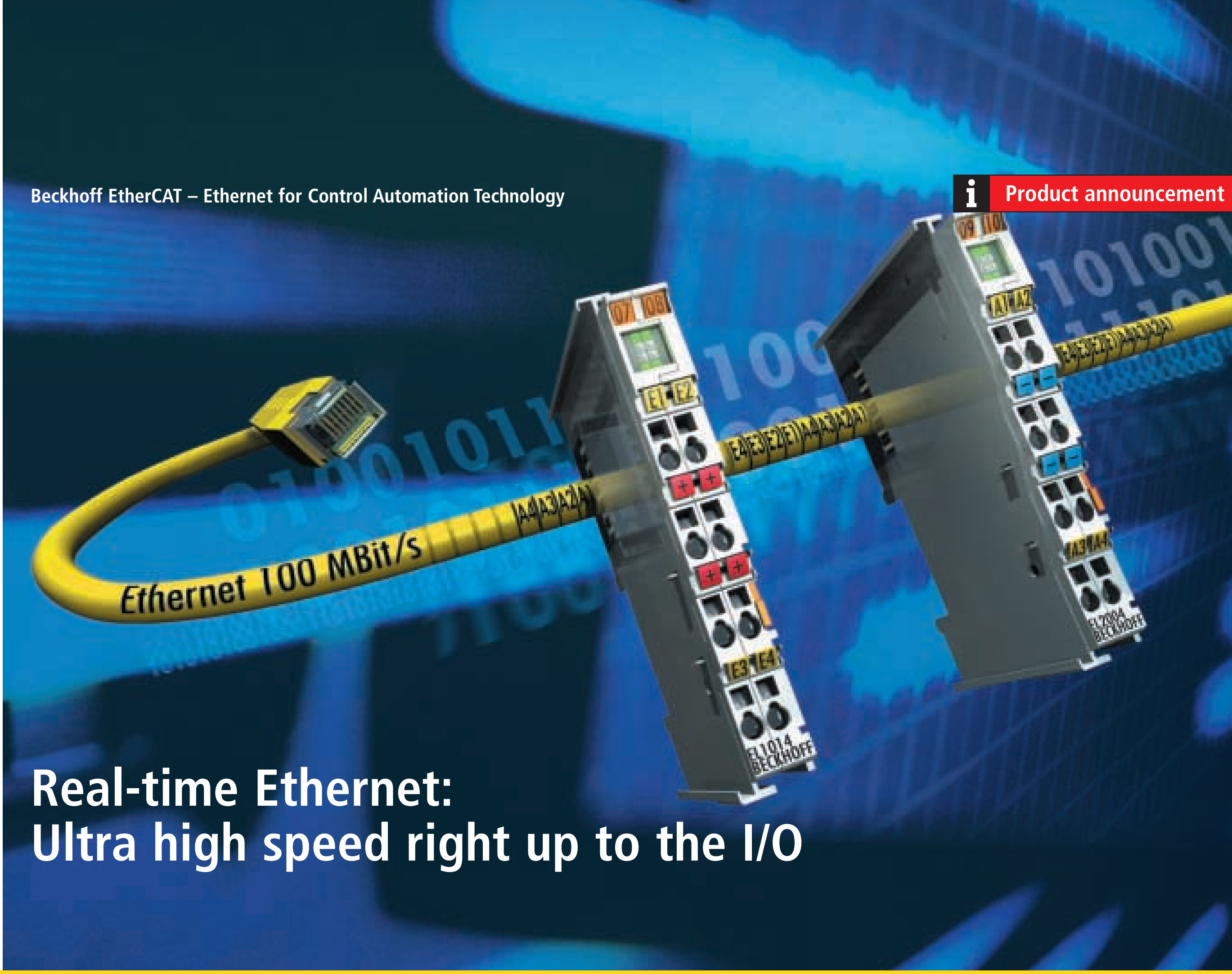
Beckhoff EtherCAT – Ethernet for Control Automation Technology

Product announcement



Real-time Ethernet: Ultra high speed right up to the I/O

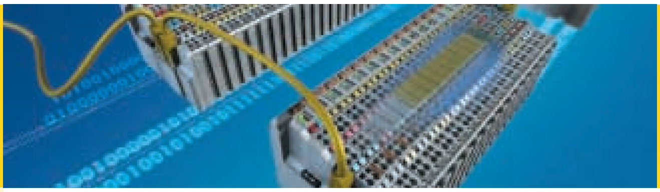
It was presented for the first time at the Hanover exhibition in Germany, and provided a talking point amongst automation engineers: EtherCAT – the new, real-time Ethernet network from Beckhoff. EtherCAT is remarkable for its exceptional performance, extremely easy wiring, and its openness to other protocols. Where conventional fieldbus systems come up against their limits, the real-time Ethernet system is setting new standards.

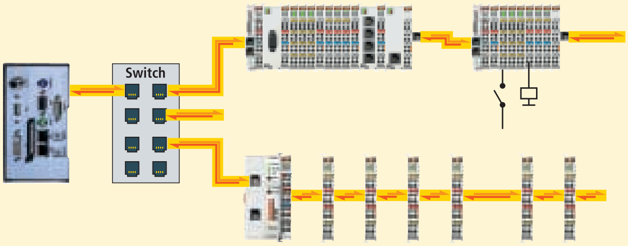
The properties speak for themselves: 1000 I/O in 30 µs, optionally twisted pair cable or optical fiber and, thanks to Ethernet and Internet technologies, optimum vertical integration. EtherCAT gives you the option of using the classic more expensive star topology or a simple low cost line structure - no expensive infrastructure components are required. EtherCAT uses very cost-effective standard Ethernet cards (NIC) while other real-time-Ethernet approaches require special and expensive cards in the controller.

The EtherCAT operating principle

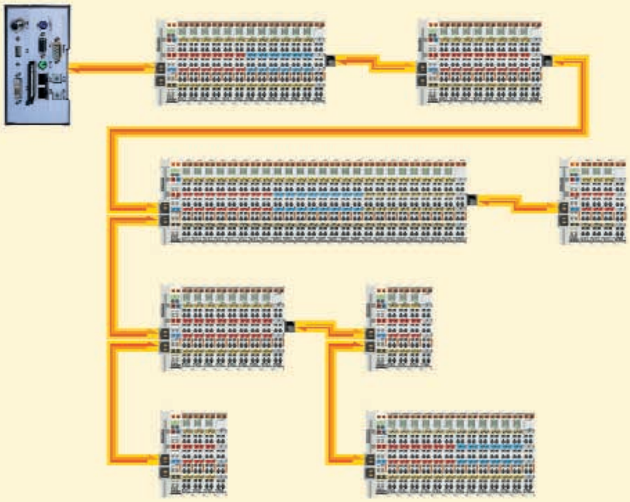
With EtherCAT technology, Beckhoff overcomes the system limitations of other Ethernet solutions: The Ethernet packet is no longer received, then interpreted and copied as process data at every connection. The newly developed FMMU (fieldbus memory management unit) in each I/O terminal reads the data addressed to it, while the telegram continues through the device. Similarly, input data are inserted while the telegram passes through. The telegrams are only delayed by a few nanoseconds.

Other Ethernet approaches cannot match the EtherCAT real-time capability. One approach includes disabling the CSMA/CD access procedure via higher level protocol layers and replacing it with a time slice procedure or a polling procedure. Another approach uses special switches that distribute Ethernet packets in a precisely controlled timely manner. These other approaches are all capable, to a certain degree, of quickly and accurately transferring data from the controller to the Ethernet node. However, these other approaches are limited because of delays from the Ethernet node to the actual I/O or drive controllers. The other approaches require a sub bus especially when using modular I/O systems. The other Ethernet approaches are made faster through synchronization of the sub bus system much like Beckhoff has done in the past with other existing fieldbus networks. However, the synchronization creates small delays to the communication bus that cannot be avoided. Beckhoff takes the next step in technology using the FMMU technology in EtherCAT.





Full duplex Ethernet in the ring, one telegram for many devices:
The EtherCAT system architecture increases the "communication efficiency".



Maximum flexibility for wiring: with or without switch, line or tree topologies can be freely selected and combined. Cost-effective twisted pair cable, selection of the transfer physics depending on requirements. Address assignment is automatic; no IP address setting is required.

Ethernet up to the terminal – complete continuity

The Ethernet backplane for the I/O modules is called E-bus. The E-bus transfers the data from one I/O point to another using a different electrical signal but not changing the Ethernet data. The first Ethernet node, called the Bus Coupler, converts the electrical signal from standard twisted pair or fiber optics to E-bus. The signal is converted to E-bus to meet electronic terminal block electrical signal requirements. The signal type within the terminal block (E-bus) is also suitable for transfer via a twisted pair line over short distances (up to 10 m). The terminal block can thus be extended very cost-efficiently. Subsequent conversion to Ethernet is possible at any time since the Ethernet data is never changed.

On the control side, very inexpensive, commercially available standard network interface cards (NIC) are used as hardware in the controller. The cards offered by Beckhoff bundle up to 4 Ethernet channels on one PCI slot and are based on the same architecture. The common feature of these interface cards is data transfer to the PC via DMA (direct memory access), i.e. no CPU capacity is taken up for the network access.

The NIC cards use the TwinCAT Y driver which operates seamlessly with the software operating system and the real-time system. This means the TwinCAT Y driver functions as a compatible network driver, and additionally as a TwinCAT Ethernet fieldbus card. The real-time system Ethernet frames have priority over the general operating system frames using an internal prioritization system. The general operating system's Ethernet frames, such as print spooling, Internet, and mail, are transmitted in the "gaps" if sufficient time is available.

At the receiving end, all the Ethernet frames received are examined by the TwinCAT I/O system, and those with real-time relevance are filtered out. All other frames are passed on to the operating system after examination, outside the context of the real-time system.

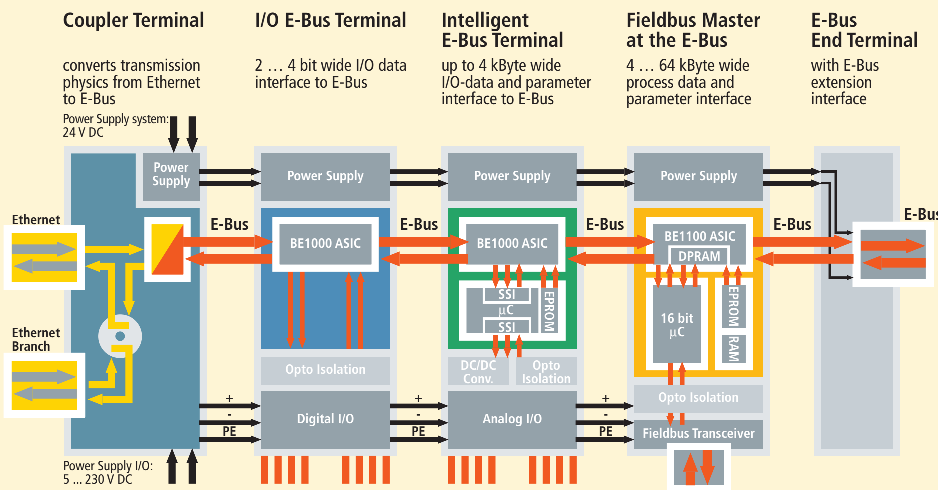
Since the Ethernet functionality of the operating system is fully maintained, all operating system-compatible protocols can be operated in parallel on the same physical network. This not only includes standard IT protocols such as TCP/IP, HTTP, FTP or SOAP, but also practically all Industrial Ethernet protocols such as Modbus TCP, ProfiNet or EthernetIP.

Optimized protocol directly within the Ethernet frame

The EtherCAT protocol uses a special Ether-type inside the Ethernet Frame. The Ether type allows transport of control data directly within the Ethernet frame without redefining the standard Ethernet frame. The frame may consist of several sub-telegrams, each serving a particular memory area of the logical process images that can be up to 4 gigabytes in size. Addressing of the Ethernet terminals can be in any order because the data sequence is independent of the physical order. Broadcast, Multicast and communication between slaves are possible. Transfer directly in the Ethernet frame is used in cases where EtherCAT components are operated with TwinCAT and in the same subnet as the control computer.

However, EtherCAT applications are not limited to TwinCAT as the control system: EtherCAT UDP packs the EtherCAT protocol into UDP/IP datagrams. This enables any control with Ethernet protocol stack to address EtherCAT systems. Even communication across routers into other subnets is possible. In this variant, system performance obviously depends on the real-time characteristics of the control and its Ethernet protocol implementation. The response times of the EtherCAT network itself are hardly restricted at all: The UDP datagram only has to be unpacked in the first station.

Protocol processing completely in hardware: The protocol ASICs are flexibly configurable. Process interface from 2 bit to 64 kB.



1000 I/Os in 30 µs | 200 analog I/Os in 50 µs | 100 axes in 100 µs

EtherCAT reaches new dimensions in network performance. Thanks to FMMU in the terminal and DMA access to the network card in the master, the complete protocol processing takes place within hardware and is thus independent of the run-time of protocol stacks, CPU performance or software implementation. The update time for 1000 I/Os is only 30 µs - including terminal cycle time. Up to 1486 bytes of process data can be exchanged with a single Ethernet frame - this is equivalent to almost 12000 digital inputs and outputs. The transfer of this data quantity only takes 300 µs.

The communication with 100 servo axes only takes 100 µs. During this time, all axes are provided with set values and control data and report their actual position and status. The distributed clock technique enables the axes to be synchronized with a deviation of significantly less than 1 microsecond.

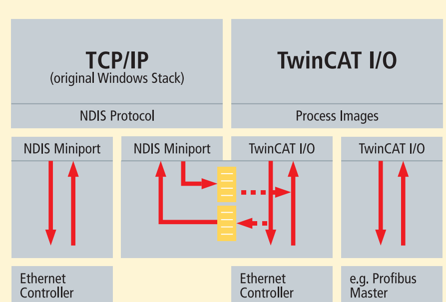
The extremely high performance of the EtherCAT technology enables control concepts that could not be realized with classic fieldbus systems. For example, the Ethernet system can now not only deal with velocity control, but also with the current (torque) control of distributed drives. The tremendous bandwidth enables status information to be transferred with each data item. With EtherCAT, a communication technology is available that matches the superior computing capacity of modern Industrial PCs. The bus system is no longer the "bottleneck" of the control concept. Distributed I/Os are recorded faster than is possible with most local I/O interfaces. The EtherCAT technology principle is scalable and not bound to the baud rate of 100 MBaud – extension to GB Ethernet is possible.

Topology – maximum flexibility

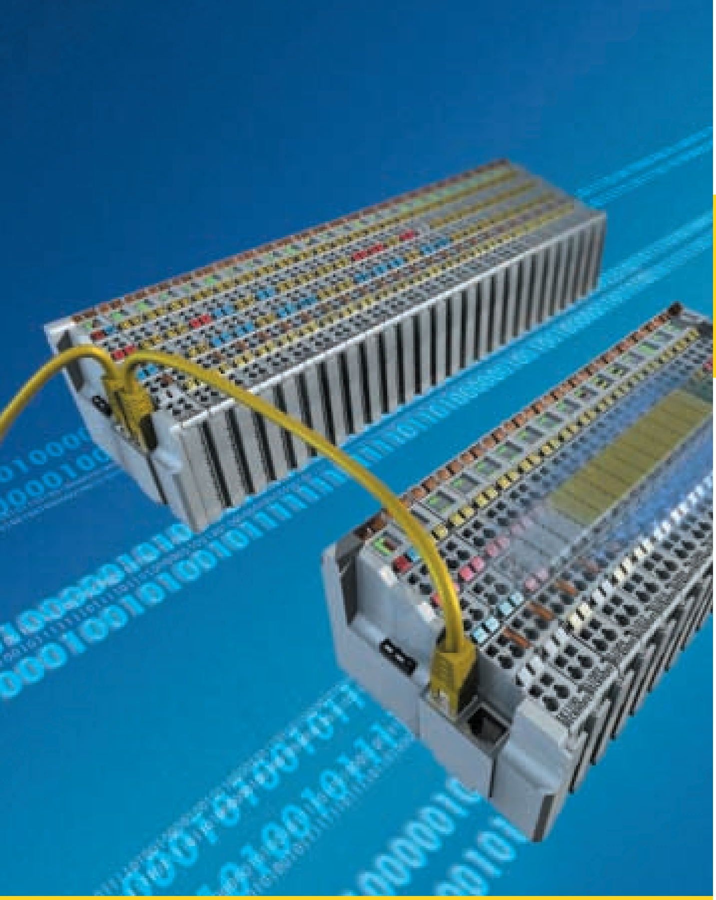
Line, tree or star: EtherCAT supports almost any topology. The bus or line structure known from the fieldbusses thus also becomes available for Ethernet. Particularly useful for system wiring is the combination of line and branches or stubs: The required interfaces exist on the couplers; no additional switches are required. Naturally, the classic switch-based Ethernet star topology can also be used.

Wiring flexibility is further maximized through the choice of different cables. Flexible and inexpensive standard Ethernet patch cables transfer the signals optionally in Ethernet mode (100Base-TX) or in E-bus signal representation. Plastic fiber optics (PFO) can be used in special applications. The complete bandwidth of the Ethernet network – such as different fiber optic and copper cables – can be used in combination with switches or media converters.

Fast Ethernet or E-bus can be selected based on distance requirements. The Fast Ethernet physics enables a cable length of 100 m between devices while the E-bus line is intended for distances of up to 10 m. The size of the network is almost unlimited since up to 65535 devices can be connected.

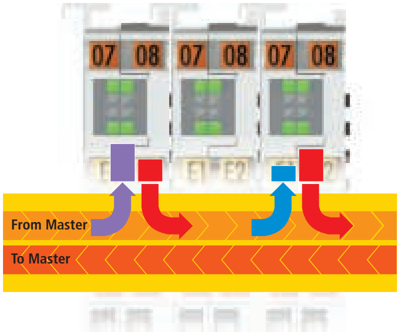


TwinCAT Y driver: operating system-compatible



EtherCAT instead of PCI

The central PC becomes smaller and more cost-effective because additional slots are not needed for interface cards since the onboard Ethernet port can be used. With increasing miniaturization of the PC components, the physical size of Industrial PCs is increasingly determined by the number of required slots. The bandwidth of Fast Ethernet, together with the data width of the EtherCAT communication hardware (FMMU chip) enables new directions: Interfaces that are conventionally located in the IPC are transferred to intelligent interface terminals at the EtherCAT. Apart from the decentralized I/Os, axes and control units, complex systems such as fieldbus masters, fast serial interfaces, gateways and other communication interfaces can be addressed. Even further Ethernet devices without restriction on protocol variants can be connected via decentralized "hub terminals". The central IPC becomes smaller and therefore more cost-effective, an Ethernet interface is sufficient for the complete communication with the periphery.



FMMU (fieldbus memory management unit): Telegram processing completely in hardware

Precise synchronization through distributed clock

Accurate synchronization is particularly important in cases where widely distributed processes require simultaneous actions. This may be the case, for example, in applications where several servo axes carry out coordinated movements simultaneously.

The most powerful approach for synchronization is the accurate alignment of distributed clocks, as described in the new IEEE 1588 standard. In contrast to fully synchronous communication, where synchronization quality suffers immediately in the event of a communication fault, distributed aligned clocks have a high degree of tolerance from possible fault-related delays within the communication system.

With EtherCAT, the data exchange is completely hardware based on "mother" and "daughter" clocks. Each clock can simply and accurately determine the other clocks' run-time offset because the communication utilizes a logical and full-duplex Fast Ethernet physical ring structure. The distributed clocks are adjusted based on this value, which means that a very precise network-wide timebase with a jitter of significantly less then 1 microsecond is available.

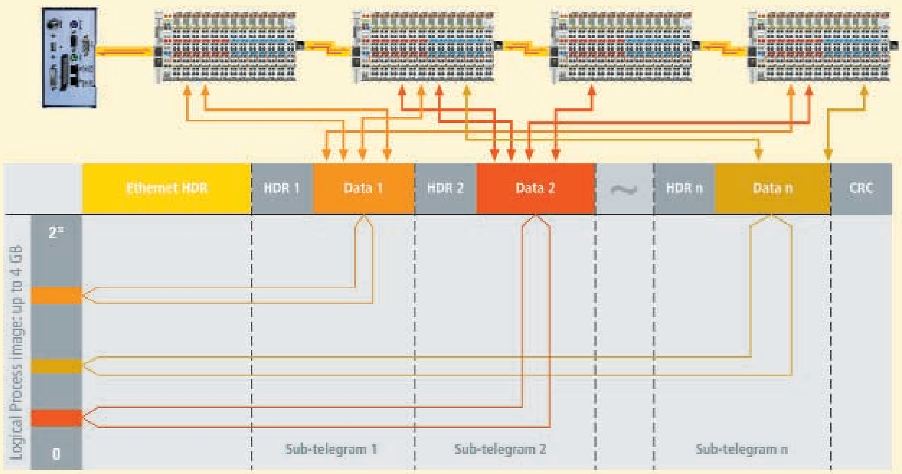
However, high-resolution distributed clocks are not only used for synchronization, but can also provide accurate information about the local timing of the data acquisition. For example, controls frequently calculate velocities from sequentially measured positions. Particularly with very short sampling times, even a small temporal jitter in the displacement measurement leads to large step changes in velocity. With EtherCAT, Beckhoff introduces new, expanded data types (timestamp data type, oversampling data type). The local time is linked to the measured value with a resolution of up to 10 ns, which is made possible by the large bandwidth offered by Ethernet. The accuracy of a velocity calculation then no longer depends on the jitter of the communication system. It is orders of magnitude better than that of measuring techniques based on jitter-free communication.

Hot connect and diagnosis

The Hot Connect function enables parts of the network to be linked and decoupled or reconfigured "on the fly"; offering flexible responses to changing configurations. Many applications require a change in I/O configuration during operation. Examples are processing centers with changing, sensor-equipped tool systems or transfer devices with intelligent, flexible workpiece carriers. The protocol structure of the EtherCAT system takes account of these requirements.

Special attention was paid to exemplary diagnostic features during the development of EtherCAT. The Beckhoff comprehensive experience with fieldbus systems shows that availability and commissioning times crucially depend on the diagnostic capability. Only faults that are detected quickly and accurately and located unambiguously can be rectified quickly.

During commissioning, the actual configuration of the I/O terminals is checked for consistency with the specified configuration. The topology should also match the configuration. I/O verification is possible during start-up and also via automatic



The process image allocation is freely configurable. Data are copied directly in the I/O terminal to the desired location within the process image: no additional mapping is required. Very large address space of 4 GB.

Openness

Beckhoff has taken every effort to ensure EtherCAT technology is fully Ethernet-compatible and truly open. The protocol tolerates other Ethernet-based services and protocols on the same physical network – usually even with minimum loss of performance. There is no restriction on the type of Ethernet device that can be connected within the EtherCAT strand via a hub terminal. Devices with fieldbus interface are integrated via EtherCAT fieldbus master terminals. The UDP protocol variant can be implemented on each socket interface. Finally, the intention is to disclose the technology once the development work is completed.

configuration upload because of the built-in topology recognition.
Bit faults during the data transfer are reliably detected through evaluation of the 32 bit CRC checksum, which has a minimum hamming distance of 4. The EtherCAT protocol, transfer physics and topology enables quality monitoring of each individual transmission segment. The automatic evaluation of the associated error counters enables precise localization of critical network sections. Gradual or changing sources of error such as EMC influences, defective push-in connectors or cable damage are detected and located, even if they do not yet overstrain the self-healing capacity of the network.

Ethernet Terminals
The existing wide range of K-bus I/O terminals from the proven Beckhoff Bus Terminal line can be networked with EtherCAT. The range includes appropriate bus couplers which are the network interface for the modular I/O terminals. This ensures compatibility and continuity with the existing system. Existing and future investments are protected.

EtherCAT Highlights

Performance
- 256 digital I/Os in 12 µs
- 1000 digital I/Os in 30 µs
- 200 analog I/Os (16 bit) in 50 µs, corresponding to 20 kHz sampling rate
- 100 servo axes in 100 µs
- 12000 digital I/Os in 350 µs
- Throughput: 10 kB/ms, distributed to 1,500 devices

Topology
- Line, tree or star topology
- Up to 65,535 devices
- Network size: almost unlimited (> 500 km)
- Operation with or without switches
- Cost-effective cabling: standard Ethernet patch cable (CAT5)
- Twisted pair physical layer:
- Ethernet 100BASE-TX, up to 100 m between 2 devices
- E-bus, industrial grade Ethernet, up to 10 m between 2 devices
- Optional fiber optic cable from 50 to 2000 m
- Hot connect/disconnect of bus segments

Address space
- Network-wide process image: 4 GB
- Device process image: 2 bit to 64 kB
- Address allocation: freely configurable
- Device address selection: automatically via software

Protocol
- Optimized protocol directly within the Ethernet frame
- Fully hardware-implemented
- For routing and socket interface: UDP datagram
- Processing while passing
- Distributed clock for accurate synchronization
- Time stamp data types for resolution in the nanosecond range
- Oversampling data types for high-resolution measurements

Diagnostic
- Breaking point detection
- Continuous "quality of line" measurement enables accurate localization of transmission faults

Interfaces
- Hub terminal for standard Ethernet devices
- Fieldbus terminals for fieldbus devices
- Decentralized serial interfaces
- Communication gateways

Openness
- Fully Ethernet-compatible
- Operation with switches and routers possible
- Mixed operation with other protocols also possible
- Internet technologies (web server, FTP, etc.)
- Compatible with the existing Bus Terminal range
- Disclosure in preparation