Using hall-effect sensors for contactless linear movement sensing

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Introduction

Many systems require a solution to translate the mechanical position of linearly moving components into electrical signals so that the electronics in the system can react to the component's position. Contact-based mechanical solutions such as potentiometers traditionally accomplished this translation by converting mechanical positions into an output voltage.

For example, a cordless power drill uses a potentiometer to translate the displacement position of the trigger to an output voltage that adjusts its speed accordingly, while a video game controller joystick uses two potentiometers to translate the x and y position of the joystick into output voltages for the x and y axes.

Because of their contact-based operation, potentiometers typically wear down faster than non-contact-based alternatives. This reduction in reliability and system lifetime is further exacerbated if the potentiometer is exposed to vibrations or external influences such as moisture, dirt or other debris.

The **Contactless, Hall-Effect Variable-Speed Trigger Reference Design** shown in **Figure 1** illustrates the use of a magnet and a linear Hall-effect sensor as an alternative to contact-based position sensing to determine the position of a moving component. In this reference design, a magnet placed on the moving trigger travels along with it. Pressing the trigger to the left causes the magnet and trigger to move to the left. The linear Hall-effect sensor detects the resulting magnetic flux density from the moving magnet and updates its output to reflect the position change of the trigger.

Since the relationship between magnetic flux density varies predictably based on the distance, it becomes possible to back-calculate the magnet-to-sensor distance (and therefore the moving component displacement) using the sensed magnetic flux density value. The mapping of the Hall-effect sensor's magnetic flux density reading to distance depends on several parameters, however: the specifications of the magnet, the magnet-to-sensor orientation, the device package, and the distance from the magnet to the sensor. This article explores how to select these parameters when designing a contactless Hall-based linear position sensing system.

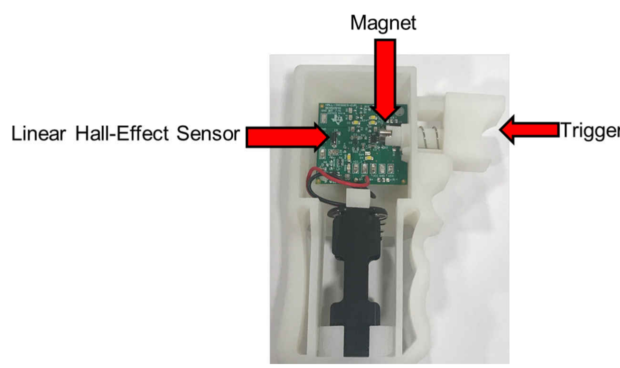

Figure 1. *TI's contactless, hall-effect variable-speed trigger reference design.*

Magnet-to-sensor orientations

When using one-dimensional (1D) Hall-effect sensors, the direction of sensor sensitivity partially determines where you can place the magnet with respect to the sensor. If a sensor is an out-of-plane sensor, which is the most common case with Hall-effect sensors, the out-of-plane sensor is sensitive to the magnetic field component that is perpendicular to the die inside the package.

For surface-mount out-of-plane 1D sensors such as the small outline transistor (SOT)-23 package shown at the top right in **Figure 2**, the Hall-effect sensor senses the magnetic field component that is perpendicular to the printed circuit board (PCB) surface.

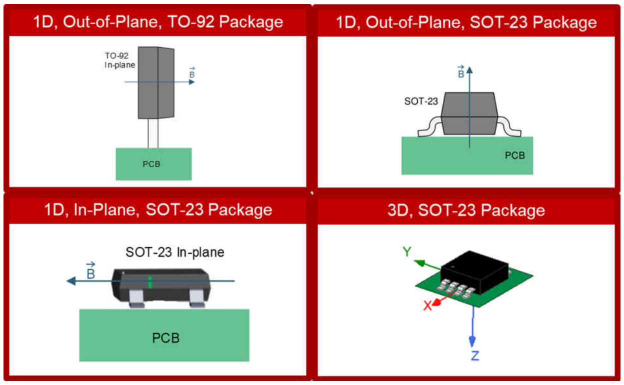

Figure 2. Clockwise from bottom left: direction of sensitivity for 1D in-plane, 1D out-of-plane, 1D out-of-plane and 3D sensors.

For through-hole sensors such as the transistor outline (TO)-92 package at the top left in **Figure 2**, the Hall-effect sensor senses the magnetic field component that is perpendicular to the marked side of the package. If the through-hole sensor is positioned to be perfectly vertical, the Hall-effect sensor will be sensitive to the magnetic field component that is parallel to the PCB.

In contrast, if the sensor is an in-plane sensor, it is sensitive to a magnetic field component that is coplanar to the device's die. The bottom-left illustration in **Figure 2** shows an in-plane sensor. Since the direction of sensitivity of this in-plane SOT-23 device is the same as the out-of-plane TO-92 device in **Figure 2**, the surface mount in-plane SOT-23 device can replace the through-hole out-of-plane TO-92 device and maintain the same direction of sensor sensitivity.

For increased magnet placement flexibility, you could also use a linear 3D Hall-effect sensor such as the **TMAG5170** or **TMAG5273**, as shown at the bottom right in **Figure 2**. Implementations of these devices often entail using two in-plane sensors and one out-of-plane sensor for implementing 3D sensing. Since they are not restricted to sensing in only one direction, 3D sensors are the best option for sensing complex magnetic fields from magnets.

One common magnet-to-sensor configuration is the **head-on configuration** shown in **Figure 3**(a), where the path of travel is along the direction of sensitivity. This particular out-of-plane SOT-23 package has a direction of sensitivity in the z axis. The magnet in this configuration also moves along the z axis and has a polarization in the z direction as well, which results in the sensor seeing only a positive or negative field, also shown in **Figure 3**(a).

Figure 3(b) shows a **slide-by-displacement** configuration in which the Hall-effect sensor senses the magnetic field component in the z direction, but the magnet moves in the y direction. The sensor is offset, but not in the traveling path. For this configuration, the sensor sees positive and negative fields if both the south and north poles of the magnet go past the sensor, as shown in the magnetic flux density graph in **Figure 3**(b).

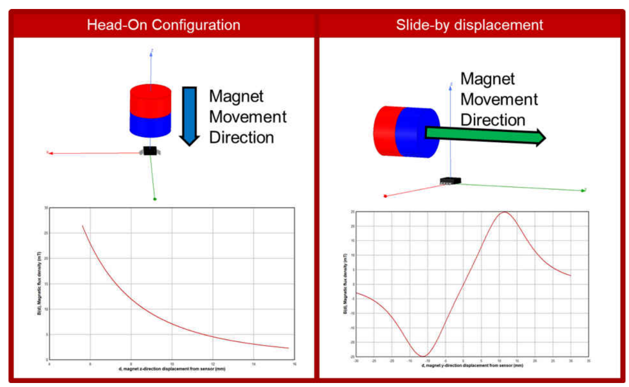

Figure 3. Magnet-to-sensor configurations: head-on (a); slide-by-displacement (b).

When selecting the output of a Hall-effect sensor, you may also need to consider the sign of the applied magnetic field. Different devices have different ways of defining a positive or negative field.

For example, assume that the surface mount out-of-plane device in **Figure 4** defines a positive field as having magnetic flux traveling from the bottom to the top of the package, and a negative field as having magnetic flux traveling from the top to the bottom of the package. You will see a positive field when applying the south pole of a magnet directly above the sensor, or when applying the north pole of a magnet directly beneath the sensor. You must select the appropriate output polarity to properly sense the magnetic field generated by the magnet.

Bipolar linear Hall-effect sensors such as the **DRV5055** detect both positive and negative fields, while unipolar sensors such as the **DRV5056** detect either positive or negative fields. Since unipolar sensors only sense one polarity, they may have more sensing resolution compared to the corresponding bipolar device; however, since bipolar devices work with both poles of a magnet, it allows the magnet to be placed without determining whether a pole of the magnet is the south or north pole.

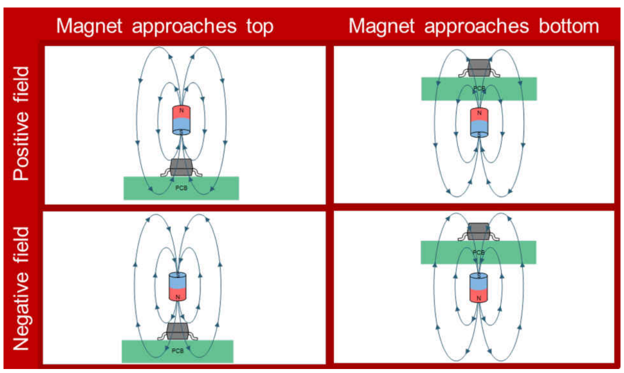

Figure 4. *Example polarity of an SOT-23 out-of-plane sensor.*

For more information on the head-on and slide-by configurations or different Hall-effect sensor outputs, see the TI training video, **Introduction to Head-On Applications**

Effect of device package type on sensed magnetic flux density

The magnetic flux density sensed by a Hall-effect sensor depends on the magnet dimensions, magnet material, and distance from the magnet to the sensing element within the Hall-effect sensor package. The location of the sensing element within the package can affect magnetic flux density readings, especially when the magnet is close to the sensor.

Hall-effect sensor device data sheets usually include the location of the sensing element within the package, as this location can vary for each device and its package types.

Figure 5 shows the location of the sensing element within a device's SOT-23 and extra-small outline no-lead (X2SON) surface-mount package options. If applying a magnet 5 mm above the PCB, the distance from the magnet to the sensing element would be smaller in the SOT-23 package (4.35 mm) than in the X2SON package (4.75 mm), giving the SOT-23 package a larger magnetic flux density magnitude than the X2SON package.

On the other hand, if you applied the magnet 5 mm below the PCB, the magnet-to-sensing element distance would be larger for the SOT-23 package (5.65 mm) than for the X2SON package (5.25 mm), thereby resulting in a smaller magnetic flux density magnitude for the SOT-23 package.

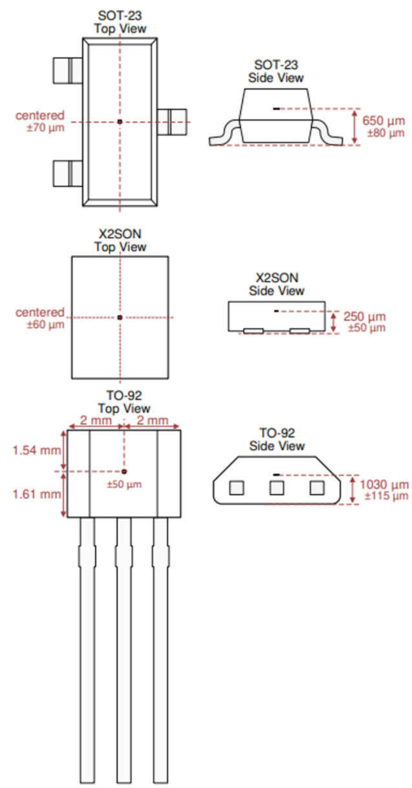

Figure 5. *Example sensing locations in SOT-23 and X2SON packages.*

With through-hole packages like the TO-92 package shown in **Figure 6**, the location of the sensing element also depends on the height of the device installation with respect to the PCB surface. In **Figure 6**(b), the installation is such that the device's sensing location is further from the PCB surface than the sensor installation in **Figure 6**(a). As a result, the two sensor installations would measure different magnetic flux densities.

In addition to the variation in results from different device installation heights, the angle of sensor placement affects readings as well. In the installation shown in **Figure 6**(c), the sensor is bent slightly toward the left compared to the installation in **Figure 6**(b), which would result in different magnetic flux densities. Bending the sensor to the right, forward or backward would also affect sensor readings. Given the variation that can result from the device installation height and angle, through-hole Hall-effect sensors require careful installation.

Using device spacers to control the package height will help eliminate the variability in sensor readings. Another option replaces through-hole out-of-plane linear Hall-effect sensors with surface-mount 1D in-plane sensors or 3D sensors.

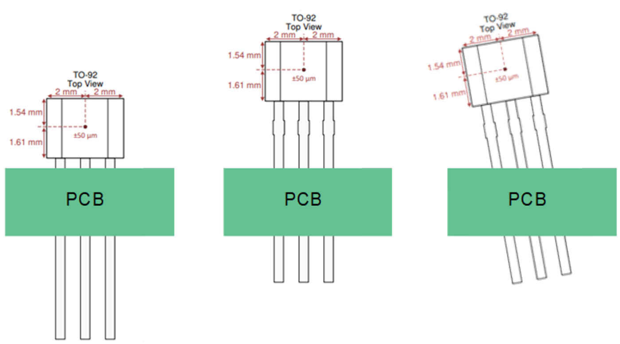

Figure 6. *Variations in though-hole sensor placement: Device installed closer to PCB(a); Device placed further from PCB with no bending (b); Device placed further from the PCB and bent to the left(c).*

Tools for determining the best magnet and sensor distance

To maximize sensing accuracy, select magnet-to-sensor distances and magnet specifications so that the sensed magnetic flux density uses as much of the device's magnetic range as possible, while still ensuring that the maximum magnetic flux density produced in the system is within the sensor's magnetic range. The process of selecting magnet-to-sensor distances and magnet specifications is often an iterative process – modifying parameters until one of the magnetic range options of the linear Hall-effect sensor can properly sense the generated magnetic flux density.

There are multiple options for determining the magnetic flux density versus the distance relationship for iterative adjustment. Calculator tools such as TI's **magnetic sensing proximity tool** can calculate the magnetic flux density for common magnet-to-sensor configurations, including head-on and slide-by configurations.

Conclusion

Contact-based position sensing solutions such as potentiometers have issues with wear and tear that reduce product lifetime and reliability. Using a magnet and a linear Hall-effect sensor instead to create a contactless linear position sensing implementation addresses these reliability issues.

To properly design a contactless Hall-based position sensing system, keep in mind the magnet-to-sensor orientation and device package type in order to build a contactless Hall-based linear movement sensing system.

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