Application Note

Position Sensing in Keyboard Applications

Alicia Rosenberger

ABSTRACT

When discussing keyboard applications, Hall-effect sensors can be used for keypress detection and 3D Hall-effect sensors can be used to detect angle rotation as well as button presses for knobs. This document includes how the added configurability offered by Hall-effect sensors can be used for keyboard applications.

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1 Introduction

As the demand for precision, durability, and customization increases for computer keyboards, the use of Hall-effect sensors becomes more desirable. Among emerging technologies in input devices for keyboards, Hall-effect sensors offers users higher configurability when compared to traditional mechanical switches. Additionally, by using Hall-effect sensors the longevity of these keyboards is able to drastically increase. This document explores the key advantages of Hall-effect sensors in keyboard applications, including the benefits over traditional mechanical switches, how Hall-effect sensors can be used for knobs, and some design considerations for keyboard applications.

2 Benefits of Hall-Effect Sensors

2.1 Hall-Effect Sensors for Keys

For keyboards, a common design used in today's designs are mechanical switches. These mechanical switches work by relying on physical contact between components in order to register keystrokes. The downside to this is that as time goes on, these mechanical components tend to degrade due to the constant friction of these moving parts. Additionally, due to the fixed nature of these switches, they can only provide an on or off response. For these reasons, Hall-effect sensors provide a great alternative to mechanical switches.

Hall-effect sensors in keyboards work by detecting changes in the magnetic field to determine key presses, rather than relying on physical contact like mechanical switches. When unpressed, the magnet rests at an elevated position as shown in Figure 2-1. As the key gets pressed, the magnet moves closer to the sensor increasing the magnetic field seen by the sensor, shown in Figure 2-2. By eliminating this need for physical contact, keys that use Hall-effect sensors are able to last significantly longer than the mechanical switch counterparts.

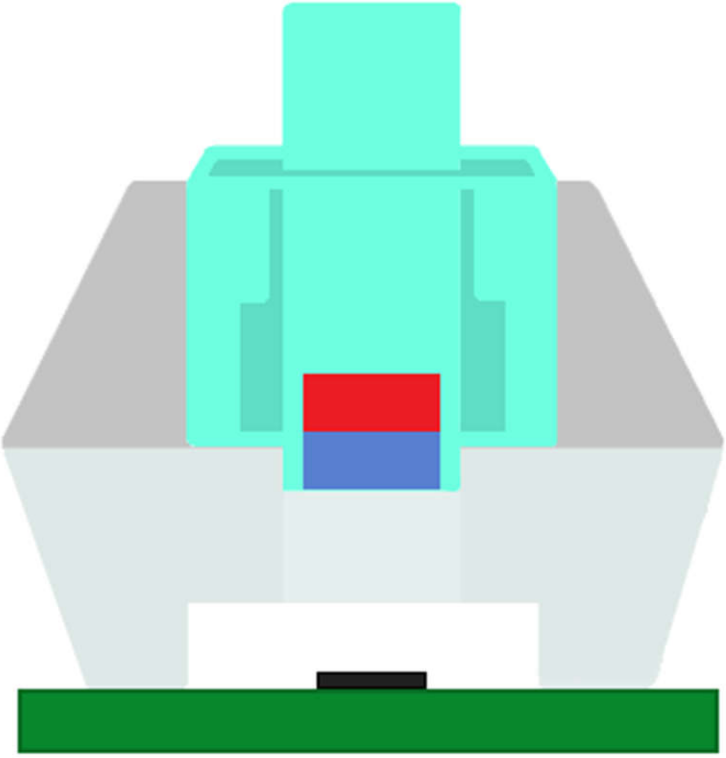

Figure 2-1. Hall-Effect Sensor With Magnetic Key Unpressed

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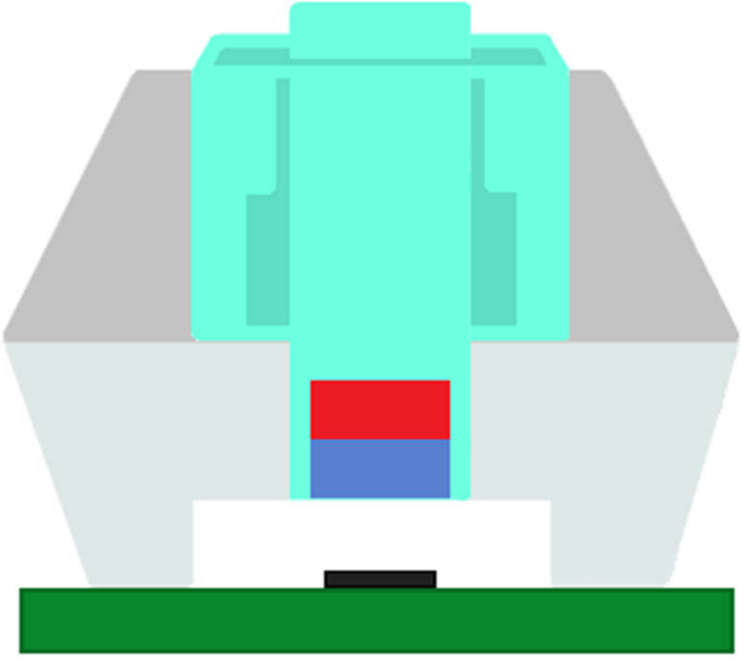

Figure 2-2. Hall-Effect Sensor With Magnetic Key Fully Pressed

With 1D linear sensors like the TMAG5253, a voltage output that is proportional to the key being pressed is provided. Depending on the polarity of the magnet, this voltage output can either increase or decrease as the magnet approaches the sensor. As shown in Figure 2-3, the TMAG5253's voltage output can decrease when the device sees a negative magnetic field and increase when the device sees a positive magnetic field.

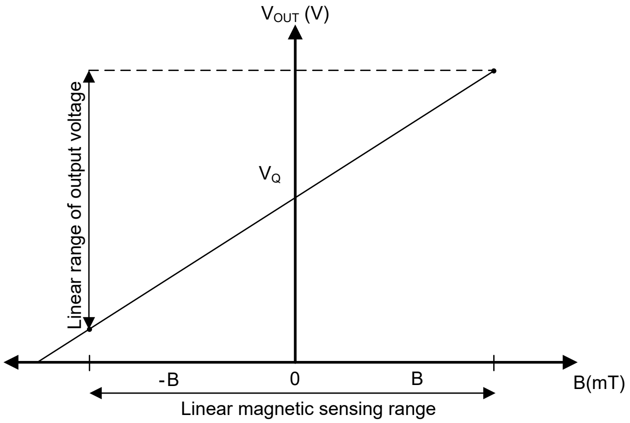

Figure 2-3. TMAG5253 Linearity of the Magnetic Response

Using this linear voltage output, an analog-to-digital converter (ADC) can be used to set the actuation point for the keyboard keys. This enables the ability to provide users with adjustable actuation points for the keyboards. By being able to customize the distance a key needs to be pressed before the key registers a keystroke, users are able to optimize the keyboard for speed, accuracy, and comfort based on preferences. Alternatively, if just an on or off functionality is required, the TMAG5231, which is a high-precision Hall-effect switch, can be used. A switch can be useful as this allows for quicker sampling as this is easier to grab data when only looking for an on or off response.

In addition to allowing for an adjustable actuation point, the TMAG5253 also has an enable pin that can be used to save power and help reduce the number of required ADCs. When designing keyboards, an important consideration is the number of keys on the keyboard. A standard full-sized keyboard typically has 104 keys which can mean that a microcontroller can need 104 ADC pins. With the enable pin offered by the TMAG5253,

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multiple devices can share the same analog output which helps to reduce system cost by reducing the number of required ADCs.

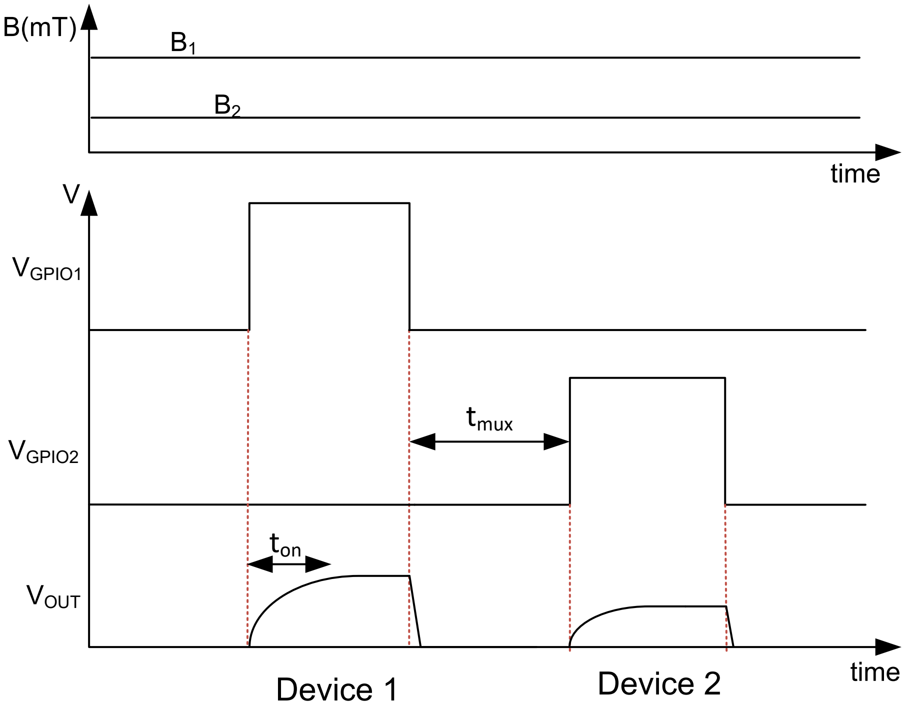

Figure 2-4. Timing Diagram for Multiplexing the Sensor Outputs

Figure 2-4 shows how a microcontroller can be used to multiplex between multiple sensors. When GPIO1 is high and GPIO2 is low, Device 1 becomes enabled and is what drives the output line whereas Device 2 is disabled. Also, when GPIO2 is toggled high and GPIO1 is low, Device 2 is enabled and drives the output line whereas Device 1 is disabled. The TMAG5253 is capable of supporting a capacitive load of 1nF. This means that if the load capacitance on each sensor is 20pF, up to 50 sensors can share the same output.

2.2 3D Hall-Effect Sensors for Knobs

While not yet common on most keyboards, keyboards with knobs are becoming increasingly popular due to the added functionality and customization options that the keyboards offer. Two of the more common implementations of knob designs include mechanical and rotary encoders. However, mechanical knobs are bulky and wear out after long-term use and contact based rotary encoders are disturbed by environmental factors such as dust and water. To help combat these issues, a 3D Hall-effect sensor can be used. 3D Hall-effect sensors are able to monitor the magnetic field from all three axis which can then be used to calculate angle and magnitude. Devices like the TMAG3001 have an integrated angle calculation engine (CORDIC) which can be used to provide angle positioning for a full 360 degrees of rotation. Additionally, the TMAG3001 also provides a magnitude calculation which can also be used to determine whether a button press has occurred.

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3 Keypress Design Considerations

3.1 Simulating Keypress Design

When designing a keyboard switch that uses a Hall-effect sensor, a key consideration is the magnetic sensing range of the sensor. To avoid saturation and be able to sense the full range of the keypress, a sensor that is able encompass the full magnetic range for the key must be chosen. The best way to make sure that the correct device variant is chosen for the application is with a magnetic simulation. Texas Instruments offers a magnetic sense simulator, called *Texas Instruments Magnetic Sense Simulator (TIMSS)*, to help streamline the design process. With this tool, users can specify the type of magnet movement, shown in Figure 3-1, as well as what kind of magnet shape to use which is shown in Figure 3-2.

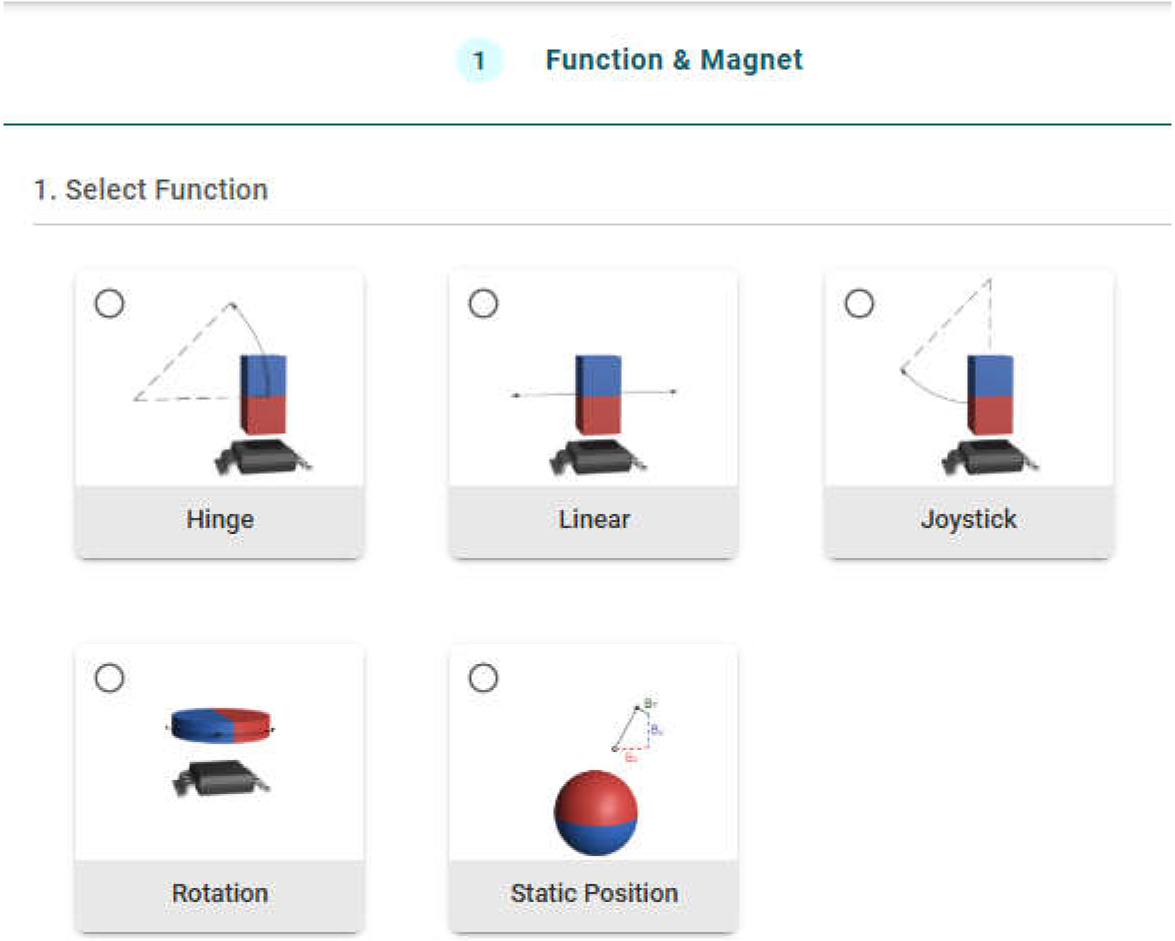

Figure 3-1. Magnet Function Selection

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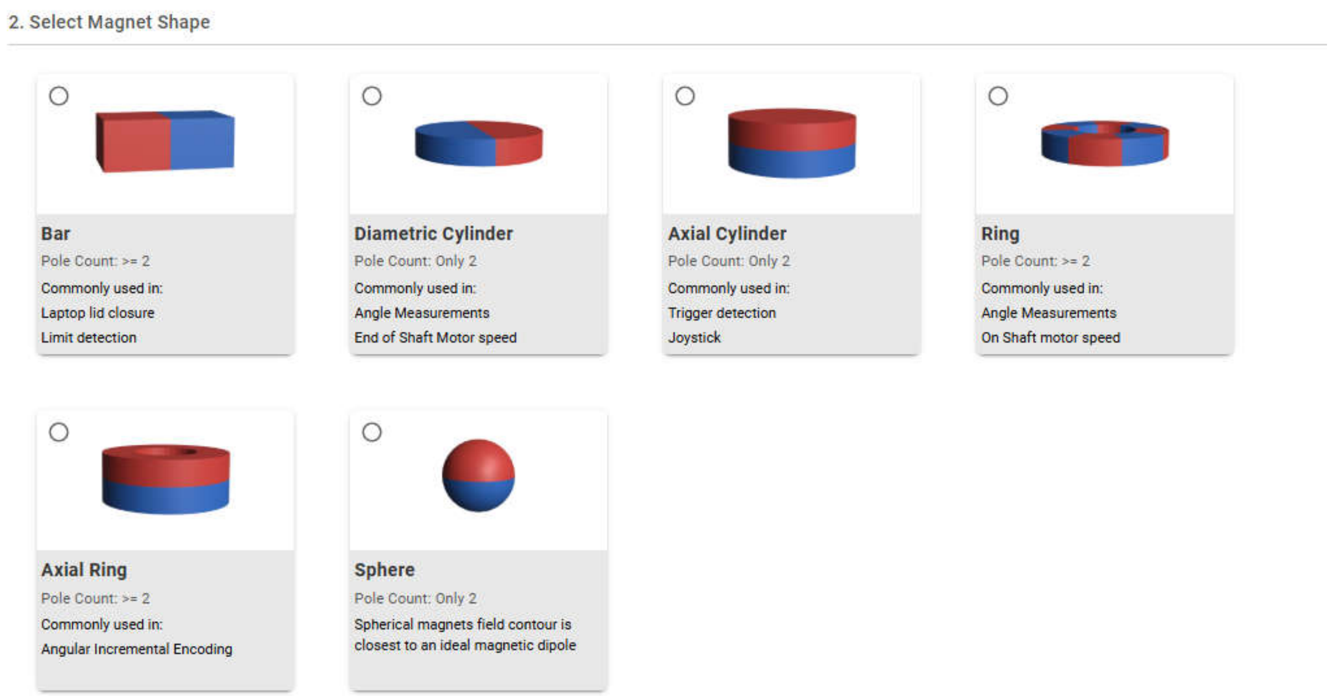

2. Select Magnet Shape

○ **Bar**
Pole Count: >= 2
Commonly used in:
Laptop lid closure
Limit detection

○ **Diametric Cylinder**
Pole Count: Only 2
Commonly used in:
Angle Measurements
End of Shaft Motor speed

○ **Axial Cylinder**
Pole Count: Only 2
Commonly used in:
Trigger detection
Joystick

○ **Ring**
Pole Count: >= 2
Commonly used in:
Angle Measurements
On Shaft motor speed

○ **Axial Ring**
Pole Count: >= 2
Commonly used in:
Angular Incremental Encoding

○ **Sphere**
Pole Count: Only 2
Spherical magnets field contour is closest to an ideal magnetic dipole

Figure 3-2. Magnet Type Selection

For the purpose of simulating a keyboard keypress design in TIMSS, an axial cylinder magnet moving linearly will be selected. From here, users can select which TI Hall-effect sensor to use in the simulation. Figure 3-3 shows an example of a common keyboard magnetic switch that gets used in keyboard applications. For these magnetic switches, the bottom of the magnet sits about 6.1mm away from the top of the sensor when unpressed. The magnet then moves about 4mm down as this is being pressed and sits 2.1mm away from the top of the sensor when fully pressed. The magnet is an axial cylinder magnet with remanence equal to that of a YX18 samarium cobalt magnet and has a diameter of roughly 2.818mm and a height of about 3.387mm. These magnet inputs are shown in Figure 3-4 along with the sensor inputs which are shown in Figure 3-5. The magnet's position, shown in Figure 3-4, is with regard to the magnet's center from the origin (0,0,0). Hence, make sure that the distance from the bottom of the magnet to the top of the sensor is correct, half of the magnet's height, 1.6935mm, needs to be added to the magnet's origin position, which is 6.1mm when unpressed, and final position, which is 2.1mm when fully pressed. Regarding the sensor's position, shown in Figure 3-5, the sensor is orientated such that the bottom of the sensor is facing the magnet with the bottom center of the package being placed at the origin.

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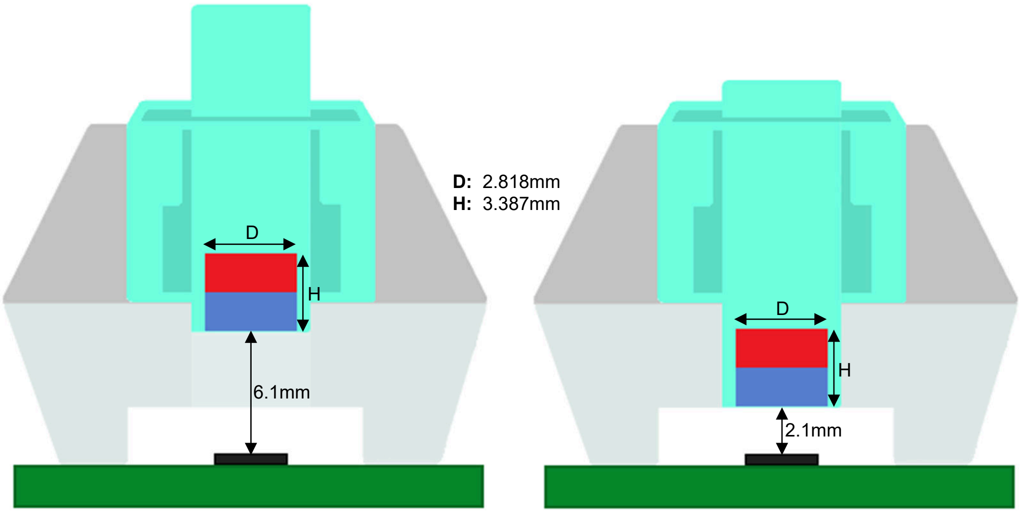
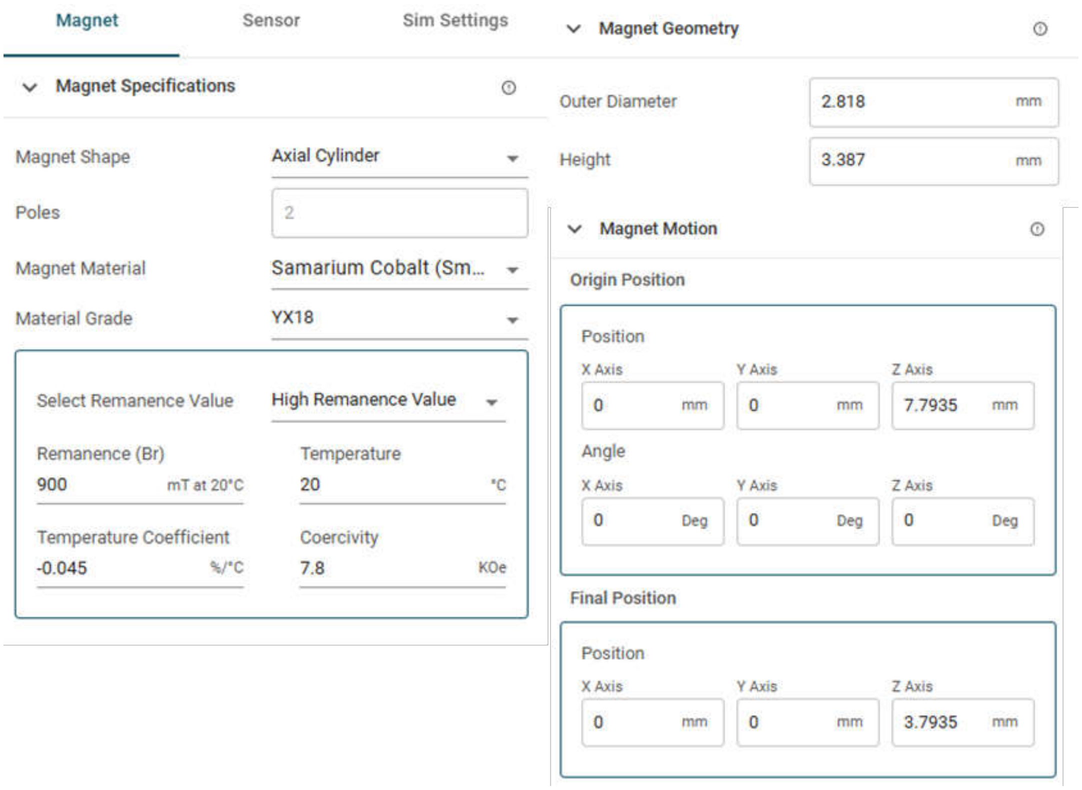


Figure 3-3. Common Keypress Application



Magnet Specifications

Magnet Shape	Axial Cylinder
Poles	2
Magnet Material	Samarium Cobalt (Sm...
Material Grade	YX18
Select Remanence Value	High Remanence Value
Remanence (Br)	900 mT at 20°C
Temperature	20 °C
Temperature Coefficient	-0.045 %/°C
Coercivity	7.8 KOe

Magnet Geometry

Outer Diameter	2.818 mm
Height	3.387 mm

Magnet Motion

Origin Position

	X Axis	Y Axis	Z Axis
Position	0 mm	0 mm	7.7935 mm
Angle	0 Deg	0 Deg	0 Deg

Final Position

	X Axis	Y Axis	Z Axis
Position	0 mm	0 mm	3.7935 mm

Figure 3-4. Keypress Magnet Input

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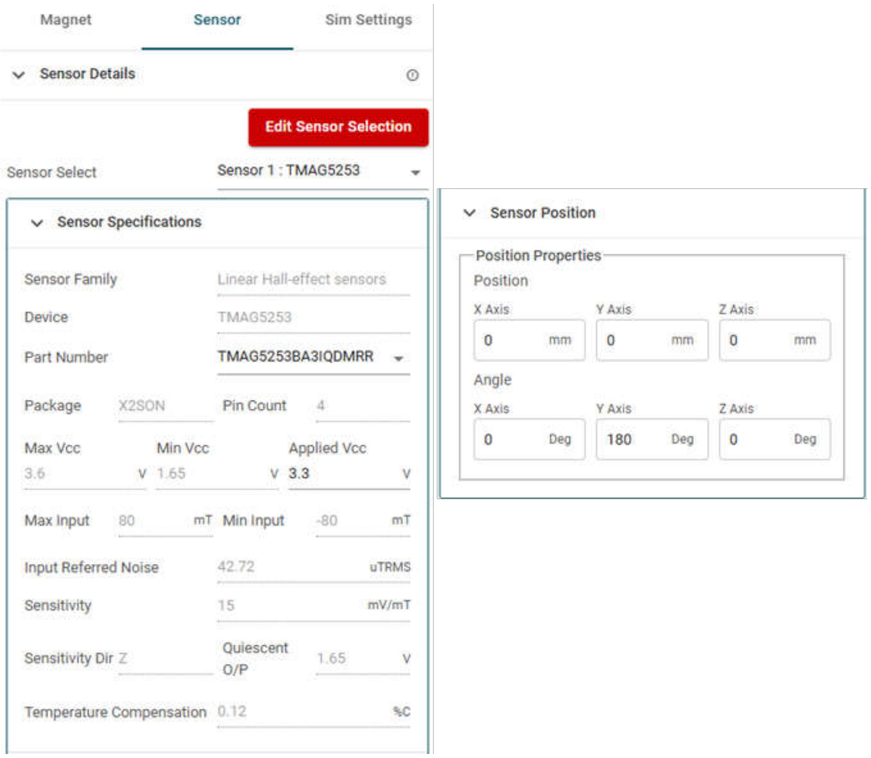


Sensor Select: Sensor 1 : TMAG5253

Sensor Specifications

Sensor Family: Linear Hall-effect sensors

Device: TMAG5253

Part Number: TMAG5253BA3IQDMRR

Package: X2SON

Pin Count: 4

Max Vcc: 3.6 V

Min Vcc: 1.65 V

Applied Vcc: 3.3 V

Max Input: 80 mT

Min Input: -80 mT

Input Referred Noise: 42.72 uTRMS

Sensitivity: 15 mV/mT

Sensitivity Dir: Z

Quiescent O/P: 1.65 V

Temperature Compensation: 0.12 %C

Sensor Position

Position Properties

Position

X Axis: 0 mm

Y Axis: 0 mm

Z Axis: 0 mm

Angle

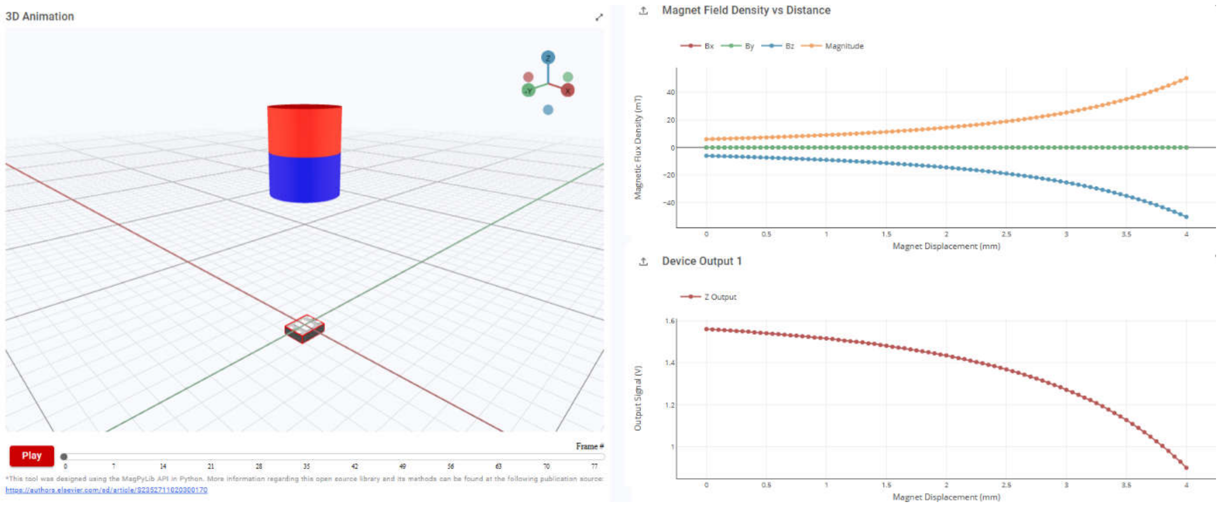
X Axis: 0 Deg

Y Axis: 180 Deg

Z Axis: 0 Deg

Figure 3-5. Keypress Sensor Input

Figure 3-6 shows the results of the TMAG5253BA3 variant which has a magnetic range of ±80mT and a typical sensitivity of 15mV/mT. From Figure 3-6, a steady increase in the magnetic field as this approaches the sensor can be observed.



*This tool was designed using the MagPyLib API in Python. More information regarding this open source library and its methods can be found at the following publication source: https://authors.elsevier.com/sd/article/S2352711020300170

Figure 3-6. TMAG5253BA3 Keypress Results

Also, Figure 3-7 shows the results from the TMAG5253BA4 variant which has an increased magnetic range of ±160mT with a lower sensitivity of 7.5mV/mT. Comparing the results from the Device Output plots of Figure 3-6 and Figure 3-7 together, the TMAG5253BA3 provides greater granularity than the TMAG5253BA4 which allows for more precise movement tracking.

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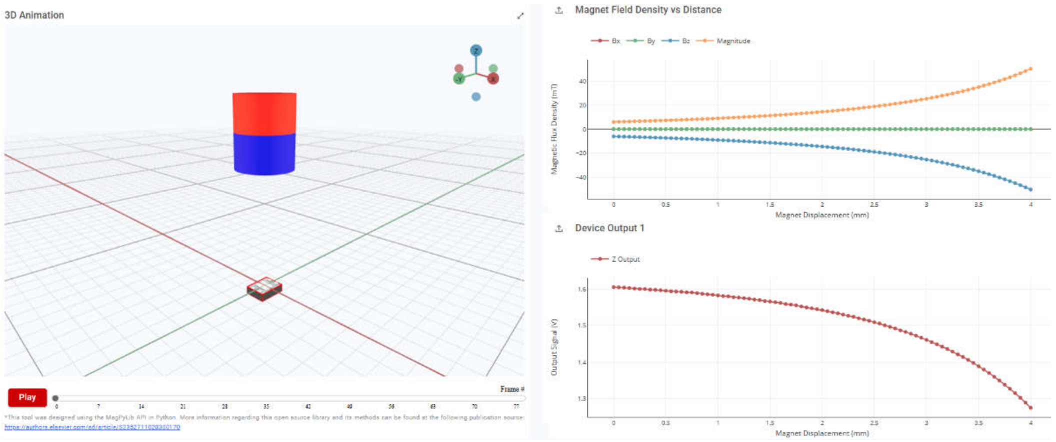
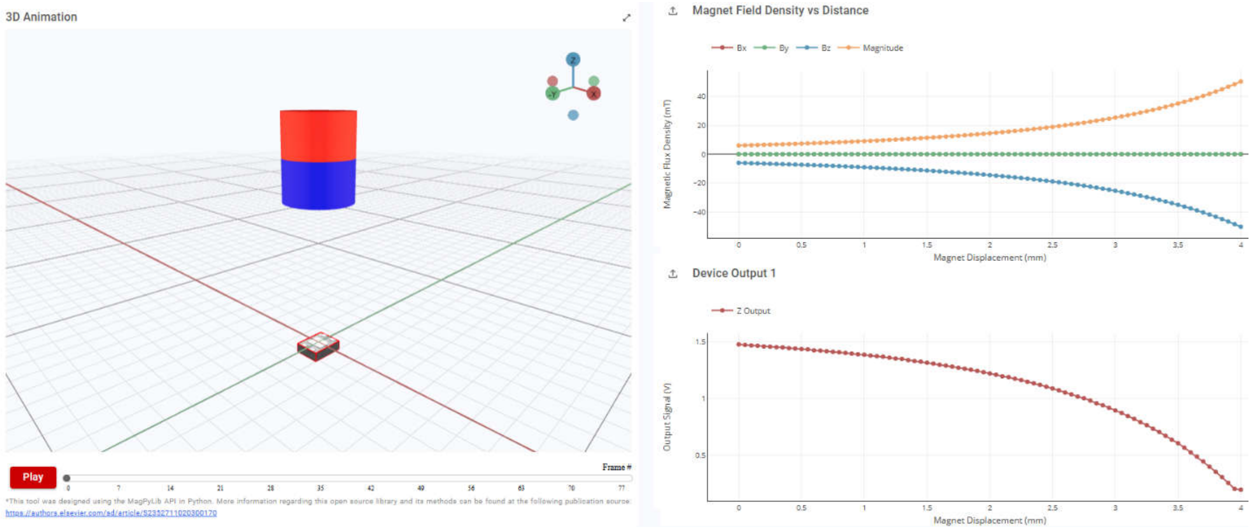


*This tool was designed using the MagPyLib API in Python. More information regarding this open source library and its methods can be found at the following publication source: https://authors.elsevier.com/sd/article/S2352711020300170

Figure 3-7. TMAG5253BA4 Keypress Results

Figure 3-8 shows the results from the TMAG5253BA2 variant which has a smaller magnetic range of ±40mT and an increased sensitivity of 30mV/mT when compared to the TMAG5253BA3 variant. However, from the Device Output 1 plot shown in Figure 3-8, when the magnet gets pretty close to the sensor, saturation occurs. If the TMAG5253BA2 variant were to be selected, there can be a period of time where no useful magnetic data can be observed due to this saturation.



*This tool was designed using the MagPyLib API in Python. More information regarding this open source library and its methods can be found at the following publication source: https://authors.elsevier.com/sd/article/S2352711020300170

Figure 3-8. TMAG5253BA2 Keypress Results

Based on the results observed in Figure 3-6, Figure 3-7, and Figure 3-8, the variant that can allow for the highest sensitivity with no saturation can be the TMAG5253BA3 variant.

3.2 Keypress Bench Results

To verify the results simulated by TIMSS, a physical bench setup was created. For these tests, both a TMAG5253BA3 and a TMAG5253BA2 were populated onto a HALL-ADAPTER-EVM breakout board. This way the results from both variants can be compared to see if the TMAG5253BA3 variant is still the option, as seen in TIMSS. The lab setup consisted of the Samarium Cobalt YX18 magnet found in magnetic keyboard switches being placed in a fixed location. The HALL-ADAPTER-EVM with the TMAG5253BA2 was then placed such that the center of the magnet was lined up with the center of the magnet. To begin, the sensor was placed in the fully pressed state so that the magnet was approximately 2.1mm away from the sensor. The sensor was then moved in increments of 0.05mm until the sensor had moved a total of 4mm away from the starting position, placing the sensor 6.1mm away from the magnet, to mimic the magnetic keyboard switch going from pressed to unpressed. Figure 3-9 shows the data results collected from the sensor during this time.

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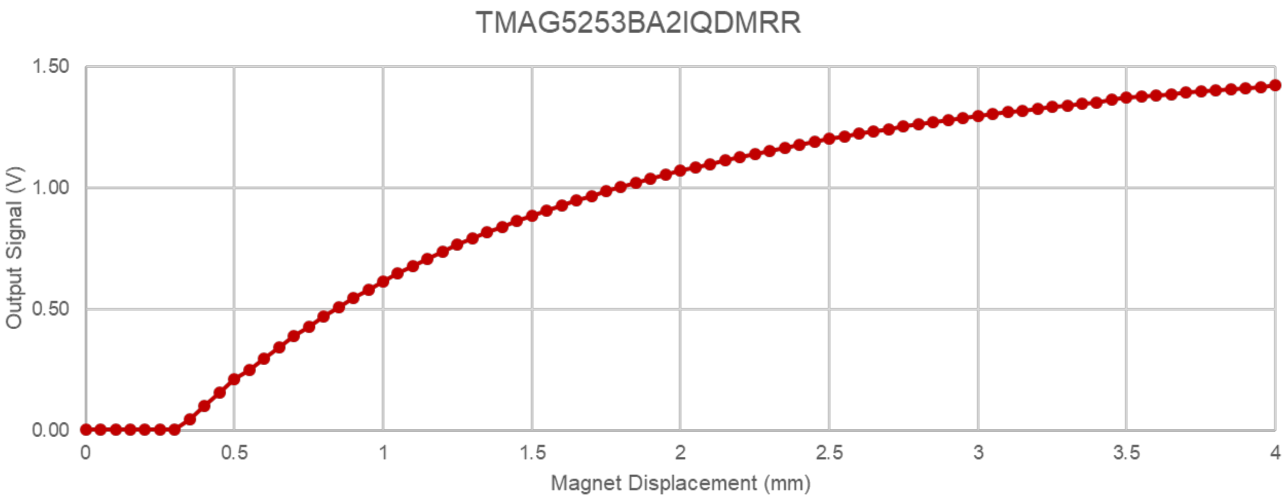

Figure 3-9. TMAG5253BA2 Bench Results

Similar to the results observed from the TIMSS simulation for the TMAG5253BA2 variant, the sensing element becomes saturated when the magnet is reaching the fully pressed state which means that no meaningful data can be extracted at this point. Figure 3-10 shows the results measured from the TMAG5253BA3. From the results shown in Figure 3-10, not only is there no saturation, but at each increment of 0.05mm, the sensor was able to observe incremental changes as the sensor was moved further away from the magnet.

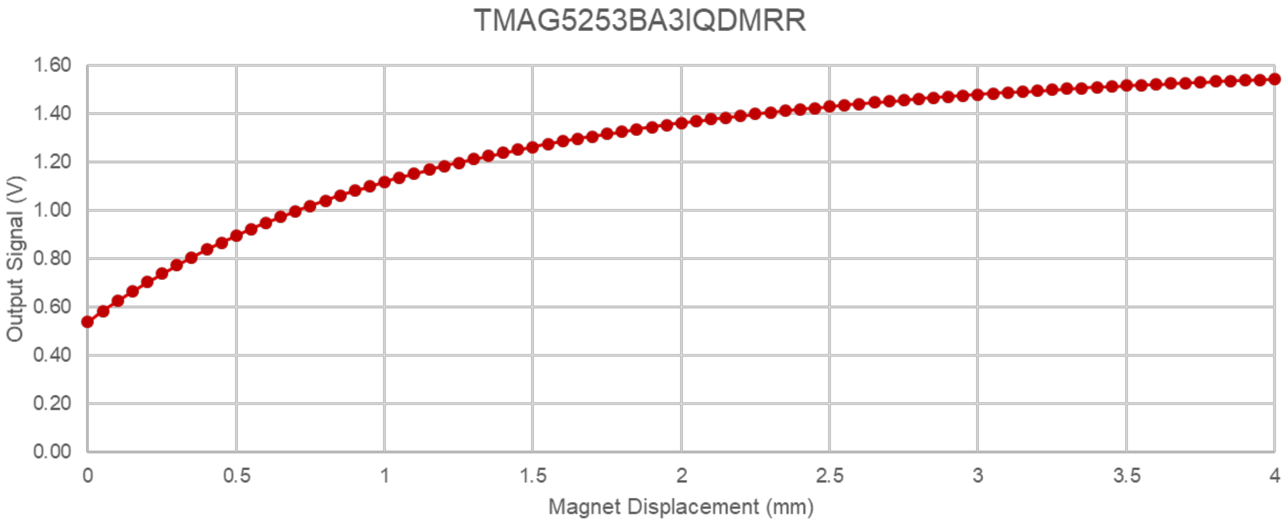

Figure 3-10. TMAG5253BA3 Bench Results

Something to keep in mind with the results observed from the above bench testing, as with all testing, is human error. While the bench setup was designed to be as accurate as possible, with a Newport linear motion controller being used to control the motion of the sensor, the sensor is not precisely aligned with the center of the magnet. Additionally, this is possible that the original position from the sensor to the magnet was not exactly 2.1mm, which can account for the slight differences seen in the bench test results when compared to the results observed from the simulation.

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4 Keyboard Design Example

Figure 4-1 shows an example keyboard design which has four keys designed to act as arrow keys as well as a knob. This design example uses four TMAG5253 devices for the arrow keys and a TMAG3001 for the knob. Additionally, an RGB LED was included for each of the arrow keys so that each key can light up with some color when unpressed and can turn white when pressed. The color of the LED is controlled by the knob, so as the knob gets rotated, the LEDs can change color. For more information on how to use 3D Hall-effect sensors for the knob or how to use 3D Hall-effect sensors for angle measurement, please see the *3D Hall-Effect Sensor for Knobs in Appliances* application note or the *Angle Measurement with Multi-Axis Hall-Effect Sensors* application note, respectively.

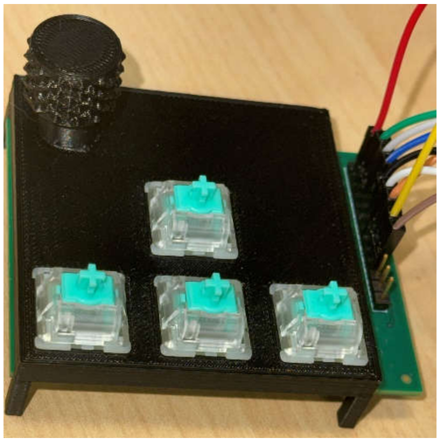

Figure 4-1. Keyboard Design Example

The schematic for the above keyboard design is shown in Figure 4-2. This keyboard example works by using a multiplexer to switch between the four ADC outputs of each of the TMAG5253s. Using an MCU to control the inputs (TMAG_EN0 and TMAG_EN1) of the multiplexer, the MCU is able to select which of the four arrow key outputs to listen to.

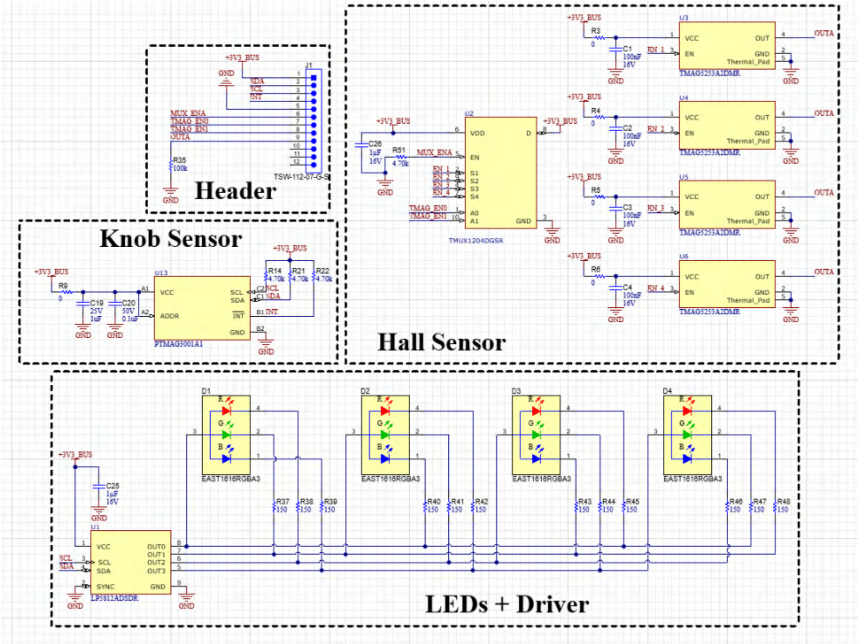

Figure 4-2. Keyboard Design Example Schematics

Table 4-1 shows the truth table for the keyboard arrow logic

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Table 4-1. Keyboard Truth Table

TMAG_EN0	TMAG_EN1	Selected Key
0	0	Left Arrow
0	1	Down Arrow
1	0	Right Arrow
1	1	Up Arrow

With the keyboard design example shown in Figure 3-10, a Texas Instruments launchpad, such as the MSP-EXP432E401Y, can be used to connect to the headers shown in Figure 3-9 to power up and interact with the board.

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5 Summary

In conclusion, Hall-effect sensors offer many benefits when it comes to keyboard applications. By allowing for contactless operation, which increases the keyboard's durability, and customizable actuation points, the performance and longevity benefits makes Hall-effect sensors an excellent fit for professional, gaming, and industrial keyboard applications. As user demand continues to grow for responsive, reliable, and customizable input devices, Hall-effect technology is geared to play a key role in high-performance keyboards.

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6 References

1. Texas Instruments, *3D Hall-Effect Sensor for Knobs in Appliances*, application note.
2. Texas Instruments, *Angle Measurement with Multi-Axis Hall-Effect Sensors*, application note.
3. Texas Instruments, *TMAG5253 Low-Power Linear Hall Effect Sensor With EN Pin in Ultra-Small Package*, data sheet.
4. Texas Instruments, *TMAG3001 Low-Power 3D Linear and Angle Hall-Effect Sensor With I2C Interface and Wake Up Detection in WCSP*, data sheet.
5. Texas Instruments, *TMAG3001 evaluation module for three-axis linear Hall-effect sensor with I²C and programmable switch*, user's guide.

Table 6-1. Table . Device Recommendation

Device	Characteristics	Design Considerations
TMAG5253	Low-power linear Hall-effect sensor with enable pin in X2SON package	Measures magnetic field strength on Z-axis and reports data via ADC output. Enable pin allows for multiple devices to share the same ADC pin and disable devices that are not being used to reduce system current consumption.
DRV5055	Linear Hall-effect sensor in SOT23 or TO-92 package	Measures magnetic field strength on Z-axis and reports data via ADC output.
TMAG5231	Low-power Hall-effect switch in SOT23 or X2SON package	Measures magnetic field strength on Z-axis and pulls high/low (depending on the variant) when BOP is crossed. Useful when only an on/off response is required.
TMAG3001	Low-power 3D linear and angle Hall-effect sensor with I2C interface and wake up detection in YBG package.	Measures magnetic field strength on X, Y, and Z axes and has an internal CORDIC to calculate angle. Offers a wakeup and sleep mode to allow for sampling while reducing average current consumption.

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