Application Note

TMAG511x 2D Latch Benefits

ABSTRACT

You can use Hall-effect sensors to determine a rotation position in brushed motor applications. Such applications include power windows in automobile, powered window blinds, water meters, volume knobs, automated gates, and smart locks. This article briefly covers the basic operating principles and the benefits of multi-Hall element devices like the TMAG5110 and TMAG5111 in rotary-encoding applications.

Encoding works on the principle that every time a sensor (like the Hall-effect latch) is exposed to an opposing magnet polarity, the output of the sensor switches states. Every state change corresponds to a discrete step of one revolution and, with a fixed, known number of steps per revolution, the user can determine the relative degree of rotation.

There are multiple key specifications Hall-effect latches in encoding applications that are covered in this article. These include Hall element count, Hall element orientation, and BOP and BRP thresholds.

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1 Hall Element Block Count

For encoding applications, binary output devices like latches or switches are used. Within a latch, a single Hall element or an averaged group of Hall elements may be used to measure the field along a single sensing axis. Downstream of the Hall element block within the latch device will be a comparator circuit that determines whether the transduced signal exceeds B_{OP} or falls below B_{RP}, thereby producing an output that is either high or low. If the ring magnet or linear array magnet is designed to move in only one direction, then the position can be determined. However, for systems in which the magnet can reverse direction (see Figure 1-1), the device output alone provides insufficient information to definitively determine position.

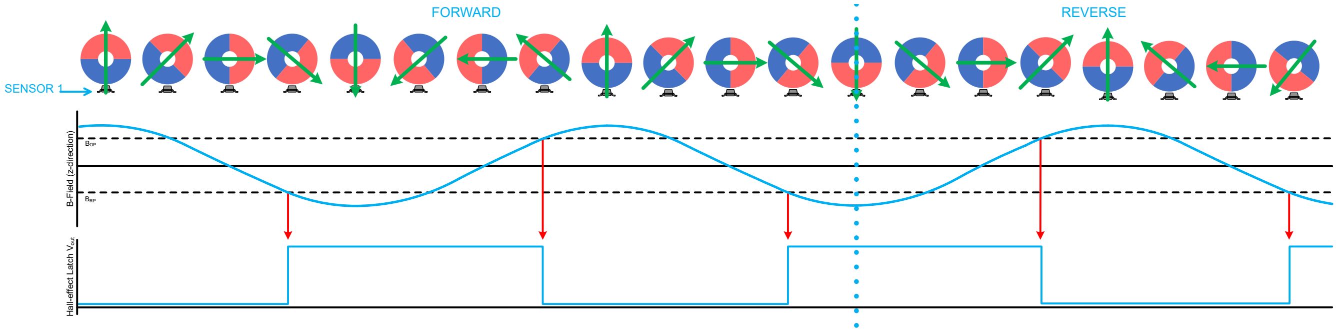


Figure 1-1. Single Latch Encoding

Consequently, Figure 1-2 shows how a minimum of two latches are used to determine not only position but speed and direction. In the past, this might have been implemented with two discrete devices (see Figure 1-3); however, recent devices have evolved such that a single device may have two distinct Hall element blocks that measure the field at two independent locations (see Figure 1-4). This advancement has led to a reduced bill of materials (BOM) count, reduced board size, and minimized design complexity.

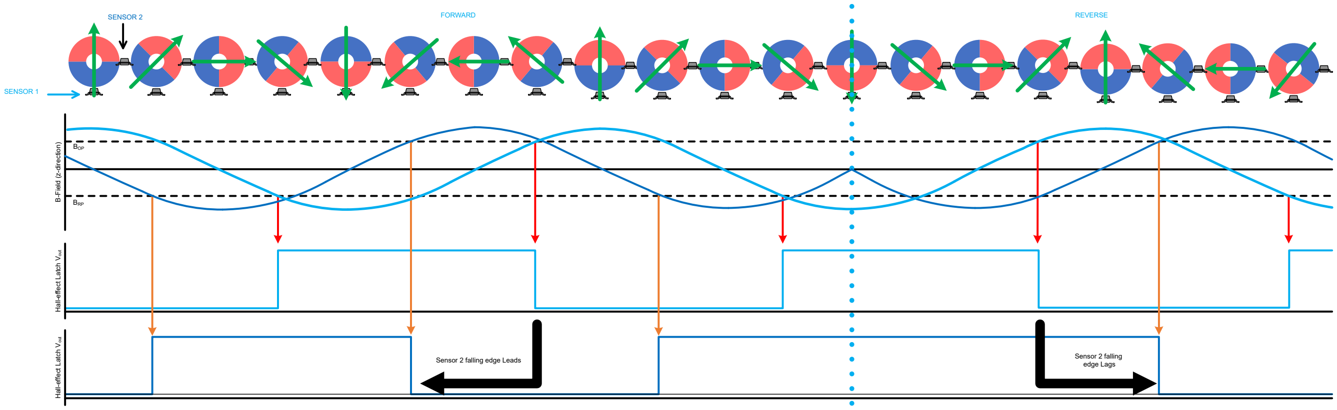


Figure 1-2. Dual Latch Encoding

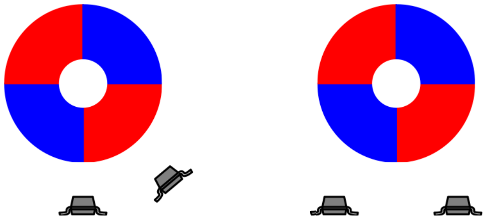


Figure 1-3. Multiple Discrete Device Implementations

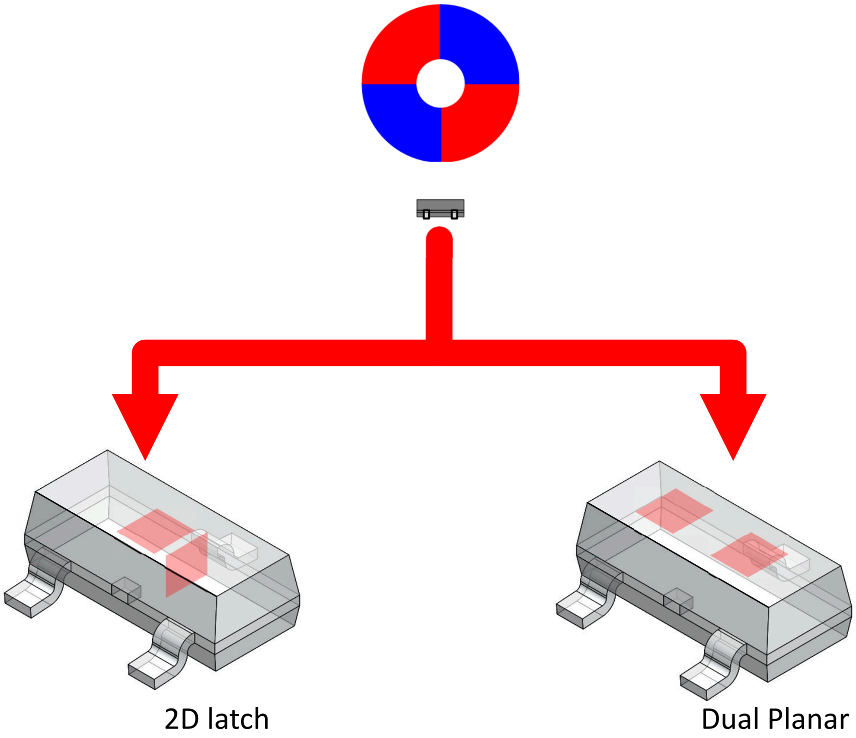
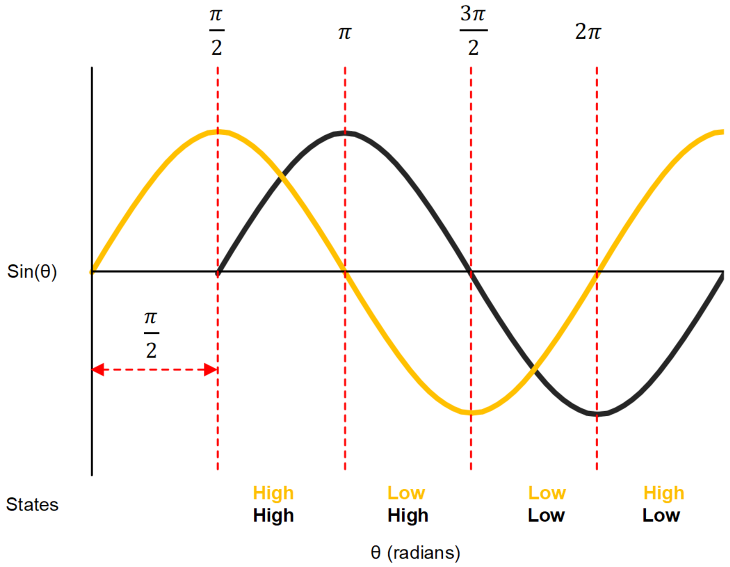


Figure 1-4. Single Device Implementations

2 Hall Element Orientation

Position resolution is dictated by the orientation of the Hall element blocks within the device. To understand why, you must first recall the concept of phase. Figure 2-1 shows two sine waves which are similar in shape to the magnetic field measured by a Hall element in an encoding application. In Figure 2-1, the black curve lags behind the yellow curve. As the period is equivalent for both periodic signals, the lag is equivalent to the phase offset. Therefore, the black curve has a π/2=90° phase offset. Maintaining 90° offset is imperative for equal separation between latch states as indicated at the bottom of Figure 2-1.



$$\left(\frac{\pi}{2} radians\right) \times \frac{180°}{\pi\ radians} = 90°$$

Figure 2-1. Phase Lag and Offset Example

Figure 2-2 shows what kind of output you might observe with a dual planar latch, assuming both Hall element blocks operate like a typical discrete latch.

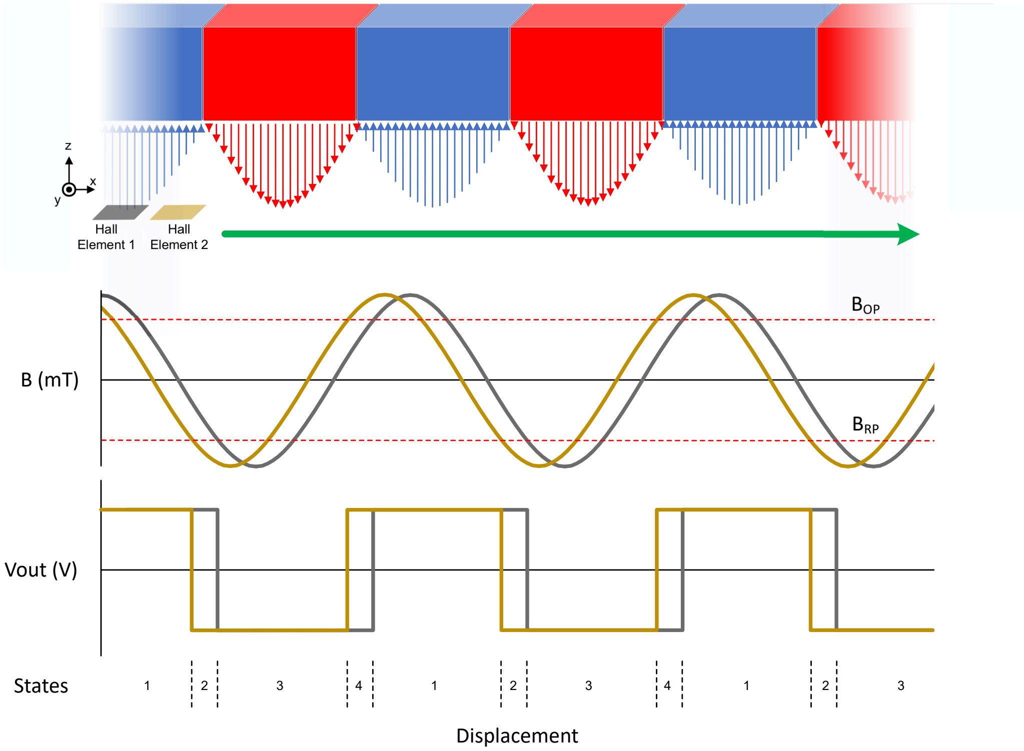


Figure 2-2. Dual Planar Operation

The Hall elements are confined to a subregion of a small device package, therefore their physical separation will be miniscule. In most cases, this leads to signals with very small phase offsets and unequal state intervals as shown in the bottom of Figure 2-2.

Consequently, Figure 2-3 shows that dual planar devices typically monitor one Hall element block for speed and position, while another pin is used for direction. The speed element will generate a state change on one device output every time the detected polarity and magnitude crosses the opposing B_{OP} or B_{RP} threshold. The direction element also is similarly monitored; however, the B_{OP} or B_{RP} comparator output is kept internal to the device and fed to some other circuitry that compares both speed and direction signals. This setup can determine if the order of the rising and falling edges have reversed. This circuitry will then provide a device output that is high when the magnet is moving in one direction, or low when the magnet is moving in the opposite direction. Therefore, dual planar devices exhibit only two resolution steps from the speed hall element per pole pair traversed, which is half of what is possible for two Hall element block devices.

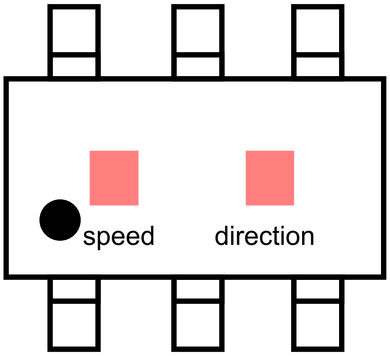


Figure 2-3. Dual Planar Diagram

Despite the resolution limitation with a dual planar device, maximal resolution is still possible from a single 2D latch device. For a 2D device like the TMAG5110 or the TMAG5111 that has orthogonal planes, it is possible to get an unconditional 90° phase shift. Figure 2-4 illustrates why this is the case. Hall element 1 that is parallel to the magnet array measures a local maximum at a pole center, while the Hall element that is perpendicular to the magnet array measures a local minimum at a pole center.

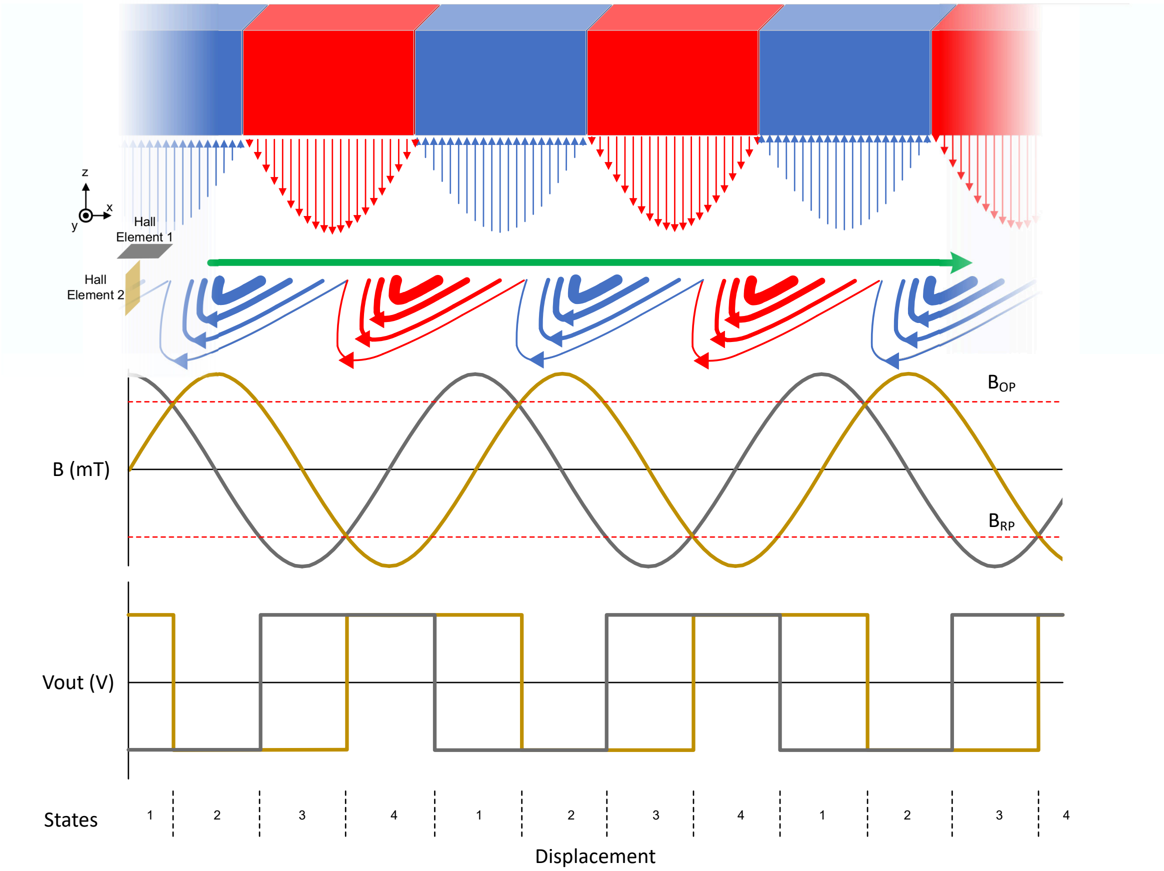


Figure 2-4. 2D Latch Operation

Aside from resolution, device orientation relative to the encoding magnet can impact device functionality. To illustrate this point, Figure 2-5 shows a configuration in which a 2D latch will typically work while a dual planar will typically not. The dual planar fails to work in this configuration because the device can only sense along the axis orthogonal to the top of the package surface. In this instance, the magnetic field is mostly parallel to the Hall element plane and any vertical component that is normal to Hall elements and detectable is in phase. The 2D latch has 3 orthogonal sensing axes, therefore it is possible to detect the field components that are out of phase (see Figure 2-5).

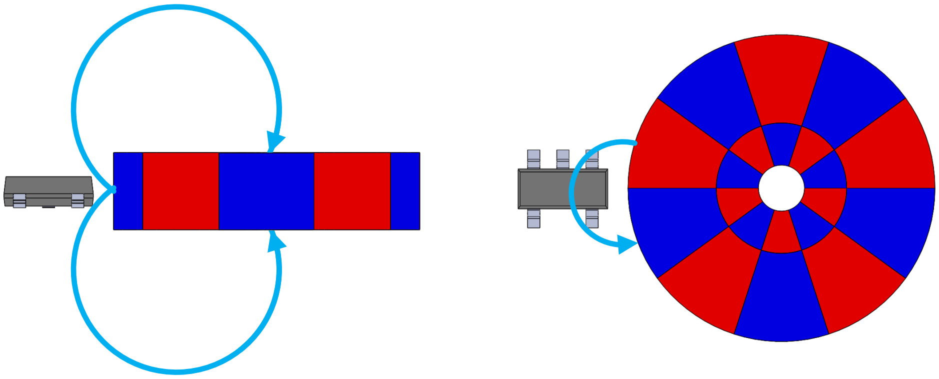
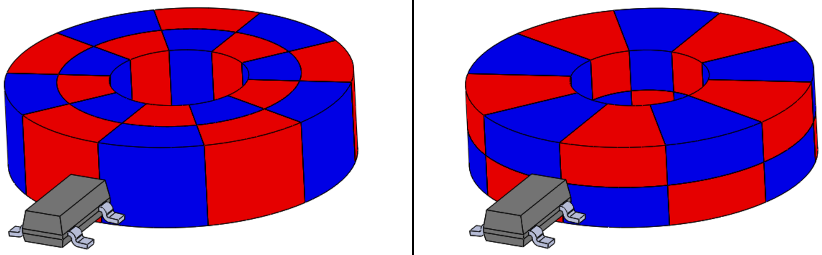


Figure 2-5. Encoding Ring Magnet Field Lines

To summarize the orientation limitations of the dual planar, Table 2-1 lists the configurations in which it may be difficult or impossible to successfully use dual planar. Figure 2-6, Figure 2-7, Figure 2-8, Figure 2-9, Figure 2-10, and Figure 2-11 show these various configurations listed in Table 2-1.

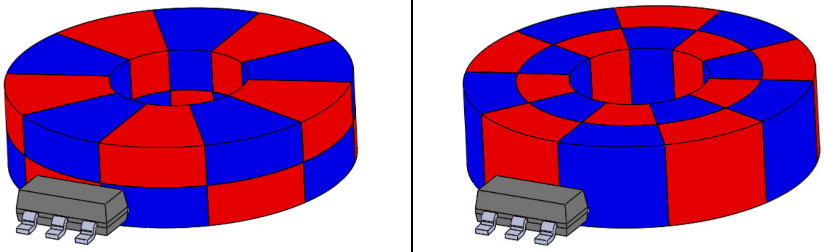
Table 2-1. 2D vs Dual

Magnet Sensor Orientation	2D	Dual Planar
Radial XY outer edge 1	Possible	Not Recommended
Axial XY outer edge 1	Possible	Not Recommended
Radial XY outer edge 2	Possible	Not Recommended
Axial XY outer edge 2	Possible	Possible
Radial ZX outer edge 1	Possible	Possible
Axial ZX outer edge 1	Possible	Possible
Radial ZX outer edge 2	Possible	Not Recommended
Axial ZX outer edge 2	Possible	Not Recommended
Radial ZY outer edge 1	Possible	Not Recommended
Axial ZY outer edge 1	Possible	Possible
Radial ZY outer edge 2	Possible	Not Recommended
Axial ZY outer edge 2	Possible	Possible
Radial XY side edge 1	Possible	Not Recommended
Axial XY side edge 1	Possible	Not Recommended
Radial XY side edge 2	Possible	Not Recommended
Axial XY side edge 2	Possible	Not Recommended
Radial ZX side edge 1	Possible	Not Recommended
Axial ZX side edge 1	Possible	Not Recommended
Radial ZX side edge 2	Possible	Possible
Axial ZX side edge 2	Possible	Possible
Radial ZY side edge 1	Possible	Possible
Axial ZY side edge 1	Possible	Not Recommended
Radial ZY side edge 2	Possible	Possible
Axial ZY side edge 2	Possible	Not Recommended



Radial XY outer edge 1

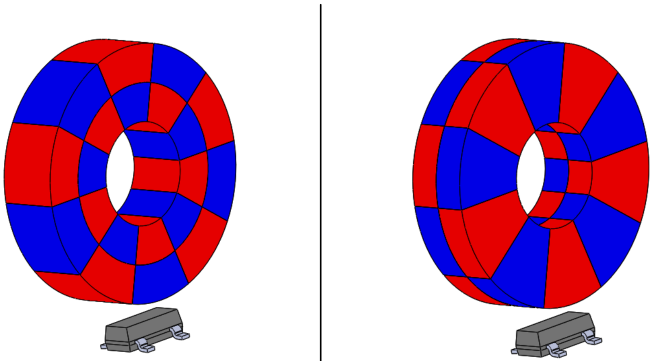
Axial XY outer edge 1



Radial XY outer edge 2

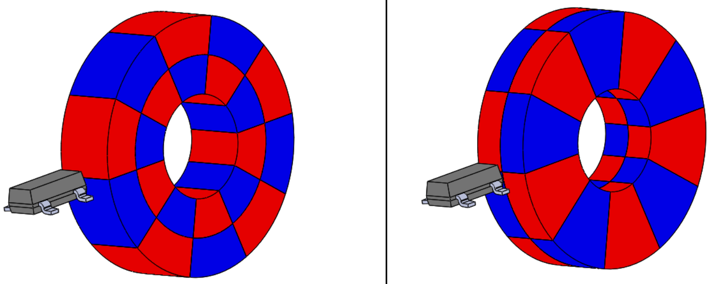
Axial XY outer edge 2

Figure 2-6. XY Outer Edge



Radial ZX outer edge 1

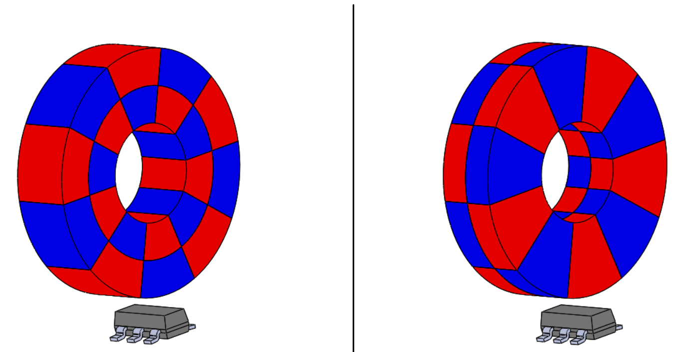
Axial ZX outer edge 1



Radial ZX outer edge 2

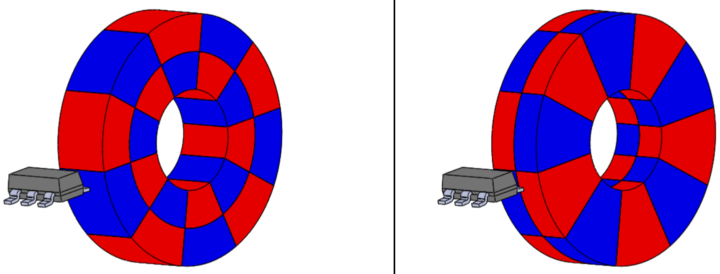
Axial ZX outer edge 2

Figure 2-7. ZX Outer Edge



Radial ZY outer edge 1

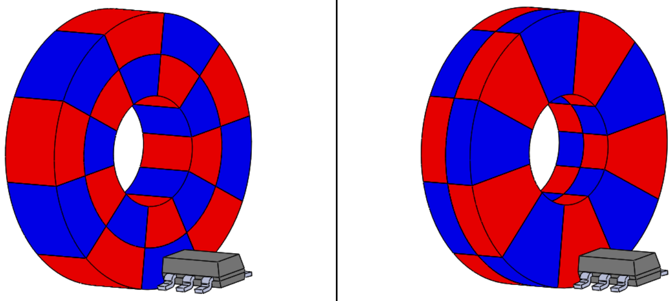
Axial ZY outer edge 1



Radial ZY outer edge 2

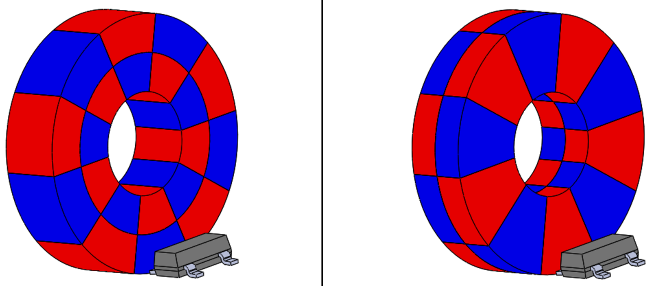
Axial ZY outer edge 2

Figure 2-8. ZY Outer Edge



Radial XY side edge 1

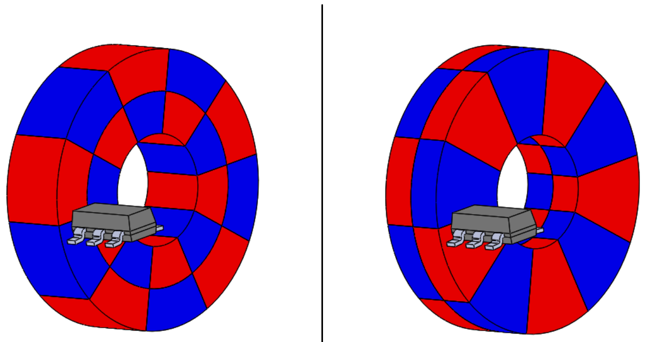
Axial XY side edge 1



Radial XY side edge 2

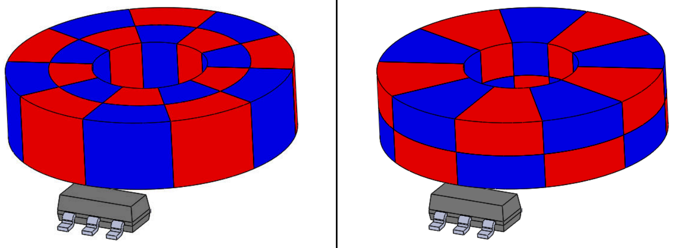
Axial XY side edge 2

Figure 2-9. XY Side Edge



Radial ZX side edge 1

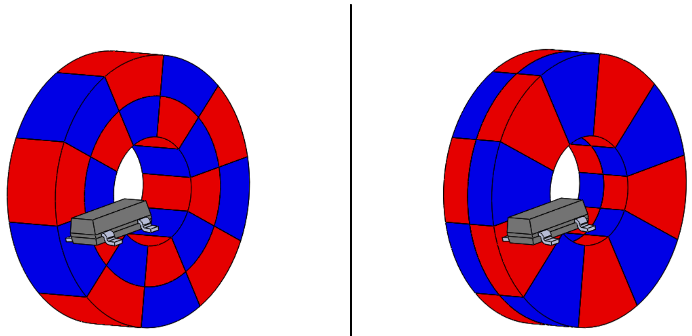
Axial ZX side edge 1



Radial ZX side edge 2

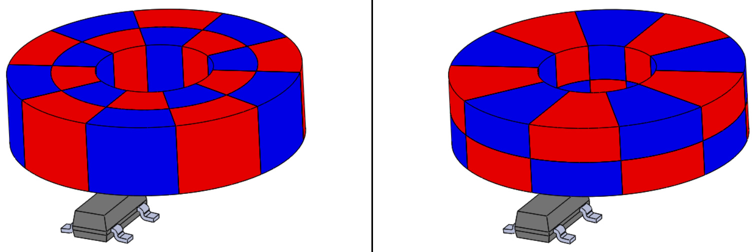
Axial ZX side edge 2

Figure 2-10. ZX Side Edge



Radial ZY side edge 1

Axial ZY side edge 1



Radial ZY side edge 2

Axial ZY side edge 2

Figure 2-11. ZY Side Edge

3 B_{OP} and B_{RP} Thresholds

Another key specification for Hall-effect latches is the threshold for B_{OP} or B_{RP}. These specifications dictate what field strength is required for the device output to go high or low. The region between these thresholds is the hysteresis region where the last crossed threshold state is maintained. The lower the device thresholds, the further the device can be spaced from the ring magnet.

To illustrate the impact, Figure 3-2 show the regions within a plane indicated in Figure 3-1 spaced 3 mm from the outer radial surface of a 10-pole, 400-mT Br, 1.59-mm inner diameter, 37.8579-mm outer diameter magnet where devices can be placed for encoding measurements. With each decrease in the B_{OP} and B_{RP} threshold, there is an increase in the possible device placement region size.

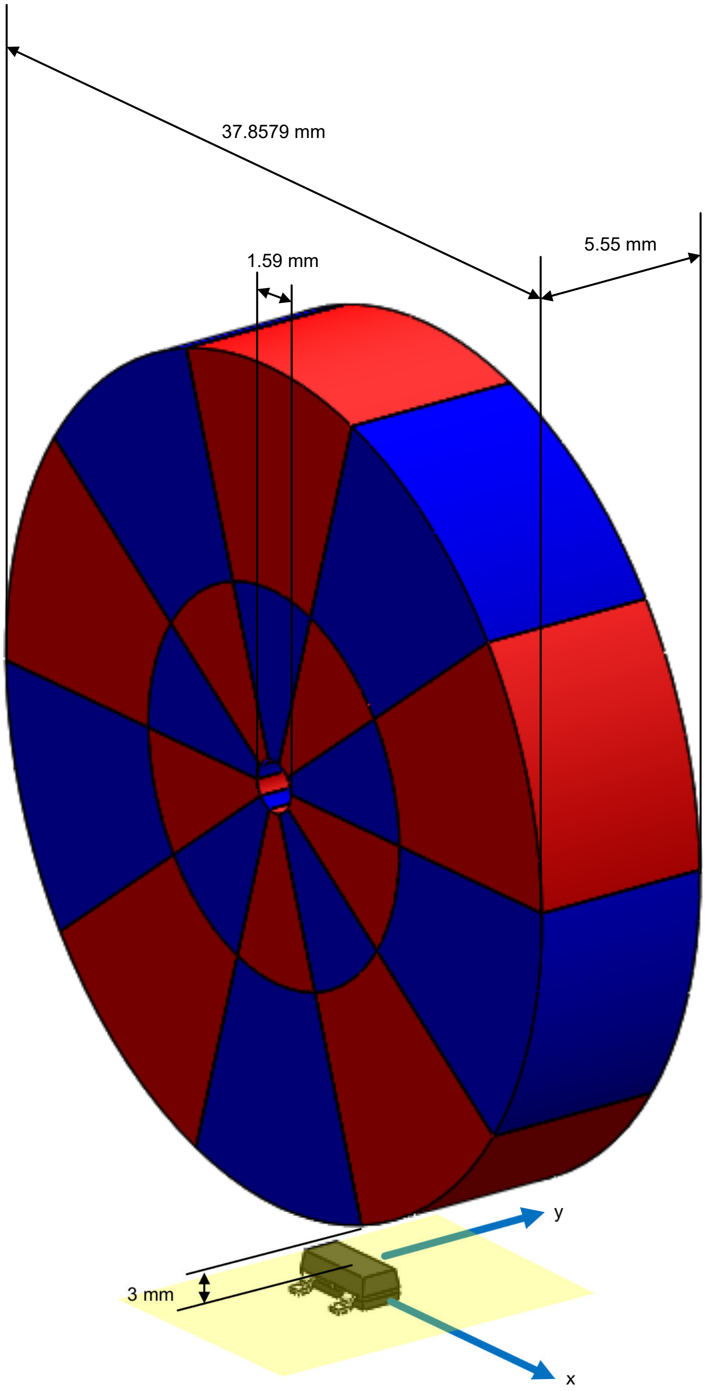


Figure 3-1. Magnet Sensor Test Conditions

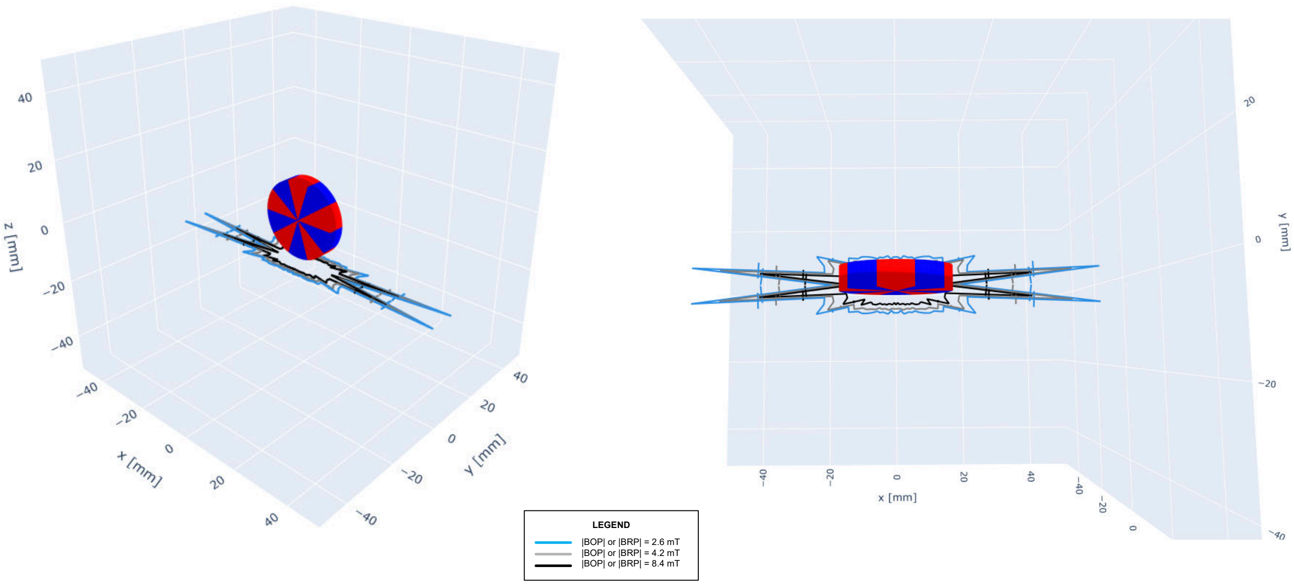


Figure 3-2. Region of Operation per B_{OP}, B_{RP} Thresholds

4 Summary

Encoding can be achieved with a single Hall-effect device, thereby reducing board size, layout precision, and cost. 2D latches provide additional resolution over dual planar devices, thereby reducing reliance on gear ratios for smaller steps. 2D latches also provide greater flexibility in placement, allowing the system designer to place their printed circuit board (PCB) in different orientations that allow greater space savings. Lastly, lower BOP and BRP thresholds allow greater flexibility in placement relative to the magnet used for encoding.

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