Chapter 9

Application-Specific Sensors

Many applications require the use of some support electronics in addition to a digital or linear type of sensor. If an application presents a sufficiently high manufacturing volume for a sensor requiring auxiliary electronics, it is often cost-effective to integrate those electronics onto the IC along with the sensor. An integrated circuit targeted towards a particular application is usually referred to as an application-specific integrated circuit, or simply an ASIC. The geartooth sensors described in Chapter 8 are examples of ASICs designed to sense spinning targets. The ICs described in this chapter are all designed to solve particular and unique problems.

9.1 Micropower Switches

User-interface controls, such as buttons and switches, increasingly control logic-level signals as opposed to directly controlling high-power loads such as motors. In low-current logic-level applications, however, mechanical switches exhibit surprisingly low reliability. Switching-current levels ranging from microamperes to milliamperes do not cause enough arcing to clean oxides from switch contacts. Additionally, logic-level voltages (3–5V) are not especially effective at breaking down oxide layers on switch closure. As a result, a mechanical switch that performs well when directly switching a power load may fail prematurely when used as a logic-level control.

Hall-effect sensors, in combination with an actuator magnet, can be used to make high-reliability user-interface controls. Since there are no contacts to corrode or wear, and no moving parts other than the actuator magnet assembly, it is possible to build logic-level controls with high expected mean-time-to-failure.

One drawback of using Hall-effect devices, however, is their relatively high current drain. A mechanical switch requires essentially zero current when not switched on. A Hall-effect switch may require 5 mA. While this may not be an issue if the control is going into a piece of line-powered equipment, for battery-powered devices low current drain is of paramount importance. For example, a typical 9V alkaline battery may be rated at about 500 mA-hours, meaning that it can deliver 1 mA for 500 hours (or 10 mA for 50 hours) before being drained. A Hall-effect sensor consuming 5 mA could only be operated for about 100 hours from this battery, or just a little over 4 days. This might not be a problem if these 100 hours represented "usage" time for the device. If the Hall-effect sensor, however, is the ON/OFF switch for the device, having to change the batteries every 4 days, whether or not the device is actually being used, would be a real problem. A battery-replacement schedule this frequent would almost certainly make the device impractical as a product.

One solution to the problem of current drain was presented in Chapter 5, which is to power the device only when you need to look at the output. While only a small amount of electronics is needed to perform the actual power switching, the electronics necessary to control the power-cycling and retain the output state of the Hall-effect sensor can be considerably more costly. The additional cost to power-cycle the sensor will often make this solution prohibitively expensive for many consumer applications.

Because portable battery-operated applications are becoming increasingly popular, a significant market has emerged for low-power Hall-effect sensors. For this reason, several manufacturers now offer micropower Hall-effect devices. These devices operate by power-cycling the Hall-effect transducer and its associated bias and amplifier circuitry. Figure 9-1 outlines how this is done. A low duty-cycle pulse generator turns on the transducer, amplifier and threshold-sensing circuitry. On the falling edge of the pulse, the outputs of the threshold sensors are latched.

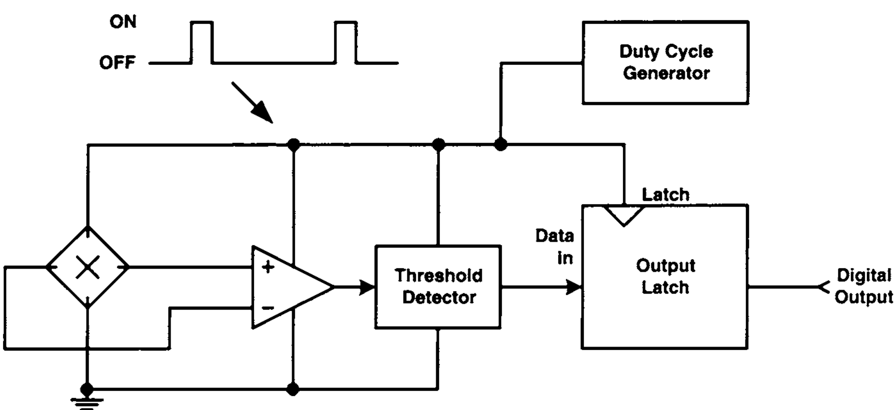

Figure 9-1: Schematic representation of power-cycled Hall sensor.

The Melexis MLX90222 is one example of a micropower Hall-effect switch. In this device, the Hall-effect transducer and amplifier are powered ON for 60 μsec (typical), during which a flip-flop is either set or reset based on whether the sensed magnetic field is greater than the device's magnetic operate point (B_{OP}) or lower than the release point (B_{RP}). In this ON state, the sensor IC draws about 0.7 mA of supply current. At the end of the ON state, the transducer and amplifier are then turned off for 40 ms (typical), after which the cycle repeats. While the transducer is in a powered-down state, the output state is maintained by a flip-flop, and the supply current is only about 10 μA. Because the total fraction of time spent in the ON state is only about 0.15%, the average current drain is only slightly higher that of the powered-down state.

Because the output state cannot be affected by changes in magnetic field when the sensor is powered down, the overall effect is like having the sensor take a "snapshot" of the applied magnetic field about 25 times a second. Another way of expressing this is that the sensor has a 25-Hz sampling rate. This is sufficiently fast for many types of user-interface controls. For a few user-interface devices, however, such as computer keyboards, a 40-ms response time may be sufficiently long to change the overall "feel" of the interface.

One application where a 25-Hz sampling rate would probably be unacceptable is where the device is used in conjunction with a ring magnet as a speed sensor. It is not difficult to envision situations where more than 25 poles/second are presented to the sensor. Even in cases where a few discrete magnets are used, the low sampling rate makes it easy for a magnet to "sneak by" the sensor undetected.

The Allegro A3210 also incorporates power-cycling circuitry, but includes an additional feature that makes it very easy to use as a replacement for magnetic reed switches. Where most Hall-effect switches turn on in response to a particular pole of a magnet, usually the south pole, the A3210 will switch ON in response to either a north or a south pole. This type of omnipolar behavior (the term "bipolar" is already taken) means that it doesn't matter which way you put the magnet into an assembly, since the sensor will turn on when either magnet pole approaches it. The magnetic response curve for this device is shown in Figure 9-2.

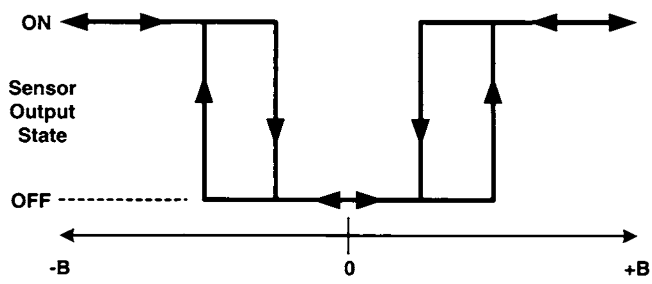

Figure 9-2: Hysteresis curve for omnipolar A3210.

The A3210's omnipolar behavior is extremcly valuablc when using the devices in high-volume manufacturing environments, because it makes the assembly insensitive to magnet orientation. Many assemblies will use rod or bar magnets that are mechanically symmetric with respect to the poles, meaning they can fit into a larger assembly in two orientations. With traditional south-pole sensitive Hall-effect switches, one of these possible orientations will result in a nonfunctional assembly. Because the A3210 will respond to either pole, a bar magnet can be inserted into the assembly in either north-facing or south-facing orientations and the assembly will still function.

9.2 Two-Wire Switches

Transmitting data signals in the form of a current as opposed to a voltage often results in a higher immunity to external electrical noise sources. For this reason, signaling methods such as the "4–20 mA current loop" are popular in noisy environments such as factory floors. Another advantage of current-loop signaling is that if the sensor can be powered by a voltage applied across the transmission leads, only two wires (V+, V–) are required, as opposed to the VCC, GROUND, OUTPUT triad required by voltage-signaling schemes.

Both because of enhanced noise immunity, and the economies offered by saving a wire, numerous automotive applications are moving to two-wire signaling schemes. Consequently, several Hall-effect sensor vendors are now providing integrated two-wire Hall-effect switches.

While one can convert a standard three-wire type of Hall switch into a two-wire device through the addition of external circuitry, there are various drawbacks to this approach. In the simplest case, a resistor may be tied between VCC and OUTPUT, as shown in Figure 9-3. When the device switches ON, the resistor is pulled to ground by the device's output, and draws additional current. The magnitude of this on-state current, however, will vary linearly with the supply voltage. While additional circuitry can be added to make the on-state current less supply-dependent, the additional components can get expensive, and this also has no effect over the off-state current, which will be dependent on the quiescent current of the sensor.

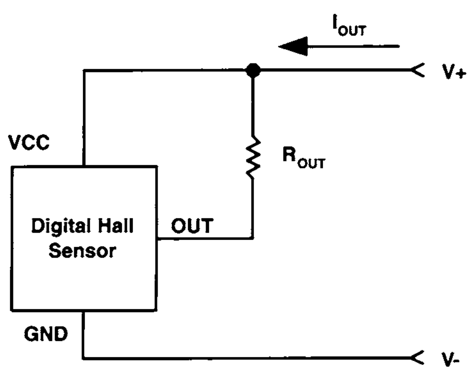

Figure 9-3: Converting a three-wire Hall-effect switch into a two-wire switch.

Two-wire integrated Hall sensors, on the other hand, provide well-specified on-state and off-state currents. This makes it much easier to design interface circuits that can reliably read their state despite power supply, temperature and manufacturing variation. The Melexis 90223 is an example of a two-wire Hall-effect switch. A functional block-diagram representation of this part is shown in Figure 9-4.

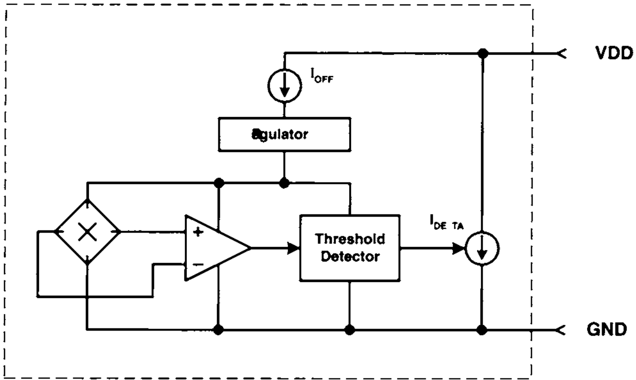

Figure 9-4: Melexis MLX90223 two-wire Hall-effect switch.

When no field is applied to the device and it is in the on-state, the current drawn through the VCC terminal ranges from 3.9 to 6.9 mA. When the applied magnetic field exceeds B_{OP} (60 gauss typical), the output current source is switched on, increasing the current drawn from the VCC terminal to between 11 and 19.4 mA.

A simple circuit for interfacing to a MLX90223 is shown in Figure 9-5. The output of this circuit is compatible with TTL or CMOS logic inputs. A 51Ω resistor is used to convert the supply current to a voltage. This voltage is then fed to a comparator, where it is compared to a threshold voltage equivalent to 9 mA of current (9 mA × 51Ω = 459 mV). This represents a value halfway between the maximum off-state current level (6.9 mA) and the minimum on-state current level (11 ma).

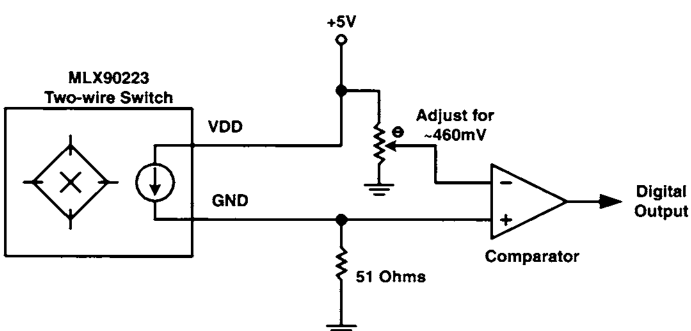

Figure 9-5: Circuit for interfacing to a MLX90223 two-wire switch.

In an actual application and depending on the operating environment, one may wish to add additional circuitry to provide noise filtering and protection from electromagnetic interference (EMI) and electrostatic discharges (ESD). A small amount of hysteresis added to the comparator will reduce the degree to which false transitions occur at its output (due to various noise sources). Finally, with some modifications, mostly in the voltage supplied to the sensor and the level of the HIGH/LOW threshold, this circuit can be adapted for use with other two-wire sensors. Because two-wire systems are becoming increasingly popular, several Hall-effect IC suppliers now offer two-wire sensors. Table 9-1 shows a few of these offerings:

Table 9-1: Two-wire Hall-effect switches.

Supplier	Two-wire Switch Models
Allegro Microsystems	A3161, A3361, A3362
Melexis USA	MLX90223
Micronas	HAL556, HAL566

9.3 Power Devices

While methods of driving incandescent lamps and relays were outlined in Chapter 5, these approaches all require the use of external discrete components. While this is acceptable in many circumstances, the use of external components can result in a design that is both physically large and relatively expensive. The additional solder joints required can significantly reduce the reliability of a design.

The Allegro UGN5140 high-current Hall-effect switch provides a single-chip means of driving small lamp and electromechanical loads. It offers an open-collector output capable of sinking up to 600 mA. It also provides an integral fly-back diode, for use when driving inductive loads such as relays and solenoids. Figure 9-6 shows a schematic representation of the UGN5140.

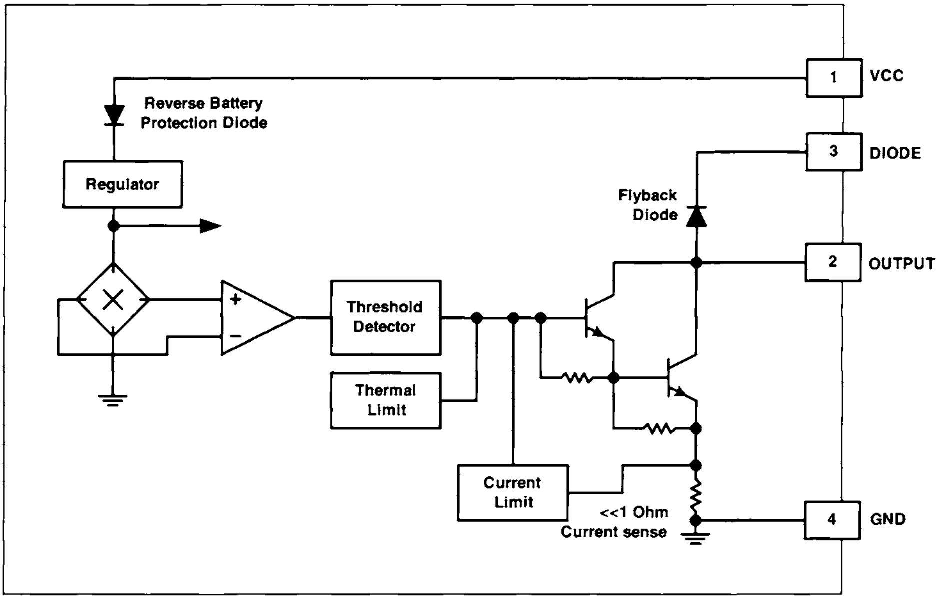

Figure 9-6: UGN5140 High-current Hall-effect switch.

The UGN5140 also provides two features that would be relatively difficult and costly to provide in a discrete power-driver. The first of these is output current limiting. In the event of a short-circuit or similar over-current condition on the output, the device will limit its output sink current to a preset threshold (typically 900 mA). This is useful when driving incandescent lamp loads (potentially several amperes), as it prevents the lamp cold-filament inrush current from damaging the sensor. The second feature is a thermal shutdown. If the internal die temperature of the UGN5140 exceeds 165°C (nominal), the sensor's output shuts off. Combined with output current limiting, this feature is useful in enabling the sensor to survive various types of output fault conditions, such as short circuits.

9.4 Power + Brains = Smart Motor Control

The Melexis US79 is an extreme example of an application-specific Hall IC in that it was designed to perform only one job: to provide control and power-driver functions for a small 2-winding brushless DC motor. This type of motor is commonly used in the cooling fans found in virtually all personal computers. A typical DC brushless fan, disassembled to expose the motor. Hall sensor, and drive electronics, is shown in Figure 9-7.

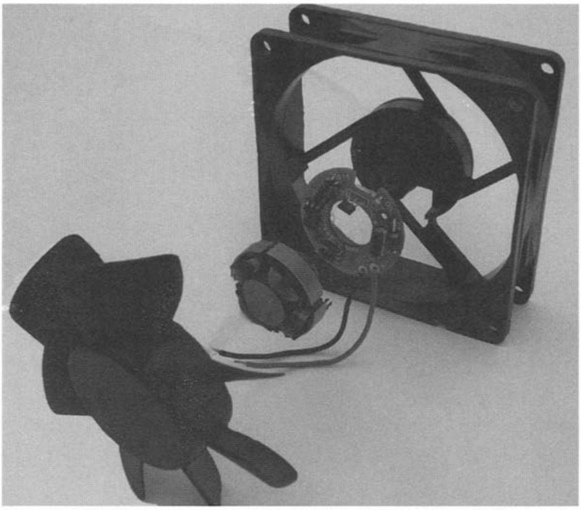

Figure 9-7: DC brushless fan using Hall-effect sensor (photo courtesy of Melexis USA).

Brushless DC motors operate by using several fixed windings to generate magnetic fields that move a magnet embedded in the rotor, causing the rotor to spin. To keep rotation continuous, the windings must be energized and de-energized at particular times depending on the position of the rotor. One way to do this is to use a Hall-effect sensor to detect the position of the rotor magnet. This information is then used to determine which winding to energize at any given time. This process of switching the windings on and off to make the motor spin is called *commutation*. Figure 9-8 shows a schematic of how the US79 is used to drive the two windings of a brushless fan. No other electronic components are required.

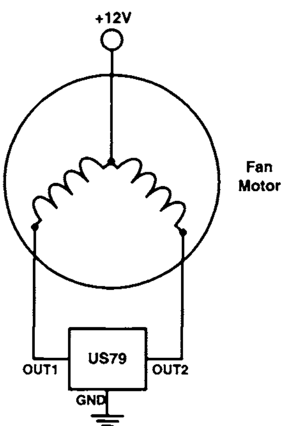

Figure 9-8: Schematic of US79 as used to drive small DC brushless motor.

Traditionally, in a brushless DC fan motor, commutation is performed with a Hall-effect sensor and numerous discrete components. While this approach works reasonably well, there are several areas for potential improvements, which are addressed by the US79. The first is component count reduction. While the cost of the individual components used in a discrete design may not be very much, for a high-volume item such as a cooling fan, even pennies count. Each discrete component used also adds assembly cost. Assembly costs in some cases can actually exceed the costs of the components. By replacing from 8 to 15 discrete components with a single device, the US79 can make the design more cost-effective.

A second advantage of a highly integrated solution like the US79 is increased reliability. Reducing component package count and the number of solder connections can greatly increase a system's mean-time-between-failures (MTBF). In an application like a computer cooling fan, the failure of the fan can cause subsequent additional failures of other components through overheating. So although the fan itself may be inexpensive and easily replaceable, subsequent failures of other parts may be considerably more costly, imposing high reliability requirements on the fan.

Finally, another advantage offered by an integrated solution over a discrete one is that significant intelligence can be placed on silicon in an IC at very little incremental cost. In the case of the US79, this includes the ability to recognize and appropriately respond to various fault conditions. For a DC fan, one of the most common failure modes is for the rotor to become mechanically jammed. This state is referred to as a *locked rotor* condition. If the commutation circuit keeps applying continuous power to a locked rotor, potentially hazardous overheating can occur, either in the motor windings or in the driver circuit. By being able to recognize a locked rotor condition, the US79 is able keep the fan from overheating. Additionally, the US79 will periodically try to restart the fan, so that if the fan rotor becomes freed, the fan will resume normal operation. Performing these functions with a discrete circuit would be complex and probably not economically feasible to implement in a device as cost-sensitive as a computer cooling fan.

This chapter has described a few of the application-specific Hall-effect sensors that are commercially available. As new applications are developed, there are sure to be many more new types of these devices offered in the future.