# AN1187

# Hall-Effect IC Applications Guide

Alex Jih, Hall Sensor Design and Application Manager, Standard Analog Business Unit

## Introduction

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

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.

### 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, the Lorentz force as Figure 1.

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

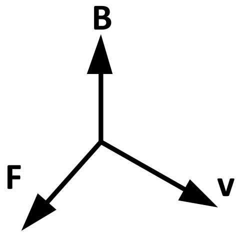



**Figure 1. Lorentz force**

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 current. When no magnetic field is present, current distribution is uniform and no potential difference is seen across the output 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 as VH ∝ I × B.

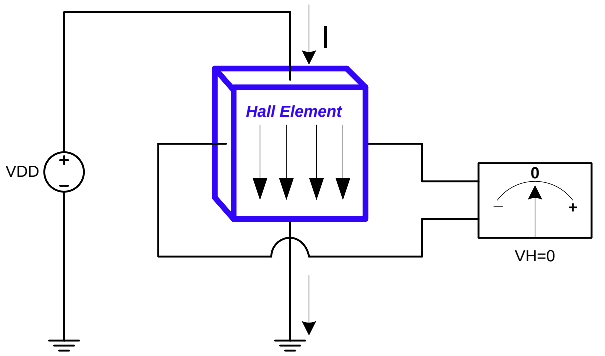



Figure 2. No magnetic field

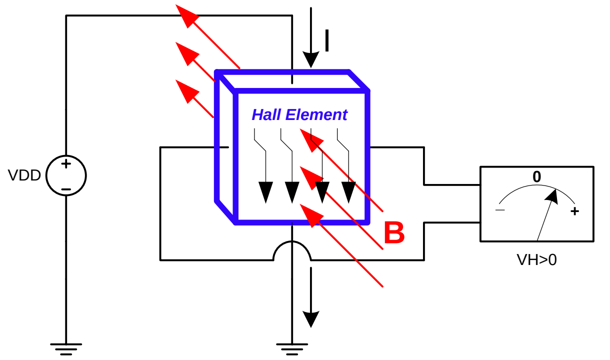



Figure 3. Magnetic field present

## Magnetic fields

The physical force exerted by a magnet can be described as lines of flux originating at the north pole of a magnet and terminating at its south pole shown in Figure 4.

In general hall sensor applications, the concept of flux density is used to describe the intensity of the magnetic field at a particular point in space. Flux density is used as the measure of magnetic field. Units of flux density include teslas(T) and webers/meter$^2$, The cgs unit of magnetic field, Gauss(Gs) is unit used in Diodes Incorporated's (Diodes) Hall sensor products.

Besides, 1T=$10^4$ Gs.


Figure 4. Magnetic flux direction

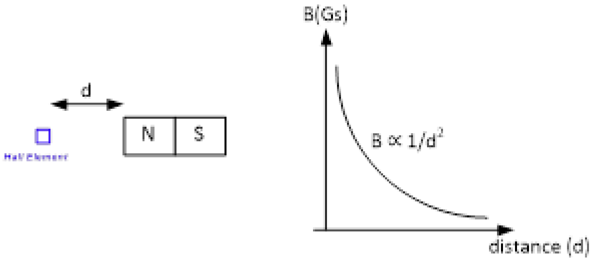



Figure 5. Magnetic flux density vs. distance

Additionally, the magnetic flux density is proportional to the inverse square of the distance. $B \propto 1/d^2$, d is distance between magnets to hall element. This means that magnetic sensing is only effective at short distances.

## Hall Element Architecture

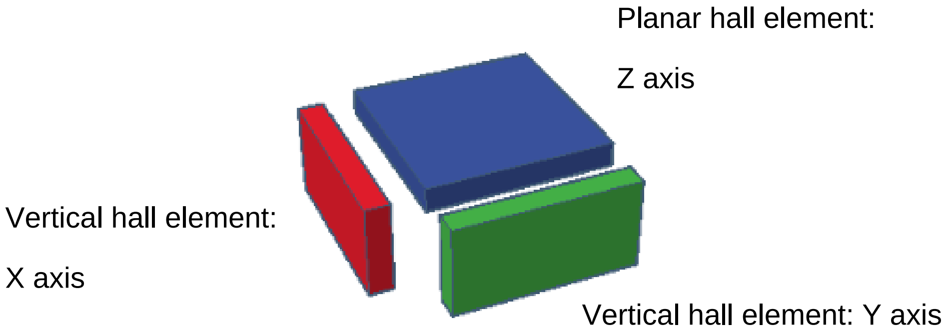



**Figure 6. Planar and vertical hall plate architecture**

### Orientation of Magnet field

For Hall devices, orientation of the field relative to the device active area is important. The active area (Hall element) of Hall devices is embedded on a silicon chip located parallel to, and slightly inside of, one particular face of the package. That face is referred to as the branded face because it is normally the face that is marked with the part number (detail information please refer to the datasheet). To optimally operate the switch, the magnetic flux lines must be oriented to cross perpendicularly through the active area (the branded face of planar Hall devices, or the sensitive edge of vertical Hall devices) and must have the correct polarity as it crosses through.

### Planar Hall Device

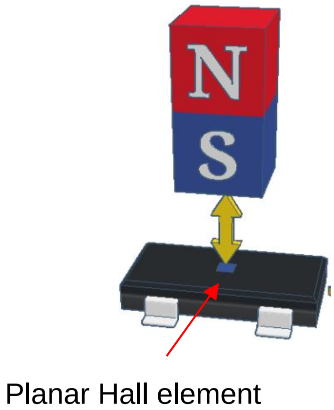



**Figure 7. Magnetic flux line on a Planar Hall device**

## Electrical Considerations

### Output transfer function

Hall sensor functionality is fundamentally linear however most devices available fit into the “digital switch” whose output is On or Off depending on the applied magnetic field. These digital switches can have Unipolar transfer function (responds to only one type of pole), Omnipolar (responds to either pole) and Latch (turns on with one pole and only turns off with the opposite pole).

In addition to these switches, ratiometric linear hall sensors are available (output is proportional to magnetic flux density detected).

Their characteristics are shown below:

### Specification definitions

**B(Gs)**: Magnetic flux density of South pole including X, Y, and Z axis.
**-B(Gs)**: Magnetic flux density of North pole including X, Y, and Z axis.
**BOP**: Magnetic operating point, defines when the output driver will be active (On)
**BRP**: Magnetic Release point, defines when the output driver will be inactive (Off)
**BHYS**: Difference between Bop and Brp, BHYS = Bop-Brp
**d**: distance between Magnet to Hall device branded side
**On:** Output at low state
**Off:** Output at high state

### Unipolar

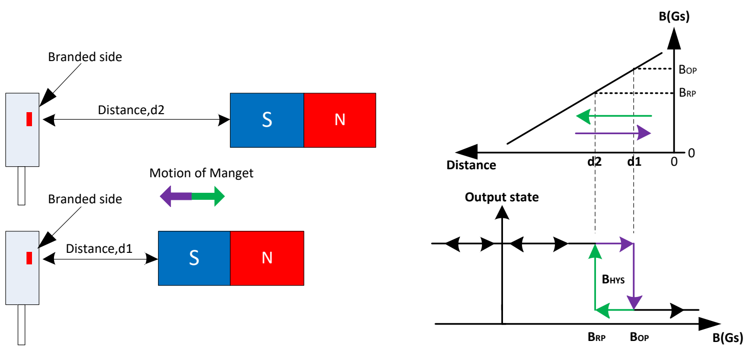



**Figure 8. Magnet flux density vs. Unipolar Output state**

### Omnipolar

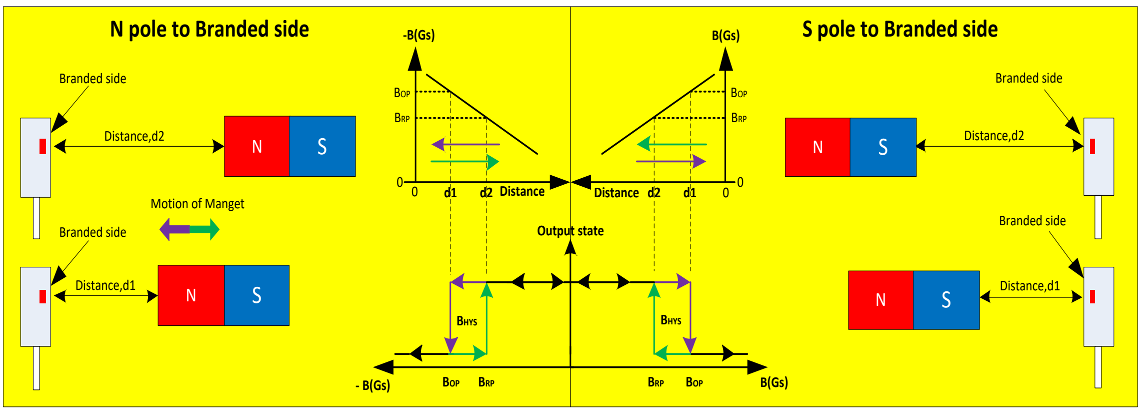



**Figure 9. Magnet flux density vs. Omnipolar Output state**

## Latch

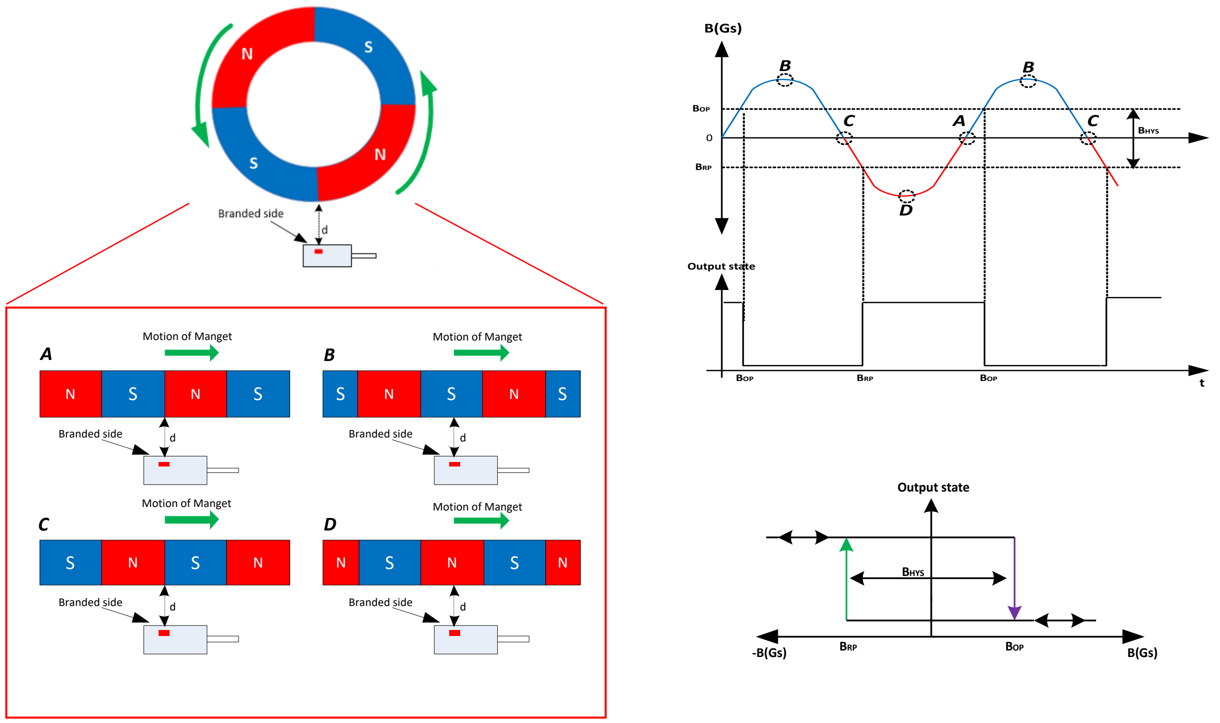



**Figure 10. Magnet flux density vs. Latch Output state**

## Ratiometric Linear

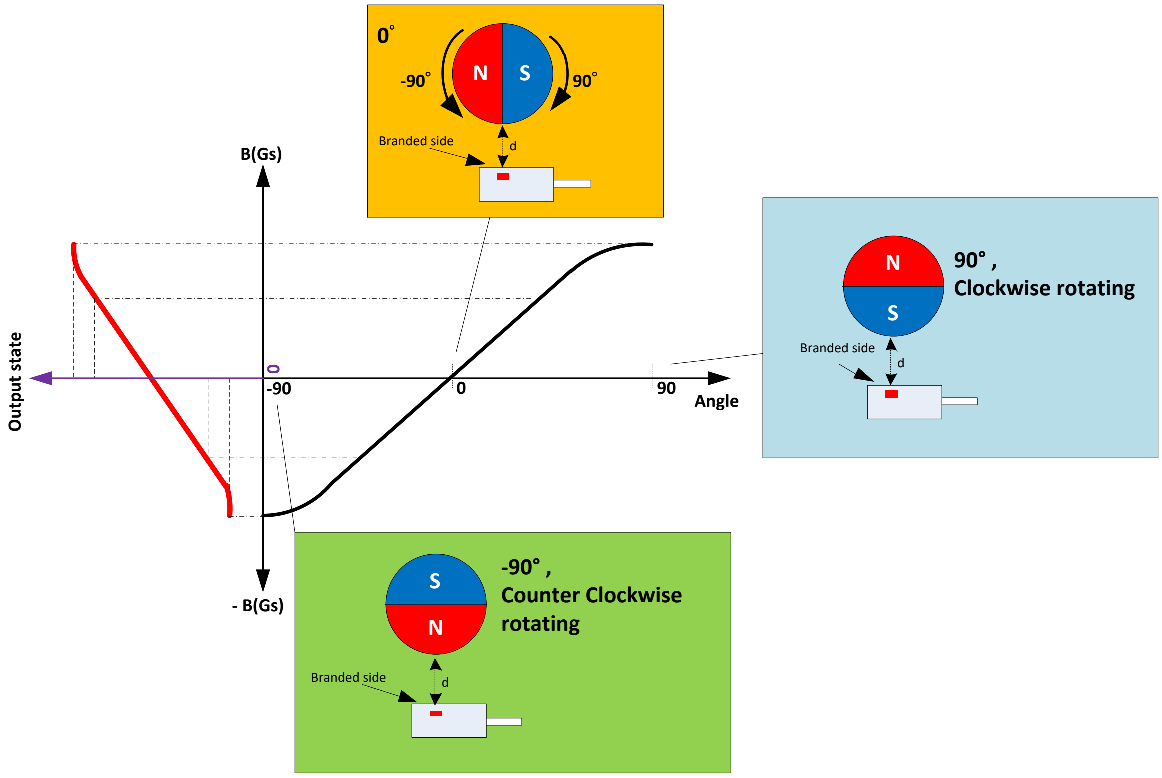



**Figure 11. Magnet flux density vs. Ratio metric linear Output state**

## Output Functionality

Digital output switches have a variety of output formats including push-pull, built-in pull-up resistor, open-drain/-collector, and current-output.

Diodes' linear/analog output devices have their output voltage ratiometric to the supply voltage.

## Specification definitions

**V**OH: Output high voltage depends on output current at datasheet

**V**OL: Output low voltage depends on output current at datasheet

**R**UP: pull-up resistor

**C**L: Output capacitor(optional)

**I**ON: Supply current on state

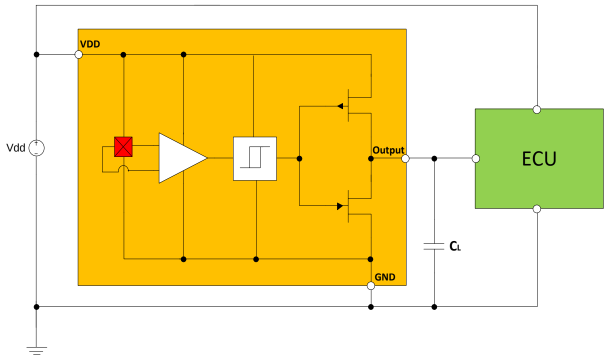
**I**OFF: Supply current off state

**V**SEN: Output Voltage Sensitivity

**V**NULL: Quiescent Output Voltage with Zero Gauss

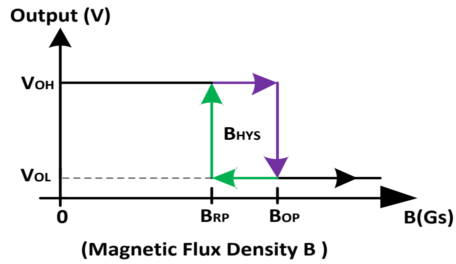
## Digital Output

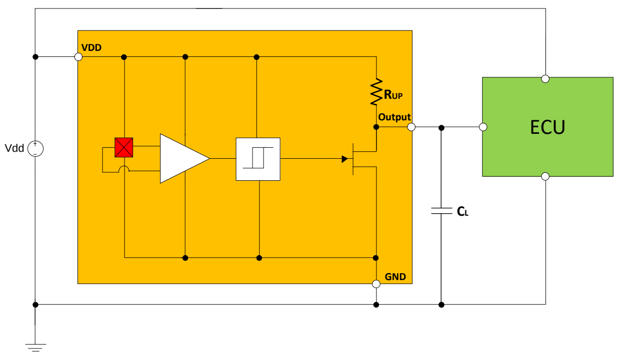
### 1. Push-pull and built-in Pull-up resistor




**Push-pull**

**Example of Unipolar**



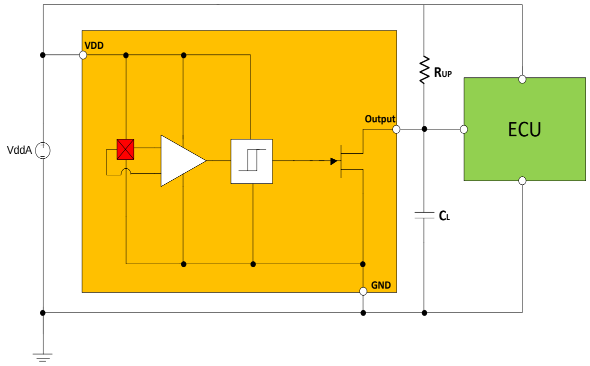




**Built-in Pull-up resistor**

Built-in Pull-up resistor (RUP) versions have their resistance in the 10k to 100kΩ range, which is usually larger than Push-pull version (PMOS RON lower than 1kΩ). This makes their output source current poor, especially with the 100kΩ pull-up resistor devices and so these quite often have to add a buffer to drive next stage.

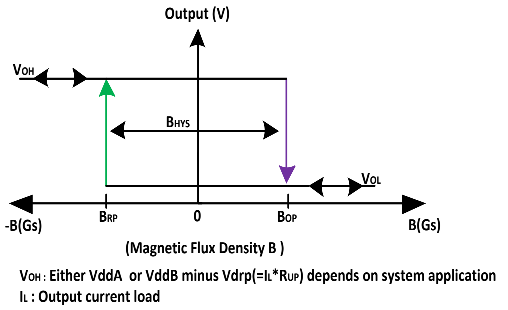
The optimum CL design value depends on system requirements. However, please note that a larger capacitance value will increase the output rise/fall time which slows down the response time/frequency.

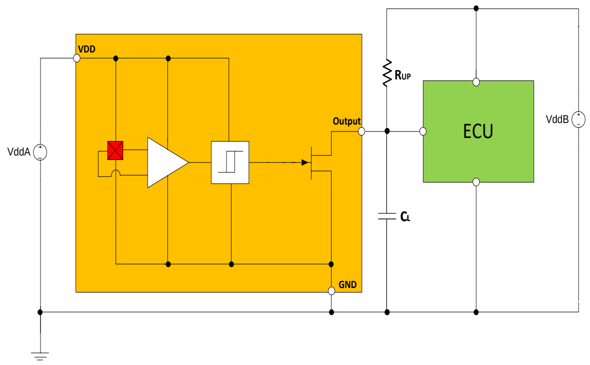
## 2. Open drain/collector




**Open drain with Pull-up on one power system**

**Example of Latch**




**Open drain with Pull-up on two power system**

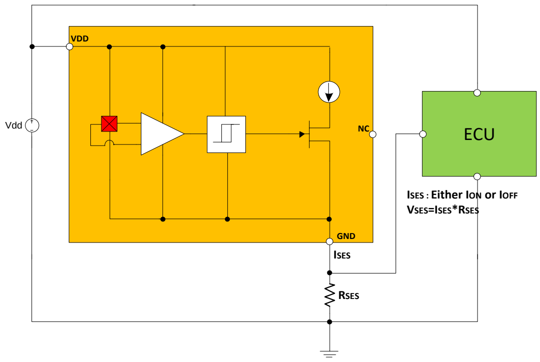
Devices with an open drain output with external pull-up resistor (RUP) allows the output to be referred to supply rails. One option is to refer the Pull-up resistor (RUP) to the same power rail as the hall sensor and ECU resulting them all employing the same power as like VddA. Another where the hall sensor and the ECU are powered from separate rails, VddA and VddB. Here the Hall device uses VddA while the pull-up resistor is referred to the same power rail as the ECU (VddB).

VddB voltage can be either lower or higher than VddA and is based on the application. Please note - the VddB voltage can't operate higher than the open drain absolute maximum ratings shown in datasheet.

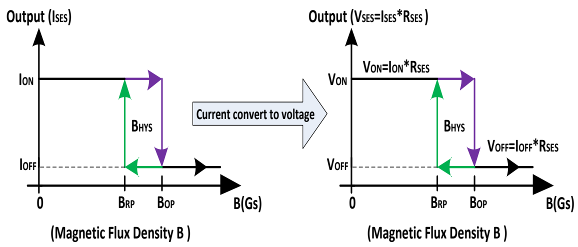
The optimum CL (filtering capacitor) design depends on system requirements. However, please note that the bigger capacitance value will increase the output rising/falling time and slow down the switching frequency. The switching frequency can be calculated by below equation:

$$f(Hz) = \frac{1}{2*2\pi*RUP*CL} \ ,$$

### 3. Current output




Example of Uni-Polar




In general, the current output is suitable for use in long cable wires for cost reduction and for enhanced noise immunity. In applications, it is necessary to add resistor (RSES) in series to Hall device GND pin and close to ECU, then the output current (ISES) will be converted to voltage (VSES). The RSES value is dependent on the application, but please note that the current output type minimum operating voltage will be limited by VSES.

For example:

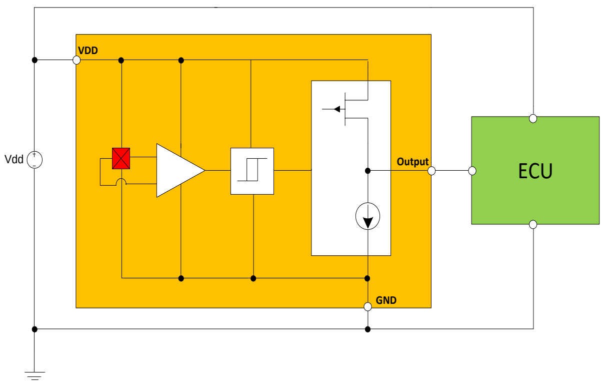
Assume the Hall device min operating voltage (VDDmin) is 2.7V, ION=14mA, IOFF=6mA, RSES =100Ω

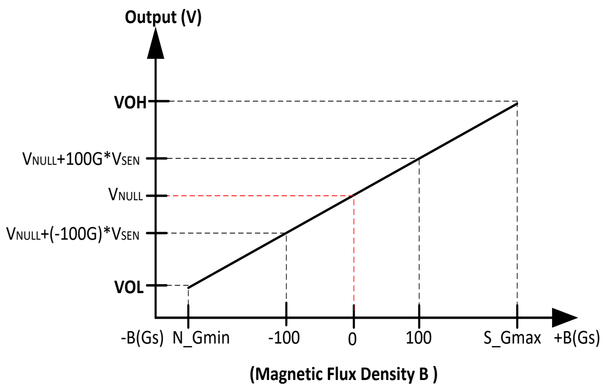
VSES_ON = ION * RSES=14mA*100Ω=1.4V, critical parameter

VSES_OFF = IOFF * RSES=6mA*100Ω=0.6V

Thus, the system power applied to hall device have to higher than 4.1V (VSES_ON+VDDmin=1.4v+2.7V) to ensure function working normal.

## Analog Output




The output voltage is proportional to magnetic flux density and is calculated by the formula:

Vout = VNULL+Gs*VSES

Where:

VSEN is Output Voltage Sensitivity in mV/Gauss – and depends on product specification.

VNULL is nominal Output Voltage with zero gauss applied; Vdd/2 is general case

For example:

Assume operating Vdd is 5V, VNULL is 2.5V(= Vdd/2), VSEN is 2.5mV/Gauss

The linear output voltage range is specified as VOH maximum 4.8V to VOL minimum 0.2V individually. From these the maximum and minimum operating gauss range and Vout at specific gauss can be calculated based on the information above.

S_Gmax

⇨ (VOH-VNULL)/VSEN =(4.8V-2.5V)/(2.5mv/G) = 920G

N_Gmin

⇨ (VOL-VNULL)/VSEN =(0.2V-2.5V)/(2.5mV/G) = -920G

Vout @ 100G

⇨ Vout = VNULL+Gs*VSES =2.5V+100G*(2.5mV/G)=2.7V

Vout @ -100G

⇨ Vout = VNULL+Gs*VSES =2.5V+(-100G)*(2.5mV/G)=2.3V

**Design Example: 2-in-1/360° laptop mode detection**

A 2-in-1 Laptop employing AH1389 dual unipolar output product is used to detect the swap to Laptop mode or Tablet mode using the AH1389's two output signal combination.

**Closed mode**: Display panel rotated angle close to 0° from hinge

**Laptop mode**: Display panel rotated angle > 0° and < 180° from hinge.

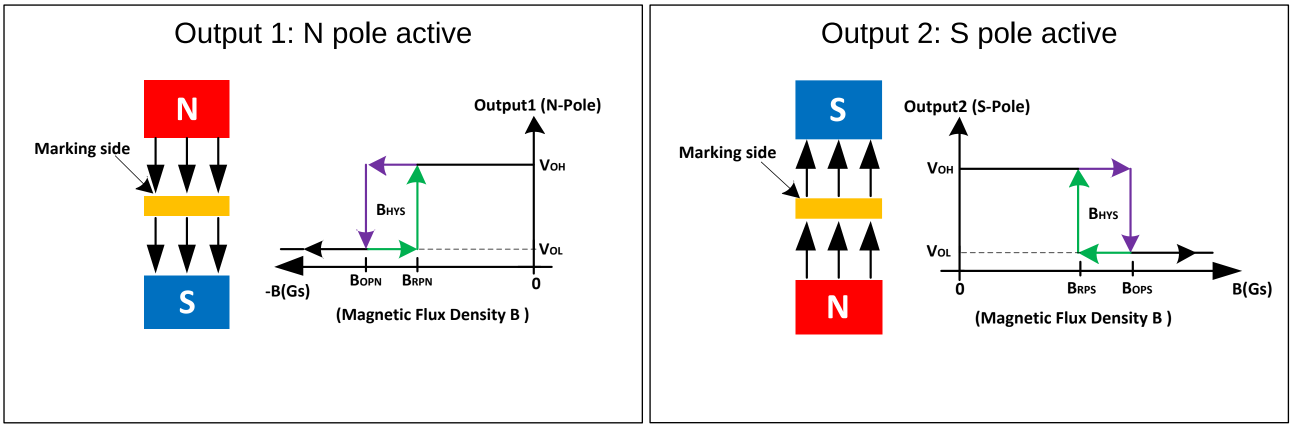
**Tablet mode**: Display panel rotated approach to 360° from hinge

## Hall Product: AH1389 Dual Unipolar characteristics

(1mT=10 Gauss)

| Symbol | Characteristics | Test Condition | Min | Typ | Max | Unit |
|---|---|---|---|---|---|---|
| $B_{OPS}$ (South Pole to Part Marking Side) Output2 | Output2 Operation Point | $V_{DD}$ = 1.85V $T_A$ = +25°C | 14 | 25 | 32 | Gauss |
| | | $V_{DD}$ = 1.6V to 3.6V $T_A$ = -40°C to +85°C | 13 | 25 | 39 | |
| $B_{OPN}$ (North Pole to Part Marking Side) Output1 | Output1 Operation Point | $V_{DD}$ = 1.85V $T_A$ = +25°C | -32 | -25 | -14 | |
| | | $V_{DD}$ = 1.6V to 3.6V $T_A$ = -40°C to +85°C | -39 | -25 | -13 | |
| $B_{RPS}$ (South Pole to Part Marking Side) Output2 | Output2 Release Point | $V_{DD}$ = 1.85V $T_A$ = +25°C | 12 | 20 | 30 | |
| | | $V_{DD}$ = 1.6V to 3.6V $T_A$ = -40°C to +85°C | 9 | 20 | 37 | |
| $B_{RPN}$ (North Pole to Part Marking Side) Output1 | Output1 Release Point | $V_{DD}$ = 1.85V $T_A$ = +25°C | -30 | -20 | -12 | |
| | | $V_{DD}$ = 1.6V to 3.6V $T_A$ = -40°C to +85°C | -37 | -20 | -9 | |
| $B_{HY}$ ($\lvert B_{OPX}\rvert-\lvert B_{RPX}\rvert$) | Hysteresis (Note 10) | — | 1 | 5 | — | |

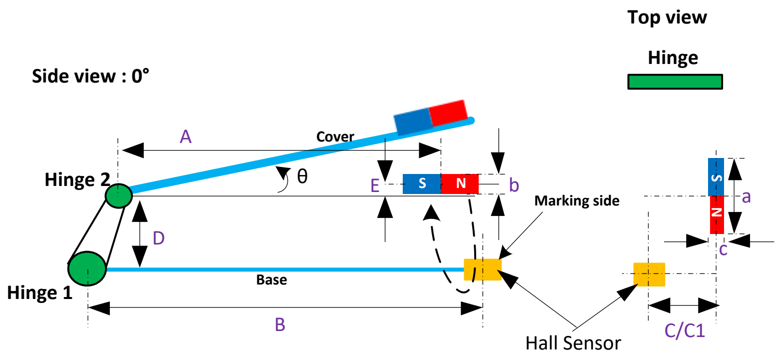
## Output State




## Magnet material example

- ✓ Magnet grade: NdFeB, N52, L 9.0mm,W:5.0mm, H:2.3mm
- ✓ Rmanence: 1.43kGauss(min) ~1.49kGauss(max)
- ✓ Coercive Force $b_{HC}$: 860KA/m
- ✓ Direction of magnetization (Oriented through length)

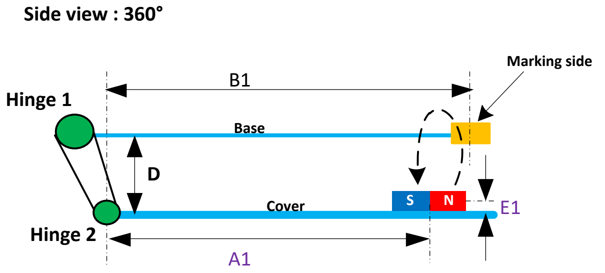
## Magnet and Hall sensor position in laptop design (dimensions not to scale)




North Pole to hall sensor marking side

**Recommended dimension**

| | Symbol | default(mm) |
|---|---|---|
| 0° | A | 19.5 |
| | B | 25 |
| | C | 1.6 (Note 1) |
| | D | 10.18 |
| | E | 0.94 |
| | L | -- |
| | a | 9 |
| | b | 2.3 |
| | c | 5 |



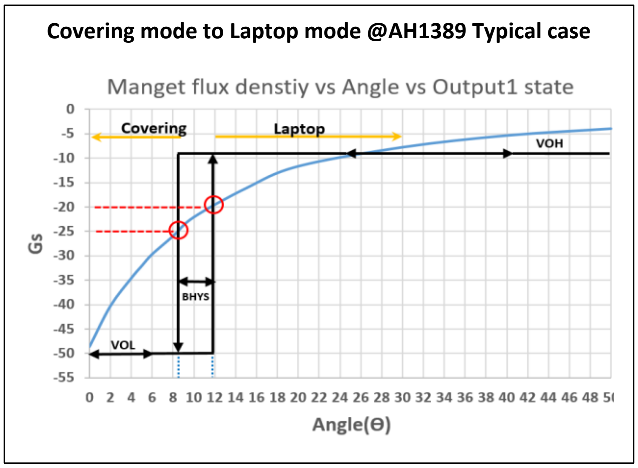

North Pole to hall sensor non marking side

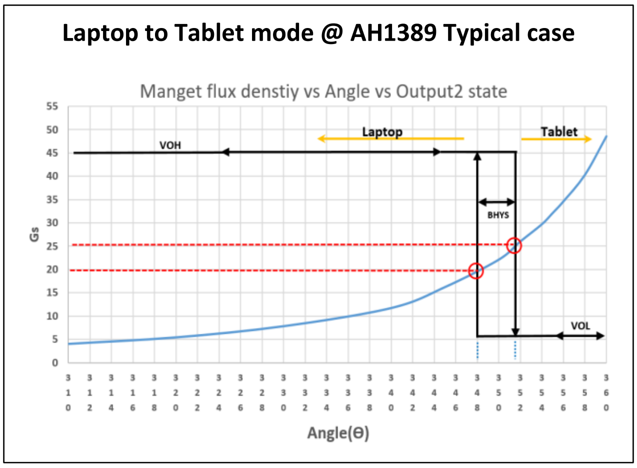
**Recommended dimension**

| | symbol | default(mm) |
|---|---|---|
| 360° | A1 | 19.5 |
| | B1 | 25 |
| | C1 | 1.6 (Note 1) |
| | D | 10.18 |
| | E1 | 0.94 |
| | L | -- |
| | a | 9 |
| | b | 2.3 |
| | c | 5 |

Note: 1. -2mm ~ +2mm is fine to symbol C and C1

### Example: Magnetic flux density vs. Panel rotating angle (Ɵ)/Output state




Open condition: with the hinge rotated angle larger than 12°, the laptop will enter Laptop mode from closed mode. Closed condition is when the hinge angle is less than 8°.

### Tablet mode:

With the hinge rotated angle is larger than 352°, if the angle is less than 348° then the laptop will go back to laptop mode.

The example above shows the ideal case; for more information about the magnet material/shape and position, and how these correspond to Diodes' Dual unipolar design please contact Diodes.

## Appendix:

1. **Magnetic flux density calculation tool:**

   https://www.diodes.com/products/analog/sensors/hall-effect-latches-and-switches/hall-effect-sensors-part-selector/

**IMPORTANT NOTICE**

1. DIODES INCORPORATED (Diodes) AND ITS SUBSIDIARIES MAKE NO WARRANTY OF ANY KIND, EXPRESS OR IMPLIED, WITH REGARDS TO ANY INFORMATION CONTAINED IN THIS DOCUMENT, INCLUDING, BUT NOT LIMITED TO, THE IMPLIED WARRANTIES OF MERCHANTABILITY, FITNESS FOR A PARTICULAR PURPOSE OR NON-INFRINGEMENT OF THIRD PARTY INTELLECTUAL PROPERTY RIGHTS (AND THEIR EQUIVALENTS UNDER THE LAWS OF ANY JURISDICTION).

2. The Information contained herein is for informational purpose only and is provided only to illustrate the operation of Diodes' products described herein and application examples. Diodes does not assume any liability arising out of the application or use of this document or any product described herein. This document is intended for skilled and technically trained engineering customers and users who design with Diodes' products. Diodes' products may be used to facilitate safety-related applications; however, in all instances customers and users are responsible for (a) selecting the appropriate Diodes products for their applications, (b) evaluating the suitability of Diodes' products for their intended applications, (c) ensuring their applications, which incorporate Diodes' products, comply the applicable legal and regulatory requirements as well as safety and functional-safety related standards, and (d) ensuring they design with appropriate safeguards (including testing, validation, quality control techniques, redundancy, malfunction prevention, and appropriate treatment for aging degradation) to minimize the risks associated with their applications.

3. Diodes assumes no liability for any application-related information, support, assistance or feedback that may be provided by Diodes from time to time. Any customer or user of this document or products described herein will assume all risks and liabilities associated with such use, and will hold Diodes and all companies whose products are represented herein or on Diodes' websites, harmless against all damages and liabilities.

4. Products described herein may be covered by one or more United States, international or foreign patents and pending patent applications. Product names and markings noted herein may also be covered by one or more United States, international or foreign trademarks and trademark applications. Diodes does not convey any license under any of its intellectual property rights or the rights of any third parties (including third parties whose products and services may be described in this document or on Diodes' website) under this document.

5. Diodes' products are provided subject to Diodes' Standard Terms and Conditions of Sale (https://www.diodes.com/about/company/terms-and-conditions/terms-and-conditions-of-sales/) or other applicable terms. This document does not alter or expand the applicable warranties provided by Diodes. Diodes does not warrant or accept any liability whatsoever in respect of any products purchased through unauthorized sales channel.

6. Diodes' products and technology may not be used for or incorporated into any products or systems whose manufacture, use or sale is prohibited under any applicable laws and regulations. Should customers or users use Diodes' products in contravention of any applicable laws or regulations, or for any unintended or unauthorized application, customers and users will (a) be solely responsible for any damages, losses or penalties arising in connection therewith or as a result thereof, and (b) indemnify and hold Diodes and its representatives and agents harmless against any and all claims, damages, expenses, and attorney fees arising out of, directly or indirectly, any claim relating to any noncompliance with the applicable laws and regulations, as well as any unintended or unauthorized application.

7. While efforts have been made to ensure the information contained in this document is accurate, complete and current, it may contain technical inaccuracies, omissions and typographical errors. Diodes does not warrant that information contained in this document is error-free and Diodes is under no obligation to update or otherwise correct this information. Notwithstanding the foregoing, Diodes reserves the right to make modifications, enhancements, improvements, corrections or other changes without further notice to this document and any product described herein. This document is written in English but may be translated into multiple languages for reference. Only the English version of this document is the final and determinative format released by Diodes.

8. Any unauthorized copying, modification, distribution, transmission, display or other use of this document (or any portion hereof) is prohibited. Diodes assumes no responsibility for any losses incurred by the customers or users or any third parties arising from any such unauthorized use.

9. This Notice may be periodically updated with the most recent version available at https://www.diodes.com/about/company/terms-and-conditions/important-notice



**www.diodes.com**