Application Report
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Designing Single and Multiple Position Switches Using TI Hall Effect Sensors

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ABSTRACT

This application report discusses the benefits and methods for using Hall Effect sensors in 1–3 positions switches.

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1 Hall Effect Switch Introduction

Many of today's applications require small form-factor buttons and switches for the most basic of user interfaces. From powering devices to mode selections, switches can be found in nearly every end equipment on the market, and come with their own challenges to implement, namely reliability, robustness, and cost. Hall effect sensors can be implemented in switching applications to provide several features: they can help to eliminate bouncing on a sensitive switch, provide water and weather barriers due to their isolative nature from their paired magnet, and add reliability and versatility to a system for increased robustness through a reduction in metallic contacts and moving parts.

2 Overview

2.1 Useful Magnet Types

When making a switch or button, the most useful types of magnets are blocks, discs, and cylinders. For discs and cylinders, these magnets may be magnetized axially (Figure 1, the first and second images from the left) or diametrically (Figure 1, the third and fourth images from the left). Block magnets are typically magnetized through the thickness of the magnet, and care must be taken to ensure that the correct dimensions are allocated. Examples of block magnet orientations are given in Figure 2 below.

2.2 Types of Magnets

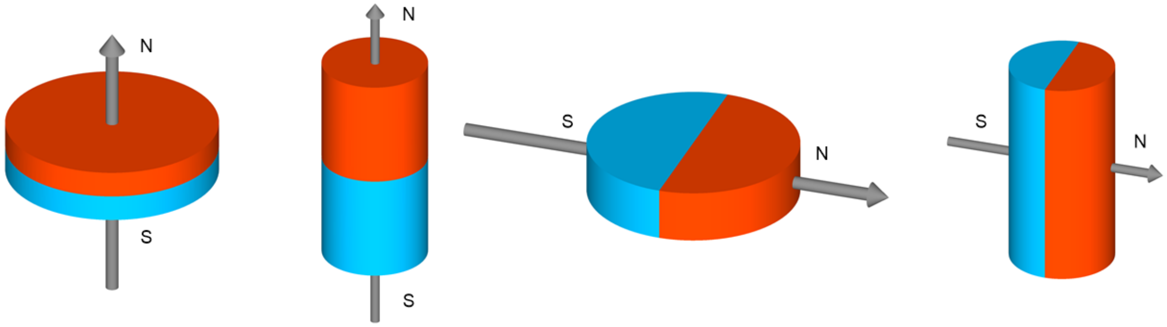


Figure 1. Axial Disc and Cylinder, Diametric Disc, and Cylinder Magnet Examples

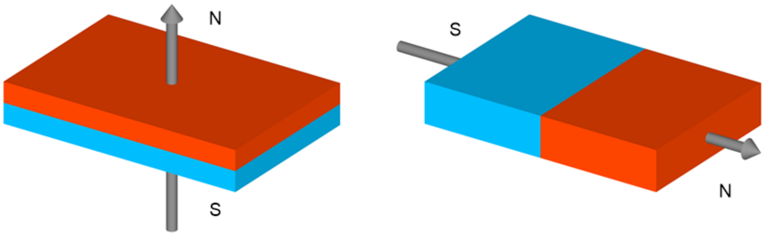


Figure 2. Block Magnet Examples

3 Device Descriptions

3.1 *DRV5021(-Q1): 2.5 V to 5.5 V Hall Effect Unipolar Switch*

The DRV5021 is a low-voltage, digital-switching Hall effect sensor for high-speed applications. Operating from a 2.5-V to 5.5-V power supply, the device senses magnetic flux density and gives a digital output based on predefined magnetic thresholds.

This device senses magnetic fields perpendicular to the face of the package. When the applied magnetic flux density exceeds the magnetic operate point (B_{OP}) threshold, the open-drain output of the device drives a low voltage. When the flux density decreases to less than the magnetic release point (B_{RP}) threshold, the output goes to high impedance. The hysteresis resulting from the separation of B_{OP} and B_{RP} helps prevent output errors caused by input noise. This configuration makes system designs more robust against noise interference.

The device operates consistently across a wide ambient temperature range of –40°C to +125°C.

3.2 *DRV5023(-Q1): 2.5 V to 38 V Hall Effect Unipolar Switch*

The DRV5023 is a chopper-stabilized Hall effect sensor that offers a magnetic sensing solution with superior sensitivity stability over temperature and integrated protection features.

When the applied magnetic flux density exceeds the B_{OP} threshold, the DRV5023 open-drain output is pulled low. The output stays low until the magnetic field decreases to less than the B_{RP} of the device, where the output then moves to a high-impedance state. The output current sink capability is 30 mA. A wide operating voltage range from 2.5 to 38 V with reverse polarity protection up to –22 V makes the device suitable for a wide range of industrial applications.

Internal protection functions are provided for reverse supply conditions, load dump, and output short circuit or overcurrent.

3.3 *DRV5032: Ultra-Low Power 1.65 V to 5.5 V Hall Effect Switch*

The DRV5032 device is an ultra-low-power digital-switch Hall effect sensor, designed for the most compact and battery-sensitive systems. The device is offered in multiple magnetic thresholds, sampling rates, output drivers, and packages to accommodate various applications.

When the applied magnetic flux density exceeds the B_{OP} threshold, the device either outputs a low voltage, or pulls to a low state through an open drain output configuration. The output stays low until the flux density decreases to less than B_{RP}, and then the output either drives a high voltage or becomes high impedance, depending on the device version. By incorporating an internal oscillator, the device samples the magnetic field and updates the output at a rate of 20 Hz or 5 Hz, for optimized low-current consumption. Omnipolar and unipolar magnetic responses are available.

The device operates from a V_{CC} range of 1.65 V to 5.5 V, and is packaged in a standard SOT-23 and small X2SON.

3.4 *DRV5033(-Q1): 2.5 V to 38 V Hall Effect Omnipolar Switch*

The DRV5033 device is a chopper-stabilized Hall Effect Sensor that offers a magnetic sensing solution with superior sensitivity stability over temperature and also features integrated protection features.

The DRV5033 responds the same to both polarities of magnetic field direction. When the applied magnetic flux density exceeds the B_{OP} threshold, the DRV5033 open-drain output goes low. The output stays low until the field decreases to less than B_{RP}, and then the output becomes a high-impedance state. The output current sink capability is 30 mA. A wide operating voltage range from 2.5 to 38 V with reverse polarity protection up to –22 V makes the device suitable for a wide range of industrial applications.

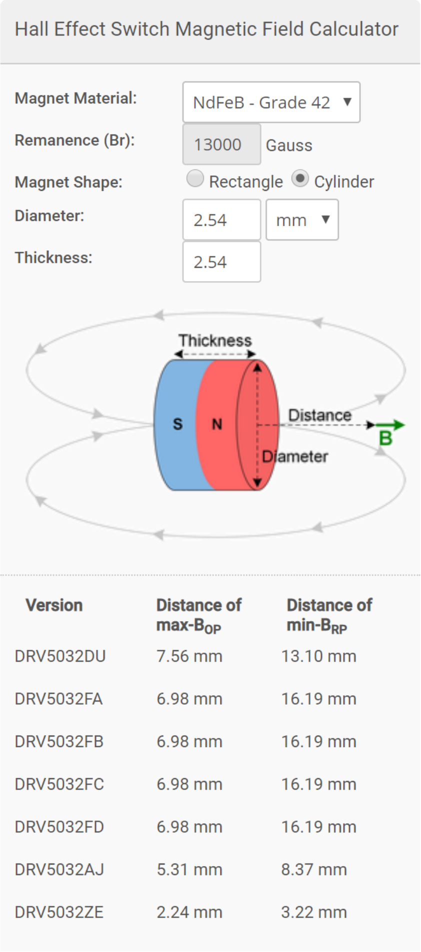
Internal protection functions are provided for reverse supply conditions, load dump, and output short circuit or overcurrent.

4 Detailed Design Procedures

Presented in the following sections are various methods for implementing push-button, two-position single output, two-position dual output, and three-position linear and radial switches. For each of these designs, major consideration was given to form factor and energy overhead, as many switches in today's modern products are optimized for small size and low-power schemes. Physical switches are not frequency dependent in most cases, so the DRV5032 family is used extensively in these designs, as the low-power features of the device are desirable in this application.

4.1 1 Position Switch (Push-Button)

The push button switch is a design challenge where the magnet approaches the sensor head on, and thus greatly simplifies the calculations for magnet selection. That said, the challenge with this design lies in the replication of a typical switch, in regards to size as well as function. As form factor is of importance here, an extremely small magnet is desired, and a variety of magnets were examined. An example using TI's Magnetic Calculator tool to determine head on values for a magnet is shown in Figure 3 below.



Hall Effect Switch Magnetic Field Calculator

Magnet Material: NdFeB - Grade 42

Remanence (Br): 13000 Gauss

Magnet Shape: ○ Rectangle ● Cylinder

Diameter: 2.54 mm

Thickness: 2.54

Version	Distance of max-B_{OP}	Distance of min-B_{RP}
DRV5032DU	7.56 mm	13.10 mm
DRV5032FA	6.98 mm	16.19 mm
DRV5032FB	6.98 mm	16.19 mm
DRV5032FC	6.98 mm	16.19 mm
DRV5032FD	6.98 mm	16.19 mm
DRV5032AJ	5.31 mm	8.37 mm
DRV5032ZE	2.24 mm	3.22 mm

Figure 3. TI Magnetic Calculator Results for DH1H1

The calculations given by the calculator tool show a quick distance solution from the face of the magnet to the Hall effect sensor location inside the package for all varieties of the DRV5032 family. Note that the sensor location may change internal to the device dependent on the package chosen, and this distance must be taken into account during mechanical design. From the several magnets examined, K&J Magnetic's DH1H1 was chosen, which is a 2.54-mm diameter x 2.54-mm thick, grade N42 neodymium magnet.

To emulate the feeling of a real push button switch, a certain amount of downward motion is required to reach the maximum B_{OP} of the sensor, and the device must also be capable of traveling a return distance equivalent to the difference between maximum B_{OP} and minimum B_{RP} so that the part is also guaranteed to release. To help facilitate this, devices of lower sensitivity are usually chosen, as they operate higher on the non-linear magnetic curve. In Figure 4, the highest and lowest sensitivity devices from the DRV5032 family are shown in relation to the DH1H1 magnet.

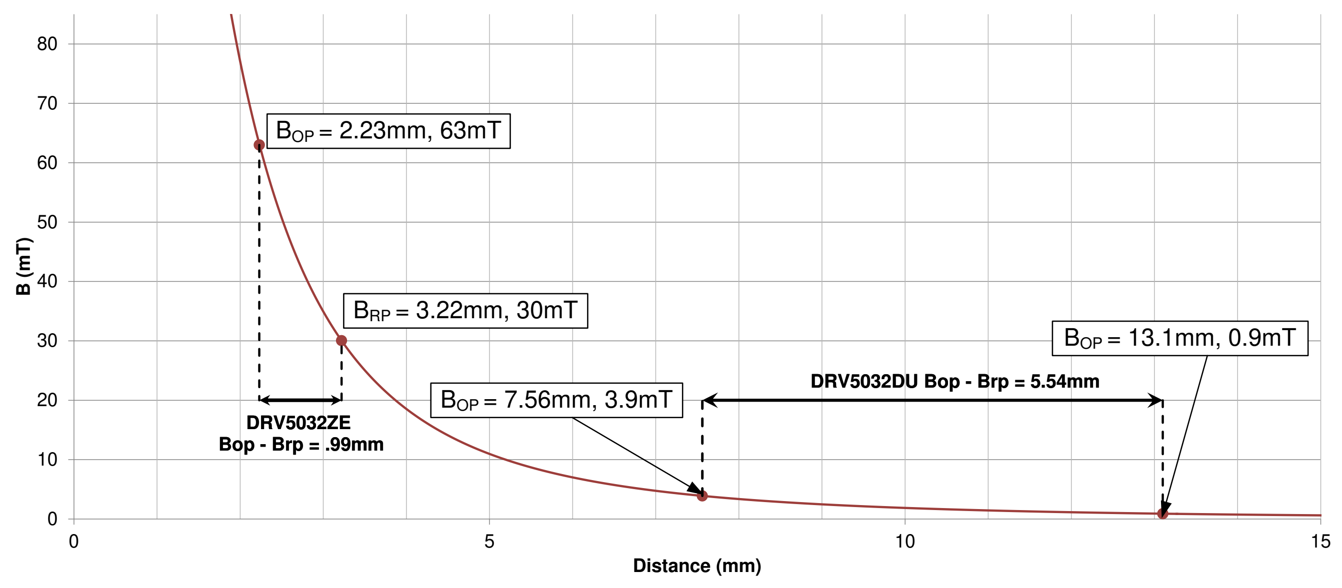


Figure 4. DRV5032ZE and DRV5032DU, B_{OP} and B_{RP} Locations and Distances

As demonstrated, while the magnitude of the difference between B_{OP} and B_{RP} is much larger, the physical distance that is traversed to transition states is much smaller, due to the exponential decay relationship at close proximity to the magnet.

The device chosen based on this factor was the DRV5032ZE, and there is now a clear mechanical design setup needed to be chosen or designed: an apparatus that rests the magnet above the sensor (internal to the device package, not the package face) by at least 3.22 mm, and allows a distance of travel such that the magnet stops at a distance less than 2.23 mm to the sensor. This is demonstrated in Figure 5.

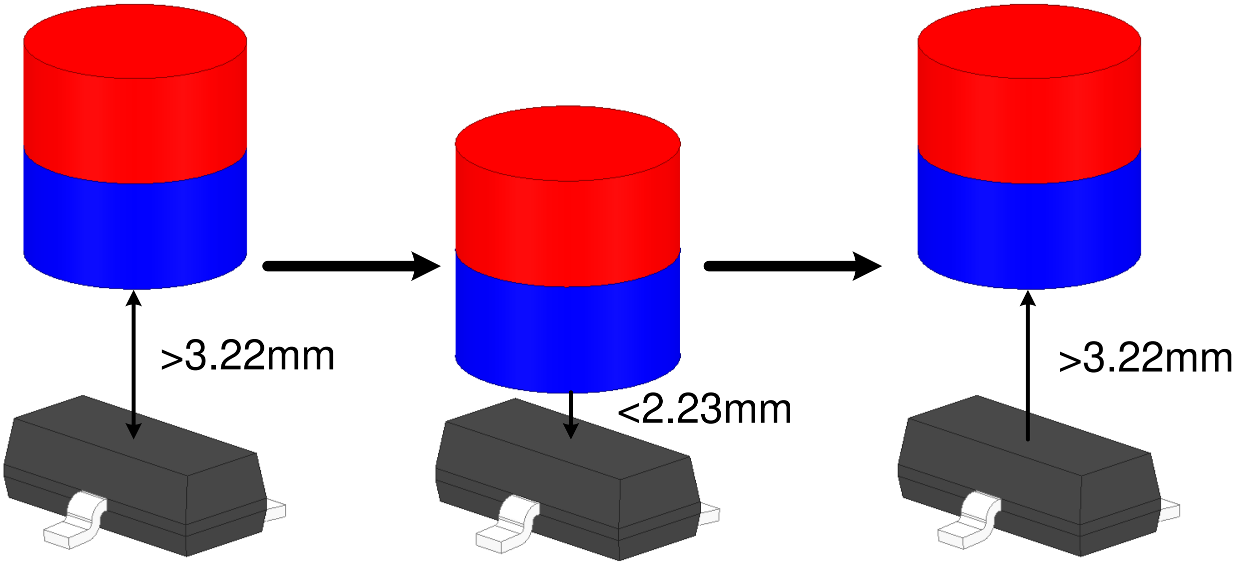


Figure 5. Head On Magnetic Travel for Single Position Switch

4.2 Two-Position Switch with Single Output

The two-position switch is similar in many ways to the single position switch, with one major difference: while the magnet still rests in a head-on approach to the sensor, the magnet now moves laterally to the sensor at an arbitrary height chosen inside the maximum B_{OP} point, calculated through the TI magnetic calculator. For simplicity's sake, the DH1H1 paired with the DRV5032ZE is again chosen for this design.

Referring to Figure 4, recall that the maximum B_{OP} of this magnet, paired with the DRV5032ZE, occurs at a distance of 2.23 mm, so any distance beneath this may be utilized. For this design, a distance of 2 mm is chosen. With this distance decided upon, it must now be determined how far the magnet may be moved laterally to the sensor to reach the minimum B_{RP} of the device.

For off-axis simulations, additional tools are required. For this paper, simulations were performed with ANSYS Electronics Desktop, but there are free tools available that can assist with this portion of design, such as the freely available KJM Magnet Calculator available on KJMagnetics' website. Note that the curve shown in Figure 6 below only provides information for a DH1H1 magnet placed 2 mm above the sensing element of the DRV5032ZE, and new data needs to be taken if this distance is chosen at a different point, or if a different magnet were chosen for the design.

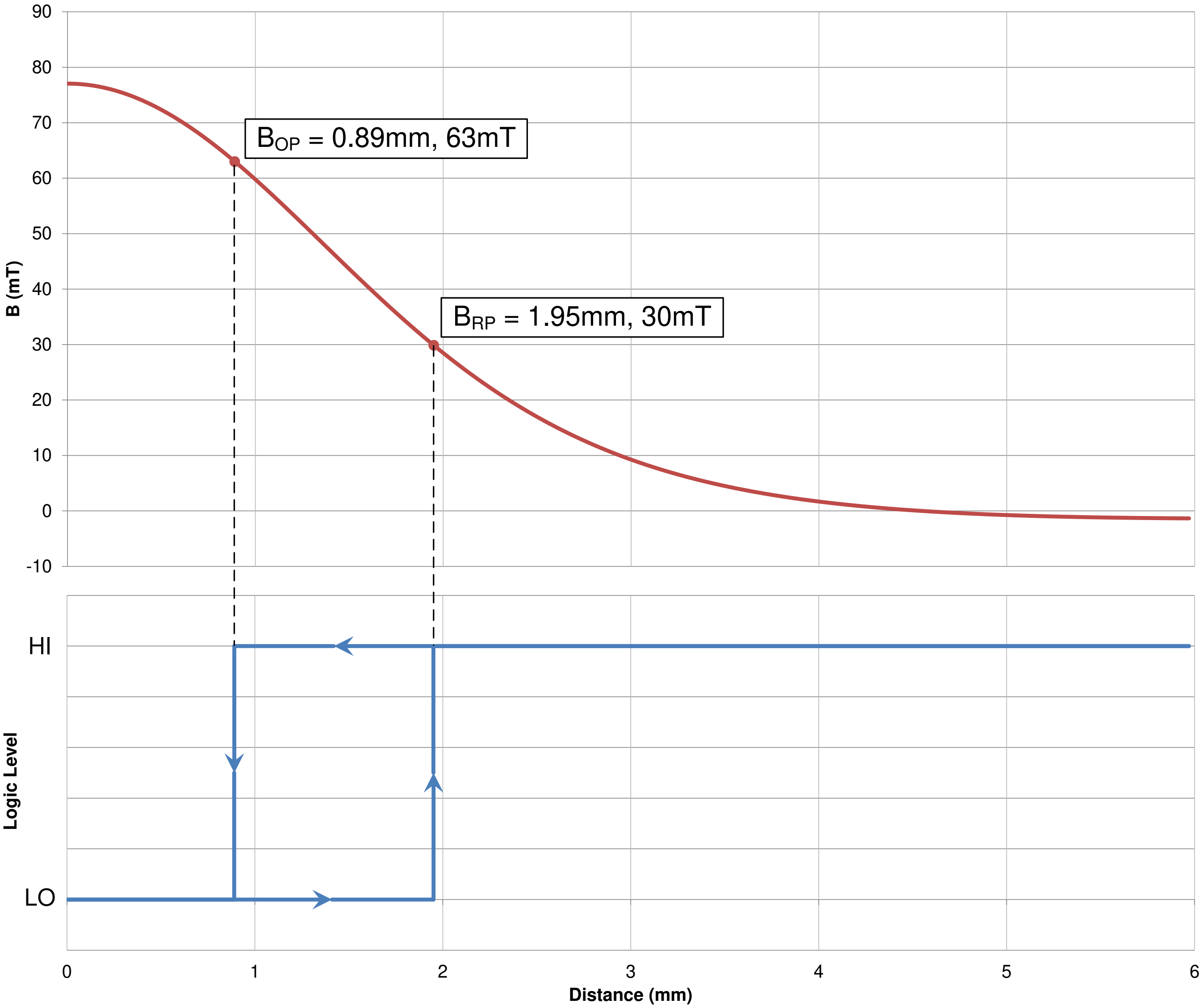


Figure 6. DH1H1 Magnetic Curve, B_{OP} and B_{RP} points, 2-mm Height

With these results, this report now has the physical distance the magnet must traverse to guarantee a release operation. It can again move to the mechanical portion of this design with the following design constraints: the magnet needs to rest 2 mm above the Hall sensing element in the DRV5032ZE, and needs to be capable of displacing the magnet at least 1.95 mm laterally away from the rest position above the sensor. This is demonstrated in Figure 7.

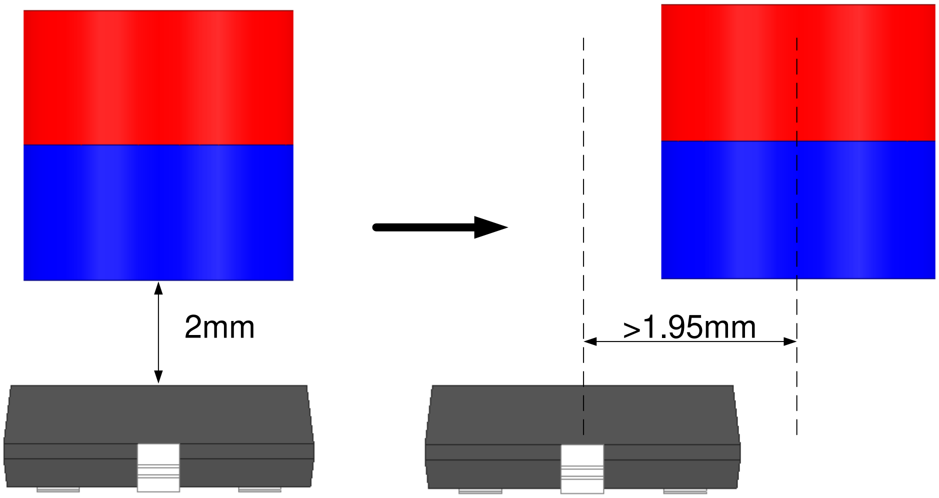


Figure 7. Lateral Magnetic Travel for Dual-Position, Single Output Switch

4.3 2 Position Switch with Dual Output

The two-position dual output switch is where the design procedure diverges from the previous two, as it now needs two total outputs. A potentially cost-effective way to do this is to access both poles of the magnet, and as a result, turn the magnet on its side to be able to utilize a single magnet in the design.

Unlike the previous switch design, where an OFF/ON state was determined using a single-output sensor, this design outputs two individual signals, utilizing a dual output unipolar device. OUT1 pulls low in the presence of a north facing magnetic signal, while OUT 2 pulls low in the presence of a south-facing magnetic signal. For the DRV5032 family, only two versions allow this configuration: the DU and FD versions.

With the magnet turned on its side, the characteristic shape of the magnetic curve changes. As a result, there are several orientations where B_{OP} or B_{RP} can be triggered on one of the outputs of the device. As this is a dual-output switch, the goal is to choose a magnet that optimizes the "dead zone," or the region in the center of the curve between the respective B_{OP}'s of the north and south sides of the magnetic variation. By minimizing the travel distance of this area, the curve quickly slews from north magnetic influence to south magnetic influence as the magnet is displaced laterally above the sensor, at an arbitrary chosen height. For this design, a height of 2.5 mm was chosen prior to choosing a magnet. In Figure 8, several magnets are examined to see how this alignment change causes the curve to shift. Note that these curves demonstrate the magnetic field of these magnets at a height of 2.5 mm, from the outer radius of the magnet to the magnetic Hall sensing element embedded in the package.

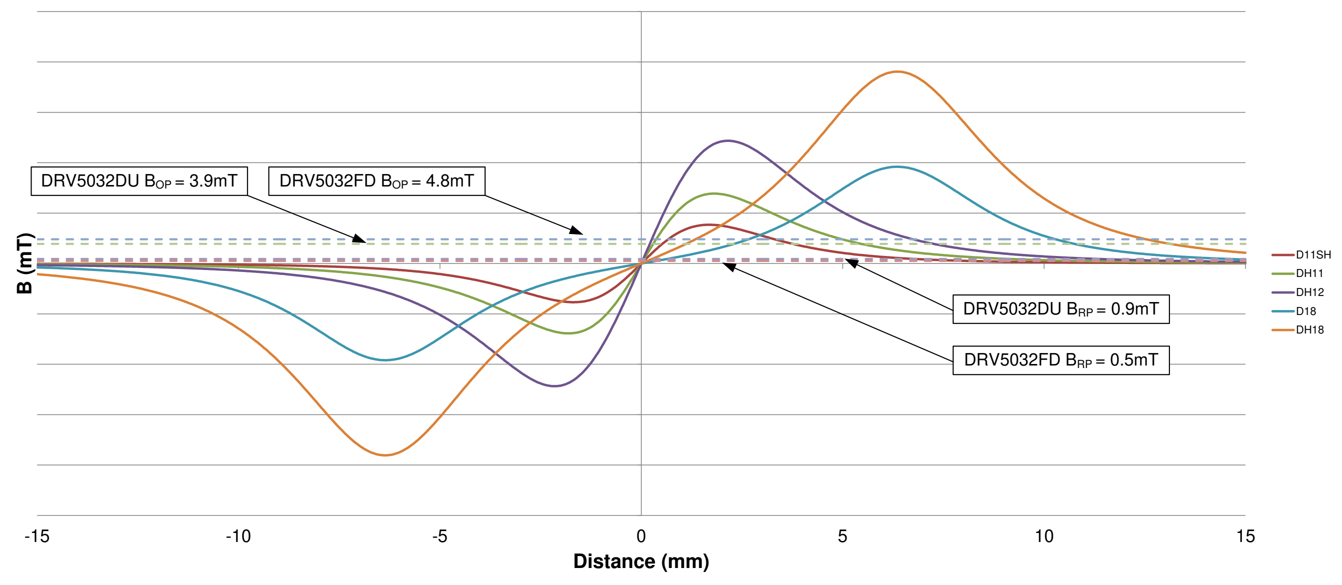


Figure 8. Magnetic Field Behaviors For Various Magnets, 2.5-mm Height

From these choices, D11SH, DH11, and DH12 all appear to work well with DRV5032DU or DRV5032FD, due to the small distance between the B_{OP}'s from the north pole and south poles. As small form-factor is desired here, the D11SH is chosen to complete this design, which is a 1.5875-mm diameter x 1.5875-mm thick, grade N42 neodymium magnet. However, DH11 and DH12 could also be made to work here. Note that these curves are only valid for the chosen height of 2.5 mm. They need to be recalculated for a different chosen height.

A detailed magnetic field curve for D11SH is shown in Figure 9 below, along with the hysteretics of the various operating and release points.

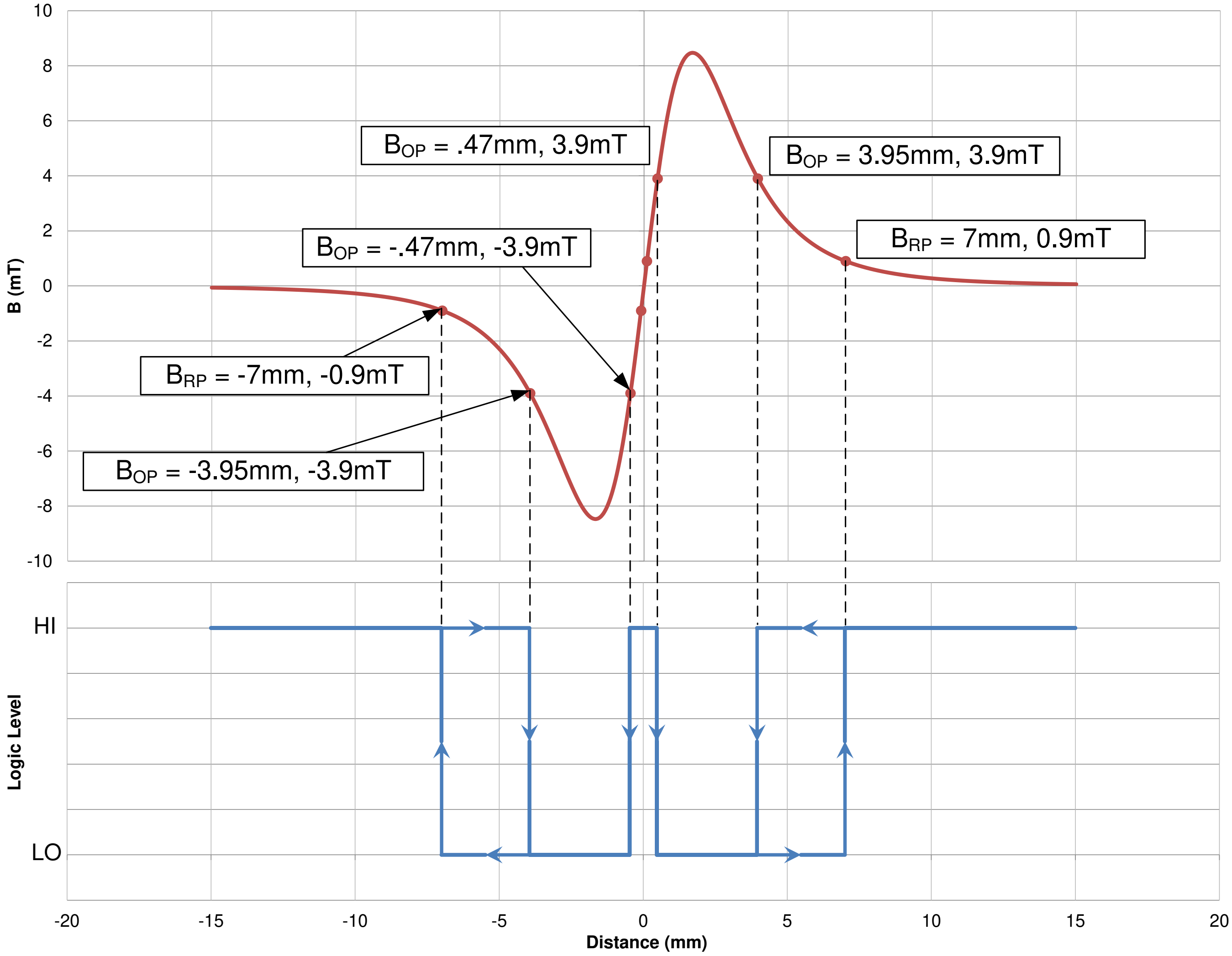


Figure 9. D11SH Magnetic Curve, B_{OP} and B_{RP} Points, 2.5mm Height

For each peak of the curve, there are two points where B_{OP} is reached. It is advised that the extremes of each of these points (-3.95 mm for north pole, 3.95 mm for south pole) be treated as maximum travel distance points; while there is a separation of 3.05 mm between operating points and the outer release points, typical values are often far less than the data sheet maximums, and movement past these points could result in unintended turn-off of the device. With this in mind, we arrive with our mechanical tolerances for a dual output switch: a minimum travel distance between the two sides of the switch of ±.47 mm (.94 mm total), and a maximum movement distance of ±3.95 mm. This movement is demonstrated in Figure 10. Note that only one orientation of movement is given, but this movement is symmetric to the center of the sensor, and is able to be reflected across the axis of the part.

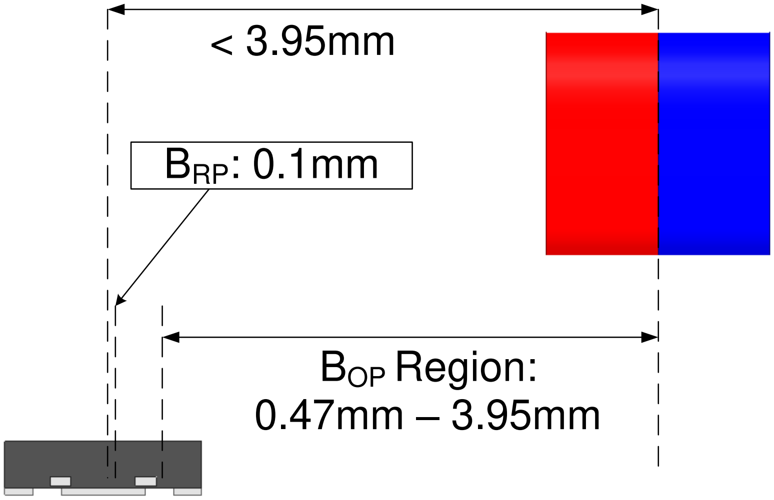


Figure 10. Dual-Position, Dual-Output Switch Lateral Movement

4.4 Three-Position Switch with Dual Output (inline)

The three-position switch design is quite similar to the two-position dual output. However, in this design, the "dead zone" is no longer minimized, and acts as a third output, where neither output of the DRV5032 is active. As such, a flatter curve is desired to elongate the travel area of this third state. Recall D18 and DH18 in Figure 8 above, as these exhibit the flatter behavior desired here. For simplicity, the D18 is chosen at a height of 2.5 mm to complete this design, which is a 1.5875 mm diameter x 12.7 mm thick, grade N42 neodymium magnet.

A more detailed magnetic field curve for D18 is shown in Figure 11 below, along with the hysteretics of the various operating and release points.

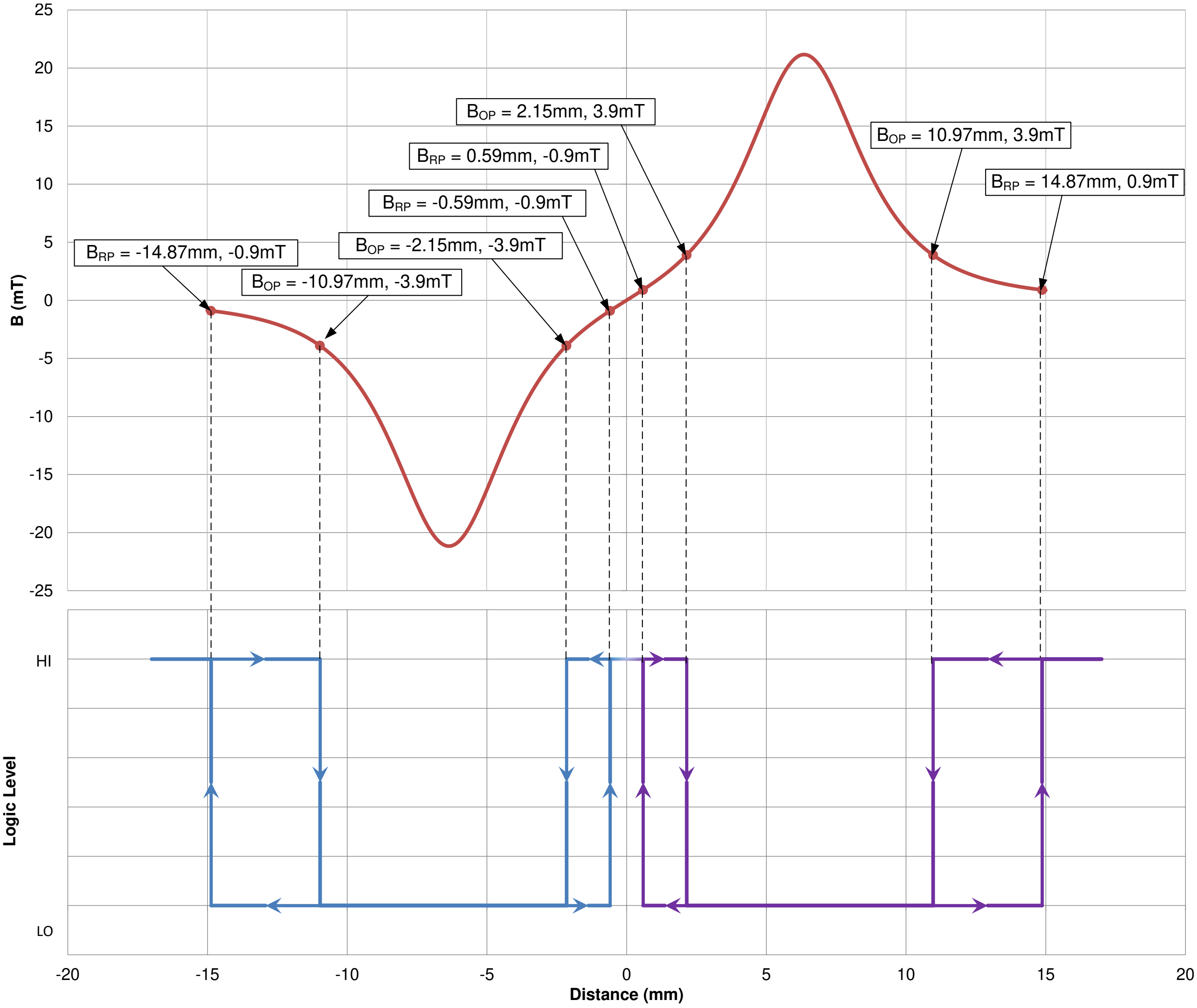


Figure 11. D18 Magnetic Curve, B_{OP} and B_{RP} points, 2.5-mm Height

From here, the design is remarkably similar to the dual output switch. Again, it is advised that the B_{OP} extremes of each of these points (-10.97 mm for north pole, 10.97 mm for south pole) be treated as maximum travel distance points for additional robustness. Following the procedure from the dual-output switch in the previous section, the design now turns to a mechanical problem with the following tolerances: a minimum travel distance between the two sides of the switch of ±.2.15 mm (4.3 mm total), and a maximum movement distance of ±10.97 mm. However, there is now a ±.59 mm (1.18 mm) section in the center of the switch that acts as an "off" position, as the magnetic field seen by the sensor is guaranteed to be clear of the minimum release point of either side. Note that this 1.18-mm region is based on the minimum B_{RP} of the device, and in practice this region is typically larger. This movement is demonstrated in Figure 12 and Figure 13 below. Note that only one orientation of movement is given, but this movement is symmetric to the center of the sensor, and is able to be reflected across the axis of the part.

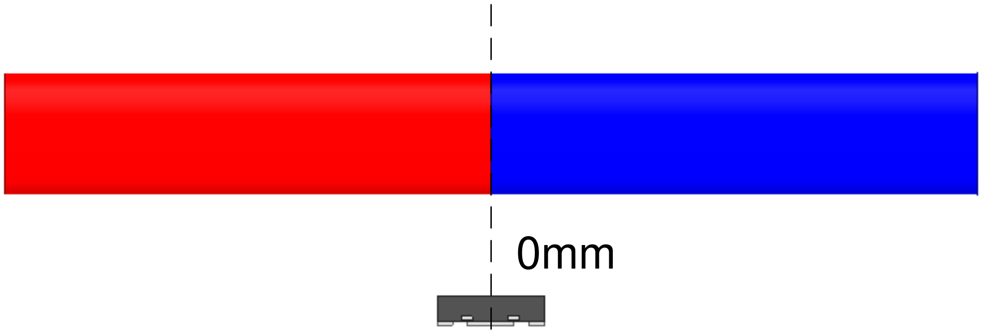


Figure 12. Three-Position Switch OFF Position

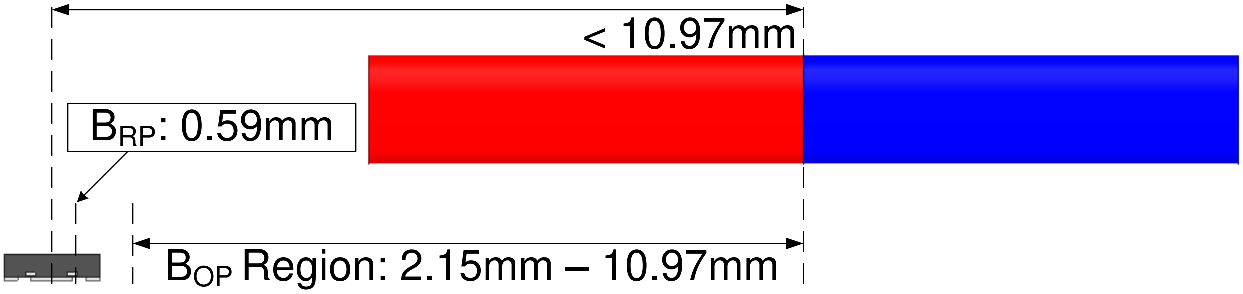


Figure 13. Three-Position Switch Lateral Movement

4.5 Three-Position Switch with Dual Output (rotational)

For rotary switch designs, disc-style magnets are typically the most convenient due to their periodic nature when used with Hall effect sensors, but for small form factor, cylindrical magnets may also be used. By rotating the cylinder magnet, a curve resemblant of the prior design is created.

As this magnet is typically embedded in a dial, a small thickness is desired, but increasing this thickness also helps with maximizing the dead zone, so a trade-off must be made here. From a quick inspection of available magnets, D14 was chosen for this simulation, which is a 1.59-mm diameter by 3.175-mm thick, axial, grade N42 neodymium magnet. A height of 2.5 mm is chosen for the magnet, and once more paired with the DRV5032DU. A detailed magnetic field curve for D14 is shown in Figure 14 below, along with the hysteretics of the various operating and release points.

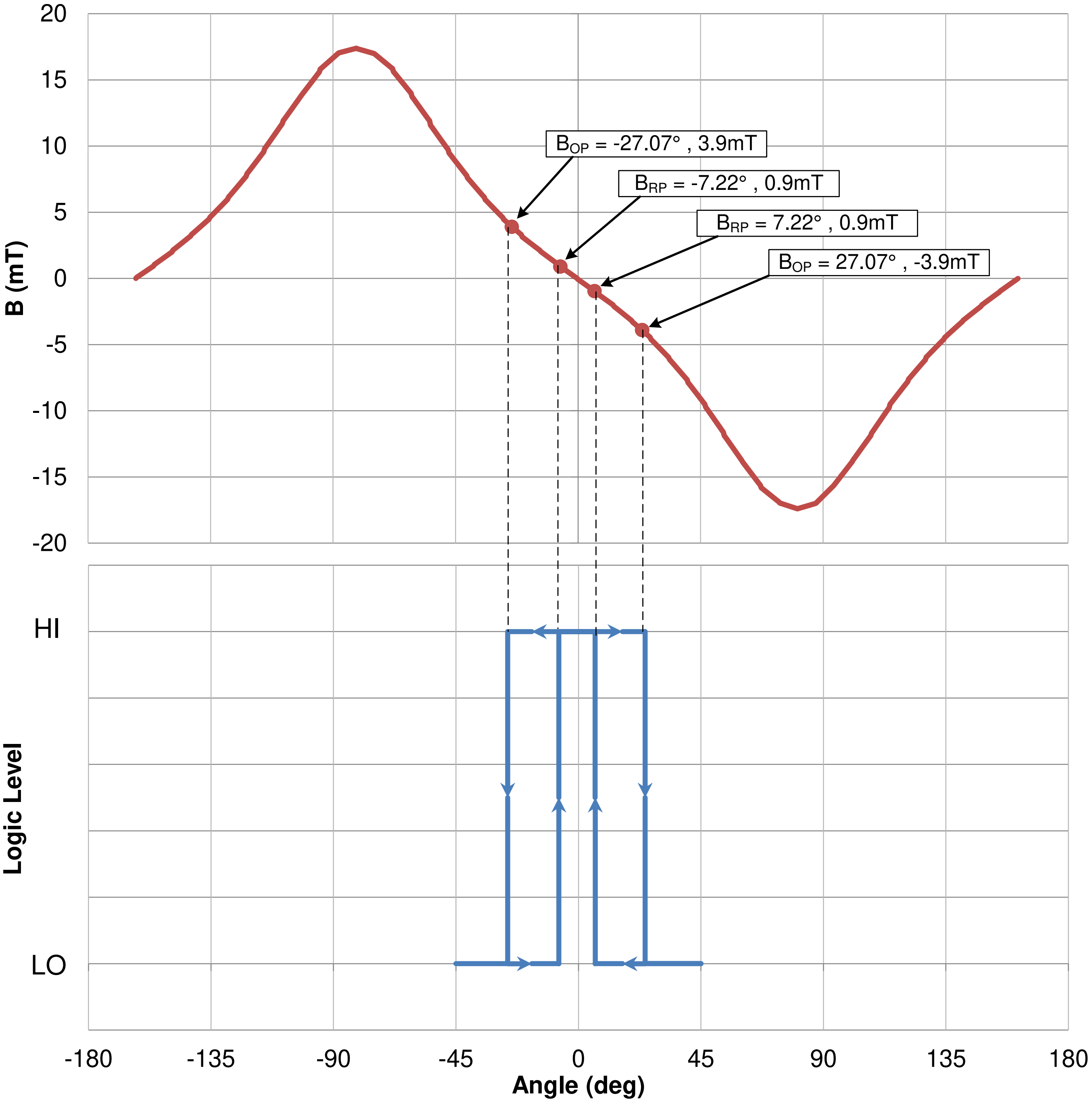


Figure 14. D42DIA Magnetic Curve, B_{OP} and B_{RP} Points, 2.5-mm Height

These results show that the magnet must be embedded in an enclosure that is capable of traveling at least ±27.07º to guarantee turn-on of either state. To ensure robustness, a few additional degrees of margin must be added, so the design is robust with a travel distance of ±30º As the dial is brought back to the center, the device is guaranteed to turn off at roughly ±7º on either side, with an approximate 14º window in the center as the "off" point where neither output of the sensor is active. The enclosure must sit with the magnet 2.5 mm above the sensor, with the sensor mounted under the edge of the radial spin at the thickest point of the magnet, as seen in Figure 15 and Figure 16.

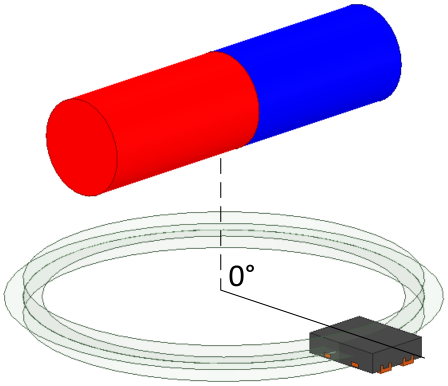


Figure 15. Three Position Rotary Switch OFF Position

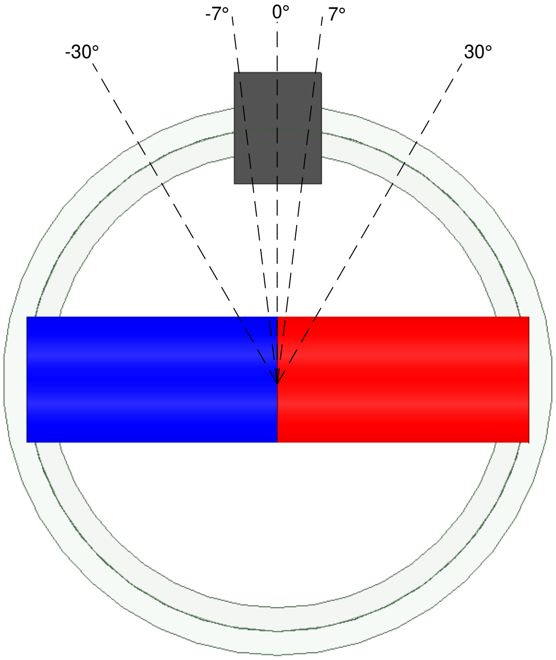


Figure 16. Rotary Magnetic Travel for Three-Position Switch

5 References

- Texas Instruments, *Overview Using Linear Hall Effect Sensors to Measure Angle Application Note*
- Texas Instruments, *Breakout Adapter for SOT-23 and TO-92 Hall Sensor Evaluation*
- Texas Instruments, *E2E forums at https://e2e.ti.com/*

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