Application Note

Understanding and Applying Hall Effect Sensor Data Sheets

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ABSTRACT

Hall effect sensors measure magnetic fields, and this article provides a baseline of information on how to interpret data sheet parameters and apply them toward system design.

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Trademarks

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1 Units

A magnet produces a magnetic field that travels from the North pole to the South pole. The total amount of field through a 2-dimensional slice is the flux, measured in units of weber. Webers per square meter indicates flux density, measured in units of tesla (T). The unit of gauss (G) also describes flux density, where 1 T = 10000 G. In millitesla, 1 mT = 10 G. Tesla is the official SI unit and used by TI data sheets, but other sources may use gauss.

2 Practical Concepts

- The flux density increases closer to a magnet.
- The flux density at the surface of the magnet depends on its material and the amount of magnetization.
- At a given distance, physically large magnets project a larger flux density.

3 Polarity

The symbol B is used for flux density. Most TI Hall sensors use the convention that magnetic fields traveling from the bottom of the device through the top are positive B, and fields traveling from the top to the bottom of the device are negative B. One exception is the TMAG5273 linear 3D Hall-effect sensor, which defines a positive field as when the magnetic fields travel from the top of the device to the bottom. Out-of-plane one dimensional (1D) position sensors are sensitive to the magnetic field component that is perpendicular to the die inside the package. On the other hand, in-plane 1D position sensors are sensitive to application of the magnet pole in the same plane as the die. 3D linear Hall sensors use one out-of-plane sensing element and two in-plane sensing elements to detect across three directions.

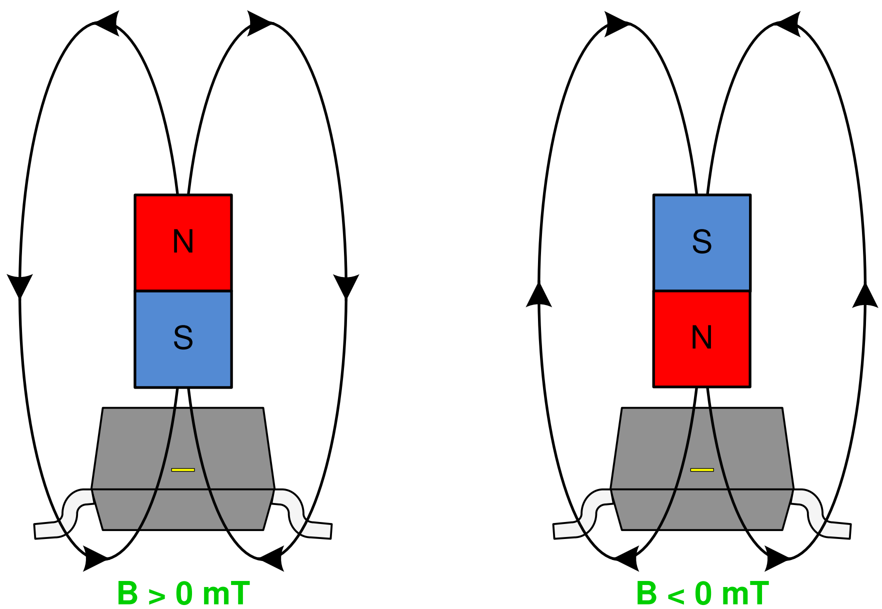

Figure 3-1. Typical Polarity of Field Directions For 1D Out-of-Plane Sensors

4 Digital Hall Sensor Functionality

Digital Hall sensors either have an open-drain or push-pull output that pulls low if B exceeds the threshold B_{OP} (the operate point). The output then stays low until B decreases below the threshold B_{RP} (the release point), then the output becomes High-Impedance for an open-drain output and pulled high for a push-pull output. B_{OP} and B_{RP} are always separated with hysteresis (B_{hys}), which prevents noise-induced toggling at a threshold. Omnipolar devices have an output that reacts to positive and negative fields the same while unipolar devices have an output that reacts to either a positive field or a negative field only.

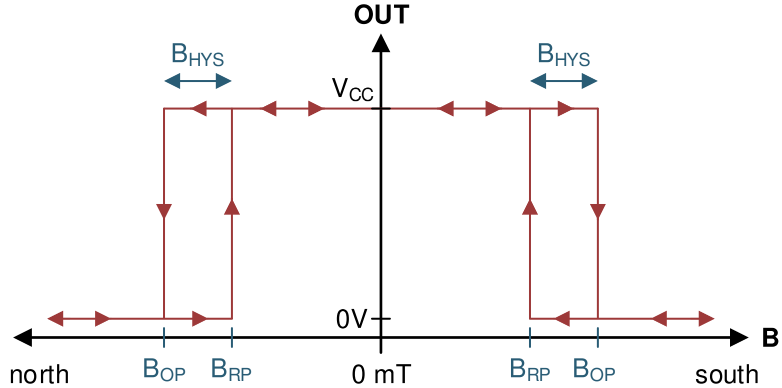

Figure 4-1. B-field Response of the DRV5032 Omnipolar Device Variants

Like all data sheet parameters, the actual B thresholds vary due to semiconductor process variation, operating voltage, and temperature.

Table 4-1. B Thresholds for DRV5032AJ

PARAMETER		MIN	TYP	MAX	UNIT
B_{OP}	Operate point	±4	±7	±9.4	mT
B_{RP}	Operate point	±3	±5.6	±7.5	
B_{hys}	Hysteresis; B_{hys} = (B_{OP} – B_{RP})	0.5	1.4	3	

A magnet and Hall sensor should be selected so that the field at the sensor exceeds the specified max-B_{OP}, to guarantee that the magnetic threshold is crossed.

4.1 Design Example with Digital Hall Sensors

Consider the switches used to control power windows in a vehicle.

Each rocker switch could contain two small magnets for the forward and backward directions, along with a digital Hall sensor mounted below each one. This ensures that when the button is not pushed, the B-field at the sensor is below the min-B_{RP}, and pushing the button brings the B-field at the sensor above the max-B_{OP}. This involves a combination of magnet and sensor selection, considering the distance of separation.

When selecting a DRV5032 switch, there are multiple device versions:

Table 4-2. DRV5032 Switch Versions

	PARAMETER	MIN	TYP	MAX	UNIT
DRV5023DU north responding unipolar output	B_{OP}	–3.9	–2.5	-1.2	mT
	B_{RP}	–3.5	–1.8	–0.9	
DRV5023DU south responding unipolar output	B_{OP}	1.2	2.5	3.9	
	B_{RP}	0.9	1.8	3.5	
DRV5023FA, DRV5032FB, DRV5032FC	B_{OP}	±1.5	±3	±4.8	
	B_{RP}	±0.5	±1.5	±3	
DRV5032FD south responding unipolar output	B_{OP}	–4.8	–3	–1.5	
	B_{RP}	–3	–1.5	–0.5	
DRV5032FD south responding unipolar output	B_{OP}	1.5	3	4.8	
	B_{RP}	0.5	1.5	3	
DRV5032AJ	B_{OP}	±4	±7	±9.5	
	B_{RP}	±3	±5.6	±7.5	
DRV5032ZE	B_{OP}	±33	±47	±63	
	B_{RP}	±30	±43	±58	

The designer must select the material and size when choosing a magnet. Available materials include ceramics and different ferromagnetic metal alloys, with tradeoffs in flux density, temperature performance, mechanical characteristics, and cost. The physical size of the magnet must be selected to produce the appropriate B-fields at the sensor. Flux concentrators that redirect and amplify the B-field of a magnet are also available.

To determine the B-field a magnet produces, measure it using a gaussmeter (or teslameter). There are several online calculators, and some magnet suppliers specify limited B-field characteristics. The field in a particular system varies based on the materials permeated and potential interactions from nearby components.

5 Linear Hall Sensor Functionality

TI's analog Hall sensors such as the DRV5055 have an analog voltage output that changes proportionally with the magnetic field.

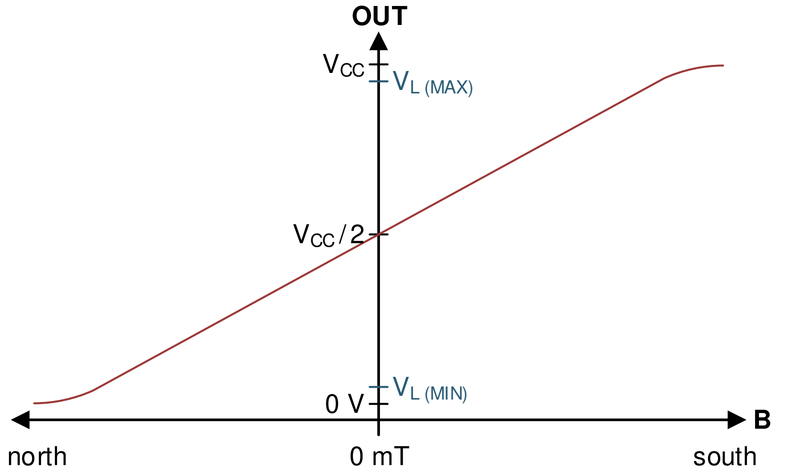

Figure 5-1. B-field Response of the DRV5055

The device uses a ratiometric architecture that can help remove error due to V_{CC} tolerance when the external analog-to-digital converter (ADC) uses the same V_{CC} for its reference. When no magnet is present (B = 0), the output voltage is V_Q , which is around $V_{CC}/2$. The presence of a magnetic field scales the output toward VCC or 0 V.

Table 5-1. Voltage Output

PARAMETER		MIN	TYP	MAX	UNIT
V_Q	Quiescent output at V_{CC}=5 V	2.43	2.5	2.57	V
	Quiescent output at V_{CC}=3.3 V	1.59	1.65	1.71	
V_L	Linear range of output voltage	0.2		V_{CC}-0.2	

The usable voltage range of this device is between 0.2 V and VCC-0.2 V because the B-response becomes nonlinear close to the rails.

The slope of the response is known as sensitivity, and measured in units of mV/mT. For ratiometric devices, this sensitivity is dependent on the V_{CC} voltage. Using the DRV5055A1 when V_{CC}=5 V as an example, typical sensitivity is 100mV/mT, meaning a B-field of 2 mT typically shifts the output by 0.2 V from $V_{CC}/2$. If V_{CC} is 5 V, that means the output would be 2.7 V. B-field >23 mT saturates the DRV5055A1, since the output drops below 0.2 V.

Table 5-2. DRV5055 Sensitivity at V_{CC} = 5 V, TA = 25°C

	PARAMETER		MIN	TYP	MAX	UNIT
DRV5055A1/Z1	S	Sensitivity	95	100	105	mV/mT
	B_L	Linear magnetic sensing range		±21		mT
DRV5055A2/Z2	S	Sensitivity	47.5	50	52.5	mV/mT
	B_L	Linear magnetic sensing range		±42		mT
DRV5055A3/Z3	S	Sensitivity	23.8	25	26.2	mV/mT
	B_L	Linear magnetic sensing range		±85		mT
DRV5055A4/Z4	S	Sensitivity	11.9	12.5	13.2	mV/mT
	B_L	Linear magnetic sensing range		±169		mT

Table 5-3. DRV5055 Sensitivity at V_{CC} = 3.3 V, TA = 25°C

	PARAMETER		MIN	TYP	MAX	UNIT
DRV5055A1/Z1	S	Sensitivity	57	60	63	mV/mT
	B_L	Linear magnetic sensing range		±22		mT
DRV5055A2/Z2	S	Sensitivity	28.5	30	31.5	mV/mT
	B_L	Linear magnetic sensing range		±44		mT
DRV5055A3/Z2	S	Sensitivity	14.3	15	15.8	mV/mT
	B_L	Linear magnetic sensing range		±88		mT
DRV5055A4/Z4	S	Sensitivity	7.1	7.5	7.9	mV/mT
	B_L	Linear magnetic sensing range		±176		mT

The DRV5055 is a bipolar Hall position sensor, which means that it responds to both positive and negative fields. If the sensed magnetic flux density is only positive, the DRV5056 device can also be used in applications. The DRV5056 is a unipolar ratiometeric Hall sensor that only responds to positive fields. Since unipolar sensors only sense one polarity, the DRV5056 has more sensing resolution compared to the DRV5056; however, since bipolar devices work with both poles of a magnet,the DRV5055 allows the magnet to be placed without determining whether a pole of the magnet is the south or north pole.

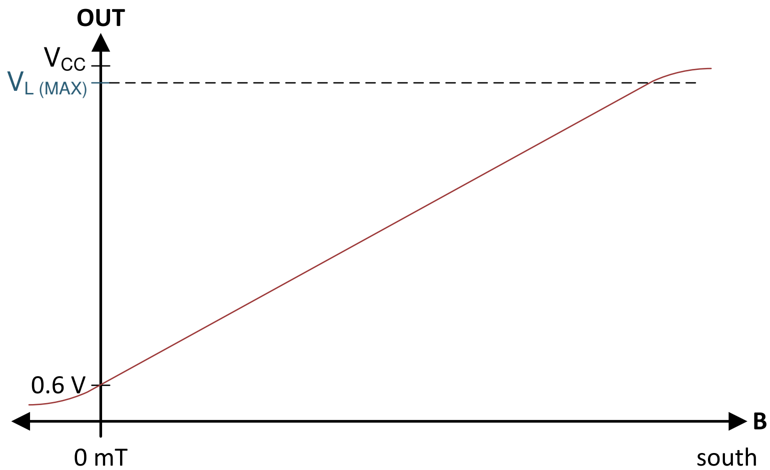

Figure 5-2. B-field Response of the DRV5056

As an alternative to analog output Hall sensors, a Hall sensor with a PWM circuit like the DRV5057 can also be used. For PWM output devices, the duty cycle ratio of the output pulse varies based on the sensed magnetic flux density. A PWM output provides more immunity to external noise.

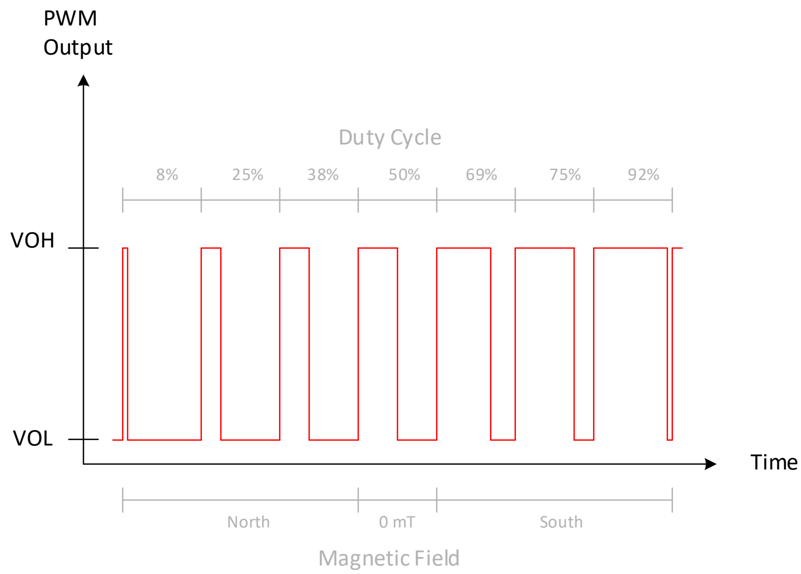

Figure 5-3. B-field Response of the DRV5057

Additionally, Hall-effect sensors with a digital communication interface like SPI or I2C is available. Example devices for this interface include the TMAG5170 (SPI) and TMAG5273 (I2C) linear 3D Hall-effect sensors.

5.1 Linearity

The linearity parameter defines how much sensitivity can change across the B-range, with a fixed operating voltage and temperature. Although sensitivity varies greatly from device to device, linearity constrains the variation for one device.

Table 5-4. Linearity Parameter

PARAMETER		MIN	TYP	MAX	UNIT
L_E	Linearity		±1		%

5.2 Noise

The output-referred noise (V_N) parameter for analog output Hall sensors describes the voltage noise present on the device output, and equals the input-referred noise times sensitivity. V_N is settled with an external RC low-pass filter.

Table 5-5. Noise Parameter

PARAMETER		MIN	TYP	MAX	UNIT
V_N	Output-referred noise DRV5055A1/Z1		12		mV_{pp}
	Output-referred noise DRV5055A2/Z2		6		
	Output-referred noise DRV5055A3/Z3		3		
	Output-referred noise DRV5055A4/Z5		1.5		
B_N	Input-referred noise at V_{CC}=5 V		0.12		mT_{pp}
	Input-referred noise at V_{CC}=3.3 V		0.2		

For linear 3D Hall-effect sensors like the TMAG5170, please note that the noise may be expressed in units of RMS noise (1-sigma) instead of the 6.6-sigma mT_{PP} mentioned above for the DRV5055. To convert the RMS noise to match the 6.6-sigma mT_{PP} mentioned above, multiply the RMS noise by 6.6.

5.3 Magnetic Flux Density Calculator

The Magnetic Sensing Proximity Tool allows calculating the magnetic flux density seen by the sensor for various magnet to sensor configurations. Download it at: Error in Magnetic Sensing Proximity Tool

5.4 Design Example with Analog Hall Sensors

Consider the following example of a directional control valve, which has three mechanical positions allowing fluid to flow in different paths.

Figure 5-4. Directional Control Valve

The DRV5055 determines which of the three positions the valve is in. The valve cylinder moves in one dimension (forward and back). By mounting the sensor in the center of the cylinder and placing a magnet on each end of the moving piece, the sensor can detect Strong North, No Field, or Strong South. If V_{CC} is 3.3 V, corresponding output voltages are roughly 0 V, 1.65 V, or 3.3 V, and a microcontroller ADC can use this to understand the valve position.

6 Information on Additional Data Sheet Specifications

The below links also provide more details on the different specifications in a Hall-effect sensor datasheet:

- Texas Instruments, Bandwidth vs. Power Tradeoffs in Hall-effect Position Sensors
- Texas Instruments, Latches and Switches – Operating and Release Point
- Texas Instruments, Magnetic Sensors: Key specifications of Linear Hall-effect Position Sensors
- Texas Instruments, Specifications of 3D Hall-effect Sensors

For any further questions, post to the Sensors Engineer to Engineer (E2E) forum at: https://e2e.ti.com/support/sensors-group/sensors/f/sensors-forum

7 Revision History

NOTE: Page numbers for previous revisions may differ from page numbers in the current version.

Changes from Revision * (June 2014) to Revision A (November 2021) **Page**

- Updated device from DRV5053 to DRV5055 throughout publication.. 1
- Added information on linear 3d Hall-effect sensors.. 1
- Added information on DRV5056.. 1
- Added information on DRV5057.. 1
- Updated device from DRV5023 to DRV5032 throughout publication.. 2