

# Exotic-transducer interfacing calls for proven techniques

*Measuring fundamental physical phenomena involves designing circuitry that conditions sensor output signals. This conclusion of a 2-part series looks at schemes for detecting acceleration and magnetic fields.*

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Whether your measurement applications involve sensing a disturbance in the earth's magnetic field or monitoring acceleration, you can often employ building-block approaches to sensor-interface-circuit designs. These signal-conditioning techniques meet the interfacing requirements of such devices as piezoelectric and pendulous accelerometers, linear variable differential transformers, rate gyros and flux-gate transducers.

## Charge-sensitive op amp detects g-force signal

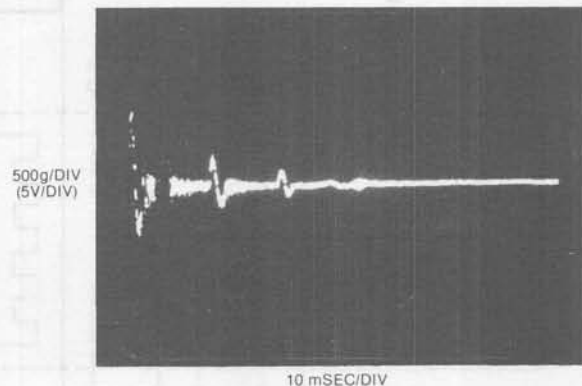
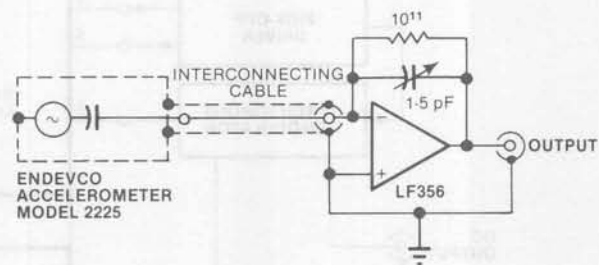
Consider, for example, the piezoelectric accelerometer, a device employing a mass-loaded ceramic or quartz element that generates an output charge proportional to its acceleration. You can ascertain an impact level's frequency and amplitude characteristics if you combine the device with Fig 1's interfacing electronics—a signal-conversion stage that employs a charge-sensitive, very-low-input-bias-current op amp with a capacitive feedback element to furnish a V/g output. (The  $10^{11}\Omega$  resistor establishes the circuit's dc stability; the variable capacitor sets the stage's charge-to-voltage conversion sensitivity.)

In the Fig 1 configuration, the accelerometer looks directly into the op amp's ground-potential summing junction. The resulting lack of voltage differential between the interconnecting cable's center conductor and shield eliminates capacitive loading and therefore prevents signal rise-time degradation. Thus, you can use long cable runs between the transducer and its amplifier. (However, employ cable that's spec'd for low triboelectric-charge effects.)

Fig 1's scope photo illustrates this design's operation. It depicts the results of mounting an accelerometer on a standard hand-held voltmeter and dropping the combination on the floor. The trace represents an initial shock level of nearly 1000g and three lower amplitude aftershocks. In other words, the 8-oz voltmeter "weighed" 500 lbs during the impact.

Although piezoelectric transducers are suitable for measuring peak or instantaneous accelerations, the

force-balanced pendulous accelerometer (Fig 2) better suits monitoring a constant acceleration. This device is basically a transformer with a pivoted, movable core. Two of the transformer's windings—the pick-off drive and sense coils—determine the core's position; the remaining two control the core's position. Additional internal elements include two temperature sensors: One merely monitors the device's operating temperature; the other works with the heater element to stabilize that temperature. (Temperature control is needed because the viscous-damped pendulum uses dampening fluid with temperature-sensitive viscosity.)



**Fig 1—Piezoelectric accelerometers generate an output charge that's proportional to a sensed shock level. By using a charge-to-voltage converting op amp, you can monitor fast, high-level impacts like the 1000g force represented by the scope trace.**

## Some sensors detect movement by not moving

Fig 2's block diagram depicts how you can meet the sensor's circuit requirements. When excited, the pick-off drive coil generates a field that couples to the sense coil via the transducer's core. When an accelerative force tries to move the core, the sense coil's changed output creates an error signal that can be synchronously demodulated and reapplied to the torque winding in a way that maintains the core's original position. You can determine the accelerative force's magnitude by measuring the torque driver's corrective-current level. And because the signal is synchronously demodulated, you can also determine the direction along the pendulum's sensitive axis in which the force occurred. Note that because the torque coil can only attract the pendulum, a separate bias coil must provide a constant force for the torque coil to work against. These combined actions prevent the pendulum from moving, and as a result, the pendulous accelerometer's accuracy, linearity and dynamic range are very high.

Fig 3 details the circuits represented by Fig 2's block diagram. Op amp A<sub>1A</sub> and its booster stage generate the bias coil's current by sensing the signal developed across a resistor and comparing it with a reference voltage in a closed-loop configuration. A transistor

phase-shift oscillator combines with another op amp (A<sub>1B</sub>) and its driver to provide the pick-off drive coil's excitation. Here, too, a current-monitoring resistor furnishes the loop's error signal. Oscillator amplitude stabilization results from the combined actions of op amps A<sub>1C</sub> through A<sub>2A</sub>; the error signal is amplified, rectified, filtered and employed as the oscillator's supply voltage.

A<sub>2C</sub> through A<sub>3B</sub>'s booster stages process the sense coil's error signal. The booster's high-level dc output drives the torque coil and thus completes the pendulum-correcting feedback loop. The error signal's synchronous demodulation occurs because of A<sub>2B</sub> and its associated FET. In this configuration, the oscillator's signal drives the op amp (and thus the FET) in an OFF/ON switching fashion. When the FET is OFF, A<sub>2D</sub>'s + input sees the error signal; when the FET is ON, the - input is operational. Thus, A<sub>2D</sub>'s gain changes from + to - synchronously with the sense coil's error signal, yielding a dc voltage whose amplitude and polarity completely define the pendulum's magnitude and direction. You calibrate this circuit by loading the accelerometer to at least one-half its sensing range and adjusting the phase trimmer for a maximum dc output level.

The remaining circuits—A<sub>3</sub> and the LM395—form the temperature-control loop. The temperature sensor's output (pin 9) forms one leg of a 4-resistor bridge. At the control temperature of 180°F, the sensor's

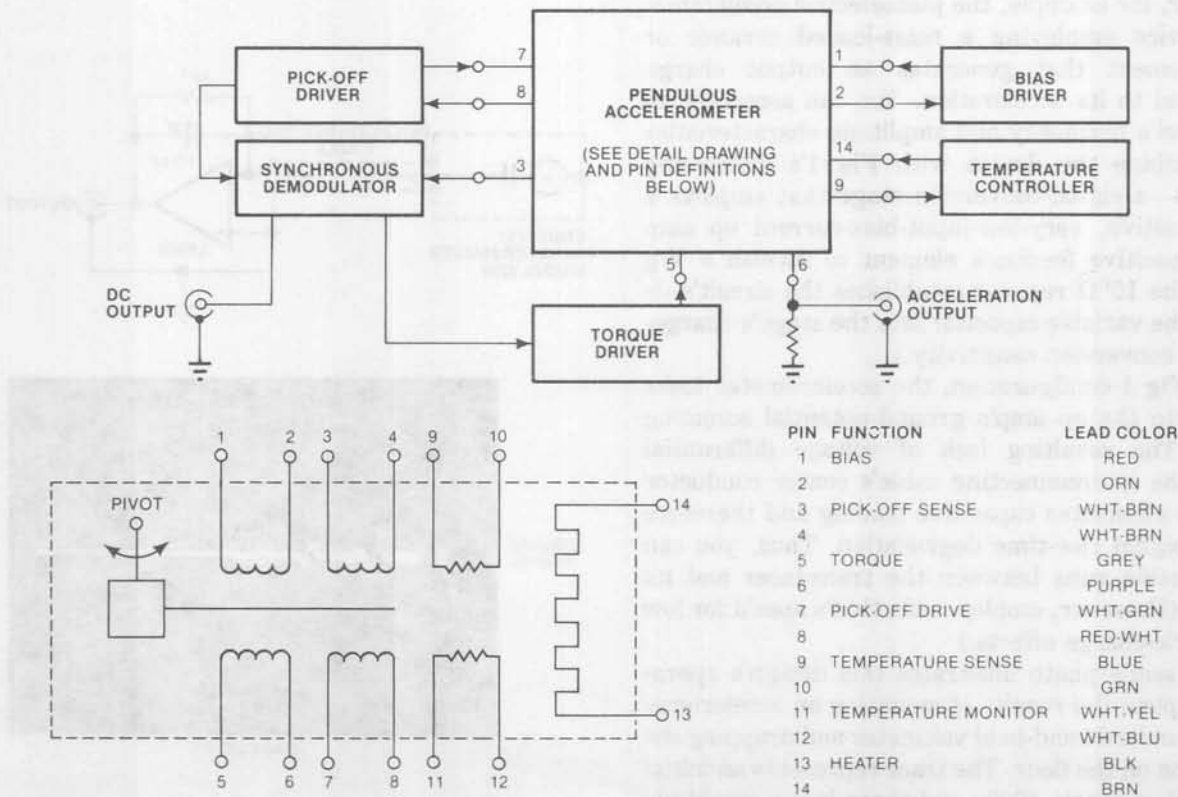
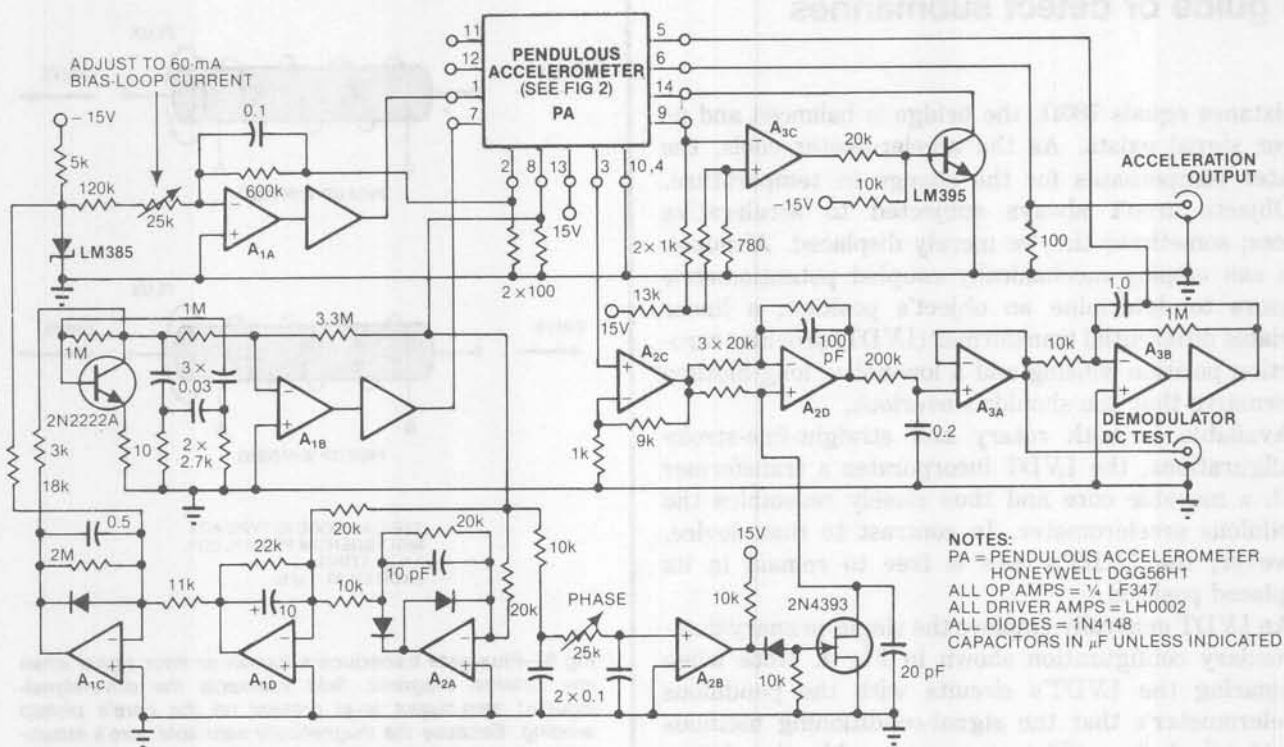
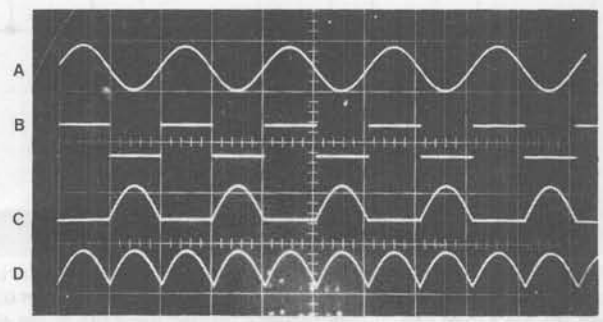
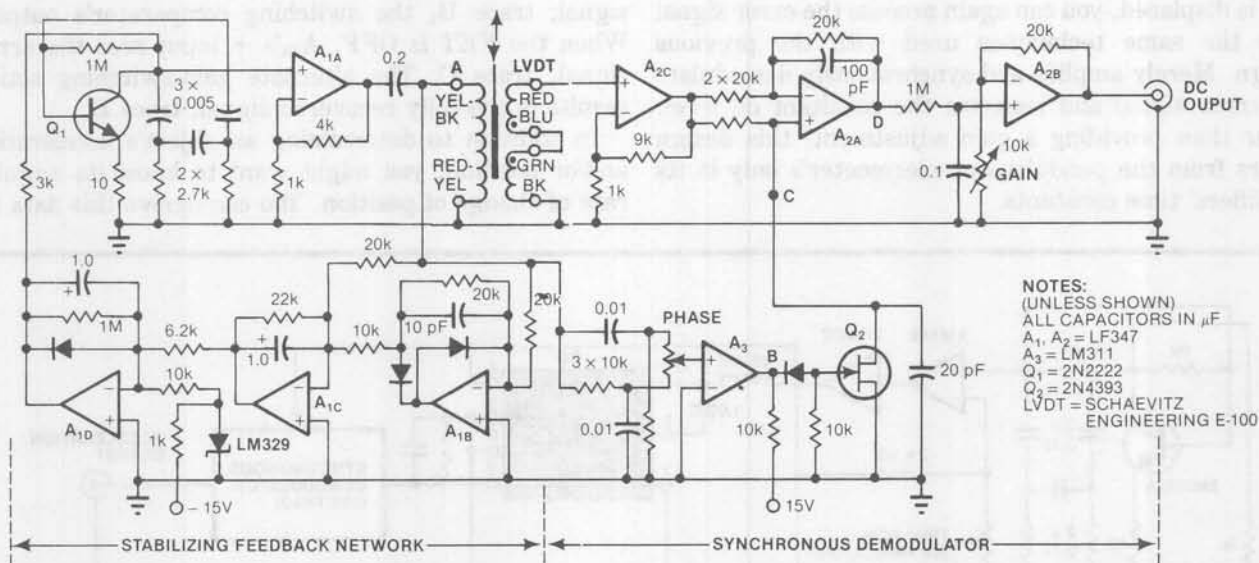


Fig 2—Pendulous accelerometers detect an external force by synchronously detecting the error signal generated when the transformer's core attempts to move. This error signal gets amplified and reapplied via the torque coil to counterbalance the core's movement; the correcting current's magnitude represents the applied force.



**Fig 3**—A transistor oscillator generates the pick-off drive coil's signal used by Fig 2's accelerometer. The drive coil's signal feeds back to the oscillator, its stabilization stages (A<sub>1C</sub> through A<sub>2A</sub>) and the A<sub>2B</sub>/FET synchronous-demodulator network. The force-induced error signal gets amplified by A<sub>2C</sub>, demodulated by A<sub>2D</sub>, and filtered and amplified by A<sub>3A</sub>, A<sub>3B</sub> and the power-booster stage before being returned to the displacement-correcting torque coil.



**Fig 4**—Linear variable differential transformers (LVDTs) sense a movable core's displacement to determine an object's position. In common with Fig 3's pendulous-accelerometer design, the LVDT's signal-conditioning scheme employs an amplitude-stabilized oscillator as an excitation source and a synchronously demodulated error amplifier. The scope photo depicts the circuit's wave shapes at the labeled circuit nodes.



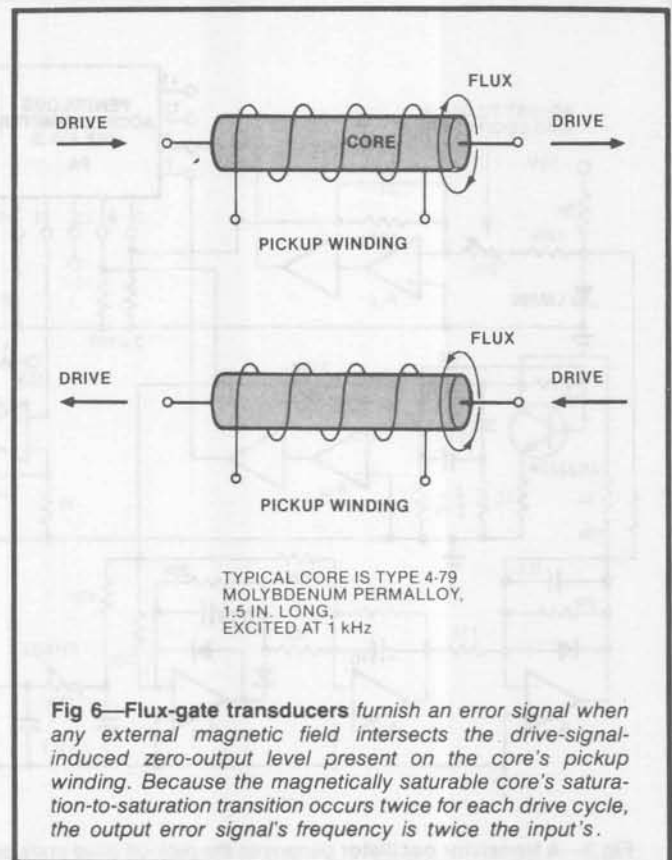
## Use the earth's magnetic field to guide or detect submarines

resistance equals  $780\Omega$ , the bridge is balanced and no error signal exists. As the accelerometer cools, the heater compensates for the change in temperature.

Objects aren't always subjected to accelerative forces; sometimes they're merely displaced. Although you can employ mechanically coupled potentiometric sensors to determine an object's position, a linear variable differential transformer (LVDT) provides zero-friction position sensing and a low-noise, long-lifetime alternative that you shouldn't overlook.

Available in both rotary and straight-line-stroke configurations, the LVDT incorporates a transformer with a movable core and thus closely resembles the pendulous accelerometer. In contrast to that device, however, the LVDT's core is free to remain in its displaced position.

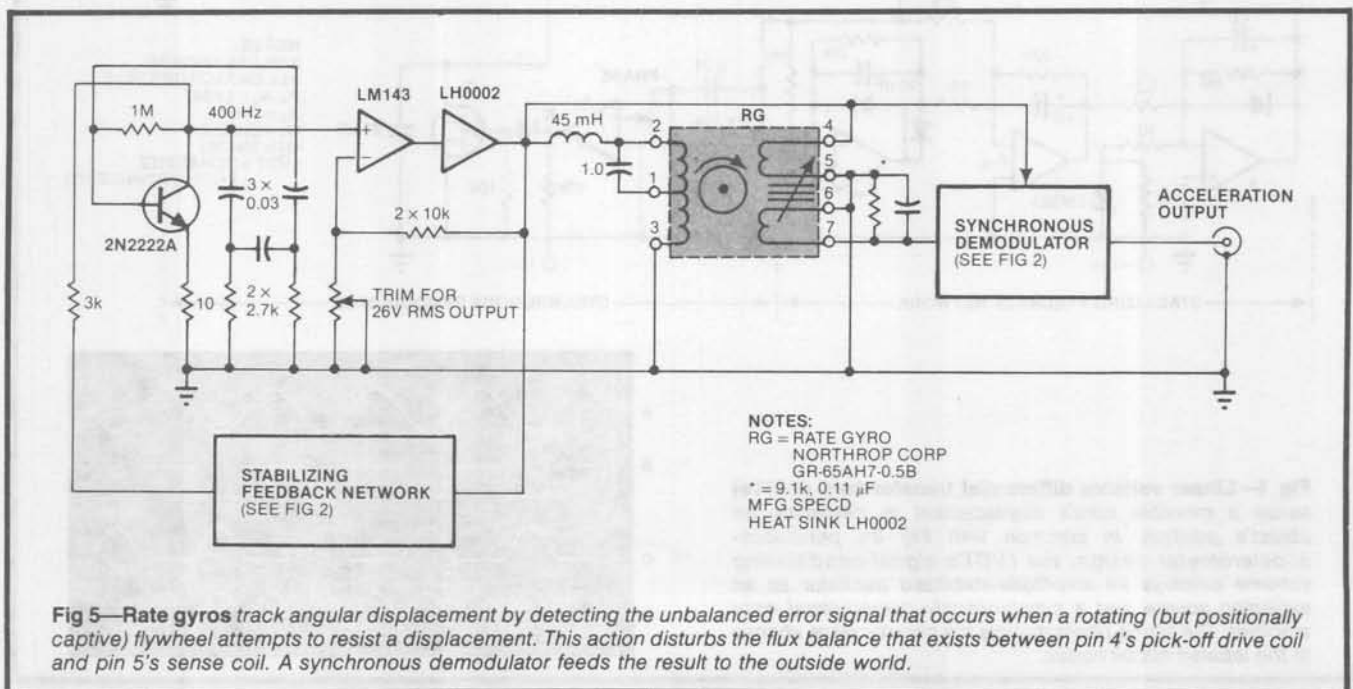
An LVDT generally employs the single-primary/dual-secondary configuration shown in Fig 4. Note when comparing the LVDT's circuits with the pendulous accelerometer's that the signal-conditioning methods are identical: An oscillator/op-amp combination drives the transducer, and the same stabilization methods apply. When the LVDT's core is in its magnetic (and usually also its geometric) center, a null condition exists, and no error signal results from the series-opposed connected secondaries. However, when the core is displaced, you can again process the error signal with the same techniques used with the previous design. Merely amplify and synchronously demodulate the error signal and measure the resultant dc level. Other than providing a gain adjustment, this design differs from the pendulous accelerometer's only in its amplifiers' time constants.



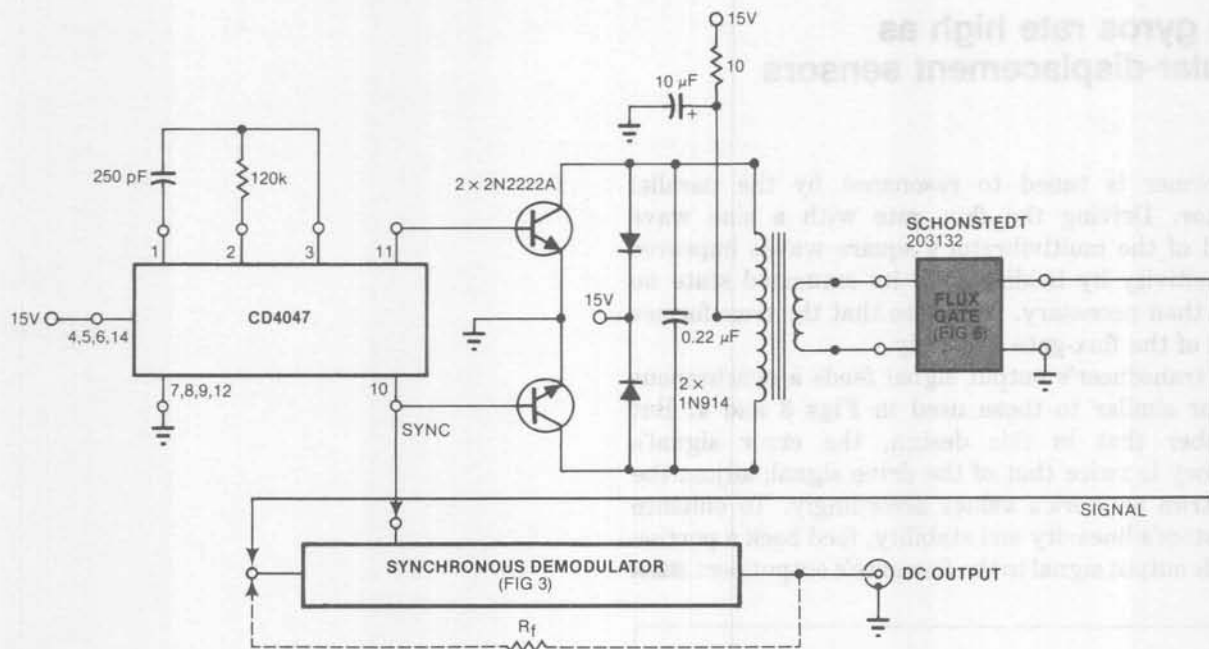
**Fig 6—Flux-gate transducers** furnish an error signal when any external magnetic field intersects the drive-signal-induced zero-output level present on the core's pickup winding. Because the magnetically saturable core's saturation-to-saturation transition occurs twice for each drive cycle, the output error signal's frequency is twice the input's.

Fig 4's accompanying waveforms demonstrate the design's functions. Trace A shows the LVDT's drive signal; trace B, the switching comparator's output. When the FET is OFF,  $A_{2A}$ 's + input sees the error signal, trace C. The alternate gain-switching action results in the fully recovered signal, trace D.

In addition to determining an object's acceleration and/or position, you might want to know its angular rate of change of position. You can derive this data by



**Fig 5—Rate gyros** track angular displacement by detecting the unbalanced error signal that occurs when a rotating (but positionally captive) flywheel attempts to resist a displacement. This action disturbs the flux balance that exists between pin 4's pick-off drive coil and pin 5's sense coil. A synchronous demodulator feeds the result to the outside world.



**Fig 7**—An RC-timed multivibrator provides the complementary drive signals for the push/pull transistor-operated sine-wave source that excites Fig 6's flux-gate sensor. Induced by an unknown external magnetic field, the gate's field-proportional output signal is processed by a synchronous detector. By feeding back a portion of the dc output signal, you can enhance the system's dynamic range and linearity.

time-differentiating a pendulous accelerometer's error signal. But employing a rate gyro yields a cleaner design.

Rate gyros, like the aforementioned transducers, sense a force by electrically sensing an unbalanced condition. Unlike standard gyros, which are unrestrained and thus can maintain their position when moved, the rate gyro is held captive in its gimbals and thus must track any positional changes. If the gyro's flywheel is electrically driven and the unit is equipped with a pick-off drive- and sense-coil scheme, you can employ signal-conditioning circuits like those used in the previous design examples.

The gyro's flywheel drive circuits (Fig 5) use the now-familiar stabilized-oscillator design—the only difference here is the required 26V rms signal level. This same signal also feeds the pick-off drive coil to provide a reference signal for the sense coil. So long as the gyro's platform remains stationary, no error signal is generated. Any angular motion, however, disturbs the flywheel's positional stability and upsets the field coupling the pick-off drive and sense coils. You process the error signal via a synchronous demodulator.

#### Use the earth as a signal source

Whereas LVDTs, rate gyros and pendulous accelerometers all employ an internally generated magnetic field to sense a force, the magnetic field itself is sometimes the force of interest. For these applications, consider using flux-gate transducers; they're far more sensitive than Hall-effect devices.

A flux-gate transducer converts an external magnetic field (such as the earth's) into an electrical signal. As

such, it's useful in metal detectors (including submarine-hunting gear), electronic compasses or similar applications where measuring the strength of—or a locally caused disturbance in—the earth's magnetic field is of interest. These devices can detect variations to within 1 gamma ( $10 \mu\text{Oe}$ ).

Although many flux-gate configurations exist, the simplest is the form shown in Fig 6. In this version, a cylindrical piece of easily saturated ferrous material is first saturated in, say, a clockwise direction and then in a counterclockwise direction by an alternating axial current. While the material is between its saturation extremes, it maintains a certain average permeability, but while saturated, this permeability ( $\mu = dB/dH$ ) equals 1; ie, an increase in driving field (H) produces the same increase in flux (B).

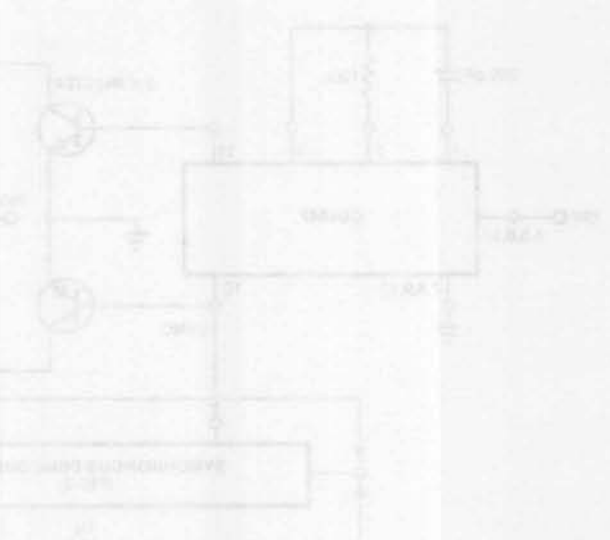
Note that if no external magnetic-field component exists along the cylinder's axis, the flux change seen by the unit's pickup winding equals zero because the excitation flux is normal to the winding's axis. If, on the other hand, an external field is present, each time the material switches from one saturation extreme to the other, it generates an output pulse on the pickup winding. This pulse is a function of the material's permeability and proportional to the external magnetic field's strength. And because the saturation-to-saturation transition occurs twice for each excitation period, the output signal's frequency is twice that of the drive signal.

In Fig 7's design, an RC-timed multivibrator provides the complementary signals that push/pull-drive the transformer-coupled transistors. (Note that the

## Rate gyros rate high as angular-displacement sensors

transformer is tuned to resonance by the parallel capacitor. Driving the flux gate with a sine wave instead of the multivibrator's square waves improves its sensitivity by holding it in its saturated state no longer than necessary. Note also that the transformer is part of the flux-gate assembly.)

The transducer's output signal feeds a synchronous detector similar to those used in Figs 3 and 4. But remember that in this design, the error signal's frequency is twice that of the drive signal; adjust the phase-trim network's values accordingly. To enhance the system's linearity and stability, feed back a portion of the dc output signal to the flux gate's output port. **EDN**



### References

1. *RCA Photomultiplier Handbook*, RCA Electro-Optics Div, Lancaster, PA.
2. Lange, S B, "The pyroelectric thermometer: A sensor for measuring extremely small temperatures." McGill University, 1971 *International Symposium on Temperature*, Washington, DC.
3. "A User's Guide to Pyroelectric Detection," *Electro-Optical Systems*, November 1978.
4. *Pyroelectric Detectors and Detection Systems*, Laser Precision Corp, Utica, NY.
5. *Multiplier Application Guide*, "Acoustic Thermometer," pg 11, Analog Devices Inc, Norwood, MA.
6. *Ultrasonic Thermometry Using Pulse Techniques*, Lynnwood and Carnevale Corp, Waltham, MA.
7. *Handbook of Measurement and Control*, Schaevitz Engineering, Pennsauken, NJ.
8. Geyer, William, "Self-balancing Flux Gate Magnetometers," *AIEE Transactions on Communications and Electronics*, Vol 77, May 1958.
9. Morris, H D, "A Low Cost Precision Inertial Grade Accelerometer," Systron Donner, *DGON Symposium on Gyro Technology*, 1976.
10. *Short Form Catalog*, Endevco Corp, San Juan Capistrano, CA.
11. *Ultrasonic Transducers*, Bulletin 31, MK109, Massa Corp, Hingham, MA.

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