Highly integrated industrial drive to connect, control and communicate

Texas Instruments

David Zaucha
Applications, Processors

Thomas Leyrer
System Architect, Industrial Communication and Control

Punya Prakash
Business Manager, Processors

Texas Instruments

Introduction

With rising energy costs and increasing government regulations, energy-efficient systems are the need of the hour. Electric motors account for 40 to 50 percent of global energy consumption and the industry is focused on improving the overall productivity of the motors. Constant-speed drives are inherently inefficient; these are being actively replaced with adaptable-speed drives controlled by processors. This new connected motor control technology is predicted to reduce energy consumption by nearly 30 percent. With this transformation in drive solution and convergence of inverter and AC drives, it is especially important that the systems continue to be reliable while being more effective.

Continuing this trend of connected drive solutions, intelligent industrial systems are adopting digital motor feedback systems. This digitization of motor control feedback coupled with industrial Ethernet for communication provides for higher efficiency in factory and energy sectors. Connected drives have a variety of communication interfaces depending on the automation system used in the field. Commissioning the communication protocol in the field provides significant cost saving in product design and product completion.

The drives industry is adopting processor-based solutions which offer higher precision to connect, control and communicate. This white paper discusses the overall drive architecture with emphasis on the highly integrated industrial drive solution by Texas Instruments.

Rule-driven integrated industrial motor control

The primary entities of a industrial motor drive are motor control, industrial communication and application to manage control and communication functions. An intelligent modular design that integrates these core functions is able to reduce platform cost while increasing platform flexibility. A single-chip drive solution employs a hybrid architecture that has the design simplicity of a compact solution with the integrated capability to support a broad range of system solutions at an economical system cost. By using a programmable infrastructure, both the high performance of a differentiated system and the flexibility to support multiple protocols, algorithms and configurations can be achieved simultaneously in a compact and highly integrated package. Central to this architecture is a modular design which provides compact and deterministic interfaces between the real-time communication, application, and control functions to permit broad flexibility in system tailoring. The modular single-chip drive solution is implemented on this foundation by incorporating the motor control peripherals with the communications and application functions. With drive synchronization on a single chip, the latency between communication and control is significantly reduced.

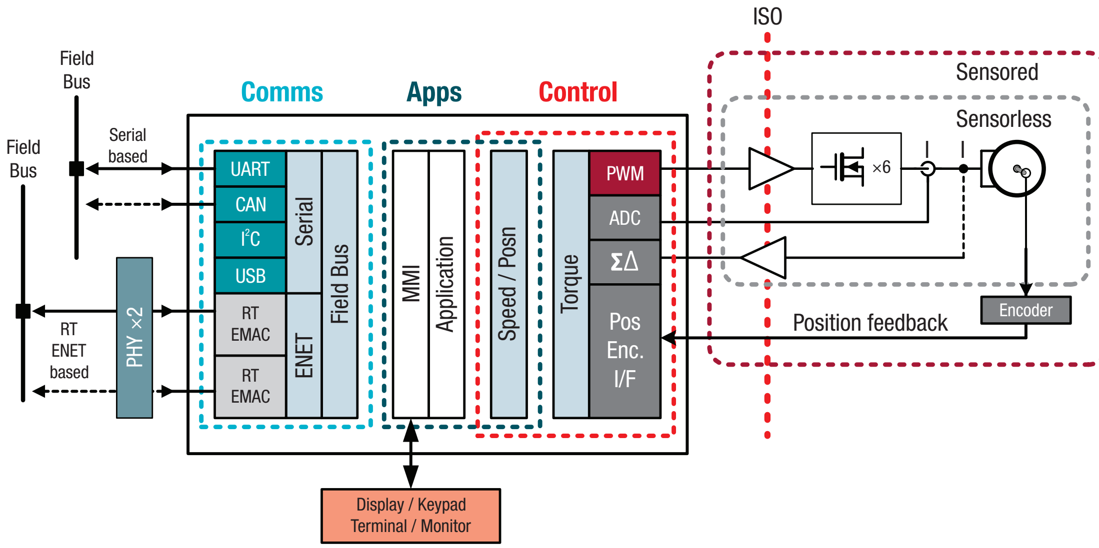


Figure 1: Industrial drive architecture overview

A highly integrated industrial drive includes motor control, industrial communication and the application to manage control and communication functions on a single-chip solution. (See Figure 1.)

- The communications interface provides the real-time communications link and synchronized system timing with the field network. The communications interface is connected to a PLC or motion controller.
- The application provides the high-level control of the drive managing the overall drive communications and control functions. This can include configuration, startup/shutdown, status, operation, motion control and other management functions.
- The control portion includes the Field Of Control (FOC) algorithm, the motor PWM controller and the current and position feedback system components which provide quiet operation and long life.

These three components of the industrial drive architecture can further be implemented in a variety of configurations. At a high level, there are three primary processor drive configurations in the industrial environment:

- Inverter
- Servo drive (single axis, motor integrated option)
- AC premium drive (multi axis, wide selection of power stage)

Inverter

Inverters are increasingly connected to a high layer control system and therefore the integration of industrial communication is moving from what was traditionally optional to being a standard feature. (See Figure 2.)

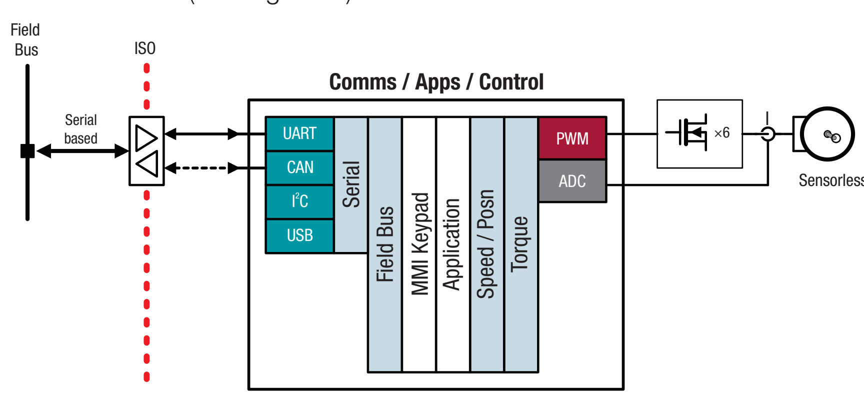


Figure 2: Inverter

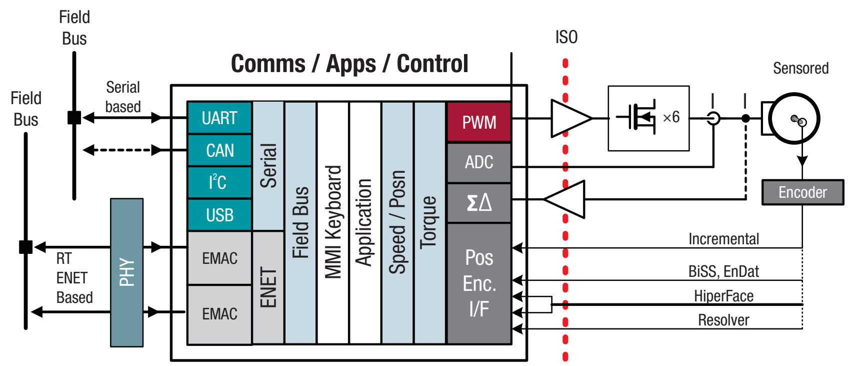


Figure 3: Servo drive with real-time Ethernet

For hot side primary drive configurations, a single chip with an integrated FOC can provide a low-cost one-axis drive. In this configuration, the isolation between the hot and cold domains is performed in the field bus interface.

Servo drive

The next increment is a cold side one-axis single-chip drive with a multi-protocol real-time Ethernet, multi-protocol encoder feedback and sigma-delta decimation filters. In this configuration, the isolation between the hot and cold domains is performed at the drive, current feedback and position feedback interface. The sigma-delta interface for current measurement provides a powerful solution when high isolation and high-precision current measurement performance are required. (See Figure 3 above.)

AC premium drive

The third architecture is a two-chip solution which provides a multi-axis drive with multiprotocol field bus and real-time Ethernet, advanced application algorithms, advanced control performance, increased hardware acceleration and high performance analog integration. (See Figure 4.)

Integration of communication function in drives

Communication is the backbone of all the industrial components for competent automation production systems. Traditional serial-based systems are moving to faster and more deterministic Ethernet-based real-time communication systems. Industrial

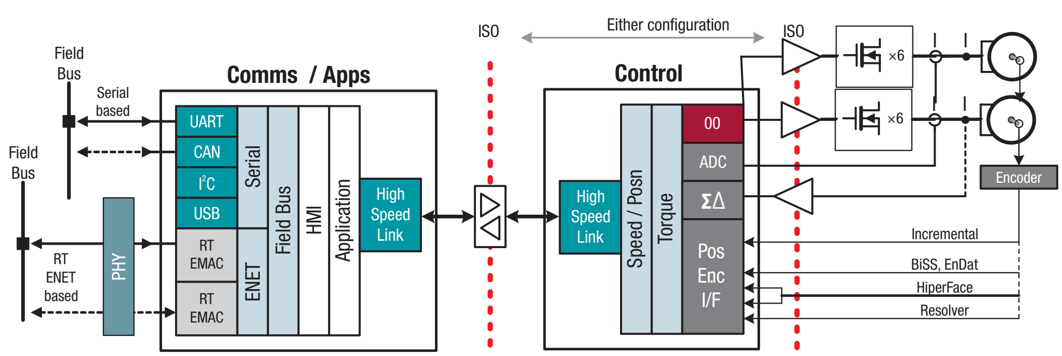


Figure 4: Multi-axis drive with real-time Ethernet

Ethernet offers higher speeds, increased connection distance and enables connection of more nodes than ever before. There are many different industrial Ethernet protocols driven by various industrial equipment manufacturers that help connect industrial systems, including motor drives. These protocols include EtherCAT®, PROFINET®, EtherNet/IP™, Sercos® III, among others. For more information on various industrial communication standards and protocol please **refer to this link**.

Ethernet and Fieldbus Protocols	Key Sponsors
EtherCAT®	Beckhoff
EtherNet/IP™	Rockwell Automation Schneider Electric
POWERLINK	B&R Automation
PROFIBUS®	Siemens
PROFINET® RT & IRT	Siemens
SERCOS® III	Rexroth Bosch group Schneider Electric

Table 1: Some of the multiple industrial communications protocols and their key sponsors

A connected industrial drive solution

TI platform architecture includes a single consolidated processor that can perform motor/motion control, real-time industrial Ethernet communications and data acquisition. The connected industrial drive is composed of an ARM® Cortex® processor plus a powerful set of programmable and fixed-function peripherals for industrial communications, measurement and control.

This permits a single device to replace multiple devices with a single easy-to-use, compact, flexible and high-performance solution. The single-chip, high-performance ARM Cortex processor includes floating-point acceleration to maximize the performance of the control loop and motion-control algorithms. (See Figure 5.)

TI processor architecture offers a quad-core programmable real-time unit (PRU) industrial communication subsystem (ICSS). This enables the Sitara™ single-chip drive family to provide concurrent industrial Ethernet, feedback protocol and control functions. The ICSS system supports PROFINET, EtherCAT, PROFIBUS, EtherNet/IP, POWERLINK, SERCOS 3 protocols, among others. See Figure 6 on the following page.

Motor drives are used in a very diverse range of industrial applications and come with wide range of voltage and power levels. Industrial drives include, but are not limited to, AC and DC drives as well as servo drives that use a motor feedback system to

Figure 5: Texas Instruments highly integrated connected industrial drive solution

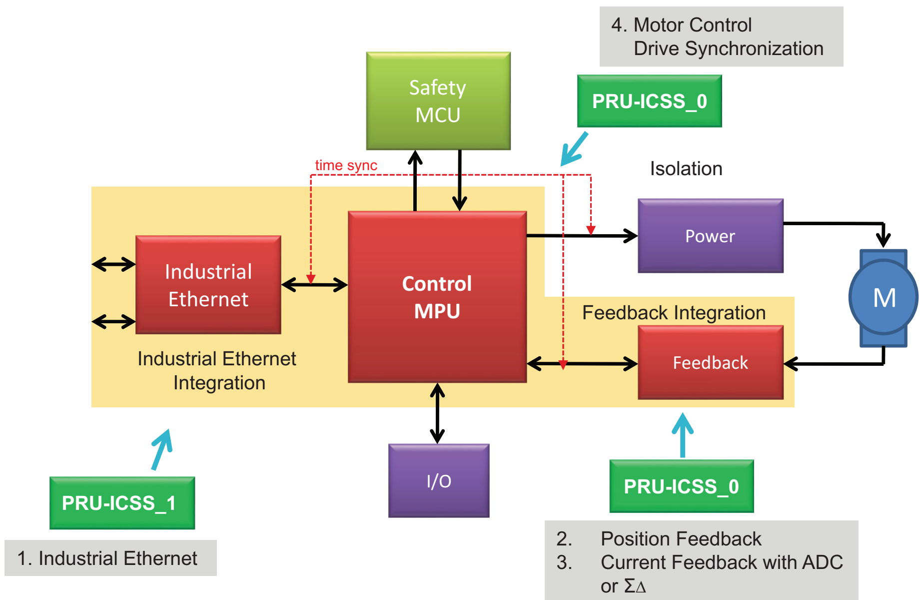


Figure 6: Integrated connected industrial drive building blocks

control and adjust the behavior and performance of servomechanisms.

The motor control functions include a motor Field Oriented Control (FOC), a multi-channel EnDat2.2 master per PRU, and multi-channel Sigma Delta Sinc3 Filter per PRU, plus multiple Pulse Width Modulators.

The Sitara single-chip drive solution also includes a number of integrated subsystems to support industrial applications including a real-time clock, Quadrature Encoder Pulse (QEP) drivers, analog-to-digital converters (ADC), a dual camera interface, dual CANs, dual Gigabit Ethernet interfaces and other peripheral interfaces (see Figure 7).

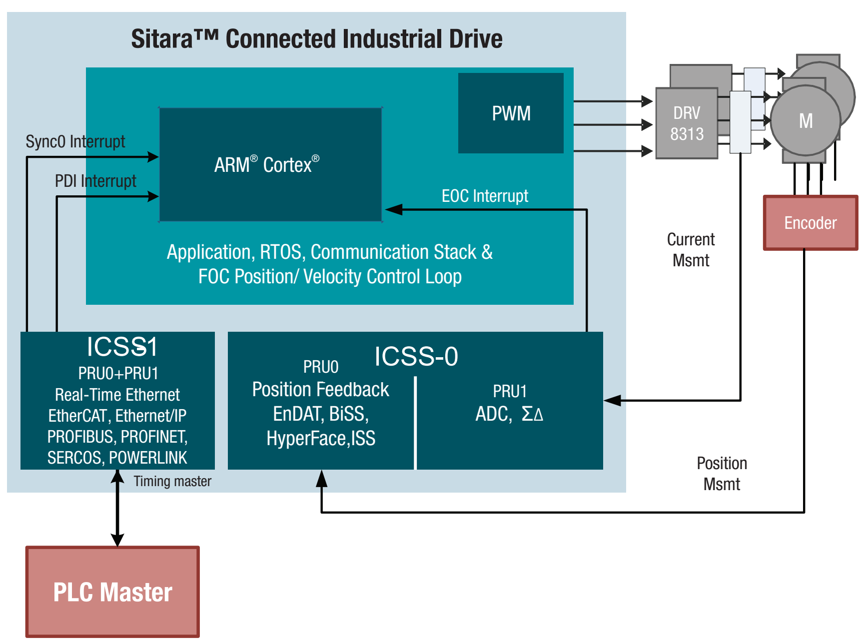


Figure 7: Connected industrial drive processor

The Sitara single-chip drive supports multiple absolute digital position encoder interfaces for absolute position/angle and speed feedback to support sensored FOC operation (see Table 2).

Protocol	EnDAT 2.2	Hiperface DSL	BiSS C
Sponsor	Heidenhain	Sick Stegman	iC Haus
Phy interface	RS-485	RS-485	RS-422/485
Speed	100 kbit – 8/16 Mbit	9.375 Mbit	1/2/5/10 Mbit
Reach	100 meter, 300m at lower speed.	100 meter	100 meter
Cable	4 wire	2 wire, motor integrated	4 wire
Max frame length	~ 31+116 bit	Continuous frame 117 bit	64 bit / frame
Delay compensation	Yes	Yes	Yes
Oversampling	Yes	Yes	Yes
Overhead channels	Two additional	8 V frames	1 bit per frame
Synchronization	Start pulse – bit time	Async pulse	Start pulse – bit time

Table 2: Multiple position encoder interfaces supported

Connected drive attributes of industrial drive software

The Sitara single-chip drive uses a modular software architecture which provides compact and deterministic interfaces between the real-time communication, application and control functions. The single-chip drive software is based upon the low-footprint TI RTOS Real-time kernel and the Industrial Software Development Kit. The SDK is optimized to support real-time industrial communications protocols such as EtherCAT, PROFIBUS, EtherNet/IP, PROFINET and others. In addition to real-time industrial communications, the SDK supports motor feedback protocols such as EnDAT and the Sigma-Delta Decimation filter for higher precision current sensing (see Figure 9 on the following page).

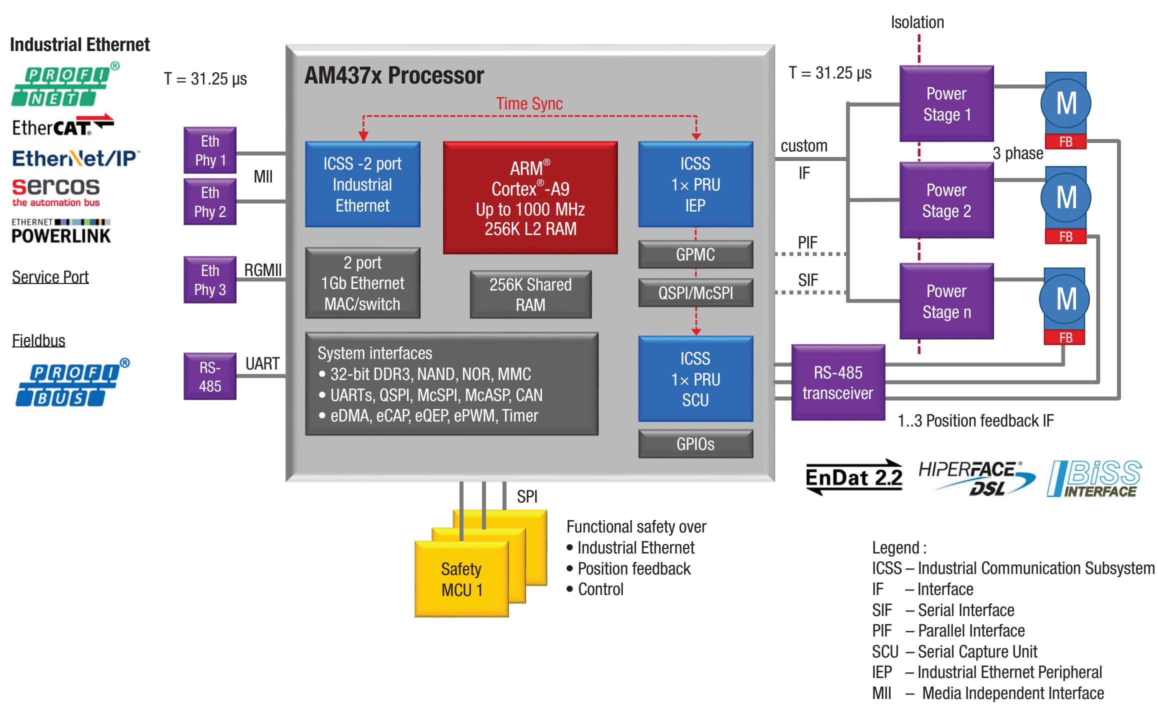


Figure 8: Sitara AM437x processor could also function as a multi-axis drive controller

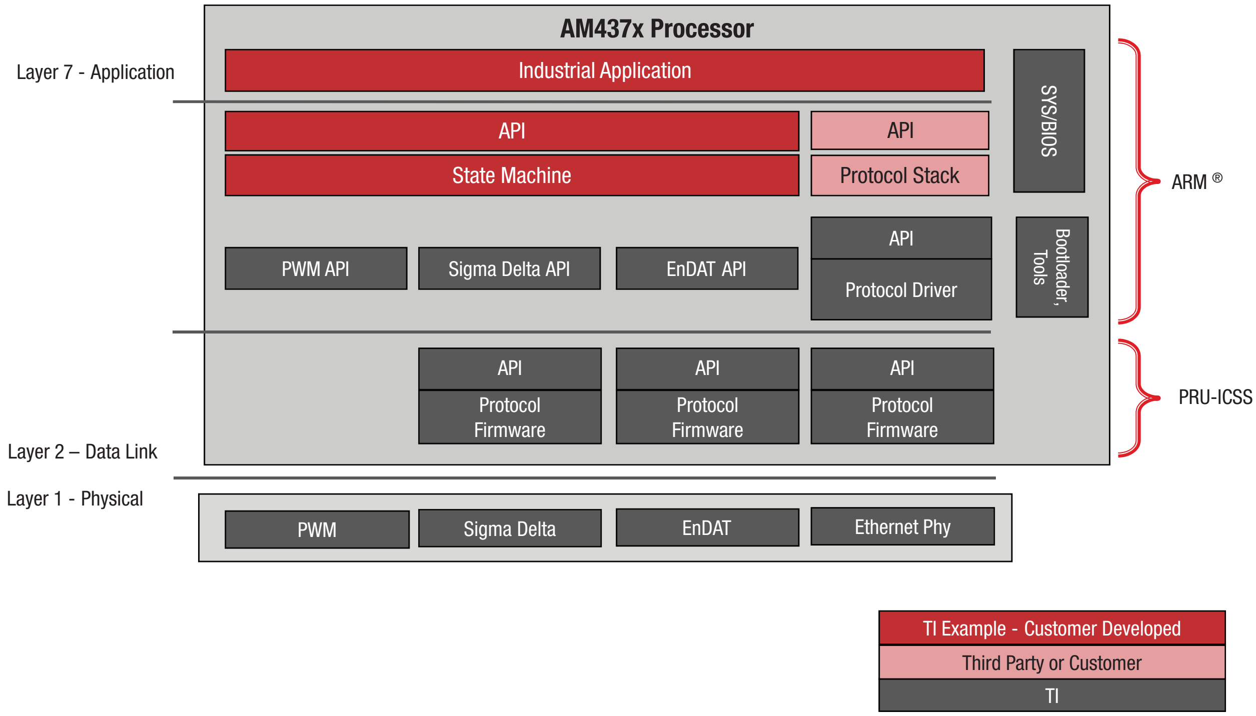


Figure 9: Industrial drive software

Single-chip drive – control cycle

Figure 10 (on the following page) shows typical industrial communications operations. EtherCAT communication consists of cyclic and acyclic communications. The cyclic communications contain the normal process information. These communications are initiated by the PLC master or motion controller at a periodic interval (every 50 to 500 μs) to exchange information with the Sitara single-chip drive. The information that is transmitted to the PLC or motion controller by the Sitara single-chip drive can include measurements and status information. The received information from the motion controller or PLC can include position sequences and other control information. The real-time portion of the industrial communications operations are performed by the PRU-ICSS exchanging output and input information with the communications stacks managed by the ARM. The received cyclic position sequences are translated by an ARM motion-control application into three motion-control sequences each communications cycle. The motion-control sequences provide the velocity / position input to a field-oriented control algorithm that generates 3-phase PWM motor control commands. The field-oriented control algorithm uses position and current feedback inputs from an EnDAT 2.2 encoder and a Delta Sigma modulator to provide closed-loop control. Status and error information from these operations are returned to the motion controller or PLC during the next communications cycle.

This processing uses only a fraction of the ARM's processing capacity. This permits the ARM to support other acyclic (non-periodic) communications and processing functions such as a web server to support other remote status, control and programming operations.

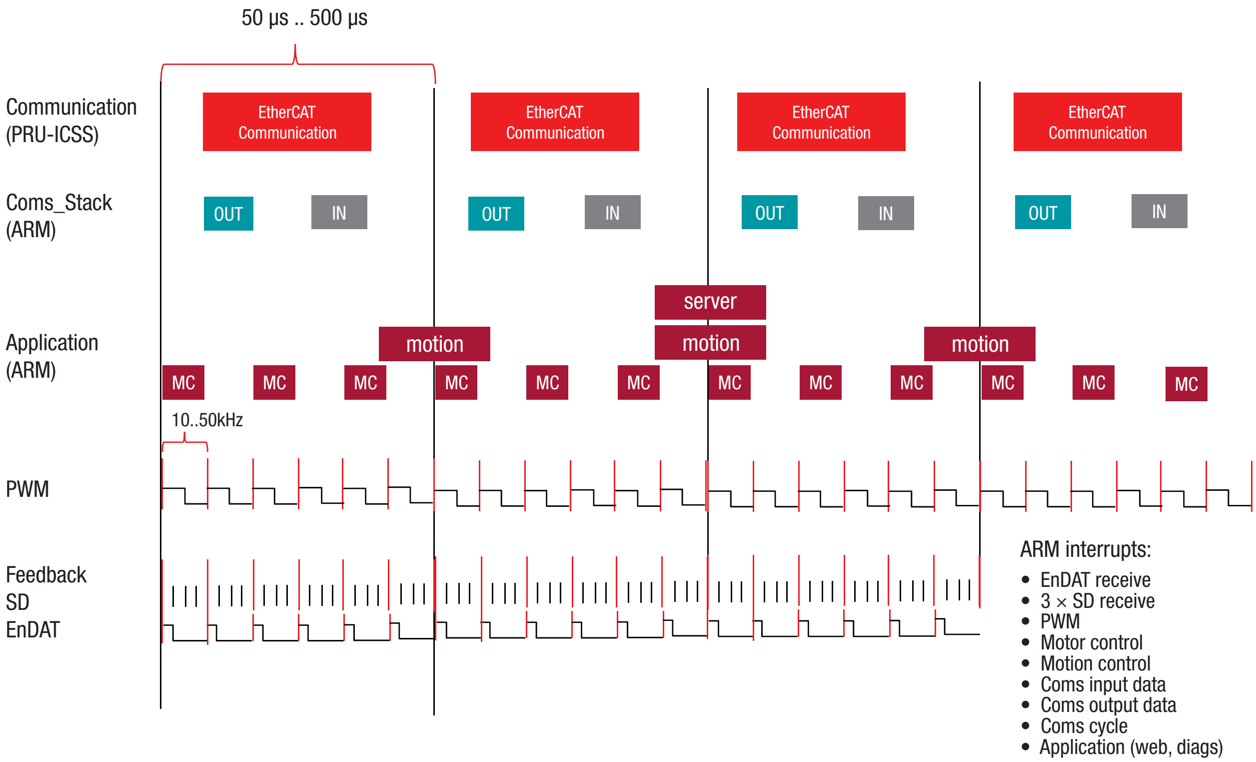


Figure 10: Connected industrial drive control cycle

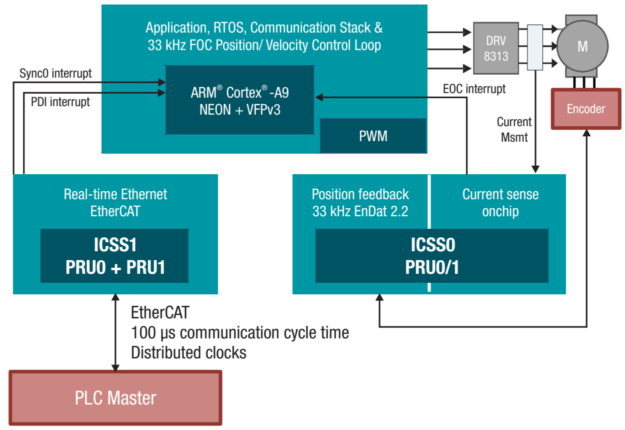
Connected industrial motor control benchmark

Single-Chip Drive for Industrial Communications and Motor Control Reference Design (**TIDEP-0025**) is a design report of a single-chip motor control benchmark using a Sitara AM437x processor at 600 MHz under the TI-RTOS. The motor control benchmark configuration is composed of a single 3-phase motor drive with current and EnDAT 2.2 position feedback. Operating concurrently with the motor control is an EtherCAT slave communicating with PLC master at a 100-µs cycle time. The EtherCAT distributed clocks are used to provide a low-jitter distributed clock. (See Figure 11 on the following page.)

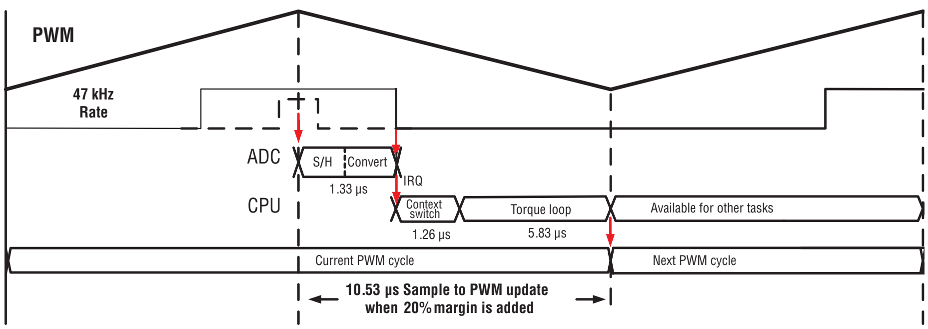
This benchmark demonstrates that a single-axis 47-kHz control loop speed is easily achievable with the 600-MHz AM437x processor with an ARM Cortex-A9 while simultaneously performing a 100-µs cycle time communication with a PLC master over the industrial Ethernet communication. While this benchmark is performed using TI-RTOS, more data on OS-independent interrupt latencies and further system-level optimization will be continued on this highly integrated single-chip industrial drive platform. (See Table 3 on the following page.)

Function	Processing time	
	Level 4 (closed speed loop)	Level 5 (closed position loop)
ADC sampling and conversion	1.33 µs	1.33 µs
SYS/BIOS interrupt latency	1.26 µs	1.26 µs
FOC close current/torque loop to PWM update	5.79 µs	5.83 µs
Elapsed time – Sample to PWM update	8.38 µs	18.42 µs
25% head room	2.1 µs	2.11 µs
Elapsed time + 25% headroom	10.48 µs	10.53 µs
Maximum operational rate	**47 kHz**	**47 kHz**

Benchmark results



Motor control benchmark configuration



Benchmark timing

Figure 11: Single-chip drive motor control configuration and benchmark timing on AM437x processors

More industrial communications TI Designs	
	• Single-Chip Drive for Industrial Communications and Motor Control
EtherCAT	• EtherCAT for Connected Industrial Drives • EtherCAT Communications Development Platform
EnDat 2.2	• EnDat2.2 for Connected Industrial Drives • Reference Design for an Interface to a Position Encoder with EnDat 2.2
ΣΔ	• Isolated Current Shunt and Voltage Measurement Reference Design for Motor Drive
PROFINET	• PROFINET Communications Development Platform
BiSS INTERFACE	• ARM MPU with Integrated BiSS C Master Interface
EtherNet/IP	• EtherNet/IP Communications Development Platform
sercos	• SERCOS III Communications Development Platform
ETHERNET POWERLINK	• Ethernet POWERLINK Development Platform
PROFIBUS	• PROFIBUS Communications Development Platform

Table 3: Some of the multiple industrial communications protocols and their key sponsors

Conclusion

The AM437x processor with integrated PRU-ICSS provides the flexibility to enable multiple protocols for position feedback on motor control and at the same time also enable multiple protocols for communication. This industry's first and only hybrid *multi-multi protocol* solution provides the ability to commission protocols in the field, in-turn providing significant cost saving in product design and product completion. The principal advantage of having a programmable solution architected for time-critical applications is the flexibility to adopt the ever-changing standards in industrial enablement while significantly reducing the overall latency.

Among the communication protocols supported by the PRU are PROFIBUS, EtherCAT, PROFINET, EtherNet/IP, SERCOS III, POWERLINK and others. The quad-core PRU in the AM437x processor is capable of supporting communication protocols and a motor feedback control protocol such as EnDat 2.2, BISS, HiperFace and others in parallel, making it a compelling single-chip industrial drive solution. The AM437x Industrial Development Kit (IDK) provides a development platform for customers to evaluate this highly differentiated multi-*multi protocol* to connect, control and communicate industrial drives using one single processor.

With the single-chip industrial drive solution, higher integration can be achieved while improving the overall product efficiency. With system integration of functional blocks to connect, control and communicate, Texas Instruments offers a solution that equips customers to build compact and differentiated products achieving better energy savings.