SERCOS III
Ethernet-based real time network for Industrial Automation

Joseph Biondo
Bosch Rexroth
Presenter – Joseph Biondo

• 20 years experience in servo and control products
• Product/technology knowledge
  – Open Networks/Ethernet
  – Motion Control/Servo Drives
  – OMAC (Open Modular Architecture Controls)
  – Machine Programming (CNC/PLC/Flowchart)
• Applications experience
  – Multi-process Machines
  – PC-based Motion/Logic Control
• Noteworthy projects
  – Commissioned 1st USA SERCOS Drive system in 1991
  – Published articles on Motion Control/Open Networks
What does SERCOS stand for?

SESerial RRealtime COCommunication SSystem
General Information
SERCOS interface

- SERCOS interface is an established standard
  - Not only physics and protocol are defined, also profiles for devices
  - Extensive functions for diagnosis
  - IEC 61491 standard since 1995
  - Only international and world-wide accepted standard for digital real time communication in drive technology

- SERCOS interface is widespread
  - Over 50 control manufacturer – over 30 drive manufacturer
  - Other communication systems are usually dominated by one or a few control manufacturers
  - More than 1.5 Million installed, in over 300,000 applications
SERCOS – Actual Status

• SERCOS interface is an **established** standard
  – Profiles and control architectures are defined – not just physics and protocol
  – Comprehensive diagnosis features
  – No license – Anyone may implement SERCOS
  – IEC 61491 standard since 1995
  – The only international and world-wide accepted standard for digital drive interface

• SERCOS interface is **widespread**
  – over 50 control manufacturers – over 30 drive manufacturers
  – Other field bus systems are usually dominated by one or very few control manufacturers
  – More than 1.7 Million nodes installed in more than 350,000 applications
## 20 Years of the SERCOS interface

<table>
<thead>
<tr>
<th>Year</th>
<th>Event</th>
</tr>
</thead>
<tbody>
<tr>
<td>85</td>
<td>Task Force &quot;Digital Drive Interface&quot;</td>
</tr>
<tr>
<td>86</td>
<td>Start of SERCOS development</td>
</tr>
<tr>
<td>87</td>
<td>Specification SERCOS I</td>
</tr>
<tr>
<td>88</td>
<td>Foundation Interests Group SERCOS</td>
</tr>
<tr>
<td>89</td>
<td>First testing laboratory at TU Darmstadt</td>
</tr>
<tr>
<td>90</td>
<td>SERCOS chip - SERCON 410B</td>
</tr>
<tr>
<td>91</td>
<td>Foundation SERCOS North America</td>
</tr>
<tr>
<td>92</td>
<td>International standard IEC 61491 (1st edition)</td>
</tr>
<tr>
<td>93</td>
<td>Foundation SERCOS Japan</td>
</tr>
<tr>
<td>94</td>
<td>European standard EN 61491</td>
</tr>
<tr>
<td>95</td>
<td>Specification SERCOS II</td>
</tr>
<tr>
<td>96</td>
<td>New SERCOS chip 16 MB - SERCON 816</td>
</tr>
<tr>
<td>97</td>
<td>New testing laboratory at University of Stuttgart</td>
</tr>
<tr>
<td>98</td>
<td>International standard IEC 61491 (2nd edition)</td>
</tr>
<tr>
<td>99</td>
<td>Start of SERCOS III development</td>
</tr>
<tr>
<td>00</td>
<td></td>
</tr>
<tr>
<td>01</td>
<td></td>
</tr>
<tr>
<td>02</td>
<td></td>
</tr>
<tr>
<td>03</td>
<td></td>
</tr>
<tr>
<td>04</td>
<td></td>
</tr>
</tbody>
</table>
General Information about SI

Quick overview of the organization

SERCOS International (SI)

- International user organization with headquarters in Stuttgart and with branches in North America and Asia
- Over 60 member companies worldwide
- Members include: Manufacturers and users of controls, drives and other automation components, as well as research institutes and federations
- Responsible for marketing, certification, technical advancement and standardization of the SERCOS real time communication standard
- Internet: www.sercos.org; www.sercos.com; www.sercos.de
Technical Characteristics
Standardization - Standards and Profiles

• Open Technology - Organization (SI), temporary guests and member companies have direct influence on standardization work
• International Standard since 1995 as IEC 61491
• Transformed to IEC 61491/revision 2 established as a component of the future profiles IEC 61800-7 and IEC 61784/61158
• Equipment profiles
  – Servo & Motion Profile
    – incl. OMAC Pack Profile (Packaging machines)
  – C2C Profile* for cross communication
  – I/O Profile*
  – SERCOS safety Profile*

Interoperability is already guaranteed as a defined open standard
Functionality is defined as profiles and thus generally usable.

* Specification finalized in 2006
SERCOS III: Next Evolution Step for SERCOS

SERCOS III = SERCOS + Ethernet
Innovation by Combining SERCOS and Ethernet

• Utilization of Standard Ethernet as Motion Network
• Re-use of well-defined and proven SERCOS mechanisms:
  – Time-slot protocol for collision avoidance
  – Hardware synchronization
  – Protocol in the real-time channel
  – Motion control profile
# SERCOS I - III Comparison

<table>
<thead>
<tr>
<th></th>
<th>SERCOS I</th>
<th>SERCOS II</th>
<th>SERCOS III</th>
</tr>
</thead>
<tbody>
<tr>
<td>Date implemented</td>
<td>1987</td>
<td>1999</td>
<td>2005</td>
</tr>
<tr>
<td>Physical media</td>
<td>Fiber optics</td>
<td>Fiber optics</td>
<td>Ethernet</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>(twisted-pair copper or Fiber optics)</td>
</tr>
<tr>
<td>Network topology</td>
<td>Ring</td>
<td>Ring</td>
<td>Ring or Line</td>
</tr>
<tr>
<td>Transmission speed</td>
<td>2/4 Mbit/s</td>
<td>2/4/8/16 Mbit/s</td>
<td>100 Mbit/s</td>
</tr>
<tr>
<td>Cycle time</td>
<td>configurable, min. 62.5 µs</td>
<td>configurable, min. 62.5 µs</td>
<td>configurable, min. 31.25 µs</td>
</tr>
<tr>
<td>Jitter</td>
<td>&lt; 1µsec</td>
<td>&lt; 1µsec</td>
<td>&lt; 1µsec</td>
</tr>
<tr>
<td>Synchronization</td>
<td></td>
<td></td>
<td>Hardware synchronization</td>
</tr>
<tr>
<td>Basic protocol</td>
<td></td>
<td>HDLC</td>
<td>Ethernet</td>
</tr>
<tr>
<td>Real-time protocol</td>
<td></td>
<td>SERCOS</td>
<td></td>
</tr>
<tr>
<td>Hardware redundancy</td>
<td>No</td>
<td>No</td>
<td>Yes (ring topology)</td>
</tr>
<tr>
<td>Cross communication (slave-to-slave)</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Controller-to-Controller Comm. &amp; Synchr.</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Service channel</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Optional IP channel</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Hot plugging</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Number of masters</td>
<td>1 per ring</td>
<td>1 per ring</td>
<td>1 per ring/linie</td>
</tr>
<tr>
<td>Number of nodes</td>
<td>254 per ring, multiple rings possible</td>
<td>254 per ring, multiple rings possible</td>
<td>254 per ring, multiple rings/lines possible</td>
</tr>
</tbody>
</table>
# Technical Characteristics

## Standardization - Standards and Profiles

<table>
<thead>
<tr>
<th>SC 65C PROJECT (2)</th>
<th>INIT</th>
<th>STAGE</th>
<th>TARGET PUB</th>
</tr>
</thead>
<tbody>
<tr>
<td>NUMBER</td>
<td>TITLE</td>
<td>DATE</td>
<td>CURRENT STAGE DATE</td>
</tr>
<tr>
<td><strong>MT9: FIELDBUS MAINTENANCE</strong></td>
<td>T. PHINNEY</td>
<td></td>
<td></td>
</tr>
<tr>
<td>IEC 61158 Serie Ed 1.0</td>
<td>APR 05</td>
<td>MCR</td>
<td>APR 05 65C / 379 / MCR</td>
</tr>
<tr>
<td>Fieldbus for use in industrial control systems</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>IEC 61784-1 Ed 2.0</td>
<td>APR 05</td>
<td>MCR</td>
<td>APR 05 65C / 360 / MCR</td>
</tr>
<tr>
<td>Profile sets relative to fieldbus</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PAS 62030 Ed 1</td>
<td>Real time Ethernet MODBUS</td>
<td>SEP 04</td>
<td>ANY</td>
</tr>
<tr>
<td>PAS 62405 Ed 1</td>
<td>Real time Ethernet Vnet/IP</td>
<td>MAR 05</td>
<td>ANY</td>
</tr>
<tr>
<td>PAS 62406 Ed 1</td>
<td>Real time Ethernet TCnet</td>
<td>MAR 05</td>
<td>ANY</td>
</tr>
<tr>
<td>PAS 62407 Ed 1</td>
<td>Real time Ethernet ETHERCAT</td>
<td>MAR 05</td>
<td>ANY</td>
</tr>
<tr>
<td>PAS 62408 Ed 1</td>
<td>Real time Ethernet Powerlink</td>
<td>MAR 05</td>
<td>ANY</td>
</tr>
<tr>
<td>PAS 62409 Ed 1</td>
<td>Real time Ethernet EPA</td>
<td>MAR 05</td>
<td>ANY</td>
</tr>
<tr>
<td><strong>PAS 62410 Ed 1</strong></td>
<td>Real time Ethernet SERCOS III</td>
<td>MAR 05</td>
<td>ANY</td>
</tr>
<tr>
<td>PAS 62411 Ed 1</td>
<td>Real time Ethernet PROFINET</td>
<td>MAR 05</td>
<td>ANY</td>
</tr>
<tr>
<td>PAS 62412 Ed 1</td>
<td>Real time Ethernet P-NET</td>
<td>MAR 05</td>
<td>ANY</td>
</tr>
<tr>
<td><strong>PAS 62413 Ed 1</strong></td>
<td>Real time Ethernet EtherNet/IP</td>
<td>MAR 05</td>
<td>ANY</td>
</tr>
</tbody>
</table>
The Evolution of SERCOS

4 most important advantages of SERCOS III

• 1. Redundant communication topology

• 2. Direct cross communication
  – Controller to Controller (C2C)
  – Slave to Slave (S2S)

• 3. Standard TCP/IP communication without additional hardware

• 4. Hot plugging of slaves during operation
The Evolution of SERCOS
More advantages of SERCOS III

- Commissioning via IP channel without SERCOS III communication
- Logical and physical addressing
- Telegram data can be recorded via sniffer in the topology (e.g. Ether-real)
- Easy migration from SERCOS II to SERCOS III
- Reduction of bus systems, one bus for all field devices
- Cost reduction with CAT5e Cabling
- Higher transmission rate (~ 6x faster than SERCOS II)
The Evolution of SERCOS Innovation

SERCOS II

**Application layer**

- **Servo & Motion Profile**
- **RT-Data**
- **SVC Channel**
- **Sync**

**Physical layer**

- **SERCON816** (optical transmission)
- 2, 4, 8, 16 Mbit/s

SERCOS III

**Application layer**

- **Motion Profile**
- **I/O Profile**
- **Drive Profile**
- **Generic Device Profiles**

**Communication layer**

- **RT Channels primary & secondary**
- **Safety**
- **Cross communication**
- **MS communication**
- **Sync**

**Physical layer**

- **SERCON100M/S/SL**
- **Ethernet Dual PHY**
- **netX with SERCOS III**
- 100 Mbit/s

Innovation by combination of SERCOS and Ethernet
The Evolution of SERCOS
Comparison to SERCOS II

- What stayed the same?
  - Servo- and Motion-Profile
    - Software compatibility on the application level
  - Cyclic and non-cyclic communication
    - Software compatibility with existing Software drivers
  - Real Time- and Synchronization performance
  - Service-Channel

- What is new with SERCOS III?
  - 2 Real Time Channels (Hardware Redundancy with Ring Topology)
  - Additional Application-Profiles (I/O-Profile, Hydraulics, FUs, and more)
  - SERCOS safety
  - IP-Channel
  - Data transmission rate
  - Cycle time (minimum 31.25 µs)
  - Reduced costs due to Ethernet-Physical layer
Topology Comparison

SERCOS II
- Fiber optical ring
- Unidirectional
- Baud rate up to 16 Mbit/s

SERCOS III
- Full-Duplex Ethernet
- Bidirectional
- Optical or copper
- Baud rate 100 Mbit/s
The Evolution of SERCOS
Comparison to SERCOS II

SERCOS II

- Communication interface for Drives only
- Integration of I/O devices possible, but seldom used

SERCOS III

Communication interface for Drives only

Combination of Drives and I/O devices

Communication interface for I/O only
SERCOS III Topology

- **CAT5e**
  - Baudrate: 100 Mbit/s
  - Cycle time: 31.25 µs ... 65 ms

- **Fast Ethernet (Full-Duplex)**
- **Standard Ethernet-Telegram**
- **Line-Topology, or**
- **Ring-Topology**
- **Cyclic real time traffic**
- **Topology at optimal costs: no switches/hubs**
- **I/O-devices**
Topology
Line and Ring

Line

Master
P1  P2

Slave 1
P1  P2

Slave 2
P1  P2

Slave 3
P2  P1

primary or secondary channel

Ring

Master
P1  P2

Slave 1
P1  P2

Slave 2
P1  P2

Slave 3
P2  P1

primary channel

secondary channel
SERCOS III Topology
Wire Break/Hot Plug

Redundant system in case of wire break

Hot-Plug ability of devices

Baudrate: 100 Mbit/s
Cycle time: 31.25 ms ... 65 ms
The ring is separated in primary line and secondary line.

Interruption may be either accidental or intentional.
Synchronization
Communication cycle

Telegram structure

MDT, AT and IP channel telegrams are embedded in Standard Ethernet frames
Technical Characteristics

Baudrate: 100 Mbit/s
Cycletime: 31.25 µs … 65 ms

Cross communication between slaves
Commissioning w/ Standard Ethernet-protocol

Direct connection of IP device to SERCOS III slave
Direct Cross Communication (C2C, S2S)

Direct Cross Communication between Master devices (C2C = Controller-to-Controller)

Direct Cross Communication between Slave devices (S2S = Slave-to-Slave)

Example: Cross Communication between Slave Device S5 and S6 via Master control M1 and M2
### Communication performance

<table>
<thead>
<tr>
<th>Cyclic data</th>
<th>Cycle time</th>
<th>No. of devices (1)</th>
<th>No. of devices (2)</th>
<th>No. of devices (3)</th>
<th>MDT / AT</th>
</tr>
</thead>
<tbody>
<tr>
<td>6 Byte</td>
<td>31.25 µs</td>
<td>8</td>
<td></td>
<td>3</td>
<td>1/1</td>
</tr>
<tr>
<td>12 Byte</td>
<td>62.5 µs</td>
<td>16</td>
<td></td>
<td>10</td>
<td>1/1</td>
</tr>
<tr>
<td>16 Byte</td>
<td>125 µs</td>
<td>30</td>
<td></td>
<td>25</td>
<td>1/1</td>
</tr>
<tr>
<td>12 Byte</td>
<td>250 µs</td>
<td>66</td>
<td>33</td>
<td>60</td>
<td>1/1</td>
</tr>
<tr>
<td>32 Byte</td>
<td>250 µs</td>
<td>34</td>
<td>17</td>
<td>31</td>
<td>1/1</td>
</tr>
<tr>
<td>12 Byte</td>
<td>500 µs</td>
<td>130</td>
<td>100</td>
<td>124</td>
<td>2/2</td>
</tr>
<tr>
<td>50 Byte</td>
<td>1 ms</td>
<td>100</td>
<td>85</td>
<td>98</td>
<td>4/4</td>
</tr>
<tr>
<td>32 Byte</td>
<td>1 ms</td>
<td>140</td>
<td>120</td>
<td>137</td>
<td>4/4</td>
</tr>
<tr>
<td>12 Byte</td>
<td>1 ms</td>
<td>254</td>
<td>220</td>
<td>249</td>
<td>4/4</td>
</tr>
</tbody>
</table>

1) without IP channel
2) with IP channel: 1500 bytes = 125 µs
3) with IP channel: 250 bytes = 20 µs
General telegram structure

- **SERCOS III** based on Standard Ethernet according IEEE 802.3

<table>
<thead>
<tr>
<th></th>
<th>IDLE</th>
<th>SSD</th>
<th>Preamble</th>
<th>SFD</th>
<th>Destination address</th>
<th>Source address</th>
<th>Ethernet Type</th>
<th>MST (S III header)</th>
<th>data field</th>
<th>FCS</th>
<th>ESD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Size</td>
<td>11+1 Byte</td>
<td>7+1 Byte</td>
<td>6 Byte</td>
<td>6 Byte</td>
<td>2 Byte</td>
<td>6 Byte</td>
<td>40-1494 Byte</td>
<td>4 Byte</td>
<td>1 Byte</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- Telegram length: 72 - 1526 Byte (overhead: 26+6 = 32 Byte)
- Telegram time: 5.8µs - 122.1µs

- Telegram length: 84 - 1538 Byte (overhead: 38+6 = 44 Byte)
- Telegram time: 6.8µs - 123.1µs

**S III Ethernet type = 0x88CD**
S III Header (MST)

- MDT/AT data are protected via FCS and transmitted by the master.
- MST is valid in MDT0...3 and AT0…3.
- MDT
  - Every slave receives the MDT and takes its data.
  - The MDT is repeated only, not changed by the slave.
  - MST in MDT0 only is used for synchronization purposes.
- AT
  - Slaves insert data in the AT data field.
  - Slaves process cross communication in AT only.
  - Every slave checks the Rx-FCS and determines the Tx-FCS.
# MDT and AT data fields

- MDT/AT data field may contain up to 3 fields
  - Hot plug
  - Service channel
  - Real-time data

<table>
<thead>
<tr>
<th>IDLE</th>
<th>SSD</th>
<th>preamble</th>
<th>SFD</th>
<th>destination address</th>
<th>source address</th>
<th>0x88CD</th>
<th>MST</th>
<th><strong>MDT/AT data field</strong></th>
<th>FCS</th>
<th>ESD</th>
</tr>
</thead>
</table>

**Diagram:**

- Hot plug field (new devices)
- Service channel field of devices
- Real-time data field of devices
Service channel structure

- **Service channel (SVC) contains**
  - SVC control word or SVC status word
  - SVC INFO
- **Length of Service channel**: 6 byte
- **Each device has an own service channel**
**Real-time data structure**

- Real-time data field contains:
  - Device control or Device status
  - configured real-time data for MS
  - Cross communication data in AT only
- Length of real-time data field: 4 byte + configured length
- Length of CC data field: 2 byte + configured length

<table>
<thead>
<tr>
<th>Hot plug field (new devices)</th>
<th>Service channel field of devices</th>
<th>Real-time data field of devices</th>
<th>Cross communication data field of devices</th>
</tr>
</thead>
<tbody>
<tr>
<td>real-time data field # 1</td>
<td>real-time data field # 2</td>
<td>real-time data field # K</td>
<td>CC #1</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>CC #2</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>CC #m</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>CC #M</td>
</tr>
</tbody>
</table>

**MDT0...MDT3**
- device control
- configurable MS real-time data (NC/MC → Slave)

**AT0...AT3**
- device status
- configurable MS real-time data (Slave → NC/MC)
Configuration overview of MDT and AT

MDT

HDR = Ethernet header
MST = S III header, SYNC
HOT = Hotplug field
SVC = Service channel
RTD = Rel-time data
CC = Cross communication
FCS = Frame check sequence

AT

HDR = Ethernet header
MST = S III header, SYNC
HOT = Hotplug field
SVC = Service channel
RTD = Rel-time data
CC = Cross communication
FCS = Frame check sequence
Number of slaves with one MDT / AT

- S III data length = 1494 Byte
- RTD: Hotplug = 8 Byte --> 1486 Byte
- SVC per device = 6 Byte / device
- Device control / status = 4 Byte / device
  - 1 cmd/feedback value = 4 Byte --> 106 devices
  - 2 cmd/feedback values = 8 Byte --> 82 devices
  - 3 cmd/feedback values = 12 Byte --> 67 devices
  - 4 cmd/feedback values = 16 Byte --> 57 devices
  - 5 cmd/feedback values = 20 Byte --> 49 devices
  - 6 cmd/feedback values = 24 Byte --> 43 devices
  - 7 cmd/feedback values = 28 Byte --> 39 devices
  - 8 cmd/feedback values = 32 Byte --> 35 devices
  - 10 cmd/feedback values = 40 Byte --> 29 devices
  - 16 cmd/feedback values = 64 Byte --> 20 devices
- 254 devices with 4 MDTs and 4 ATs
  - 3 cmd/feedback values = 12 Byte --> 254 axes
    (MDT0..3/AT0..3)
Technical characteristics

Baudrate: 100 Mbit/s
Cycle time: 31.25 µs ... 65 ms

Redundancy, e.g. with cable break
Hot Plugging of devices

Hot-Plug Device
Hot plugging

- Hot plugging is possible with ring only
- A ring break has to initiated first
- Master must be prepared for the HP slave
- Hot plug consists of 3 phases (HP0 to HP2)
- HP0: HP field is used
  - master transmits identical parameter for all HP slaves
  - master checks slave address of first HP slave
  - slave activates parameterization level
- HP1: HP field is used
  - master transmits different parameter for each HP slave
  - master switches to Service channel communication
- HP2: Service channel (SVC) is used
  - master transmits additional parameter for CP4
  - master activates the real-time communication in the HP
Hot plug structure

- **Hot plug field contains:**
  - Device address
  - HP control word or HP status word
  - HP INFO
- **Length of Hot plug: 8 byte**
Hot plugging one device with line (1)

**HP0 Step 1**
- **master**
- **slave 1...n-1**
- **slave n**
- **slave n+1**

Slave n signals LINK on Py to master

**HP0 Step 2**
- **master**
- **slave 1...n-1**
- **slave n**
- **slave n+1**

Master transmits HP0-Parameter in HP-field

Master transmits HP0-Parameter in HP-field
Hot plugging one device with line (2)

**HP0 Step 3**
Acknowledge slave n+1 in LB
MHP-ADR=0xFF

- Master
- Slave 1...n-1
- Slave n
- Slave n+1

- FF
- FF&LB S III-LINK on Py
- All HP0-Parameter received,
  FF&LB

**HP0 Step 4**
HP with n+1
MHP-ADR=0xFF
SHP-ADR=n+1

- Master
- Slave 1...n-1
- Slave n
- Slave n+1

- Several cycles
- Master reads SHP-ADR=n+1
- FF
- Master commands FF
- FF&LB
  Ack to master
  Slave checks
  SHP-ADR on Py and Pz
Hot plugging one device with line (3)

HP1 Step 5
MHP-ADR=n+1
SHP-ADR=n+1
Master transmits HP1-Parameter

Master transmits several cycles
SHP-ADR=n+1

CP4

Slave in HP1

HP1 Step 6
MHP-ADR=n+1
SHP-ADR=n+1
Master switches to SVC

Master switches from HP to SVC
End of HP1-Transmission with slave n+1
Hot plugging one device with line (4)

HP2 Step 7 (SVC)
Init SVC like CP1
Master transmits necessary parameter, like CP2/CP3

- Master communicates with slave n+1 via SVC

HP2 Step 8 (CP4)
Master activates CP4
Slave activates RTD & Op-mode

- Master communicates with slave n+1 via SVC & RTD in CP4
Direct Cross Communication (C2C, S2S)

Direct Cross Communication between Master devices (C2C = Controller-to-Controller)

Direct Cross Communication between Slave devices (S2S = Slave-to-Slave)

Example: Cross Communication between Slave Device S5 and S6 via Master control M1 and M2
Live demonstration of SERCOS III

- Three panels show Cross Communication of controls and drives
- One panel shows commissioning and diagnostics over IP communication
Technical Characteristics

Baudrate: 100 Mbit/s
Cycletime: 31.25 µs ... 65 ms

Cross communication between slaves
Commissioning w/ Standard Ethernet-protocol

Direct connection of IP device to SERCOS III slave
Technical Characteristics
IP Communication – Ring topology
Technical Characteristics
IP Communication – Line topology

World Wide Access
Local Service on the Machine

PC1
Ethernet (Office)
IP
Master
P1, P2
I/O
PC2
PC3

45
Technical Characteristics
Download/Upload mechanism via IP

- Standard PC is easily connected to the available SERCOS III Port
- Standard PC sends Standard Ethernet telegrams, no SERCOS III telegrams
- Download/Upload over IP-channel in non-real-time mode in line topology
- Standard TCP/IP communication possible without an active SERCOS III communication
Initialization
Communication phases (CP0 to CP4)

1 = no S III within 65 ms or communication error
2 = max. telegram losses exceeded
CP = Communication phase
CPS = Communication phase switching
NRT = non real-time mode
HP = Hot plugging
**CP0**

**Communication timing**

- **t6init** = begin of IP channel
- **t7init** = end of IP channel
- **tscyc** = communication cycle time
- Jitter of +/- 50µs for low performance applications

0-100µs Jitter

<table>
<thead>
<tr>
<th>MDT0</th>
<th>AT0</th>
</tr>
</thead>
<tbody>
<tr>
<td>6µs</td>
<td>44µs</td>
</tr>
</tbody>
</table>

1ms ≤ tscyc ≤ 65ms

- **t6init** = 650 µs
- **t7init** = 950 µs

= 300 µs

MDT0 = 300 µs
CP0
MDT / AT structure

<table>
<thead>
<tr>
<th>IDLE</th>
<th>SSD</th>
<th>preamble</th>
<th>SFD</th>
<th>destination address</th>
<th>source address</th>
<th>type</th>
<th>MST</th>
<th>MDT/AT data field</th>
<th>FCS</th>
<th>ESD</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- **SERCOS type = MDT0**
  - **phase = 0**
  - **CRC**
  - 40 bytes padding to min. frame size
  - 512 bytes

- **SERCOS type = AT0**
  - **phase = 0**
  - **CRC**
  - SADR #0, SADR #1, ●●●●●●●, SADR #254, SADR #255
  - 2 Byte, 2 Byte

- **IDLE** = 7+1 Byte
- **SSD** = 6 Byte
- **preamble** = 6 Byte
- **SFD** = 2 Byte
- **destination address** = 4 Byte
- **source address** = 2 Byte
- **type** = 4 Byte
- **MST** = 2 Byte
- **MDT/AT data field** = 40 bytes
- **FCS** = 4 Byte
- **ESD** = 512 bytes

**Data Field:**
- **SADR #0, SADR #1, ●●●●●●●, SADR #254, SADR #255**
- **2 Byte, 2 Byte**

**CRC:**
- **1 Byte, 1 Byte, 4 Byte, 2 Byte, 2 Byte**

**Frame Size:**
- **7+1 Byte, 6 Byte, 6 Byte, 2 Byte, 4 Byte**

**Total Frame Size:**
- **512 bytes**
CP0

Address recognition, Slave function

- **SERCOS type**: AT0
- **phase**: 0
- **CRC**

### Function of Slave with address #254
(e.g. with address switch)

- **TADR**
- **SADR**

<table>
<thead>
<tr>
<th></th>
<th>SADR #0</th>
<th>SADR #1</th>
<th>SADR #254</th>
<th>SADR #255</th>
</tr>
</thead>
<tbody>
<tr>
<td>R</td>
<td>W</td>
<td>R</td>
<td>W</td>
<td></td>
</tr>
<tr>
<td>+1</td>
<td>+1</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- **TADR** = topology address
- **SADR** = SERCOS address, available via switch or IDN
### CP0

**Address recognition, Master**

- 4 devices without addressing error
- addresses #1, #10, #11 and #254

<table>
<thead>
<tr>
<th>AT0 data field</th>
<th>SADR #0</th>
<th>SADR #1</th>
<th>SADR #10</th>
<th>SADR #11</th>
<th>SADR #254</th>
<th>SADR #255</th>
</tr>
</thead>
<tbody>
<tr>
<td>contents</td>
<td>0x0004</td>
<td>0x0001</td>
<td>0x0001</td>
<td>0x0001</td>
<td>0x0001</td>
<td>0x0000</td>
</tr>
</tbody>
</table>

- 4 devices with addressing error
- addresses #1, #1, #1 and #254

<table>
<thead>
<tr>
<th>AT0 data field</th>
<th>SADR #0</th>
<th>SADR #1</th>
<th>SADR #10</th>
<th>SADR #11</th>
<th>SADR #254</th>
<th>SADR #255</th>
</tr>
</thead>
<tbody>
<tr>
<td>contents</td>
<td>0x0004</td>
<td>0x0003</td>
<td>0x0000</td>
<td>0x0000</td>
<td>0x0001</td>
<td>0x0000</td>
</tr>
</tbody>
</table>

- Diagnostics in the Master
  - wrong address
  - same address (add-on to S II)
  - additional address
Automatic address allocation

- **In CP0**
  - Slave without SADR (=0) determines the TADR only
  - Slave with SADR (≠0) determines additionally the TADR

- **In CP2**
  - Master reads IDN SADR and TADR of each slave
  - TADR defines the physical order in the topology
  - MUXSVC only used for slaves with TADR
  - Master can assign a SADR to the slave
**CP1 / CP2**

**Communication timing**

- \( t_6\text{init} = \text{begin of IP channel} \)
- \( t_7\text{init} = \text{end of IP channel} \)
- \( t_{scyc} = \text{communication cycle time} \)

Jitter of +/- 50µs for low performance applications

\( 1\text{ms} \leq t_{scyc} \leq 65\text{ms} \)

\( t_6\text{init} = 650 \mu s \)

\( t_7\text{init} = 950 \mu s \)

\( 0-100\mu s \) Jitter

\( = 300 \mu s \)

- MDT0
- MDT1
- AT0
- AT1
- IP channel
- MDT0

Diagram showing the timing relationships between the channels and the IP channel.
### CP1 / CP2

#### MDT / AT structure

<table>
<thead>
<tr>
<th>IDLE</th>
<th>SSD</th>
<th>preamble</th>
<th>SFD</th>
<th>destination address</th>
<th>source address</th>
<th>type</th>
<th>MST</th>
<th>MDT / AT data field</th>
<th>FCS</th>
<th>ESD</th>
</tr>
</thead>
</table>

#### SERCOS type = MDT0
- phase = 1 or 2
- CRC
- dev.#0 MuxSVC
- dev.#1 SVC
- dev.#126 SVC
- dev.#127 SVC
- dev.#0 TADR
- dev.#127 device control

#### SERCOS type = MDT1
- phase = 1 or 2
- CRC
- dev.#128 SVC
- dev.#129 SVC
- dev.#254 SVC
- dev.#255 SVC
- dev.#128 device control
- dev.#255 device control

#### SERCOS type = AT0
- phase = 1 or 2
- CRC
- dev.#0 MuxSVC
- dev.#1 SVC
- dev.#127 SVC status
- SVC INFO
- dev.#0 TADR
- dev.#127 device status

#### SERCOS type = AT1
- phase = 1 or 2
- CRC
- dev.#128 SVC
- dev.#129 SVC
- dev.#255 SVC status
- SVC INFO
- dev.#128 device status
- dev.#255 device status

- 1 Byte
- 1 Byte
- 4 Byte
- 6 Byte
- 6 Byte
- 4 Byte
Communication Sequence in CP3/CP4

- Up to 4 telegrams per data direction (max. 6,000 byte)
- IP channel integrated in separate time slot, no modification of the telegrams necessary
Communication Timing in CP3/CP4

**Method 1**

- t1
- t6 (begin of IP)
- min = MTU
- t7 (end of IP)
- tscyc

**Method 2**

- t6
- min = MTU
- t7
- t1
- tscyc
Physical delay times
Slave

Slave delay: FPGA meas. 600ns
IDN Tx-delay (ns), PHY+SERCON100?
IDN Rx-delay (ns), PHY+SERCON100?

Cable delay: CAT5 ca. 5 ns / m (max. 500 ns / 100 m)

<table>
<thead>
<tr>
<th>PHYRx</th>
<th>PHYTx</th>
<th>Device</th>
<th>Manufacturer</th>
</tr>
</thead>
<tbody>
<tr>
<td>220ns</td>
<td>90ns</td>
<td>KS8721BL</td>
<td>Micrel</td>
</tr>
<tr>
<td>215ns</td>
<td>60ns</td>
<td>DP83843</td>
<td>NSC</td>
</tr>
<tr>
<td>170ns</td>
<td>50ns</td>
<td>LXT973</td>
<td>Intel</td>
</tr>
<tr>
<td>600ns</td>
<td></td>
<td>netX</td>
<td>Hilscher</td>
</tr>
</tbody>
</table>

PHY Rx
-----------------------------
<table>
<thead>
<tr>
<th>PHYRx</th>
<th>RX</th>
<th>TX</th>
<th>FCS</th>
<th>PHYTx</th>
<th>Delay</th>
</tr>
</thead>
<tbody>
<tr>
<td>170ns</td>
<td>160ns</td>
<td>160ns</td>
<td>0ns</td>
<td>50ns</td>
<td>540ns</td>
</tr>
<tr>
<td>170ns</td>
<td>80ns</td>
<td>80ns</td>
<td>0ns</td>
<td>50ns</td>
<td>380ns</td>
</tr>
<tr>
<td>170ns</td>
<td>80ns</td>
<td>0ns</td>
<td>40ns</td>
<td>50ns</td>
<td>340ns</td>
</tr>
<tr>
<td>170ns</td>
<td>40ns</td>
<td>0ns</td>
<td>40ns</td>
<td>50ns</td>
<td>300ns</td>
</tr>
</tbody>
</table>

PHY Tx

SERCOS III Slave
Synchronization generation

Synchronization is generated by the MST field of MDT0 only.
## Synchronization with MST

### Master determines the Synchronization Accuracy

- **Start in Master:**
  - **stable synchronization signal**
  - **propagation delay: Master to Slave?**
  - **2,24 µs (28 Byte, constant duration)**

### Data Field Structure

<table>
<thead>
<tr>
<th>Type</th>
<th>IDLE</th>
<th>SSD</th>
<th>preamble</th>
<th>SFD</th>
<th>destination address</th>
<th>source address</th>
<th>type</th>
<th>MST</th>
<th>MDT data field</th>
<th>FCS</th>
<th>ESD</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>≥12 Byte</td>
<td>7+1 Byte</td>
<td>6 Byte</td>
<td>6 Byte</td>
<td>2 Byte</td>
<td></td>
<td></td>
<td>MST</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**SERCOS type (MDT0):**
- **Synchronization delay time**
- **SERCOS cycle**
- **AT transmission time**
- **IP channel**

- **≥12 Byte**
- **7+1 Byte**
- **6 Byte**
- **6 Byte**
- **2 Byte**
- **4 Byte**

**S III: hardware function**

### Other RTE systems uses IEEE1588

- **S III: hardware function**

### Note

- **dependent of physical order**
SERCOS III Hardware

- FPGA or gate-array solution
  - SERCON100M/S based on Xilinx Spartan-3 Hardware and Altera Cyclone II Hardware
  - To be used in medium quantity applications
  - Gate-array realization is very simple and cost effective
- Integrating SERCOS III interface into universal communication controllers
  - Very cost effective
  - Possibility to realize “Single Chip devices“
  - Support of multiple Real-Time Ethernet protocols
Flexibility in the choice of the cable type

- Useful for industrial applications
- Cable type and Shielding
  - min. CAT5e with S/UTP
  - Industry: CAT5e with S/STP (SERCOS III)
- Use of Patch cable or Crossover cable possible
  - Length 100m (max.)
  - S III specifies ground connection of shielding and unused wires
- Harting RJ 45
  - IP 20
- Harting RJ 45, M12, IP 67
- Profinet
- Ethernet Powerlink
- EtherCAT
- ODVA
- SERCOS III (RJ45, IP 20 & IP 67)
Flexibility in wiring

- Each Slave has two Ports (P1 and P2)
- Port 1 and Port 2 are interchangeable

⇒ Eliminates connection errors leading to faster commissioning
SERCOS safety
Safe Real time communication with SERCOS

C..consumer   P..producer   M..SERCOS master   S..SERCOS slave  

Single-Cast  Multi-Cast

Cross Communication (C2C)

1 Single-Cast-Connection  2 Multi-Cast-Connection  3 Safe Cross Communication  4 … over SERCOS networks  5 Safe C2C Communication
SERCOS safety
Application example

- Classical system architecture

- Up to three different networks
  - I/O interface
  - Safety interface
  - Drive interface

- Not the best solution
  - Costs of topology
  - Total cost of ownership
    - Training, service, maintenance
SERCOS safety
Application example

- SERCOS safety solution

- One continuous network for standard and safety communication
  - Additional Drive interface isn’t applicable
  - Simplified topology

- Integrated safety logic
  - Network between Motion Control and Safety Control isn’t required
In Review - SERCOS III Topology

- Fast Ethernet (Full-Duplex)
- Standard Ethernet-Telegram
- Line-Topology, or
- Ring-Topology
- Cyclic real time traffic
- Topology at optimal costs: no switches/hubs
- I/O-devices

CAT5e

Baudrate: 100 Mbit/s
Cycle time: 31.25 µs … 65 ms
In Review - Advantages

- Well proven SERCOS-Mechanism in combination with worldwide well known network physical layer (Ethernet)
- **Compatible** with SERCOS II
  - Easy migration of existing software drivers
  - Identical data exchange mechanism and **Service channel**
- **Reduction of costs through Ethernet** Physical layer
- **Simpler handling** with CAT5e cable (manufacturing, installation)
- **Hardware based Synchronization** with Ring and Line Topology
- **Logical addressing** (independent of physical order)
- **Real-time** and **non real-time** communication is kept in SERCOS III protocol
  - **RT channel**: command and actual values
  - **IP channel**: Integration of existing Ethernet units (via gateway), Routing capability for proprietary protocols
- **Higher data transmission** rate (~ 6x faster)
In Review - Advantages

- **Reduction** of cycle time down to **31.25 µs**
  - Capability to support centralized drive concepts
- Integration of **I/O-Functionality**
- **Data exchange** between controllers
  - Parameter values, Axis command/status values, lead axis groups,
  - Synchronization of Controls on hard real time level
- **Cross communication** of devices
  - Takes place in the **RT channel**, all telegrams are transparent for each device.
  - E.g. Axis groups (Gantry Axes)
  - Mutually fast monitoring
- **Safe communication** for drive integrated safety functions
  - Transmission of safe and unsafe data via the same mechanism
- **Hot plugging** of devices during operation
- **Redundancy** with ring topology (**More uptime**)
Thanks for Your Attention!

For further information, please contact:

Joseph Biondo
Bosch Rexroth Corporation
5150 Prairie Stone Parkway
Hoffman Estates, IL 60192
Email: joe.biondo@boschrexroth-us.com

Web Addresses:

www.sercos.org
www.sercos.com
www.sercos.de
www.boschrexroth-us.com/automationhouse