# Achieve greater precision, reliability with integrated magnetic sensing technology

Texas Instruments

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**Each time you climb into your car, you enter a world of magnetic sensing, with tiny sensors reporting whether the doors are closed and seat belts buckled properly. Sensors also automatically guide seats into place, help open windows, turn steering column switches on and off, and track how you turn the steering wheel or press the accelerator.**

Several magnetic sensors are located, under the hood, detecting speed and position in the car's engine, transmission and electric motors. Other sensors monitor fluid levels, track body and wheel position, perform a number of safety checks, and sense currents for a variety of electrical feedback and measurement functions.

A new automobile today may have as many as 70 magnetic sensors to enhance operation, safety and convenience. More are being added all the time due to technology advancements that deliver greater accuracy and reliability in smaller sizes with lower cost.

The same trend can be observed in the electronic and electromechanical world in general. In addition to widespread use in vehicles, magnetic sensors find application in equipment including industrial motors and robots, medical systems, office machines, home appliances, and even handheld tablets and cellphones. Like so many other semiconductor devices that make the modern world go round, magnetic sensors are invisible to end users but indispensable for many of the functions that we have come to take for granted. **Figure 1** lists some of these uses.

What enables the ubiquity of magnetic sensors today is their small size and affordability. Semiconductor manufacturers have applied advanced production techniques to enable analog integrated circuit (IC) products that include sensors, bringing the advantages of miniaturization to what were once space-consuming devices. At the same time, the cost of the permanent magnets integrated within some magnetic sensors has dropped, helping push the trend toward affordability that comes with advanced manufacturing, as well as increasing functionality. The need for improved reliability, safety and accuracy has motivated end product developers to take advantage of the inexpensive magnetic sensors that are now available on chips along with other circuitry. As a result, applications are mushrooming, with a market estimated to pass $2 billion and 20 billion units in the next five years, with the majority in the automotive segment.

Texas Instruments (TI) devotes significant development effort to magnetic sensing. TI's portfolio of magnetic sensors gives equipment manufacturers an array of options for their varied application needs. The company's advanced analog process technology makes possible the on-chip integration of complete sensing solutions that include both the sensing element and other circuitry. TI process

## Automotive

### Powertrain

- Crank and camshaft
- Engine and transmission
- Throttle position
- Brushless DC motors
- Oil, brake, other fluid levels
- Exhaust gas recirculation (EGR) position, current sensing

### Safety and vehicle control

- Wheel speed
- Chassis height
- Strut, suspension position
- Steering wheel angle, electronically assisted steering
- Acceleration pedal position
- Passenger occupation

### Body

- Steering column control
- Seatbelt presence
- Seat position, electric windows and mirrors
- Door latches, sunroof

### Information

- Navigation compass

## Non-automotive

### Industrial

- DC motors
- Heating, ventilation and air conditioning (HVAC) position
- Elevator floor detection
- Hoist end position
- Deep bore liquid detection

### Digital still cameras and camcorders

- Image stabilization
- Motor commutation
- Display open and close

### Home appliances

- Washing machine
- Dishwasher
- Instant water heater
- Coffee machine
- Microwave oven
- Cooker cover

### Office machines

- Fax machine door close
- Copier and printer paper level

### Medical

- Automated lab equipment
- Pacemaker
- Hearing aid
- Smart pills
- Drug delivery fluid level

### Aerospace, marine

- Navigation compass
- Wind speed and direction
- Anchor, rudder, hatch position

### Mobile phones

- Open and close
- Electronic compass
- Autofocus

***Figure 1***. *The wide world of magnetic sensing.*

innovation enabled the industry's first integrated fluxgate magnetic sensors for extremely high-precision measurement. For the growing world of magnetic sensing, the company's technology continues to drive the development of solutions for an ever-expanding range of end uses.

## Advantages of magnetic sensing

Because magnetic sensors do not require physical contact, they help prevent wear on parts. For instance, magnetic sensors allow turn indicators and other switches on a steering column to switch on and off without using mechanical contacts. Similarly, a brushless DC motor that uses magnetics to sense the electrical angle of the rotor avoids the eventual wearing away of brush contacts and the maintenance required to replace them. Additionally, magnetic sensors are largely unaffected by the presence of dirt, dust and even moisture when properly packaged. This relative immunity to contamination provides a big advantage in the severe environment where most factory equipment and car engines operate.

IC integration makes sensors small and cost-effective, and enables them to be combined with circuitry for other operations. One important application use for integrated magnetic sensors is in the control of motor drives, not only to replace DC motor brushes but also to sense shunt currents for feedback on rotor position and speed in AC motors. Position and speed encoder functions like these, both rotational and linear, are also critical for motion control, especially in robotics, where motion has to be smooth and precise in three dimensions, often with compensation for variable loads.

Magnetic sensors can trigger various types of on-off latches for doors and covers, or for shutting down equipment for safety, such as when a human being comes dangerously near an industrial robot. The same principle can activate smoke alarms and other devices to perform functions such as running self-test programs when a magnet is waved near them. Other designs provide a more linear signal output for monitoring currents. This feature is often used for circuit feedback and diagnostics in any number of electronic systems, for variable position and speed sensing, and for activating levels of response to changing conditions in automobile engines, industrial processes, medical monitors and other areas.

## Types of integrated magnetic sensors

There are a number of sensing methods based on electromagnetic fields, each with its own operating characteristics and level of affordability. Two significant types of sensors that lend themselves to integration in silicon processes are Hall effect and fluxgate magnetic sensors.

*Hall effect sensors* are the most popular magnetic sensors. They are robust, with high voltage ratings, a wide operating range without saturation in intense magnetic fields, and utility in multi-axis (multi-directional) magnetic fields. In chip integration, these sensors require no additional steps or unusual materials. This makes the manufacturing process economical and enables the creation of cost-effective IC solutions for many applications.

**Figure 2** shows the principle of Hall effect operation. When a magnetic field is present at a right angle to the current flowing through a conductor, a voltage potential, called Hall voltage, is developed. This field induces a voltage ($V_H$), which can be amplified to provide a signal for readout or conversion and further processing. The simplicity of the Hall effect makes for straightforward integration of the sensor element alongside analog and mixed-signal circuitry that may provide signal conversion, control functions and communications in the same device.

*Fluxgate sensors* perform more sensitive detection of magnetic fields than Hall effect sensors and thus tend to be used in applications where extremely high precision is required. Whereas the magnetic field detection range of Hall effect sensors is measured throughout the millitesla (mT) range, fluxgate sensors can detect from very low milliteslas down into picoteslas (pT). Integrated fluxgate sensors are relatively immune to temperature changes and

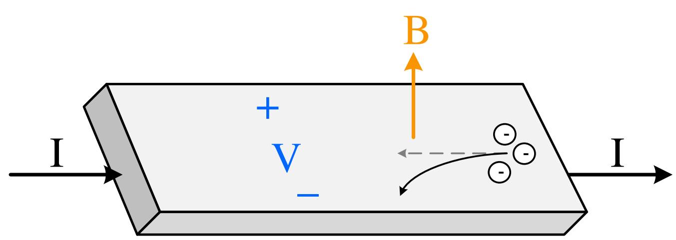



***Figure 2**. The Hall effect produces a measurable voltage proportional to the interacting electric current and magnetic field.*

introduces very little noise and baseline offset in the output. They offer fast, high-resolution response with low parasitics to a magnetic field in a single axis. Because of their high level of sensitivity, these types of sensors must be carefully shielded in the application to avoid field saturation and interference from stray magnetic fields.

Fluxgate magnetic sensor operation is based on two solenoid coils—an excitation or drive coil and a pick-up coil. An alternating current through the excitation coil creates a magnetic field that induces a current in the pick-up coil. In a magnetically neutral field, the input current to the excitation coil and output current from the pick-up coil are identical and cancel each other. If there is a difference between them that creates a detectable output current, it results from the presence of an ambient magnetic field. The design of the device provides for reading the level of this difference as a measurement of the ambient magnetic field.

**Figure 3** illustrates the architecture of fluxgate sensors as implemented with TI's manufacturing process. Notable architectural enhancements include the use of two cores and a third coil for compensation. Known as a Förster-type fluxgate, this differential architecture cancels offset, improves output linearity, and extends the sensing range up to ±2 mT.

## TI innovation in magnetic sensing solutions

TI offers solutions that integrate either Hall effect or fluxgate magnetic sensors. The operating characteristics of these two sensor types complement each other, allowing application developers to select the most optimum sensor for a wide range of requirements. TI's integration capabilities provide a variety of on-chip functions,

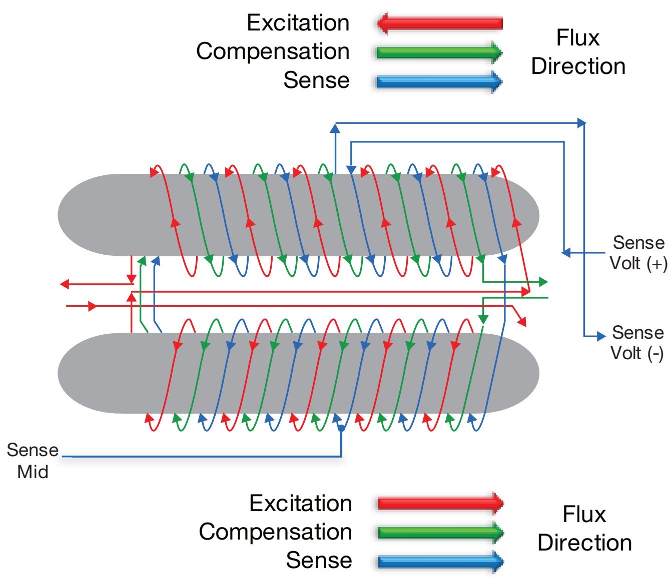


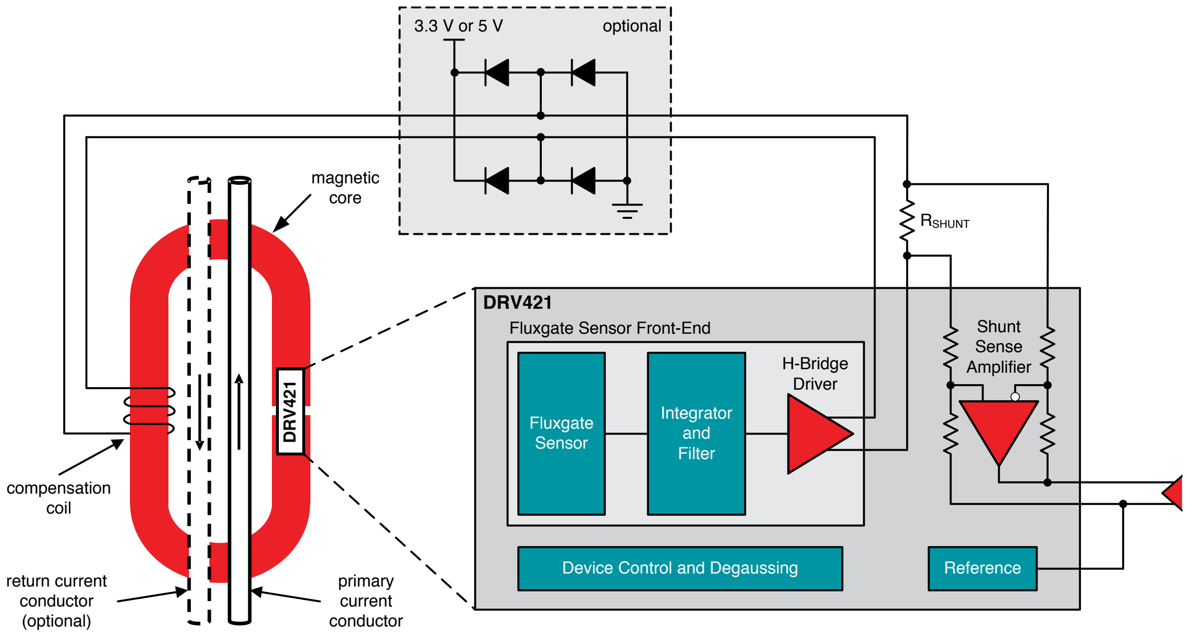

***Figure 3**. The Förster-type fluxgate includes two parallel magnetic cores and three sets of interwound solenoid coils.*

and in-depth development support for the devices helps simplify the design process.

Equipment manufacturers use TI's digital and analog Hall effect sensors for position, speed and acceleration detection, object recognition, index counting and other applications. Selections offer robust protection, with best-in-class operating voltages up to 38 volts (V) and temperature up to 175°C. The recently released DRV5032 ultra-low-power sensor draws less than 1 microamp (µA), helping prolong charge life in battery-powered applications. Extremely small package options help reduce the bill of materials and board space for cost-optimized designs. Digital sensors offer latch, unipolar and omnipolar switch sensor functions, while analog sensors provide a linear output for bipolar sensing that is fully protected with reverse battery and load dump protection of up to 40 V. Reference design and evaluation modules (EVMs) that speed development time with TI's Hall effect sensors include an incremental rotary encoder using contactless magnetic sensing in vehicles, a 24-V brushless DC outrunner motor with closed-loop speed control, and low-power magnetic tamper detection.

To achieve the industry's highest resolution in on-chip magnetic sensing, TI has developed fluxgate sensor products based on a unique manufacturing process. These fluxgate sensors lend themselves to high-voltage uses and are well suited for precise applications such as motor control and battery monitoring. TI selections provide open- and closed-loop options with integrated signal conditioning, degauss and diagnostic features. Time-saving reference designs and EVMs provide accurate measurement for three-phase inverter currents up to 150 A (maximum), a ±100-A bus bar current sensor for single-supply open-loop current sensing, and a displacement sensor with non-isolated high-side current and voltage sensing.

**Typical Application**



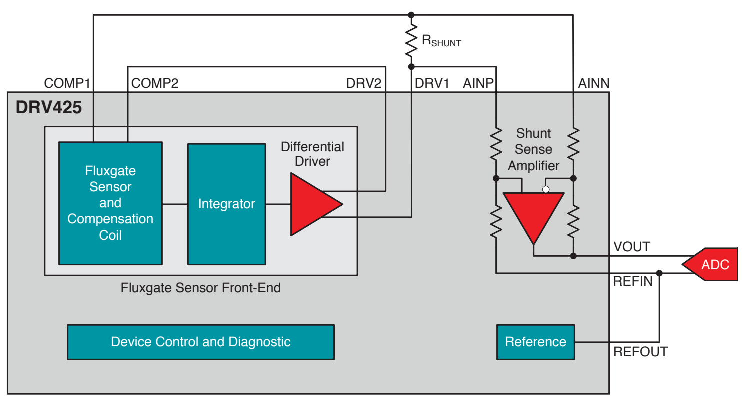




***Figure 4**. High-resolution DRV421 and DRV425 integrated fluxgate magnetic sensors simplify closed- and open-loop current-sensing designs.*

**Figure 4** illustrates the extent of internal integration in two of TI's fluxgate sensors, the DRV421 and DRV425, plus how these devices are tailored for use in closed- and open-loop designs.

The technology at the heart of these products was developed by TI to enable the production of the industry's first current-sensing IC with a fully integrated fluxgate device and compensation coil driver. Complementing the sensing element itself are novel excitation and readout circuits created for high-precision measurements. An innovative technology requires advanced characterization methodologies, which were specifically developed for the stand-alone fluxgate device using a conventional method of extracting the second-order harmonic at the sensor output.

## A future of magnetic sensing

Magnetic sensing is increasingly important in almost all fields of electrically operated systems. Vehicles, industrial equipment, medical diagnostics, home and office appliances, personal electronics—these and other applications are rapidly adopting magnetic sensors for sensing position, speed, current, and measurement of a variety of other conditions. Magnetic sensors provide precise, reliable output that is extending the reach of developers in many directions.

TI's innovative analog technology differentiates the company's Hall effect sensor products by providing exceptionally high-voltage and low-current operation. The company's analog technology also enabled the industry's first integrated fluxgate sensors for outstandingly high-resolution output. TI's wide range of other products makes possible a great variety of multi-functional integrated sensing solutions in the future to meet our customers' requirements. With the breadth and depth of TI's process technology, manufacturing and design expertise at work to develop new sensing solutions, the future of sensing promises to be magnetic.

## For more information, check out:

- TI's DRV5032 ultra low power sensor
- TI's DRV421 and DRV425 fluxgate sensors
- TI's complete sensing product portfolio

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