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SMARTER SMART METER AND EDGE-AI DATA LOGGER DESIGN WITH MRAM

A TECHNICAL EVALUATION OF CRITICAL-TO-QUALITY PARAMETERS AND MEMORY TECHNOLOGY COMPARISON

Executive Summary

Smart meters and Edge-AI data loggers are integral to modern energy management and industrial automation systems. These devices require memory solutions that offer fast write speeds, low power consumption, high endurance, and reliable data retention. MRAM (Magnetoresistive Random Access Memory) combines these features, making it a highly suitable memory technology for smart energy and industrial applications. This paper explores the critical-to-quality (CTQ) parameters for smart meters and edge loggers, provides a comparative analysis of memory technologies, and proposes a future-ready AI-based architecture utilizing MRAM.

1. INTRODUCTION

Smart meters and AI-based edge data loggers enable accurate, real-time monitoring of energy consumption and industrial parameters. They continuously record data, transmit it wirelessly, and support over-the-air (OTA) updates. The memory embedded in these devices must offer not only non-volatility and fast access but also be highly durable. MRAM addresses these demands more effectively than traditional options.

2. CRITICAL-TO-QUALITY (CTQ) PARAMETERS

SRAM, DRAM and EEPROM are popular choices, and FeRAM has become an option in the past years. However, with MRAM, there is a new contender that checks all the marks.

Feature	MRAM	FeRAM	EEPROM	SRAM	DRAM
Non-volatility	Yes	Yes	Yes	No	No
Write Endurance	~10^14	10^10–10^15	10^5–10^6	Unlimited	Unlimited
Write Speed	~10 ns	~50 ns	~10ns	~10 ns	~10 ns
Power Consumption	Low	Very Low	Moderate	High	High
Data Retention	>10 years	>10 years	>10 years	Volatile	Volatile
OTA Suitability	High	Moderate	Low	N/A	N/A

Table 1: Comparative analysis of MRAM with other mainstream memory technologies

MRAM offers virtually unlimited write cycles, with endurance levels exceeding 10^14 cycles. This outperforms EEPROM (10^5–10^6 cycles) and FeRAM (10^10–10^15 cycles), making MRAM optimal for systems with frequent data logging.

Write operations in MRAM occur at speeds comparable to SRAM (approximately 10 ns), enabling efficient firmware updates and fast data buffering.

At the same time, MRAM consumes significantly less power than EEPROM during writes and eliminates the refresh cycles required by DRAM, making it suitable for battery-powered devices.

Another major advantage of MRAM is the fact that it retains data for over 10 years, ensuring robustness in harsh environmental conditions and protection from sudden power failures.

Especially in AI-enhanced edge systems, memory must support rapid and frequent access. MRAM’s read/write characteristics align well with requirements for embedded AI model execution, sensor data fusion, and predictive analytics.

3. AI-BASED SMART METER ARCHITECTURE USING MRAM

A modern smart meter design integrates MRAM as the non-volatile memory core alongside key processing and communication components. This architecture supports OTA updates, local AI-based decision-making, and power-efficient operation.

3.1 Functional Analysis and Characteristics

The architecture of an AI-enhanced smart meter integrating MRAM (Fig.1) is built around a modular embedded system comprising five principal components: a microcontroller unit (MCU), MRAM for non-volatile memory, an AI accelerator, a power management unit (PMU), and the metering/load interface. This configuration is designed to deliver high-performance, energy-efficient data acquisition, processing, and logging in edge environments.

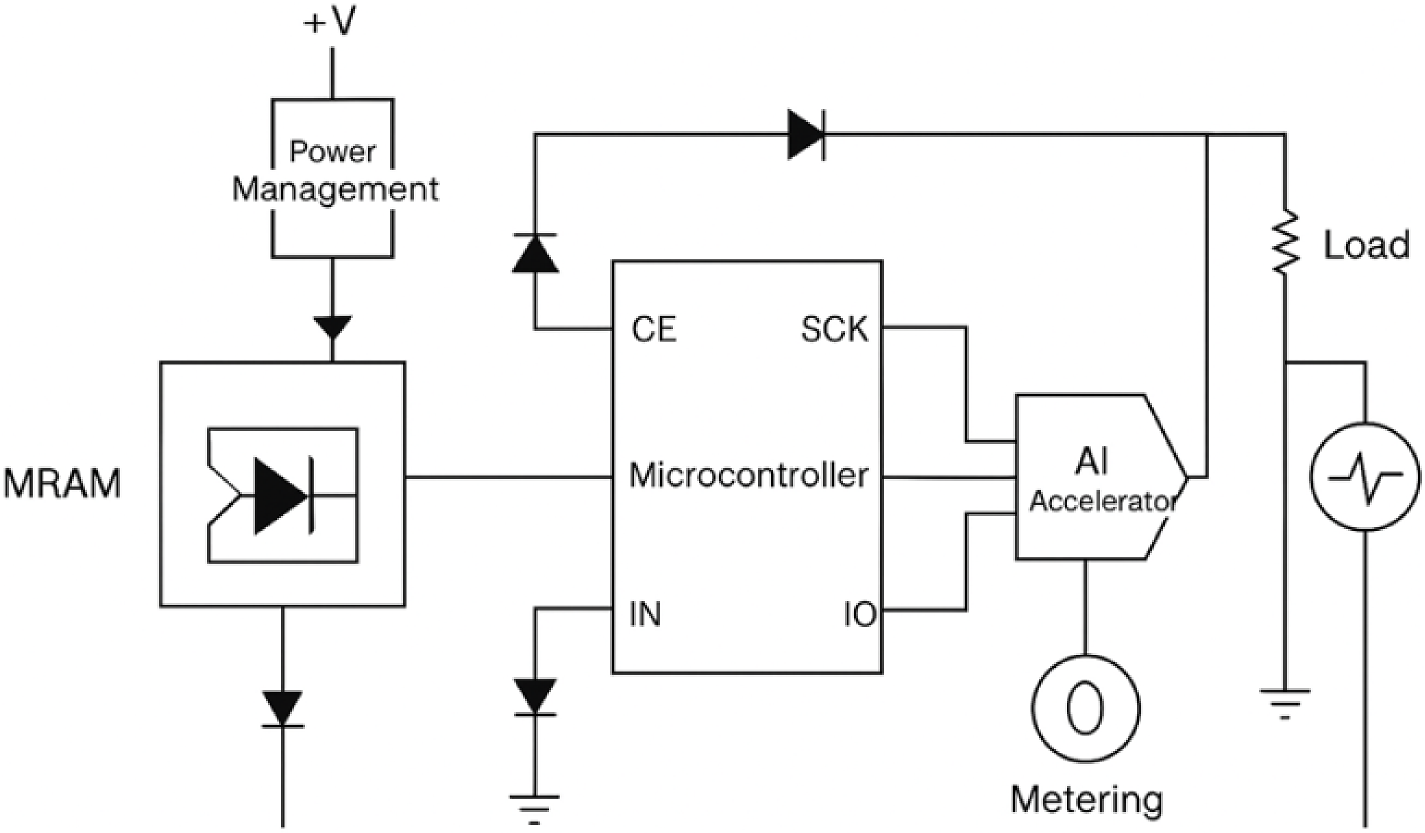

Figure 1: Architecture of an AI-enhanced smart meter integrating MRAM.

At the core, the microcontroller serves as the system's command center, orchestrating data flow, managing peripheral interfaces, and executing firmware tasks including real-time metering, communication handling, and power control. It is connected to MRAM, which acts as the primary non-volatile memory. MRAM offers byte-level access, write endurance exceeding 10^{14} cycles, and data retention beyond 10 years without the need for refresh cycles or wear-leveling algorithms, making it vastly superior to EEPROM or Flash in this context. The fast access time (~10 ns) also supports OTA firmware updates and instantaneous data logging.

The AI accelerator, tightly coupled with the MCU via digital I/O or memory-mapped interfaces, performs local inferencing tasks such as anomaly detection, consumption forecasting, and pattern recognition, enabling autonomous edge intelligence without reliance on cloud processing. The outputs of these computations can be stored in MRAM, ensuring secure and persistent retention of inference results or model updates.

Supporting these processing elements, the power management unit provides a regulated supply voltage derived from either mains or battery sources. The PMU incorporates diodes and filter capacitors to protect against surges and reverse polarity while optimizing power sequencing to minimize consumption during standby. This allows the system to operate with ultra-low power budgets – critical for remote and battery-operated deployments.

The metering interface connects analog front-end sensors, such as current transformers (CTs) and voltage dividers to the system, enabling accurate sampling of real-time electrical parameters. The MCU processes this data and, when needed, triggers AI-based evaluations or control actions. The system also includes a load control mechanism, allowing it to modulate or disconnect loads based on predefined rules or learned behavior.

Overall, the architecture delivers a high degree of integration and resilience. It enables persistent, high-speed data logging, real-time control, and AI-driven analytics in a compact, energy-efficient platform. The use of MRAM eliminates conventional NVM bottlenecks, while the AI accelerator ensures the system can adapt and respond intelligently to dynamic operating conditions. This makes it ideally suited for next-generation smart meters deployed in both residential and industrial energy monitoring systems.

4. DESIGN CONSIDERATIONS & CONCLUSION

Based on the architecture outlined above, we recommend two critical design considerations for future edge-AI data loggers and smart meters:

- **Scalability and Density:**
  Advances in MRAM fabrication continue to increase density and capacity, making it viable for more data-intensive applications.

- **Cost Implications:**
  While the initial cost of MRAM may be higher, its durability and minimal maintenance result in a lower total cost of ownership over time.

MRAM's unique combination of endurance, speed, energy efficiency, and data retention makes it an optimal memory solution for smart meters and edge data loggers. Its support for AI processing and OTA firmware upgrades positions MRAM as a key enabler of future smart infrastructure.

ABOUT US

MEMPHIS Electronic has been in the memory business for over 30 years. Due to our focus on memory only, we developed into a Memory Competence Center with an unmatched line card of over 18 different memory manufacturers (Samsung, Nanya, SK Hynix, Winbond, Huawei, SkyHigh, Ramxeed, Intelligent Memory, Apacer, Longsys, ESMT, Biwin and many more). We combine this with comprehensive supply chain solutions.

From legacy to latest components and modules, from standard to specialty memories – if it's a memory, we can help. Memory experts in 17 locations worldwide provide regional support and manufacturer recommendations, to ensure customers find the most suitable technology solution for every project.

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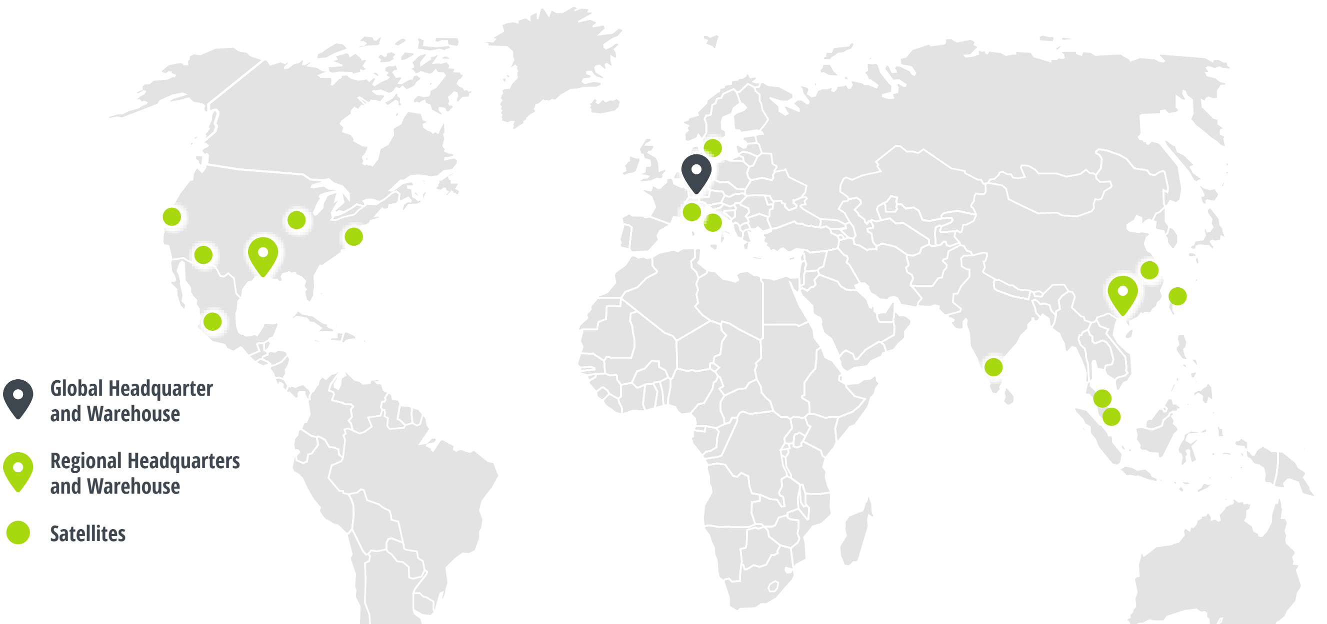

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