

Next Generation Performance with XtremeSense™ TMR Technology

ABSTRACT

As current and position sensing demand continues to increase, driven by the applications and use cases that employ them, the demands for performance and accuracy in sensor technology are rendering legacy solutions, like Hall-effect and shunt, obsolete. Enter the Tunnel Magnetoresistance effect (TMR).

DESCRIPTION

Unlike conventional elements, TMR is the latest magnetic sensor technology and has the inherent advantages of being less susceptible to temperature change, while offering both extremely high magnetic sensitivity and low noise.

Other advantages of this new go-to solution include high SNR, low power consumption, programmable overcurrent detection and fault pin, bidirectional sensing, and high-voltage isolation to ensure safety.

Highly versatile TMR technology solutions provide high-end performance for demanding applications and can be incorporated into existing designs with better performance while lowering overall total solution cost.

Finally, TMR is dramatically simpler than traditional solutions, with its reduced component count, delivering less reliance on the supply chain.

Within xMR technologies (AMR, GMR, TMR), there is a false assumption that these provide similar levels of performance, stability, and robustness. In fact, the intrinsic sensitivity of TMR is high, orders-of-magnitude higher than other xMR technologies.

While many magnetic sensor companies worldwide are featuring TMR-based products due to their higher level performance benefits, all solutions are not created equal. Allegro's sensors are a premium performance solution, based on XtremeSense™ TMR which provides the highest accuracy, low power, high bandwidth, high sensitivity, temperature stability, low noise, and the smallest size by comparison to other magnetic technologies.

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WHAT IS THE RESOLUTION OF THE MAGNETIC SENSOR?

Sensor resolution refers to the minimum value of a magnetic field characteristic (field strength, angular orientation, or equivalent electric current for example) which the sensor can resolve.

The sensor resolution is determined by evaluating the signal-to-noise ratio (SNR) of the sensor in its operating conditions. It should not be confused with the analog-to-digital converter (ADC) resolution of the device.

The intrinsic sensitivity of TMR is high, orders-of-magnitude higher than other xMR technologies. Consequently, a competitive advantage in SNR needs to focus on reduction of the sensor noise. Years of research and development at Allegro MicroSystems have resulted in TMR sensor designs with the lowest noise on the market. This low noise technology appears in all XtremeSense™ TMR-based sensors and yields industry-leading resolution numbers such as:

- 5 mA on CT110 Current Sensor, 30 kHz Bandwidth
- 10 mA on CT430 Current Sensor, 1 MHz Bandwidth
- 0.005°C on CT310 Angle Sensor

The figure below shows a typical open-loop Hall-effect sensor left, in red) and a close-loop flux-gate current sensor (right, in red) along with the XtremeSense™ TMR-based CT4xx current sensor (in blue).

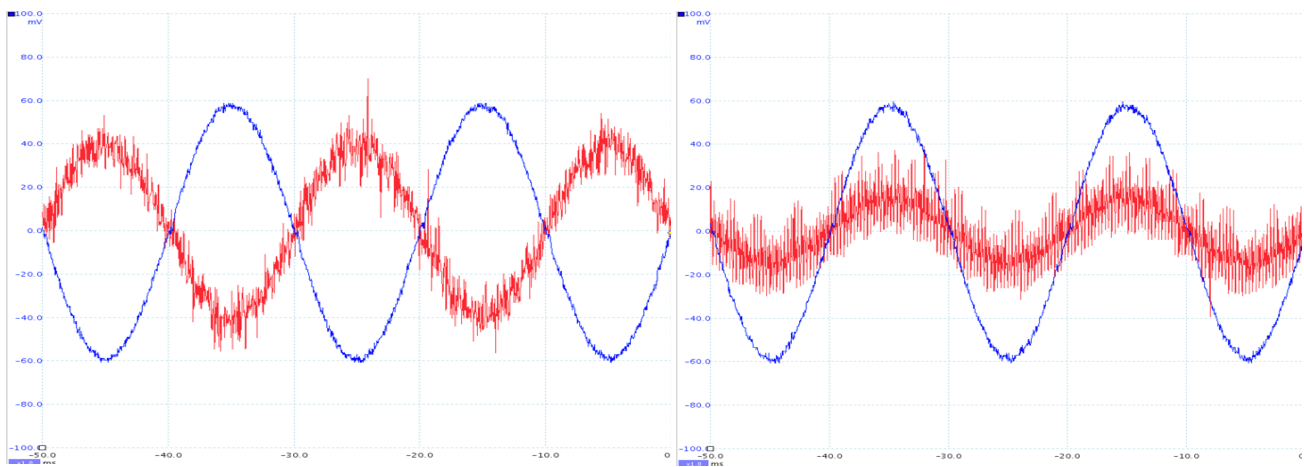


Figure 1: Current sensor loop comparison

HOW LINEAR IS THE OUTPUT?

Like all magnetic sensors, the response curve of TMR sensors to external magnetic fields is not intrinsically linear, and biasing techniques are generally required to define and optimize the linear range of operation. Over a large field range, this leads to typical linearity errors as shown below.

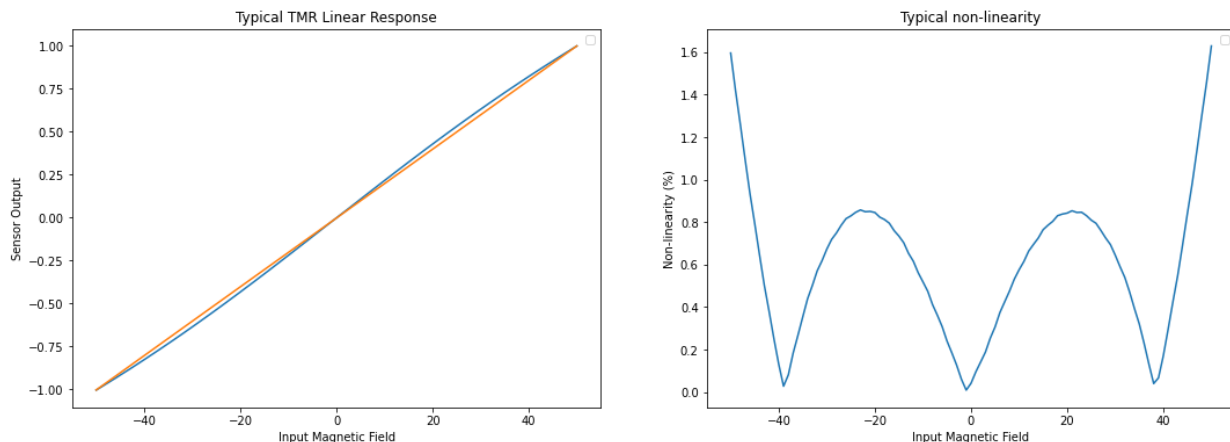


Figure 2: Typical TMR Technology Non-linearity Curves

In all cases, the higher the magnetic field amplitude, the closer the TMR is to saturation and therefore the less linear the sensor response. Even if the sensor response is far from saturation, linearity performance is strongly degraded outside of the center of the response curve. The challenge is then to extend the linear range of the sensor without sacrificing other parameters. By design, in numerous applications, XtremeSense™ TMR provides less than 0.1% linearity error (see graph below), a high level of performance that can only be matched by costly and power-hungry closed-loop biasing designs.

The figure below shows typical linearity error over temperature of Hall-sensors (left), AMR (center) and XtremeSense™ TMR (right).

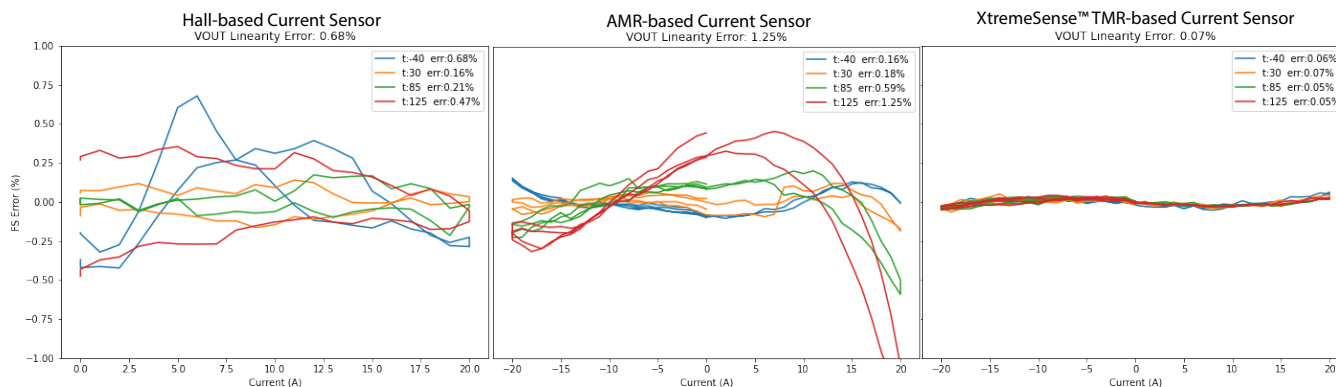


Figure 3: Typical linearity error over temperature of three solutions

IS THERE ANY MAGNETIC HYSTERESIS?

Commonly known as the memory effect, magnetic hysteresis is found in all ferromagnetic materials which are at the core of xMR sensors. Therefore, this behavior must be controlled and eliminated in the response of linear or angular sensors in order to ensure the repeatability and stability of the sensor output. The figure below shows a typical hysteretic response curve that will generate unwanted offsets and change of sensitivity, reducing the accuracy and potential applications of xMR products. This type of response has, by design, been eliminated in XtremeSense™ TMR sensors. The figure below illustrates the negligible hysteresis of an XtremeSense™ TMR linear sensor, with values so low that they can be ignored in the product design.

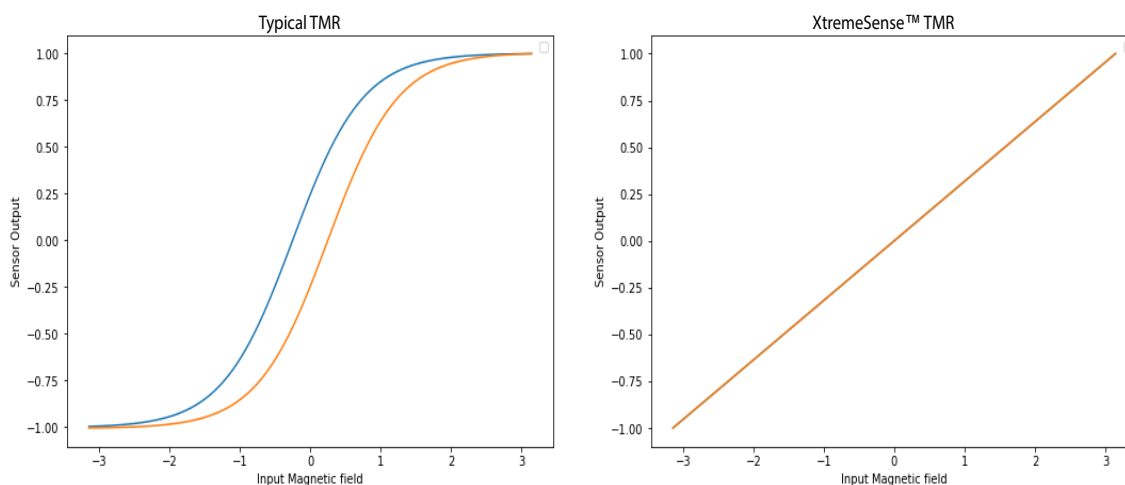
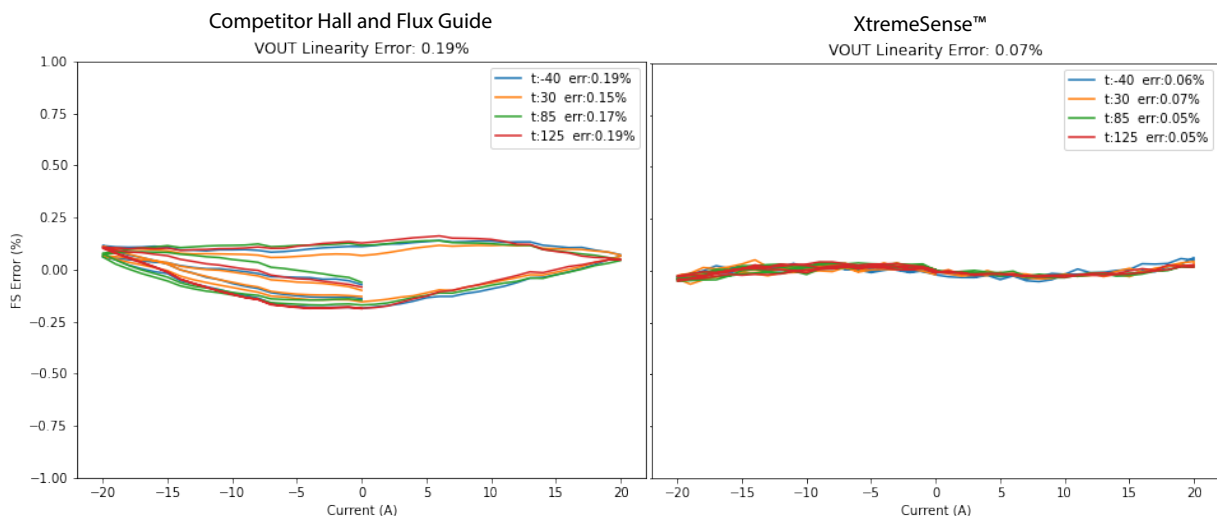


Figure 4: Magnetic Hysteresis comparison across typical TMR solutions versus XtremeSense™ TMR

As shown below, hysteresis effects also appear in competing sensor technologies (such as Hall-effect), which uses magnetic flux-guide structures to generate a sensor response along various geometric axes. XtremeSense™ TMR sensors do not use ferromagnetic flux-guide structures to achieve multi-axis sensitivities, therefore eliminating this potential source of error.



**Figure 5: Hysteresis comparison across different technologies.
Hall-effect is seen at left versus XtremeSense™ TMR at right.**

HOW WILL THE SENSOR RESPOND TO CROSS-AXIS MAGNETIC FIELDS?

An ideal linear magnetic sensor should respond to the magnetic field along its sensitivity axis, but should not be affected by orthogonal fields, also known as cross-axis magnetic fields. XtremeSense™ TMR sensors, by design, exhibit very small influence to cross-axis fields as illustrated in the figure below.

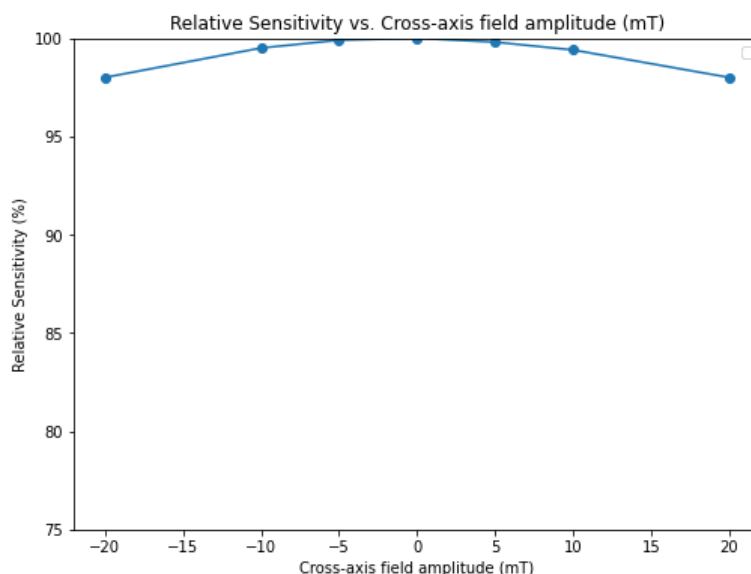


Figure 6: Graph of XtremeSense™ TMR sensors interaction with cross-axis fields

WHAT HAPPENS IF VERY STRONG MAGNETIC FIELDS ARE ACCIDENTLY APPLIED TO THE SENSOR?

Contrary to the majority of xMR sensors on the market, the robust design of XtremeSense™ TMR sensors allows them to survive, under operating temperatures, any accidental magnetic field without permanent damage to the sensor. Novel materials, optimized sensor fabrication and process optimization all contribute to this achievement.

For example, in the case of linear sensors based on XtremeSense™ TMR technology, all the main sensor characteristics are retained and return to normal operating performance once the strong magnetic field is eliminated. Depending on the exact conditions, there can be a small output voltage offset shift. Such offset shift is subsequently stable and only requires an offset recalibration, if desired, to eliminate any performance impact on total accuracy.

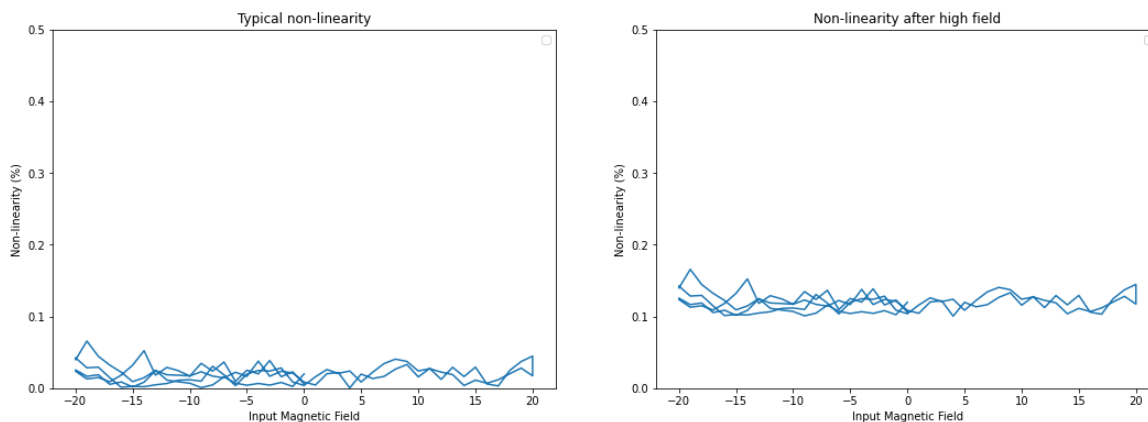


Figure 7: Minor offset shift (right) occurs when XtremeSense™ TMR sensors accidentally contact magnetic fields

HOW MUCH MIGHT OFFSET AND SENSITIVITY VARY OVER TEMPERATURE?

XtremeSense™ TMR sensors are designed to operate in harsh environments including high temperatures up to 150C. Proprietary materials development, as well as robust and specific sensor geometries are utilized to reduce the variation over temperature of both sensitivity and gain.

The temperature performance achieved by XtremeSense™ TMR allows it to be naturally competitive with Hall-effect sensors with active temperature compensation.

In turn, if combined with active temperature compensation circuitry, XtremeSense™ TMR based sensors can achieve less than 40 ppm/°C of output gain variation, vastly surpassing similar open-loop Hall-effect based sensors, and matching higher end closed-loop current sensors.

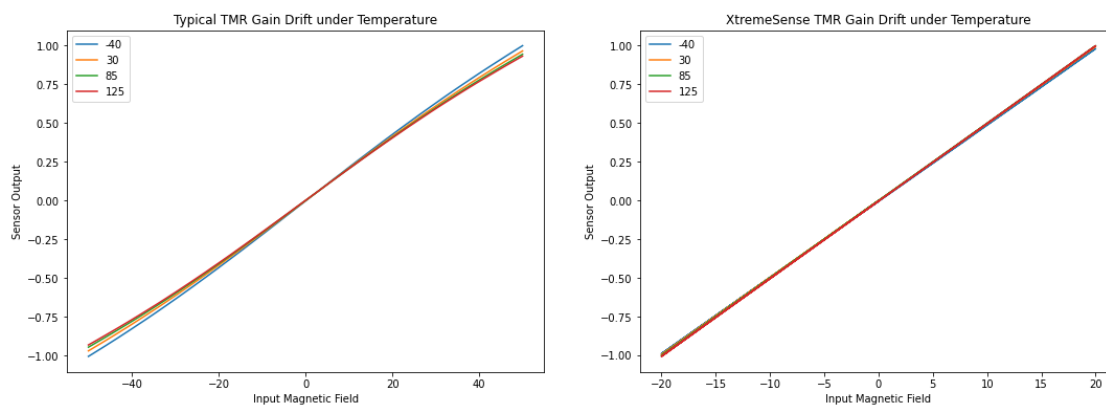


Figure 8: Offset and gain drift under temperature for Hall-effect and AMR-based current sensors

The figures below show offset and gain drift over temperature of a Hall-effect based current sensor (left) and AMR based current sensor (right).

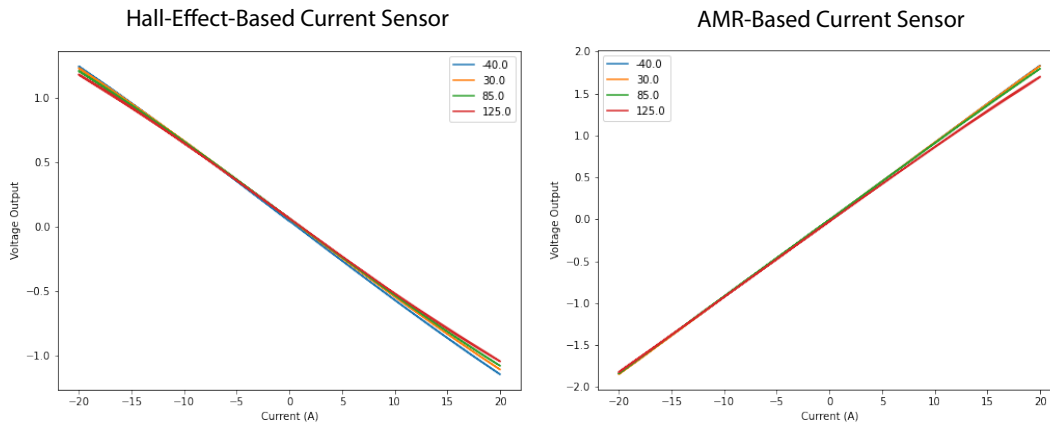


Figure 9: Offset and gain drift over temperature for Hall-effect and AMR-based current sensors

HOW ARE THESE SENSORS MANUFACTURED?

The manufacturing process, from silicon wafer front-end, to magnetic sensor process, to back-end integration, is just as critical and difficult to master as the basic TMR materials development. While competitors might focus exclusively on TMR materials development to achieve high sensitivity, the development of XtremeSense™ TMR has always been focused on integration of the technology directly in a standard CMOS process in order to ensure high-performance, low cost, and high reliability for mass-market adoption. All xMR technologies make use of ferromagnetic elements such as Ni, Fe and Mn which are not standard in Si CMOS manufacturing, and the possible impact of the TMR process on the rest of the CMOS circuitry needs careful consideration.

XtremeSense™ TMR is a CMOS compatible technology, and can be integrated between metal layers without consuming precious die area on the substrate nor requiring corresponding keep-out zones. To ensure quality, Allegro MicroSystems employs a state-of-the-art die manufacturing process on 200 mm-diameter silicon wafers.

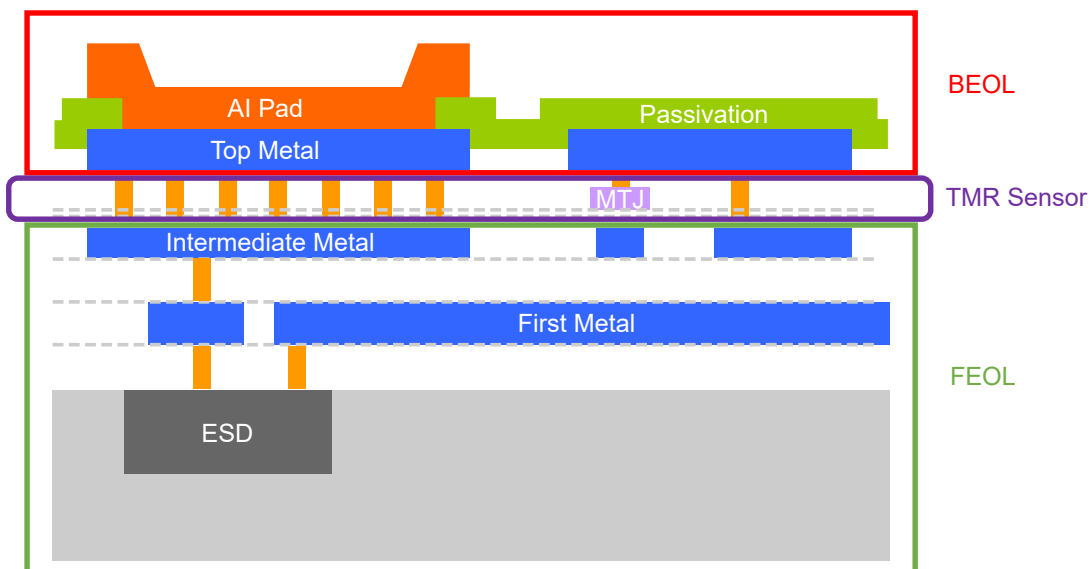


Figure 10: Illustration of XtremeSense™ TMR construction

The image below illustrates the complexity of a multi-die package versus the simplicity of the monolithic solution enabled by XtremeSense™ TMR technology.

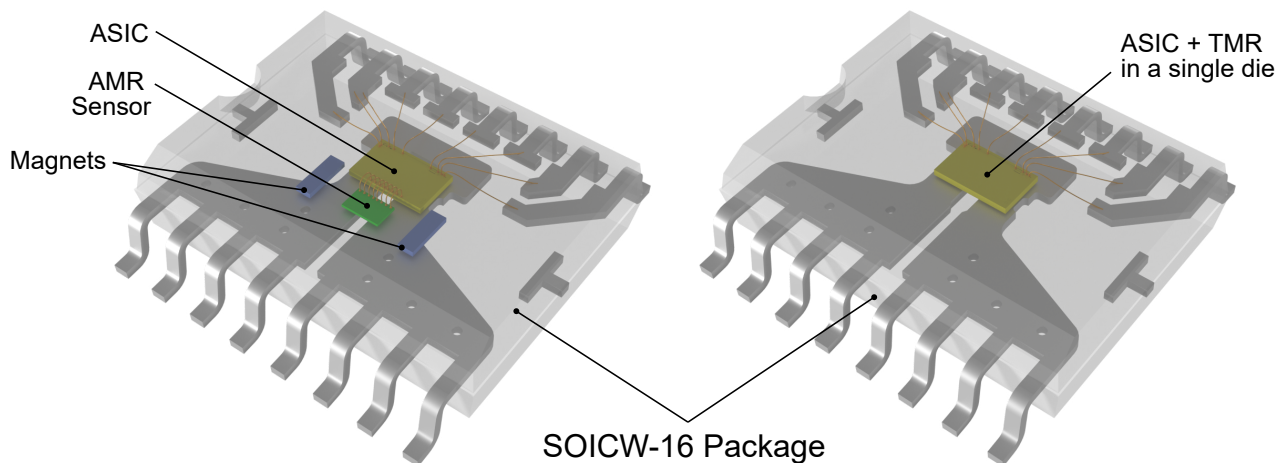


Figure 11: Multi-die package vs. monolithic package design

CONCLUSION

Allegro MicroSystems' XtremeSense™ TMR sensors showcase the advantages of TMR sensors to rethink and simplify solutions in the high precision, high current application space, offering designers clear advantages that allow them to avoid previous compromises in their designs.

Allegro's TMR sensor advancements in design, magnetic development, process integration, testing, and more delivered the intended results. TMR technology is gaining momentum within the semiconductor world. Allegro continues to lead, satisfying the current and emerging needs of its partners.

XtremeSense™ TMR enables Allegro's sensors to be a positive disruptive solution in the market place with premium performance, built-in robustness, and simple integrated chip designs.

Allegro offers a wide selection of magnetic sensors based on its patented XtremeSense™ TMR technology in automotive, industrial and consumer electronics applications. XtremeSense™ TMR technology is at the core of the Allegro magnetic sensor family, which includes integrated magnetic switches as well as angle, position and current sensors.

Revision History

Number	Date	Description
–	March 5, 2024	Initial release
1	June 26, 2024	Title Update

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