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Hall Element Application Guide

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Introduction

The Hall effect was discovered by Dr. Edwin Hall in 1879 while he was a doctoral candidate at Johns Hopkins University in Baltimore.

He found that when a magnet's field was placed perpendicular to one face of a thin gold rectangle where current flowed through, 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 was perpendicular to the conductor.

How does the Hall effect work?

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.

The fundamental physical principle behind the Hall effect is the Lorentz force: when an electron moves along a direction, *v*, perpendicular to the applied magnetic field, *B*, it experiences a force, *F*. This is the Lorentz force, as seen Figure 1.

$$\vec{F} = q\vec{v}\ x\ \vec{B}$$

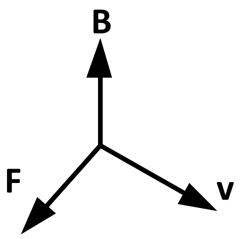


Figure 1. Lorentz force

Figure 2 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 the current. When no magnetic field is present, current distribution is uniform and no potential difference is seen across the output, as shown in Figure 2.

When a perpendicular magnetic field is present, as shown in Figure 3, 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 (*VH*).

The interaction of the magnetic field and the current is $VH \propto I \times B$.

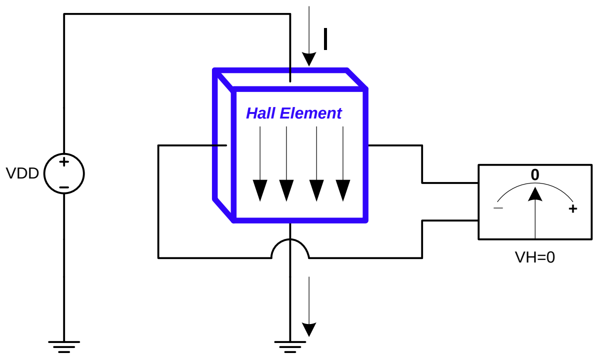


Figure 2. No magnetic field

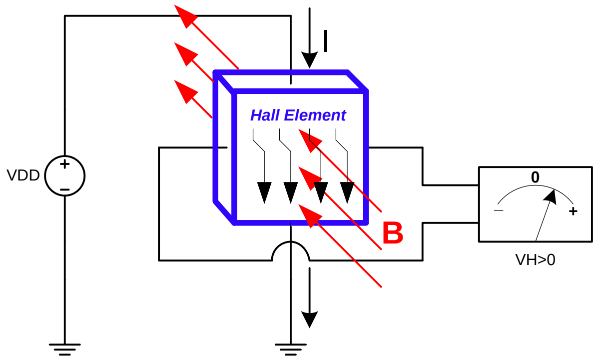


Figure 3. Magnetic field is present

Hall Element

A Hall element is a magnetic sensor that detects a magnetic field and outputs an analog signal proportional to the magnetic flux density.

Materials

The primary semiconductor materials currently used as Hall elements are shown in Table 1 along with their unique characteristics.

InSb (Indium Antimonide)

- Supersensitive with bigger temperature drift and is suitable for switch/latch/motor magnetic-sensing applications.

InAs (Indium Arsenide)

- Highly sensitive with low-temperature drift and is suitable for precise motion and position control applications such as robot joints and industrial machine tools.

GaAs (Gallium Arsenide)

- Has ultra-low temperature drift and is suitable for linear-sensing applications such as OIS (optical image stabilizer) systems.

Silicon (Si)

- One of the more common Hall element materials with very low sensitivity and can be integrated into a standard CMOS process.

Diodes Incorporated (Diodes) provides two kinds of Hall products for user selection. One is the InSb Hall element and the other is the Si-base integrated Hall IC. For more details on our products, please refer to the Diodes website: https://www.diodes.com/products/analog/sensors/.

Offset Voltage

Hall elements may generate an output voltage even when no magnetic field is applied. This is called an offset voltage. The offset component of the Hall element can be represented by a bridge circuit of four resistance values, as shown in Figure 3a.

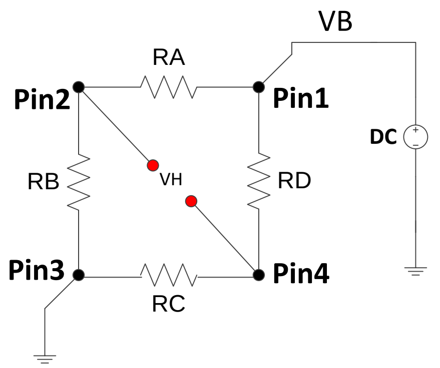


Figure 3a. Equivalent circuit of a Hall element

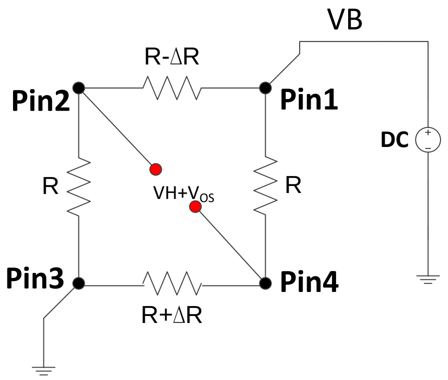


Figure 3b. Mismatch of four resistors

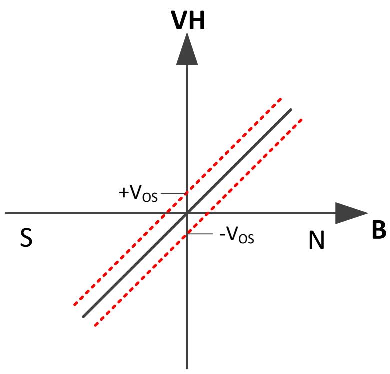


Figure 3c. Output voltage w/wo an offset voltage

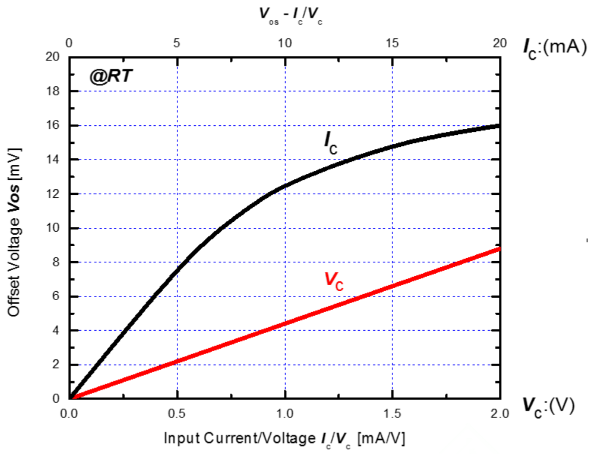


Figure 3b. offset voltage ***V****os* as a function of electrical stimuli ***Ic/ Vc***

If all four resistors are equal, the offset voltage will be zero. When an offset voltage is present due to a resistor mismatch, as with Figure 3b, the output voltage characteristic will be shifted, as shown in Figure 3c.

This offset voltage is generated due to unintended variations in the manufacturing process and the offset voltage is also temperature and applied voltage VC/Current IC dependent as Figure 3b.

Drive Mode

There are two different types of operations to drive the Hall element. One is with the constant voltage (*VC*), and other is with the constant current (*IC*), as seen in Figure 4.

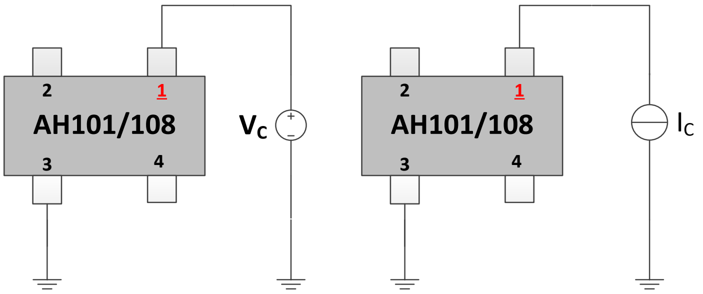


Figure 4. Voltage and current operating mode

Voltage Mode V_C

When a fixed voltage (*VC*) is applied across terminals 1 and 3, the output voltage (*VH*) at terminals 2 and 4 can be expressed by the following equation:

$$VH = \mu H \cdot (W / L) \cdot VC \cdot B + V_{OS}$$

Where *μH* is the electron mobility, *W* is the width of the element surface, *L* is the length of the element surface, and V_{OS} is the offset voltage. The temperature characteristic of the output voltage of an element with constant voltage drive is determined by the temperature characteristic of *μH*.

Current Mode I_C

When a constant current (*IC*) is inputted to terminals 1 and 3, the output voltage at terminals 2 and 4 can be expressed by the following equation:

$$VH = RH \cdot (1 / d) \cdot IC \cdot B + V_{OS}$$

Where *RH* is the Hall coefficient, *B* is the magnetic flux density, *d* is the thickness of the semiconductor film, and V_{OS} is the offset voltage. The Hall coefficient is defined as follows using an electron charge (*e*) and carrier concentration (*n*):

$$RH = 1 / (e \cdot n)$$

The temperature characteristic of the output voltage with a constant current drive is determined by the temperature characteristic of the Hall coefficient.

Hall voltage (*VH*) characteristics on the voltage (*VC*) or current mode (*IC*) is shown in Figure 5, 6, and 7.

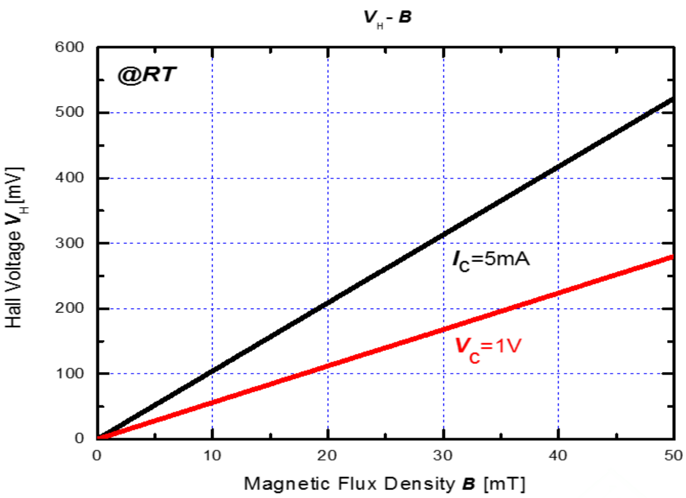


Figure 5. Hall voltage (V_H) as a function of magnetic flux density (**B**)

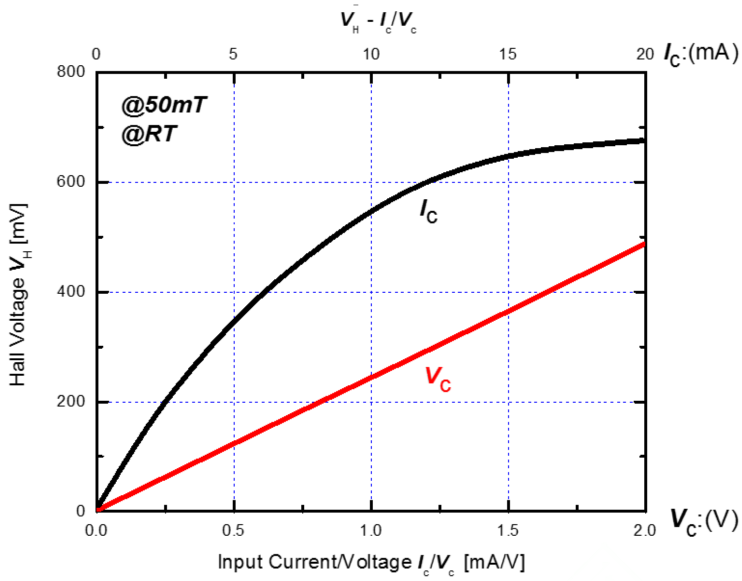


Figure 6. Hall voltage (V_H) as a function of electrical stimuli (I_c/V_c)

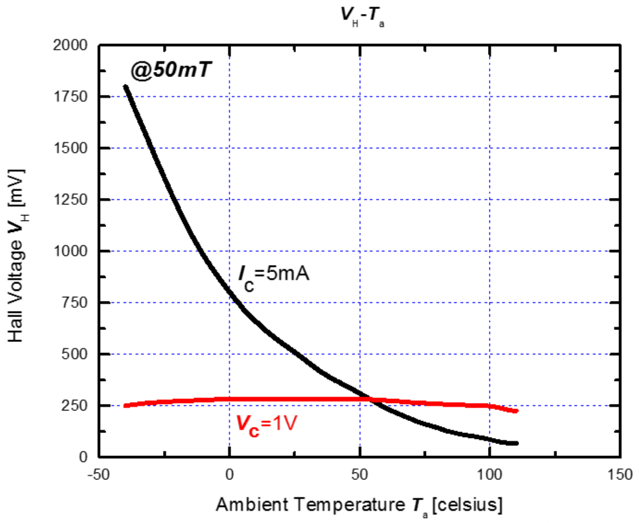


Figure 7. Hall voltage (V_H) as a function of ambient temperature (T_a)

Hall Voltage *VH* vs. Magnet pole

Diodes provides five InSb Hall elements for user selection, as shown in Table 1

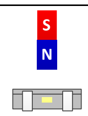
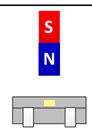
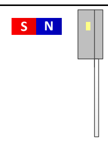
Products	Package Type	VH @ B=500Gs, VC=1V, TA = 25°C	Vos @ TA = 25°C	Magnet Pole to Brand Side
AHE101	SOT23-4	168mV ~ 415mV	+/- 5mV	
AHE108		168mV ~ 370mV	+/- 7mV	
AHE102		196mV ~ 465mV	+/- 7mV	
AHE300	SIP-4	168mV ~ 320mV	+/- 7mV	

Table 1 Hall element Products

Users may have questions on how to set up Hall elements in their design, as well as how to retrieve the correct output voltage while employing a Hall element for the first time. Below are examples for reference.

AH101/AH108

Applied 1V on Pin1 to Pin3. The positive *VH* voltage will be generated between Pin2 and Pin4 when magnet pole *N* is to the brand side, as in Figure 8.

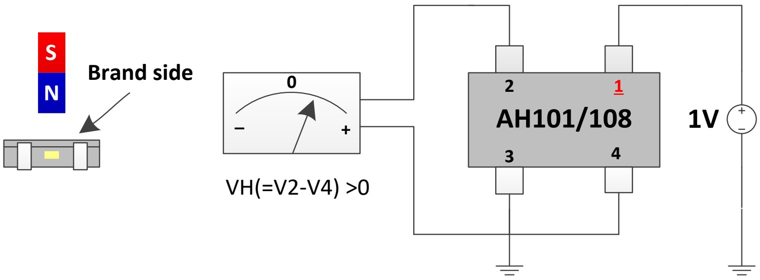


Figure 8. AH101/AH108 *VH* vs Magnet pole *N*

However, in the same setup, a negative *VH* voltage can be generated between Pin2 and Pin4 when the magnet pole *S* is to the brand side, as in Figure 9.

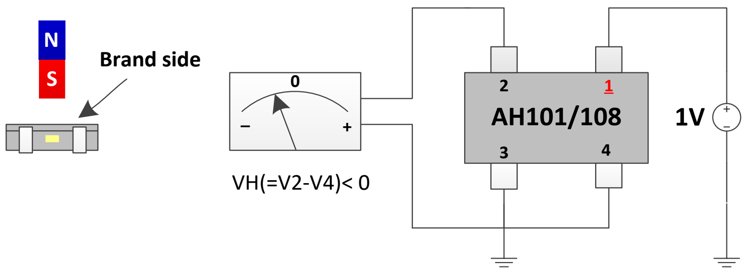


Figure 9. AH101/AH108 *VH* vs Magnet pole *S*

AH102

1V is applied onto Pin1 to Pin3. The Negative *VH* voltage will be generated between Pin2 and Pin4 when magnet pole *N* is to the brand side, as in Figure 10.

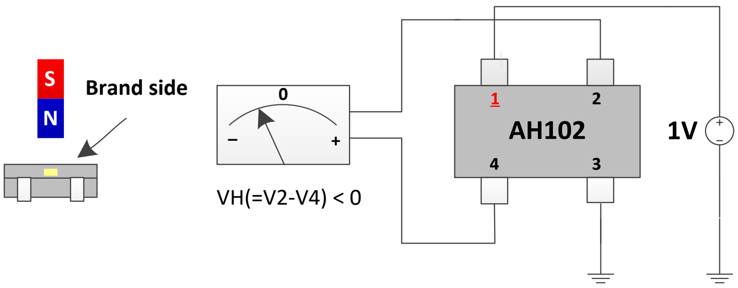


Figure 10. AH102 *VH* vs Magnet pole *N*

However, in the same setup, the positive *VH* voltage can be generated between Pin2 and Pin4 when magnet pole *S* is to the brand side, as in Figure 11.

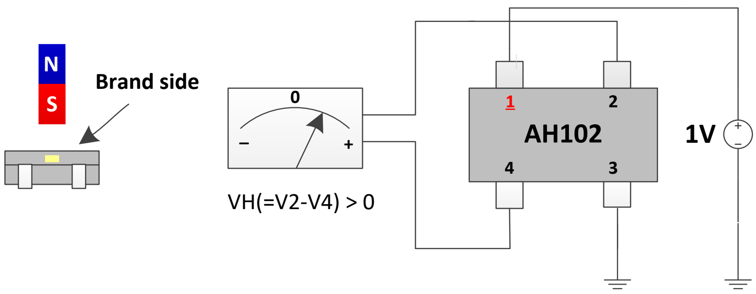


Figure 11. AH102 *VH* vs Magnet pole *S*

AHE300

1V is applied onto Pin1 to Pin3. The positive *VH* voltage will be generated between Pin2 and Pin4 when magnet pole *N* is to the brand side, as in Figure 12.

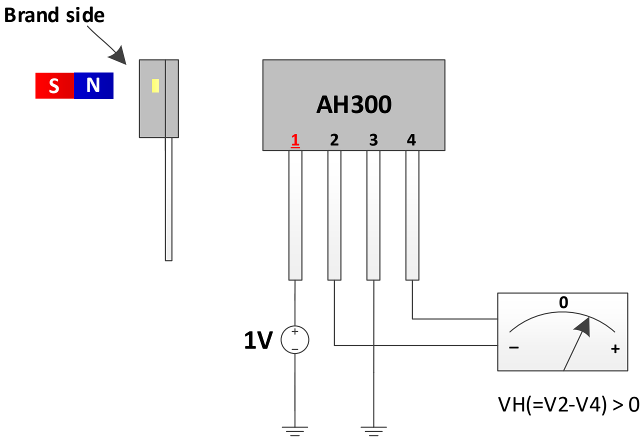


Figure 12. AH300/AH322 *VH* vs Magnet pole *N*

However, in the same setup, the negative *VH* voltage can be generated between Pin2 and Pin4 when magnet pole S is to the brand side, as in Figure 13.

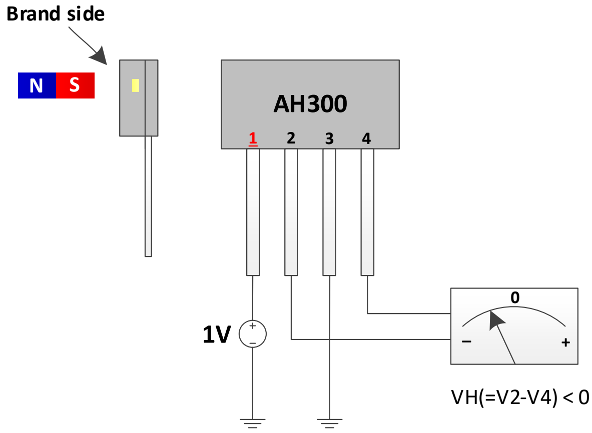


Figure 13. AH300/AH322 *VH* vs Magnet pole *S*

Note:

In the SOT23-4, the upper-side Pin1/Pin2 is quite symmetrical to the bottom-side Pin3/Pin4. This symmetry may lead to human error, resulting in a 180° rotation issue when mounted to the PCB. Even when the Hall element is rotated 180°, the Hall output voltage (*VH*) will be the same as previous non-rotated results if all the same setups include a magnet pole to the brand side, as seen in Figure 14.

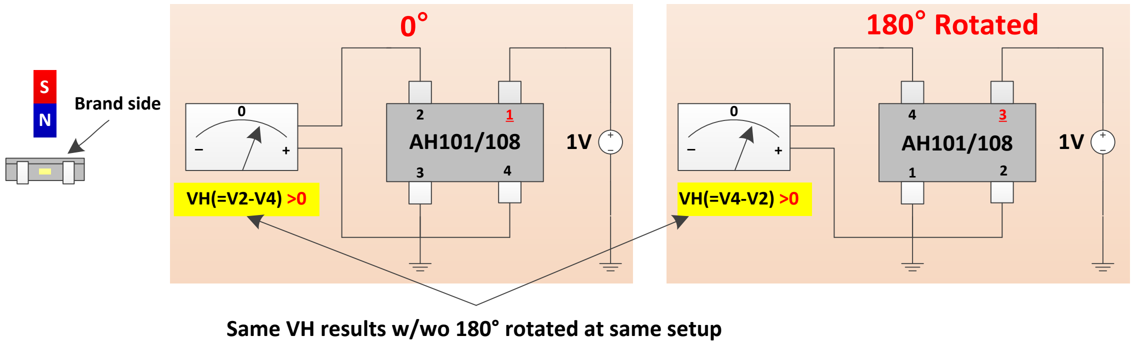


Figure 14. Hall output voltage with and without the SOT23-4 being rotated 180°

Applications

Hall elements are mainly used for BLDC motor and linear position detection. These applications benefit from:

- Contactless application with long lifetimes;
- Miniaturization for surface mount applications;
- Fast response times with no-contact bunce.

Hall elements in BLDC (brushless) motor applications

Many DC motors include brushes, as shown in Figure 15. Current flow is switched to the coils through the brushes, which repeatedly contacts the commutator as it rotates. This repeated physical contact between the brushes and the commutator causes the brushes to wear out.

Therefore, integrating a Hall element into the BLDC can provide a contactless, long-lifetime, and maintenance-free motor that rotates with the direct current, as shown in Figure 16.

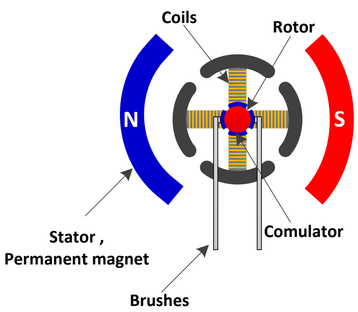


Figure 15. Brushed DC motor

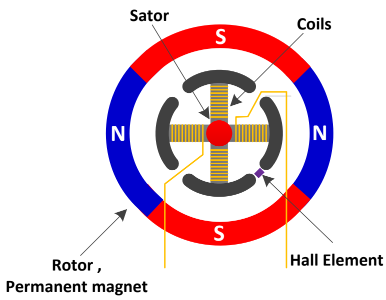


Figure 16. Brushless DC motor with Hall element

Based on the information of the magnetic field detected by the Hall element, as shown in Figure 17, the current is varied to the coil to create an electromagnetic driver IC, as seen in Figure 18. The strength and direction of the magnetic field generated by the electromagnets are controlled in a timely manner, and the rotor is rotated by the force of repulsion and attraction between the magnets of the rotor and the electromagnets of the coils.

In addition, BLDC efficiency, such as in rotational speed and jitter, may be affected if the duty ratio is not quite symmetrical with the north/south pole switching, possibly due to a V_{OS} problem. However, this phenomenon can be improved by using a highly sensitive Hall element.

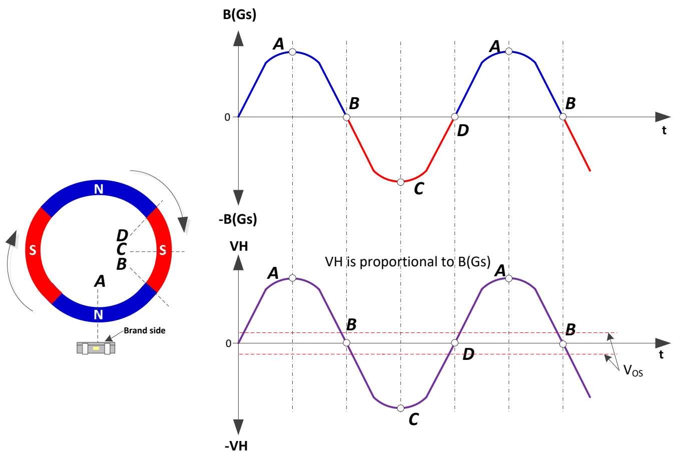


Figure 17. Hall element *VH* vs. ring magnet

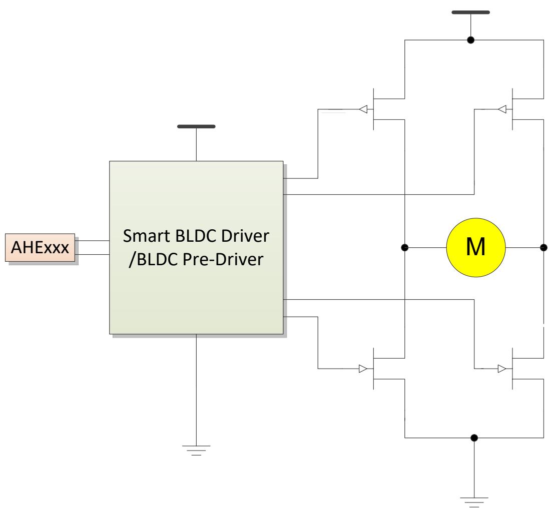


Figure 18. Hall element *VH* vs. ring magnet

Diodes provides smart BLDC drivers and pre-drivers for user selection. For more detailed information, please refer to our website: https://www.diodes.com/products/power-management/motor-control/.

Hall elements in linear position detection

Hall elements have good linearity with magnetic flux density and can thus be employed for position detection. Based on this, the Hall element voltage can be amplified by RF/R ratio when the amplified voltage (*VO*) is proportional to magnetic flux density. The user can detect the position variation by monitoring the *VO* voltage.

Figure 19 shows an example of a linear signal amplifier with a Hall element. Output transfer function of distance vs. magnetic flux density is shown in Figure 20.

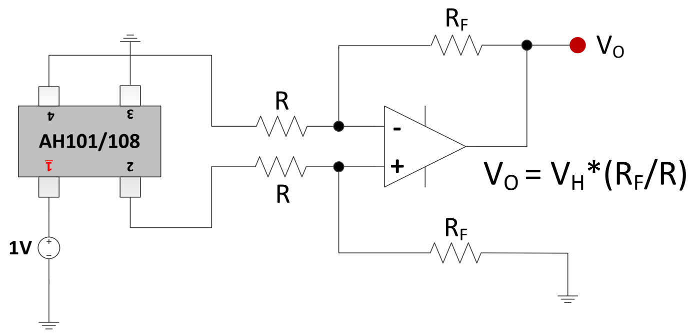


Figure 19. Linear signal amplifier circuits

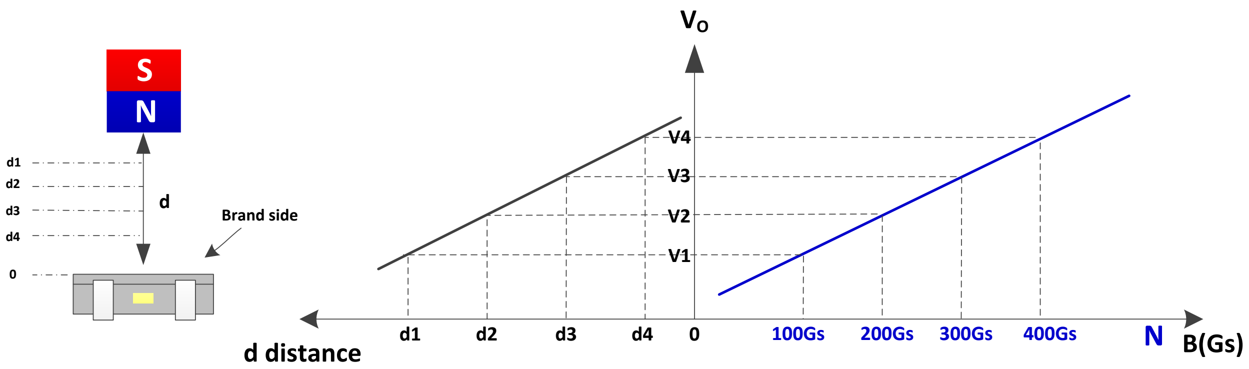


Figure 20. Output transfer function

Hall elements in current sensors

An **open-loop current sensor**, as seen Figure 21, consists of a Hall element placed in the air space of a magnetic core. They measure both AC and DC and provide electrical isolation between the input and output sections, with the galvanic isolation ensuring no-contact measurement. The amplified Hall signal represents the sensor output.

Figure 21 illustrates the principles behind the Hall current sensor. The magnetic flux produced in proportion to the primary current, *IP*, induced in the magnetic circuit, passes through the Hall element inserted in the gap of the magnetic circuit. This results in a potential difference, *VH*, expressed by the formula shown in the Figure 21.

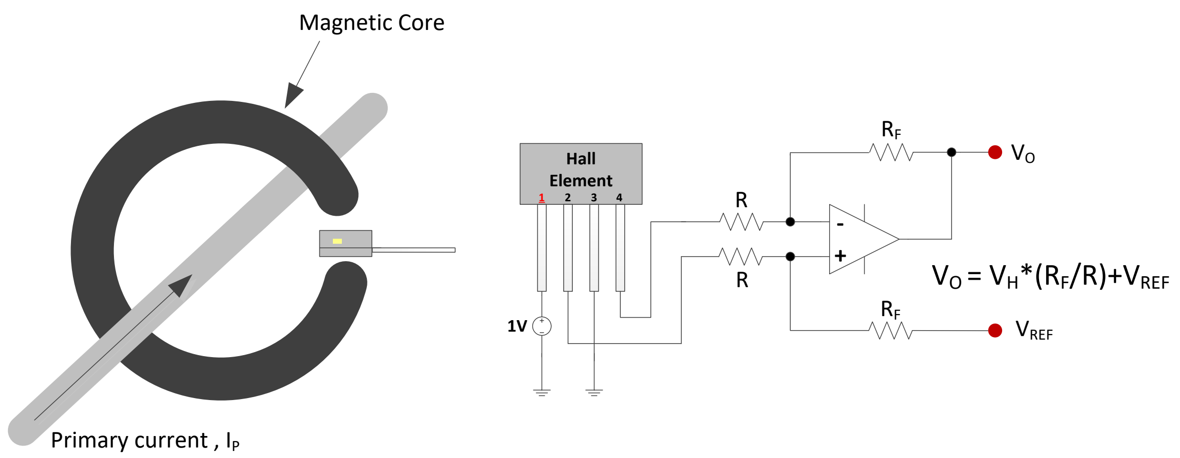


Figure 21. Open-loop current sensor

A **closed-loop current sensor**, as seen in Figure 22, applies a feedback current to the secondary winding to produce a magnetic field that opposes the magnetic field generated by the primary current. A Hall element is placed in the gap of the core that surrounds the primary current line, and the secondary winding (*N* turns) is wound around the core. The feedback circuit applies a feedback current (*IP/N*) to the secondary winding so that the output of the Hall element will always be zero, thus counteracting the magnetic field generated by the primary current. This feedback current is converted to a voltage by a load resistor (*RL*), making it possible to obtain a voltage proportional to the primary current.

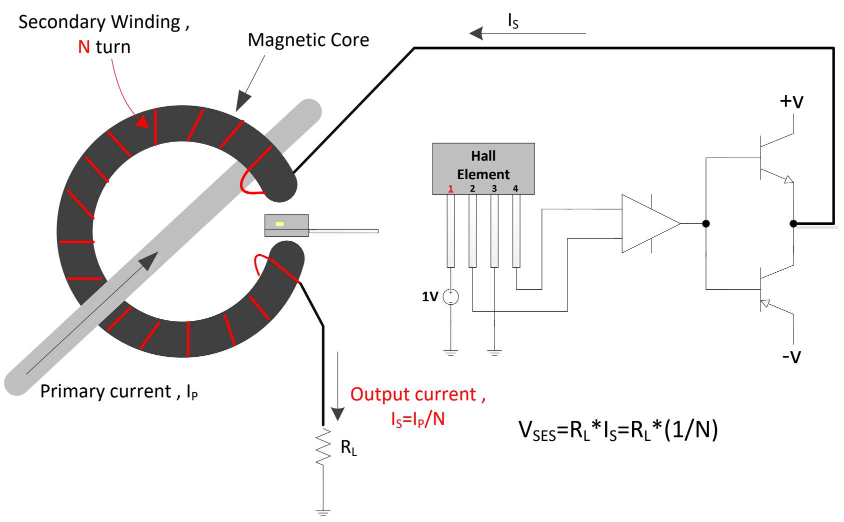


Figure 22. Closed-loop current sensor

Closed-loop and open-loop current sensors have their own advantages and disadvantages, as shown in Table 3 below. Knowing which type to select depends on the user's requirements for their system applications.

Current Sensor	Power Consumption	Accuracy and Linearity	Response Time	Isolation	Dynamic Range	Cost
Open Loop	Low	Good	Fast	electrical isolation	Wider	Low
Closed Loop	High	Best	Faster	Nonelectrical isolation	Narrower	High

Table 2. Comparison table of open-loop vs. closed-loop current sensor

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