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CONVERSION FROM MECHANICAL TO HALL-EFFECT AND TMR SWITCHES

Abstract

Hall-effect and XtremeSense tunnel magnetoresistance (TMR) switch integrated circuits (ICs) offer a variety of benefits when used as replacements for mechanical switches. Over time, mechanical switches with moving parts tend to wear out, resulting in degradation of switching consistency and requiring premature repairs or replacements. Hall-effect and TMR switch IC technology offers a solid-state sensing solution when seeking replacements for an application's mechanical components, but at first glance may appear difficult to simply drop-in.

This application note discusses the technical considerations necessary to aid with the replacement of an on/off mechanical switch with a Hall-effect or TMR switch. Included are an overview of the basic process for converting existing systems and discussion about the numerous advantages gained when upgrading to a contactless Hall-effect or TMR switch.

Solid State (Hall/TMR), Reed, and Micro-Switches: Advantages and Disadvantages

Table 1 offers an overview of the three switch solutions discussed in this document. Both a reed switch and a Hall-effect (or TMR) switch employ a contactless sensing architecture that actuates an output signal in response to a magnetic field. The third commonplace technology is the micro-switch, which is operated by physical contact with the switch actuator and does not typically require the use of a magnetic field. Out of the three switch technologies discussed here, a micro-switch is perhaps the most susceptible to mechanical damage because it contains multiple components subject to contact wear. This includes the internal contact terminals and the external actuator surface. Long-life applications will be at a disadvantage if a micro-switch is employed.

While reed switches offer a reduced quantity of wear points

Table 1. Switch Technology Comparison

Parameter	Hall-Effect and TMR [1]	Reed	Micro-Switch
Accuracy Over Time	Best	Good	Good
Reliability/Wear	Best	Better	Good
Temperature Stability/Compensation	Best	Good	Good
Magnetic Field Required?	Yes	Yes	No
Actuation	Contactless	Contactless	Contact
Operation	Solid State	Mechanical	Mechanical
Current Consumption, Standby	110 nA	0 µA	0 µA
Current Throughput	3 mA	> 1 A	> 1 A
Fault Detection [2]	Best	Low	Low
Susceptibility to Damage from Overcurrent Events	Low	High	High

[1] Reference TMR switch is the CT8132. Refer to the device datasheet for specific recommendations and guidelines.
[2] Fault detection-capable switches available; contact Allegro for details.

over micro-switches, Hall-effect and TMR switches are not subject to any wear and offer a predictable and reliable performance capability over the lifetime of an application. Allegro's magnetic Hall-effect and XtremeSense TMR switches offer extremely consistent magnetic switching performance and carry the qualifications required for a dependable service life.

Finally, mechanical switches have led the market in power consumption and resulting energy efficiency. Unlike reed and micro-switches, solid-state Hall and TMR switches do consume power across all modes of operation. However, the latest innovative micropower Hall and nanopower TMR switches, such as Allegro's APS11753 (Hall) and CT8132 (TMR), have broken this barrier and can consume well less than 1 μW (110 nA at 1.8 V) during continuous operation, allowing them to fulfill new energy requirements.

Hall-Effect Switch

Allegro's Hall-effect switch ICs include a fully temperature-compensated signal path. The Hall-effect switch, in its most basic form, consists of a Hall element, amplifier, signal filters, threshold comparator(s), and a transistor output. Traditionally, the devices employ an open-drain transistor for the output which connects the output pin to ground once actuated by either the detection or absence of a magnetic field. However, to reduce power consumption, the APS11753 micropower Hall switch employs a push-pull output that eliminates the need for the pull-up resistor used in an open-drain output configuration. Allegro's APS11753 micropower Hall-effect switch operates on single supply voltages as low 2.2 V, consuming less than 5 μA of continuous supply current. The APS11753 block diagram is shown in Figure 1 for reference.

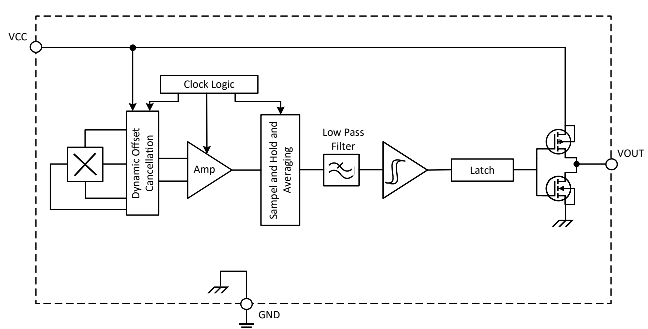

Figure 1. APS11753 micropower Hall switch block diagram

When considering the replacement of a two-terminal mechanical switch with a three-terminal Hall-effect sensor, Allegro has a circuit configuration recommendation; this simple circuit is discussed in the Conversion section of this document. For the purpose of this document's example application, the three-pin Allegro APS11700 micropower Hall-effect switch is used for its large supply headroom (24 V) and high output drive capability (40 mA) that are better suited for this type of circuit. For further information on the Allegro APS11753 and APS11700, refer to the product datasheets found on www.allegromicro.com.

TMR Switch

TMR magnetic switches are very similar to Hall-effect switches but use a tunneling magnetoresistance transducer instead of a Hall plate to detect the external magnetic field. Allegro's XtremeSense TMR sensors, like the CT8132, introduce many new capabilities to include faster response times and better SNR (signal to noise) ratios. The higher signal level from the TMR transducer relaxes the noise requirements for the signal conditioning circuitry allowing for these switch designs to achieve much lower power levels (sub μW).

Also different from Hall switches that typically sense in the Z-axis, TMR devices sense magnetic fields in the X- or Y-axis, parallel to the face of the IC, making them an easy drop-in alternative for magnetic reed switches.

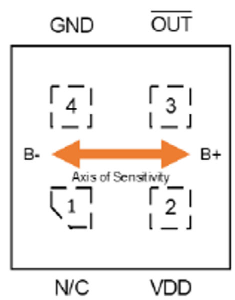

Figure 2: CT8132 TMR switch axis of sensitivity

Reed Switch

Reed switches offer high isolation and operate in an inductive manner similar to that of a Hall-effect sensor. Instead of using a Hall-effect sensing element (i.e., Hall-effect plate) to generate a proportional internal voltage and actuate the output, a reed switch actuates the connection or disconnection between its internal contacts through induction as a direct result of the applied magnetic field.

The ferrous reed blades within a reed switch are considered components of the magnetic circuit, and their contact surfaces are the primary locations which suffer from wear and tear, thus affecting the magnetic circuit. The lifetime expectancy of a reed switch corresponds heavily with the loading conditions being used, as the contact surfaces can become high resistance or disintegrate.

Micro-Switch

Micro-switches rely on direct physical contact with the object (i.e., target) being sensed. These types of switches are similar to reed switches in that their operation is mechanical and results in the connection or disconnection between internal metal contact surfaces. For the reasons discussed above, metal contacts are disadvantageous for some applications.

Unlike a magnetically actuated sensor such as a Hall-effect switch or a reed switch, a micro-switch is actuated directly or indirectly by making contact with the object being detected. Hall-effect switches and reed switches are contactless, and by means of an applied magnetic field, they can detect movement through a non-metallic obstruction.

Power Consumption

Power consumption is a critical parameter for those considering changing from a passive component such as a reed switch to an active component like a Hall-effect or TMR switch. Traditional Hall-effect sensors consume around 20 mW of energy in a 3.3 V system. However, recent developments such as the APS11753 family of micropower Hall-effect switches enable much lower power consumption, as low as 13 µW in a 3.3 V system. Allegro's XtremeSense TMR switches like the CT8132 push low-power performance even further, consuming just 200 nW on supplies as low as 1.8 V. See Figure 3 and Figure 4 for characterization plots.

Temperature Stability

Systems employing a permanent magnet should expect to have a change in the magnetic field strength when exposed to high and low temperatures. In applications such as household appliances, this effect is nominal. However, where large temperature fluctuations are expected and/or where optimized switching performance is required, a Hall-effect sensor is a superior choice over its mechanical counterparts.

Allegro's Hall-effect switches incorporate several key features for stable performance across temperature. First, an averaging technique named chopper stabilization enables the cancellation of environmentally induced stresses such as thermal expansion.

The second feature is the Hall-effect switch sensitivity temperature coefficient. When sensing some magnetic materials, such as samarium-cobalt, a drift in magnetic field strength over temperature will occur. The switch usually needs to become more sensitive as the magnet strength decreases (higher temperatures) and less sensitive when the magnet strength increases (lower temperatures). As a result of this feature, the on and off thresholds of the switch can be dynamically matched to the expected magnetic field drift, or if no drift is expected, the thresholds can remain at a fixed level over temperature. This behavior is depicted in Figure 5.

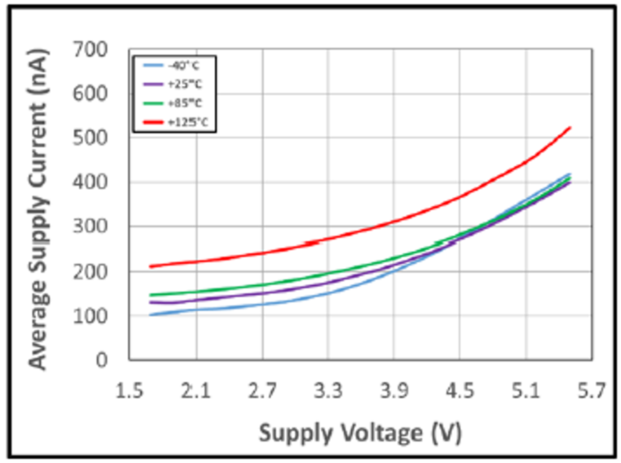

Figure 3: Power consumption for the CT8132EK

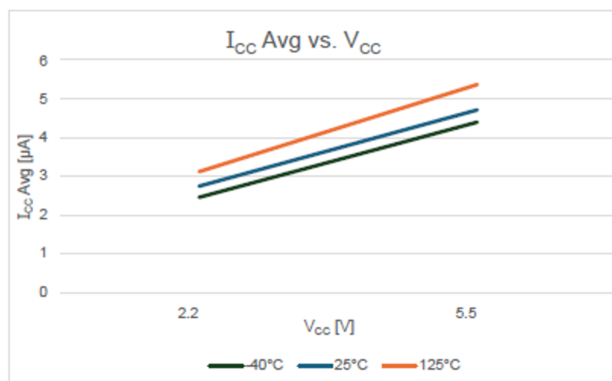

Figure 4. Power consumption for the APS11753

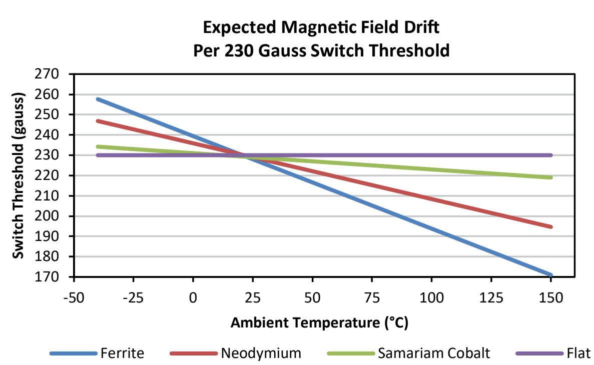

Figure 5. Expected Magnetic Field Drift and Threshold Tracking

Conversion

Converting from a reed or a micro-switch to a Hall-effect or TMR switch can be completed more easily after following the techniques used in this application guide. The main obstacles encountered when retrofitting a Hall-effect (or TMR) switch into an existing mechanical switch application are listed below:

- The implementation of a permanent magnet (existing micro-switch applications)
- The backwards compatibility of the voltage signals for the on and off switch states

Allegro's recommended permanent magnet suppliers can be found in the Insights and Innovations section of the Allegro website, www.allegromicro.com/Insights-and-Innovations. The type of magnet chosen should depend on system requirements, but typically a small axially magnetized cylinder or block magnet, as pictured in Figure 6, can be used.

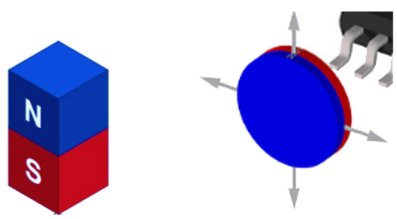

Figure 6. Axially Magnetized Magnets

The remainder of this document focuses on configuring the Hall-effect or TMR switch electrical circuit so that its output signals are backwards-compatible with existing software or signal voltage level requirements.

Example: Mechanical Switch Replacement

In this example, a micro-switch in a refrigerator door application is being replaced. Here, a magnet is not currently used. For detailed discussion on magnet attributes, design guidelines, and selection, consult the Hall-Effect IC Applications Guide, AN27701, found on the Allegro website.

Before the conversion, the system operates as follows: the micro-switch is physically released and depressed when the refrigerator door is opened and closed. This in turn controls the illumination within the refrigerator's interior cooling area.

Replacing the micro-switch with a Hall-effect switch will require the same electrical signals to be generated for indicating the "closed" and "opened" door positions. The Hall-effect switch in this example has three terminals: VCC, VOUT, and GND. These three terminals can be reduced into the two wires needed for backwards-compatibility with the micro-switch circuit. These wires are depicted as node A and node B in Figure 7.

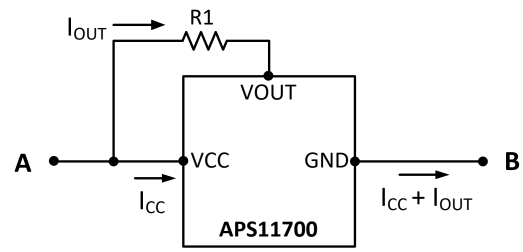

Figure 7. Two-Wire Circuit for APS11700

In this example, the Hall-effect switch VOUT pin leakage current (< 1 µA) is nominal and not considered.

CIRCUIT AND OPERATION: A two-wire circuit with a three-pin device such as the APS11700 can be achieved by using a correctly sized pull-up resistor, R1, connected between the open-drain VOUT pin and the VCC pin, as shown in Figure 7. This allows wires/nodes A and B to be routed to the controller circuit.

In this example, using an inverted output polarity switch configuration, the door-closed position corresponds with the presence of a magnet and the Hall-effect switch output is in the off (output high) state. The open position, when the door and magnet are pulled away from the Hall-effect switch, corresponds with the sensor output in the on (output low) state.

For this circuit, the micropower APS11700 Hall switch is chosen for its ability to operate on supplies as high as 24 V and to deliver load currents up to 20 mA through its open-drain output. These features greatly simplify the circuit design.

FORMULA REPRESENTATION: The two door positions, open and closed, can be distinguished by the two discrete voltage levels measured across a sense resistor, for example, R2 in Figure 8. A voltage is generated at the I/O node as a result of the current flowing through the resistor.

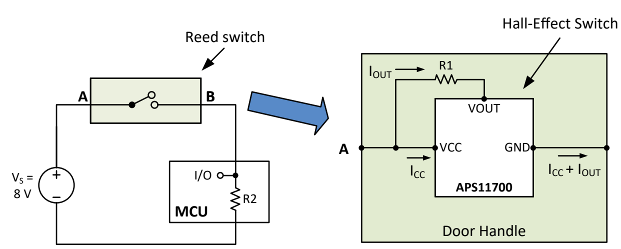

Figure 8. Refrigerator Door Micro-Switch Conversion Circuit

During the door closed condition, the only current flowing though R2 is the Hall-effect switch supply current, I_{CC}, which flows into the Hall-effect switch VCC pin and exits through the GND pin, eventually passing through R2 to ground. This level is identified as $V_{R2(CLOSED)}$.

In the complementary state, the door-opened condition, the Hall-effect switch output sink current is added. The output sink current flows into the VOUT pin and also exits through the GND pin, increasing the overall current passing through R2. This level is identified as $V_{R2(OPENED)}$. Both conditions are described below.

Equation 1:

Closed State: $V_{R2(CLOSED)} = I_{CC} \times R_2$

Equation 2:

Opened State: $V_{R2(OPEN)} = (I_{CC} + I_{OUT}) \times R_2$

Equation 1 and 2 shown above represent the voltage measured across the controller's sense resistor, R2, for the two operating positions of the example system's door. Voltage ranges for these two door handle positions can be determined by considering several specification limits on the Hall-effect switch datasheet. These include supply current, I_{CC}, and output saturation voltage, $V_{OUT(SAT)}$, which are shown in Table 2. Next, look at a key specification from the APS11700 datasheet to calculate the remaining value, I_{OUT}, and ultimately V_{R2} for the two door positions.

Table 2. APS11700 Datasheet Specification

Parameter	Symbol	Min.	Typ.	Max.	Unit
Average Supply Current (–40°C to 85°C)	I_{CC}	2	6	15	µA
Output Saturation Voltage	$V_{OUT(SAT)}$	–	100	500	mV

Since $I_{CC} << I_{OUT}$ during sleep mode, the output current, I_{OUT}, can be approximated by the equation below, using the typical values from Table 2, with R_1 = 280 Ω and R_2 = 280 Ω:

Output Current:

$I_{OUT} = (V_S) / (R_1 + R_2)$
$I_{OUT} = (8\ V) / (280\ \Omega + 280\ \Omega)$
$I_{OUT} = (8\ V) / (560\ \Omega) = 14.3\ mA$

Then, by using Equation 1 and Equation 2, solve for V_{R2} using the typical values from Table 2:

Closed State:

$V_{R2(CLOSED)} = 6\ \mu A \times 280\ \Omega = 1.7\ mV$

Opened State:

$V_{R2(OPEN)} = (6\ \mu A + 14.3\ mA) \times 280\ \Omega = 4.0\ V$

In this installation, a lookup table such as that in Table 3 may be created to identify the state of the door. Factors influencing the voltage ranges may include supply voltage tolerances, resistor tolerances, and Hall-effect switch datasheet limits. Proper consideration must be taken to ensure the voltage across the Hall-effect switch VCC and GND terminals exceeds the supply voltage requirements from the datasheet. For this example, with the APS11700, greater than 3.3 V is retained across the terminals at all times.

Table 3. V_{R2} Voltage Level Ranges

Door State	Min.	Typ.	Max.	Unit
Closed	1	1.7	2.4	mV
Opened	3.75	4.0	4.25	V

To achieve its low power consumption, the APS11700 duty cycles between sleep and awake modes. The awake period (t_{AWAKE}) is typically only 50 µs in duration, but during this time I_{CC} for the APS17000 can reach levels as high as 4 mA. During this intermittent condition, the V_{R2} open and close levels may increase. The system software within the MCU can easily be designed to accommodate these minor fluctuations in voltage levels when the APS11700 is in its awake state.

$I_{OUT(AWAKE)} = (V_S - (I_{CC} \times R_2)) / (R_1 + R_2)$
$I_{OUT(AWAKE)} = (8\ V - (4\ mA \times 280\ \Omega) / (280\ \Omega + 280\ \Omega)$
$I_{OUT(AWAKE)} = (8\ V - 1.12\ V) / (560\ \Omega) = 12.3\ mA$

Solving for VR2 during the APS11700 awake period:

Closed State (Awake):

$V_{R2(CLOSED)} = 4\ mA \times 280\ \Omega = 1.12\ V$

Opened State (Awake):

$V_{R2(OPEN)} = (4\ mA + 12.3\ mA) \times 280\ \Omega = 4.6\ V$

Conclusions

Digital position Hall-effect and TMR switches can enable significant enhancements to systems currently employing mechanical reed or micro-switches and are also an excellent choice for new switch applications. By using a micropower Hall-effect switch such as the Allegro APS11700 or APS11753, power consumption is minimized to below 20 µW or significantly less. Allegro TMR switches like the CT8132 can reduce power consumption to well less than 1 µW.

While not discussed in this document, other three-terminal Hall-effect switches (like the APS11202) can be employed in the same manner as a mechanical switch replacement and may enable additional open-circuit or short-circuit detection capability. Devices such as the APS11450 diagnostic Hall-effect switch dynamically control the output current, I_{OUT}, in such a manner that various circuit faults can be easily detected.

The benefits provided by a solid-state component such as a Hall-effect switch range from accuracy and durability to transient rejection and open/short-circuit protection. The contactless nature of a magnetic sensor reduces system wear and accuracy drift over time, retaining the optimized performance attained during the original design. Applications using micro-switches must implement a low-cost permanent magnet, but the final system is much less susceptible to mechanical wear and tear. In many cases, the Hall-effect switch application circuit can be configured for backwards compatibility.

The Allegro APS11700 and APS11760 micropower vertical and planar Hall-effect switches were the first micropower Hall-effect sensors to enable up to 24 V supply operation yet also allowing just 3.3 V operation to absolutely minimize the power consumption. The APS11753 and CT8132 (TMR) offer even further power savings for the latest generation of single supply, battery powered devices. For a full list of Hall-effect switches, visit the Allegro MicroSystems website.

Revision History

Number	Date	Description
–	May 11, 2020	Initial release
1	May 22, 2025	Extensively revised to include TMR switches

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