How to add Industrial Ethernet to Computer Numeric Control (CNC) Router Machine

4-axis CNC Router Machine with 250KHz control loop through Industrial Ethernet

Thomas Mauer
Industrial Systems Team, Factory Automation and Control
Agenda

• Industrial Ethernet in Factory Automation
• Industrial Ethernet Standards
• Simple Open Real-Time Ethernet (SORTÉ) Protocol
• CNC Router with Industrial Ethernet
• Programmable Real-time Unit and Industrial Ethernet Subsystem (PRU-ICSS) and the Industrial Ethernet Interface (MII_RT)
• TI Designs, Analog and Embedded Products for Industrial Ethernet
• Summary
Industrial Ethernet in Factory Automation
Increasing the Efficiency and Flexibility of Industrial Process Automation

Wireless Technologies
- Bluetooth
- Wi-Fi
- NFC
- Wireless HART

Wired Technologies
- IEEESN
- Powerlink
- EtherCAT
- Profinet/IP
- EtherCAT/TP
- EnDat 2.2
- HIPERFACE D5
- 10-Link

Factory Level
- ERP
- MES

Control Level
- Fieldbus
- PLC
- HART
- DeviceNet
- Wireless Sensors
- PLC
- Gateway
- Sensor HUB
- 4-20 mA
- Point to point
- Fieldbus

Field Level
- Functional Safety Domain
- Industrial Ethernet
- 1-3 axis drive
- Motor integrated drive
- conveyor belt with e.g. 16 motors
- 6-axis robot arm
- IPC
- Vision

Input Output Cycle Time
- 100 ms
- 1 ms
- 31.25 ms

Texas Instruments
CNC Router Machine System Block Diagram

- Topology: Star wiring; step and direction (dir); position and error feedback
- Control unit: Step and direction generation based on feedback
- Motor (M): Stepper motor
- Driver unit (D): Power Stage
- Motor feedback (FB): position, temperature, fault, error
- Challenges & motivation to use industrial Ethernet in CNC route machine:
  - Reduce cabling by moving from star to line topology
  - Simplifying two way communication combining step/dir and feedback in one wire
  - Being able to increase wiring distance between control unit and driver unit
  - Adding process data protection (CRC) to resist against EMI
Industrial Ethernet Standards
Popular Industrial Ethernet Standards

Top 5 Ethernet based standards

• Profinet RT/IRT
  – Factory automation including drives, strong in Europe

• EtherCAT:
  – Large IO systems and drives, getting momentum in Asia

• Ethernet/IP
  – IEEE compliance, CIPSync for drives, strong in Process Automation

• Powerlink
  – Open technology, popular in inverters, strong in China

• Sercos III
  – Optimized technology for drives, supports network redundancy via ring topology
Simple Open Real-Time Ethernet (SORTÉ) Protocol
Simple Open Real-Time Ethernet (SORTÉ) Overview

- Fast and efficient real-time Ethernet protocol implementation on PRU-ICSS
  - Master and device(s) network line topology
  - 4µs cycle time for process data exchange with one Master and 4 devices
  - 100Mbit, full duplex

- Removes external ASIC or FPGA support and integrates industrial Ethernet
- Training and programming example for real-time Ethernet on PRU-ICSS
  - Fully customizable PRU firmware
  - PRU firmware provided in source code
  - Reference PRU firmware with user’s guide, PRU firmware and ARM driver software
SORTRE State Machine

- **Timing**
  - n * 1ms
  - n * 1ms
  - n * 1ms (100 syncs)
  - cycle time
  - async event

- **State**
  - Discovery
  - Parameterization
  - Synchronization
  - IO Exchange
  - Alarm, Link-Loss, Reconnect

- **Description**
  - detect slaves
  - report IO structure
  - set network parameters
  - set application parameters
  - set diagnostic/error parameters
  - run port line delay measurement
  - run network time synchronization
  - report sync status
  - cyclic IO data exchange
  - cyclic time synchronization
  - continuous network monitor
  - detect packet error
  - detect timing error
  - detect topology change
  - report and reconnect
CNC Router with Industrial Ethernet
CNC Router Machine – Traditional Solution

- Stepper Motor (M) – a step pulse is translated in a motor steps
- Power stage (D)
- Feedback (FB) – position, temperature, motor stall, error
- Two wires for step & direction (dir)
- Multiple wires for position & error

Control Unit 250 kHz
CNC Route Machine with SORTE Solution

- 100 Mbit full duplex Ethernet replaces step/dir/pos/error/…
- Up to 100 meter cable length between each device – with specific TI PHYs up to 150 meter
- “Safe payload” through CRC protection
SORTÉ Demonstration Panel

Industrial Ethernet with 4 μs cycle time (SORTÉ)

4-axis CNC with 250 KHz control loop

Video: https://www.youtube.com/watch?v=HS4qJPGAH-c
Programmable Real-time Unit and Industrial Communication Subsystem (PRU-ICSS) and the Real-Time Ethernet Interface
Programmable Real-time Unit for Industrial Communication Subsystem (PRU-ICSS)

- Industrial Ethernet
- Serial Fieldbus
- Encoder Feedback
- Backplane Communication
- Sigma Delta filter
- Custom Interfaces
- Signal Processing
- Application Synchronization
Benefits of Using PRU-ICSS for Industrial Ethernet

• Integrates industrial Ethernet communication function into application processor
  – Removes external ASICS and FPGAs
  – Fast data path over shared memory interface
  – PRU-ICSS handles all real-time critical tasks
  – Protocol stack (none real-time critical) operates on application processor

• PRU-ICSS supports multi-protocol industrial Ethernet and fieldbus communication
  – EtherCAT, PROFINET RT/IRT, Ethernet/IP, Sercos, Powerlink, standard Ethernet MAC and Switch, PROFIBUS
  – Dedicated PRU firmware for each protocol, examples with Processor SDK and PRU-ICSS-INDUSTRIAL-SW add-on SW package

• Protocol changes through PRU firmware update
• New industrial protocols through new PRU firmware
• Enables customer to differentiate their products by writing their own PRU firmware (trainings and examples are available)
TI Designs, Analog and Embedded Products for Industrial Ethernet
TI Designs on Industrial Ethernet

• SORTE TI Designs
  – TIDEP-0085 – SORTE master
  – TIDEP-0086 – SORTE device
  – TIDEP-0061 – 4-axis CNC Router

• Industrial Ethernet TI Designs
  – TIDEP0032 – Multi-protocol Industrial Ethernet
  – TIDEP0064 – Real-time Ethernet tracer
  – TIDEP0010 and TIDEP0039 – Sercos
  – TIDEP0001 – EtherCAT
  – TIDEP0003 – Ethernet/IP
  – TIDEP0008 and TIDEP0029 - PROFINET IRT
  – TIDEP0028 – Powerlink
  – TIDA-00204 – DP83867 Gbit PHY
  – TIDA-00207 – DP83848 PHY
  – TIDA-00299 – AMIC110 ICE
Processor with PRU-ICSS support

Processor w/ PRU-ICSS

Products

- Sitara™ AMIC110
- Sitara™ AM335x
- Sitara™ AM437x
- Sitara™ AM57x
- KeyStone2 66AK2G02

Features

- 10/100 Ethernet Speeds
- Capable of supporting Industrial Ethernet protocols, Interface protocols, and Ethernet communication protocols
  - EnDat, Hiperface DSL, BiSS, HSR, PRP, 1588, plus list below

Protocols Supported

- PROFI® BUS 
  TIDEP0002
- PROFI® NET
  TIDEP0008
- EtherCAT®
  TIDEP0001
- SERCOS III
  TIDEP0010
- ETHERCAT®
  TIDEP0010
- ETHERNET
  TIDEP0010
- POWERLINK®
  TIDEP0010
- EtherNet/IP®
  TIDEP0010

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Texas Instruments
## Industrial Development Kits

<table>
<thead>
<tr>
<th>Model</th>
<th>CPU</th>
<th>ICSS</th>
<th>Ethernet</th>
<th>Interfaces</th>
<th>Price</th>
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<tr>
<td>TMDSICE3359</td>
<td>ARM Cortex™ A8</td>
<td>PRU-ICSS (Ethernet)</td>
<td>-</td>
<td>Profibus</td>
<td>$189</td>
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<tr>
<td>TMDSICE110*</td>
<td>ARM Cortex™ A8</td>
<td>PRU-ICSS (Ethernet)</td>
<td>-</td>
<td>Host i/f</td>
<td>$195</td>
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<td>TMDSIDK437X</td>
<td>ARM Cortex™ A9</td>
<td>PRU_ICSS (Ethernet)</td>
<td>Gigabit EMAC</td>
<td>Encoders, PWM</td>
<td>$329</td>
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<td>TMDXIDK5728</td>
<td>2 x ARM Cortex™ A15</td>
<td>PRU_ICSS (Ethernet)</td>
<td>Gigabit Switch</td>
<td>PCIe</td>
<td>$899</td>
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<tr>
<td>K2GICE*</td>
<td>ARM Cortex™ A15</td>
<td>PRU_ICSS (Ethernet)</td>
<td>Gigabit EMAC</td>
<td>PCIe</td>
<td>$335</td>
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*NEW board*
Industrial Ethernet Physical Layer Transceiver (PHY)

- **Part number DP83822**
  - 10/100Mbps Industrial Ethernet PHY with IEEE 1588 SFD
  - Supports 100BASE-TX and 100BASE-FX
  - Fast-Link-Down detection

- **Part number DP83867**
  - 10/100/1000Mbps Industrial Ethernet Gigabit PHY with IEEE 1588 SFD
  - Supports 100BASE-TX and 1000BASE-T

- **Part number DP83848**
  - “Gold Standard” 10/100Mbps Industrial Ethernet PHY
  - Supports 100BASE-TX

- **Part number DP83630**
  - 10/100Mbps Industrial Ethernet PHY with IEEE 1588 HW Timestamp
  - Supports 100BASE-TX and 100BASE-FX
Summary
Industrial Ethernet Summary

- PRU-ICSS integrated in AM3x, AM4x, AM5x and K2G processor family
- Support of multi-protocol industrial Ethernet with TI processor family
- Integrates industrial Ethernet communication into the application processor
- Removes external communication ASIC and FPGA
- Many example protocol applications with Processor SDK and PRU-ICSS

Industrial Software
**SORTE Summary**

- Simple Open Real-Time Ethernet (SORTE) is a process data efficient and fast real-time Ethernet protocol leveraging PRU-ICSS and MII_RT
- Delivered as PRU firmware source code
  - Enables customer differentiated products
  - Fully customizable PRU Firmware
- Real-time Ethernet programming example for PRU-ICSS and MII_RT (build your own protocol)