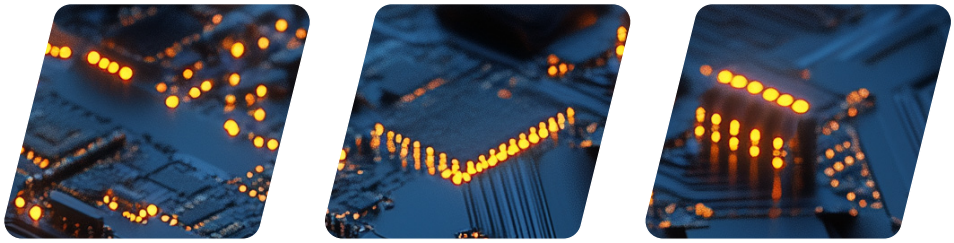
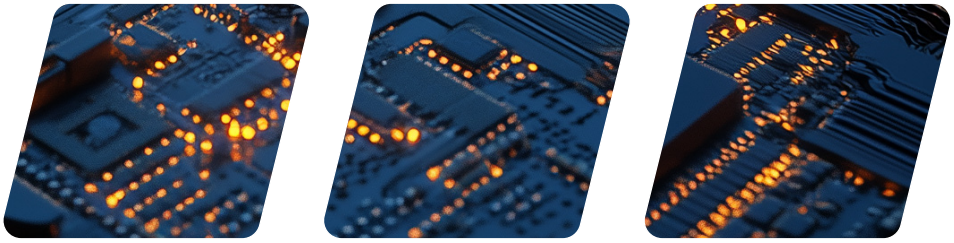


Enhancing Human-Machine Interfaces with Advanced User Context Awareness



White Paper

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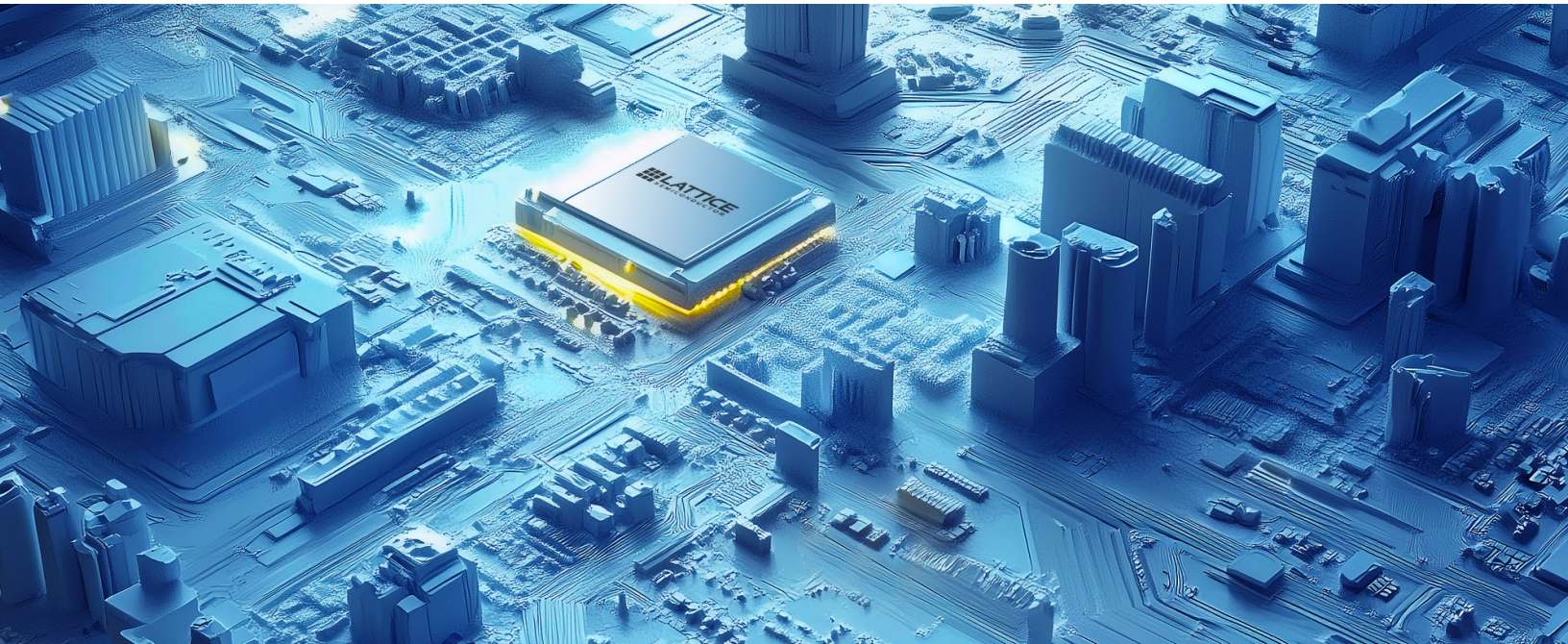
ABSTRACT

Industries are rapidly shifting from static human-machine interfaces (HMIs) to intuitive, context-aware systems to meet growing user expectations for ease, safety, and efficiency. The Lattice sensAI™ solution stack empowers developers to build low power, edge-optimized HMIs using purpose-built, pre-trained AI models for vision and audio processing. By integrating context-aware capabilities like gesture recognition, gaze tracking, and voice commands, Lattice sensAI enables safer, more efficient, and personalized user experiences. This white paper outlines the limitations of traditional HMIs, the transformative potential of context-aware interfaces, and how Lattice's low power FPGA-based solutions drive innovation while promoting sustainability through significant energy savings.

GLOSSARY

HMI	Human-Machine Interface, the system enabling interaction between humans and machines
Edge AI	AI processing performed locally on devices, reducing latency and cloud dependency
FPGA	Field-Programmable Gate Array, a reconfigurable hardware platform for efficient AI tasks
Context-aware HMI	An interface that adapts to user behavior and environmental cues using AI
Lattice sensAI	Lattice Semiconductor's solution stack for vision and audio AI at the edge



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1. The Shift Toward Simpler and More Intuitive Interfaces

Traditional human-machine interfaces (HMIs) are rigid, inefficient, and reliant on buttons, touchscreens, and static menus. They require users to adapt to the machine rather than the other way around, and they often require significant training, precise manual operation, and attention-intensive tasks. See Figure 1.

This rigidity leads to several critical pain points:

- **Complexity and Training Burden:** In industrial settings, operators often require extensive training to navigate complex interfaces, which slows onboarding and increases error rates.
- **Safety Risks:** Cumbersome controls in automotive environments contribute to driver distraction, a leading cause of accidents.
- **Lack of Adaptability:** Legacy HMIs fail to adjust to user behavior or environmental changes, resulting in inefficient workflows and missed opportunities for personalization.
- **Energy Inefficiency:** Traditional systems, particularly those relying on CPU/GPU-based AI, consume significant power, conflicting with sustainability goals in the manufacturing and automotive sectors.
- **Limited Context Awareness:** Without the ability to interpret user intent or environmental cues, HMIs remain reactive rather than proactive, reducing their utility in dynamic settings.

Industry trends, including labor shortages, stringent safety regulations, and the push for greener technologies compound these challenges. As industries strive for greater efficiency, safety, and user satisfaction, there is an urgent need for HMIs that leverage AI to understand context, anticipate needs, and operate with minimal user effort.

Figure 1: Manual, Rigid, and Non-Intuitive: The Hurdles of Conventional HMI Systems

2. Critical Industry Trends Amplify the Urgency for Adaptive HMI

Several critical industry trends are intensifying the need for transformation toward intelligent, adaptive HMIs:

- **Rising User Expectations:** Consumers increasingly demand intuitive, seamless, and personalized interactions from machines and systems.
- **Economic Impact:** Inefficient HMIs increase training costs, reduce throughput, and elevate error rates, directly affecting profitability. In contrast, intuitive interfaces enhance productivity and user satisfaction, delivering measurable ROI.
- **Enhanced Safety and Compliance:** Regulatory pressures require reduced operational risks and enhanced operator safety. In industrial settings, unintuitive interfaces contribute to errors, with 70% of manufacturing downtime linked to human error (Yole Group, 2024). In automotive applications, distracted driving due to cumbersome controls causes over 3,000 fatalities annually in the U.S. (NHTSA, 2023). See Figure 2.

- **Sustainability Imperatives:** Industries are adopting greener technologies, emphasizing energy-efficient operations to reduce environmental footprints. For intuitive HMI tasks at the edge, GPUs typically consume over 5 W, whereas FPGAs can deliver the same functionality using less than 500 mW—offering a 10x reduction in power consumption and significantly lowering environmental impact.
- **Market Trends:** By 2030, 80% of HMIs in industrial and automotive systems will integrate AI-driven vision and audio capabilities, driven by trends like generative AI and augmented reality (Crank Software, 2025).

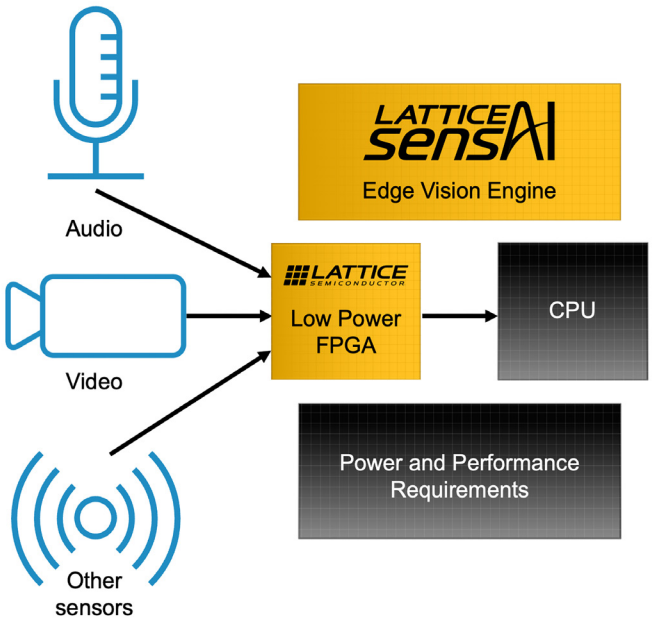
The convergence of these factors underscores the need for context-aware HMIs that enhance safety, streamline operations, and support environmental sustainability. Organizations that embrace these technologies will gain a competitive edge, while those that lag risk obsolescence in rapidly evolving markets.

Figure 2: Inattention by Interface: When HMI Draws Focus from Critical Tasks

3. Lattice sensAI: Accelerating Context-aware HMI Development

The Lattice sensAI™ Edge Vision Engine is a comprehensive tool for building context-aware HMIs optimized for edge applications. It combines low-power FPGAs, purpose-built, pre-trained AI models, and developer-friendly tools to enable vision and audio AI capabilities such as gesture recognition, face identification, and audio event detection. Unlike traditional CPU/GPU-based edge AI systems, which consume multiple watts of power and rely on cloud connectivity, Lattice FPGAs deliver always-on processing at less than 500 mW, reducing energy use by more than 90% in some cases. This supports sustainability by enabling features like human detection to power down systems when not in use, conserving energy during idle states. The AI models in Lattice's sensAI Edge Vision Engine tool are designed to operate at extremely low power in Lattice FPGAs, but they are also optimized for devices with more resources, such as CPUs (x86 or ARM) and GPUs. See Figure 3.

Figure 3: Lattice sensAI Integrates Vision and Audio AI for Low Power, Edge-Native HMIs



Key Features:

- **Vision AI**
  - Body Detection and Tracking: Accurately identifies and tracks human bodies for interactive applications.
  - Face Detection and Tracking: Enables facial recognition, user authentication, and analysis of facial expressions.
  - Face Identification: Recognizes and verifies individuals for security and personalization.
  - Gesture Detection and Tracking: Supports touchless interactions using hand and body gestures.
  - Gaze Tracking: Detects user focus for adaptive UI/UX, accessibility enhancements, and safety applications.
  - Object Detection: Recognizes and tracks objects in real time for enhanced situational awareness.
- **Audio AI**
  - Speaker Identification: Identifies individuals based on voice patterns for secure, hands-free authentication.
  - Voice Command Detection: Identifies keywords to enable hands-free operation.
- **Low Power Design**
  - Optimized for Lattice's low power FPGAs, enabling always-on sensing with microwatt-level idle states.
- **Scalability**
  - Supports diverse hardware platforms (FPGA, ARM, and x86) for flexible integration.
- **Rapid Deployment**
  - Pre-trained models and tools like Lattice sensAI™ Studio streamline development.

4. Enabling Context-aware HMI with Low Power, Always-On Vision and Audio

The Lattice sensAI solution stack offers distinct advantages for businesses striving for market leadership:

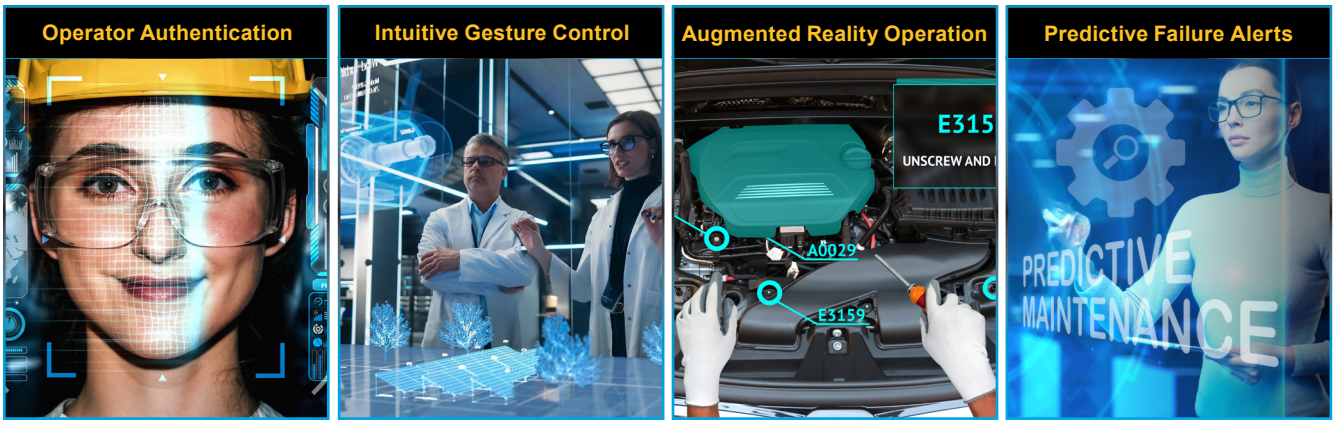
- **Purpose-built, Pre-trained AI Models:** Includes advanced models for human detection, face tracking, gesture tracking, and gaze tracking—each rigorously validated to ensure high reliability and accuracy.
- **Exceptional Power Efficiency:** Significantly reduced power consumption enables continuous operation with minimal environmental impact, supporting sustainability goals.
- **Real-Time Performance:** Ultra-low latency and high responsiveness optimize user interaction and operational performance.

- **Robust Security:** Features secure boot and encryption to protect sensitive data in edge and cloud-connected systems.
- **Scalability and Flexibility:** Supports cross-platform integration with FPGA, ARM, or x86 SoCs, adapting to diverse use cases.
- **Proven Reliability:** Over 50 million units deployed, ensuring performance across high-volume applications.
- **Faster Time-to-Market:** Pre-trained models reduce development time by 40% compared to custom AI pipelines.

Industrial HMI Use Case Example

In a smart factory, Lattice sensAI enables HMIs that detect operator presence via face identification, unlock access, and load personalized settings. Gesture recognition allows touchless control, reducing contamination in clean rooms or hazardous environments. Gaze tracking ensures operators remain focused on critical tasks, pausing operations if attention drifts. Audio AI detects voice commands or machinery anomalies, enhancing safety and uptime. These features reduce errors, streamline workflows, and save energy by powering down interfaces when no operator is present. See Figure 4.

Figure 4: The Lattice sensAI Enables HMIs



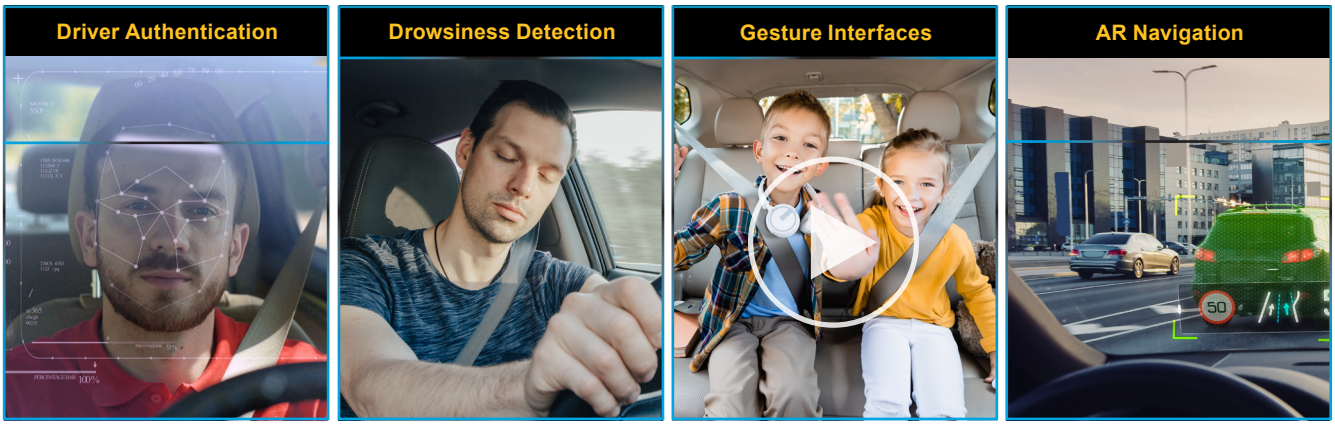
THE SYSTEM	TECHNICAL DETAILS
Authenticates via secure face ID Activates voice and gesture controls for hands-free navigation (e.g., “start machine” or swipe) Overlays AR maintenance guides, with a generative AI assistant providing troubleshooting tips Analyzes motor vibrations to predict failures, displaying alerts on a dashboard	Hardware: Lattice Certus™-NX FPGA with MIPI CSI-2 camera, I2S microphone, MIPI DSI for smart glasses, and sensor interface. Models: Lattice face ID, gesture tracking, voice command detection Impact: 20% reduction in errors, 30% faster training, 15% less downtime

Automotive HMI Use Case Example

The Lattice sensAI powers adaptive HMIs in vehicles that personalize settings based on face identification, seat position, and infotainment preferences. Gaze tracking monitors driver attention, dimming non-essential displays to reduce distraction. Gesture controls allow passengers to navigate entertainment systems without physical contact, enhancing comfort. Audio AI processes voice commands even in noisy environments, while contextual awareness adjusts interfaces based on driving scenarios (e.g., reducing volume in heavy traffic). These capabilities enhance safety, personalization, and energy efficiency. See Figure 5.

The Lattice sensAI also empowers OEMs, developers, and end-users with tangible benefits—from faster development to smarter, more responsive HMIs.

Figure 5: Lattice sensAI Powers Adaptive HMIs in Vehicles



THE SYSTEM	TECHNICAL DETAILS
Recognizes driver's face ID and adjusts seats/mirrors Tracks driver's attention and fatigue, triggering an emergency alert when necessary. Enables voice and gesture controls for passengers Tracks the driver's gaze overlaying AR navigation cues on a HUD	Hardware: Lattice Avant Models: Face ID, gaze tracking, speech recognition, gesture tracking Impact: Reduction in driver distraction, higher user satisfaction

5. Conclusion

Adopting intelligent, context-aware HMIs marks a significant technological advancement—enabling industries to greatly enhance user experiences, improve operational efficiency, and support sustainability initiatives. The Lattice sensAI solution stack—combining powerful FPGA technology, robust AI models, and comprehensive development tools—positions businesses to lead in this evolving landscape. By enabling intuitive, real-time interactions and reducing both operational costs and environmental impact, Lattice empowers organizations to achieve superior performance and long-term, sustainable growth.

6. Appendix

FPGA vs. CPU/GPU Comparison:

FEATURE	LATTICE FPGA	CPU/GPU-BASED SYSTEM
Power Consumption	<500 mW	>5 W
Latency	Low (Nearest to sensor inference)	Higher (Farthest from sensor inference, sometimes cloud-reliant)
Sustainability	Highest (Idle power down)	Low (Constant streaming and always powered on)
Security	Secure boot, hardware encryption, and local data processing	Vulnerable to cloud attacks, software-based security

Optimizing AI algorithms for FPGAs is essential, as FPGAs provide key advantages over CPUs and GPUs, including parallel processing, customizable hardware acceleration, and significantly lower power consumption. Their unmatched flexibility allows developers to fine-tune AI models for specific applications, maximizing computational efficiency while minimizing energy usage. These benefits enable real-time performance, reduce energy costs, and support compatibility with compact, battery-powered devices—making FPGAs an ideal platform for edge-based HMI applications.

Lattice's Computer Vision Model Performance Metrics

Lattice evaluates the performance of its HMI models based on accuracy, latency, and model size, using the Lattice CrossLink™-NX-33 FPGA as a reference. Actual performance may vary depending on the specific FPGA selected for deployment.

MODEL	ACCURACY	LATENCY	SIZE
Face Detection	95% F1	25 ms	652 kB
Face Landmarks and Face Validation	1.13 px for Landmarks 99% F1 for Validation	28 ms	920 kB
Hand Detection and Landmarks	3.54 px 96% mAP	52 ms	983 kB
Face Identification	97% accuracy	63 ms	1,653 kB

Note: Metrics are based on testing in controlled environments with standard datasets. Performance may vary based on lighting, noise, or hardware configurations. The landmarks are computed at 96x96 resolution.

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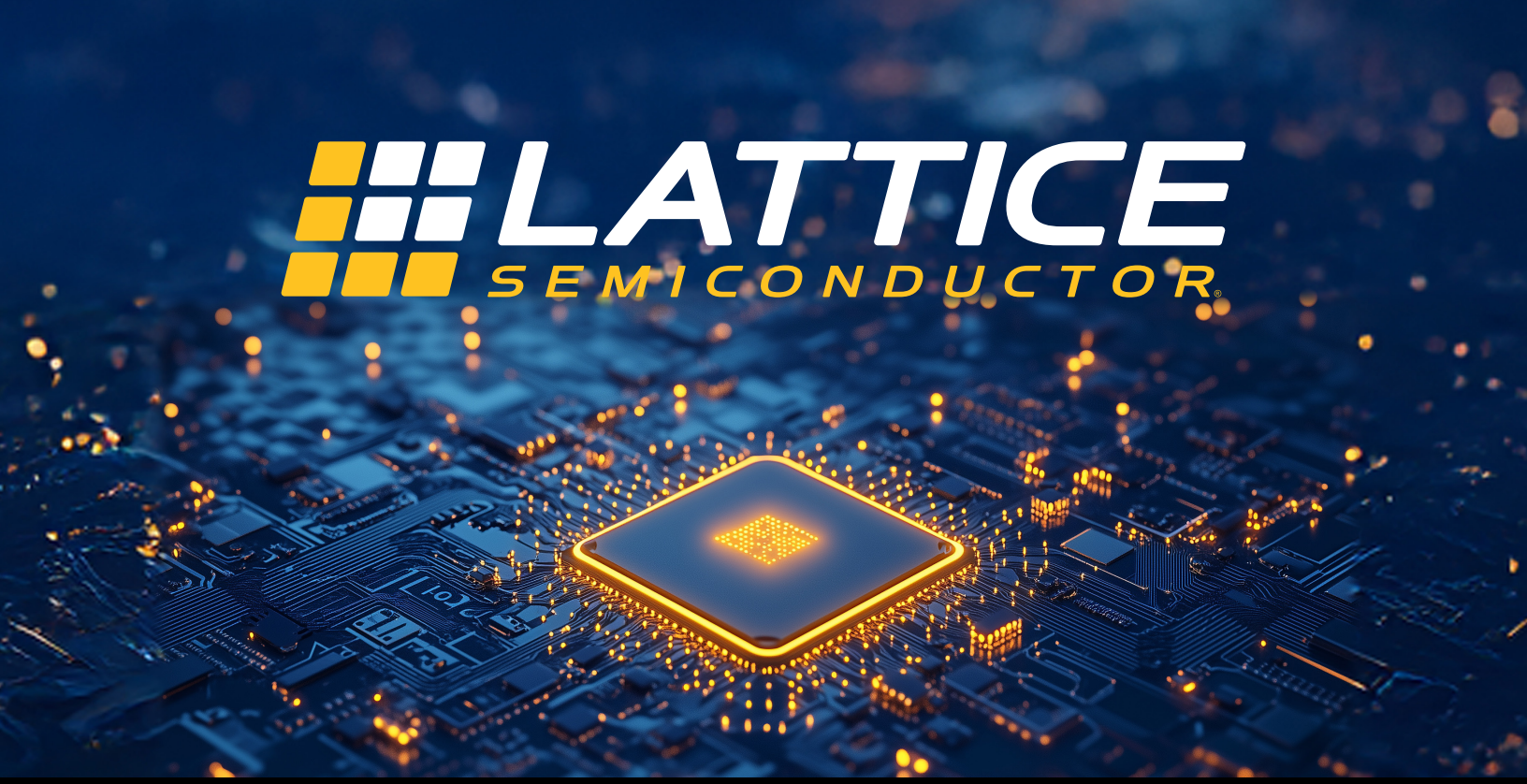

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