Setting the Standard for Automation™

SERCOS III
Ethernet-based real time network for Industrial Automation

Joseph Biondo

Bosch Rexroth

Standards
Certification
Education & Training
Publishing
Conferences & Exhibits

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

Rexroth
Bosch Group

SERCOS interface

What does SERCOS stand for ?

SErial Realtime COmmunication System

General Information
SERCOS interface

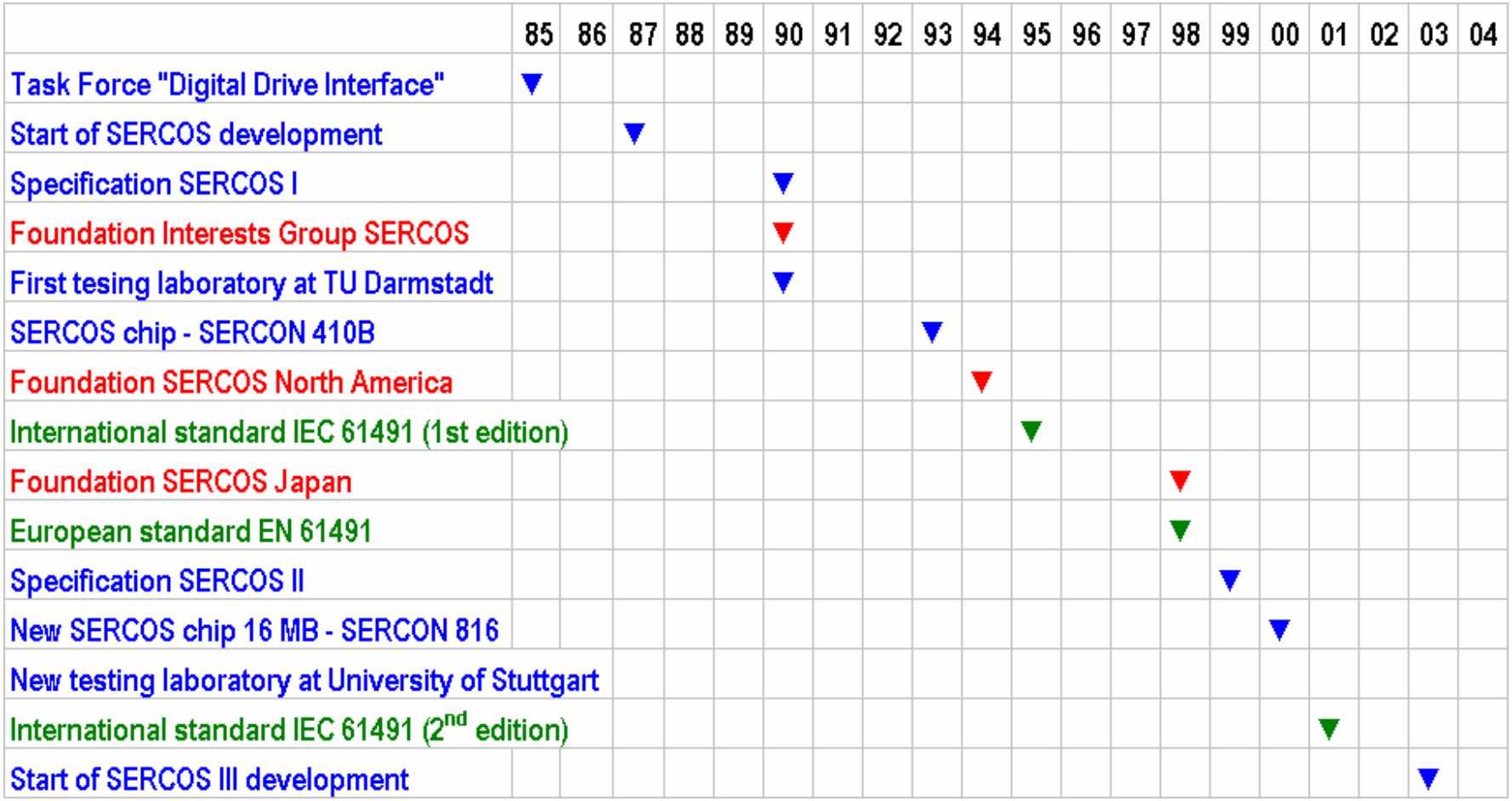
- SERCOS interface is an **established** standard
  - Not only physics and protocol are defined, also profiles for devices
  - Extensive functions for diagnosis
  - IEC 61491 standard since 1995
  - Only international and world-wide accepted standard for digital real time communication in drive technology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



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

General Information
Member Companies

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

	SERCOS I	SERCOS II	SERCOS III
Date implemented	1987	1999	2005
Physical media	Fiber optics	Fiber optics	Ethernet (twisted-pair copper or Fiber optics)
Network topology	Ring	Ring	Ring or Line
Transmission speed	2/4 Mbit/s	2/4/8/16 Mbit/s	100 Mbit/s
Cycle time	configurable, min. 62,5 µs	configurable, min. 62,5 µs	configurable, min. 31,25 µs
Jitter	< 1µsec	< 1µsec	< 1µsec
Synchronization	Hardware synchronization		
Basic protocol	HDLC		Ethernet
Real-time protocol	SERCOS		
Hardware redundancy	No	No	Yes (ring topology)
Cross communication (slave-to-slave)	No	No	Yes
Controller-to-Controller Comm. & Synchr.	No	No	Yes
Service channel	Yes	Yes	Yes
Optional IP channel	No	No	Yes
Hot plugging	No	No	Yes
Number of masters	1 per ring	1 per ring	1 per ring/linie
Number of nodes	254 per ring, multiple rings possible	254 per ring, multiple rings possible	254 per ring, multiple rings/lines possible

Technical Characteristics

Standardization - Standards and Profiles

SC 65C PROJECT (2) NUMBER TITLE	INIT DATE	STAGE CURRENT STAGE DATE REF DOC	 NEXT STAGE DATE	TARGET PUB DATE
MT9: FIELDBUS MAINTENANCE			**T. PHINNEY**	
IEC 61158 Serie Ed 1.0 Fieldbus for use in industrial control systems	APR 05	MCR APR 05 65C / 379 / MCR		**AUG 07**
IEC 61784-1 Ed 2.0 Profile sets relative to fieldbus	APR 05	MCR APR 05 65C / 380 / MCR		**AUG 07**
PAS 62030 Ed 1 Real time Ethernet MODBUS	SEP 04	ANW SEP 04 65C / 341 / NP		
PAS 62405 Ed 1 Real time Ethernet Vnet/IP	MAR 05	ANW MAR 05 65 / 352 / NP		
PAS 62406 Ed 1 Real time Ethernet TCnet	MAR 05	ANW MAR 05 65 / 353 / NP		
PAS 62407 Ed 1 Real time Ethernet ETHERCAT	MAR 05	ANW MAR 05 65 / 355 / NP	**CDV APR 06** **FDIS JAN 07**	
PAS 62408 Ed 1 Real time Ethernet Powerlink	MAR 05	ANW MAR 05 65 / 356A / NP		
PAS 62409 Ed 1 Real time Ethernet EPA	MAR 05	ANW MAR 05 65 / 357 / NP		
PAS 62410 Ed 1 Real time Ethernet SERCOS III	MAR 05	ANW MAR 05 65 / 358 / NP		
PAS 62411 Ed 1 Real time Ethernet PROFINET	MAR 05	ANW MAR 05 65 / 359 / NP		
PAS 62412 Ed 1 Real time Ethernet P-NET	MAR 05	ANW MAR 05 65 / 360 / NP		
PAS 62413 Ed 1 Real time Ethernet EtherNet/IP	MAR 05	ANW MAR 05 65 / 361 / NP		**AUG 07**

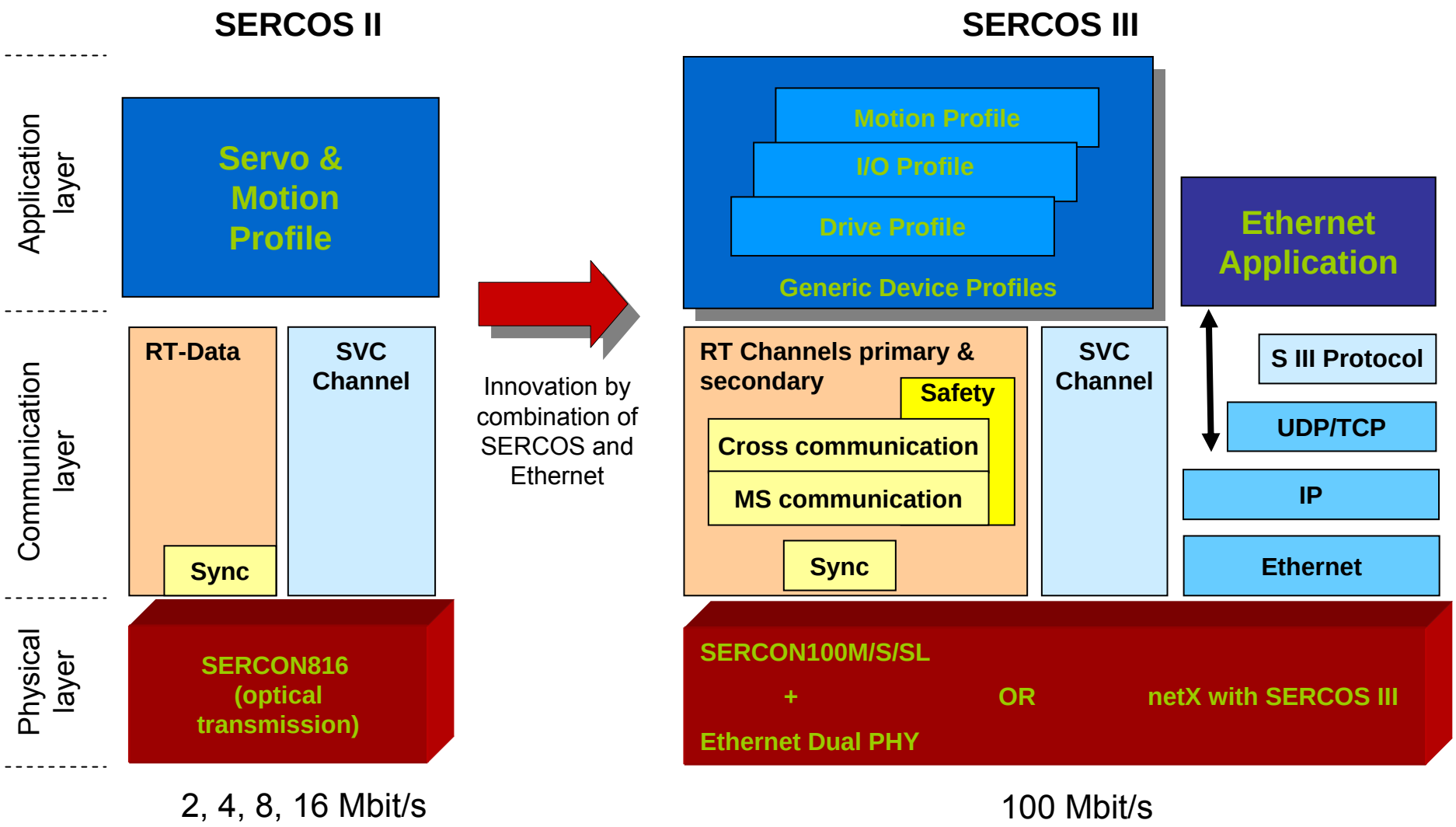
The Evolution of SERCOS
4 most important advantages of SERCOS III

- 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 S 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

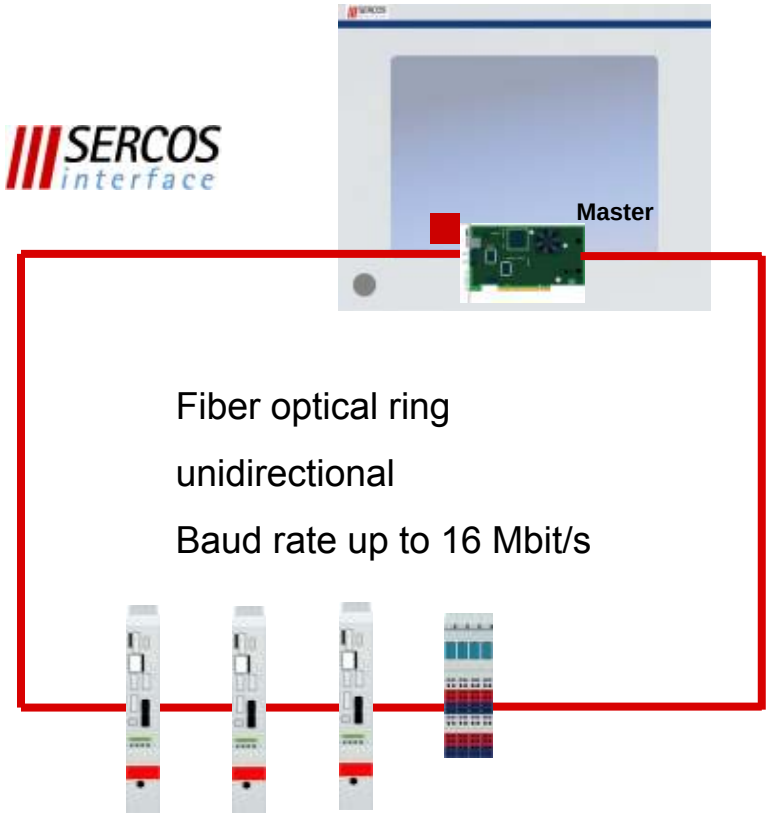


The Evolution of SERCOS
Comparison to SERCOS II

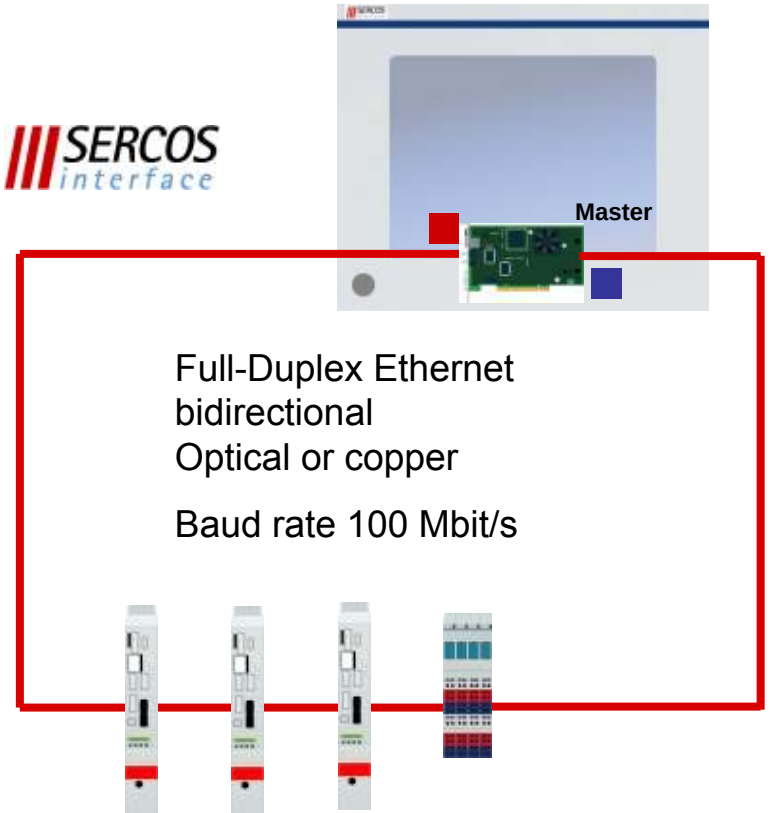
- What stayed the same?
  - Servo- and Motion-Profile
    - Software compatibility on the application level
  - Cyclic and non-cyclic communication
    - Software compatibility with existing Software drivers
  - Real Time- and Synchronization performance
  - Service-Channel
- What is new with SERCOS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

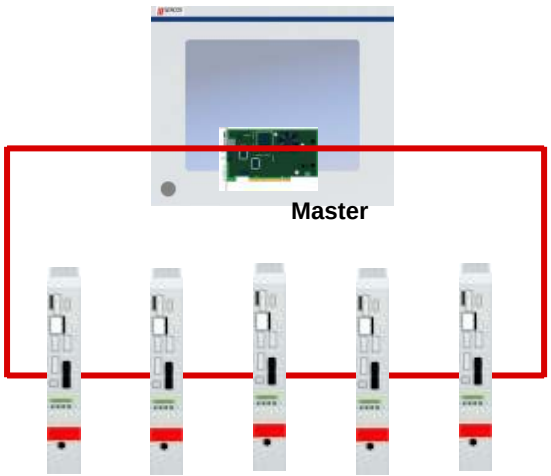


SERCOS III



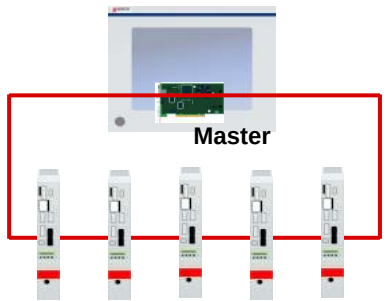
The Evolution of SERCOS
Comparison to SERCOS II

SERCOS II

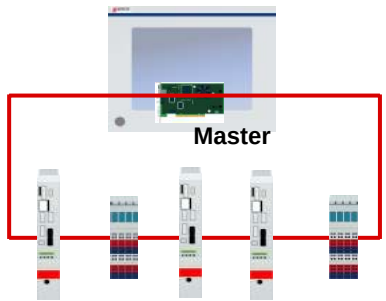


- Communication interface for **Drives** only
- Integration of I/O devices possible, but seldom used

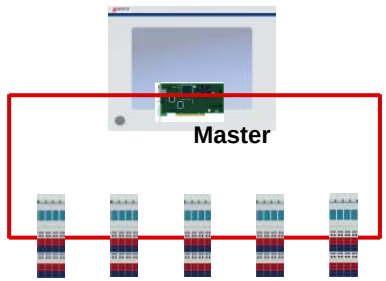
SERCOS III



Communication interface for **Drives** only

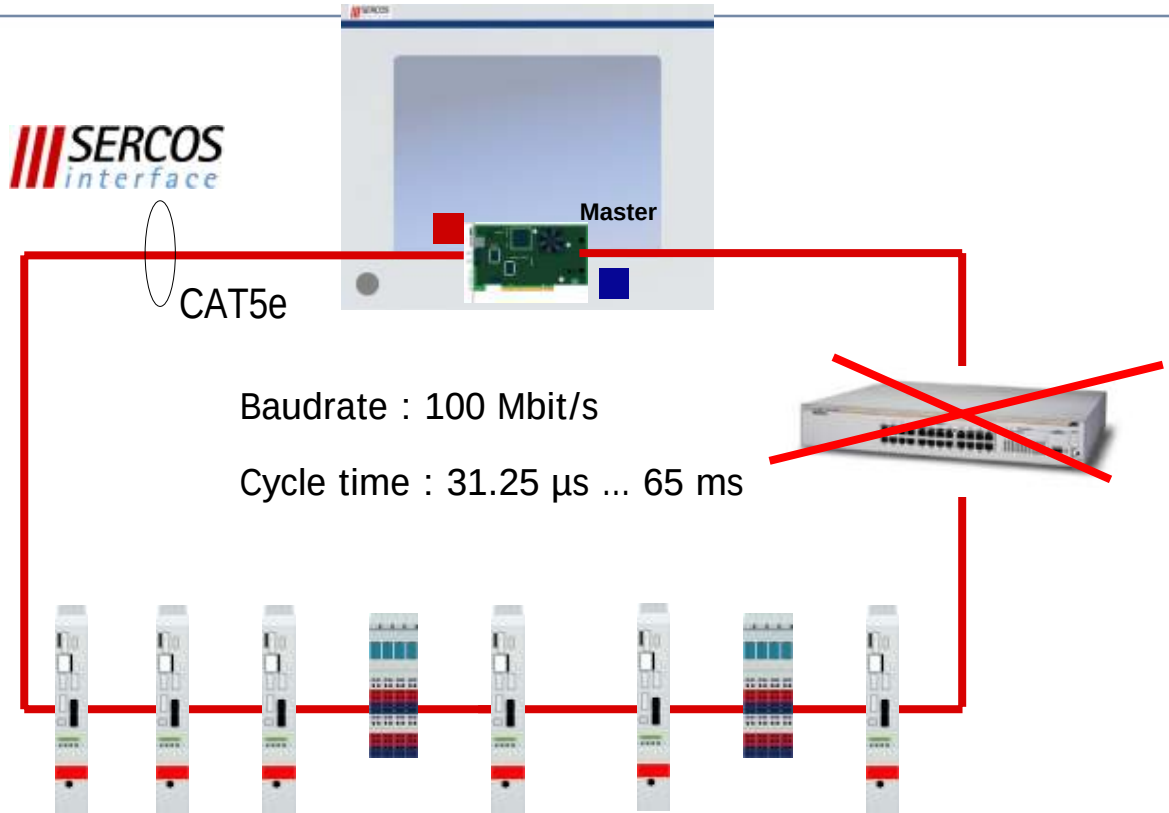


Combination of **Drives** and **I/O devices**



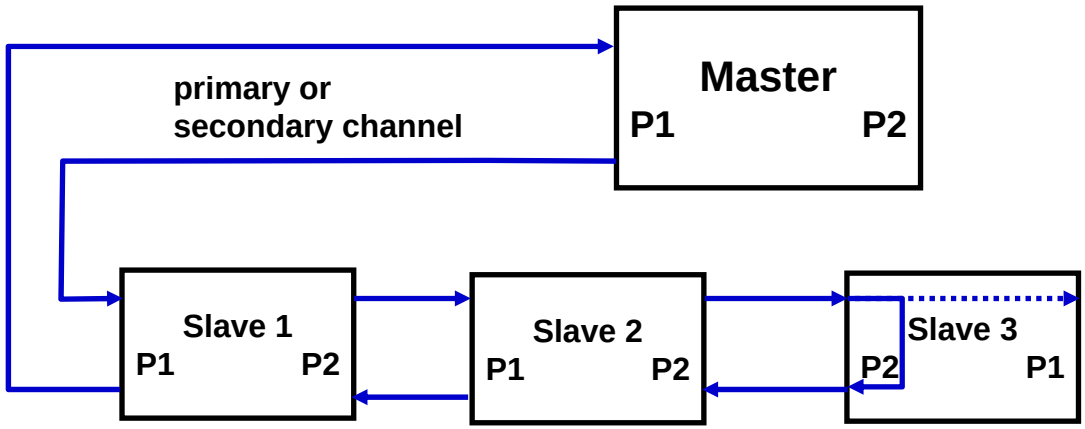
Communication interface for **I/O** only

SERCOS III Topology

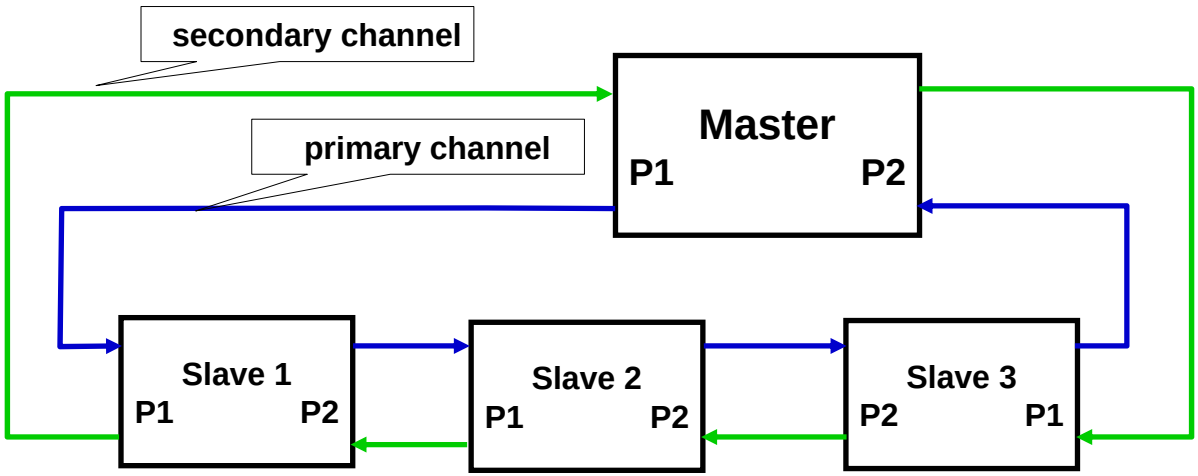


- Fast Ethernet (Full-Duplex)
- Standard Ethernet-Telegram
- Line-Topology, or
- Ring-Topology
- Cyclic real time traffic
- Topology at optimal costs: no switches/hubs
- I/O-devices

Topology
Line and Ring



Line

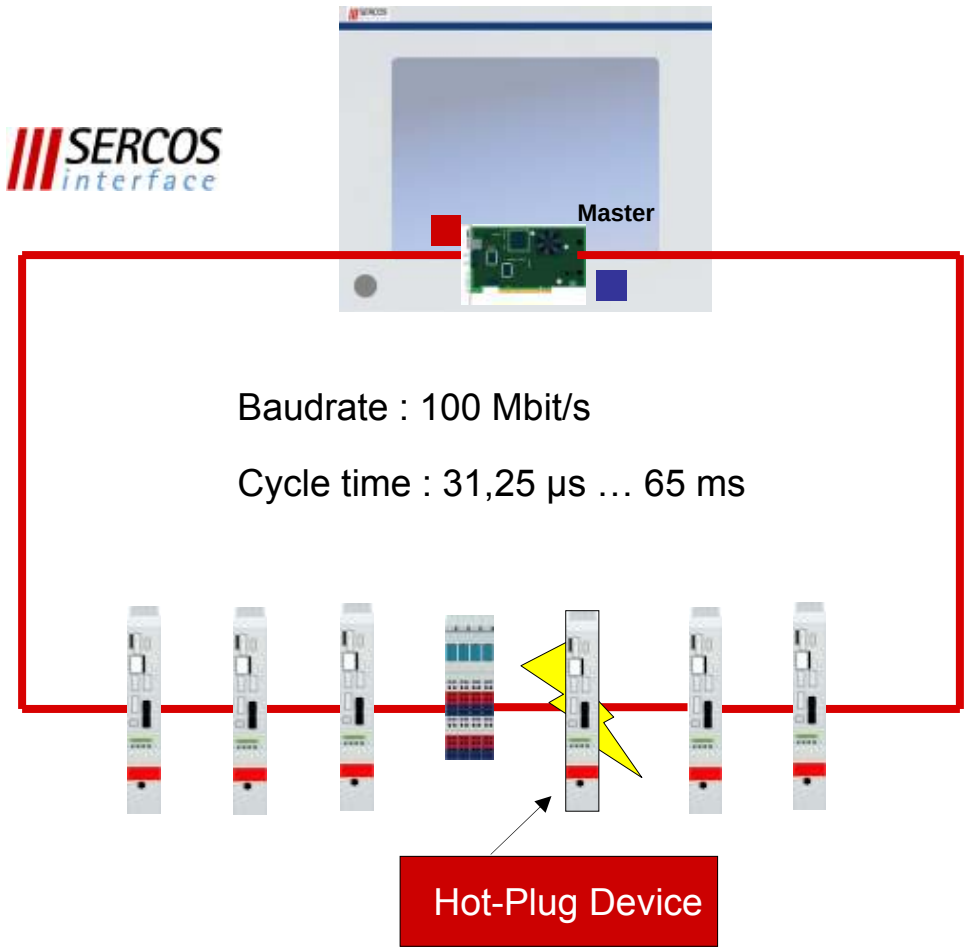


Ring

SERCOS III Topology
Wire Break/Hot Plug

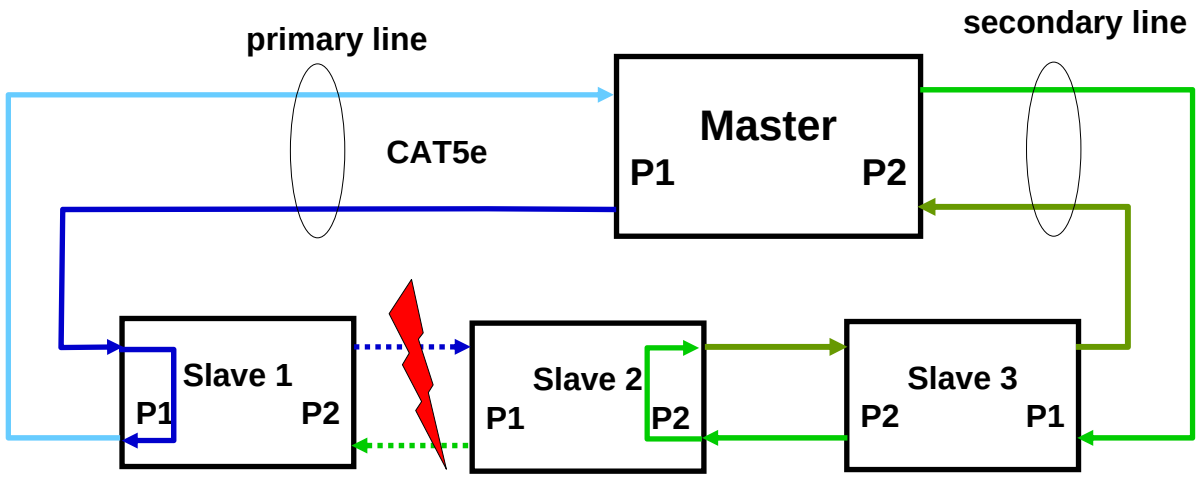
Redundant system in case of wire break

Hot-Plug ability of devices



Topology
Ring break

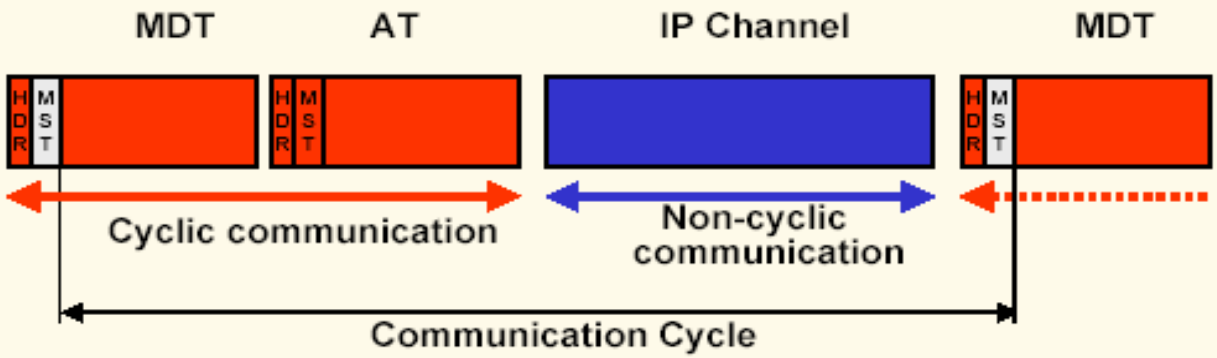
The ring is separated in primary line and secondary line.



Interruption may be either accidental or intentional

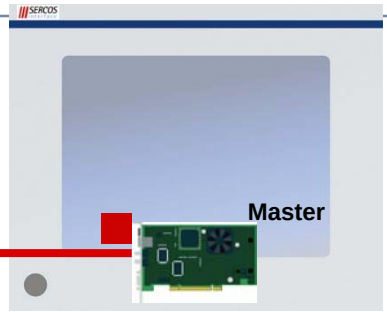
Synchronization
Communication cycle

Telegram structure



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

Technical Characteristics

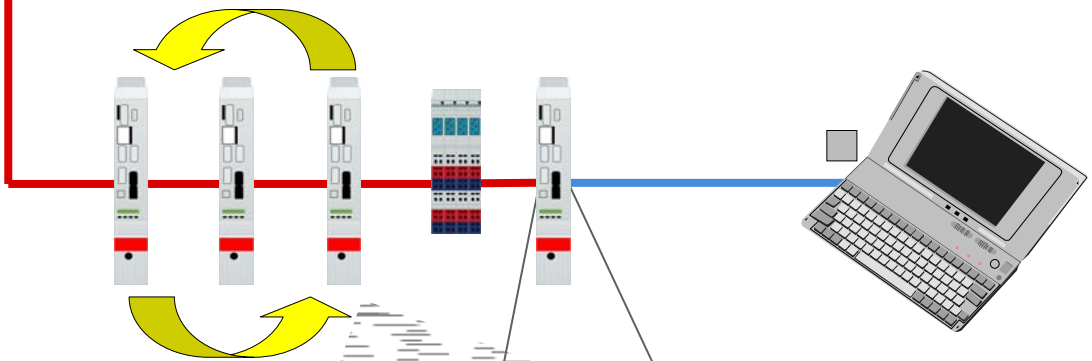


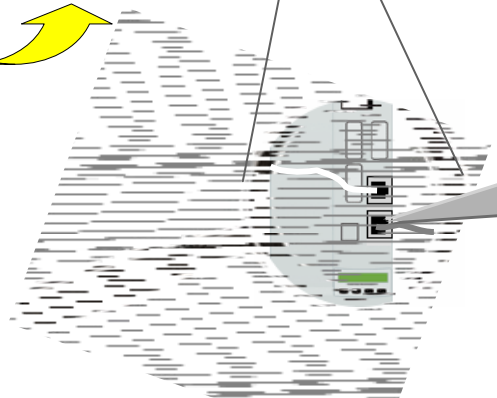
Cross communication between slaves

Commissioning w/ Standard Ethernet-protocol

Baudrate : 100 Mbit/s

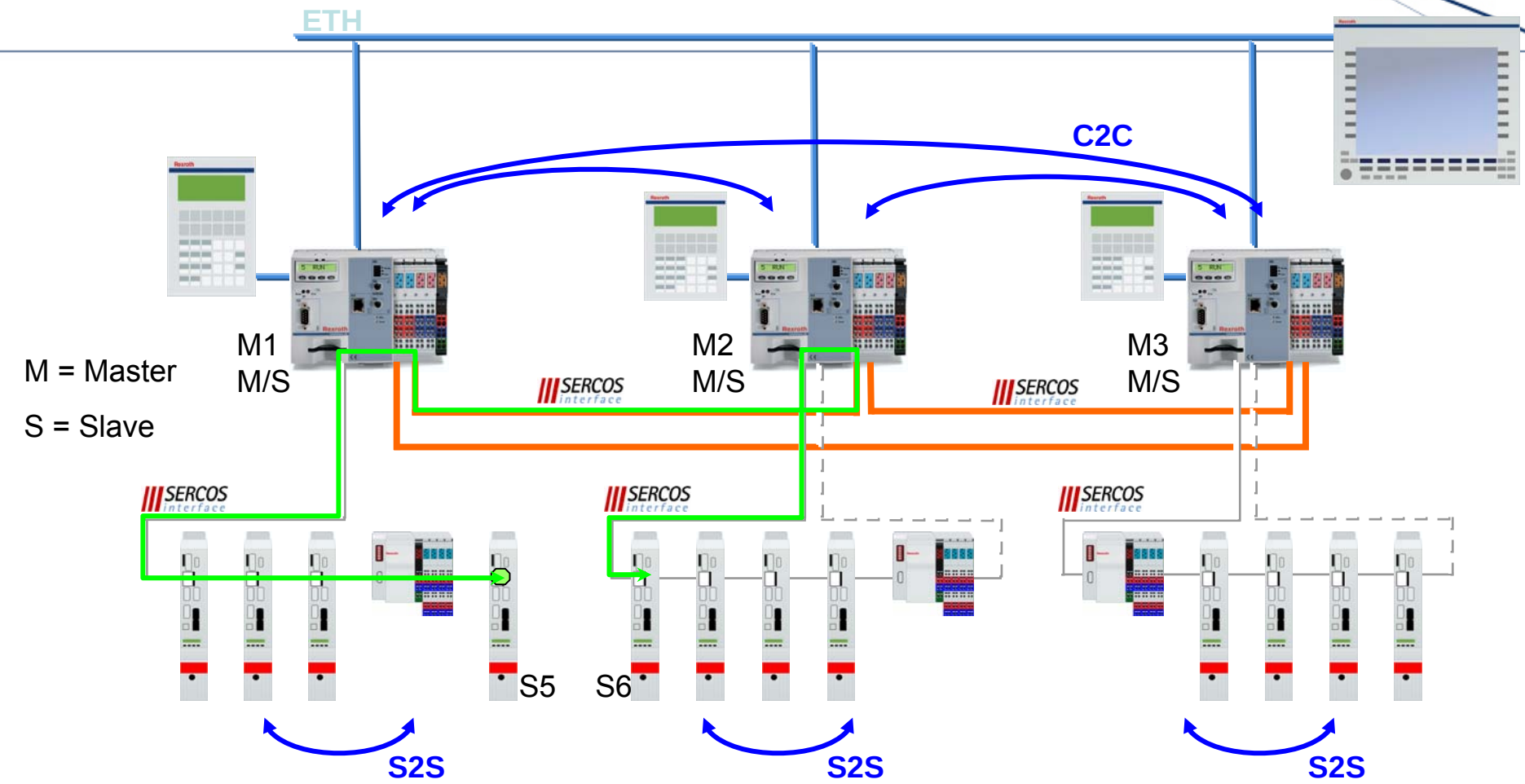
Cycletime : 31.25 µs ... 65 ms





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

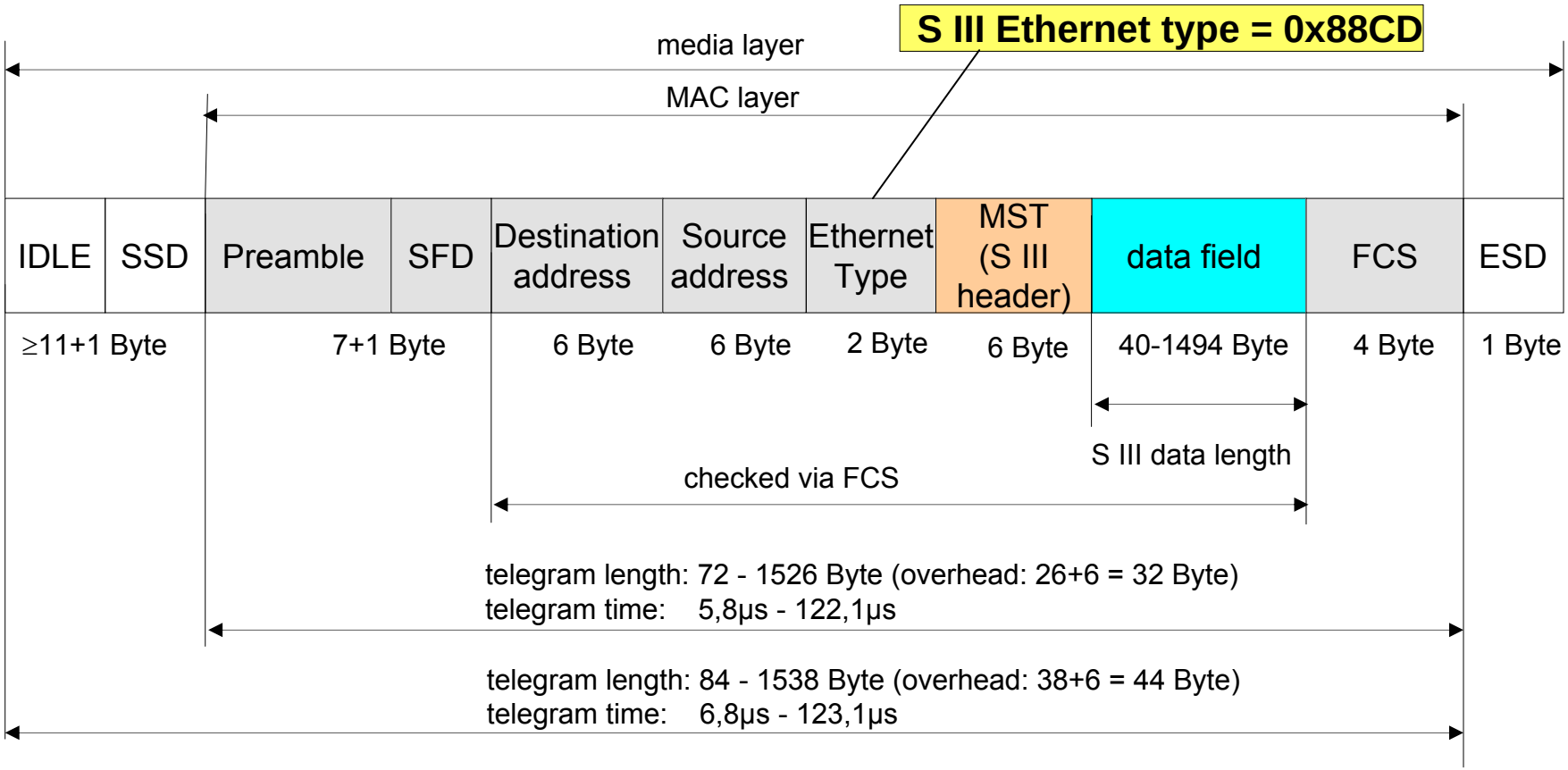
Cyclic data	Cycle time	No. of devices (1)	No. of devices (2)	No. of devices (3)	MDT / AT	
6 Byte	31,25 us	8		3	1/1	
12 Byte	62,5 us	16		10	1/1	
16 Byte	125 us	30		25	1/1	
12 Byte	250 us	66	33	60	1/1	10 devices / S II
32 Byte	250 us	34	17	31	1/1	
12 Byte	500 us	130	100	124	2/2	20 devices / S II
50 Byte	1 ms	100	85	98	4/4	
32 Byte	1 ms	140	120	137	4/4	
12 Byte	1 ms	254	220	249	4/4	

1) without IP channel

2) with IP channel: 1500 bytes = 125 µs

3) with IP channel: 250 bytes = 20µs

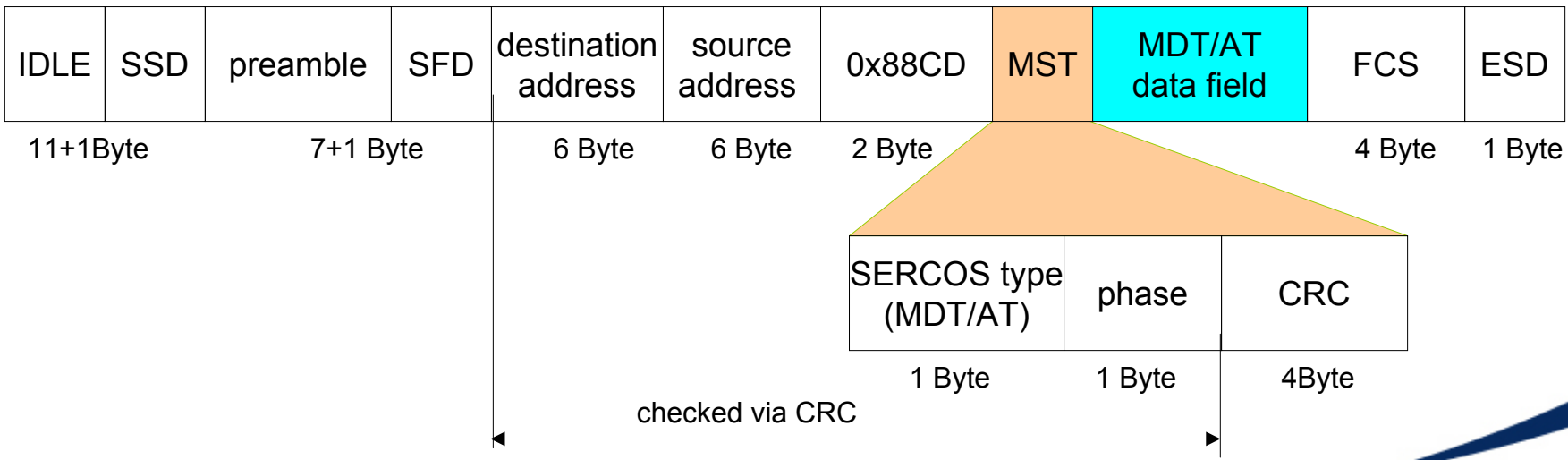
General telegram structure



- SERCOS III based on Standard Ethernet according IEEE 802.3

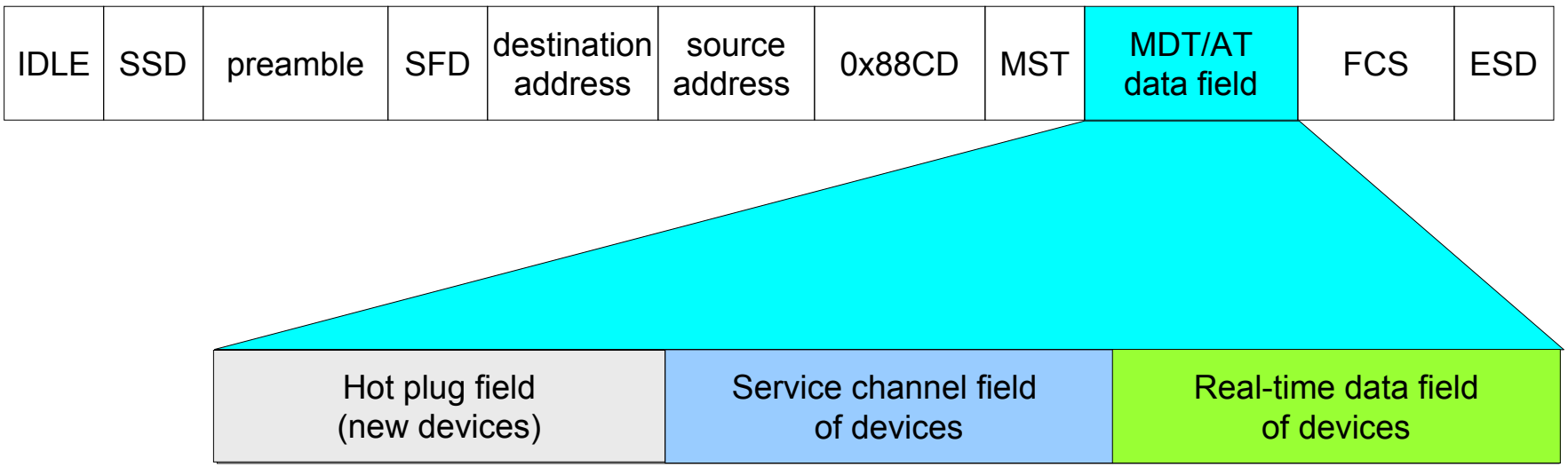
S III Header (MST)

- 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 take 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



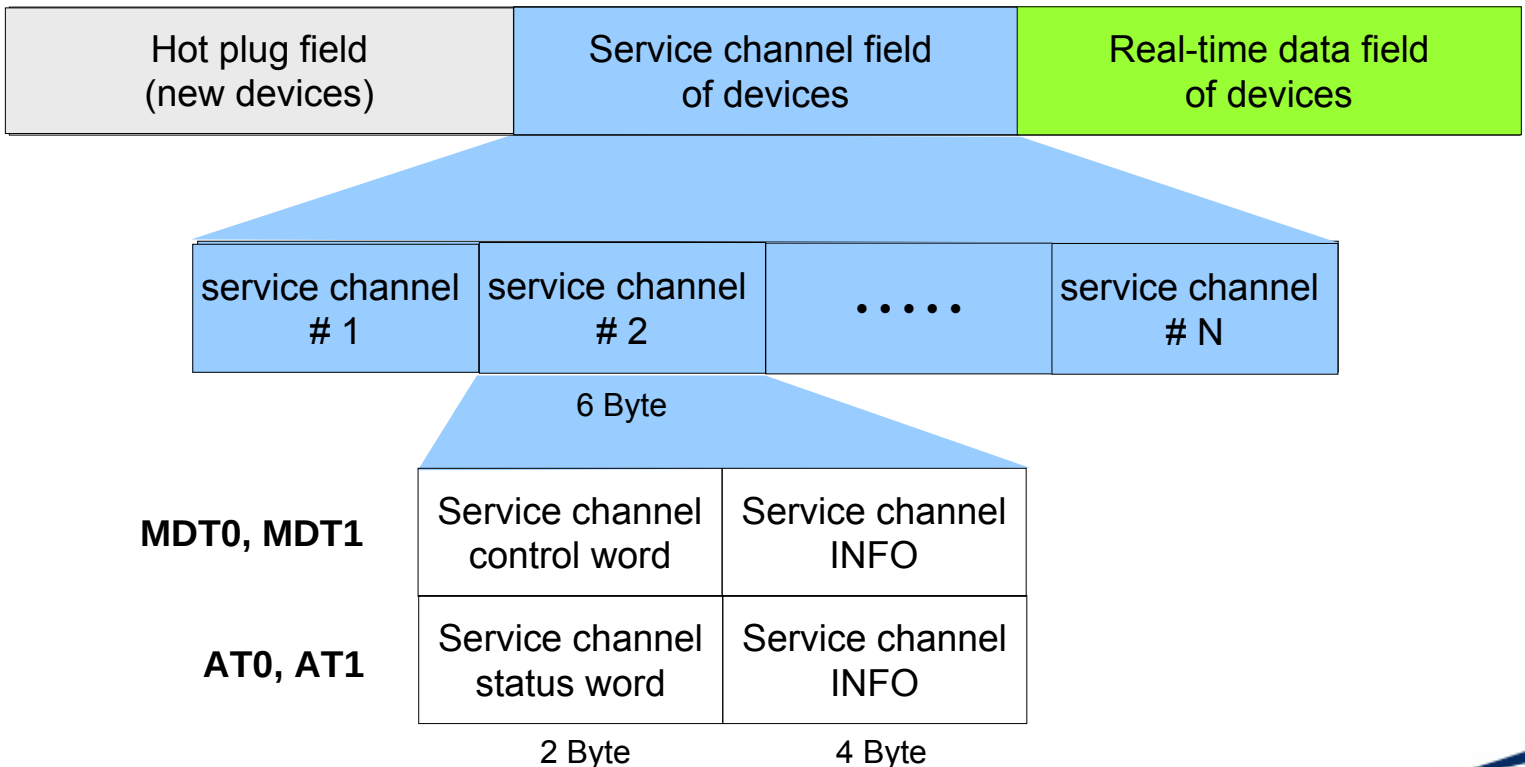
MDT and AT data fields

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



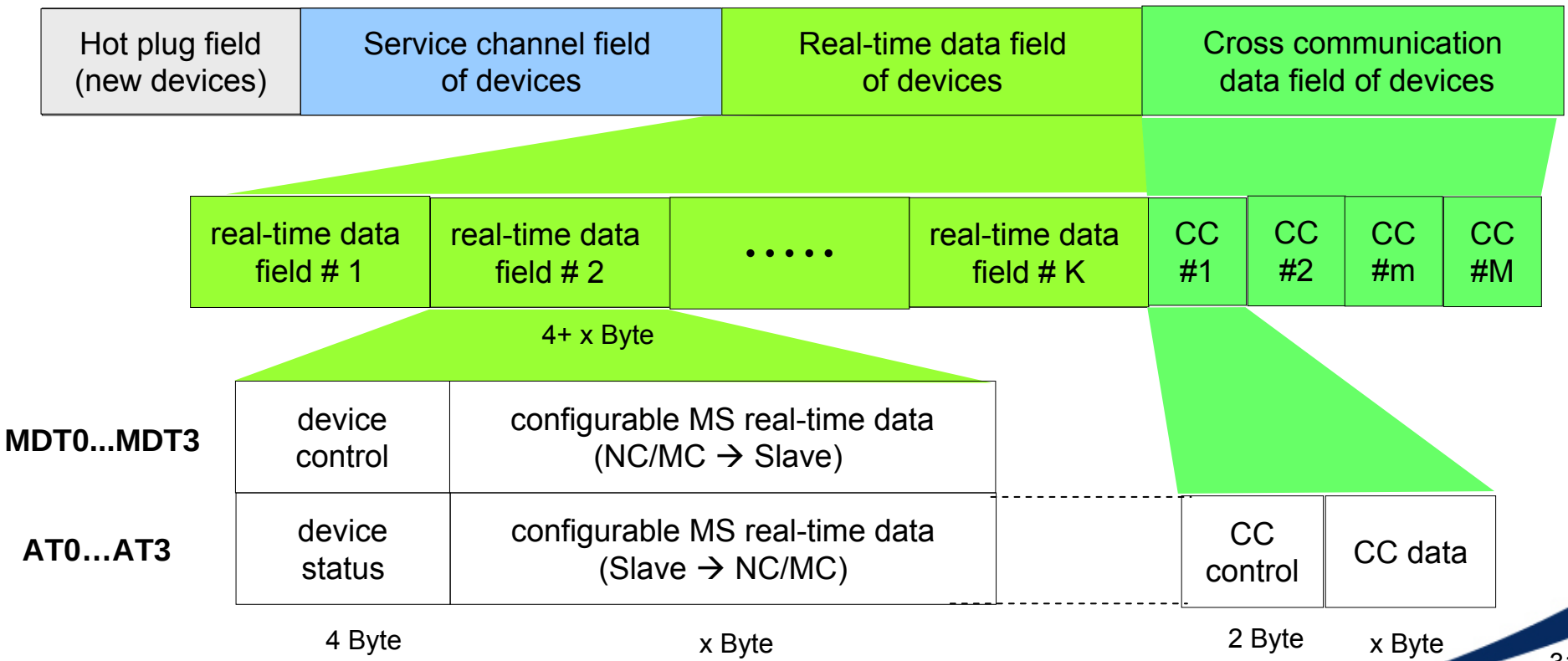
Service channel structure

- 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

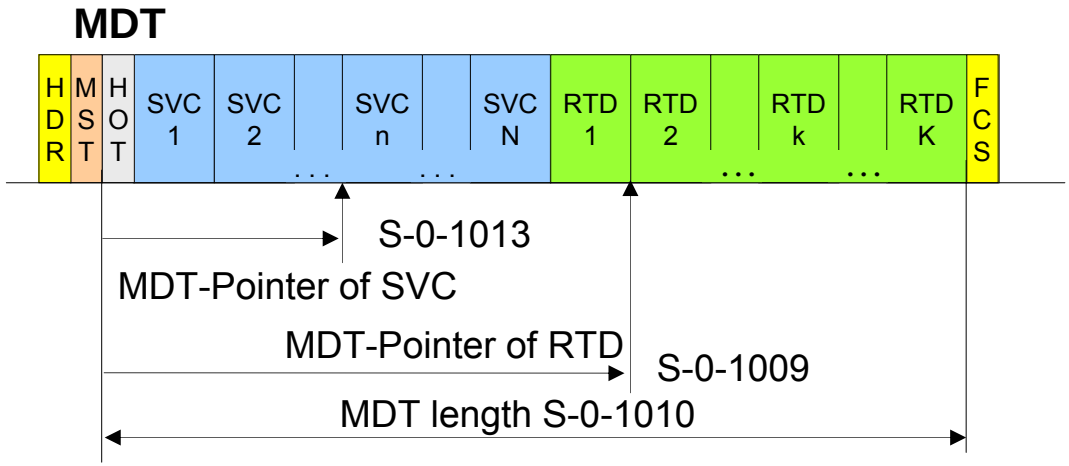


Real-time data structure

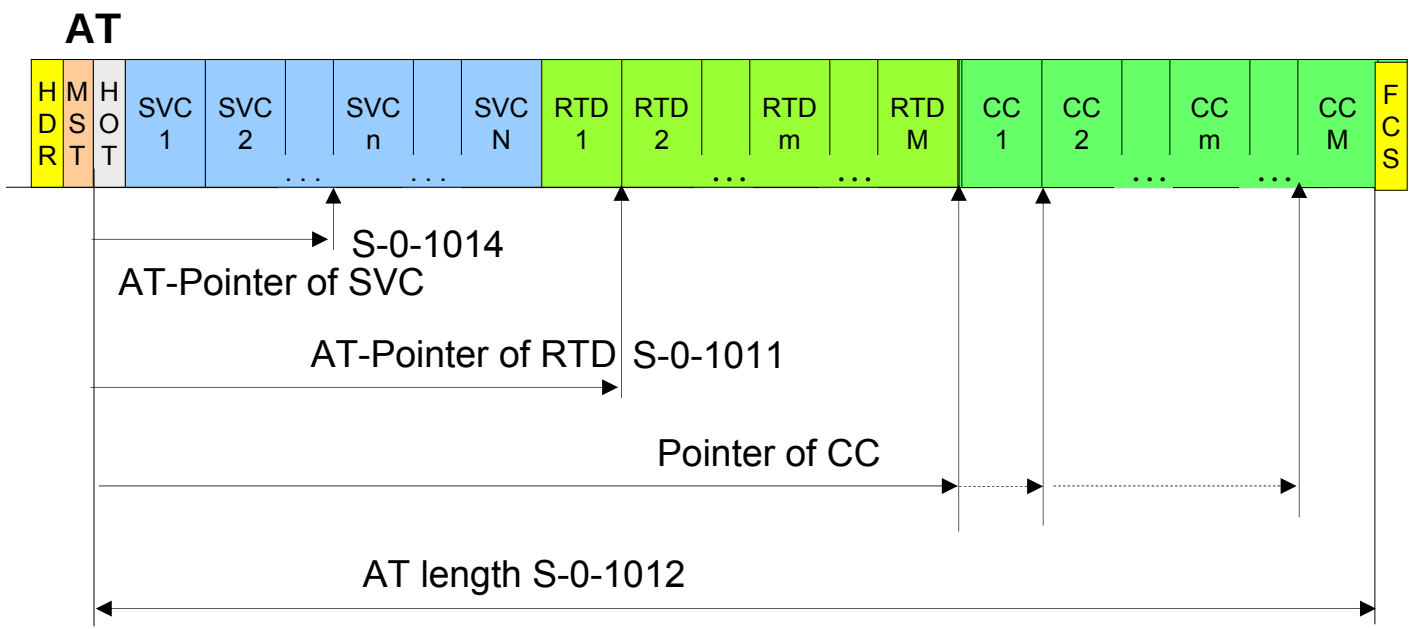
- Real-time data field contains:
  - Device control or Device status
  - configured real-time data for MS
  - Cross communication data in AT only
- Length of real-time data field : 4 byte + configured length
- Length of CC data field : 2 byte + configured length



Configuration overview of MDT and AT



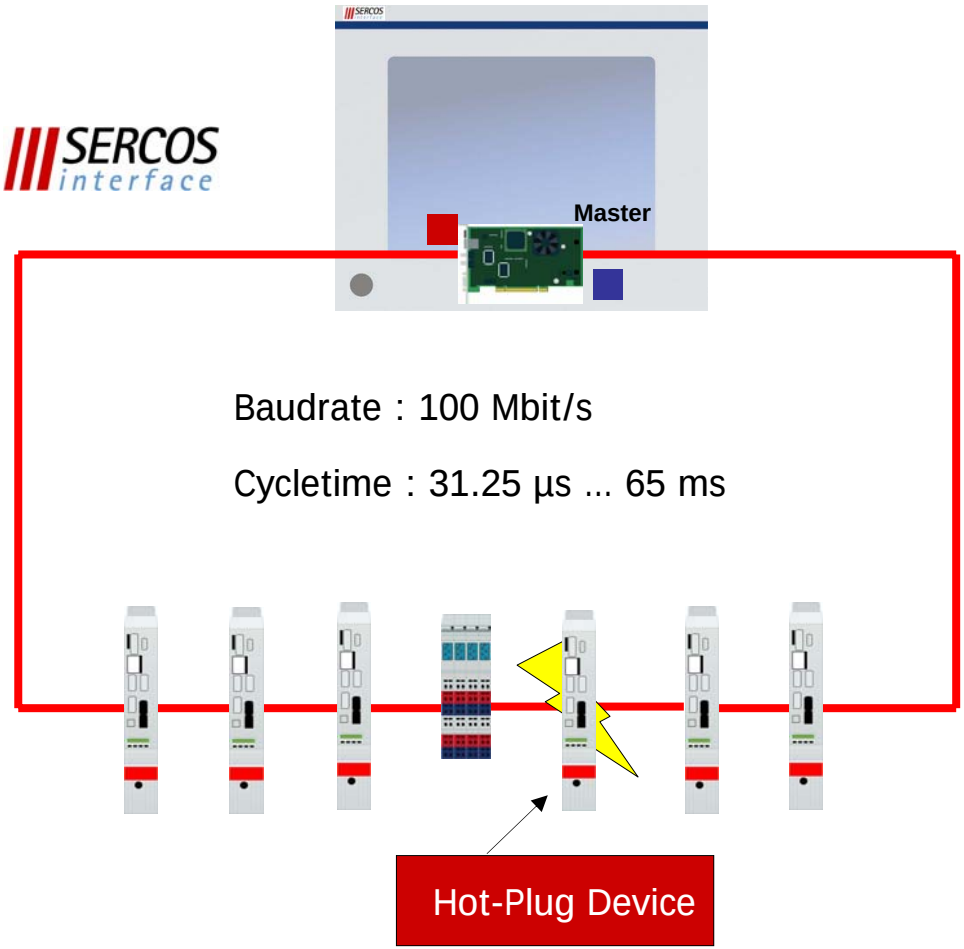
HDR = Ethernet header
MST = S III header, SYNC
HOT = Hotplug field
SVC = Service channel
RTD = Rel-time data
CC = Cross communication
FCS = Frame check sequence



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



Redundancy, e.g. with cable break

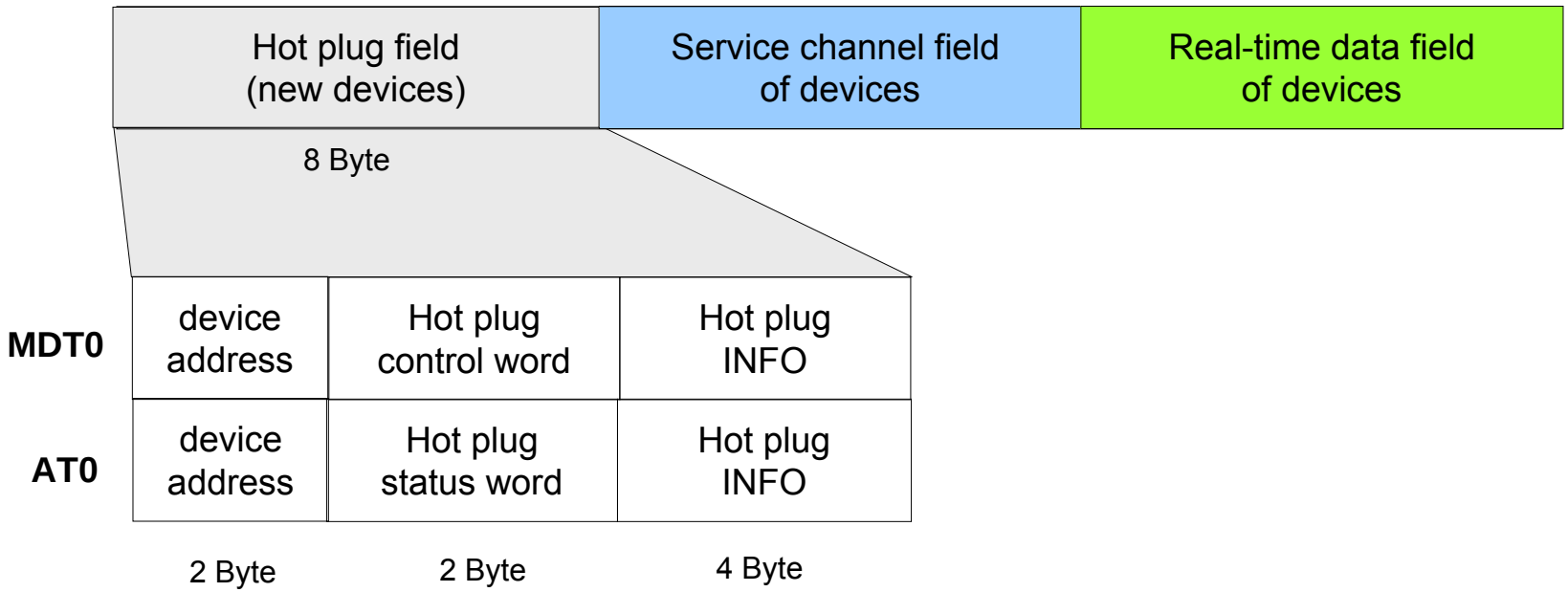
Hot Plugging of devices

Hot plugging

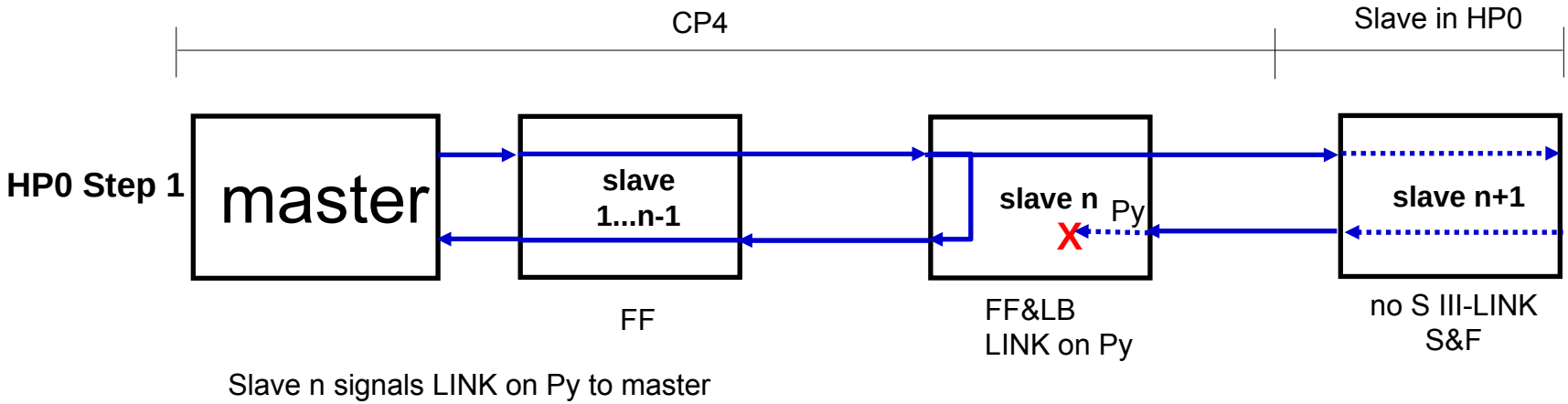
- Hot plugging is possible with ring only
- A ring break has to initiated first
- Master must be prepared for the HP slave
- Hot plug consists of 3 phases (HP0 to HP2)
- HP0: HP field is used
  - master transmits identical parameter for all HP slaves
  - master checks slave address of first HP slave
  - 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

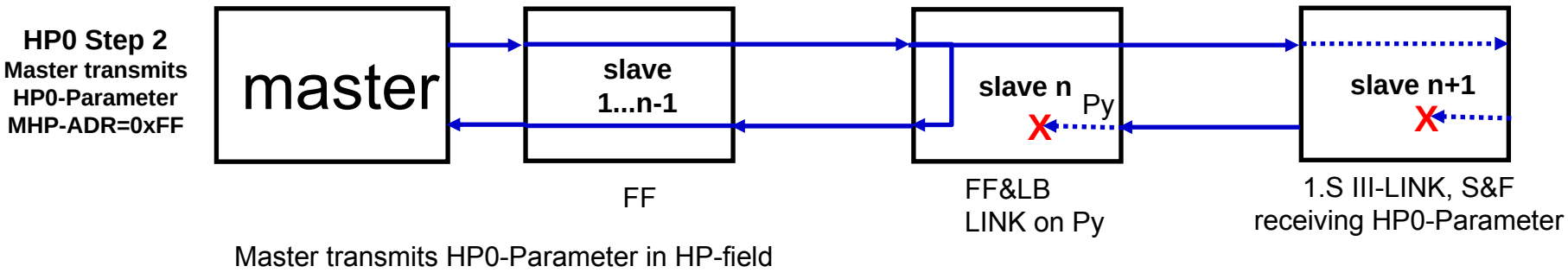
Hot plug structure

- **Hot plug field contains:**
  - **Device address**
  - **HP control word or HP status word**
  - **HP INFO**
- **Length of Hot plug: 8 byte**

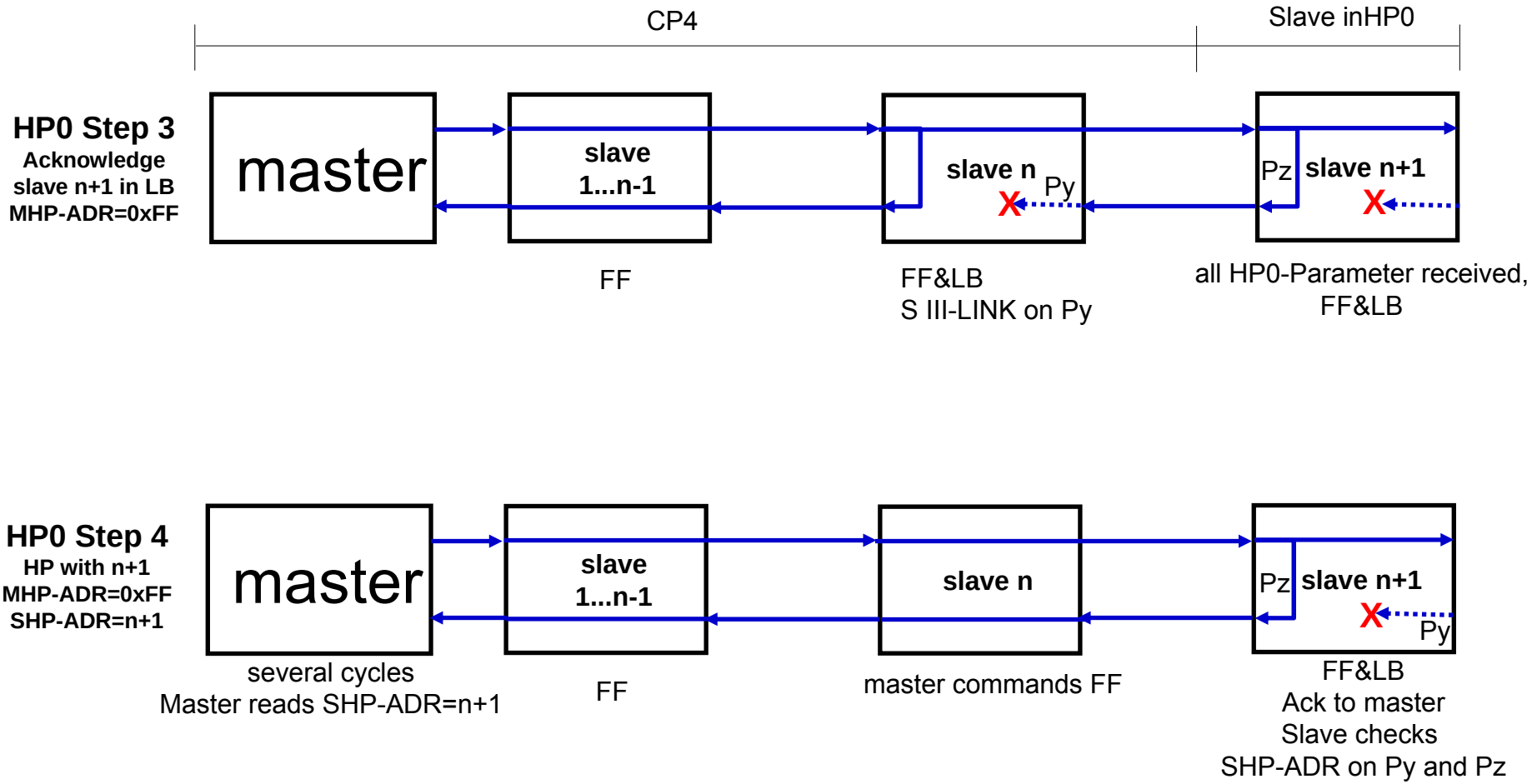


Hot plugging one device with line (1)

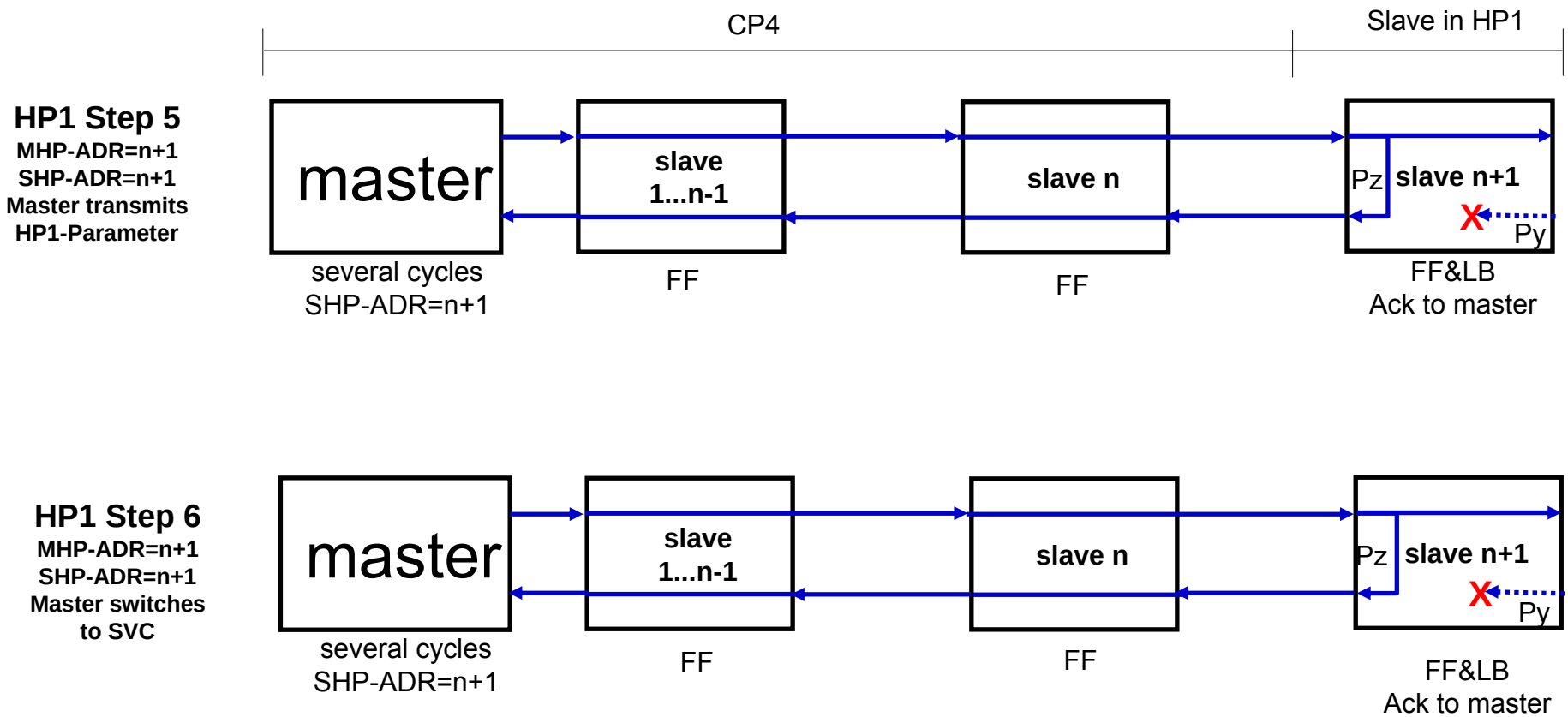




Hot plugging one device with line (2)

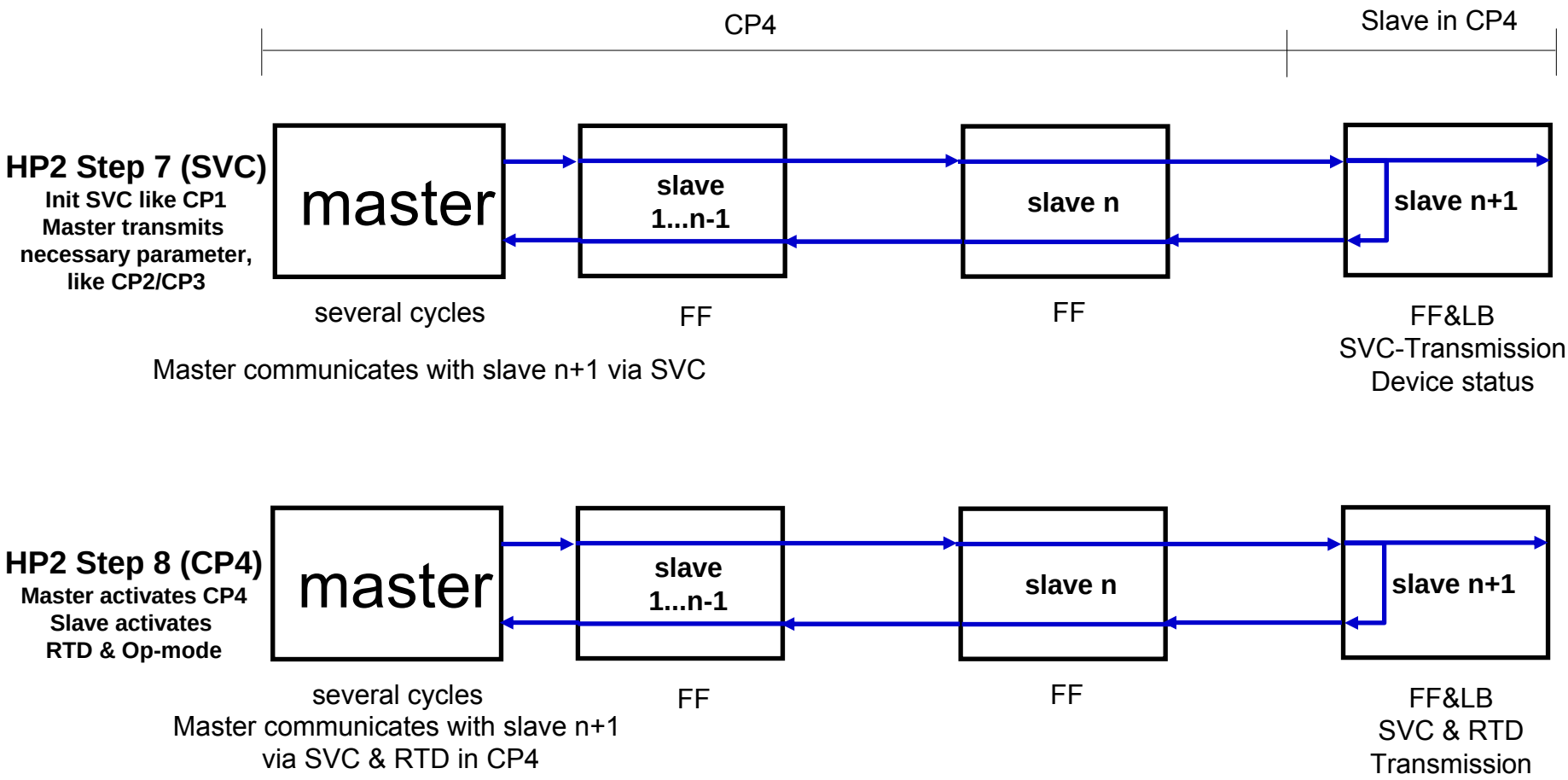


Hot plugging one device with line (3)

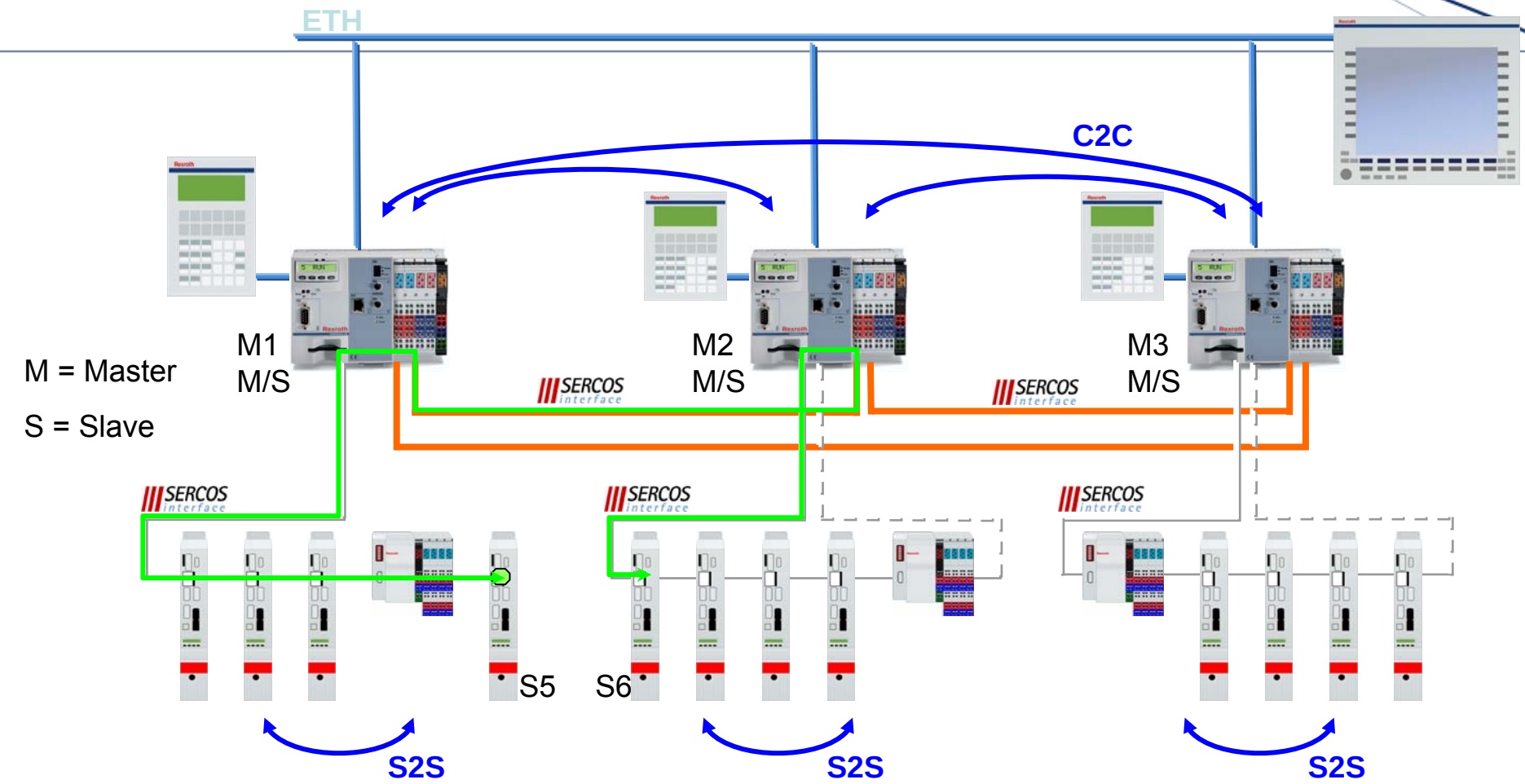


Master switches from HP to SVC
End of HP1-Transmission with slave n+1

Hot plugging one device with line (4)



Direct Cross Communication (C2C, S2S)

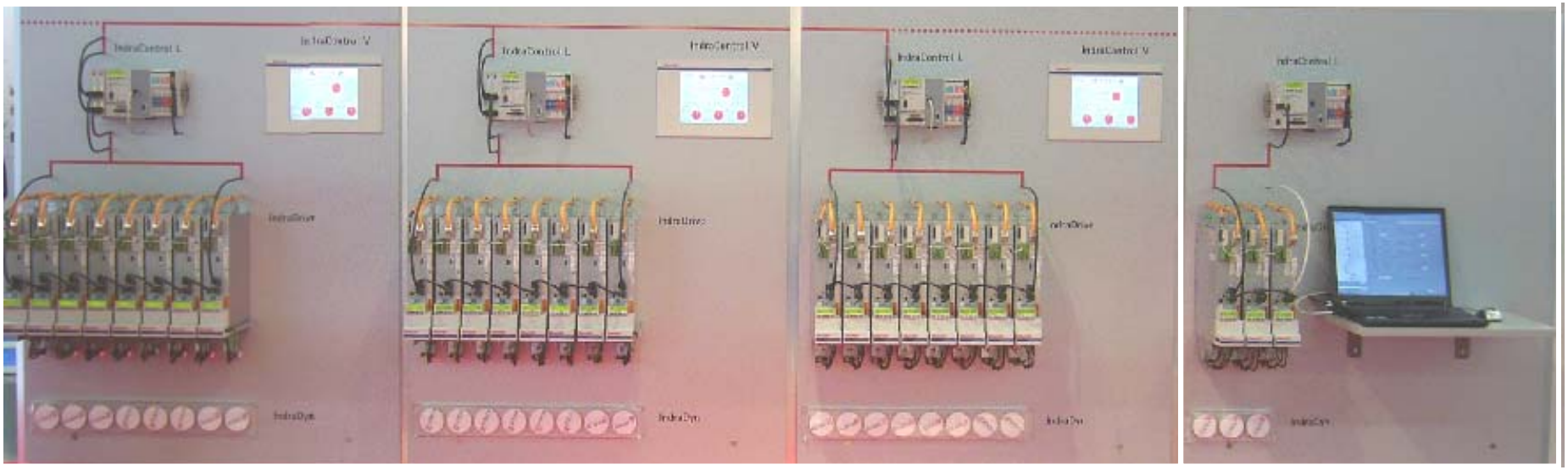


Direct Cross Communication between Master devices (C2C = Controller-to-Controller)

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

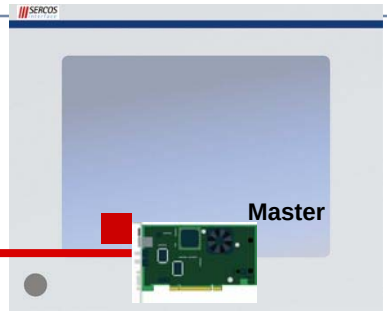
Technical Characteristics
Direct Cross Communication (C2C, S2S) - live



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

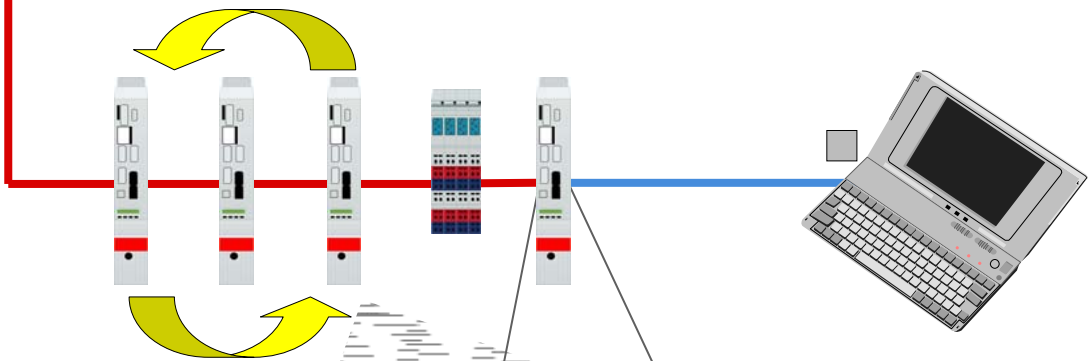


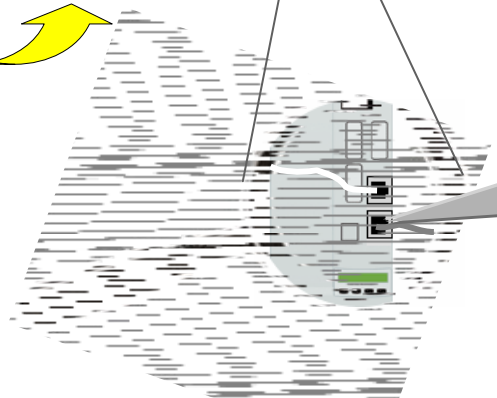
Cross communication between slaves

Commissioning w/ Standard Ethernet-protocol

Baudrate : 100 Mbit/s

Cycletime : 31.25 µs ... 65 ms

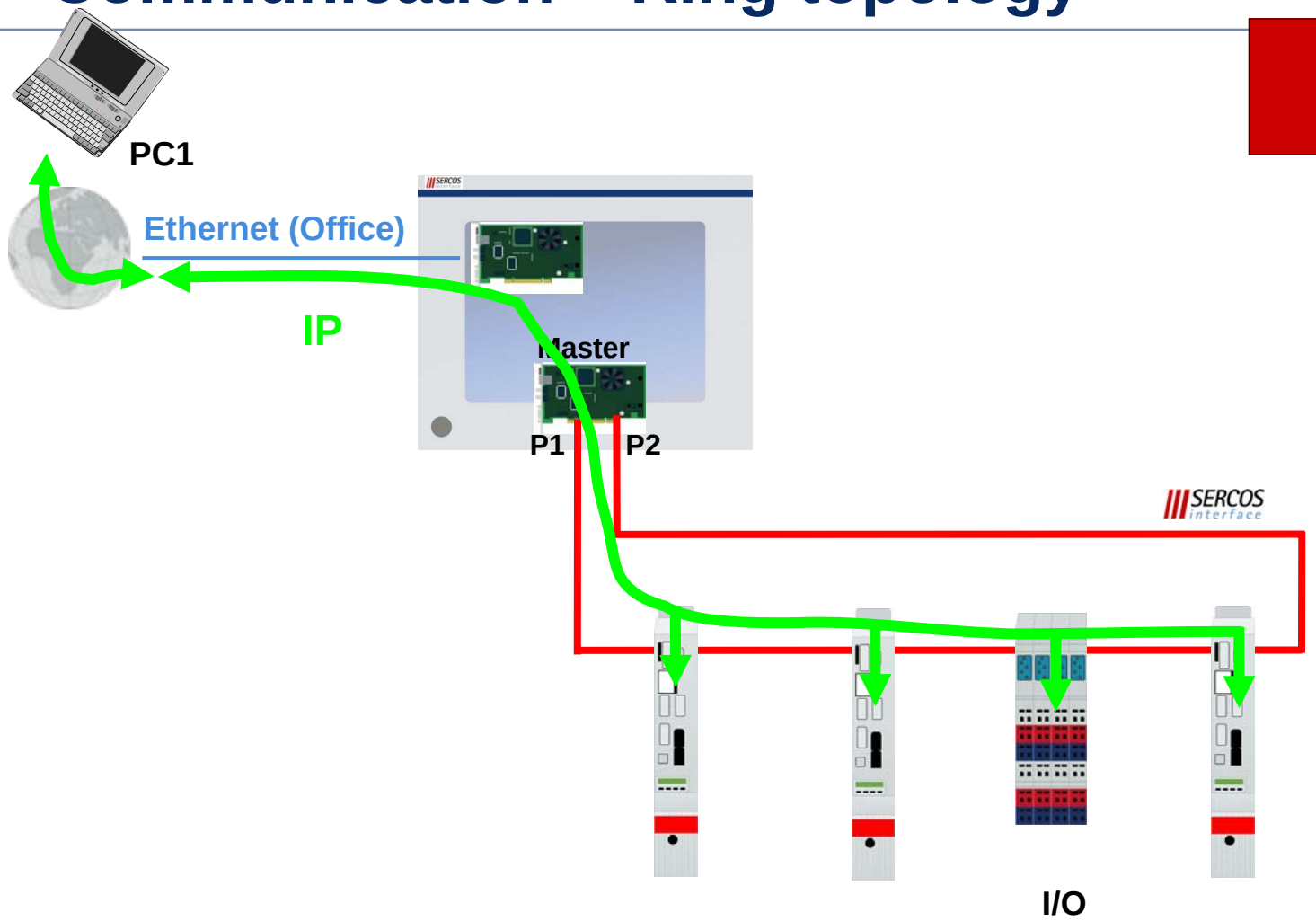




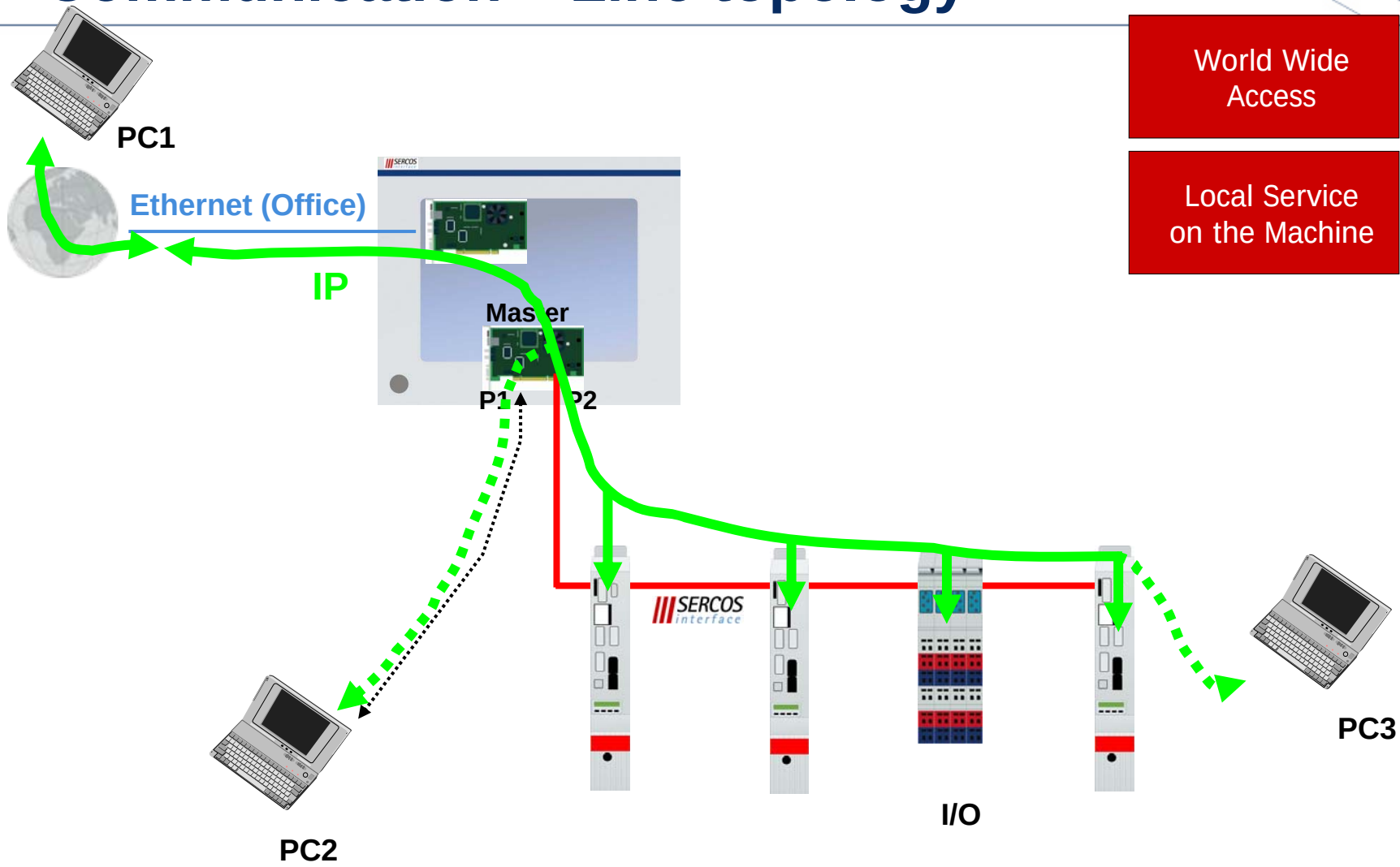
Direct connection of IP device to SERCOS III slave

Technical Characteristics
IP Communication – Ring topology

World Wide Access



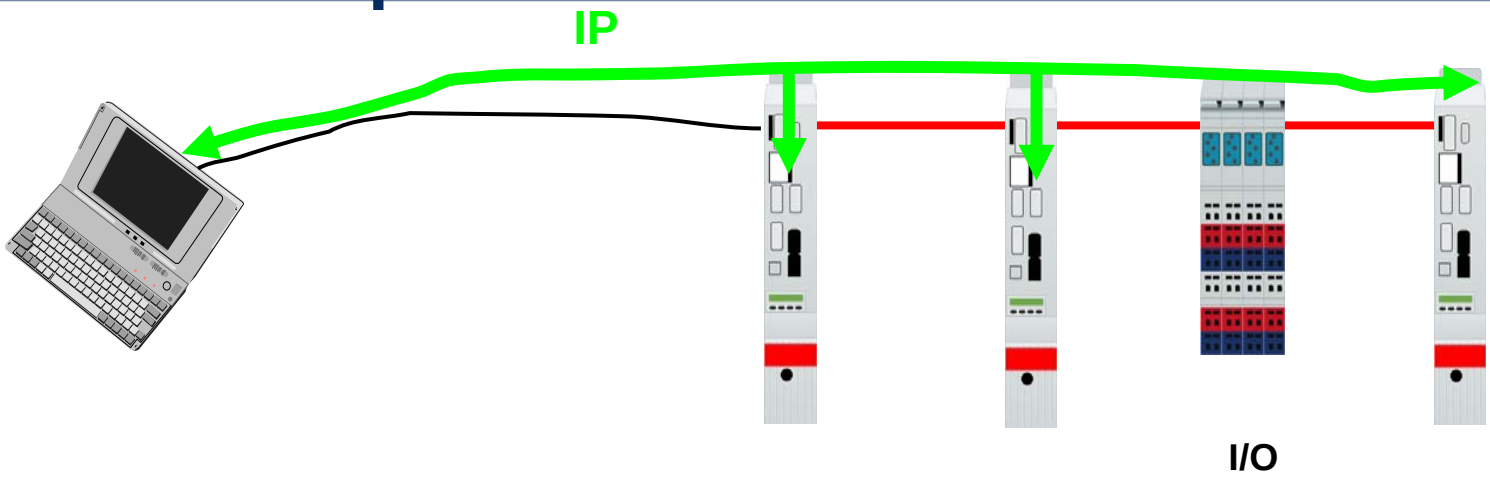
Technical Characteristics
IP Communication – Line topology



World Wide Access

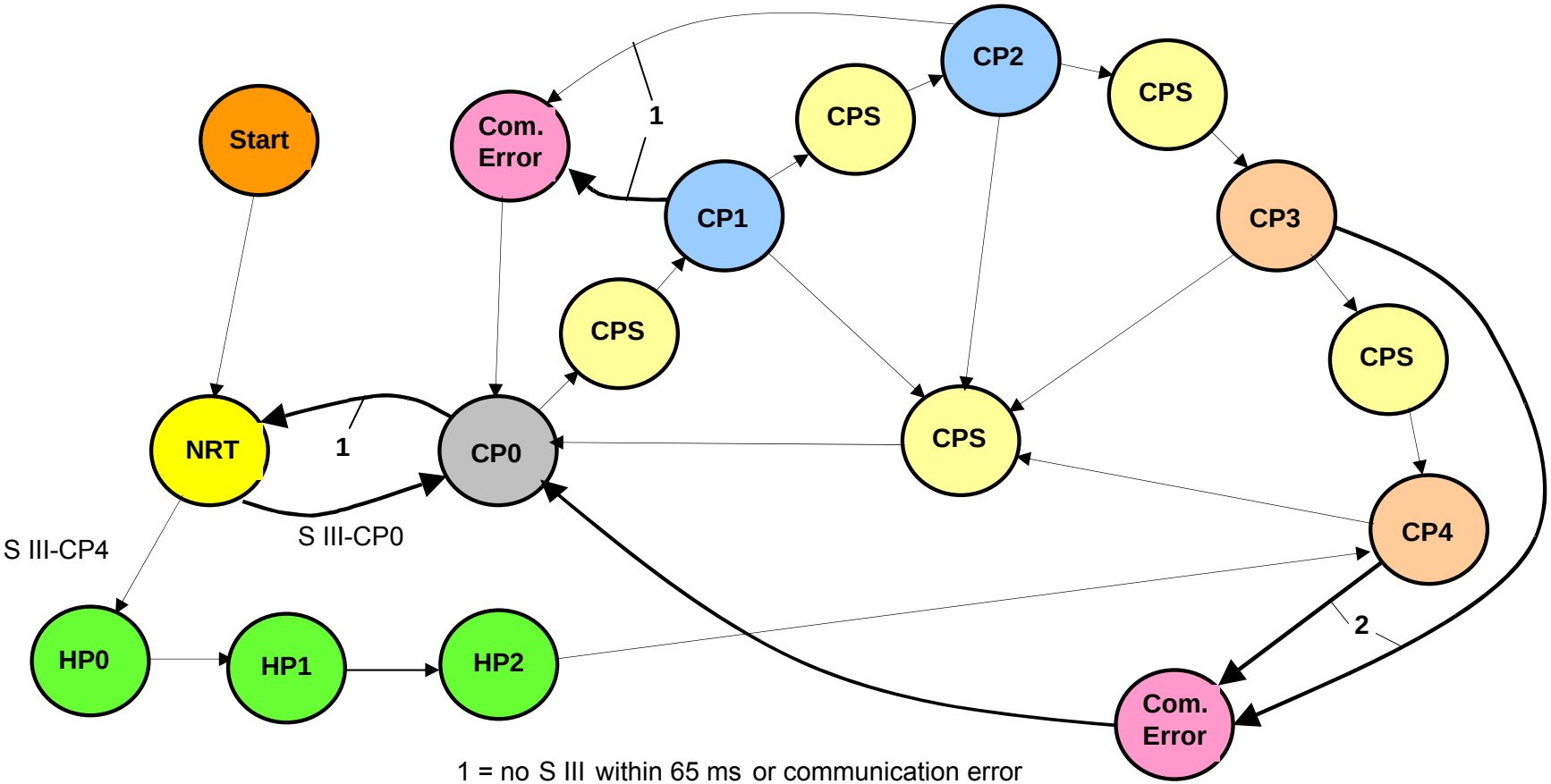
Local Service on the Machine

Technical Characteristics
Download/Upload mechanism via IP



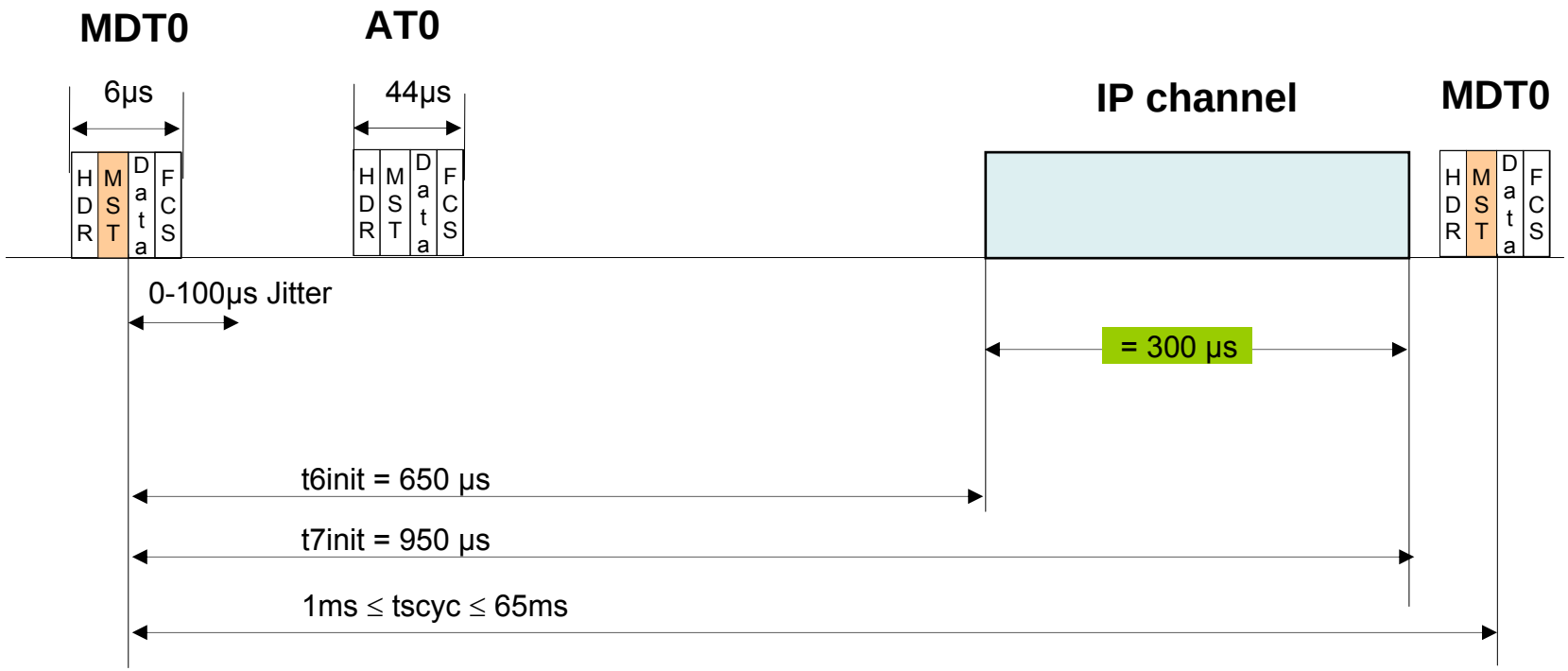
- Standard PC is easily connected to the available SERCOS III Port
- Standard PC sends Standard Ethernet telegrams, no SERCOS III telegrams
- Download/Upload over IP-channel in non-real-time mode in line topology
- Standard TCP/IP communication possible without an active SERCOS III communication

Initialization
Communication phases (CP0 to CP4)



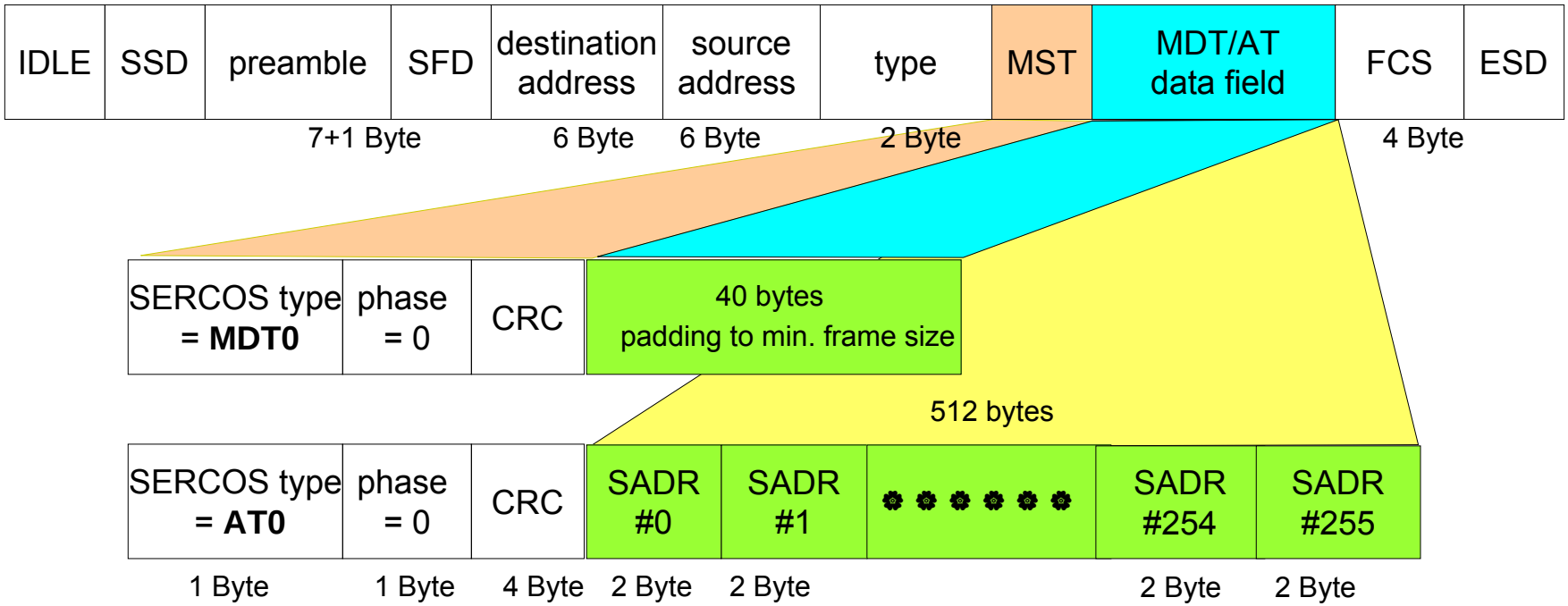
1 = no S III within 65 ms or communication error
2 = max. telegram losses exceeded
CP = Communication phase
CPS = Communication phase switching
NRT = non real-time mode
HP = Hot plugging

CP0
Communication timing

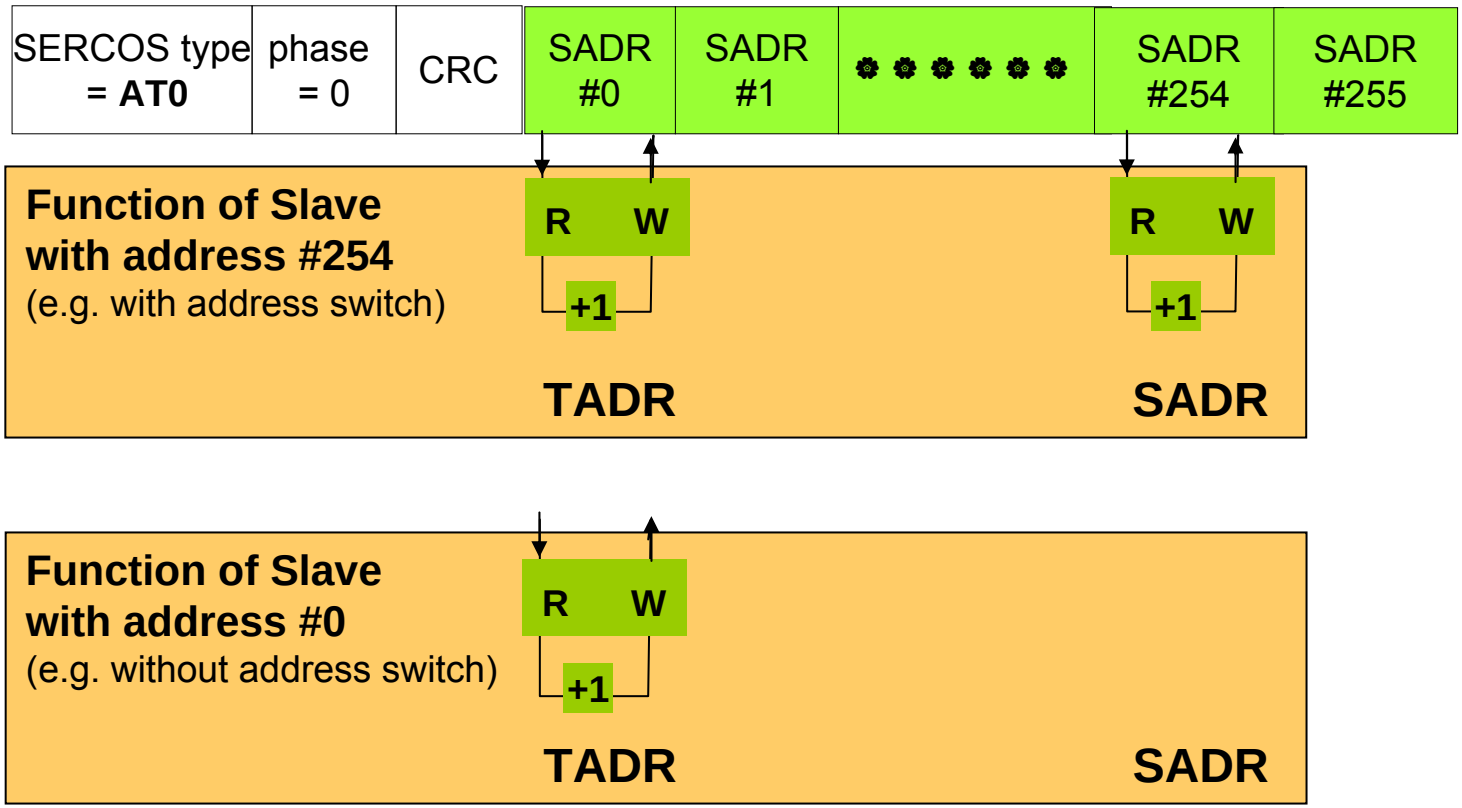


t6init = begin of IP channel
t7init = end of IP channel
tscyc = communication cycle time
Jitter of +/- 50µs for low performance applications

CP0
MDT / AT structure



CP0
Address recognition, Slave function



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

AT0 data field	SADR #0	SADR #1	❁ ❁ ❁ ❁ ❁ ❁	SADR #10	SADR #11	❁ ❁ ❁ ❁ ❁ ❁	SADR #254	SADR #255
contents	0x0004	0x0001		0x0001	0x0001		0x0001	0x0000

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

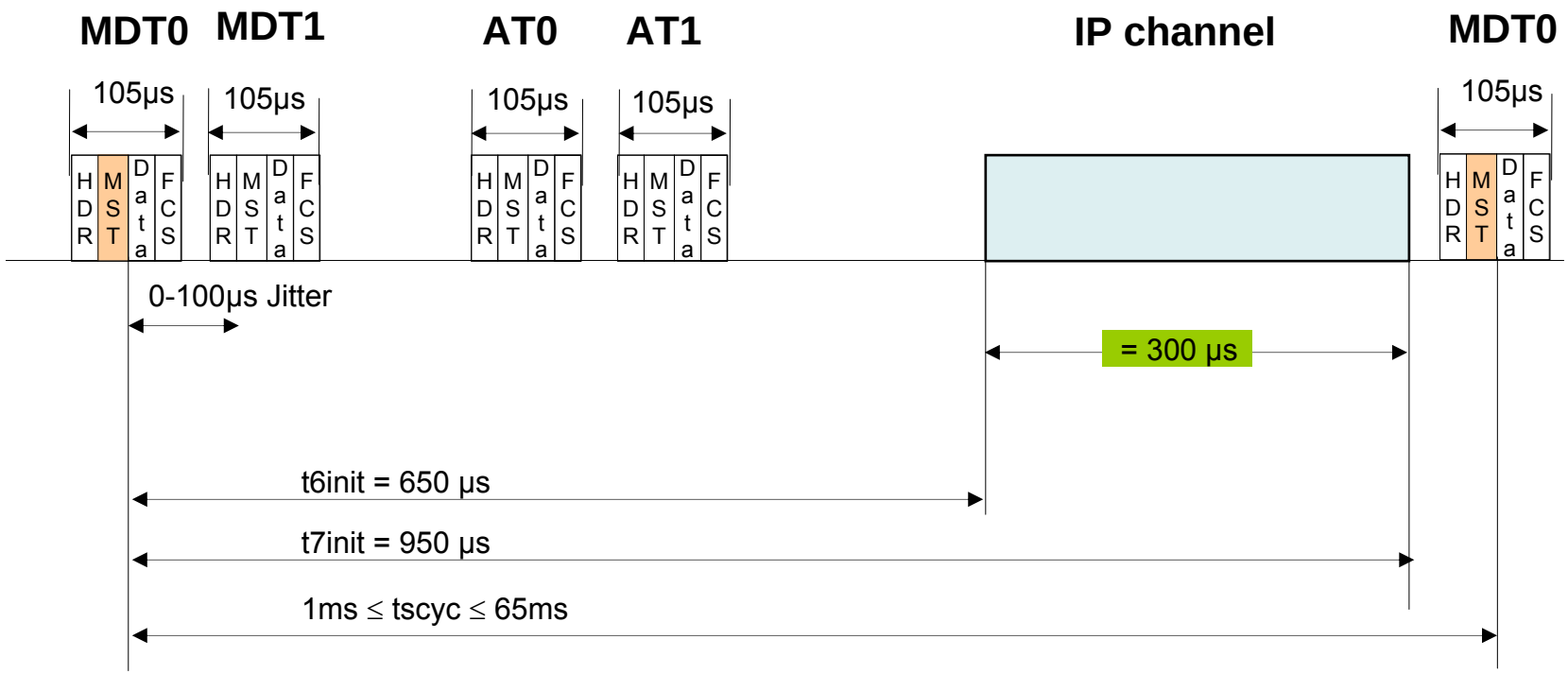
AT0 data field	SADR #0	SADR #1	❁ ❁ ❁ ❁ ❁ ❁	SADR #10	SADR #11	❁ ❁ ❁ ❁ ❁ ❁	SADR #254	SADR #255
contents	0x0004	0x0003		0x0000	0x0000		0x0001	0x0000

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

Automatic address allocation

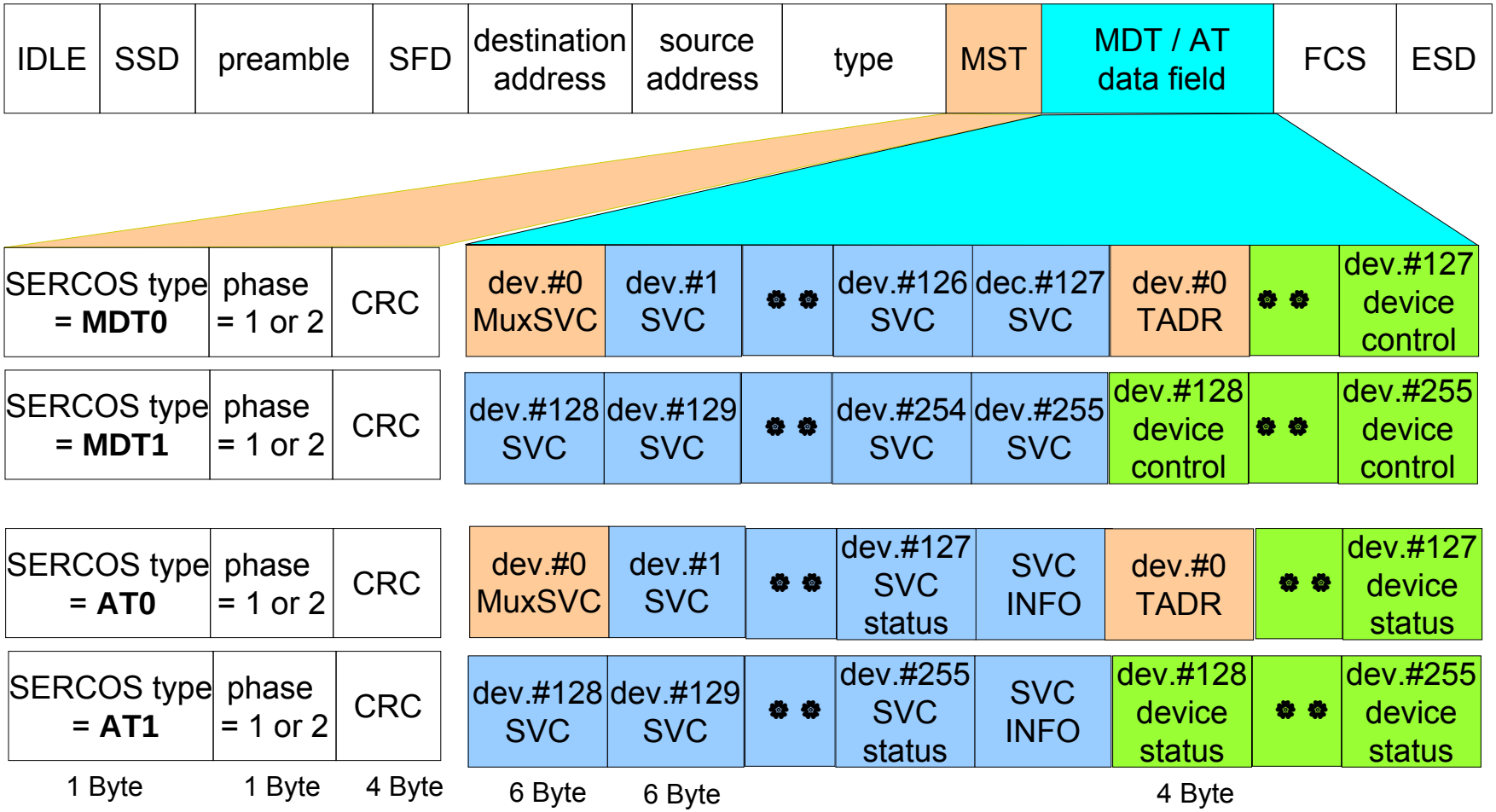
- In CP0
  - Slave without SADR (=0) determines the TADR only
  - Slave with SADR (≠0) determines additionally the TADR
- In CP2
  - Master reads IDN SADR and TADR of each slave
  - TADR defines the physical order in the topology
  - MUXSVC only used for slaves with TADR
  - Master can assign a SADR to the slave

CP1 / CP2
Communication timing

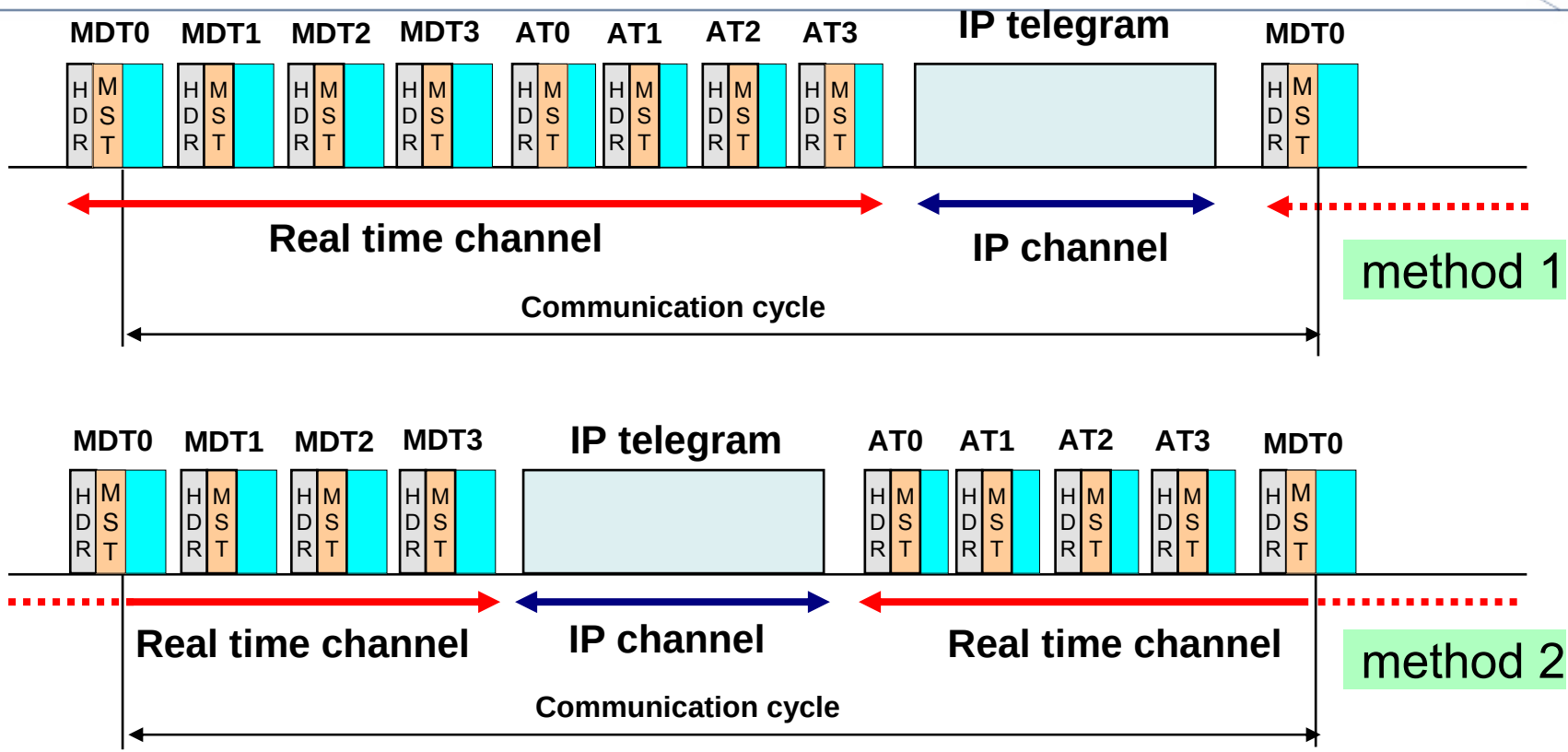


t6init = begin of IP channel
t7init = end of IP channel
tscyc = communication cycle time
Jitter of +/- 50µs for low performance applications

CP1 / CP2
MDT / AT structure

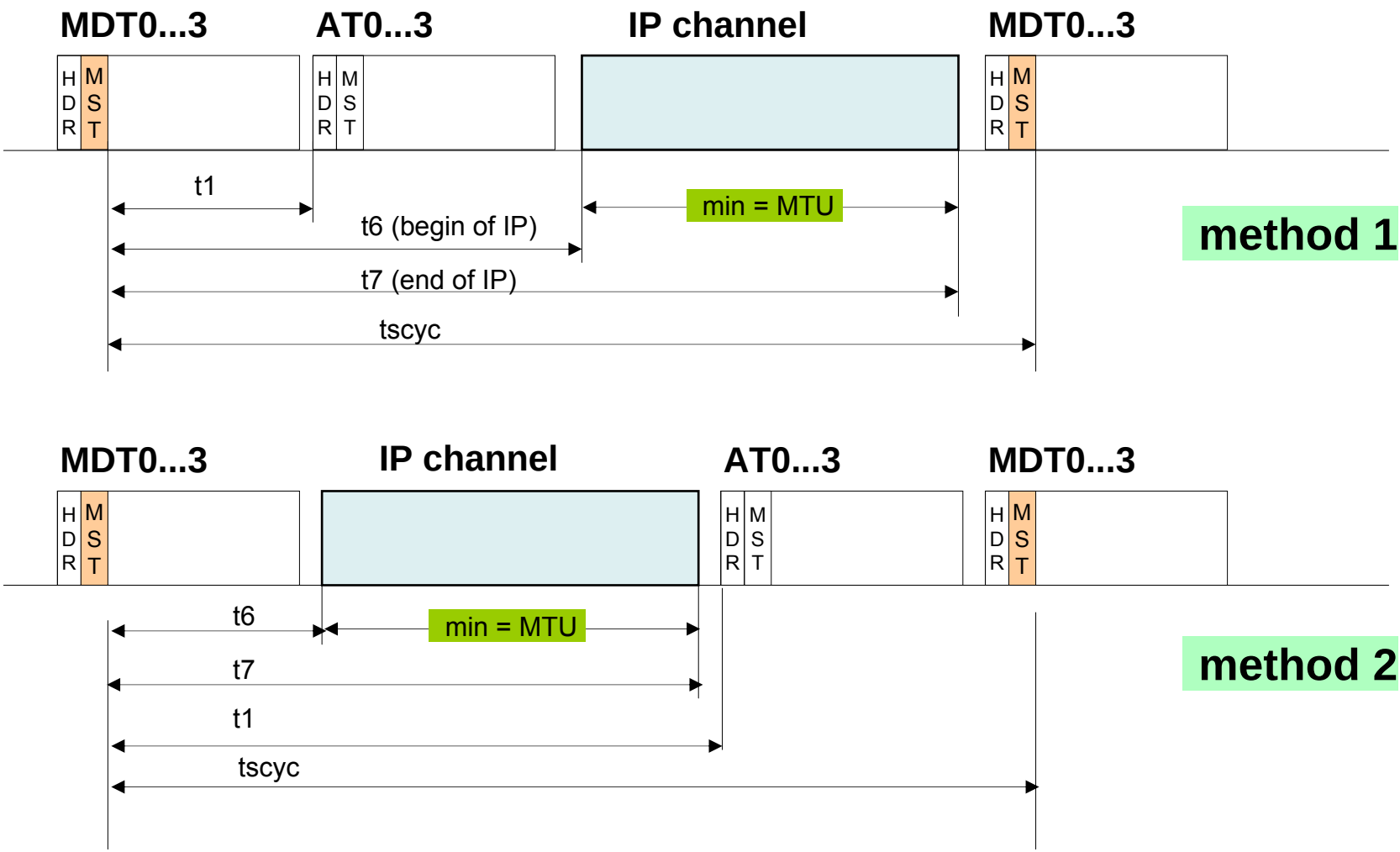


Communication Sequence in CP3/CP4



- 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

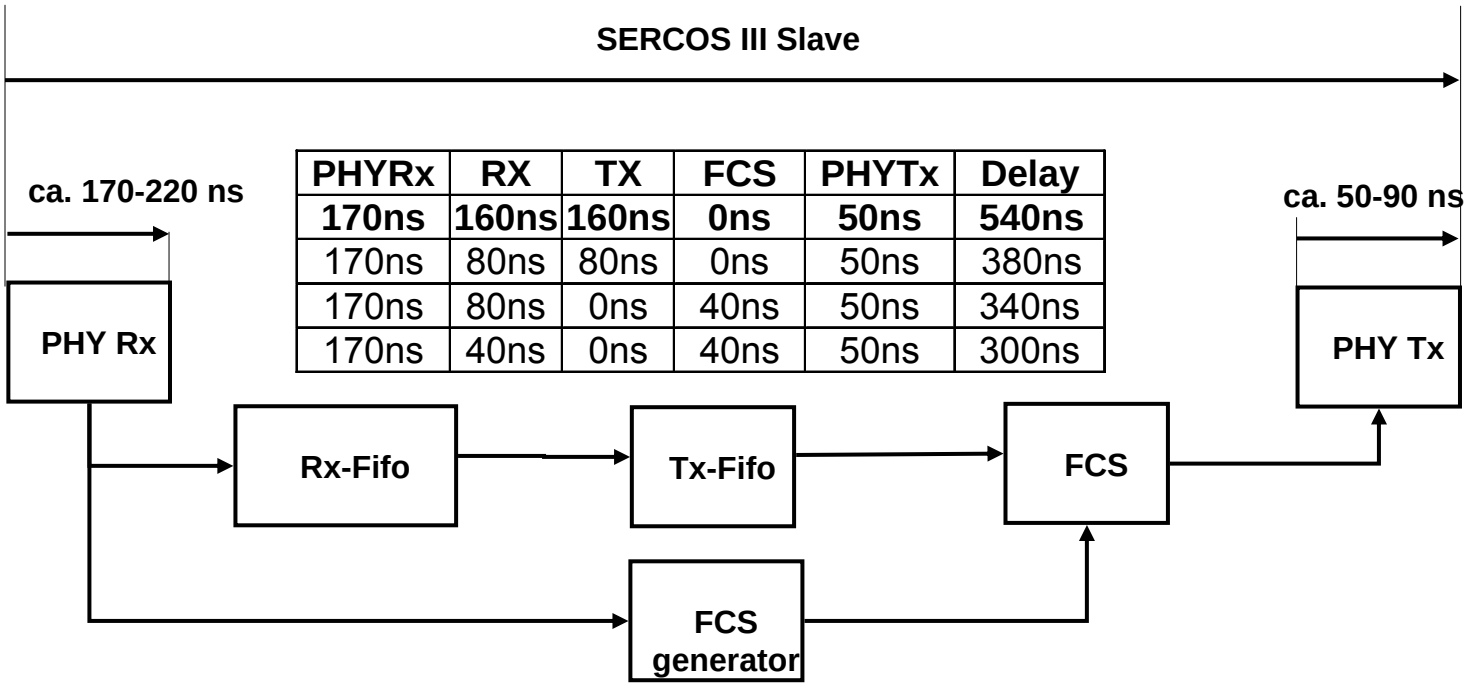


Physical delay times
Slave

PHYRx	PHYTx		
220ns	90ns	KS8721BL	Micrel
215ns	60ns	DP83843	NSC
170ns	**50ns**	**LXT973**	**Intel**
600ns with PHY		netX	Hilscher

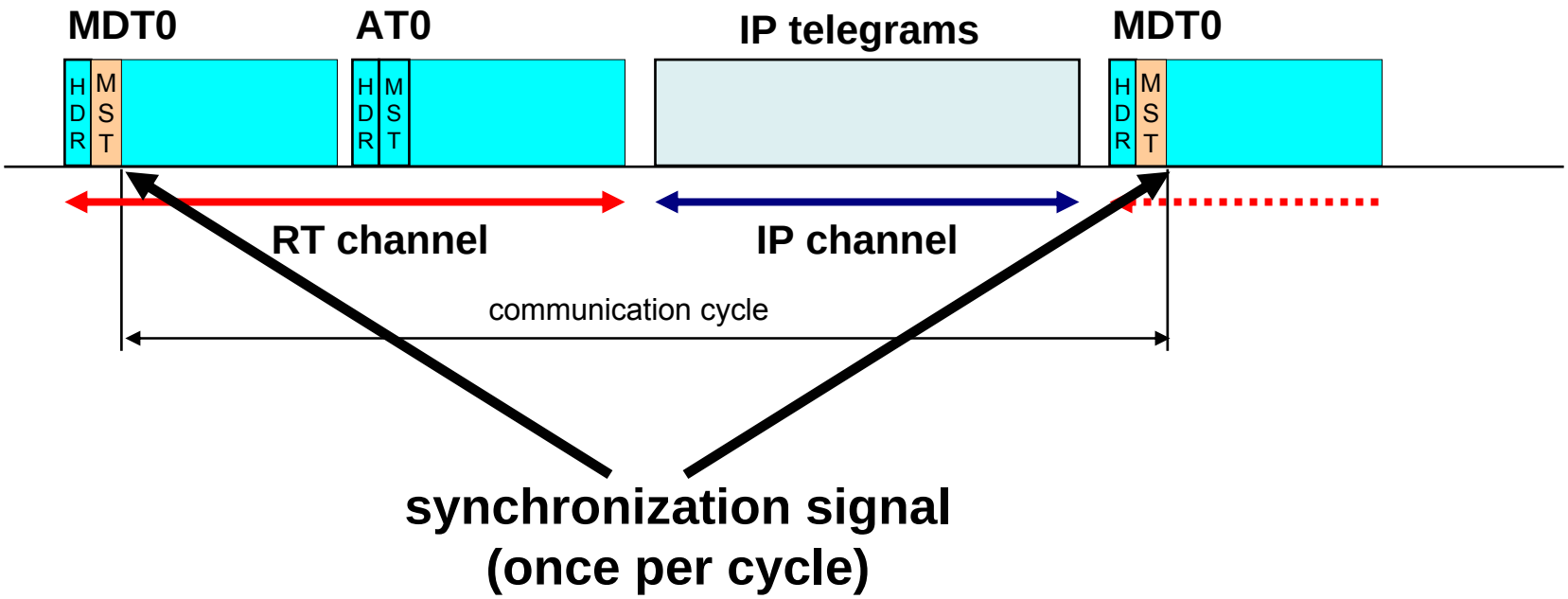
Slave delay: FPGA meas. 600ns
IDN Tx-delay (ns), PHY+SERCON100?
IDN Rx-delay (ns), PHY+SERCON100?

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



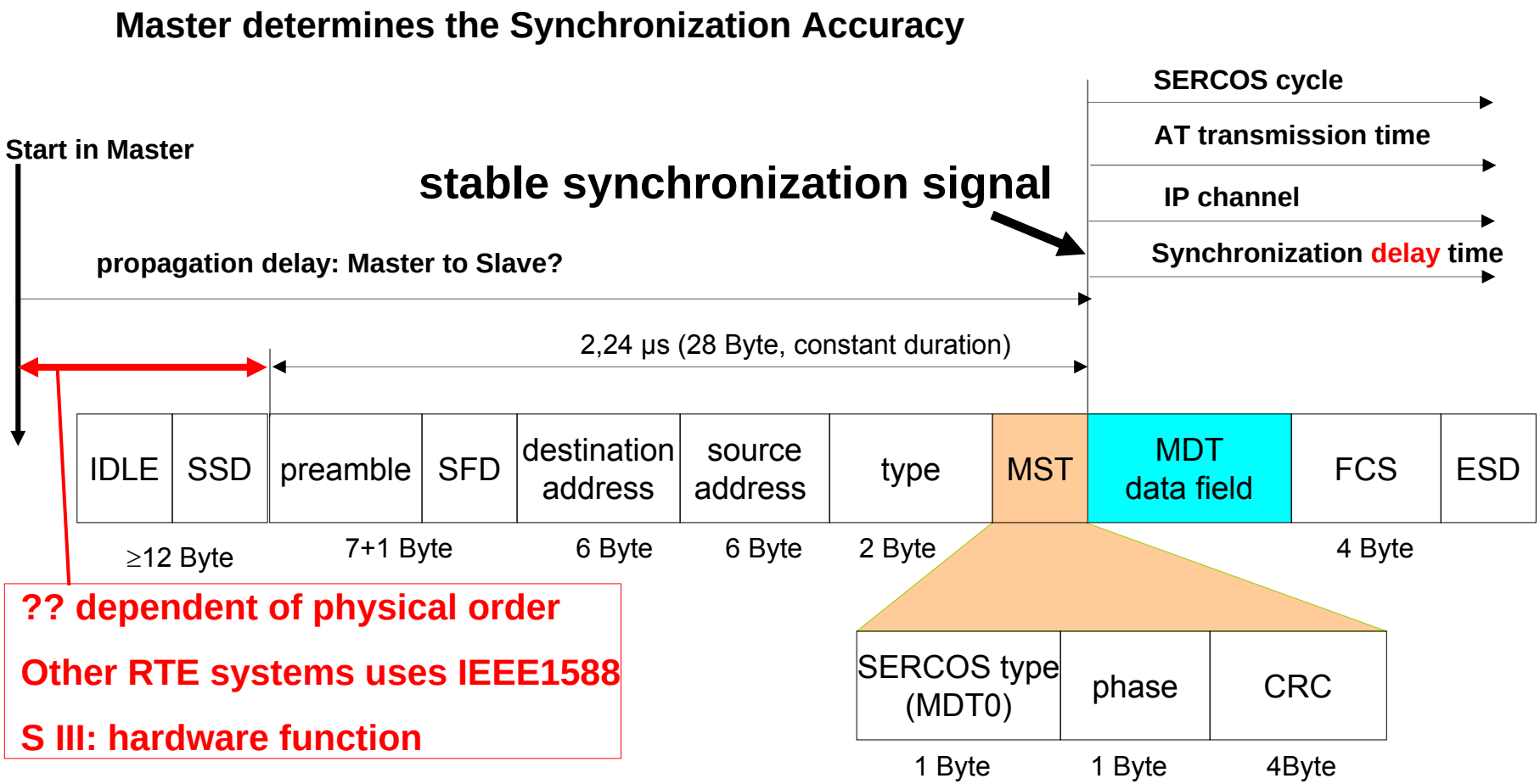
PHYRx	RX	TX	FCS	PHYTx	Delay
170ns	**160ns**	**160ns**	**0ns**	**50ns**	**540ns**
170ns	80ns	80ns	0ns	50ns	380ns
170ns	80ns	0ns	40ns	50ns	340ns
170ns	40ns	0ns	40ns	50ns	300ns

Synchronization generation



Synchronization is generated by the MST field of MDT0 only.

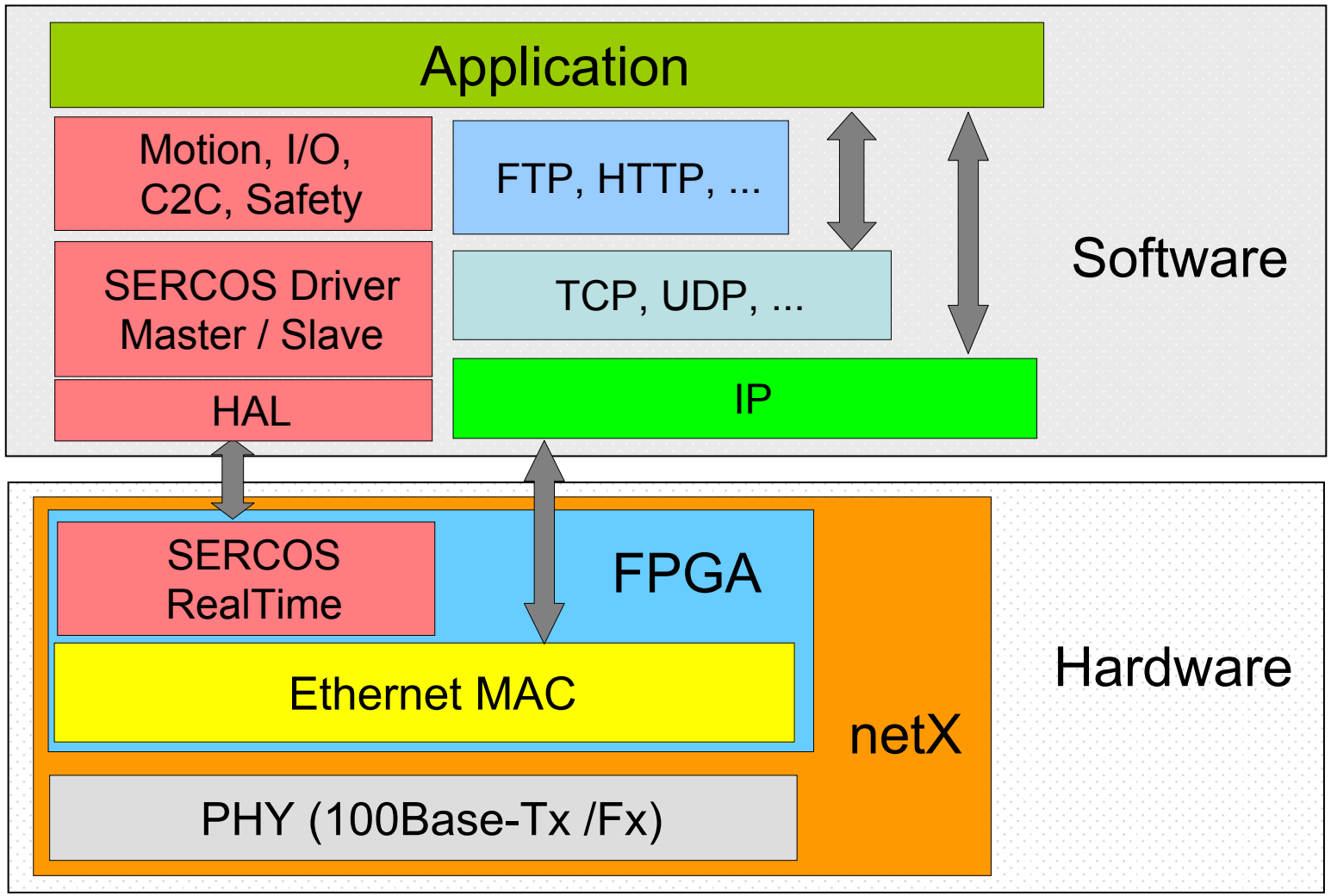
Synchronization with MST



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

Communication layer



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.)

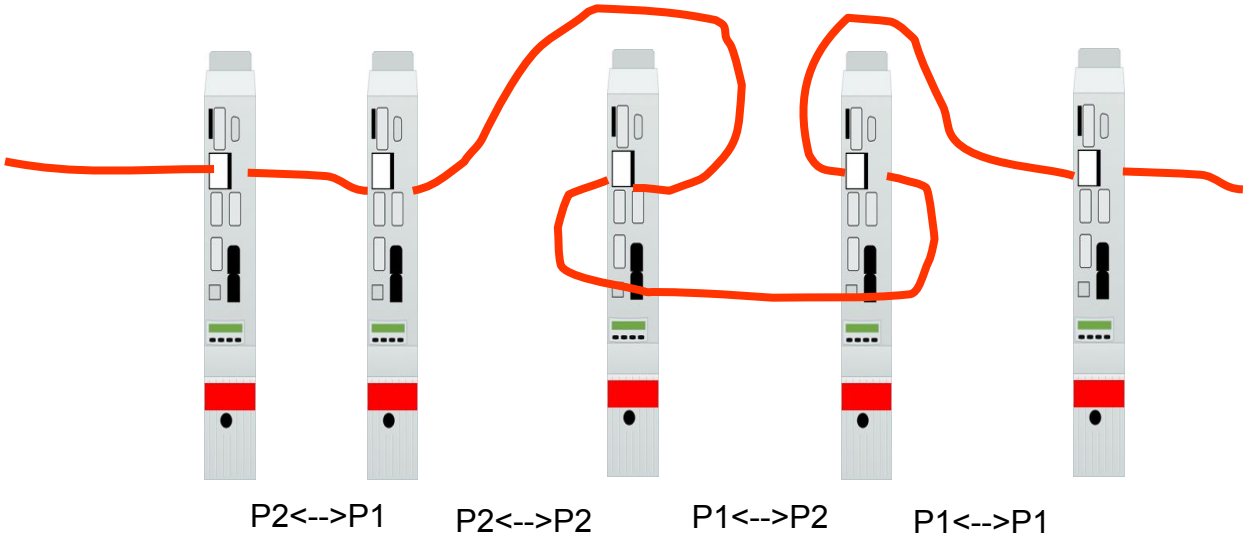
⇨ **S III specifies ground connection of shielding and unused wires**

- ProfiNet
- Ethernet Powerlink
- EtherCAT
- ODVA
- SERCOS III (RJ45, IP 20 & IP 67)

Harting
RJ 45
IP 20

Harting
RJ 45, M12,
IP 67

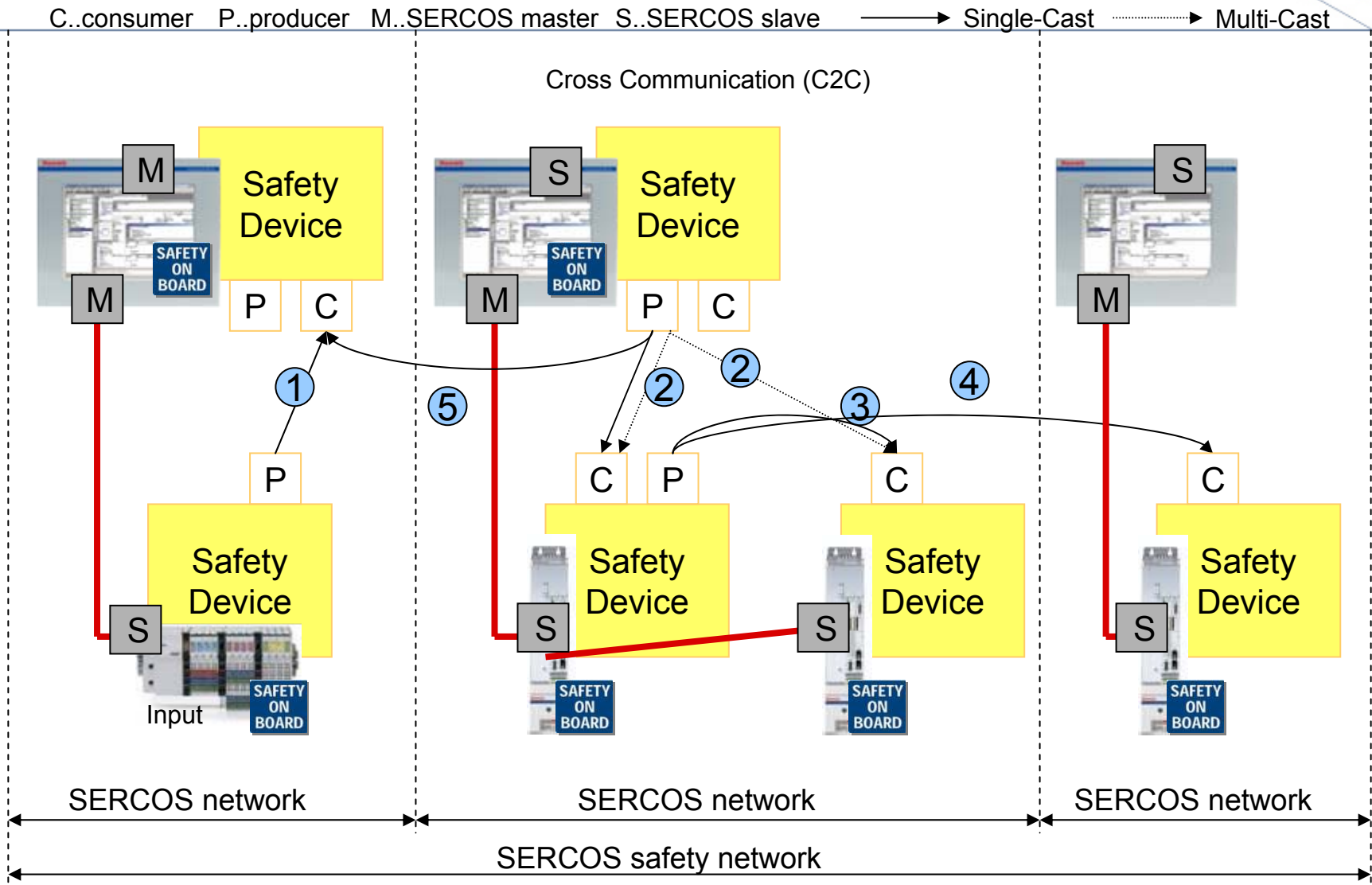
Flexibility in wiring



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

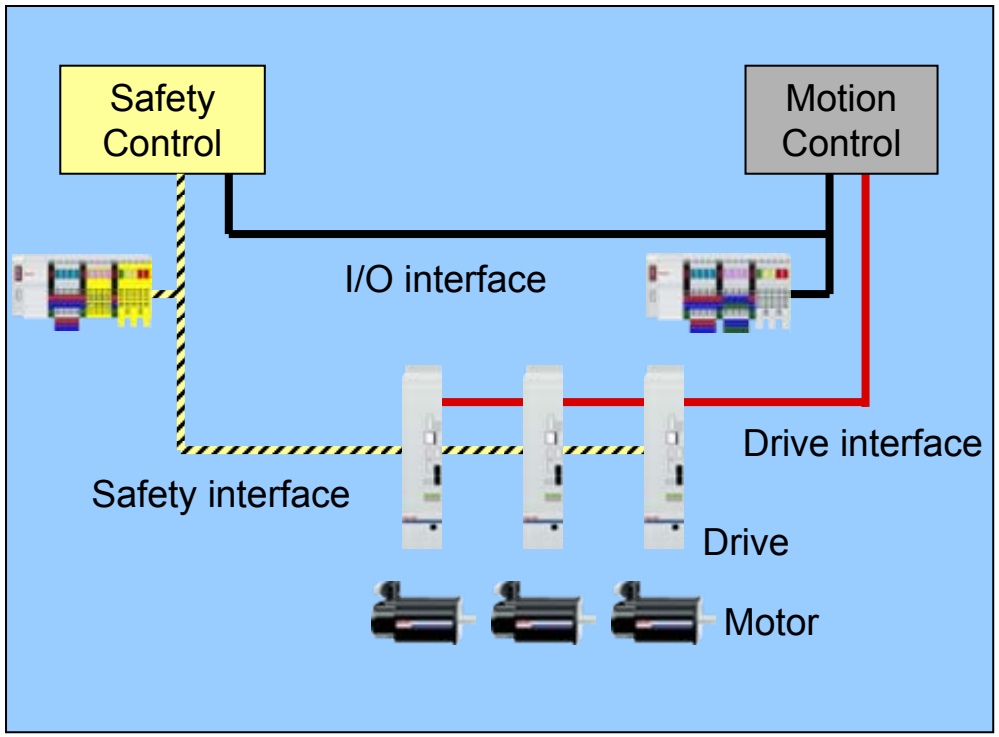
⇨ Eliminates connection errors leading to faster commissioning

SERCOS safety
Safe Real time communication with SERCOS



SERCOS safety
Application example

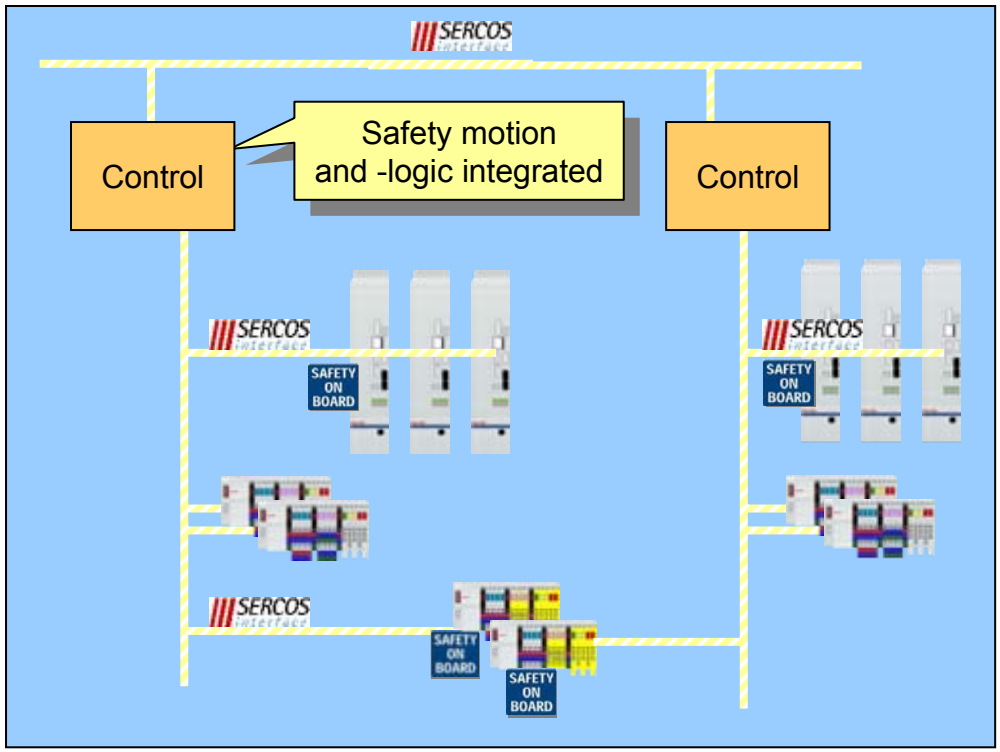
- Classical system architecture



- 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

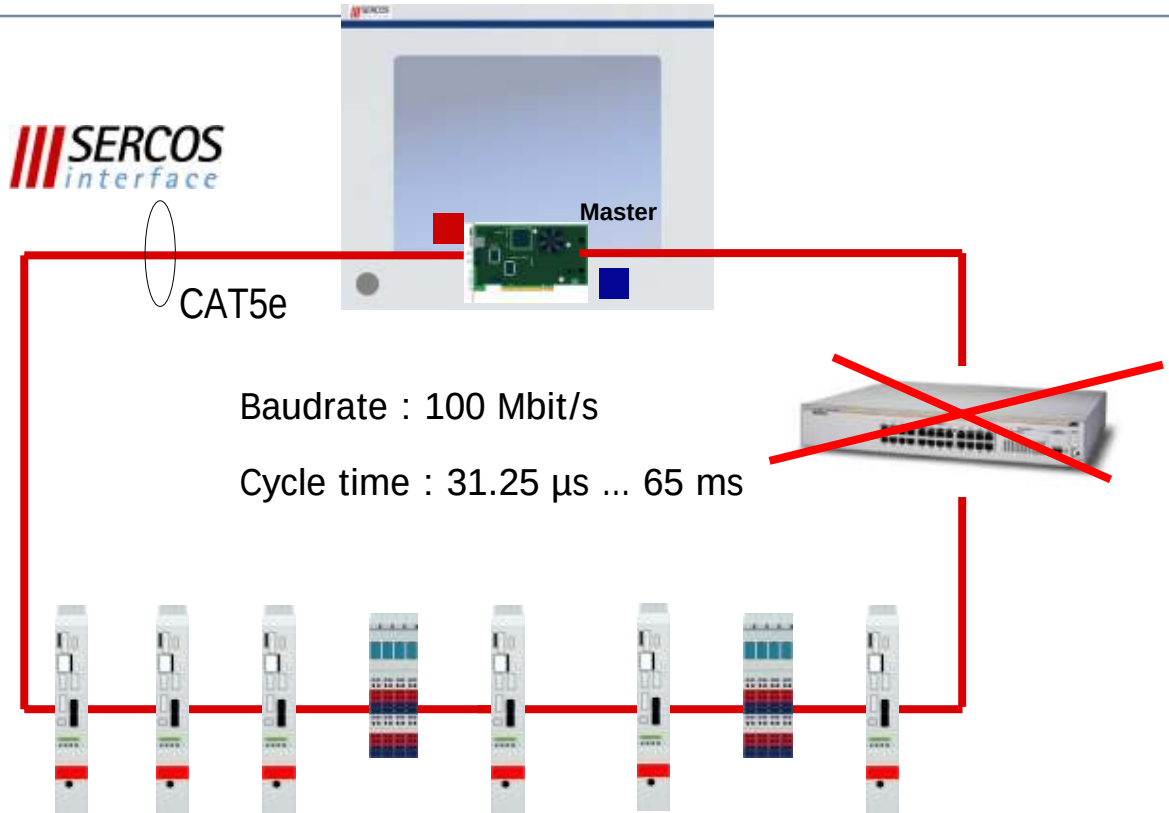
SERCOS safety
Application example

- 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

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