Is Your Current Sensing Architecture the Weak Link in Your Steering System?

Shaun Milano
Sr. Director, Applications Marketing
Allegro MicroSystems

The Unseen Challenge in ASIL-D Steering

Engineers developing Electric Power Steering (EPS) systems must deliver instantaneous and precise motor control to support modern ADAS and steer-by-wire architectures. A critical architectural decision often overlooked early in the design process is the choice of current sensing methodology.

Traditional current sensing approaches can increase hardware complexity, expand software development requirements, and consume valuable PCB area. These tradeoffs often force difficult compromises between performance, cost, and functional safety validation effort. As EPS systems move toward ASIL-D compliance, engineers are increasingly searching for architectures that simplify certification while improving control performance. Current sensing architecture plays a central role in achieving these goals.[1]

---

[1] Allegro MicroSystems – *Electric Power Steering Solutions*
https://www.allegromicro.com/en/applications/automotive/electric-power-steering

The Architectural Evolution of Current Sensing

Precise phase current measurement is fundamental to EPS motor control. The selected architecture determines not only the hardware BOM, but also the achievable control performance and software complexity. This has led to a clear architectural evolution as designers seek to overcome the limitations of earlier approaches.

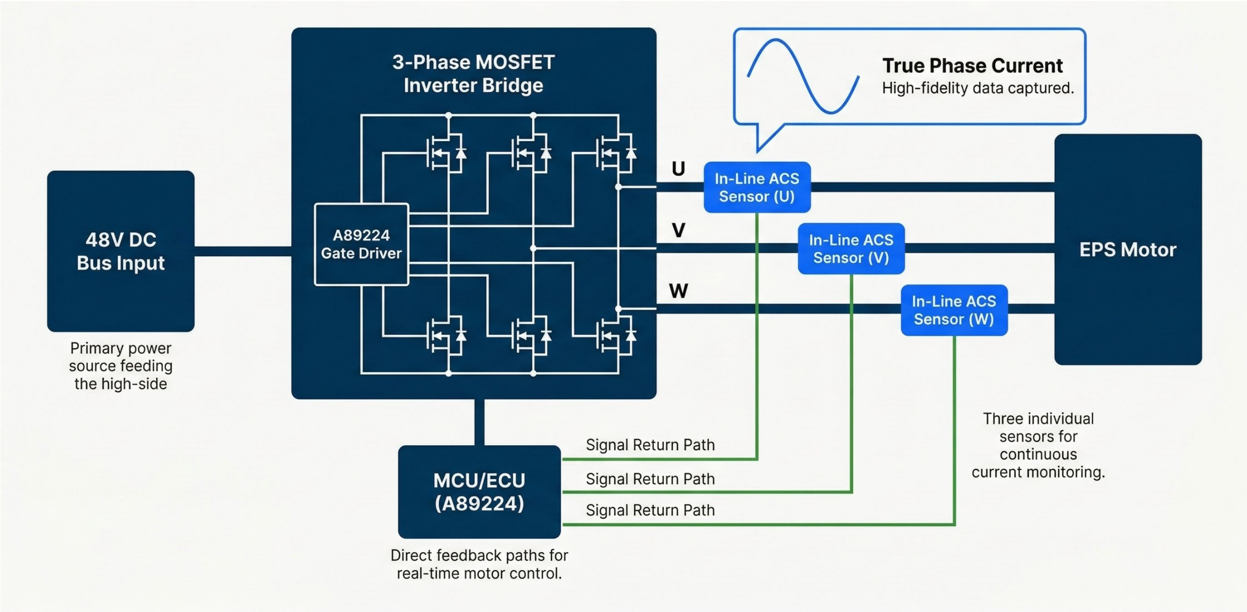

Figure 1. In-Line current sensing architecture for 48V EPS systems

Architecture 1: Traditional Single Low-Side Shunt Sensing

A common low-cost implementation uses a single shunt resistor on the inverter low side. While this approach minimizes component cost, it introduces significant limitations in demanding applications such as EPS.

- **Measurement Limitations:** Low-side shunt current can only be measured while the low-side MOSFET is conducting. This restricts sampling to short time intervals during the PWM cycle and creates measurement gaps at extreme duty cycles.[2] For EPS systems requiring fast torque response, these blind zones reduce measurement fidelity and control bandwidth.
- **Poor Low-Speed Performance:** Low-speed, high-torque conditions, such as parking maneuvers, create particularly narrow sampling windows. Under these conditions, the signal-to-noise ratio decreases and current reconstruction accuracy degrades.[2] These operating points are among the most critical for steering feel and driver perception.
- **Complex Reconstruction Algorithms:** Because the phase current is not measured directly, it must be reconstructed mathematically from intermittent samples. This reconstruction is sensitive to PWM timing variation, switching noise, and dead-time distortion, all of which translate directly into torque ripple and degraded steering smoothness.

---

[2] Allegro MicroSystems – *Recent Trends in Hall-Effect Current Sensing (Application Note AN295045)*
https://www.allegromicro.com/-/media/files/application-notes/an295045-recent-trends-in-hall-effect-current-sensing.pdf

- **Thermal and Size Penalties:** All inverter power flows through this single shunt. At the high currents required by EPS, this necessitates a large, high-power resistor that generates significant heat (I^2R losses) and consumes valuable PCB area, complicating thermal management.
- **Diagnostic Weakness:** This architecture offers very limited diagnostic capability. It is extremely difficult for the system to distinguish between a sensor fault, a wiring failure, or a genuine motor phase failure. This ambiguity makes a designer's life difficult, complicating the safety analysis and hindering the ability to build a robust fault-tolerant system.

Architecture 2: Multi-Phase Low-Side Sensing

To solve the complex software reconstruction problem, a common next step is to use a shunt for each low-side phase. It is possible to use two shunts and rely on reconstruction for the third phase, a full three-phase approach allows for redundancy and helps with safety certification. Multi-phase architecture does eliminate the need for mathematical reconstruction, providing a much cleaner signal to the control algorithm.

- **What it Doesn't Solve**: It does not solve the fundamental timing problem. Measurement is still restricted to the narrow window when the low-side MOSFETs are active, meaning performance at low and high duty cycles remains compromised. All low-side shunt architectures, whether using one, two, or three shunts, shift significant and unavoidable complexity into the system's firmware due to the fundamental timing problem. The software is burdened with two critical, timing-sensitive tasks. It must precisely **track inverter states** to know when a valid measurement can even occur and then perfectly **synchronize ADC sampling** to capture the signal within this narrow, and often noisy, time window.
- **The New Trade-Off**: This approach triples the board space for shunts and amplifiers and requires two or three dedicated high-speed ADC channels and pins on the microcontroller, consuming valuable system resources.

Architecture 3: In-Line (In-Phase) Sensing

The most robust architecture places the sensor directly in the motor phase path. This provides a continuous measurement of the actual current waveform without reconstruction and independent of the PWM state, solving both the reconstruction and timing problems simultaneously. (Figure 1)

This architecture can be realized with either in-line shunt resistors or with integrated magnetic sensors. While in-line shunts achieve the goal of continuous measurement, they still require much higher component counts, more expensive external amplifiers with high common-mode-rejection and still suffer from significant power loss (I^2R) with more complex thermal management and layout challenges. In emerging 48V systems, the amplifier must withstand high common-mode voltages and fast transients (di/dt), requiring expensive, specialized components and careful layout to achieve the necessary isolation and noise immunity. This is where an optimized, integrated solution provides a decisive advantage.

The Allegro Advantage: Optimized In-Line Sensing

Allegro's integrated magnetic current sensors are engineered to be the optimal implementation of the in-line sensing architecture, avoiding the limitations of both low-side and discrete in-line shunt approaches.[3]

Algorithmic Simplicity and Performance

Because the full, continuous waveform is available, control algorithms can use straightforward filtering or averaging techniques rather than complex reconstruction algorithms. The result is cleaner current signals, reduced algorithm complexity, and vastly improved low-speed torque control.

Minimal Power Loss and Thermal Burden

Shunt resistors dissipate power proportional to I^2R losses. Allegro integrated current sensors such as the **ACS37220** feature a primary conductor resistance of 100 μΩ.[4] At high currents, this produces 2-3x lower power dissipation than typical shunt resistor solutions. Lower power loss reduces thermal stress and improves system efficiency.[5]

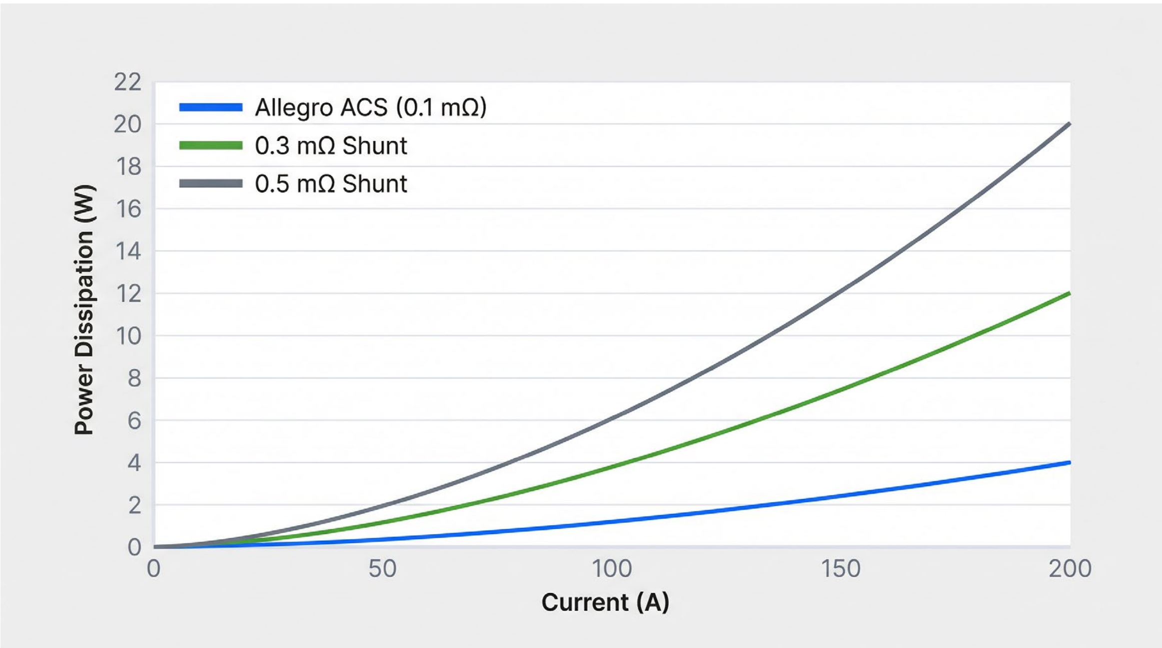

Figure 2. Current vs. power dissipation for shunt and Allegro fully integrated current sensor IC package

---

[3] Allegro MicroSystems – Magnetic Sensors as an Alternative to Shunt Resistors, https://www.allegromicro.com/en/insights-and-innovations/blogs/replace-the-shunt

[4] Allegro MicroSystems – ACS37220 Datasheet, https://www.allegromicro.com/-/media/files/datasheets/acs37220-datasheet.pdf

[5] Allegro MicroSystems – Integrated Current Sensors Overview, https://www.allegromicro.com/en/products/sense/current-sensor-ics/integrated-current-sensors

Reduced Board Space and Component Count

Integrated current sensors combine the conductor and signal conditioning into a single package. Compared to discrete shunt and amplifier implementations, integrated magnetic sensors can significantly reduce component count and PCB area.[5] The ACS37220, for example, is available in a compact 4x4 mm QFN package suitable for high-current automotive applications.[4] Full integration also allows for faster design cycles on new platforms.

A Streamlined Path to Functional Safety

Current sensing is a safety-critical element of EPS motor control, and the chosen architecture directly impacts the robustness of the safety concept and the complexity of the certification effort.

The Diagnostic Weakness of Low-Side Architectures

Low-side sensing architectures, particularly single-shunt designs, offer very limited independent diagnostic capability. It is extremely difficult for the system to distinguish between a sensor fault, a wiring failure, or a genuine motor phase failure, often requiring complex and indirect software methods to even attempt a diagnosis. This ambiguity complicates the safety analysis and can lead to a less robust system.

The In-Line Architectural Advantage

An in-line sensing architecture is inherently safer and more diagnosable. By placing a sensor on each motor phase, the system can perform straightforward and powerful diagnostics in real-time.

- **Plausibility Checks:** The firmware can continuously verify that the sum of the phase currents is approximately zero ($I_a + I_b + I_c \approx 0$). A deviation from this indicates a sensor fault or a wiring failure, allowing for immediate and unambiguous fault detection with minimal algorithm complexity.
- **Simplified Failure Analysis:** This direct measurement makes it far easier to design a system that can reliably detect and react to critical failures, which is fundamental to achieving a high ASIL rating.

While the architecture provides the foundation, the choice of component is equally critical. Allegro's integrated sensors are designed to provide a more reliable and feature-rich building block for the customer's safety concept.

- **Automotive-Grade Robustness:** The ACS37220 is an AEC-Q100 Grade 0 qualified device, ensuring it is highly reliable and designed to operate across the full automotive temperature range.
- **Reduced Complexity and Fewer Failure Points:** By integrating the sensing element and signal conditioning into a single IC, the Allegro solution dramatically reduces component count compared to a discrete shunt-and-amplifier circuit. A simpler system has fewer external points of failure, which simplifies the customer's safety analysis (e.g., FMEDA) and results in a more reliable design.
- **Built-in Diagnostics:** The ACS37220 includes valuable hardware features like an overcurrent detection output. This allows the sensor to provide a fast, independent fault flag directly to the microcontroller, offloading a critical monitoring task from the software and simplifying the safety implementation.

By choosing an in-line architecture with Allegro's robust, integrated sensors, designers are not just improving performance; they are building on a foundation that is inherently more diagnosable, more reliable, and better equipped to meet the stringent demands of functional safety.

Conclusion

The choice of current sensing architecture is a foundational design decision in modern EPS systems. While multi-shunt low-side architectures offer an incremental improvement over single-shunt designs, they fail to solve the fundamental timing limitations and add significant component count.

True in-line sensing is the superior architecture, and Allegro's integrated magnetic sensors represent its most optimized implementation. By providing accurate and continuous current feedback in a compact, low-loss, and pre-certified integrated solution, Allegro in-line current sensors enable EPS designers to improve performance and simplify the path to functional safety compliance. Allegro ICs are also 48V ready for next-generation steering systems, enabling designers a faster path to implementation in new platforms.

Explore EPS solutions from Allegro MicroSystems. ⟶