

# Chapter 2

# Hall Effect Sensors

## Introduction

The Hall effect was discovered by Dr. Edwin Hall in 1879 while he was a doctoral candidate at Johns Hopkins University in Baltimore. Hall was attempting to verify the theory of electron flow proposed by Kelvin some 30 years earlier. Dr. Hall found when a magnet was placed so that its field was perpendicular to one face of a thin rectangle of gold through which current was flowing, a difference in potential appeared at the opposite edges. He found that this voltage was proportional to the current flowing through the conductor, and the flux density or magnetic induction perpendicular to the conductor. Although Hall's experiments were successful and well received at the time, no applications outside of the realm of theoretical physics were found for over 70 years.

With the advent of semiconducting materials in the 1950s, the Hall effect found its first applications. However, these were severely limited by cost. In 1965, Everett Vorthmann and Joe Maupin, MICRO SWITCH Sensing and Control senior development engineers, teamed up to find a practical, low-cost solid state sensor. Many different concepts were examined, but they chose the Hall effect for one basic reason: it could be entirely integrated on a single silicon chip. This breakthrough resulted in the first low-cost, high-volume application of the Hall effect, truly solid state keyboards. MICRO SWITCH Sensing and Control has produced and delivered nearly a billion Hall effect devices in keyboards and sensor products.

## Theory of the Hall Effect

When a current-carrying conductor is placed into a magnetic field, a voltage will be generated perpendicular to both the current and the field. This principle is known as the Hall effect.

Figure 2-1 illustrates the basic principle of the Hall effect. It shows a thin sheet of semiconducting material (Hall element) through which a current is passed. The output connections are perpendicular to the direction of current. When no magnetic field is present (Figure 2-1), current distribution is uniform and no potential difference is seen across the output.

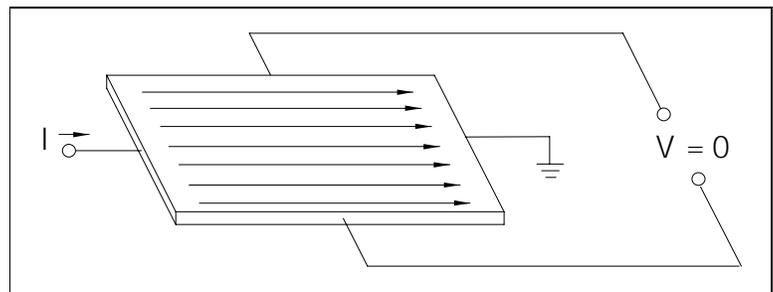


Figure 2-1 Hall effect principle, no magnetic field

When a perpendicular magnetic field is present, as shown in Figure 2-2, a Lorentz force is exerted on the current. This force disturbs the current distribution, resulting in a potential difference (voltage) across the output. This voltage is the Hall voltage ( $V_H$ ). The interaction of the magnetic field and the current is shown in equation form as equation 2-1.

$$V_H \propto \mathbf{I} \times \mathbf{B}$$

Formula (2-1)

Hall effect sensors can be applied in many types of sensing devices. If the quantity (parameter) to be sensed incorporates or can incorporate a magnetic field, a Hall sensor will perform the task.

## Chapter 2 • Hall Effect Sensors

The Hall voltage is proportional to the vector cross product of the current ( $I$ ) and the magnetic field ( $B$ ). It is on the order of  $7 \mu\text{v}/\text{V}_s/\text{gauss}$  in silicon and thus requires amplification for practical applications.

Silicon exhibits the piezoresistance effect, a change in electrical resistance proportional to strain. It is desirable to minimize this effect in a Hall sensor. This is accomplished by orienting the Hall element on the IC to minimize the effect of stress and by using multiple Hall elements. Figure 2-3 shows two Hall elements located in close proximity on an IC. They are positioned in this manner so that they may both experience the same packaging stress, represented by  $\Delta R$ . The first Hall element has its excitation applied along the vertical axis and the second along the horizontal axis. Summing the two outputs eliminates the signal due to stress. MICRO SWITCH Hall ICs use two or four elements.

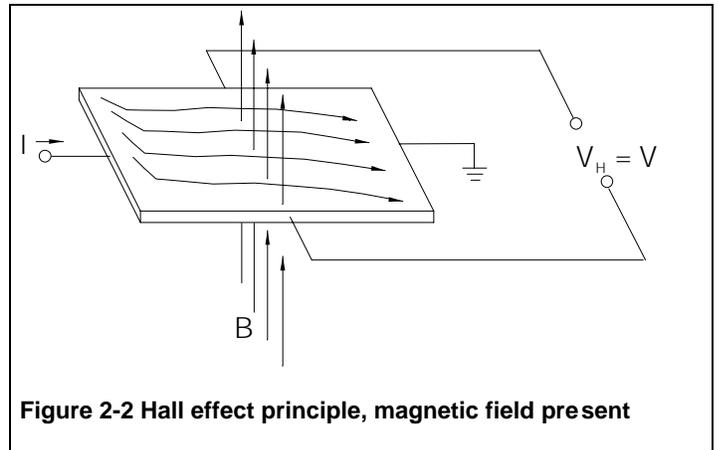


Figure 2-2 Hall effect principle, magnetic field present

### Basic Hall effect sensors

The Hall element is the basic magnetic field sensor. It requires signal conditioning to make the output usable for most applications. The signal conditioning electronics needed are an amplifier stage and temperature compensation. Voltage regulation is needed when operating from an unregulated supply. Figure 2-4 illustrates a basic Hall effect sensor.

If the Hall voltage is measured when no magnetic field is present, the output is zero (see Figure 2-1). However, if voltage at each output terminal is measured with respect to ground, a non-zero voltage will appear. This is the common mode voltage (CMV), and is the same at each output terminal. It is the potential difference that is zero. The amplifier shown in Figure 2-4 must be a differential amplifier so as to amplify only the potential difference – the Hall voltage.

The Hall voltage is a low-level signal on the order of 30 microvolts in the presence of a one gauss magnetic field. This low-level output requires an amplifier with low noise, high input impedance and moderate gain.

A differential amplifier with these characteristics can be readily integrated with the Hall element using standard bipolar transistor technology. Temperature compensation is also easily integrated.

As was shown by equation 2-1, the Hall voltage is a function of the input current. The purpose of the regulator in Figure 2-4 is to hold this current constant so that the output of the sensor only reflects the intensity of the magnetic field. As many systems have a regulated supply available, some Hall effect sensors may not include an internal regulator.

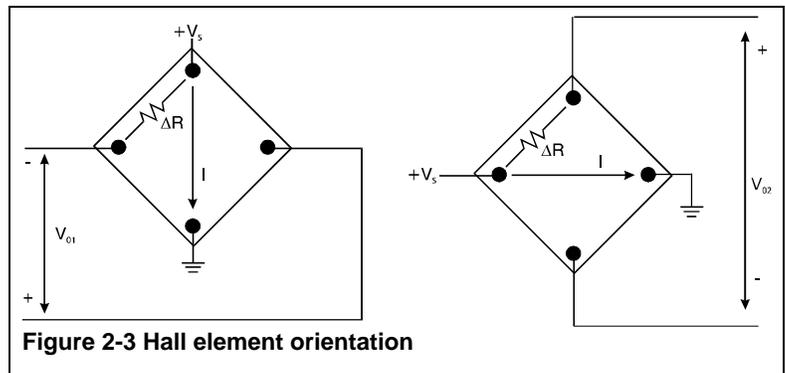


Figure 2-3 Hall element orientation

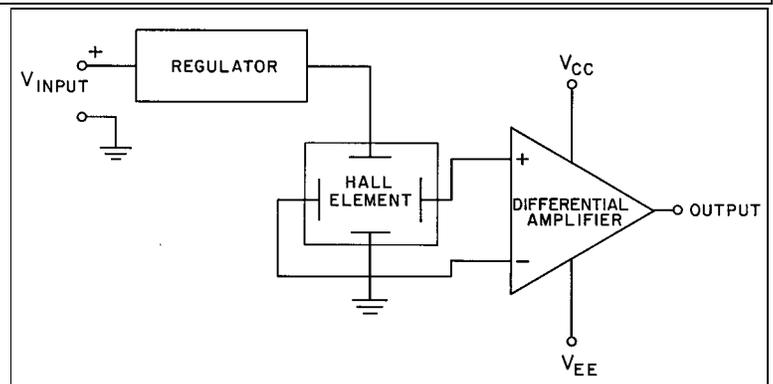


Figure 2-4 Basic Hall effect sensor

### Analog output sensors

The sensor described in Figure 2-4 is a basic analog output device. Analog sensors provide an output voltage that is proportional to the magnetic field to which it is exposed. Although this is a complete device, additional circuit functions were added to simplify the application.

The sensed magnetic field can be either positive or negative. As a result, the output of the amplifier will be driven either positive or negative, thus requiring both plus and minus power supplies. To avoid the requirement for two power supplies, a fixed offset or bias is introduced into the differential amplifier. The bias value appears on the output when no magnetic field is present and is referred to as a null voltage. When a positive magnetic field is sensed, the output increases above the null voltage. Conversely, when a negative magnetic field is sensed, the output decreases below the null voltage, but remains positive. This concept is illustrated in Figure 2-5.

The output of the amplifier cannot exceed the limits imposed by the power supply. In fact, the amplifier will begin to saturate before the limits of the power supply are reached. This saturation is illustrated in Figure 2-5. It is important to note that this saturation takes place in the amplifier and not in the Hall element. Thus, large magnetic fields will not damage the Hall effect sensors, but rather drive them into saturation.

To further increase the interface flexibility of the device, an open emitter, open collector, or push-pull transistor is added to the output of the differential amplifier. Figure 2-6 shows a complete analog output Hall effect sensor incorporating all of the previously discussed circuit functions.

The basic concepts pertaining to analog output sensors have been established. Both the manner in which these devices are specified and the implication of the specifications follow.

### Output vs. power supply characteristics

Analog output sensors are available in voltage ranges of 4.5 to 10.5, 4.5 to 12, or 6.6 to 12.6 VDC. They typically require a regulated supply voltage to operate accurately. Their output is usually of the push-pull type and is ratiometric to the supply voltage with respect to offset and gain.

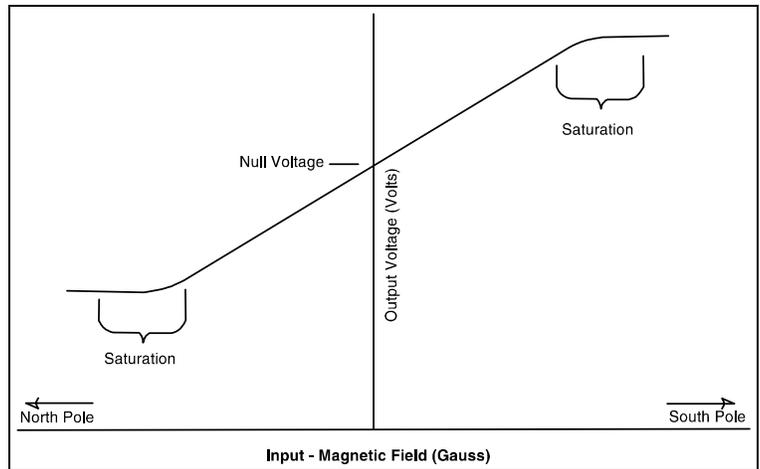


Figure 2-5 Null voltage concept

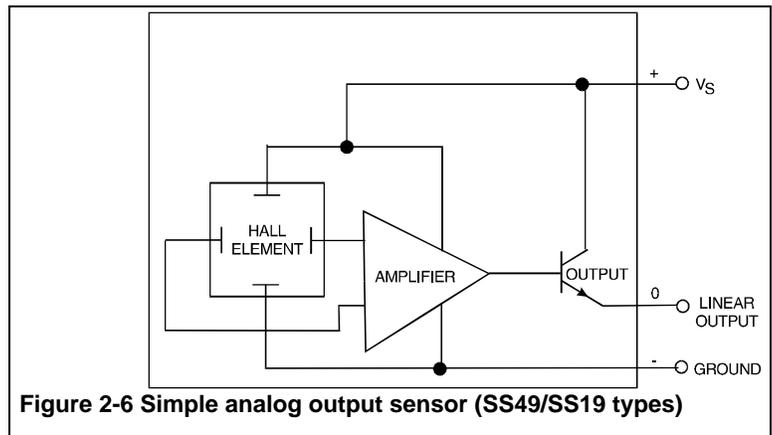


Figure 2-6 Simple analog output sensor (SS49/SS19 types)

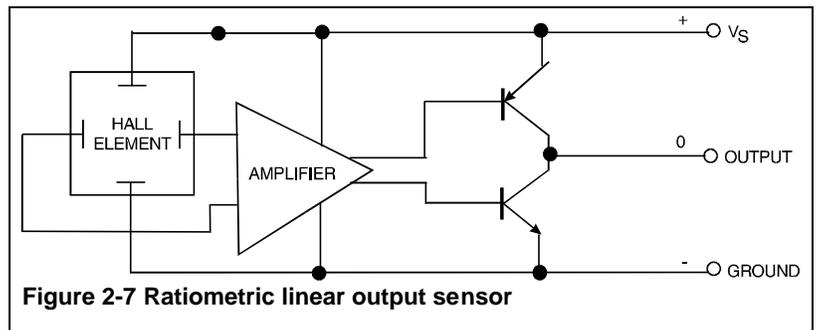


Figure 2-7 Ratiometric linear output sensor

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Figure 2-7 illustrates a ratiometric analog sensor that accepts a 4.5 to 10.5 V supply. This sensor has a sensitivity (mV/Gauss) and offset (V) proportional (ratiometric) to the supply voltage. This device has “rail-to-rail” operation. That is, its output varies from almost zero (0.2 V typical) to almost the supply voltage ( $V_s - 0.2$  V typical).

### Transfer Function

The transfer function of a device describes its output in terms of its input. The transfer function can be expressed in terms of either an equation or a graph. For analog output Hall effect sensors, the transfer function expresses the relationship between a magnetic field input (gauss) and a voltage output. The transfer function for a typical analog output sensor is illustrated in Figure 2-8.

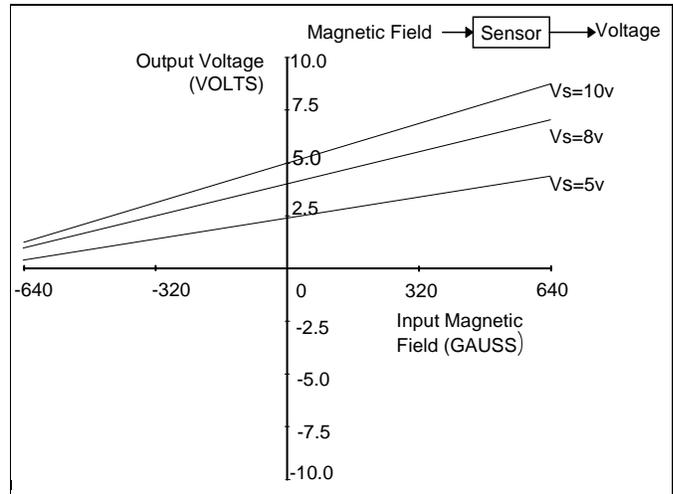


Figure 2-8 Transfer function . . . Analog output sensor

Equation 2-2 is an analog approximation of the transfer function for the sensor.

$$V_{out} \text{ (Volts)} = (6.25 \times 10^{-4} \times V_s)B + (0.5 \times V_s) \quad (2-2)$$

$$-640 < B(\text{Gauss}) < +640$$

An analog output sensor’s transfer function is characterized by sensitivity, null offset and span.

Sensitivity is defined as the change in output resulting from a given change in input. The slope of the transfer function illustrated in Figure 2-8 corresponds to the sensitivity of the sensor. The factor of  $\{B (6.25 \times 10^{-4} \times V_s)\}$  in equation 2-2 expresses the sensitivity for this sensor.

Null offset is the output from a sensor with no magnetic field excitation. In the case of the transfer function in Figure 2-8, null offset is the output voltage at 0 gauss and a given supply voltage. The second term in Equation 2-2,  $(0.5 \times V_s)$ , expresses the null offset.

Span defines the output range of an analog output sensor. Span is the difference in output voltages when the input is varied from negative gauss (north) to positive gauss (south). In equation form:

$$\text{Span} = V_{OUT} @ (+) \text{ gauss} - V_{OUT} @ (-) \text{ gauss} \quad (2-3)$$

Although an analog output sensor is considered to be linear over its span, in practice, no sensor is perfectly linear. The specification linearity defines the maximum error that results from assuming the transfer function is a straight line. Honeywell’s analog output Hall effect sensors are precision sensors typically exhibiting linearity specified as -0.5% to -1.5% (depending on the listing). For these devices, linearity is measured as the difference between actual output and the perfect straight line between end points. It is given as a percentage of the span.

The basic Hall device is sensitive to variations in temperature. Signal conditioning electronics may be incorporated into Hall effect sensors to compensate for these effects. Figure 2-9 illustrates the sensitivity shift over temperature for the miniature ratiometric linear Hall effect sensor.

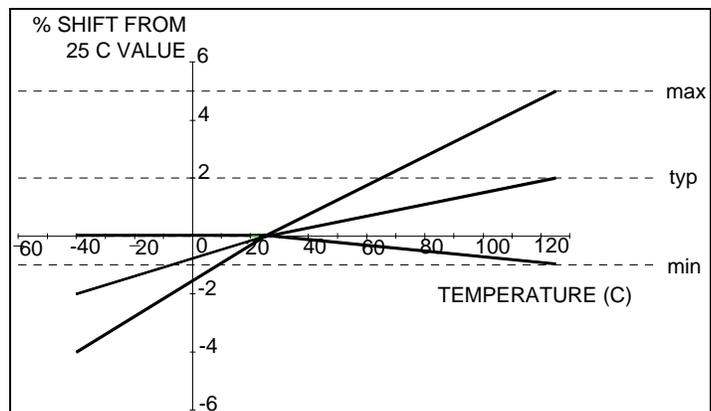


Figure 2-9 Sensitivity shift versus temperature

### Digital output sensors

The preceding discussion described an analog output sensor as a device having an analog output proportional to its input. In this section, the digital Hall effect sensor will be examined. This sensor has an output that is just one of two states: ON or OFF. The basic analog output device illustrated in Figure 2-4 can be converted into a digital output sensor with the addition of a Schmitt trigger circuit. Figure 2-10 illustrates a typical internally regulated digital output Hall effect sensor.

The Schmitt trigger compares the output of the differential amplifier (Figure 2-10) with a preset reference. When the amplifier output exceeds the reference, the Schmitt trigger turns on. Conversely, when the output of the amplifier falls below the reference point, the output of the Schmitt trigger turns off.

Hysteresis is included in the Schmitt trigger circuit for jitter-free switching. Hysteresis results from two distinct reference values which depend on whether the sensor is being turned ON or OFF.

### Transfer function

The transfer function for a digital output Hall effect sensor incorporating hysteresis is shown in Figure 2-11.

The principal input/output characteristics are the operate point, release point and the difference between the two or differential. As the magnetic field is increased, no change in the sensor output will occur until the operate point is reached. Once the operate point is reached, the sensor will change state. Further increases in magnetic input beyond the operate point will have no effect. If magnetic field is decreased to below the operate point, the output will remain the same until the release point is reached. At this point, the sensor's output will return to its original state (OFF). The purpose of the differential between the operate and release point (hysteresis) is to eliminate false triggering which can be caused by minor variations in input.

As with analog output Hall effect sensors, an output transistor is added to increase application flexibility. This output transistor is typically NPN (current sinking). See Figure 2-12. The features and benefits are examined in detail in Chapter 4.

The fundamental characteristics relating to digital output sensors have been presented. The specifications and the effect these specifications have on product selection follows.

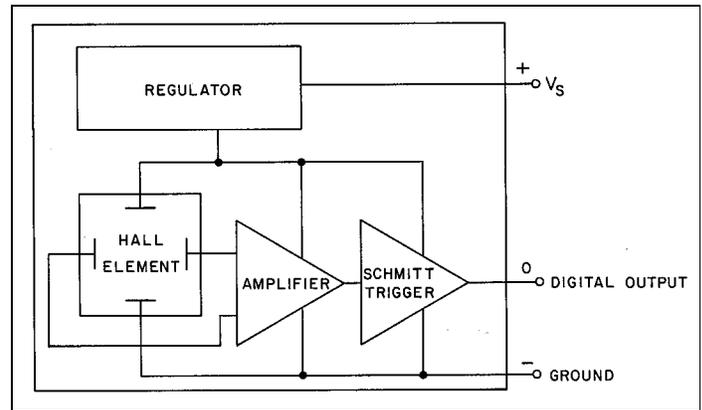


Figure 2-10 Digital output Hall effect sensor

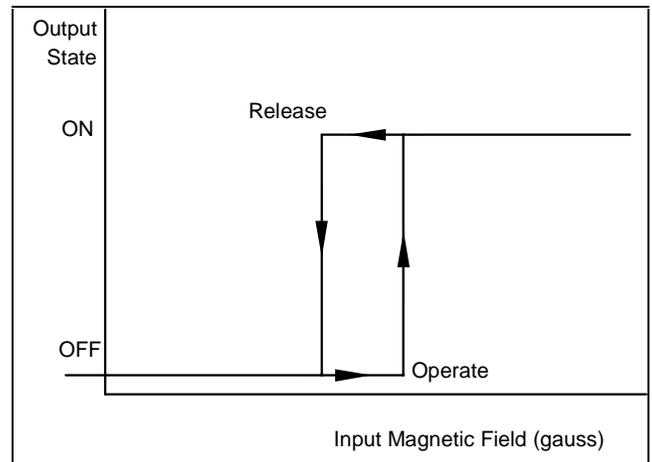


Figure 2-11 Transfer function hysteresis . . . Digital output sensor

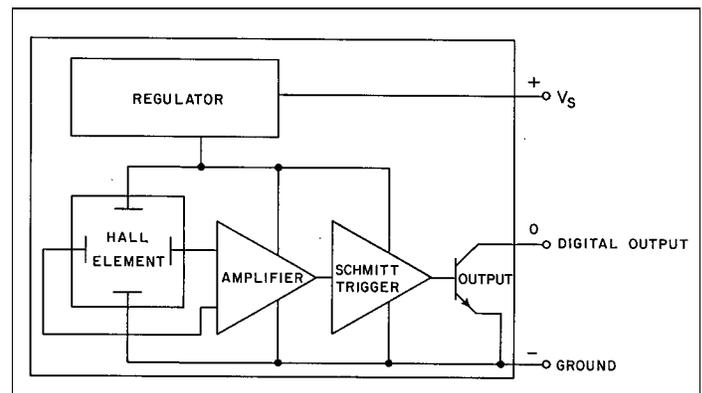


Figure 2-12 NPN (Current sinking) . . . Digital output sensor

**Power supply characteristics**

Digital output sensors are available in two different power supply configurations - regulated and unregulated. Most digital Hall effect sensors are regulated and can be used with power supplies in the range of 3.8 to 24 VDC. Unregulated sensors are used in special applications. They require a regulated DC supply of 4.5 to 5.5 volts ( $5 \pm 0.5$  v). Sensors that incorporate internal regulators are intended for general purpose applications. Unregulated sensors should be used in conjunction with logic circuits where a regulated 5 volt power supply is available.

**Input characteristics**

The input characteristics of a digital output sensor are defined in terms of an operate point, release point, and differential. Since these characteristics change over temperature and from sensor to sensor, they are specified in terms of maximum and minimum values.

Maximum Operate Point refers to the level of magnetic field that will insure the digital output sensor turns ON under any rated condition. Minimum Release Point refers to the level of magnetic field that insures the sensor is turned OFF.

Figure 2-13 shows the input characteristics for a typical unipolar digital output sensor. The sensor shown is referred to as unipolar since both the maximum operate and minimum release points are positive (i.e. south pole of magnetic field).

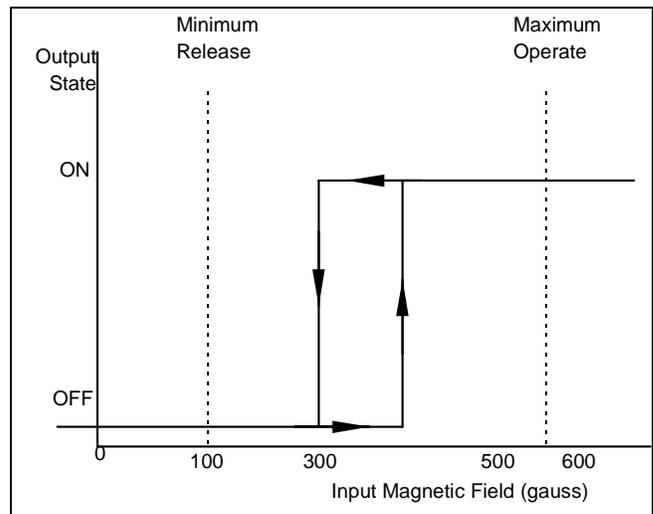
A bipolar sensor has a positive maximum operate point (south pole) and a negative minimum release point (north pole). The transfer functions are illustrated in Figure 2-14. Note that there are three combinations of actual operate and release points possible with a bipolar sensor. A true latching device, represented as bipolar device 2, will always have a positive operate point and a negative release point.

**Output characteristics**

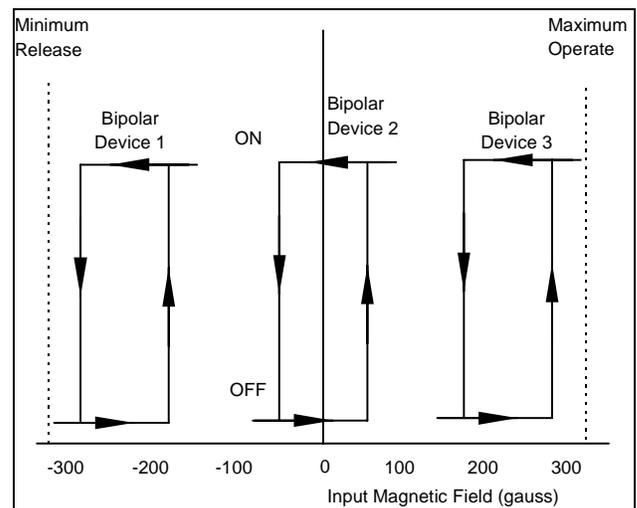
The output characteristics of a digital output sensor are defined as the electrical characteristics of the output transistor. These include type (i.e. NPN), maximum current, breakdown voltage, and switching time. The implication of this and other parameters will be examined in depth in Chapter 4.

**Summary**

In this chapter, basic concepts pertaining to Hall effect sensors were presented. Both the theory of the Hall effect and the operation and specifications of analog and digital output sensors were examined. In the next chapter, the principles of magnetism will be presented. This information will form the foundation necessary to design magnetic systems that actuate Hall effect sensors.



**Figure 2-13 Unipolar input characteristics . . . Digital output sensor**



**Figure 2-14 Bipolar input characteristics . . . Digital output sensor**

# Application Examples

## Introduction

This chapter presents a variety of customer applications as well as a variety of concept illustrations. These applications represent some of the most popular and effective ways of utilizing Hall effect sensing devices. However, the use of these products is far from being limited to these illustrations. In many cases, variations of the concept, may be used in other applications as well.

The following is a partial list of applications/products where MICRO SWITCH Hall effect sensors have been successfully applied.

## Digital output sensor applications

- RPM/speed detectors (motor control)
- Timing measurement (photographic equipment)
- Ignition timing
- Position sensors (as low as .002" detection)
- Pulse counters (printers, motor drives)
- Valve position sensors
- Joy stick applications
- Door interlocks
- Current sensing (motor control systems)
- Fan/damper detection
- Brushless DC motors
- Tachometer pick-up
- Flow meters (replaces reed switches)
- Relays (replaces elect/mech contacts)
- X/Y & indexing tables
- Proximity detectors
- Security (magnetic card or key entry)
- Banking machines (automatic tellers)
- Telecommunications (on/off hook detector)
- Pressure sensors
- Limit switches
- Lens position sensors
- Paper sensors
- Test equipment
- Shaft position sensors
- Vending machines
- Embossing machines

### Linear output sensor applications

- Current sensing
  - Disk drives
  - Variable frequency drives
  - Motor control protection/indicators
  - Power supply protection/sensing
- Position sensing
  - Pressure diaphragms
  - Flow meters
  - Damper controls
  - Brushless DC motors
  - Wiperless/contactless potentiometers
- Encoded switches
  - Rotary encoders
- Voltage regulators
- Ferrous metal detectors (biased Hall)
- Vibration sensors
- Magnetic toner density detection
- Tachometers

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### Flow rate sensor

Figure 7-1 illustrates a concept that uses a digital output bipolar sensor and magnets mounted to an impeller to measure flow rate for a water softener. In this design, the softener can be made to automatically recharge on demand, instead of on a timed basis. Demand is determined by measuring the amount of water that has passed through the softener. When a certain level is reached, the recharge cycle begins.

There are various methods for designing Hall effect flow meters, but the general principle is the same: each actuation of the sensor, by a magnet or by shunting the magnetic field, corresponds to a measured quantity of water. In the example shown, the magnetic field is produced by magnets mounted on the impeller blade. The impeller blade is turned by the water flow. The sensor produces two outputs per revolution.

Besides the immediate savings derived by the proper usage of the salt, this approach provides more reliability, and longer life and the assurance of a continuing supply of softened water.

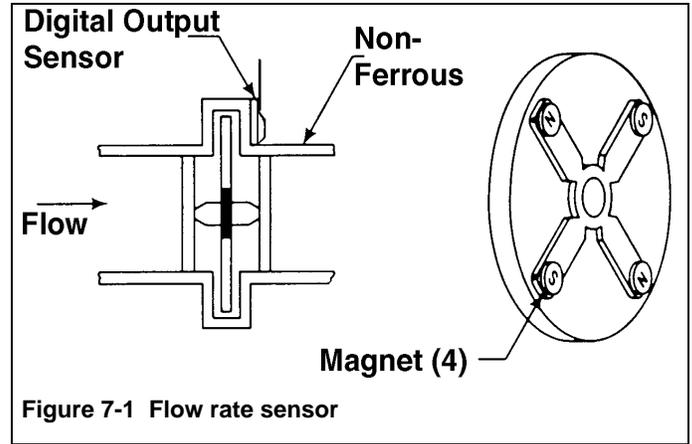


Figure 7-1 Flow rate sensor

### Sequencing Sensors

Sequencing and/or duration of a number of operations can be achieved by different kinds of mechanical configurations, as illustrated by Figure 7-2. In the first example, Figure 7-2A, a number of ferrous disks or cams are clamped to a common shaft. The disks are rotated in the gaps of Hall effect vane sensor. A disk rotating in tandem with its mate is used to create a binary code which can establish a sequence of operations. Programs can be altered by replacing the disks with others having a different cam ratio.

Operation is stated in terms of the position of the disk located in the gap with respect to the center line of the sensor. In the absence of the disk (a cut-out), flux from the magnet reaches the digital output sensor and the output is ON. When the disk material is in the gap, flux is shunted from the transducer and the output changes state.

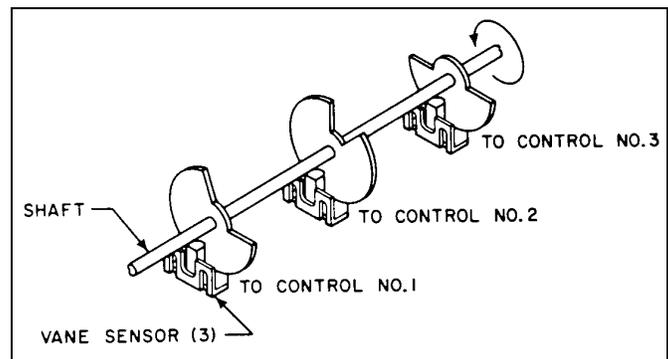


Figure 7-2A Cam-operated vane sensors

Another approach to establishing a series of events is illustrated by Figure 7-2B. Ring magnets are mounted on a rotating shaft. The outputs from the bipolar sensors can be varied by increasing or decreasing the number of pole-pairs on the ring magnets.

There are numerous configurations that could accomplish the sequencing/duration task. The possibilities are endless.

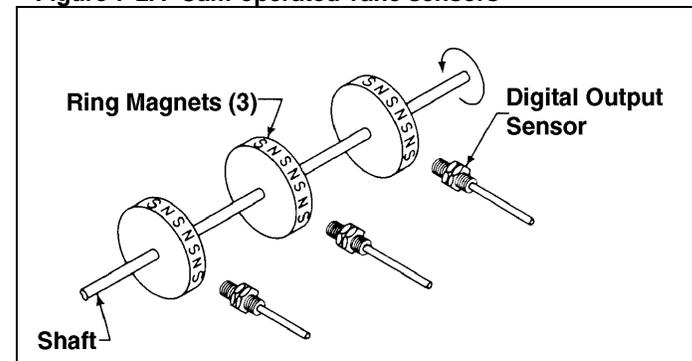


Figure 7-2B Ring magnet operated sensors

**Proximity sensors**

Figure 7-3 illustrates two concepts for developing a proximity sensor that can be used for accurate positioning. In the first example, Figure 7-3A, four digital output unipolar sensors are threaded into an aluminum housing and actuated individually by four magnetic actuators.

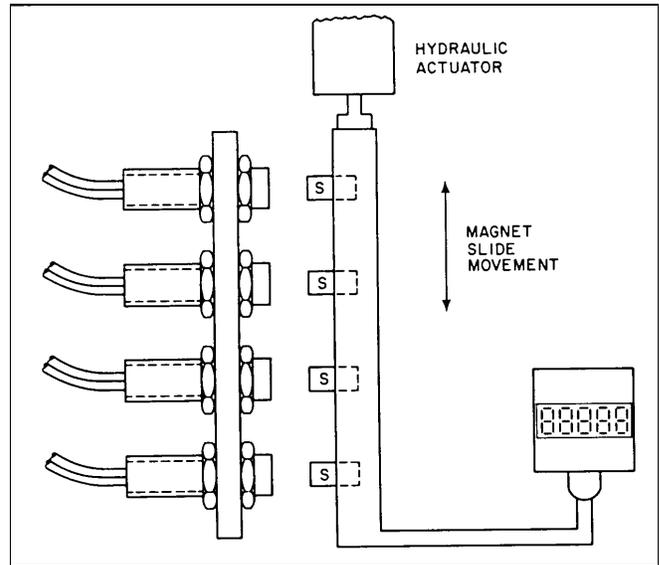
In use, event signals are generated by the sensors which represent distances measured from a reference surface. These signals define the acceptable dimensional limits between which the item under test must generate electrical pulses. In a known application, each of the sensors has accumulated at least 8 million operate/release cycles per month and is still operating, without replacement or maintenance.

In the second example, Figure 7-3B, four digital output bipolar sensors are actuated by one magnet mounted on a rod. Applications using this concept can achieve linear positioning accuracy of .002". Sensing various lens locations for photo-processing equipment is an ideal application for this concept. It could also be used to sense the precise location of a moving table for a 35mm slide mounter.

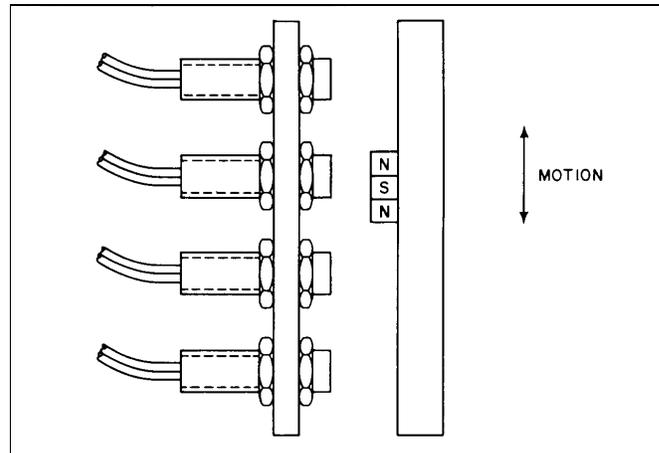
**Office machine sensors**

Office machines are being designed that operate more reliably than ever before. Copiers, fax machines, computer printers - anything in the office with moving parts.

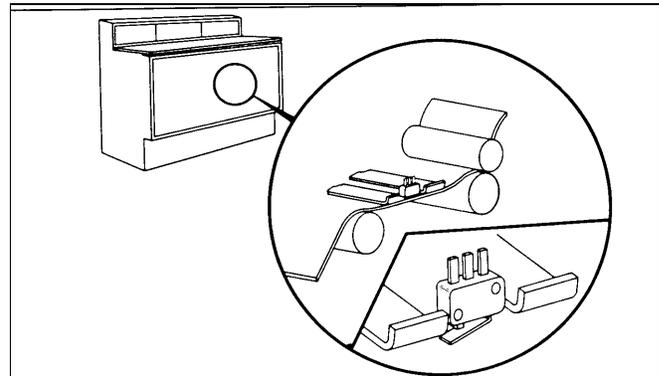
Figure 7-4 illustrates a concept using a mechanically operated Hall effect switch to detect paper flow. Advantages of this approach include: no contacts to become gummy or corroded; very low force operation; extremely long life and direct interface with logic circuitry.



**Figure 7-3A Proximity sensors**



**Figure 7-3B Proximity sensors**



**Figure 7-4 Paper detection sensor**

### Linear output sensor concepts

Linear output Hall effect sensors can provide mechanical and electrical designers with significant position and current sensing capabilities. These sensors combine a Hall effect integrated circuit chip with the state-of-the-art thick film technology. Linear output sensors can be used in a wide variety of sensor applications. Position sensing of cams, shafts, floats and levers, temperature sensing, current sensing, and circuit fault detection are just a few of the many possible applications.

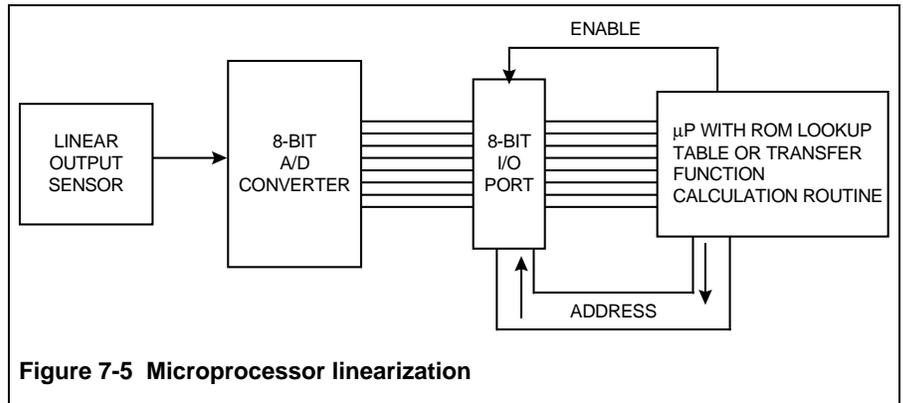


Figure 7-5 Microprocessor linearization

The output voltage of a linear sensor as a function of magnetic field (from a permanent magnet or an electromagnet) is linear, while the output voltage as a function of distance may be quite non-linear. Several methods of converting the voltage output of a linear sensor to one which compensates for the non-linearity of the magnetics as a function of distance are possible. One method of obtaining a linear relationship between distance and gauss is shown in Figure 7-5. This involves converting the analog output to digital form. The digital data is fed to a microprocessor which linearizes the output through a ROM look-up table, or transfer function computation techniques.

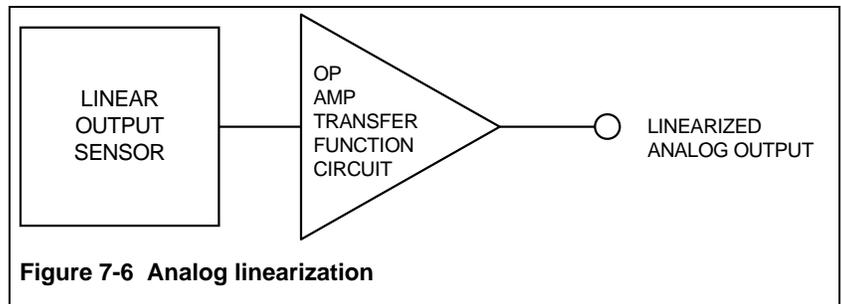


Figure 7-6 Analog linearization

Figure 7-6 diagrams a second method which involves implementing an analog circuit which has the necessary transfer function, to linearize the sensor's output.

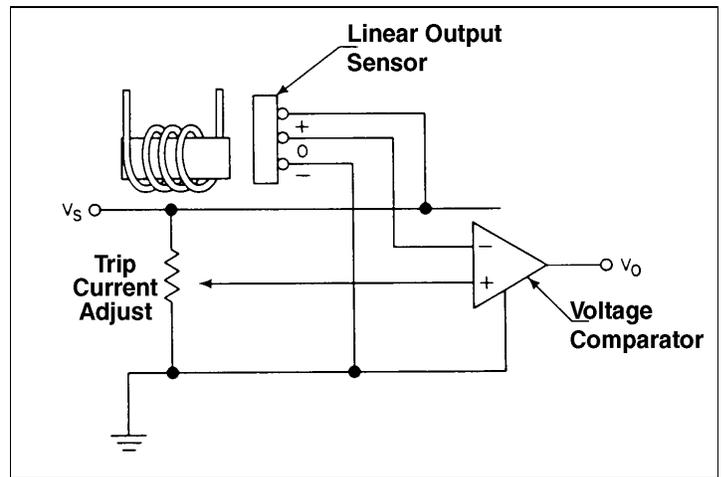


Figure 7-7 Adjustable current sensor

### Adjustable current sensor

Figure 7-7 illustrates a concept approach for an adjustable trip point current sensor used in welding equipment. In this example a toroid core and linear output sensor are combined with a remotely located voltage comparator to produce a precision digital output. The sensor's operate point could be made to vary by less than 20 gauss over the entire temperature range. Thus, a very accurate current sensor with high repeatability over a wide temperature range can be achieved without designing a complex magnetic system.

**Linear feedback sensor**

Linear output sensors have many possible applications where monitoring and linear feedback is needed for analog control systems. A typical application is in a mechanical system where position is controlled by an input voltage, or current sensing in a regulated current power supply. This concept is illustrated in Figure 7-8, where the position of the magnet carrier is automatically adjusted to correspond to the potentiometer setting.

Automated heating, ventilating, and air conditioning (HVAC), and process control are areas where sensors using the principles shown in Figure 7-8 can be used. By mounting a magnet in a valve actuator or damper, exact position can be determined.

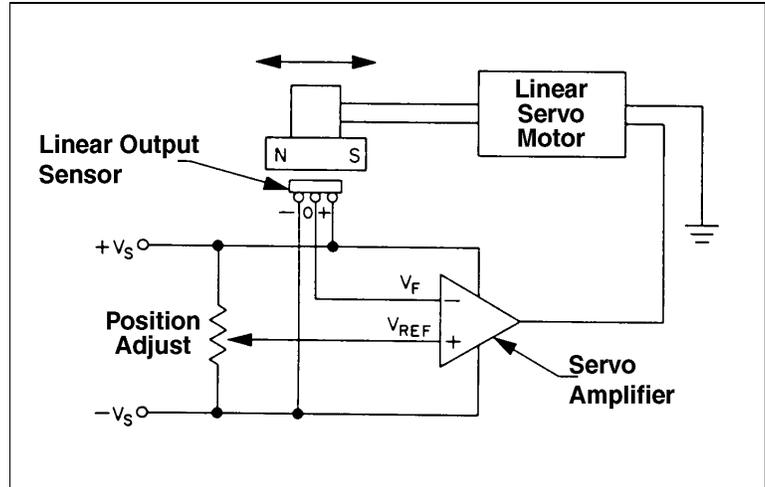


Figure 7-8 Linear feedback sensor for analog control systems

**Multiple position sensor**

Figure 7-9 illustrates how several positions or current levels can be sensed by using several voltage comparators with a linear output sensor. This allows convenient indexing of a mechanical device or current detection of several levels, such as normal current, slight overload, and short circuit. The position sensor shown in Figure 7-9 has three digital outputs, each indicating a different position of the magnet. A sensor of this type could be used in robot control to initiate a move fast, slow down, and stop command.

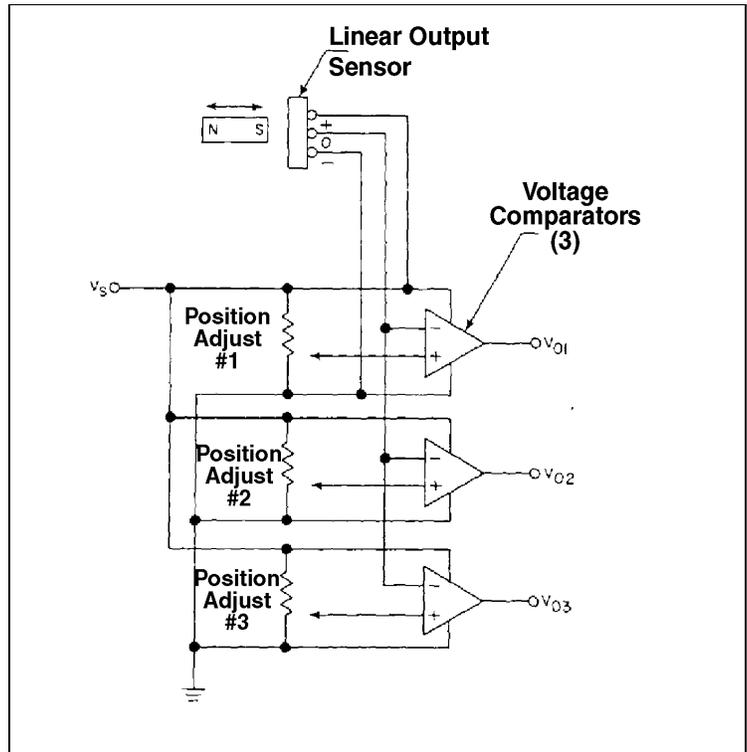


Figure 7-9 Multiple position sensor

### Microprocessor controlled sensor

Figure 7-10 illustrates a concept that combines a digital-to-analog converter and a voltage comparator with a linear output sensor to produce a programmable digital output sensor. A distinct advantage of this approach is that the sensor does not require constant monitoring by the microprocessor. Using data latches in the D/A converter, the microprocessor presets the value where an operation is to take place, then continues with other processing until the sensor/voltage comparator combination signals the microprocessor through the interrupt mode.

Sensors using this principle can be used in motor current monitoring. The monitor checks for overload, undercurrent, and phase failure, all under microprocessor control. The microprocessor allows programming of desired operate current levels and time delays. This approach allows operation over a wide dynamic range of currents without changing components such as heater elements, shunts, or current transformers.

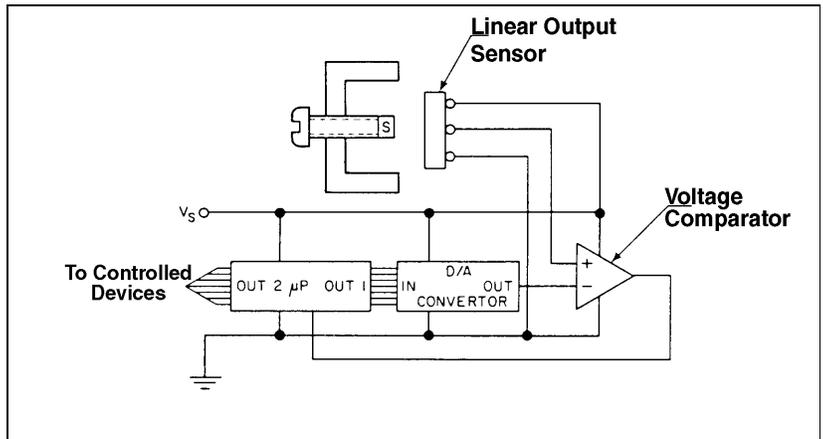


Figure 7-10 Microprocessor controlled sensor

### Anti-skid sensor

Figure 7-11 shows a possible solution for controlling the braking force of a wheel so that it doesn't lock-up. A biased Hall effect sensor is used. The sensor is positioned to sense an internal tooth gear. The gear could be the disk brake hub.

The reaction time of the braking system will determine the frequency of the signal as a function of wheel revolution.

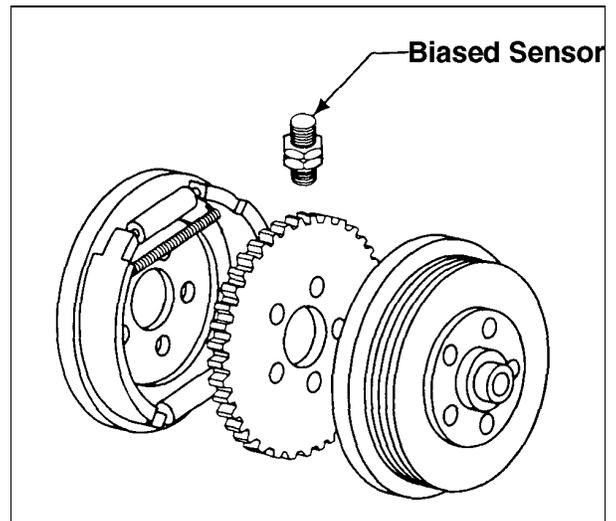


Figure 7-11 Anti-skid sensor

### Door interlock and ignition sensor

Figure 7-12 illustrates a concept approach that uses a digital output bipolar sensor to provide a signal that energizes the inside courtesy lights to provide an extra measure of safety.

A sensor is positioned so that a magnet rotates by it when the key is turned in the door lock. Ice, water and other problems associated with adverse environmental conditions are eliminated. This approach could also serve as an electrical interlock for the ignition system.

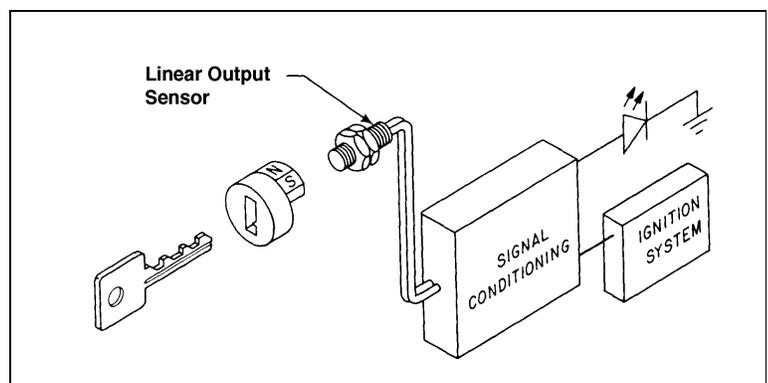


Figure 7-12 Door interlock sensor

### Transmission mounted speed sensor

Figure 7-13 illustrates a simple concept approach for designing a transmission speed sensor. A digital output bipolar sensor is actuated by sensing the magnetic field created by a rotating ring magnet driven by the speedometer output shaft. The frequency of the output signal is proportional to speed. Advantages of this approach are: the output signal is not affected by changes in speed, fast response, long life and high system reliability.

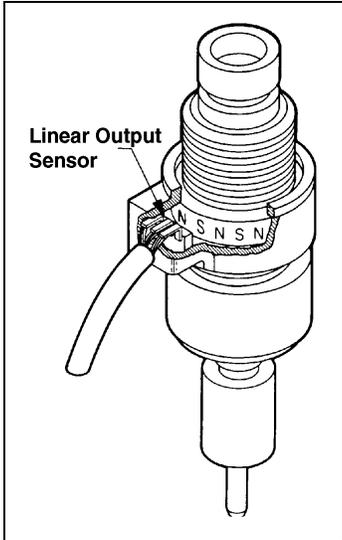


Figure 7-13 Speed sensor

### Crankshaft position or speed sensor

A temperature compensated  $-40^{\circ}\text{C}$  to  $+150^{\circ}\text{C}$  ( $-40^{\circ}\text{F}$  to  $302^{\circ}\text{F}$ ) vane operated sensor is mounted in the damper hub lip, as illustrated in Figure 7-14. The frequency of the output signal will be proportional to the speed of the crankshaft, even down to zero speed. Since the magnetic field is being interrupted, vibration, eccentricity and end play tolerance have little effect on the output signal. Notches in the lip can be used as timing marks to indicate the position of the crankshaft. Direct interfacing of the sensor to the on-board microprocessor adds additional reliability to the system.

### Distributor mounted ignition sensor

Figure 7-15 illustrated how the points in the distributor can be replaced by a vane operated sensor. A cup-shaped vane, with as many teeth as there are engine cylinders passes through a digital output vane sensor. The resultant logic level pulses trigger ignition system firing without the use of points. The major advantages of this approach are low speed operation (output signal not affected by changes in speed), fast response, simplified system design and high system reliability. Automotive ignition systems are one of the toughest applications with a temperature range of  $-40^{\circ}\text{C}$  to  $150^{\circ}\text{C}$  and 4.5 to 24 VDC voltage range.

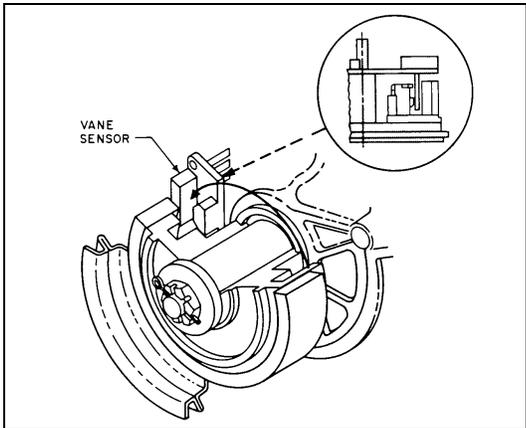


Figure 7-14 Speed sensor

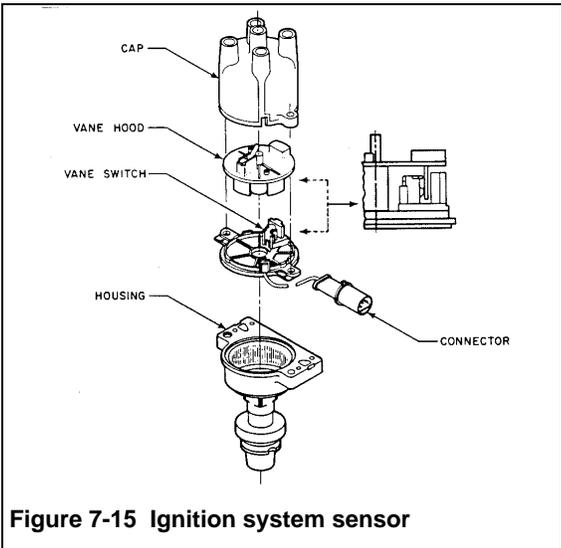


Figure 7-15 Ignition system sensor

### Level/tilt measurement sensor

A digital output unipolar sensor can be installed in the base of a machine with a magnet mounted in a pendulum fashion as illustrated in Figure 7-16. As long as the magnet remains directly over the sensor, the machine is level. A change in state of the output as the magnet swings away from the sensor is indication that the machine is not level. A linear output sensor/magnet combination could also be installed in such a manner as to indicate degree of tilt.

### Brushless DC motor sensors

Brushless DC motors differ from conventional DC motors in that they employ electronic (rather than mechanical) commutation of the windings. Figure 7-17 illustrates how this electronic commutation can be performed by three digital output bipolar sensors. Permanent magnet materials mounted on the rotor shaft operate the sensors. The sensors sense the angular position of the shaft and feed this information to a logic circuit. The logic circuit encodes this information and controls switches in a drive circuit. Appropriate windings, as determined by the rotor position, are magnetic field generated by the windings rotates in relation to the shaft position. This reacts with the field of the rotor's permanent magnets and develops the required torque.

Since no slip rings or brushes are used for commutation; friction, power loss through carbon build-up and electrical noise are eliminated. Also, electronic commutation offers greater flexibility, with respect to direct interface with digital commands.

The long maintenance-free life offered by brushless motors makes them suitable for applications such as; portable medical equipment (kidney dialysis pumps, blood processing equipment, heart pumps), ventilation blowers for aircraft and marine submersible applications.

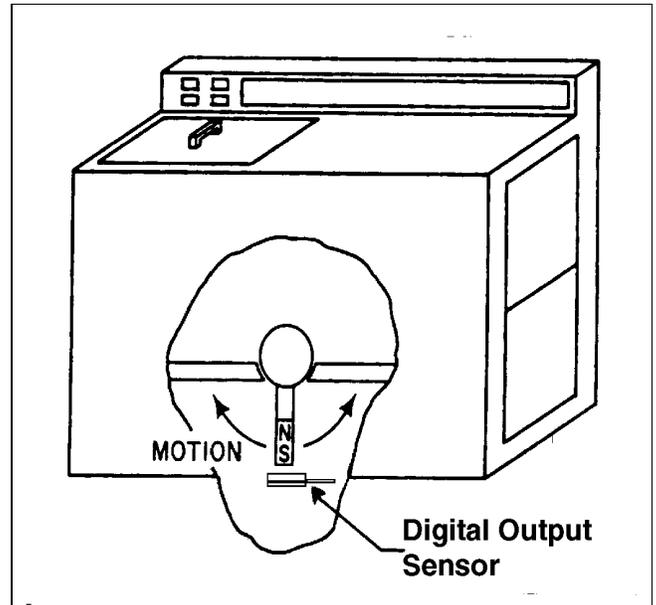


Figure 7-16 Level/tilt sensor

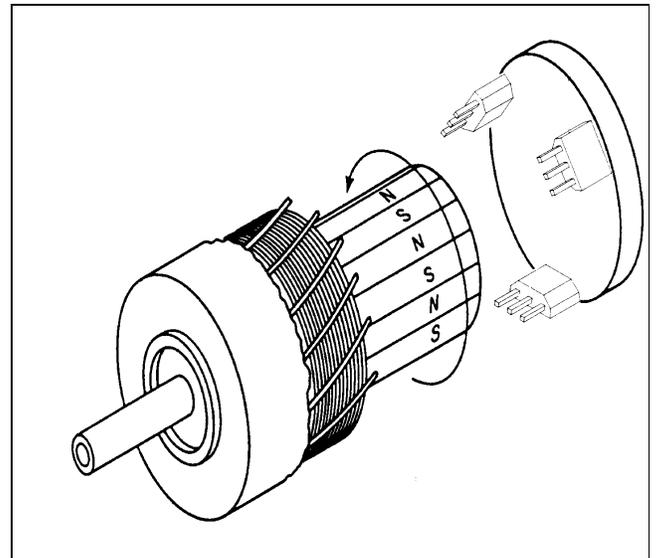


Figure 7-17 Brushless DC motor sensors

### RPM sensors

The RPM sensor is one of the most common applications for a Hall effect sensor. The magnetic flux required to operate the sensor may be furnished by individual magnets mounted on the shaft or hub or by a ring magnet. Figure 7-18 illustrates some basic concepts for designing RPM sensors.

Most of the RPM sensor functions listed below can be accomplished using either a digital or linear output sensor. The choice depends on the application's output requirements.

- Speed control
- Control of motor timing
- Zero speed detection
- Tape rotation
- Under or overspeed detection
- Disk speed detection
- Automobile or tractor transmission controller
- Fan movement
- Shaft rotation counter
- Bottle counting
- Radical position indication
- Drilling machines
- Linear or rotary positioning
- Camera shutter position
- Rotary position sensing
- Flow-rate meter
- Tachometer pick-ups

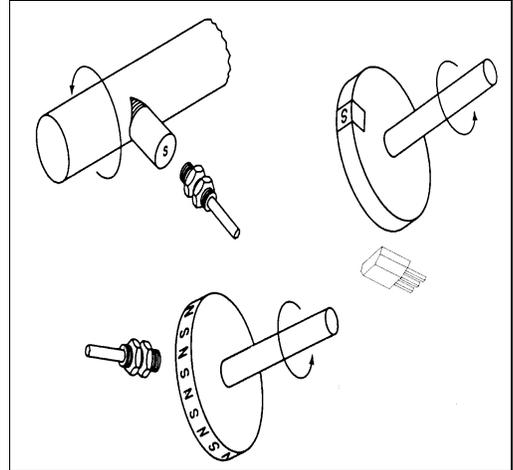


Figure 7-18 Basic RPM sensors

### Remote conveyor sensing

Figure 7-19 illustrates a simple solution for keeping tabs on a remote conveyor operation. A digital output unipolar sensor is mounted to the frame of the conveyor. A magnet mounted on the tail pulley revolves past the sensor to produce one output per revolution. This output can be used to provide an intermittent visual or audible signal at a remote location to assure that all is well. Any shutdown of the conveyor will interfere with the normal signal and alert operators of trouble. With no physical contact, levers or linkages, the sensor can be installed and forgotten.

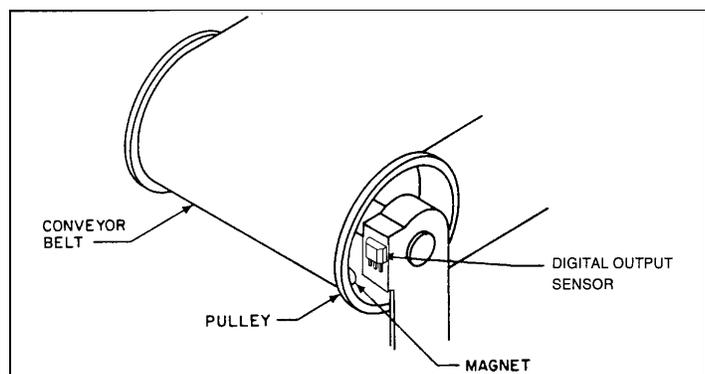


Figure 7-19 Remote conveyor sensing

### Remote reading sensor

A digital output bipolar sensor actuated by a rotating ring magnet or interrupting the flux field in a vane sensor can initiate almost any action. Figure 7-20 illustrates two concept approaches for a remote reading sensor.

Self service gas stations have created a demand for pumps with remote reading capabilities. Every ON/OFF operation of the sensor could correspond to .1 gallon. Another approach could use a vane switch interrupted by an impeller blade. Once again each operation of the sensor could correspond to a measured amount.

The mechanical mechanism in a utility meter can be replaced with a ring magnet and bipolar sensor to provide a pulse output. These pulses are counted electronically to determine power usage. The reading is stored in a transponder and data fed to a master computer by telephone lines. Working through the telephone company, this system can extract meter readings, analyze usage and control high-energy-using appliances (such as air conditioners) by shutting them off during peak usage periods.

The small size, exceptional long life, logic compatibility and non-contacting operation of the sensor are ideal for applications of this type.

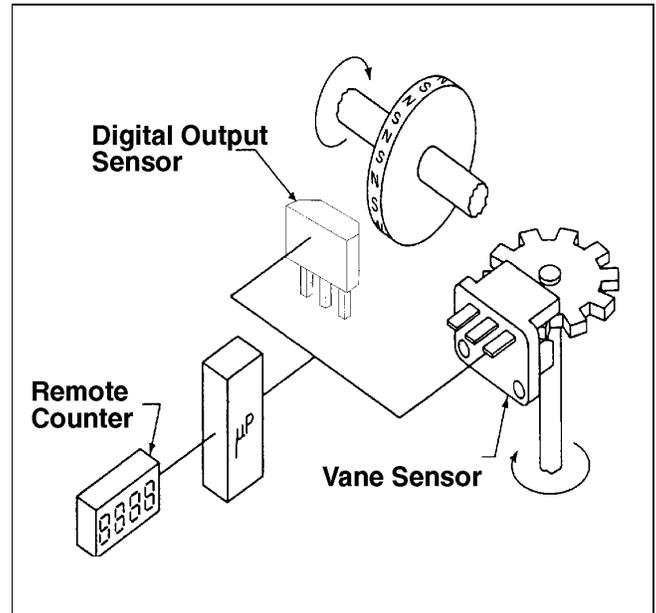


Figure 7-20 Remote reading sensor

### Current sensors

Linear output Hall effect sensors can be used to sense currents ranging from 250 milliamperes to thousands of amperes. The isolated (no passive connection required) analog voltage produced by the sensor can be modified by adding amplifiers or comparators to achieve digital outputs, level shifting, temperature compensation, gain changes or other desired parameters. Linear sensors offer both high frequency response (AC) and DC measurements. When a linear sensor is positioned near a current carrying conductor, the output voltage developed is proportional to the magnitude of the field surrounding the conductor. Since the field magnitude at a particular point is proportional to the current level.

The simplest current sensor configuration consists of a linear output sensor mounted near a conductor as illustrated in Figure 7-21. This type of configuration is usually used to measure relatively large current surges around high voltage lines or equipment found in electrical power plants.

The sensitivity of the simple current sensing system shown in Figure 7-21 can be increased by adding a flux concentrator (refer to chapter 3) to the sensor. With the addition of a flux concentrator, these sensors can be used to check over or under speed, overload (current surges), undercurrent and phase failure for large motors or generators.

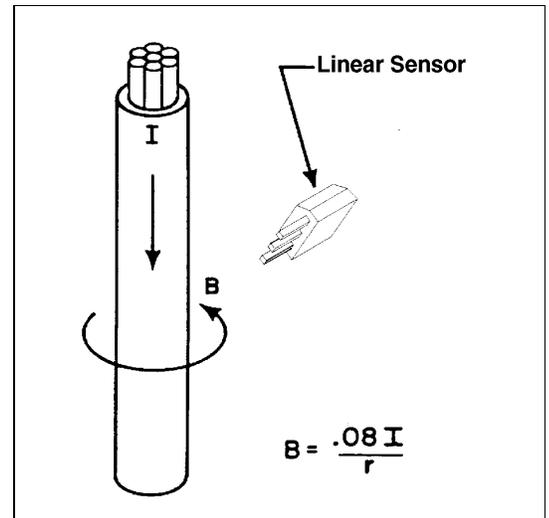


Figure 7-21 Simple current sensor

Figure 7-22 illustrates an even more sensitive current sensor system. This approach consists of a toroid core with a linear sensor positioned in the gap. The core encloses the sensor and acts as an additional flux concentrator. These sensors are able to measure currents from 250 milliamperes to approximately 1000 amperes.

Selecting the core material for the toroid requires some care. For example, cold rolled steel has high remanence. The magnetic induction remains after removal of the applied magnetomotive force, therefore, this would be a poor choice. Ferrite materials, silicon steels, or permally are logical choices because of high permeability and low remanence. Your final choice must be based on actual testing in the application. Values of residual induction given by the materials suppliers are usually for a closed magnetic loop. Current sensors requires large air gaps, therefore, application characteristics should be measured. The residual induction values given by suppliers do, however, provide relative indications for material comparison.

Coil position on the toroid core is not critical. The wire used should be capable of carrying the maximum current continuously. The maximum wire gage provides minimum voltage drop. Count the number of turns as the number in the center of the core.

Current sensors using toroids are useful in systems which require a broad dynamic range, no series resistance and a linear measure of current. An additional benefit is that the sensor can provide isolation from two dissimilar power supplies as might be found in such applications as motor controls with current feedback.

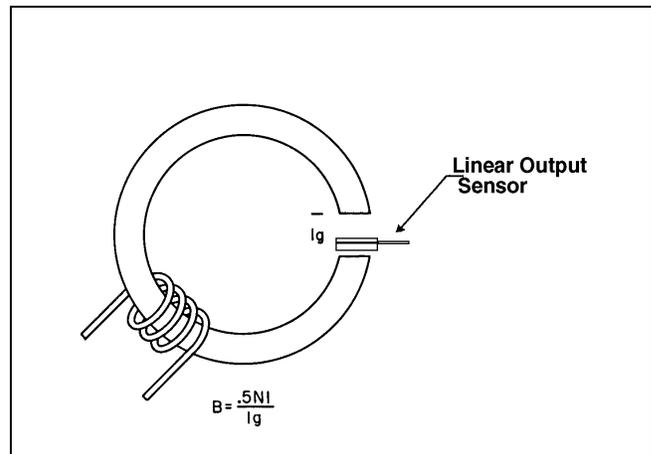


Figure 7-22 Low level current sensor

### Flow rate sensor

Figure 7-23 illustrates a concept design for a flow meter using a biased linear output sensor. As the flow rate through the chamber increases, a spring loaded paddle turns a threaded shaft. As the shaft turns, it raises a magnetic assembly that actuates the sensor. When flow rate decreases, the coil spring causes the assembly to lower thus reducing the output voltage of the sensor.

The magnetics and screw assembly are designed to provide a linear relationship between the measured quantity, flow rate, and the output voltage of the sensor.

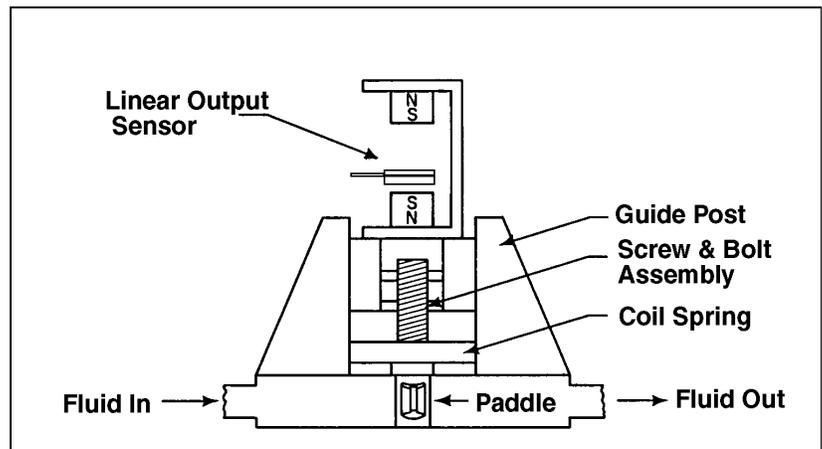


Figure 7-23 Flow rate sensor

If only critical flow is important, the magnetics can be modified to use the bipolar slide-by mode. Using bipolar slide-by, a high resolution measure of flow rate can be achieved at a critical level.

### Piston detection sensor

Figure 7-24 illustrates two possible solutions for detecting position of the piston in a high-pressure non-ferrous cylinder. In the first example, Figure 7-24A, plastic form ring magnets are implanted in the grooves of the piston. Three linear output sensors are mounted on the outside of the cylinder to detect top and bottom stroke and indicate mid position for the analog control system. An advantage of this approach is; since the magnets need no external power, they can be sealed inside the cylinder.

In the second approach, Figure 7-24B, the piston is made of ferrous material (cylinder non-ferrous). Once again three linear output sensors are mounted on the outside of the cylinder. In this case bias magnets are used to “fine tune” the characteristics of the magnetic system. In operation, whenever the ferrous piston passes by the sensing face of the sensor, it acts like a flux concentrator to increase the field detected.

Advantages of both approaches include; small size of sensors, no external power for the magnets, temperature range of -40°C to +150°C (-40°F to +302°F) and the ability to operate in contaminated environments.

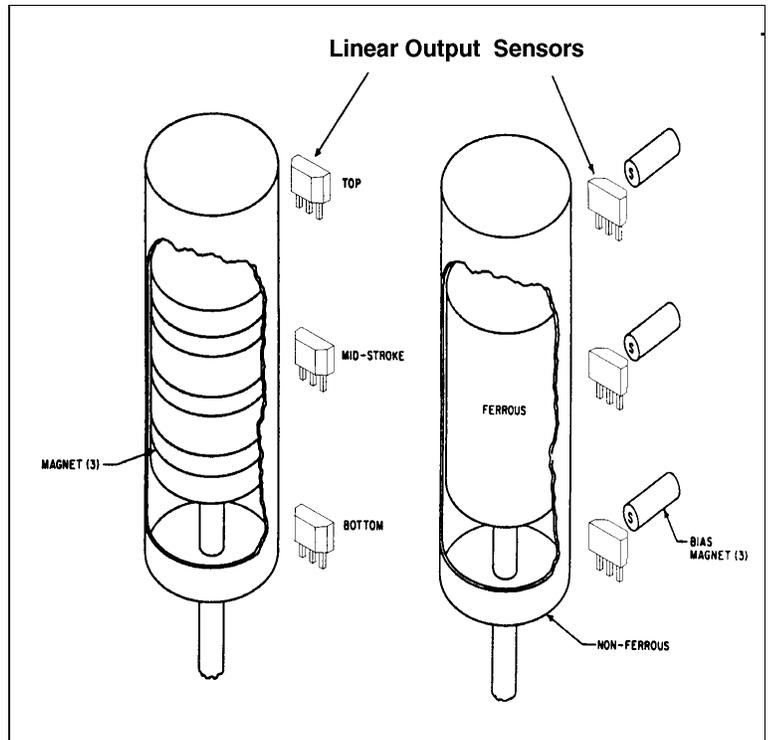


Figure 7-24 Piston detector sensors

### Temperature or pressure sensor

The properties of a linear output sensor allow quantities other than position and current to be sensed. When a linear sensor is combined with appropriate magnetics, it can be used to measure temperature or pressure. Figure 7-25 illustrates this concept.

In pressure sensing, a magnetic assembly is attached to a bellows assembly. As the bellows expands and contracts, the magnetic assembly is moved. If the sensor is placed in close proximity to the assembly, an output voltage proportional to pressure input can be achieved.

Temperature measurement works similarly to pressure, except that a gas with a known thermal expansion characteristic is sealed inside the bellows assembly. As the chamber is heated, the gas expands causing a voltage from the sensor that is proportional to the temperature.

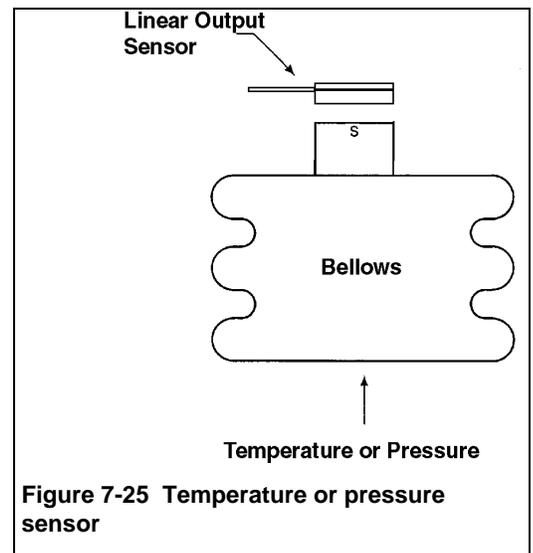


Figure 7-25 Temperature or pressure sensor

### Magnetic card reader

A door interlock security system can be designed using a linear output sensor, magnetic card and a microprocessor linearization circuit as illustrated in Figure 7-26. In this example the card slides-by the sensor producing an output. This analog signal is converted to digital, to provide a crisp signal to operate the relay. When the relay's solenoid pulls-in, the door can be opened.

For systems that require additional security measures, a series of magnet can be molded into the card. A constant speed motor-driven tray slides this multi-coded card past the sensor or an array of linear output sensors, generating a series of pulses. These pulses are addressed to a decoding unit that outputs a signal when the correct frequency is present. Or it could generate a multi bit encoded function, that allows entry to selected units.

Computer systems and banking terminals are ideal applications for this concept.

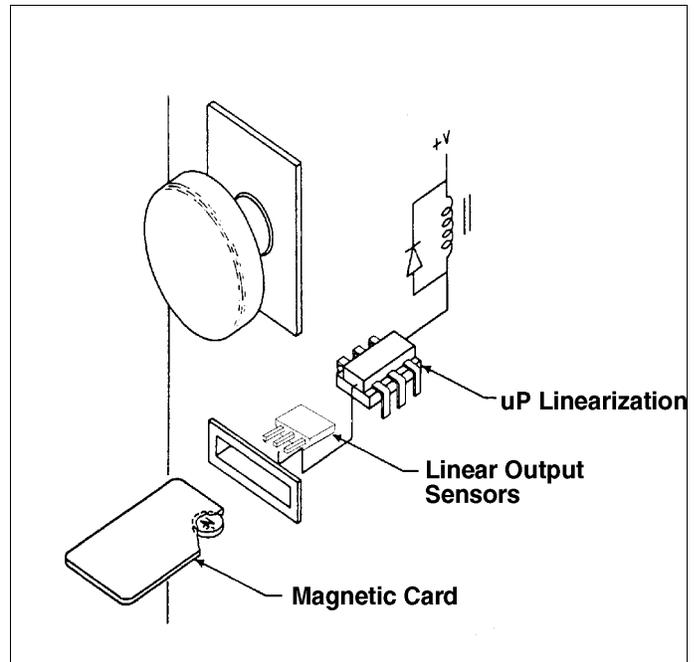


Figure 7-26 Magnetic card reader

### Throttle angle sensor

Figure 7-27 illustrates a concept that uses a linear output sensor to provide a signal proportional to the angular position of the throttle butterfly valve. The arm of the throttle is contoured to provide the desired non-linear characteristics. The magnet is mounted on the choke lever.

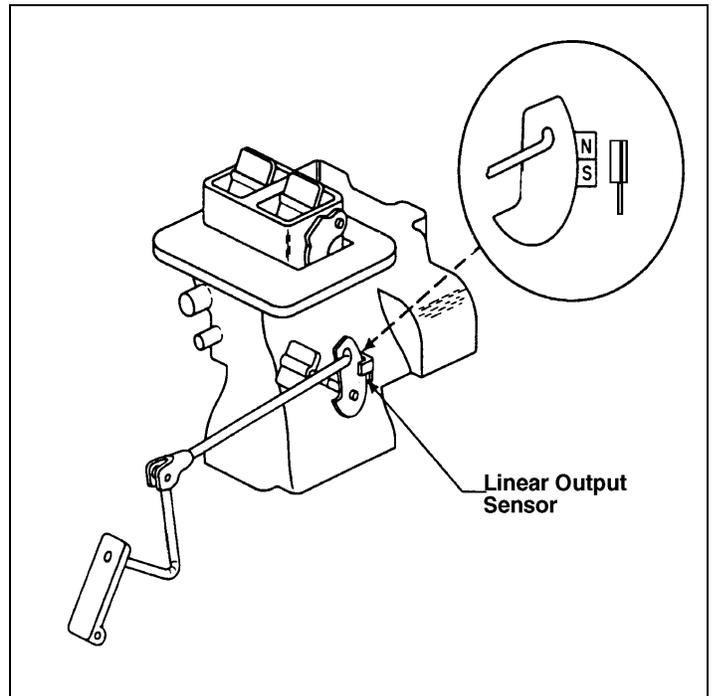


Figure 7-27 Throttle angle sensor

### Automotive sensors

Figure 7-29 suggests many concepts where Hall effect sensors can be applied as monitoring, positioning or safety feedback devices for the automotive market. Both digital and linear output sensors are used in such applications as: flow meters, current sensors, position sensors, interlocks, pressure sensors, RPM sensors, etc.

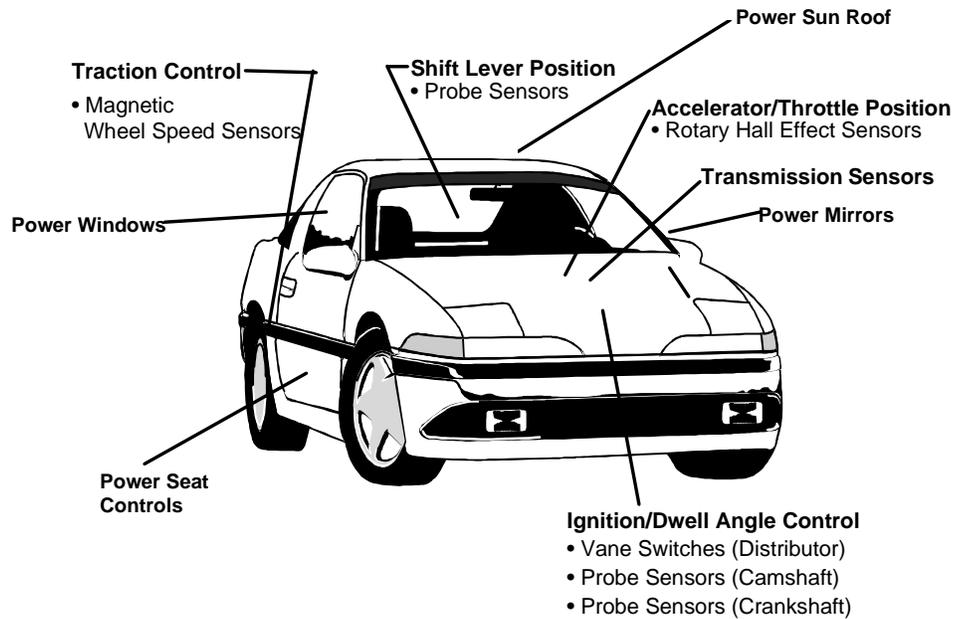


Figure 7-29 Automotive sensor concepts