

Electrical equipment of industrial machines — Serial data link for real-time communication between controls and drives

The European Standard EN 61491:1998 has the status of a
British Standard

ICS 35.240.50

NO COPYING WITHOUT BSI PERMISSION EXCEPT AS PERMITTED BY COPYRIGHT LAW



Document Sharing Hub

National foreword

This British Standard is the English language version of EN 61491:1998. It was derived by CENELEC from IEC 61491:1995.

The CENELEC modifications have been implemented at the appropriate places in the text and are indicated by a side line in the margin.

The UK participation in its preparation was entrusted to Technical Committee GEL/44, Safety of machinery — Electrotechnical aspects, which has the responsibility to:

- aid enquirers to understand the text;
- present to the responsible international/European committee any enquiries on the interpretation, or proposals for change, and keep the UK interests informed;
- monitor related international and European developments and promulgate them in the UK.

A list of organizations represented on this committee can be obtained on request to its secretary.

From 1 January 1997, all IEC publications have the number 60000 added to the old number. For instance, IEC 27-1 has been renumbered as IEC 60027-1. For a period of time during the change over from one numbering system to the other, publications may contain identifiers from both systems.

Cross-references

Attention is drawn to the fact that CEN and CENELEC Standards normally include an annex which lists normative references to international publications with their corresponding European publications. The British Standards which implement these international or European publications may be found in the BSI Standards Catalogue under the section entitled “International Standards Correspondence Index”, or by using the “Find” facility of the BSI Standards Electronic Catalogue.

A British Standard does not purport to include all the necessary provisions of a contract. Users of British Standards are responsible for their correct application.

Compliance with a British Standard does not of itself confer immunity from legal obligations.

Summary of pages

This document comprises a front cover, an inside front cover, pages i and ii, the EN title page, pages 2 to 248 and a back cover.

This standard has been updated (see copyright date) and may have had amendments incorporated. This will be indicated in the amendment table on the inside front cover.

This British Standard, having been prepared under the direction of the Electrotechnical Sector Committee, was published under the authority of the Standards Committee and comes into effect on 15 March 1999

© BSI 06-1999

ISBN 0 580 30731 X

Amendments issued since publication

Amd. No.	Date	Comments

Contents

	Page
National foreword	Inside front cover
Foreword	2
Text of EN 61491	7

ICS 35.240.50

Descriptors: Machines, electrical equipment, digitally controlled drives, interface for numerical control, transfer medium, data transfer, protocol structure, data contents, layers, error handling, functional sequences, identification numbers

English version

Electrical equipment of industrial machines Serial data link for real-time communication between controls and drives

(IEC 61491:1995, modified)

Équipement électrique des machines
industrielles
Liaison des données sérielles pour
communications en temps réel entre unités de
commande et dispositifs d'entraînement
(CEI 61491:1995, modifiée)

Elektrische Ausrüstung von
Industriemaschinen
Serielle Datenverbindung für
Echtzeit-Kommunikation zwischen
Steuerungen und Antrieben
(IEC 61491:1995, modifiziert)

This European Standard was approved by CENELEC on 1998-08-01. CENELEC members are bound to comply with the CEN/CENELEC Internal Regulations which stipulate the conditions for giving this European Standard the status of a national standard without any alteration.

Up-to-date lists and bibliographical references concerning such national standards may be obtained on application to the Central Secretariat or to any CENELEC member.

This European Standard exists in three official versions (English, French, German). A version in any other language made by translation under the responsibility of a CENELEC member into its own language and notified to the Central Secretariat has the same status as the official versions.

CENELEC members are the national electrotechnical committees of Austria, Belgium, Czech Republic, Denmark, Finland, France, Germany, Greece, Iceland, Ireland, Italy, Luxembourg, Netherlands, Norway, Portugal, Spain, Sweden, Switzerland and United Kingdom.

CENELEC

European Committee for Electrotechnical Standardization
Comité Européen de Normalisation Electrotechnique
Europäisches Komitee für Elektrotechnische Normung

Central Secretariat: rue de Stassart 35, B-1050 Brussels

© 1998 CENELEC — All rights of exploitation in any form and by any means reserved worldwide for CENELEC members.

Foreword

The text of the International Standard IEC 61491:1995, prepared by IEC TC 44 Safety of machinery — Electrotechnical aspects, together with the common modifications prepared by the Technical Committee CENELEC TC 44X, Safety of machinery: electrotechnical aspects, was submitted to the formal vote and was approved by CENELEC as EN 61491 on 1998-08-01.

The following dates were fixed:

- latest date by which the EN has to be implemented at national level by publication of an identical national standard or by endorsement (dop) 1999-08-01
- latest date by which the national standards conflicting with the EN have to be withdrawn (dow) 1999-08-01

Annexes designated “normative” are part of the body of the standard.

Annexes designated “informative” are given for information only.

In this standard, Annex A to Annex E and Annex ZA are normative and Annex F to Annex K are informative.

Annex K and Annex ZA have been added by CENELEC.

In this European Standard the common modifications to the International Standard are indicated by a vertical line in the left margin of the text.

The document also includes a number of non identified editorial corrections to the text of IEC 61491:1995.

Contents

	Page
Foreword	2
1 Scope	7
2 Normative references	7
3 Definitions and abbreviations	7
3.1 Definitions	7
3.2 Abbreviations	10
4 General requirements	13
4.1 Overview	13
4.2 System overview	14
4.3 Data transmission	18
4.4 Initialization	22
4.5 Error and status messages	23
5 Transfer medium and physical layer	23
5.1 General	23
5.2 Topology	23
5.3 Optical signals on the transmission line	25
5.4 Time performance of bit transmission	28
5.5 Bit coding	33
5.6 Telegrams and fill characters	34
5.7 Connection to the optical fibre	35
6 Data transfer and data link layer	40
6.1 General	40
6.2 Telegram structure	41
6.3 Timing of the transmission (communication cycles)	43
7 Protocol structure	46
7.1 General	46
7.2 General protocol structure	47
7.3 Cyclic data exchange (CP ₄)	49
7.4 Non-cyclic data exchange (service channel)	59
8 Data contents	71
8.1 Data types and data structure	71
8.2 General parameters	77
8.3 Definition of telegram contents	81
8.4 Drive operation modes	83
8.5 Standard operation data	84
8.6 Scaling of operation data	86
8.7 Drive parameters	92
8.8 Mechanics	98

	Page	Page
9 Initialization of the SYSTEM interface	99	Annex G (informative) Attenuation on the transmission line 226
9.1 General	99	Annex H (informative) Determination of the transmission timeslots 227
9.2 Communication phase 0 (CP ₀)	100	Annex I (informative) Processing operation data 229
9.3 Communication phase 1 (CP ₁)	100	Annex J (informative) Procedure command execution 235
9.4 Communication phase 2 (CP ₂)	102	Annex K (informative) Additional scaling 241
9.5 Communication phase 3 (CP ₃)	102	Annex ZA (normative) Normative references to international publications with their corresponding European publications 248
9.6 Communication phase 4 (CP ₄) — end of initialization	103	Figure 1 — Topology 14
10 Error handling	103	Figure 2 — Operation modes 15
10.1 Drive safety functions	103	Figure 3 — Overview of data field structure (CP ₃ and CP ₄) 18
10.2 Failure of telegrams	104	Figure 4 — Transfer layers 19
10.3 Changing the communication phases	106	Figure 5 — Timed access method 19
10.4 Monitoring (overview)	106	Figure 6 — Communication cycle 20
10.5 Reaction to handshake timeout	107	Figure 7 — Topology 24
10.6 Reaction to error messages in the service channel	107	Figure 8 — Optical transmission line 25
10.7 Error counters in the master and the slave	108	Figure 9 — Structure of a single-core cable (example) 27
11 Functional sequences	109	Figure 10 — Optical signal envelope 30
11.1 General	109	Figure 11 — Display of jitter (J_{noise}) 30
11.2 Allocation of real-time bits	109	Figure 12 — Input-output performance of a slave 32
11.3 Homing	112	Figure 13 — Example of an NRZI-coded signal 34
11.4 Measurements	117	Figure 14 — General telegram structure 34
11.5 Position spindle procedure command	118	Figure 15 — Fill signal 35
11.6 Switching of parameter sets and the gear ratio	120	Figure 16 — Functions of a master connection 35
11.7 Starting/stopping functions	121	Figure 17 — Valid transmitting signals during transitions from fill signal to telegram delimiters 37
11.8 Park axis procedure command	123	Figure 18 — Valid transmitting signals during transitions from telegram delimiters to fill signal 38
11.9 Positive stop drive procedure command	123	Figure 19 — Functions of a slave connection 39
11.10 Drive controlled synchronous operation procedure command	124	Figure 20 — Ring with two slaves 40
11.11 Drive controlled gear engaging procedure command	126	Figure 21 — Access to the transfer medium 44
Annex A (normative) Identification numbers in numerical order	128	Figure 22 — Required time intervals between telegrams 46
Annex B (normative) Identification numbers in alphabetical order	135	Figure 23 — Validity of command values and feedback acquisition time in the drives 46
Annex C (normative) Description of IDNs	141	Figure 24 — Data block structure 47
Annex D (normative) SYSTEM interface — Compliance classes	210	
Annex E (normative) Coded character set	222	
Annex F (informative) Functional principles of the repeater circuit	222	

	Page		Page
Figure 25 — Data fields of the Master Data Telegram	48	Figure 53 — Torque/force data scaling type diagram	91
Figure 26 — Data field of the Drive Telegram	48	Figure 54 — Acceleration data scaling type diagram	92
Figure 27 — Structure of the Master Synchronization Telegram	49	Figure 55 — Adaptation of the velocity proportional gain	93
Figure 28 — BOF field	49	Figure 56 — Adaptation of the velocity integral action time	93
Figure 29 — ADR field	49	Figure 57 — Synchronous spindle operation diagram (example)	96
Figure 30 — INFO field	50	Figure 58 — Electronic gearing diagram (example)	98
Figure 31 — FCS field	50	Figure 59 — Timing diagram for CP ₀	100
Figure 32 — EOF field	50	Figure 60 — Structure of the ID request telegram	101
Figure 33 — Structure of the Master Data Telegram	51	Figure 61 — Structure of the ID acknowledge telegram	101
Figure 34 — Master service INFO field k	53	Figure 62 — Telegram transmission starting times of CP ₁ and CP ₂	101
Figure 35 — Operation data of the MDT	53	Figure 63 — Allocation of IDN $\neq 0$ to the real-time bits (No other allocation was active before)	110
Figure 36 — Example of MDT (with data records of standard telegram 2 for velocity control operation mode)	54	Figure 64 — Allocation of IDN = 0 to the real-time bits (other allocation was active before)	110
Figure 37 — Structure of the Drive Telegram	55	Figure 65 — Allocation of IDN $\neq 0$ to the real-time bits (other allocation was active before)	111
Figure 38 — Drive service INFO field m	57	Figure 66 — Bit sequence for drive controlled homing	112
Figure 39 — Operation data of the AT	57	Figure 67 — Drive controlled homing diagram	113
Figure 40 — Example of a Drive Telegram (standard telegram 2 for velocity control operation mode)	58	Figure 68 — Bit sequence for control unit controlled homing (case 1)	114
Figure 41 — Timing diagram for cyclic operation	58	Figure 69 — Bit sequence for control unit controlled homing (case 2.1)	114
Figure 42 — Function of the real-time bits	59	Figure 70 — Bit sequence for control unit controlled homing (case 2.2)	115
Figure 43 — Service channel data transport scheme	60	Figure 71 — Incremental feedback system	116
Figure 44 — Service channel handling diagram	61	Figure 72 — Distance-coded feedback system	116
Figure 45 — Communications step proceeding diagram	63	Figure 73 — Bit sequence to achieve the displacement to the referenced system	117
Figure 46 — State machine for procedure command execution	68	Figure 74 — Bit sequence for measuring	117
Figure 47 — Procedure command execution without interrupt	69	Figure 75 — Velocity diagram for spindle positioning (Velocity feedback > spindle positioning speed)	118
Figure 48 — Procedure command execution with interrupt	70		
Figure 49 — Procedure command execution with error message	70		
Figure 50 — Timing diagram for CP _{3/4}	78		
Figure 51 — Position data scaling type diagram	88		
Figure 52 — Velocity data scaling type diagram	89		

	Page		Page
Figure 76 — Velocity diagram for spindle positioning (Velocity feedback $\leq$ spindle positioning speed)		Figure I.2 — Examples for processing operation data	235
Figure 77 — Velocity diagram for spindle positioning (Velocity feedback = 0)	119	Figure J.1 — Explanation for procedure command execution examples	235
Figure 78 — Bit sequence while writing new position values (IDN 00153 or 00180)	119	Figure J.2 — Examples of procedure command executions	240
Figure 79 — Bit sequence for switching spindle positioning mode	120	Figure K.1 — Extended position data scaling type diagram	242
Figure 80 — Bit sequence for switching parameter sets and/or gear ratio	120	Figure K.2 — Extended velocity data scaling type diagram	243
Figure 81 — Bit sequence during start-up	121	Figure K.3 — Extended torque/force data scaling type diagram	244
Figure 82 — Bit sequence during shut-down	121	Figure K.4 — Extended acceleration data scaling type diagram	245
Figure 83 — Bit sequence for C1D error	122	Table 1 — Typical operation data for cyclic transmission	16
Figure 84 — Bit sequence for park axis	123	Table 2 — Typical data for non-cyclic transmission	17
Figure 85 — Bit sequence for positive stop drive	123	Table 3 — Transmitter specifications (all data for λ_p)	26
Figure 86 — Velocity diagram for lead and synchronous spindle during angle synchronous operation mode	124	Table 4 — Receiver specifications (all data for λ_p)	26
Figure 87 — Position feedback diagram for lead and synchronizing spindle during angle synchronous operation mode	125	Table 5 — Cable specifications	27
Figure 88 — Drive controlled gear engaging procedure command	126	Table 6 — System data of the optical transmission line	28
Figure C.1 — Structure of slave arrangement	127	Table 7 — Transmission data parameters	31
Figure C.2 — Example of the structure of an IDN list	162	Table 8 — Possible slave input signals	32
Figure C.3 — Example of the configuration of the signal status word	185	Table 9 — Possible slave output signals	33
Figure C.4 — Position polarity parameter	148	Table 10 — Valid slave output signals	33
Figure C.5 — Velocity polarity parameter	156	Table 11 — Specifications of the clock adjustment times	33
Figure C.6 — Velocity window	152	Table 12 — Basic functions of the connection	35
Figure C.7 — Torque polarity parameter	175	Table 13 — Address field values during transmitting	42
Figure D.1 — Compliance class structure	159	Table 14 — Address field values during reception	42
Figure F.1 — Example of an implanted DPLL	210	Table 15 — Error messages	65
Figure F.2 — DPLL status diagram	224	Table 16 — Procedure command control	66
Figure F.3 — DPLL timing	225	Table 17 — Procedure command acknowledgment (data status)	67
Figure H.1 — Determination of the AT transmission starting time	226	Table 18 — Loss or failure of master synchronization telegram (MST)	105
Figure H.2 — Determination of the MDT transmission starting time	227	Table 19 — Failure of master data telegrams (MDT)	105
Figure H.3 — Evaluation of t_{MTSY}	228	Table 20 — Failure of drive telegrams (AT)	106
Figure I.1 — Explanation for processing operation data sample	228		
	229		

	Page
Table 21 — States of error counters 1 in the master for MST and AT failures	108
Table 22 — States of error counter 1 in the drives for MST-failures in CP ₃ and CP ₄	108
Table 23 — States of error counter 1 in the drives for MDT-failures in CP ₄	108
Table 24 — States of error counters 2 in the master for AT-failures	108
Table 25 — States of error counter 2 in the drives for MST-failures	109
Table 26 — States of error counter 2 in the drives for MDT-failures	109
Table C.1 — Structure of drive operation modes	150

1 Scope

This International Standard defines a real-time optical serial interface between the control unit and its associate drives which is utilized to transmit periodic and non periodic data.

This interface is intended to apply to industrial machines, such as machine tools, with multiple drives and can be operated in torque, velocity, or position interface operation modes.

NOTE In this standard, SYSTEM interface refers to this serial data link for real-time communication between controls and drives.

2 Normative references

The following normative documents contain provisions which, through reference in this text, constitute provisions of this International Standard. At the time of publication, the editions indicated were valid. All normative documents are subject to revision, and parties to agreements based on this International Standard are encouraged to investigate the possibility of applying the most recent editions of the normative documents indicated below. Members of the IEC and ISO maintain registers of currently valid International Standards.

IEC 60874-2:1993, *Connectors for optical fibres and cables — Part 2: Sectional specification for fibre optic connector — Type F-SMA*.

ISO/IEC 646:1991, *Information technology — ISO 7-bit coded character set for information interchange*.

ISO/IEC 3309:1993, *Information technology — Telecommunications and information exchange between systems — High-level data link control (HDLC) procedures — Frame structure*.

ISO/IEC 7498:1994, *Information technology — Open Systems Interconnection — Basic Reference Model: The Basic Model*.

ISO 7776:1986, *Information processing systems — Data communications — High-level data link control procedures — Description of the X.25 LAPB-compatible DTE data link procedures*.

3 Definitions and abbreviations

3.1 Definitions

For the purposes of this International Standard, the following definitions shall apply.

3.1.1

access procedure

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

3.1.2

attenuation

fact that the optical power at the receiver is less than at the transmitter

3.1.3

bit stuffing

after five logical “1”s, the transmitter automatically inserts a zero which is then removed again by the receiver. This zero causes a change in signal edges which makes it possible for the receiver to retrieve a receiving clock (see ISO/IEC 3309)

3.1.4

broadcast

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

3.1.5

coded character set; code

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

3.1.6

communication cycle

accumulation of all telegrams between two master synchronization telegrams

3.1.7

control word

two adjacent bytes inside the master data telegram containing commands for the addressed drive

3.1.8

cycle time

time span between two consecutive cyclically recurring events

3.1.9

cyclic communication

the periodic exchange of telegrams

3.1.10

cyclic data

the part of the telegram which does not change its meaning during cyclic operation of the interface

3.1.11

cyclic operation

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

3.1.12

data exchange — demand dependent; non cyclic transmission (service channel)

transmission of information after a request was sent by the master

3.1.13

drive enable

command to close the feedback loop(s)

3.1.14

drive on

command that the power stage can be activated

3.1.15

drive (amplifier) telegram (AT)

telegram sent by the drive (slave)

3.1.16

F-SMA connector

connector meeting the F-SMA standard in accordance with IEC 60874-2

3.1.17

feedback

measured process values

3.1.18

feedforward

command value used to compensate the lag in the control loop

3.1.19

fibre optic cable

transmission medium for serial data transmission of optical signals

3.1.20

fill signals

sequence of seven “1”s followed by a “0”

3.1.21

frame check sequence (FCS)

check character sequence consists of 16 bits which is generated by means of a cyclic redundancy check (CRC) character polynomial in accordance with the ITU-T X.25. [See ISO/IEC 3309 and ISO 7776]

3.1.22

identification number (IDN)

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

3.1.23**SYSTEM interface:**

- 1) physical characteristics of the interface circuits;
- 2) protocol and access method;
- 3) application.

3.1.24**ISO/OSI reference model**

communication layers which are architecture guidelines for defining communication protocols
[see ISO/IEC 7498]

3.1.25**machine zero point**

machine related point (in each axis) to which all position data are referred

3.1.26**master data telegram (MDT)**

telegram transmitted by the master sending data to the slave(s) in a single ring

3.1.27**master synchronization telegram (MST)**

telegram transmitted by the master sending a time synchronization signal to the slave(s) in a single ring

3.1.28**master**

station which assigns the other stations in the ring (i.e. slaves) the right to transmit

3.1.29**non-cyclic transmission**

non-periodic exchange of data at the request of the master

3.1.30**no return to zero inverted (NRZI) (coding of data)**

signal exchanges taking place only at regular, fixed points in time in synchronization with the transmitting clock pulse of the bit rate. A signal edge change is assigned to a logical 0 only

3.1.31**operating cycle**

period of the control loop within the drive or the control unit

3.1.32**phase locked loop [digital] (DPLL)**

circuit which retrieves the receiving clock from the data stream received

3.1.33**physical layer (bit transmission layer)**

first layer of the ISO-OSI reference model layers in which the bit transmission is defined

3.1.34**protocol**

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

3.1.35**recovery of clock**

sufficiently frequent alternation of the signal making it possible for the receiver to retrieve the receiving clock from the data stream with the help of the phase locked loop

3.1.36**reference point**

feedback-system related point (in each axis) to which the feedback and command values are referred after a homing procedure

3.1.37**repeater function**

telegram that has been received is passed on reclocked and logically unchanged to the next station on the ring

3.1.38**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 only in one direction

3.1.39**scaling data**

data which determines the weight of the transferred operation data

3.1.40**slave**

device in the ring which is assigned by the master the right to transmit

3.1.41**status word**

two adjacent bytes inside the drive telegram containing status information

3.1.42**(telegram) address field**

address field (eight bits) containing the address of the device

3.1.43**telegram**

message

3.1.44**(telegram) delimiter**

beginning and ending identifiers of a telegram (eight bits: 01111110)

3.1.45**topology**

physical network architecture with respect to the connection between the stations of the communication system

3.1.46**transmission medium**

collective term for the real form of the physical connection between the stations of a communication network, for instance, fibre optic cable

3.1.47**zero bit stream**

consists exclusively of logical zeros which, in NRZI coding, results in a regular signal edge change on the transmission line (only used in test mode)

3.2 Abbreviations

For the purpose of this International Standard, the following abbreviations apply:

3.2.1 A: amplifier (drive)

3.2.2 ADR: address of a telegram. Drive address is XX [$1 \leq XX \leq$]

3.2.3 AHS: service transport handshake of the drive

3.2.4 AT: drive (amplifier) telegram

3.2.5 AT_m: drive (amplifier) telegram from drive XX which is assigned to data record m

3.2.6 BOF: begin of frame

3.2.7 C1D: class 1 diagnostic

3.2.8 C2D: class 2 diagnostic

3.2.9 C3D: class 3 diagnostic

- 3.2.10 CCIT:** consultative committee on international telephone and telegraph
- 3.2.11 CNA:** container for non-cyclic data transfer of the drive (amplifier)
- 3.2.12 CNM:** container for non-cyclic data transfer of the master
- 3.2.13 CZA:** container for cyclic data transfer of the drive (amplifier)
- 3.2.14 CZM:** container for cyclic data transfer of the master
- 3.2.15 CP:** communication phase
- 3.2.16 CRC:** cyclic redundancy check
- 3.2.17 DAT:** duration of drive telegram
- 3.2.18 DMDT:** duration of master data telegram
- 3.2.19 DMST:** duration of master sync telegram
- 3.2.20 DPLL:** digital phase locked loop
- 3.2.21 EOF:** end of frame
- 3.2.22 FCS:** frame check sequence
- 3.2.23 HS:** handshake (see AHS and MHS)
- 3.2.24 IDLE:** data transmission interrupted
- 3.2.25 IDN:** identification number
- 3.2.26 i:** sequence of different rings on one control unit, labelled as $i = 1 \dots l$
- 3.2.27 l:** number of rings on one control unit
- 3.2.28 INFO:** information
- 3.2.29 J:** jitter
- 3.2.30 J_{noise} :** jitter of the optical signal
- 3.2.31 J_{t1} :** jitter in t_1
- 3.2.32 J_{t2} :** jitter in t_2
- 3.2.33 J_{tsyc} :** jitter in t_{syc}
- 3.2.34 K:** number of data records in the MDT (see also M)
- 3.2.35 K_v (K_v -factor):** gain of the position loop regulator
- 3.2.36 k:** time sequence of data records in the MDT, labelled as $k = 1 \dots K$
- 3.2.37 k_{os} :** optical power overshoot
- 3.2.38 LED:** light emitting diode
- 3.2.39 LSB:** least significant bit
- 3.2.40 M:** number of drives in one ring (see also K)
- 3.2.41 m:** time sequence of the ATs, labelled as $m = 1 \dots M$
- 3.2.42 MDT:** master data telegram
- 3.2.43 MHS:** service transport handshake of the master
- 3.2.44 MSB:** most significant bit
- 3.2.45 MST:** master sync telegram
- 3.2.46 n:** velocity
- 3.2.47 n_{min} :** shot-off velocity in the drive after C1D error
- 3.2.48 n_x :** velocity threshold
- 3.2.49 NBYCA:** number of bytes in the configurable data record of the AT
- 3.2.50 NBYCM:** number of bytes in the configurable data record of the MDT
- 3.2.51 NC:** numerical control (also control unit or controller)
- 3.2.52 NRZI:** no return to zero inverted
- 3.2.53 OSI:** open system interconnection
- 3.2.54 P:** power
- 3.2.55 P_{RmaxH} :** maximum received power at optical high level

- 3.2.56 P_{RmaxL} : maximum received power at optical low level
- 3.2.57 P_{RminH} : minimum received power at optical high level
- 3.2.58 P_{TmaxH} : maximum transmission power at optical high level
- 3.2.59 P_{TmaxL} : maximum transmission power at optical low level
- 3.2.60 P_{minH} : minimum transmission power at optical high level
- 3.2.61 P_x : power threshold
- 3.2.62 R_xCLK : receiving clock
- 3.2.63 R_xD : received data
- 3.2.64 $SLKN$: slave identification parameter, slave arrangement
- 3.2.65 T : torque
- 3.2.66 T_f : additive torque command value (feed forward)
- 3.2.67 T_{limit} : limit value for the torque
- 3.2.68 T_x : threshold torque
- 3.2.69 t_1 : AT transmission starting time
- 3.2.70 $t_{1,m}$: AT transmission starting time with data record m of drive XX
- 3.2.71 $t_{1min,m}$: shortest AT transmission starting time with data record m of drive XX after receiving the MST
- 3.2.72 t_{1min} : shortest AT transmission starting time
- 3.2.73 t_2 : MDT transmission starting time
- 3.2.74 t_3 : command value valid time
- 3.2.75 t_4 : feedback acquisition capture point
- 3.2.76 t_5 : minimum feedback processing time
- 3.2.77 $t_{5,m}$: the minimum time which drive XX with data record m needs to process its captured feedback value for the next AT
- 3.2.78 t_{ATAT} : transmit to transmit recovery time in a slave with several drives
- 3.2.79 t_{ATMT} : transmit/receive transmission time
- 3.2.80 $t_{ATMT,M}$: transmit/receive transmission time which drive M needs between transmitting its AT and being prepared for receiving an MDT
- 3.2.81 t_{ATRP} : maximum transition time in a slave to switch from transmitting an AT to repeater function
- 3.2.82 $t_{ATRP,1}$: maximum transition time in slave 1 to switch from transmitting an AT to repeater function
- 3.2.83 t_{BIT} : arithmetic mean value of the bit transmission time in normal operating mode
- 3.2.84 $t_{BITtest}$: arithmetic mean value of the bit transmission time in zero bit stream test mode
- 3.2.85 t_{BITnom} : nominal value of the bit transmission time
- 3.2.86 t_{cad} : clock adjustment time of a DPLL
- 3.2.87 t_{cadmax} : maximum allowed clock adjustment time of an input to the master
- 3.2.88 t_{cadmin} : minimum clock adjustment time of an input to a slave
- 3.2.89 $t_{cadreal}$: maximum possible clock adjustment time of an output from a slave
- 3.2.90 t_{del} : time which the optical signal time is delayed by a repeating slave
- 3.2.91 t_f : time required by the optical signal to pass from P_{TminH} to P_{TmaxL} on the falling edge
- 3.2.92 t_{fri} : time for the optical low level at the input of a slave (see Figure 12)
- 3.2.93 t_{fro} : time for the optical low level at the output of a slave (see Figure 12)
- 3.2.94 t_{MTSG} : command value processing time
- 3.2.95 $t_{MTSG,K}$: time required by the slave which is served by the last data record(s) in the MDT to make the command values available for that drive XX which is assigned to data record K
- 3.2.96 t_{MTSY} : receive to receive recovery time in a slave
- 3.2.97 $t_{MTSY,K}$: recovery time of the last slave after the reception of an MDT to switch over for receiving the next MST (the last slave is the one which is served with data record K)

- 3.2.98 $t_{N_{cyc}}$: control unit cycle time
- 3.2.99 t_{os} : duration of optical power overshoot
- 3.2.100 t_r : time required by the optical signal to pass through P_{TmaxL} to P_{TminH} on the rising edge
- 3.2.101 $t_{R_{cyc}}$: drive control loop cycle time
- 3.2.102 $t_{r_{fi}}$: time for the optical high level at the input of a slave (see Figure 12)
- 3.2.103 $t_{r_{fo}}$: time for the optical high level at the output of a slave (see Figure 12)
- 3.2.104 t_{RPAT} : maximum transition time in a slave to switch from the repeater function to the transmitter function for the AT
- 3.2.105 $t_{RPAT,2}$: maximum transition time in slave 2 to switch from the repeater function to the transmitter function for the AT
- 3.2.106 t_{Scyc} : communication cycle time
- 3.2.107 **TxCLK**: transmitting clock
- 3.2.108 **TxD**: transmitted data
- 3.2.109 v : velocity feedback value
- 3.2.110 v_1 : velocity feedback value of drive 1
- 3.2.111 v_f : additive velocity command value (feed forward)
- 3.2.112 **XX**: address of a drive
- 3.2.113 x : position feedback value
- 3.2.114 x_1 : position feedback value of drive 1
- 3.2.115 x_1^* : position command value of drive 1
- 3.2.116 x_m^* : position command value of drive XX with data record m
- 3.2.117 ε_1 : rotor position of drive 1.
- 3.2.118 **(1 0 0 ...)B**: binary digits
- 3.2.119 **(0 A F ...)H**: hexadecimal digits

NOTE Unassigned digits are decimal.

4 General requirements

4.1 Overview

The SYSTEM interface uses optical data transmission between control units and drives. In this way, any interference is eliminated.

Under normal operating conditions, one fibre optic ring can be connected to up to eight drives at a communication cycle time of 2 ms. The exact number of drives which can be serviced per ring depends on the cycle time, the selected data volume, and the data rate (currently 2 Mbit/s). A larger number of drives per ring is possible with a data rate of 4 Mbit/s. The number of drives per control unit can also be expanded by using more fibre optic rings.

The SYSTEM interface specification standardizes the formats and scaling factors for operation data exchange between control units and drives. During initialization, the operation of the interface is configured according to the performance characteristics of the control unit and the drives. Therefore, the velocity and/or position control is implemented by either the drive or the control unit. Due to the flexibility of data message formats, other control structures and operating modes besides the ones presently used are now possible.

The control unit is capable of synchronizing all connected drives by way of cyclic data exchange for command and feedback values, including exact equidistant timing and synchronization of gated measurements and command values. Communication cycle times may be selected between 62 μ s, 125 μ s, 250 μ s or any integer multiple of 250 μ s.

In addition, the control panel of the control unit can be used to display and input drive-specific data, parameters and diagnostic information which are available via an asynchronous service channel and standardized data records.

Command and feedback values in short or long words can be transmitted between the control unit and each drive in both directions. Optional data (e.g. parameters, diagnostic texts) of two bytes per drive are transmitted during every cycle. This data can be requested individually by the control unit. Errors in command and feedback values are corrected automatically through cyclic communication. The last valid command and feedback values are used until the next cycle. Two consecutive erroneous transmissions will cause the drives to halt.

Practical example

User data transmission at 2 Mbit/s data rate, 2 ms communication cycle time and eight drives on one fibre optic ring:

Cyclic data per drive:

- from control unit to every drive:
 - 32 bits command value (e.g. velocity or position);
 - 16 bits limit value (e.g. torque);
- from every drive to control unit:
 - 32 bits feedback value (e.g. velocity or position);
 - 16 bits feedback value (e.g. torque).

In addition, there is up to 8 kbits/s per drive for non-cyclic data transmission.

4.2 System overview

This subclause provides information about the fundamental technical characteristics of the SYSTEM interface, without establishing specific definitions. For the reader who has never heard of this interface, this subclause will serve as a preface to the specific details which follow in later clauses.

NOTE The user of this standard who is already familiar with the fundamental characteristics of this interface may skip this subclause and continue with the specifics in clause 5.

With the SYSTEM interface, a control unit can serve one or several ring structures, depending on the requirements. One example is shown in Figure 1.

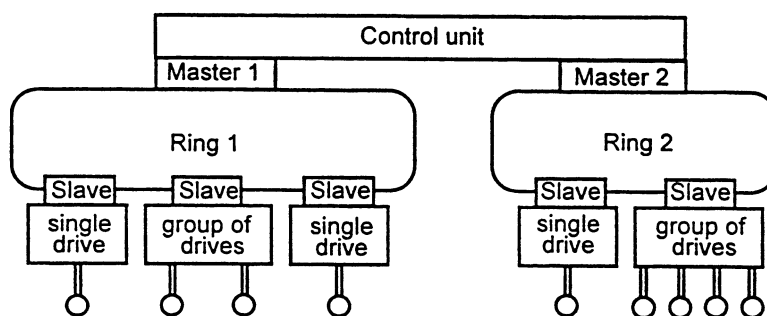


Figure 1 — Topology

The connection of the control unit on a ring is called a master. This master directs and controls any communication within one ring.

A slave is the connection between one or more drives and the ring. As shown in Figure 1, a group of drives such as several feed drives can be clustered and tied into the ring through a single connection. Individual participants are connected to each other via transmission segments which consist of fibre optics made of plastic or glass and standardized connectors.

The information exchanged in such a ring depends greatly on the distribution of tasks between the control unit and the drives. Direct exchange of information takes place only between the control unit and the drives and not among the drives themselves.

4.2.1 Operating modes

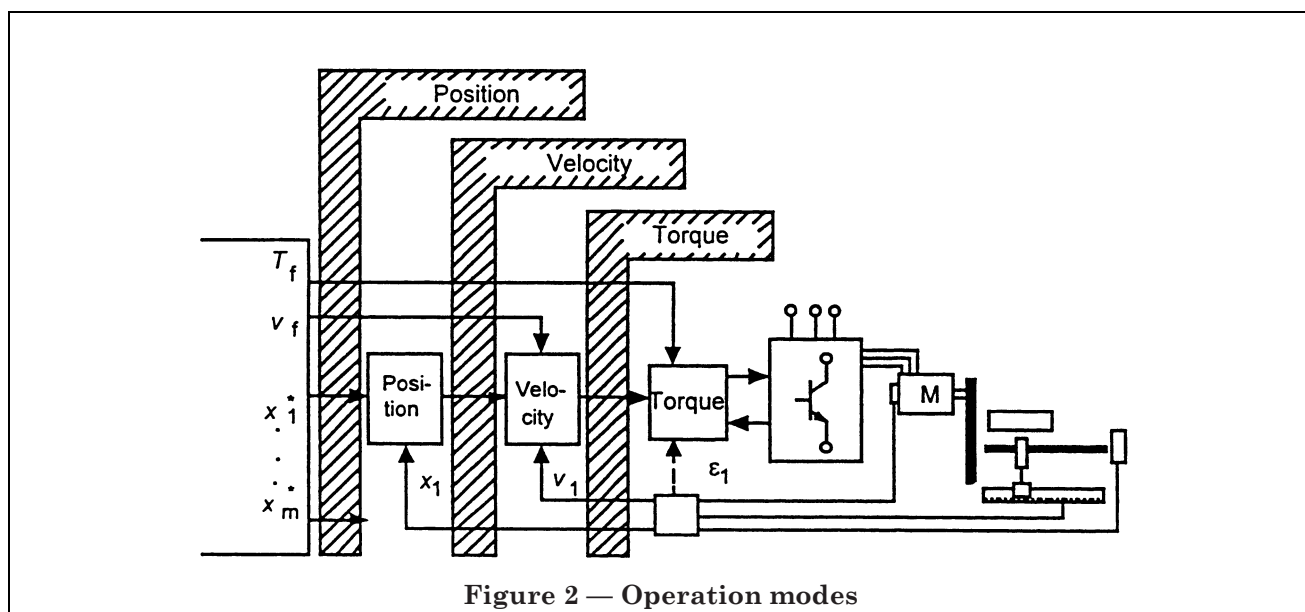
In a machine, several drives perform tasks which are coordinated by the control unit. Figure 2 shows only one of several drives. The coordinated command values are shown on the left side of Figure 2. In the control structures used presently, the closed control loops for torque, velocity, and position are cascaded. This example shows a cascaded structure where all relevant time constants decrease for underlying control circuits (at least by a factor of two to four).

The SYSTEM interface is capable of handling all the operating modes shown in Figure 2, including:

- a) only torque control in the drives;
- b) velocity and torque control in the drives;
- c) all closed control loops, including position control in the drives.

NOTE Velocity and torque control in the drives [b) above] corresponds to the concept of commonly used analogue interfaces.

For torque control, typical cycle times of 250 μ s can be achieved by using microcomputers to control the motor torque. Whether or not torque command values can be transmitted via an interface with the same cycle time depends on the ability of the control unit to generate new command values every 250 μ s. Such a short cycle time creates quite a load for the SYSTEM interface. A ring with such a short cycle time can only support a few drives. In this case, it may be necessary to implement several rings (see Figure 1).



Since with digital data transmission there is practically no limitation of resolution, it is possible to put all closed control loops inside the drives. Then both position command values as well as feedforward signals for velocity and torque can be transmitted. Where the control unit generates coordinated commands for position, velocity, and torque for all axes based on a dynamic path model, then a contouring control system with good dynamic properties and with minimum following distance can be created.

Where desired, different operating modes can be applied to different axes. In addition, each axis can have a main operating mode and several secondary operating modes, which the control unit can toggle during operation.

Drives which are equipped with a SYSTEM interface do not need to be capable of all the operating modes mentioned above. The only requirement is to adequately document the particular mode of operation (or variation thereof) and the subset of variables and parameters supported by the appropriate components (see Annex D for compliance classes for the drives and control unit).

4.2.2 Transmission modes

The SYSTEM interface allows for synchronization during cyclic data transmission. This means that the operating cycle of the control unit can be synchronized with the communication cycle and the operating cycle of the drive so that beats between individual cycles can be prevented and the dead times in the control loops are reduced to a minimum. It also implies that new command signals become active concurrently in all drives and that all drives take measurements at the same time, so that they can be sent back to the control unit as feedback values. This requires that the transmission cycles are strictly equidistant.

The data in the control loops need to be precise and punctual. Untimely data are of no value. When a transmission error is discovered, the communication cycle continues and the old data or an estimated value may be used for one communication cycle. To repeat the transmission with old data (for the purpose of correcting the error) is meaningless, since during the next communication cycle (e.g. 1 ms later), new command data will be transmitted. In the event of repeated transmission errors, a predetermined reaction such as halting the system shall ensue.

The non-cyclic transmission mode does not have to fulfill strict real-time requirements. Here, the correctness of the data is acknowledged or is secured by repeating the transmission.

4.2.3 Data contents

Annex A and Annex B contain a comprehensive list of transmittable data (as well as procedure commands) which are predetermined in the SYSTEM interface. There, the reader will find a description of individual data. In this subclause only an overview is presented, organized according to the mode of transmission (cyclic/non-cyclic) and the mode of operation. Table 1 shows data that are typically transmitted cyclically (which means fast and synchronous).

In essence, during a communication cycle one control word is sent from the control unit to each drive and a status word is sent back from each drive to the control unit. Configurable operation data can be transmitted bidirectionally between the control unit and each drive cyclically. Table 1 gives some typical representations. The three operating modes are shown with command and feedback values.

Table 1 — Typical operation data for cyclic transmission

	Position data	Velocity data	Torque data
Control unit to drive	Control word		
	Position command value	Velocity command value	Torque command value
	Additive position command value	Additive velocity command value	Additive torque command value
Drive to control unit	Status word		
	Position feedback value 1	Velocity feedback value	Torque feedback value
	Position feedback value 2		

Both the control word and the status word are organized into a drive-related and a transmit-related part. Non-cyclic transmissions are controlled by means of the transmit-related part (control/acknowledge steps). Each control and status word reserves two additional real-time bits for cyclic transmission.

The drive-related part of the control word contains the desired modes of operation. This part is also used to transmit the commands for “drive on” and “drive enable”. The drive-related part of the status word transmits grouped messages of errors and warnings which are divided in three classes. This part also issues messages indicating whether the drive is ready to operate or ready for power-up.

Table 2 demonstrates that typically a much broader spectrum of data is exchanged by the non-cyclic transmission mode. This exchange is, however, much slower than the cyclic mode.

Table 2 — Typical data for non-cyclic transmission

Data related to the operating mode of the SYSTEM interface		
Position data	Velocity data	Torque data
Positive limit value	Positive limit value	Positive limit value
Negative limit value	Negative limit value	Negative limit value
	Bipolar limit value	Bipolar limit value
Polarities	Polarities	Polarities
Reference distance 1	Homing velocity	
Reference distance 2		
Reversal clearance		
Position switch points 1 to 16		
Probe value 1 or 2 positive edge		
Probe value 1 or 2 negative edge		

As mentioned earlier, a component (drive or control unit) which is equipped with the SYSTEM interface does not need to support all possible data and procedure commands included in this standard. The system provides lists of data and procedure commands which are applicable for the appropriate component. These lists can be read from a drive by means of the control unit, thus providing all necessary information concerning that particular drive.

The data to be transmitted and the sequence shall be determined during initialization.

Finally, during initialization it is useful to transmit scaling data as a group. In this way the data formats used by the internal operating algorithms of the drive will be recalculated and changed in accordance with the specifications of SYSTEM interface.

4.2.4 Data block

The SYSTEM interface is not just a data transmission system, but provides a large number of data and procedure commands which can be used for the operation of machines and their control units and drives. All data, procedure commands and all supplementary information are summarized in a data block which contains a name, attribute, units, minimum and maximum input values as well as the data itself.

Access to the data or to the supplementary information is only possible via an identification number (IDN). There are 2^{16} IDNs available. The range from 0 to 32 767 is reserved for standard data which are defined by the SYSTEM interface.

There will always be special applications for which none of the generally defined parameters apply. IDNs 32 768 to 65 535 are reserved for product specific data which can be defined by the manufacturers of control units and drives. No general compatibility can exist for these data and procedure commands.

4.2.5 Telegram structure

The general telegram structure is shown in Figure 3. All telegram delimiters are initiated during bit transfer and are invisible on higher layers.

4.2.5.1 Addresses and frame check sequence

Telegrams which originate from the master have the destination address in the address field. One special destination address is the broadcast address (255). This address is used exclusively by the master. Telegrams which originate from the drives have the source address in their address fields.

The frame check sequence is calculated automatically using a standardized CRC-check.

4.2.5.2 Data record

In Figure 3, parts b) to e), only the data field of a telegram is shown.

- b) the master sync telegram (MST);
- c) the telegram from drive "XX" (AT_m);
- d) the master data telegram (MDT).

The data field of the MDT consists of K data records, where $K = M$ is the total number of drives in the ring. The data field of the AT consists only of one data record.

According to Figure 3 e), all data records consist of two parts: one has a fixed structure and the other has a variable structure which is configured during initialization, depending on the application. The part with the fixed structure consists of the following:

- for the MDT: a control word and 2 bytes which are called the “container for non-cyclic data transfer of the master (CNM)”;
- for the ATs: a status word and 2 bytes which are called the “container for non-cyclic data transfer of the drive (amplifier = A) (CNA)”.

The variable structure (i.e. length, amount and sequence of 2- and 4-byte sizes) of the configurable part of the data record is specified during initialization based on the application. This serves as a container for data which is transmitted cyclically (CZM/CZA).

When initialization is complete, the length of every data field is known and remains constant during operation. That ensures that all telegrams within the communication cycle (see Figure 6) have fixed lengths during operation and are transmitted according to a time-fixed pattern (see Figure 5).

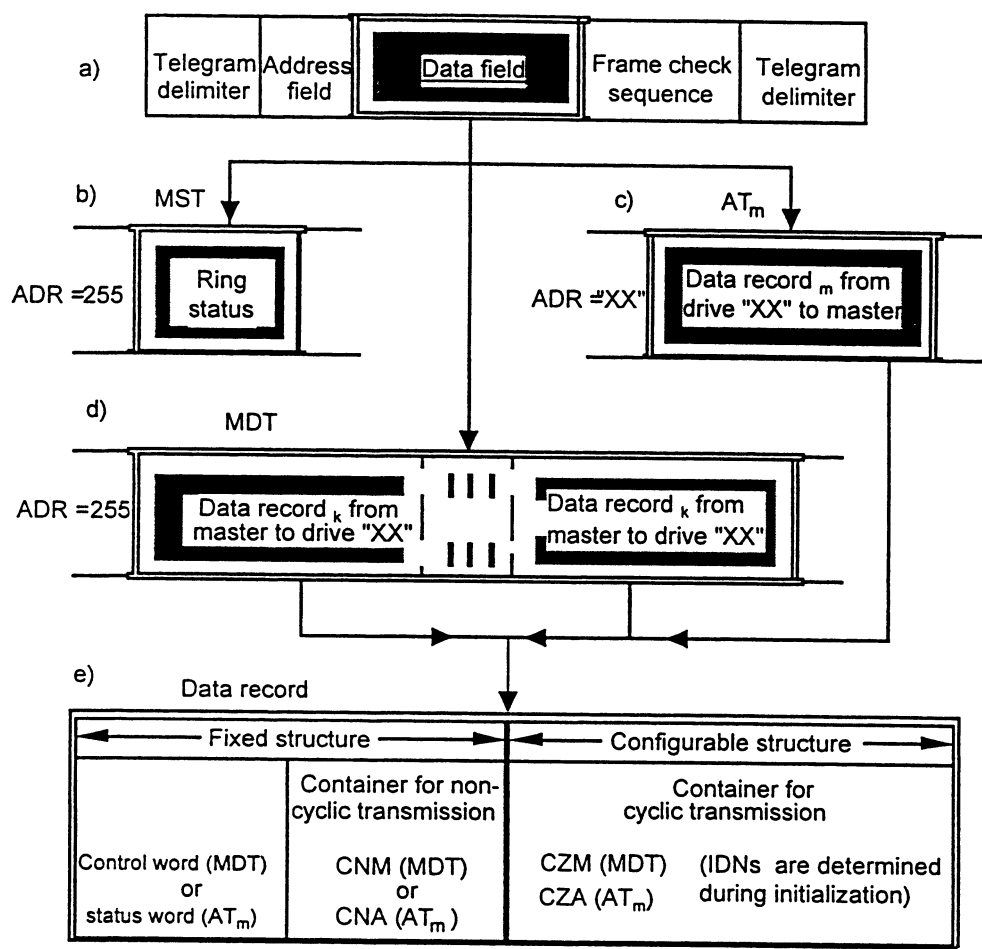


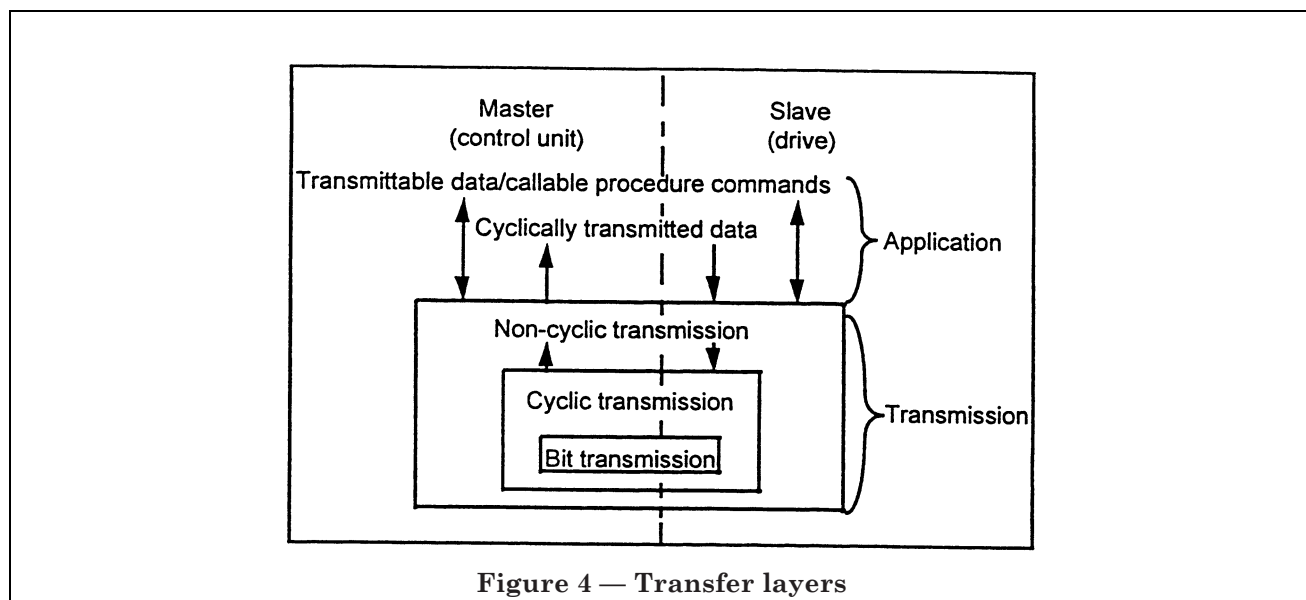
Figure 3 — Overview of data field structure (CP₃ and CP₄)

4.3 Data transmission

In 4.2, several system characteristics were outlined. That subclause deals with communication functions as well as hierarchical functions which are not a part of the communication area and hence are not part of the ISO/OSI reference model (see ISO/IEC 7498).

This subclause introduces transfer layers as well as appropriate protection measures in accordance with levels 1 and 2 in the ISO/OSI reference model (see ISO/IEC 7498).

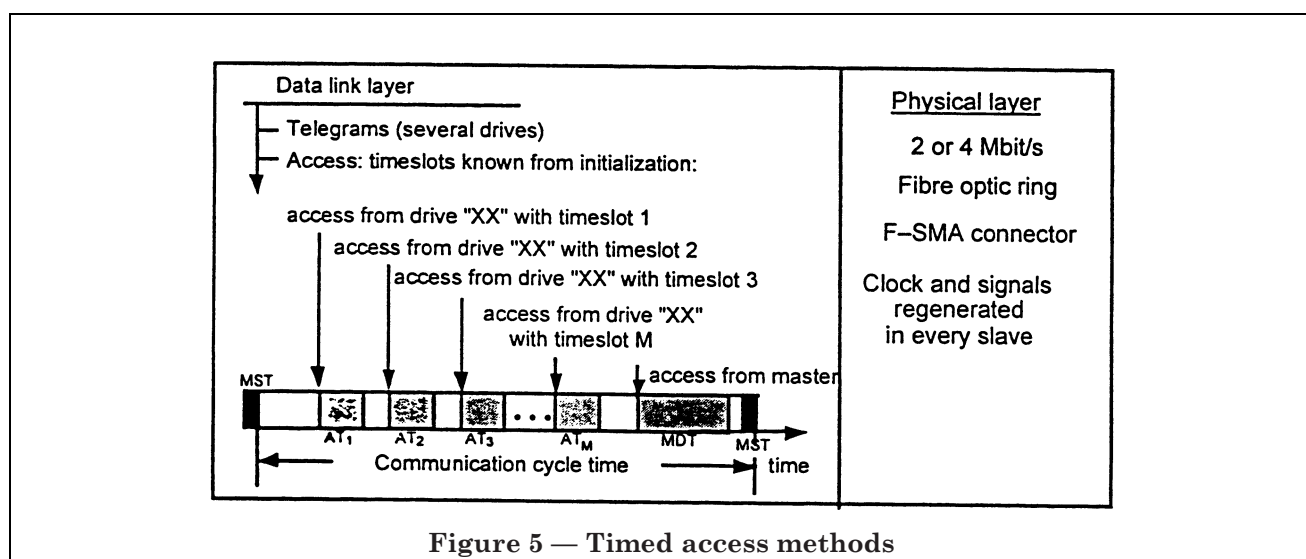
Figure 4 is a schematic showing the organization of the transfer layers between the master and slave. The highest transfer layer is the non-cyclic transfer. It has its own transfer security mechanism. Application layers lie above non-cyclic transfers (not shown in Figure 4). They are procedure commands which are themselves supported by non-cyclic transfers.



Non-cyclic transfer is supported by cyclic transfer. The user has access to cyclic as well as non-cyclic transfer. Fundamentally, all data is transferable non-cyclically (slow) and only a subset is meant to be transmitted cyclically.

4.3.1 Access to the transfer medium

Figure 5 shows the access to the ring. It is regulated through a timeslot method. During initialization, every drive is told when to transmit its data to the ring. Thus, every drive has the ability to use its internal clock to access the ring. In this way a deterministic, strictly synchronous execution can be achieved with minimal administrative effort. This simple method is possible because the data traffic flow is so strictly defined.



4.3.2 Communication cycle

As shown in Figure 6, all cyclic data is exchanged between the master and all its drives during a single communication cycle (e.g. 1 ms).

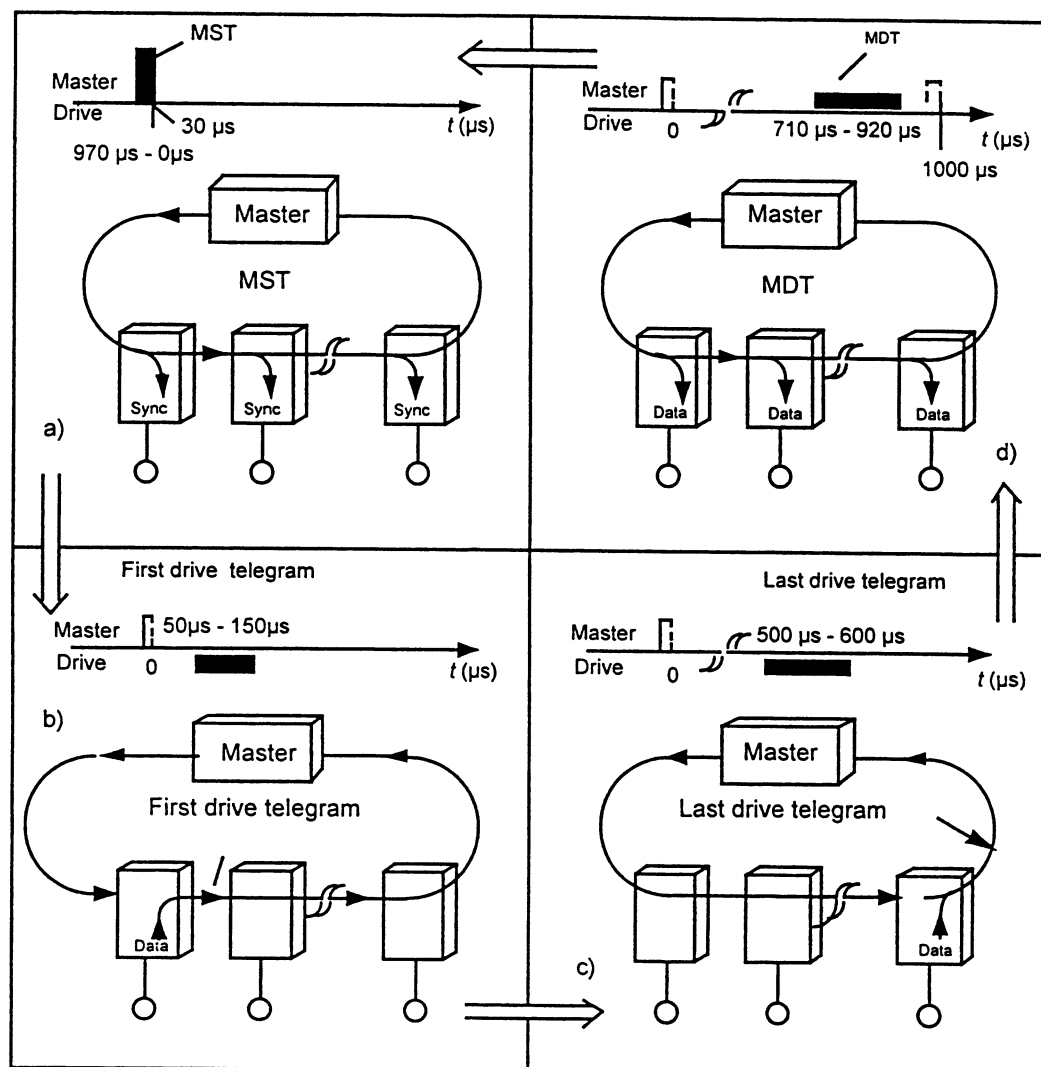


Figure 6 — Communication cycle

As shown in Figure 6 a), the communication cycle starts when the master broadcasts a MST to all units. All drives receive this message concurrently. On the basis of this MST, every drive shall synchronize its transmit timeslot and its feedback acquisition capture point, and should synchronize its internal processing, especially its control loops. This type of synchronization minimizes and stabilizes the dead time of the command signal which improves the dynamic behaviour as compared to control loops which are not synchronized by a synchronization telegram.

The synchronization telegram is very short (approx. 30 µs). Its data field, which is only 1 byte long, determines the command status of the ring (= desired communication phase). Since this condition remains constant during operation, even bit stuffing will not cause any temporal fluctuations.

As shown in Figure 6 b), when the first predetermined timeslot is reached, the first drive transmits its drive telegram (AT) to the ring. The AT has its own address (= source address) and the data for the master (e.g. feedback values, status).

An AT sent in this fashion is simply passed on by other drives to the master (repeater function). As shown in Figure 6 c), all other drives transmit their ATs to the master during their predetermined timeslots.

The master monitors whether all drives transmit correctly. After receiving the first AT, the control unit can start evaluating and processing this AT based on the required tasks.

At the end of the cycle, as shown in Figure 6 d), the master transmits a lengthy MDT to all drives. This broadcast of data is received concurrently by all drives. Each drive knows its data slot within the MDT, as this is defined during initialization. In this manner, all axes are supplied with new command values synchronously.

Immediately after the communication cycle is elapsed, the master starts the next cycle with the MST. Allowable times are: 62 µs, 125 µs, 250 µs as well as integer multiples of 250 µs.

Short communication cycle times only allow for a few participants and are mainly used for “torque control” operating mode. Longer communication cycle times allow for more participants and are therefore used for “position control” operating mode.

The cycle time during which the control unit provides new command values for the drives is called t_{Ncyc} . The operating cycle inside of the control unit should be an integer multiple of the communication cycle time. If the operating cycle time is longer than the communication cycle time, the same calculated values can be transmitted n times in consecutive telegrams:

$$t_{Ncyc} = n \cdot t_{Scyc}, \quad n = 1, 2, \dots \quad (n \text{ is not related to the abbreviations}).$$

Developers of micro-processor controlled drives have to take care that the operating algorithm inside the drive should be oriented to the data transmission:

- one or more internal operating cycles of the drive should fit into the communication cycle:
- $z \cdot t_{Rcyc} = t_{Scyc}, \quad z = 1, 2, \dots \quad (z \text{ is an integer});$
- the operating algorithm should be synchronized with the MST.

During a control unit operating cycle and a communication cycle, when the drive control program is executed several times, intermediate values for command values will be interpolated inside the drives.

4.3.3 Non-cyclic data transfer

Non-cyclic transfer is initiated and controlled by the master. Its entire control will be executed by the master. A slave cannot start a non-cyclic transfer; it can only respond.

Non-cyclic transfers are based on cyclic transfers, as mentioned earlier.

Two bytes (CNM/CNA) are reserved in the MDT and in the AT respectively for the demand dependent non cyclic data exchange. When data longer than two bytes are to be transmitted (e.g. a name or a list of IDNs), the transmission has to be distributed over several communication cycles since there are only two bytes available for transmission of this data.

Parts of the control word respective of the status word provide the handshake signals required for transport and process control. Unlike the cyclic data where data cannot be repeated, the receiver does not need to react in the same cycle. The master recognizes the situation where a slave has not yet taken the required data from the CNM and repeat the transmission up to 10 times. Once the CNM is empty, the master may send more data. At the end of the last transmission, the processing can begin in the slave (i.e. reading or writing data). This is indicated to the master to prevent the master from overloading the slave with data. After a successful command read and processing, the slave sends data back to the master. In this case, the same acknowledgment method is employed as when the master sends data to the slave.

The duration of the process (timeout) is not set via the SYSTEM interface. The master can, however, break the process in the slave at any time, provided that a break is still possible in the slave.

When an error occurs during the processing in the slave, for example when data is write protected, an error flag is set in the drive status word. Simultaneously, the reason for the error is transmitted in the CNA.

4.3.4 Procedure commands

The master can transmit procedure commands to the drives. Depending on the type of procedure command, it may trigger lengthy and complex processes within the drive. Examples of such processes are:

- control unit-controlled homing procedure;
- probing cycle procedure;
- park axis procedure;
- drive-controlled synchronous operation procedure.

Procedure commands have technically the same structure as other data. The attribute identifies that the data is handled as a procedure command. In this case, the operation data is replaced by the procedure command control. The CNM/CNA is used for the command transmission and transmission control in such a way as the non-cyclic data exchange uses the CNM/CNA. The processing in the slave typically starts a complex function.

Because there is a bit available in the status word to indicate changes in the procedure command acknowledgement (i.e. procedure command executed), it is possible to activate more than one procedure command at the same time or to start a required data exchange when one or more procedure commands are activated.

The master has the ability to set or activate a procedure command in the slave via the procedure command control so as to enable, interrupt or cancel the processing. When an error occurs in a slave, a detailed error message is transmitted to the master.

4.4 Initialization

After powering up, the system goes through several states (i.e. communication phases) before the normal operating state (= Communication phase 4) is reached. This subclause discusses these phases (communication phases 0 to 3).

Communication phase 0 (CP₀)

After the master electronics are supplied with power and internal preparations and checks have been successfully concluded, the master begins transmitting master synchronization telegrams (MST). The set condition is “communication phase 0”.

When the slave electronics are powered up, it will work as a “repeater”. This means the slave passes the received telegrams on to the next participant on the ring. When all physically present slaves are working as repeaters in the ring, the MSTs will be sent on to the input of the master.

After the master has received its own MST 10 times without interruption, then it switches to communication phase 1. Thus, the master shall be able to transmit and receive a telegram simultaneously. A slave, however, needs only to either transmit or receive a telegram at any given point in time.

As shown in the following phases, communication is set up in steps through:

- the insertion of a rudimentary drive and master-data telegram;
- successive completion of above-mentioned telegrams; and
- the introduction of timeslots for all telegrams.

Communication phase 1 (CP₁)

The master issues “communication phase 1” as the current communication phase through its MST and begins to transmit the MDT of communication phase 1. Each drive is addressed individually by the master. The MDT contains only *one* data record, CZM is not installed. The content of CNM has no influence and the control word remains constant.

The information which is being transmitted by the MDT mentioned above is given by the address “XX”. During communication phase 1, when a drive receives a MDT addressing it, it responds with a rudimentary communication phase 1 AT to indicate that the drive is present and ready for communication phase 2.

The master will attempt to receive a response from one of the drives. If necessary the master asks several times. When all anticipated drives have responded, the master switches to communication phase 2.

Communication phase 2 (CP₂)

The MDT in communication phase 2 has the following structure:

- the address of a defined drive;
- only *one* data record;
- the data record has no container for cyclic transfer (CZM).

For communication phase 2, the protocol for non-cyclic transfer is operating. However, during one cycle, data exchange can take place with a single drive only.

In communication phase 2

- a) communication parameters (e.g. timeslots for subsequent communication phases);
- b) the parameters that define the cyclic transmission configuration

shall be exchanged.

Before defining these configuration parameters, the control unit shall know which parameters can be supported by the individual drives (including modes of operation). The operator can retrieve this information from manufacturer's specifications for specific drives. The control unit can retrieve the same information from the list of supported data and procedure commands stored in the drive (see IDN 00017, IDN 00025).

In communication phase 2, additional data beyond the minimum structure [a) and b)] can be transmitted, such as data for the selection of drive characteristics. However, this additional data can be transmitted during later, more time-efficient communication phases.

Now the master sends the procedure command "CP₃ transition check" to each drive. During the processing of this procedure command, every drive checks internally whether error free operation in communication phase 3 is possible (i.e. if the drive has received the necessary parameters for communication phase 3). After each drive has responded to this procedure command with a "procedure command correctly executed", the master can issue a communication phase 3 in the MST.

Communication phase 3 (CP₃)

In communication phase 3, the entire communication cycle and all telegrams contained therein is complete just as in normal operation (= communication phase 4), with the exception that the contents of the containers for cyclic transfer (CZM/CZA) are still meaningless. The timeslots which were defined in communication phase 2 are to be obeyed from now on. As of this communication phase, the master can exchange data with the drives through simultaneous, non-cyclic transfer. This is why the data for selection of the drive characteristics can be transmitted to the drives in a more time-efficient manner in communication phase 3.

Finally, the master sends the procedure command "CP₄ transition check" to each drive. At this point every drive checks internally whether error-free operation in communication phase 4 will be possible. After each drive has responded to this procedure command with "procedure command correctly executed," the master can issue communication phase 4 in the MST (i.e. normal operation). This completes the initialization.

4.5 Error and status messages

Grouped messages of diagnostic classes 1, 2 and 3 (C1D, C2D, C3D) are used in the status word of each drive.

A C1D message means that an error condition was discovered in the drive, leading to a shut-down with subsequent $t = 0$ after the speed is less than $n_{\min}$. This process is executed by the drive itself.

A C2D message means a warning indicating a possible shut-down.

C3D messages are pure status messages (e.g. " $n_{\text{feedback}} < n_x$ " or " $T > T_x$ ").

5 Transfer medium and physical layer

5.1 General

This clause specifies the physical layer in detail (e.g. optical signals on the output of the master) including the signal specifications (e.g. data rate, jitter).

Some signal names and signal parameters are represented as abbreviations (e.g. RxD). Abbreviations help to organize the block diagrams more clearly. The specification determines signal parameter conditions (e.g. upper, lower limits; intervals).

5.2 Topology

5.2.1 Line connection between the control unit and the drives

The topology consists of optical point-to-point transmission lines and subscribers. A transmission line consists of fibre optic cables having no optical branches. Transmission takes place in only one direction. The master and the slaves are part of the network (subscribers).

Figure 7 shows the structure in connection with the control unit and the drives. The control unit may encompass one or more masters. A master handles only one ring on the physical level as well as in the overlying protocol layers. Slaves are used to connect the drives to the optical fibre ring. On the physical level, a slave represents the connection of one or more drives to the optical fibre ring. Logically, one slave with several drives acts the same as several slaves with one drive each. Although the slaves are connected to each other physically through the optical fibre ring, all transmission of information takes place directly between the master and the drives. A star-shaped topology is created if every master has only one slave connected to itself.

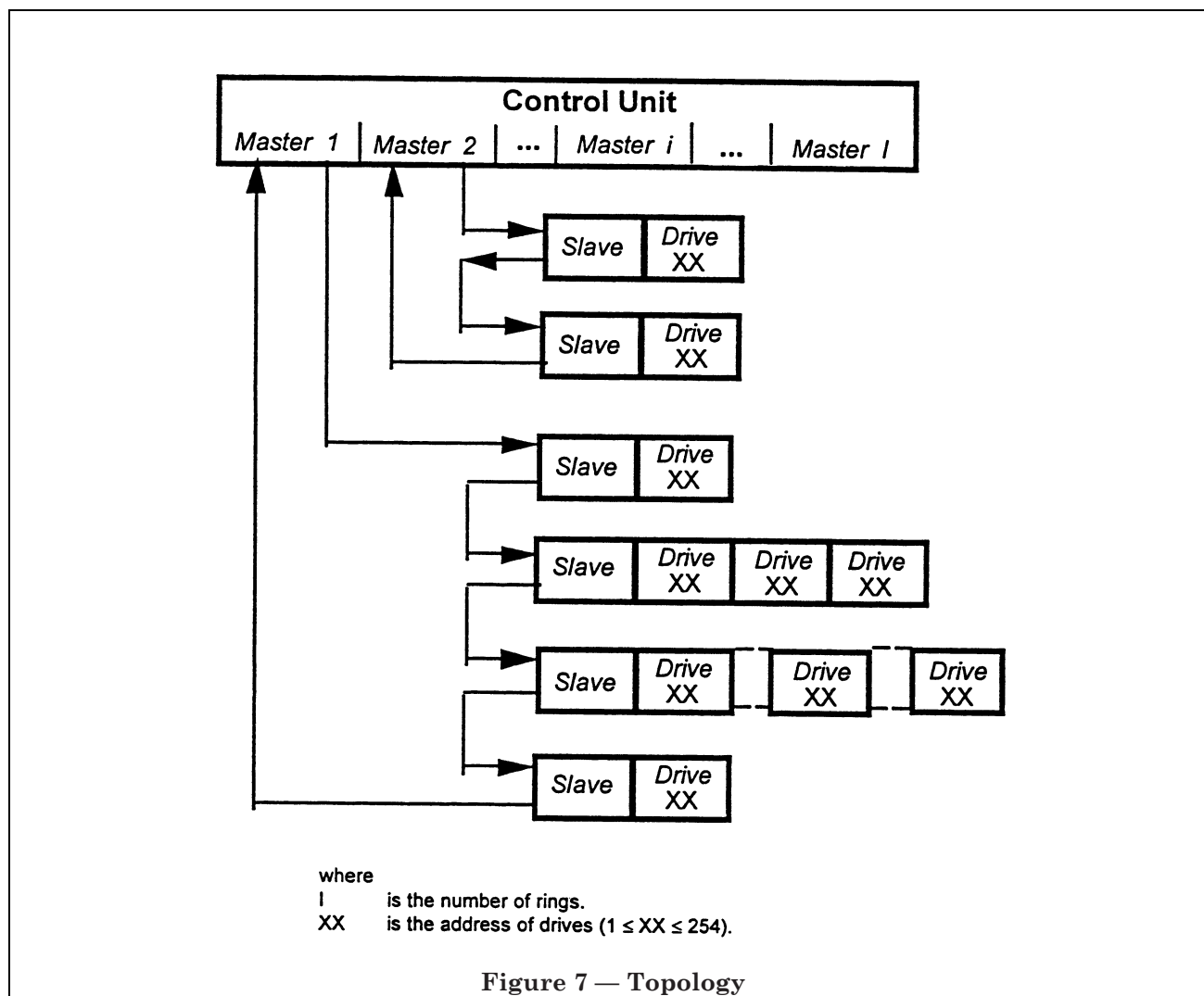


Figure 7 displays the topology. The physical arrangement of slaves in the rings is independent from the set drive address for the slave, as well as from the timing sequence of transmitting the drive telegrams.

The number of drives in a ring is $M = K$. The sequence of the AT is labelled as 1, 2, ..., M and the sequence of the drive data records in the MDT is labelled as 1, 2, ..., K.

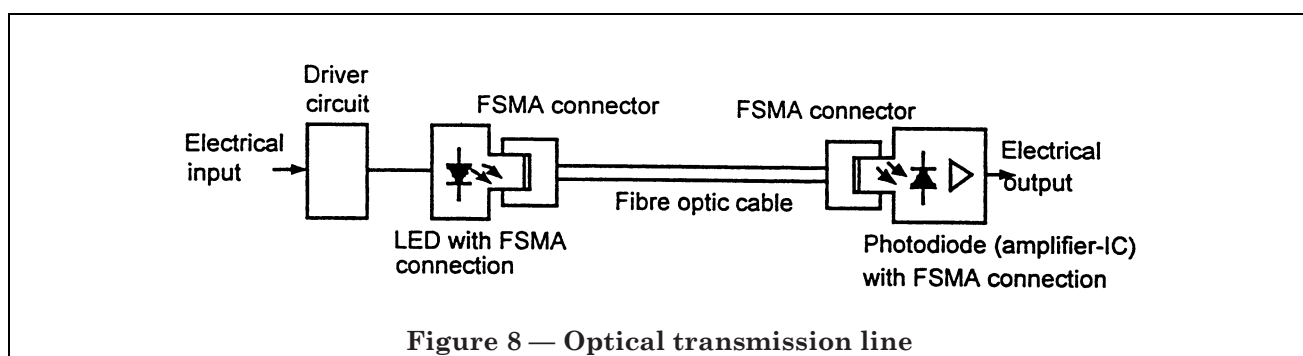
The SYSTEM interface determines any exchange of information within a ring. Any cooperation of rings is controlled by the control unit and is not subject to this standard.

5.2.2 Structure of the transmission lines

The connectors used correspond to standard F-SMA connectors (see IEC 60874-2). The transmitter and receiver components are built into housings which have F-SMA connections for optical interfaces. The structure of the optical transmission line is shown in Figure 8.

The driver circuit for the transmitting LED is activated by an electrical impulse. The high-performance LED (transmitter) emits red light of a wavelength in the range from 640 nm to 675 nm (peak wavelength in the range from 0 °C to 55 °C). The LED is contained in a light-proof housing. The housing is equipped with an F-SMA screw-type connection to receive an F-SMA plug. The transmission power is switchable between “low attenuation” and “high attenuation”. Attenuation taking place along the transmission line is caused by the fibre optic cable and possibly other couplings (in addition to the F-SMA plug connections on transmitting and receiving elements).

These additional couplings may become necessary when routing through a wall, for example. The factors which contribute to attenuation along the line are explained in more detail in Annex G.



The fibre optic cable is made of plastic or glass and has a step index profile. Fibre optic cables and cores can be used. For fibre optic materials currently in use, the attenuation is approximately 220 dB/km for plastic and 6 dB/km for glass.

The receiver component consists of a photodiode and an integrated amplifier circuit, which are contained in light-proof housings with F-SMA connectors.

The signal is allowed to be inverted while passing through a slave (i.e. a light-on signal at the optical slave input does not necessarily lead to a light-on signal at the optical output).

5.3 Optical signals on the transmission line

Optical power levels on the transmission line have units of dBm or mW which are related as follows:

$$\text{Level [dBm]} = 10 \cdot \log(\text{level [\mu W]}/1\,000).$$

The optical signals given in Table 3, Table 4, Table 5, and Table 6 for the transmitter, the receiver, and the transmission line are measured with a plastic fibre optic cable with a 1 mm core diameter and a length of 1 m as specified in Table 5.

Optical levels and edges (status changes) along the transmission line are specified by means of the following parameters:

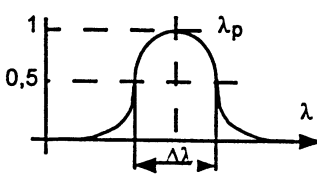
- a) $P_{T\max L}$, the maximum transmission power at an optically low level: when the optical signal falls below this level, it is at a logic low state;
- b) $P_{T\min H}$, the minimum transmission power at an optically high level: when the optical signal goes above this level, it is at a logic high state;
- c) $P_{T\max H}$, the maximum transmission power at an optically high level: stationary signals shall never exceed this limit. An rising optical edge, however, may dynamically exceed the upper limit of the optically high level. This makes it possible to accent the rising edge (minimizing the rise time). Both the magnitude as well as the duration of the excess signal level are limited;
- d) k_{os} , factor for optical power overshoot: this parameter indicates by which factor the maximum optical transmission power may be exceeded dynamically. The excess power level is only permissible during an optical status change from low to high (rising signal edge).

The optical signal shall pass through $P_{T\max L}$ to $P_{T\min H}$ in a monotonic manner (which means that the signal noise is less than 100 nW = -40 dBm). Therefore, the logic high level between $P_{R\max L}$ and $P_{R\min H}$ can be recognized definitely without generating additional signal changes. In the receiver, the decision (comparison) threshold between high and low levels shall be within the interval $P_{R\max L}$ and $P_{R\min H}$.

5.3.1 Transmitter specifications

Unless stated otherwise, these specifications are valid throughout the temperature range from 0 °C to + 55 °C.

Table 3 — Transmitter specifications (all data for λ_p)

Position	Low attenuation		High attenuation	
	dBm	μW	dBm	μW
Maximum transmission power at low optical level: P_{TmaxL}	– 31,2	0,75	– 28,2	1,5
Minimum transmission power at high optical level: P_{TminH}	– 10,5	90	– 7,5	180
Maximum transmission power at high optical level: P_{TmaxH}	– 5,5	280	– 3,5	450
Transmitting diode wavelength Peak wavelength Spectral bandwidth	$\lambda_p = 640 \text{ nm to } 675 \text{ nm}$ (0 °C to 55 °C) $\Delta\lambda \leq 30 \text{ nm (25 °C)}$ (bandwidth at half of the maximum intensity)			
Exceeding high level by a maximum factor	$k_{os} = 120 \%$			
Temperature range	0 °C to 55 °C			

5.3.2 Receiver specifications

Unless stated otherwise, these specifications are valid throughout the temperature range from 0 °C to + 55 °C.

In order to process the data correctly, the receiver must adhere to Table 4. Since the bandwidth of the fibre optic cable is relatively wide, distortion of the optical signals is insignificant.

Table 4 — Receiver specifications (all data for λ_p)

Units		dBm	μ W
Maximum received power at low optical level:	P_{RmaxL}	– 31,2	0,75
Minimum received power at high optical level:	P_{RminH}	– 20	10
Maximum received power at high optical level:	P_{RmaxH}	– 5	320
Bit error rate		$\leq 10^{-9}$	
Temperature range		0 °C to 55 °C	

5.3.3 Fibre optic cable

The fibre optic cable consists of plastic or glass with a step index profile.

Structural example:

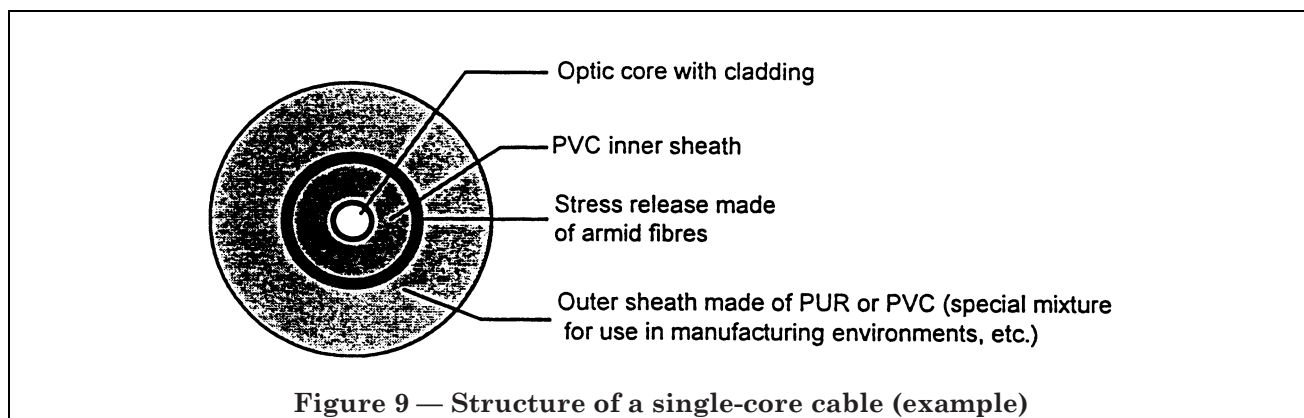


Table 5 — Cable specifications (example)

	plastic fibre	glass fibre
Core diameter	980 μm	200 μm
Cladding diameter	1 000 μm	230 μm
Numeric aperture	0,47	0,37
Bandwidth	$\geq 5 \text{ MHz} \cdot 1 \text{ km}$	$\geq 10 \text{ MHz} \cdot 1 \text{ km}$

5.3.4 Connectors

Connectors for fibre optic cables shall:

- correspond to F-SMA standard (see IEC 60874-2);
- have a quality level of at least 5;
- have a metallic connector ring.

In addition, it is recommended to have a strain relief for fibre optic cables.

5.3.5 System data of the optical transmission path

Table 6 — System data of the optical transmission line

Position	Low attenuation		High attenuation	
	dBm	μ W	dBm	μ W
Maximum transmission power at low optical level: P_{TmaxL}	– 31,2	0,75	– 28,2	1,5
Minimum transmission power at high optical level: P_{TminH}	– 10,5	90	– 7,5	180
Maximum transmission power at high optical level: P_{TmaxH}	– 5,5	280	– 3,5	450
Line attenuation	$\leq 4,4$ dB		$\leq 7,4$ dB	

	dBm	mW
Maximum received power at low optical level: P_{RmaxL}	– 31,2	0,75
Minimum received power at high optical level: P_{RminH}	– 20	10
Maximum received power at high optical level: P_{RmaxH}	– 5	320
Transmitting diode: — peak wavelength — spectral line bandwidth at half of the maximum intensity	$\lambda_p = 640$ nm to 675 nm $\Delta\lambda \leq 30$ nm (25 °C)	
Dynamic power (P_{RmaxH} to P_{RminH})	15 dB	
System value (P_{TminH} to P_{RminH})	9,5 dB (low attenuation) 12,5 dB (high attenuation)	
System reserve (including lifetime of transmitting diode)	$\geq 5,1$ dB	
Data rate	2 Mbit/s (NRZI) 4 Mbit/s (NRZI)	
Bit error rate	$\leq 10^{-9}$	
Temperature range	0 °C to 55 °C	

5.4 Time performance of bit transmission

The distance between rising and falling edges of the optical signal are specified in this subclause. An edge is a change in level between the optically low and optically high levels. The specification is based on an envelope which has been defined for the optical signal. Any optical output signal of a transmitter shall remain within this specific envelope at all times. Furthermore, the run-time performance between optical slave input and output is specified. A slave shall be synchronized to the transmission clock of the bit stream coming into its optical input. Although the transmission clock of a slave may deviate from the clock at its input for a short time, the slave needs to be synchronized to the predetermined clock (e.g. by means of a phase locked loop). Thus, all units connected to the ring are required by definition to transmit the same averaged transmission clock pulse. In other words, all units use the transmission clock pulse of the master. The slave is synchronized to the transmission clock on its optical input by means of light-on edges (rising edges).

5.4.1 Master and slave in test mode

In this subclause, the run-time performance at the optical output of the master is specified while the master is operating both in its normal as well as its test mode. The test mode can be activated externally by special means (e.g. pressing a key). Master and slave shall then be able to provide a continuous signal light, as well as a zero bit stream at the optical output, without the presence of an input signal.

Continuous light signal test mode:

A continuous light signal implies a logical high level without a level change at the optical output. This mode is only required for the master. The slave may generate a continuous light signal, depending on whether or not a continuous light signal comes in at the optical input. Due to its function as a repeater the slave shall be able to echo the light which it receives at its optical input (or the lack thereof), at its optical output.

NOTE A slave is allowed to invert the optical signal.

Zero bit stream test mode:

The zero bit stream test mode implies that the transmitter shall transmit consecutive zeros which, based on the NRZI code, result in continuous level changes in the signalling pattern of the transmission clock (this results in a 1 MHz signal for a data rate at 2 Mbit/s). The slaves shall use its local clock to synchronize the transmitting clock at its optical output signal. No clock adjustments may occur at the optical output (e.g. , due to the phase locked loop, $\rightarrow t_{\text{cad}}$) and only statistically distributed jitter of the optical signal is allowed. This requirement is important because it allows the system to isolate and separate jitter noise ($\rightarrow J_{\text{noise}}$) from possible clock adjustments due to the phase locked loop ($\rightarrow t_{\text{cad}}$), as will be discussed later. The curve shapes of optical signals which are generated while the system is in the zero bit stream test mode, are not allowed to deviate from the signals during normal mode near the rising and falling edges (e.g. different rise and fall times, different excess levels during the test mode). It means especially that the same driver circuit shall be used during the zero bit stream test mode as is used during normal mode.

The following parameters are used to specify the optical output signal of the master and slave (see Figure 10 and Figure 11):

- a) t_r : this is the time delay between points 1 and 2 ($= 1-1'$ or $2-2'$). It is an upper limit of the time required by the optical signal to pass through P_{TmaxL} to P_{TminH} on the rising edge.
- b) t_f : this is the time delay between points 3 and 4 ($= 3-3'$ or $4-4'$). It is an upper limit of the time required by the optical signal to pass through P_{TminH} to P_{TmaxL} on the falling edge.

NOTE See item g) regarding t_r and t_f .

- c) t_{os} : this parameter indicates for how long the maximum optical transmission power may be exceeded dynamically. This interval starts at time ①.

- d) t_{BIT} : this is the arithmetic mean value (measured over several seconds) of the transmission clock period (duration of a bit cell) by the master (not in test mode) and corresponds to the reciprocal value of the data rate. The nominal duration is described by t_{BITnom} .

t_{BIT} is measured between edges with the same direction ($= 2^* t_{\text{BIT}}$) at optical power levels of $45 \mu\text{W} \pm 10 \mu\text{W}$ (low attenuation position) or $90 \mu\text{W} \pm 20 \mu\text{W}$ (high attenuation position). t_{BIT} is considered to be constant in the range of seconds. Only fluctuations due to noise are allowed.

A relatively long measurement duration of t_{BIT} ensures that the influence of short-term deviations of the delays between edges (jitter $\rightarrow J_{\text{noise}}$) is negligible.

Hence, t_{BIT} describes the time between points 1 and 3 as well as the time between points 3 and 5 (which corresponds to point 1 of the next period) (see Figure 10).

- e) t_{BITtest} : this is the arithmetic mean value measured over several seconds of the master or slave transmission clock period (duration of a bit cell) in the zero bit stream test mode. All measurements and properties of t_{BITtest} correspond to t_{BIT} .

- f) J_{noise} : this parameter describes the jitter of the optical signal. It is the purely statistical deviation of the distance between both edges, compared with the value t_{BITtest} measured over a long time interval. J_{noise} is obtained by overlaying the signals of several periods (e.g. on an oscilloscope) such that they come together at one optical power level (e.g. P_{TmaxL} on the falling or rising edge). The jitter of the optical signal is then determined by the width of the overlaid optical signals (which gives a time). This width may not exceed the value J_{noise} in the power region between P_{TmaxL} and P_{TminH} resp. vice versa.

By this definition, the jitter of the optical signals is limited, that is, the signal curve shapes shall be reproducible in the power region P_{TmaxL} through P_{TminH} resp. vice versa.

g) Remark: Note that the times t_r and t_f are not fully available as rise time and fall time. Due to non-symmetrical ON/OFF performance of the driver circuit (duty cycle, propagation delay), the falling edge can be time-shifted with respect to the rising edge, resulting in a remaining difference for $t_{\text{BIT test}}$. In this case, the high level can be extended by some time interval and the low level could be shortened by the same interval. This extending/shortening interval is not considered part of the rising and falling interval. In addition, the signal with added J_{noise} shall remain completely within the envelope, which implies that the jitter shall be taken into consideration for the times t_r and t_f .

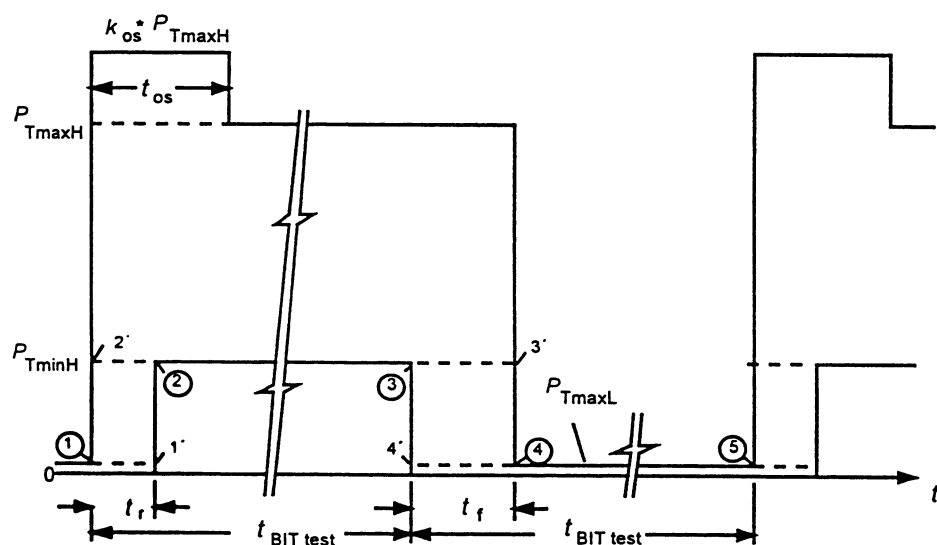
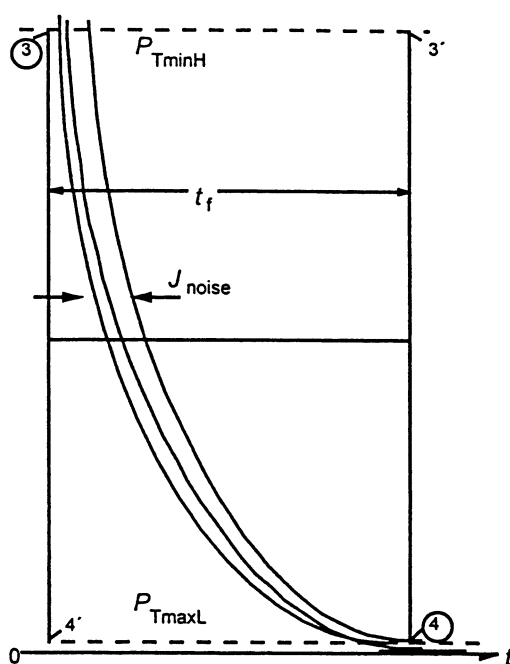


Figure 10 — Optical signal envelope

Figure 11 — Display of jitter (J_{noise})

5.4.2 Data rate

The data rate is the baud rate measured at the optical output of the master. Its nominal value is 2 or 4 Mbit/s. The measured value is allowed to deviate by $\pm 0,01\%$. The baud rate is a time average measured over several seconds. The short-term performance (nanoseconds range) may deviate slightly and is specified through J_{noise} .

Table 7 — Transmission data parameters

Transmission rate	Baud rate = (2,000 $\pm$ 0,000 2) Mbit/s	Baud rate = (4,000 0 $\pm$ 0,000 4) Mbit/s
Bit times	$t_{\text{BIT}} = (500,00 \pm 0,05) \text{ ns}$	$t_{\text{BIT}} = (250,00 \pm 0,025) \text{ ns}$
	$t_{\text{BITnom}} = 500 \text{ ns}$	$t_{\text{BITnom}} = 250 \text{ ns}$
	$t_{\text{BITtest}} = (500,00 \pm 0,05) \text{ ns}$	$t_{\text{BITtest}} = (250,00 \pm 0,025) \text{ ns}$
Times for curve shapes	$t_{\text{os}} = 200 \text{ ns}$	$t_{\text{os}} = 100 \text{ ns}$
	$t_{\text{r}} = 100 \text{ ns}$	$t_{\text{r}} = 40 \text{ ns}$
	$t_{\text{f}} = 150 \text{ ns}$	$t_{\text{f}} = 110 \text{ ns}$
Jitter	$0 \leq J_{\text{noise}} \leq 10 \text{ ns}$	$0 \leq J_{\text{noise}} \leq 10 \text{ ns}$

5.4.3 Input-output performance of the slave

In this subclause, the input-output performance of the slave is specified, especially its synchronization performance, as follows: a slave receives a signal with a certain clock at its optical input. The mean value of this clock is equal to the transmitting clock of the master. In the long run, a slave shall be synchronized to this clock (by evaluation of one of the rising or falling edges).

The slave generates its own local clock. This local clock is used to receive and to transmit data. The local clock of a slave runs freely between the synchronizing edges of the incoming bit stream. During synchronization, the slave adjusts the phases of the local clock (phase locked loop). This performance can be observed at the optical output because the duration of the high or low level becomes shortened or lengthened with respect to the average bit duration (t_{BIT}). The amount of shortening or lengthening is called clock adjustment time t_{cad} .

Clock adjustment time is not allowed to exceed a specific value (t_{cadmax}). In addition, the implemented maximum clock adjustment time (t_{cadreal}) of every slave shall be specified by the manufacturer (e.g. $t_{\text{BIT}}/16$).

The optical signal shall run through the range $P_{\text{TmaxL}} - P_{\text{TminH}}$ resp. vice versa of the envelope always at the same position (taking J_{noise} into account). If the envelope can be shifted over the optical signal (due to short rise and fall times), this possible shift shall not be taken into account as a “bonus” to the clock adjustment.

A slave shall be able to receive signals correctly if their clock adjustment time is smaller or equal to the maximum clock adjustment time, t_{cadreal} , implemented in that slave. When the slaves are physically located in the ring in an ascending t_{cadreal} sequence, the system makes sure that correct receiving conditions are established for any slave. The receiver of the master, being the last unit in the ring, shall be able to process the maximum allowable clock adjustment time t_{cadmax} .

In addition to the clock adjustment time just described, a minimum clock adjustment time (t_{cadmin}) shall be specified, which at least every slave shall be able to process correctly at its input. The input/output performance of a slave is specified by the following parameters:

- t_{rff} : this is the time between points 1 and 3 in Figure 12 on the receiver input.
- t_{fri} : this is the time between points 3 and 5 in Figure 12 on the receiver input.
- t_{cadreal} : this is the maximum clock adjustment time (shortening or lengthening a level) which a slave generates at its optical output. This value is specified by the manufacturer. The slave shall also be able to correctly process this maximum clock adjustment time at its input, within the scope of the specified bit error rate.
- t_{cadmin} : this is the minimum clock adjustment time which a slave shall be able to process correctly within the scope of the specified bit error rate.

- e) t_{cadmax} : this is the upper limit for $t_{cadreal}$ and also describes the maximum clock adjustment time the master shall be able to process correctly within the scope of the specified bit error rate.
- f) t_{rfo} : this is the time between points 1 and 3 in Figure 12 at the transmitter output.
- g) t_{fro} : this is the time between points 3 and 5 in Figure 12 at the transmitter output.
- h) t_{del} : this is the time delay of the envelope between the optical input and output, measured at the slave (see Figure 12). This parameter describes the signal delay (run-time) of the optical signal through a slave in a repeater mode (see 5.7.2). The delay is measured between the light-ON edge at the optical input and the associated light signal edge at the optical output (in non-inverting slaves, this is the light-ON edge; in inverting slaves, this is the light-OFF edge).

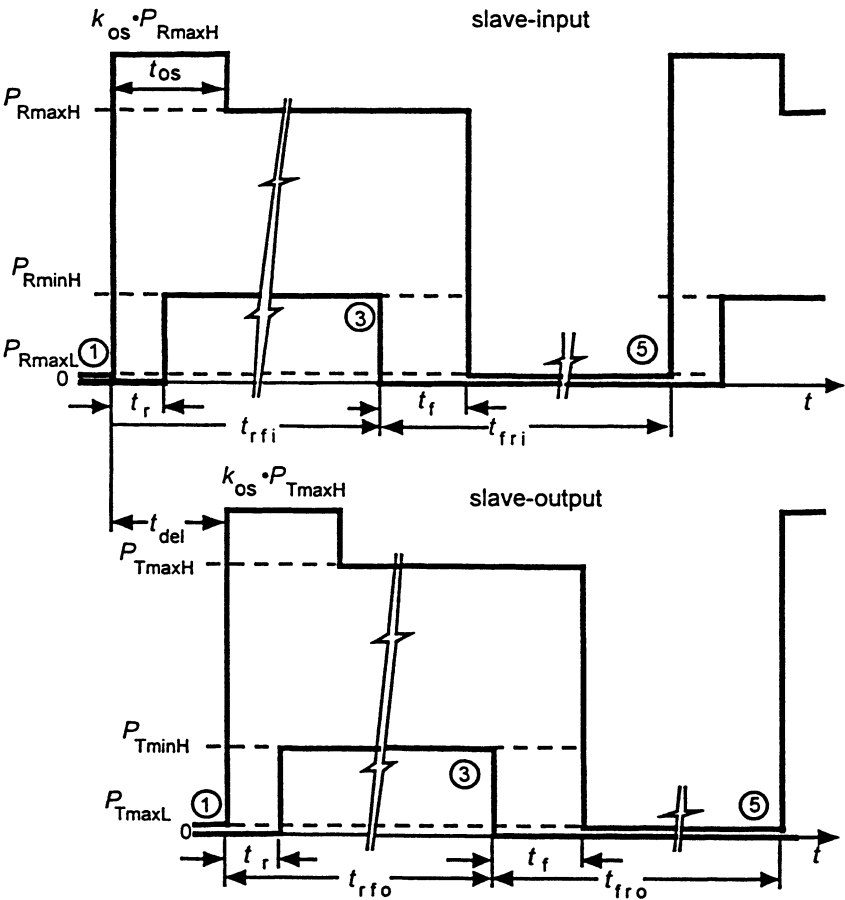


Figure 12 — Input-output performance of a slave

A receiver can be fed with one input signal according to cases a) or b) of Table 8. Changing between cases a) and b) is not possible. This means that clock adjustment time will shorten or lengthen either just the high level, or just the low level.

Table 8 — Possible slave input signals

Case	t_{rfi}	t_{fri}
a)	$i * t_{BIT} - t_{cadreal} \leq t_{rfi} \leq i * t_{BIT} + t_{cadreal}$	$j * t_{BIT}$
b)	$i * t_{BIT}$	$j * t_{BIT} - t_{cadreal} \leq t_{fri} \leq j * t_{BIT} + t_{cadreal}$
NOTES		
1	i and j are ordinary digits; i is not identical to the sequence of rings as given in the abbreviations	
2	Normal operation When switching from telegram to fill signal and vice versa	
i, j	1 ... 8	1 ... 12
i + j	2 ... 16	2 ... 20

The slave shall be able to do the following tasks with these specific input signals:

- 1) receive and process data correctly within the scope of the bit error rate;
- 2) generate valid output signals.

Valid output signals have a signal timing within the specified limits and are generated according to cases c) or d) of Table 9. It means that the slave can either shorten or lengthen only the high level or only the low level through clock adjustment, but not alternate between the two.

Table 9 — Possible slave output signals

Case	t_{rfo}	t_{fro}
c)	$m \cdot t_{BIT} - t_{cadreal} \leq t_{rfo} \leq m \cdot t_{BIT} + t_{cadreal}$	$n \cdot t_{BIT}$
d)	$m \cdot t_{BIT}$	$m \cdot t_{BIT} - t_{cadreal} \leq t_{rfo} \leq n \cdot t_{BIT} + t_{cadreal}$
NOTE m and n are ordinary digits. They are not identical to the explanation given in the abbreviations.		

Four cases are distinguished for the allowable values m and n:

Table 10 — Valid slave output signals

Status\slave	Non-inverting slave		Inverting slave	
Repeater	i = m; j = n		i = n; j = m	
Slave transmits own telegram	Normal operation i, j = 8 m, n = 1 .. 8 m+n = 2 .. 16	When switching from telegram to fill signal (1 .. 12) (2 .. 20)	Normal operation i, j = 8 m, n = 1 .. 8 m+n = 2 .. 16	When switching from telegram to fill signal (1 .. 12) (2 .. 20)
NOTE Numbers in brackets represent values which may occur when switching from telegram to fill signal.				

5.4.3.1 Clock adjustment

Table 11 — Specifications of the clock adjustment times

t_{cadmin}	$= t_{BITnom}/64$
t_{cadmax}	$= t_{BITnom}/11$
$t_{cadreal}$	$0 \leq t_{cadreal} \leq t_{cadmax}$

5.4.3.2 Signal delay due to the slave

Signal delay due to the slave (in repeater status) is specified as follows:

$$t_{BITnom} \cdot 0,5 \leq t_{del} \leq t_{BITnom} \cdot 1,5$$

5.4.4 Idealized waveform

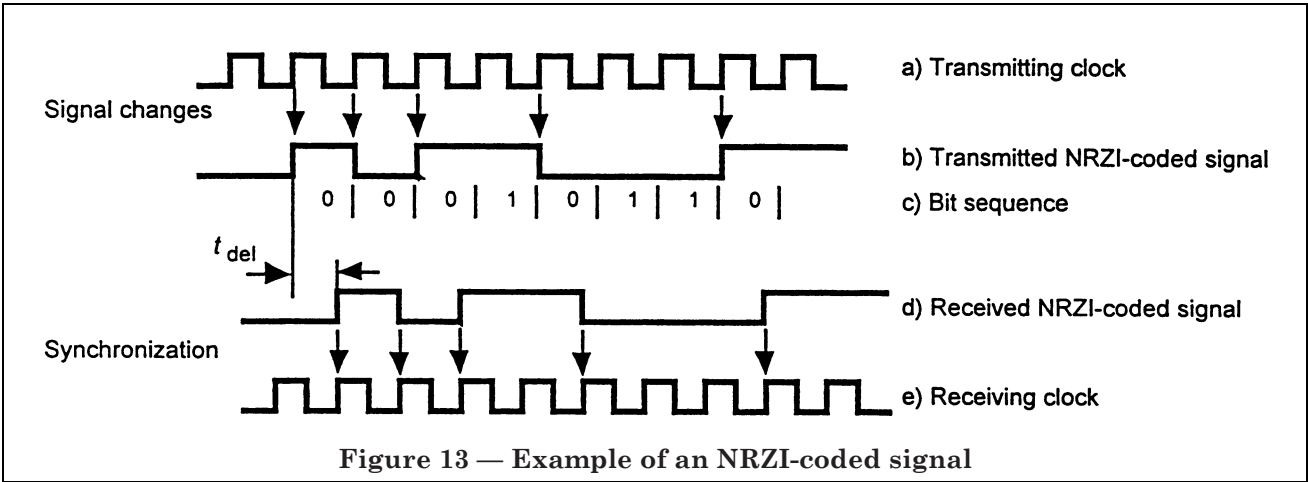
The idealized waveform is characterized by status changes of the optical signal. The optical signal is replaced by rectangular wave shapes of equal height and infinitely short rise and fall times. The status change (edge) of the idealized waveform (rectangle) is defined at the transmitter output as the instant of time at which the optical power equals $45 \mu W \pm 10 \mu W$ (low attenuation position) or $90 \mu W \pm 20 \mu W$ (high attenuation position). Both threshold levels always fall within the interval P_{TmaxL} and P_{TminH} .

All subsequent times are measured between the status changes defined above.

5.5 Bit coding

Signals on the transmission lines are NRZI-coded (NRZI = no return to zero inverted). Signal changes are only allowed to take place in synchronization with the transmitting clock. Every time a zero is transmitted, the signal changes its status in synchronization with the transmitting clock, whereas the signal remains unchanged when a 1 is transmitted.

By a suitable method (→ bit-stuffing), the transmitter ensures that enough zeros occur in the transmitted bit stream. This generates additional signal changes. In this way, conditions are created which make it possible to retrieve a receiving clock from the received signal. The retrieved receiving clock also has a fixed phase position with respect to the clock of the transmitter. The clock is retrievable by means of a digital phase locked loop (DPLL) which is synchronized to the signal change of the received signal transformed to an electrical signal. Figure 13 d) is an example of a NRZI-coded signal. Therefore, the transmitting clock provides the pattern for the system timing via the signal transitions.



5.6 Telegrams and fill characters

On the physical level it is sufficient to know that a telegram starts and ends with the bit sequence 01111110. This bit sequence is also known as a delimiter. Due to bit-stuffing, this bit sequence is prevented from occurring inside the telegram (see Figure 14, 6.2, and 7.2).

← Administrative segment →		← User application data →	← Administrative segment →	
Telegram delimiter	Address field	Data field	Frame check sequence field	Telegram delimiter
(BOF)	(ADR)	(configurable length)	(FCS)	(EOF)
01111110	8 bits	j × 8 bit	16 bits	01111110

Figure 14 — General telegram structure

Other fields of the telegram belong to higher protocol layers and are discussed elsewhere.

Where a unit does not supply its own telegram to the ring, two possibilities arise:

- a) the master transmits a so-called fill signal (fill bits) between its own telegrams. They consist of a sequence of one binary 0 and seven binary 1's (i.e. 01111111). This generates a symmetric fill signal with 16 times the period of the transmitting clock, due to NRZI-coding;
- b) Between its own telegrams, a slave transmits with its synchronized local clock the physically regenerated, received signals (repeater mode).

During the transition from telegram to fill signal (master) or from telegram to repeater mode (slave), signal changes shall follow the pattern of the current clock.

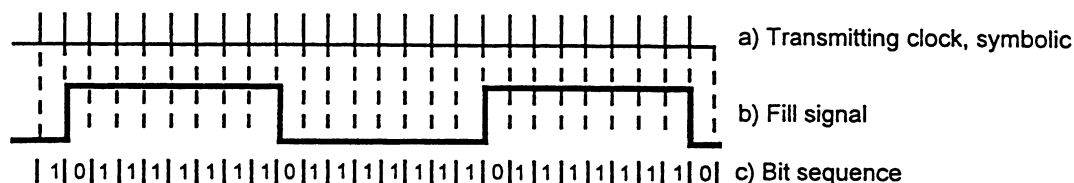


Figure 15 — Fill signal

NOTE Due to bit-stuffing and a), the slave physically located first in the ring can derive its local clock from its received signal at any time. Because of b), this is also the case for all subsequent units, all the way to the receiver of the master. In this way, digital phase locked loops, which are eventually used to obtain the local clock, remain locked on, preventing time-consuming synchronization before the start of the actual telegram.

5.7 Connection to the optical fibre

In this subclause, the connection to the optical fibre for master and slave as well as their interaction are described in more detail.

Table 12 shows all basic functions to be performed by a connection.

Table 12 — Basic functions of the connection

Function to be performed by →		Master	Slave
1	Retrieve clock from received signal	x	x
2	Regenerate and transmit received signal		x
3	Transmit 01111111 as fill signal	x	
4	Transmit own telegram	x	x
5	Phase-correct and spike-free transition between numbers	4 → 3 3 → 4	4 → 2 2 → 4

5.7.1 Master connection

Figure 16 shows an example of the functions of connecting a master.

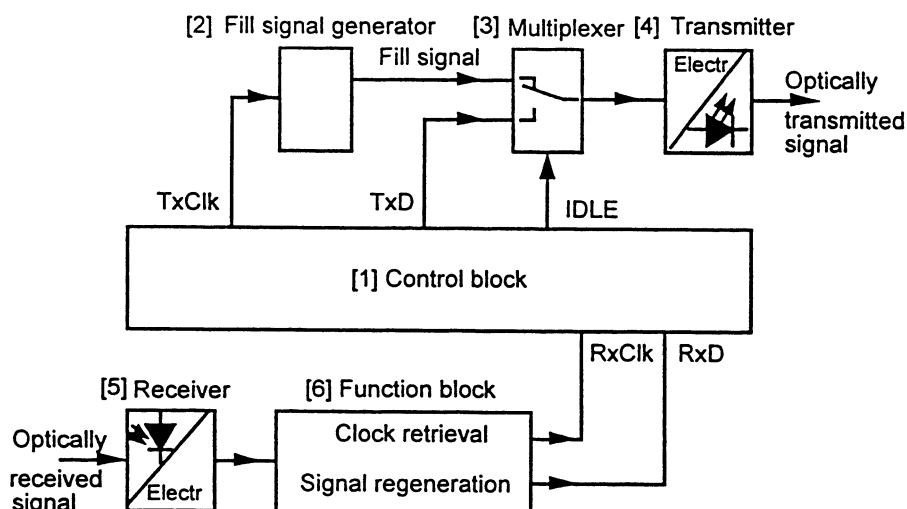


Figure 16 — Functions of a master connection

The control block [1] constructs the telegram to be sent according to Figure 14 and converts it into a NRZI-coded signal. As the receiver, the control block [1] recognizes out of the NRZI-coded and regenerated received signal whether it is a telegram for the master based on the telegram delimiters and the address field. Other functions are checking the telegram and transmitting only correct data fields to the signal processing unit.

Except for NRZI coding/decoding and the generation/recognition of the telegram delimiters, the functions above will be discussed with higher protocol layers.

5.7.1.1 *Generating a fill signal*

According to Figure 16, the control block [1] generates the transmitting clock (TxClk) for the master. It is sent to the fill signal generator [2], where the fill signal is generated according to Figure 15.

As long as the master is transmitting the fill signal (IDLE = 1), this signal reaches the electro-optical converter [4] via the switch [3]. The switch shall work so that a signal change at its output always coincides with the pattern of the transmitting clock. In this way, subsequent units can use phase locked loops for clock retrieval, which will then always be synchronized to the transmitting clock of the master.

Function block [6] will be discussed in **5.7.2**.

5.7.1.2 *Switching*

During transitions from fill signal (01111111) to telegram delimiters:

- a) the bit string 01111111 may be interrupted at any point; and
- b) up to two arbitrary (transitioning) bits “xx” may be inserted (reason: simplifies implementation).

All signal changes generated this way shall, however, follow the pattern of the transmitting clock.

Figure 17 shows some examples of valid signal patterns of the transmitting signal during transitions from fill signal to a telegram to be sent, where occasionally inserted (transitioning) bits are shaded.

According to Figure 17, bit sequences having several delimiters can be generated. The receiver shall be able to recognize the highlighted, double-lined signal as the leading telegram delimiter.

During the transition from telegram delimiters to fill signals, that is, after the bit sequence 01111110 (delimiter):

- a) up to four arbitrary transitioning bits may be inserted;
- b) followed by switching to an arbitrary point in the bit sequence 01111111 (fill bits).

All generated signal changes shall follow the pattern of the transmitting clock. Figure 18 shows some examples. Occasionally inserted (transitioning) bits are shaded. It is possible to have several delimiters appear. A receiver shall be able to recognize the first delimiter as an enclosing telegram delimiter.

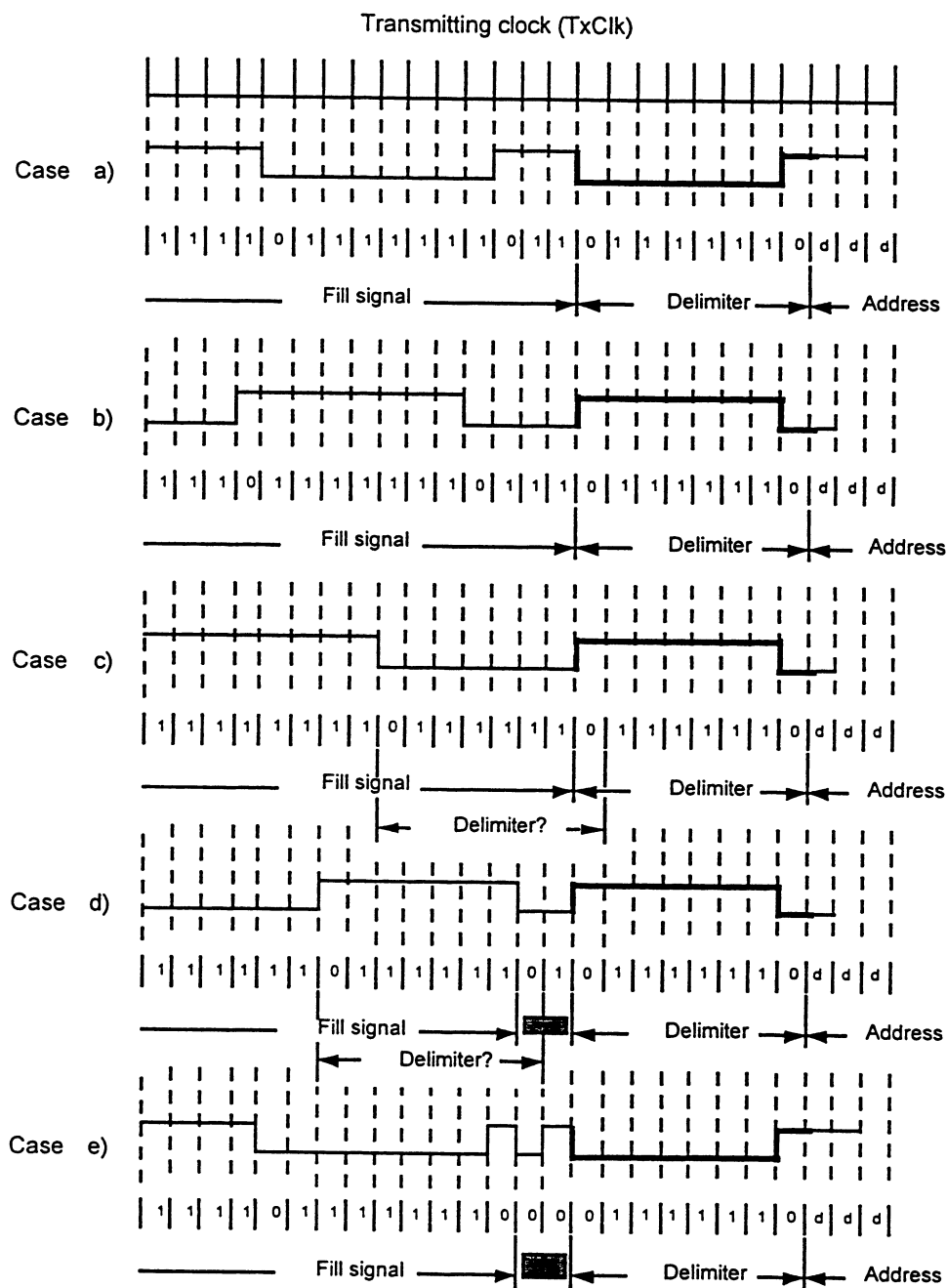


Figure 17 — Valid transmitting signals during the transition from fill signal to telegram delimiters

In Figure 18, case e) is identified by the fact that two consecutive edges of opposite directions are separated by a maximum of 12 transmitting clock cycles (t_{BIT}) and two sequential edges with the same direction are separated by a maximum of 20 transmitting clock cycles (t_{BIT}). This is important for the layout of a DPLL.

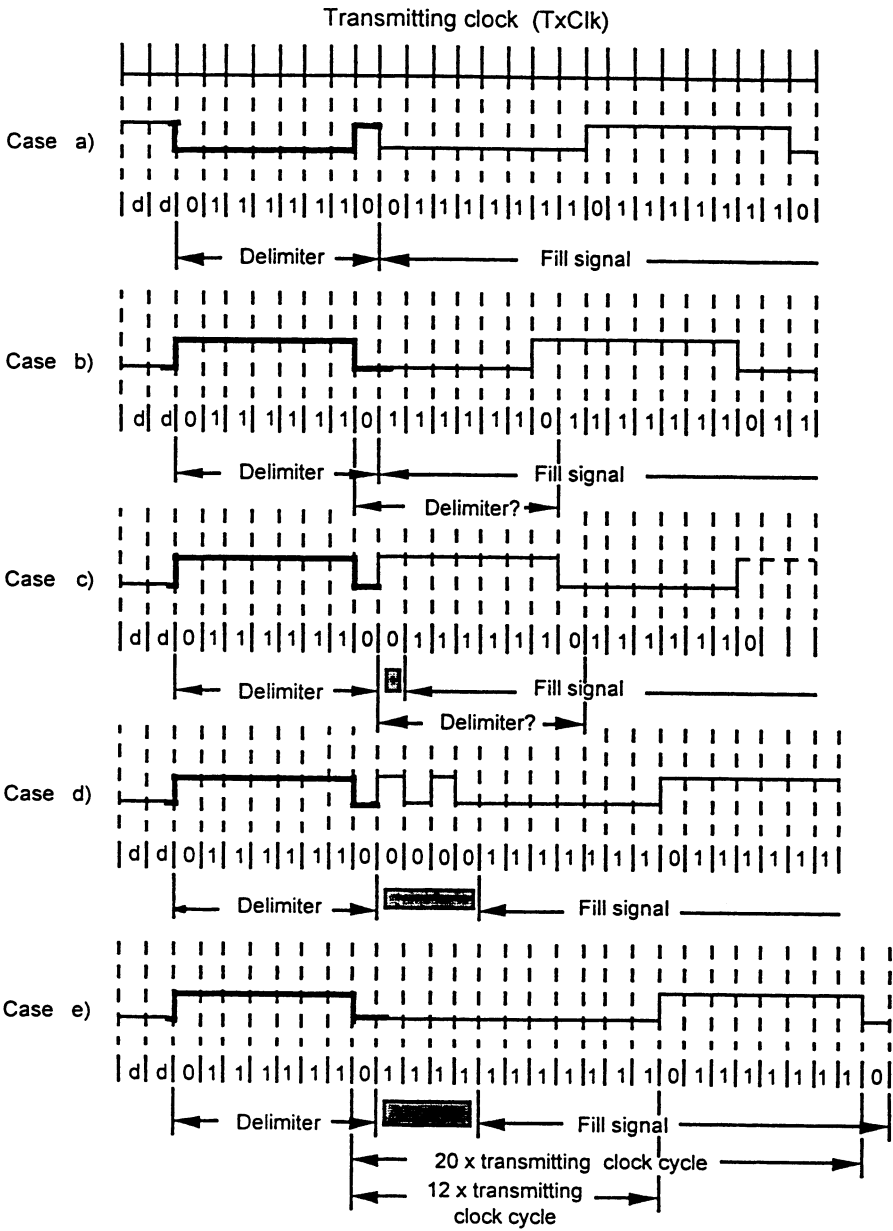
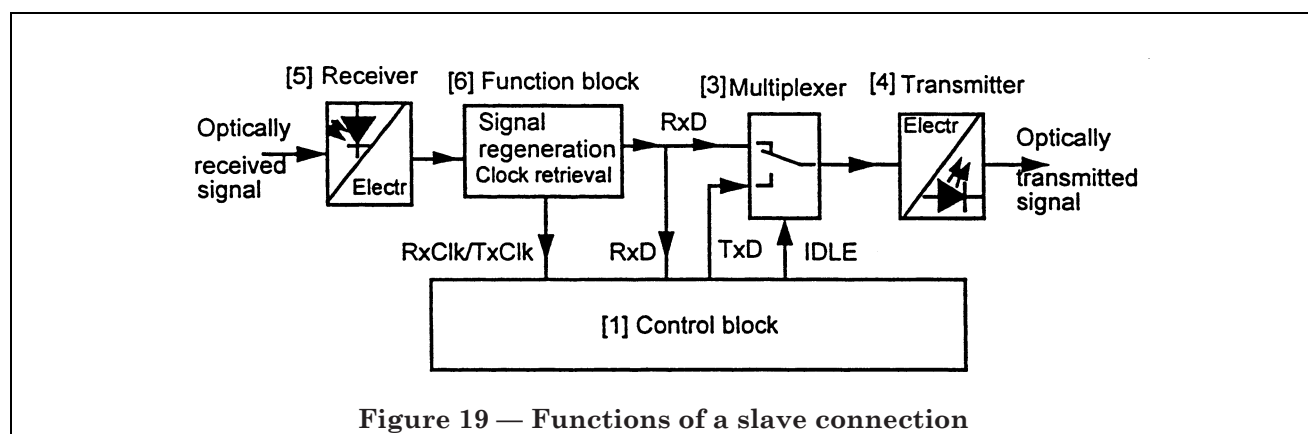


Figure 18 — Valid transmitting signals during the transition from telegram delimiter to fill signal

5.7.2 Slave connection

Figure 19 shows the functions of a slave connection.



The function block [6] has the following tasks:

- a) to retrieve the clock from the electrical received signal (clock retrieval, possibly with DPLL). The clock retrieved in [6] is used as transmitting and receiving clock for [1] (note, that for the master, transmitting and receiving clocks are different signals);
- b) to regenerate the received signal, care shall be taken that any signal changes take place according to the pattern of the clock retrieved in a). Where the slave does not need to transmit its own telegram, the regenerated received signal is sent (repeater mode, IDLE = 1).

The multiplexer [3] shall work according to the transitioning parameters as shown in 5.7.1.2.

Power supply:

In order to perform the above functions, the electronic components shall continue to work (e.g. during start-up and diagnostics), even when the power supply of the associated drives is shut-down. The slaves shall at least be able to regenerate the stream of data and to function as repeaters by transmitting the data.

5.7.3 Interactions of the connections

In Figure 20, the interaction of the connection of two slaves in a ring is illustrated. The assumption is made that slave 1 is in the process of transmitting a telegram to the master. The multiplexer [3] in the master transitions through the fill signal so that the function block [6] of slave 1 can retrieve the clock from it. Slave 2 switches through its regenerated received signal (i.e. the slave 1 telegram) to the master. The master, in turn, retrieves the receiver clock from the received signal by means of its function block [6]. Note that all three phase locked loops in Figure 20 shall be synchronized at any time. This synchronization shall always be maintained, even when a transition [3] is activated. During switch over of [3], it is important to avoid any signal edges which do not follow the clock pattern.

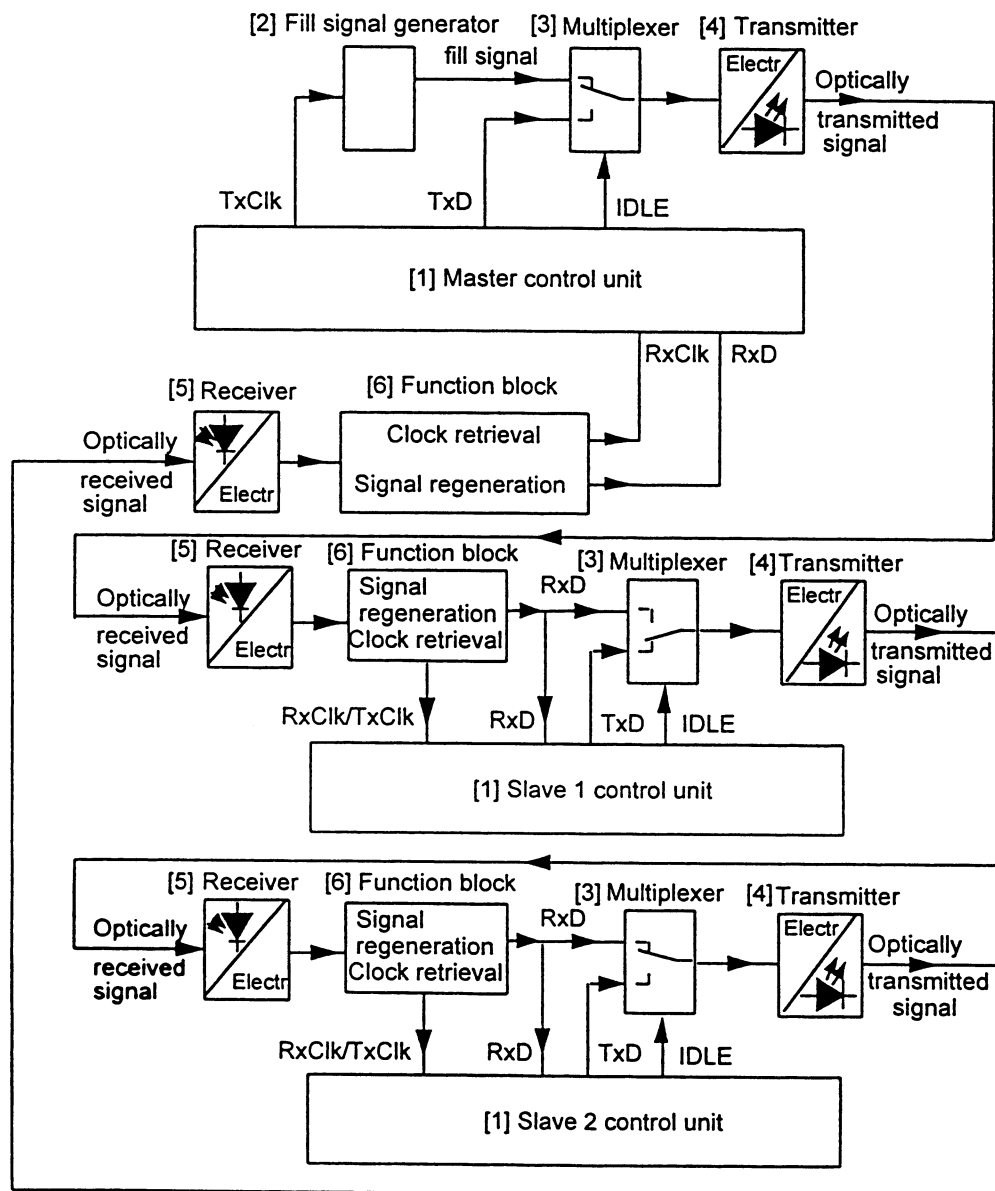


Figure 20 — Ring with two slaves

6 Data transfer and data link layer

6.1 General

In this clause, the structure of telegrams (frame structure) is described.

The interface specification recognizes three types of telegrams:

- master synchronization telegram (MST). This type of telegram is broadcast by the master at the beginning of a transmission cycle. MSTs are very short and serve to synchronize the timing within the transmission cycle.
- master data telegram (MDT). The master sends this type of telegram once during a cycle. MDTs are lengthy and serve to transmit data from the control unit to the drives (e.g. command values).

- c) drive telegrams (AT). These telegrams are sent by the slaves and serve to transmit data from the drives to the control unit (e.g. feedback values).

As determined by these definitions, no direct data transmission takes place between drives.

6.2 Telegram structure

Data transmission takes place in telegrams (see Figure 14 for general telegram structure).

6.2.1 Telegram delimiters

All frames shall start and end with the delimiter "01111110". All data stations which are attached to the data link shall continuously search for this sequence.

6.2.2 Bit stuffing

Bit stuffing ensures that no delimiter appears within the address field, data field, and frame check sequence. This is accomplished as follows:

- the transmitter shall examine the frame contents between the two delimiters, including the address field, the data field, and the frame check sequence and shall insert a "0" bit after all sequences of five continuous "1" bits to ensure the delimiter is not simulated inside the telegram;
- the receiver shall examine the frame content and shall discard any "0" which directly follows five continuous "1" bits.

6.2.3 Address field

Addresses shall have values between $0 \leq \text{ADR} \leq 255$. An address of 0 is the restricted address (no-station address) and 255 is the broadcast address (all-station address).

The address XX of a drive is $0 \leq \text{XX} \leq 254$ and is set on the device (e.g. via a selector). In a ring, no two drive addresses may be set to the same value $\text{XX} \geq 1$. Only $\text{XX} = 0$ may occur several times and indicates that no drive telegrams are being generated by this drive. This makes it possible to remove drives logically from the ring (e.g. for testing purposes). The repeater function of associated slaves, however, shall remain intact. The content of the address field is defined differently depending on the current communication phase as shown below:

- a) non-cyclic operation ($\text{CP}_0 \dots \text{CP}_2$). These communication phases are used during the initialization of the interface. In this case non-cyclic means that the master can communicate during one cycle with one drive only;
- b) cyclic operation (CP_3, CP_4). These communication phases are used during initialization (CP_3) and during normal operation (CP_4) of the interface. In this case cyclic means that, during a given cycle, the control unit can communicate with all drives (with $\text{XX} \geq 1$).

6.2.3.1 Content of the address field during transmission

Drive telegram (AT):

- a telegram which is sent by a slave shall have values in its address field which are set on the drives assigned to it (source addressing). All values between $1 \leq \text{XX} \leq 254$ are allowed.

Master synchronization telegram (MST):

- the MST is sent by the master and contains the value 255 in its address field.

Master data telegram (MDT):

- the MDT is sent by the master and contains in its address field the value of the drive which is going to receive the telegram (target addressing).
 - a) Non-cyclic operation of the interface: all addresses excluding 0 and 255 are allowed.
 - b) Cyclic operation of the interface: only the value 255 (broadcast address) is allowed.

Table 13 — Address field values during transmitting

		Communication phase	
Transmitter		Non-cyclic operation (phases 0, 1, 2)	Cyclic operation (phases 3, 4)
master	MST	255	255
master	MDT	$1 \leq \text{ADR} \leq 254$	255
slave	AT	$1 \leq \text{ADR} \leq 254$	

6.2.3.2 Content of the address field during receiving

Slave:

- a) during cyclic operation, a slave receives all telegrams with the value 255 in the address field (all other values indicate ATs which the slave does not receive);
- b) during non-cyclic operation, the slave receives the MSTs ($\text{ADR} = 255$) and all telegrams whose address fields have values between $1 \leq \text{ADR} \leq 254$, and which are set on the drives assigned to the slave.

Master:

The master receives all telegrams with values between $1 \leq \text{ADR} \leq 254$ in their address fields.

Table 14 — Address field values during reception

		Communication phase	
Receiver		Non-cyclic operation (phases 0, 1, 2)	Cyclic operation (phases 3, 4)
slave	MST	255	255
slave	MDT	$1 \leq \text{ADR} \leq 254$	255
master	AT	$1 \leq \text{ADR} \leq 254$	

6.2.4 Data field

All transmitted data is allowed to have arbitrary bit sequences of length $j \times 8$ bits, as long as it follows the rules as described in later clauses.

6.2.5 Frame check sequence (FCS) field

The frame check sequence consists of a 16-bit sequence. It shall be the “1”s complement of the sum (modulo 2) of:

- a) the remainder of:

$X^K * (X^{15} + X^{14} + \dots + X^2 + X + 1)$ divided (modulo 2) by the generator polynomial

$$X^{16} + X^{12} + X^5 + 1$$

where K is the number of bits in the frame existing between, but not including, the final bit of the opening delimiter and the first bit of the frame check sequence excluding bits inserted for transparency (bit stuffing bits),

- b) the remainder of the division (modulo 2) by the generator polynomial

$$X^{16} + X^{12} + X^5 + 1$$

of the product of X^{16} by the content of the frame existing between, but not including, the final bit of the opening delimiter and the first bit of the frame check sequence excluding bits inserted for transparency.

As a typical implementation, at the transmitter, the initial content of the register of the device computing the remainder of the division is preset to all “1”s and is then modified by division of the operator polynomial (as described above) of the address and data fields; the ones complement of the resulting remainder is transmitted as the 16-bit frame check sequence.

At the receiver, the initial content of the register of the device computing the remainder is preset to all “1”s. The final remainder after multiplication by X^{16} and then division (modulo 2) by the generator polynomial,

$$X^{16} + X^{12} + X^5 + 1,$$

of the serial incoming protected bits and the frame check sequence will be:

0001 1101 0000 1111 (X^{15} through X^0 , respectively)

in the absence of transmission errors.

NOTE This text is identical to ISO/IEC 3309, 4.6.2

6.2.6 Order of bit transmission

The order of bit transmission of the address and data fields shall be low-order bit first (i.e. the first bit of the sequence number that is transmitted shall have the weight 2^0). Where two bytes make up a 16-bit word or where four bytes form a 32-bit word, the lowest-valued byte will always be transferred first.

When there are several operation data in the configurable part of the data record, then the LSB of the low byte of the first operation data shall be sent first.

The frame check sequence shall be transmitted to the line commencing with the bit of the coefficient with the highest term (X^{15}).

6.2.7 Invalid telegrams

A telegram is invalid:

- a) where it is not properly bounded by delimiters at the beginning and the end;
- b) where the length enclosed by the delimiters does not correspond to the length defined during initialization (e.g. shorter than 32 bits).

Invalid telegrams shall be ignored by the receiver. Telegrams ending with seven or more sequential binary 1's instead of the defined delimiter shall be ignored by the receiver.

6.3 Timing of the transmission (communication cycles)

A synchronous error-free media access control is used. Telegrams are exchanged in fixed communication cycles. The master starts the communication cycle strictly equidistant with the communication cycle time t_{Syc} by transmitting the master synchronization telegram (MST).

This MST is transmitted as a broadcast telegram to all stations and reaches all drives simultaneously not taking into account the time delay of the ring. The MST is especially short, since it only has information about the status of the ring in its data field. The content of the data field remains constant during the same communication phase so that bit-stuffing (see 6.2.2) does not cause jitter at the end of the telegram.

The drive telegram is called AT_m , where m represents the number of the transmission timeslot for the associated drive XX ($m = 1, 2 \dots M$; M = the number of drives in the ring). The transmission timeslot describes the time interval within which a slave is allowed to transmit an AT from one of its connected drives. The beginning of the m th AT transmission timeslot follows $t_{1,m}$ after the end of the MST. This timeslot is stored by the drive (slave) as an IDN (i.e. in a variable slave memory which can be read or written to by the master).

The sequence of timeslots determines the timing of the ATs which is independent of the physical order of the ring as well as the defined drive address. The master is the recipient of the ATs. Slave units positioned between the master and the transmitting slave transmit the telegrams by means of its repeater function.

The MDT is sent out at time t_2 after the end of the MST after all ATs have been sent within a communication cycle. All drives are receivers of the MDT. The next cycle starts with the transmitting of the next MST.

From now on, “beginning of frame” (telegram), BOF, is the signal edge point which marks the leading binary 0 of the opening delimiter. Similarly, end of frame (telegram), EOF, is the signal edge point of the last binary 0 of the closing delimiter.

6.3.1 Transfer medium access

Figure 21 shows the medium access during CP_3 and CP_4 (cyclic operation). The medium access during $CP_0 - CP_2$, which are used during initialization, is given in clause 9.

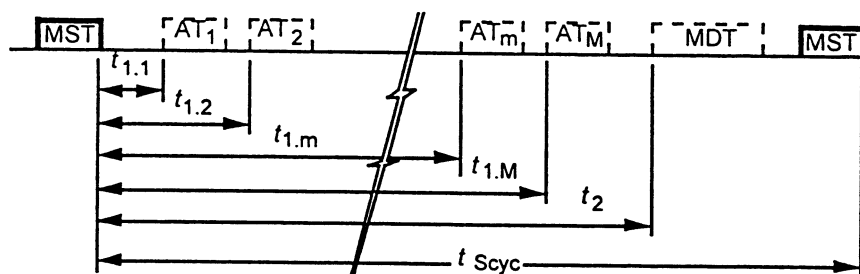


Figure 21 — Access to the transfer medium

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

6.3.1.1 Cycle times

The following reference values have been determined for the cycle time, t_{Scyc} (communication cycle time), of the transmission cycles:

$$t_{\text{Scyc}} = 0,25 \text{ ms} * i \quad \text{for } i = 1 \text{ to } 260$$

$$t_{\text{Scyc}} = 0,25 \text{ ms} * 2^i \quad \text{for } i = -1, -2$$

NOTE i is an ordinary integer and not related to the abbreviations.

This cycle time is allowed to have some jitter. The jitter describes the deviations from the t_{Scyc} value in the distance between the ends of two MSTs. $J_{t_{\text{Scyc}}}$ is determined as follows:

$$J_{t_{\text{Scyc}}} = \min \{5 \text{ ms}; 0,005 * t_{\text{Scyc}}\} + 4 * t_{\text{BIT}}$$

Therefore, the actual time interval between the end of an MST and the end of the j th following MST has a minimum value of:

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

and a maximum value of:

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

NOTE j is an ordinary integer and 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).

6.3.1.2 Telegram transmission times

During the initialization phase, the master inquires about some time parameters from the slaves (see 6.3.2). With this information, it is possible to calculate a collision-free distribution of transmission timeslots for the telegrams within the communication cycles.

The master proceeds to transmit the AT transmission starting time, $t_{1,m}$, for all connected drives to each slave as well as the transmission starting time of the MDT t_2 . These starting times of the transmitting timeslots for the telegrams are defined next. Jitter has been incorporated in $t_{1,m}$ and t_2 :

- t_2 MDT transmission starting time: this is the nominal time interval between the end of the MST and the beginning of the MDT during CP₃ and CP₄. The master stores this time interval in an IDN in the drives (see clause 8).
- J_{t2} Jitter in t_2 : this is the maximum deviation of the beginning of the MDT. It is the allowed deviation of the time interval t_2 . J_{t2} is determined as follows:

$$J_{t2} = \min \{5 \text{ ms}; 0,005 * t_{\text{Scyc}}\} + 4 * t_{\text{BIT}}$$
The actual time interval between the end of a MST and the beginning of a MDT shall lie between $t_2 - J_{t2}$ and $t_2 + J_{t2}$.
- t_1 AT transmission starting time: this is the nominal time interval between the end of the MST and the beginning of the AT. Every drive has its determined $t_{1,m}$. This parameter has been determined by the master and is stored in the associated drive as an IDN.
- J_{t1} Jitter in t_1 : this is the maximum deviation of the beginning of the AT. It is the allowed deviation of the time interval t_1 . J_{t1} is determined as follows:

$$J_{t1} = \min \{5 \text{ ms}; 0,005 * t_{\text{Scyc}}\} + 4 * t_{\text{BIT}}$$
The actual time interval between the end of a MST and the beginning of an AT_m shall lie between $t_{1,m} - J_{t1}$ and $t_{1,m} + J_{t1}$.

Figure 21 shows the starting times of the transmission timeslots.

6.3.2 Time parameters

6.3.2.1 Time parameter for the time intervals between telegrams

The following time parameters are characteristic values of slaves. They are requested by the master from every slave during initialization, excluding the values for t_{ATRP} and t_{RPAT} .

- $t_{1\text{min}}$ Shortest AT transmission starting time. $t_{1\text{min},m}$ is the minimum time after the MST that drive XX with data record m can transmit its AT. This parameter is stored in all drives as an IDN.
- t_{ATRP} Maximum transition time of a slave to switch from transmitting the AT to the repeater function (see 5.7.1.2). This time interval shall not exceed $4 * t_{\text{BIT}}$
- t_{RPAT} Maximum transition time of a slave to switch from repeater function to transmit the AT (see 5.7.1.2). This time interval shall not exceed $2 * t_{\text{BIT}}$
- $t_{\text{ATMT},M}$ Transmit/receive transition time in the drive M (ADR XX) to switch from transmitting an AT to the ready state for receiving the MDT. This parameter is stored in all drives as an IDN.
- $t_{\text{MTSY},K}$ Receive to receive recovery time needed by the slave which is served with data record K in order to be ready to receive the MST from the end of the MDT. This parameter is stored in all drives as an IDN.
- t_{ATAT} Transmit to transmit recovery time needed by a slave with several drives, in order to transmit another drive telegram after the end of a drive telegram. The actual time required may be exceeded by J_{t1} . This parameter is stored as an IDN in all drives which belong to the same slave. Otherwise, such an IDN is not available.

The minimum distance to be maintained between the end of one AT and the following telegram can be determined from the following parameters:

- t_{ATRP} , where another AT follows the current AT which is not sent by the same slave;
- t_{ATAT} , where another AT follows the current AT which is sent by the same slave;
- t_{ATMT} , where the MDT follows the AT.

These defined time parameters are shown in Figure 22.

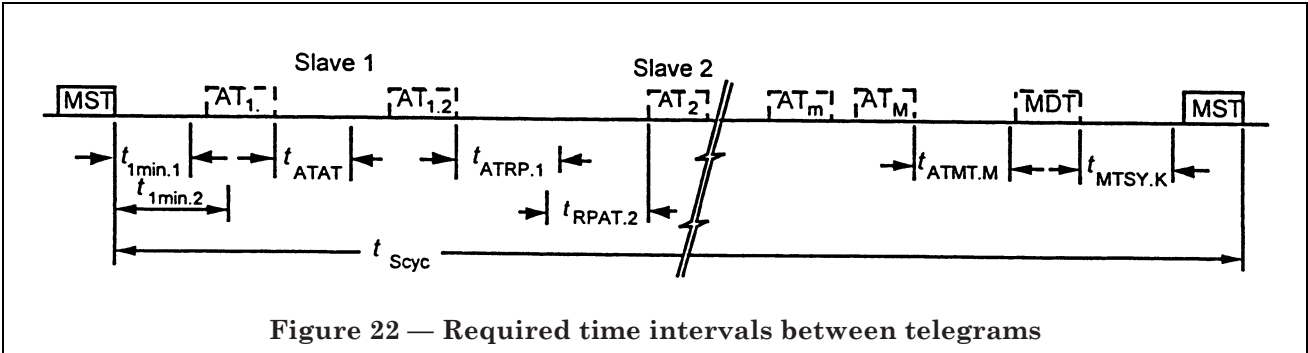


Figure 22 — Required time intervals between telegrams

6.3.2.2 Parameters for handling command and feedback values

The MST not only controls the access to the ring but also assists in orienting the processing within the drives. Designs are possible in which the drives can provide feedback values for the control unit. These values shall be captured in all affected drives simultaneously. The capture point indicated by t_4 referenced to the end of the MST is stored in the drives as an IDN. The drives already have a default time interval t_5 stored as an IDN. This time interval indicates the minimum amount of time needed between the capture point t_4 and the end of the next MST, to allow the drive to proceed the captured feedback value for the following AT.

t_3 has been defined as another parameter. This parameter indicates after which time interval, counting from the end of the MST, the drive is allowed to access the new command values transmitted in the MDT. Therefore, for drives which work in coordination, the same time point can be determined for command value validity. The master stores t_3 as an IDN in the drives. In order to determine t_3 , the parameter t_{MTSG} (command value proceeding time) has to be stored in the drives as an IDN. This parameter describes the minimum time required by the slave to proceed the new command value(s) for the drive(s) after the MDT. Figure 23 illustrates these time intervals.

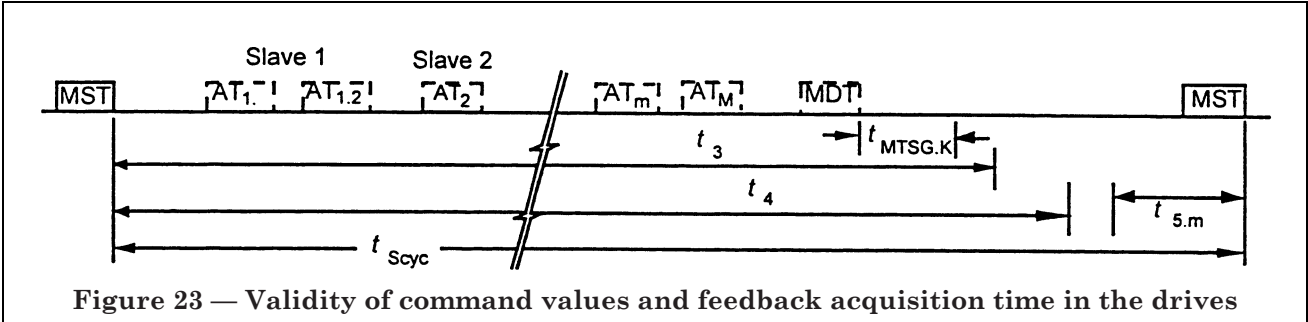


Figure 23 — Validity of command values and feedback acquisition time in the drives

7 Protocol structure

7.1 General

In this clause, the data exchange between the master and the slaves and vice versa is described. The data exchange in the SYSTEM interface consists of the transmission of operation data and procedure commands. All operation data and procedure commands are assigned to an IDN. Every IDN has an associated data block which consists of several elements.