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Magnetoresistive Elements for Motor Vehicle Sensors

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Magnetoresistive elements (MR elements) are widely used as detection devices for non-contact sensors. This paper discusses MR elements and MR-based sensors (MR sensors) under development at Fujitsu TEN.

The structure and characteristics of MR elements and devices are discussed.

Principles of magnetic potentiometers, rotation speed sensors, and accelerometers using MR sensors are discussed, and some automotive applications are presented.

1. Introduction

Sensors for automotive applications operate in harsh environments. They must not only be sensitive and accurate, but must be immune to vibration and contamination, and must operate under a wide range of temperatures.

The series of MR sensors to be described meet these environmental criteria. Their non-contact principle of operation makes them superior to contact devices in terms of accuracy and durability.

2. MR element

The magnetoresistive element is widely used as a detector in non-contact sensors. Our MR element is characterized by the use of ferromagnetic metal film and an original electrode structure.

2.1 Features of MR element

Our MR element has the following features:

(1) Wide operating temperature range
(2) Small output temperature coefficient
(3) Highly sensitive for weak magnetic field detection
(4) Magnetic field polarity sensitive

Features (1) and (2) result from the use of permalloy (iron-nickel alloy) ferromagnetic film. Features (3) and (4) are advantages of our original electrode structure.

2.2 Principle of magnetoresistive element

2.2.1 Magnetoresistance effect

The resistance of some ferromagnetic substances is dependent on the direction and intensity of magnetization. This phenomenon is called the magnetoresistance effect.

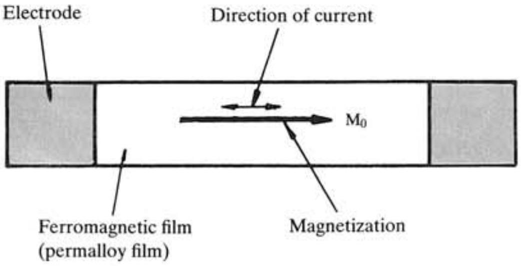
Figure 1-a illustrates the principle of operation of the magnetoresistive element. The ferromagnetic film forms an easily-magnetizable axis in the longitudinal direction and is magnetized along this axis. When the electrode is energized, a current flows parallel to the direction of magnetization.
When an external magnetic field is applied in the lateral direction of the ferromagnetic metal film, the direction of magnetization rotates as shown in Figure 1-b. The angle of rotation of magnetization is proportional to the intensity of the applied magnetic field. The rotation of magnetization changes the resistance of the ferromagnetic film. Since the resistance varies according to the intensity of the applied magnetic field, a magnetic sensor can be fabricated if an appropriate electric circuit is connected.

The characteristic curve (Fig. 1-c) indicates that the sensitivity and linearity are poor in the region of low magnetic field strength. What is worse, since the characteristic curve is symmetrical, it is impossible to distinguish the magnetic polarities. These drawbacks are inherent in the magnetoresistive element structure in Fig. 1-a.

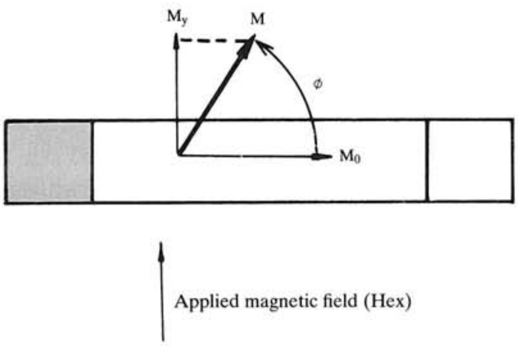
2.2.2. Barber pole type electrode[1), 2)]

Our MR element uses a barber pole electrode to solve the problem above. The barber pole electrode is a diagonally striped electrode pattern formed on the ferromagnetic film (Fig. 2-a). Current flows perpendicular to the longitudinal direction of the stripe. Without an external magnetic field, there is an angle between the direction of magnetization and the direction of the current.

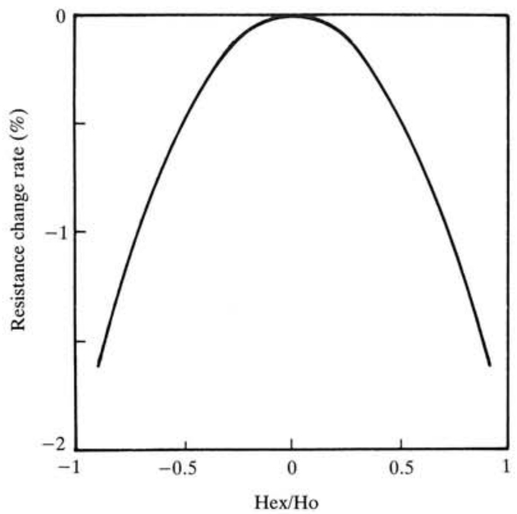
This electrode structure helps greatly to improve the sensitivity and linearity of the device to low magnetic field strengths and to distinguish polarity (Fig. 2-b).



a) Electrode structure

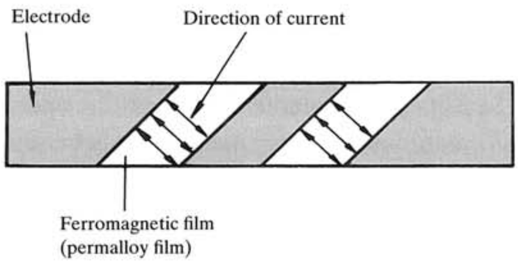


b) Rotation of magnetization depending on the applied magnetic field

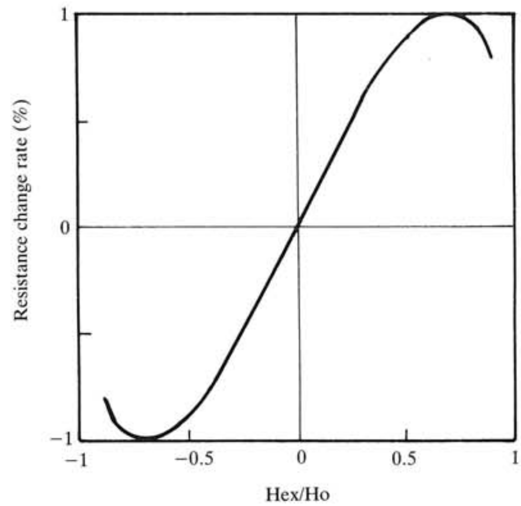


c) Resistance change rate

Figure 1. Principle of magnetoresistive element



a) Electrode structure



b) Resistance change rate (%)

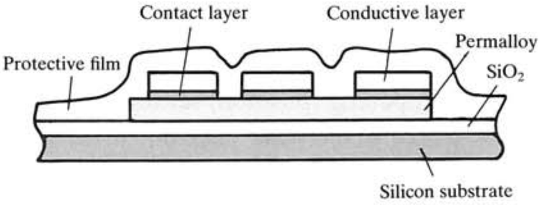
Figure 2. Barber pole electrode

2.3 Structure of MR element

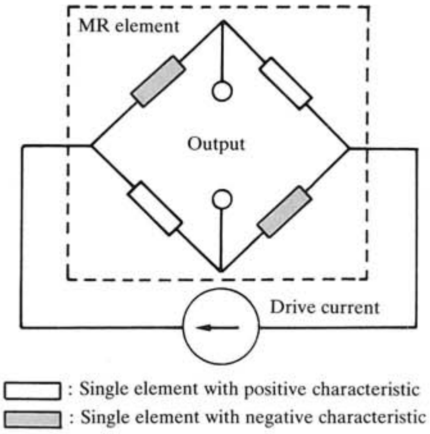
Figure 3-a is a cross section of an MR element. Permalloy is used for the ferromagnetic film. Magnetic, contact, and conductive layers are laminated on a silicon wafer. The surface of the substrate is oxidized and the entire element is covered with a protective film.

In practice, two pairs of single MR elements with opposite characteristics (four elements) are combined in a bridge configuration for improved sensitivity (Fig. 3-b). Single elements with opposite characteristics are obtained by reversing the inclinations of the electrodes.

For use as an analog element, the MR elements are laser-trimmed to reduce resistance variation of the individual elements and are treated to reduce the magnetic hysteresis.



a) Structure of single element



b) Bridge configuration

Figure 3. Structure of MR element

3. MR sensor

The MR element can be used as a sensor if the characteristic to be sensed can be represented by a change in a magnetic field. A magnetic circuit is used for this purpose. The circuit consists of a permanent magnet and magnetic plates. Its structure depends on the characteristic to be sensed.

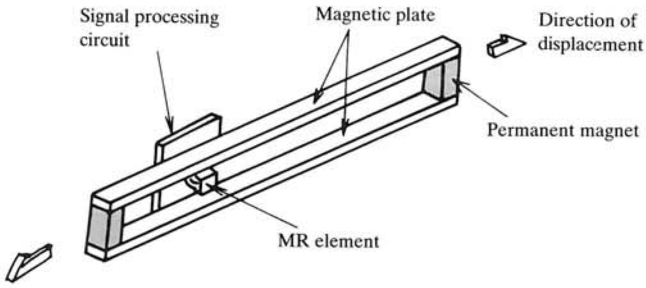
3.1 Magnetic potentiometer

The magnetic potentiometer sensor detects linear displacements or angles of rotation using a magnetic circuit of the leakage field type. Its output is an analog voltage. This is an absolute-type sensor which detects absolute position.

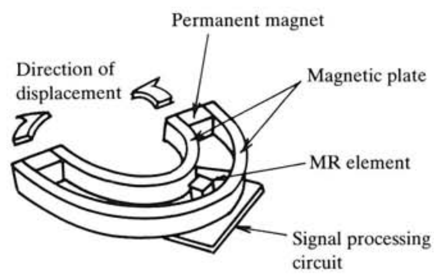
3.1.1 Characteristics

The characteristics of the magnetic potentiometer are:

(1) High durability: Non-contact detection
(2) Noiseless: No slider as in conventional slide potentiometers
(3) Contamination resistant: Magnetic operation
(4) Highly linear analog output for accuracy
(5) No initialization on power-on reset



a) Translational type



b) Rotational type

Figure 4. Structure of magnetic potentiometer

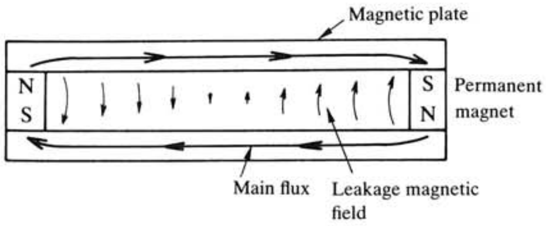
3.1.2 Structure

The magnetic circuit of the magnetic potentiometer consists of two permanent magnets linked with two magnetic plates. The shape of the magnetic plates varies according to whether operation is translational or rotational (Fig. 4). The magnetic circuit is directly connected to the detection axis. As the detection axis moves, the magnetic circuit moves linearly or rotates.

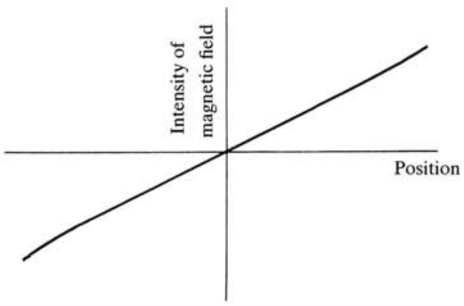
The MR element is placed between the two magnetic plates. For compactness, the MR element is installed directly on the carrier with the signal processing circuit.

3.1.3 Principle

The main flux flows in the closed loop of the magnetic circuit. However, some flux flows directly between the magnetic plates, generating a leakage magnetic field between the magnetic plates. The intensity of the leakage field changes continuously from one of the permanent magnets to the other (Fig. 5-a). It is 0 at the midpoint of the magnetic circuit. The MR element's output depends on its position within the leakage magnetic field (Fig. 5-b).



a) Flux flow



b) Distribution of leakage magnetic field

Figure 5. Principle of magnetic potentiometer

3.1.4 Automotive applications

Some automotive magnetic potentiometer applications are presented below.

(1) Height sensor

This is a rotational sensor which detects the vertical motion of the car body. The sensor is placed between the frame and the suspension arm. The sensor body is fixed to the frame. When the car height changes, the suspension arm moves vertically and the motion is transmitted via a link to the rotation shaft of the sensor (Fig. 6).

This sensor is used in car height and suspension control for improved stability and driving comfort.

(2) Steering angle sensor

This sensor detects the steering angle of the wheels. If rack-and-pinion steering is used, the angle can be sensed from the travel of the rack. Since the rack moves parallel to the frame, a translational sensor is used.

Like the height sensor, the steering angle sensor is used in car height and suspension control systems. This sensor can improve the steering response of four-wheel steering (4WS) systems.

(3) Throttle opening (position) sensor

This sensor detects the position of the throttle valve. It is a rotational sensor directly attached to the throttle shaft. The throttle valve controls the amount of the air supplied to the engine. It is opened and closed by the throttle shaft which is connected to the accelerator pedal.

The throttle opening sensor is used for engine and transmission control.

Figure 6. Magnetic potentiometer (Height sensor)

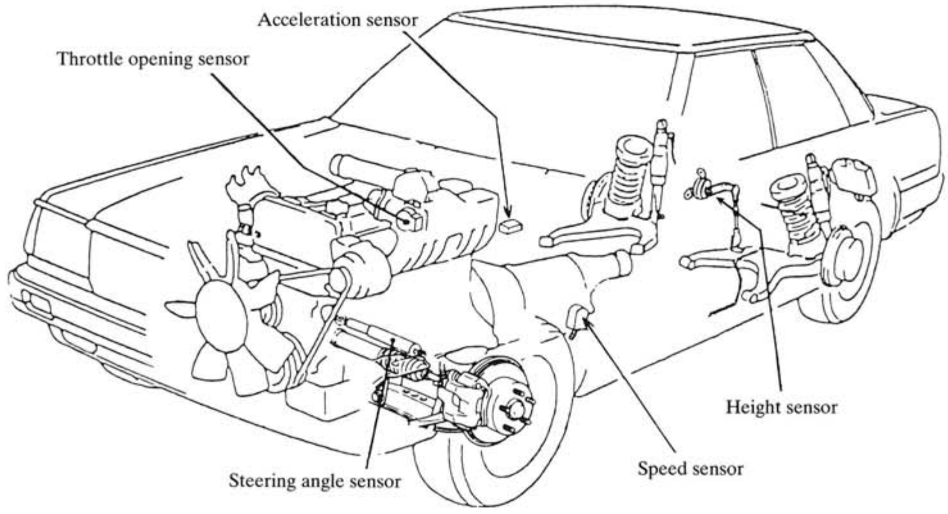


Figure 7. Installation of MR sensors

3.2 Rotation speed sensor

The rotation speed sensor is an incremental rotational sensor which uses a gear-like magnetic circuit on the rotor and stator to produce either a high or low output.

3.2.1 Characteristics

The rotation speed sensor has the following characteristics:

(1) Compared with multipolar magnetic sensors, the MR rotation speed sensor can produce multiple-pulse outputs and can be made small.

(2) Since the sensor detects the absolute value of the magnetic flux, its output is stable over a wide range of speeds, including the halt condition.

(3) The sensor is resistant to contamination and high temperatures because operation is magnetic.

3.2.2 Structure

The rotor consists of a permanent magnet magnetized in the direction of the shaft and two gears (A and B) between which the permanent magnet is placed. Gears A and B are assembled concentrically with a 1/2-pitch phase difference (Fig. 8-a).

The stator gear consists of two half-sections (C and D). The half-sections are also configured for a 1/2-pitch phase difference (Fig. 8-a).

The MR element is placed in the gap between the half-sections of the stator and is mounted on the signal processor printed circuit board (Fig. 8-b).

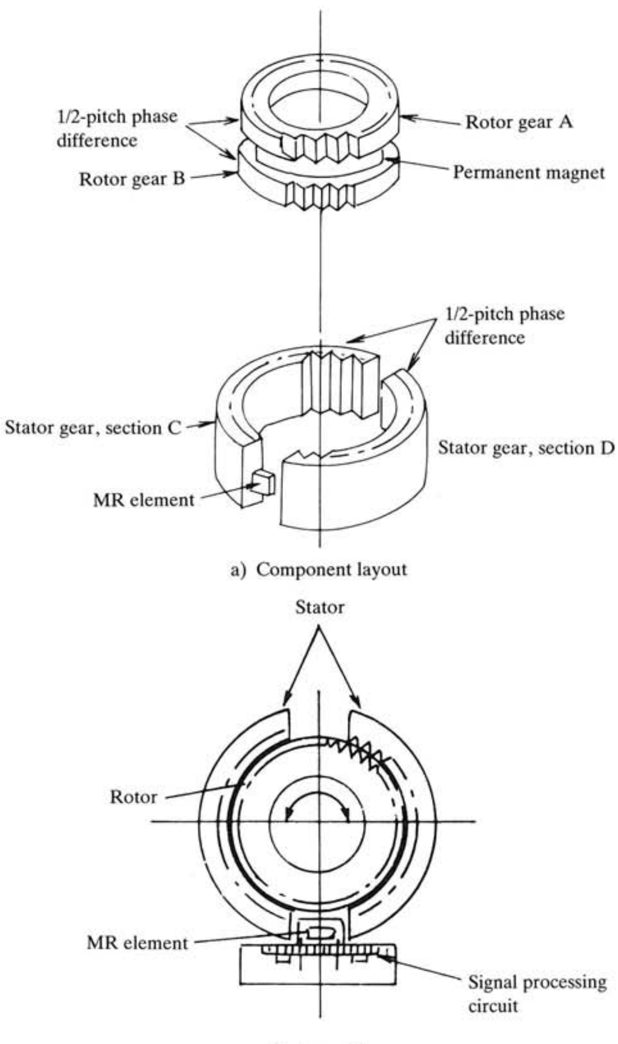


Figure 8. Structure of rotation speed sensor

3.2.3 Principle

The reluctance of the gap between the rotor and stator gears is low when the tooth crests face each other (facing) and high when the crests and roots face each other (back facing). This causes a variation in the flux passing through sections C and D. As a result, flux directly linking sections C and D is generated around their circumference. This flux is alternating — that is, the flux changes direction with each single-pitch turn of the rotor. These flux changes are detected by the MR element.

3.2.4 Automotive application

This sensor can be used for an automobile speedometer.

(1) Speedometer

This sensor detects the speed at which the car is running. The speed is detected from the rotation of the transmission gear. Conventional speed sensors are based on a reed switch which detects the rotation of transmission gear via a meter cable. Meter cable aging and distortion affect detection accuracy.

This problem is solved by attaching the MR sensor directly to the transmission. This is possible because the MR sensor is highly resistant to temperature, vibration, and contamination (Fig. 10).

Figure 10. Rotation speed sensor (speedometer)

3.3 Accelerometer

The accelerometer detects acceleration by means of the deflection of a metal spring. It produces an analog output.

3.3.1 Characteristics

The accelerometer has the following characteristics:

(1) The accelerometer is small and light and can be mounted on a printed circuit board.

(2) The accelerometer is shock resistant and durable

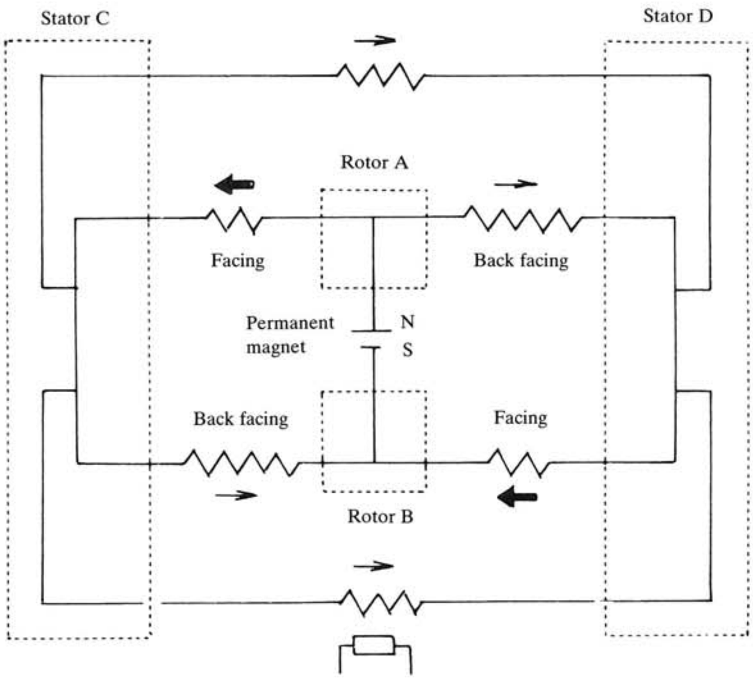


Figure 9. Electrical equivalent circuit of the rotation speed sensor magnetic circuit

because the spring is the only moving component.

(3) Since the output is an analog voltage, acceleration detection is accurate.

3.3.2 Structure

The accelerometer has a nonmagnetic metal cantilever spring at its center. A permanent magnet is attached to the free end of the cantilever, and MR elements are placed opposite the magnet (Fig. 11).

The accelerometer is housed in a magnetically shielded and hermetically sealed case. The case is filled with oil to damp the movement of the cantilever assembly.

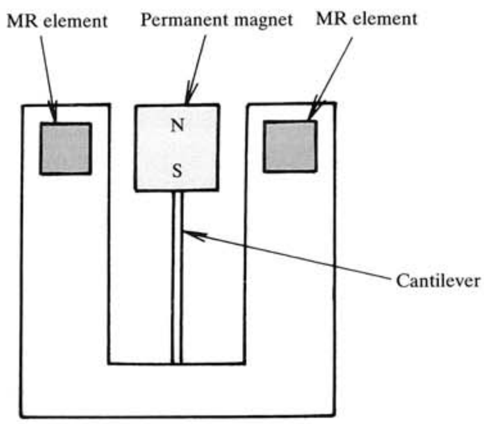


Figure 11. Structure of accelerometer

3.3.3 Principle

When the car accelerates, the inertia of the cantilever and magnet assembly causes the assembly to deflect in proportion to the amount of acceleration. The deflection of the magnet changes the magnetic field around the MR element. The acceleration is determined by the change in the magnetic field (Fig. 12).

3.3.4 Automotive applications

The accelerometer can be used in the following systems:

(1) Antilock brake system: Detection of speed with respect to ground
(2) Suspension control system: Detection of lateral acceleration and vertical car movement
(3) Security system: Detection of raising the car

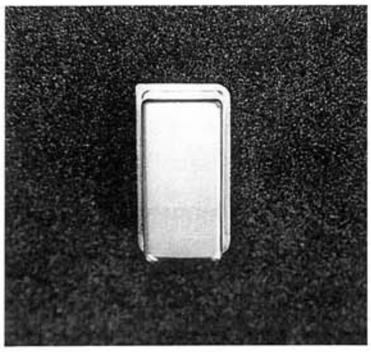


Figure 13. Accelerometer

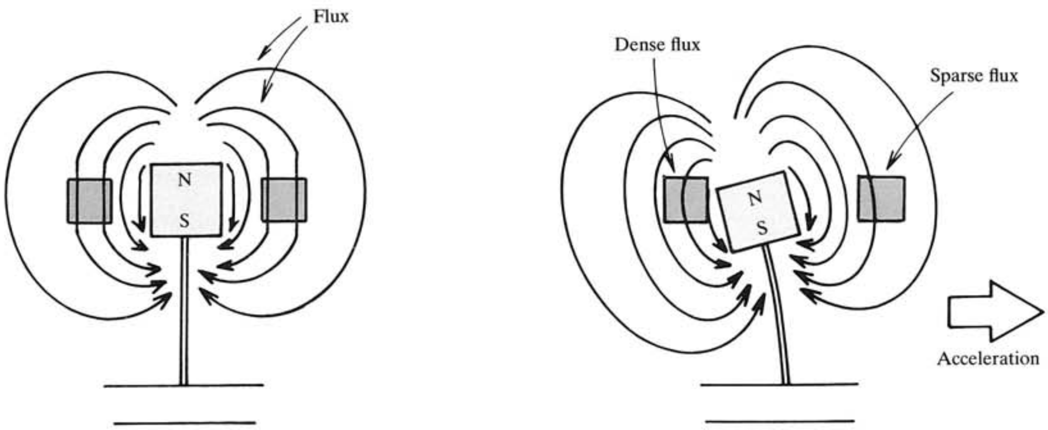


Figure 12. Principle of accelerometer

4. Conclusion

Microcomputers have progressed remarkably with advances in semiconductor technology. It is now possible to install microcomputers in automotive controllers for advanced control.

Fujitsu TEN with its many years of microcomputer experience, designs, manufactures, and markets a wide variety of microcontroller-based automotive electronic equipment. The use of automotive electronic equipment will continue to increase in terms of application and sophistication. However, performance improvement will be limited if efforts are focused on single dedicated microcontrollers. In other words, it will be indispensable for performance and economy that individual controllers be integrated into a single system which allocates and monitors the functions of the individual elements in the system.

We have developed a general-purpose MR element with a wide range of uses. Its operating principle and characteristics make it particularly suitable for automotive application. These sensors, coupled with microcontrollers, will make possible the development of more powerful and advanced control systems.

References

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