Application Brief

Hall-Effect Sensors for Steering Column Control

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Introduction

As the automotive industry continues to make advancements in vehicle electrification, automation, and connectivity, traditionally mechanical vehicle control systems are now being replaced with electronic implementations. These *drive-by-wire* systems can allow for more precise operation, simpler maintenance, and enhanced safety features due to digitally-controlled manipulation of vehicle controls. Electronic control modules also provide more flexibility for placement within the vehicle and in the design of the system itself.

For instance, traditional gear shifters rely on a mechanical connection to the transmission gearbox and must be located in close proximity to the transmission of the vehicle. Shift-by-wire systems capture input from the driver to remotely shift gears using actuators. As a result, the shifter can be replaced by a dial, push-buttons, or a steering column module similar in style to a traditional turn indicator or wiper control.

Magnetic position sensors offer an increasingly popular approach to eliminate mechanical contact points, reduce overall design size, provide diagnostics, and other integrated features that improve safety.

Steering column modules that include the controls for the turn signals, wipers, headlights, and column gear shifters benefit from the mechanical simplification and system diagnostics that drive-by-wire modules provide.

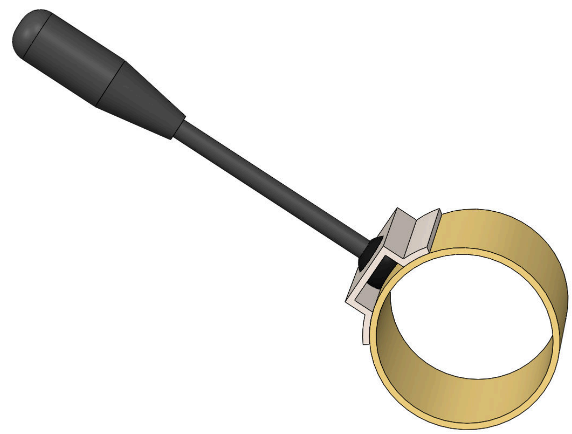

Figure 1. Steering Column Control Module

Eliminating Mechanical Contact

Historically, steering column controls such as levers, knobs, and joysticks have been implemented using electromechanical components. In most cases, these are monitored using either a small pressure switch or a potentiometer.

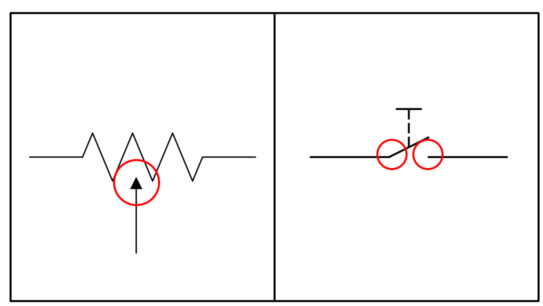

Figure 2. Common Mechanical Failure Points

However, wear and tear is a significant drawback associated with both of these mechanical components. Over time, electrical contacts in the switch strike plate or the wiper within the potentiometer are prone to degrade due to mechanical wear, oxidation, or by gathering other surface contaminants such as dust or grime. As the quality of the mechanical contact is reduced, the reliability of the control becomes a significant concern, particularly in automotive controls. Consider a faulty headlamp, wiper, or turn indicator control. Failure of any of these functions can present a significant user-safety risk.

Magnetic sensing eliminates a mechanical fail point in the system. Magnetic fields are able to permeate non-ferromagnetic materials which allows the magnet and sensor to move freely and are immune to contaminants.

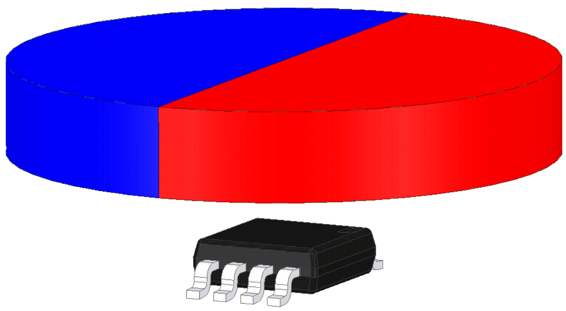

Figure 3. Contact-Free Position Measurements

For example, the TMAG5170-Q1 (shown in Contact-Free Position Measurements) is able to track the angular position of a rotating diametric magnet above the sensor without making any physical contact. This type of configuration is useful to replace various knobs and dials within a control system.

Minimizing Design Size

Another significant concern in automotive controls is the overall design size required to monitor a large array of mechanical switches. For each switch monitored by a general purpose input/output (GPIO), there can be a significant amount of peripheral circuitry for robust position tracking. In advanced systems where upwards of 100 or more switches are available, this results in a bulky PCB design.

Consider a turn indicator control which operates the headlights shown in Multifunction Position Detection.

The lever must have the ability to trigger at least nine discrete positions to operate the high beams, flash-to-pass, and turn indicators. Additionally, a knob is commonly added to the end of the shaft to select between the off, parking lights, and standard headlamp settings.

All of these positions can be implemented with several resistive contact plates and pressure switches. Each of these components requires biasing circuitry and GPIO controls. In fixtures where the available space for electronic components is limited, use magnetic position sensors that can detect multiple settings.

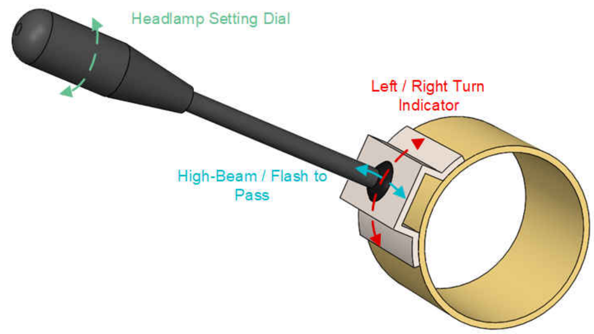

Figure 4. Multifunction Position Detection

In this example, all functions can be implemented using only two TMAG5170-Q1 sensors. This device is a 3D linear Hall-effect sensor which can be programmed to detect any of the B-field vector components produced by a nearby permanent magnet. For instance, an axial cylinder magnet can be placed within the assembly with the sensor aligned to the neutral position. Here the field is entirely directed in the Z-direction of the sensor. As the indicator shaft is moved to the various positions, the X and Y field components can be used to calculate the direction of motion and the distance traveled.

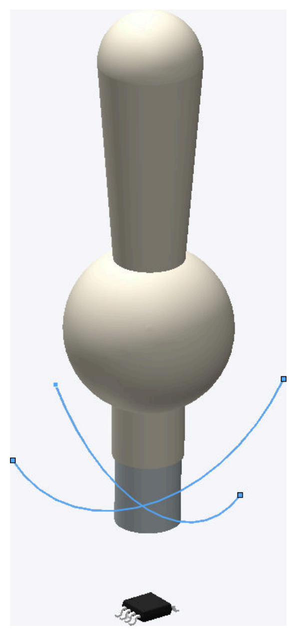

Figure 5. Joystick Motion

The second sensor is conveniently placed at the end of the shaft and placed on-axis with a rotating magnet in the headlight dial control as shown in Multifunction Position Detection. The axis of rotation of the diametric cylinder magnet is placed directly above the sensor. Each headlight setting is easily detected based on the angle of the X and Y components of the magnetic field using the magnet orientation previously shown in Contact-Free Position Measurements.

TMAG5170-Q1 communicates via serial-peripheral interface (SPI), and the two sensor outputs must be periodically read by the host microcontroller. The sensors can share the same SPI bus, but require separate chip-select inputs. With a single controller reading the outputs of both sensors, the total design size can be quite small.

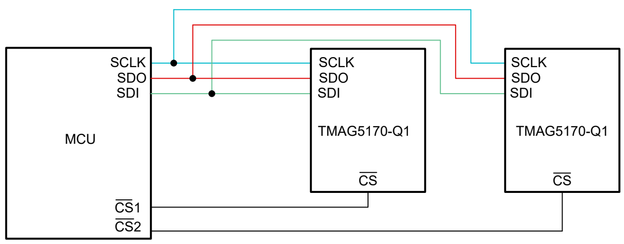

Figure 6. Simplified Block Diagram

Diagnostics and Functional Safety

Safety is another critical concern when designing automotive controls. Compared to discrete mechanical implementations, magnetic position sensors can reduce operational risk and improve reliability of the system due to built-in safety mechanisms, redundancy features, and functional safety capabilities. These sensors not only monitor system performance for abnormal behavior to prevent system failures, but also help reduce possible hazards caused by the malfunctioning behavior of a module with a damaged device or faulty wiring.

TMAG5170-Q1 includes multiple diagnostic features to detect and report both system- and device-level failures. The device monitors several parameters including temperature, magnetic assembly integrity, power supply integrity, and communication integrity. The device also performs self-diagnostics to monitor the accuracy and performance of the sensor itself. In contrast, mechanical components do not provide any system- or device-level diagnostic checks. Additional circuitry is needed to detect component-level failures or monitor performance degradation of discrete designs such as pressure switches and potentiometers. This supplemental circuitry can add cost and complexity to the overall system.

In instances where safety is of greater concern, a redundant sensor is often required to achieve the highest safety ratings. For applications where this is a concern, TMAG5170D-Q1 must be considered. This device boasts two independently operated die in a single package. The sensors are stacked vertically with the sensing elements closely aligned. This format reduces system level mismatch errors that arise as a result of placing the die side-by-side or from using two singulated devices.

Wake and Sleep for Power Savings

An additional requirement for many user controls within the steering column is that certain features must function when the engine is not running. In this case, the system operates from battery power only and requires minimal current consumption. An additional feature of TMAG5170-Q1 is that this device has an integrated wake and sleep feature. In this mode, the sensor enters a low-power sleep mode and periodically enables the Hall-effect sensor to take a reading.

Increasing the delay between conversions is another way to greatly reduce the current requirement for the system. The wake and sleep mode of TMAG5170-Q1 operates with intervals of 1, 5, 10, 15, 20, 30, 100, 500, and 1000 ms. For a dual-channel configuration, the expected typical current consumption for a single TMAG5170-Q1 sensor is shown in Table 1.

Table 1. TMAG5170 Wake and Sleep Current Consumption

Wake and Sleep Interval (ms)	Average Current Consumption (µA)
1	297.19
5	74.65
10	39.04
15	26.68
20	20.39
30	14.05
50	8.92
100	5.05
500	1.93
1000	1.54

Conclusion

Steering column control modules which incorporate several functions along a single control arm are designed to adopt 3D Hall-effect sensors which eliminate unnecessary mechanical contact points that tend to wear out over time and require additional circuitry to enable diagnostic functions. Integrated functions and diagnostics in devices such as TMAG5173-Q1, TMAG5170-Q1, and TMAG5273 improve the readability of the drive-by-wire modules while maintaining a minimal size.

For more information, see the following device recommendations and supporting documentation.

Table 2. Alternative Device Recommendation

Device	Characteristics	Design Considerations
TMAG5170 (TMAG5170-Q1)	Commercial (Automotive) grade linear 3D Hall-effect position sensor with SPI available in 8-pin VSSOP package and hardware integrity up to ASIL B.	Communicates over four-wire SPI to provide complete magnetic vector sensitivity. This device is able to track a wide range of magnet positions, though careful planning is still required to make sure all input conditions map to a unique position.
TMAG5170D-Q1	Automotive grade linear 3D Hall-effect position sensor in a dual die form factor. Each die communicates independently over SPI and is available in a 16 pin TSSOP package.	The stacked die aligns the sensing elements of each device closely within a single package. Supplies and SPI pins are not shared between sensors and must be routed separately.
TMAG5273	Commercial grade Linear 3D Hall-effect position sensor with I2C interface available in 6-pin SOT-23 package.	Similar to the TMAG5170, but communicates over a two-wire I2C interface with wider sensitivity tolerance specifications.
TMAG5173-Q1	Automotive grade linear 3D Hall-effect position sensor with I2C interface available in 6-pin SOT-23 package and hardware integrity up to ASIL B.	Communicates over two-wire I2C interface with comparable performance to TMAG5170.

Table 3. Related Technical Resources

Name	Description
Absolute Angle Measurements for Rotational Motion Using Hall-Effect Sensors	A short discussion about how 3D sensors are used to measure angle position from a rotating magnet.
Measuring 3D Motion With Absolute Position Sensors	An introduction to capturing motion of a pivoting magnet common in joystick applications using linear Hall-effect sensors.
Designing Joysticks with Hall-effect Sensors	A video overview and demonstration discussing joystick design.
Angle Measurement With Multi-Axis Linear Hall-Effect Sensors	A thorough discussion of angle measurements using 3D Hall-effect sensors and an example design with test data of a push-button knob.
TMAG5170UEVM	GUI and attachments incorporate angle measurement using a precise three-dimensional, linear Hall-effect sensor.
TMAG5173EVM	GUI and attachments incorporate joystick function using a three-dimensional linear Hall-effect sensor.
TMAG5170DEVM	GUI and attachments incorporate angle measurement using dual three dimensional Hall-effect sensors.
TI Precision Labs - Magnetic Sensors	A helpful video series describing the Hall effect and how to use the Hall effect in various applications. A video on CORDIC calculations is included.