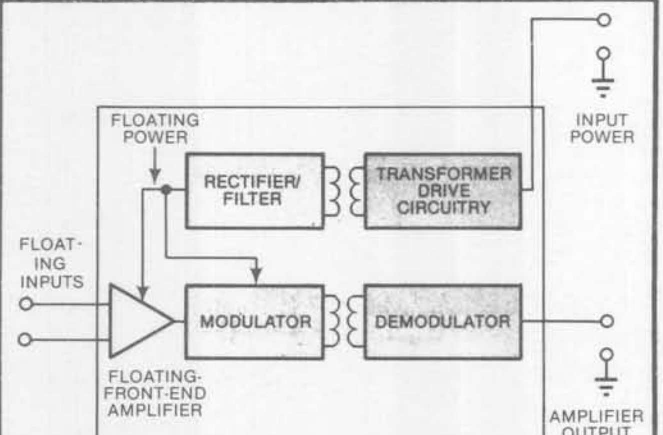


Fig 1—A traditional isolation amplifier *uses dual transformers to separate the input-signal line from the power and output-signal lines. This approach typically results in about a 2.5-kV max input-isolation voltage.*

Isolation amplifiers find use mainly in assuring safe and reliable analog measurements. They surmount the problems of high common-mode voltages in applications such as medical test instruments and completely isolate or interrupt ground loops or paths in equipment such as that used in industrial process-control systems.

Designing isolation amplifiers mandates careful attention to two key factors: isolating the power supply from the input-signal line and galvanically separating the input- and output-signal lines. The first half of the task generally involves the most effort.

Input isolation proves complex

Conventional isolation amplifiers employ a magnetic transformer to convey power to the circuit's floating front end **(Fig 1)**. Although this transformer galvanically separates the power supply from the input terminals, it increases in size and cost when common-mode voltages exceed about 2.5 kV. Moreover, its leakage currents can total as much as 2 μA.

To separate the input- and output-signal lines, conventional isolation amplifiers modulate the floating front end's output onto a carrier signal. This signal traditionally passes via another magnetic transformer to the circuit's output terminals. Modulation schemes include pulse width, pulse amplitude and voltage to frequency. Here again, though, magnetic transformers become bulky and inefficient as common-mode voltages and leakage currents rise. And isolation limits depend

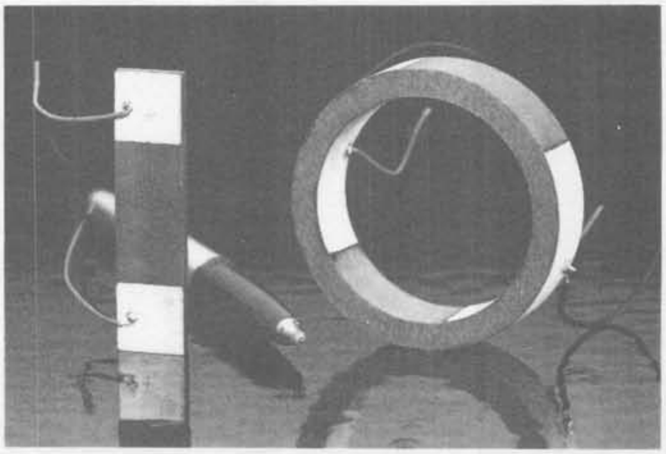


Fig 2—Able to perform as acoustic transformers, *piezoceramic materials come in various sizes and shapes, such as this thin bar and thick toroid (shown with a ballpoint pen for dimensional reference). Observe that two pairs of leads make input and output connections to each piece of piezoceramic material.*

Traditional isolation amplifiers employ magnetic transformers

on the transformer's breakdown rating.

Even when an optoisolator replaces the modulation transformer with a frequency- or light-intensity-coding approach, power requirements for operating the floating front end still require the power transformer. What's more, optoisolators arc under excessive common-mode voltages.

Other methods for transmitting electrical energy with high isolation exist, such as using microwave devices and solar cells, but they prove expensive, inefficient and impractical. Batteries are an alternative power source, but they have maintenance and reliabiliy limitations.

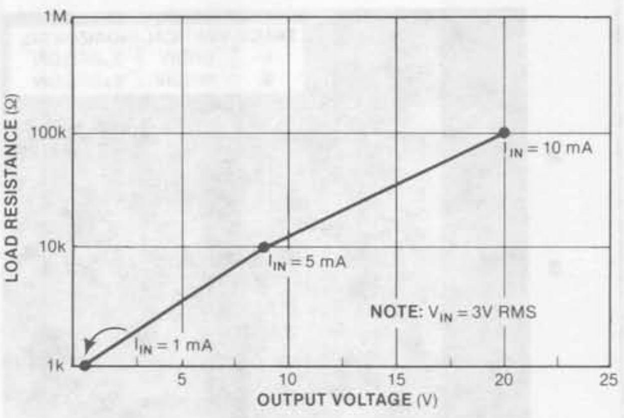
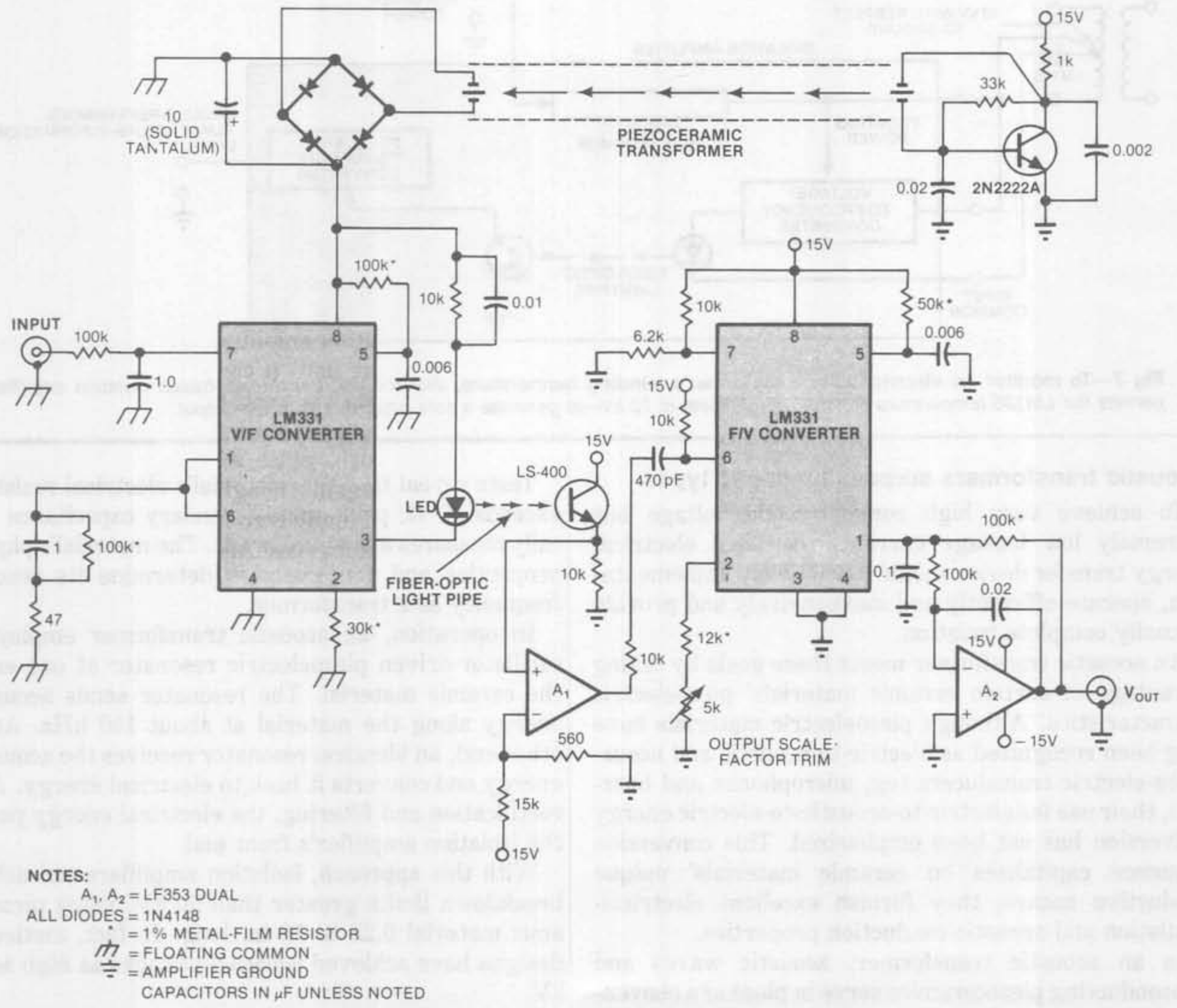


Fig 3—This typical load line *traces an acoustic transformer's performance at resonance. Note that for a constant 3V rms drive voltage and a varying 1- to 100-kΩ load resistance, the acoustic transformer draws up to 10 mA as its output voltage increases to 20V.*



NOTES:
A_1, A_2 = LF353 DUAL
ALL DIODES = 1N4148
* = 1% METAL-FILM RESISTOR
= FLOATING COMMON
= AMPLIFIER GROUND
CAPACITORS IN µF UNLESS NOTED

Fig 4—An innovative isolation-amplifier design *employs piezoceramic material as an acoustic transformer and a fiber-optic lightpipe to separate the input-signal line from the power and output-signal lines, respectively. In this approach, breakdown-voltage limits escalate to 20 to 100 kV.*

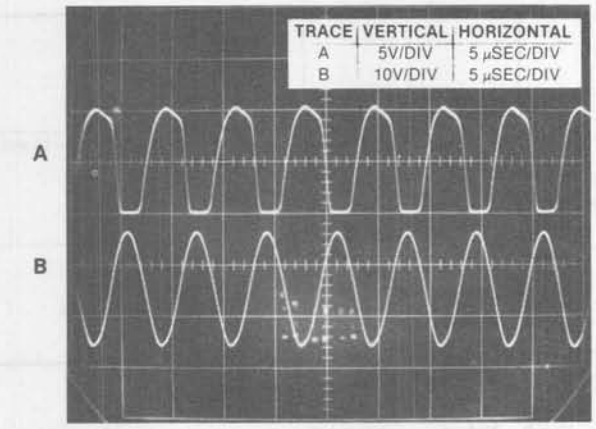


Fig 5—The 2N2222A transistor's output *(from **Fig 4**'s circuit) shows an irregularly shaped sine wave (trace **A**) delivered to the acoustic transformer's input. The transformer's high-Q properties cause it to filter and amplify the waveform into a smooth sinusoid **(B)** at its output.*

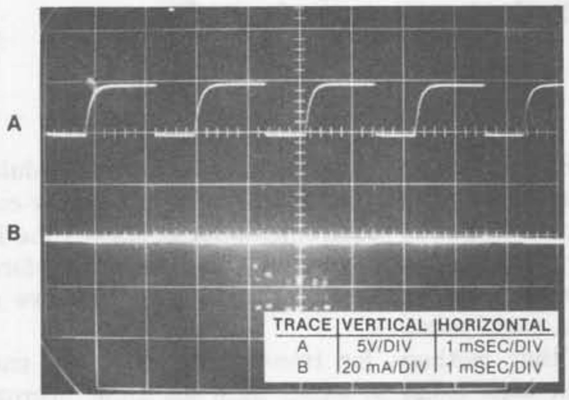


Fig 6—Trace A depicts the LM331 voltage-to-frequency converter's output *(from **Fig 4**'s circuit). This output drives the LED that couples to the fiber-optic lightpipe. Trace **B** indicates the LED's current waveform. Whenever the converter's output is LOW, the LED saves power by passing an extremely narrow (20 mA) light-encoded pulse.*

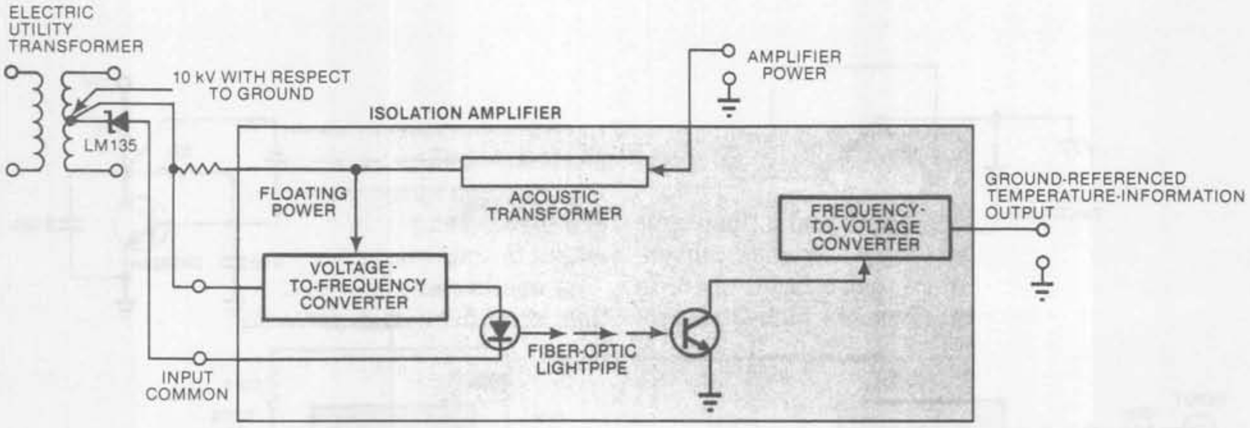


Fig 7—To monitor an electric-utility transformer's winding temperature, *this acoustic-transformer-based isolation amplifier permits the LM135 temperature sensor—which floats at 10 kV—to generate a safe ground-referenced output.*

Acoustic transformers surpass magnetic types

To achieve very high common-mode voltage but extremely low leakage current, the ideal electrical energy transfer device should permit easy implementation, operate efficiently and inexpensively and provide virtually complete isolation.

An acoustic transformer meets these goals by taking advantage of certain ceramic materials' piezoelectric characteristics. Although piezoelectric materials have long been recognized as electric-to-acoustic and acoustic-to-electric transducers (eg, microphones and buzzers), their use for electric-to-acoustic-to-electric energy conversion has not been emphasized. This conversion sequence capitalizes on ceramic materials' unique conductive nature; they furnish excellent electrical-insulation and acoustic-conduction properties.

In an acoustic transformer, acoustic waves and nonconducting piezoceramics serve in place of a conventional transformer's magnetic flux and conductive core. **Fig 2** shows two acoustic-transformer types; you make either type by merely bonding a pair of leads to each end of the piezoceramic material.

Tests reveal that this material's electrical resistance exceeds $10^{12}\Omega$; primary-to-secondary capacitance typically measures a few picofarads. The material's physical properties and configuration determine its resonant frequency as a transformer.

In operation, an acoustic transformer employs an oscillator-driven piezoelectric resonator at one end of the ceramic material. The resonator sends acoustical energy along the material at about 150 kHz. At the other end, an identical resonator receives the acoustical energy and converts it back to electrical energy. After rectification and filtering, the electrical energy powers the isolation amplifier's front end.

With this approach, isolation amplifiers can achieve breakdown limits greater than 20 kV, using piezoceramic material 0.25 to 12 in. long. In fact, meticulous designs have achieved isolation voltages as high as 100 kV.

As an additional advantage, acoustic transformers cost less than their magnetic counterparts. Further, they possess higher operating efficiency because the piezoceramic material is tuned to its natural resonance

An acoustic transformer isolates the power supply from the input

point.

Fig 3 depicts a typical acoustic transformer's output characteristics when driven at resonance. Note that the transformer's power-transfer efficiency can exceed 75%, depending on load conditions. Short-circuit output current for this device equals 35 mA.

Fiber optics upgrades input/output isolation

The other key design factor in designing isolation amplifiers—nearly total input-to-output line separation—is accomplished via fiber optics by stretching both lines further apart than an optoisolator can. This optical-encoding method works as it would in a typical optoisolator, but with an increased distance between transmitter and receiver yielding higher isolation voltages.

In practice, a light-emitting diode (LED) transmits optically encoded signals through a single-fiber cable to a photodiode receiver. The exact cable length depends on the particular circuit requirements.

Put it all together

Combining an acoustic transformer and a fiber-optic link in an isolation amplifier **(Fig 4)** extends conventional breakdown limits by more than a factor of 10. In this circuit, the acoustic transformer's high-Q characteristics allow self resonance in a manner similar to that of a quartz crystal. Resonance eliminates the need for a stable oscillator to drive the acoustic transformer.

To start operation, the 2N2222A transistor excites the piezoceramic transformer's primary **(Fig 5).** At the secondary, four diodes and a capacitor rectify and filter the transformer's electrical output. This output in turn energizes the LM331 V/F converter.

The converter transforms its amplitude-based input signal into a frequency-based output. This signal then drives an LED, whose output travels along a fiber-optic cable.

Each time the V/F converter's output goes LOW, a narrow (20-mA) spike passes through the LED via the 0.01-μF capacitor **(Fig 6).** This short duty cycle keeps the average current value small, minimizing power requirements.

At the receiver end, a photodiode detects the light-encoded signals. It in turn passes the signals to the LM331 for demodulation.

Amplifier accommodates varied uses

An acoustic-transformer/fiber-optic isolation amplifier finds use in diverse applications. In one example, an LM135 transducer tracks the winding temperature of an electric-utility transformer operating at 10 kV **(Fig 7).** The transducer's output biases the isolation amplifier's input. Temperature information at the amplifier's output is thus safely referenced to ground.

In another ground-referenced application, the isolation amplifier's high-common-mode voltage blocking

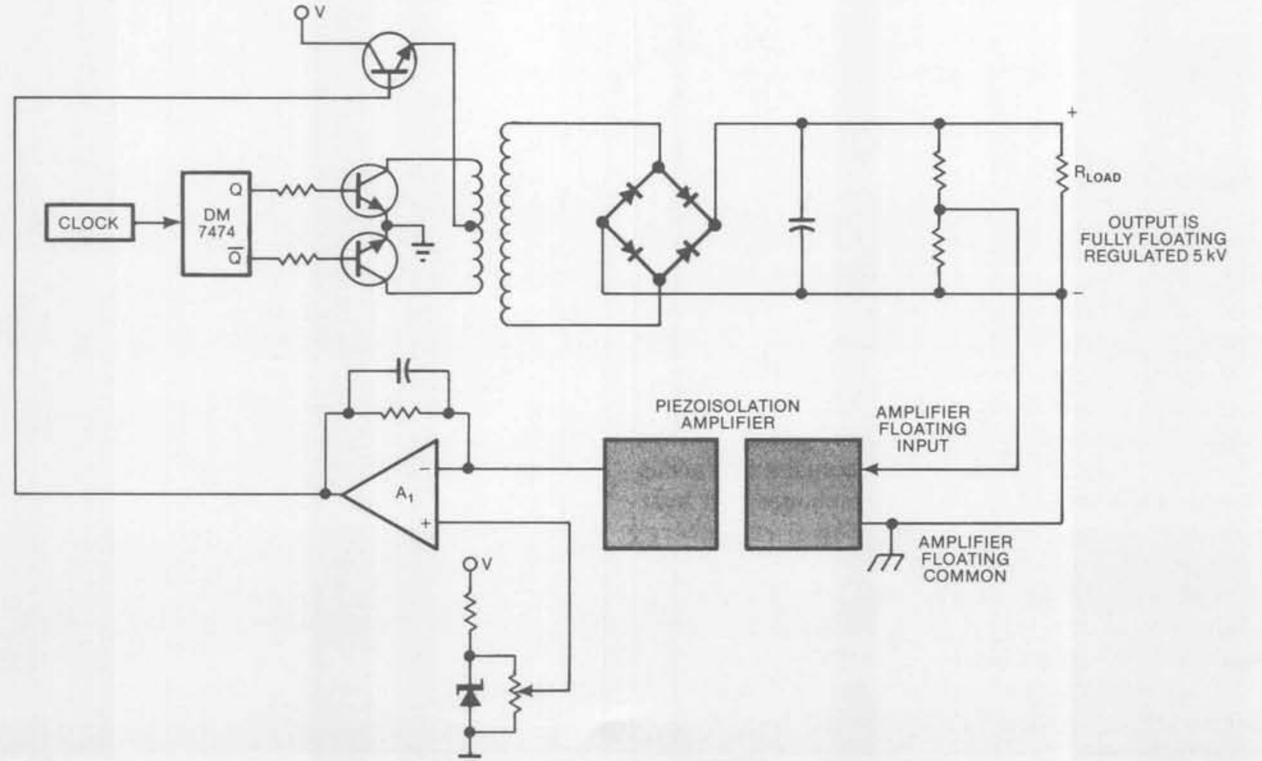


Fig 8—The piezoisolation amplifier *in this application provides a ground-referenced feedback path for the 5-kV regulated power supply. The power supply's output thus fully floats.*

A fiber-optic link galvanically separates output and input lines

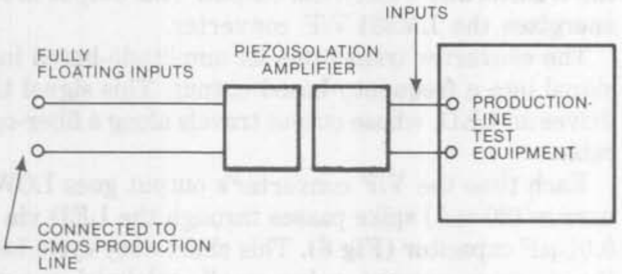


Fig 9—Production-line test equipment *for checking CMOS products is fail-safe isolated via a piezoisolation amplifier. This amplifier keeps static discharge away from the sensitive CMOS parts even when the test equipment develops a substantial charge.*

allows a 5-kV regulated power supply's output to fully float (**Fig 8**). Here, a push/pull dc/dc converter generates the high-voltage output. The isolation amplifier provides a ground-referenced output-feedback signal to op amp A_1, which controls the transformer's drive, completing the feedback loop.

For a fail-safe test application, an acoustic/fiber-optic amplifier isolates instrument inputs connected to CMOS ICs on a production line (**Fig 9**). This arrangement prevents static-discharge damage, even when the instruments have accumulated a substantial charge. **EDN**

References

Transducer Interfacing Handbook, Analog Devices Inc, Norwood, MA, 1980, pg 175.

Piezoceramic Catalog 761-01, Channel Industries Inc, Santa Barbara, CA, 1980.

Author's biography

Jim Williams, applications manager with National Semiconductor's Linear Applications Group (Santa Clara, CA), specializes in analog-circuit design 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.