WHITE PAPER

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TEXAS INSTRUMENTS

Reducing the Cost, Power and Size of Connectivity in IoT Designs

Introduction

The continuing evolution of microprocessor (MPU) and microcontroller (MCU) architectures has led to increasing intelligence in embedded designs. These "smarter" products are now being further enhanced through the addition of Internet of Things (IoT) connectivity. This connectivity introduces a whole new world of capabilities to businesses and users alike, including a superior user experience, remote operation, automated control and intelligent networking. In many cases, connectivity substantially enhances the utility, serviceability and versatility of embedded systems.

The value of the IoT comes from its interconnectedness. An IoT system must often be able to connect in two directions: down to its sources of data such as sensors or other IoT devices, as well as up into the cloud to a data aggregator or centralized control point. Connecting to data sources requires support for a wide range of machine-to-machine (M2M) protocols running over interfaces such as I2C, SPI or UART. For many applications, the industry and application define the types of M2M interfaces a system requires.

Connecting to the cloud through the Internet requires an IP-based interface, typically Ethernet for wired connectivity and Wi-Fi for wireless applications. The ubiquity of 10/100 Ethernet makes it a compelling option when secure connectivity to a wired product line is needed. The challenge for developers is to implement this connectivity at the lowest cost and power without compromising performance or reliability.

Integrating the PHY

Traditionally, the Ethernet MAC has been integrated onto MCUs to reduce cost and design complexity. The Ethernet PHY, on the other hand, has been implemented as a separate component due to analog integration challenges. Many applications, however, could also benefit from integrating the PHY as well.

With the introduction of the TM4C129x MCU family from Texas Instruments (TI), the advantages of an MCU with integrated MAC/PHY are now available. TI has developed the technology necessary to overcome the challenges of analog integration to bring its industry-leading Ethernet PHY and 10/100 MAC technology together with an ARM® Cortex®-M4-based MCU core. The TM4C129x MCU provides an effective solution for OEMs needing to connect their systems to the cloud so they can take full advantage of the capabilities enabled by the IoT.

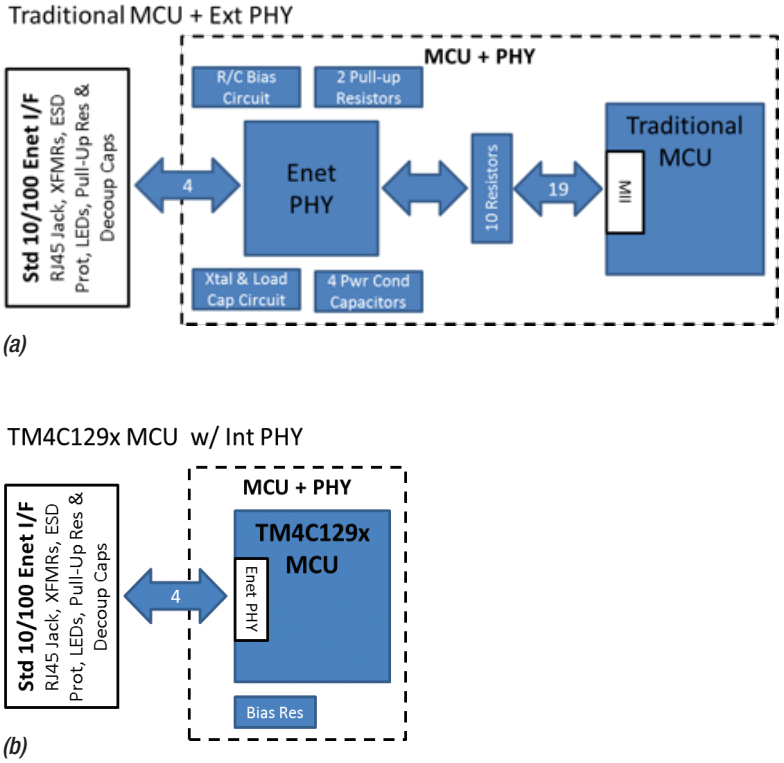

*Figure 1: A traditional Ethernet-enabled system **(a)** is built around an external PHY requiring numerous passives and other components. When the Ethernet PHY is integrated into the MCU **(b)**, board space requirements drop substantially, as do power consumption and system cost.*

Figure 1a shows a traditional Ethernet-enabled system built around an external PHY. Note that in addition to the PHY, the system also requires numerous passives and other components. In comparison, Figure 1b shows an equivalent system using an integrated PHY. When the PHY is integrated, many of the supporting components are no longer necessary.

As can be seen in Figure 2, integrating the PHY yields savings and benefits similar to those achieved when the Ethernet MAC was first integrated into an MCU:

Cost savings: The number of external and passive components required is substantially reduced when the PHY is integrated (see Figure 1b). This results in both BOM and assembly cost savings of up to 91%.

Power savings: Active power savings can reach up to 58 mA, or a 76% reduction. Standby power savings are highly dependent upon the implementation and can range from no benefit up to 10.2 mA, or a 74% reduction. Reducing power consumption increases the power efficiency of systems, reducing operating costs for line-powered devices and increasing operating life for battery-powered systems.

Board space savings: An integrated PHY still requires a few external components, such as a transformer and some form of electrostatic discharge (ESD) protection to protect the MCU from external shock. The overall board space savings, however, are still on the order of a 93% to 96% reduction. This frees up PCB space for additional features and functionality.

Reduced noise: Extraneous system noise is reduced because of the removal of several external signals and the elimination of a crystal. This provides greater signal margin for developers, easing routing constraints and design complexities.

Accelerated design: Integrating the PHY simplifies design for engineers, enabling faster implementation and troubleshooting.

Increased reliability: As a complete interface, the integrated MAC/PHY of the TM4C129x MCU is a proven and reliable implementation. Eliminating external components also reduces the number of potential points of failure in the system, further increasing reliability and reducing overall costs.

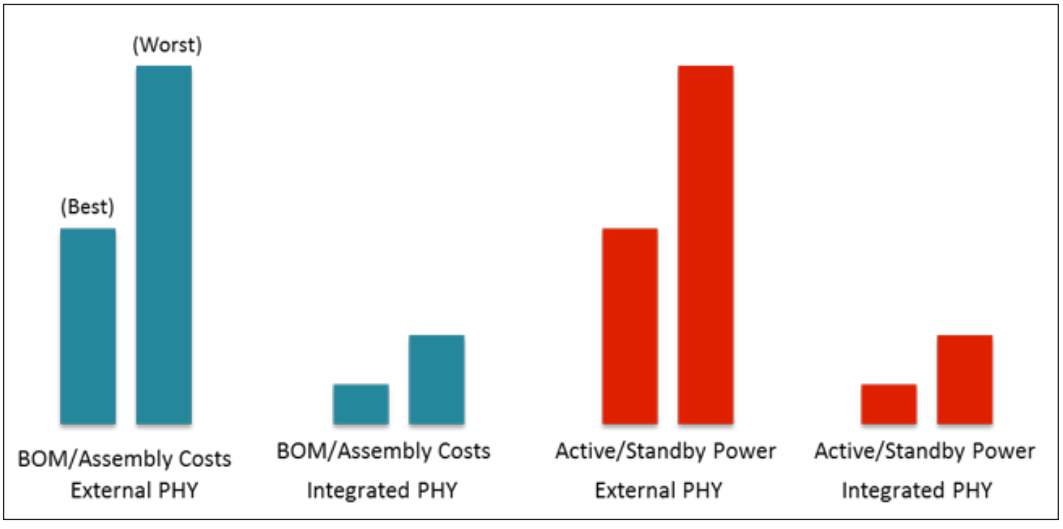

Figure 2: Significant cost, power and board space savings can be achieved when the Ethernet PHY is integrated onto the MCU as opposed to a traditional Ethernet implementation using an external PHY.

These figures are based on a comparison of the PHY portion of the design only and are dependent upon the application, actual implementation, use case, product volume and other factors. To help designers estimate the savings they might see in their own applications, TI offers several product evaluation options.

TI's TM4C129x MCU family

As the industry's first ARM Cortex-M4 MCU with integrated 10/100 MAC/PHY, the TM4C129x MCU architecture (see Figure 3) is ideally suited for a wide range of embedded applications. Key features available within the TM4C129x MCU family include:

- Up to 120 MHz ARM Cortex-M4 providing 150 DMIPS
- Industry's first integrated 10/100 Ethernet MAC+PHY
- Cryptographic capabilities, including hardware-based AES, DES, HASH and CRC acceleration
- Up to 1024 KB flash and 256 KB SRAM memory footprint
- Optional integrated LCD controller
- Elevated data protection with capabilities to protect Flash and EEPROM, including temper detection and control plus JTAG/debug lockout
- USB support, including High Speed, Full Speed, On the Go (OTG)/Host/Device
- Fast 12-bit ADCs with conversion rates up to two MSPS to enable both accuracy and high performance
- Support for many more high-current GPIOs (up to 12mA) than competitive devices
- High-reliability flash offering a minimum 100,000 write/erase cycles, an order of magnitude better than the industry standard
- Support for motion control, including a quadrature encoder interface (QEI) and advanced timers with PWM outputs
- Battery-backed hibernate mode for increased power savings
- Advanced processing capabilities including digital signal control and floating point

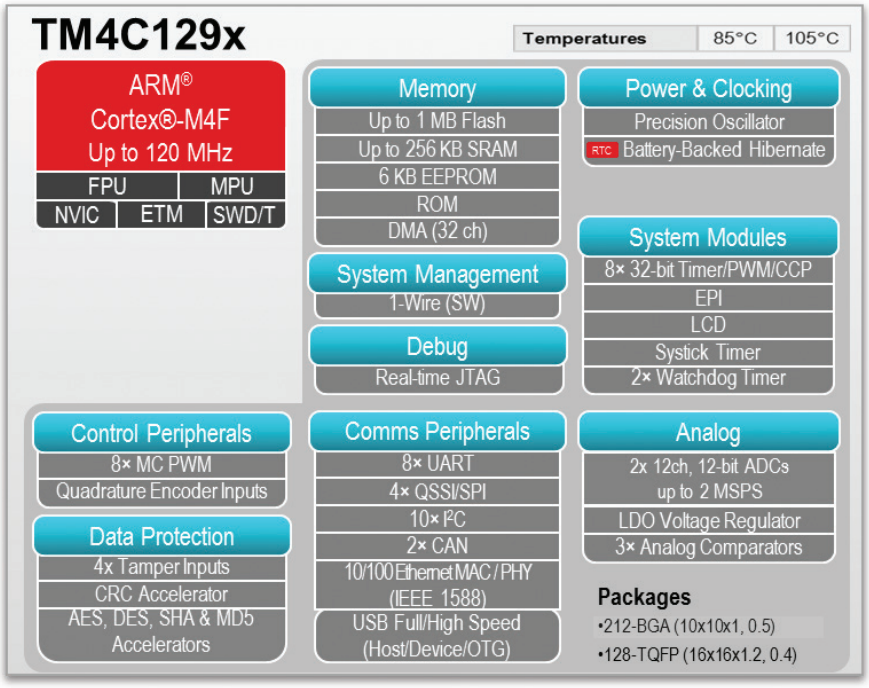

Figure 3: As the industry's first ARM Cortex-M4 MCU with integrated 10/100 MAC/PHY, TI's TM4C129x MCU has the performance, capabilities and peripherals needed to make it ideally suited for a wide range of embedded applications.

Key Features

TM4C PN	FLASH (KB)	SRAM (KB)	BATT-BACKED HIBERNATE	PACKAGE	ETH MII	ETH PHY	CRYPTO	LCD	COMPUTE	TM4C TMS SUPERSET PN
TM4C1290NCPDT	1024	256	Y	128-TQFP	-	-	-	-	-	TM4C1292NCPDTI3
TM4C1292NCPDT	1024	256	Y	128-TQFP	Y	-	-	-	-	
TM4C1294KCPDT	512	256	Y	128-TQFP	-	Y	-	-	-	TM4C1294NCPDTI3
TM4C1294NCPDT	1024	256	Y	128-TQFP	-	Y	-	-	-	
TM4C129CNCPDT	1024	256	Y	128-TQFP	-	-	Y	-	-	TM4C129DNCPDTI3
TM4C129DNCPDT	1024	256	Y	128-TQFP	Y	-	Y	-	-	
TM4C129EKCPDT	512	256	Y	128-TQFP	-	Y	Y	-	-	TM4C129ENCPDTI3
TM4C129ENCPDT	1024	256	Y	128-TQFP	-	Y	Y	-	-	
TM4C1290NCZAD	1024	256	Y	212-BGA	-	-	-	-	-	TM4C1299NCZADI3
TM4C1292NCZAD	1024	256	Y	212-BGA	Y	-	-	-	-	
TM4C1294NCZAD	1024	256	Y	212-BGA	-	Y	-	-	-	
TM4C1297NCZAD	1024	256	Y	212-BGA	-	-	-	Y	-	
TM4C1299KCZAD	512	256	Y	212-BGA	-	Y	-	Y	-	
TM4C1299NCZAD	1024	256	Y	212-BGA	-	Y	-	Y	-	
TM4C129CNCZAD	1024	256	Y	212-BGA	-	-	Y	-	-	TM4C129XNCZADI3
TM4C129DNCZAD	1024	256	Y	212-BGA	Y	-	Y	-	-	
TM4C129ENCZAD	1024	256	Y	212-BGA	-	Y	Y	-	-	
TM4C129LNCZAD	1024	256	Y	212-BGA	-	Y	Y	Y	-	
TM4C129XKCZAD	512	256	Y	212-BGA	Y	Y	Y	Y	-	
TM4C129XNCZAD	1024	256	Y	212-BGA	Y	Y	Y	Y	-	

Table 1: The TM4C129x MCU family offers a variety of configurations to best match the requirements of different IoT applications.

There are currently 20 base devices in the TM4C129x MCU family (see Table 1), offering a variety of configurations to best match the requirements of different IoT applications.

For systems that have a need for an external PHY, the TM4C129x MCU family does offer devices that just integrate the MAC. Systems that can benefit from the cost, power, and board space savings made possible by the TM4C129x MCU include:

- Solar inverters
- Communications adapters / concentrators
- Networked industrial meters / controllers / gateways
- Industrial HMI control panels / displays
- Networked residential / commercial building systems
- Cloud-connected vending machines
- Networked Industrial inverters / motor drives
- Security access systems
- Industrial sensors
- Industrial automation

  and many others.

Beyond the PHY

The advantages of the TM4C129x MCU for IoT applications go far beyond just the PHY savings it offers (see Figure 4). After all, the Ethernet interface is only one part of a system. Today's IoT devices need a fully-integrated processor capable of providing:

- Advanced human-machine interface (HMI) capabilities
- High-speed data aggregation
- Greater reliability
- Elevated data protection
- Reduced target footprint for board-space limited systems
- Integrated industrial control capabilities

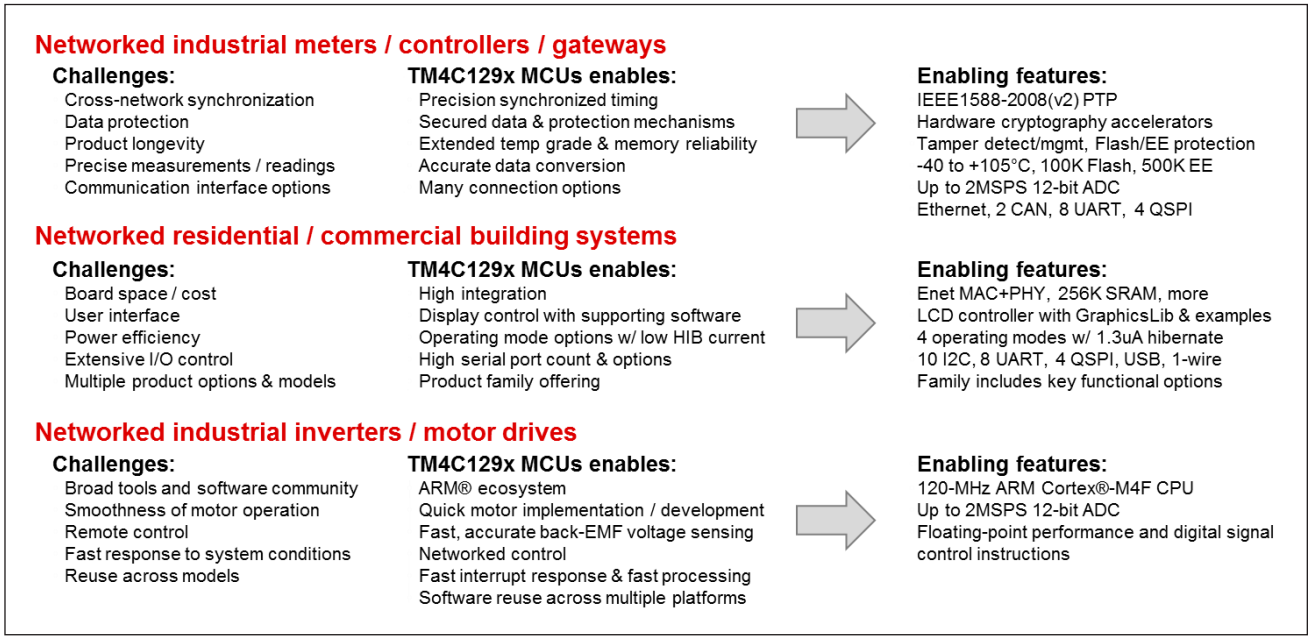

Figure 4. The advantages of the TM4C129x MCU go far beyond just the PHY savings it offers. Its architecture has been designed to address the design challenges typical of many IoT applications along with many others.

For example, legacy HMI systems based on mechanical buttons and dials cannot provide the level of visualization and control that today's systems require. New rich HMI interfaces providing greater connectivity and control also require a processor with more on-chip resources and processing capabilities. In addition, the processor must provide industrial-level reliability through features such as an extended operating temperature range and extended cycle non-volatile memories with greater capacity.

Connectivity, communications and control

Key to the value of the TM4C129x MCU is the combination of connectivity, communication and control it offers. In terms of hardware, the TM4C129x MCU has an unparalleled breadth of advanced communication peripherals integrated into its architecture. These peripherals include Ethernet MAC+PHY, two CANs, External Parallel Interface (EPI), USB On-The-Go/Host/Device, four Quad SSI/SPI, up to 10 I2C and up to eight UART.

Each of the family members offers a different combination of peripherals to provide an optimized implementation for the wide variety of IoT applications. In this way, OEMs can increase device connectivity without sacrificing price, performance or power efficiency. In addition, the TM4C129x MCU is built using processes proven to meet the strict requirements of the automotive industry to assure reliability over a variety of harsh environmental operating conditions.

Firmware also plays an essential role in facilitating communication to the cloud. Every interface on the TM4C129x MCU is supported by production-ready drivers plus a full suite of software and networking stacks. Developers also have access to TI's extensive peripheral, graphics, USB and sensor libraries (see Figure 5). This foundation of low-level support enables developers to focus their design efforts on application development rather than having to create extensive system firmware from scratch.

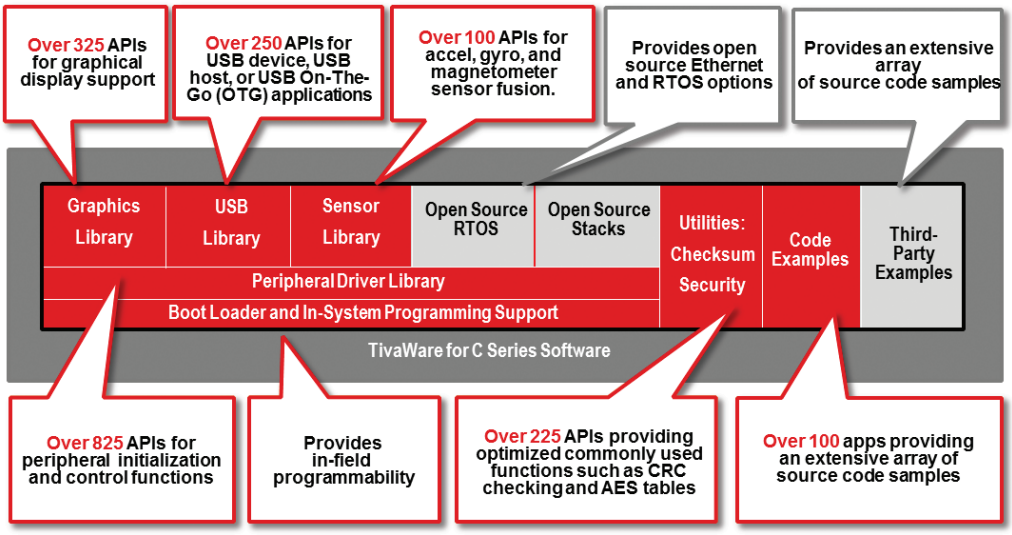

Figure 5. TI provides a wide range of low-level support firmware and libraries — including peripheral, graphics, USB and sensors — to accelerate design, increase overall system reliability and reduce development costs

Control is another major design concern for many IoT applications. Connected devices often need to control multiple outputs and events. For example, a single system may include lighting, sensing, motion and temperature sensing. TI provides more than 60 example applications to assist developers in aggregating sensor data collection and analysis, as well as overall system management and control. These example applications illustrate how to effectively utilize the sensing and control peripherals of the TM4C129x MCU, including multiple PWM outputs, dual quadrature encoder inputs, fast 12-bit ADCs and on-chip comparators.

The availability of integrated hardware interfaces backed by firmware and application code simplifies IoT device development and enables OEMs to accelerate time to market. Code is well organized and documented, and it provides a consistent API for initializing and using peripherals. Overall system reliability is increased as well, given that firmware and application code have been proven in the field. And, because developers do not need to become experts in the low-level driver implementation details, development costs are reduced.

Furthermore, all programming can be in C, even interrupt service routines and startup code. This simplifies and accelerates product development while providing OEMs with confidence that designs can be easily migrated to new platforms as TI introduces them in the future. Libraries can be downloaded free of charge as royalty-free source code. Numerous examples are provided that demonstrate how to fully leverage the rich peripheral functionality available. In addition, the libraries and boot loader are stored in on-chip ROM to free up the programmable flash memory for application use.

TM4C129x-MCU-based designs can also leverage the standard TI libraries and tool chains — including Code Composer Studio™ integration development environment, Keil's Microcontroller Development Kit, the IAR Embedded Workbench, Mentor Embedded Sourcery CodeBench, and GCC — giving developers the flexibility to work within the development environment of their choice. TI's extensive ecosystem of partners also provides developers with a broad range of software, middleware and design services. In addition, the TM4C129x MCU is fully supported by TI's distribution partners, field engineers and TI E2E™ forums.

Getting started

Developers have several options for conducting their own evaluation of the benefits and capabilities of the TM4C129x MCU family. The TM4C1294 Connected LaunchPad (EK-TM4C1294XL) is an evaluation kit available for only $19.95. It provides a cost-effective way to quickly prototype and experiment on the TM4C129x MCU.

For developers wanting a complete development kit, the TM4C129X Connected Development Kit (DK-TM4C129X) offers a full-featured platform for evaluating and developing with the TM4C129x MCU. This development kit has many features, including an LCD, and provides access to the MCU's internal signals. Both kits support TI's extensive libraries and application code as well as partner development tool chains.

With its 120-MHz ARM Cortex-M4 CPU and industry-first integrated 10/100 Ethernet MAC+PHY, the TM4C129x MCU enables a new class of highly connected systems. Designed to meet the industrial demands of many IoT systems, the high-level of integration of the TM4C129x MCU combines performance and reliability with greater cost, power and space savings. Developers can also bring products to market faster through the use of the embedded industry's leading development tools and by building on the numerous libraries and example applications provided by TI.

Additional resources:

TM4C129x MCU: http://www.ti.com/product/tm4c1294ncpdt
Datasheet: www.ti.com/lit/gpn/tm4c1294ncpdt
TM4C1294 Connected LaunchPad (EK-TM4C1294XL): http://www.ti.com/tool/ek-tm4c1294xl
TM4C129X Connected Development Kit (DK-TM4C129X): http://www.ti.com/tool/dk-tm4c129x
TI Software libraries: http://www.ti.com/tool/sw-tm4c
E2E Forum: http://e2e.ti.com/support/microcontrollers/tiva_arm/default.aspx
Training: http://www.ti.com/product/TM4C1294NCPDT/support#training
To order samples or parts: http://www.ti.com/product/TM4C1294NCPDT/samplebuy

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