avalanchetechnology

Powering the Industrial Internet of Things

AN AVALANCHE TECHNOLOGY WHITEPAPER

Contents

The Industrial Internet of Things

When most people think of the Internet of Things, they think of Nest thermostats, smart watches, and refrigerators that talk to you.

But home automation and personal tech will not be primary beneficiaries of the Internet of Things. While everyone is talking about home and consumer applications, it turns out that will be a tiny slice of IoT's impact. The real ROI will come in industrial automation.

Nigel Coe, Managing Director of Wolfe Research, puts it simply: "The industrial sector is broadly expected to be the largest beneficiary of the Internet of Things development." [1]

The IBM Institute for Business Value estimates that the average factory produces one terabyte of production data daily, and only 1% is analyzed or acted upon in real time.

Often referred to as Factory 4.0 or Industry 4.0, Artificial Intelligence and the automation of industry allows manufacturers to analyze real-time data to improve decision making. Smart factories providing live data to technicians—and executives—lead to lower costs, improved uptime and productivity, and the ability to quickly pivot to new market conditions.

There is no question AI is transforming industry. Danny Sabour, Avalanche Technology VP of Marketing and Business Development, maps the arc of AI and Machine Learning's contribution: "It starts with solving business problems, then moves to bringing dark data alive and fusing different data leading to insight. That allows autonomous action based on this insight, and ultimately to solving problems that humans can't."

Today, little data is analyzed in real time. In fact, the IBM Institute for Business Value estimates that the average factory produces one terabyte of production data daily, and only 1% is analyzed or acted upon in real time. [2]

But *Engineering Journal* says the change is inevitable: "Our next generation of industry— Industry 4.0—holds the promise of increased flexibility in manufacturing, along with mass customization, better quality, and improved productivity. It thus enables companies to cope with the challenges of producing increasingly individualized products with a short lead-time to market and higher quality."[3]

Across the industrial sector, the days of centralized industrial systems with dumb nodes transmitting data to central control systems are becoming a thing of the past. These systems relied on reliable synchronous, low latency communication links.

Today, it's different. New smart factories take a modular approach, running virtual systems to monitor physical processes, which rely on decentralized decisions. What used to happen to improve efficiency by using data analytics is now happening at the nodes with AI and machine learning.

In this new model, aging communication systems will simply not be able to handle the amount of data that is being generated by the node that needs to be sent to the Cloud.

With the decision making moving to the nodes, the processing systems now track and maintain the exact status of mission critical decisions independently, since it's no longer in a central location.

This improved decision making allows for automated preventative maintenance, and enables managers to adjust production in real-time to respond to changes in the day's market. Most importantly, it also minimizes data traffic from the nodes to the Cloud, ensuring that the network doesn't collapse.

"This is in our view the first step in the Industrial Internet of Things," says Nigel Coe, "capturing data to monitor and ensure the integrity of the production." [4]

An Exploding Industry

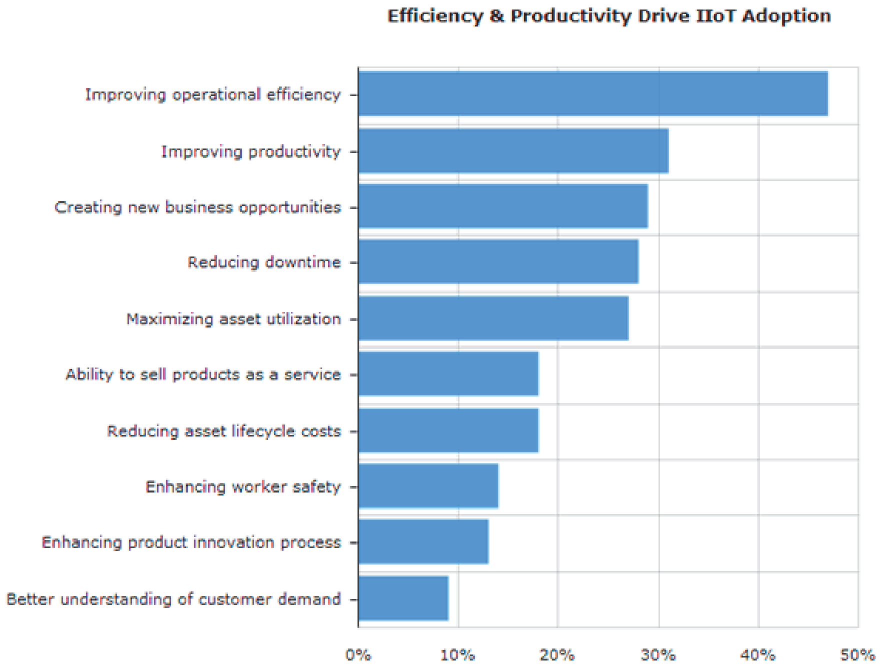
Morgan Stanley says Industrial Internet of Things companies comprise a $42 billion market, with the potential to grow at a 15% to 18% compound annual growth rate through 2020. That equals $90-$110 billion. [5]

According to *ZDNet*, IoT spending "is forecast to reach $745 billion in 2019 — up from the $646 billion spent in 2018 — and likely to hit $1 trillion in 2022. The vast majority of that spending will be by businesses." [6]

This industrial sector is growing quickly enough that it now has its own acronym: IIoT, the Industrial Internet of Things, to differentiate it from consumer IoT. Steve Ranger of *ZDNet* explains: “The Industrial Internet of Things refers to the billions of industrial devices — anything from the machines in a factory to the engines inside an aeroplane — that are filled with sensors, connected to wireless networks, gathering and sharing data.” [7]

And manufacturers are paying attention: Over 70 % of respondents to a Morgan Stanley/ *Automation World* survey thought it important to develop strategies related to the IIoT. They also expect their spending to jump from 8% of a capital budget to 18%. [8]

The benefits to factories are many. According to the Morgan Stanley/*Automation World* survey, improving operational efficiency and productivity are the most critical business drivers among manufacturers adopting the IIoT. [9]



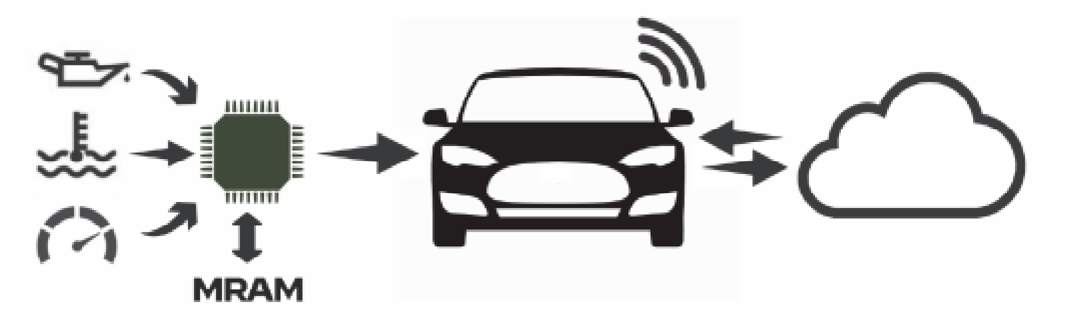
Sources: Morgan Stanley-Automation World Industrial Automation Survey, AlphaWise

Distributed IIoT

IIoT is growing at a staggering pace, but many companies still rely on centralized decision making. An example is Rolls-Royce's IIoT factories, where they receive trillions of data points from customer engines. But Caroline Gorski at Rolls-Royce's RD Data Labs is up against a limitation: "If you use sensors everywhere, you get nowhere because it's too expensive and it's too imprecise. Rolls-Royce picks where its IoT solutions can make data visible...." [10]

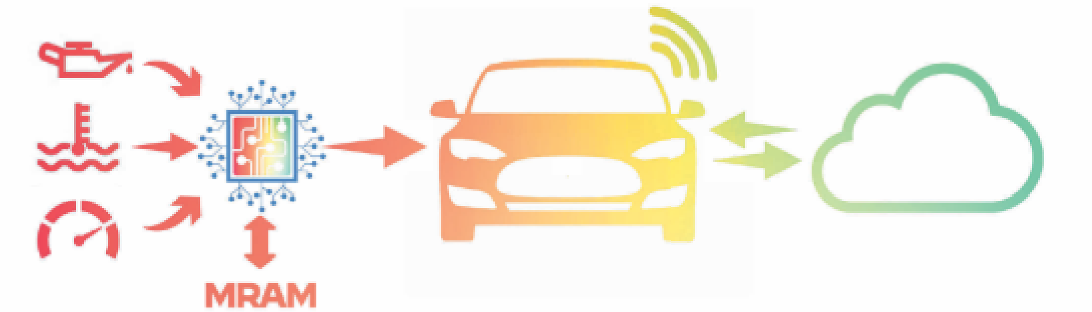
Since decision making is in the Cloud, they can't afford too much sensor data. Which means they decide which data is relevant and could be missing a problem that would become visible by viewing all sensor data. Say oil pressure and engine temp are fluctuating and there's a low RPM. Each data point can be solved for, but you might miss that the combination shows a faulty gasket. Moving to a distributed model could solve this issue. Analyzing all the data points at the source—in real time—would identify the gasket issue before it becomes critical.

CLOUD-BASED MODEL



1 Sensor Fusion combines multiple sensor inputs into packets
2 The data is stored locally in a persistent, high-performance memory such as MRAM
3 The data is sent back to the cloud when there is 3G/4G or WiFi (at home) connectivity
4 Analytics is performed and determines there is a problem (ex: gasket problem after 1000 hours of engine use.)
5 Analysis is sent back to the automobile to inform the driver that the car needs servicing

DISTRIBUTED MODEL



1 Sensor Fusion combines multiple sensor inputs into the AI engine and learns/determines action based on sensor variation
2 The data is stored locally in a persistent, high-performance memory such as MRAM
3 AI determines there is a gasket which needs replacing and turns on the engine warning light
4 Data is sent back to the cloud
5 Analytics is performed to generate new improved inference engines
6 New inference engine is sent to the IoT node

Potential Benefits

Amazon points out three tactical benefits of distributed IIoT applicable to manufacturers:

1. **Predictive Quality analytics** extracts actionable insights from industrial data sources such as manufacturing equipment, environmental conditions, and human observations to optimize the quality of factory output.

Amazon estimates 20% of a manufacturing company's annual sales are lost to poor quality. IIoT allows manufacturers to "build predictive quality models which help them build better products. Higher quality products increase customer satisfaction and reduce product recalls."

"IIoT allows manufacturers to "build predictive models which help them build better products. Higher quality products increase customer satisfaction and reduce product recalls."

—AMAZON

2. **Asset Condition Monitoring** captures the state of your machines and equipment to determine asset performance.

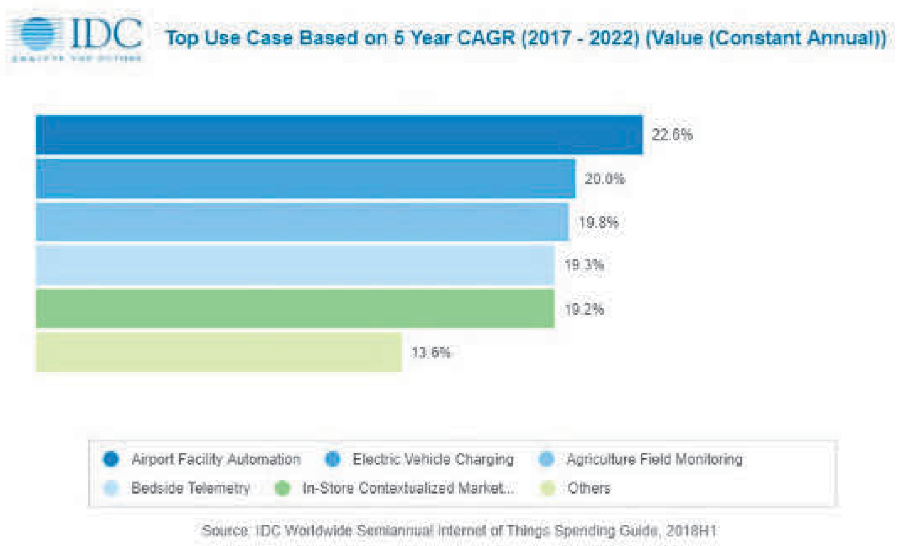
Amazon sees that "equipment downtime can impact scheduled production time. Sending device health indicators to the cloud lets operations staff know the health and status of equipment to prevent productivity and efficiency losses."

3. **Predictive Maintenance analytics** captures the state of industrial equipment to identify potential breakdowns before they impact production resulting in an increase in equipment lifespan, worker safety, and the supply chain optimization. [13]

The ServiceMax whitepaper, "After The Fall: Cost, Causes and Consequences of Unplanned Downtime," notes that 82% of companies have experienced at least one unplanned downtime outage over the past 3 years. This costs between $.20 to $1.20 for every $20 made. [11]

With distributed decision making and the nodes taking on more responsibility, data flow is dramatically reduced. This means improved system reliability, leading to higher quality product and dramatically reduced downtime.

With better product and reduced downtime, a wide variety of industry verticals are jumping on the IIoT bandwagon. The research firm IDC sees use cases from airport automation to agriculture monitoring.



Steve Ranger at *ZD Net* says "Right now, the IIoT is of particular interest to the manufacturing, retail, utilities and transport industries". IIoT projects can give manufacturers a better idea of how their production lines are operating, and to make better predictions about when particular machines will need servicing, which will reduce unexpected downtime.

"Utilities can use the IIoT to cut down on the cost of sending staff to check on remote installations by making them self-monitoring," he continues. "Retailers can understand where the bottlenecks are in their supply chain, and transport companies can better understand the performance of their vehicle fleets. But these aren't the only interested sectors: health care and government are also likely to be big IIoT adopters and while at the moment it's mostly being explored by larger organizations, it may become more widely adopted as the price of hardware and services comes down." [12]

Bottom Line ROI

Clearly the use cases for IIoT spread far and wide. But what exactly can companies hope to achieve by investing? What specific efficiencies can be gained?

Belden, the cable and connectivity company, points to four areas where IoT is transforming a wide variety of factories:

Innovation: Mobilizing employees to move across the factory floor and access data anytime or anywhere drives new thinking. iPads and other devices enable innovation and predictive maintenance. Mobile flexibility improves the ability to gain early warnings when production, machinery or network performance is about to degrade.

Efficiency: Now the gap between the data center and control room is gone. Best practices and common goals can be shared collaboratively between IT and manufacturing. In addition, people, equipment, works in process and finished goods can be quickly identified and adjusted in real-time.

Agility: Visibility is no longer confined to the factory walls. The extended supply chain is linked to distribution to create dynamic workflows. An expandable infrastructure minimizes costs and effort to improve processes, including safety, control, security and LAN.

Risk: Traditional security devices — keypad entry, call boxes, cameras — can all be linked. And a rugged industrial networking infrastructure means less risk and more consistent manufacturing uptime. [13]

The Big Picture

In its recent report "Industrial Internet: Pushing the Boundaries of Minds and Machines," General Electric sees this Industrial Revolution opening "new frontiers to accelerate productivity, reduce inefficiency and waste and enhance the human work experience" that could possibly be worth a staggering $10 to $15 trillion to the global economy.

The report continues: "The full potential of the industrial Internet will be felt when the three primary digital elements — intelligent devices, intelligent systems and intelligent automation — fully merge with the physical machines, facilities, fleets and networks. When this occurs, the benefits of enhanced productivity, lower costs and reduced waste will propagate through the entire industrial economy." [14]

Industry Week spoke with Don Busiek, general manager of manufacturing software at GE Intelligent Platforms, at a San Francisco event for the launch of the report:

Busiek: "There is a huge shift happening in manufacturing today. With the advent of new technologies, smarter assets and smarter devices, today's advanced factories have essentially become data centers driving intelligence across the enterprise.

"Historically if you look at manufacturing software, it has been siloed systems; it has been systems that didn't talk to each other," explains Busiek. "They didn't talk, they didn't relate, so as a plant manager you couldn't compare your performance against another plant."

"With the advent of the industrial Internet," he continues, "suddenly plants have the ability to tie all of their data across multiple plants, even view it over the web on their handheld devices and finally be able to understand and compare their performance across the enterprise and the performance of equipment across different lines."

Doing so, "all of a sudden you can structure your schedule across your plant with more intelligence. You can schedule your shift, your personnel with more intelligence. You can even program the heating in your building with more intelligence."

"That's where it's going," he says. "Toward that concept of a connected world, where all of your devices are rolling up data, but you're slicing it. It's not the thousands of pieces of data; you're slicing it in such a way that it is presented to the right user at the right time based on their role."

"To me, that's the smart factory of the future." [15]

A Roadmap for Success

Everyone agrees that IIoT is extending automation beyond traditional factory walls. Today, always-on connectivity and real-time analytics are a requirement. But the key is for smart factories to embrace distributed AI decision making.

The goal must be to minimize the amount of data moving between the factory control center or Cloud to the Edge and to millions of nodes.

"Take Siri," explains Avalanche's Danny Sabour. "When you program it, it sends your voice to the Cloud and all of the analysis is done there. Today, in Smart Factories, the goal is to have the analytics done at the node and free up the network, with the cloud focused on generating the training models for the nodes."

In the nodes - whether a traffic light or a piece of machinery — the requirement has evolved to AI-based learning behavior. In this new model, data cannot be continually sent back to the control center.

On the Edge, systems — including MES, ERP, SCADA, etc. — are also doing more work. Here the processing of data for visualization, caching and filtering happens. Communication and sharing also live on the Edge.

With the Edge and nodes taking on added responsibilities, the control center/Cloud is freed up to focus on constructing deep learning and training models, and pushing them out to the Edge and nodes.

While the computing power and the storage ability to make all of this happen is in place, the weak link is in networking. Which means, in this new model, the entire goal is to relay and transfer as little data as possible between layers.

Sounds good in theory, but how is it accomplished?

"With the industrial Internet, suddenly plants have the ability to tie all of their data across multiple plants, even view it over the web on their handheld devices and finally be able to understand and compare their performance."

—DON BUSIEK, GE

Let's start with the nodes. This new generation of compute capable, intelligent IIoT nodes contain neuroprocessors making local AI-based decisions. This includes analyzing and combining raw sensor data, solving the problem, including reconfiguring the actual node if necessary. These nodes may not be connected at all times, and they may be running on a battery. And there may be billions of them, all requiring low power and persistence. In the case of a Cloud or Edge power outage, they cannot afford to wait to reload.

At the Edge, data is fused and intermediate patterns are shared with adjacent domains. The Edge architecture is similar to the Cloud, but with the addition of CPU cores, which are ideal for machine learning. The Edge requires speed and, for this learning, persistent memory.

And, as we said before, the Cloud collects all data for long term analysis and training.

MRAM Powers IIoT

Reducing network traffic and downtime requires pushing analysis and decision making to the Edge. To facilitate this, Edge nodes require memory with four characteristics:

Persistence: The ability to retain memory contents when power is removed is critical for systems that must keep track of the exact state it is in. In the event of a power disruption, the system can resume from the exact state when the power was interrupted.

High Endurance: The device's memory cells must support a large number of write cycles before failure. This is important because the memory will be used in conjunction with cache memory (SRAM) where it will provide temporary storage of data and calculations. In high performance embedded systems and AI, memory is intensely written to.

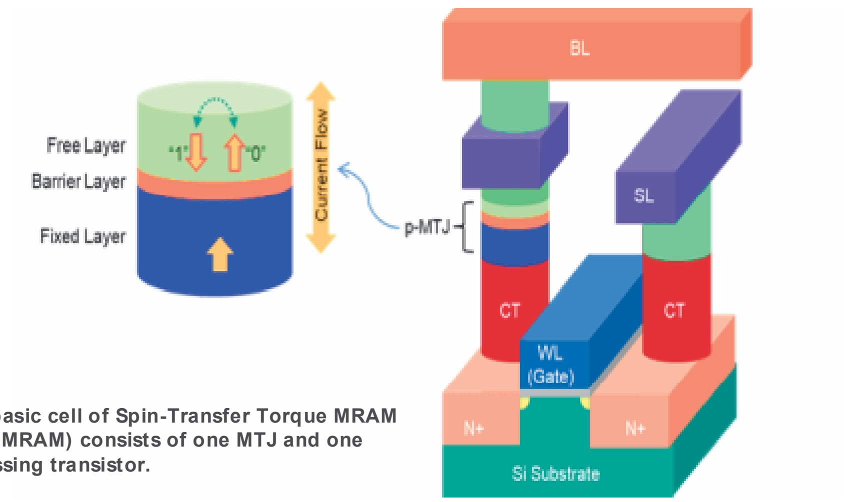
Fast Write: This is critical to the performance of the system. The longer the write time, the longer the processor will idle waiting for the memory to complete the write operation before it can access the information. In addition, for data logging systems, the memory must record (write) the information quickly, to ensure it is secure in the event of a power disruption.

Low Power: The power consumption of an IIoT/AI system is critical in moving the data analysis and decision making from the cloud to the Edge node. While power is not a concern in a cloud data center where the total power consumption is large, as applications move towards the Edge node, power becomes a concern. In many cases, the power supply of a system is limited or even battery operated. Any reduction in system power consumption is critical.

These four requirements are matched perfectly by **High Reliability, High Density, Small Form factor and Instant Access** MRAM, which is able to deliver a unified memory architecture.

MRAM is uniquely positioned to deliver the memory requirements for AI all the way from the Edge to the node. The real-time processing performance of AI is directly tied to the amount of cache on the chip, which is typically comprised of SRAM. Yet, SRAM does not scale well. And, as CPU process technologies shrink, cache densities have grown from 40% of the chip area to over 80%. This drives up cost and power consumption.

MRAM features a smaller cell size than SRAM, which allows for the higher densities needed by AI processors. In addition, it significantly reduces the SRAM cache size, alleviating the cost and power issue.



The basic cell of Spin-Transfer Torque MRAM (STT-MRAM) consists of one MTJ and one accessing transistor.

Avalanche's STT-MRAM technology features a proprietary perpendicular magnetic tunnel junction (p-MTJ) element which includes a magnetic fixed layer, a dielectric barrier layer and a changeable ferromagnetic storage layer. The magnetic orientation of the fixed layer is fixed during the manufacturing process. The structure of the p-MTJ element can be tailored for any industrial performance spec or application needs.

Avalanche's Perpendicular Spin Torque Transfer MRAM technology delivers the next generation scalable embedded unified memory architecture with the benefits of low latency, low power, infinite endurance, high performance and scalability to lower geometry nodes.

Avalanche offers discrete and embedded MRAM. Discrete devices are the perfect solution in IIoT, where MRAM is used to enable Highly reliable solutions with low power. Embedded MRAM macros (provided through foundry partners) enable quick and efficient implementation of complex and cost effective SoC designs.

But why MRAM, as opposed to other persistent memories?

Let's go back to the requirements for distributed IIoT:

- **High Reliability**
- **Persistence**
- **Endurance**
- **Fast Write**
- **Small Form Factor**
- **Low Power**
- **Total Cost of Ownership/ Bill of Materials**

Technology Comparison

	Retention Established Memories						Emerging memories		
	DRAM	SRAM	NOR	T_MRAM	NAND	FRAM	PCM	RRAM	AVA-SPMEM™ Today
Non-Volatile	x	x	√	√	√	√	√	√	√
Read Speed	√	√	x	-	-	-	√	√	√
Write Speed	√	√	x	-	x	-	-	x	√
Read Power	√	√	-	x	√	√	√	√	√
Write Power	√	√	x	x	-	√	-	-	√
Standby Power	-	x	√	-	√	√	√	√	√
Cell Size	√	x	√	x	√	x	√	√	√
Endurance	√	√	x	√	x	√	x	x	√
Retention	x	x	√	√	x	√	√	√	√
Rad Hard	x	x	x	√	x	√	√	√	√

Each technology offers only one or more of the attributes required for a High Reliability IIoT solutions.
NOR Flash with its slow write and limited Endurance is mainly used for Boot code and cannot be relied upon as a reliable Non-Volatile memory.
NAND Flash with high density does not have any of other attributes necessary to be used in a system. Due to its extremeley limited endurance and slow initial latency, it remains as a bulk storage memory and is further limited by the requirement of a system level controller to manag the bad blocks and having to remap them after limited write cycles.
PCM and **RRAM** also suffer from limited endurance and slow writes which need to be hidden behind a system level controller. As such, no system designer will not trust critical data to them.

The remaining real contendors for a system level designer are Avalanche **P-SRAM**, **nvSRAM**, **B^2SRAM** and **FRAM**. These 4 solutions can be compared based on features, capabilities and benefits:

Avalanche P-SRAM Overview
Avalanche's Persistent SRAM (P-SRAM) is unlike conventional RAM and stores data in magnetic storage elements (pMTJ STT-MRAM). The elements are formed from two ferromagnetic plates separated by a thin insulating layer. Each element stores a magnetization; one is set to a fixed polarity and the other programmable (storage element - parallel or anti-parallel) based on an external field. These two elements formulate a memory cell. The direction of current flow through the memory cell sets the state of the storage element

(Logic 0 – parallel; Logic 1– antiparallel) during programming which can be sensed during read. P-SRAM is a single monolithic solution requiring no external batteries or capacitors to maintain non-volatility.

nvSRAM Overview

nvSRAM is a combination of two technologies, namely SRAM with an integral shadow E2PROM. Information is made non-volatile by loading SRAM contents into the E2PROM or vice versa through a variety of methods which are user selectable.

SRAM to E2PROM: The contents of SRAM are loaded into E2PROM using AutoStore and UserStore methods. AutoStore occurs automatically upon power loss and the energy needed comes from an external capacitor. The UserStore method is generated either by using a hardware pin or a software sequence while power is available.
E2PROM to SRAM: The contents of E2PROM are loaded into SRAM upon power-up.
As mentioned above, the nvSRAM technology is a combination of SRAM and E2PROM technologies on the same die. A non-volatile E2PROM element is incorporated in each SRAM cell. In normal operation modes, the memory operates as an SRAM. During power-up or power-down, SRAM data is transferred or recalled in parallel to/from the E2PROM. SRAM has unlimited endurance, while the number of storage cycles in the E2PROM are limited to 500,000 cycles or less during the product's lifetime.

B^2SRAM Overview

B^2SRAM is a combination of SRAM, control logic and battery elements embedded in a single package. The battery can be integrated inside the package or can be housed on top of the package and then mechanically attached.
When the supply voltage (VCC) dips below a specified level, the internal battery is switched on to sustain the contents in the memory array until VCC returns to its valid condition.

A B^2SRAM includes three major components: a standard SRAM, a power sensor/switch chip, and a battery. The power sense/switch control circuitry constantly monitor VCC for an out-of-tolerance condition. When such a condition occurs, the battery is automatically switched on and write protection is disabled to prevent any data corruption.

FRAM Overview

FRAM (also known as FeRAM)is a random-access memory similar in construction to DRAM but using a ferroelectric layer instead of a dielectric layer to achieve non-volatility.

FeRAM's advantages over Flash include: lower power usage, faster write performance and a much greater maximum read/write endurance (about 10^{10} to 10^{14} cycles). FRAMs have data retention times of more than 10 years at +85 °C. Market disadvantages of FRAM are much lower storage densities than other Non-Volatile Memories at much higher cost. Like DRAM, FRAM's read process is destructive, necessitating a write-after-read architecture.

Technical Comparison of Non-Volatile Memories

Data Endurance & Retention

Data Endurance specifies the number of program/erase (write) cycles before the device cannot be used anymore. Similarly, Data Retention specifies how long data can be stored before it starts to deteriorate.

	pMTJ STT-MRAM	Toggle MRAM	FRAM	nvSRAM [1]	B^2SRAM [1]
Data Endurance	10^{16} Write cycles	10^{18} Write cycles	10^{14} Write cycles	SRAM – Unlimited EEPROM - 500,000 Store Cycles	Unlimited
Data Retention (85°C)	20 Years	20 Years	20 Years	EEPROM – 10 Years	6 Months

Notes:
1. Products using Batteries or Supercaps are not RoHS Compliant

Density

The density of these devices represents the number of bits of data that can be stored in a device. It is represented ad Kilobit Kb (1000 Bits of data), Megabit "Mb" (1,000,000 bits of data) or Gigabit "Gb" (1,000,000,000 bits of data). Some manufacturers can stack up to 4 devices in a single package. Customers in some cases put multiple devices on a board to increase the density.

	pMTJ STT-MRAM	Toggle MRAM	FRAM	nvSRAM	B^2SRAM
Available Density	1Mb – 1Gb [1]	256Kb – 32Mb [1]	256Kb – 8Mb [1]	64Kb – 16Mb	256Kb – 64Mb

Notes:
1. Monolithic as well as stacked dies.

Performance

Performance in this case is measured as access time to the device. In a Parallel devices the access time is measured in nano second "ns". The smaller number indicates how long it takes to read or write the device. In Serial devices "access speed" is measured in MHz. This is the clock fequency which drives the device. The larger the number the faster the access time.

	pMTJ STT-MRAM	Toggle MRAM	FRAM	nvSRAM	B^2SRAM
Performance	35ns	35ns	108MHz	25-45ns	25-54ns [1]

Notes:
1. Battery backed-up devices optimize the standby power consumption to maximize retention, and hence sacrifice access time in the process.

Power Up Requirements

Most devices require a mimimal period of time before the internal logic has reached the proper working voltage levels. This is measured in Microseconds. In the case of nvSRAM, this time is much longer as the saved copy of the data is copied from the storage array to the working SRAM array. In BBSRAM devices, the required time before the device is accessed is much longer to assure stability of operation.

	pMTJ STT-MRAM	Toggle MRAM	FRAM	nvSRAM	B^2SRAM
Power Up Requirements	250µs	400µs	450µs	20ms [1]	125ms [2]

Notes:
1. Data is available 550 us after V_{CC} reaches V_{SWITCH} on power-up. This is the time needed to move data from E^2PROM to SRAM.
2. Chip Enable must be maintained High (Logic 1) for at least 125ms after power-up. During this time, the device cannot be accessed.

Power Down Requirments

nvSRAM and B^2SRAM both need extra time during power down. In the case of nvSRAM the working copy of the data is copied from the SRAM array to the non-Volatile array (known as AUTOSTORE). In the case of B^2SRAM the power must be taken down under control to avoid data corruption

	pMTJ STT-MRAM	Toggle MRAM	FRAM	nvSRAM	B^2SRAM
Power Down Requirements	No Condition	No Condition	No Condition	AutoStore [1]	Slew Rate Control [2]

Notes:
1. The AutoStore nvSRAM recognizes a voltage loss at approximately 2.70V and automatically transfers the SRAM contents into E^2PROM.
2. CC must drop from 2.70V to 0V in no less than 300µs – Slew rate control required.

Board Space

All the devices shown below except for FRAM are available in 16Mb density. In order to reach 16Mb, at least 2 FRAM devices must be placed on the board to achieve this density.

In addition, the minimum space is the size of the device plus any support circuitry. nvSRAM and BBSRAM both require extra circuitry to support powering up the devices in the form of capacitors or batteries.

As such MRAM represents the best alternative. Avalanche's STT-MRAM is designed with an upgrade path in mind. The next genertaion of devices will support up to 1Gb with the same ball assignment. Thus eliminating the need to redesign the board.

	pMTJ STT-MRAM	Toggle MRAM	FRAM	nvSRAM	B^{2}SRAM
Board Space	48-Ball FBGA (MRAM) (10mm x 10mm)	48-Ball FBGA (MRAM) (10mm x 10mm)	8-Pin WSON (4mm x 4mm)	Capacitor Required 48-Ball FBGA (6mm x 10mm)	Lithium Ion Battery Required Power Switch Logic Required 48-Ball FBGA (B^{2}SRAM) (8mm x 9.5mm)
16Mb	(10mm x 10mm) [1]	(10mm x 10mm) [1]		> (6mm x 10mm) [4]	> (8mm x 9.5mm) [5]
32Mb	(10mm x 10mm) [2]	(10mm x 10mm) [2]			> (16mm x 19mm) [6]
64Mb	(10mm x 16mm) [1]	> (40mm x 40mm) [3]			> (32mm x 38mm) [6]
256Mb	(10mm x 16mm) [1]				
1Gb	(10mm x 16mm) [2]				

Notes:
1. Monolithic
2. Stacked die
3. Assumes a minimum as 4 dies have to be placed on board
4. Extra space needs to be added on board to accommodate a Capacitor
5. Extra space needs to be added on board to accommodate a Battery
6. Assumes 2 or 4 dies to be placed on board as well as extra space needed for the Battery

While several options offer some of these, none offers all — except MRAM. Given its persistence, high-endurance, high-read/write performance, and low power consumption, MRAM becomes the clear choice.

"With Avalanche MRAM, we solve the memory needs of the system all the way from the cloud to the node" explains Danny Sabour. "Think about a power grid control center for all of the power distribution in a major metropolitan city. Then think of MRAM on the Edge and all of the way out to the nodes — to each of the millions of traffic lights. It's transformative."

About Avalanche

Avalanche Technology, headquartered in Fremont, California, is the world leader in Spin Transfer Torque Magnetic RAM (STT-MRAM) non-volatile memory leveraging perpendicular magnetic tunnel junction (pMTJ) cell structure manufactured on standard CMOS process.

Backed by more than 300+ granted patents around cell, circuit, and system design leveraging MRAM, our technology and products provide breakthrough speeds, unlimited endurance and non-volatility while reducing power and cost. With such attributes, our technology will serve and exceed our customers' objectives as a replacement for SRAM, eFlash, and ROM in embedded applications in addition to discrete SRAM, non-volatile SRAM, NOR and DRAM.

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