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SYSTEM ADVANTAGES OF HIGH-RESOLUTION WHEEL SPEED SENSING

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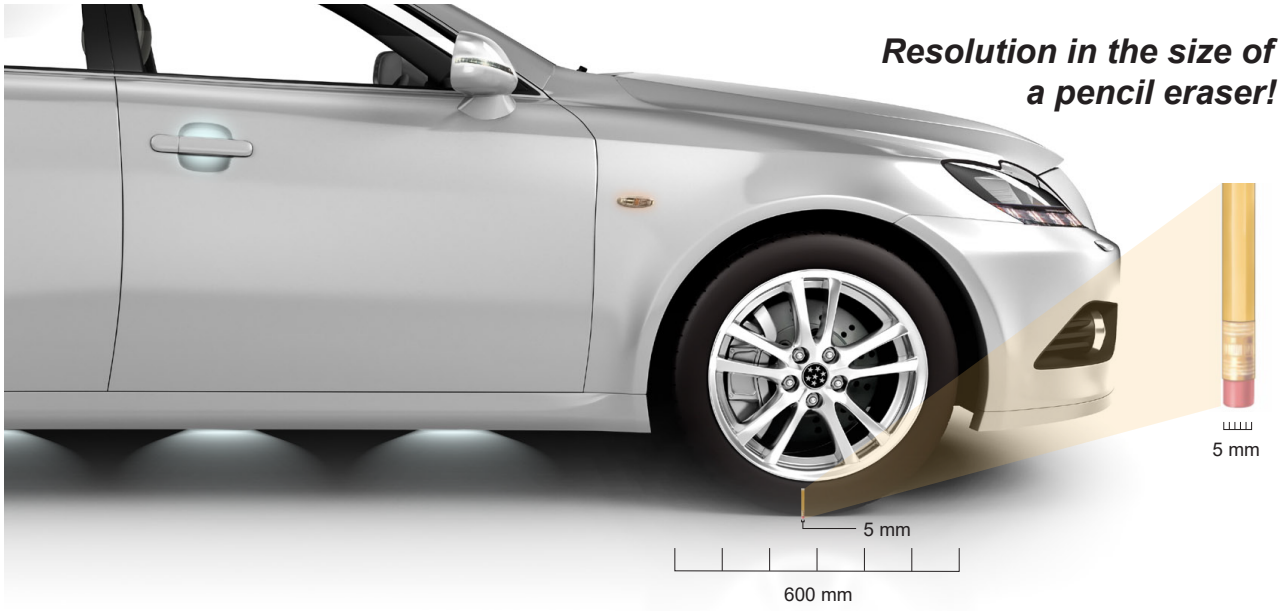

With the vehicle market trending toward fully automated driving in the near future, the need for high resolution in the wheel speed sensor (WSS) business becomes essential. Allegro, with input from market leaders, has released the first high-resolution wheel speed sensor (HRWSS) that targets this demand. The official production release puts Allegro in the position to propose a fully integrated high-resolution WSS IC to the market, supporting both passenger and truck vehicles. The ability to put an HRWSS on the market provides OEMs with the capability to assess future needs based on system performance. Allegro is committed to expanding the product family to adapt to the evolving needs of this business.

Advanced driver assistance systems (ADAS) are the primary application where high-resolution wheel speed sensing will become essential. The Society of Automotive Engineers (SAE) defines six Levels of Driving Automation™ in the SAE J3016™. These levels range from SAE Level 0™ (fully manual) to SAE Level 5™ (fully automated). ADAS starts at SAE Level 2™, where the vehicle can control both steering and accelerating/decelerating. The anti-braking system is a critical component in the evolution to higher ADAS levels, and Allegro believes that HRWSS supports ADAS SAE Level 3™ and greater.

With the adoption of park-assist and hill-hold systems, high-resolution wheel speed sensing must be able to provide highly accurate wheel position data at a faster rate compared to standard sensors. Park-assist applications depend on the SAE level and range, from simple parking trajectory guidance to the driver, up to fully automated parking without the driver input. Hill hold is a control performed at the vehicle level to prevent large backward movement when starting to drive up a hill. The faster the vehicle movement data is given at the automatic braking system (ABS), the better the hill-hold control. The Allegro HRWSS can give an encoder increment with direction data within a 5 mm tire displacement for a 2-meter tire circumference with a ring magnet of 48 pole pairs, being four times higher resolution than the standard WSS on the market. The Allegro high-resolution

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solution uses an established differential sensing method with advanced digital processing algorithms to generate additional output pulses with a controlled equidistant phase separation. Direction detection is updated on all output pulses, including high-resolution pulses, giving immediate direction change data to prevent uncontrolled vehicle movement. Other benefits of high-resolution wheel speed sensing are faster angular and air-gap vibration detection and recovery, and increased robustness for true wheel rotation detection, which becomes quite critical in park-assist or hill-hold applications.

ADAS is not the only application to benefit from high-resolution sensing; integrated tire pressure monitoring systems (iTPMS) will also gain an advantage from the additional information and the greater accuracy. An iTPMS uses and compares WSS data received from all four wheels to increase safety and improve fuel efficiency as deflated tires rotate at a greater angular velocity than correctly inflated ones. The Allegro giant magnetoresistance (GMR) based high-resolution WSS with four times more data and ultra-low jitter on all output pulses, including high-resolution pulses, provides a robust solution for the iTPMS market.

Key requirements and implications for high-resolution WSS applications are shown in Table 1. As the automotive industry defines the future of ADAS and safety systems, Allegro will be there to define the sensor solutions, working collaboratively throughout the supply chain to improve driver feel and, most importantly, safety.

The next sections highlight the features and accompanying benefits of the current solution.

Table 1: Key Requirements and Implications for High-Resolution WSS Applications

OEM Requirements	Allegro HRWSS Features	System Level Benefit
Higher resolution factor	Programmable option between 2× and 4×.	Increases number of increments for the same tire. Programmable resolution offers high flexibility to the OEM for optimizing their system.
Ultra-low jitter	Ultra-low jitter on all pulses including high-resolution pulses.	Industry-leading jitter performance over full air-gap range enables ultra-precise detection of vehicle position and movement to support new ADAS and iTPMS applications.
Direction detection on all pulses including high resolution	Direction is reevaluated on each pulse.	Higher resolution on direction detection.
Safety	ASIL D system with increased number of safety mechanisms at IC level.	IC redundancy and additional safety checkers enable SAE level 3 and above ADAS solutions.
Vibration immunity	Fast vibration detection and recovery.	World-class vibration immunity to guarantee correct detection of true vehicle movement (forward and reverse).
Wide magnetic field range	Fully proven GMR technology over extended temperature range, validated through volume production.	Enables flexibility of sensor position and ring magnet size.
Specific output protocol	AK and pulse-width (PW) output protocol encoding for different data.	Covers worldwide market demand and ECU capabilities.
EMC robustness	Integrated capacitor.	Capacitor inside UB package providing a robust integrated EMC solution.
Stray field immunity	Use of differential signals.	Reject common mode stray field preventing false pulses.
Wide operating ambient temperature range	–40°C to 150°C.	Grade 0 AEC-Q100 automotive standards, supporting harsh braking scenarios.

ALLEGRO HIGH-RESOLUTION WSS SOLUTIONS

High-Resolution Speed Sensing

The market standard for resolution factor is dependent on each use case. The general trend observed is 2× to 4×, depending on the application ring magnet.

For the higher SAE levels, the goal is to increase the number of increments up to the quantity needed to achieve a reasonable parking speed. It might seem that increasing the number of pole pairs on the ring magnet would be the easiest solution to increase position resolution. While this approach is valid to an extent, if the ring magnet has too many pole pairs, the amplitude of the differential signal reduces, which greatly impacts air-gap range and sensor mounting flexibility. A larger-diameter ring magnet could improve the differential signal amplitude; however, ring magnet diameter is limited by system size, so this approach implies a cost increase. The Allegro single-sensor HRWSS solution offers higher resolution through patented digital processing and is compatible with a large variety of ring magnets.

The Allegro HRWSS solution provides improved position and direction data for the same wheel rotation. In such cases, the Allegro high-resolution product offers 2× or 4× resolution (see Figure 1), achieving high resolution up to a reasonable parking speed of 30 km/h.

High-resolution WSS can also benefit applications in which the number of pole pairs on an existing magnetic encoder does not support sufficient resolution. For example, the Allegro high-resolution product using 2× resolution doubles the number of increments per magnetic cycle, preventing the need to redesign the magnetic target.

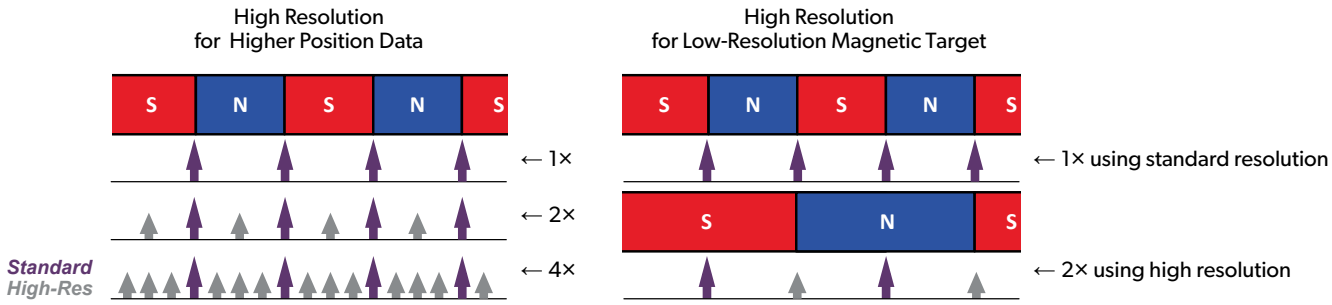


Figure 1: Allegro resolution capability (gray arrows indicate high-resolution pulse; purple arrows indicate standard-resolution pulse).

Equidistant Pulse Maintained Over Full Air-Gap Window

Wheel position data, which is key for park-assist applications, requires highly accurate pulse position data. Standard wheel speeds use thresholds at the steepest slope of the magnetic signals to generate equidistant output commutations. The main advantage to using the steepest slope is to reduce noise effect on the output switching accuracy. With high resolution, this same method with additional thresholds on the magnetic signal would suggest setting thresholds near or around the peak of the magnetic cycle, reducing edge jitter and duty cycle accuracy due to the slope and potential noise commonly seen on the signal. An example showing the switching accuracy for a 2× resolution using a standard threshold method is shown in Figure 2. Duty cycle variation can be observed from the combination of slope change and the introduction of thermal noise. The noise impact on pulse accuracy is increased as commutation points approach the signal peak.

Allegro uses a different approach than standard commutation to maintain good control of pulse accuracy and equidistant spacing. A patented processing algorithm uses real-time magnetic signals to determine the precise position at which to output a pulse, indicating positional displacement of the wheel.

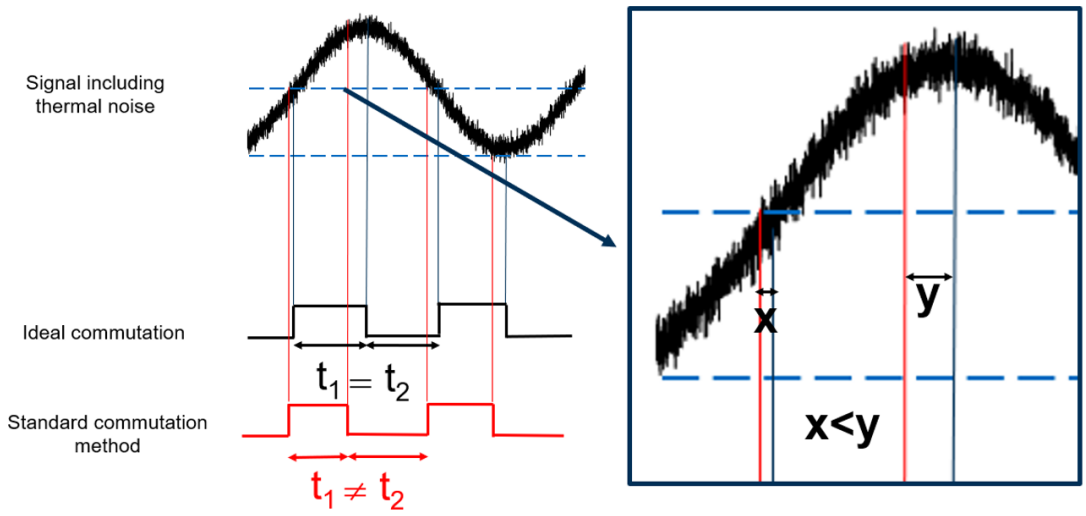


Figure 2: Threshold location effect on pulse position accuracy.

Direction Detection

The criteria for ADAS for SAE Level 3 and greater imply that full control of vehicle movement is required. At the sensor level, this translates into a direction update on each pulse, including high-resolution pulses.

In this case, the Allegro HRWSS is able to detect direction immediately on the next pulse, high resolution or not, which reduces the fraction of magnetic period needed to detect direction change from 0.5 T_{CYCLE} to 0.125 T_{CYCLE} for a 4× resolution sensor. This is illustrated in Figure 3, which compares direction change detection for a standard WSS versus a high-resolution WSS using 4× resolution, with direction data indicated by the arrows.

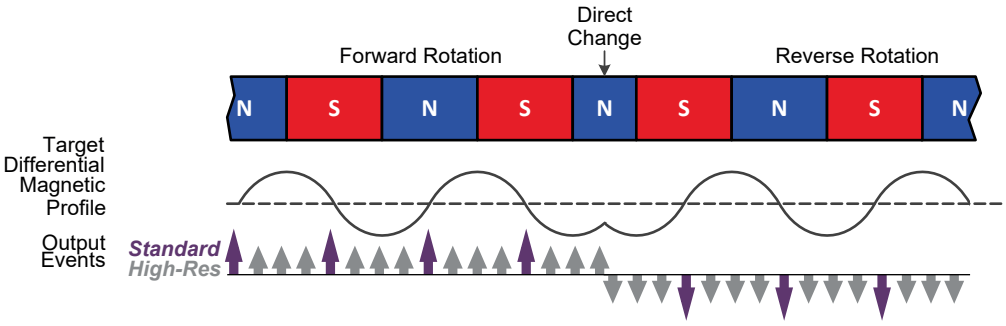


Figure 3: Direction change detection with high resolution.

Vibration Immunity and Fast Recovery

Park-assist and hill-hold applications require rapid detection of vehicle movement. The system must distinguish between vibrations and true rotation as soon as possible. Allegro wheel speed sensors use a dedicated algorithm for vibration detection. This feature is enhanced with high resolution because the period between two pulses is reduced compared to standard WSS, spanning a greater portion of the encoder period, increasing vibration detection capability. The same principle applies for vibration recovery with high resolution, as shown in the vibration scenario in Figure 4.

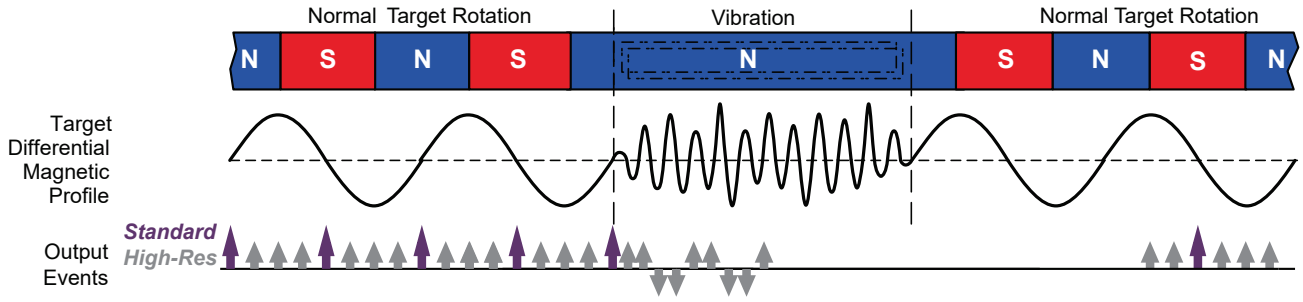
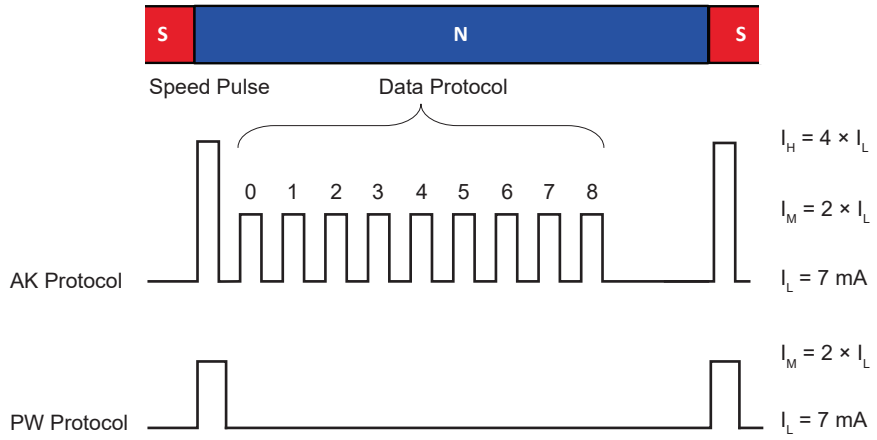


Figure 4: Vibration recovery using high resolution.

Possibility for New Data on High-Resolution Output Protocol

The Allegro HRWSS offers different output protocols to increase compatibility with electronic control unit (ECU) capabilities and market demand. The AK and PW protocols have been identified as the main output protocols and are supported by the Allegro HRWSS, as illustrated in Figure 5.



AK Bit #	Definition
0	Air-Gap Warning
1	Free Assignable
2	Free Assignable
3	Direction Validity
4	Direction
5	Free Assignable
6	Free Assignable
7	Free Assignable
8	Parity

Figure 5: Output protocol options.

High-resolution output pulses give the possibility to implement more data in the output protocol. Allegro uses a high-resolution AK output protocol to encode position data on three free assignable bits (5 through 7, as shown in Figure 6), while air-gap data are given on the same bits for the zero-crossing AK message. The Allegro sensor also dissociates zero-crossing pulses from high-resolution pulses using AK bit 2.

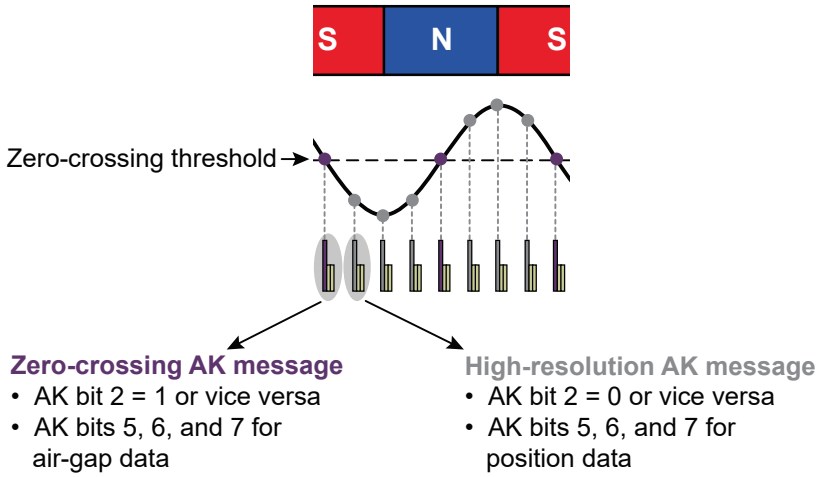


Figure 6: Distinction of high-resolution vs. standard pulses.

Jitter and iTPMS

Indirect tire pressure measurement is possible by comparing the wheel rotational speed of the four ABS sensors illustrated in Figure 7. Lower jitter enables a more accurate estimation of tire pressure, including the ability to detect smaller pressure variations in the tires and to simultaneously reduce the latency of warnings. With an edge jitter goal of < 0.07% of the magnetic period over the entire air-gap window, the use of magnetoresistive (MR) sensing technology is required. The Allegro high-resolution solution uses GMR elements with a sensitivity 50 times greater than Hall elements. The GMR technology enables ultra-low jitter over a wide air-gap window, on all pulses, including high-resolution pulses. Maintenance of low jitter on high-resolution pulses allows the ECU to use the additional pulses per magnetic cycle to reduce the detection time of a deflated tire.

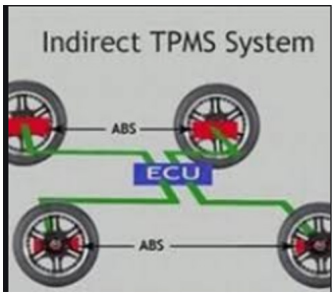


Figure 7: Indirect TPMS system using HRWSS.

CONCLUSION

With requirements growing more stringent to achieve the criteria for SAE Level 3 and greater, Allegro continuously improves signal processing methods and algorithms for high-resolution WSS to achieve current expectations and to exceed future expectations in braking and ADAS applications.

WORKS CITED

https://www.synopsys.com/automotive/autonomous-driving-levels.html

Revision History

Number	Date	Description	Responsibility
–	April 28, 2021	Initial release	S. Bastien, C. Graham
1	January 17, 2022	Lightly reworked to reflect the Allegro A19360 device	S. Bastien, C. Graham
2	January 13, 2023	Lightly edited per updates to technical writing style guidelines	S. Bastien, C. Graham

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