Two state selector

TI Precision Labs – Magnetic sensors

Presented and Prepared by Patrick Simmons

Hello, and welcome to the TI precision labs series on magnetic position sensing. My name is Patrick Simmons, and I’m an applications engineer in the Current & Position Sensing product line. In this video, I will be covering the topic of two state selectors using Hall-effect sensors.

Applications

Two state selectors can come in many forms including a slider, a toggle, a button, or a dial and can therefore be found in all types of applications in which a user selects between two different outcomes. For instance, the device is either powered on or off, the light is on or off, or the drill is either moving forward or reverse. These binary actions simply require a selector with two generally distinguishable states, which are typically at the bounds of the monitored selector path. All states or positions in between are expected to be brief, transitory, and do not need to be monitored.

In this video we will discuss how you can implement this functionality using Hall-effect switches. We will walk you through the general process, introduce key specifications, alert you of possible design challenges, and provide you with tools to stream line your design process.

Design process overview

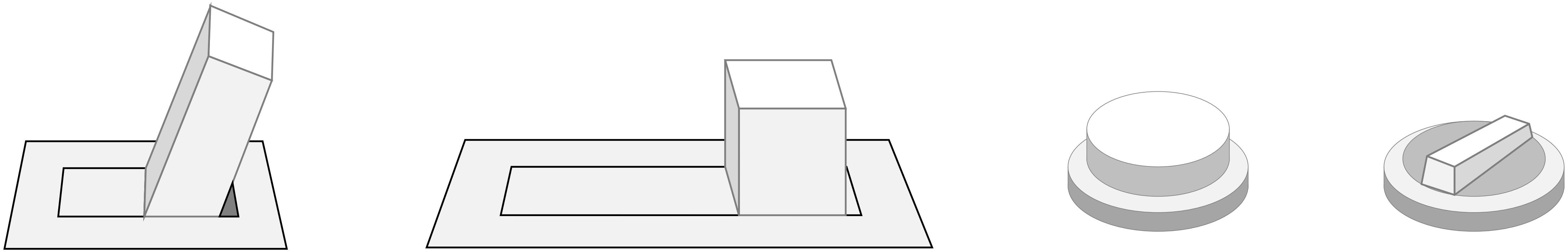
1. Identify general implementation.
2. Define mechanical constraints including tolerances.
3. Determine B-field curve for various magnets within price point.
4. Determine suitable devices within price point.
5. Iterate.

On that note lets get started with the design process…

The design can be summarized into these 5 basics steps. (click) (click)

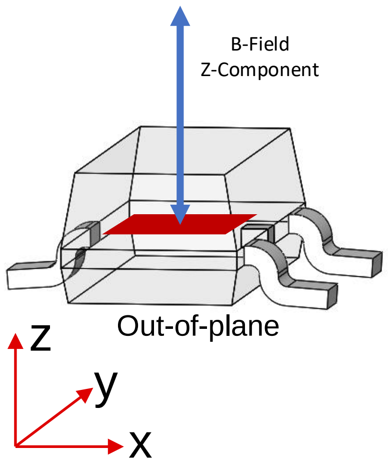
And the first will be choosing the fundamental implementation.

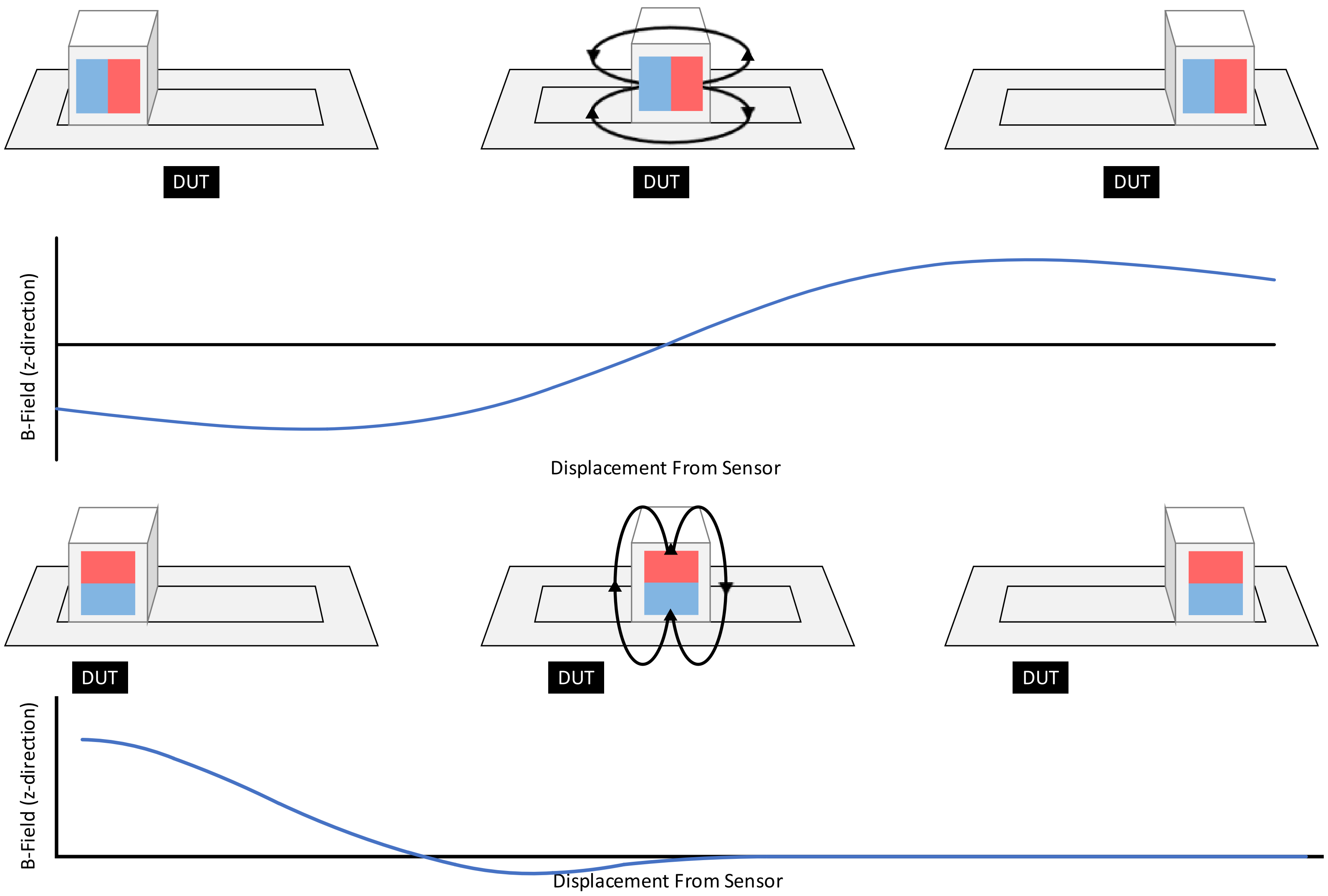
Mechanical implementation



One key aspect of the fundamental implementation is mechanical. A toggle, slider, button, and dial are just a few mechanical implementations you may consider for your design. Deciding which mechanical assembly is best for you will ultimately hinge upon space constraints, design complexity, material cost, aesthetics and ergonomics.

Magnetic implementation





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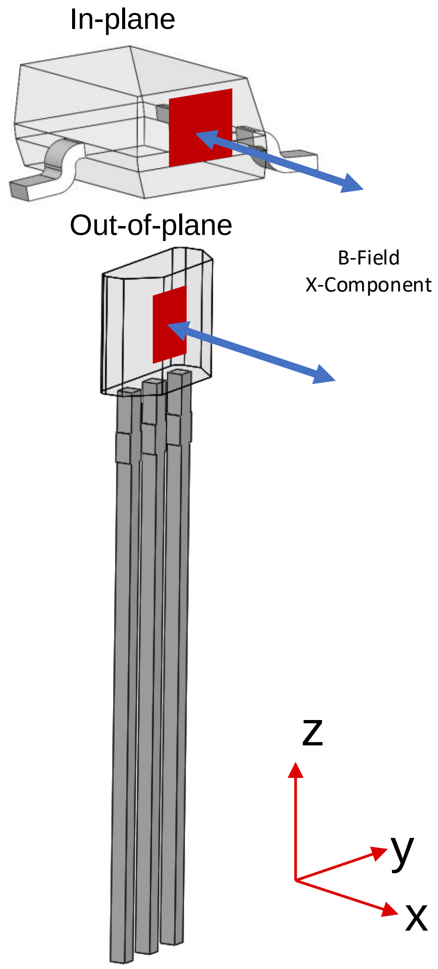
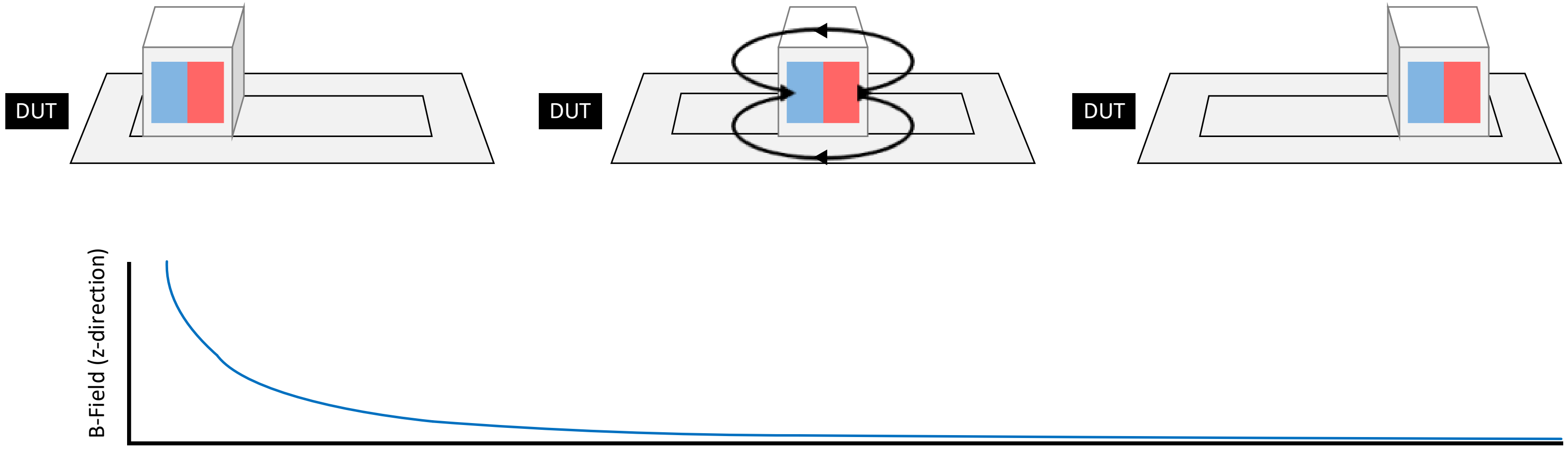
Upon choosing a mechanical implementation, you subsequently need to consider a magnetic implementation. In this case we decided to proceed with a slider implementation, and with the slider there are multiple magnetic implementations. In both of these cases, the magnet is in the sliding element while our device under Test, DUT, is placed nearby in a fixed location. Also in both cases, we are using a Out-of-plane Hall-sensor with a Hall element that senses along the z-axis. The key differences that we can discern here between these two examples, is the orientation of the magnet and the location of our Hall Sensor. In the top example, the magnet North and South poles run horizontally while in the bottom example the poles run vertically. As the B-field of the magnet wraps from North to South, we can expect the direction of the field will be different when both sliding elements are in the same location. Due to this change in direction of the B-field a Hall-effect latch would be more appropriate for the top example where the DUT sees both strong positive and negative fields, while an Hall-Effect switch would be more appropriate for the bottom example where the DUT sees a strong change in magnitude for one polarity.

Magnetic implementation





Aside from the aforementioned examples, you could alternatively sense in the x-direction with an in-plane surface mount sensor like the TMAG5123 or with one of our typical out-of-plane thru-hole TO-92 offerings. In this case a Hall-effect switch would be the most appropriate choice as the device only sees one magnetic polarity.

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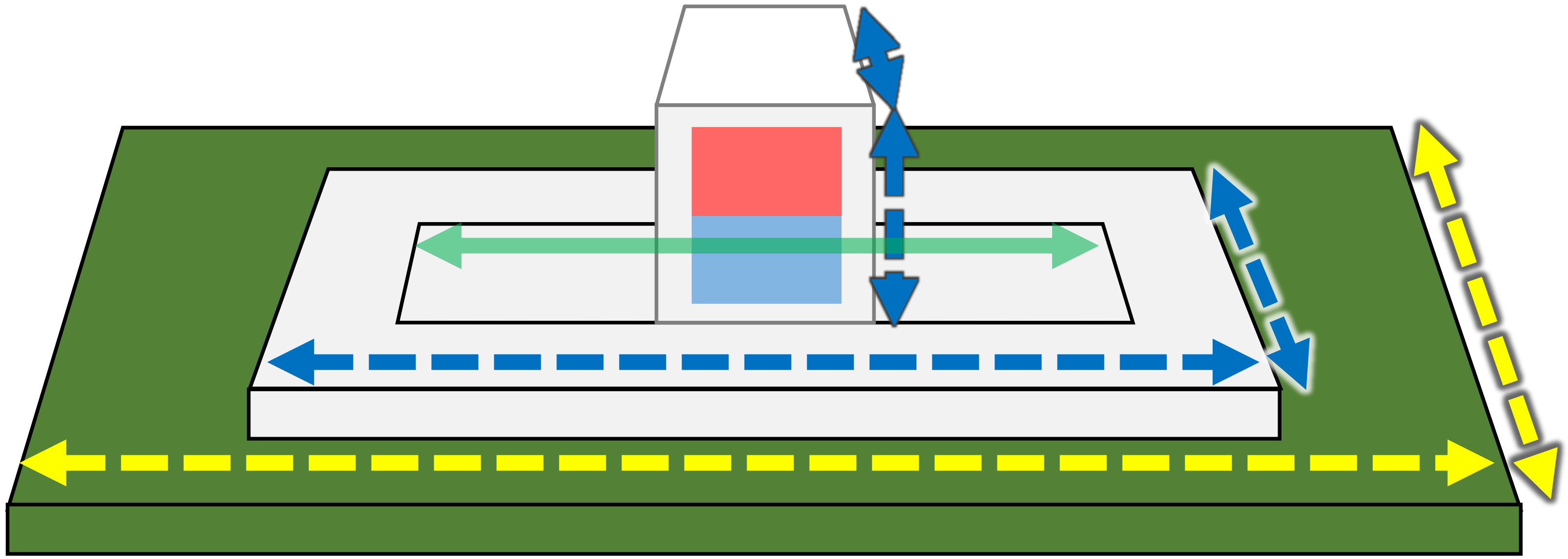
5. Iterate.

Having selected a general sensing implementation, we can move on to the second step, which is defining our mechanical constraints including tolerances.

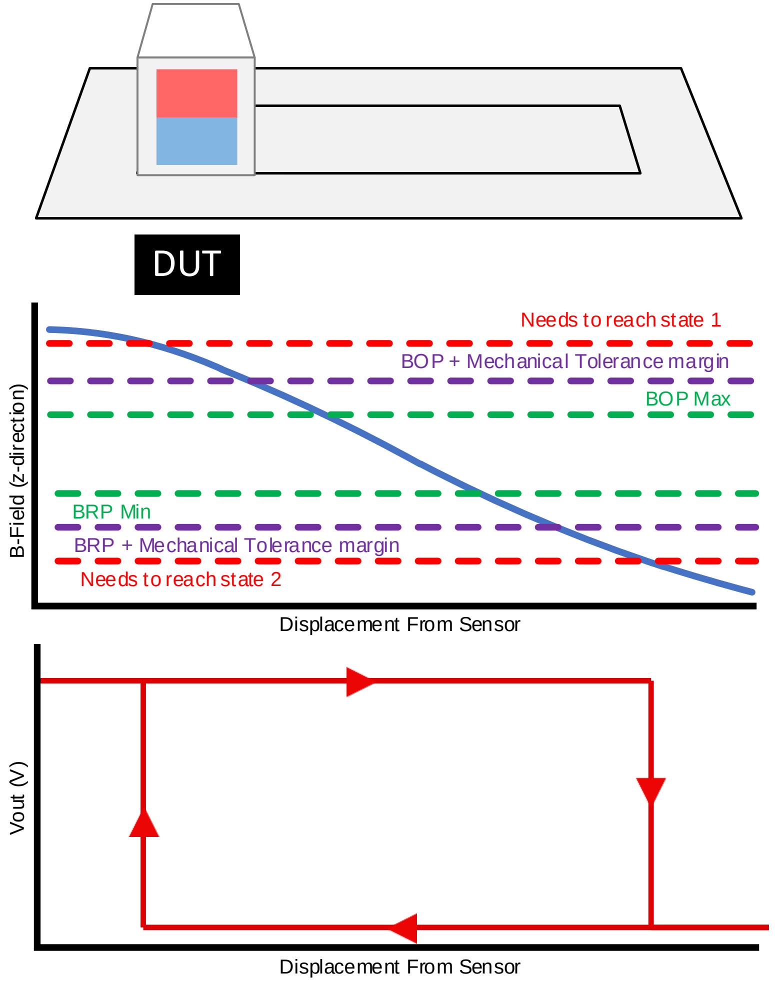
Mechanical constraints

- Available board space for fixture
- Dimensions of mechanical switch fixture
- Displacement distances



Mechanical constraints can be generalized into four categories. The first would be the board space you have available for placing the selector, the second would be the dimensions your mechanical selector fixture needs to conform, and the third would be your allowable displacement distance.

Mechanical constraints - Transition points



TEXAS INSTRUMENTS

The fourth critical constraint, would be the transition points where your end user must absolutely observe a state change. This constraint bounds the region in which your magnetic Hall-sensor thresholds need to be. These thresholds are BOP and BRP and we can expect that these specs will have some variation due to device tolerance and system manufacturing tolerance. Therefore good design requires there to be adequate margin between the Hall-effect position sensor transition point at which your two state selector absolute transition point.

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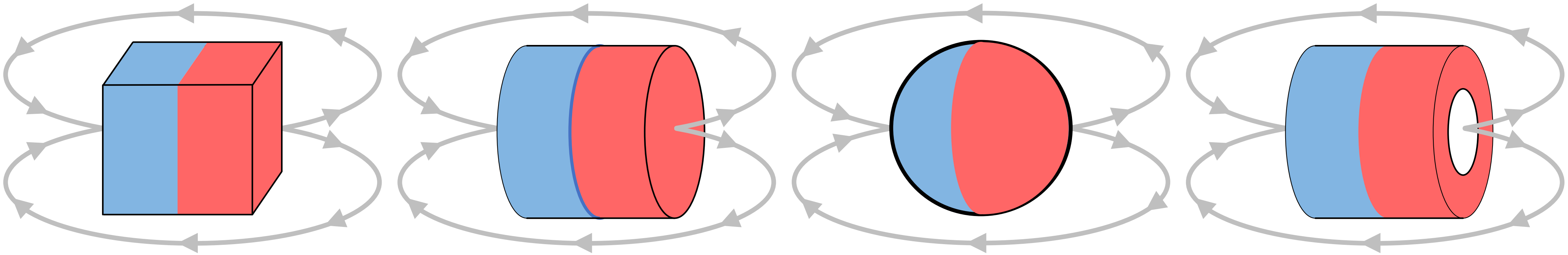
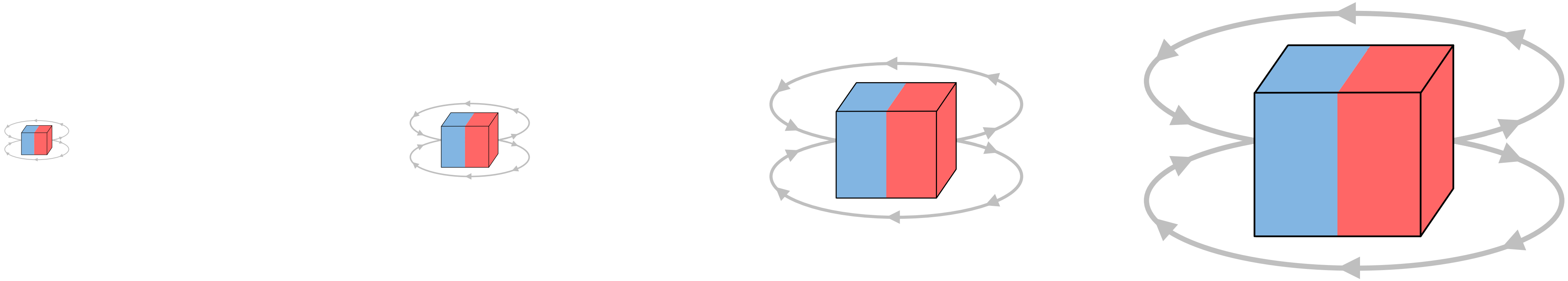
After specifying our mechanical constraints, we now have a tangible path to take in selecting the components needed to create the position feedback system. The first component we will examine for the position feedback system is the magnet.

Selecting a magnet

SHAPE



SIZE



COMPOSITION

$SrFe_2O_3$ < $SmCo_5$ < $AlNiCo_5$ < NdFeB

There are numerous types of magnets available on the market. A key characteristic is the magnet’s shape. Here are just a few of the dipole shaped magnets you could possibly use. Another important parameter will be size. In conjunction with size, varying the ratio between length and thickness or width and thickness can also have a significant impact on magnet’s field strength. Lastly, the magnet composition, which relates to magnet remanence, affects field strength.

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Upon determining the B-curve characteristic for you desired magnet, we now can move on to the step of selecting a device.

Selecting the right device

Recommended type of devices

- Omnipolar switch, unipolar switch, latch

Key specifications

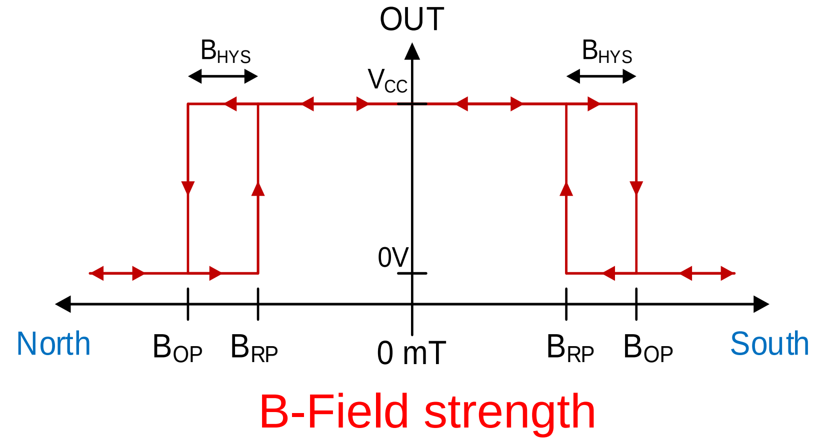
7.6 Magnetic Characteristics

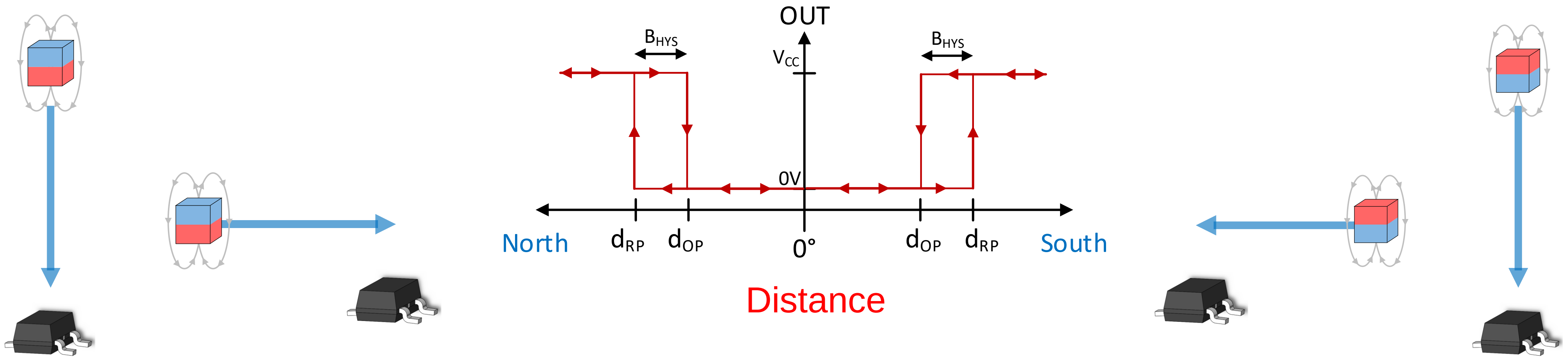
for V_{CC} = 1.65V to 5.5V, over operating free-air temperature range (unless otherwise noted)

PARAMETER		TEST CONDITIONS	MIN	TYP	MAX	UNIT
DU VERSION						
B_{OP}	Magnetic threshold operate point	OUT1 pin (north)	–3.9	–2.5	–1.2	mT
		OUT2 pin (south)	1.2	2.5	3.9	
B_{RP}	Magnetic threshold release point	OUT1 pin (north)	–3.5	–1.8	–0.9	mT
		OUT2 pin (south)	0.9	1.8	3.5	
B_{HYS}	Magnetic hysteresis: $\lvert B_{OP} – B_{RP} \rvert$	Each Output	0.1	0.7	1.9	mT

As we are essentially looking at binary states of open or closed, omnipolar switches, unipolar switches, and latches all are viable options. The key specifications for our design with these devices include BOP, BRP, and Bhys which can be found in the Magnetic Characteristics table in the device datasheet.

Omnipolar switch output

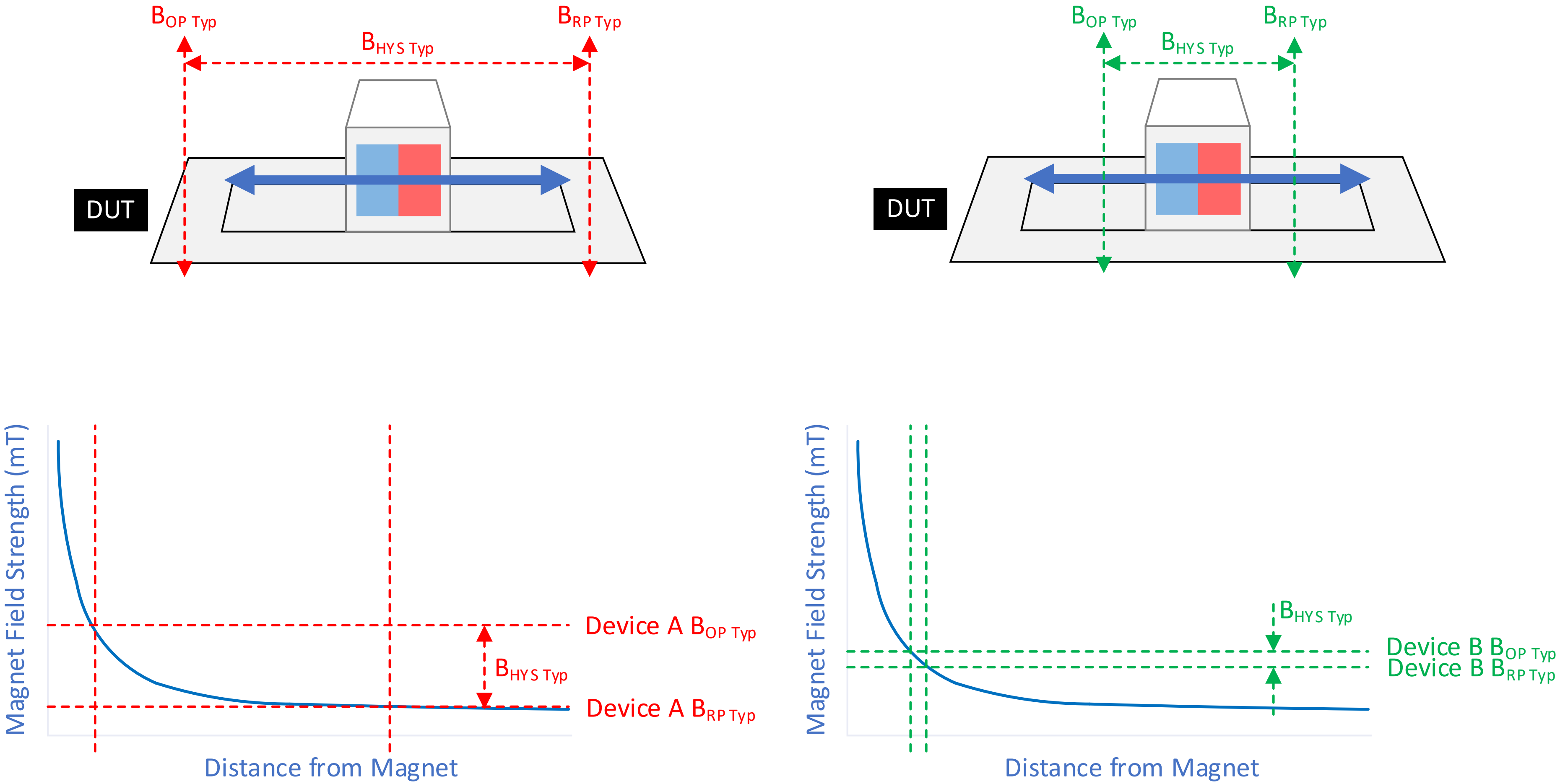




Typically in an omnipolar switch datasheet, you will see an active-low plot that indicates the sensor output will transition low when the measured magnetic flux exceeds BOP and will transition back to high when the measured magnetic flux drops below BRP. Bhys will define the difference in magnitude between BOP and BRP.

From this we can create another general behavior diagram to help us anticipate what behavior to expect in our operating conditions. Magnetic field strength exponential decay with increasing distance from the device. Therefore (click) we can expect the sensor output will be typically high when the magnet is far way and low when the magnet is close to the device.

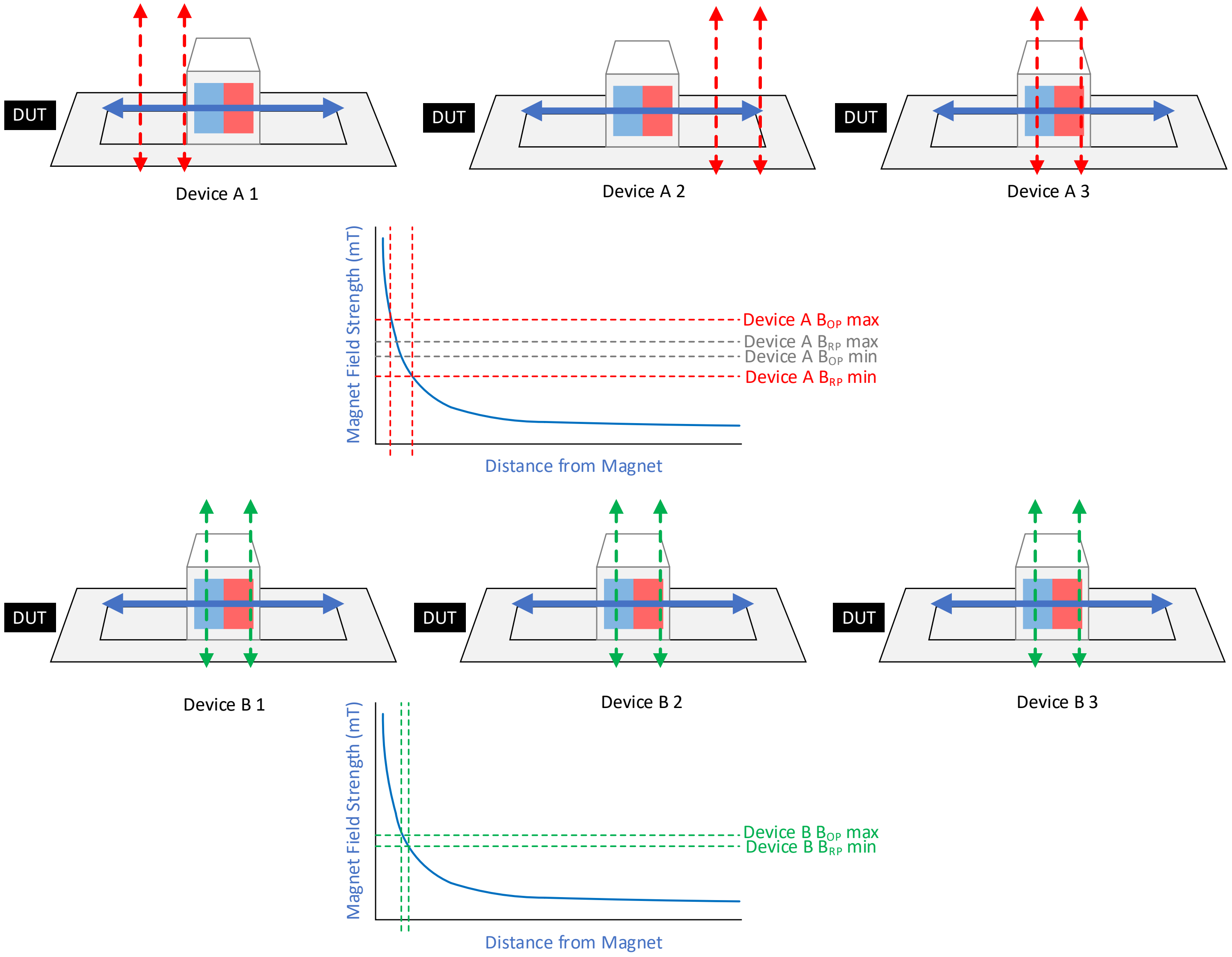
Design challenges - Hysteresis region size



As noted previously, Bhys is one of the important device specifications. This specification defines the magnetic hysteresis of the device. When the selector crosses the BOP threshold the device outputs low until the selector crosses BRP, and after crossing the BRP threshold the device outputs high until the BOP threshold is crossed. The minimum hysteresis size is not so important as the selector is expected to be either on the far left or far right normally with only a very brief transitory duration in the center. However, the max hysteresis size is very important. As your selector might only cross one threshold, or it could cross neither BOP or BRP threshold such as the example on the left.

To ensure your design works, the threshold points need to be well within the selector's range of motion, such as in the example on the right. Aside from looking for a device with a smaller Bhys specification, you might also trying using devices with higher BOP and BRP specifications if your spatial hysteresis region is too large.

Design challenges - Transition region variation



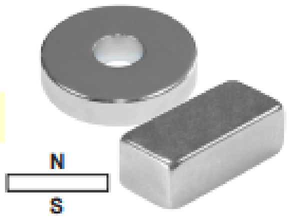
One other nuance to be aware of that might be directly related to Hall Switch specifications is transition region variation…

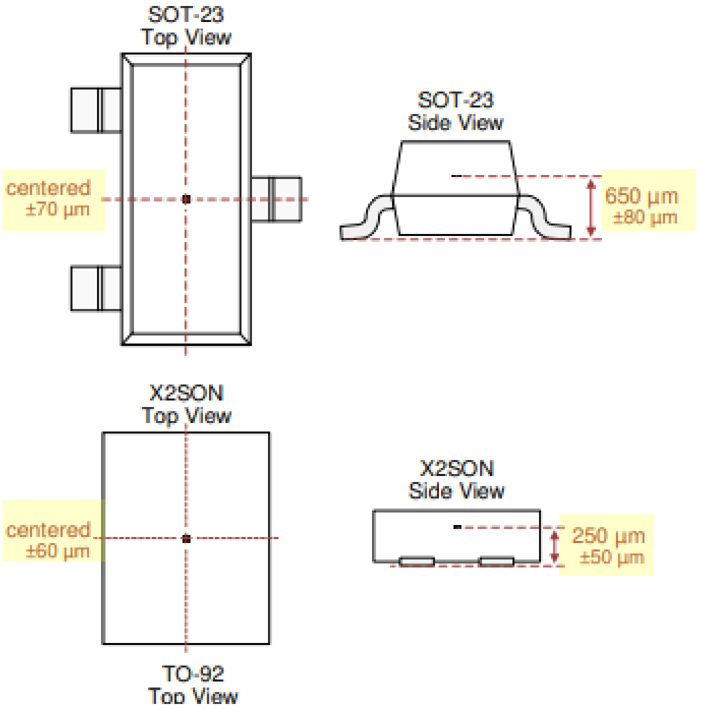
How much tolerance there is on BOP and BRP will influence how much variation you could expect between transition regions amongst identically designed equipment. Smaller tolerances on BOP and BRP will lead to the greatest repeatability from the sensor. As you can see with device A, there is a wide region of variation for either BOP or BRP in the graph, which means one slider with device A might have the sliding element almost completely to the left before triggering low, while another slider with device A might have the sliding element almost completely to the right before triggering low. As for device B the BOP and BRP tolerance is too small to be distinguished on the graph, consequently every slider with device B has nearly identical on and off transition points.

Design challenges - Mechanical variation

Features
- Operates best at temperatures below 180°F (82°C)
- Tolerance ±0.005” on all dimensions

NOTE: *Avoid grinding, as flash fires may occur from rare earth material dust particles. Crystalline structured material is easily chipped, cracked or broken.*



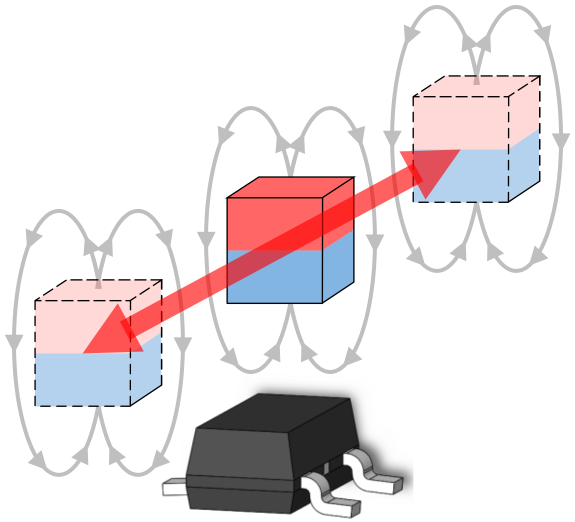


Printed Circuit Board Thickness:

Thickness tolerances may vary 10% (min.+/- 0.005”)

HIGH-PRECISION DRIVE AND LINEAR ENCODER TECHNOLOGY

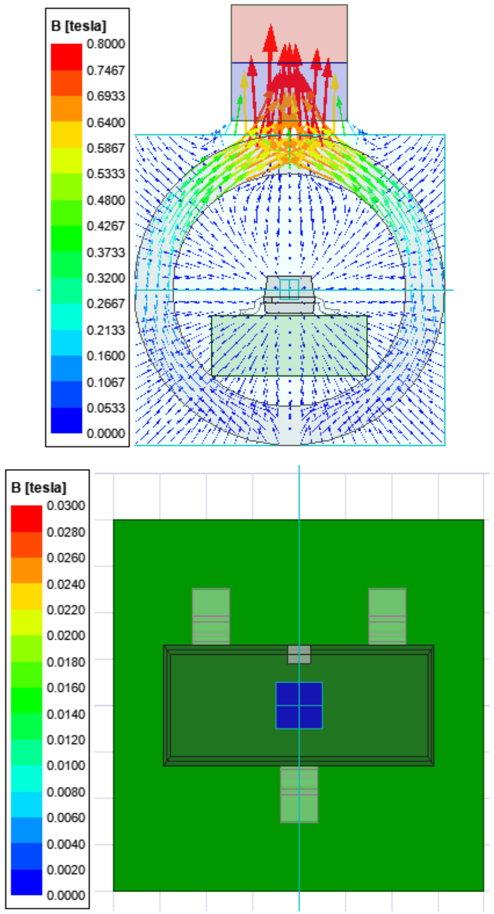
A high-quality build and components ensure a level of repeatability and accuracy that other pick and place machines in the MC385V2V's price range can't match. High-precision, ball-screw drive, and linear encoders ensure placement accuracy of 30 µm, 3 Sigma.

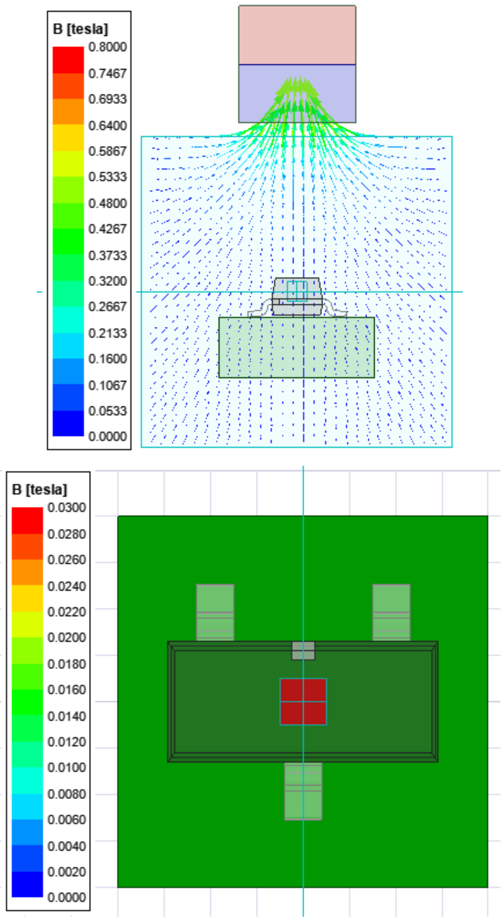


As the design involves more than just the sensor…

We can anticipate that there will also be variation due to tolerances in manufacturing of the magnet, the Hall-element placement within the device package, the Hall-sensor pcb, the system fixture, and the physical placement of the magnet.

Design challenges - Material influence





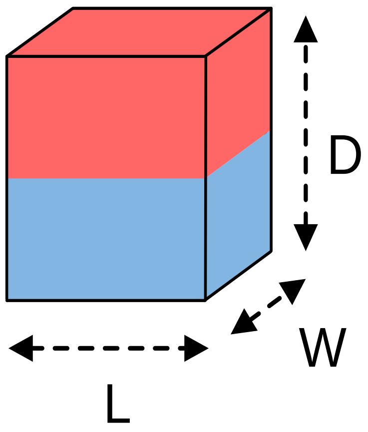
Aside from mechanical tolerances specific to the Hall-effect portion of your design. There is also one other mechanical aspect of your system that influence your sensor detection. This would pertain to the materials you use, both within your two state selector as well as in the enclosure or fixture in which your two state selector is housed.

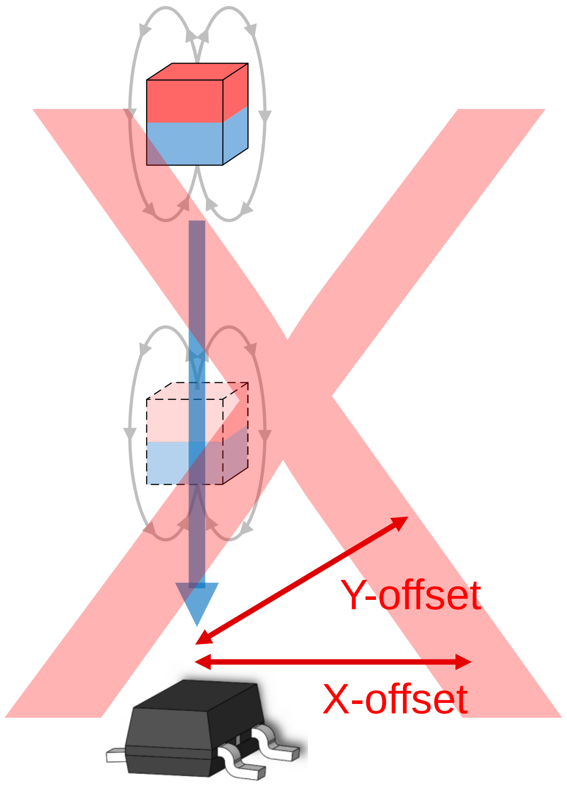
Like current, magnetic fields like to travel the path of least resistance, or in this case least reluctance. Nearby system structures can either concentrate, divert, or not influence the field from your magnet depending on the structure's permeability and geometry. Reluctance is inversely proportional to permeability and high permeability – low reluctance materials include mu metal and iron based materials.

To illustrate the concept of how material influences the field, here we show a SOT-23 with a magnet suspended above. In the left example, we have a mu metal cylinder which wraps around our device. We can observe that the B-field concentrates within this cylinder and in the aerial view of the device below we can see that the field observed by the Hall element is basically 0mT. By comparing to the unshielded example on the right, we can see that at least 30mT were diverted away from being measured.

Calculation

$$B = \frac{B_r}{\pi}\left[arctan\left(\frac{LW}{2z\sqrt{4z^2 + L^2 + W^2}}\right) - arctan\left(\frac{LW}{2(D+z)\sqrt{4(D+z)^2 + L^2 + W^2}}\right)\right]$$





- Does not account for offsets

There is yet one other aspect that may appear to be a challenge to th…Which would be calculating the expected magnetic flux…

Some of you may have already found equations for calculating the magnetic flux relative to your chosen magnet such as this block equation shown here. And you might also have found that such equations do not account for offsets such as the x and y offset displayed in this head-on example.

Tools

- Finite Element Method Magnetics (FEMM)
- ANSYS
- TI proximity tool

Fortunately there are remedies to this particular challenge. Its possible to use such modeling software such a Finite Element Method Magnetics as well as ANSYS to tackle your most demanding magnetic conditions. Yet these tools themselves may not be free as well as they may require significant time to learn, build your model in, and get proper simulation results. Thankfully, TI has taken the liberty of simplifying the process even further with our own tool which allows you to put in all relevant design constraints so that it can build the model and execute the calculations or simulations for you.

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Now equipped with the tools to help you determine the expected flux you will measure according to magnet position relative to the sensor, you can now move on to the final basic step… Iterate.

Due to the non-linear characteristic of magnetic flux and the number of variables that influence it, your first design attempt might need some optimization. Fortunately, the aforementioned tools provide quick feedback and thereby enable you to sweep through how various variables will affect your design and allow you to quickly get to prototyping your first build.

To learn more about magnetic position sensing, visit ti.com/halleffect.

That concludes this video - thank you for watching! Please try the quiz to check your understanding of the content.

For more information and videos on magnetic position sensors please visit ti.com/halleffect.