EtherCAT

The Ethernet Fieldbus.
EtherCAT is:
- Faster
- Synchronization
- Industrial Ethernet
- Flexible
- Easier to configure
- Cost effective
- Easier to implement
- Well proven
- Open
- Conformance
- Safety
- Redundancy
- Versatile

Why Ethernet for Automation?

• Today at controller level: state-of-the-art
• Advantages for fieldbuses:
  – lower costs because the use of commodity technology
  – Ethernet technology is driven by the office sector
  – access to internet technology (e.g. webserver)
  – reduction of interfaces
• But: Common Ethernet does not achieve fieldbus requirements as…
  – Low cost, performance, deterministic (real time),…
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EtherCAT - The Ethernet Fieldbus.

- EtherCAT is real time down to the I/O level
- No underlying sub-systems any more
- No delays in gateways
- In- and outputs, sensors, actuators, drives, displays: everything in one system!
EtherCAT is faster

- Transmission Rate:
  - 2 x 100 Mbit/s (Fast Ethernet, Full-Duplex)

- Update Times:
  - 256 digital I/O in 11 µs
  - 1000 digital I/O distributed to 100 nodes in 30 µs = 0.03 ms
  - 200 analog I/O (16 bit) in 50 µs, 20 kHz Sampling Rate
  - 100 Servo-Axis (each 8 Byte In + Out) in 100 µs = 0.1 ms
  - 12000 digital I/O in 350 µs
EtherCAT is faster

- Bandwidth Usage of Ethernet for I/O and Drives:
  - Ethernet Frame: ≥ 84 Bytes
    incl. Preamble + IPG (interpacket gap)

  - with 4 Byte input + 4 Byte output per node:
    - 4,75% application data ratio at 0 µs reaction time/node
    - 1,9% application data ratio at 10 µs reaction time/node
EtherCAT is faster

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Bandwidth Usage Comparison:
- At 4 Byte user data per node:
  - Polling / Timeslicing: ~ 2..5 %
- From 2 Bit user data per node:
  - EtherCAT: ~ 80..97 % (Full Duplex, 2 x 100 MBit/s)
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Functional Principle: Ethernet „on the fly“

• Analogy Fast Train:
  - “Train” (Ethernet Frame) does not stop
  - Even when watching “Train” through narrow window one sees the entire “Train”
  - “Car” (Sub-Telegram) has variable length
  - One can “extract” or “insert” single “persons” (Bits) or entire “groups” (Bytes) – even multiple groups per train
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Functional Principle: Ethernet „on the fly“

- Process data is extracted and inserted on the fly:
  - Process data size per slave almost unlimited (1 Bit…60 Kbyte, if needed using several frames)
  - Compilation of process data can change in each cycle, e.g. ultra short cycle time for axis, and longer cycles for I/O update possible
  - in addition asynchronous, event triggered communication
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Functional Principle: Ethernet „on the fly“

- Minimal protocol overhead via implicit addressing
  - Optimized telegram structure for decentralized I/O
  - Communication completely in hardware: maximum (+ predictable!) performance
  - No switches needed if only EtherCAT devices in the network
  - Outstanding diagnostic features
  - Ethernet-compatibility maintained
Performance: Application Example

- 40 Axis (each 20 Byte Input- and Output-Data)
- 50 I/O Station with a total of 560 EtherCAT Bus Terminals
- 2000 Digital + 200 Analog I/O, Bus Length 500 m
- Performance EtherCAT: Cycle Time = 276 µs at 44 % Bus Load, Telegram Length = 122 µs

![Graph comparing cycle times of different protocols]

- EtherCAT: 276 µs
- SERCOS III: 479 µs
- Profinet IRT: 763 µs
- Powerlink: 2347 µs
- Profinet I/O: 6355 µs

...in spite of this cycle time still 56% bandwidth remaining, e.g. for TCP/IP
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‘Slow’ Control Systems benefit, too

- Reaction time with legacy fieldbus I/O:

-\[ T_{mpd} \]
-\[ T_{I/O} \]
-\[ T_{I/O} \]
-\[ T_{I/O} \]
-\[ T_{I/O} \]
-\[ T_{I/O} \]
-\[ T_{I/O} \]
-\[ T_{I/O} \]
-\[ T_{I/O} \]
-\[ T_{I/O} \]
-\[ T_{I/O} \]
-\[ T_{I/O} \]

\( T_{mpd} \): Master Processing Delay

\( T_{I/O} \): Local I/O Update Time
  (local Extension Bus + Firmware)
‘Slow’ Control Systems benefit, too

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**System Architecture with EtherCAT:**

- **no dedicated Master Device any more**
- **on underlying extension bus any more**
‘Slow’ Control Systems benefit, too

- System Architecture with EtherCAT:

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$T_{DMA} = \text{Time for Data Transfer from/to Ethernet Controller via Direct Memory Access: negligible}$
‘Slow’ Control Systems benefit, too

- Reaction Time with EtherCAT:

  - Reaction time reduced significantly with the same controller performance
  - No underlying local I/O cycles and extension bus delays any more
  - Due to the very simple protocol no dedicated master systems (e.g. plug-in cards) required

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Fieldbus: requires Mapping in Control System

- Traditional fieldbus system generate *physical* process image
- This has to be mapped to *logical* process image(s)
Fieldbus: requires Mapping in Control System

- The same applies to control system with just one process image
- Resorting of process data ("Mapping") is required, too
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EtherCAT: Mapping moved into Slave Devices

- Control System is unburdened, master becomes very simple
- Data is transmitted according to the application requirements: extremely fast, flexibly and efficiently
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Direct Memory Access saves time

- **Fieldbus cards**: up to 30% of CPU time for data copying

- **EtherCAT**: MAC is PCI Bus master, data is provided by DMA directly to PC RAM: CPU relieved more performance
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EtherCAT Propagation Delay Measurement (1)

- EtherCAT Node measures time difference between leaving and returning frame
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EtherCAT Propagation Delay Measurement (2)

- EtherCAT Node measures time difference between leaving and returning frame

© EtherCAT Technology Group, 2009
Distributed Clocks

- Precise Synchronization (<< 1 µs!) by exact adjustment of Distributed Clocks
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External Clock Synchronization: IEEE 1588

- Switchport with integrated IEEE 1588 Boundary Clock
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**Distributed Clocks**

- Long Term Scope View of two separated devices
- 300 Nodes in between, 120m Cable Length

**Graph:**
- Simultaneity: ~15 ns
- Jitter: ~ +/-20 ns
EtherCAT is Industrial Ethernet!

- EtherCAT uses Standard Ethernet Frames: IEEE 802.3
- Alternatively via UDP/IP (if IP Routing is needed)
- no shortened frames

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• fully transparent for TCP/IP
• all Internet technologies (HTTP, FTP, Webserver,…) available without restricting the real time capabilities!
• full tool access to devices at real time operation – with and without TCP/IP
EtherCAT is Industrial Ethernet!

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- Any Ethernet Device can be connected to Switchport
- Access to Webserver with Standard Browser
EtherCAT is Industrial Ethernet!

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• Virtual Ethernet Switch routes any Ethernet Frame
• From inside as well as from outside the segment
Switchport: Any Ethernet Protocol

- Interface to any Ethernet Device or Network
- Ethernet Frames are inserted into EtherCAT Protocol:
  - ‘Ethernet over EtherCAT’
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Vertical Integration (1)

- …via Switchport

  + any Ethernet Protocol can be used
  + requires only one Ethernet Port (at IPC/Controller)
  + EtherCAT performance is not limited
Vertical Integration (2)

- ...via 2. Ethernet Port

- + any Ethernet Protocol can be used
- + EtherCAT performance is not limited
- but: requires second Ethernet Port (at IPC/Controller)
Vertical Integration (3)

- ...via Switch

- + any Ethernet Protocol can be used
- + requires only one Ethernet Port (at IPC/Controller)
- but: performance reduced by switch delay (and generic Ethernet traffic)
EtherCAT wiring is more flexible

- Standard Ethernet Topology: Star
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EtherCAT wiring is more flexible

- Flexible tree structures – arbitrarily extendable
  - Topology variants like Line, Star, Tree, Daisy Chain
  - Drop Lines possible; can be used in any combination!
  - Up to 65,535 nodes for each EtherCAT segment
  - Standard Ethernet cabling
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EtherCAT wiring is more flexible

- Ethernet Signal Variants of EtherCAT:
  - 100BASE-TX (up to 100 m between 2 nodes)
  - 100BASE-FX (longer distances between 2 nodes)
  - LVDS (for modular devices)

- Any number of physical layer changes allowed

*LVDS: Low Voltage Differential Signaling according to ANSI/TIA/EIA-644, also used in IEEE 802.3ae (10Gigabit Ethernet)
EtherCAT Extra Large System Test

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10.056 EtherCAT Nodes
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EtherCAT instead of PCI

- Protection of your investment
- smooth migration path from legacy fieldbus to EtherCAT
- seamless integration of existing fieldbus devices, e.g.:
  - AS-Interface
  - CAN, CANopen
  - CC-Link
  - ControlNet
  - DeviceNet
  - Ethernet/IP
  - FIPIO
  - Interbus
  - IO-Link
  - Lightbus
  - LONWorks
  - Modbus Plus, RTU, TCP
  - MPI
  - PROFINET
  - PROFINET IO
  - …

- maximum system expandability with low cost fieldbus gateways
EtherCAT instead of PCI

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• Update Times (examples):
  - Process image update-time via PCI (500 Bytes input and output data each): 400 µs
  - Process image update-time via EtherCAT (1,500 Bytes input and output data): 150 µs
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EtherCAT instead of PCI

- No Slots in Control System (IPC or PLC) required any more
- Nevertheless maximum expandability
EtherCAT is easier to configure

- **Addressing**
  - No manual address setting required
  - Addresses can be assigned automatically
  - Addresses can be kept
    - no new addressing if nodes are added

**EtherCAT is:**
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EtherCAT is easier to configure

- **Topology:**
  - Automatic topology target/actual comparison

- **Diagnosis:**
  - Diagnosis with exact localization

- **Network planning:**
  - Performance independent of:
    - Slave implementation
    - Topology (no Switches/Hubs)
EtherCAT is lower costs (1): Engineering

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**Implementation / Tools:**
- Standard Network Monitor Tools, e.g. MS Network Monitor or Wireshark: free of charge
- Parser Software: free of charge

**Less effort for Network planning:**
- Simplified configuration
- Default settings will work, no network tuning

**Improved Diagnosis:**
- Faster error handling leads to less downtime

**Faster Setup:**
- No address setting required
EtherCAT is lower costs (2): Hardware

Master:
- no dedicated plug in card (co-processor)
- on-board Ethernet Port is fine

Slave:
- low cost Slave Controller
  - FPGA or ASIC
  - for simple devices: no µC needed
  - no powerful µC needed

Infrastructure:
- no Switches/Hubs required
- Standard Ethernet Cabling + Connectors
EtherCAT is easier to implement: Slave

- **Slave Implementation:**
  - All time critical functions implemented on ASIC or FPGA
    - ESC handles Real-time Protocol in Hardware
  - Integrated Communication State Machine
  - Network Performance independent of
    - Slave-µC Performance
    - Protocol Stack
  - For usage with or without µC (Host CPU)
    - Integrated DPRAM (1…8kByte)
    - Integrated Distributed Clock Handling
    - Ultra precise interrupts to µC
**EtherCAT Slave Controller Features: ASIC (1)**

<table>
<thead>
<tr>
<th>Name</th>
<th>ET1100</th>
<th>ET1200</th>
<th>netX5</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Type</strong></td>
<td>ASIC</td>
<td>ASIC</td>
<td>ASIC</td>
</tr>
<tr>
<td><strong>Hardware Supplier</strong></td>
<td><strong>BECKHOFF</strong></td>
<td><strong>BECKHOFF</strong></td>
<td><strong>hilscher</strong></td>
</tr>
<tr>
<td><strong>Package</strong></td>
<td>BGA128 0,8mm Pitch</td>
<td>QFN48 0,5mm Pitch</td>
<td>BGA201 0,8mm Pitch</td>
</tr>
<tr>
<td><strong>Size</strong></td>
<td>10 x 10 mm</td>
<td>7 x 7 mm</td>
<td>13 x 13 mm</td>
</tr>
<tr>
<td><strong>μC Interface</strong></td>
<td>serial/parallel (8/16-bit, async)*</td>
<td>serial*</td>
<td>serial (SPI), parallel (8/16/32-bit, async)</td>
</tr>
<tr>
<td><strong>Digital I/O</strong></td>
<td>32</td>
<td>8-16*</td>
<td>16</td>
</tr>
<tr>
<td><strong>DPRAM</strong></td>
<td>8 kByte</td>
<td>1 kByte</td>
<td>6 kByte</td>
</tr>
<tr>
<td><strong>SyncManager</strong></td>
<td>8</td>
<td>4</td>
<td>8</td>
</tr>
<tr>
<td><strong>FMMUs</strong></td>
<td>8</td>
<td>3</td>
<td>8</td>
</tr>
<tr>
<td><strong>Distributed Clocks</strong></td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td><strong>No. Of Ports</strong></td>
<td>2-4 (MII/E-bus)*</td>
<td>2-3 (E-bus/max. 1xMII)*</td>
<td>2 (MII)</td>
</tr>
<tr>
<td><strong>Specials</strong></td>
<td>Routable with standard PCB</td>
<td>-</td>
<td>Multi Protocol Support</td>
</tr>
</tbody>
</table>

* configurable
EtherCAT Slave Controller Features: ASIC (2)

<table>
<thead>
<tr>
<th>Name</th>
<th>netX 100</th>
<th>netX 500</th>
<th>netX50</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type</td>
<td>ASIC</td>
<td>ASIC</td>
<td>ASIC</td>
</tr>
<tr>
<td>Hardware Supplier</td>
<td>[Image]</td>
<td>[Image]</td>
<td>[Image]</td>
</tr>
<tr>
<td>Package</td>
<td>BGA345 1mm Pitch</td>
<td>BGA345 1mm Pitch</td>
<td>PBGA 1mm Pitch</td>
</tr>
<tr>
<td>Size</td>
<td>22x22 mm</td>
<td>22x22 mm</td>
<td>19x19 mm</td>
</tr>
<tr>
<td>µC Interface</td>
<td>µC-Bus (internal, 32-bit)</td>
<td>µC-Bus (internal, 32-bit)</td>
<td>µC-Bus (internal, 32-bit)</td>
</tr>
<tr>
<td>Digital I/O</td>
<td>16 (GPIO)</td>
<td>16 (GPIO)</td>
<td>32 (GPIO)</td>
</tr>
<tr>
<td>DPRAM</td>
<td>256/400 Byte (Mailbox/Process Data)</td>
<td>256/400 Byte (Mailbox/Process Data)</td>
<td>6 kByte</td>
</tr>
<tr>
<td>SyncManager</td>
<td>4</td>
<td>4</td>
<td>8</td>
</tr>
<tr>
<td>FMMUs</td>
<td>3</td>
<td>3</td>
<td>8</td>
</tr>
<tr>
<td>Distributed Clocks</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>No. Of Ports</td>
<td>2 (100BASE-TX)</td>
<td>2 (100BASE-TX)</td>
<td>2 (100BASE-TX)</td>
</tr>
</tbody>
</table>

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### EtherCAT Slave Controller Features: FPGA

<table>
<thead>
<tr>
<th>Name</th>
<th>ET1810/ET1811/ET1812</th>
<th>ET1815/ET1816/ET1817</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type</td>
<td>FPGA + IP Core</td>
<td>FPGA + IP Core</td>
</tr>
<tr>
<td>Hardware Supplier</td>
<td><a href="https://www.altera.com">ALTERA</a></td>
<td><a href="https://www.xilinx.com">XILINX</a></td>
</tr>
<tr>
<td>Supported Chips</td>
<td>Cyclone I+II+III, Stratix I+II+III+IV+GX+II GX, Arria GX</td>
<td>Spartan 3+3E+3A+3AN+3ADSP, Virtex II+II Pro+II Pro X+4+5</td>
</tr>
<tr>
<td>Package</td>
<td>FPGA dependent</td>
<td>FPGA dependent</td>
</tr>
<tr>
<td>Size</td>
<td>FPGA dependent</td>
<td>FPGA dependent</td>
</tr>
<tr>
<td>μC Interface</td>
<td>serial/parallel (8/16-bit, async) AVALON®*</td>
<td>serial/parallel (8/16bit, async) OPB®*</td>
</tr>
<tr>
<td>Digital I/O</td>
<td>8-32*</td>
<td>8-32*</td>
</tr>
<tr>
<td>DPRAM</td>
<td>1...60 kByte*</td>
<td>1...60 kByte*</td>
</tr>
<tr>
<td>SyncManager</td>
<td>0...8*</td>
<td>0...8*</td>
</tr>
<tr>
<td>FMMUs</td>
<td>0...8*</td>
<td>0...8*</td>
</tr>
<tr>
<td>Distributed Clocks</td>
<td>Yes*</td>
<td>Yes*</td>
</tr>
<tr>
<td>No. Of Ports</td>
<td>2 (MII)</td>
<td>2 (MII)</td>
</tr>
<tr>
<td>Specials</td>
<td>Several IP Core License models available</td>
<td>Several IP Core License models available</td>
</tr>
</tbody>
</table>

*configurable

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EtherCAT is easier to implement: Master

- Master Implementation:
  - e.g. with Master Sample Code (Source)
  - EtherCAT Configuration Tool
  - XML Data format of ESI and ENI
EtherCAT is easier to implement: Master

- Example: Master with just one process image
  - typical e.g. for small controllers with one control task
  - up to 1488 Byte Process data size
  - Header for Process Data communication remains constant

```
<table>
<thead>
<tr>
<th>Ethernet Header</th>
<th>ECAT</th>
<th>EtherCAT Telegram</th>
<th>Ethernet</th>
</tr>
</thead>
<tbody>
<tr>
<td>DA</td>
<td>SA</td>
<td>Type</td>
<td>Frame HDR</td>
</tr>
<tr>
<td>6 Bit</td>
<td>6 Bit</td>
<td>2 Bit</td>
<td>2 Bit</td>
</tr>
</tbody>
</table>
```

- Master can be implemented with minimal effort
- No separate communication processor required (e.g. on plug-in card)
- Much simpler that legacy fieldbus systems
- Very much simpler than competing Industrial Ethernet approaches…
EtherCAT is well proven

- In series production since 2003
- Numerous applications
- Great product variety of available EtherCAT products
EtherCAT is:
- Faster ✓
- Synchronization ✓
- Industrial Ethernet ✓
- Flexible ✓
- Easier to configure ✓
- Cost effective ✓
- Easier to implement ✓
- Well proven ✓
- Open ✓
- Conformance
- Safety
- Redundancy
- Versatile

EtherCAT Architecture + Device Profiles

EtherCAT Device

File System, Bootloader
HTTP, FTP,…

DEVICE Application

The SERCOS® Standard

The CANopen Standard

Process Data

File Access

TCP
UDP
IP

Ethernet

Service Channel

IDN

IEC 61800-7-204
IEC 61800-7-304

Object Dictionary

SDO

EN 50325-4
IEC 61800-7-201
IEC 61800-7-301

PDO Mapping

AT MDT

Mailbox

EtherCAT Slave Controller

Ethernet Physical Layer

FoE
EoE
SoE
CoE
CoE/SoE

File System, Bootloader
HTTP, FTP,…

DEVICE Application

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IEC 61491 EtherCAT Servodrive Architecture

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IEC 61800-7-204 is the SERCOS* Drive Profile

*SERCOS interface™ is a trademark by SI e.V.
EtherCAT in IEC 61800-7

IEC 61800-7: Generic Interface and use of profiles for power drive systems

IEC 61800-7-1: Interface Definition

Annex A: Mapping to DS402
Annex B: Mapping to CIP
Annex C: Mapping to PROFIdrive
Annex D: Mapping to SERCOS*

IEC 61800-7-200: Profile Specifications

IEC 61800-7-201: Profile CIA 402
IEC 61800-7-202: Profile CIP Motion
IEC 61800-7-203: Profile PROFIdrive
IEC 61800-7-204: Profile SERCOS*

IEC 61800-7-300: Mapping of Profiles to Network Technologies

IEC 61800-7-301
Mapping to CANopen
Mapping to EPL
Mapping to EtherCAT

IEC 61800-7-304
Mapping to SERCOS I/II
Mapping to SERCOS III
Mapping to EtherCAT

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© EtherCAT Technology Group, 2009
EtherCAT is an open technology

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• Foundation: November 2003
• Tasks: Support, Advancement and Promotion of EtherCAT
• The world’s largest organization dedicated to Industrial Ethernet
• more than 940* member companies from 45 countries in 6 continents:
  – Device Manufacturers
  – End Users
  – Technology Providers
• Membership is open to everybody

*as of Feb 2009
EtherCAT is an open technology

- Protocol is disclosed completely:
  - EtherCAT is IEC, ISO and SEMI Standard
    (IEC 61158, IEC 61784, ISO 15745, SEMI E54.20)

- Slave Controller from several sources available
- Slave Controller provides interoperability
- ETG organizes Interoperability Testing („Plug Fests“), Workshops and Seminars
- Conformance Testing + Certificates

EtherCAT is:
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- Master Stacks for various RTOS available*, including Open / Shared Source!
  - eCos
  - Intime
  - Linux with RT-Preempt
  - MICROWARE OS-9
  - On Time RTOS-32
  - PikeOS
  - Proconos OS
  - Real-Time Java
  - RMOS
  - RT Kernel
  - RT-Linux
  - RTXC Quadros
  - RTAI Linux
  - QNX
  - VxWin + CeWin
  - VxWorks
  - Windows CE
  - Windows XP/XPE with CoDeSys SP RTE
  - Windows XP/XPE with TwinCAT RT-Extension
  - XENOMAI Linux

*as of May 2009
EtherCAT Technology Group and IEC

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- Management Board of IEC has approved Liaison of EtherCAT Technology Group with IEC SC65C WG 11/12/13 + JWG10 (SC65C: Digital Communication)

- Thus ETG is official IEC Standardization Partner
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ETG Team Worldwide
ETG Membership Development

- As of April 2009: 1000 Members
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ETG: Active Members

- Much more important than membership figures: How many are active, how many implement the technology?
- Dec 2008: More than **690 Implementation Kits** sold to ETG Members (25% Master, 75% Slaves), plus there are Open + Shared Source masters!
- SPS/IPC/Drives 2008: 60 Vendors with over 180 different EtherCAT Devices at ETG booth:
  - 25 different drives from 16 manufacturers jointly operating in one network
  - 15 different functional Masters in one setup, using 10 different operating systems
  - Safety devices (master + slave devices) from 2 manufacturers operating in one system
  - Master to Master and redundancy live demo
EtherCAT: Large Product Selection

I/O, Controller, HMI, Servo Drives, Variable Speed Drives, Sensors, Slave + Master Development Kits, Control Panels, Hydraulic Valves and Pneumatic Valves, …

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- Well proven ✓
- Open ✓

Conformance and Interoperability

- Conformance and interoperability are very important factors for the success of a communication technology
  - Conformity to the specification is an obligation to all users of the EtherCAT technology
  - Therefore the **EtherCAT Conformance Test Tool** (CTT) is used
  - Test Cases for the CTT are provided by the Working Group „Conformance“ within the ETG community
  - The **EtherCAT Conformance Test** proves conformance officially with issuing a certificate after passing the test at an official **EtherCAT Test Center** (ETC)
Safety over EtherCAT: Features (1)

EtherCAT is:
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- Conformance ✓
- Safety ✓
- Redundancy ✓
- Versatile ✓

Safety over EtherCAT (FSoE) defines a safety communication layer for the transportation of safety process data between Safety over EtherCAT devices.

- FSoE is an open technology within the EtherCAT Technology Group (ETG).
- The protocol is developed according to IEC 61508
  - It meets the Safety Integrity Level (SIL) 3
  - Residual Error Probability $R(p) < 10^{-9}$
- The protocol is approved by an independent Notified Body (TÜV)
Safety over EtherCAT: Features (2)

EtherCAT is:
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- Open ✓
- Conformance ✓
- Safety
- Redundancy
- Versatile

Safety over EtherCAT®

- FSoE Frame is mapped in the cyclic PDOs
  - Minimum FSoE Frame-Length: 6 Byte
  - Maximum FSoE Frame-Length: depending on the number of safe process data of the Slave Device
  - Therefore the protocol is suitable for safe I/O as well as for functional safe motion control

- Confirmed transfer from the FSoE Master to the FSoE Slave and vice versa.

- Safe Device Parameter can be downloaded from the Master to the Slave at Boot-Up of a FSoE Connection

- Certified products with Safety over EtherCAT are available since 2005.
Safety over EtherCAT: Features (3)

EtherCAT is:
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Safety over EtherCAT®

- The FSoE specification has no restrictions according to:
  - Communication layer and interface
    The communication layer is not part of the safety measures:
    black channel
    (assumed unsolved bit error rate: $p = 10^{-2}$)
  - Transmission speed
  - Length of safe process data
    (length of safe process data is arbitrary)

- Routing via unsafe gateways, fieldbus systems or backbones is possible
Safety over EtherCAT: Routing

EtherCAT is:
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- Conformance ✓

- Safety
- Redundancy
- Versatile

• Can be routed via non-safe gateways
• Can be routed via fieldbus systems
• One Safety technology for (almost) all bus systems
Safety over EtherCAT: Software Architecture

- Black channel approach
  - with safety and non-safety data on the same bus
EtherCAT is:
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Safety over EtherCAT: Hardware Architecture

- One channel communication system
  - Model A according to IEC 61784-3 Annex A

![Diagram showing the hardware architecture for safety over EtherCAT.](image)
Safety over EtherCAT: Frame Structure

- Ethernet telegram

  - Safety over EtherCAT frame
    - The FSoE Frame is a data container mapped in the process data of the devices
    - A new FSoE Frame is recognized if at least one bit has changed according to the last frame
    - For every 2 Byte SafeData a 2 Byte CRC is calculated
    - Up to n Byte SafeData can be transmitted
## Safety over EtherCAT: Safety Measures

<table>
<thead>
<tr>
<th>Error</th>
<th>Measure</th>
<th>Sequence Number</th>
<th>Watchdog</th>
<th>Connection ID</th>
<th>CRC Calculation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unintended repetition</td>
<td>☑</td>
<td></td>
<td></td>
<td></td>
<td>☑</td>
</tr>
<tr>
<td>Loss</td>
<td>☑</td>
<td>☑</td>
<td></td>
<td></td>
<td>☑</td>
</tr>
<tr>
<td>Insertion</td>
<td>☑</td>
<td></td>
<td></td>
<td></td>
<td>☑</td>
</tr>
<tr>
<td>Incorrect sequence</td>
<td>☑</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Corruption</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>☑</td>
</tr>
<tr>
<td>Unacceptable delay</td>
<td></td>
<td></td>
<td>☑</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Masquerade</td>
<td></td>
<td></td>
<td>☑</td>
<td></td>
<td>☑</td>
</tr>
<tr>
<td>Repeating memory errors in Switches</td>
<td>☑</td>
<td></td>
<td></td>
<td></td>
<td>☑</td>
</tr>
<tr>
<td>Incorrect forwarding between segments</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>☑</td>
</tr>
</tbody>
</table>
Safety over EtherCAT: Implementation Example

- Decentralized Safety-Logic
- Standard PLC routes the safety messages

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- Versatile ✓
Safety over EtherCAT: Advantages

- Fully integrated solution:
  - safe and standard communication in one channel
- Reduction of fieldbuses and interfaces
- Central configuration, diagnosis and maintenance for safe and 'unsafe' I/O in one tool
- Safety application makes full use of EtherCAT advantages:
  - Short reaction times
  - Almost unlimited number of nodes
  - Large network extensions
  - Cable redundancy options
  - High Flexibility with Hot Connect
EtherCAT: High availability

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- Cabling redundancy
  - 2nd Ethernet port needed on master side only
- Hot Swap of devices
- Hot Connect of network segments
- Master Redundancy with Hot Swap
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Without Redundancy: Normal Operation

EtherCAT Master
RX Unit
TX Unit
RX
TX
MAC 1
RX
TX

Slave 1
RX
TX
TX
RX

Slave 2
RX
TX
TX
RX

... ...

Slave N
RX
TX
TX
RX

© EtherCAT Technology Group, 2009
Without Redundancy: Cable Failure

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- Versatile

Without Redundancy: Node Failure

EtherCAT Master
- RX Unit
- TX Unit
- MAC 1
- RX
- TX

Slave 1
- RX
- TX
- TX
- RX

Slave 2
- RX
- TX
- TX
- RX

Slave N-2
- RX
- TX
- TX
- RX

Slave N-1
- RX
- TX
- TX
- RX

Slave N
- RX
- TX
- TX
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With Redundancy: Normal Operation

EtherCAT Master

RX Unit
TX Unit

MAC 1
RX Unit
TX Unit
MAC 2

Slave 1
RX TX
TX RX

Slave 2
RX TX
TX RX

Slave N
RX TX
TX RX

Only 2nd Ethernet Port required – no special Interface Card

© EtherCAT Technology Group, 2009
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EtherCAT: various system architecture

- Master to Slave
- Slave to Slave
- Master to Master
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- Versatile ✓

EtherCAT and Wireless Communication

- Wireless Devices can be connected via Switchport
- Wireless segment does not slow down EtherCAT communication
- Protocol: EtherCAT Automation Protocol
  - Pushed and/or Polled Process Data Exchange
- Wireless Segment transparent for Master Device

![Diagram showing wireless communication setup with Switchport and RFID Reader](image-url)
**EtherCAT** is:
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### Why do Companies choose EtherCAT?

- **High Performance**
  - EtherCAT is the fastest Industrial Ethernet technology
- **Flexible Topology**
  - Benefit not only for widely distributed applications
- **Ease of Use**
  - Easy configuration and maintenance
- **Low Cost**
  - Inexpensive implementation & infrastructure
- **Functional Safety**
  - Safety communication integrated
- **Product Variety**
  - Great variety of available EtherCAT products
EtherCAT Application Fields

- Fast applications, e.g.:
  - packaging machines
  - high speed presses
  - injection molding machines
  - woodworking machines
  - machine tooling (CNC)
  - test beds
  - robotics
  - …

- Widely distributed applications, e.g.:
  - materials handling
  - logistics
  - data acquisition
  - …
EtherCAT Application Fields

- Due to low cost master and simple wiring as well:
  - Small Embedded Controller
  - Small PLCs
  - Any PC based Control Application
    • with or without real time requirements

- EtherCAT allows one to apply fieldbus technology where cost issues require direct wiring today
EtherCAT - The Ethernet Fieldbus.

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Please visit www.ethercat.org for more information

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