Successfully Tackling the Industrial Internet of Things

A Guide to Developing IIoT Applications

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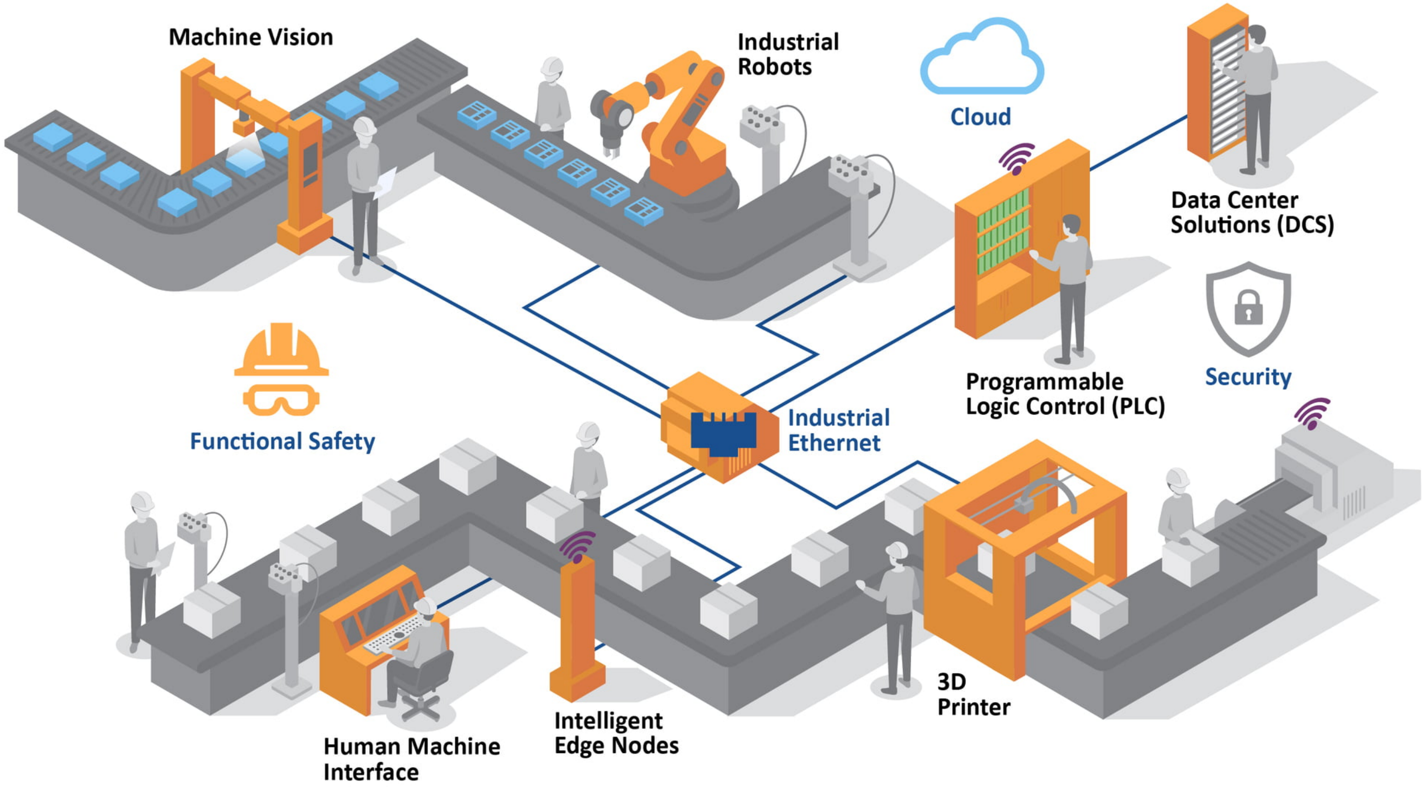
When it comes to industrial applications, you can either work harder or smarter. Generally, the best path is to work smarter. Over the years, optimized machines have displaced humans for menial tasks, providing higher productivity, accuracy and quality while reducing the cost of finished goods. Today's manufacturing facilities build upon the highly networked industrial systems of the past with one key difference: more data sharing.

Whereas manufacturing data was used solely for process control, today it's collected for analysis in the cloud as we move to Industry 4.0 to enable continuous optimization and improvement. The Industrial Internet of Things (IIoT) makes this data sharing possible. The IIoT refers to the sensors, systems and platforms that link the big data gathered in



manufacturing facilities with digital twins, dashboards, Artificial Intelligence (AI) analysis tools and Augmented Reality (AR).

Semiconductors are central to the success of IIoT deployments. Semiconductors include devices that convert analog signals into digital data, processors that gather, process and forward such data, IEC 62243-capable cryptography devices to secure connections and connectivity solutions that pass the data on through wires or the ether.

Microchip Technology has been a trusted partner of industrial electronics engineers for decades, responding to requests for innovation, offering long time availability with client-managed obsolescence and designing chips that deliver years of reliable operation in challenging manufacturing environments.

One of the most significant issues for engineers is maintaining an overview of the available technology so that, when the next development challenge arises, they know which components best deliver the required solution. This guide seeks to provide an overview of the available technology, examining the many different domains of IIoT and the range of solutions available. We hope you will discover how Microchip can accompany you on your journey from prototyping to production.

"Microchip Technology has been a trusted partner of industrial electronics engineers for decades

Yours, ***Markus Austermayer***
Segment Leader Europe - IoT & Ecosystem

Reducing the Attack Surface With Secure Elements

While IIoT opens up enormous benefits for those who embrace the technology, merging the worlds of Operational Technology (OT) with Information Technology (IT) also places it at the mercy of bad actors and hackers. Since the discovery of Stuxnet, a computer worm that targets Supervisory Control and Data Acquisition (SCADA) systems based on Programmable Logic Controllers (PLCs), in 2010, industrial automation systems have been subjected to further attacks. These attacks have caused severe damage to manufacturing equipment and plants.

Although OT systems are more obscure in their structure than IT systems, this hasn't stopped hackers from using OT systems for executing attacks. This vulnerability has highlighted the need to tighten security, ensure that software is checked for authenticity before execution and limit who can apply changes to installed systems.

The industry has coalesced around IEC 62443, a series of standards that recognize the security needs of Industrial Automation and Control Systems (IACS), their performance requirements and risk management goals. IEC 62443-4 provides guidance for product suppliers, developers of PLCs, DSCs or networking devices and the fourth and sometimes third tier.

General	**IEC 62443-1-1** Terminology, Concepts and Models	**IEC TR-62443-1-2** Master Glossary of Teams and Abbreviations	**IEC TR-62443-1-3** System Security Conformance Metrics	**IEC TR-62443-1-3** IACS Security Lifecycle and Use-Cases	
Policies & Procedures	**IEC 62443-2-1** Establishing an Industrial Automation and Control System Security Program	**IEC TR-62443-2-2** IACS Protection Levels	**IEC TR-62443-2-3** Patch Management in the IACS Environment	**IEC TR-62443-2-4** Requirement for IACS Service Providers	**IEC TR-62443-2-5** Implementation Guidance for IACS Asset Owners
System	**IEC TR 62443-3-1** Security Technologies for IACS	**IEC TR-62443-3-2** Security Risk Assessment and System Design	**IEC TR-62443-3-3** System Security Requirments and Security Levels		
Component	**IEC 62443-4-1** Product Development Requirements	**IEC 62443-4-2** Technical Security Requirments for IACS Components			

The IEC 62443 standard provides the guidelines used by industrial equipment manufacturers

Devices must fulfill Foundational Requirements (FRs), such as identification and authentication control, system integrity and data confidentiality. Hardware devices, such as the ATECC608 Secure Element (SE) and TA100 trust anchor module, can be combined with any MCU or MPU. With a very low power consumption, they offer protected storage for keys, certificates or data and hardware support for asymmetric signing, verification and key agreement according to ECDSA:FIPS186.3.

If your system connects to cloud platforms such as AWS IoT Core or Microsoft Azure, you can use preprovisioned Trust&GO devices. Pre-configured devices preprovisioned with default generic certificates are also available with TrustFLEX, while TrustCUSTOM offers complete flexibility. Developers and device manufacturers benefit from Microchip's secure manufacturing facilities, even when ordering smaller quantities of units. This SE hardware is also fully supported by the CryptoAuthLib and Trust Platform Design Suite software libraries and development kits.

One of the core challenges with embedded systems is establishing trust from the moment the first instruction of the firmware is executed. Platform root of trust solutions support cyber resiliency that anchors the secure boot process using runtime firmware protection upon which an entire chain of trust is built. This is the approach taken by devices such as the CEC17xx and MEC17xx platform root of trust MCUs.

The CEC1736 development board eases access into the world of root of trust and secure firmware execution.

These Arm® Cortex®-M4-based devices hold the host application processor in reset during

How do you tackle industrial security?

- We don't currently have an approach.
- We're still developing our approach.
- We have security competency in house.
- We're using external partners.

Post answer

startup as they execute an immutable secure bootloader. With this initial trust established, the host processor's firmware is loaded, decrypted and authenticated from an external SPI Flash. If all is well, the host processor can execute its firmware. From this point on, the CEC17xx and MEC17xx devices continue to monitor SPI and I^2C interfaces against unauthorized accesses or commands using the Soteria firmware that supports secure firmware updates and other advanced security features.

Security features permeate the other programmable devices offered by Microchip. These include the PolarFire® family of FPGAs and SoC FPGAs, with their cryptographically secure supply chain, side-channel-resistant crypto accelerators and Physically Unclonable Function (PUF)-based key storage. Families of MCUs such as the PIC32CM Lx family offer secure boot and Arm TrustZone® technology, which supplies both asymmetric and symmetric key cryptography and customizable certificate storage slots.

Microchip also supports developers from project kick-off thanks to Microchip University courses, such as the Cryptography Primer course that provides the required security fundamentals.

Find Out More

Microchip's SHIELDS UP! webinar series also provides ongoing support. A collection of trusted partners is also available to provide guidance on the security issues surrounding the development of embedded IIoT systems.

Find Out More

New Wired Industrial Networking Technology

Upgrading the Wire

Upgrading the Wire

The role of connectivity in industrial automation has changed over the years. In the past, sensors and actuators were connected to PLCs, resulting in “islands of automation”. Today, IIoT ensures that the data flowing is also captured and analyzed, making it easier to find efficiencies and improvements as the worlds of IT and OT merge. While current loops of 4–20 mA delivered process data over large distances in the past, newer physical layer technologies, such as EIA-485, Modbus, ASi-5, IO-Link and CAN, have largely displaced them. These also provide support for bi-directional communication, more straightforward installation and higher bandwidth when combined with PROFIBUS or DeviceNet protocols.

However, today’s industrial machines generate increasing amounts of data or have multiple nodes requiring real-time control that is accurate to the millisecond. Both of these issues can be solved by increasing the bandwidth, so naturally, Ethernet is a possible solution. However, while its bandwidth has steadily increased to support IT needs, Ethernet has lacked the bandwidth reservation and hard real-time guarantees required by industrial automation.

	Ethernet/IP	POWERLINK	EtherCAT®	Sercos III	PROFINET
Real-time approach	S/S	O/S	O/M	O/M	O/M
Existing profile	DeviceNet	CANopen	CANopen	Sercos II	PROFIBUS
Centralized control	✓	✓	✓	✓	✓
Decentralized control	✓	✓	-	✓	✓
Topology					
Tree	✓	✓	-	-	✓
Star	✓	✓	-	-	✓
Ring	✓	✓	✓	✓	✓
Daisy-chain	✓	✓	✓	✓	✓

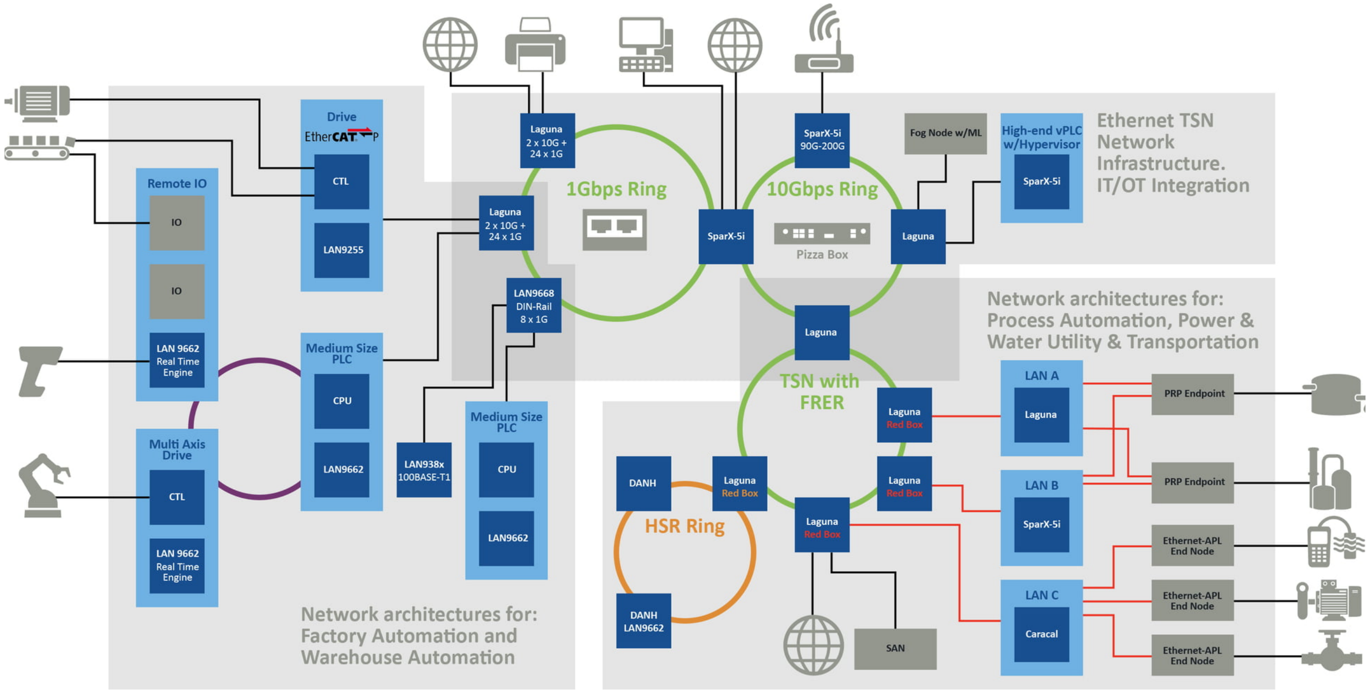
O/M = Open Software/Modified Ethernet; O/S = Open Software/Standard Ethernet; S/S = Standard Software/Standard Ethernet

Five Common Industrial Ethernet Approaches

Despite this, automation system providers have leveraged Ethernet’s high bandwidth to deliver these real-time requirements. By modifying the software stack, response times for 100 axes under 1 ms with jitter below 1 ms are possible at data rates of 100 Mbits/s. Industrial Ethernet now commands a 66 percent market share, with EtherNet/IP, OPC UA, PROFINET and EtherCAT® making up more than two-thirds of that.

Learn More About EtherCAT®

EtherCAT has established itself in control and regulation applications. Thanks to the simple processing of data telegrams as they pass through daisy-chained slaves, the microprocessors (MPUs) in PLCs can focus on their control tasks rather than on data communication. Devices such as the LAN9255 simplify their integration into drives by offering two 100BASE-TX full-duplex EtherCAT device controllers alongside SAM E53 MPUs that feature powerful 32-bit Arm® Cortex®-M4 processors. Rapid prototyping is straightforward thanks to an evaluation board and configuration file that generate the EtherCAT Slave Stack Code (SSC).



Automation Network Solutions

Industrial networks also benefit from additions to the IEEE 802.1 and 802.3 specifications that build in guaranteed end-to-end latency, known generally as Time Sensitive Networking (TSN). These are implemented in layer 2 (Data Link) rather than in the application layers as implemented by PROFINET, meaning a matching Ethernet is also needed. The Linux-capable ATSAMA5 and ATSAMA7G45 are ideal candidates, especially when targeting power-over-data line (PoDL) end device designs. IP blocks supporting IEEE 1588 v2 are also available for the PolarFire range of FPGAs. Otherwise, classic embedded applications supporting TSN can be implemented using the SAME70 or SAME53/54 families of microcontrollers.

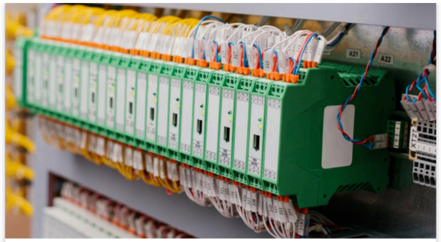
Microchip also offers a range of gigabit TSN-enabled industrial Ethernet switches with the VSC754xTSN and VSX755xTSN devices, or four 100BASE-T1 ports with the LAN9370. To achieve nanosecond-accurate IEEE 1588 timing, dedicated clock management is required. Network synchronizers, such as the ZL30802, and multiplier and frequency synthesizers, such as the ZL30251 and ZL30267, generate ultra-low jitter clock trees with their fanout buffers in small footprint packages.

Factory Control

- Sensors
- Actuators
- Assembly lines
- Packaging lines

In-Cabinet Racks

- Intra-system management interface in racks
- Fans, temperature sensors, voltage monitors, DC-DC converters and optical modules



Control Units

- On/off switches
- Buttons
- Converters
- Relays and input/output cards

Industrial Control and Factory Automation

Another development is in the physical layer of Ethernet. Most will recognize the bundle of eight twisted-pair cables connected to an RJ45 connector. This could be overkill for industrial sensors, which is why Single Pair Ethernet (SPE) developed. Thanks to changes at the physical layer, 10 Mbits and more are possible in half-duplex multi-drop and full-duplex networks using a single, unshielded twisted pair while conforming to EMC standards and remaining unaffected by noisy electrical environments. It also makes for lighter, more flexible cabling when coupled with the smaller, more compact M8 connectors. Applications range from sensors and actuators to cameras and robotics.

Learn About Single Pair Ethernet (SPE)

> **Applications range from sensors and actuators to cameras and robotics.**

Cost-effective and low-power single-chip transceivers are available. These include the LAN8670/1/2 that supports 10BASE-T1S half-duplex point-to-point over segments of at least 15m, or multi-drop mixing segments up to at least 25m in length with up to at least eight PHYs, as defined by the standard. In addition, power over the data lines can deliver up to 60W or 500 mW in Zone 0 intrinsically safe applications.

The different versions of the LAN867x transceiver provide support for the MII or RMII interfaces and the Serial Management Interface (SMI) offers standardized access to the configuration registers. Thanks to the PLCA collision avoidance feature, you can achieve high-bandwidth utilization and keep RF emissions in check to fulfill EMC and EMI requirements.

Automation technology in our manufacturing facilities is growing in capability, placing more demands on the electronic systems used. More robots and vision systems demand higher bandwidth for data and tighter tolerances and guarantees for data delivery to achieve accurate control. Silicon devices that support these industrial networking technologies, along with development boards and software drivers, support development teams as they address the needs of these demanding applications.

Learn more about the technologies mentioned in this chapter:

Factory Automation

ATSAME53

Ethernet Switches for TSN

When do you expect to transition to TSN in your products?

- [ ] In the next 5 years
- [ ] In the next 12 months
- [ ] In the next 6 months
- [ ] We are currently transitioning.
- [ ] We would like to learn more about Microchip’s solutions.

Post answer

Wireless for Industrial Networks

Breaking the Tether

Breaking the Tether

Given a choice, most engineers would opt for a wired connection instead of a wireless connection. The satisfying sound of a connector latching with a socket provides a certain level of comfort and, if things don't work, at least there are connections to probe. However, wireless connections do offer many advantages in the world of industrial automation. Due to their untethered nature, Autonomous Guided Vehicles (AGVs) require a wireless solution to enable them to remain connected to central systems as they make their way around the factory.

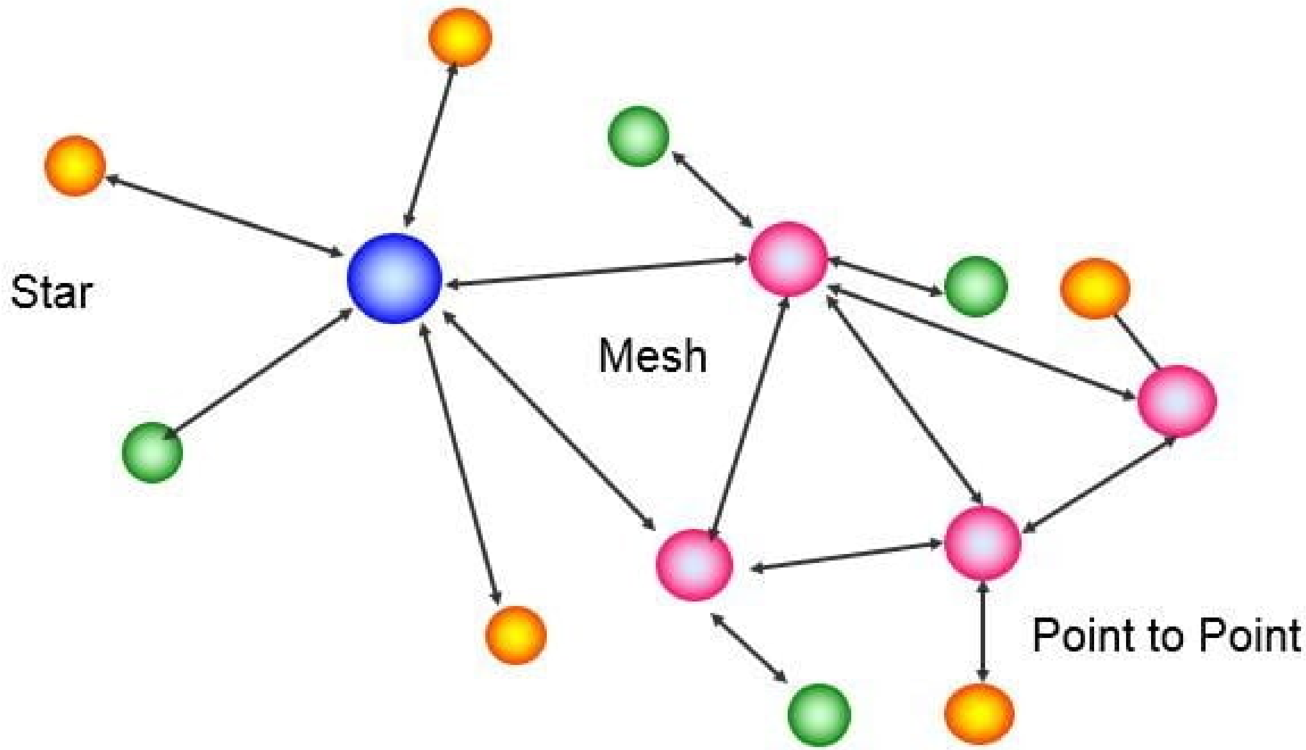
Field engineers also need to install and test equipment. Armed with a smartphone or tablet, wireless connectivity is the only option for connectivity. Using Bluetooth®, sensors can be configured and tested at the installation location without returning to a central control panel. Another often-quoted adage is "never change a running system". Older installations may not offer the connectivity required to integrate the installations into an IIoT platform, but in such cases, wireless sensors and gateways can offer a method for increasing the intelligence of such systems without breaking into the existing installation.

Although wireless connectivity used to be considered a black art that became more complex with an increase in frequency, development teams can now easily deploy gigahertz radio transceivers while focusing on the features of their application. The WBZ451 is an excellent example of a highly integrated radio module with global regulatory certification. Available in two versions, one with an integrated antenna and the other fitted with a U.FL connector for an external antenna, these devices are powered by the PIC32CX-BZ2, a family of MCUs with Arm Cortex-M4F cores.

The 2.4-GHz radio transceiver is certified for Bluetooth® Low Energy (LE) 5.2, Zigbee 3.0

and IEEE 802.15.4 protocols. Thanks to a hardware arbiter, time division coexistence between Bluetooth and 802.15.4 networks can be achieved, meaning both can operate reliably in parallel. This allows smartphones featuring Bluetooth to be used for device provisioning and configuration while the networked IIoT functionality operates over Zigbee or other 802.15.4 Wireless Personal Area Networks (WPANs).

Learn More About PIC32CX-BZ2 Family



Low-Cost Embedded Wireless Connectivity for Commercial and Smart Home Networks

The MPLAB Harmony v3 framework simplifies software development by offering drag-and-drop code generation and a broad range of application examples.

2.4 GHz has proven to be very popular but in offices and factories, this bandwidth suffers from overcrowding due to the number of devices operating in this bandwidth. Sub-GHz radios, such as the AT86RF215, provide an alternative with support from 389 to 1020 MHz in bands suited for use in Europe, China, North America, Korea and Japan. A second transceiver that operates simultaneously is also included in the 2.4 GHz band. Thanks to the fulfillment of multiple 802.15.4 modulation modes, this radio can be deployed with a range of physical layers, including Zigbee, 6LoWPAN and Microchip's proprietary MiWi™ networking protocol.

Of course, any data collected needs to be fed back to central systems for analysis and display on dashboards. The typical wireless interface that supports this is Wi-Fi® and developers will usually require a gateway solution to provide a bridge from 802.15.4-WPAN implementations. The WFI32E01 integrates industry-leading, low-power Wi-Fi connectivity in a highly integrated SoC powered by a 200-MHz MIPS® processing core. Explicitly designed for IIoT applications, the module is provided with either an integrated antenna or U.FL connector. An optional Trust&GO hardware secure element is also available, preprovisioned to streamline secure network authentication with popular cloud providers.

Learn More About MPLAB X IDE

Naturally, these solutions are supported with a range of evaluation boards and example code easily accessible through MPLAB X IDE, Microchip's free embedded software development environment. Most of Microchip's development boards also include an integrated debugger to simplify the first steps taken on the path to application creation. Developers can also make use of the many real-life code examples provided on GitHub.

Microchip Technology on GitHub

Explore the products and technologies discussed in this chapter:

Bluetooth LE

Wi-Fi

Zigbee

Sub-GHz

MiWi

Processing Solutions for PLCs to Sensors

Distributed Intelligence

Distributed Intelligence

IIoT implementations are highly intelligent. With the miniaturization of electronics and the rapid growth in computing performance, more PLCs are processing data locally and the “thinking” is being pushed deeper into the system. Even sensors are becoming more clever, undertaking significant data processing before data is passed up and through the network. But powering these sensors delivers challenges, with the expectation that Power-over-Data Line (PoDL) can be used even for Single Pair Ethernet (SPE) implementations. This can limit allowable power consumption to the 500- to 800-mW range.

Embedded Linux® offers a wealth of functionality supported by the open-source community, ensuring that standard capabilities, such as file systems and connectivity, are ready to go. This leaves development teams able to concentrate primarily on their application and its functionality. But the type of hardware needed for this operating system does not typically fall in the domain of low power.

Learn More About Linux OS for MPUs

This all changes with the SAMA5D2 and SAMA5D3 series of MPUs. These MPUs feature Arm Cortex-A5 processors that can be clocked at up to 500 or 536 MHz, respectively, and contain 128 kB of SRAM and 2 × 32-kB L1 caches. SAMA5D2 MPUs also feature 128 kB of L2 cache. In active mode and with all peripherals in use, these devices draw less than 150 mW of power while the low-power mode with SRAM and register retention see this drop to under 0.5 mW. These MPUs are also unique in running Linux and integrating Profinet, OPC-UA and TSN/T1S in a single chip with the lowest power.

If more performance is required, there is room to grow with the SAMA7G5 series. Operating at up to 1 GHz, they utilize the Arm Cortex-A7 complete with TrustZone, a

floating-point unit, and level 1 and 2 caches. Dual Ethernet (gigabit and 10/100) along with six CAN-FD provide plenty of connectivity, and high-performance crypt accelerators simplify the implementation of IEC 62443. At room temperature, processor power consumption lies under 350 mW at 1 GHz, while a camera application streaming over Ethernet requires under 670 mW. The rich range of ultra-low-power modes can draw as little as 9 mW (25°C) depending on the wake-up response time required.

Microchip has supported mainline Linux with the kernel, bootloader and drivers under development since 2004 and shares these components through the linux4sam.org website. The Long-Term Support (LTS) kernels provide maintenance for up to six years. Embedded applications can also be built using the tools provided by the Yocto Project and Builtroot is also supported. AT91bootstrap provides a second-level bootloader that can pass control to U-Boot.

You can get started using the ATSAMA5D27-SOM1-EK1, a fast prototyping and evaluation platform that combines the SAMA5D2 MPU with 1 Gb DDR2 DRAM, power management, 64 Mb QSPI Flash and 10Base-T/100Base-TX Ethernet in module form. The kit also provides a 12-bit camera interface and mikroBUS™ connectors to expand functionality.

The ATSAMA5D27-SOM1-EK1 offers rapid prototyping of Linux applications using this low-power MPU.

ATSAMA5D27-SOM1-EK1

While you can use Linux to tackle a wide array of embedded applications and take advantage of the real-time support when using the PREEMPT_RT patch, there are occasions where a dedicated MCU that features a real-time kernel is needed. Solutions like FreeRTOS provide exceptional documentation and integrate ready-to-run examples into the MPLAB development environment. Fulfilling functional safety criteria is simplified with Azure RTOS ThreadX, a real-time operating system with pedigree.

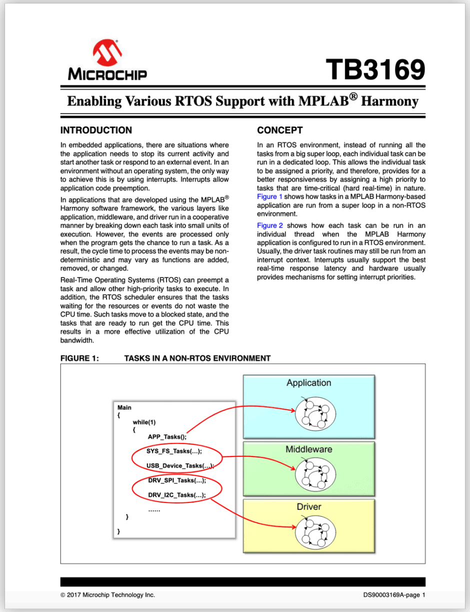
Alternatively, Zephyr offers a compact kernel for SAM D, E, L, R, and V MCUs, along with protocol stacks for connectivity and support for firmware updates. Microcontrollers in these series, like the SAME7x family with its Arm Cortex-M7 processor, provide a similar connectivity offering as their Linux-capable cousins, including 10/100 Mbps Ethernet with IEEE 1588, dual CAN-FD, and a USB device/host.

Learn more about the products and technologies mentioned:

Datasheet: RTOS Support with MPLAB Harmony

32-bit Low-power MPUs

Linux4SAM



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Enabling Various RTOS Support with MPLAB® Harmony

INTRODUCTION

In embedded applications, there are situations where the application needs to stop its current activity and start another task or respond to an external event. In an environment without an operating system, the only way to achieve this is by using interrupts. Interrupts allow application code preemption.

In applications that are developed using the MPLAB® Harmony software framework, the various layers like application, middleware, and driver run in a cooperative manner by breaking down each task into small units of execution. However, the events are processed only when the program gets the chance to run a task. As a result, the cycle time to process the events may be non-deterministic and may vary as functions are added, removed, or changed.

Real-Time Operating Systems (RTOS) can preempt a task and allow other high-priority tasks to execute. In addition, the RTOS scheduler ensures that the tasks waiting for the resources or events do not waste the CPU time. Such tasks move to a blocked state, and the tasks that are ready to run get the CPU time. This results in a more effective utilization of the CPU bandwidth.

CONCEPT

In an RTOS environment, instead of running all the tasks from a big super loop, each individual task can be run in a dedicated loop. This allows the individual task to be assigned a priority, and therefore, provides for a better responsiveness by assigning a high priority to tasks that are time-critical (hard real-time) in nature. Figure 1 shows how tasks in a MPLAB Harmony-based application are run from a super loop in a non-RTOS environment.

Figure 2 shows how each task can be run in an individual thread when the MPLAB Harmony application is configured to run in a RTOS environment. Usually, the driver task routines may still be run from an interrupt context. Interrupts usually support the best real-time response latency and hardware usually provides mechanisms for setting interrupt priorities.

FIGURE 1: TASKS IN A NON-RTOS ENVIRONMENT

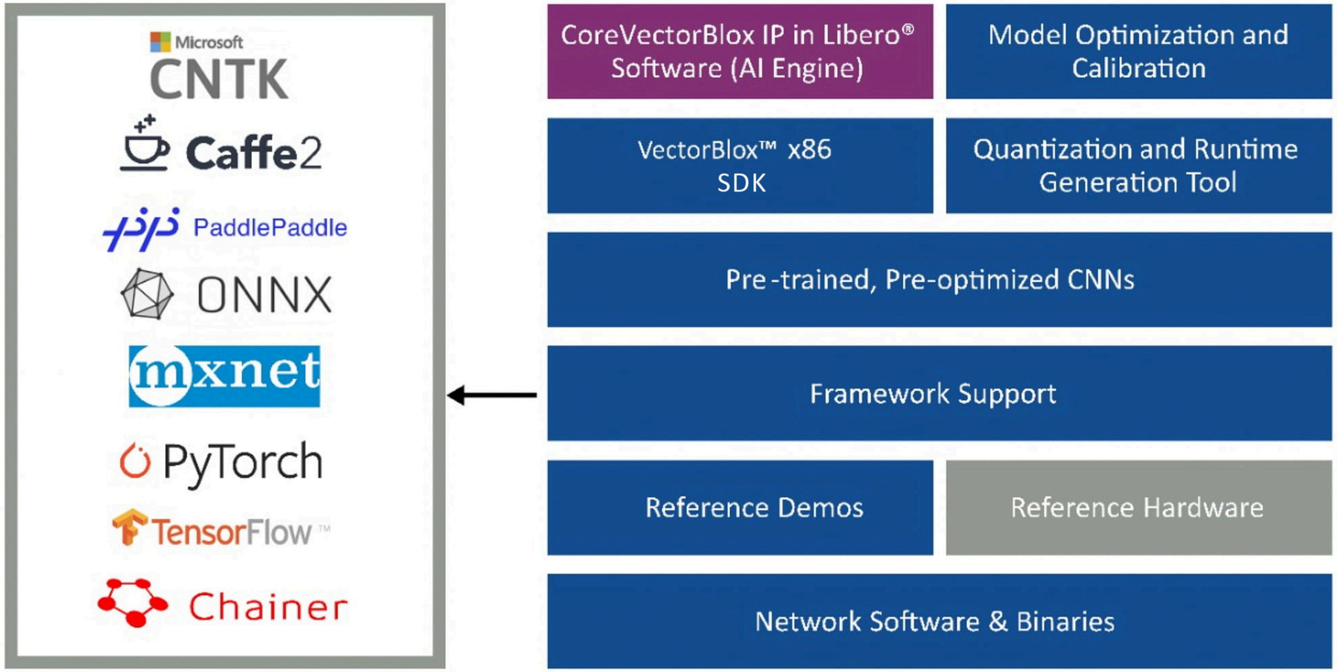
Artificial Intelligence (AI) and Machine Learning (ML)

The Thinking Factory

The Thinking Factory

Artificial Intelligence (AI) wields great power in industrial systems. In the past, a manufacturing site relied upon a tenured engineer to prophesize pending machine failure. Now, AI can do the same, developing its skill in a matter of days. While AI is often the term used, most intelligent technologies are Machine Learning (ML) models created by studying data patterns. The applications for AI range from detecting imminent bearing failure in drives to quality assessments of soldering on Printed Circuit Boards (PCBs).

ML is a very data-hungry application, but thanks to IIoT deployments, industrial systems are providing the required data. Sometimes, ML applications require labeled data to make sense of the information. However, solutions that work with unlabeled data are also available, relying on self-learning algorithms to make sense of it all.



"With some clever mathematics, it's possible to train a model with even a minimal data set.

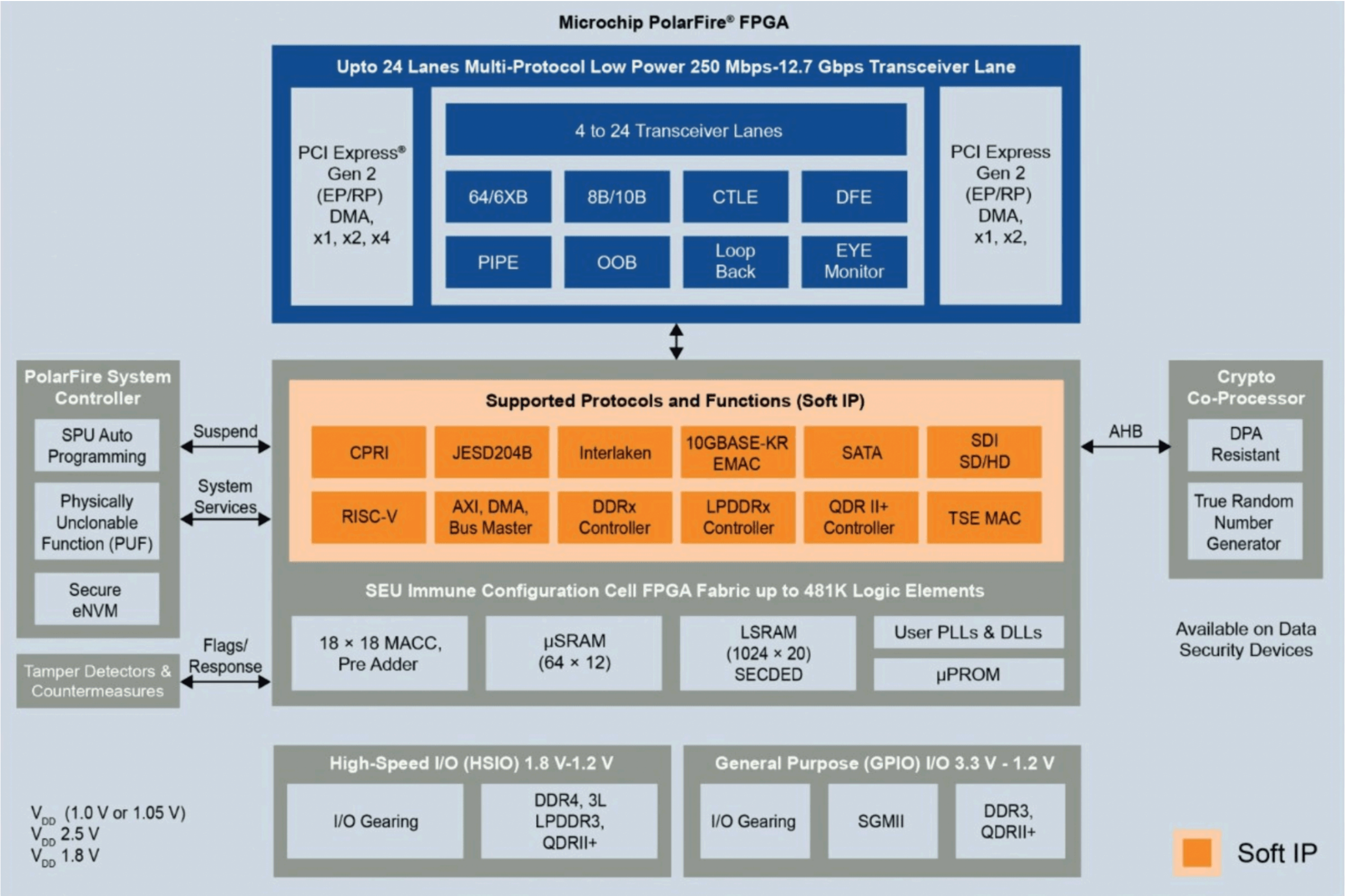
With some clever mathematics, it's possible to train a model with even a minimal data set.

Once trained, the next step for ML is deployment. AI can be exceptionally processing intensive and many applications rely on the power of cloud computing to execute the algorithms. However, it also requires a big enough data pipe to get the data there. That could be a challenge in a manufacturing environment with hundreds of cameras. Instead, engineers are looking at ML deployment at the edge.

ML at the edge means the algorithm works on the data at its source (i.e., where the sensor and local system are located). Because of the massive quantity of data that is processed here, the data connection upstream requires less bandwidth and passed messages are often limited to a pass or fail output. Because such ML tasks are clearly defined, the algorithms can be optimized to the performance offered by embedded systems.

ML for Edge Applications

Field-Programmable Gate Arrays (FPGAs) are one option, optimizing vision system ML models for the lowest-power operation. Microchip's range of PolarFire® FPGAs operates at five to ten times lower static power and 30 to 50% lower total power than competing technologies, making them well suited for thermal- and power-constrained environments. They are also available as SoC solutions with multicore RISC-V cores to support complete applications.



PolarFire® FPGAs

The VectorBlox™ Accelerator Software Development Kit (SDK) provides algorithm development, integrating with the most common ML frameworks such as TensorFlow, ONNX and Caffe2. You can optimize models by removing layers only required for the learning phase.

PIC32 MCUs

Thanks to quantization, the number of bits needed can also be reduced from 32 bits of floating point down to 8-bit integers. This delivers almost the same accuracy while using less memory.

VectorBlox™ Accelerator SDK

For less complex applications, today's microcontrollers (MCUs) offer more than enough performance to execute the neural networks behind ML. Devices such as the PIC32 or SAM families of MCUs, with their rich sets of analog and digital peripherals and communication interfaces, are supported by "tinyML" platforms.

SAM MCUs

To build ML models, insights can be gathered by analyzing time series data, audio or images. Supported by online tools, training is expeditious, delivering a model that can be imported into application source code in a matter of hours.

Learn more about the products and technologies mentioned:

Smart Predictive Maintenance

ML for Edge Applications

Where are you on the AI/ML journey for your industrial application?

- [ ] We've already integrated advanced AI/ML into our application.
- [ ] We're undertaking the first steps.
- [ ] We want to learn more about Microchip's solutions.
- [ ] We're still reviewing the AI/ML landscape to select the best solution for our needs.

Post answer

Industrial Drives and Servo Control

Driving Machines Intelligently

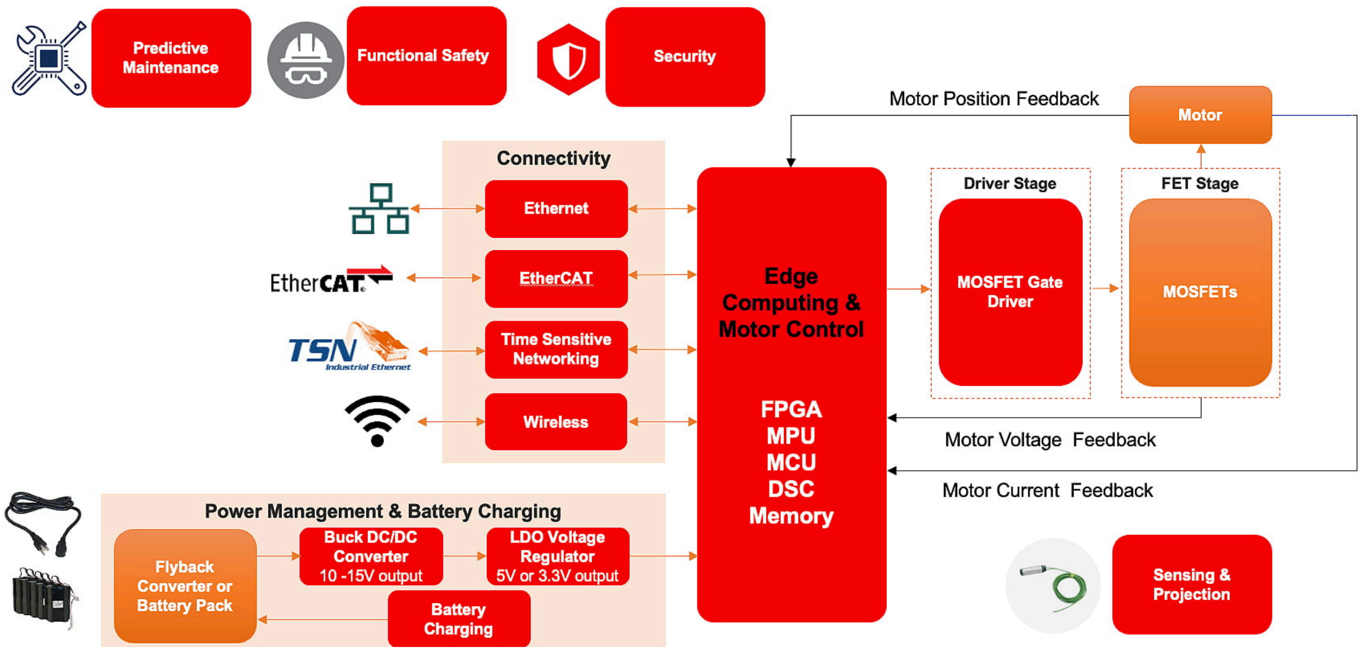
Driving Machines Intelligently

According to the International Federation of Robotics, more than half a million robots are installed around the world, covering tasks as diverse as handling, welding, assembly, dispensing and processing. But this isn't the only area of growth. Collaborative robots (cobots) and Autonomous Guided Vehicles (AGVs) are also increasing in market share. Rather than being stuck behind safety screens, these devices operate alongside human operators. Their roles range from moving workpieces around factories and storage facilities to participating in the manufacturing process. Beyond robots, manufacturing continues to demand traditional drives for conveyor belts, actuators, compressors and pumps.

Motor suppliers and the semiconductor industry have been innovating to develop solutions that provide higher efficiency and lower system cost. As a result, brushless motors have grown in popularity, but innovative approaches are needed to control them without the mechanical commutation of brushed motors. Sensors are an obvious solution to monitor the rotor but they add to the expense and are another potential point of failure. That has led to the development of software control algorithms that determine rotor angles by other means.

Devices such as dsPIC33 Digital Signal Controllers (DSCs) combine the real-time control capabilities of an MCU with the math support of a digital signal processor. Operating at up to 100 MHz and providing up to two cores, these cost-optimized devices are well suited for sensorless brushless DC motor control, vector or Field-Oriented Control (FOC) of AC induction and Permanent Magnet Synchronous Motors (PMSMs).

However, this domain demands more than processor performance. This is why the dsPIC33 family of DSCs also integrates high-resolution Pulse-Width Modulation (PWM) with dead-time compensation, high-speed 12-bit Analog-to-Digital Converters (ADCs), analog comparators, op amps and Programmable Gain Amplifiers (PGAs). All these blocks are also tightly coupled with the CPU to create fast and predictable control loops. Zero-Speed/Maximum-Torque (ZS/MT) control algorithms are also available, providing sensorless control at zero and low speeds while delivering maximum torque with Interior Permanent Magnet (IPM) motors.



Industrial Robot Core Block Diagram

For those looking for an MCU, there are plenty of 32-bit devices with peripherals tuned to motor control applications. The SAM S70, powered by a 300-MHz Arm® Cortex®-M7 core, is a great option for dual-motor designs that include FOC. For integration of IEEE 1588 Ethernet and CAN FD, the SAM E70 MCU offers exceptionally fast control loops alongside industrial connectivity. For cost-constrained designs, devices like the PIC32CM MCU include a dedicated motor control PWM with a Positional Decode (PDEC). For more connectivity, you should consider SAM D2x and C2x devices. Driven by Arm Cortex-M0+ cores with up to 256 KB of Flash, these MCUs offer 5V operability and support everything

32-bit MCUs for Motor Control

FPGAs are an alternative to DSCs and MCUs in motor control. Thanks to their programmable logic blocks, they can be tuned to the application's demands to provide high-speed control interfaces and supporting multiple motors is as easy as replicating functional blocks. The SmartFusion® 2 System-on-Chip (SoC) FPGA combines an FPGA with an Arm Cortex-M3 processor and embedded Flash and is available in a dual-axis motor control starter kit. Using the demonstration code provided, you can explore using FPGAs for sensorless PMSM control and micro-stepping of stepper motors.

SmartFusion 2 FPGAs for Multi-axis Motor Control

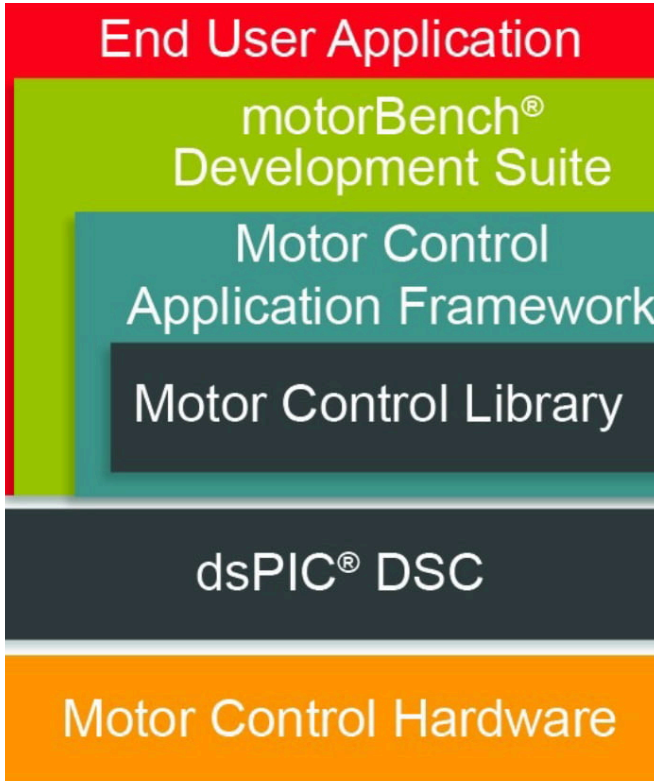
Drive circuitry is a critical part of a motor control design, linking the outputs of the DSC or FPGA with the MOSFETs or IGBTs selected. Fast, predictable delays and switching times are essential, along with low-capacitance inputs and high-voltage, high-current outputs. As drives shrink so they can be mounted on the motor being controlled, the need for innovative and compact packaging becomes another critical design requirement.

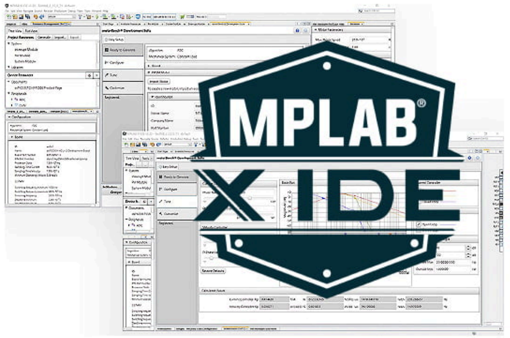
Microchip offers a comprehensive range of MOSFETs drivers, covering low-side, high-side, half- and full-bridge, and three-phase needs. Suited to low figure of merit (FOM) MOSFETs are drivers such as the MCP14700, a high-speed synchronous solution with both high and low-side drivers. Peak output current lies at 2 A and can drive loads of 3,300 pF in 10 ns. Available in a 3 × 3 × 0.9 mm DFN package, they offer space savings over traditional surface outline devices.

MOSFET Drivers

The drive for more efficiency, higher power density, and reduced forced cooling is pushing some developers to evaluate wide bandgap alternatives to silicon MOSFETs. Silicon carbide (SiC) offers higher switching speeds, greater robustness, and less $R_{DS(ON)}$ variation over temperature, enabling these design requirements to be met.

The MSC090SMA70 is ideal for motor drives offering as low as 15 mΩ in compact, surface-mount D3PAK or traditional leaded TO-247 three and four-pin package.





Finally, control algorithms are an essential requirement for any engineering team. Support is available through the motorBench® Development Suite that generates source code for the MPLAB® X Integrated Development Environment (IDE), accelerating the deployment of FOC algorithms.

MathWorks®

You can also use Simulink®, motor models provided by MathWorks® and MPLAB IDE device blocks to generate and deploy embedded code directly to a DSC.

A range of development kits is available for brushless motor control applications.

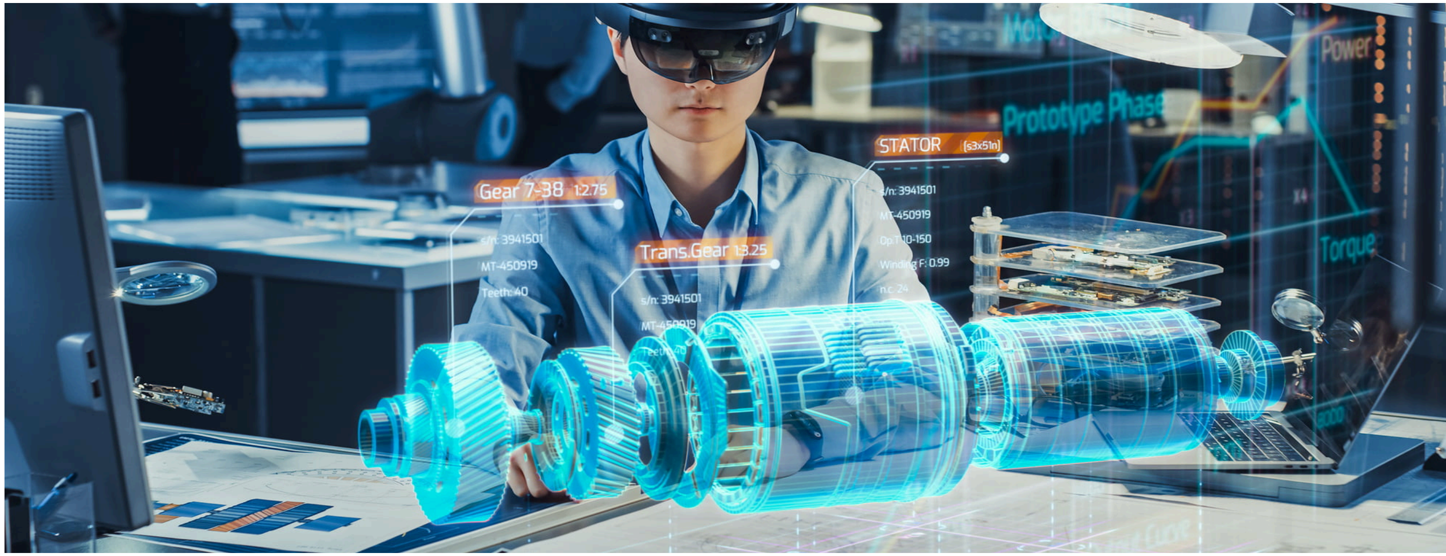
Find Out More

Explore the products and technologies mentioned in this chapter:

dsPIC33 DSCs for Advanced Motor Control

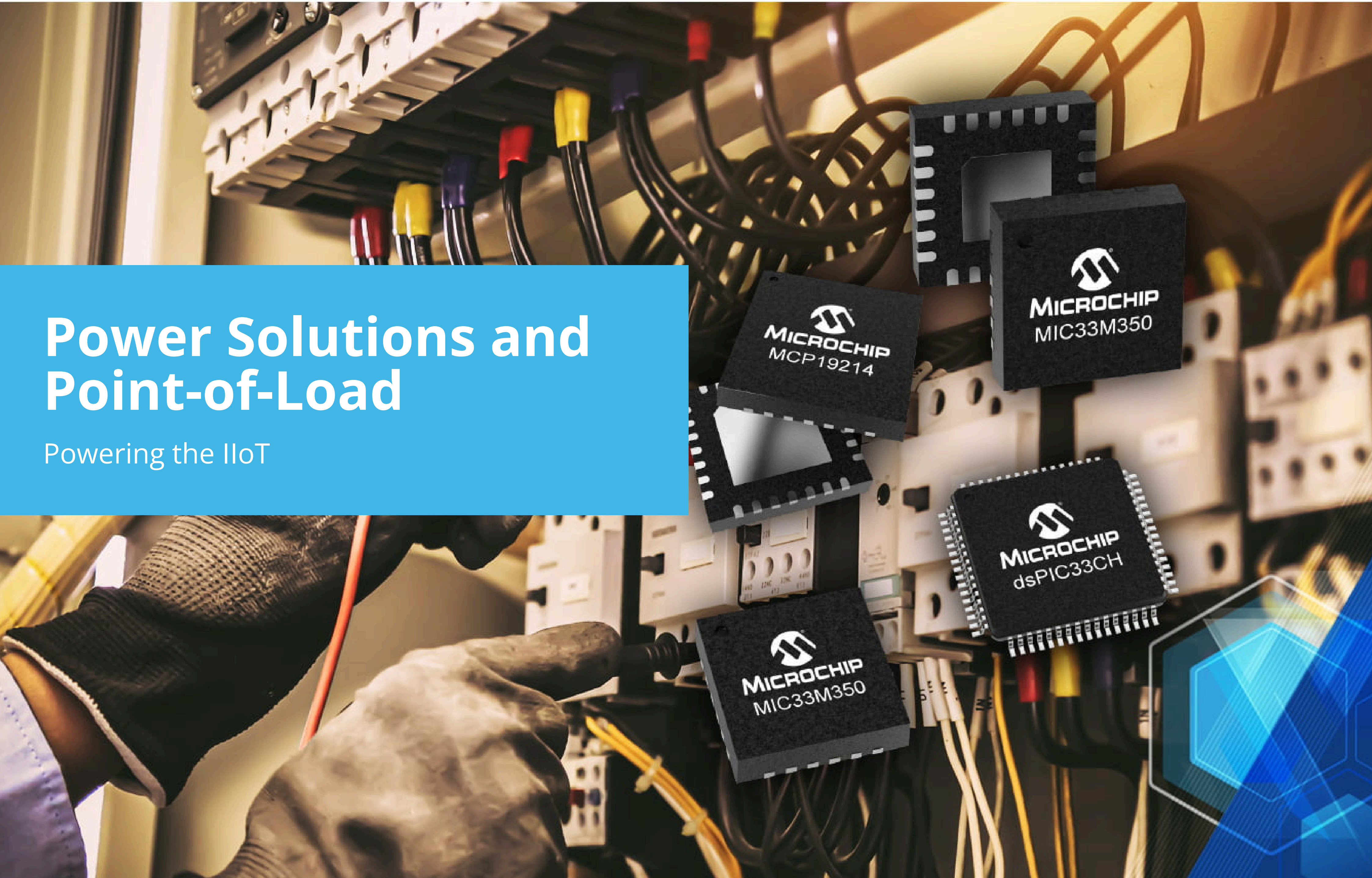
PMSM Control

motorBench Development Suite



Power Solutions and Point-of-Load

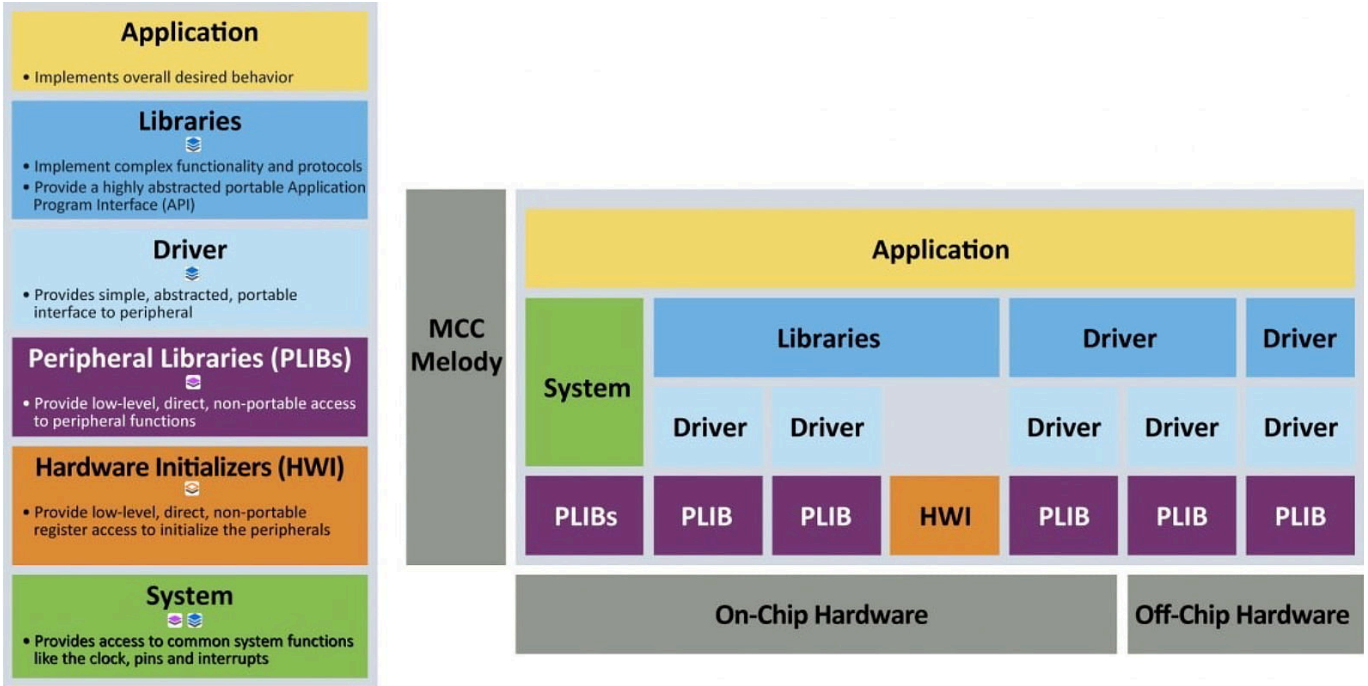
Powering the IIoT



Powering the IIoT

While industrial systems can be quite clever, from fine control of heavy loads through to incredible precision and accuracy, each function encounters a common issue: the tradeoffs of power. Today's challenges primarily revolve around efficiency, which impacts many other aspects of the design. For example, highly efficient designs develop less heat, which means passive dissipation can often displace forced air cooling. As industrial systems become more highly integrated, it is also vital to reduce the size and weight of power converters. Magnetics, such as transformers and inductors, can only be reduced by increasing switching frequencies, something that also demands improvements in switching technology and a move to Wide Bandgap (WBG) devices.

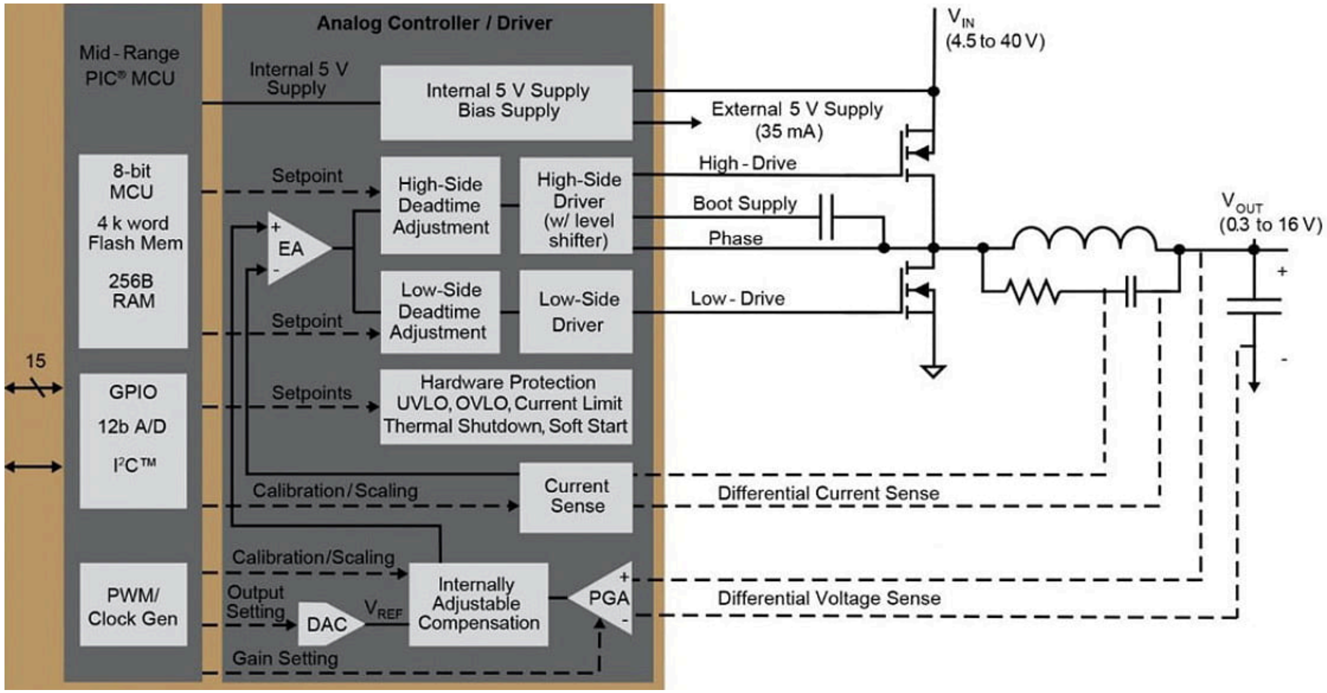
Powering FPGAs



MPLAB Code Configurator (MCC) Melody

The quality of the power delivered plays a significant factor in the precision of the system being built. For example, the output of CMOS image sensors can vary considerably if the voltage to the internal Analog-to-Digital Converters (ADCs) is not kept within the margins required. Digital devices, such as MCUs, DSCs, FPGAs and other SoC devices, also need stable power, often delivered with specific sequencing to ensure correct startup and shutdown.

Processors such as the PolarFire® FPGA and SoC families demand multiple supplies for core logic, input/output pins, the internal Phase-Locked Loop (PLL) and any transceivers used. Synchronous buck power modules such as the MIC33M350 deliver up to 3A current at programmable core voltages ranging from 0.6V to 3.3V from a 2.4V to 5.5V input voltage.
They use a Constant On-Time (COT) control architecture switching at around 1.2 MHz to provide a conversion efficiency of 95% with a ±1.5% output accuracy over line, load and temperature. Thanks to its HyperLight Load® mode, the module offers very high efficiency at light loads and an ultra-fast transient response. With a high level of integration,



“DEPA” MCP19123 Analog Power Controller

only input and output capacitors are needed to complete the design.

Analog PWM controllers for power supplies still command a lot of market share. However, with the growth in connectivity and monitoring through IIoT, there remains an open question regarding the integration of the intelligence required. Digitally Enhanced Power Analog (DEPA) devices retain the benefits of analog power control loops by augmenting them with digital oversight. Solutions such as the MCP19214 support various topologies (boost, flyback, Ćuk and

SEPIC) to deliver two outputs from an input of up to 42V using independent control loops. The integrated 8-bit processor is used to configure reference voltages, slope compensation and other parameters while also offering I^2C to implement PMBus® communication.

Digitally Enhanced Power Analog

Full digital power is supported by the dsPIC33 family of DSCs with a built-in DSP engine for implementing digital control loops with both dynamic and predictive algorithms. The high-precision Pulse-Width Modulation (PWM) modules, offering 250-ps duty cycle, phase shift, period and dead time control, are complemented by high-speed analog and are well suited to implementing Power Factor Correction (PFC) and other topologies. Reference designs also provide a starting point for high-power solutions, such as a 30 kW Vienna 3-phase PFC.

30 kW Vienna 3-phase Power Factor Correction (PFC) Reference Design

This leverages the latest WBG Silicon Carbide (SiC) technology, such as 1200V SiC diodes and 700V SiC MOSFETs.

One key challenge for digital power is developing and implementing the control loops for the DSC, but this is simplified thanks to the MPLAB PowerSmart™ memory starter kit. Supporting the dsPIC® DSC family, the kit offers multiple tools to rapidly develop discrete compensation filters from the first to sixth order. It then generates digital Switch Mode Power Supply (SMPS) controller code, eliminating the need to write DSP source code that is imported into MPLAB X IDE for

the MCU. Communication software and low-level drivers that use the other DSC peripherals can be defined using the MPLAB Code Configurator (MCC) Melody.

Are you considering replacing silicon power devices with Wide Bandgap (WBG) alternatives like Silicon Carbide (SiC)?

- Not currently
- Yes, in three months
- Yes, in six months
- Yes, in twelve months or more

Post answer

Learn more about the products and technologies mentioned in this chapter:

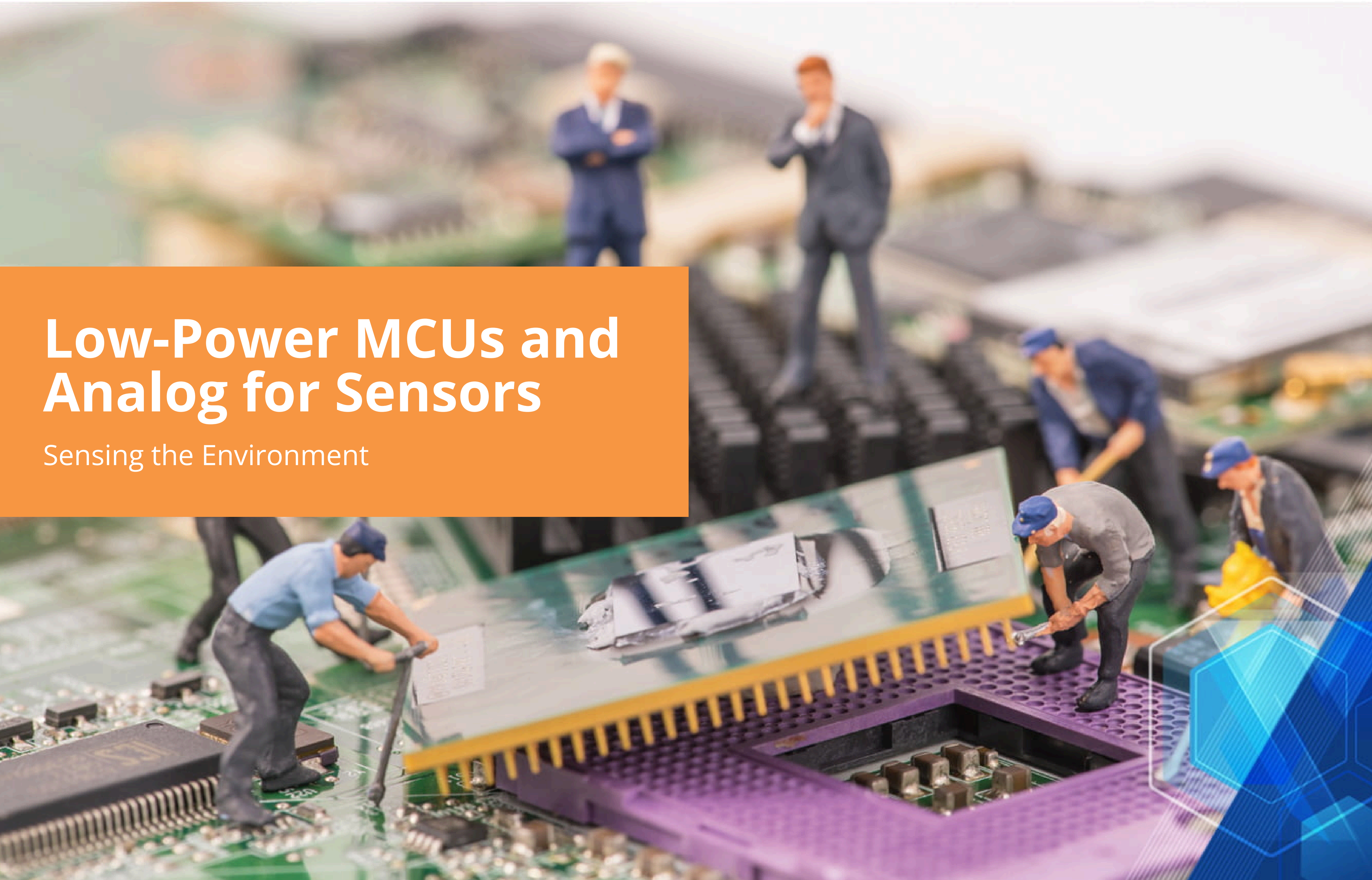
Full Digital Power

Silicon Carbide (SiC) Solutions

MPLAB Code Configurator Melody

Low-Power MCUs and Analog for Sensors

Sensing the Environment

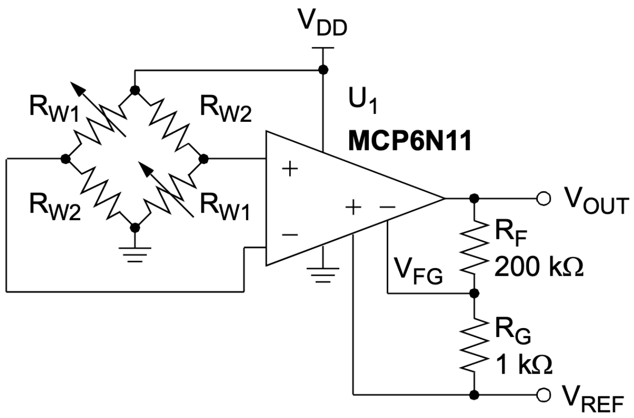


Sensing the Environment

Industrial engineering has always sought to improve the control of complex processes, which require having the optimal sensors to monitor them. Sensor designs must draw little power and be reliable to support decades-long operation. The sensing element requires further data processing, initially in the form of analog filtering and often digitally after that. From here, the data is transferred digitally to a logic or process controller via an industrial network.

Resistance Temperature Detectors (RTDs) are passive sensors with an excellent relationship between temperature and resistance. With tolerances of down to ±0.15°C (DIN Class A), they are made of pure metals, such as platinum, nickel or copper, and are increasingly replacing thermocouples in applications operating below 600°C. Such sensors come in a range of wiring options.

Two-wire sensors are the simplest while three- and four-wire options use a circuit such as an unbalanced Wheatstone bridge to compensate for the impact of the lead length.



The MCP6N11 can be used as a Wheatstone bridge in conjunction with an RTD temperature sensor.

MCP6N11 Instrumentation Amplifier

Low-power instrumentation amplifiers are well suited for building the analog front-ends around RTDs. The MCP6N11 is a single-supply solution (1.8V to 5.5V) with a bandwidth of 500 kHz and nominal current consumption of just 800 µA. Five minimum gain options (1, 2, 5, 10 and 100 V/V) are easily configured using two external resistors, ensuring that input offset voltage and noise can be optimized for the application. These devices also a calibration function that corrects the input offset voltage.

Conversion to a digital output is supported by devices such as the MCP3550, a 22-bit Analog-to-Digital Converter (ADC) in a tiny 8-pin MSOP package. This device also draws a very low current from its single supply of 2.7V to 5.5V with a conversion typically requiring 100 µA at 2.7V and 120 µA at 5.0V. The delta-sigma design offers output noise as low as 2.5 μV_{RMS} with a total unadjusted error of 10 ppm. Fully differential inputs feed a third-order delta-sigma modulator and a fourth-order modified SINC decimation filter, delivering the converted result via a three-wire SPI interface to the host MCU.

MCUs have also made significant advancements in power consumption. While some of these are in the basic active and static operation states, many creative features allow peripherals to operate in the background while portions of SRAM retain data. The 8-bit eXtreme Low Power (XLP) PIC® MCU family is designed to draw very little power in their deepest sleep mode, as low as 9 nA, while running currents are as low as 30 µA/MHz.

Low-power MCUs

Core Independent Peripherals (CIPs) are also integrated, providing autonomy for some peripherals that allows them to operate at low power independently of the CPU, only engaging it when data processing or transfer is required. XLP can be found in 8-bit MCUs, such as the PIC18F K42 and K40 families and the PIC16F191xx, and some 16-bit devices, such as the PIC24FJ128 family.

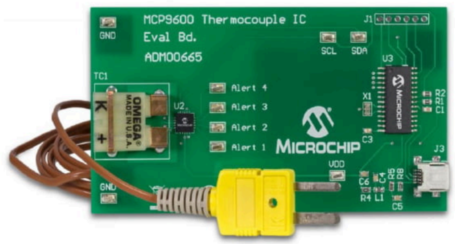
CIPs are also available in the AVR DD family of MCUs that also provides Multi-Voltage I/O (MVIO), reducing device count when interfacing with sensors and ICs of differing supply voltage. A Configurable Custom Logic (CCL) block also allows the construction of combinatorial and sequential logic for internal and external signals that can operate independently of the CPU.

AVR DD Family of AVR® MCUs

Even 32-bit performance is available with such power-saving capability. The PIC32CM Lx family uses the ultra-low-power Arm Cortex-M23 processor coupled with a SleepWalking capability. This allows the clock to select peripherals that will be temporarily engaged without having to wake the CPU from standby mode. Dynamic power domain gaiting can achieve additional power savings by leaving the power domain switched off until the peripheral is required to perform its task.

PIC32CM Low-power Features

Higher temperatures are monitored using thermocouples, and luckily, the circuitry around these devices has become much simpler.



The MCP9600 evaluation board allows you to develop thermocouple designs rapidly.

Devices like the MCP960x are fully integrated, deliver measurements with an accuracy of up to ±0.5°C via I^2C to a host MCU and include cold-junction compensation, failure detection features, ADC and filtering. With support for type K, J, T, N, S, E, B and R thermocouples (as designated by NIST ITS-90), these devices provide simple and low-power temperature sensing for all industrial sensor developers.

Read more about the products and technologies mentioned in this chapter:

MCP3551 Single-channel ADC

Thermocouple ICs

PIC32CM Low-power Features

Temperature Sensors

Enabling IIoT Innovation With Microchip

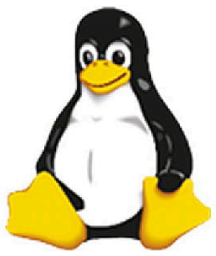
Industrial design engineers make the world we live in possible. The machines and systems they build deliver everything from chemicals and plastics to transportation solutions and consumer electronics. Their skills have delivered highly programmable control devices that integrate with a range of networked actuators and sensors. Thanks to IIoT and ML, processes are monitored, analyzed and optimized continuously to drive down costs and improve efficiency.

All these systems rely upon advancements in semiconductor technology to integrate high-performance processors, leverage low-power techniques and deliver high levels of integration in power converters and signal conditioning. Perhaps the greatest challenge in recent years has been increasing the level of security. This is a complex topic that requires considered analysis and reliance on industry-standard cryptographic approaches, requiring teams to demonstrate compliance with current standards while monitoring the changes leading to new security directives and regulations.

“Perhaps the greatest challenge in recent years has been increasing the level of security.

Microchip understands the challenges developers in this space are facing, which is why their portfolio of solutions for IIoT continues to grow yearly.

On top of this, their teams ensure that development boards and evaluation systems are in place to demonstrate how such applications can be implemented using the most appropriate semiconductor solutions. This is backed up with free software that includes development environments, software libraries and configuration tools to easily create complex applications. By working with industry partners, designers can utilize operating systems such as Linux and RTOSs directly from within the Microchip development ecosystem.



Tackling a new protocol or technology or getting started with development tools or libraries can consume a considerable amount of time—time that developers, quite frankly, don't have. Thanks to Microchip University, engineers have access to Microchip developers' collective knowledge with courses covering everything from the basics to advanced concepts.

Software is a massive part of today's applications and developers should be supported with a wide range of tools. From development environments, such as MPLAB X IDE, to configuration tools, such as MPLAB Code Configurator (MCC) Harmony, Microchip covers a range of peripheral libraries and protocol stacks that are thoroughly tested and MISRA compliant.

Access development tools, digital devices, analog parts and support through Microchip Purchasing and Client Services, their online platform. Take advantage of a vast inventory of products, fast shipping and a project list tool to help you and your team, even when ordering just a single part.

Your project remains Microchip's priority over its lifetime. They have a 25-year practice of not putting customers through costly redesigns due to a product's End of Life (EOL). Instead, they offer long-time availability and client-managed obsolescence, delivering products as long as there are customers who want them. Only in situations where a Microchip supplier makes it impossible to continue production will they stop manufacturing a device. Even in this situation, they are committed to finding alternative products with minimal disruption.

With a global sales and support network and partners in almost all technology areas, Microchip experts are knowledgeable and accessible.

Explore Microchip's products, development tools and resources:

Microchip University

Evaluation Boards

SW Development Tools

SW Configuration Tools

Global Sales & Distribution

Integrated Development Environments and Compilers

MPLAB® X IDE

This expandable, highly configurable software program incorporates powerful tools to help you discover, configure, develop, debug and qualify embedded designs for most of our MCUs and DSCs.

Learn More

MPLAB® Xpress IDE

This online IDE, which is part of the MPLAB cloud tools ecosystem, is a perfect starting point for new users of PIC® and AVR® MCUs.

Learn More

MPLAB® XC Compilers

Available as free, unrestricted-use downloads, our award-winning MPLAB XC C Compilers are comprehensive solutions for your project's software development.

Learn More

Microchip Studio IDE

This IDE can be used for developing and debugging AVR and SAM MCU applications. It can also import your Arduino sketches as C++ projects.

Learn More

Thank you for reading

Successfully Tackling IIoT Applications

Contact Markus Austermayer,
Segment Leader Europe - IoT & Ecosystem,
to help with your next IIoT design challenge.

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