Transformers and optocouplers implement isolation techniques

Maintaining high precision can be a formidable task when you're taking measurements in industrial environments. Fortunately, there are ways to overcome this problem using readily available components.

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High electrical-noise levels and excessive common-mode voltages complicate making safe, precise measurements in industrial environments. This article shows how to use transformers and optoisolators to isolate motors, transducers, converters or other real-world interfaces from control circuitry.

The conflicting requirements for high accuracy and total input-to-output isolation call for unusual design techniques. Typically, you use transformers and optoisolators to galvanically isolate the input terminals of a signal-conditioning amplifier from its output terminal. This technique breaks the common ground connection and eliminates noise and common-mode voltages.

A simple, isolated signal conditioner

Several examples demonstrate how to include these isolation devices in your circuits. In the first, a wide-band audio transformer permits safe, ground-referenced monitoring of a motor powered directly from a 115V ac line **(Fig 1a)**. The floating amplifier's inputs connect across a brush-type motor. The R_1R_2 network and the transformer's turns ratio divide the motor voltage by 100 and simultaneously allow a ground-referenced amplifier output. The neon bulb

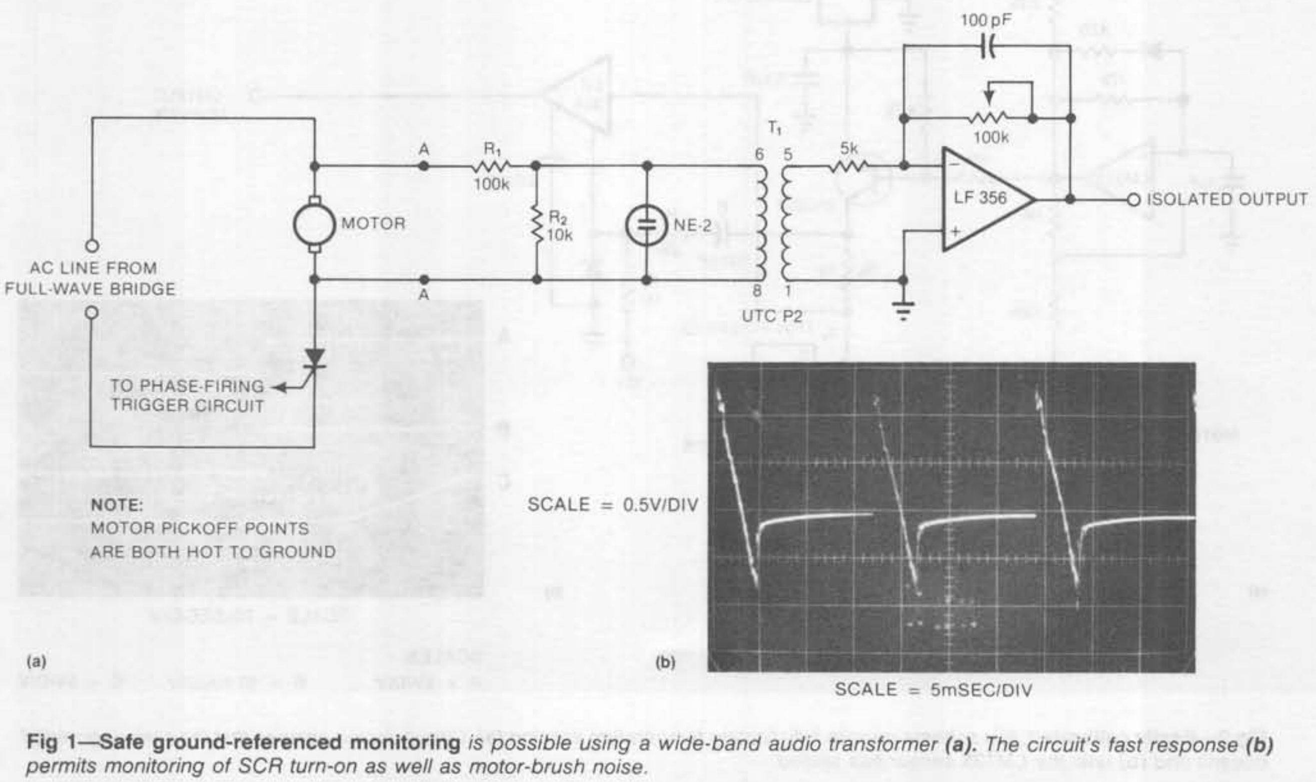
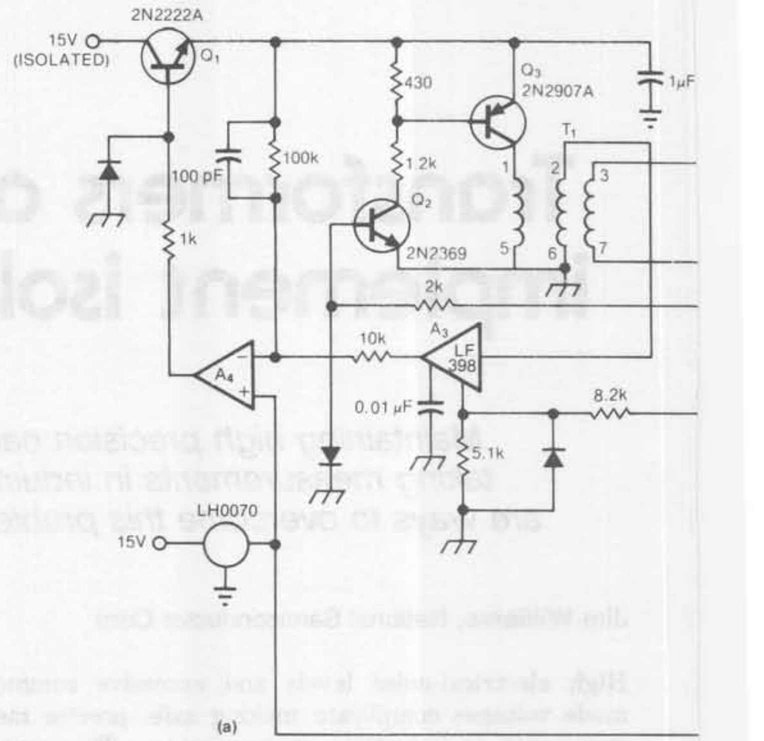


Fig 1—Safe ground-referenced monitoring *is possible using a wide-band audio transformer* **(a)**. *The circuit's fast response* **(b)** *permits monitoring of SCR turn-on as well as motor-brush noise.*

Maintaining isolation is tricky when transducers need excitation



NOTES:
IS ISOLATED GROUND
T_1—TRW PC-SSO-32
T_2—UTC P2
DIODES ARE IN4148

suppresses line transients, while the 10-kΩ pot in the amplifier's feedback loop trims the circuit for a precise 100:1 scale factor.

You must calibrate the network before connecting it to the motor. That procedure is simple—apply a 10V rms sine wave at points A-A and adjust the pot until the amplifier's output equals 100 mV rms. Despite the design's simplicity, though, network performance is impressive: Rise time measures roughly 10 µsec, full-power bandwidth spans 15 Hz to 45 kHz and the −3-dB point lies beyond 85 kHz.

Fig 1b illustrates the motor's waveform at the ground-referenced circuit output. The circuit's isolated wide-band response permits safe monitoring of the SCR's fast rise time as well as the motor's brush noise.

Isolating temperature measurements

A second example also uses an isolation transformer, this time to operate an LM135 temperature sensor in a fully floating fashion (**Fig 2a**). In this circuit, an LM311 generates a 100-µsec pulse (at approximately 20 Hz) that biases a pnp transistor. The voltage that develops across T_1's primary (trace A in **Fig 2b**) is a direct function of the secondary voltage established by the

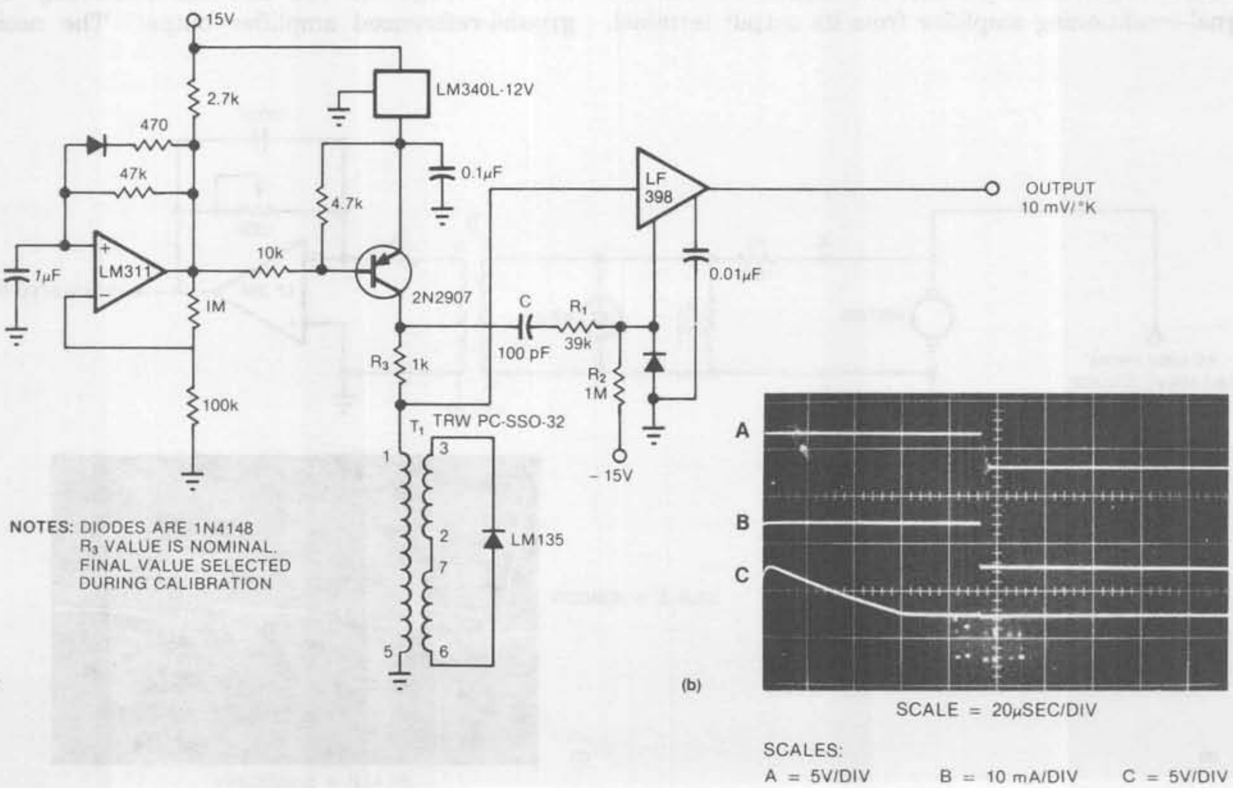


Fig 2—Easily calibrated, *this scheme permits fully floating temperature sensing* ***(a)****. Circuit design ensures that the sampling period doesn't end* ***(b)*** *until the LM135 sensor has settled.*

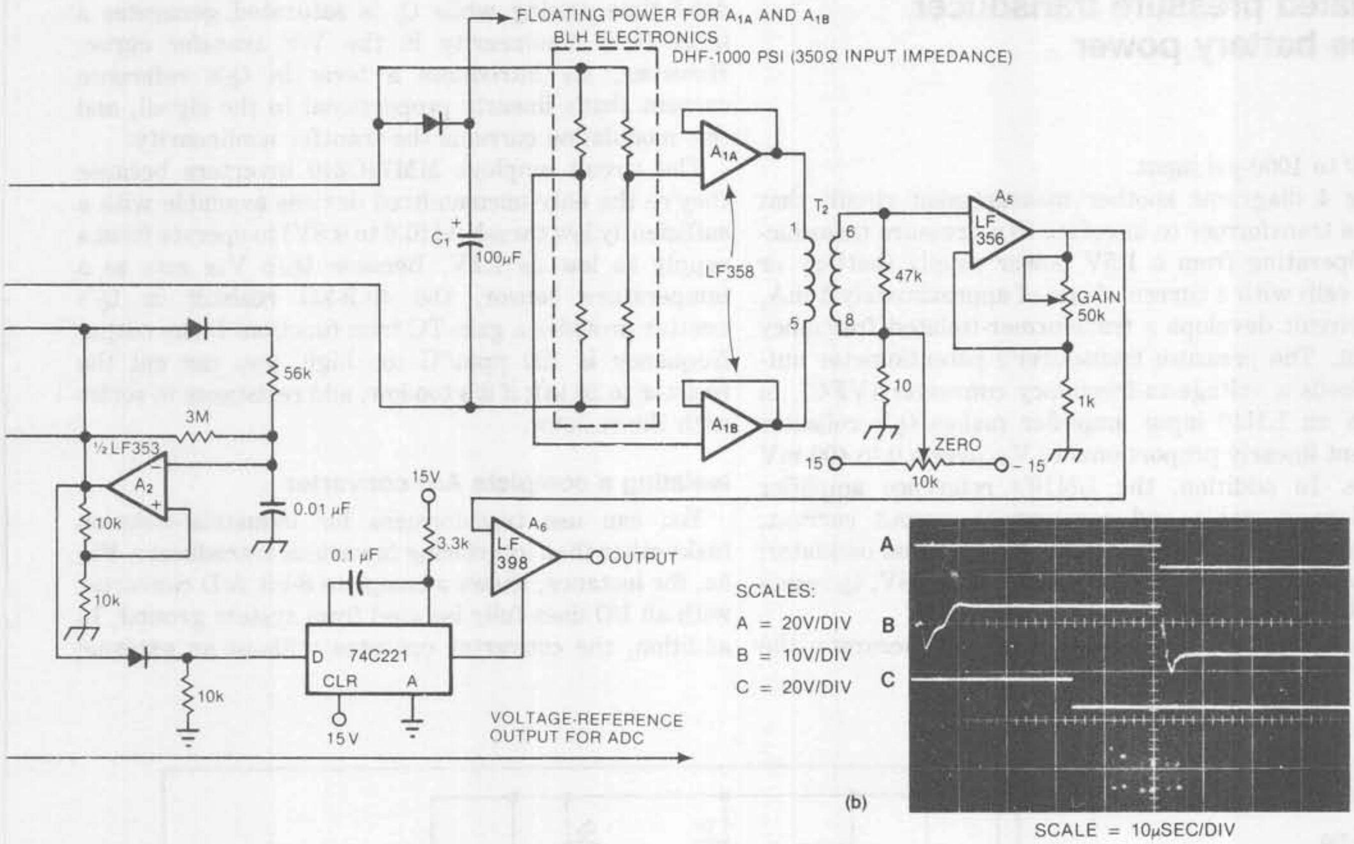


Fig 3—In addition to supplying floating drive *to the strain-gauge bridge, this network furnishes transducer output-signal amplification* ***(a).*** *Because the Sample command—trace C in* ***(b)***—*occurs while T_2's output is settled, network output is a dc representation of pressure-transducer output.*

LM135's clamp level. Of course, the voltage varies with the sensor's temperature reading in accordance with normal operation.

The LF398 sample/hold amplifier monitors the transformer's primary voltage and provides a dc output. The R_1R_2C network generates a trigger pulse for the LF398 that ensures that the sampling period doesn't terminate until after the LM135 settles. The LM340L −12V voltage regulator provides power-supply rejection.

To calibrate the circuit, first substitute an LM336 2.5V diode of known breakdown potential for the LM135. Then vary R_3 until circuit output equals the substitute diode's breakdown voltage. Replace the LM135 and the circuit's ready for use.

Pressure measurements present problems

Transformers also suit difficult isolation applications, such as those using strain gauges, where you must feed excitation power while maintaining total isolation from ground. This requirement arises, for example, in industrial-measurement situations when the transducer is physically connected to a structure that floats at a high common-mode voltage.

Fig 3a illustrates one way to solve such an isolation problem. A transformer (T_1) generating a pulse with a servo-controlled amplitude excites the strain bridge. For this pulse generation, the sampled output-pulse amplitude gets stored as a dc level, and this information goes to a feedback loop that controls the voltage applied to the output switch.

A_2 functions as an oscillator and simultaneously drives Q_2 and Q_3 and the LF398's (A_3) Sample pin. At the end of A_2's output pulse, A_3 outputs a dc level equal to the output pulse driving the strain bridge. T_1's dual secondary allows accurate magnetic sampling of the strain-bridge output pulse with no sacrifice in electrical isolation. A_4 compares A_3's output to the LH0070 10V reference, while Q_1's emitter provides the dc supply for the Q_2Q_3 switch.

This servo action develops constant-amplitude drive pulses (equal to the LH0070's reference output) for the strain-gauge transducer (trace A, **Fig 3b**). C_1 stores some of the pulse energy and powers the LM358 dual followers, which then unload the transducer's bridge output and drive T_2's primary. T_2's output amplitude (trace B, **Fig 3b**) represents the transducer's output.

After amplification, this potential goes to a sample/hold amplifier (A_6), and the 74C221 generates A_6's Sample command (trace C, **Fig 3b**). Because this command occurs during the settled portion of T_2's output pulse, A_6's output is a dc representation of the strain-gauge pressure transducer's amplified output.

As before, circuit calibration is simple: Insert a strain-bridge substitution box (BLH Model 625, for example) for the transducer and dial-in the respective values for zero and full-scale output (usually supplied with individual transducers). Then adjust the circuit's zero and gain pots until a 0 to 10V output corresponds

Isolated pressure transducer uses battery power

to a 0 to 1000-psi input.

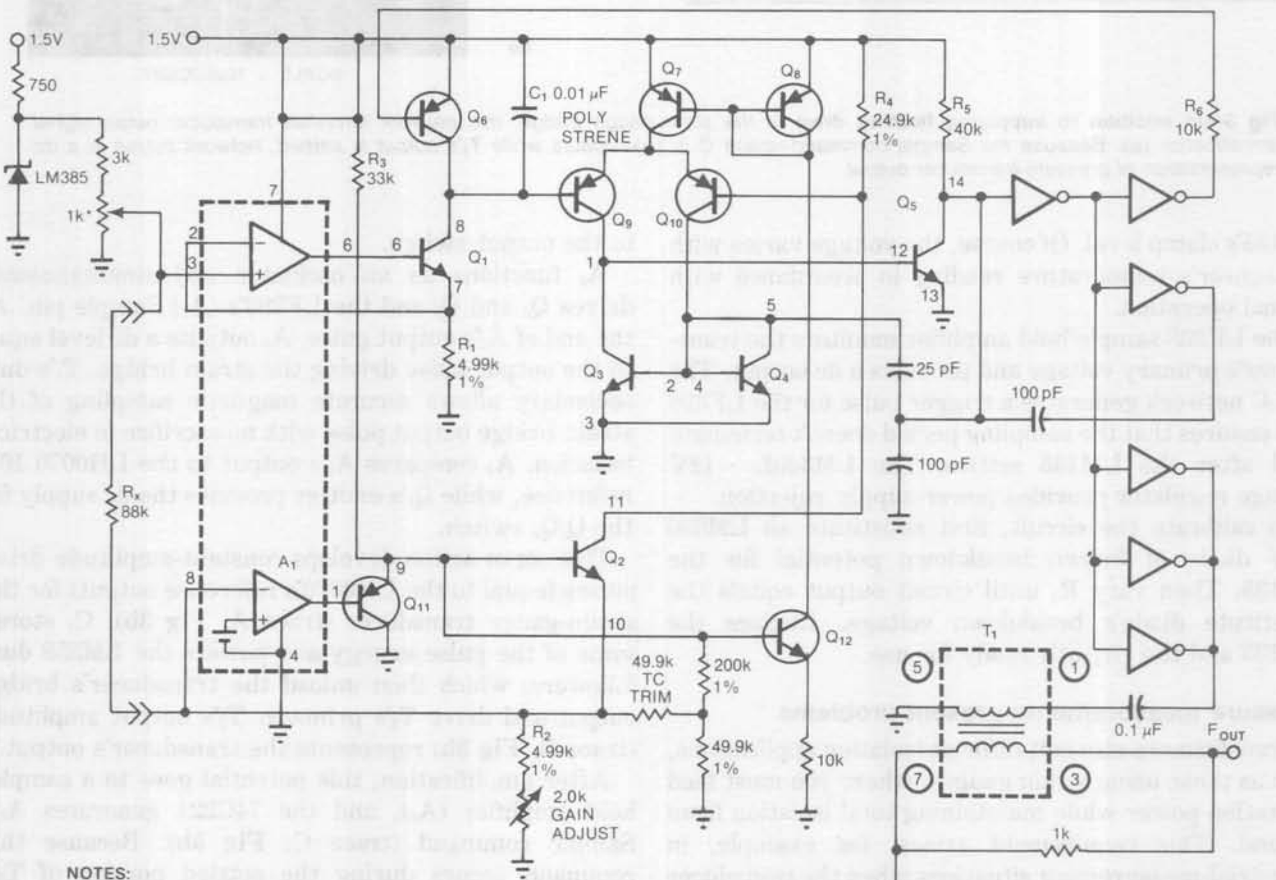
Fig 4 diagrams another measurement circuit that uses a transformer to interface to a pressure transducer. Operating from a 1.5V power supply (battery or solar cell) with a current drain of approximately 1 mA, this circuit develops a transformer-isolated frequency output. The pressure transducer's potentiometer output feeds a voltage-to-frequency converter (VFC), in which an LM10 input amplifier makes Q_1's collector current linearly proportional to V_{IN} over a 0 to 400-mV range. In addition, the LM10's reference amplifier develops a stable and constant Q_2 output current. Transistors Q_3 through Q_{10} form a relaxation oscillator; every time the voltage across C_1 reaches 0.8V, Q_6 resets it to 0V differential.

Normally, this basic circuit isn't very accurate; the dead time arising while Q_6 is saturated generates a large (1%) nonlinearity in the V/F transfer curve. However, R_X introduces a term in Q_2's reference current that's linearly proportional to the signal, and this modulation corrects the transfer nonlinearity.

The circuit employs MM74C240 inverters because they're the only uncommitted devices available with a sufficiently low threshold (0.6 to 0.8V) to operate from a supply as low as 1.2V. Because Q_{12}'s V_{BE} acts as a temperature sensor, the 49.9-kΩ resistor in Q_2's emitter provides a gain-TC trim function: If the output frequency is 100 ppm/°C too high, you can cut the resistor to 20 kΩ; if it's too low, add resistance in series with the resistor.

Isolating a complete A/D converter

You can use transformers for industrial-isolation tasks other than interfacing to various transducers. **Fig 5a**, for instance, shows a complete 8-bit A/D converter with all I/O lines fully isolated from system ground. In addition, the converter operates without an external



NOTES:
▷ INVERTERS = 1/8 MM74C240
Q_1 THROUGH Q_5 = 1/5 LM3046
Q_6 THROUGH Q_{12} = 2N3906 OR 2N2907
Q_{12} = 2N3904 OR ANY NPN SILICON
A_1 = LM10CLH LOW-VOLTAGE OP AMP
T_1 = TRW PC-SSO-32

*PRESSURE TRANSDUCER—GIANNINI CONTROLS 0-15 PSIA-1 kΩ

Fig 4—Capable of operating from battery or solar cell, *this pressure-measurement circuit has a fully isolated frequency output.*

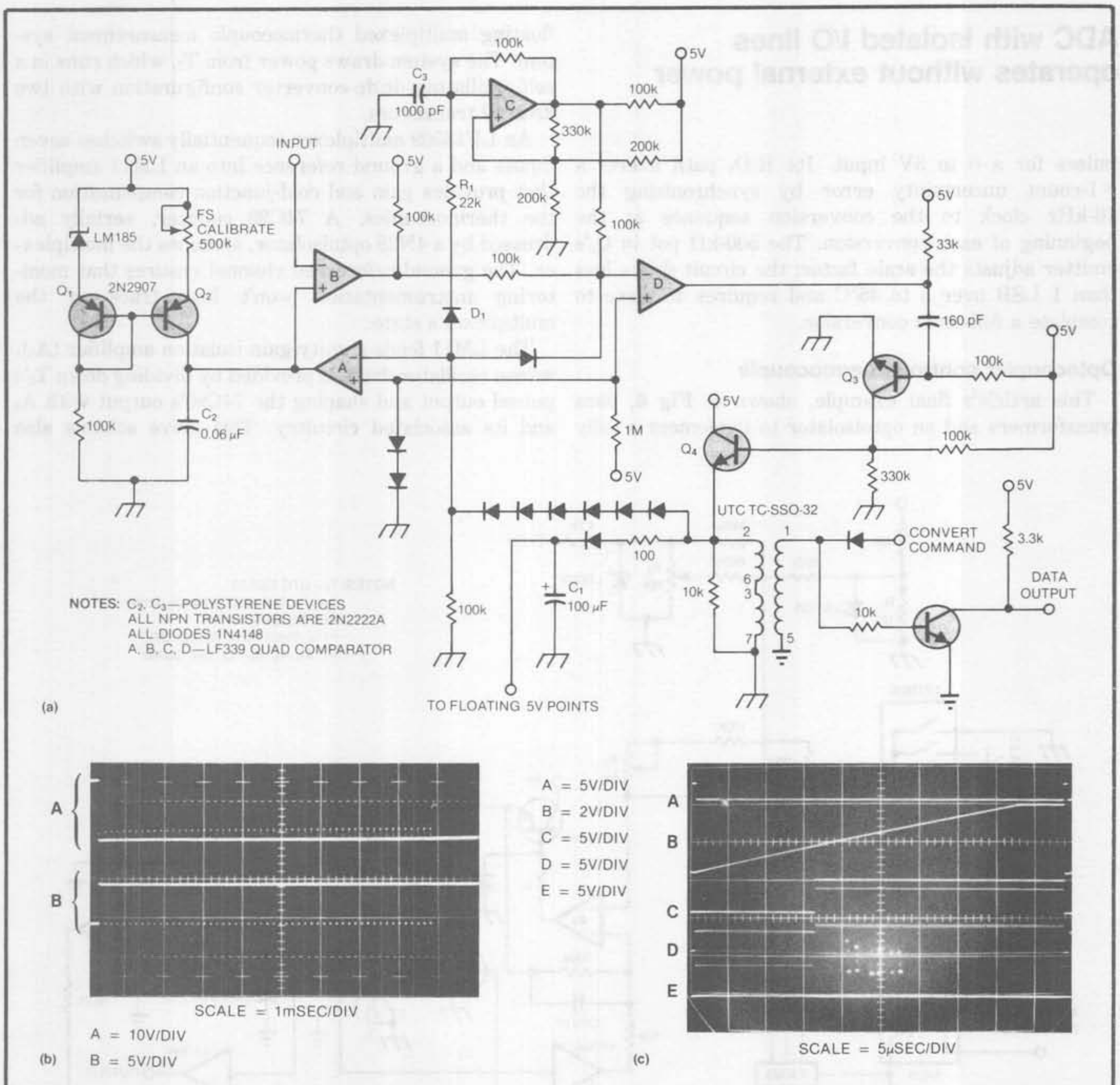


Fig 5—Requiring no power supply, *this 8-bit A/D converter has all input and output lines fully floating from system ground* **(a).** *Circuit output—trace B in* **(b)**—*appears as a series of pulses, and network power gets derived from the voltage change across* C_1*—trace A in* **(c).**

power supply.

To initiate circuit operation, apply a pulse (trace A, **Fig 5b**) to the transformer's Convert input. This pulse simultaneously forces the Data Output line LOW (trace B, **Fig 5b**) and propagates across the isolation transformer. The secondary winding charges C_1 to 5V (trace A, **Fig 5c**)—the supply voltage for the floating ADC. This winding's voltage also starts the A/D conversion by biasing comparator A's inverting input LOW, and the biasing forces comparator A's output LOW, discharging C_2 (trace B, **Fig 5c**).

Simultaneously, the 100-kHz oscillator (trace D, **Fig 5c**) formed by comparator D and associated components gets forced LOW (trace E, **Fig 5c**) by two series resistor/diode combinations. Note the lack of oscillation while the Convert command pulse is HIGH. When that command goes LOW, the Q_1Q_2 current source charges C_2. During this period, comparator C's oscillator is enabled, and comparator D outputs a stream of 10-kHz clock pulses.

When the ramp voltage across C_2 (trace B, **Fig 5c**) exceeds the circuit's input, comparator B's output goes HIGH (trace C, **Fig 5c**), forcing comparator D LOW. The number of pulses that comparator D outputs is directly proportional to the input voltage. Q_3 and Q_4, used to modulate the data pulse stream back across the transformer, amplify these pulses. The diode string ensures that the data doesn't inadvertently trigger comparator A.

The design shown in **Fig 5a** produces 0 to 300 output

ADC with isolated I/O lines operates without external power

pulses for a 0 to 3V input. Its R_1D_1 path averts a +1-count uncertainty error by synchronizing the 10-kHz clock to the conversion sequence at the beginning of each conversion. The 500-kΩ pot in Q_2's emitter adjusts the scale factor; the circuit drifts less than 1 LSB over 5 to 45°C and requires 45 msec to complete a full-scale conversion.

Optocoupler controls thermocouple

This article's final example, shown in **Fig 6**, uses transformers and an optoisolator to implement a fully floating multiplexed thermocouple measurement system. The system draws power from T_2, which runs in a self-oscillating dc/dc-converter configuration with two 2N2219 transistors.

An LF13509 multiplexer sequentially switches seven inputs and a ground reference into an LM11 amplifier that provides gain and cold-junction compensation for the thermocouples. A 74C90 counter, serially addressed by a 4N28 optoisolator, switches the multiplexer. The ground-referenced channel ensures that monitoring instrumentation won't lose track of the multiplexer's state.

The LM11 feeds a unity-gain isolation amplifier (A_1), whose oscillator drive is provided by dividing down T_2's pulsed output and shaping the 74C90's output with A_4 and its associated circuitry. This drive scheme also

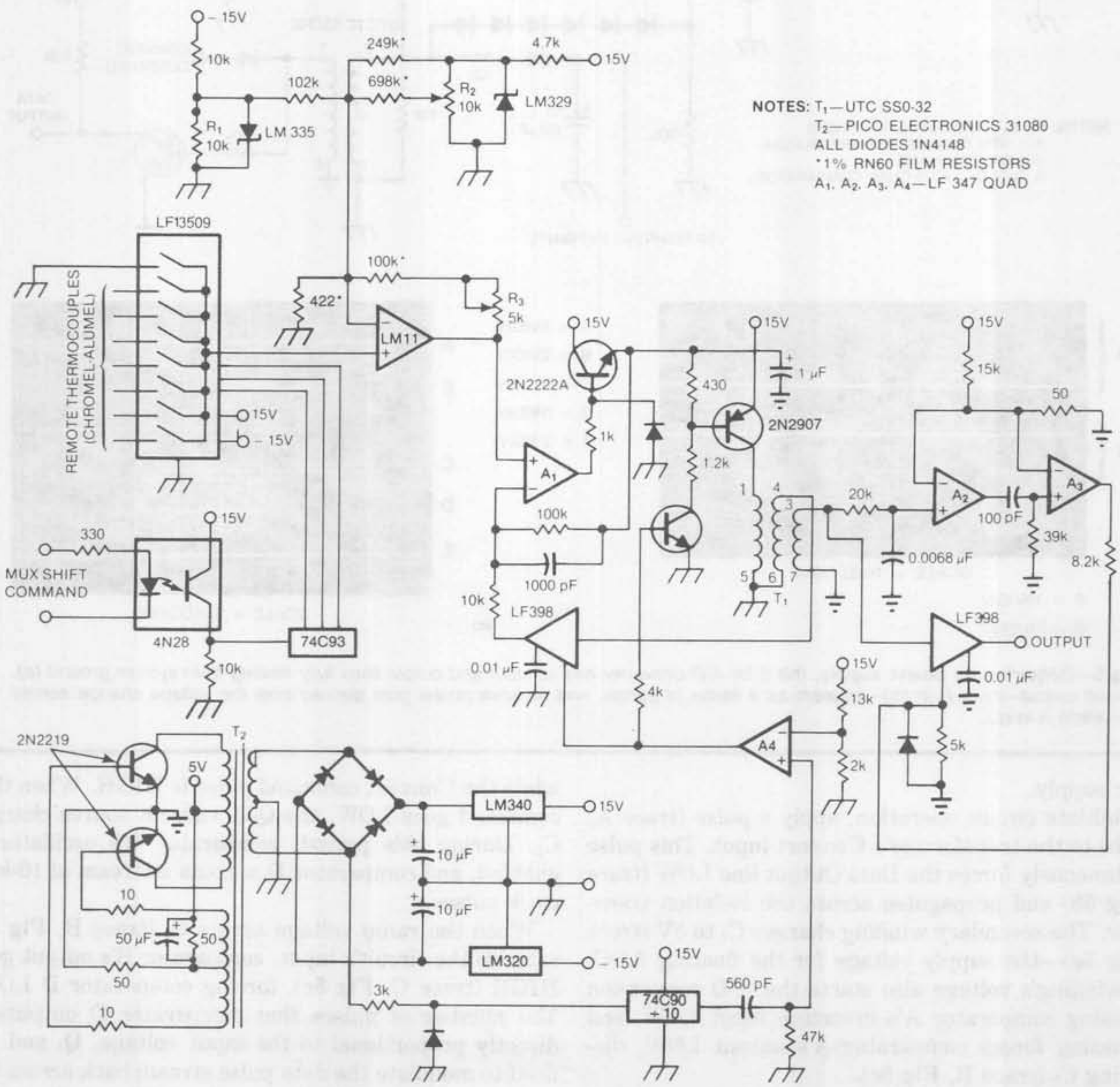


Fig 6—Supplying power to its floating system, *this thermocouple measurement system employs a multiplexer that sequentially switches seven inputs and a ground reference.*

Transformer, optoisolator combine in multiplexed thermocouple system

prevents unwanted interaction between the dc/dc converter and isolation amplifier.

The network develops a pulse across T_1's primary—pulse amplitude depends directly on the LM11's output. T_1's secondary feeds the pulse into an LF398 sample/hold amplifier. The trigger pulse for this amplifier is delayed to ensure that T_1 output sampling occurs well after settling.

Outputs from the LF398 and LM11 are identical. You can therefore monitor the fully floating thermocouple with grounded test equipment or computers. The most effective cold-junction compensation results when you hold thermocouple leads and LM335 isothermal.

Calibration for the circuit involves a 6-step procedure. First, adjust R_3 to set the LM11's gain at 245.7. Then short the noninverting input of the LM11 and LM329 to floating common, then adjust R_1 for a circuit output of 2.982V at 25°C. Next, remove the short across the LM329, then adjust R_2 for a circuit output of 246 mV at 25°C. Finally, remove the short from the LM11's input and the circuit is ready to use. **EDN**