INNOVATION WITH PURPOSE

METHODS AND VALIDATION OF STRAY MAGNETIC FIELD MITIGATION IN MAGNETIC SPEED SENSOR ICS

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INTRODUCTION

While tremendous progress has been made in recent years on the technological underpinnings of magnetic sensor ICs, the environments in which these devices are used have been rapidly changing in ways that confound their usage. The increasing density of high-power electronics inside automotive and industrial applications has led to the rise of the phenomena of stray fields—the presence of extraneous magnetic fields that interfere with the successful tracking of a target object via its magnetic profile.

Allegro MicroSystems has been designing magnetic sensor ICs for more than thirty years and is a leader in the supply of magnetic sensor ICs for the automotive industry. The increase of electrification in vehicles and the proliferation of external magnetic perturbations in applications has required Allegro to adapt its designs to mitigate stray field effects in order to continue to offer accurate speed sensor ICs.

Stray fields are a particular challenge for magnetic sensor ICs since they are a disturbance of the very effect that is intended to be sensed. One way to consider this predicament is to imagine trying to read a scrolling news ticker while there are nearby lights flashing on and off. Whether or not one is able to read the words as they appear depends on the size and clarity of the text, as well as the intensity and orientation of the distracting light sources. In the same way, magnetic sensor IC performance during stray field events depends on the quality of the desired signal as well as the intensity and orientation of stray field sources.

This document provides an overview of the phenomena of stray magnetic fields, its various sources, solutions developed to minimize its effects, and product proposals tolerant to stray field perturbations.

SOURCES OF STRAY FIELDS

For most applications, stray field perturbations are induced by an electrical device, actuator, coil, or a high-current cable mounted near the sensor IC. In some instances, the source of the magnetic perturbation can also be external to the vehicle, as in the case of tram or train rails, or has been observed on some bridges where the residual effect of the construction and test process is a permanent DC magnetic field over the bridge.

The above-mentioned perturbations will generate a magnetic stimulus in addition to the magnetic signal to be sensed, acting like an added DC offset to the signal or an added AC fluctuation. The impact on the speed sensor IC could be output inaccuracy, additional output edges, or even latch-up in a worst-case scenario.

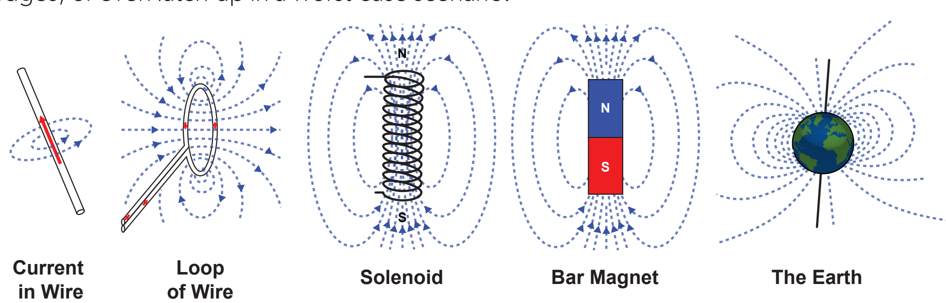

Figure 1: Magnetic Field Sources

In engine management, cam and crank speed sensor ICs provide the information necessary for an ECU to determine engine position and the timing of fuel injection for a given cylinder. The engine environment is becoming increasingly condensed, and the sensor ICs must provide accurate output while sometimes exposed to magnetic perturbation from an actuator mounted next to it. Well-known examples are fuel injectors using a coil to move the injection nozzle, engine starter generating some magnetic field pulses at start-up, and the operation of coil-driven engine valves. Actuators are not the only source of perturbation—a simple cable next to the device will generate a magnetic field. The level of perturbation will depend on the distance from the sensor IC to the cable and on the level of current—in hybrid vehicles, a peak current level of 300 to 500 A peak flowing through a cable is common and may generate significant magnetic perturbation. The Biot-Savart Law as shown in Equation 1, can be used to calculate the magnetic field produced by this scenario (illustrated in Figure 4).

Equation 1: $$B = \frac{\mu_0 I}{2\pi r}$$

Here, μ_0 is the permeability of the free space, I is the current flowing in the conductor, r is the distance from the conductor to the sensor IC, and a long wire (relative to r) is assumed. Assuming 500 A flowing in a conductor placed 10 cm away from a sensing element yields Equation 2 below.

Equation 2: $$B = \frac{(4\pi \times 10^{-7}\ {}^{H}/_{m})(500\ A)}{(2\pi)(0.01\ m)} = 10\ G$$

Thus, the stray field seen by a sensing element under these conditions would be 10 G.

Transmission speed sensor ICs typically encounter relatively little stray field interference due to their location. In general, being set back from the engine block, they are distanced from major sources of stray fields like starter coils, and because they are inserted into the transmission, they can benefit from some amount of shielding from the case. There are still some stray field sources to consider, such as shift solenoids, but they are typically minor and very manageable.

Finally, wheel speed sensor ICs see numerous sources of stray field interference including railroad tracks, heating coils embedded in garage floors, powerlines, and (again) high current wires throughout the vehicle.

TARGET IMPACT

Allegro speed sensor ICs provide speed (and/or direction) information for a rotating target by means of digital output transitions representing target profile (speed only output) or output pulses with defined width depending on direction of rotation (speed and direction). The target will be one of two types: a ring magnet or ferromagnetic target.

A ring magnet target is a magnetic trigger wheel generally made of plasto-magnetic material which is magnetized in such a way that a period is made of adjacent north and south magnetic poles. The target can have as many of these pole-pairs (periods) as magnetization and required dimension permit, though a range of 30 to 90 pole-pairs are used in targets across applications. Since such targets are made of material which cannot concentrate external magnetic fields, they will not influence speed sensor IC performance over stray field. That is, the stray field performance of the speed sensor IC can be tested with or without the target.

Ferromagnetic targets are used in a majority of applications and require the magnetic sensor IC to be back-biased by a magnet to detect rotation. These targets will influence speed sensor IC stray field performance because they concentrate magnetic lines—including those of stray magnetic fields—toward the magnetic sensor elements. For such cases, it is therefore recommended to perform stray field tests with the application target.

To illustrate the impact of ferromagnetic targets on an external magnetic field, the field strength can be measured with and without a ferromagnetic target in a Helmholtz coil. When a ferromagnetic target is placed in a Helmholtz coil, it acts as a concentrator of the flux lines and significantly increases the level of magnetic perturbation at the sensor position as illustrated in Figure 2. For example, applying a field of 1000 A/m RMS will generate 36 G peak-to-peak of homogenous AC perturbation in the flux density at the sensor IC location (at the center of the coil) when no ferromagnetic material (target) is installed. If a target is placed in the coil, the flux density at the sensor IC location can increase up to 103 G peak-to-peak at an air gap of 2.5 mm. The air gap is defined as the distance from active face of the sensor IC to the target tooth.

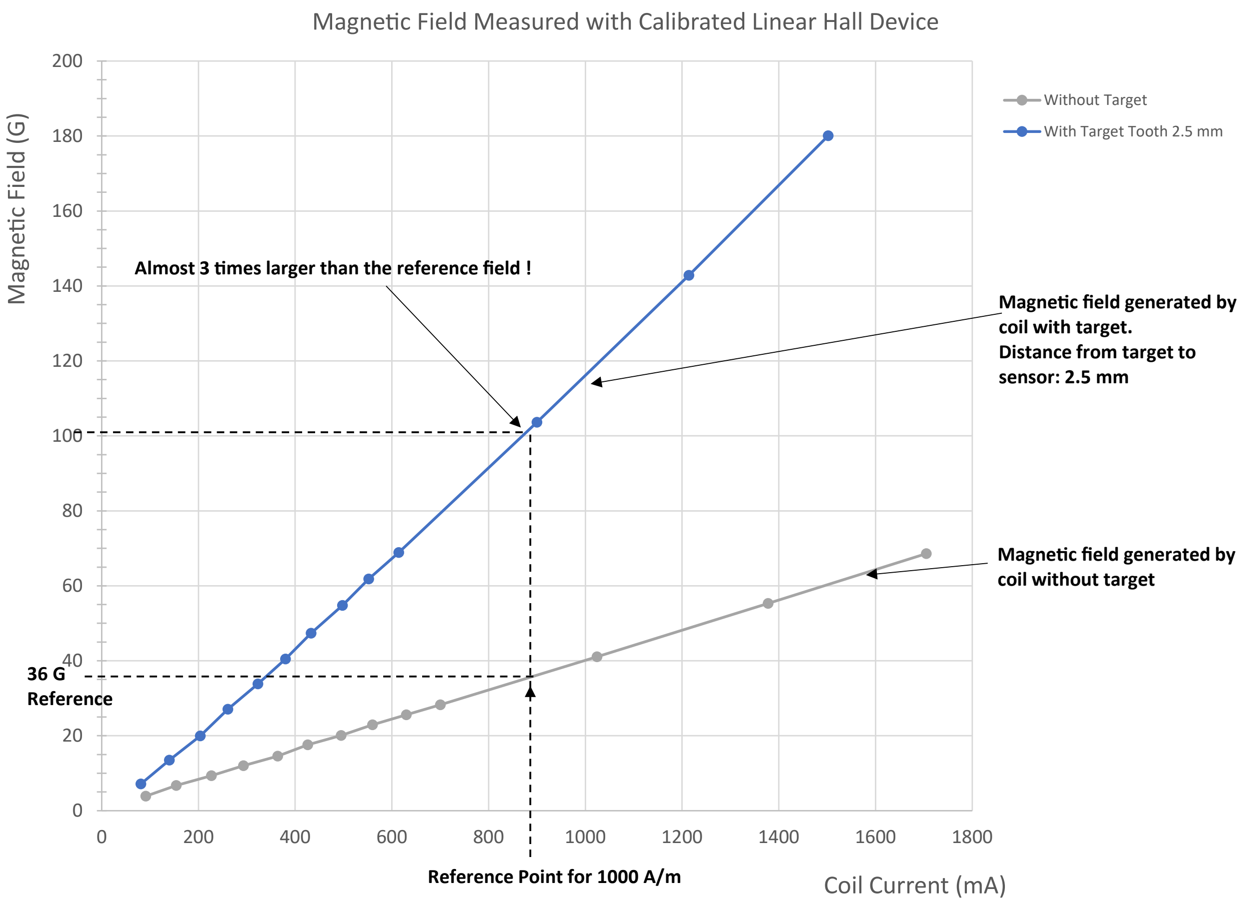

Figure 2: Impact of Ferromagnetic Target in a Helmholtz Coil

TEST METHODOLOGIES

The first major specification on the testing of stray fields was the US DOD's MIL-STD-461 in 1967, and this document is the origin of the radiating loop coil as it is used to this day. At present, the primary specification defining stray magnetic field testing is the ISO 11452-8 standard, "Immunity to Magnetic Fields"; however, most automotive manufacturers have created their own offshoot specifications, some even with variant waveforms. A composite of these various specifications is included in Figure 3.

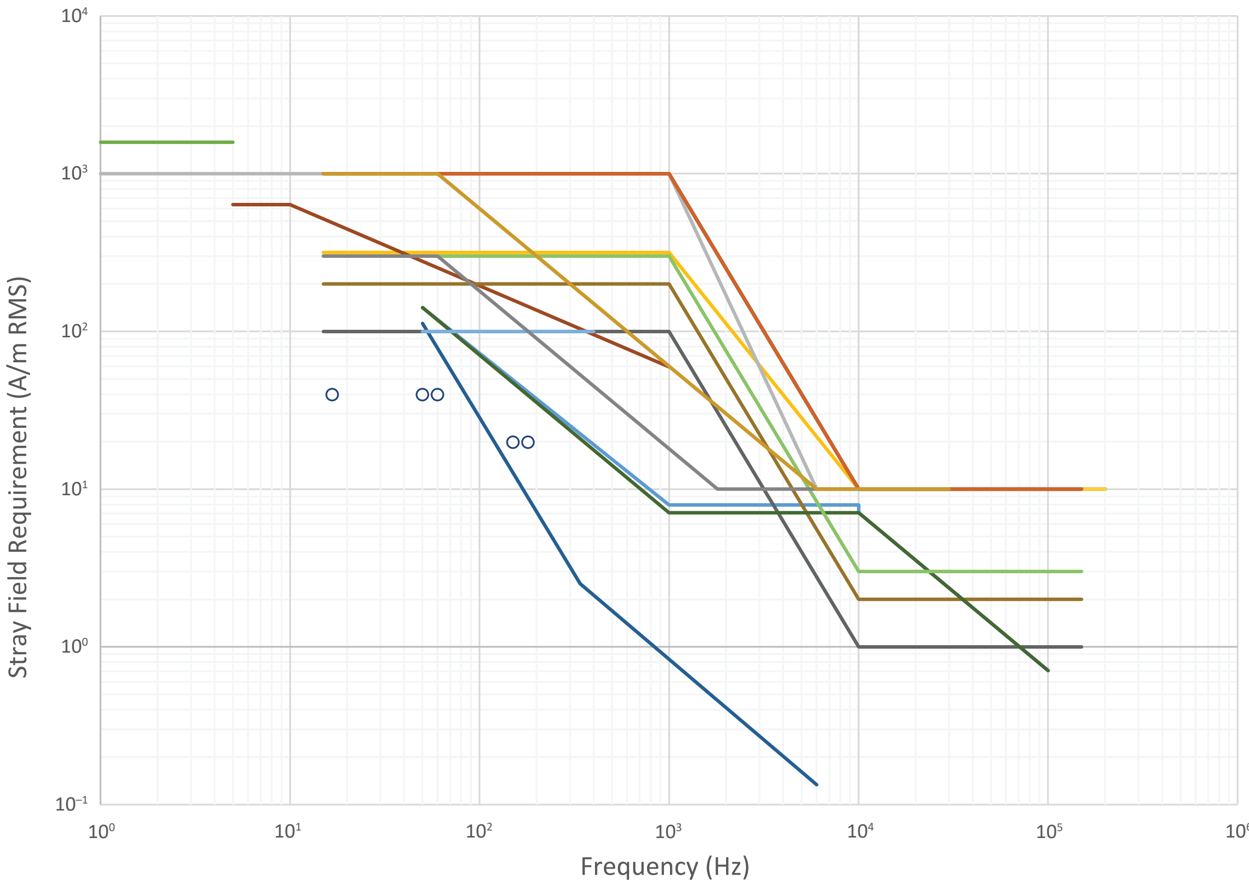

Figure 3: Stray Field Requirements

To test magnetic sensor ICs to these various specifications, three established test methodologies are commonly used: the single current wire, Helmholtz coil, and radiating loop tests.

The single current wire test specification is defined by the customer to be as close as possible to the application configuration. It consists of positioning a wire (generally a straight wire) at a distance, r, to the sensor IC under test (and its corresponding rotating target) in a specified orientation. A specified current, I, is then forced through the wire as illustrated in Figure 4. The current is generally applied continuously (DC) but can also consist of an applied current step.

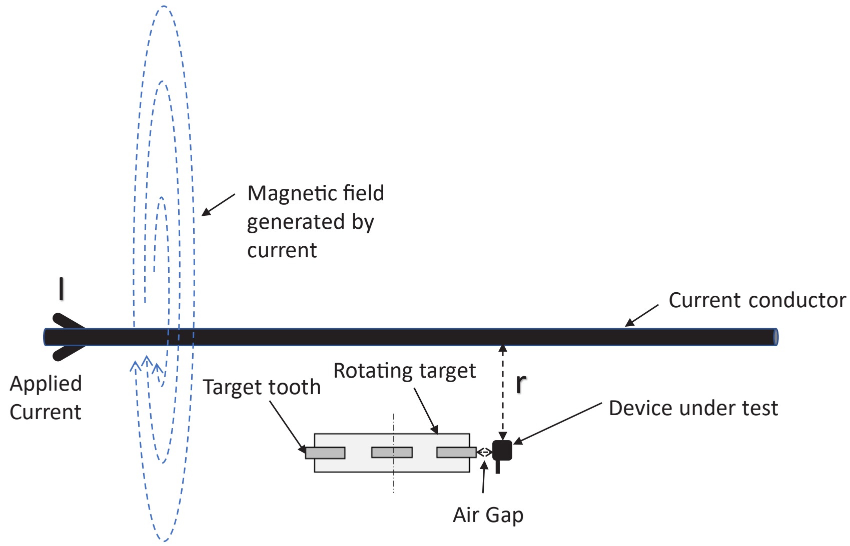

Figure 4: Single Current Wire Test

The Helmholtz coil test consists of two identical circular coils symmetrically placed and separated by a distance equal to the radius of the coils as illustrated in Figure 5. The radius is generally specified by ISO 11452-8 to be a minimum of 150 mm, which has the advantage to generate a relatively large homogenous magnetic field zone around its center and permits for a full system to be tested. Often defined as the "reference" setup in ISO11452-8 specification, the ISO standard also refers to the radiating loop coil as an "optional" setup.

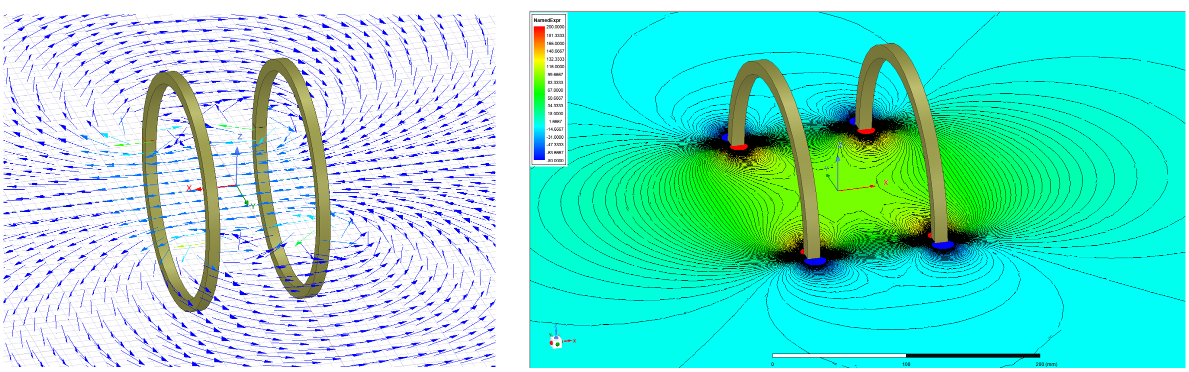

Figure 5: Helmholtz Coil Generating Large Homogeneous Field Area

Finally, the radiating loop coil test uses a single 12 cm diameter, 20-turn coil which is calibrated to a test point 5 cm from its center. In contrast with the Helmholtz coil, the radiating loop is more susceptible to misalignment because it does not have a large homogenous field. However, for the same reason it is less impacted by nearby metal objects, like ferromagnetic targets.

MITIGATION METHODOLOGIES

There are several methods manufacturers can employ to mitigate the stray field interference that will be seen by a sensor IC, including wire routing, shielding, and IC and field source orientation.

Proactive wire routing can greatly diminish the scale of stray field interference by orders of magnitude. By maximizing the physical distance between any high-current conductors and sensor ICs sensitive to magnetic interference, manufacturers can leverage the inverse nature of the Biot-Savart law as explored in Equation 1 and Equation 2.

Disregarding complex active techniques, magnetic shielding can be broken down to two methods, with the major difference between them being the frequency of the external field. For alternating field in general, a conductive surface—such as sheet metal—can reflect radiation through eddy currents which respond with an opposing field. The conductor thickness necessary for this shielding depends on the material properties and the frequency of the signal due to the skin effect; higher frequencies have a smaller skin depth and thus require less material as described in Equation 3.

Equation 3: $$\delta = \sqrt{\frac{2\rho}{\omega\mu}} = \sqrt{\frac{\rho}{\pi f \mu_r \mu_0}}$$

Here, δ is the skin depth, ρ is the resistivity of the material, μ_r is the relative permeability of the material, and μ_0 is the permeability of free space. The other method of shielding, for low-frequency or constant magnetic fields, also involves the use of a metal surface, but the primary factor is the magnetic permeability of the material rather than conductivity. With shielding constructed from such metals, the magnetic field is redirected through rather than reflected by the surface. These shielding methods are illustrated in Figure 6.

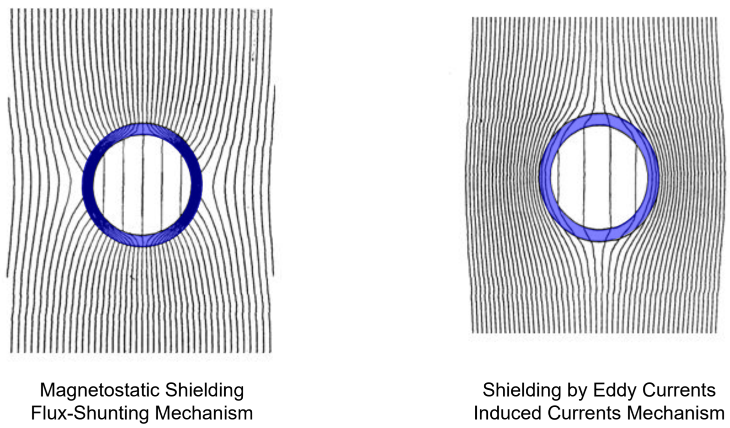

Figure 6: Flux Shunting and Eddy Currents

The orientation of the interference field source relative to the magnetic sensor IC is also an important consideration. Hall-effect-based speed sensor ICs are sensitive to fields perpendicular to the die (into the branded face of the IC) whereas GMR-based speed sensor ICs are sensitive to fields in the plane of the die (parallel to the branded face of the IC). Where possible, sources of stray field interference can be oriented such that its incidence angle as seen by the speed sensor IC reduces or even eliminates interference.

The same example of 500 A flowing into a single-current wire explored in Equation 2 can be used to demonstrate the impact of sensor orientation. In an experiment, the Allegro single Hall cam sensor ATS16301PSL was positioned at 10 cm from the wire, but at two different sensing positions along the target rotation axis—at 0° and 90°, as illustrated in Figure 7. This experiment highlighted the implied magnetic offset was doubled when the sensitive axis of the device was aligned with the external perturbation, and a small offset likely generated by the target concentrating magnetic flux lines remained observable when the perturbation was applied to the non-sensitive orientation.

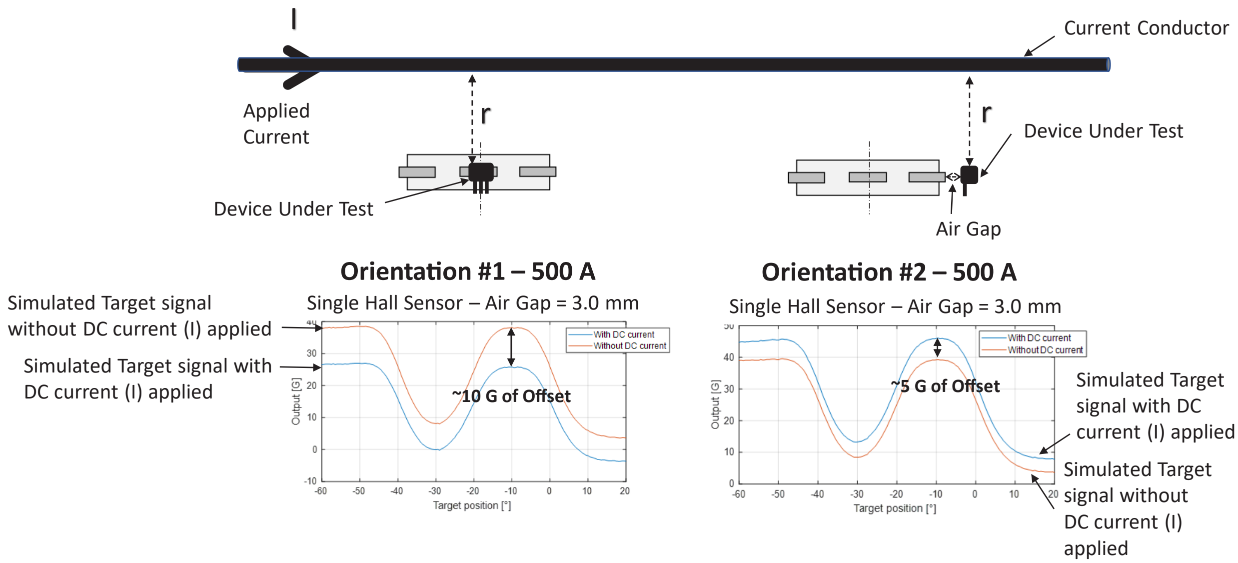

Figure 7: Impact of External Field Orientation to Single Hall Cam Sensor (ATS16301PSL)

There are several device-side methods which can also be used to mitigate any stray field interference, including magnet design in packages with integrated magnets (back-biased devices), differential sensing architectures, and the fine tuning of certain algorithm parameters.

Magnet design in back-biased devices can be made to improve the ratio of external magnetic perturbation over sensing signal peak-to-peak, somewhat like a magnetic signal-to-noise ratio. The simplest way is to design the largest magnet possible—so long as magnetic field strength stays within device input range, of course—leading to a larger sensing signal and smaller external magnetic field impact. Some other magnet designs require less magnetic material but more technical shapes, like "donut" or "sandwich" magnets. The main advantage of these technical designs is to maintain a high sensing magnetic signal range while minimizing the common mode (baseline) field at the sensing location—this allows for both higher stray field rejection and minimization of offset drift over temperature.

Differential sensing is a simple if powerful method to mitigate stray field interference. To the extent that the wavelength of any interference is sufficiently large relative to the spacing of sensor elements internal to the IC, the interference will present as a common mode signal and thus will be mathematically eliminated in a differential sensing architecture.

There are several algorithmic adjustments which can be made to mitigate stray field interference. The most common of these used in Allegro speed sensor ICs is dynamic signal tracking. The benefit of this feature is to eliminate any switch point error due to offset. For example, the DC magnetic offset generated by the single current wire in Figure 4 would have no effect in most Allegro speed sensor ICs, because the peak tracker would eliminate this offset. A second feature of Allegro speed sensor ICs minimizing impact of external magnetic perturbation is the switch-point calculation method using a percentage of the signal peak-to-peak to define switch point. Any impact on sensitivity is attenuated or even eliminated. Determination of the threshold level for switch point and the peak-to-peak hysteresis is a subtle way to mitigate AC magnetic perturbation effects. It has been observed that the amplitude of stray field interference as seen by the sensor IC is larger under certain target conditions than others—when sensing a tooth as opposed to a valley, for example. Thus, the threshold position can be adjusted in the direction of the sensing region that experiences the lowest stray field interference amplitude, while the peak-to-peak hysteresis can be adjusted to marginally exceed the highest stray field interference amplitude. These adjustments can greatly increase performance even in the presence of significant interference.

The sensing element technology also plays a role. The same single current wire scenario previously explored (500 A flowing in a single current wire and sensor IC positioned 10 cm away) was simulated to compare a single Hall cam sensor IC, the ATS16301PSL, to Allegro's newest GMR cam sensor, the ATS16351PSM. Since the sensing signals were different, it was more appropriate to compare the level of offset to the signal amplitude in percentage of the peak-to-peak as displayed in Figure 8.

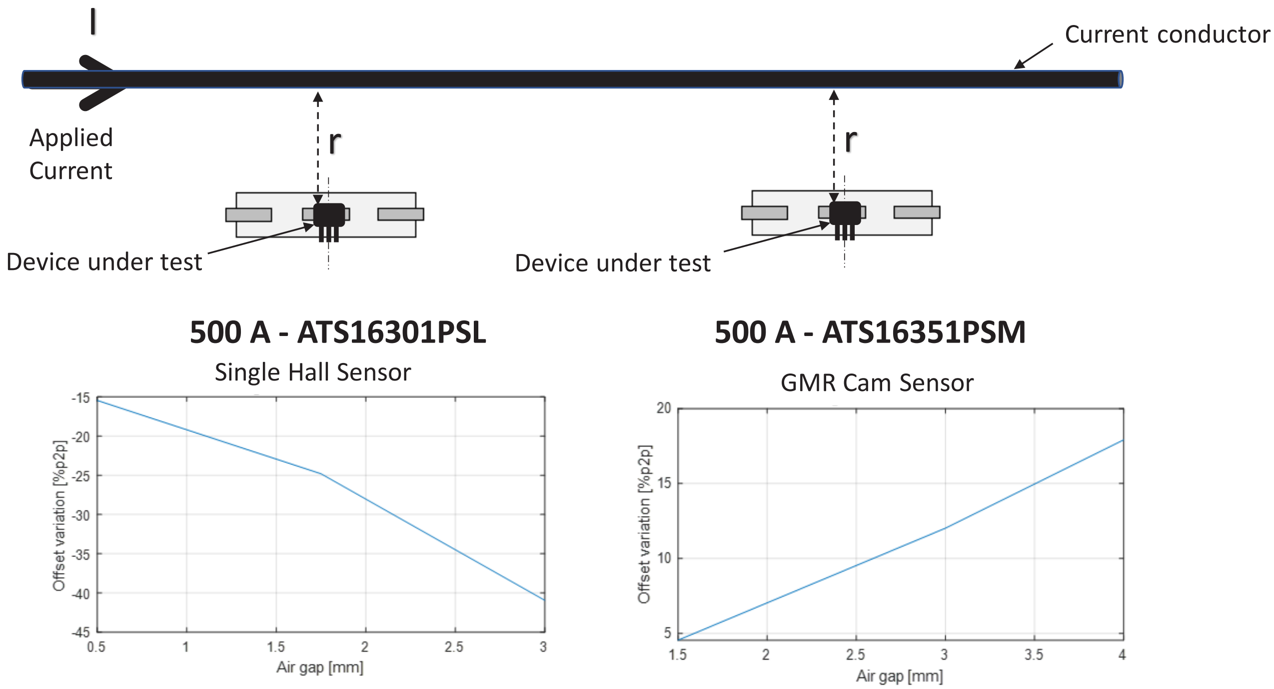

Figure 8: Comparison of Hall and GMR Cam Sensor ICs Over a Single Current Wire Magnetic Perturbation

CONCLUSION

As discussed throughout this document, the sources of stray magnetic fields are numerous, multiplying, and are increasingly proximate to magnetic sensor ICs across applications. Allegro MicroSystems continues to adapt to these evolving challenges by both implementing the mitigation methodologies discussed here and pursuing active research on new solutions. Rigorous testing using the three methods discussed here establishes the efficacy of these efforts and ensures device performance to any relevant specifications—the ISO 11452-8 standard or customer specific.

Allegro's comprehensive magnetic speed sensor IC portfolio includes both GMR and Hall technologies, both back-biased and non-back-biased, with many output protocol options—a solution for any application need. Some of the available stray-field-tested Hall and GMR options for various applications are included in Table 1 below.

Table 1: Released Allegro Speed Sensor ICs

Device	Technology	Application Area
ATS16351	Back-Biased GMR	Cam
ATS16951	Back-Biased GMR	Crank
A1696	Hall	Crank
ATS696	Back-Biased Hall	Crank
A19520	Hall	Transmission
ATS19520	Back-Biased Hall	Transmission
ATS19580	Back-Biased GMR	Transmission
A19420	Hall	Transmission
ATS19420	Back-Biased Hall	Transmission
A19350	GMR	Wheel Speed
A19200	Hall	Wheel Speed
A19250	GMR	Wheel Speed
ATS19200	Back-Biased Hall	Wheel Speed
A17501	Hall	xEV Speed
A17502	Hall	xEV Speed

It is important to note that many of these devices can also be used in various industrial applications. Contact an Allegro sales representative for more information.

Revision History

Number	Date	Description
–	March 25, 2022	Initial release