GIANT MAGNETORESISTANCE VERSUS HALL EFFECT—A COMPARISON OF TECHNOLOGIES FOR SPEED SENSOR APPLICATIONS

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INTRODUCTION

Automotive and industrial systems rely on speed sensor technology to sense the rotational movement of a magnetic encoder or a ferrous gear. Hall-effect technology offers a time-tested and trusted speed sensing solution. However, newly emergent cutting-edge devices that leverage the magnetoresistance (MR) effect may be able to deliver significant performance improvements. Allegro MicroSystems giant magnetoresistance (GMR) effect technology [1] offerings build on lessons learned from experience with Hall-effect devices to enable new options for speed sensing system design. To help users determine if the new GMR technology is appropriate for a specific application, this application note compares Hall-effect and GMR technologies and provides straightforward reference tables to help users choose the best device. Proper use of a GMR device may allow for revolutionary breakthroughs in system-level capabilities.

OVERVIEW OF BASIC PRINCIPLES

Hall-Effect Technologies

Hall-effect sensing elements generate a voltage that is proportional to the magnitude of a nearby magnetic field. Hall sensor technology is an application of Lorentz force, which is the force exerted on electrons as the electrons move across a plate perpendicular to a magnetic field. The electron movement ultimately induces a voltage difference across the plate, as shown in Figure 1. Amplification of this induced voltage change is the basis of the Allegro Hall-effect speed sensor technology.

[1] https://www.allegromicro.com/en/insights-and-innovations/allegro-technology/gmr-technology

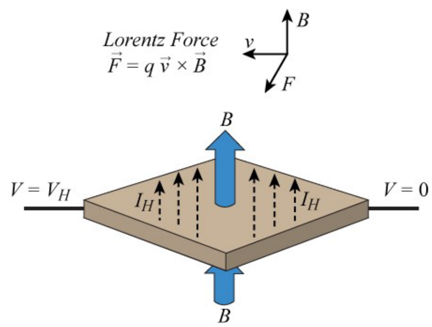

Figure 1: Simplified Hall plate diagram.

Hall-effect device characteristics significant to speed sensing applications include:

- Unidirectional magnetic field sensitivity: A planar Hall-effect device is only sensitive to magnetic fields in one direction—into the branded face of the packaged integrated circuit (IC), perpendicular to the silicon.
- Linear transducer output: Over a large signal range, the transducer output remains linear.
- High field strength robustness: The ability to withstand strong magnetic fields enables operation with a very small minimum air gap and a moderate maximum air gap.

To facilitate most design requirements, Allegro Hall-effect devices are typically available either:

- With a back-biasing magnet included inside the package, which simplifies system design; or
- Without an integrated magnet, which facilitates use of specific magnetic encoder or custom magnet designs.

GMR Technologies

GMR sensing elements respond to magnetic vectors, and GMR sensor technology operates on the principles of spin-transport electronics. In a magnetoresistor, electron scattering rates increase or decrease as a function of the interaction of the spin state of the electrons and the magnetic orientation of the medium in which the electrons travel. Electron scatter increases the mean free path of the electron flow, which effectively alters the resistance of the medium. Thus, in the presence of a magnetic field, the resistance value of a magnetoresistor changes as a function of the cosine of the applied external magnetic field relative to the reference layer in the plane parallel to the silicon surface, as shown in Figure 2.

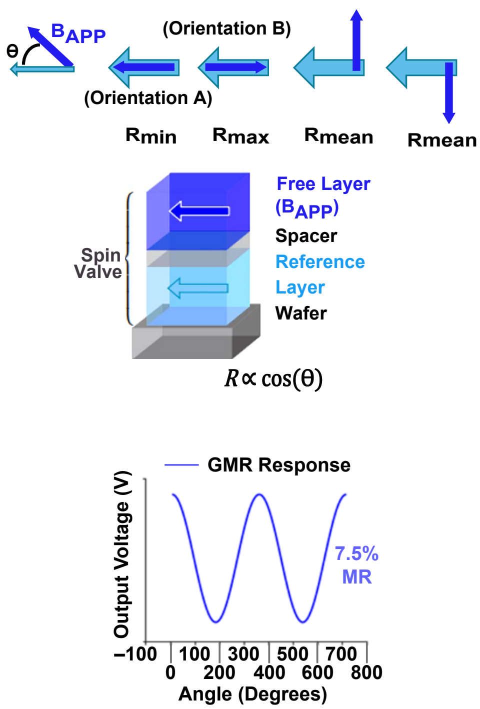

Figure 2. Simplified GMR structure and response to applied magnetic field orientation.

Allegro GMR transducers are built in a complex *stack* of additional layers (of various proprietary formulations) over an independent BiCMOS process as shown in Figure 3. The process achieves a monolithic single-die solution. Compared to multi-die predecessors that employ one die for the BiCMOS core IC and another for the MR sensing elements, the single-die approach is a simpler, more robust solution with a smaller form factor.

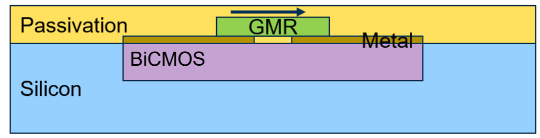

Figure 3: GMR sensor IC monolithic solution—Simplified layer cross section.

HOW TO CHOOSE A TECHNOLOGY

To enable designers to select the best technology for an application, performance metrics of interest for transducers that use the Hall effect and the GMR effect are discussed here and are compared in Table 1.

Table 1: Transducer Type Performance Metric Comparison

Performance Metric	Hall	GMR
Sensitivity	Low to medium	High, roughly 50 times greater than Hall
Linearity	Large linear range	Limited linear range
Sensing Range (Response Area)	Virtually infinite magnetic range	Limited and related to sensitivity [1]
Sensing Plane	Perpendicular to IC: Planar Hall Parallel to IC: Vertical Hall	Parallel to IC [2]
Air Gap	Closest minimum air gap, and moderate maximum air gap	Potentially limited minimum air gap, but large maximum air gap (greater than 50% improvement compared to Hall, in most cases)
Jitter/ Repeatability	Standard	Best edge repeatability
Sensing Principle	Lorentz force	Spin-transport electronics

[1] Allegro designs are capable of operation in the saturation regions, design dependent.

[2] Allegro back-biased designs are compatible with Hall mountings. Allegro SIP packages can sense in parallel and perpendicular orientations.

Sensitivity

Compared to a Hall-effect device, GMR technology offers much greater transducer sensitivity, which results in:

- Better maximum air gap, which eases mechanical tolerances and provides design margin and flexibility; and
- Lower jitter (greater repeatability) performance, which increases the accuracy of the speed data so as to provide the system with better clarity and less noise.

Air Gap

The increased sensitivity of a GMR device imposes certain minimum air gap restrictions and linearity considerations. For example, the Allegro ATS19580 back-biased GMR transmission speed sensor IC—the successor to the Allegro ATS19520 Hall-effect sensor IC—requires a minimum air gap of 1.5 mm. This represents a 1 mm increase in the minimum air gap (the Hall-effect device has a minimum air gap of 0.5 mm). However, the 4.5 mm maximum air gap of the GMR device is 1.7 mm greater than the 2.8 mm maximum air gap of the Hall-effect device. Thus, the GMR solution represents a maximum air gap improvement of greater than 60% and a total air gap range improvement of greater than 30%.

Repeatability

GMR-effect sensor ICs improve repeatability compared to Hall-effect counterparts. For example, at the maximum air gap, the Allegro A19571 GMR transmission speed sensor IC provides a full order-of-magnitude improvement in jitter compared to its Allegro Hall-effect predecessor A19520.

Sensor Field Orientation

As previously discussed, sensor field orientation is another important consideration: GMR elements sense fields in the plane of the silicon (parallel to the IC), whereas typical Hall-effect devices sense fields perpendicular to the IC. To reduce design considerations related to this orientation change and to facilitate transition from predecessor Hall-effect technology to GMR technology, the new ATS19580 GMR device is designed to be a drop-in replacement for the predecessor ATS19520 Hall-effect device.

SIMPLIFIED SELECTION TABLES

As discussed throughout this document, each technology has its relative strengths. The simplified priority-driven technology selection guide in Table 2 summarizes these strengths to help designers determine the most appropriate technology for an application.

Table 2: Simplified Technology Selection Guide

Scenario	Small Minimum Air Gap	Large Maximum Air Gap	Low Jitter	Selection Advice
1	High Priority	Low Priority	Low Priority	Hall
2	Low Priority	High Priority	Low Priority	GMR
3	Low Priority	Low Priority	High Priority	GMR

For GMR-suitable applications, the selection of popular Allegro GMR sensors in Table 3 summarizes strengths of individual products to help designers determine the best device for specific application needs.

Table 3: Released Allegro GMR Speed Sensor ICs

Part Number [1]	Target Type	Description [2]
Wheel Speed Sensor ICs		
A19250 [3]	Magnetic Encoder	High-Accuracy Speed
A19350 [4]	Magnetic Encoder	High-Accuracy Full-Pitch Vibration-Tolerant Speed and Direction
Transmission Sensor IC		
A19570 [5]	Magnetic Encoder	Large Air Gap, Full-Pitch Vibration-Tolerant, Small-Pitch Speed and Direction
A19571 [6] (GMR alternative to predecessor A19520 [7] Hall-effect device)	Magnetic Encoder	Large Air Gap, Full-Pitch Vibration-Tolerant, Large-Pitch Speed and Direction
Transmission Sensor IC, Back-Biased		
ATS19580 [8] (GMR alternative to predecessor ATS19520 [9] Hall-effect device)	Ferrous Gear	Large Air Gap, Full-Pitch Vibration-Tolerant, Speed and Direction Sensor IC with Integrated Magnet

[1] All products are offered with integrated electromagnetic-compatible (EMC) protection components in a single overmolded package.
[2] All products offer ISO 26262 ASIL integrated diagnostics and certified design process with optional reporting protocol.
[3] https://www.allegromicro.com/en/products/sense/magnetic-speed/wheel-speed-sensor-ics/a19250
[4] https://www.allegromicro.com/en/products/sense/magnetic-speed/wheel-speed-sensor-ics/a19350
[5] https://www.allegromicro.com/en/products/sense/magnetic-speed/transmission-sensor-ics/a19570
[6] https://www.allegromicro.com/en/products/sense/magnetic-speed/transmission-sensor-ics/a19571
[7] https://www.allegromicro.com/en/products/sense/magnetic-speed/transmission-sensor-ics/a19520
[8] https://www.allegromicro.com/en/products/sense/magnetic-speed/transmission-sensor-ics/ats19580
[9] https://www.allegromicro.com/en/products/sense/magnetic-speed/transmission-sensor-ics/ats19520

CONCLUSION

The Allegro MicroSystems comprehensive magnetic speed sensor portfolio includes both GMR and Hall technologies. With many output protocol options, the Allegro portfolio offers a solution for any application need. The guidance in this application note should be used to help select the most suitable device type for a specific speed sensing application.

Revision History

Number	Date	Description	Responsibility
–	December 17, 2021	Initial release	Z. E. Richards

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