KSY14 – the Ultra-flat, Versatile Hall Sensor

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Hall sensors are semiconductors that are sensitive to a magnetic field and can produce voltages in the presence of constant or varying magnetic fields. The new KSY14 sensor is suitable not only for purposes such as non-contacting current and power measurement but also for contactless positional detection of objects, lengths and angles. The sensor comes in an extremely flat, miniature package and can be used at continuous operating temperatures up to 175 °C.

Physics of the Hall effect

The magnetic-field-sensitive KSY14 sensor is based on the Hall effect. In 1879 the American physicist Edwin Hall discovered that a voltage can be obtained from the sides of a strip-shaped conductor through which current is passing as soon as a magnetic field is applied perpendicularly to the conductor (Fig.1). To verify the presence of this voltage, Hall used thin gold layers on glass.

The reason for the Potential difference is the Lorentz force. In a magnetic field this deflects charge carriers perpendicular to their original direction of motion. The charges then accumulating at the edges of the conductor create an electric field that results in the Hall voltage. An important characteristic of the Hall sensor for the user is the direct proportionality of the Hall voltage U_H both to the magnetic flux density B and to the control current I_1.

$$U_H = K_{B0}\, B\, I_1 \qquad (1)$$

where K_{B0} is the sensitivity of the Hall sensor.

The maximum possible output signal of a Hall sensor is primarily determined by the conductor material and its dimensions.

$$K_{B0} = R_H / d = (e\, n\, d)^{-1} \qquad (2)$$

R_H Hall constant, dependent on material
d thickness of conductor
e elementary charge
n charge carrier density

The thinner the conductor, the more pronounced is the Hall effect, see eqn. (1) and (2). The conductor thicknesses that are required, depending on the application, can be produced by different means: grinding (20 µm), etching of a ready ground layer (4 to 5 µm), vapour deposition of thin layers on a substrate (2 to 5 µm), epitaxy (1 to 10 µm), ion implantation (approx. 0.3 µm). The downward limit is set by the reduced mobility of the charge carriers in thin layers compared to solid material.

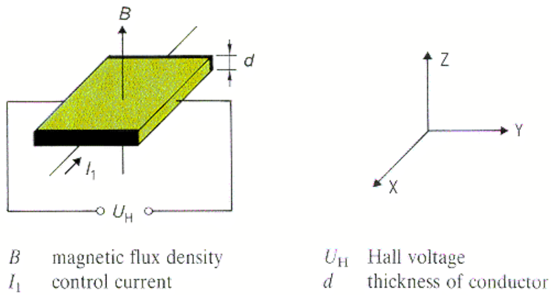

Fig. 1 The Hall effect: on a thin, strip-shaped electrical conductor (xy plane) a voltage (in y direction) appears across the current direction (x) if a magnetic field is applied perpendicularly to the conductor (z direction)

The linearity of the characteristic and the sensitivity of the Hall sensor are also influenced by its shape and dimensions. A symmetrical cross shape was selected for the KSY14, which is preferable to the rectangular shape because of the better linearity and its reproducibility in fabrication.

Metals and semiconductors are possible as conductor materials. Metals have a very high charge-carrier concentration. But the Hall constants are inversely proportional to it, so their Hall constants (Table 1) and thus the Hall voltages achievable are very small. For the best use of the Hall effect therefore, electrically conducting materials with low charge-carrier concentration are desirable in other words semiconductors.

Material	R_H in cm^3/As	μ_e in cm^2/Vs	E_g in eV
Metals	10^{-4}	10	-
Ge	10^{+3}	3900	0.75
Si	10^{+6}	1500	1.16
InSb	380	77000	0.23
GaAs	10^{+4}	8000	1.52

Table 1 Hall constants R_H, mobility μ_e and energy gap E_g of selected materials

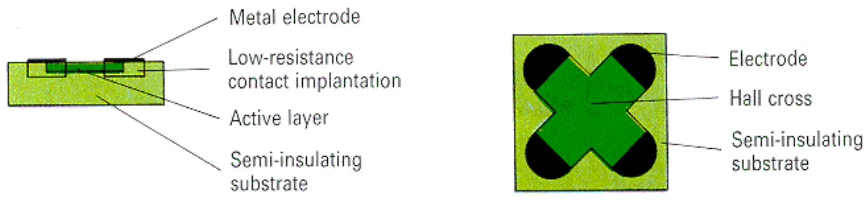

Fig. 2 Structure of GaAs chip (section and plan view) of KSY14 Hall sensor

To make a Hall sensor technically useful, what is needed is minimal internal resistance and thus low resistivity of the selected semiconductor material, accompanied by high sensitivity. The resistivity *r* of a material is in turn determined by charge-carrier density. Proceeding on the basis of pure electron conduction the relationship is as follows:

$$r = (n\, e\, \mu_e)^{-1} \qquad (3)$$

n	charge-carrier density
e	elementary charge
μ_e	mobility of electrons

Low charge-carrier concentration plus low resistivity can therefore only be achieved by high mobility of the charge carriers. The elemental semiconductors silicon (Si) and germanium (Ge) have a large Hall constant but comparatively low mobility.

There was no real breakthrough in technical exploitation of the Hall effect until after the discovery of the high mobility of the III-V semiconductors (elements from the main groups III and V of the periodic system). As Table 1 shows, indium antimonide (InSb) is best of all with μ_e = 77000 cm^2/Vs. A disadvantage of InSb in many applications is the high temperature dependence.

Technical advances in materials production in recent years have considerably improved the suitability of gallium arsenide (GaAs) for Hall sensors. The large energy gap of 1.52 eV leads to very low temperature dependence. So GaAs is extremely suitable for use at high temperatures.

Design and characteristics of KSY14

The starting material for the chip of the KSY14 Hall sensor, which operates safely over a very wide temperature range (-40 to +175 °C), is semi-insulating, monocrystalline gallium arsenate. The thin conducting layer is produced by ion implantation. The material is bombarded with accelerated ions in a high vacuum. This doping of the material means that the charge-carrier density and thus the sensitivity and resistance can be precisely controlled. A further advantage of the process is the small layer thickness that can be produced (approx. 0.3 µm). Fig.2 shows the prepared chip with its Hall cross and the four connecting electrodes. The chip is attached to a non-magnetic substrate with good thermal conductivity.

The chip is enclosed in a moulding compound as a protection against external effects. This is a special, high-temperature compound permitting sustained temperatures up to 175 °C, which is important for automotive applications for instance. Furthermore the compound, an epoxy resin, is exceptionally resistant to chemicals.

An extremely flat, miniature package measures 2.1 mm × 3 mm × 0.7 mm (Fig.3). In an application the minimal distance to the chip means a large signal and only a small measurement error. The four pins (two for driving, two for signal output) are conveniently all brought out on the same side and are coated with pure tin. So the receptacle for the component can be made very simple and small.

Choice of GaAs as the chip material produces the following features in the KSY14 Hall sensor:

- high sensitivity K_{B0},
- high temperature stability and small temperature coefficients TC_{UH}, TC_{R10} and TC_{R20},
- high linearity of the signal F_L,
- low offset voltage U_{R0},
- wide frequency range from zero into the MHz region.

Table 2 lists the maximum ratings and characteristics of the KSY14.

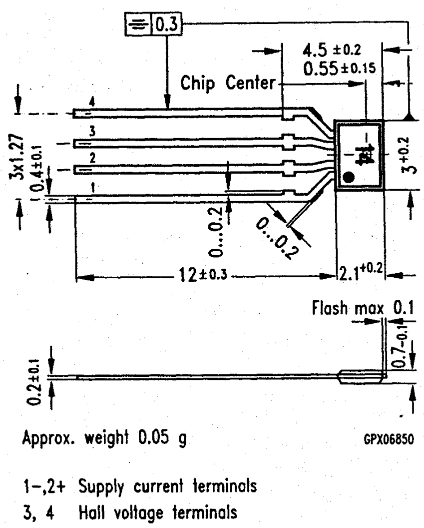

Fig. 3 Dimensions of KSY14

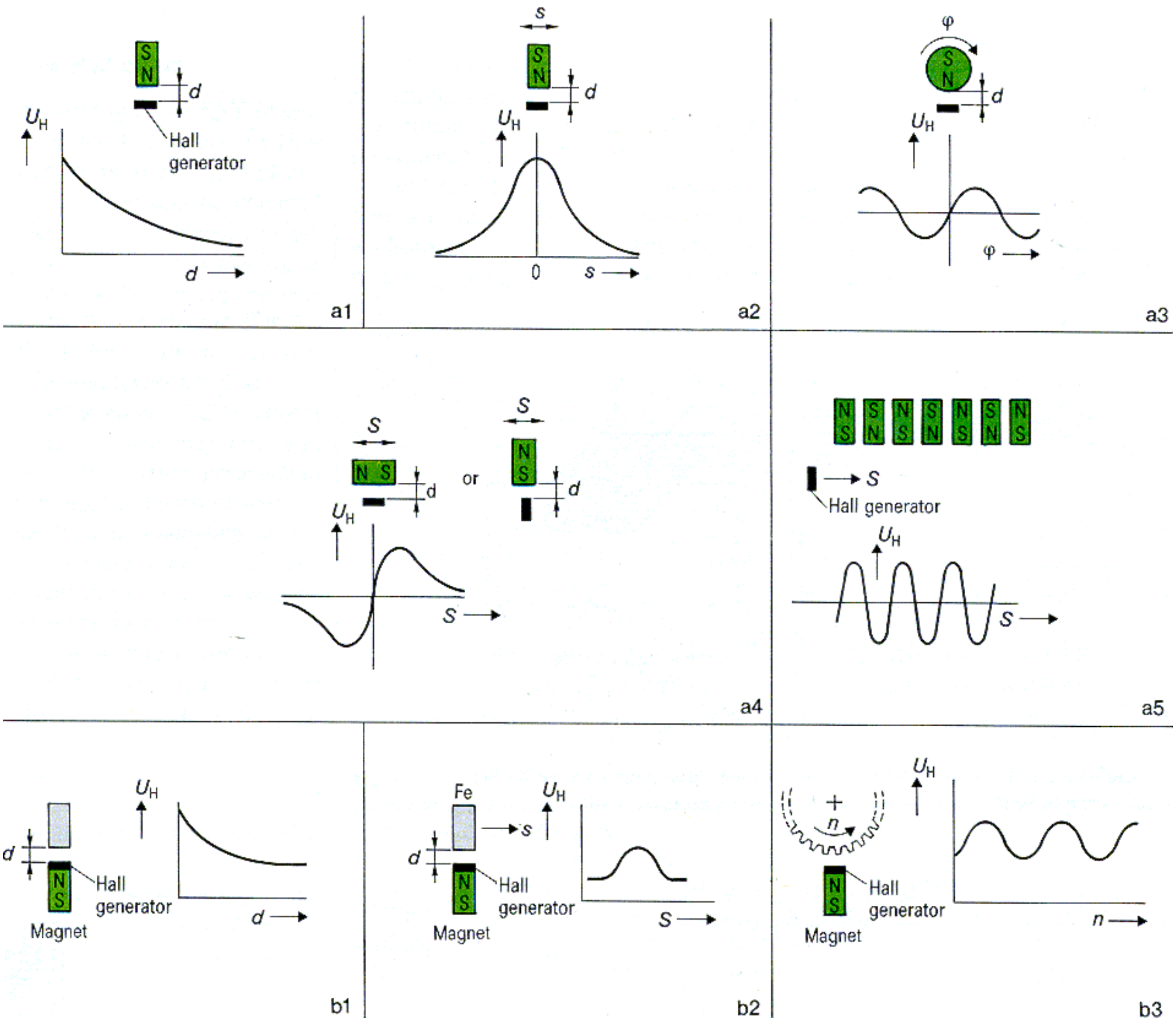

Fig. 4 KSY14 signal characteristics produced by illustrated configurations and movements of sensor and magnet. In figures a1 to a5 a permanent magnet generates the signal, in figures b1 to b3 a soft-iron component

Possible applications of KSY14

The KSY14 can be used in a variety of applications. Its advantages over other sensor systems become very apparent when you have the following kind of requirements:

- very small air gap (maximum thickness of KSY14 is 0.7 mm),
- high ambient temperatures (up to 175 °C),
- contactless detection of position (i. e. no wear and virtually unlimited useful life),
- harsh operating conditions (dirt, chemicals, dampness, etc),
- floating current and power measurement on electrical loads,
- independence of the sensor signal from speed.

According to equation (1) the output signal of the Hall sensor is proportional to the magnetic flux density and to the control current. This means that

- it will detect all quantities that can transmit their state or changes of state by way of magnetic fields,
- all quantities that can be converted into electric current can drive a Hall sensor,
- and the device can be used where two quantities have to be multiplied (in a power meter, for example).

Among the many practical uses for the KSY14 are

- flow-rate measurements,
- fully automatic scales,
- magnetic materials inspection (e. g. detection of cracks),
- modulation of small direct currents and voltages,
- vibration measurements (out-of-balance).

Some of the most common applications are briefly outlined below.

Contactless position detection

The detection of position is essential for controlling the movement of mechanical devices like production robots and machine tools. A sensor system based on the KSY14 permits detection of position in everything from a simple proximity detector through to precise measurement of displacement and angle.

This contactless method means freedom from wear and reliability of results. The Hall sensor is driven either directly by a permanent magnet or, mounted on a magnet, by soft-iron components.

Many different kinds of signals can be obtained with the KSY14, these being determined by the configuration, the arrangement of the sensor and the direction of movement of the transmitter relative to the receiver (Fig. 4).

The simplest configurations are open magnetic circuits. With closed magnetic circuit or concentrators, it is possible to bunch the magnetic field lines and thus increase sensitivity (Fig. 5).

Digital position detection

The signal can be digitised in conjunction with a threshold switch. Typical fields of application for digital position detection are

- electronic switches,
- counting tasks,
- speed measurement on gear wheels,
- angle measurement,
- sensing of coded data.

In the automotive area in particular there are uses like detection of ignition time and rpm. The output signal from the KSY14 is independent of the speed, so it is especially reliable for use in rpm sensors.

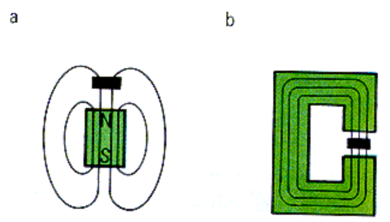

Fig. 5 Distribution of magnetic field lines a in open magnetic circuit, b in closed magnetic circuit

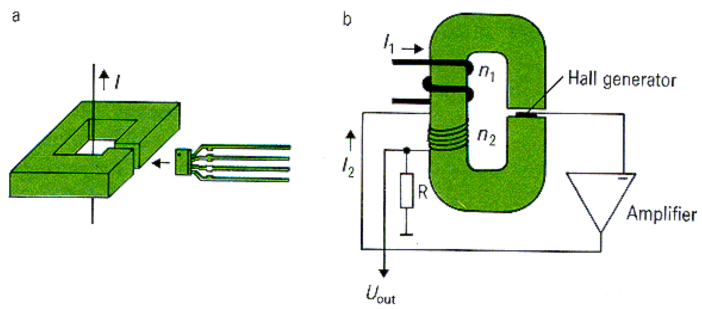

Fig. 6 Principle of floating current measurement a measuring the magnetic field around the conductor, b using 12 to compensate the field produced by 11, where the Hall sensor functioning as a null detector

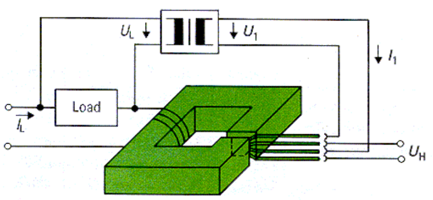

Fig. 7 Power measurement with Hall sensor. The current is detected by its magnetic field, while the voltage drop across the load produces the control voltage for the Hall generator

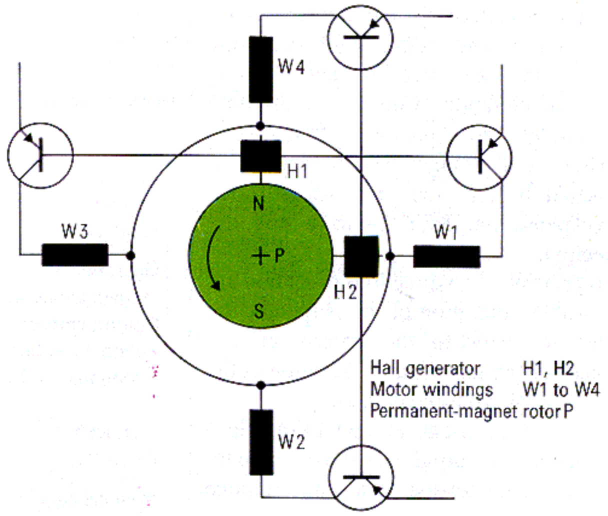

Fig. 8 Principle, of brushless DC motor. The position of the permanent magnet rotor is determined by the two Hall sensors at right angles to one another and the fixed windings are driven via the Transistors

Analog position detection

This is a method for continuous sensing of position, and indirectly for measuring quantities like force, pressure, torque and acceleration. Concrete application examples are pressure transducers, where a diaphragm with a magnet attached is deflected, and scales (force compensation, KSY14 as a null detector).

In principle, two directions of motion are possible: alteration of the perpendicular distance between the transmitter and receiver (air gap *d*), and alteration of the horizontal distance (path *s*).

The configurations a1 and b1 in Fig.4 produce an output signal with a nonlinear characteristic. They are suitable for cases where the nonlinear characteristic of a measurement transducer (as with the diaphragm of a pressure sensor) can be compensated or the output signal is electronically linearized. For more precise position measurement a linear signal characteristic is necessary (a4 in Fig.4). The extent of the linear range depends on the magnet dimensions and, to a lesser extent, on the distance between transmitter and receiver. It is advisable to inject the control current. Temperature compensation, especially necessary for precision measurements, is reduced here to the influence of the material-related temperature coefficient of the sensitivity [1,3].

Floating current measurement

Current is measured here by measuring the magnetic field surrounding the conductor through which the current is passing. To improve sensitivity at low currents, it is advisable to concentrate the magnetic flux with the aid of a soft-iron yoke, the KSY14 Hall sensor being positioned in the latter's very small air gap (Fig.6a). A familiar application of this kind is the current measuring clamp. If the demands on measurement accuracy are stringent, the characteristics of the yoke material should not be neglected. Remanence and saturation can impair the linearity of the sensor signal.

A compensating circuit with negative feedback is recommended for precision measurements. As Fig.6b shows, the first winding conducts the current to be measured I_1 and generates a corresponding magnetic field in the iron yoke. Just enough current I_2 flows in the second winding to cancel the magnetic field. The KSY14 Hall sensor plus an amplifier working as a null detector are used to control the current in the second winding.

Maximum ratings

Parameter	Symbol	Value	Unit
Operating temperature	q_A	-40 .. 175	°C
Storage temperature	q_{stg}	-50 .. 180	°C
Control current	I_1	7	mA
Thermal conductance	$G_{th\,A}$	>1.5	mW/K
mounted on heat-sink	$G_{th\,case}$	> 2.2	mW/K

Characteristics (q_A = 25°C)

Parameter	Symbol	Value	Unit
Nominal supply current	I_{1N}	5	mA
Open circuit sensitivity	K_{B0}	190 .. 260	V/AT
Open circuit Hall voltage $I_1 = I_{1N}$, B = 0.1 T	U_H	95 .. 130	mV
Ohmic zero voltage $I_1 = I_{1N}$, B = 0 T	$\|U_{R0}\|$	= 20	mV
Zero voltage change in temperture range 25° to 75°C	$\|D_{R0}\|$	= 2	mV
Linearity of Hall voltage B = 0 to 0.5 T B = 0 to 1 T	F_L	= 0.2 = 0.7	%
Control and Hall internal resistance B = 0 T	R_{10}, R_{20}	900 .. 1200	Ω
Temperature coefficient of open circuit Hall voltage $I_1 = I_{1N}$, B = 0.1 T	TC_{UH}	-0.03 .. -0.07	%/K
Temperature coefficient of internal resistances B = 0.1 T	TC_{R10}, TC_{R20}	0.1 .. 0.18	%/K

Table 2 Maximum ratings and characteristics of KSY14 Hall sensor

Measuring power in electrical loads (Fig. 7)

Because the sensor signal is directly proportional to two quantities at the same time, see eqn. (1), it is possible to multiply these two quantities. So, for example, one can determine the power in an electrical load by purely electrical means. The load current I_L is detected in a floating manner by the magnetic field that it generates, and in this way the magnetic control field for the Hall sensor is produced. The operating voltage U_L of the load delivers the control current I_1 for the KSY14 by way of a transformer. Taking $B \sim I_L$, $I_1 \sim U_L$ and equation (1) therefore, the Hall voltage is a measure of the power in the load:

$$U_H \sim I_L\, U_L \qquad (4)$$

Using a Hall sensor it is also possible to measure power in situations where one encounters difficulties with conventional power meters, e. g. pulse-width modulated voltages at higher frequencies [8].

Brushless DC motor

Brushless DC motors with Hall sensors have proven themselves as drives for sensitive electric apparatus like video recorders, audio recorders, ventilators, etc. Their advantages over conventional motors are

- no startup difficulties like those produced by corroded commutator bars,
- silent running,
- no wear,
- no sparking and thus no radio-frequency interference,
- no phase effects on the line.

The motor is composed of fixed windings, a permanent-magnet rotor and two Hall sensors at right angles to one another, plus the circuit (Fig.8). The Hall sensors signal the position of the rotor. Depending on the power of the motor, Transistors or thyristors will be used as the switching elements.

Magnetic-field measurement

Because of its small active area, the KSY14 can detect magnetic flux density virtually point by point. It reacts to magnetic flux density from 10^{-4} up to several Tesla. Although not specially designed for such purposes, the KSY14 is suitable for many applications of this kind, in particular where space conditions are tight and an attractively priced solution is aimed at. With a second Hall sensor magnetic-field gradients can also be measured.

References

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Further Information

The actual KSY series of GaAs Hall elements provides sensors made of vapour phase and MOVPE epitactical material in wired and SMT packages:

Type	Material	Package	Leadframe
KSY 13	Ion implanted GaAs	SOT 143	Magnetic
KSY 14		SOH	Non magnetic
KSY 16		MW6	
KSY 44	MOVPE GaAs	SOH	
KSY 46		MW6	

SMT packages SOT143 and MW6 are in SOT23 size with 4 and 6 pins. SOH is a ultra flat wired package.

The Infineon Technologies portfolio of Sensors contains:

- Magnetic sensors (GaAs Hall sensors, Si Hall-IC switches, InSb magnetoresistors and Giant magnetoresistors)
- Pressure sensors
- Temperature sensors
- Motion sensors

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