

Revolutionizing EV Charging With Allegro Technology

By Emil Pavlov





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Executive Summary

Consumer Roadblocks to Mass Adoption

Several barriers prevent consumers from fully embracing EVs:

- High cost of EVs and charging infrastructure.
- Insufficient charging station availability and inconvenient locations.
- Prohibitively long charging times compared to gasoline refueling.
- Range anxiety stemming from limited EV battery range and charging infrastructure.
- Concerns about charger reliability and lack of standardization across charging networks.
- While promising, bidirectional charging lacks availability, cost transparency, and standardization.

EVCI System Challenges

To meet the growing demand for EV charging, manufacturers and developers face several system-level challenges:

- Demand for higher power chargers and increased power density to facilitate faster charging.
- The transition to 800 V systems necessitates advanced thermal management solutions.
- Increased charger density requires strategic placement and a mix of charging speeds.
- Cost-effectiveness hinges on reducing manufacturing and installation costs.
- High operational uptime through robust design and predictive maintenance is crucial.
- Grid integration and capacity require load management strategies and potential grid upgrades.

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Introduction: The EV Charging Challenge

The global electric vehicle (EV) market is experiencing remarkable growth. In 2023, the global EV market represented 18% of all cars sold worldwide [1]. However, a critical hurdle remains toward wider adoption: consumer anxieties about EV charging. Despite global EV growth, concerns about charging time, range, the availability of charging stations, and charger reliability prevent many potential buyers from embracing electric vehicles. These hesitations not only impact individual purchasing decisions but also pose a significant challenge to the automotive industry's ambitious electrification goals.

This whitepaper delves into the complexities of EV charging infrastructure (EVCI), examining the key challenges and opportunities that lie ahead. This whitepaper explores how consumer concerns translate into system-level requirements for EV charger manufacturers, driving the need for faster charging, increased power density, greater efficiency, and enhanced reliability.

Allegro MicroSystems, a leading provider of power and sensing solutions for motion control and energy-efficient systems, is committed to enabling a seamless and sustainable transition to electric mobility. This whitepaper showcases Allegro's innovative semiconductor solutions, including its isolated gate drivers, current sensors, and thermal management solutions, which are specifically designed to address the demanding requirements of next-generation EV chargers.

Consumer Concerns: The Roadblocks to Mass Adoption

To accelerate the transition to electric mobility, it is crucial to address consumer concerns head-on and provide clear, data-driven solutions. Key barriers identified through consumer surveys and studies are examined next.

Cost/Affordability

While EV prices are steadily declining, the initial cost remains a significant barrier. A 2023 Autolist.com survey found that 42% of respondents cited cost as their top concern. This highlights the need for more affordable options. A 2023 EV Driver Survey [2] revealed a wide price range, with the Tesla Model 3 averaging 49,454 US dollars and the Chevrolet Bolt at 27,756 US dollars.

Beyond the sticker price, charging costs are influenced by home charging setup, public charging costs, and time spent charging. 78% of electric vehicle owners can charge their cars at home [2], but electricity prices are not consistent across all regions, and free Level 2 charging is hard to find in some regions [3]. As a result, EV drivers are less satisfied with public charging options, especially pricier DC fast charging, which is often necessary when away from home [4]. The time spent charging is also a perceived cost, particularly for those relying on public charging. A 2023 Shell Recharge survey found that 57% of respondents desire charging locations that allow them to work while charging.

Installing a Level 2 home charger for faster charging requires an upfront investment of 500 to 2,000 US dollars [5], a significant expense, especially for lower-income households. A 2023 Autolist.com survey [6] found that 46% of respondents making under 30,000 dollars cited upfront costs as a major hurdle, compared to 33% of those making over 30,000 dollars. While EVs often have lower operating costs over their lifespan, only 20% of respondents in the 2023 EV Driver Survey cited cost savings as a primary motivator.

Lack of Charging Stations

The lack of robust and accessible charging infrastructure is a major roadblock to widespread EV adoption. This concern stems from a shortage of charging stations, inconvenient locations, and difficulties in installing home chargers. J.D. Power [7] found that nearly half of potential EV buyers (49%) are deterred by the limited availability of charging stations. The European Automobile Manufacturers' Association (ACEA) estimates that Europe alone needs 3.4 mil-

lion operational public charging points by 2030, a tenfold increase from 2021.

Beyond the sheer number of chargers, strategic placement is crucial. A J.D. Power study [4] found that 20% of EV drivers experience frustration due to inconvenient charger locations, and 45% of respondents cited charging locations being too far apart as a major concern [2]. This highlights the need for strategically placed chargers, particularly in high-traffic areas.

Home charging is not feasible for a large segment of the population that lack dedicated off-street parking. The World Resources Institute found that less than 10% of US residents have public EV charging within a quarter mile of their home. These challenges underscore the need for a comprehensive and strategic approach to EVCI development, ensuring chargers are strategically placed and accessible to all.

Charging Speed

For many drivers considering switching to an electric vehicle, charging time is a major concern. People are accustomed to the quick refueling experience of gasoline cars, which EVs don't yet match. This "time-to-charge" disparity is a significant factor in purchasing decisions. EV drivers want to spend less time waiting for their car to charge and more time driving, especially when they're on the go. Faster charging would make EVs much more convenient and appealing to a wider range of drivers. It would also help reduce "range anxiety"—the concern people have about running out of charge before reaching their destination. Faster charging will make the EV experience closer to the familiar ease of refueling a gasoline car.

Studies show that even though charging technology is improving, charging time remains a pain point. Several studies [4][7][8] reveal increasing dissatisfaction with charging times. The 2023 study found that cost and speed were the least satisfying aspects of public charging, with satisfaction for DC fast charging speeds steadily declining. At home, using a Level 1 charger is much slower and less convenient than a Level 2 charger [8]. Another study [9] found that people want even faster charging, especially for long journeys. No one wants to add a significant amount of time to their trip just to charge their car.

Range Anxiety

Range anxiety, the fear of running out of charge, is a major barrier to EV adoption. This stems from perceived limitations of EV batteries and charging infrastructure compared to the well-established network of gas stations.

Data confirms this concern. Autolist.com [6] found that "worried about range on a single charge" was the third most common reason for not buying an EV, cited by 39% of respondents. This concern is particularly acute for longer trips. A survey [4] found that 46% of those who had used DC fast charging on a road trip said charging locations were "too far apart." Another survey [3] found that range anxiety has replaced upfront cost as the second most important reason not to buy an EV, highlighting the need to address this issue.

Interestingly, the average EV range is already sufficient for most daily trips, sitting at 215 to 249 miles [5]. This means a US citizen needs to charge once or twice a week on average, while Europeans only need to charge every other week.

Charger Reliability

Reliable EVCI is crucial for a positive EV ownership experience. A non-functional charger can derail a trip, amplifying range anxiety and creating a negative perception of EV ownership.

Charger reliability remains a significant challenge. A survey [2] found that the most significant concern for users of public DC fast-charging networks was encountering broken or non-functional chargers. This is corroborated by two other surveys [4][10], which found that 20% of users experienced "non-charge visits" due to malfunctioning stations.

These malfunctions can impact various aspects of the charging process, including network failures, payment system failures, charger initiation failures, vehicle-to-charger communication failures, and unmonitored charger failures [11].

The consequences go beyond inconvenience, with drivers expressing frustration and anxiety, especially on longer trips. Frequent media reports about charging network reliability issues further erode consumer confidence [3].

Adding to the complexity is the lack of standardization across charging networks. Two studies [9][12] reveal that EV drivers are often frustrated by the need for multiple apps and charging cards to access different networks, hindering interoperability and consistent reliability.

Bidirectional Charging

The idea of an electric car that not only takes power from the grid but also gives it back is compelling. Imagine using your EV to power your home during an outage or even selling energy back to the grid for a profit. This is the promise of bidirectional charging, a technology poised to revolutionize how people think about electric vehicles. However, for many consumers, this exciting future feels distant because bidirectional charging remains largely unavailable.

A J.D. Power study [8] found that 35% of premium EV owners and 29% of mass-market EV owners are interested in paying extra for bidirectional charging. This strong interest highlights a desire for EVs to be more than just vehicles; consumers want them to be active participants in the energy ecosystem. However, several roadblocks prevent this technology from gaining widespread traction.

Most EV manufacturers currently don't offer bidirectional charging capabilities, restricting consumer choice and forcing them to rely on traditional unidirectional charging. This lack of options leaves consumers feeling stuck on the sidelines of a potentially transformative technology. The cost of bidirectional EVCI remains a mystery for many consumers, creating hesitation and preventing them from making informed decisions. The lack of standardized technology and clear information about compatibility with different vehicles and grid systems is a major concern. Consumers are left wondering if bidirectional chargers will work with their current or future EV model, discouraging them from investing in a technology that might quickly become obsolete.

Many consumers are simply unaware of bidirectional charging and its potential benefits. Beyond the lack of options and cost uncertainties, consumer anxieties are a major roadblock for bidirectional charging. A study by the World Resources Institute [13] found that 94% of respondents were concerned about at least one aspect of VGI, with data privacy being the most frequently cited concern (73% of respondents). This anxiety stems from the need for bidirectional charging systems to access data about vehicle location, charging schedules, and energy usage. Consumers are understandably wary of sharing this information, fearing potential misuse or privacy breaches. Concerns about battery life are also prevalent, with 80% of respondents expressing worry about the impact of bidirectional charging on their EV battery's longevity. This anxiety is understandable, given that EV batteries are a significant expense, and consumers want to ensure their investment lasts.

Understanding EV Charging Infrastructure (EVCI)

Consumer concerns about EV charging are not merely individual preferences; they translate into critical challenges for EVCI system manufacturers. Addressing these challenges is paramount to creating a charging experience that is convenient, reliable, and affordable, ultimately driving the mass adoption of electric vehicles.

To fully grasp the complexities of these challenges, it is essential to understand the diverse landscape of EV charging solutions available today. EV chargers are broadly categorized into different levels, each with its own set of characteristics, advantages, and limitations. How consumer concerns shape the technical requirements and innovations needed in EVCI, the types of EV chargers, and how they factor into the challenges faced by EVCI manufacturers are examined next.

Types of EV Chargers: A Spectrum of Solutions

Level 1 chargers are the most basic form of EV charging and are typically provided with the vehicle at the time of

purchase. These chargers use a standard 120V AC household outlet, making them incredibly convenient for home charging. Level 1 chargers are the most cost-effective option, often requiring no additional installation costs for homeowners with existing outlets. Their compatibility with standard outlets makes them widely accessible, requiring no specialized electrical infrastructure. The extended charging times associated with Level 1 chargers make them well-suited for overnight charging when the vehicle is not in use. However, Level 1 chargers deliver the slowest charging speeds among all charger types. This can be a significant drawback for users who require quicker recharging or have limited time for charging. Level 1 chargers are primarily used for home charging, providing a convenient way to replenish the vehicle's battery overnight or during periods of low usage.

Level 2 chargers offer a significant step up in charging speed compared to Level 1 chargers. These chargers operate on a 240V AC circuit, similar to those used for electric dryers or ovens, and require dedicated installation. Level 2 chargers deliver significantly faster charging speeds than Level 1, making them suitable for both home and public charging scenarios. Level 2 chargers are compatible with a wide range of EVs, making them a versatile choice for public charging stations. Installing a Level 2 charger involves the cost of a dedicated electrical circuit, which can vary depending on the specific location and existing electrical infrastructure. Level 2 chargers are a popular choice for homeowners who desire faster charging speeds than Level 1, reducing the time required to fully charge their EVs. Level 2 chargers are commonly found in public charging stations, workplaces, and multi-unit dwellings, providing a convenient and relatively fast charging option for EV owners on-the-go.

DC fast chargers (DCFC) are designed for rapid charging, making them ideal for long-distance travel and situations where minimal downtime is crucial. Unlike Level 1 and Level 2 chargers, which use AC current, DCFCs convert AC power to DC directly, bypassing the vehicle's onboard charger and delivering power directly to the battery. DCFCs offer the fastest charging speeds available, capable of providing a substantial charge in a fraction of the time required by Level 1 or Level 2 chargers. For instance, a Tesla Model 3 with a 75-kWh battery requires over 12 hours to charge using a 6.6-kW onboard charger; however, this time can be dramatically reduced to approximately 10 minutes with a 500-kW charger [14]. DCFCs are strategically located along major highways and travel corridors, enabling EV owners to quickly recharge their vehicles and continue their journeys. DCFCs are increasingly found in urban charging hubs, catering to the needs of EV owners who reside in densely populated areas with limited home charging options. However, DCFCs are more expensive to install and maintain than Level 1 and Level 2 chargers due to their more complex technology and higher power requirements.

High-power charging (HPC) and megawatt charging systems (MCS), which are even faster charging technologies aimed at both light-duty passenger vehicles and heavy-duty vehicles like trucks and buses. HPC emerged as a response to the increasing demand for faster charging speeds, driven by the adoption of larger battery capacities in electric vehicles. Key players like Tesla, with its Supercharger network, and companies like ABB and Ionity have been instrumental in pushing HPC adoption. HPC, with its higher voltage and current capabilities, is already being deployed, particularly in Europe and China, to support the charging needs of a wide range of electric vehicles. This technology can deliver a substantial amount of charge in a short period, making it suitable for long-haul trucking and commercial vehicle applications, as well as offering reduced charging times for passenger EVs.

Meanwhile, MCS, which operates at megawatt power levels, is primarily targeted towards heavy-duty commercial vehicles due to its extremely high power output. MCS is still largely in the standardization phase, led by the Charging Interface Initiative (Char-IN), with various stakeholders working together to define the technology specifications and protocols. Several manufacturers are actively involved in developing and testing MCS prototypes, paving the way for its future implementation. Once implemented, MCS will enable ultrafast charging for heavy-duty vehicles, potentially reducing charging times to minutes rather than hours. The widespread adoption of HPC and MCS will be crucial for the electrification of transportation across all vehicle segments, paving the way for a cleaner and more sustainable future.

Table 1: Charging Speeds and Typical Use Cases Across EV Charger Levels

Charging Type	Current	Power Level (kW)	Max. Voltage (V)	Max. Current (A)	Typical Charging Time	Where Found
Level 1	AC	1 to 2	120 (US – Single phase)	8 to 12	8 to 12 hours or more	Home (US)
Level 1	AC	3 to 7	230 (EU – Single-Phase)	16 to 32	8 to 12 hours or more	Home (EU)
Level 2	AC	7 to 19.2 (US) / 22 (EU)	208 to 240 (US – Double-Phase) / 400 (EU – Three-Phase)	16 to 80 (US) / 16 to 32 (EU)	1.8 to 13.3 hours	Home, Workplace, Public, Hotels, Parking Garages
DCFC (Direct Current Fast Charging)	DC	50 to 350	400 (800 less common)	100 to 350	20 minutes to 1 hour	Public (especially along highways and in cities)
High-Power Charging (HPC)	DC	350	920	500	LDV 10 to 30 mins, HDV 0.5 to 4 hours	Public charging hubs
Megawatt Charging System (MCS) (still in definition)	DC	Up to 3.75 MW	1250	3000	HDV <1 hour	Public charging hubs for HDV

While these various EV charger levels cater to a range of needs and charging speeds, they also present unique challenges for EVCI system manufacturers. These challenges directly impact the consumer concerns of charging speed, cost, reliability, and the availability of EVCI.

To address these consumer concerns, EVCI manufacturers must overcome several key system-level hurdles. It is important to consider these system challenges in more detail.

EVCI System Challenges

The rapid adoption of electric vehicles presents a unique set of challenges for developing a robust and efficient charging infrastructure. These challenges are not merely technical hurdles; they directly impact the consumer experience, influencing perceptions of EV ownership and ultimately affecting the pace of EV adoption. To create a charging experience that is convenient, reliable, and affordable, EVCI manufacturers must address these system-level challenges head on.

Higher Power Demands

The desire for faster EV charging is a direct response to consumer expectations shaped by the convenience of quickly refueling gasoline-powered vehicles. The different levels of EV chargers offer varying charging speeds, with Level 1 and Level 2 chargers often falling short of consumer expectations for rapid charging. To meet these expectations, EVCI systems must deliver significantly more power to the vehicle battery in a shorter time, necessitating higher power chargers.

This push for faster charging not only translates to higher power levels but also often requires increased power density within the EVCI system. Space constraints can be a significant factor in charger design, particularly for pole-mounted chargers or when retrofitting older chargers to meet newer standards and expectations. In some cases, system manufacturers may want to increase the power output of a charger without changing the chassis size, further

emphasizing the need for higher power density.

The automotive industry is rapidly transitioning from 400 V to 800 V battery systems in electric vehicles. This transition is fueled by the ever-increasing demand for faster charging and improved performance. This already reaches the limitations of current EVCI, particularly Level 1 and Level 2 charging, which offer maximum power levels of 1.92 kW and 19.2 kW, respectively. Such power levels are inadequate for meeting the needs of EV users who seek shorter charging times, especially given the larger battery capacities found in modern EVs.

The shift to 800 V systems brings numerous benefits, including:

- **Reduced charging times:** Higher voltage enables faster energy transfer, significantly reducing the time required to charge an EV battery.
- **Increased efficiency:** 800 V systems can operate with lower currents, minimizing energy losses during transmission and improving overall efficiency.
- **Smaller cable sizes:** Lower currents allow for the use of thinner and lighter cables, reducing vehicle weight and cost.

However, this transition also presents challenges, particularly in terms of thermal management. As power density increases, so does the need for more effective cooling solutions.

WBG technology, with its superior performance characteristics, is uniquely positioned to address the demands of 800 V systems. SiC and GaN devices offer lower power losses, higher switching frequencies, and higher junction temperatures compared to traditional silicon devices [15]. These characteristics make them ideal for handling the higher voltages and power levels associated with 800 V systems.

Here is a comparison table highlighting the key differences between 400 V and 800 V systems:

Table 2: Trade-offs of System Voltage for EV Chargers

Feature	400 V System	800 V System
Charging Speed	Slower	Faster
Efficiency	Lower (especially in charger)	Higher (especially in powertrain)
Current Levels	Higher	Lower
Cable Size and Weight	Thicker and heavier	Thinner and lighter
Cost	Currently lower	Currently higher
Component Availability	More readily available	Still emerging
WBG Suitability	GaN and SiC (with appropriate topologies)	SiC preferred, GaN possible

The transition to 800 V systems marks a significant step forward in the evolution of electric vehicles, enabling faster charging, improved performance, and increased efficiency. WBG technology, with its ability to handle higher voltages and power levels, is poised to play a crucial role in this transition, paving the way for a future where EVs are not only more sustainable but also more practical and appealing to consumers.

Increased Charger Density

The rapid growth of the EV market, driven by increasing consumer interest and supportive government policies, necessitates a corresponding expansion of the EVCI. Simply put, more EVs on the road require more chargers to support them. However, it's not just about increasing the sheer number of chargers; it's also about ensuring that these chargers are strategically deployed to maximize their utilization and convenience. This involves a multifaceted approach that includes strategic placement of chargers where EV drivers need them most, such as along major highways and travel corridors, in urban centers and shopping districts, and at workplaces and multi-unit dwellings. Additionally, deploying a mix of charging speeds, including Level 2 AC chargers for longer stops and DC fast chargers

for quick top-ups, is essential to cater to diverse charging needs and optimize charger utilization. Finally, the charging infrastructure must be designed with scalability in mind to accommodate the continued growth of the EV fleet and adapt to future technological advancements. For example, as one study [16] points out, the number of public and workplace chargers will need to increase by about 27% compounded annually from 2024 to meet projected demand.

Cost-Effectiveness

While the performance and availability of EV chargers are paramount, the cost of these chargers is a critical factor influencing their widespread deployment. For electric mobility to be accessible to a broad range of consumers, EV charging solutions must be affordable for both individuals and businesses investing in EVCI. This necessitates a focus on reducing manufacturing costs through advancements in power electronics technology, particularly the adoption of wide-bandgap (WBG) semiconductors. WBG devices offer superior performance characteristics compared to traditional silicon-based devices, enabling the development of more efficient, compact, and ultimately, more cost-effective chargers. Additionally, streamlining the installation process of EV chargers can significantly reduce deployment costs. This includes designing chargers that are easy to integrate with existing electrical infrastructure and minimizing the need for specialized installation labor. Finally, government subsidies and incentives play a crucial role in making EV chargers more affordable for consumers. These incentives can take various forms, such as tax credits for charger purchases, rebates for installation costs, and grants for businesses investing in EVCI.

Reliability and Operational Uptime

The reliability of EV chargers is paramount to ensuring a positive user experience and maximizing the return on investment for charging station operators. Charger downtime translates to lost revenue for operators and, more importantly, can lead to frustration and inconvenience for EV drivers. To ensure high operational uptime, EV chargers must be designed to withstand the rigors of continuous operation in various environmental conditions. This includes using high-quality components, implementing robust thermal management systems, and ensuring adequate protection against voltage surges and other electrical faults. Furthermore, integrating smart technologies into EV chargers can enable predictive maintenance, where potential issues are identified and addressed before they escalate into major failures. This proactive approach can significantly reduce downtime and maintenance costs. Lastly, the ability to remotely monitor charger performance and diagnose issues is crucial for minimizing downtime. This allows operators to quickly identify and resolve problems, often without the need for on-site technicians. A briefing [11] highlights the importance of addressing various types of charger malfunctions, including network failures, payment system issues, and communication errors between the charger and the EV.

Grid Integration and Capacity

The increasing demand for EV charging, driven by the rapid adoption of EVs, presents significant challenges for the electrical grid. As more EVs are plugged in, especially during peak hours when residential energy consumption is already high, the load on the grid increases significantly. This can lead to voltage fluctuations, transformer overloads, and even blackouts if the grid infrastructure is not adequately prepared. To ensure a smooth transition to electric mobility and meet consumer expectations for reliable and convenient charging, it is crucial to consider the impact of EV charging on the grid and implement strategies to mitigate potential issues.

Load management strategies can help distribute EV charging load more evenly throughout the day, minimizing stress on the grid during peak hours. This can involve incentivizing EV owners to charge their vehicles during off-peak hours, using smart charging technologies to automatically adjust charging rates based on grid conditions, and coordinating charging with renewable energy generation. In some cases, grid upgrades may be necessary to accommodate the increased load from EV charging. This could involve upgrading transformers, installing new distribution lines, and implementing advanced grid technologies such as voltage regulation and dynamic line rating. The "Transportation Electrification Impact Study" [17] emphasizes the importance of considering grid upgrades in EVCI

planning, highlighting the need for a holistic approach that considers both the charging network and the supporting grid infrastructure. Vehicle-to-grid (V2G) technology offers a promising solution to grid integration challenges. V2G technology allows EVs to not only draw power from the grid but also feed power back into the grid when needed. This bidirectional energy flow can help balance grid load, support renewable energy integration, and even provide ancillary services to the grid, such as voltage support and frequency regulation.

Driving EVCI Innovation: Charged by Allegro's Semiconductor Solutions

The WBG Advantage: Enabling Next-Generation EVCI

WBG semiconductors, encompassing materials like gallium nitride (GaN) and silicon carbide (SiC), have emerged as the cornerstone for crafting high-performance EV charging solutions. These next-generation materials possess superior properties that directly address the system-level hurdles encountered in EV charger design. One of the most significant advantages is their higher breakdown voltage. SiC and GaN materials exhibit breakdown field strengths roughly ten times greater than silicon [18]. This inherent robustness allows engineers to create more compact and efficient designs, especially for high-power applications like EV charging. This translates to smaller charger footprints and a reduction in material costs, a crucial factor in the cost-sensitive automotive industry.

Another key benefit of WBG devices lies in their faster switching speeds. They can transition between on and off states significantly faster than their silicon counterparts. This rapid switching capability leads to several advantages. First, it drastically reduces switching losses [19]. For example, a 4.5 kV SiC JBS diode has a reverse-recovery current that is less than one fifth of a comparable Si 4.5 kV p-i-n diode. Furthermore, the switching characteristics of GaN diodes remain almost unchanged over a wide temperature range, according to the same paper. This enhanced efficiency not only minimizes wasted energy but also reduces heat generation within the charger. Consequently, smaller passive components, such as inductors and capacitors, can be employed, further contributing to the development of compact charger designs. Second, faster switching speeds enable faster response times, a critical factor in implementing advanced safety features like short-circuit protection. This rapid response is particularly crucial for high-power applications like EV charging, where safety is paramount.

Finally, WBG materials exhibit improved thermal conductivity compared to silicon. They can dissipate heat more effectively, allowing for higher power densities within the charger. This reduces the reliance on complex and bulky cooling systems, leading to smaller charger sizes, lower costs, and increased reliability. One paper [20] examines various cooling techniques for WBG inverters, emphasizing the impact of improved thermal conductivity on charger design. For instance, this paper highlights a study where double-sided cooling of a SiC power module resulted in a 35% reduction in thermal resistance. Additionally, a study using a WBG switch in a special high-temperature package with integrated microchannel liquid cooling showed results for peak power dissipation capability up to 5 kW/cm², significantly higher than that of a Si die. One paper [21] states that "Silicon Carbide technologies show higher efficiency, from 8% to 12%, over the commonly used IGBT technology for 750V dc-link." This signifies a potential efficiency improvement of 8% to 12% in traction inverters by switching from Si to SiC. Another paper [14] states that the state-of-the-art EV WPT charger products exhibit only 90% to 93% efficiency. However, a GaN-based single-stage bidirectional series-resonant DAB AC/DC converter for a 48 V battery achieved a peak efficiency of 97.2% and a power density of 3 kW/L. Another paper [19] shows that the static and dynamic characteristics of SiC SBD in antiparallel with Si IGBT were improved, in which the power losses were reduced by 10%. One document [15] states that for motor drive applications, the power density is improved by 206% to 334% when using WBG compared to Si-based EV systems. An article [22] shows that a GaN-based design for power-factor correction (PFC) circuits can reach a power density of 9.5 kW/L, excluding heatsink and EMI filter volumes. Another article [18] shows that a commercially available 10.5 kW OBC with Si MOSFETs has a power density of 0.6 kW/L. By replacing Si MOSFETs with SiC MOSFETs, the power density can be increased to 2 kW/L. By using 10 kW GaN devices, the power density can reach 4 kW/L. WBG devices have a high junction temperature, T_{jmax} , of 175°C to 200°C (Si T_{jmax} = 150 °C). This means SiC can

operate at 25°C to 50°C higher temperatures than Si. In essence, WBG semiconductors offer a compelling suite of advantages that directly address the challenges of EV charger design. Their superior material properties pave the way for creating more efficient, compact, reliable, and cost-effective charging solutions, accelerating the transition towards a future dominated by electric vehicles.

Allegro's Solutions: Delivering on the Promise of WBG Technology for Superior EV Charging

The automotive industry is undergoing a profound transformation, driven by the increasing demand for electric vehicles (EVs). Consumers are eager to embrace electric mobility, but concerns about charging times, charger availability, and cost remain significant barriers to widespread EV adoption. Allegro MicroSystems is at the forefront of this transformation, providing innovative semiconductor solutions that address these challenges and enable a new era of superior EV charging experiences. Their expertise in power and sensing technologies, combined with their commitment to innovation, allows them to deliver solutions that meet the demanding requirements of next-generation EVCI.

Isolated High-Voltage Gate Drivers for WBG

Allegro MicroSystems understands the critical role that isolated gate drivers play in maximizing the potential of WBG semiconductors, such as GaN and SiC, for EV charging applications. Allegro's isolated gate drivers are carefully designed to optimize the performance of these advanced semiconductors, enabling a new era of superior EV charging experiences.

Allegro's isolated gate drivers are specifically designed to harness the high switching frequencies inherent in GaN and SiC devices. This capability translates to significantly reduced switching losses, leading to enhanced efficiency and faster energy transfer during the charging process. By minimizing power dissipation, Allegro's gate drivers contribute to faster charging times, allowing EV owners to spend less time plugged in and more time on the road.

The increased efficiency enabled by Allegro's gate drivers allows for more compact EV charger designs. The reduced heat generation associated with WBG technology, coupled with optimized gate drivers, allows for smaller heat sinks and other passive components. This miniaturization contributes to a reduction in the overall size and weight of EV chargers, making them more convenient to install and use.

The low common-mode capacitance, a hallmark of Allegro's isolated gate drivers, further enhances their performance by reducing voltage and current noise. This reduction in noise contributes to a cleaner signal, minimizing interference and improving the overall stability of the EV charging system. The reduced EMI also translates to a smaller inductance needed for further filtering, contributing to a more compact design. For example, Allegro's isolated gate drivers boast a 14 times smaller common-mode capacitance compared to conventional solutions, resulting in a 23 dB reduction in EMI and significantly reduced power dissipation. This translates to a 1.3 W efficiency gain per half-bridge, further enhancing the overall efficiency of the EV charger.

Allegro's isolated gate drivers enhance the cost-effectiveness of WBG-based EV chargers by increasing efficiency and reducing switching losses. This leads to lower energy consumption during charging, benefiting both the environment and charging station operators through reduced operating costs.

A unique characteristic of Allegro's isolated gate drivers is the integrated isolated supply. This innovative approach eliminates the need for external bias supply components, such as DC-DC converters or bootstraps, significantly reducing the bill of materials (BOM) cost and simplifying the overall design. This high level of integration, combined with the reduced EMI and smaller inductance requirements, significantly increases the system power density, allowing for more compact and efficient EV chargers. Allegro's products require, on average, only half the components compared to competitors, and the system can achieve double the power density.

Due to the high level of integration and simplified design enabled by Allegro's isolated gate drivers, their customers report an average of 50% faster design time. This accelerated development process allows for quicker time-to-market,

enabling EV charger manufacturers to stay ahead of the curve in this rapidly evolving industry.

Allegro's isolated high-voltage gate drivers are essential components in unlocking the full potential of WBG technology for EV charging. By enabling faster charging times, smaller charger designs, and increased cost-effectiveness, Allegro's gate drivers pave the way for a more sustainable and convenient EV charging experience.

Current Sensors

Precise and reliable current sensing is crucial for optimizing the performance, safety, and cost-effectiveness of EV chargers. Current sensors must meet the stringent requirements of this demanding application, providing accurate current measurements that enable faster charging times, enhanced safety features, and a more affordable charging infrastructure.

Accurate current monitoring allows for the optimization of power delivery to the vehicle battery, maximizing charging speed without compromising safety. Wide current measurement ranges and high bandwidth capabilities ensure accurate readings even at the high currents required for fast charging.

Allegro's innovative current sensor packages enable more compact charger designs, contributing to increased charger density. Their sensors offer exceptional power density and power capability in general, allowing for smaller footprints and reduced PCB space compared to traditional shunt-based solutions. This miniaturization allows for more chargers to be deployed in space-constrained environments, supporting the expansion of the charging infrastructure.

Allegro is committed to providing cost-effective solutions for precise current measurement, and their current sensors are no exception. Integrated isolation eliminates the need for external isolation components, simplifying the design and reducing BOM costs. The lower heat generation compared to shunts further reduces the need for bulky and expensive heat sinks, contributing to a more cost-effective overall solution. Allegro's integrated conductor current sensors offer reinforced isolation up to 572 Vrms.

Allegro's current sensors are designed for high reliability and long operating life, crucial factors for ensuring a positive user experience and maximizing the return on investment for charging station operators. Their sensors are built to withstand the rigors of continuous operation in various environmental conditions, ensuring accurate and dependable current measurements over the long term.

Allegro's current sensors feature integrated isolation, eliminating the need for external isolation components and simplifying charger designs. This integration contributes to a smaller footprint, reduced BOM cost, and enhanced reliability. Their current sensors are also designed for ease of use, simplifying the integration process for charger manufacturers. Their straightforward operation and clear documentation streamline the design process, reducing development time and effort.

Compared to traditional shunt-based solutions, Allegro's current sensors generate significantly less heat. This reduced heat dissipation allows for smaller heat sinks and a more compact overall design, contributing to increased charger density and lower costs. Allegro offers a wide range of innovative current sensor packages, including options with unmatched power density and power capability. These packages are designed to meet the specific requirements of EV charging applications, enabling compact and efficient charger designs.

Allegro's current sensors provide highly accurate current measurements, essential for optimizing power conversion efficiency and ensuring the safe operation of EV chargers. This accuracy allows for precise control of the charging process, maximizing charging speed without compromising safety. Allegro's current sensors offer an unmatched bandwidth of 5 MHz, achieved through the innovative combination of coil and Hall-effect sensing technologies. This high bandwidth is particularly important for WBG-based chargers, which operate at higher switching frequencies.

Allegro's TMR current sensor portfolio provides even greater performance advantages, including better sensitivity, lower noise, faster bandwidth, and lower power consumption. These sensors are ideal for applications requiring the highest levels of precision and efficiency.

For enhanced safety, Allegro's current sensors offer integrated, user-programmable overcurrent detection. This feature provides a critical layer of protection for EV charging systems, ensuring safe operation even under fault conditions. The user configurability allows for customization to meet the specific requirements of different charger designs, further enhancing their versatility.

For higher current applications, Allegro also offers a range of field sensors for various sensing implementations, including c-core, u-core, and coreless options, using both Hall and TMR technology. Allegro was the first to release a coreless current sensor and the first to release an ASIL C rated current sensor, demonstrating their commitment to innovation and safety in current sensing technology.

Allegro's current sensors are essential components in enabling the next generation of high-performance, reliable, and cost-effective EV chargers. By providing accurate current measurements, their sensors contribute to faster charging times, enhanced safety features, and a more affordable EVCI, paving the way for a future where EV charging is as seamless and convenient as refueling a traditional vehicle.

Thermal Management

As consumers push for higher charging power and faster charging times, Allegro MicroSystems is innovating solutions for effective thermal management. This emphasis on power density brings with it increased thermal challenges. As noted in one article [23], a megawatt charging system (MCS), for example, might need to handle 13 kW of losses at 1 kA in a single junction box. To reduce charging times for commercial vehicles by increasing the current to 3 kA, the same technology would need to cope with losses closer to 130 kW. Clearly, thermal management is a critical factor in enabling these higher-power systems.

Allegro offers a range of intelligent motor drivers that enable efficient and quiet cooling solutions, contributing to enhanced charger reliability, longevity, and user satisfaction. Their intelligent motor drivers integrate sophisticated motor control algorithms that enable efficient fan operation right out of the box. These algorithms optimize fan speed based on real-time temperature measurements, ensuring optimal cooling performance while minimizing energy consumption and noise. This integration saves valuable design time for charger manufacturers, allowing them to focus on other aspects of charger development.

The high level of integration in Allegro's motor drivers also contributes to a more compact and cost-effective charger design. By integrating essential components, such as the gate driver and control circuitry, their motor drivers reduce the need for external components, minimizing PCB space and BOM costs. This integration is particularly beneficial in EV charging applications, where space constraints and cost optimization are paramount.

Allegro's motor controllers are renowned for their extremely quiet operation, a crucial factor in enhancing the user experience at EV charging stations. Noise pollution from cooling fans can be a significant nuisance, especially in residential areas or near businesses. Allegro's quiet motor drivers minimize noise levels, creating a more pleasant charging experience for EV owners and the surrounding community.

Effective thermal management is crucial for ensuring charger reliability and longevity. Allegro's intelligent motor drivers contribute to this goal by maintaining optimal operating temperatures for critical components, preventing overheating and premature failure. The robust design and high-quality components used in their motor drivers further enhance their reliability, ensuring consistent performance over the long term.

Allegro's intelligent motor drivers are essential components in enabling the next generation of high-performance, reliable, and cost-effective EV chargers. By providing efficient and quiet cooling solutions, their motor drivers contribute to a more sustainable and convenient EV charging experience, addressing the key system challenges of power, density, cost, and reliability.

Modular Design

As the EV charging landscape rapidly evolves, the ability to adapt and scale becomes paramount. EV charger manufacturers need systems that can keep pace with technological advancements and changing consumer demands without requiring complete overhauls. This is where the concept of modular design emerges as a critical factor in EVCI. Allegro MicroSystems recognizes this need and offers a product portfolio that empowers manufacturers to embrace modularity, unlocking a range of benefits.

Allegro's approach to modularity centers around providing compact, highly integrated components that serve as building blocks for scalable EV charging systems. Their isolated gate drivers and current sensors, for example, are designed with this philosophy in mind.

Instead of relying on a single, high-power system, modular design allows for the use of multiple, smaller power modules stacked together. This approach offers several advantages. First, it simplifies the design and manufacturing process, as working with smaller modules is inherently easier and more cost-effective than developing a single, larger system. Second, it provides system designers with unparalleled flexibility. They can easily adjust the power output of the charger by adding or removing power modules as needed, catering to a wide range of charging requirements without significant design changes.

Modularity extends beyond just power scaling. It also allows for easy adaptation to different charging standards, both present and future. As new standards emerge, supporting even faster charging speeds, charger manufacturers can seamlessly integrate these advancements by upgrading individual modules without requiring a complete system redesign. This future-proofing capability is essential in the rapidly evolving EVCI landscape.

Upgrading a modular EV charger is as simple as swapping out older modules with newer, more advanced ones. This ease of upgrade extends the lifespan of the EVCI, maximizing the return on investment for operators. Additionally, if a module malfunctions, it can be quickly and easily replaced without affecting the operation of the other modules, minimizing downtime and maintenance costs.

Allegro's highly integrated products are particularly well-suited for modular EVCI designs. Their isolated gate drivers, for example, integrate numerous features and require fewer external components, resulting in a compact footprint. This compactness, combined with integrated isolation and advanced thermal management, makes them ideal for building densely packed, yet efficient, power modules. The reduced component count further enhances reliability, as there are fewer points of potential failure.

By embracing modularity, EVCI manufacturers can respond to the dynamic needs of the market with agility and cost-effectiveness. Allegro MicroSystems is committed to providing the building blocks for this modular future, enabling a more sustainable, scalable, and adaptable charging infrastructure.

Reliability and Longevity

In the realm of EVCI, reliability isn't just a desirable feature—it's a fundamental necessity. EV charger downtime translates to lost revenue for operators and, more importantly, can lead to frustration and inconvenience for EV drivers, potentially hindering the wide-spread adoption of electric vehicles. Allegro MicroSystems understands this critical need and has built a reputation for developing robust, long-lasting solutions, drawing upon their extensive experience in the demanding automotive industry.

Allegro's commitment to reliability is deeply rooted in their DNA. They have been a trusted supplier of automotive-grade components for decades, consistently delivering products that meet the stringent quality and performance standards of the automotive sector. This experience translates directly to their EVCI solutions, ensuring they can withstand the rigors of continuous operation in diverse and often challenging environmental conditions.

Allegro's dedication to reliability extends beyond just using high-quality components. It's embedded in their design philosophy and reflected in the rigorous testing procedures their products undergo. Allegro's isolated gate drivers,

current sensors, and motor drivers are designed with robust thermal management systems, ensuring optimal operating temperatures for critical components and preventing overheating that could lead to premature failure.

Furthermore, Allegro's products incorporate integrated features that enhance reliability and longevity. For instance, their isolated gate drivers feature integrated isolation, eliminating the need for external components and potential points of failure. Their current sensors offer integrated overcurrent protection, safeguarding the charging system from fault conditions. These integrated features not only enhance reliability but also contribute to a more compact and cost-effective overall design.

The benefits of reliable EVCI are multifaceted. First and foremost, it minimizes maintenance and replacement costs. With fewer failures and longer lifespans, operators can significantly reduce downtime and the associated expenses, maximizing the return on their investment.

Equally important is the enhanced user experience that comes with reliable EVCI. When chargers consistently function as expected, EV owners can charge their vehicles with confidence, knowing they won't be stranded by malfunctioning equipment. This positive experience is crucial for building trust in electric mobility and encouraging wider EV adoption.

Allegro MicroSystems is dedicated to empowering the EVCI industry with solutions that stand the test of time. By prioritizing reliability and longevity in their product development, Allegro contributes to a robust and dependable EV charging ecosystem, benefiting both operators and EV owners alike.

Conclusion: Partnering for a Sustainable Electric Future

Allegro's Commitment to EVCI Innovation

As the world transitions to electric mobility, the need for a robust, efficient, and accessible EVCI has never been greater. The shift towards a sustainable transportation future hinges on overcoming consumer concerns about charging and empowering manufacturers with the technologies to build next-generation EV chargers. Allegro MicroSystems stands as a committed partner in this endeavor, delivering innovative semiconductor solutions that are shaping the future of EV charging.

Allegro's expertise in power and sensing technologies, particularly in the realm of wide-bandgap (WBG) semiconductors, positions them at the forefront of EV charging innovation. Their WBG-oriented solutions directly address the critical challenges of EV charger design, enabling faster charging times, increased efficiency, reduced size and weight, and lower overall costs.

Allegro's isolated high-voltage gate drivers are designed to maximize the performance of GaN and SiC devices. By minimizing switching losses and enabling higher switching frequencies, their gate drivers contribute to significantly faster charging times and increased power density. This translates to a superior charging experience for EV owners and a more cost-effective charging infrastructure for operators.

Complementing their gate drivers are Allegro's innovative current sensors, which provide the precise and reliable current measurements essential for optimizing power delivery and ensuring the safe operation of EV chargers. Their current sensors, with their integrated isolation, high bandwidth, and low noise characteristics, are instrumental in enabling the development of compact, efficient, and reliable EV charging solutions.

Beyond individual components, Allegro is committed to supporting the EV charging ecosystem with a modular design approach. Their products are designed to serve as building blocks for scalable EV charging systems, allowing manufacturers to easily adapt to evolving standards and future-proof their investments.

Allegro's commitment to reliability, deeply rooted in their decades of experience in the demanding automotive industry, underpins all their EV charging solutions. They understand that charger downtime is unacceptable, and they design

their products to withstand the rigors of continuous operation, ensuring a positive user experience and maximizing the return on investment for charging station operators.

Collaborating for a Seamless Transition

Allegro MicroSystems is actively partnering with EV charger manufacturers to accelerate the transition to a sustainable electric future. We invite you to contact us to discuss your specific EV charging application requirements and explore how our innovative solutions can help you achieve your design goals. Together, we can create a world where EV charging is as seamless and convenient as refueling a traditional vehicle, paving the way for widespread electric mobility.

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Revision History

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–	September 18, 2024	Initial release

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