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Real-time Ethernet SERCOS III



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Real-time Ethernet SERCOS III

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Real-time Ethernet SERCOS III

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German Publication Number DE 102 37 097 A1.

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The text of this PAS is based on the following document:

This PAS was approved for publication by the P-members of the committee concerned as indicated in the following document

Draft PAS	Report on voting
65C/358/NP	65C/374/RVN

Following publication of this PAS, the technical committee or subcommittee concerned will transform it into an International Standard.

It is intended that the content of this PAS will be incorporated in the future new editions of the various parts of the IEC 61158 series and IEC 61784 series according to the structure of these series.

This PAS shall remain valid for an initial maximum period of three years starting from 2005-08. The validity may be extended for a single three-year period, following which it shall be revised to become another type of normative document or shall be withdrawn.

INTRODUCTION

This PAS relates to the integration of SERCOS III fieldbus specification in future editions of IEC 61158 and IEC 61784 series.

It shows in various clauses what updates are required in each of these individual standards. All definitions, abbreviations and symbols that relate to SERCOS III appear together in Section F, which belongs to the updates of IEC 61784-2, as a temporary fix.

NOTE 1 Some sections of this PAS still refer to IEC 61491. As it has been decided to split this standard into future IEC 61800 series, under consideration, (power drive systems) and IEC 61158/61784 series (communication) according to 65C/365/RQ, references to these new standards will be incorporated later on, in accordance with the relevant SC22G and SC65C working groups.

NOTE 2 For the reader who is unfamiliar with SERCOS interfaces, 17.3 of Section F can serve as a preface to the specific details which follow in later clauses.

NOTE 3 A temporary "Type S" has been allocated for SERCOS III.

The SERCOS/CPF16 standard structure is described in the table below.

IEC 61784-1 (new edition)	Communication profiles CP16/1 and CP16/2.	
	CP16/1 fits to the existing SERCOS specification IEC 61491:2002 (fibre optic media, 2 and 4 Mbit/s). IEC 61491 (new edition) shall not specify any communication and refer instead to CP16/1 in IEC 61784-1 after release of its new edition according to this structure proposal.	
	CP16/2 fits to the 2 nd SERCOS generation (fibre optic media, 2, 4, 8 and 16 Mbit/s), which is downwards compatible to IEC 61491:2002 (CP16/1) while specifying additional features.	
IEC 61784-2 (1 st edition)	Communication profiles CP16/3.	
	CP16/3 fits to the newest, real-time Ethernet SERCOS generation, which is application compatible to IEC 61491:2002 (CP16/1) and CP16/2 while specifying additional communication features.	Defined in the PAS.
IEC 61158-2 (new edition)	Physical layer specification for all CPF16 profiles (Type not yet known)	
	Type specifications for CP16/1 and CP16/2	
	Type specifications for CP16/3	Defined in the PAS
IEC 61158-3 (new edition)	Data Link layer service specification for all CPF16 profiles (Type not yet known)	
	Type specifications for CP16/1 and CP16/2	
	Type specifications for CP16/3	Defined in the PAS
IEC 61158-4 (new edition)	Data Link layer protocol specification for all CPF16 profiles (Type not yet known)	
	Type specifications for CP16/1 and CP16/2	
	Type specifications for CP16/3	Defined in the PAS

IEC 61158-5 (new edition)	Application Link layer service specification for all CPF16 profiles (Type not yet known)	
	Type specifications for CP16/1 and CP16/2	
	Type specifications for CP16/3	Defined in the PAS
IEC 61158-6 (new edition)	Application Link layer protocol specification for all CPF16 profiles (Type not yet known)	
	Type specifications for CP16/1 and CP16/2	
	Type specifications for CP16/3	Defined in the PAS

Section A – Update of IEC 61158-2

0 Introduction

0.5 Major Physical Layer variations specified in IEC 61158-2

0.5.1 Type S: optical media and twisted-pair wire

Type S specifies the following synchronous transmission:

- a) optical fibre medium, at 2, 4, 8 and 16 Mbit/s;
- b) twisted-pair wire medium, at 100 Mbit/s, according to ISO/IEC 8802-3 – 100Base-TX;
- c) optical fibre medium, at 100 Mbit/s, according to ISO/IEC 8802-3 – 100Base-FX

2 Normative references

IEC 61491:2002, *Electrical equipment of industrial machines – Serial data link for real-time communication between controls and drives.*

ISO/IEC 8802-3:2001, *Information technology – Telecommunications and information exchange between systems – Local and metropolitan area networks – Specific requirements – Part 3: Carrier sense multiple access with collision detection (CSMA/CD) access method and Physical Layer specifications.*

29 Type S: Medium Attachment Unit: Ethernet 100Base-TX and 100 Base-FX

29.1 Transfer medium part of physical layer

29.1.1 Basics

The physical layer of the SERCOS profile is according to ISO/IEC 8802-3. Therein the transmission mode and the physical layer are specified. The transmission rate is 100 Mbit/s.

29.1.2 Topology

29.1.2.1 General

A SERCOS network uses slaves with integrated repeaters which have a constant delay time (t_{rep} , input → output). The topology consists of point-to-point transmission lines and participants. The master and the slaves are part of the network and are its participants. The connection line between the participants is a shielded CAT5 (or better) cable.

Each participant has two communication ports (port 1 and port 2). Port 1 (P1) and port 2 (P2) are interchangeable (see slave 3 in Figure 1 and Figure 2 for an example).

The topology can be either a ring structure or a line structure. A ring has two logical channels (see Figure 1) and a line has only one logical channel (see Figure 2).

The difference between ring and line structure is that the ring has a built-in redundancy against transmission media errors (e.g. cable break) and is therefore preferred.

A control unit may have one or more master interfaces depending on configuration. Each master handles only one network on the physical layer.

Slave interfaces are used to connect the devices to the network. At the physical layer, a slave represents the connection of one or more devices to the network. Logically, one slave with several devices acts the same as several slaves with each one device. The slaves are connected to each other physically through the network. Communication takes place between the master and the slaves; cross communication between the slaves is also supported.

The physical arrangement of slaves in the network is independent from the predefined device address ADR for the slave, as well as from the sequence of the real-time data fields in the AT and MDT. See 33.3.2 "Device address ADR" in IEC 61158-4, as well as 16.2 "Data transfer in RT channel" in IEC 61158-5.

Any slave can recognize the topology at any time, since there is a distinction between primary and secondary telegrams. This is important when a slave is added to the communication at a later point in time (hot plug). When a slave receives telegrams with the same SERCOS type on both ports (MDT0-P or MDT0-S) it recognizes a line. When it receives a MDT0-P on one port and a MDT0-S on the other port, it recognizes a ring.

29.1.2.2 Ring structure

The ring structure consists of a primary and secondary channel. All slaves work in forwarding mode (see Figure 1). Redundancy against cable break is achieved through this ring. It is also possible to open the ring and insert/remove slaves during operation (hot plug).

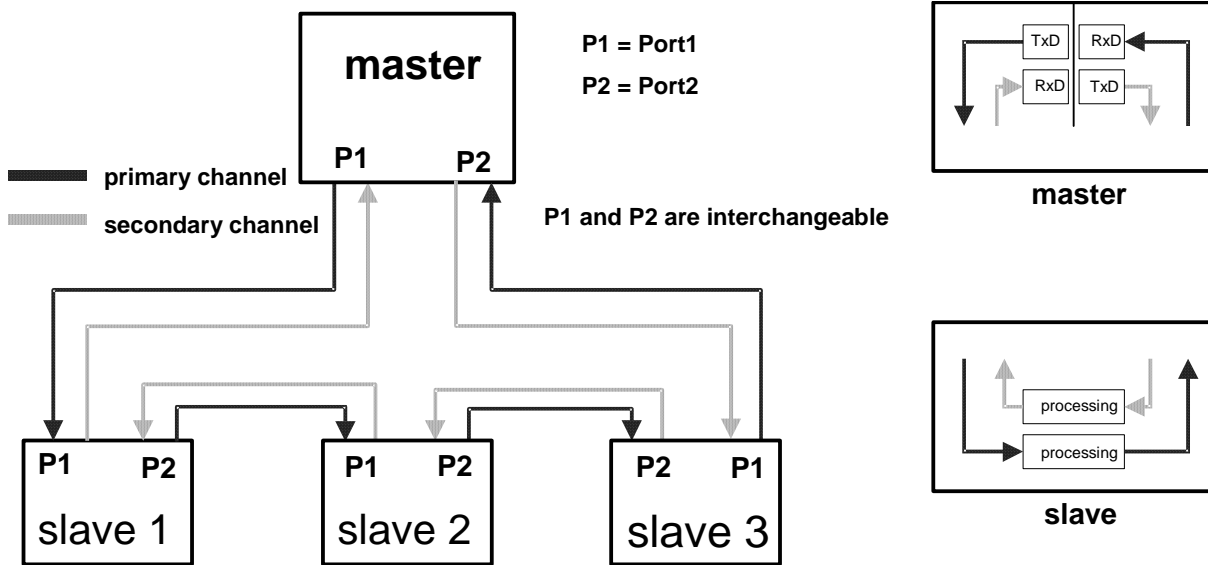


Figure 1 – Ring structure

29.1.2.3 Line structure

The line structure consists of either a primary or secondary channel. The last physical slave performs the loopback function. This is shown in Figure 2 with the loopback of slave 3. All other slaves work in forwarding mode. No redundancy against cable break is achieved. It is also possible to insert and remove slaves during operation (hot plug). This is restricted to the last physical slave. The ports which are not used for SERCOS communication (e.g., master port 2 and slave 3 port 1) can be used with IP communication. The master may communicate with slaves using two lines.

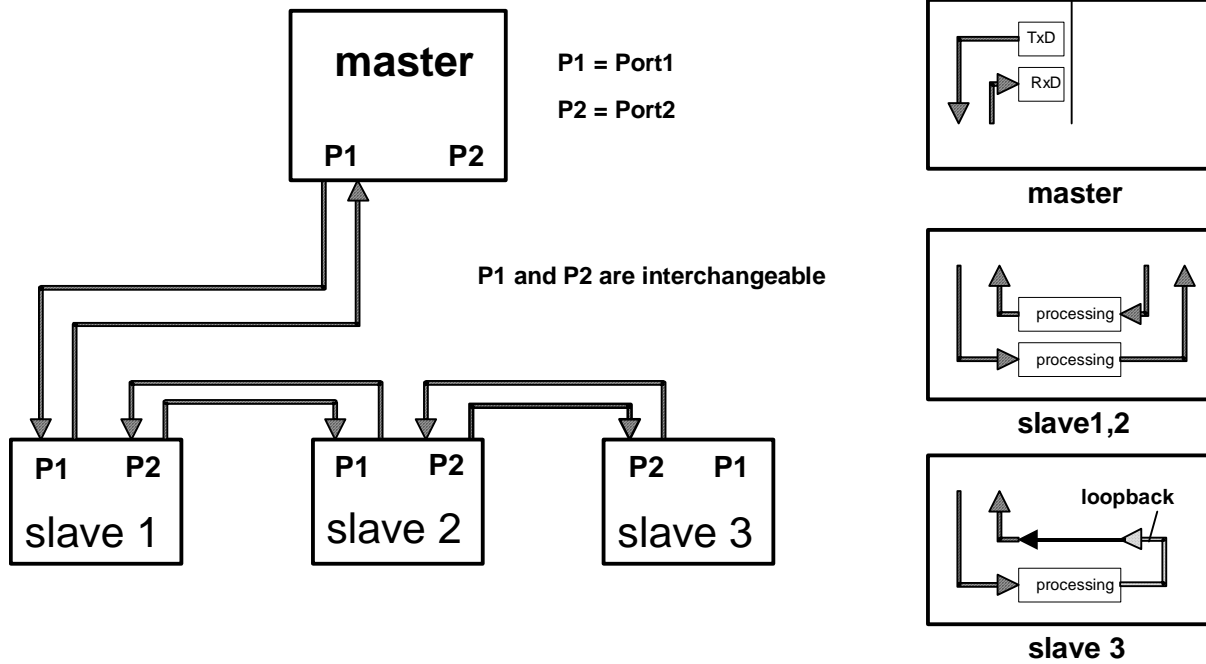


Figure 2 – Line structure

29.1.2.4 Transmission media

29.1.2.4.1 Transmission medium 100Base-TX

The characteristics of the 100Base-TX network are specified in ISO/IEC 8802-3. To ensure maximum noise immunity only shielded cables and connectors shall be used.

SERCOS devices shall use the MDI-X-ports with auto crossover function. The advantage is that standard cables as well as crossover cables (TxD / RxD) can be used.

29.1.2.4.2 Transmission medium 100Base-FX

The characteristics of the 100Base-FX network are specified in ISO/IEC 8802-3.

29.2 Communication mechanisms

29.2.1 General

Master and slave have the same hardware properties. Each port is assigned to a processing unit and a multiplexer (see Figure 3). The functions in the master and the slave depend on the topology and on the time slot within the communication cycle (RT channel or IP channel).

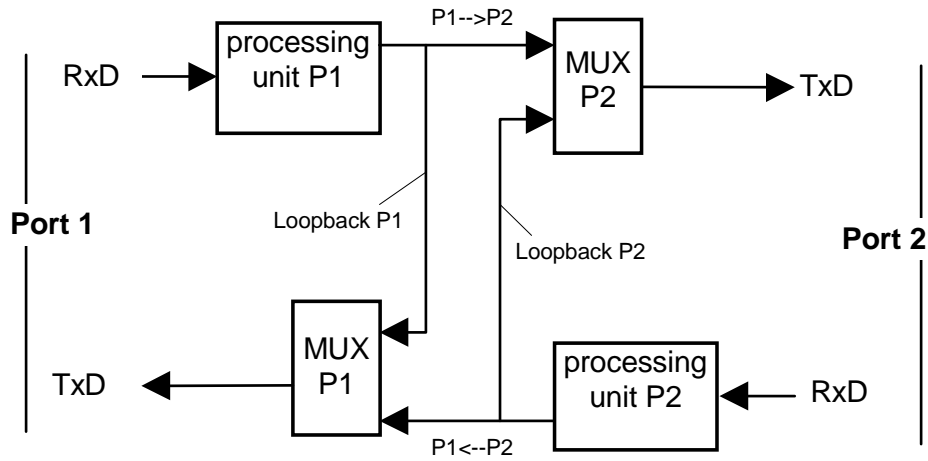


Figure 3 – Block diagram of master and slave

29.2.2 Forwarding

In the slave, the data from RxD (P1) shall be passed on with or without change to TxD (P2). The data from RxD (P2) shall be passed on with or without change to TxD (P1). See “Forwarding P1 → P2” and “Forwarding P2 → P1” in Figure 4). While the RT channel is active, the data shall be passed on, delayed by t_{REP} . While the IP channel is active, forwarding shall always be active and data shall be passed on, either at once or later in time, depending upon communication load.

In the master, forwarding shall always be switched off while the RT channel is active. While the IP channel is active, forwarding shall be:

- switched off if the master is connected to a single line configuration (only P1 or P2 is connected) or to an error-free ring configuration;
- activated if the master is connected to two independent lines or to a faulty ring configuration. Depending on the master’s functionality, the telegrams may be passed on either at once or later in time.

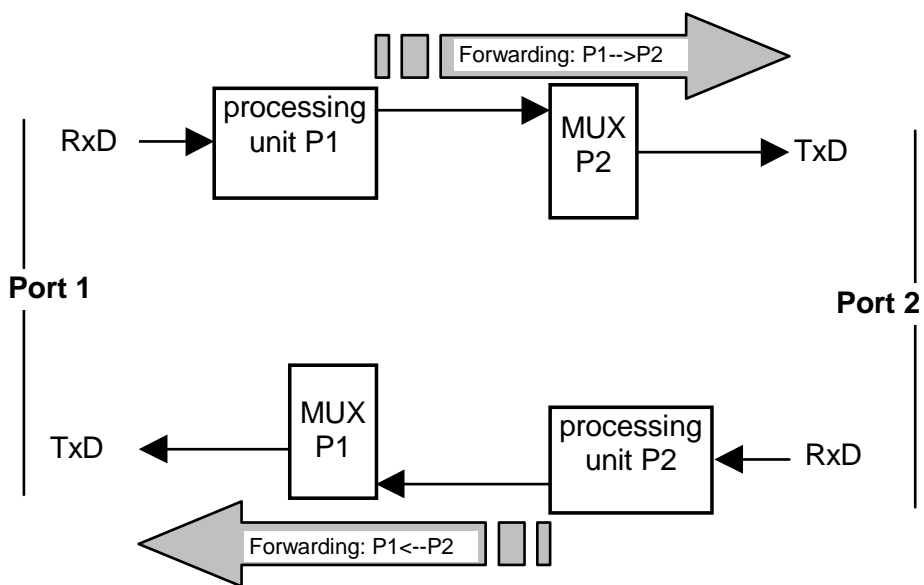


Figure 4 – Forwarding

29.2.3 Loopback

In the slave, the data from RxD (P1 or P2) shall be passed on with or without change to TxD (P1 and P2). Loopback may be activated either at P1 or P2 depending on the topology, but not at both ports simultaneously. The states are called “loopback P1”, respectively “loopback P2”. See Figure 5. While the IP channel is active, loopback shall never be active. While the RT channel is active, the slave shall activate loopback in the following (and only in those) cases:

- during CP0, as soon as an MDT0 has been received at a port (P1 or P2), but only as long as no MDT0 has been received at the other port;
- when the slave is the last physical one in the line topology;
- when a cable fault is detected.

The master shall have no loopback functionality.

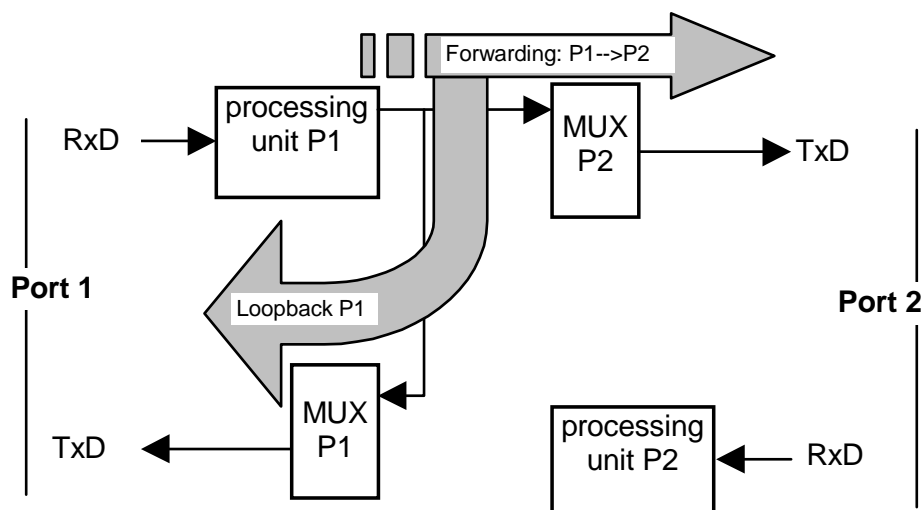


Figure 5 – Loopback

29.2.4 Device behaviour by addresses 0 and 255

Slaves with device addresses 0 and 255 shall also behave as described in 29.2.2 and 29.2.3. They shall also evaluate MDT0 in the same matter as the slaves with other addresses.

29.2.5 Redundancy of RT-Communication with ring topology

29.2.5.1 Ring topology without fault

Figure 6 shows an error free ring topology. The master shall send all telegrams with the same content on the P channel and on the S channel. Each slave shall receive both telegrams, work on the assigned data fields in P and S channel, and pass them on in their respective channels. Likewise, the master shall receive the telegrams from the slaves twice and process the data from the slave only once (either P or S channel).

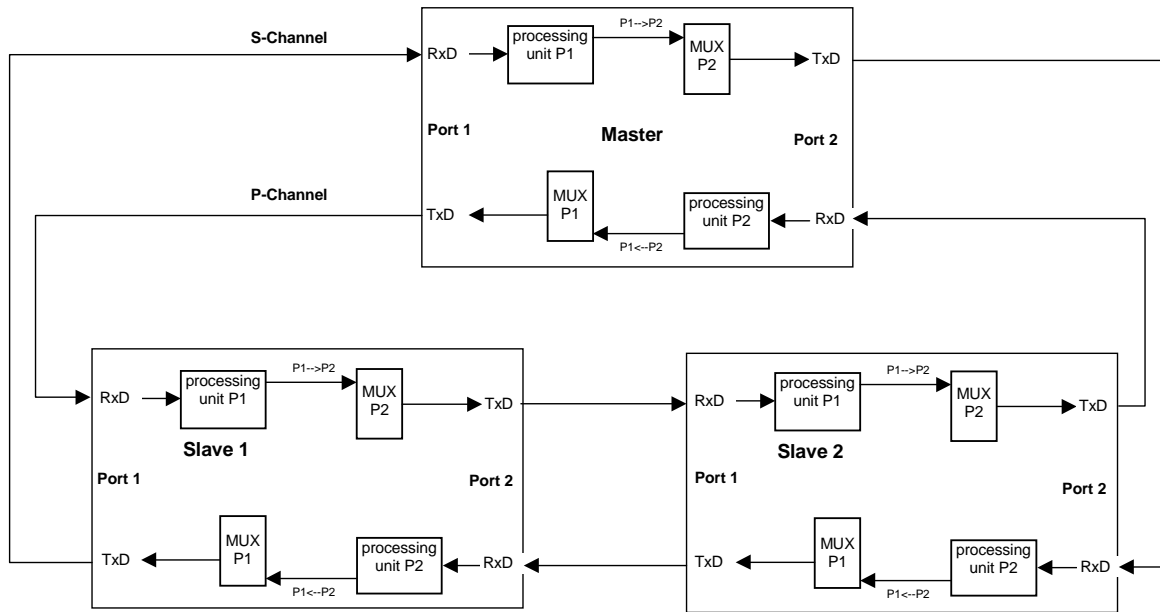


Figure 6 – Ring topology example with 2 slaves (example)

29.2.5.2 Cable faults between slaves

29.2.5.2.1 Case 1: Double channel interruption between two slaves

Figure 7 shows a first example of a faulty ring topology. Slave 1 shall detect an interruption at RxD of port 2 and close loopback at port 1. Slave 2 shall detect an interruption at RxD of port 1 and close loopback at port 2. The master shall receive the telegrams from slave 1 at port 1 only, and those from slave 2 at port 2 only.

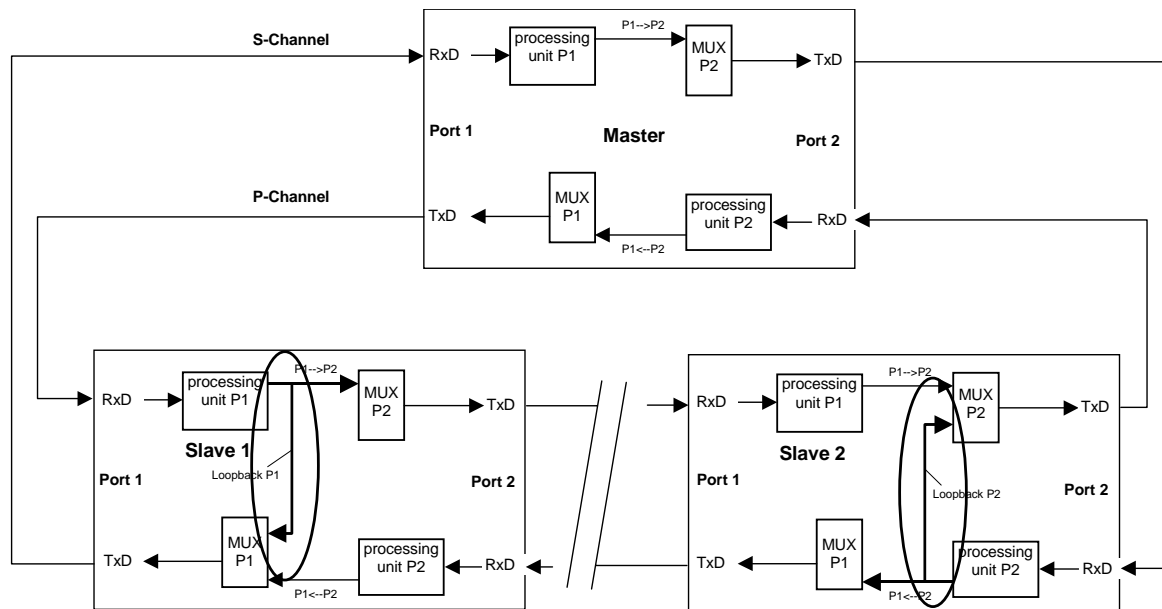


Figure 7 – Double channel interruption between two slaves (example)

29.2.5.2.2 Case 2: Single channel interruption between two slaves

Figure 8 shows another faulty ring topology example. Slave 1 shall detect an interruption at RxD of port 1 and close loopback at port 2. The master shall receive the telegrams from all slaves at port 1. At port 2, the master receives the telegrams from slave 2 in addition.

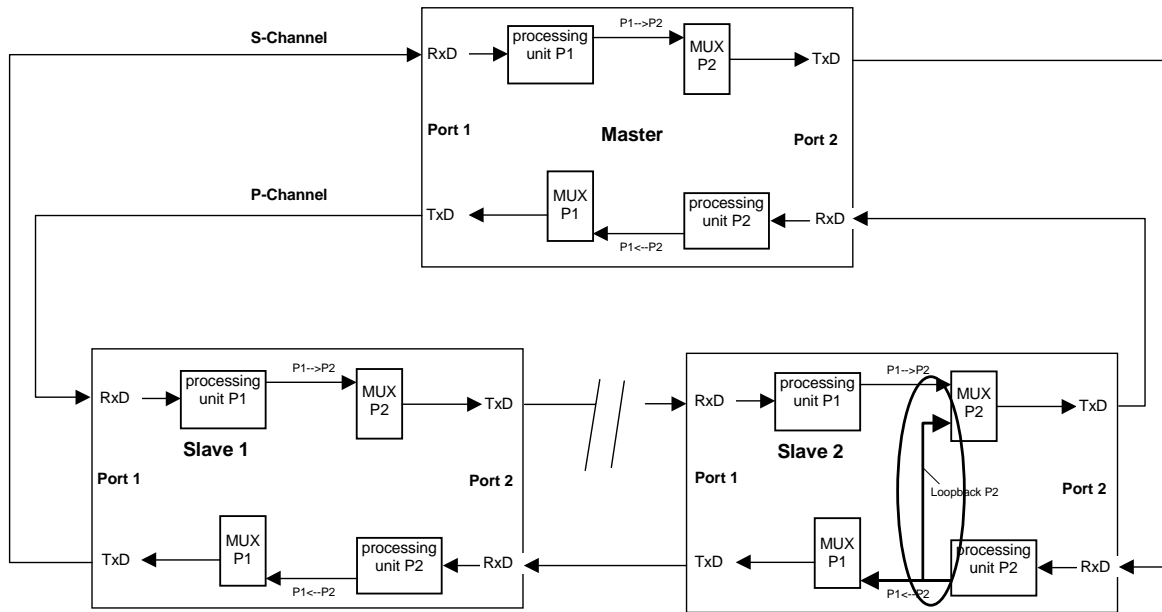


Figure 8 – Single channel interruption between two slaves (example)

29.2.5.3 Cable faults between master and slave

29.2.5.3.1 Case 1: Double channel interruption between master and slave

Figure 9 shows another faulty ring topology as an example. Slave 1 shall detect an interruption at RxD of port 1 and close loopback at port 2. The master shall detect an interruption at RxD of port 1. The master shall receive the telegrams from all slaves at port 2 only.

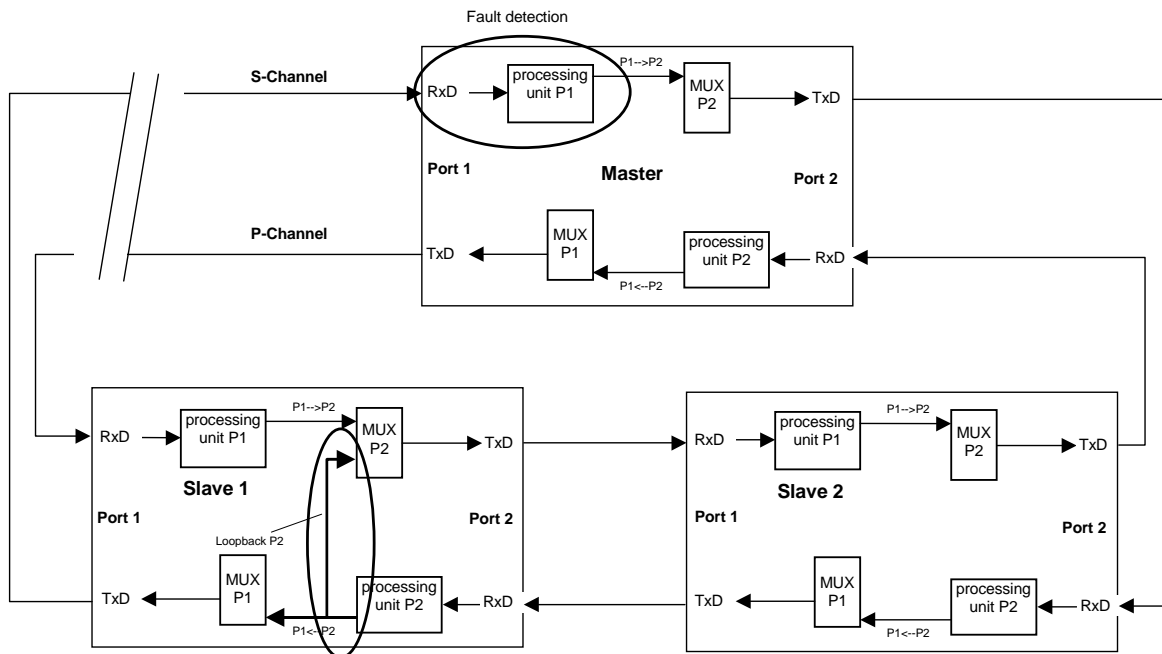


Figure 9 – Double channel interruption between the master and a slave (example)

29.2.5.3.2 Case 2: Single channel interruption between master output and slave

Figure 10 shows another faulty ring topology example. Slave 1 shall detect an interruption at RxD of port 1 and close loopback at port 2. The master shall receive the telegrams from all slaves twice.

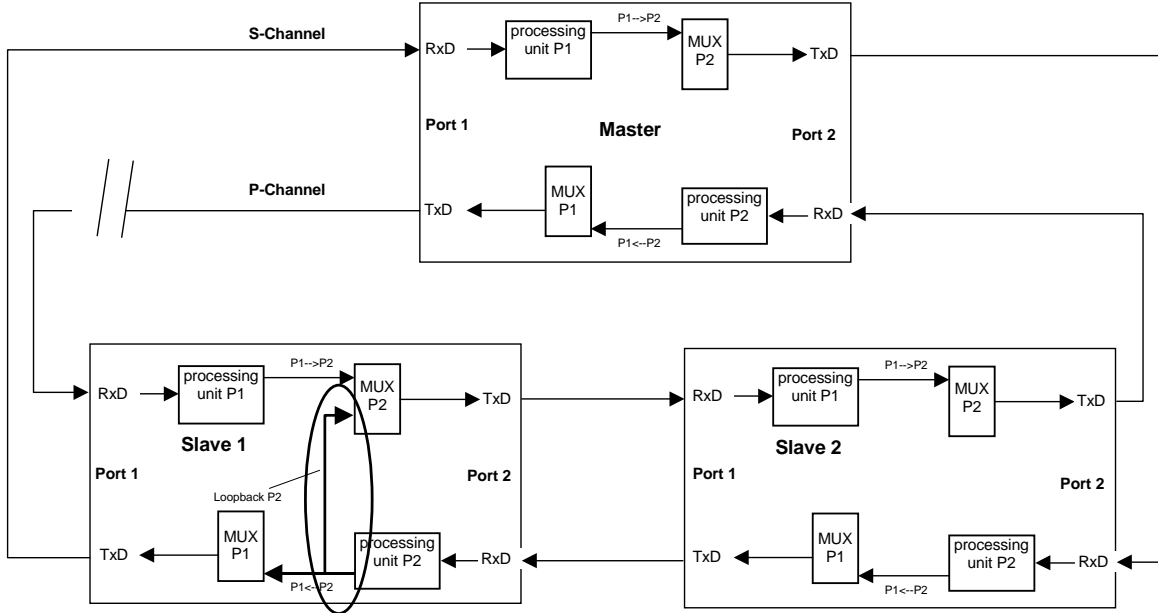


Figure 10 – Single channel interruption at master output (example)

29.2.5.3.3 Case 3: Single channel interruption between master input and slave

Figure 11 shows another faulty ring topology example. The master shall detect an interruption at RxD of port 1. The master shall receive the telegrams from all slaves at port 2 only.

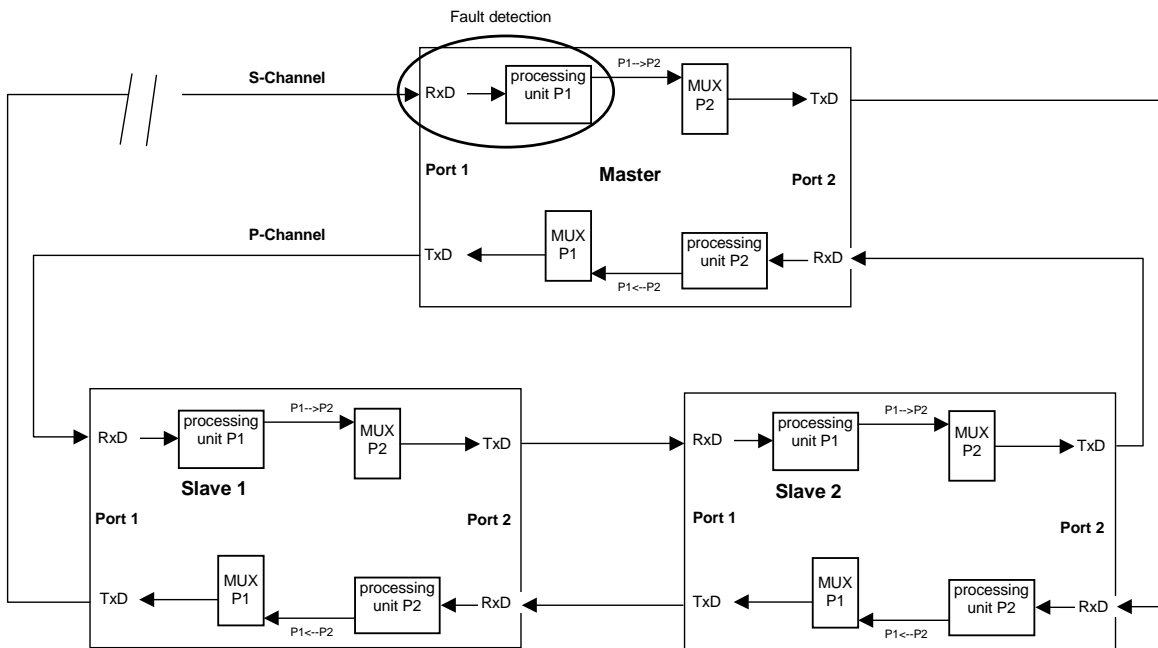


Figure 11 – Single channel interruption at master input (example)

29.2.6 IP communication mechanisms

29.2.6.1 Slaves within a line or a ring

Should a slave receive a telegram while IP channel is active and as it is transmitting an IP telegram, the currently transmitted IP telegram shall not be interrupted and the incoming telegram shall be stored.

Slaves shall always send their own IP telegrams on both ports (P1 and P2). The following conditions shall all be met before doing it:

- when it is forwarding a telegram, the slave shall wait that this telegram has been fully forwarded;
- the remaining IP channel duration is long enough to fully transmit its own IP telegram;
- its memory has enough free capacity for storing at least one new incoming IP telegram with maximum length.

Should a slave receive an MDT0 while it is sending an IP telegram, then it shall immediately interrupt this sending and forward the MDT0.

29.2.6.2 Slave in the last position within a line

Although the last slave in a line has its loopback active, it shall check for any incoming IP telegram on its other port. It shall forward IP telegrams when its IP channel is active, provided that the remaining duration of this IP channel is long enough to fully transmit this IP telegram. Otherwise, or if the IP channel is not active, the last slave shall store all incoming IP telegrams. It shall forward one or several of them as soon as IP channel is active again, provided that the remaining duration of this new IP channel is long enough.

Section B – Update of IEC 61158-3

1 Scope and object

1.1 Overview

Type S — A DL-service which provides a superset of those services expected of OSI Data Link Protocols as specified in ISO/IEC 8886.

2 Normative references

IEC 61491:2002, Electrical equipment of industrial machines - Serial data link for real-time communication between controls and drives.

ISO/IEC 8802-3:2001, Information technology - Telecommunications and information exchange between systems - Local and metropolitan area networks - Specific requirements - Part 3: Carrier sense multiple access with collision detection (CSMA/CD) access method and Physical Layer specifications.

21 Type S: Data Link concepts, services and management

21.1 Data transfer and data link layer

21.1.1 General

In this subclause, the telegram structure (frame structure) is described. Telegrams are according to the Ethernet standard ISO/IEC 8802-3.

SERCOS header specifies two sub types of SERCOS telegrams:

- **Master data telegram (MDT):** The MDTs transmit data from the master to the slaves;
- **Device telegram (AT):** The ATs transmit data from the slaves to the master.

Furthermore, ISO/IEC 8802-3 Ethernet protocols can be transported.

21.1.2 Real-time telegram types

21.1.2.1 General

Real-time telegrams are transmitted in the real-time part of the communication cycle time (RT channel). They transport mainly command values and actual values. SERCOS defines two types of real-time telegrams (MDT and AT).

21.1.2.2 Master data telegram (MDT)

SERCOS specifies 4 MDTs (MDT0 to MDT3). The MDTs are transmitted by the master and received by each slave. The MDTs contain all information (e.g., synchronisation, command values, digital outputs ...) which is sent from the master to the slaves through the real-time channel.

MDT0 is always transmitted. MDT1 through 3 are transmitted only if required and depend on the total amount of data to be transmitted to the slaves. The master always sends the same number of MDTs during each communication cycle.

21.1.2.3 Device telegram (AT)

SERCOS specifies 4 ATs (AT0 to AT3). The ATs are transmitted by the master with empty data fields. Each slave inserts its data into its allocated data field within the AT. The ATs contain all information (e.g., feedback values, digital inputs ...) which is sent from the slaves to the master as well as between the slaves through the real-time channel.

AT0 is always transmitted. AT1 through 3 are transmitted only if required and depend on total amount of data to be transmitted to the master. The master always sends the same number of ATs during each communication cycle.

21.1.2.4 Cycle time

The following reference values have been determined for the communication cycle time, t_{Scyc} .

$t_{Scyc} = 31,25\mu s, 62,5\mu s, 125\mu s, 250\mu s$ and integer multiples of $250\mu s$ up to $65\,000\mu s$.

This cycle time is allowed to have some jitter. The jitter describes the deviations from the t_{Scyc} value in the distance between two MDT0. J_{tScyc} shall belong to a class as in Table 1.

Table 1 – Synchronisation classes

Synchronisation	Jitter of MDT0 J_{tScyc}
high performance class	$\leq \pm 1\mu s$
low performance class	$\leq \pm 50\mu s$

Therefore, the actual time interval between the MDT0 and the following MDT0 has a minimum value of:

$$j \times t_{Scyc} * 0,9999 - J_{tScyc} \quad (j = 1, 2, 3, \dots),$$

and a maximum value of:

$$j \times t_{Scyc} * 1,0001 + J_{tScyc} \quad (j = 1, 2, 3, \dots).$$

NOTE j is an arbitrary, strictly positive integer, and is not related to the abbreviations.

The factors 0,9999 or 1,0001 take into account the deviation of the communication cycle time t_{Scyc} , compared to the accuracy of the usual crystal oscillators (± 100 ppm). Note that the jitter shall not accumulate over several periods (i.e., the average value shall be zero).

21.1.2.4.1 Telegram transmission times

During the initialization phase, the master inquires for time parameters from the slaves. See subclause 14.2. "Communication phase 2 (CP2)" in IEC 61158-6. With this information, it is possible to calculate a collision-free distribution of transmission time-slots of the telegrams within the RT channel.

The master transmits to each slave the AT transmission starting time, t_1 , as well as the beginning and ending times of the IP channel, t_6 respectively t_7 . These starting times for the transmitting time-slots for the telegrams are defined next.

Jitter has been incorporated in t_1 :

t_1 AT transmission starting time: this is the nominal time interval between the beginning of MDT0 and the beginning of the AT0. This parameter has been determined by the master and is stored in the associated devices as an IDN.

J_{t1} Jitter in t_1 : this is the maximum deviation of the beginning of the AT0. It is the allowed deviation of the time interval t_1 . The actual time interval between the beginning of MDT0 and the beginning of AT0 shall lie between $t_1 - J_{t1}$ and $t_1 + J_{t1}$. J_{t1} shall have the same value as the jitter of MDT0, J_{Isyc} . See Table 1.

t_6, t_7 Time-slot of IP channel (t_6 begin of IP channel, t_7 end of IP channel). Within the IP channel there are no special time-slots. Every participant can send its IP telegrams during this time-slot. The time parameters (t_6 and t_7) are set by the master in communication phase 2 (CP2).

Figure 4 "Access to the transfer medium" (subclause 33.2.2.2.1) in IEC 61158-4 shows the timing of the transmission time-slots.

21.1.2.5 Timing parameters

The following time parameters are characteristics of the network.

t_{rep} time by which the received signal is delayed by a forwarding slave (input to output). This parameter is saved as an IDN in the slave.

t_{cable} time by which the transmitted signal is delayed by the cable (approx., 5 ns/m).

t_{ring} time between the transmitted and received signal at the master. The master measures the ring delay in CP0. The ring delay contains all forwarding and cable delays in the network and is used for synchronisation purposes.

21.1.2.6 MDT partitioning

A service channel and a configurable real-time data field (RTD) are defined in the MDT for each slave. S-0-1013 sets the offset for the service channel. S-0-1009 sets the offset for the real-time data field. S-0-1010 contains the length of the MDT (see Figure 1). These parameters are transmitted by the master to the slaves in CP2.

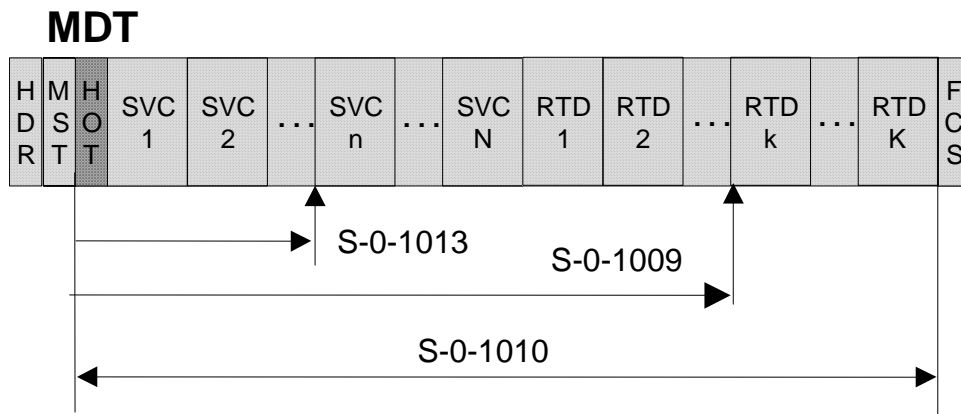


Figure 1 – Partitioning of MDT data fields

21.1.2.7 AT partitioning

A service channel and a configurable real-time data field are defined in the AT for every device. S-0-1014 defines the offset for the service channel. S-0-1011 defines the offset for the

real-time data field. S-0-1012 defines the length of the AT (see Figure 2). These parameters are transmitted from the master to the slaves in CP2.

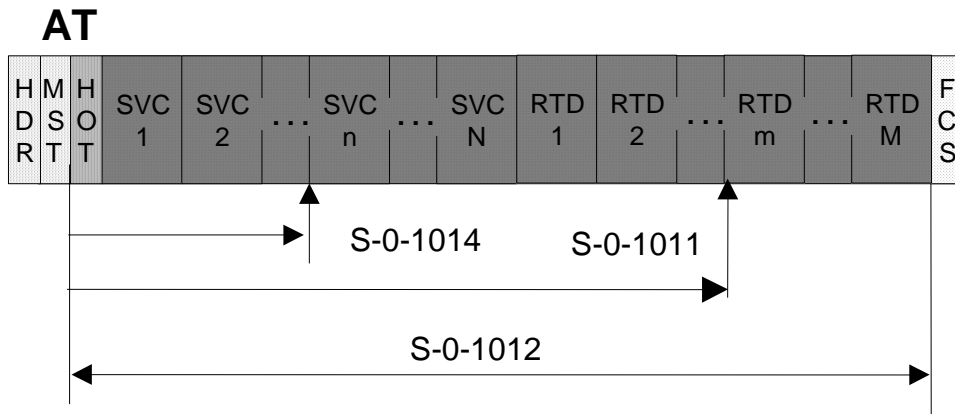


Figure 2 – Partitioning of AT data fields

21.1.3 MDT and AT combinations

The allocations of the service channels (SVC) and the real-time data fields (RTD) in the MDT as well as in the AT are configured with parameters (see Figure 1 and Figure 2). The RTD lengths in the MDTs and the ATs depend on the configuration and may be different. The number of MDTs and ATs may be different. This configuration shall meet the following requirements:

- 1) All service channels shall be configured directly after the hot plug field.
- 2) All real-time data fields shall be configured directly after the last service channel.
- 3) All SVCs of a device shall be transmitted within one telegram (MDT and AT). The telegram shall be filled up with SVCs as much as possible before using the next telegram.
- 4) All RTDs of a device shall be transmitted within one telegram (MDT and AT). The telegram shall be filled up with RTDs as much as possible before using the next telegram.

Figure 3 shows examples of valid telegram combinations of MDTs and ATs.

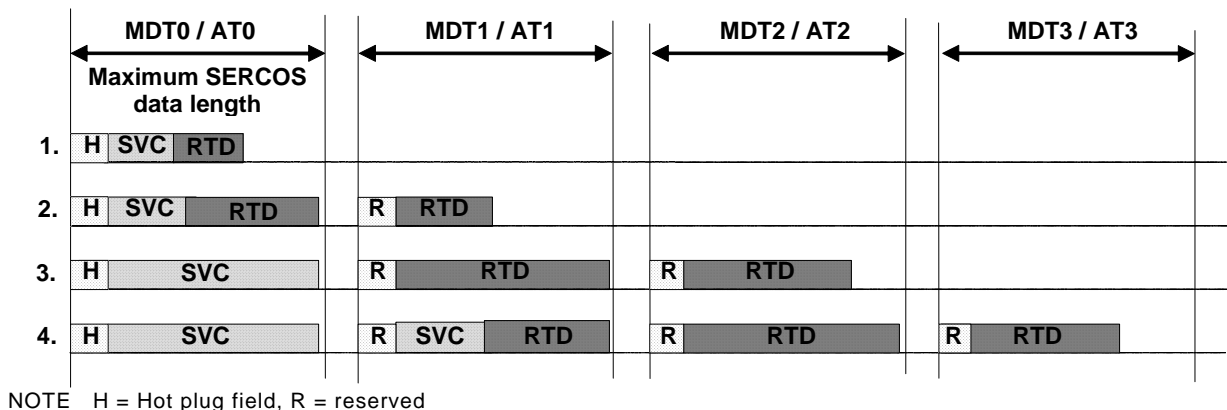


Figure 3 – Examples of valid telegram combinations

Section C – Update of IEC 61158-4

1 Scope and object

1.1 Overview

Type S — A DL-protocol for the Type S DL-service. The maximum system size is 2 links of 255 nodes.

1.2 Specifications

1.2.1 Type S: Additional characteristics

This protocol provides a highly-optimized means of interchanging fixed-length real-time data and variable-length segmented messages between a single master device and a set of slave devices, or between slave devices directly, interconnected in a line or in a ring topology. The ring topology provides for redundant communication paths, and in case of an error it automatically switches to a set of two lines without disturbing the communication. The exchange of real-time data is totally synchronous by configuration and is unaffected by the messaging traffic.

The device addresses are set by the user, e.g., using a selector. Additional devices may be added whenever required, even during operation, without affecting the already existing address selections. The determination of the number, identity and characteristics of each device may be configured or may be detected automatically at start-up.

This protocol provides in addition a standard Ethernet means of interchanging data and files in non real-time way between standard devices such as personal computers and the interconnected devices. This feature provides a way of addressing each individual device even if the device addresses have not yet been set.

2 Normative references

IEC 61491:2002, *Electrical equipment of industrial machines - Serial data link for real-time communication between controls and drives.*

ISO/IEC 8802-3:2001, *Information technology - Telecommunications and information exchange between systems - Local and metropolitan area networks - Specific requirements - Part 3: Carrier sense multiple access with collision detection (CSMA/CD) access method and Physical Layer specifications.*

5 DL-protocol elements common to multiple DL-protocol Types

5.1 Frame check sequences

Table 1 – FCS length, polynomials and constants by protocol Type

Protocol	Item	Value
Type S	$n-k$	32
	G(x)	$x^{32} + x^{26} + x^{23} + x^{22} + x^{16} + x^{12} + x^{11} + x^{10} + x^8 + x^7 + x^5 + x^4 + x^2 + x + 1$ (note 1)
	NOTE 1: Refer to ISO/IEC 8802-3 for a thorough description of this polynomial.	

33 Type S: Data Link protocol definition

33.1 General

In this subclause, the telegram structure (frame structure) is described. Telegrams follow the Ethernet standard ISO/IEC 8802-3.

SERCOS telegrams are indicated by the Ethernet type field number (0x88CD).

SERCOS header specifies two sub-types of SERCOS telegrams:

- **Master data telegram (MDT):** The MDTs transmit data from the master to the slaves;
- **Device telegram (AT):** The ATs transmit data from the slaves back to the master.

Furthermore ISO/IEC 8802-3 Ethernet protocols can be transported.

33.2 Data transfer and data link layer

33.2.1 Real-time telegram structure

33.2.1.1 General

Data transmission takes place in telegrams. The general structure of real-time telegrams has been shown in Figure 1.

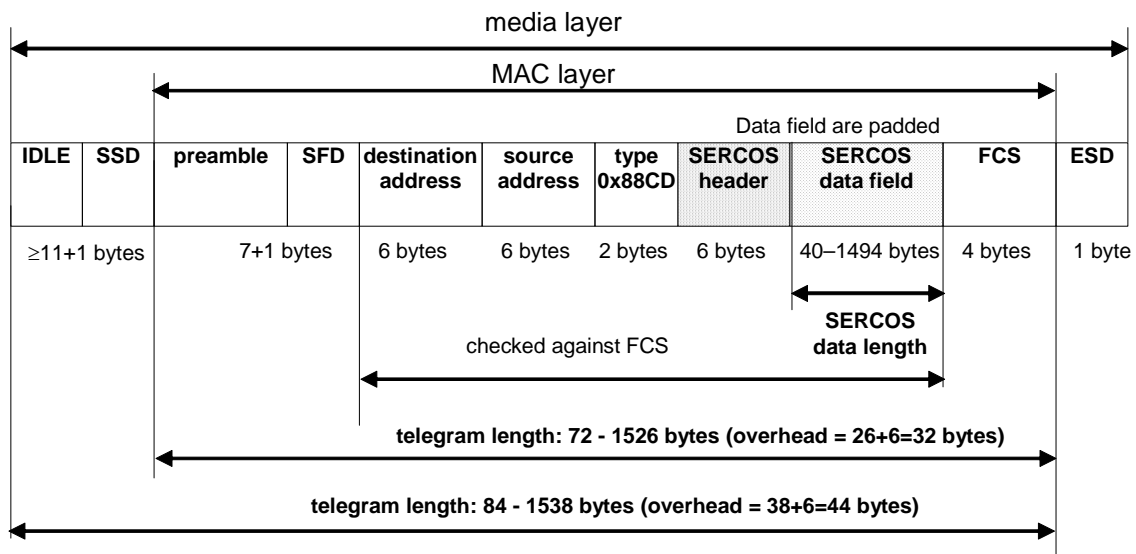


Figure 1 – General telegram structure

33.2.1.2 Telegram delimiters

To receive telegrams correctly the following telegram delimiters are needed:

- Inter Packet Gap (IPG ≥ 12 bytes, IDLE and SSD);
- Preamble (7 bytes);
- Start Frame Delimiter (SFD, 1 byte);
- End Stream Delimiter (ESD, 1 byte).

33.2.1.3 Destination address (DA)

Length: 6 bytes

The master transmits MDTs and ATs to all slaves using the broadcast address 0xFFFFFFFF as destination address.

33.2.1.4 Source address (SA)

Length: 6 bytes

The source address in the real-time telegrams is always the MAC address of the master.

33.2.1.5 Type / length

Length: 2 bytes

The type / length contains the unique SERCOS Ethernet type field number (0x88CD).

33.2.1.6 Data field

Length: 46 bytes to 1500 bytes

All transmitted data is allowed to have arbitrary bit sequences, whereas the total number of bytes follows the rules below.

The data field contains:

- SERCOS specific header (6 bytes) ;
- SERCOS data (40 bytes to 1494 bytes);
- padding bytes shall be inserted whenever the SERCOS data is shorter than 40 bytes.

33.2.1.7 Frame check sequence (FCS)

Length: 4 bytes

A cyclic redundancy check (CRC) is used by the transmit and receive algorithms to generate a CRC value for the FCS field. The frame check sequence (FCS) field contains a 4 byte (32-bit) cyclic redundancy check (CRC) value. This value is computed as a function of the contents of the destination address, source address, type, data and pad (in other words, all MAC layer fields except the preamble, SFD and FCS fields). The FCS is generated by the transmitter. The encoding is defined by the Type S generating polynomial of Table 1, section 5.1.

33.2.2 Timing of the transmission (communication cycle)

33.2.2.1 General

The sequence of transmitting synchronisation, RT-data telegrams and IP telegrams is repeated every communication cycle. The time slots for the RT channel and the IP channel and the transmission time of the AT are transmitted during initialization and are therefore known by each slave. Figure 2 shows two principle arrangements of RT channel and IP channel. Both methods are possible and can be parameterized by the master (see Figure 4). Within the IP channel there are no special time slots. Every participant may send its IP telegrams during this time slot depending upon configuration.

A synchronous collision-free media access control is used in the RT channel. Telegrams are exchanged in fixed communication cycles. The master starts the communication cycle strictly equidistant with the communication cycle time t_{Cyc} , by transmitting the MDT0. The next communication cycle starts with the transmitting of the next MDT0.

The MDTs (MDT0 through MDT3) are transmitted as broadcast telegrams to all slaves. The MDT0 contains the synchronisation information and the status of the communication in the MDT MST field. The content of the MDT MST field remains constant during the same communication phase.

The ATs (AT0 through AT3) are transmitted by the master with an empty data field. Each slave inserts its data into its allocated data field within the ATs. The sequence of the device data fields within the ATs is independent of the physical order of the topology as well as the predefined device address. The master is the final recipient of the ATs. Slave units positioned between the master and the transmitting slave transmit the telegrams by means of their forwarding function.

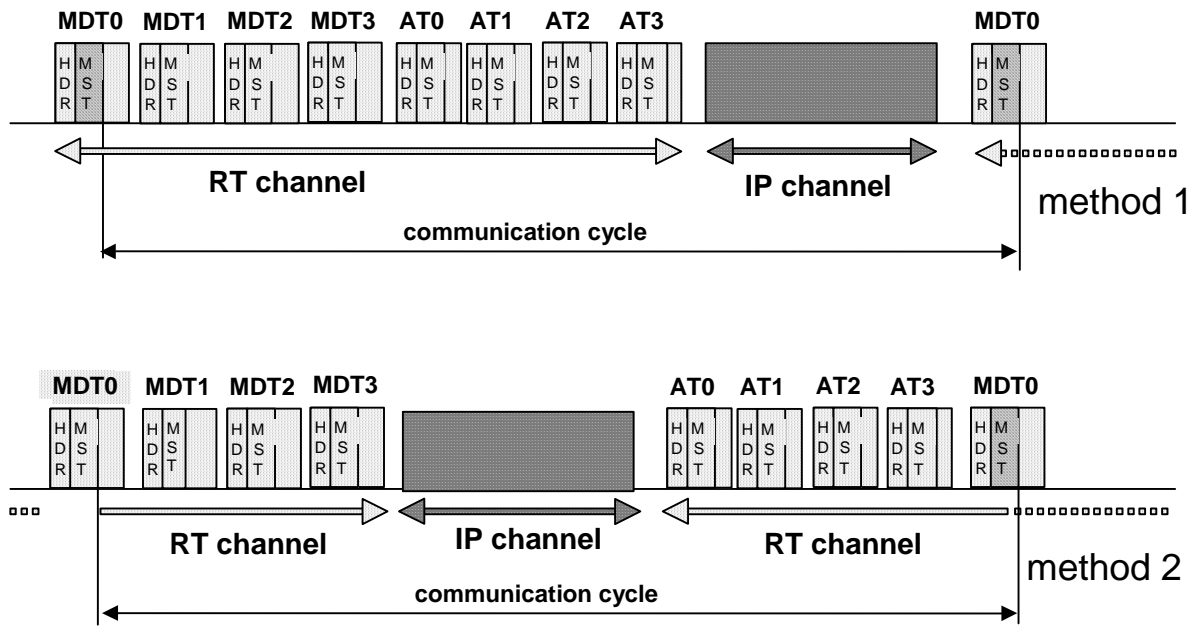


Figure 2 – Telegram sequence in CP3/CP4

33.2.2.2 Transfer medium access

33.2.2.2.1 General

Figure 4 shows the medium access during CP3 and CP4 (cyclic operation). The medium access during CP0 – CP2, which are used during initialization, is given in subclause 14.2 “Initialization of the RT communication” in IEC 61158-6.

In the following text all timings refer to the "beginning of telegram" (see Figure 3). It refers to the edge time of the last binary code 1 of the Start Frame Delimiter (SFD).

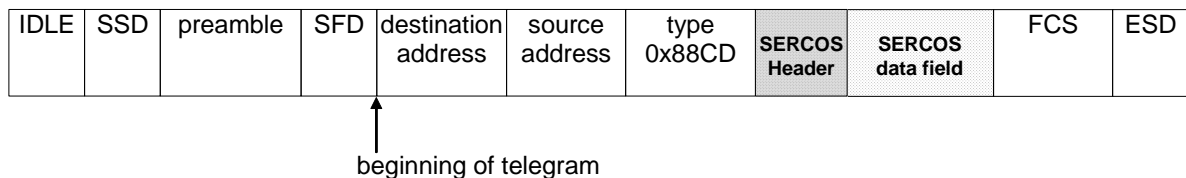


Figure 3 – Beginning of telegram

Medium access is specified by time parameters which shall follow specific limits. Some times are allowed to have a certain amount of jitter.

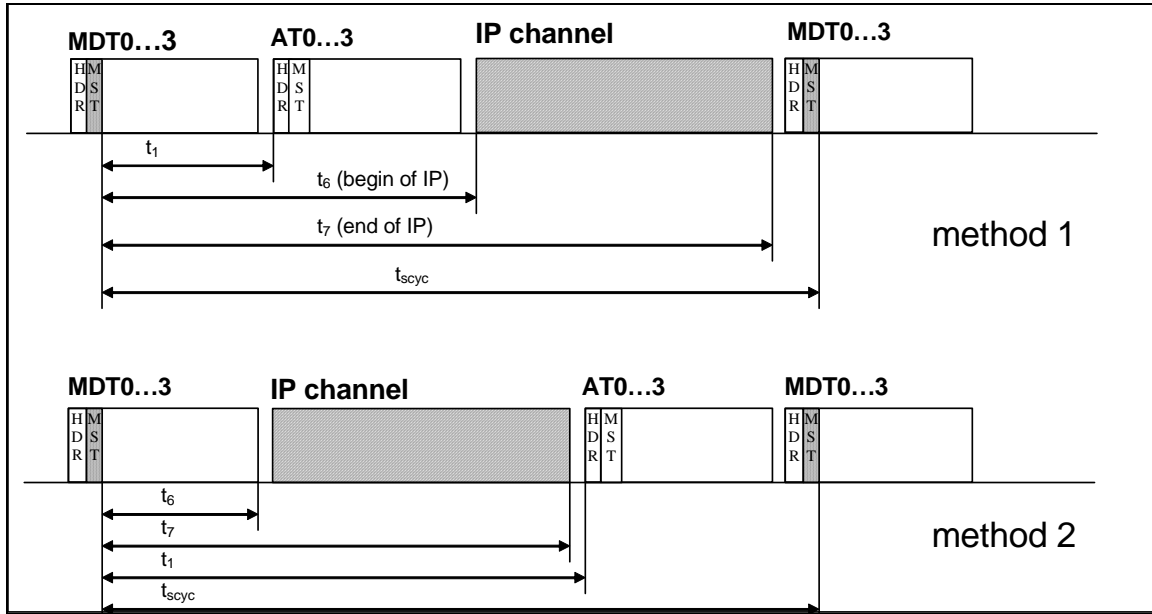


Figure 4 – Access to the transfer medium

NOTE Some control units calculate the new command values only after having received all actual values. In method 1 there is more time available for the calculation of the command values. Method 2 is more appropriate for position control since the control unit can calculate the new command values while still receiving the actual values.

33.3 Protocol structure in the RT Channel

33.3.1 SERCOS telegram structure

33.3.1.1 General

Every SERCOS telegram has a SERCOS header and a SERCOS data field (see Figure 1). Two SERCOS telegram types are specified: MDTs and ATs.

33.3.1.2 SERCOS header

Length: 6 bytes

The SERCOS header contains the SERCOS specific telegram types. The structure is shown in Figure 5. The SERCOS header specifies the SERCOS types only.

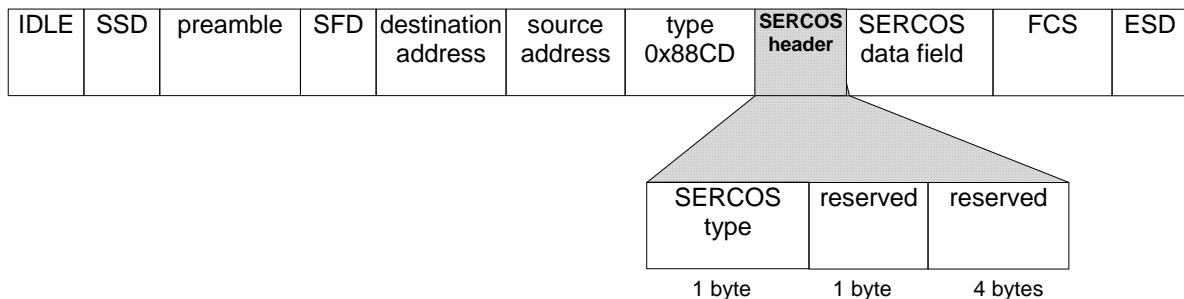


Figure 5 – SERCOS header

The telegram type (see Table 2) is 1 byte long; the following 5 bytes are reserved and specified in the SERCOS telegrams.

Table 2 – SERCOS types

SERCOS type	Description
Bit 7	Primary or secondary telegram
0	Telegram on the primary channel (P-Telegram)
1	Telegram on the secondary channel (S-Telegram)
Bit 6	MDT or AT
0	MDT
1	AT
Bits 5 - 2 = 0	reserved
Bits 1, 0	Telegram number
00	Telegram number 0
01	Telegram number 1
10	Telegram number 2
11	Telegram number 3

NOTE All other bit combinations are reserved.

33.3.2 Device address ADR

The device address ADR shall be in the range $0 \leq \text{ADR} \leq 254$. It is set by the user on the device, e.g., using a selector. No two devices may be set to the same address.

As an exception, device address ADR 0 may occur several times and indicates that no telegrams are being generated by this device. This makes it possible to remove devices logically from the communication (e.g., for testing purposes).

The address value 255 is reserved.

33.3.3 MDT structure

33.3.3.1 General

The MDT contains the MDT MST field and the MDT data field.

33.3.3.2 MDT MST field

33.3.3.2.1 MDT MST field summary

Length: 6 bytes

The SERCOS header of an MDT is called MDT MST (see Figure 6) and contains

- the MDT SERCOS type (see Table 4);
- the MDT phase (see Table 5);
- the CRC (see subclause 33.3.3.2.5).

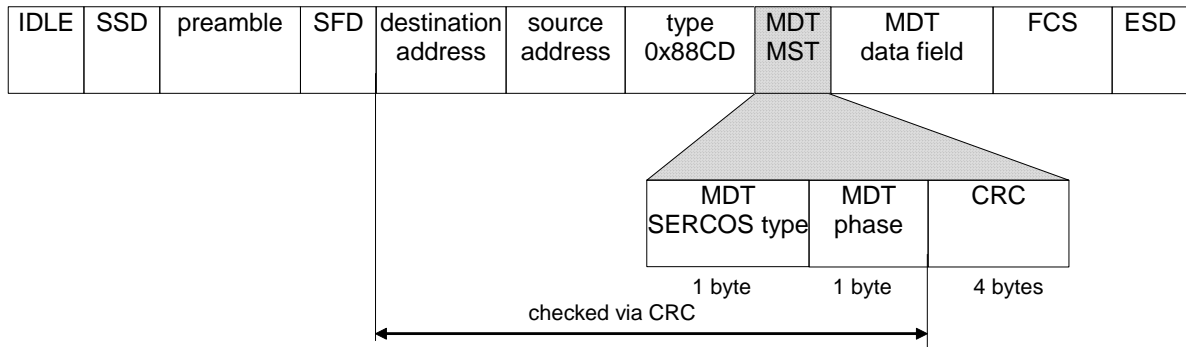


Figure 6 – MDT MST field

33.3.3.2.2 Evaluation of MDT MST in the slave

The MDT MST is generated by the master and evaluated by the slaves. The slave shall evaluate the MDT MST according to Table 3.

Table 3 – MDT MST fields to consider by the slave

	MDT SERCOS type	MDT phase	CRC
MDT0	yes	yes	yes
MDT1	yes	no	no
MDT2	yes	no	no
MDT3	yes	no	no

33.3.3.2.3 MDT SERCOS type

Length: 1 byte

The MDT SERCOS type indicates the various SERCOS telegrams. It is coded in the telegram whether it is an MDT or an AT in the primary or secondary channel. In a line topology the master decides whether the telegrams are marked as primary or secondary telegrams, depending upon configuration.

This type is generated by the master and transmitted in every MDT. Its structure is shown in Table 4.

Table 4 – MDT SERCOS type

MDT SERCOS type	Description
Bit 7	Primary or Secondary telegram
0	MDT on the primary channel
1	MDT on the secondary channel
Bit 6 = 0	MDT
Bit 5-2 = 0	reserved
Bit 1, 0	Telegram number
00	MDT0
01	MDT1
10	MDT2
11	MDT3

33.3.3.2.4 MDT Phase

Length: 1 byte

The phase contains the status of the SERCOS communication. The phase is generated by the master and transmitted in every MDT. The structure is shown in Table 5.

Table 5 – MDT Phase

Phase	Description
Bit 7	Communication phase switching (CPS)
0	current CP
1	new CP
Bit 6-4	reserved
Bit 3-0	Communication phase (CP)
0000	CP0
0001	CP1
0010	CP2
0011	CP3
0100	CP4
0101 - 1111	reserved

NOTE All other bit combinations are reserved

33.3.3.2.5 Cyclic redundancy check (CRC) of MDTs

Length: 4 bytes

The cyclic redundancy check (CRC) is used by the transmit and receive algorithms to generate a CRC value for the CRC field. The CRC field contains a 4 byte (32-bit) cyclic redundancy check (CRC) value. This value is computed as a function of the contents of the source address, destination address, type/length, SERCOS type and phase. The CRC is generated by the master and transmitted in every MDT (MDT0 to MDT3). This CRC is used for synchronisation purposes in MDT0 only. The encoding is defined by the Type S generating polynomial of Table 1, section 5.1.

33.3.3.3 MDT Data field**33.3.3.3.1 General**

In the data field the telegram data are transmitted from the master to all slaves.

The MDT data field (see Figure 7) contains 2 or 3 fields:

- (always) the MDT hot-plug field (see Figure 8);
- (optionally) the MDT service channel field (see Figure 9) for all devices;
- (optionally) the MDT real-time data field (see Figure 11) for all devices.

Subclause 21.1.3 “MDT and AT combinations” in IEC 61158-3 shows examples of valid MDT data fields.

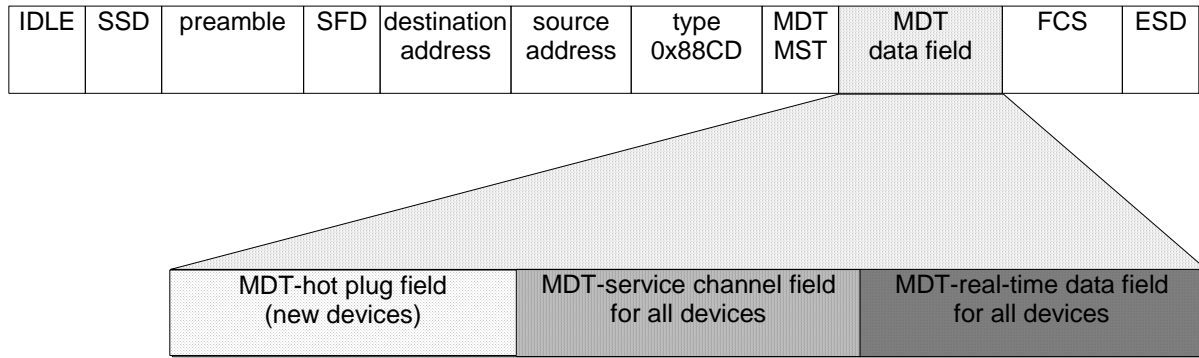


Figure 7 – MDT data field

33.3.3.3.2 MDT Hot plug field

33.3.3.3.2.1 MDT Hot plug field summary

Length: 8 bytes

The MDT hot plug field (see Figure 8) contains:

- the device address (see Table 6);
- the MDT service channel control (see Table 7);
- the MDT service channel INFO (see subclause 33.3.3.3.2.3).

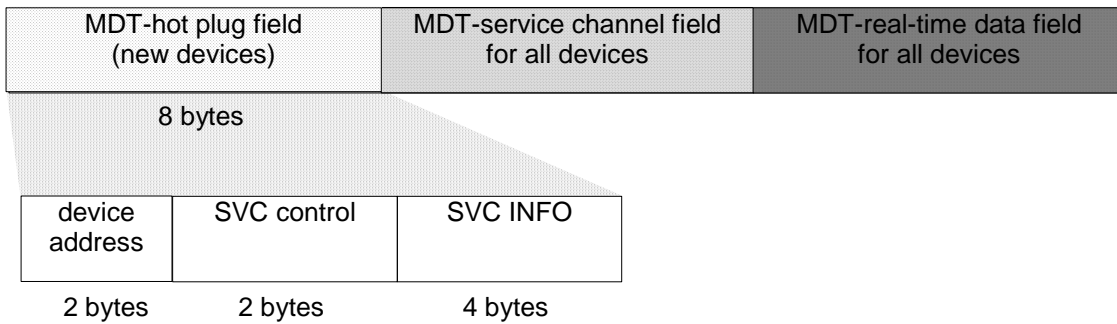


Figure 8 – MDT Hot plug field

33.3.3.3.2.2 Device address

Length: 2 bytes

The structure of device address ADR is shown in Table 6.

Table 6 – Device address

Device address	Description
Bit 15-8	Reserved
Bit 7-0	Device address
0	Logical device removal (see subclause 33.3.2)
1 - 254	Device addresses for operation
255	Reserved (see subclause 33.3.2)

33.3.3.3.2.3 SVC control and SVC INFO

Refer to the MDT service channel field as described in subclause 33.3.3.3.3.

33.3.3.3.3 MDT service channel field

33.3.3.3.3.1 MDT service channel field summary

Length: 6 bytes per device

The MDT service channel field (see Figure 9) contains all service channels (SVC) of the configured devices. Each device has an own service channel. The service channel for each device contains:

- the MDT service channel control (see Table 7);
- the MDT service channel INFO.

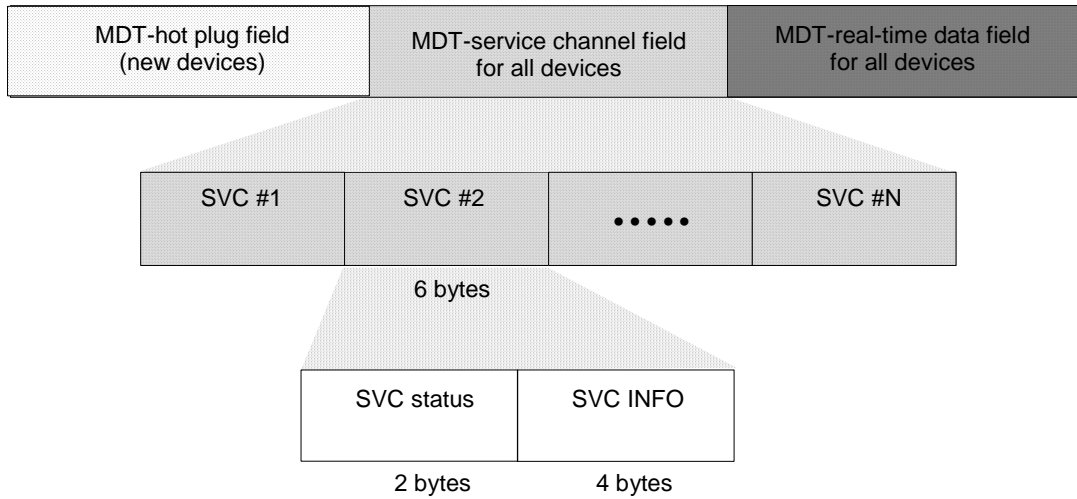


Figure 9 – MDT Service channel

33.3.3.3.3.2 SVC control

Length: 2 bytes

The structure of service channel (SVC) control is shown in Table 7.

Table 7 – Service channel control

SVC control	Description
Bit 15-6	Reserved
Bit 5-3	Data block elements (see subclause 14.4.2 “Service channel transport mechanism” in IEC 61158-6)
000	Element 0: Closed SVC or transmission cancellation in progress
001	Element 1: IDN of operation data. The SVC is closed for the previous IDN and opened for the new IDN
010	Element 2: Name of operation data
011	Element 3: Attribute of operation data
100	Element 4: Unit of operation data
101	Element 5: Minimum value of operation data
110	Element 6: Maximum value of operation data
111	Element 7: Operation data
Bit 2	End of element transmission
0	Transmission in progress
1	Last transmission
Bit 1	R/W
0	Read SVC INFO
1	Write SVC INFO
Bit 0	MHS
0/1	SVC transport handshake of the master (toggle bit)

Note: all other bit combinations are reserved

33.3.3.3.3.3 SVC INFO

Length: 4 bytes

The structure of service channel (SVC) INFO is shown in Figure 10. The SVC INFO is the container for SVC data exchange from the master to a slave which takes place in steps in special data fields of the MDT. If only 2 bytes are transmitted in a step, then the value is in the low word. In this case the high word value shall be don't care.

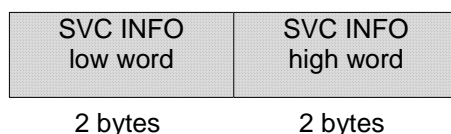


Figure 10 – SVC INFO

33.3.3.3.4 MDT real-time data field

33.3.3.3.4.1 General

The MDT real-time data field (see Figure 11) contains all real-time data of the configured devices. Each device has its own real-time data field and contains:

- the device control (see Table 8);
- the configured real-time data (e.g., command values, ...).

33.3.3.3.4.2 Device control

Length: 4 bytes

The structure of device control is shown in Table 8.

Table 8 – Device control

Device control	Description
Bits 31-16	Reserved
Bit 15 - 8	Reserved for application profiles
Bit 7	Real-time control bit 2 (S-0-0302)
Bit 6	Real-time control bit 1 (S-0-0300)
Bits 5 - 0	Reserved

Note: all other bit combinations are reserved

33.3.3.3.4.3 Configurable MDT RT-data

The configurable real-time data field of the MDT (see Figure 11) is specified in subclause 16.2.1 “Configurable MDT RT-data” of IEC 61158-5.

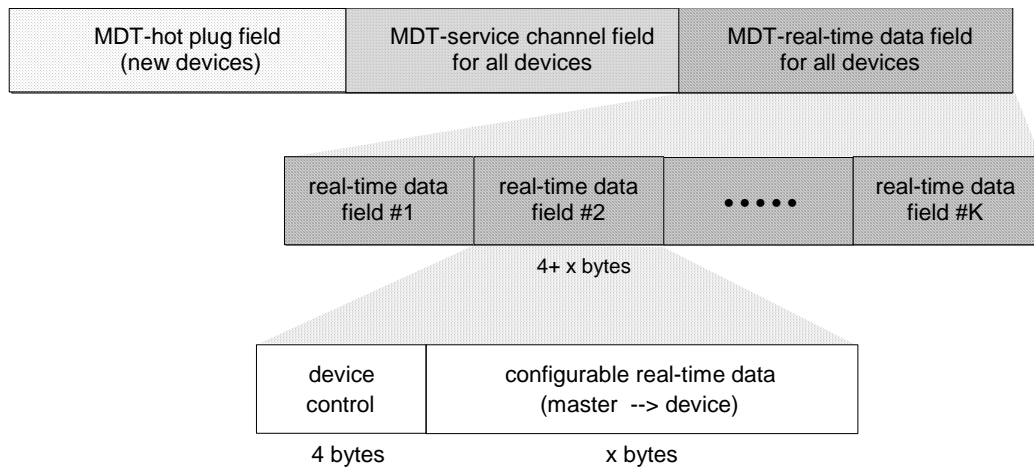


Figure 11 – MDT Real-time data

33.3.4 AT structure

33.3.4.1 General

The AT contains the AT MST field and the AT data field.

33.3.4.2 AT MST field

33.3.4.2.1 AT MST field summary

Length: 6 bytes

The SERCOS header of the AT is called AT MST (see Figure 12) and contains the same information as the MDT MST,

- AT SERCOS type (see Table 10);
- AT phase (see 33.3.4.2.4);
- CRC (see 33.3.4.2.5).

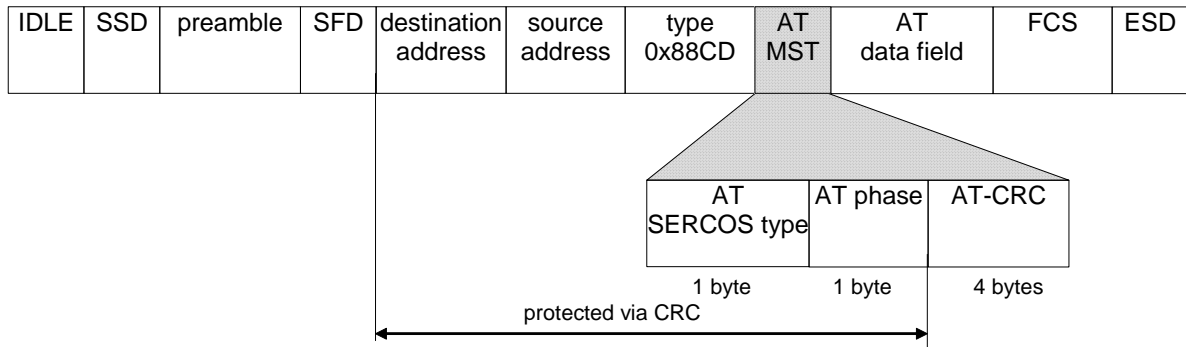


Figure 12 – AT MST field

33.3.4.2.2 Evaluation of AT MST in the slave

The AT MST is generated by the master and evaluated by the slaves. The slave shall evaluate the AT MST according to Table 9.

Table 9 – AT MST fields to be considered by the slave

	AT SERCOS type	AT Phase	CRC
AT0	yes	no	no
AT1	yes	no	no
AT2	yes	no	no
AT3	yes	no	no

33.3.4.2.3 AT SERCOS type

Length: 1 byte

The AT SERCOS type indicates the various SERCOS telegrams. The SERCOS type of all ATs is generated by the master. The structure is shown in Table 10.

Table 10 – AT SERCOS type

AT SERCOS type	Description
Bit 7	Primary or Secondary telegram
0	AT on the primary channel
1	AT on the secondary channel
Bit 6 = 1	AT
Bit 5 – 2 = 0	Reserved
Bit 1, 0	Telegram number
00	AT0
01	AT1
10	AT2
11	AT3

33.3.4.2.4 AT Phase

Length: 1 byte

The phase contains the status of the SERCOS communication. The phase of all ATs is generated by the master and has the same value as for the MDT. The phase of an AT is not evaluated by the slave (see Table 9).

33.3.4.2.5 Cyclic redundancy check (CRC) of AT

Length: 4 bytes

The cyclic redundancy check (CRC) is used by the transmit and receive algorithms to generate a CRC value for the CRC field. The CRC field contains a 4 byte (32-bit) cyclic redundancy check (CRC) value. This value is computed as a function of the contents of the source address, destination address, type/length, telegram AT SERCOS type and phase. The AT-CRC is generated by the master. The AT-CRC is not evaluated by the slave (see Table 9). The encoding is defined by the Type S generating polynomial of Table 1, section 5.1.

33.3.4.3 AT Data field

33.3.4.3.1 General

In the AT data field the telegram data are transmitted from all slaves to the master.

The AT data field (see Figure 13) contains 2 or 3 fields:

- (always) the AT hot plug field (see Figure 14);
- (optionally) the AT service channel field (see Figure 15) for all devices;
- (optionally) the AT real-time data field (see Figure 16) for all devices.

Subclause “MDT and AT combination” 21.1.3 in IEC 61158-3 shows examples of valid AT data fields.

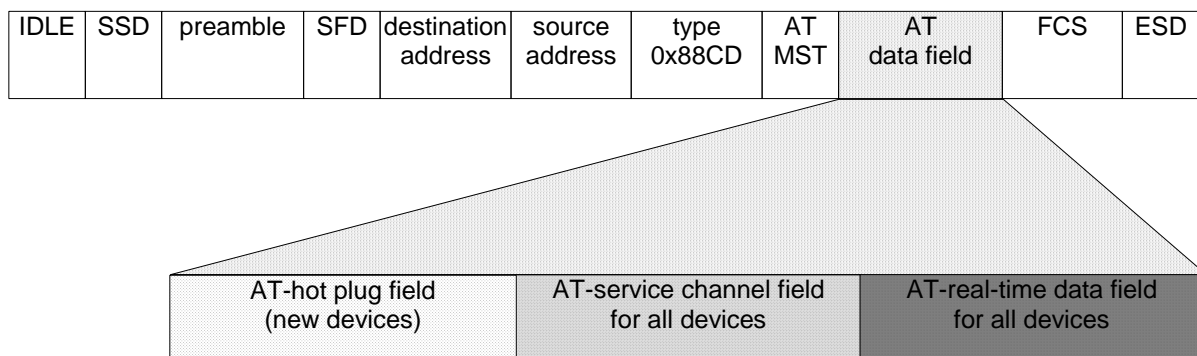


Figure 13 – AT data field

33.3.4.3.2 AT Hot plug field

33.3.4.3.2.1 AT Hot plug field summary

Length: 8 bytes

The hot plug field as shown in Figure 14 contains:

- the device address (see Table 6);
- the AT service channel status (see Table 11);
- the service channel INFO.

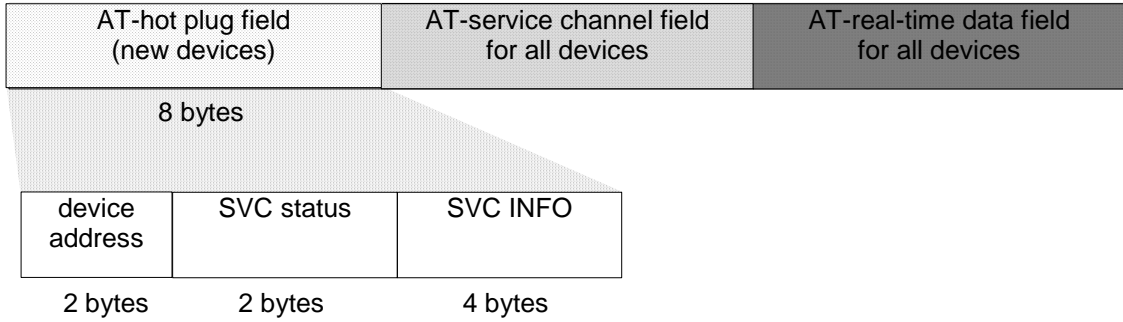


Figure 14 – AT Hot plug field

33.3.4.3.2.2 Device address

See 33.3.3.3.2.2.

33.3.4.3.2.3 SVC status and SVC INFO

The structure of the service channel (status and INFO fields) is described in subclause 33.3.4.3.3.

33.3.4.3.3 AT service channel fields

33.3.4.3.3.1 AT service channel fields summary

Length: 6 bytes per device

The AT service channel field contains all service channels of the configured devices. Each device has its own dedicated service channel. The service channel for each device contains:

- the service channel status (see Table 11);
- the service channel INFO.

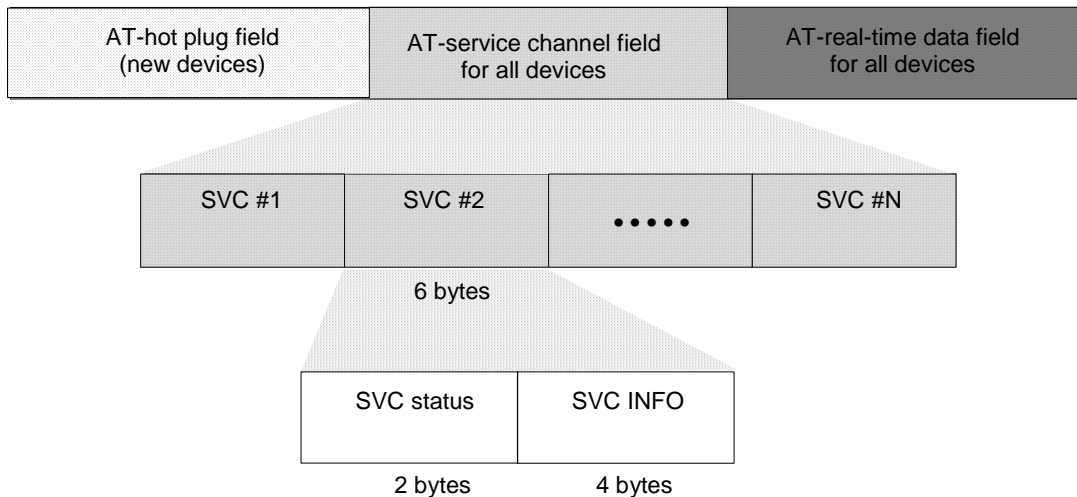


Figure 15 – AT Service channel

33.3.4.3.3.2 SVC channel status

Length: 2 bytes

The structure of service channel (SVC) status is shown in Table 11.

Table 11 – Service channel status

SVC status	Description
Bit 15-4	Reserved
Bit 3	SVC process
0	SVC not valid (SVC is not processed by the slave)
1	SVC valid (SVC is processed by the slave)
Bit 2	SVC error
0	No error
1	Error in SVC, error message in SVC INFO
Bit 1	Busy
0	Step finished, slave ready for new step
1	Step in process, new step not allowed
Bit 0	AHS
0/1	SVC transport handshake of the slave (toggle bit)

NOTE all other bit combinations are reserved

33.3.4.3.3 SVC INFO

Length: 4 bytes

The structure of service channel (SVC) INFO is shown in Figure 10. The SVC INFO is the container for SVC data exchange from a slave to the master which takes place in steps in special data fields of the AT. If only 2 bytes are transmitted in a step, then the value is in the low word. In this case the high word shall be don't care.

33.3.4.3.4 AT real-time data field

33.3.4.3.4.1 General

The AT real-time data field (see Figure 16) contains all real-time data of the configured devices. Each device has its own dedicated real-time data field and contains:

- the device status (see Table 12) and
- the configured real-time data (e.g. feedback values, ...).

33.3.4.3.4.2 Device status

Length: 4 bytes

The structure of device status is shown in Table 12.

Table 12 – Device status

Device status	Description
Bit 31-16	Reserved
Bits 15, 14	Device ready to operate
00	Device not ready, internal checks not yet concluded successfully (CP0 to CP3)
01	Device logic ready for application (CP4)
10	reserved for application profile
11	reserved for application profile
Bit 13	Device shut-down error in C1D (S-0-0011, see IEC 61491)
0	No shut-down
1	Device is shut down due to error
Bits 12-8	reserved for application profile
Bit 7	Real-time status bit 2 (S-0-0306)
Bit 6	Real-time status bit 1 (S-0-0304)
Bit 5	Procedure command change bit (see IEC 61491)
0	No change in procedure command acknowledgement
1	Changing procedure command acknowledgment
Bit 4	Reserved
Bit 3	Reserved for application profile
Bit 2-0	Reserved

NOTE All other bit combinations are reserved.

33.3.4.3.4.3 Configurable AT RT-data

The configurable real-time data field of the AT (see Figure 16) is specified in 16.1.2 of IEC 61158-5.

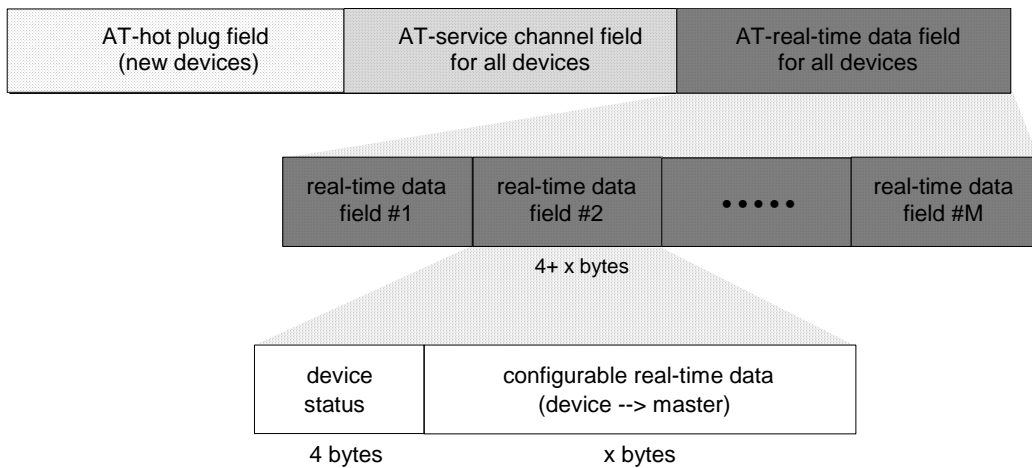


Figure 16 – AT Real-time data

Section D – Update to IEC 61158-5

2 Normative references

IEC 61491:2002, *Electrical equipment of industrial machines - Serial data link for real-time communication between controls and drives.*

ISO/IEC 8802-3:2001, *Information technology - Telecommunications and information exchange between systems - Local and metropolitan area networks - Specific requirements - Part 3: Carrier sense multiple access with collision detection (CSMA/CD) access method and Physical Layer specifications.*

16 Type S: Communication model specification

16.1 Telegram flow through the network

16.1.1 Telegrams on the transmission medium with ring structure

The master sends the MDTs and ATs at the same time on Port 1 and Port 2 (see Figure 1). Data flows on both channels from the master through the slaves and back to the master. Figure 1 portrays the delay time between the master and the slaves in both channels.

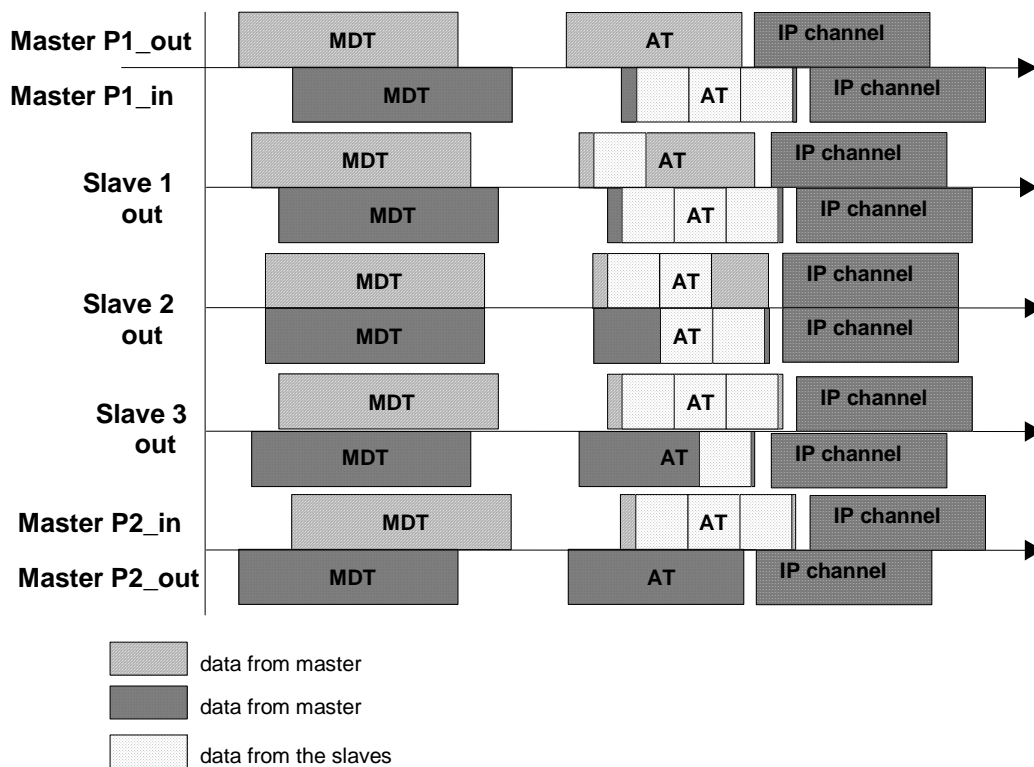


Figure 1 – Data flow with a ring structure example

16.1.2 Telegrams on the transmission medium with line structure:

The master sends the MDTs and ATs only on port P1 (or P2) (see Figure 2). Data flows from the master through the slaves till the last one in the line is reached. It then loops and flows in reverse direction through the slaves back to the master. Figure 2 shows the delay time between the master and the slaves.

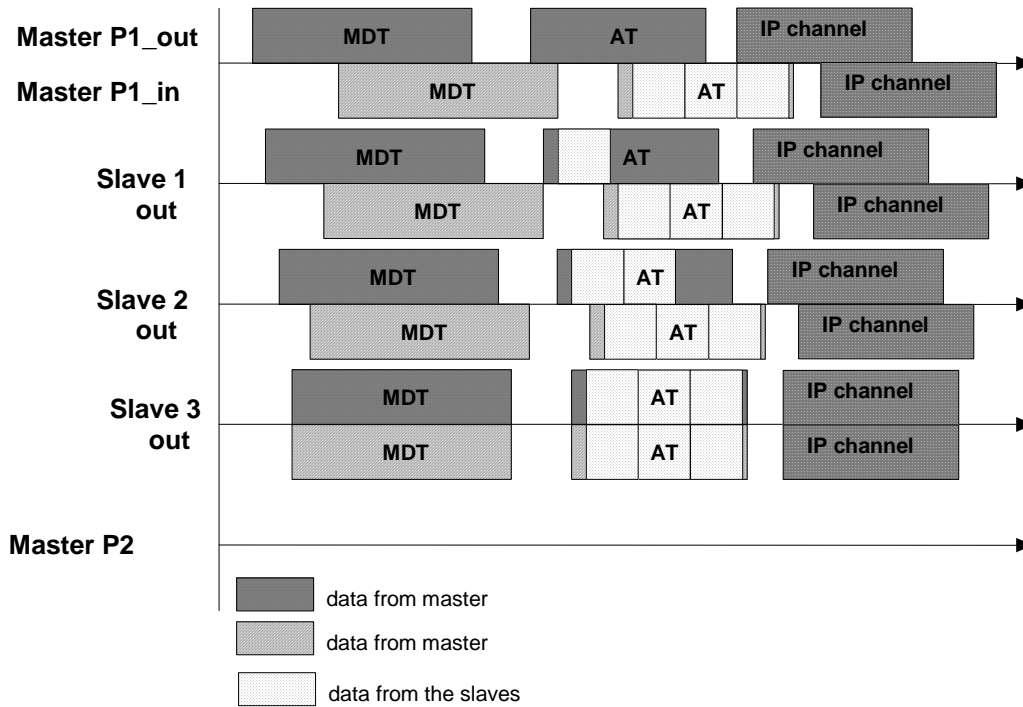


Figure 2 – Data flow with line structure

16.2 Data transfer in RT channel

16.2.1 Configurable MDT RT-data

The configurable real-time data field of the MDT (see Figure 11) can be used for transmitting individual real-time data to any device. Only element 7 of the data block, configured in two, four or eight byte length can be used. The telegram type parameter S-0-0015 determines which operation data is included in the configurable real-time data field of the MDT. The appropriate operation data for standard telegrams is defined by this parameter. The structure of the application telegram is determined by the configuration list labelled S-0-0024.

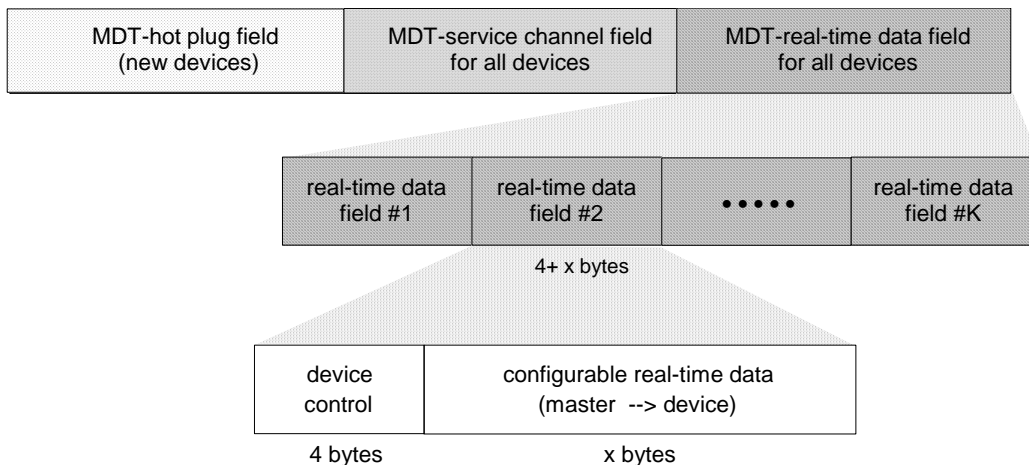


Figure 3 – MDT Real-time data

16.2.2 Configurable AT RT-data

The configurable real-time data field of the AT (see Figure 16) can be used for transmitting individual real-time data to any device. Only operation data configured in two, four or eight byte length can be used. The telegram type parameter S-0-0015 determines which operation

data is included in the configurable real-time data field of the AT. The appropriate operation data for standard telegrams is defined by this parameter. The structure of the application telegram is determined by the configuration list labelled S-0-0016.

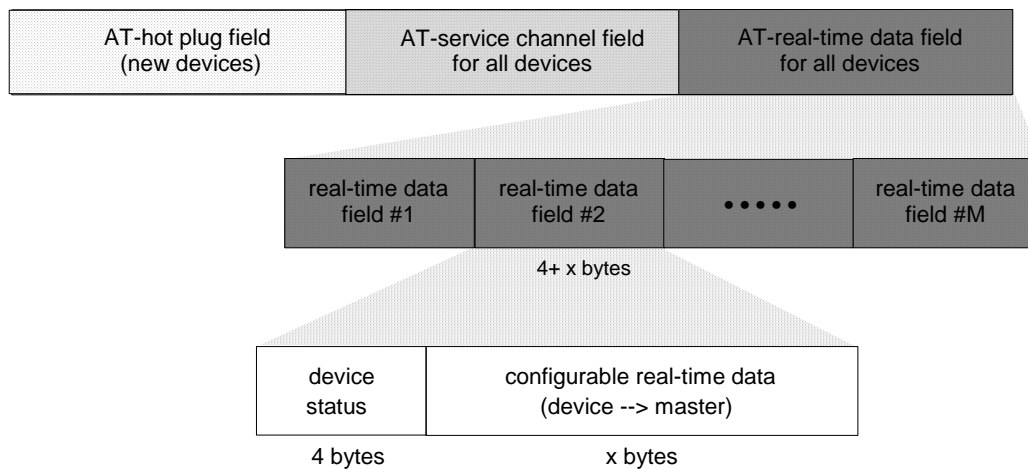


Figure 4 – AT Real-time data

The structure of the application telegram is determined by the configuration list labelled S-0-0016. An example of an AT configuration is shown in Figure 5. The configuration of the real-time data in the MDT and AT is specified in the IEC 61491.

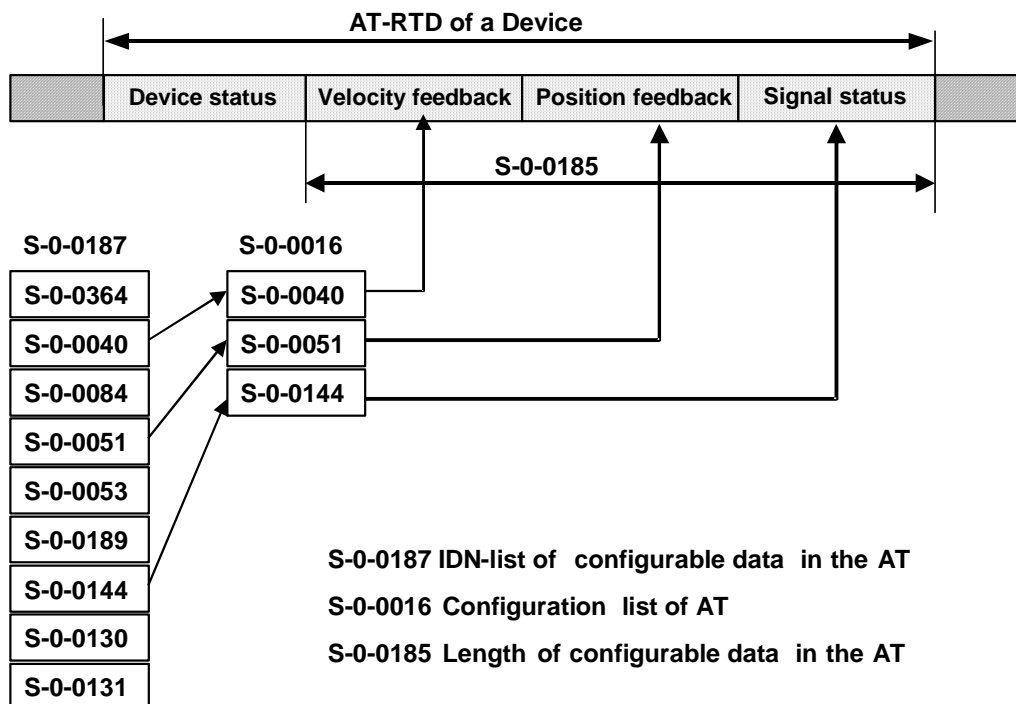


Figure 5 – Configuration example of AT real-time data

16.3 Standard IP communication

16.3.1 General

Before SERCOS real-time has been initialized, communication with the slaves is possible using standard IP mechanisms. As soon as initialization has started or is done, IP communication is possible only in the IP channel.

During the IP channel (time slot between t_6 and t_7) the participants send their IP telegrams simultaneously on both ports. Forwarding (P1 ↔ P2) is active in all slaves (see Figure 6). It is active in the master only by a two-line topology (see Figure 7).

IP telegrams may be forwarded either immediately or later on depending on communication load (refer to 29.2.6.1 “Slaves within a line or a ring” in IEC 61158-2).

Loopback shall never be active while the IP channel is on, even if a participant detects a communication interruption and becomes the last one in a line configuration (see Figure 8).

No device specific slots are allocated for the data in the IP channel.

Table 1 – Telegram transmission in RT and IP channels

	RT channel	IP channel
Transmission type	slave: insertion into AT	complete Ethernet telegrams
Transmission time	slave: independent on both ports	identical transmission on both ports

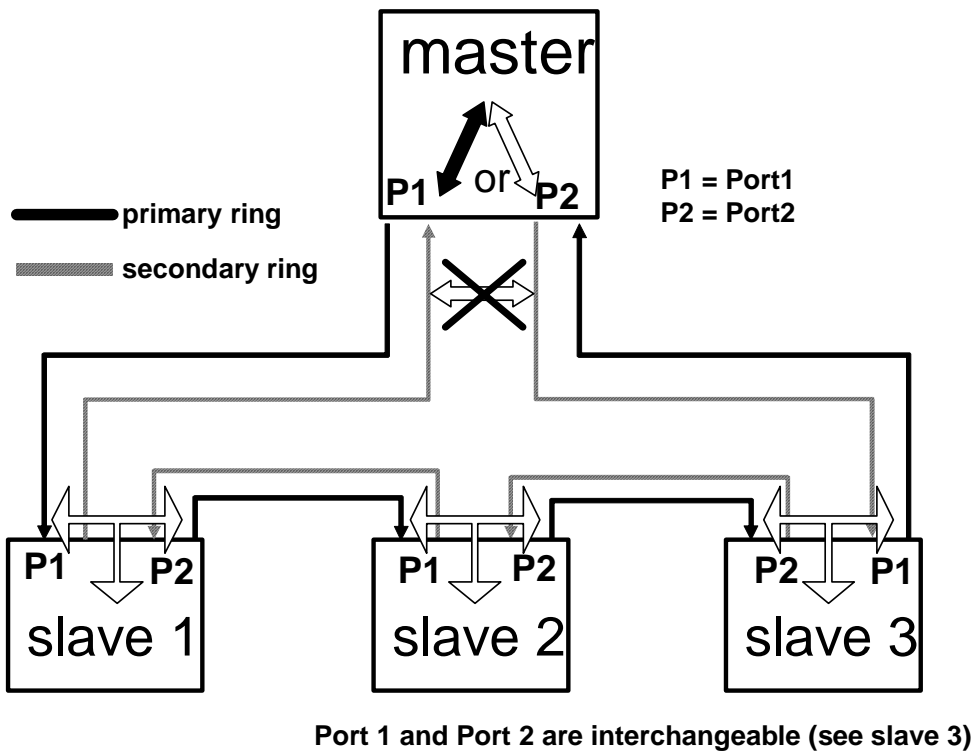
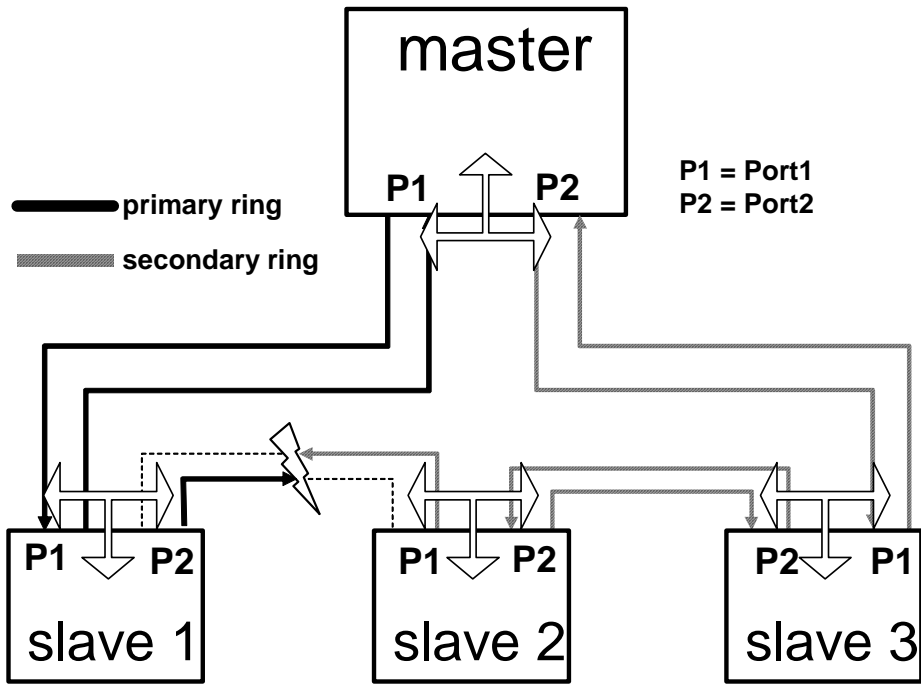


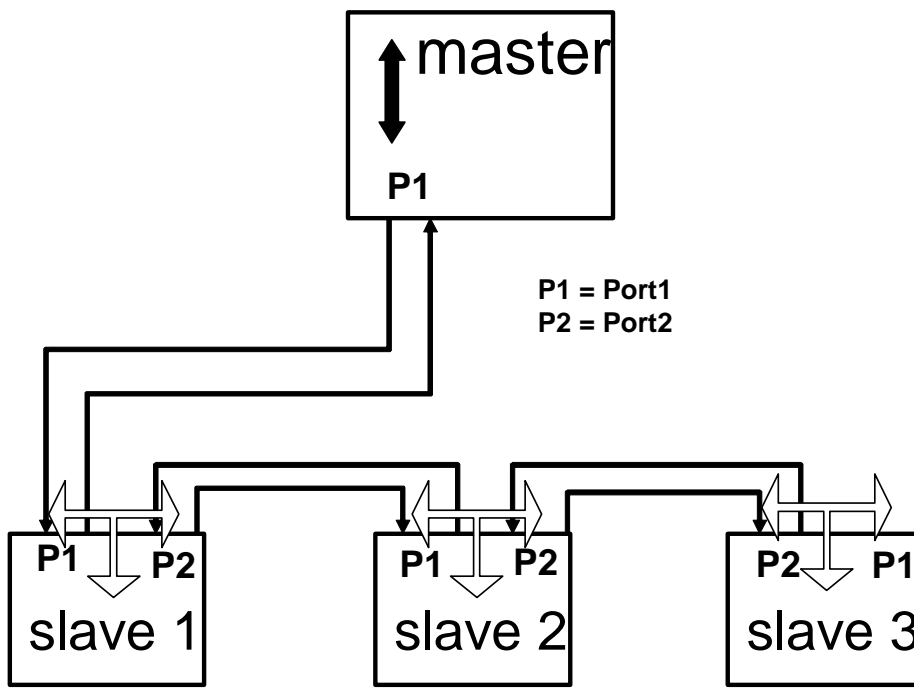
Figure 6 – Forwarding and loopback in IP channel – error-free ring configuration



Port 1 and Port 2 are interchangeable (see slave 3)

Figure 7 – Forwarding and loopback in IP channel – faulty ring configuration

NOTE Interruption may be either accidental or intentional.



Port 1 and Port 2 are interchangeable (see slave 3)

Figure 8 – Forwarding and loopback in IP channel – line configuration

16.3.2 IP telegrams

The IP channel handles most Ethernet telegrams.

16.3.3 IP addressing

Since every slave transmits complete Ethernet telegrams, it needs a unique MAC address.

No additional special Ethernet initialization is needed to use the IP channel.

16.4 Initialization of the RT communication

16.4.1 General

This subclause describes the telegram structure and the transmission timings during network initialization. Initialization is divided into five communication phases (CPs).

16.4.2 Communication phase 0 (CP0)

16.4.2.1 Structure of the telegrams in CP0

The MDT MST field is used in the MDT0 only; the MDT data field is padded and not used (see Figure 9).

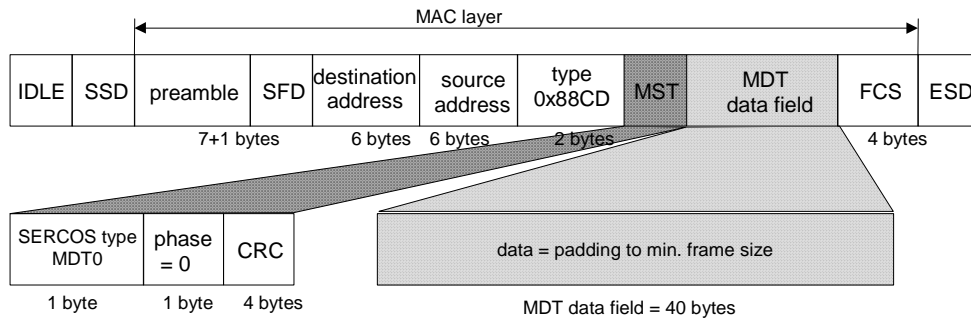


Figure 9 – MDT0 structure in CP0

The AT0 contains the AT MST and the AT data field with 256 device addresses (2 bytes each). The master transmits the AT0 and sets the content to 0 (see Figure 10).

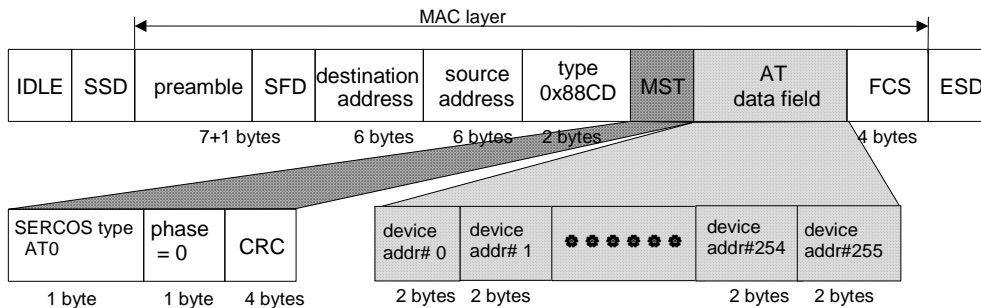


Figure 10 – AT0 structure in CP0

16.4.2.2 Telegram transmission timing of CP0

The communication cycle time is preset by the master with $1 \text{ ms} \leq t_{\text{Scyc}} \leq 65 \text{ ms}$. The telegram timing of CP0 is shown in Figure 11. No transmission time is defined for AT0, it has to be transferred before time t_{6init} is started.

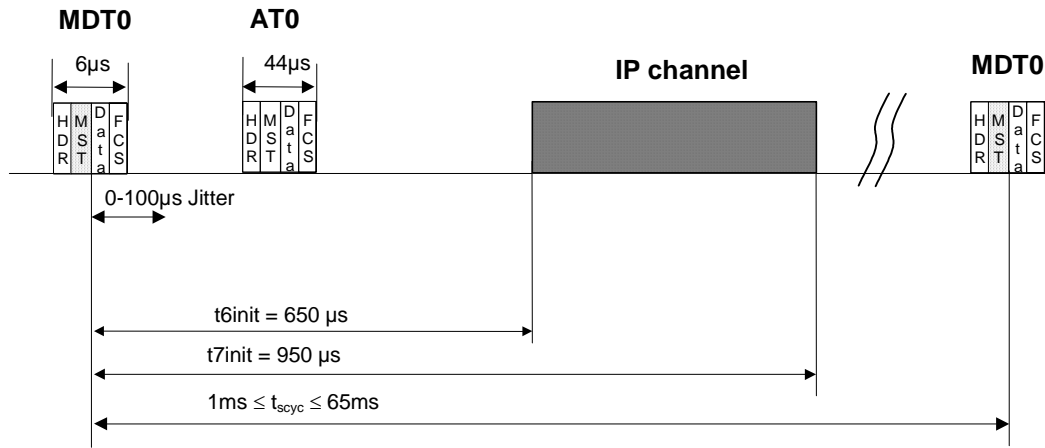


Figure 11 – Timing diagram of CP0

16.4.3 Communication phase 1 (CP1)

16.4.3.1 Structure of the telegrams in CP1

The MDT data field of the MDT0 contains the service channel and the device control of device addresses 0 to 127. The MDT data field of the MDT1 contains the service channel and the device control of device addresses 128 to 255. See Figure 12.

A slave is requested, if the handshake bit (MHS) is set to 1 in the corresponding SVC control. The SVC INFO and the device control are don't care.

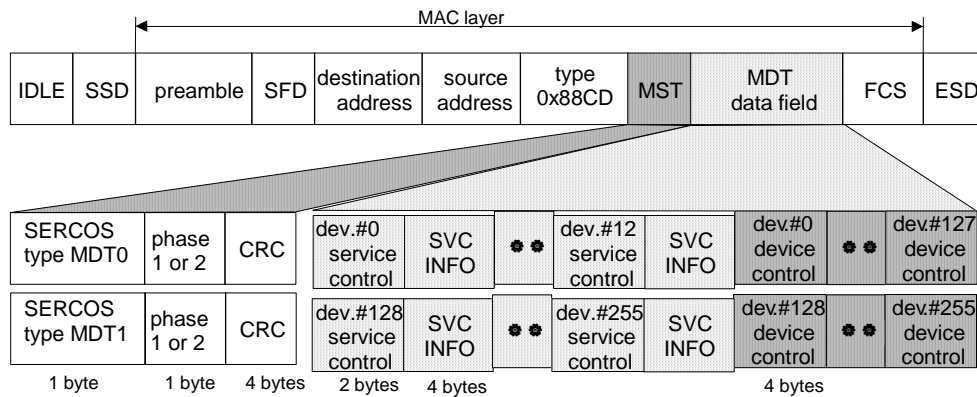


Figure 12 – MDT structure in CP1 and CP2

The AT data field of the AT0 contains the service channel and the device status of device addresses 0 to 127. The AT data field of the AT1 contains the service channel and the device status of device addresses 128 to 255. See Figure 13.

The slave responds by setting the handshake bit (AHS) and valid bit (SVC valid) to 1 in the corresponding SVC status. The SVC INFO is don't care; the shut-down bit is active in the device status. The bits ready to operate (15 and 14) are set to 0.

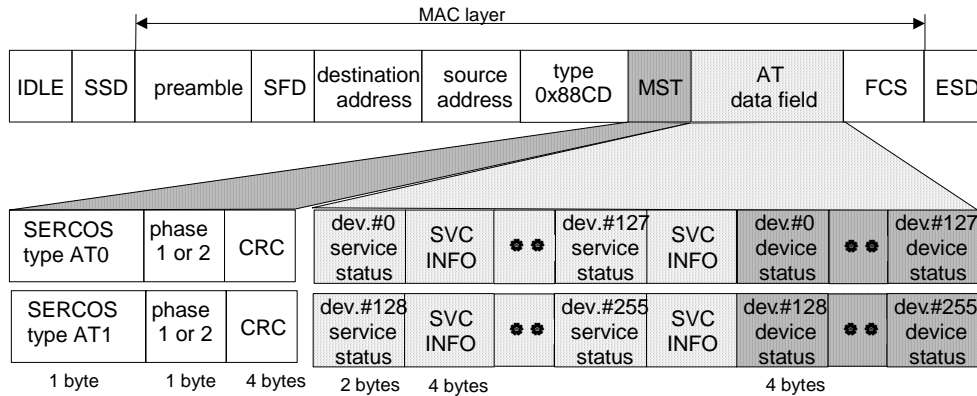


Figure 13 – AT structure in CP1 and CP2

16.4.3.2 Telegram transmission timing in CP1

The communication cycle time is preset by the master with $1\text{ ms} \leq t_{\text{scyc}} \leq 65\text{ ms}$. The telegram transmission starting times during CP1 and CP2 are shown in Figure 14. No transmission times are defined by MDT1, AT0 and AT1; all telegrams have to be transferred before the time $t_{6\text{init}}$ is started. The master shall not send MDT1 nor AT1 if the time $t_{6\text{init}}$ (begin of IP channel) is exceeded by the AT1 (e.g. jitter too large).

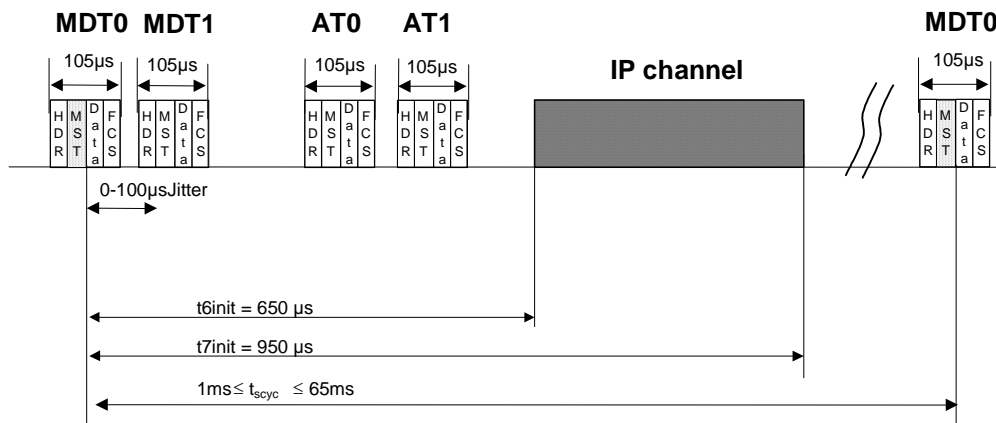


Figure 14 – Timing diagram of CP1 and CP2

16.4.4 Communication phase 2 (CP2)

16.4.4.1 Structure of the telegrams in CP2

Telegrams in CP2 have the same structure as in CP1, but the contents of SVC INFO are now valid. The MDT structure is shown in Figure 12, the AT structure is shown in Figure 13.

The content of device control is don't care. In the device status field, the shut-down bit and the procedure command change bit are active.

16.4.4.2 Telegram transmission timing in CP2

Telegram transmission starting times are the same as in CP1 (see 16.4.3.2 and Figure 14).

16.4.5 Communication phase 3 (CP3)

16.4.5.1 Structure of the telegrams in CP3

The MDT is structured as shown in 33.3.3 “MDT structure” in IEC 61158-4. Only the service channel and device control are used. The configurable real-time data of the MDT do not matter, but they shall have the number of bytes required for CP4. The positions of the service channels and the real-time data fields in the MDT relevant to the individual slaves were transmitted during CP2 with the corresponding communication parameters.

Depending on the application profile some bits in the device control are valid starting CP3 and up to CP4.

The AT is structured as shown in 33.3.4 “AT structure” in IEC 61158-4. Only the service channel and the device status are used. The configurable real-time data of the AT do not matter, but they shall have the number of bytes required for CP4. The positions of the service channels and the real-time data fields in the AT relevant to the individual slaves were transmitted during CP2 with the corresponding communication parameters.

In the device status the shut-down bit and the procedure command change bit are active. The bits “Device ready to operate” (bits 15 and 14) are set to 0. Depending on the application profile some bits in the device status are valid starting CP3 and up to CP4.

16.4.5.2 Telegram transmission timing in CP3 and CP4

Telegram transmission starting times are specified by the parameters which were transmitted during CP2 and correspond to the time-slots for CP3 and CP4. See subclause 33.2.2 “Timing of the transmission (communication cycle3)” and Figure 4 “Access to the transfer medium” in IEC 61158-4).

16.4.6 Communication phase 4 (CP4)

16.4.6.1 Structure of the telegrams in CP4

The MDT is structured as shown in 33.3.3 “MDT structure” in IEC 61158-4. The configurable real-time data are valid and filled with command values which have been determined by the parameters transmitted in CP2. The positions of the service channels and the real-time data fields in the MDT relevant to the individual slaves are transmitted during CP2 with the corresponding communication parameters. The device control that depends on the application profile is valid.

The AT is structured as shown in 33.3.4 “AT structure” in IEC 61158-4. The configurable real-time data are valid and filled with actual values which have been determined by the parameters transmitted in CP2. The device status that depends on the application profile is valid. The bits “Device ready to operate2 (15 and 14) are set to 01. Further combinations are specified in the application profiles.

16.4.6.2 Telegram transmission timing in CP4

Telegram transmission starting times are specified by the communication parameters which were transmitted during CP2. See 33.2.2 “Timing of the transmission (communication cycle3)” and Figure 4 “Access to the transfer medium” in IEC 61158-4).

16.4.7 Switching of communication phases (CPS)

16.4.7.1 General

Every switching of the communication phase is pre-set in the MDT0 by the master and thus transmitted to the slaves. During phase switching (CPS), IP communication is not allowed.

16.4.7.2 Service channel initialization

In CP1, each service channel starts with the following status:

- the MHS-bit in the MDT and the AHS-bit and the SVC valid bit in the AT shall be set to 1 (see 14.4.3 “Service channel initialization” in IEC 61158-6). All other control or status bits of the service channel shall be set to 0;
- all bits in the SVC INFO fields are invalid.

Starting with CP2, the service INFO fields in the MDT and the AT become valid. This implies that the master, and a slave servicing several devices, freezes the status of the service channel before switching from one device to another. When addressing this device again at a later time, the master is set to this frozen status.

16.5 Communication error handling

The master’s and slaves’ reactions in case of communication error within the RT channel are described in the application profile IEC 61491.

16.6 Identification numbers in numerical order

Table 2 shows the list of communication-specific IDNs in numerical order. Additional, application-specific IDNs appear as annex A in IEC 61491.

Table 2 – Communication-specific IDNs in numerical order

IDN	Name
S-0-0000	(reserved)
S-0-0005	Minimum feedback processing time (t_5)
S-0-0007	Feedback acquisition capture point (t_4)
S-0-0008	Command value valid time (t_3)
S-0-0014	Interface status
S-0-0015	Telegram type
S-0-0016	Configuration list of AT
S-0-0024	Configuration list of MDT
S-0-0028	MST error counter
S-0-0029	MDT error counter
S-0-0096	Slave arrangement (SLKN)
S-0-0097	Mask class 2 diagnostic
S-0-0098	Mask class 3 diagnostic
S-0-0134	Device control word
S-0-0135	Device status word
S-0-0140	Controller type
S-0-0141	Motor type
S-0-0142	Application type
S-0-0143	SERCOS Interface version
S-0-0185	Length of the configurable data record in the AT
S-0-0186	Length of the configurable data record in the MDT
S-0-0187	IDN list of configurable data in the AT
S-0-0188	IDN list of configurable data in the MDT
S-0-0301	Allocation of real-time control bit 1

IDN	Name
S-0-0303	Allocation of real-time control bit 2
S-0-0305	Allocation of real-time status bit 1
S-0-0307	Allocation of real-time status bit 2
S-0-0413	Bit number allocation of real-time control bit 1
S-0-0414	Bit number allocation of real-time control bit 2
S-0-0415	Bit number allocation of real-time status bit 1
S-0-0416	Bit number allocation of real-time status bit 2
S-0-1001	Control unit cycle time (t_{Ncyc})
S-0-1002	Communication cycle time (t_{Scyc})
S-0-1006	AT transmission starting time (t_1)
S-0-1009	RTC position of data record in MDT
S-0-1010	Length of MDT
S-0-1011	RTC position of data record in AT
S-0-1012	Length of AT
S-0-1013	SVC position of data record in MDT
S-0-1014	SVC position of data record in AT
S-0-1015	Ring delay
S-0-1016	Slave delay
S-0-1017	Transmission starting time IP channel
S-0-1018	SYNC delay
S-0-1019	MAC address
S-0-1020	IP address
S-0-1021	SYNC-Jitter
S-0-1022	Ring control
S-0-1023	Ring status
S-0-1024	Hardware identification

16.7 Data contents

16.7.1 Data block structure

16.7.1.1 General

All operation data are assigned IDNs.

Every IDN has an underlying data block. Data blocks are used in different data types to supply additional information, which is required to allow the display and input of data and the use of universal routines by means of the control terminal.

This additional information is necessary for handling arbitrary slave-related data. With this information, anonymous operation data can be interpreted by the control unit.

The data block structure is shown in Table 3. In a data block, elements 1, 3, and 7 are mandatory and are always present. Elements 2, 4, 5, and 6 are optional and can be supported. Elements 5 and 6 are mandatory for cycle time parameters (S-0-0001, S-0-0002) only. The appropriate elements of the data blocks are selected via the service channel control bits in the control word.

16.7.1.2 Element 1: structure of IDN

When written and read via the service channels, the appropriate data are addressed by means of the IDNs. Beyond that, operation data within the configurable part of the data records of the AT and MDT are defined by means of the IDNs.

IDNs have a range of 2^{16} which is subdivided into the two ranges for standard data and product data. Every range is subdivided into eight parameter sets.

IDNs are generally transferred in telegrams as 16-bit binary numbers.

Operation data which are not included in standard data but which are required for a specific function of the product shall be specified by the appropriate manufacturer in the product data record.

Table 3 describes the structure of IDNs.

Table 3 – Structure of IDNs

IDN	Description
Bit 15	
0	Standard data (normative)
1	Product data (determined by manufacturer)
Bit 14-12	Parameter set 0-7
000	Parameter set 0
...	...
111	Parameter set 7
Bit 11-0	Data block number from 0 to 4095

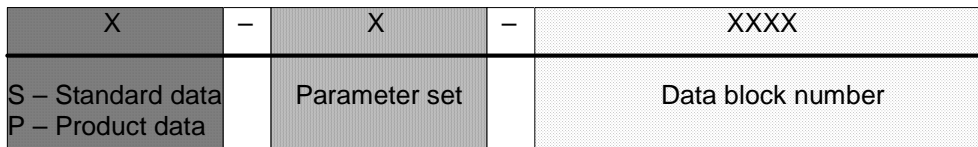


Figure 15 – General structure of IDN

As this specification encompasses only standardized operation data in parameter shall be set to 0.

16.7.1.3 Element 2: name of operation data

Name length: maximum 64 bytes.

The name consists of 64 bytes maximum. It has two length specifications of two bytes each, and a character string of 60 characters maximum (60 bytes). Bytes 1 and 2 of the name specify the length of the programmed text in bytes. Bytes 3 and 4 of the name indicate the maximum number of characters available for text in a slave if the name is changeable. Text longer than that specified by these bytes cannot be stored in the slaves. Length specifications of the initial four bytes are coded for hexadecimal digits.

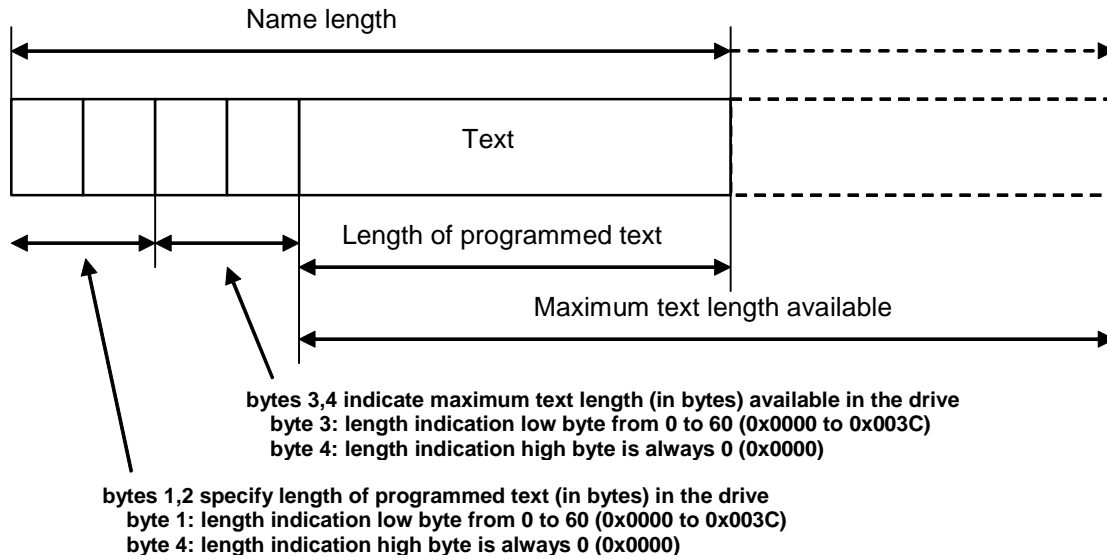


Figure 16 – Name structure

It is advisable to program text length in even numbers since the service channel can only transfer words.

If the programmed text has a length of 0, only the two length indications are transmitted. Bytes 1 and 2 will then contain the value 0.

Reading: In order to complete a read command in the service channel, the master requires bytes 1 and 2. Bytes 3 and 4 are only read by the master to prevent writing text which is too long.

Writing: When writing a name, the master sets bytes 1 and 2 according to the length of the programmed text. The text shall not be longer than specified in bytes 3 and 4. During writing the slave ignores bytes 3 and 4 and inserts its available length during reading.

16.7.1.4 Element 3: attribute of operation data

Attribute structure: Length four bytes.

Every data block has an attribute which allows for an intelligible representation of various operation data by means of universal routines. The attribute contains all information which is needed to display operation data intelligibly. The attribute makes it possible to convert the transferred operation data into intelligible display data and vice versa. The conversion has no impact on the data itself. If data needs to be scaled, specific scaling parameters are supplied. Every scaling modification needs a change in the attributes of the affected data.

Table 4 – Element 3 of IDNs

Bit 31	(Reserved)
Bit 30	Write protected in CP4
0	Operation data is write-able
1	Operation data is write protected
Bit 29	Write protected in CP3
0	Operation data is write-able
1	Operation data is write protected
Bit 28	Write protected in CP2

0 1	Operation data is write-able Operation data is write protected
Bits 27-24	Decimal point: Places after the decimal point indicate the position of the decimal point for the display and input of appropriate operation data. This is additional display information. Decimal point = 0, for data type "floating-point number".
0000 1111	no places after decimal point 15 places after decimal point (maximum)
Bit 23	(Reserved)
Bits 22-20	Data type and display format: Data type and display format are used to convert the operation data and the minimum and maximum input value to the correct display format
	Data type Display format
000	binary number binary
001	unsigned integer unsigned decimal
010	integer signed decimal
011	unsigned integer hexadecimal
100	extended character set text
101	unsigned integer IDN
110	floating-point number signed decimal with exponent (float) (single or double precision, ANSI/IEEE Std 754-1995)
111	reserved
Bit 19	Function of operation data: the function of operation data indicates that this operation data is used to call up procedure command functions in a slave.
0 1	Operation data or parameter Procedure command
Bits 18-16	Data length: data length is required so that the control unit is able to complete service channel data transfers correctly.
000 001 010 011 100 101 110 111	reserved operation data is two bytes long operation data is four bytes long operation data is eight bytes long variable length with one-byte data strings variable length with two-byte data strings variable length with four-byte data strings variable length with eight-byte data strings
Bits 15-0	Conversion factor: the conversion factor is an unsigned integer used to convert numeric data to display format. The conversion factor shall be set to a value of 1 when it is not needed for data display (e.g., for binary display, character string or floating-point number).

Valid combinations of the display formats and data length:

Table 5 – Valid combinations of the display formats

Data length	Display format						
	binary	unsigned decimal	signed decimal	hex	text	IDN	float
2 byte	yes	yes	yes	yes		yes	
4 byte	yes	yes	yes	yes			yes
8 byte	yes	yes	yes	yes			yes
1 byte list					yes		
2 byte list	yes	yes	yes	yes		yes	
4 byte list	yes	yes	yes	yes			yes
8 byte list	yes	yes	yes	yes			yes

16.7.1.5 Element 4: operation data unit

Unit length: maximum 16 bytes.

The unit element consists of 16 bytes maximum. It has two length specifications of two bytes each, and a character string of 12 characters maximum (12 bytes). Bytes 1 and 2 of the unit specify the length in the programmed text in bytes. Bytes 3 and 4 of the unit indicate the maximum number of characters available for text in a slave where it is changeable. Text longer than that specified by these bytes cannot be stored in the slaves. Length specifications of the initial four bytes are coded for hexadecimal digits. Operation data has no unit where the data type is either a binary number or a character string.

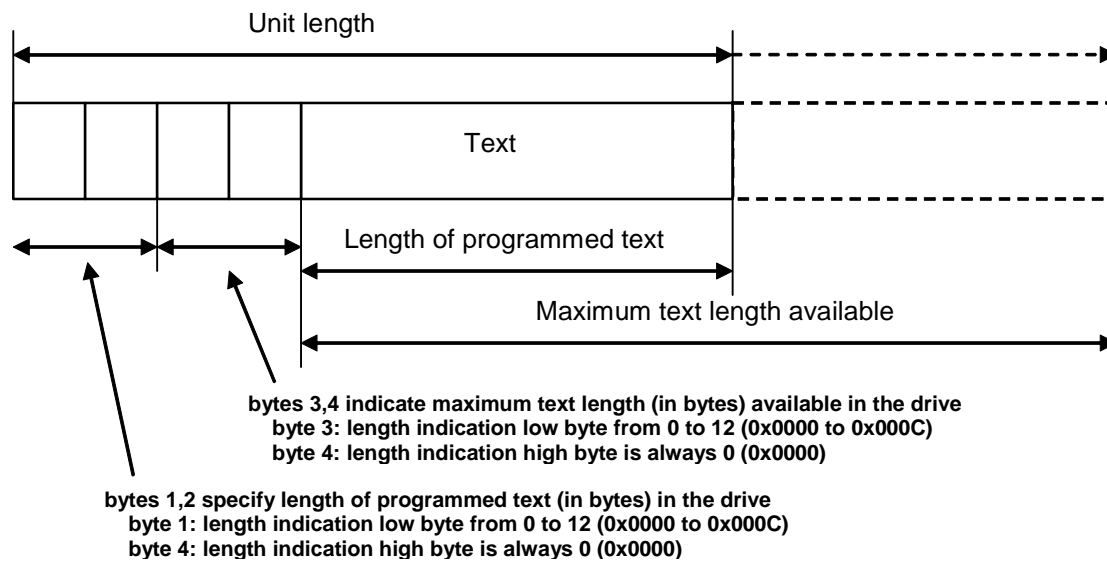


Figure 17 – Unit structure

It is advisable to program text length in even numbers since the service channel can only transfer words.

If the programmed text has the length 0 only the two length indications are transmitted. Bytes 1 and 2 will then contain the value 0.

Reading: In order to complete a read command in the service channel, bytes 1 and 2 are required by the master. Bytes 3 and 4 are only read by the master to prevent writing text which is too long.

Writing: When writing a unit, the master sets bytes 1 and 2 according to the length of the programmed text. The text shall not be longer than specified in bytes 3 and 4. During writing the slave ignores bytes 3 and 4 and inserts its available length during reading.

16.7.1.6 Element 5: minimum input value of operation data

Data length: Same as operation data.

The minimum input value is the smallest numerical value for the operation data which can be processed by the slave.

When, in a write request, the value for the operation data is lower than the minimum input value, the operation data is not changed.

The operation data has no minimum input values if a binary number or a character string is used or when the operation data is of variable length.

Display: The minimum input value is displayed like the operation data.

16.7.1.7 Element 6: maximum input value of operation data

Data length: Same as operation data.

The maximum input value is the largest numerical value for the operation data which can be processed by the slave.

When, in a write request for the operation data, the maximum input value is exceeded, the operation data is not changed.

The operation data has no maximum input value if a binary number or character string is used or if the operation data is of variable length.

Display: The maximum input value is displayed like the operation data.

16.7.1.7.1 Element 7: operation data

The operation data length is divided in four groups:

- fixed length with two bytes;
- fixed length with four bytes;
- fixed length with eight bytes;
- variable length up to 65 532 bytes.

Length specifications for the variable length only are coded in the initial four bytes for hexadecimal digits.

Structure of operation data with variable length is shown in Figure 18.

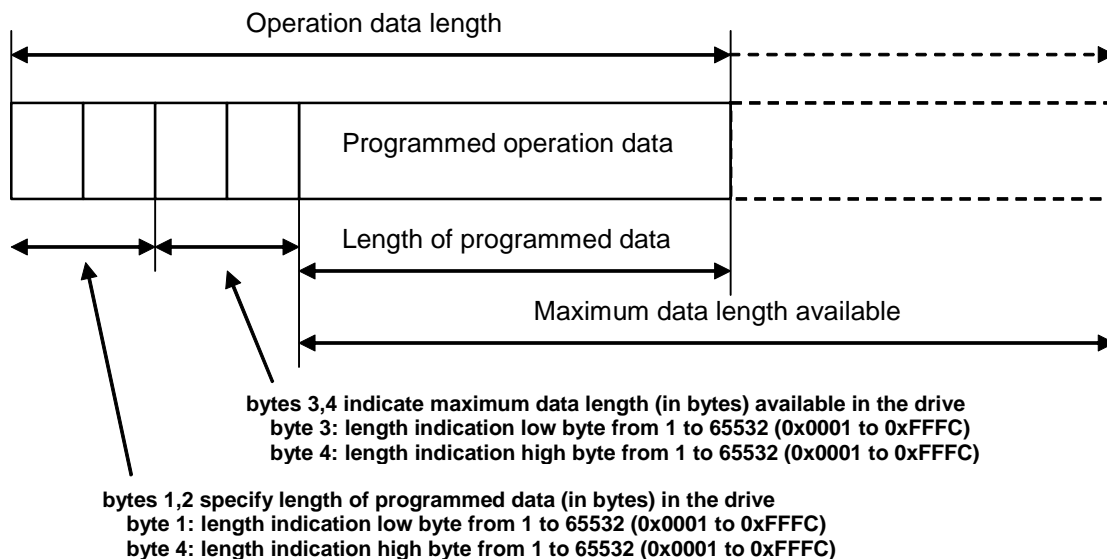


Figure 18 – Structure of operation data with variable length

Operation data with variable length consists of length indicators in the initial four bytes, followed by the programmed operation data.

Files or tables can be loaded from the control unit to the slaves or vice versa by means of the transfer of operation data with variable length (e.g., the IDN-list of all operation data in a slave).

It is advisable to program the length of the operation data in an even number of bytes since the service channel can only transfer words.

When the operation data has the length 0, only the two length indications are transmitted. Bytes 1 and 2 will then contain the value 0.

Reading: in order to complete a read command in the service channel correctly, the master requires bytes 1 and 2. Bytes 3 and 4 are only read by the master to prevent writing operation data which is too long.

Writing: when writing operation data, the master sets bytes 1 and 2 according to the length of the programmed data. The data shall not be longer than specified in bytes 3 and 4. During writing, the slave ignores bytes 3 and 4 and inserts its available length during reading.

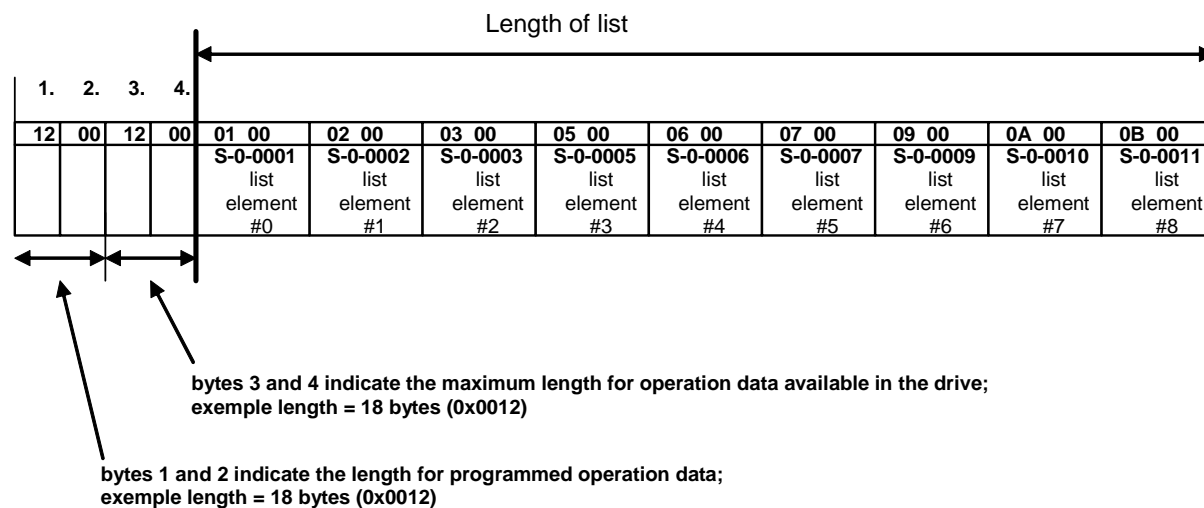


Figure 19 - Example of the structure of an IDN-list

16.7.2 Application-specific data

The application-specific data content is specified in IEC 61491.

Section E – Update to IEC 61158-6

2 Normative references

IEC 61491:2002, *Electrical equipment of industrial machines – Serial data link for real-time communication between controls and drives*

ISO/IEC 8802-3:2001, *Information technology – Telecommunications and information exchange between systems - Local and metropolitan area networks – Specific requirements – Part 3: Carrier sense multiple access with collision detection (CSMA/CD) access method and Physical Layer specifications.*

Internet Engineering Task Force (IETF), Request for Comments (RFC):

- *RFC 768, User Datagram Protocol;*
- *RFC 791, Internet Protocol;*
- *RFC 792, Internet Control Message Protocol;*
- *RFC 793, Transmission Control Protocol;*
- *RFC 903, Address Resolution Protocol.*

3 Terms and definitions

3.6 Conventions

3.6.1 Conventions for Type S

None.

3.7 Conventions used in state machines

3.7.1 State machine conventions for Type S

None.

14 Type S

14.1 Protocol structure in the IP channel

14.1.1 General

This protocol is used for exchanging and transmitting large amounts of non real-time data from one participant to the other (control unit ↔ device ↔ device).

14.1.2 Standard Ethernet protocols

Application layer services shall be mapped onto the TCP/UDP/IP protocol suite as defined in RFC 768, 791, 792, 793 and 903.

14.2 Initialization of the RT communication

14.2.1 General

This subclause describes the transition states of the communication after the network has been completed and all stations have been powered up. This initialization is divided up into five communication phases (CPs). CP0 and CP1 are used for recognizing the participating slaves. In CP2, the timing and data structure of the protocols for CP3 and CP4 are prepared.

The initialization takes place in ascending sequence (see Figure 1). The master shall initiate the CPs by setting the MDT0-Phase (phase field of the MDT MST, see subclause 33.3.3.2.4 “MDT Phase” in IEC 61158-4). The slaves shall follow accordingly. The initialization shall be concluded by switching to CP4, which is a real-time operation with valid real-time data.

Only in case of a communication error shall the slaves switch to CP0. If the slaves don't receive any MDT0 within 65 ms they shall switch to NRT.

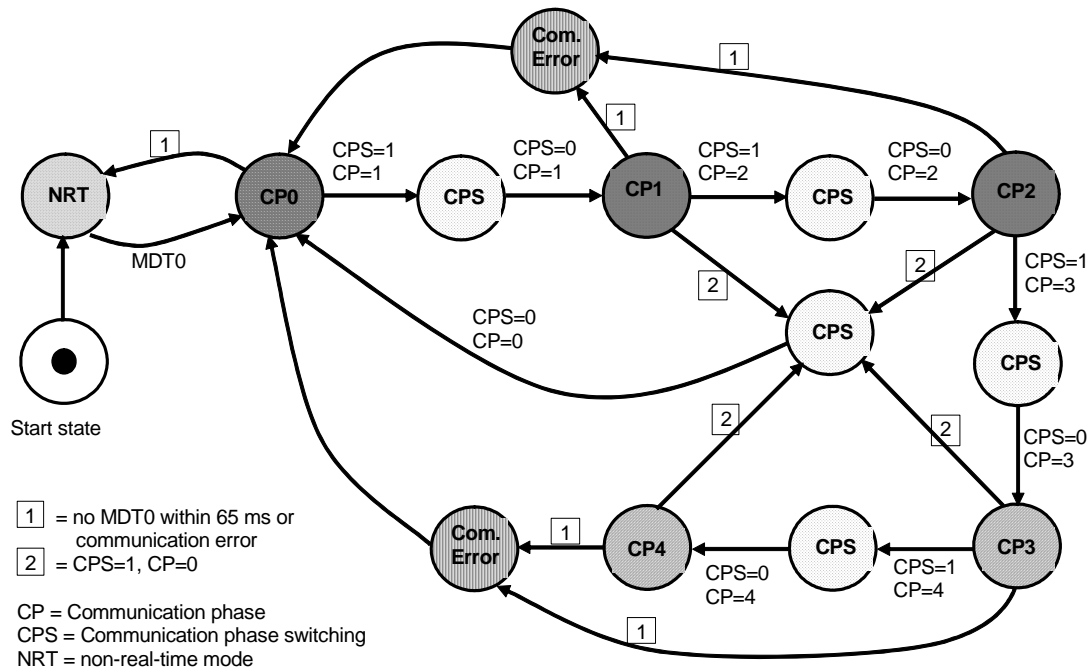


Figure 1 – Communication phase transitions

14.2.2 Non real-time mode (NRT)

After all slaves in the network have been powered up, and after internal checks are error-free, all slaves operate in NRT mode.

In NRT mode the service channel is not active, but the optional IP channel is active.

If the slave receives a MDT0 in NRT mode the sending of an IP telegram is cancelled immediately and the MDT0 is sent instead.

After this, the slave shall activate CP0 as well as the loopback at the port at which the slave has received the MDT0.

14.2.3 Communication phase 0 (CP0)

14.2.3.1 General

CP0 may be entered from any higher phase and is the only phase which may be entered from any other phase. Network initialization always begins with CP0.

In CP0 the service channel is not active, but the optional IP channel is active.

Slaves with device address ADR=0 shall support CP0 in the same way as slaves with ADR > 0.

During CP0, the master shall send MDT0 (see Figure 9 “MDT0 structure in CP0” in IEC 61158-5) and AT0 dependent of the given topology on one or both ports to check the wiring (ring is closed), to check all present slaves in the received AT0 (device address 0 to 255) and to measure the ring delays. The master transmits the AT0 and sets the content to 0 (see Figure 10 “AT0 structure in CP0” in IEC 61158-5). The master evaluates the ring delays (P-Channel and/or S-Channel) for synchronisation purposes.

The slave reads and increments the content of corresponding device address field in the AT. At the end of CP0 the AT data field contains the number of devices that reacted to each device address (see Figure 10 “AT0 structure in CP0” in IEC 61158-5). The slave processes AT0-P on the P-Channel and AT0-S on the S-Channel only once per communication cycle. The slave shall not process an AT0-P on the S-Channel and vice versa.

If the slave does not receive an MDT0 on the other port the loopback is activated without error message. The loopback is re-opened if an MDT0 is received on the other port.

14.2.3.2 Leaving CP0

The master waits for its MDT0 and AT0 to be received. The device addresses in the AT0 may be compared with the device addresses known to the master. Deviations shall be evaluated by the master (e.g., generate an error message). When the ring is closed and the master has received 100 AT0 with the same content, the master initiates to switch to CP1 (see subclause 14.2.8).

When the ring cannot be closed within the time set by the master, the master remains in CP0 and generates a message. The scope of the message and at what point it has to be activated is a function of the master.

Where CP0 is initiated as a response to a previous communication error, a routine in the master may be used to cause an automatic advance routine to CP2 with the possibility of error diagnostics, as specified by its manufacturer or depending upon configuration..

If a slave does not receive a MDT0 in CP0 within the time window of 65ms it switches to NRT mode.

14.2.3.3 Examples in CP0

14.2.3.3.1 General

The process in CP0 is explained in two examples with ring topology. In the first example each slave is set to a different device address. In the second example three slaves are set to the same device address. The master recognizes the multiple set of the device address in the AT data field.

14.2.3.3.2 CP0 without device address overlapping

This example (Figure 2) shows a process in which the master recognizes a set of device addresses without any overlapping. In Table 1 the process in the primary channel is shown.

The master transmits an AT with an allocated data field for each device in every communication cycle (all contents of the device addresses are 0). Each slave reads the respective data field in the AT, increments its value and writes it back to the device address field. If each device address is set only once, the respective device address fields in the AT contain the value 1 (see Figure 3).

In this example the master recognizes 4 slaves with the addresses #10, #1, #11 and #254.

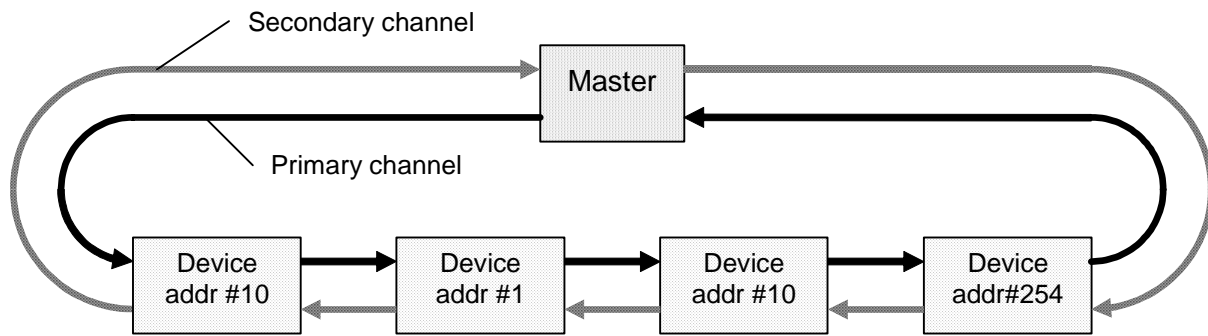


Figure 2 – Address adjusting without overlapping

Table 1 – Example without address overlapping in CP0 (P channel)

	slave 1	slave 2	slave 3	slave 4	Comments
Communication cycle	device address #10	device address #1	device address #11	device address #254	
n	R=0, W=1 Value=1	no change Value=0	R=0, W=1 Value=1	no change Value=0	slave 2 and slave 4 did not write any data
n+1	R=0, W=1 Value=1	R=0, W=1 Value=1	R=0, W=1 Value=1	R=0, W=1 Value=1	all slaves wrote data
n+2	R=0, W=1 Value=1	R=0, W=1 Value=1	R=0, W=1 Value=1	R=0, W=1 Value=1	all slaves wrote data
n+101	R=0, W=1 Value=1	R=0, W=1 Value=1	R=0, W=1 Value=1	R=0, W=1 Value=1	master received 100 AT with same content and ends CP0

NOTE 1 R = read, W = write

NOTE 2 Value=1 means the content in the telegram.

ATO data field contents	device addr #0	device addr #1	*****	device addr #10	device addr #11	*****	device addr #254	device addr #255
	0x0000	0x0001		0x0001	0x0001		0x0001	0x0000

Figure 3 – AT data field without address overlapping in CP0

14.2.3.3.3 CP0 with device address overlapping

This example (Figure 4) shows a process in which the master recognizes an erroneous set of device addresses. Table 2 shows the process in the primary channel only.

The master transmits an AT with an allocated data field for each device in every communication cycle (all contents of the device addresses are 0). Each slave reads the respective data field in the AT, increments its value and writes it back to the device address field. If a device address is set several times, the respective device address fields in the AT contain the number of the identical device addresses (see Figure 5).

In this example the master recognizes 4 slaves, 3 of which with the address #1 and one with the address #254.

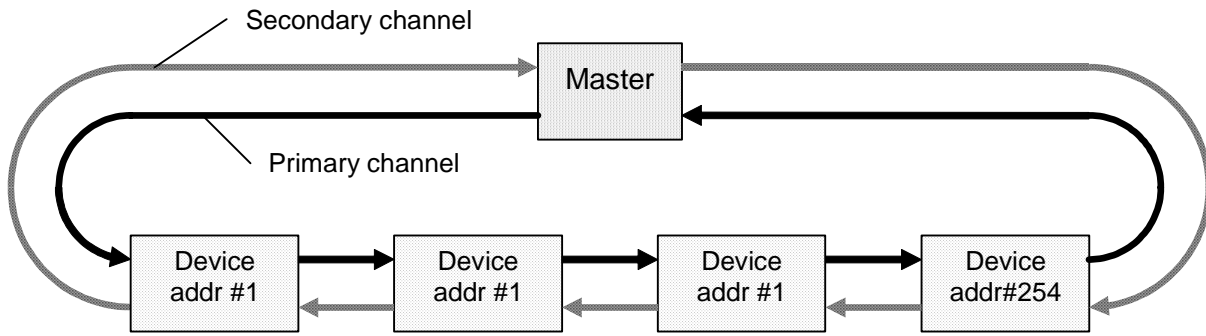


Figure 4 – Address adjusting with overlapping

Table 2 – Example with address overlapping in CP0 (P channel)

	slave 1	slave 2	slave 3	slave 4	Comments
Communication cycle	device address #1	device address #1	device address #1	device address #254	
n	R=0, W=1 Value=1	no change Value=1	R=1, W=2 Value=2	no change Value=0	slave 2 and slave 4 did not write any data.
n+1	R=0, W=1 Value=1	R=1, W=2 Value=2	no change Value=2	R=0, W=1 Value=1	slave 3 did not write any data
n+2	R=0, W=1 Value=1	R=1, W=2 Value=2	R=2, W=3 Value=3	R=0, W=1 Value=1	all slaves wrote data
n+3	R=0, W=1 Value=1	R=1, W=2 Value=2	R=2, W=3 Value=3	R=0, W=1 Value=1	all slaves wrote data
n+102	R=0, W=1 Value=1	R=1, W=2 Value=2	R=2, W=3 Value=3	R=0, W=1 Value=1	Master received AT with identical content 100 times and ends CP0.

NOTE 1 R = read, W = write.

NOTE 2 Value=1 means the content in the telegram. Only one device with address 254 is on the ring.

ATO data field contents	device addr #0	device addr #1	*****	device addr #10	device addr #11	*****	device addr #254	device addr #255
	0x0003	0x0000		0x0000	0x0000		0x0001	0x0000

Figure 5 – AT data field with address overlapping in CP0

14.2.4 Communication phase 1 (CP1)

14.2.4.1 General

CP1 is used to determine which slaves will be activated in CP2 to CP4. Slaves that are not participating in the communication uses the device address 0 as their address (see subclause 33.3.2 “Device address ADR” in IEC 61158-4). Slaves that are not being addressed in CP1 and whose address is not 0 shall behave like slaves with the device address 0. No slave shall react in CP1 when address 0 or 255 is queried.

In CP1 the service channel is initialised, the optional IP channel is active.

Slaves with device address ADR=0 shall no longer respond to the telegrams during phases CP1 and CP2 other than to forward the telegrams.

The master sends MDT0 and MDT1 to request the corresponding slave to insert data into AT0 or AT1. AT0 and AT1 are transmitted by the master with an allocated AT data field (contents is 0). The master shall not send the MDT1 and AT1, if the time t_6 (begin of IP channel) is exceeded by the AT1 (e.g., jitter too large) or the master supports device addresses 1 to 127 only.

A requested slave inserts the response into the corresponding AT service channel.

A device address might have to be queried several times. The master requests the slaves with MDT0 and MDT1 and it expects a response in AT0 and AT1.

The master repeats this request until the addressed slave acknowledges or until the HS timeout (see IEC 61491) has elapsed. When a slave does not respond, the master may address it again depending upon configuration.

This request procedure is repeated until the identification time has elapsed. The identification time is defined by the master.

14.2.4.2 Leaving CP1

After the master has identified the slaves on the ring, the master initiates to switch to CP2 (see subclause 14.2.8).

When the identification time is exceeded or deviations to the stored device addresses are detected, the initialization is not continued. The master may respond with an error message and remains in CP1 depending upon configuration.

If a slave does not receive a MDT0 in CP1 within 65ms it switches to CP0.

14.2.5 Communication phase 2 (CP2)

14.2.5.1 General

During CP2, the slaves are addressed specifically by their corresponding service channel. For CP2 and higher phases, they shall support complete service channel functionality. The optional IP channel is active.

As a minimum, the communication parameters required for CP3 and CP4 and the parameters for determining the length and contents of the MDTs and ATs are transmitted to the slaves (see subclause 33.2.2.2 "Transfer medium access" in IEC 61158-4). The slave shows in "IDN-list of operation data for CP2" which data shall be transferred in CP2 (see S-0-0018).

The master transmits the ring delays to all slaves for synchronisation purposes. The slaves adjust the synchronisation time depending on the ring delays. The master may determine the physical order of the slaves depending upon configuration.

The entire information exchange takes place via the mechanisms of the service channel (see subclause 14.4). The reliability of transmission is guaranteed by the MHS and AHS bits as well as the HS timeout. Further parameter exchanges can take place in CP2 or CP3. No slave shall react in CP2 when the device addresses 0 or 255 are queried. If a slave is not requested in CP1, then it shall not react to a request in CP2.

14.2.5.2 Leaving CP2

The transition from CP2 to CP3 shall follow the following procedure:

- 5) The master activates the procedure command “CP3 transition check” as defined in S-0-0127.
- 6) The slave then has to determine the validity of the parameters for CP3
- 7) The slave acknowledges the procedure command positively (e.g. “Procedure command executed correctly”).
- 8) After the positive procedure command acknowledgment, the master shall delete the procedure command in the slave,
- 9) The master then initiates to switch to CP3 (see subclause 14.2.8).

When the slave is not yet ready to switch over (i.e., the parameters required for CP3 have not yet been completely calculated), the slave shall set the procedure command acknowledgment – “procedure command not yet executed”.

When there are additional invalid parameters still present after the procedure command has been processed, the slave shall respond with the procedure command acknowledgment – “Error, procedure command execution impossible”. In this case, the master shall remain in CP2 and, depending on the capabilities of the master, try to renew the parameters identified as invalid or to send an error message to allow further initialization by means of an intervention by the operator. In the faulty case, the slave shall save the IDNs of the invalid data into the “IDN-list of invalid operation data for CP2” (see S-0-0021).

After the master has transmitted further parameters (depending on S-0-0021) to the slave in CP2, the procedure command “CP 3 transition check” has to be activated once more.

The check for validity of the parameters by the slave shall refer only to general criteria (e.g., minimum, maximum). It cannot recognize if all parameters that have been transmitted by the master are correct with respect to the master data and the total installation. This means that even when a slave acknowledges the “CP3 transition check” positively, there may be incorrect communication parameters with respect to the total installation which can lead to a disruption of the communication.

When CP2 was attained by an automatic advance routine after an error, this error shall be corrected first before a transition to CP3 can take place.

The master can also switch to CP0. The cause may be communication error or human intervention (e.g., the operator).

If a slave does not receive a MDT0 in CP2 within 65ms it switches to CP0.

14.2.6 Communication phase 3 (CP3)

14.2.6.1 General

Starting with CP3, the exchange of data is done via the telegrams defined for CP4. The master sends the configured MDTs and ATs to all slaves.

During CP3, the parameters for the slaves are set by means of the service channel. The slave shows in "IDN-list of operation data for CP3" which data in CP3 shall be transferred (see S-0-0019). Transmission reliability for the service channel is guaranteed by the MHS and AHS-bits as well as the HS timeout.

The optional IP channel is active, if the master sets $t_6 = t_7 = 0$ the IP channel is deactivated in CP3 and CP4.

All bits in the device control and device status that are dependent of the application profile are set to 0 during communication phases 0 to 2. In CP3, the application profile shall be activated.

14.2.6.2 Leaving CP3

The transition from CP3 to CP4 shall follow the following procedure

- 10) The master activates the procedure command “CP4 transition check” as defined in S-0-0128.
- 11) The slave then has to determine the validity of the parameters for CP4.
- 12) Afterwards, the slave completes the processing of the parameters that are required for operating the slave.
- 13) The slave then activates the synchronisation.
- 14) And finally, the slave acknowledges the procedure command positively (e.g., “Procedure command executed correctly”).
- 15) After receiving the positive procedure command acknowledgment, the master shall delete the procedure command in the slave.
- 16) The master then initiates to switch to CP4 (see 14.2.8).

When the slave is not yet ready to switch over (i.e., the parameters required for operating the slave have not yet been completely calculated), the slave shall set the procedure command acknowledgment – “procedure command not yet executed”.

When there are additional invalid parameters still present after the procedure command has been processed, the slave shall respond with the procedure command acknowledgment – “Error, procedure command execution impossible”. In this case, the master shall remain in CP3 and, depending on the capabilities of the master, try to re-establish the parameters identified as invalid or send an error message indicating that human intervention (e.g., operator) is required. In the faulty case, the slave shall save the IDNs of the invalid data into the “IDN-list of invalid operation data for CP3” (see S-0-0022).

After the master has transmitted further parameters (depending on S-0-0022) to the slave in CP3, the procedure command “CP 4 transition check” has to be activated once more.

The master also can switch to CP0. The cause may be communication errors or human intervention (e.g., the operator).

14.2.7 Communication phase 4 (CP4) – end of initialization

14.2.7.1 General

Upon switching to CP4 the initialization is complete.

14.2.7.2 Leaving communication phase 4 (CP4)

CP4 can only be terminated by a return to CP0. The reason for this may be communication errors or human intervention (e.g., operator). Any slave which recognizes CP0 shall shut down itself in the best possible manner. The method of shutting down the slaves is part of the application profiles.

14.2.8 Switching of communication phases (CPS)

14.2.8.1 Sequence of CP switching in the master

- 17) In order to switch communication phase, the master sets the condition in the MDT MST (CPS = 1 and new CP value in phase field). The master shall determine the current CP, the current CP+1 or CP0 as the new CP.
- 18) The master determines a time-out of 200 ms and waits till the slaves no longer write data to the ATs. For this purpose the master checks the device address of all slaves to see if it is 0; and in CP1 to CP4 it also checks the RT valid bit to see if it is 0.

- a) If the master still receives data from the slaves after the time-out (in CP0: device address $ADR \neq 0$, in CP1 to CP4: RT-Valid = 1), it produces an error message showing the respective device addresses. After deleting the error, the master interrupts the phase switch and switches to CP0.
 - b) If the master receives a communication error in the slave's C1D (only possible in CP1 to CP4) during time-out, it displays an error message, deactivates the time-out and stays in the current CP in order to fix the error. If the error can be fixed the phase switch is continued, if it cannot be fixed the master deletes the error and switches to CP0.
- 19) If the device address = 0 or RT valid = 0, the master stops the transmission of MDTs or ATs and prepares the new CP.
- 20) After all internal preparations are done, the master starts sending MDTs and ATs again.
- a) The master sets either the condition 'phase switch completed with new CP' (CPS = 1 and new CP value in phase field).
 - b) The master sets condition 'phase switch to CP0' (Phase, CPS = 1 and CP0).
- 21) The master again sets a time-out of 200 ms and waits till all slaves restart writing data to ATs. The master therefore checks all slaves' device address in CP0 to see if it is $\neq 0$; and in CP1 to CP4, the RT valid bit to see if it is 1.
- a) If the master after the time-out does not receive any more data from the slaves (in CP0: device address $ADR = 0$, in CP1 to CP4: RT-Valid = 0), it displays an error message showing the respective device addresses. After deleting the error the master switches to CP0.
 - b) If the condition (Device address $ADR \neq 0$ or RT-Valid = 1) is true, the new CP is active and the switch is complete.

14.2.8.2 Sequence of CP switching in the slave

- 22) The slave recognizes the phase switch in the MDT0 (Phase, Bit CPS = 1 and new CP). The slave checks if the new CP is valid. The RT data in the MDTs are disregarded.
- a) If the CP is valid the slave does not write RT data to the ATs any more and waits till it does not receive MDT0 any more. After that the slave sets a new time-out of 500 ms and prepares the new CP internally.
 - b) If the CP is invalid the slave generates a communication error in C1D and sends it to the master. The slave stays in the same CP.
- 23) After the master sends no MDT0 the slaves waits for another MDT0.
- a) If the slave after the time-out does not receive MDT0 from the master it stores the error and can display it (e.g. LED), after that it switches to CP0.
 - b) If the slave receives the MDT0 with a valid condition (Phase, CPS = 0, and CP = OK), then the new CP is active and the switch is completed. The slave restarts evaluating the RT data in the MDT and writes data to the AT.
 - If the slave receives an MDT0 with the condition (Phase, CPS = 1, CP = OK), it waits for the valid condition (see paragraph 23)b)).
 - If the slave receives an MDT0 with the condition (Phase, CPS = 1 and CP0), it activates the phase switch once more.
 - If the slave receives an MDT0 with invalid condition (CP is not OK), it stores the error and displays it on the device (e.g. LED). The slave then switches to CP0.

14.3 Synchronisation

The master measures the ring delays in CP0 and takes these into account to determine the synchronisation time. The master transmits in CP2 the synchronisation time to all slaves. With the procedure command "CP3 transition check" (S-0-0127) the synchronisation in the slave is activated. The slave acknowledges the command positively if the slave is synchronised. If it cannot synchronise within a determined time-out, it sends a negative acknowledgement.

The synchronisation is generated once per communication cycle by the MDT-MST of MDT0 only (see Figure 6). The MDT MST is protected via CRC by the master. The end of the MDT MST is a constant in every communication cycle and yields a stable synchronisation signal. The slaves check the MDT MST data via CRC and evaluate the data of MDT MST.

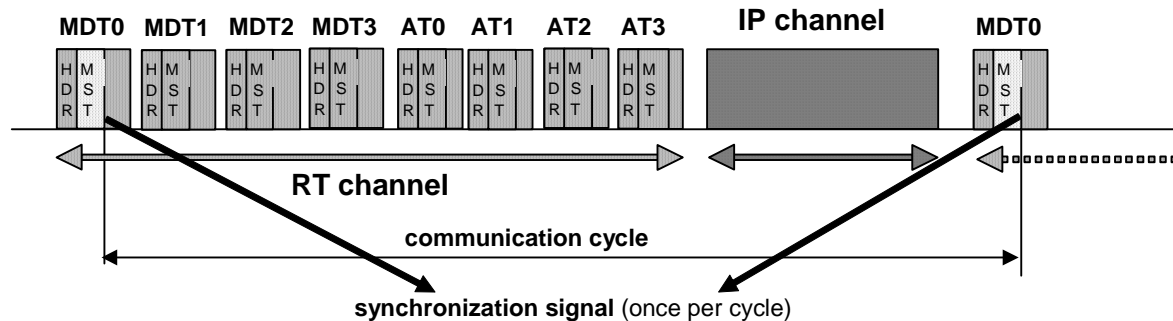


Figure 6 – Synchronisation timing

In line or ring topology each slave receives two MDT MSTs. This occurs in two synchronisation signals with a constant delay (see Figure 7). These two signals shall be combined to one synchronisation trigger.

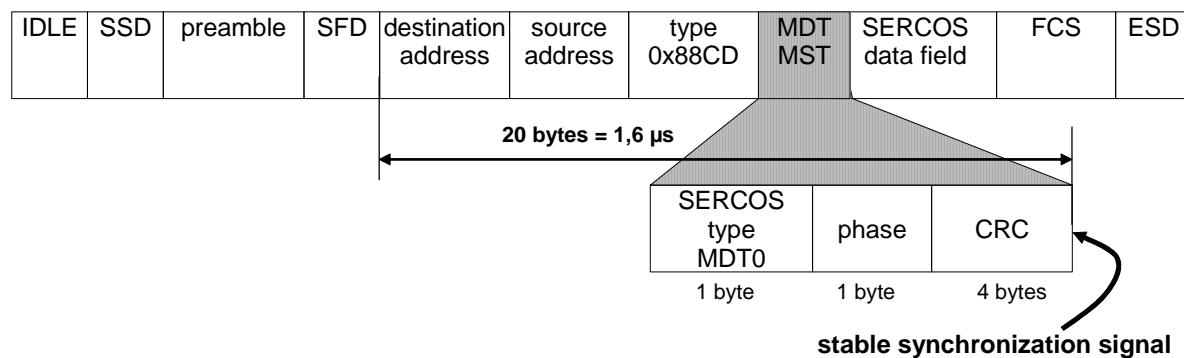


Figure 7 – Synchronisation signal generation

14.4 Service channel (SVC)

14.4.1 General

In addition to the real-time transmission of data, SERCOS provides the ability to transmit non-real-time data in the RT channel. To transmit this data, the device service INFO field is reserved for the service channel in the MDT and in the AT. Special SVC control and SVC status of the MDT and the AT are used to control execution in the service channel. Therefore, the master is able to support a separate service channel for every connected device.

During a SVC transmission, the following operations are possible:

- initialization of the SERCOS communication;
- transmission of all elements of a data block;
- transmission of procedure commands;
- changing limit values on demand;
- changing control loop parameters on demand;
- obtaining detailed status messages from a device;
- diagnostic functions,

- etc.

Any SVC transmission is always initiated and controlled by the master. The operations, 'read element' or 'write element', are from the perspective of the master. All operations are always related to the last transmitted IDN.

The service channel is initialized during CP2 and is functional for the remainder of the communication phases.

14.4.2 Service channel transport mechanism

The SVC transport of operation data or of a procedure command is handled via a predetermined handling and proceeding sequence (see Figure 8 and Figure 9) for individual actions. The master shall strictly follow the the outline of these diagrams.

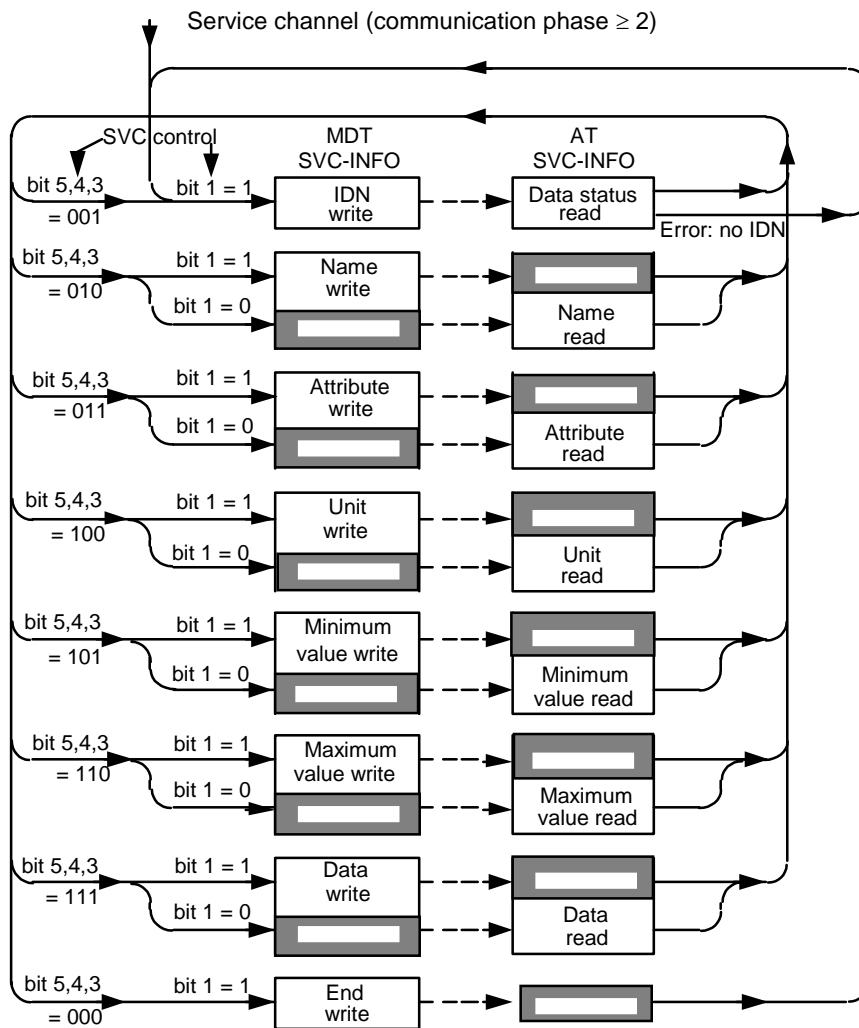


Figure 8 – Service channel handling diagram

Selection of IDN

The transmission starts with the opening of the service channel by sending the IDN of the data block (SVC control, bits 5, 4, 3 = 001, element 1). The slave responds by writing the IDN with the data status or the procedure command acknowledgment.

Selection of data block element

During the next step, the master indicates which elements of the data block shall be processed. For this purpose, the master sets bits 5, 4 and 3 accordingly in the SVC control.

Read/Write

Following this, the master indicates in bit 1 whether the element will be read or written to. While writing, the SVC INFO field of the MDT is filled with the appropriate data for the slave (contents of the AT SVC INFO field are invalid). When reading is selected, the slave inserts the appropriate data in the SVC INFO field of the AT (contents of the SVC INFO field of the MDT are invalid).

Transmission steps

Depending on the length of the data block elements which need to be transmitted and of the length of the SVC INFO field, several steps may be required.

Every step transports four bytes of data.

Table 3 shows the necessary steps for the individual elements of a data block.

Table 3 – List of IDNs element and step numbers

Element number	Description	Requirement	Number of steps
1	IDN	Mandatory	1
2	Name	Optional	1 to 16
3	Attribute	Mandatory	1
4	Unit	Optional	1 to 4
5	Minimum input value	Optional	1 or 2
6	Maximum input value	Optional	1 or 2
7	Operation data	Mandatory	Fixed length: 1 or 2
			Variable length: 1 to 16 384
Closing the service channel			1

The master indicates in bit 2 of the SVC control a transmission in progress (bit 2 = 0) or the transmission of the last 4 bytes (bit 2 = 1). A transport with just one step is immediately set by the master as the last transmission (bit 2 = 1).

The error messages “element transmission too short” or “element transmission too long” are executed by the slave only when the length of the actual transmitted element is not in coincidence with the states of bit 2 in the SVC control.

End of transmission

The SVC transmission of operation data or a procedure command ends with the transmission of the IDN for the next operation data or procedure command.

Changing of data block element

Changing the data block element is possible without an error message only when the following bits have the status given in Table 4.

Table 4 – Condition for modifying data block elements

Information	SVC control bit	SVC status bit	bit value
Transmission in progress	bit 2		0
Handshake bits equal	bit 0	bit 0	MHS = AHS
Busy		bit 1	0
SVC valid		bit 3	1

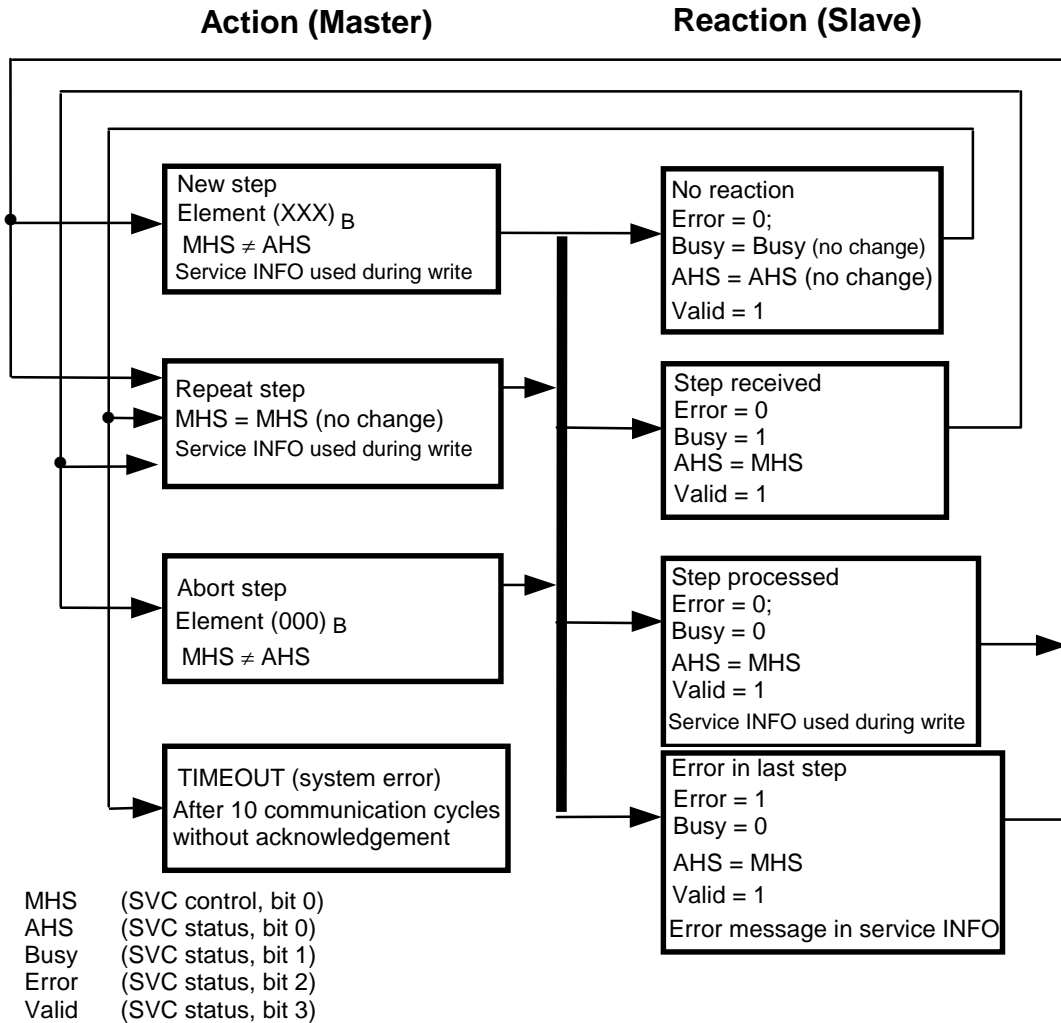


Figure 9 – Communication step proceeding diagram

14.4.2.1 SVC valid

The slave shall set “SVC valid” (SVC status, bit 3) to 1 (valid) as soon as it has finished handling the required service channel action. It shall set it back to 0 (not valid) if it is unable to handle the master’s demand (MHS ≠ AHS). In a ring topology, the slave may handle the SVC enquiries either on the primary or on the secondary channel, depending upon configuration. In a line topology, the slave shall handle the SVC enquiries only on one channel (primary or secondary) as required by the master.

The master shall evaluate the slave’s SVC answer only if it reads “SVC valid” (SVC status, bit 3). It shall not evaluate it if “SVC valid” = 0 (invalid). The master shall scan the SVC in the primary or secondary depending on the topology.

The time-out of SVC valid is the same as HS time-out (see 14.4.2.2).

14.4.2.2 Handshake bits

During SVC transmissions, the transport of every step is secured by two service transport handshake bits. These are the bits 0 in the SVC control (MHS) and in the SVC status (AHS).

For every new step during the transmission, the master toggles the MHS-bit. The slave recognizes by the toggled MHS-bit that a new step needs to be executed. After the slave has received the required step and secured it for processing, it proceeds to set its AHS-bit equal to the MHS-bit. By comparing the MHS-bit with the AHS-bit, the master and the slaves are always able to recognize the actual transport status during SVC transmission. See Table 5.

Table 5 – SVC channel evaluation

Master's perspective	AHS bit = MHS bit (SVC valid = 1)	The step was received by the slave and secured, slave starts processing. The master shall wait for processing acknowledgment (busy = 0, bit 1 in the SVC status)
	AHS bit ≠ MHS bit or SVC valid = 0	The steps were not yet received or secured by the slave. The master shall repeat the last step
Slave's perspective	MHS bit = AHS bit	the master does not require a new step, slave repeats the last step
	Master MHS-bit ≠ slave AHS-bit	the master requests a new step

The service transport handshake bits enable the slaves and the master to insert 'wait cycles' during the transmission, e.g.:

- when more than one cycle will be required for receiving or transmitting a step;
- when a new step has not been recognized due to an error during the transmission;
- when the master will not issue any new steps at this time.

During every "wait cycle", the master or the slave transmits the data of the previous communication cycle into the SVC INFO field.

After a maximum of 10 communication cycles, the master sets a "time-out" condition when the slave does not acknowledge the proper reception of a step by matching its AHS-bit or if the Valid bit is 0.

14.4.2.3 Busy bit

The slave is able to control any SVC transmission through the busy bit. The busy bit indicates that the slave is processing or just finishing the requested step at this time. Not until the slave sends the processing acknowledgement (busy bit = 0) is the master allowed to start the next step. The busy bit allows the slave to prevent the master from forcing the steps on the slave too quickly.

SERCOS defines no "time-out" parameter for the processing acknowledgment (busy) of the slave. After some time, the master should be able to interrupt a step which was not acknowledged by the slave, by closing the service channel.

14.4.2.4 Service channel error messages

Errors can occur in the transport mechanism of the service channel (e.g., when the lengths of the operation data differ between the master and the slave, or vice versa, or where the IDN is undefined). In order to announce errors discovered by the slave, an error bit (bit 2) is defined in the SVC status. When this bit is set, the SVC INFO field of the AT contains an error code.

The slave is allowed to report an error message only when a new processing step is issued by the master, that is in any of following cases:

- MHS-bit ≠ AHS-bit (step not yet secured);
- busy bit = 1 (step still in process).

When the slave recognizes an error, it ignores the actual step, interrupts and acknowledges by:

- setting the AHS-bit equal to the MHS-bit (when not already acknowledged in a previous cycle);
- setting the error bit to 1 (SVC status, bit 2);
- sending the error codes in the SVC INFO field (see subclause 33.3.4.3.2.3 “SVC status and SVC INFO” in IEC 61158-4);
- setting the busy bit to 0 and
- setting the SVC valid to 1.

Where the master intends to repeat the transmission of an element after an error message, the lowest-valued byte of the element is transmitted first.

All possible error messages are shown in Table 6; the unused codes are reserved.

Table 6 – Error messages

Error code	Description
0x0nnn	General error
0x0000	No error in the service channel
0x0001	Service channel not open
0x0009	Invalid access to closing the service channel
0x1nnn	Element 1 (IDN)
0x1001	No IDN
0x1009	Invalid access to element 1
0x2nnn	Element 2 (Name)
0x2001	No name
0x2002	Name transmission too short
0x2003	Name transmission too long
0x2004	Name cannot be changed (read only)
0x2005	Name is write-protected at this time
0x3nnn	Element 3 (Attribute)
0x3002	Attribute transmission too short
0x3003	Attribute transmission too long
0x3004	Attribute cannot be changed (read only)
0x3005	Attribute is write-protected at this time
0x4nnn	Element 4 (Unit)
0x4001	No units
0x4002	Unit transmission too short
0x4003	Unit transmission too long
0x4004	Unit cannot be changed (read only)
0x4005	Unit is write-protected at this time

Error code	Description
0x5nnn	Element 5 (Minimum input value)
0x5001	No minimum input value
0x5002	Minimum input value transmission too short
0x5003	Minimum input value transmission too long
0x5004	Minimum input value cannot be changed (read only)
0x5005	Minimum input value is write-protected at this time
0x6nnn	Element 6 (Maximum input value)
0x6001	No maximum input value
0x6002	Maximum input value transmission too short
0x6003	Maximum input value transmission too long
0x6004	Maximum input value cannot be changed (read only)
0x6005	Maximum input value is write-protected at this time
0x7nnn	Element 7 (Operation data)
0x7002	Operation data transmission too short
0x7003	Operation data transmission too long
0x7004	Operation data cannot be changed (read only)
0x7005	Operation data is write-protected at this time (e.g., Communication phase)
0x7006	Operation data is smaller than the minimum input value
0x7007	Operation data is greater than the maximum input value
0x7008	Invalid operation data: Configured IDN will not be supported, invalid bit number or bit combination
0x7009	Operation data write protected by a password
0x700A	Operation data is write protected, it is configured cyclically. (IDN is configured in the MDT or AT. Therefore writing via the service channel is not allowed).
0x700B	Invalid indirect addressing: (e.g., data container, list handling)
0x700C	Operation data is write protected, due to other settings. (e.g., parameter, operation mode, drive enable, drive on etc.)
0x700D	reserved
0x700E	reserved
0x700F	reserved
0x7010	Procedure command already active
0x7011	Procedure command not interruptible
0x7012	Procedure command at this time not executable (e.g., in this phase the procedure command can not be activated).
0x7013	Procedure command not executable (invalid or false parameters)

14.4.3 Service channel initialization

In CP1, each service channel starts with the following status:

- the MHS-bit in the MDT and the AHS-bit in the AT are set to 1 (see 14.4.2);
- the SVC valid is set to 1. All other bits in SVC control or SVC status are set to 0;
- any bits in the SVC INFO fields are invalid.

Starting with CP2, the SVC INFO fields in the MDT and the AT become valid. This implies that the master and a slave servicing several devices freeze the status of the service channel before switching from one device to another. When addressing this device again at a later time, the master is set to this frozen status.

14.5 Procedure command functions via the service channel

The SERCOS procedure command functions can be transmitted through the service channel. A procedure command is considered a special type of non-real-time data which, when transmitted through the service channel, invokes fixed functional processes in both the slaves and the master. These processes may take up some time. Hence, a procedure command only causes a functional process to start. After a procedure command has started its function, the service channel becomes available again immediately for the transmission of non-real-time data or for more procedure commands.

Contrary to non-real-time data transmission whose proceeding is finished with the last transmitted step, the end of a procedure command during a lengthy procedure command execution is indicated by the procedure command change bit (bit 5 in the device status). The master is able to interrupt a procedure command during its execution.

Every procedure command has been assigned an IDN and an appropriate data block. Not all elements of the data block are defined, however, and other elements have a predetermined form. In this subclause, only special processes of the procedure command functions in the service channel are discussed.

14.5.1 Procedure command control and acknowledgment

A procedure command function always prompts a procedure command control from the master to the slave and a procedure command acknowledgment from a slave to the master. The procedure command control is element 7 of the data block (element 7 is always represented as a bit list for procedure commands). See Table 7.

Procedure command control allows procedure commands to be:

- set;
- enabled for execution;
- interrupted during execution;
- cancelled.

The slave acknowledges the transmission of a procedure command from the master via the service channel with its AHS-bit, the busy bit and the SVC valid in its SVC status.

Table 7 – Procedure command control

Bits 15-2	(Reserved)
Bit 1	
0	Interrupt procedure command execution
1	Enable procedure command execution
Bit 0	
0	Cancel procedure command
1	Set procedure command

When starting the initializing (CP0), all procedure commands inside the master shall be disabled and then the procedure command control shall be updated appropriately internally in the master.

The procedure command acknowledgment is part of the data status (see Table 8).

In order to receive a procedure command acknowledgment, the master writes the IDN of the procedure command via the service channel.

When acknowledging a procedure command, the slave indicates the actual status of the procedure command as given in Table 8. Bits 0 and 1 of the procedure command acknowledgment are simply copies of the procedure command control and indicate the actual status of the procedure command.

The procedure commands are treated as non-real-time data in the Slave.

If the master activates a procedure command, it can take several communication cycles till the slave generates the corresponding procedure command acknowledgment. Therefore the master should scan the procedure command acknowledgment as shown in Table 8.

Table 8 – Procedure command acknowledgment (data status)

Bits 15-9	(Reserved)
Bit 8	
0	Operation data is valid
1	Operation data is invalid
Bits 7-4	(Reserved)
Bit 3	
0	No procedure command error
1	Error, procedure command execution is impossible
Bit 2	
0	Procedure command executed correctly
1	Procedure command not yet executed
Bit 1	
0	Procedure command execution is interrupted
1	Procedure command execution is enabled
Bit 0	
0	Procedure command is not yet set
1	Procedure command is set

With the beginning of initialization (CP0), all procedure commands within the slave shall be disabled and then the procedure command acknowledgment shall be updated appropriately internally in the slave.

14.5.1.1 Procedure command change bit

In order to inform the master of the end of a procedure command being executed in the slave, a procedure command change bit has been reserved in the device status (bit 5).

Only the following changes in the procedure command acknowledgment will set the procedure command change bit:

- procedure command executed correctly (positive acknowledgment, bit 2 changes from 1 to 0);
- error, procedure command execution impossible (negative acknowledgment, bit 3 changes from 0 to 1).

All other changes of the procedure command acknowledgment (e.g., an interrupt) are not indicated by the procedure command change bit.

The master shall read the data status by writing the IDN of the procedure command and check the procedure command acknowledgment contained therein. This indicates whether the procedure command was executed positively or negatively.

At negative procedure command acknowledgment, the master should read the diagnosis (if desired) before the procedure command is cancelled.

When a procedure command is cancelled by the master, all effects of the procedure command on the procedure command change bit in the slave are cancelled as well. Where the master has activated several procedure commands concurrently, all resulting procedure command acknowledgments shall be checked after setting the procedure command change bit in order to determine which procedure command caused the change.

As a rule, the master shall cancel a procedure command after it has been processed, irrespective of whether it was acknowledged positively or negatively.

A procedure command is cancelled by setting bit 0 in the procedure command control to 0. This is independent from the actual procedure command execution state.

The state machine Figure 10 describes the allowed state changes for procedure commands.

For procedure command control (CC), only the 0x00 through 0x03 values are allowed. If the value is invalid, the slave generates the error message “invalid data” in the SVC INFO.

A state change to “procedure command not set” (CA = 0x00), is only possible by cancelling the procedure command.

Where more than one procedure command execution is active and the “procedure command change bit” is set by more than one procedure command, this bit is reset in the device status when all procedure commands which had set the bit are cancelled.

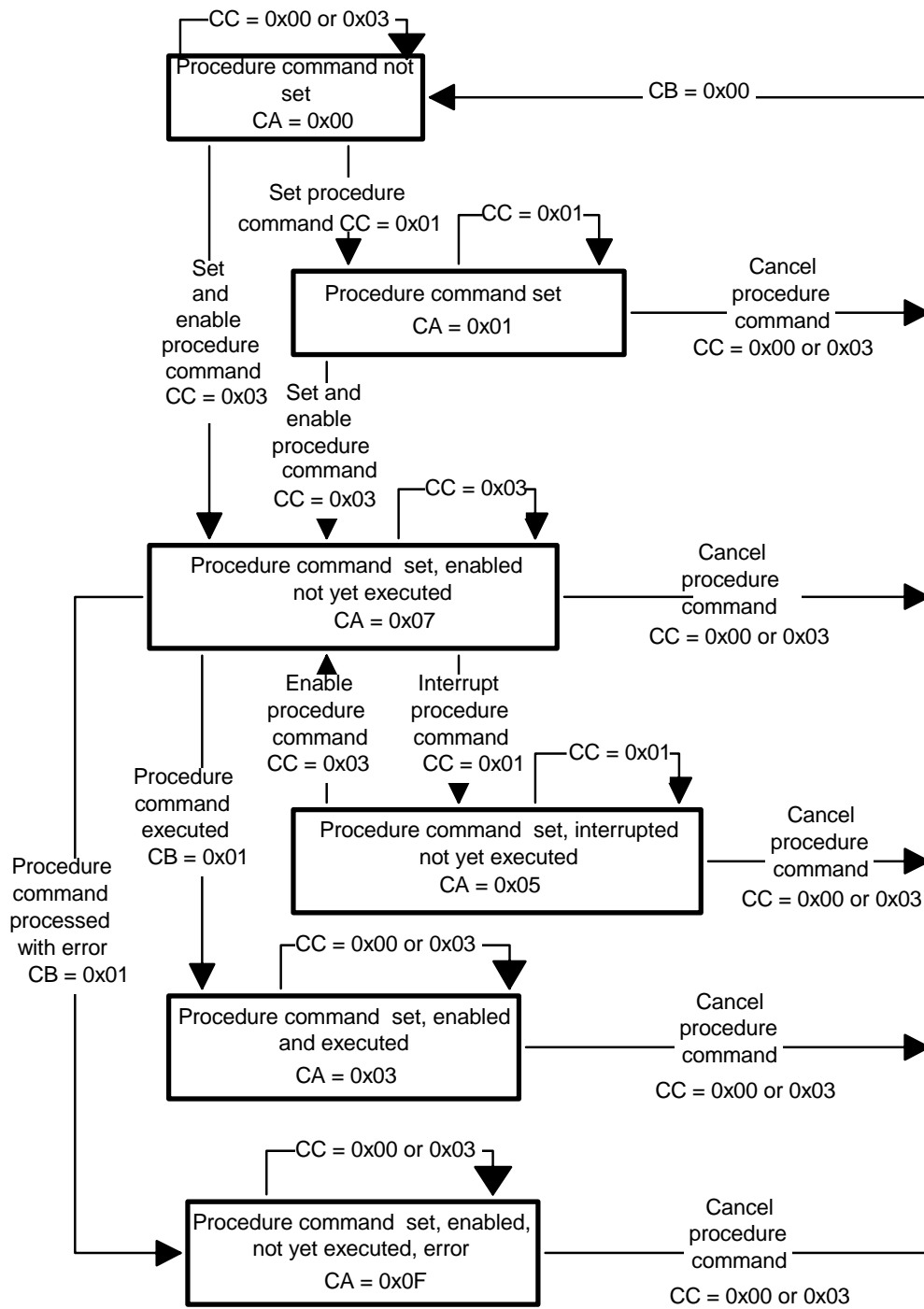


Figure 10 – State machine for procedure command execution

Figure 11 shows the sequence of procedure command handling should be met by the master:

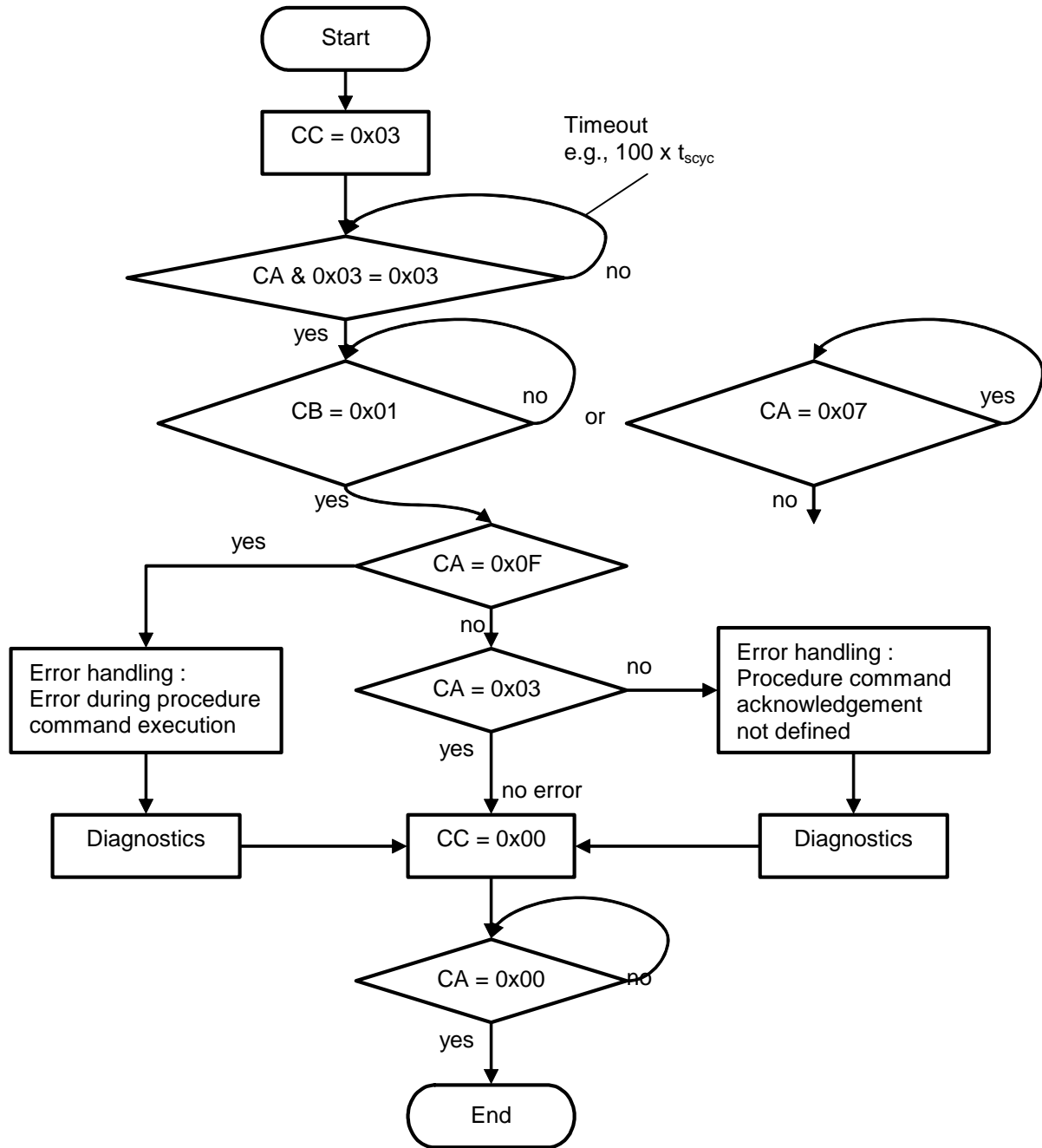


Figure 11 – Interaction of procedure command control and acknowledgement

14.5.1.2 Procedure command execution

In the following examples of processes, the interactions between the master and the slave are shown, including procedure command executions with or without interruption and procedure command executions with error messages.

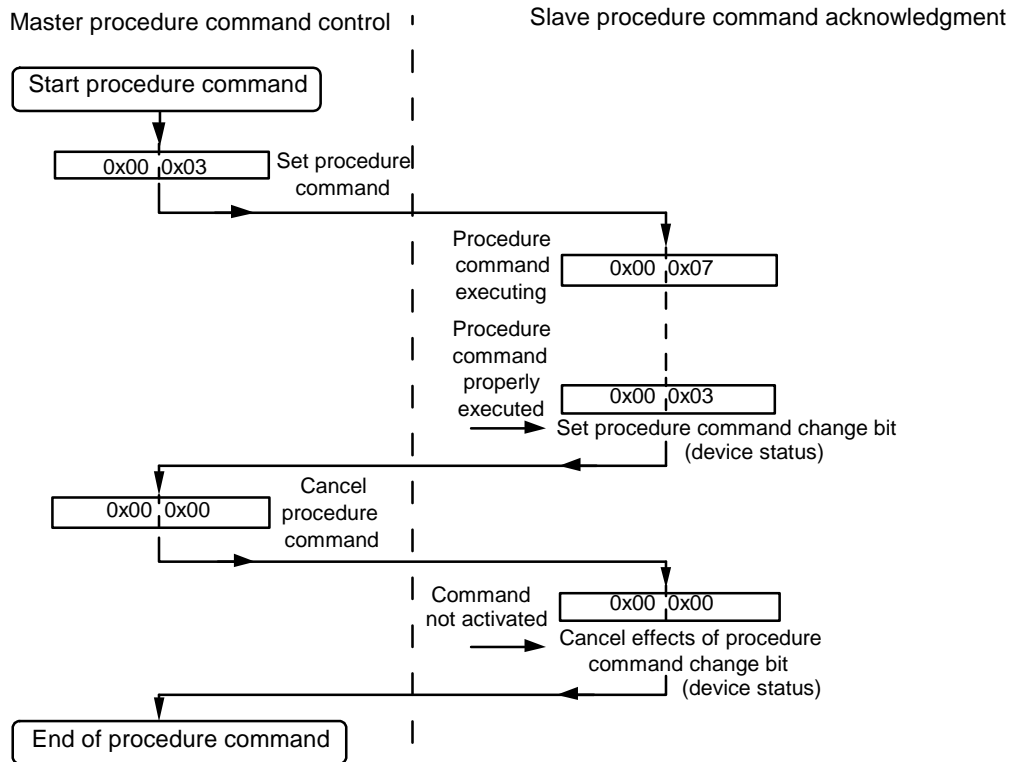


Figure 12 – Procedure command execution without interrupt

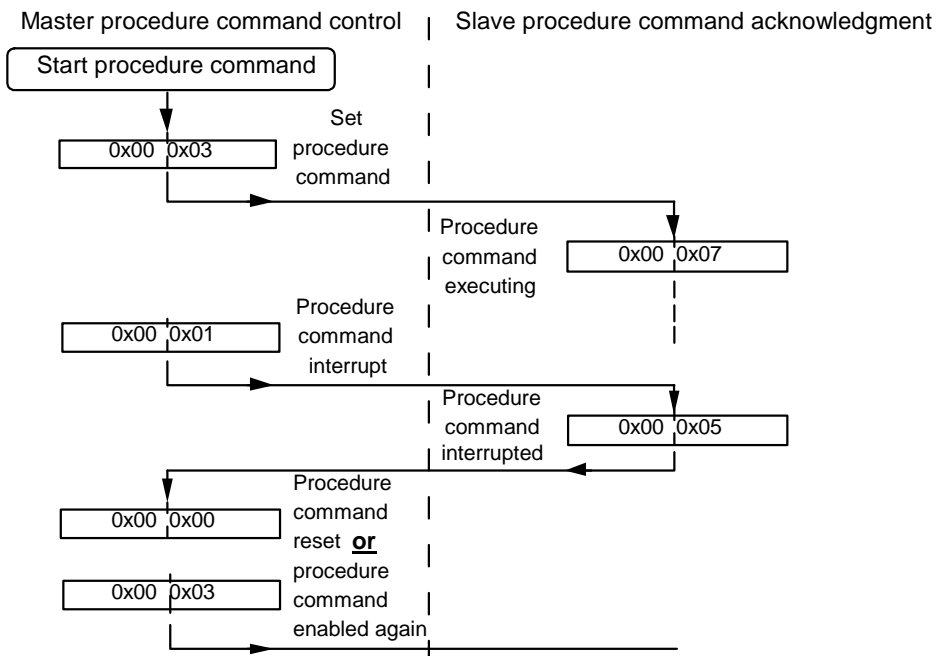


Figure 13 – Procedure command execution with interrupt

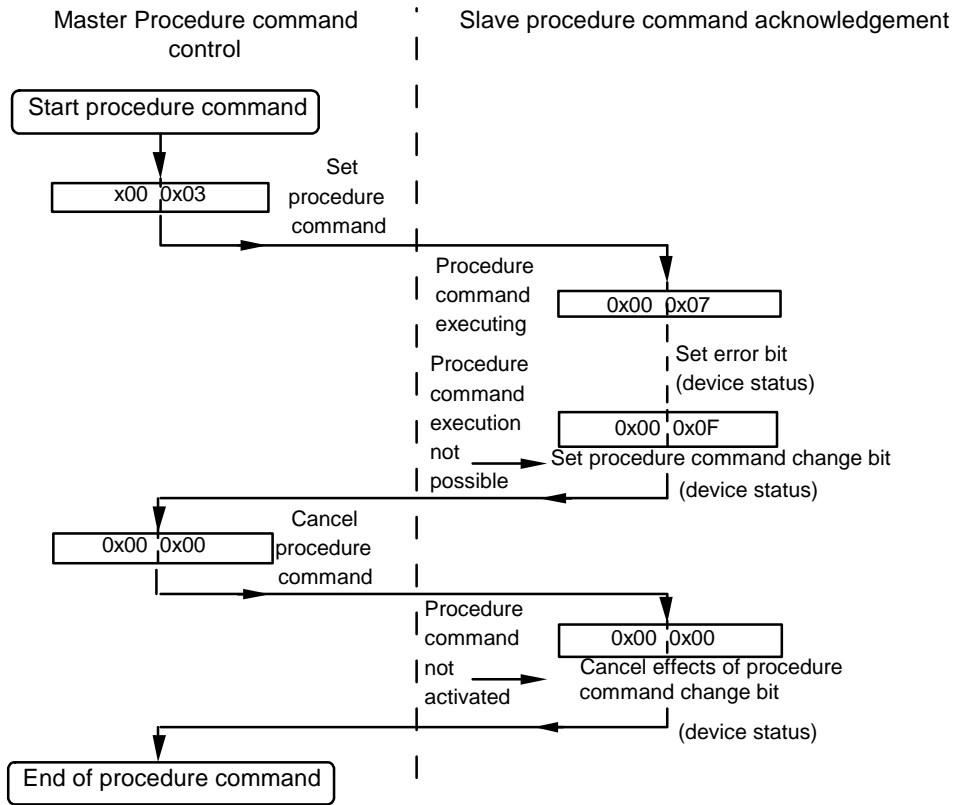


Figure 14 – Procedure command execution with error message

Section F – Update to IEC 61784-2

Overview

It should be noted that this update is based on 65C/350/CD (future IEC 61784-2). As this future document has not yet been published, it appears here in *italics* for reader's convenience. Only the SERCOS III relevant parts are in roman type.

DIGITAL DATA COMMUNICATIONS FOR MEASUREMENT AND CONTROL –

Part 2: Additional profiles for ISO/IEC 8802-3 based communication networks in real-time applications

INTRODUCTION

This part of IEC 61784 provides additional communication profiles (CP) to the existing Communication Profile Families (CPF) of IEC 61784-1 and additional CPFs with one or more CPs. These profiles meet the industrial automation market objective of identifying Real-Time Ethernet (RTE) communication networks coexisting with ISO/IEC 8802-3 – commonly known as Ethernet. These RTE communication networks use provision from ISO/IEC 8802-3 for the lower communication stack layers and additionally provide more predictable and reliable real-time data transfer and means for support of precise synchronisation of automation equipment.

More specifically, these profiles help to correctly state the compliance of RTE communication networks with ISO/IEC 8802-3, and to avoid the spreading of divergent implementations.

Adoption of Ethernet technology for industrial communication between controllers and even for communication with field devices promotes use of Internet technologies in the field area. This availability would be unacceptable if it causes the loss of features required in the field area for industrial communication automation networks, such as:

- *real-time,*
- *synchronised actions between field devices like drives,*
- *efficient, frequent exchange of very small data records.*

Features of the current fieldbus systems, see IEC 61784-1 Communication Profile Families, should be improved the same way as the properties of Ethernet networks in terms of transmission bandwidth and network span.

Another implicit but essential requirement is that the typical Ethernet communication capabilities as used in the office world are fully retained, so that the software involved remains applicable.

The market is in need of several network solutions, each with different performance characteristics and functional capabilities, matching the diverse application requirements. Description of RTE performance indicators of a communication profile enables the user to match compliant network devices to application dependant performance requirements of an RTE network.

5.1 specifies basic principles of performance indicators required to express RTE performance of a CP. 5.2 describes the view of application requirements and Annex C provides guidance on how to build application dependant classes. An application dependant class could be used to find out a suitable CP. Clause 4 specifies how conformance of a device to the CPF or CP should be stated.

1 Scope

This part of IEC 61784 specifies

- *performance indicators supporting classification schemes for Real-Time Ethernet (RTE) requirements;*

- profiles and related network components based on the International Standards ISO/IEC 8802-3, IEC 61158, and IEC 61784-1;
- RTE solutions that are able to run in parallel with ISO/IEC 8802-3 based applications.

These communication profiles are called *Real-Time Ethernet communication profiles*.

NOTE The RTE communication profiles use ISO/IEC 8802-3 communication networks and its related network components or IEC 61588 and may in some cases amend those standards to obtain RTE features.

2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

IEC 61158 (all parts), *Digital data communications for measurement and control – Fieldbus for use in industrial control systems*

IEC 61588:2004, *Precision clock synchronisation protocol for networked measurement and control system*

IEC 61784-1:2003, *Profile sets for continuous and discrete manufacturing relative to fieldbus use in industrial control systems*

ISO/IEC 8802-1:1996(E), *ANSI/IEEE Std 802.1 Local and metropolitan area networks - Virtual bridged local area networks.*

ISO/IEC 8802-3:2001, *Information technology - Telecommunications and information exchange between systems - Local and metropolitan area networks - Specific requirements - Part 3: Carrier sense multiple access with collision detection (CSMA/CD) access method and Physical Layer specifications*

IEEE 802.1D, 1998 Edition (ISO/IEC 15802-3:1998), *IEEE Standard for Information technology--Telecommunications and information exchange between systems--IEEE standard for local and metropolitan area networks--Common specifications--Media access control (MAC) Bridges*

IEEE 802.1Q, 1998 Edition, *IEEE Standard for Information technology--Telecommunications and information exchange between systems--IEEE standard for Local and metropolitan area networks - Virtual bridged local area networks*

ISO 15745-1:2003, *Industrial automation and systems integration – Open systems application integration framework – Part 1: Generic reference description*

IEC 61491:2002, *Electrical equipment of industrial machines – Serial data link for real-time communication between controls and drives.*

3 Terms, definitions, abbreviated terms, acronym and conventions

3.1 Terms and definitions

For the purposes of future IEC 61784-2, some of the following terms and definitions have been compiled from the referenced documents. The terms and definitions of ISO/IEC 8802-3, IEEE 802.1D and IEC 61588 series shall be fully valid for Part 2 of IEC 61784, unless otherwise stated.

3.1.1

cyclic

repetitive in a regular manner

[IEC 61158-6: Ed. 3]

3.1.2

daisy-chain

a ring configuration where the loop is open

3.1.3

drift

change of time difference between two clocks measured within a specific interval

NOTE 1 The drift may depend upon manufacturing, aging, mechanical shocks and temperature.

NOTE 2 Indicates how much one clock appears to be diverging from the observer.

3.1.4

end node

end-point of a link in a network

3.1.5

field area

place in a manufacturing or process site where field devices are located

3.1.6

frame

a unit of data transmission on an ISO/IEC8802-3 MAC (Media Access Control) that conveys a protocol data unit (PDU) between MAC Service users

[IEEE Std. 802.1Q – 1998]

3.1.7

jitter

temporal change in clock signal or temporal change in otherwise regular event

3.1.8

link

transmission path between two adjacent nodes

[derived from ISO/IEC 11801]

3.1.9

message

ordered series of octets intended to convey information

[derived from ISO 2382-16.02.01]

NOTE Normally used to convey information between peers at the application layer.

3.1.10

node

end-point of a link in a network or a point at which two or more links meet

[derived from IEC 61158-2]

NOTE A node may be either a switch or an RTE end device or both.

3.1.11

packet

logical grouping of information used to describe a unit of data at any layer to convey the upper layer user data to its peer layer

NOTE A packet is identical to the PDU at each layer in terms of the OSI reference model. A data link layer packet is a frame.

3.1.12

peer nodes

pair of nodes, connected with a point-to-point link

3.1.13

phase

elapsed fraction of a cycle, measured from some fixed origin

NOTE Phase is often expressed as an angle, where the time for a complete cycle is represented as 360 degrees along a time axis.

3.1.14

PTP-slave

clock in the state PTP_slave

[according to IEC 61588:2004]

3.1.15

PTP-master

clock in the state PTP_master

[according to IEC 61588:2004]

3.1.16

R-port

port in a communication device, which is part of a ring structure

3.1.17

real-time

the ability of a system to provide a required result in a bounded time

3.1.18

real-time communication

transfer of data in real-time

3.1.19

Real-Time Ethernet (RTE)

ISO/IEC 8802-3 based network that includes real-time communication

NOTE 1 Other communication can be supported, providing the real-time communication is not compromised.

NOTE 2 This definition is dedicated but not limited to ISO/IEC 8802-3. It could be applicable to other IEEE 802 specifications, for example IEEE 802.11.

3.1.20**ring**

a network configuration where each node is connected to exactly two adjacent nodes in a circular topology

NOTE Ring may also be referred to as loop.

3.1.21**RTE end device**

device with at least one active RTE port

3.1.22**RTE end node**

end node with RTE capability

3.1.23**RTE port**

MAC-sublayer point of attachment of an RTE end device to a local area network

NOTE This definition is derived from that of bridge port in ISO/IEC 10038: 1993, as applied to local MAC bridges

3.1.24**schedule**

temporal arrangement of a number of related operations

3.1.25**switch**

a MAC bridge as defined in IEEE 802.1D:1998

3.1.26**switched network**

network containing also switches

NOTE Switched network means that the network is based on IEEE 802.1D and IEEE 802.1Q with MAC bridges and priority operations.

3.2 Abbreviated terms and acronyms

<i>APDU</i>	<i>Application Protocol Data Unit</i>
<i>CP</i>	<i>communication profile [according to IEC 61784-1]</i>
<i>CPF</i>	<i>Communication Profile Family [according to IEC 61784-1]</i>
<i>CRC</i>	<i>cyclic redundancy check</i>
<i>CSMA-CD</i>	<i>Carrier Sense Multiple Access with Collision Detection</i>
<i>DA</i>	<i>Destination MAC Address</i>
<i>DL</i>	<i>Data Link layer (as a prefix)</i>
<i>DLL</i>	<i>DL-Layer</i>
<i>DUT</i>	<i>device under test</i>
<i>FCS</i>	<i>frame check sequence</i>
<i>ID</i>	<i>Identifier</i>
<i>LAN</i>	<i>Local Area Network</i>
<i>MAC</i>	<i>Media Access Control</i>
<i>PDU</i>	<i>Protocol Data Unit</i>
<i>PTP</i>	<i>Precision Time Protocol [IEC 61588:2004]</i>
<i>RTE</i>	<i>Real-Time Ethernet</i>
<i>RT-Ethernet</i>	<i>Real-Time Ethernet</i>

3.3 Conventions

3.3.1 Conventions common to all layers

3.3.1.1 (Sub)clause selection tables

(Sub)clause selection for all layers is defined in tables, as shown in Table 1 and Table 2. The selected base specifications are indicated just before the selection table(s). Selection is done at the highest (sub)clause level possible to define the profile selection unambiguously.

Table 1 – Layout of profile (sub)clause selection tables

Clause	Header	Presence	Constraints

Table 2 – Contents of (sub)clause selection tables

Column	Text	Meaning
Clause	<#>	(sub)clause number of the base specifications
Header	<text>	(sub)clause title of the base specifications
Presence	NO	This (sub)clause is not included in the profile
	YES	This (sub)clause is fully (100%) included in the profile in this case no further detail is given
	—	Presence is defined in the following subclauses
	Partial	Parts of this (sub)clause is included in the profile
Constraints	See <#>	Constraints/remarks are defined in the given subclause, table or figure of this profile document
	—	No constraints other than given in the reference document (sub)clause, or not applicable
	<text>	The text defines the constraint directly, for longer text table footnotes or table notes may be used

If sequences of (sub)clauses do not match the profile, then the numbers are concatenated.

EXAMPLE concatenated subclauses

3.4 – 3.7	—	NO	—
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3.3.1.2 Service selection tables

If selection of services is defined in a table the format of Table 3 is used. The table identifies the selected services and includes service constraints, as explained in Table 4.

Table 3 – Layout of service selection tables

Service ref.	Service name	Usage	Constraint

Table 4 – Contents of service selection tables

Column	Text	Meaning
Service ref.	<#>	(sub)clause number of the base specifications where the service is defined
	—	Not applicable
Service name	<text>	The name of the service
Usage	M	Mandatory
	O	Optional
	—	Service is never used
Constraints	See <#>	Constraints/remarks are defined in the given subclause, table or figure of this profile document
	—	No constraints other than given in the reference document (sub)clause, or not applicable
	<text>	The text defines the constraint directly, for longer text table footnotes or table notes may be used

If selection of service parameters is defined in a table the format of Table 5 is used. Each table identifies the selected parameters and includes parameter constraints, as explained in Table 6.

Table 5 – Layout of parameter selection tables

Parameter ref.	Parameter name	Usage	Constraint

Table 6 – Contents of parameter selection tables

Column	Text	Meaning
Parameter ref.	<#>	(sub)clause number of the base specifications where the service is defined
	—	Not applicable
Parameter name	<text>	The name of the service parameter
Usage	M	Mandatory
	O	Optional
	—	Attribute is never present
Constraints	See <#>	Constraints/remarks are defined in the given subclause, table or figure of this profile document
	—	No constraints other than given in the reference document (sub)clause, or not applicable
	<text>	The text defines the constraint directly, for longer text table footnotes or table notes may be used

3.3.2 Physical Layer

No additional conventions are defined.

3.3.3 Data Link Layer

3.3.3.1 Service profile conventions

No additional conventions are defined.

3.3.3.2 Service and parameter selections

These are described using the common conventions, see 3.3.1.2.

3.3.4 Application Layer

3.3.4.1 Service profile conventions

ASE and class selection is described using (sub)clause selection tables, see 3.3.1.1. If the usage of selected ASE and classes is further constrained this is specified in the profile (e.g. an optional item of the base standard is mandatory in the profile).

If selection of class attributes is defined in a table the format of Table 7 is used. The table identifies the selected class attributes and includes their constraints, as explained in Table 8.

Table 7 – Layout of class attribute selection tables

Attribute	Attribute Name	Usage	Constraint

Table 8 – Contents of class attribute selection tables

Column	Text	Meaning
Attribute	<#>	Attribute number of the base specification class
	—	Not applicable
Attribute Name	<text>	The name of the attribute
Usage	M	Mandatory
	O	Optional
	—	Attribute is never present
Constraints	See <#>	Constraints/remarks are defined in the given subclause, table or figure of this profile document
	—	No constraints other than given in the reference document (sub)clause, or not applicable
	<text>	The text defines the constraint directly, for longer text table footnotes or table notes may be used

3.3.4.2 Service and parameter selections

These are described using the common conventions, see 3.3.1.2.

4 Conformance to communication profiles

A statement of compliance with an RTE Communication Profile Family (CPF) Profile of this future Part 2 of IEC 61784 shall be stated¹ as either

Compliance to IEC 61784-2:2007 CPF n <Type> or

Compliance to IEC 61784-2 (Ed.1.0) CPF n <Type>

and a statement of compliance with a communication profile (CP) of part of IEC 61784 shall be stated as either

Compliance to IEC 61784-2:2007 CP n/n <Type> or

Compliance to IEC 61784-2 (Ed.1.0) CP n/n <Type>

where the Type within the angle brackets < > is optional and the angle brackets are not to be included. Type could be any character string.

A conformance statement should be supported with appropriate documentation as defined in Clause 6.

¹ In accordance with ISO/IEC Directives

5 RTE performance indicators

5.1 Basic principles of performance indicators

A network that includes real-time communication and is based on the ISO/IEC 8802-3 standard is called Real-time Ethernet (RTE) network. Users of RTE networks have different requirements for different applications. In order to satisfy these requirements in an optimal way RTE communication networks complying with CPs described in this standard will exhibit different performance.

Performance indicators (specified in 5.3) shall be used to specify capabilities of an end-device and an RTE communication network as well as to specify requirements of an application. Performance indicators will be used as a set of interaction means between the user of the RTE CP and the manufacturer of RTE CP compliant end-devices and network components. 5.2 specifies the application requirements view.

Performance indicators represent:

- d) capabilities of an end-device,
- e) capabilities of an RTE communication network
- f) as well as requirements of an application.

A consistent set of performance indicators (specified in 5.3) is used to represent the RTE capabilities. Some of the performance indicators are interdependent; in this case some indicator values depend on the value of others to provide a consistent set.

NOTE The interdependence is due to physical or logical constraints, which cannot be violated. For example the indicator "Throughput RTE (90%)" and "Throughput Non-RTE (90%)" cannot happen at the same time because that would describe a transmission load of 180%.

No general boundary values to specify RTE performance are specified for the indicators in this standard, but device suppliers need to specify boundary values for a CP based product if they claim to be compliant to this standard.

Technology specific CPF subclauses specify:

- g) selection of performance indicators out of possible performance indicators defined in 5.3 relevant to a given CP, optionally with their individual limits or ranges.
- h) interdependence between performance indicators.
- i) optionally, lists with consistent performance indicators values.
Each of the lists has one leading performance indicator. The leading performance indicator is preset to a fixed value (typically optimised to have the best overall performance). The other performance indicators in the list are shown with their related consistency limits.
- j) optionally, a more comprehensive representation of the relation between performance indicators (Figure 1 shows an example of a graphical representation).

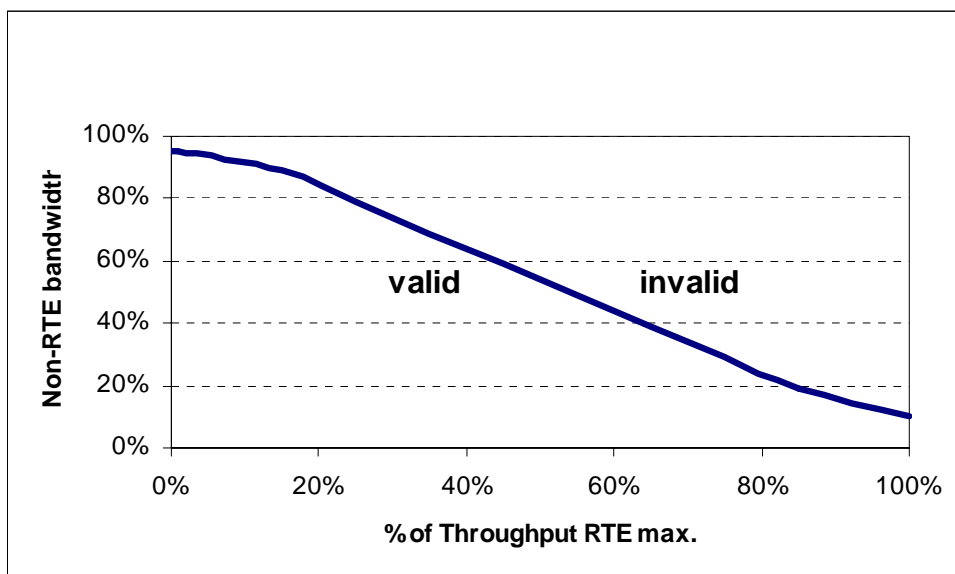


Figure 1 – Example of graphical representation of consistent indicators

The supplier of end-devices and RTE communication networks shall provide at least one consistent set of performance indicators. The boundary values given by the supplier should be based on conformance test principles specified in 6.

NOTE 1 A set of lists with consistent performance indicators is only given when interdependence between performance indicators exists.

NOTE 2 Applications may have requirements where one particular indicator has higher importance than all the others. Such applications will find useful the opportunity to select the consistent indicator list with the relevant leading indicator. Other applications may have requirements where several indicators are of equally high importance. For such applications, a graphical or otherwise more comprehensive representation of the relation between consistent indicators is more appropriate. Figure 1 is an example of a graphical representation of consistent indicators given by a CP.

5.2 Application requirements

The capabilities of an RTE communication network are specified in 5.3 as indicators. The indicators are used to match application requirements to the capabilities of components compliant to one or more CP(s) of this part of IEC 61784.

Figure 2 shows an abstract view of application requirements and the matching process of RTE communication network capabilities. A profile is suitable if its indicator values at least meet the required indicator values.

NOTE 1 A principle for selecting the matching CP is described in ISO 15745-1.

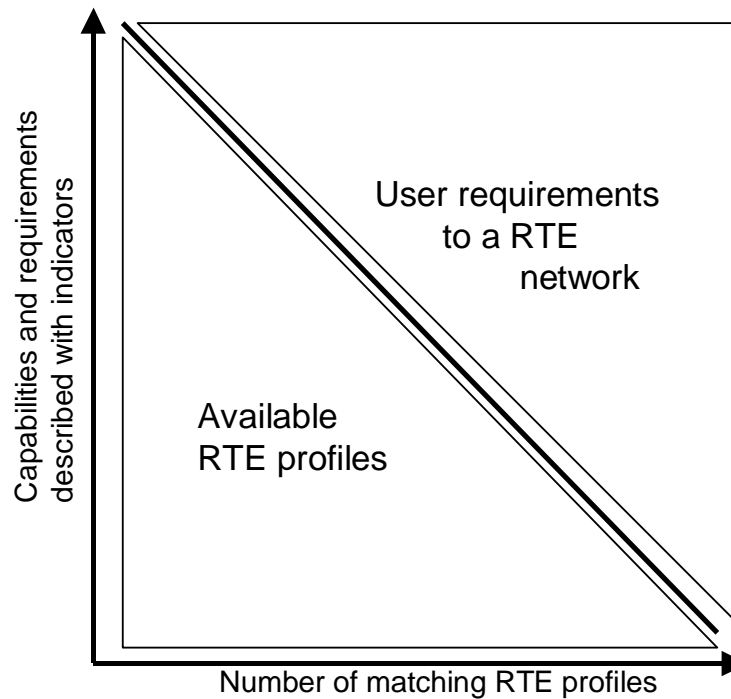


Figure 2 – Abstract view of application requirements and component capabilities matching

The informative Annex C gives guidance how to build an application dependent class.

NOTE 2 The application dependent class should be a subset of a CP x/y to be suitable for this application.

5.3 Performance indicators

5.3.1 Delivery Time

Delivery time shall indicate the time needed to convey an APDU (message payload) from one node (source) to another node (destination). The delivery time is measured at the interface between the Application Process and the (Fieldbus) Application Layer Application Entity.

NOTE 1 A description of the Application Layer concept with a description of Application Process and Application Entity is given in IEC 61158-5 clause 4.

The maximum delivery time shall be stated for two cases:

- no transmission errors and
- one lost frame with recovery

NOTE 2 The permanent failure condition is described in 5.3.9.

5.3.2 Number of end nodes

Number of end nodes shall state the maximum number of RTE end nodes supported by a CP.

NOTE The network devices like a switch are not counted in the number of nodes.

5.3.3 Basic network topology

The basic network topology supported by a CP shall be stated out of the topologies listed in Table 9, or as a combination.

Table 9 – Basic network topology types

Basic network topology	CP
<i>hierarchical star</i>	<i>CP m/1</i>
<i>ring (loop)</i>	<i>CP m/2</i>
<i>daisy-chain</i>	<i>CP m/3</i>
NOTE A real topology could be any combination of the three basic topologies.	

5.3.4 Number of switches between end nodes

Number of switches between end nodes supported by a CP.

5.3.5 Throughput RTE

Throughput RTE shall indicate the total amount of APDU data (by octet length) on one link per second.

5.3.6 Non-RTE bandwidth

Non-RTE bandwidth shall indicate the percentage of bandwidth, which can be used for Non-RTE communication on one link. Additionally the total link bandwidth shall be specified.

NOTE The indicators throughput RTE and Non-RTE bandwidth are related to each other.

5.3.7 Time synchronisation accuracy

Time synchronisation accuracy shall indicate the maximum deviation between any two node clocks.

5.3.8 Non time-based synchronisation accuracy

Non time-based synchronisation accuracy shall indicate the maximum jitter of the cyclic behaviour of any two nodes, using triggering by periodical events over the network for establishing cyclic behaviour.

NOTE 1 This factor accounts for coherency of data or actions triggered by the event, and it is a measure of the coherency spread.

NOTE 2 The event can be unicast, multicast or broadcast, or made of a set of simpler events.

5.3.9 Redundancy recovery time

Redundancy recovery time shall indicate the maximum time from failure to become fully operational again in case of a single permanent failure.

NOTE If a permanent failure occurs, the delivery time of a message is the redundancy recovery time.

6 Conformance tests

6.1 Concept

This part of IEC 61784 specifies the methodology of a conformance test for devices with RTE capabilities for one or more CPs. The concept of this conformance test is to verify the capabilities of a device under test (DUT) against a consistent set of indicators of a CP. The conformance test shall assure the interoperability of devices which claim compliance with the same CP. Figure 3 gives an overview about the conformance test related to this part of IEC 61784.

NOTE Conformance test implementation and conformance test execution are not defined in this standard.

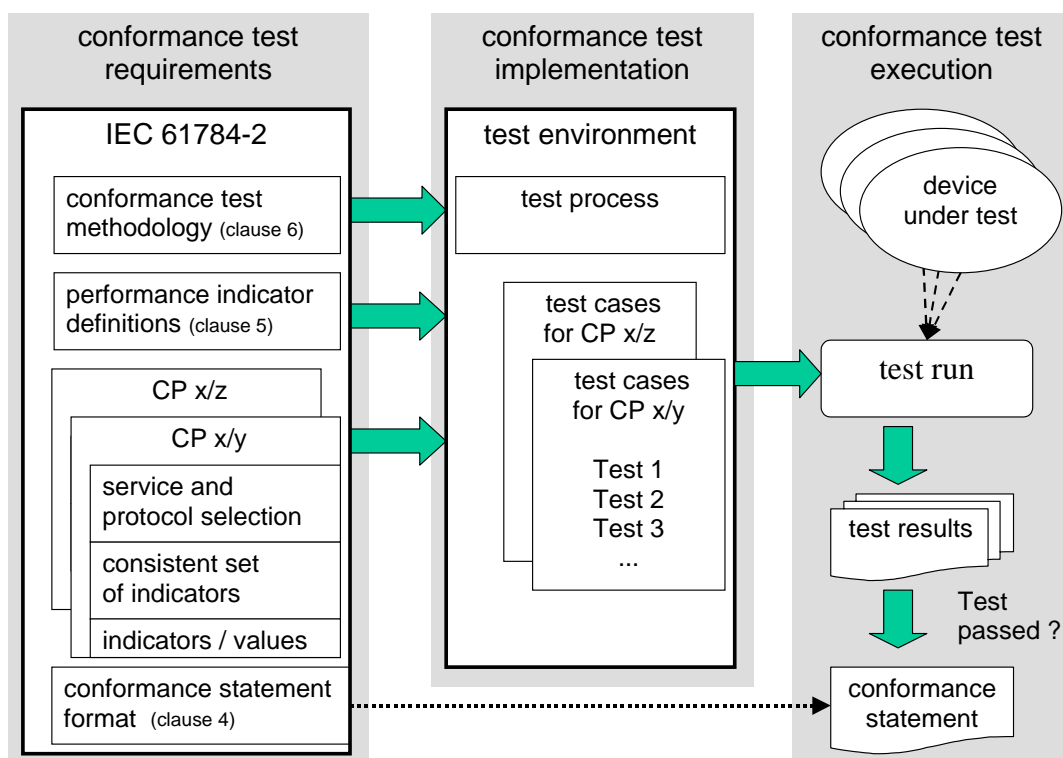


Figure 3 – Conformance test overview

6.2 Methodology

Test cases shall be developed in a way that tests are repeatable. Test results shall be documented and shall be used as the basis for the conformance statement.

Conformance tests of a device shall include, as appropriate, the verification of:

- the availability and correctness of the specified CP functionality,
- network related indicator values,
- device related indicator values,

as specified for a CP and the required indicator values for the device under test.

NOTE 1 It is assumed that the quality of the test cases guarantees the interoperability of a tested device. If any irregularities are reported the test cases will be adapted accordingly.

NOTE 2 A description of conformance testing process is given in ISO/IEC 9646.

6.3 Test conditions and test cases

Test conditions and test cases shall be defined and documented based on a specific CP. This shall include the following indicators, when applicable:

- *number of nodes*
- *network topology*
- *number of switches between nodes*
- *RTE throughput*
- *non-RTE bandwidth*

Some of these indicators may be emulated. Effect of the emulation shall be documented.

For each measured indicator (see 6.4), test condition and test case documents shall be prepared and shall describe:

- *test purpose*
- *test setup*
- *test procedure*
- *criteria for compliance*

Test setup describes the equipment setup necessary to perform the test including measurement equipment, device under test, auxiliary equipment, interconnection diagram, and test environmental conditions.

Test procedure describes how the test should be performed, which also includes description of specific set of indicators required to perform this test. The criteria for compliance define test results accepted as compliance with this test.

6.4 Test procedure and measuring

The measured indicators shall include, when applicable:

- *delivery time*
- *RTE throughput*
- *non-RTE bandwidth*
- *time synchronisation accuracy*
- *non-time based accuracy*
- *redundancy recovery time*

The test procedure shall be based on the principles of 6.3.

The sequence of measuring actions to complete a test run shall be provided.

The number of independent runs of the test shall be provided.

The method to compute the result of the test from the independent runs shall be provided if applicable.

6.5 Test report

The test report shall contain sufficient information so that the test can be repeated.

The test report shall contain at least:

- *the reference to the conformance test methodology according to 6.2,*
- *the reference to the performance indicator definitions according to Clause 5,*
- *the reference to the used CP according to this part of IEC 61784,*
- *a description of the conformance test environment including network emulators, measurement equipment and the person or organization responsible for test execution, and the date of testing,*
- *the device under test, its manufacturer, and hardware and software revision,*
- *the number and type of devices connected to the network together with the topology,*
- *a reference to the test case specifications,*
- *the measured values,*
- *a statement according compliance with the CP.*

7 *Communication Profile Family 2 (ControlNet) - RTE communication profiles*

7.1 *General overview*

7.2 *Profile 2/x*

7.2.1 *Physical Layer*

7.2.2 *Data Link Layer*

7.2.3 *Application Layer*

7.2.4 *Performance indicator selection*

8 *Communication Profile Family 3 (PROFIBUS, PROFINET) - RTE communication profiles*

9 *Communication Profile Family 4 (P-NET) - RTE communication profiles*

10 *Communication Profile Family 6 (INTERBUS) - RTE communication profiles*

11 *Communication Profile Family 10 (Vnet/IP) - RTE communication profiles*

12 *Communication Profile Family 11 (TCnet) - RTE communication profiles*

13 *Communication Profile Family 12 (EtherCAT) - RTE communication profiles*

14 *Communication Profile Family 13 (ETHERNET Powerlink) - RTE communication profiles*

15 *Communication Profile Family 14 (EPA)- RTE communication profiles*

16 *Communication Profile Family 15 (MODBUS-RTPS)- RTE communication profiles*

17 Communication Profile Family 16 (SERCOS)- RTE communication profiles

17.1 Definitions

17.1.1

access procedure

Procedure by which one station gains access to the network and transmits data.

17.1.2

attenuation

Fact that the signal power at the receiver is less than at the transmitter.

17.1.3

broadcast

Transmission to all devices in a network without any acknowledgment by the receivers.

17.1.4

coded character set; code

Set of unambiguous rules that establish a character set and a one-to-one relationship between the characters of the set and their representation by one or more bit combinations.

17.1.5

communication cycle

Accumulation of all telegrams between two MDT0s.

17.1.6

cycle time

Time span between two consecutive cyclically recurring events.

17.1.7

cyclic operation

Operation in which devices in the communication network are addressed and queried one after the other at fixed, constant time intervals.

17.1.8

element

Part of IDNs. Each IDN has 7 elements, whereas each one has a specific meaning (i.e. number, name, data, etc.).

17.1.9

device

A slave in the communication network, e.g. a drive or I/O stations.

17.1.10

device control

Four adjacent bytes inside the master data telegram containing commands for each device.

17.1.11

device (acknowledge) telegram (AT)

Telegram that is sent by the master, in which the slaves insert their data.

17.1.12

device status

Four adjacent bytes inside the device telegram containing status information.

17.1.13

feedback

Measured process values.

17.1.14

forwarding

Mode by which a device passes on a received telegram to the other port, either changed or unchanged.

17.1.15

frame check sequence (FCS)

Check character sequence consisting of 32 bits which is generated by means of a cyclic redundancy check (CRC) character polynomial in accordance with the Ethernet standard (ISO/IEC8802-3).

17.1.16

identification number (IDN)

Designation of operating data under which a data block is preserved with its attribute, name, unit, minimum and maximum values, and the data.

17.1.17

hot plug

Possibility to open the communication ring and insert or remove slaves while the network is still in real-time operation.

17.1.18

IP channel

Defined by times t_6 and t_7 within the communication cycle and passes most ISO/IEC8802-3 Ethernet protocols.

17.1.19

ISO/OSI reference model

Communication layers which are architecture guidelines for defining communication protocols (see ISO/IEC 7498).

17.1.20

line structure

Network topology in which the transmission medium is routed from station to station in the form of a line.

17.1.21

loopback

Mode by which a device passes on a received telegram to the same port and to the other port, either changed or unchanged.

17.1.22

master data telegram (MDT)

Telegram transmitted by the master sending data to the slaves in the topology.

17.1.23

master data telegram (MDT)

Station which assigns the other stations in the topology (i.e., slaves) the right to transmit.

17.1.24

non real-time transmission

Exchange of data via service channel or IP channel.

17.1.25**pad**

A sequence of bytes added to assure that the telegram is long enough for proper operation.

17.1.26**participant**

All active transmitters and receivers, that is all masters and slaves.

17.1.27**physical layer**

First layer of the ISO-OSI reference model.

17.1.28**protocol**

Convention about the data formats, time sequences, and error correction in the data exchange of communication systems.

17.1.29**real-time communication**

Periodic exchange of telegrams.

17.1.30**real-time data**

The part of the telegram that does not change its meaning during cyclic operation of the interface.

17.1.31**ring structure**

Network topology in which the transmission medium is routed from station to station in the form of a ring. The information is transmitted in both directions.

17.1.32**SERCOS**

Serial Real-time COmmunication system interface.

17.1.33**SERCOS type**

Part of the SERCOS-specific telegram header.

17.1.34**service channel**

Non real-time transmission of information upon master request during RT channel.

17.1.35**slave**

Device in the topology that is subordinate to a master for its right to transmit.

17.1.36**S-0-nnnn**

Designation of IDNs.

17.1.37**telegram**

Frame

**17.1.38
topology**

Physical network architecture with respect to the connection between the participants in the communication system.

**17.1.39
transmission medium**

Collective term for the real form of the physical connection between the stations of a communication network.

17.2 Abbreviations

For the purpose of this Specification, the following abbreviations apply:

ADR	Device address ($1 \leq \text{ADR} \leq 254$) adjusted directly on the device e.g. using a selector switch.
AHS	Service transport handshake of the device (acknowledge HS)
AT0...3	Device telegrams (acknowledge telegrams)
AT MST	SERCOS header in AT
AT-P	AT on the primary communication channel (indicated by the master)
AT-S	AT on the secondary communication channel (indicated by the master)
C1D	Class 1 diagnostic
C2D	Class 2 diagnostic
CC	Cross communication between participants
C3D	Class 3 diagnostic
CA	Procedure command acknowledgment
CB	Procedure command change bit (device status, bit 5)
CC	Procedure command control
CP	Communication phase
CPS	Communication phase switching
CRC	Cyclic redundancy check
DA	Destination address
DAT	Duration of device telegram
DMDT	Duration of master data telegram
EFD	End frame delimiter
ESD	End stream delimiter
FCS	Frame check sequence (see ISO/IEC 8802-3)
HS	Service channel handshake (see AHS and MHS)
IDLE	Inter packet gap (see IPG)
IDN	Identification number
i	Sequence of different topologies on one master, labelled as $i = 1 \dots l$
l	Number of topologies on one master
INFO	Service channel information
IPG	Inter packet gap (see IDLE)
J	Jitter
J_{t1}	Jitter in t_1
J_{tscyc}	Jitter in t_{Scyc}
K	Number of real-time data fields in the MDTs (see also M)
k	Time sequence of real-time data fields in the MDTs, labelled as $k = 1 \dots K$

LSB	Least significant bit
M	Number of real-time data fields in the ATs (see also K)
m	Time sequence of real-time data fields in the ATs, labelled as $m = 1 \dots M$
Mbit/s	Megabit per second
MC	Motion control or motion controller (see also NC)
MDT0	Master data telegram, slave evaluates the synchronisation data
MDT1...3	Master data telegrams, slave doesn't evaluate the synchronisation data
MDT MST	SERCOS header in MDT
MDT-P	MDT on the primary communication channel (indicated by the master)
MDT-S	MDT on the secondary communication channel (indicated by the master)
MHS	Service transport handshake of the master
MSB	Most significant bit
N	Number of service channels in the MDTs and ATs
n	Time sequence of service channels in the MDTs and ATs, labelled as $n = 1$ through N
NC	Numerical control, control unit or controller (see also MC)
NRT	Non real-time mode
OSI	Open System Interconnection
P1	Port 1
P2	Port 2
P-channel	Primary communication channel
ppm	parts per million
RT	Real-time
RTC	Real-time channel
RTD	Real-time data in MDT or AT
RxCLK	Receiving clock
RxD	Received data
SA	Source address
SFD	Start frame delimiter
SLKN	Slave identification parameter, slave arrangement
S-channel	Secondary communication channel
SSD	Start stream delimiter
SVC	Service channel
t_1	AT transmission starting time
t_3	Command value valid time
t_4	Feedback acquisition capture point
t_5	Minimum feedback processing time
$t_{5.m}$	Minimum time which device with real-time data field m needs to process its captured feedback value for the next AT
t_{cable}	Time by which the transmitted signal is delayed by the cable (approx., 5 ns/m)
t_{rep}	Time by which the received signal is delayed by a forwarding slave (input-output)
t_{ring}	Time between the transmitted and received signal at the master
t_{MTSG}	Command value processing time
$t_{\text{MTSG.K}}$	Time required by the slave which is served by the last real-time data field(s) in the MDT to make the command values available for that device which is assigned to real-time data field K

t_{Ncyc}	Control unit cycle time
t_{Rcyc}	Device cycle time
t_{Scyc}	Communication cycle time
TxCLK	Transmitting clock
TxD	Transmitted data
0x0..9A..F	Hexadecimal digits

17.3 General overview

Communication Profile Family 16 defines profiles based on IEC 61158-2 through IEC 61158-6, protocol Type S (SERCOS), and on other standards (see Clause 2).

The SERCOS fieldbus family consists of three distinct standards. Communication profile 16/1 is based on fibre-media physical layers and operates at 2 and 4 Mbit/s. Communication profile 16/2 is similar to 16/1, but operates also at 8 and 16 Mbit/s, and provides for additional features. Communication profile 16/3 is based on ISO/IEC 8802-3 (Ethernet) MAC and physical layers; it provides again for additional features.

Table 10 – SERCOS types

Layer	Profile 16/1	Profile 16/2	Profile 16/3
Application	Type S of IEC 61158-5, -6	Type S of IEC 61158-5, -6	Type S of IEC 61158-5, -6
Data Link	Type S of IEC 61158-3, -4	Type S of IEC 61158-3, -4	Type S of IEC 61158-3, -4
Physical	Type S of IEC 61158-2	Type S of IEC 61158-2	Type S of IEC 61158-2

NOTE Profiles 16/1 and 16/2 are specified in IEC 61784-1.

17.4 Summary of SERCOS concepts

This sub-clause provides information about the fundamental technical characteristics of SERCOS, without establishing specific definitions. For the reader who is unfamiliar with this interface, this sub-clause will serve as a preface to the specific details which follow in later clauses.

SERCOS allows for synchronisation during cyclic data transmission. Depending on the configuration, the operating cycle of the master may be synchronised with the communication cycle and with the operating cycle of the devices. In that way beats between individual cycles can be prevented and latency delays can be reduced to a minimum. Slave output signals may become active and slave input signals may be sampled concurrently in all devices.

SERCOS provides for communication between a master and several slaves. SERCOS telegrams are not addressed individually to each slave; they are instead common to all slaves. Slots within these telegrams are individually allotted to each slave. The slave may then read in its slot the data that is addressed specifically to it by the master; likewise it may also write data that it addresses to the master. The slot allocation is defined by the master during initialization, depending upon configuration. Other transmission modes are available for data that do not have to fulfil strict real-time requirements.

SERCOS is not just a data transmission system. It provides a large number of data and procedure commands which can be used for the operation of machines. All data, procedure commands, and all supplementary information are summarized in data blocks, which contain each an identification number (IDN), a name, attributes, units, minimum and maximum input values as well as the data itself.

Communication profile 16/3 provides for additional features, as compared to 16/1 and 16/2:

- Profile 16/3 uses Ethernet's physical layer as per ISO/IEC 8802-3.
- A communication cycle provides for real-time and non real-time communication (see Figure 4). The real-time portion is an inherent part of the communication cycle. The non real-time communication may optionally be used, and in that case the master has to set the time-slot for the non real-time communication during initialization.
- For the logging on or off of participants there are data fields (hot-plug fields) in the real-time telegrams. The procedures for logging on and off are specified.
- The cross communication is part of the real-time communication and must be accounted for when configuring the ATs. The master determines the participants in cross communications.
- The ring topology offers redundancy during communication. In case of a failure of one of the transmission lines (e.g. cable break), the master can still communicate with all its slaves without interruption. Thus reliability and availability of the network are enhanced.

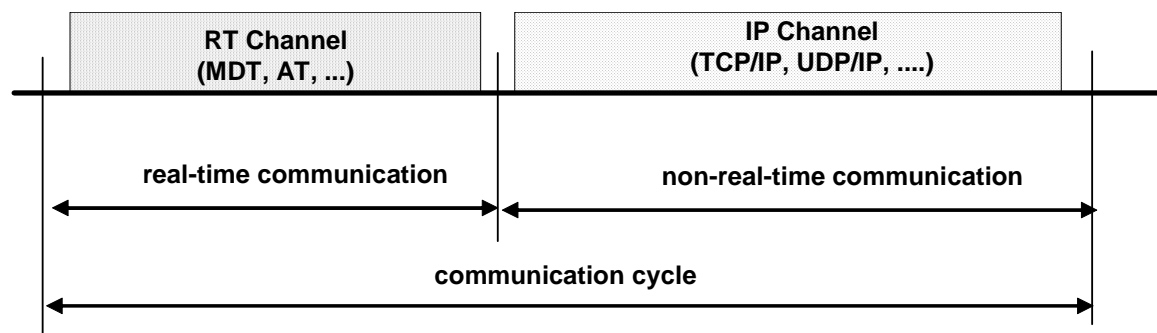


Figure 4 – General communication cycle

17.5 Profile 16/1– SERCOS I

This Communication Profile is specified in the new edition of IEC 61784-1 as it is not Ethernet-based.

17.6 Profile 16/2 – SERCOS II

This Communication Profile is specified in the new edition of IEC 61784-1 as it is not Ethernet-based.

17.7 Profile 16/3 – SERCOS III

17.7.1 Physical Layer

17.7.1.1 General

The physical layer is based on Ethernet hardware.

The topology can be either a ring structure or a line structure (see Figure 5).

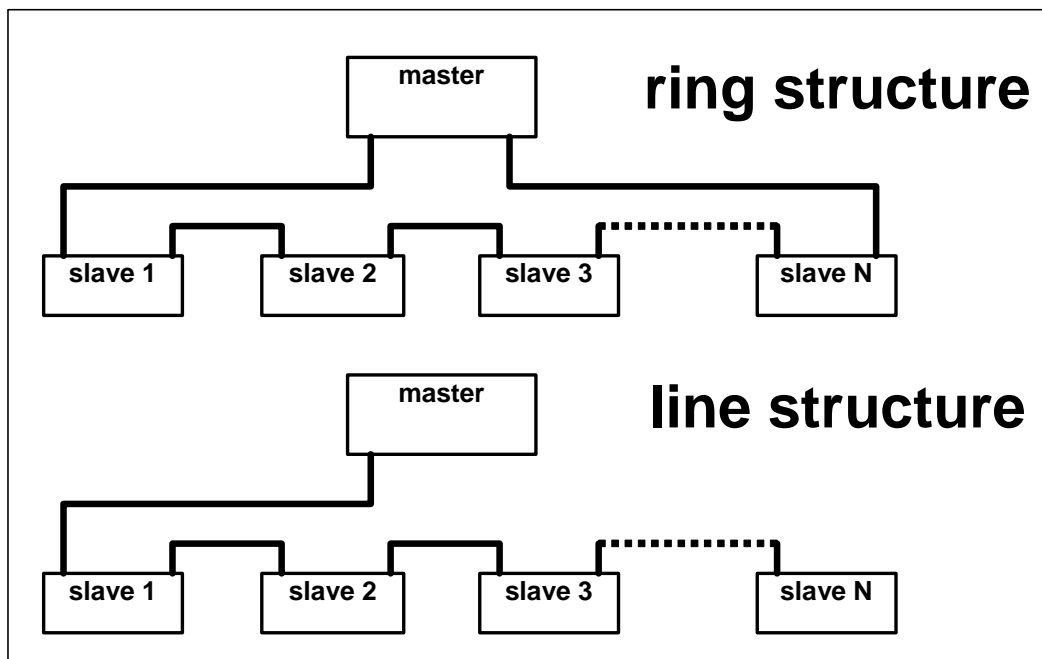


Figure 5 – Ring and line structure

17.7.1.2 Master and slave relationship

Figure 6 shows network structure examples. The unit may have one or more master interfaces depending on configuration. Each master handles only one network on the physical layer as well as in the overlying protocol layers.

Application specific terms are used in this figure. Although not relevant in this specification they may be useful as they illustrate typical uses of the SERCOS fieldbus. These terms are:

- Control unit – Part of a machine automation system that controls the whole machine.
- Drive – Part of machine automation that supplies and controls one motor.
- Drive group – Group of several drives that communicate through a network using one slave.
- Hybrid group – Group of one or several drives and an I/O station that communicate by a network using one slave.
- I/O-Station – Connection point of sensors and actuators that are managed by the control unit.

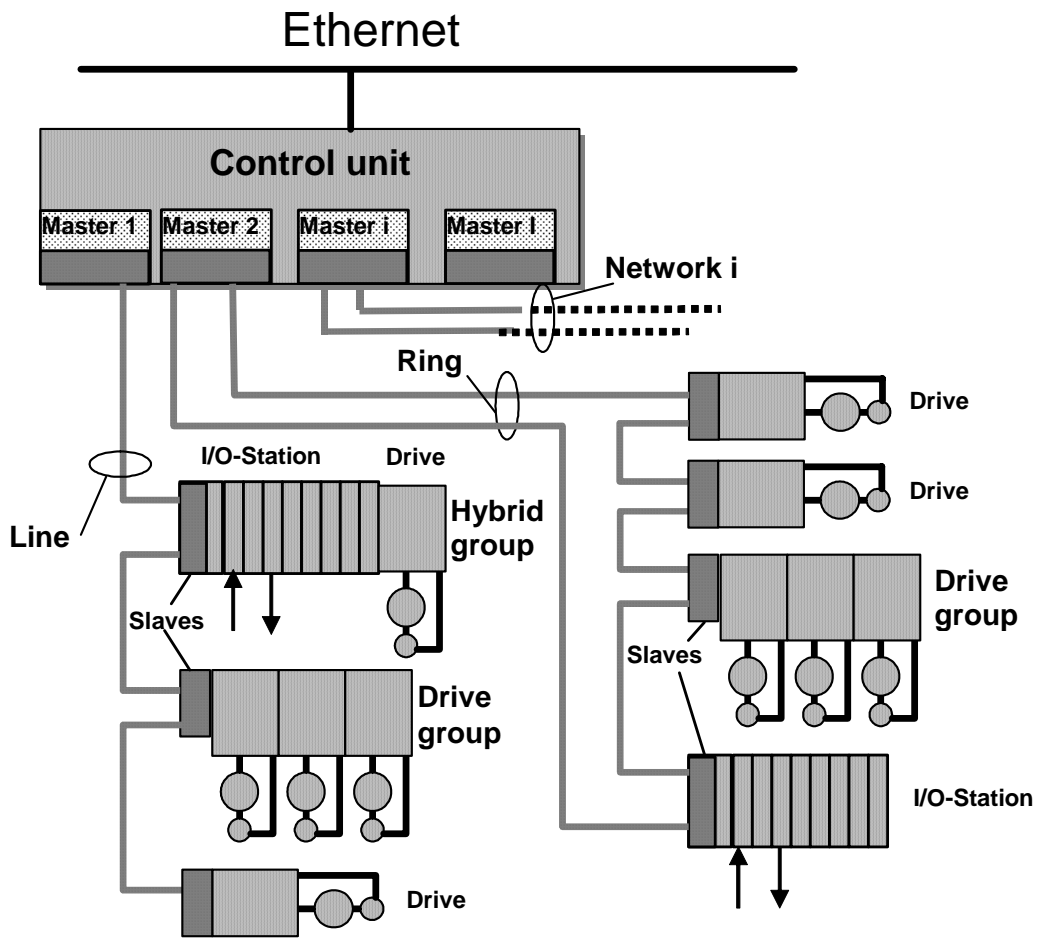


Figure 6 – Topology example

17.7.1.3 Physical Layer selection

Table 11 specifies the PhL selection within IEC 61158-2 for this profile.

Table 11 – CP 16/3: PhL selection

Clause	Header	Presence	Constraints
0	Introduction	YES	—
1	Scope	YES	—
2	Normative references	Partial	Used as needed
3	Terms and definitions	—	
3.1	Common terms and definitions	Partial	Used when applicable
3.2 – 3.8	—	NO	—
3.9	Type S: Terms and definitions	YES	—
4	Symbols and abbreviations	—	
4.1	Symbols	—	
4.1.2 – 4.1.6	—	NO	—
4.1.7	Type S: Symbols	YES	—
4.2	Abbreviations	—	
4.2.1 – 4.2.6	—	NO	—
4.2.7	Type S: Abbreviations	YES	—
5	Data Link Layer – Physical Layer interface	—	
5.1	General	Partial	Used as needed
5.1-5.7	—	NO	
6	Station Management – Physical Layer interface	—	
6.1	General	Partial	Used as needed
6.1-6.7	—	NO	
7	DCE Independent Sub layer (DIS)	—	
7.1	General	Partial	Used as needed
7.1-7.7	—	NO	
8	DTE-DCE interface	—	
8.1	General	Partial	Used as needed
8.1-8.7	—	NO	
9	Medium Dependent Sublayer (MDS)	—	
9.1	General	Partial	Used as needed
9.1-9.7	—	NO	
10	MDS – MAU interface	—	
10.1	General	Partial	Used as needed
10.1-10.7	—	NO	
11 – 28	—	NO	—
29	Type S: Medium Attachment Unit: Ethernet 100Base-TX or 100Base-FX	YES	—

17.7.2 Data Link Layer

17.7.2.1 General

CP16/3 profile uses Ethernet ISO/IEC 8802-3, type II frames (see Figure 7). Every CP16/3 telegram consists of:

- the Ethernet frame;
- the SERCOS header;
- the data field of minimum 40 bytes to maximum 1494 bytes.

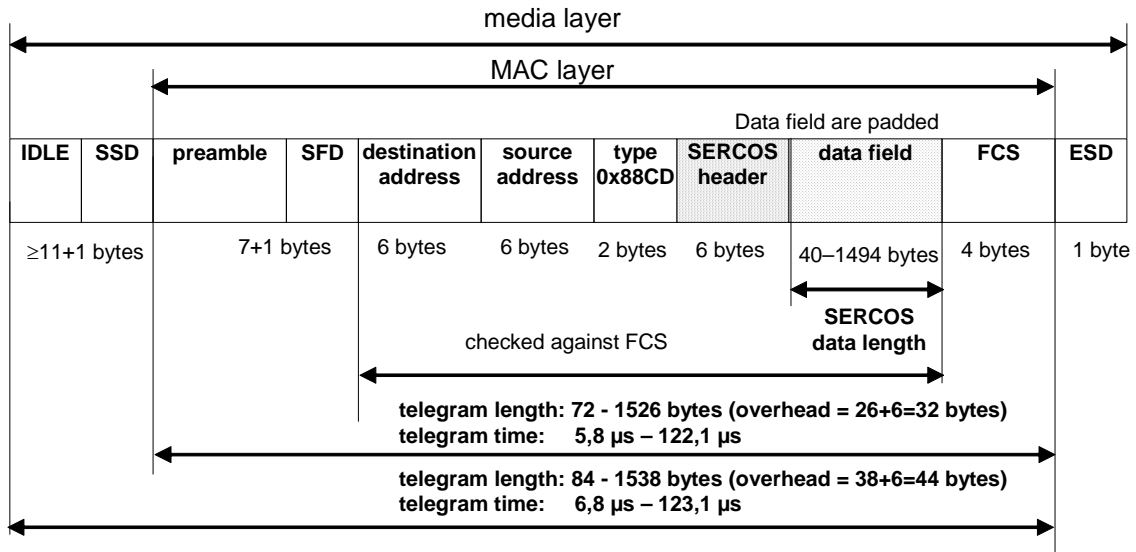


Figure 7 – General telegram structure

17.7.2.2 DLL service selection

Table 12 specifies the DLL service selection within IEC 61158-3 for this profile.

Table 12 – CP 16/3: DLL service selection

Clause	Header	Presence	Constraints
0	Introduction	YES	—
1	Scope	YES	—
2	Normative references	Partial	Use as needed
3	Terms and definitions	—	
3.1 – 3.3	Common terms and definitions	Partial	Use as needed
3.4 – 3.10	—	NO	—
3.11	Type S: Additional Data Link Service terms and definitions	YES	—
4	Symbols and abbreviations	—	
4.1	Common symbols and abbreviations	Partial	Use as needed
4.2 – 4.8	—	NO	—
4.9	Type S: Symbols and abbreviations	YES	—
5	Conventions	—	
5.1	General conventions	Partial	Use as needed
5.2 – 5.8	—	NO	—
6 – 20	—	NO	—
21	Type S: Data Link concepts, services and management	YES	—

17.7.2.3 DLL protocol selection

Table 13 specifies the DLL selection within IEC 61158-4 for this profile.

Table 13 – CP 16/3: DLL protocol selection

Clause	Header	Presence	Constraints
0	Introduction	YES	—
1	Scope	—	
1.1	Overview	Partial	Type S only
1.2	Specifications	—	
1.2.1-1.2.8	—	NO	—
1.2.9	Type S: Additional characteristics	YES	—
1.3 – 1.5	—	YES	—
2	Normative references	Partial	Use as needed
3	Terms and definitions	—	
3.1 – 3.3	—	Partial	Use as needed
3.4 – 3.10	—	NO	—
3.11	Type S: Additional terms and definitions	YES	—
4	Symbols and abbreviations	—	
4.1	Common symbols and abbreviations	Partial	Use as needed
4.2 – 4.8	—	NO	—
4.9	Type S: Additional symbols and abbreviations	YES	—
5	DL-protocol elements common to multiple DL-protocol Types	Partial	Use as needed
6 - 32	—	NO	—
33	Type S: Data Link protocol definition	YES	—
Annex A – 0	—	NO	—

17.7.3 Application Layer

17.7.3.1 General

SERCOS communication consists of two different logical communication channels:

- RT channel (real-time channel);
- IP channel (non real-time channel).

17.7.3.2 Real-time channel

The real-time channel is processed in every communication cycle. Its function is to:

- synchronise the slaves with the master;
- exchange command values and feedback values between master and each slave within each communication cycle (real-time data transmission);
- write and read parametric data of the slave by the master on request (service channel transmission);
- exchange cross communication data between the slaves.

17.7.3.3 IP channel

The IP channel is a communication channel which can be accessed on demand. Its protocol is based on the Internet standard IP (e.g., TCP/IP, UDP/IP, ...). Its function is to:

- exchange data between master and slaves (operator interface data, file transfer,...);
- exchange data between slaves;
- provide for transparent IP communications between master/slaves and a standard Ethernet device (e.g., standard network interface cards found on most personal computers).

17.7.3.4 Synchronisation

Synchronisation information is generated by the master. The slaves synchronise their processing with the master. The master assures the synchronisation of all slaves by sending the master synchronisation information at a fixed repetition rate t_{sync} . The master synchronisation information is received by all slaves.

17.7.3.5 Communication cycle

The cycle is initiated by the master and is determined once and for all during initialization phases of the network. A communication cycle consists of the following telegrams:

- **Up to four Master Data Telegram MDT:** The MDTs are transmitted by the master and received by each slave. They contain all information sent from the master to the slaves through the real-time channel.
- **Up to four Device Telegram AT:** The ATs are transmitted by the master without information. Each slave inserts its data into its allocated data field in the ATs. The ATs contain all information sent from the slaves to the master through the real-time channel and the slaves cross communication data.
- **IP telegrams:** These are standard non real-time IP telegrams that can be used for any purpose, and even be omitted. Most ISO/IEC 8802.3 Ethernet frames can be transmitted via this IP channel. The IP channel length has a fixed duration and determines the maximum number of IP telegrams that can be sent during this duration.

This sequence of transmitting synchronisation, RT-data telegrams and IP telegrams is repeated every communication cycle. The time-slots for the RT channel and the IP channel and the transmission time of the AT are transmitted during initialization and therefore known by each slave. Figure 8 shows two principle arrangements of RT and IP channels. Both methods are possible and are parameterized by the master. Within the IP channel there are no special time-slots. Every participant sends its IP telegrams during this time-slot.

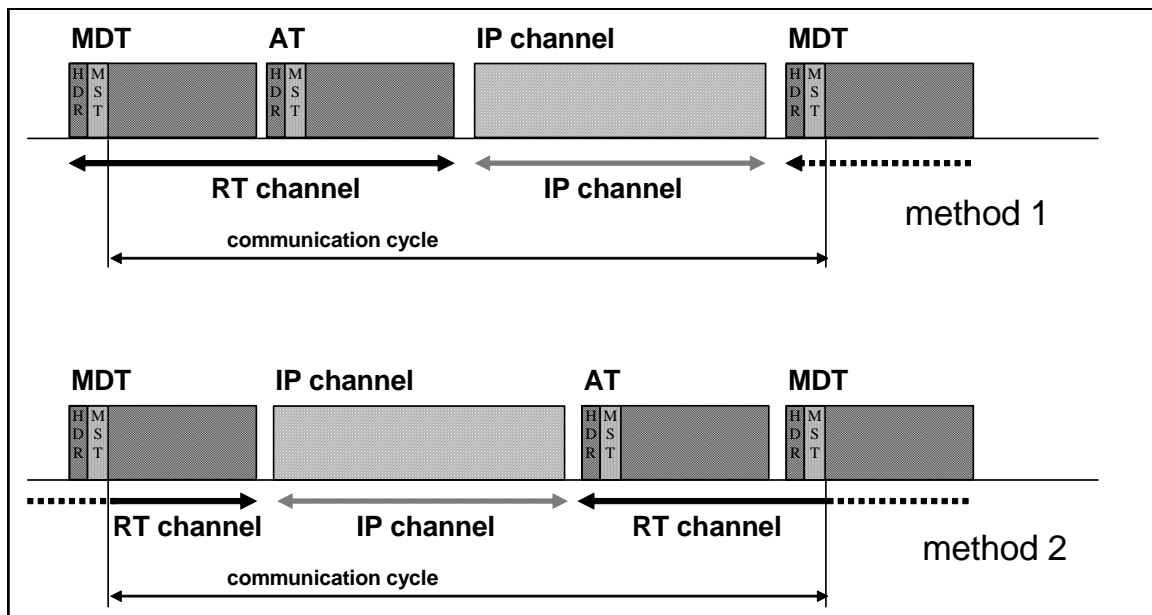


Figure 8 – General structure of communication cycle

The master sends the master data telegram (MDT) to all slaves. This telegram contains:

- synchronisation information (MDT MST);
- successive data records for each slave containing control information, service channel data and command values from the control unit.

The slaves transmit their data by inserting it into the AT. Within their data fields in the telegram the slaves transmit status information, service channel data and actual values to the master and to other slaves.

The number and the lengths of the RT data telegrams (MDT and AT) is fixed according to a configuration that is also determined during the initialisation.

17.7.3.6 Cross communication

As the slaves transmit their real-time data within the ATs to both connected ports, all other slaves have the possibility to read it as they forward these ATs. This data is transmitted without any master participation, and is thus available immediately within the same cycle to all slaves. This feature may be used in applications where slaves have to process data from other slaves.

17.7.3.7 Hot plug

The last slave in a line configuration monitors continuously its unused port and, should an additional device get connected, it forwards all received telegrams to this new device. The SERCOS communication and its timings remain unchanged and stable. If the additional device supports the SERCOS protocol, it sends the real-time telegrams (MDTs and ATs) back. Using the hot plug fields in MDTs and ATs, the master and the additional device can communicate. After processing through the hot plug procedure, the additional device becomes the last slave within the line configuration.

17.7.3.8 AL service selection

Table 14 specifies the AL service selection within IEC 61158-5 for this profile.

Table 14 – CP 16/3: AL service selection

Clause	Header	Presence	Constraints
0	Introduction	YES	—
1	Scope	YES	—
2	Normative references	Partial	Use as needed
3	Terms and definitions	Partial	Use as needed
4	Concepts	Partial	Use as needed
5	Data type ASE	Partial	Use as needed
6 –15	—	NO	—
16	Type S: Communication model specification	YES	—

17.7.3.9 AL protocol selection

Table 15 specifies the AL protocol selection within IEC 61158-6 for this profile.

Table 15 – CP 16/3: AL protocol selection

Clause	Header	Presence	Constraints
0	Introduction	YES	—
1	Scope	YES	—
2	Normative references	Partial	Use as needed
3	Terms and definitions	—	
3.1 – 3.3	—	Partial	Use as needed
3.4	Other terms and definition	—	
3.4.1 – 3.4.2	—	Partial	Use as needed
3.4.3 – 3.4.11	—	NO	
3.4.12	Type S definitions	YES	
3.5	Abbreviations and symbols	—	
3.5.1 – 3.5.2	—	Partial	Use as needed
3.5.3 – 3.5.11	—	NO	
3.5.12	Type S Abbreviations and symbols	YES	
3.6	Conventions	—	
3.6.1	—	Partial	Use as needed
3.6.2 – 3.6.11	—	NO	
3.6.12	Conventions for Type S	YES	
3.7	Conventions used in state machines	—	
3.7.1 – 3.7.11	—	NO	
3.7.12	State machine conventions for Type S	YES	

Clause	Header	Presence	Constraints
4 –13	—	NO	—
14	Type S	YES	—

17.7.4 Performance indicator selection

17.7.4.1 Communication cycle

Communication is executed in communication cycles. The length of the communication cycle is determined during initialisation. Defined values are 31 μ s, 25 μ s, 62,5 μ s, 125 μ s, 250 μ s and integer multiples of 250 μ s up to 65 000 μ s.

17.7.4.2 Delivery Time

Delivery time when after initialization (CP4) is given by the following equation:

$$t_{\text{delivery}} = t_{\text{Scyc}} + t_{\text{ring}} = t_{\text{Scyc}} + (\text{total number of participants} \cdot t_{\text{rep}} + \text{total cable length [m]} \cdot 5 \text{ ns})$$

Example 1: A network that operates at 31,25 μ s cycle time with 8 slaves (that means 9 participants together with the master), a worst-case $t_{\text{rep}} = 0,5 \mu$ s and a total cable length of 50 m performs at $t_{\text{delivery}} = 31,25 + 9 \cdot 0,5 + 50 \cdot 0,005 = 37,0 \mu$ s.

Example 2: A network that operates at 500 μ s cycle time with 162 slaves (that means 163 participants together with the master), a worst-case $t_{\text{rep}} = 0,5 \mu$ s and a total cable length of 1'000 m performs at $t_{\text{delivery}} = 500 + 163 \cdot 0,5 + 1\ 000 \cdot 0,005 = 586,5 \mu$ s.

17.7.4.3 Number of end nodes

The maximum number of end nodes is 254.

17.7.4.4 Basic network topology

The basic network topology can be either a daisy-chain (line structure, see definition 17.1.20) or a ring (ring structure, see definition 17.1.31).

17.7.4.5 Number of switches between end nodes

General use switches are not permitted between any two participants. Only the free port of the last slave in a line structure may be connected to a switch if required by the configuration, e.g., for communication with devices via TCP/IP or UDP/UDP.

17.7.4.6 Throughput RTE

Throughput RTE depends on configuration and can reach 11.692.000 bytes of APDU data per second (e.g., a configuration with 153 slaves, each receiving 32 data bytes/cycle and transmitting 32 data bytes/cycle).

17.7.4.7 Non-RTE bandwidth

Non-RTE bandwidth depends on configuration. As no collision is possible in the network, the full Ethernet 100 MHz bandwidth is available, together for RTE and Non-RTE data.

17.7.4.8 Time synchronization accuracy

Once the initialization process has been completed (CP4), the maximum deviation between any two node clocks in the network does not exceed twice the jitter, due to the specified telegram propagation time monitoring.

17.7.4.9 Non time-based synchronization accuracy

SERCOS (CP16/3) specifies 2 performance classes as shown in Table 16.

Table 16 – Synchronisation performance classes

Performance class	MDT0 jitter $ J_{tscycl} $
high performance	$\leq 1 \mu s$
low performance	$\leq 50 \mu s$

17.7.4.10 Redundancy recovery time

In the ring topology, a single permanent failure does not produce any failure.

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