Magnetoresistive Current Sensor Improves Motor Drive Performance

A new coreless, wireless magnetoresistive current sensor reduces the required PCB footprint area and offers performance superior to that of standard open-loop and closed-loop Hall effect based current sensors.

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As motor drive electronics continue to decrease in size and cost, the need for small, low-cost, high-performance, noise-immune current sensors dramatically increases. Design engineers used to have three choices for measuring current: resistive shunt, current transformer and Hall Effect based sensors. The shunt works on the principle of Ohm's law; the current transformer and Hall effect sensors are based on Ampere's law. Each technology has its own tradeoffs. Shunts offer low-cost DC and AC sensing but insert a voltage drop and do not provide isolation. Current transformers are also inexpensive and provide isolation, but work only for AC current. Hall effect based sensors, both open and closed-loop, provide isolation and DC to high-frequency (200 kHz) AC operation, but have limitations in cost, size, linearity, and temperature performance. Now, a new technology based on magnetoresistive sensing offers to improve on the high accuracy of Hall effect sensors while significantly reducing the size by eliminating the magnetic core required by the Hall based sensors.

Magnetoresistor

A magnetoresistor (MR) is a two-terminal device that changes its resistance with a change in magnetic field. The magnetoresistive effect has been known for more than 130 years; however, it is only in the last 30 years that advances in microelectronic thin film techniques allowed its practical use. Almost every conducting material exhibits some magnetoresistance. However, the magnetoresistive effect is particularly large in permalloys, which are nickel-iron alloys and other ferromagnetic materials. MR devices are very sensitive to magnetic fields, significantly more so than Hall sensors. A class of magnetoresistors with an even larger sensitivity than standard MR devices is known as Giant MagnetoResistors (GMRs), whose applications include products ranging from virtual reality position sensors to hard disk drive read/write heads.

MR and GMR devices change their resistance with magnetic fields parabolically, therefore, a magnetoresistor cannot detect magnetic field polarity. Magnetoresistors have other disadvantages including a limited linear range, poor temperature characteristics (2500 ppm/°C typical), a wide range of sensitivities from device to device, a magnetic memory, and high costs. These drawbacks for the most part discouraged their use in current sensors.

New Current Sensor Technology

Recent developments in magnetoresistive technology have provided breakthroughs that have minimized the MR disadvantages and capitalized on the high sensitivity of the devices. By Placing four highly symmetrical MR devices in a Wheatstone bridge configuration, the dependence on sensitivity and offset variability over temperature is eliminated. Individual MR devices still change over temperature, however, they all change at the same rate, yielding a zero net drift at the output of the bridge. This configuration adds the benefit of immunity to external homogeneous magnetic fields. Again, all the MR devices will sense the field and change, but the output of the bridge will remain unchanged. This is extremely important when measuring small magnetic field gradients in a noisy magnetic field environment. This fact, coupled with the high sensitivity of the MRs , allows a current sensor to be manufactured without a magnetic core. Typically, a magnetic core is required in Hall effect–based current sensors to both increase the flux density and shield the sensor from external fields. The additional flux density is required due to the lower sensitivity of Hall sensors. The MR design, has high sensitivity and is immune to external magnetic fields, therefore, does not need the core. The requirement for a magnetic core has several disadvantages: it is costly, large, adds nonlinearities, has a residual magnetism, and it limits the frequency response due to eddy current heating effects. By eliminating the core, these disadvantages are also eliminated. Figure 1 shows a schematic representation of the MR Wheatstone bridge in the current sensor.

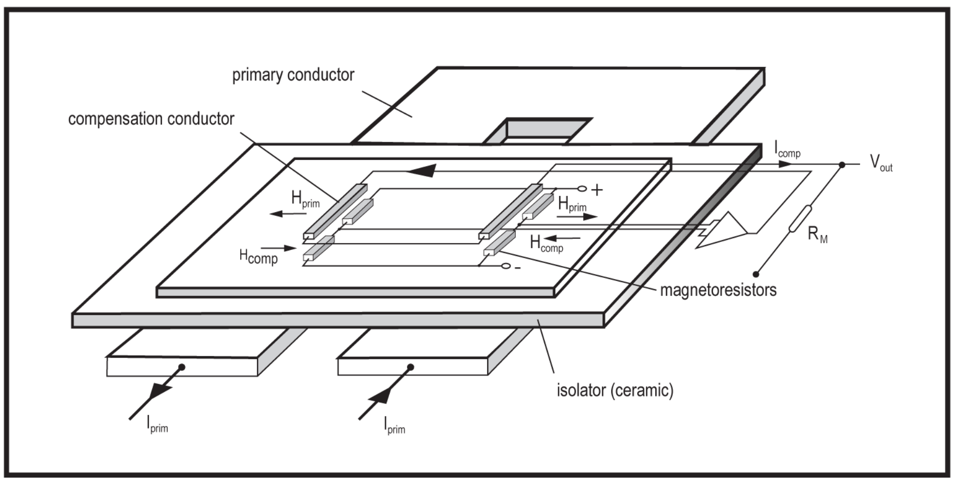

Figure 1. MR Wheatstone bridge, compensation and primary bus bar.

The limited linearity range and nondirectional ability of typical MR devices is solved by a process known as barberpole biasing, Barberpole biasing, so named because of the pattern on the conductive strips formed on the MR devices, effectively shifts the operation of the MR 45 degrees off center. Barberpole biasing works by altering the direction of the current through the device rather than changing the direction of the device's magnetization. This changing the angle of the magnetization field shifts the operation down the parabola, providing both a linear region and one that is sensitive to magnetic field polarity. If the barberpole biasing is placed at a –45° angle, the operating point shifts down the other side of the parabola (see Figure 2). This allows the manufacture of two MR devices side by side with opposite-direction barberpoles, resulting in one device increasing resistance while the other decreases resistance when both are exposed to the same magnetic field.

Barberpole biasing does introduce some disadvantages. First, due to the conducting nature of the barberpole strips, the area of the MR device is partially shorted, lowering its sensitivity. Second, the direction of the device's magnetization can switch if exposed to a high field in the opposite direction of the easy axis. This inverts the slope of the resistance change with respect to the magnetic field, which causes the Wheatstone bridge to no longer function properly. This effect is eliminated by placing biasing magnetics next to the Wheatstone bridge, that increase the field in the direction of the easy axis. The addition of the biasing magnets lower the sensitivity of the Wheatstone bridge, but increase the linear operating range. Figure 3 shows this graphically, with the magnetic field H, coming from the biasing magnets.

The actual physical placement of the four MR devices is extremely critical. The devices are measuring gradient fields which change inversely proportional to the distance and the square of the distance from the source of the magnetic field. This requires exact positioning of the MR devices with respect to the current-carrying conductor to be measured. The actual devices must match each other in sensitivity and all temperature drifts, which typically requires the devices to be deposited in close proximity. To eliminate the effects of any temperature gradients over the substrate, the devices need to be close to each other. The direction of the deposited barberpoles in each MR is another critical placement issue. The MR devices can be arranged to maximize the Wheatstone bridge output. This is accomplished by directing the barberpoles so that the output of one leg of the Wheatstone bridge increases while the other decreases, effectively doubling the sensitivity.

The output of the MR Wheatstone is connected to the input of an operational amplifier that is connected as a difference amplifier. This amplifier in turn drives a push-pull output stage consisting of a matched bipolar junction transistor pair.

This output stage in turn drives the compensating current loop to drive the flux gradient to zero. The current required to null the flux is the output, with a laser-trimmed resistor converting this current to a voltage. The pinout of the current sensor is shown in Figure 4. Figure 5 shows the available family of devices ranging from 5 to 50A.

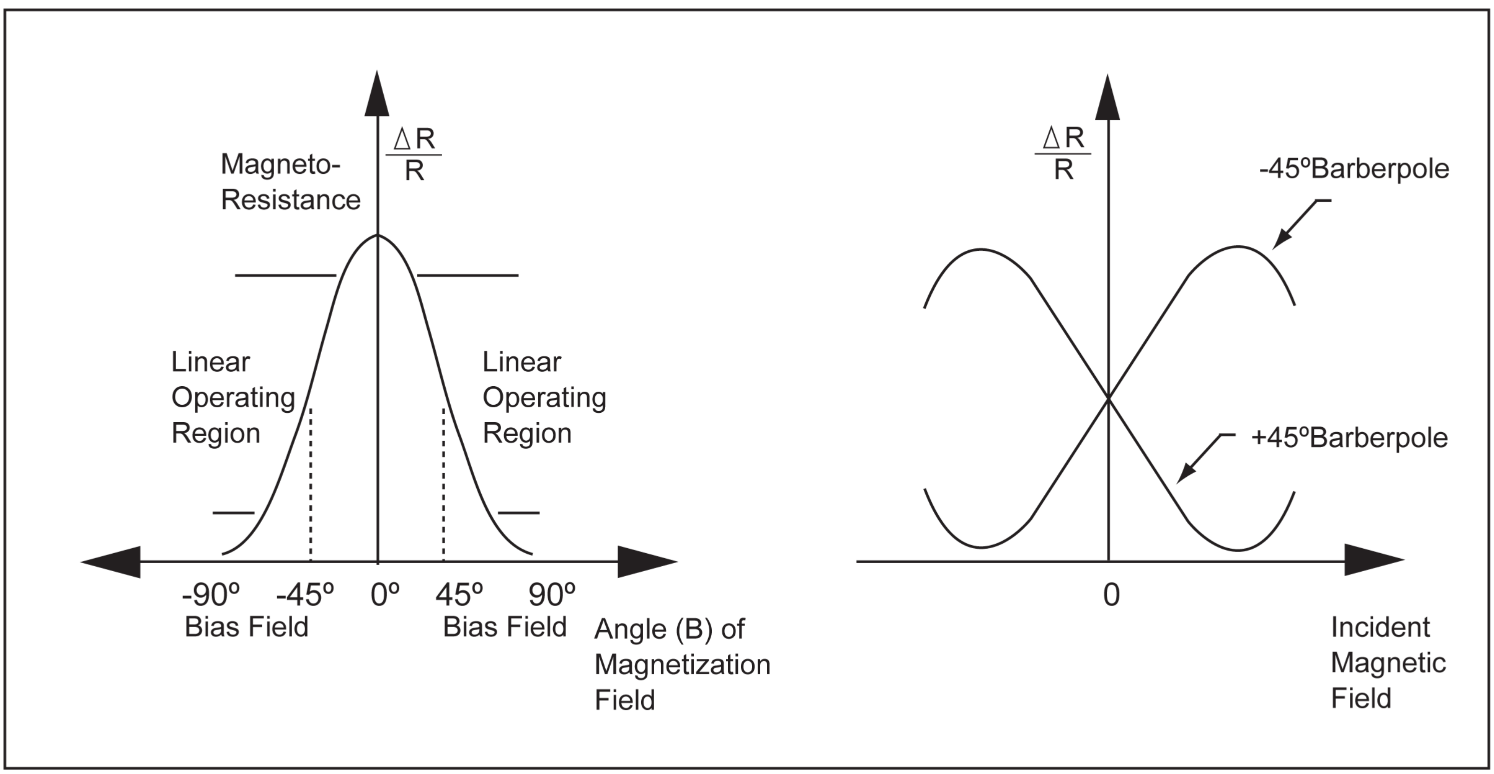

Figure 2. Effects of placing barberpoles on the MR device. Depending on the orientation of the barberpoles, the resistance can increase or decrease with increasing magnetic field.

Application

The small size, speed of response, low cost, and linearity make the magnetoresistive current sensor a great solution for current regulation of a miniature, 50 W maximum, three-phase brushless motor PWM controller.

The current sensor monitors the current on the +24 VDC bus. The output of the sensor feeds into a comparator that compares it to a voltage set by a digital/analog converter (DAC). The DAC essentially controls the torque of the drive by determining when the comparator triggers with respect to the current being sensed. The output of the comparator controls the commutation control circuit, which fires the gates of the three pairs of MOSFETs that drive the motor. When the DAC voltage is equal to the motor drive current, the comparator (via the controller) controls the firing of the drive transistors, which can increase the torque, maintain it, or decrease it. The current sensor thus acts both as a feedback element for torque control and as a fault condition monitor.

Other applications of the NT magnetoresistive current sensor in motor drives include conveyor systems, storage/retrieval systems, precision measurement systems, automated guided vehicles, elevators/escalators, pick-and-place machines, winding machines, and stamping and indexing equipment. The NT current sensor may also be used in uninterruptible power supplies (UPS), circuit breakers, and a variety of other load monitoring applications.

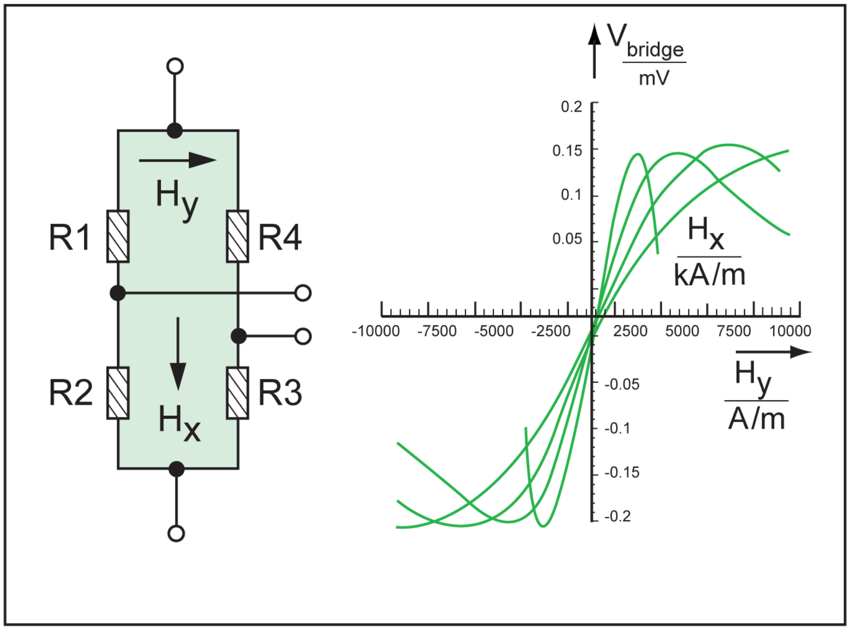

Figure 3. Biasing Magnetic Field H_X from the permanent magnet helps increase the linear region of operation while decreasing device sensitivity.

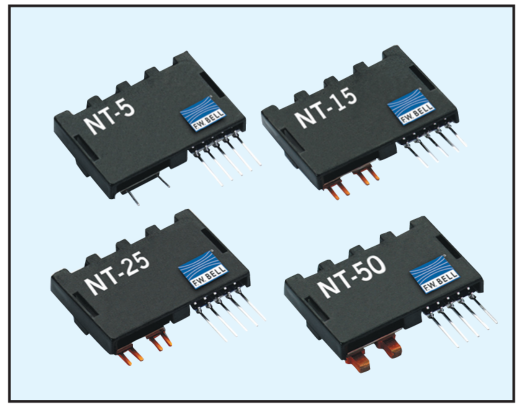

Figure 5. Commercially available magnetoresistor based current sensors ranging from 5 to 50A.

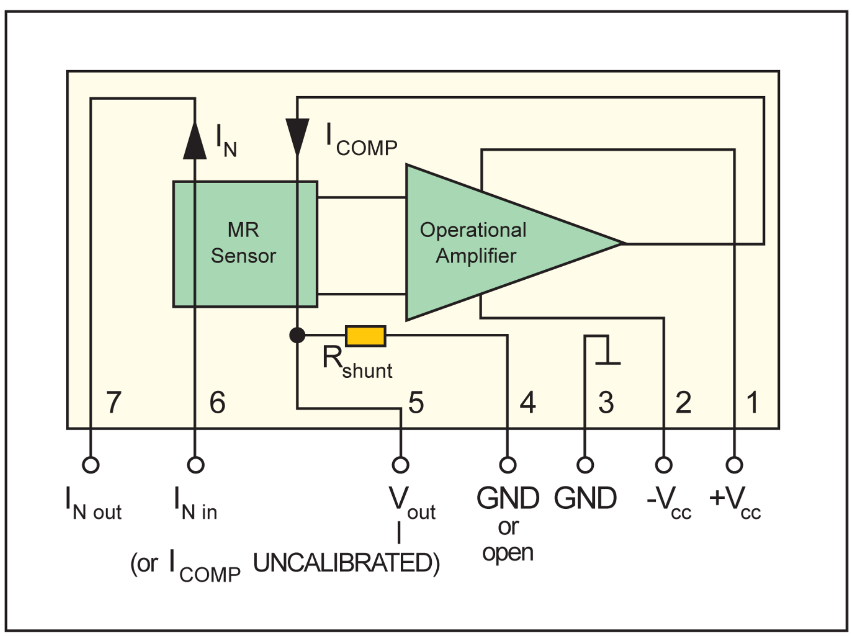

Figure 4. Magnetoresistive Current Sensor

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