EtherCAT Modular Device Profile

Part 6220: IO-Link Master

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ABBREVIATIONS

µC	Microcontroller
C	Conditional
CMD	Command
CoE	CANopen over EtherCAT
DC	Distributed Clock
DPRAM	Dual-Ported RAM
ENI	EtherCAT Network Information (EtherCAT XML Master Configuration)
EoE	Ethernet over EtherCAT
ESC	EtherCAT Slave Controller
ESI	EtherCAT Slave Information (EtherCAT Devices Description)
ESM	EtherCAT State Machine
ETG	EtherCAT Technology Group
FMMU	Fieldbus Memory Management Unit
FoE	File Access over EtherCAT
FPMR	Configured Address Physical Read Multiple Write
FPRD	Configured Address Physical Read
FPRW	Configured Address Physical ReadWrite
FPWR	Configured Address Physical Write
I/O	Input/Output
IDN	Identification Number (Servo Profile Identifier)
IEC	International Electrotechnical Commission
INT	Integer
IRQ	Interrupt Request
LRD	Logical Read
LRW	Logical ReadWrite
LSB	Least Significant Bit
LWR	Logical Write
M	Mandatory
MAC	Media Access Controller
MI	(PHY) Management Interface
MII	Media Independent Interface
MSB	Most Significant Bit
NIC	Network Interface Card
NOP	No Operation
ns	nanoseconds (10^{-9} seconds)
O	Optional
OD	Object Dictionary
OS	Oversampling
PDO	Process Data Object
PreOp	Pre-Operational
RD	Read
SDO	Service Data Object
SM	SyncManager
SoE	Servo Profile over EtherCAT
SOF	Start of Frame
SPI	Serial Peripheral Interface
SU	Sync Unit
WD	Watchdog
WKC	Working Counter
WR	Write
XML	eXtensible Markup Language

1 Scope

1.1 General

The Modular Device Profile (MDP) defines a modeling of structures within in a device. Mainly the object dictionary structure and corresponding behaviour of the entries is defined by the MDP. The intention is to provide an easy way for master and configuration tools to handle the devices.

A modular structure can be used for all kind of devices that supports physical or logical modules. This can be for example:

- Gateways from Fieldbuses to EtherCAT
- Extendable bus coupler with an internal backbone (e.g. sliced I/Os)
- Multi Axis servo drives (physical modules) with each axis having independent operation modes (logic modules)

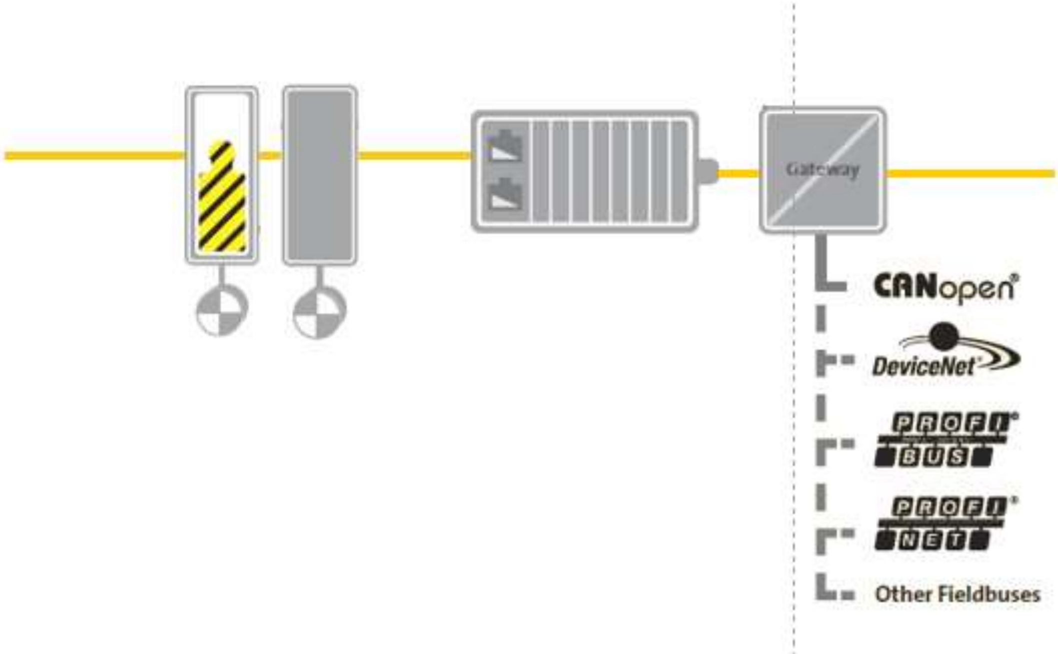

Figure 1: Example of MDP devices

The Device Description for Devices according to the MDP Profile is defined in [7].

2 References

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

ETG Standards

[1] ETG.1000.2: Physical Layer service definition and protocol specification

[2] ETG.1000.3: Data Link Layer service definition

[3] ETG.1000.4: Data Link Layer protocol specification

[4] ETG.1000.5: Application Layer service definition

[5] ETG.1000.6: Application Layer protocol specification

[6] ETG.1020: EtherCAT Protocol Enhancements

[7] ETG.2000: EtherCAT Slave Information

[8] ETG.2100: EtherCAT Network Information

[9] ETG.5001.1: Modular Device Profile – Part 1: General MDP Device Model

[10] ETG.5001.4: Modular Device Profile – Part 4: MDP Safety Module Specification

Other References

[11] IEC 61158-x-12 (all parts for type 12): Industrial communication networks – Fieldbus specifications

[12] IEC 61784-2: Industrial communication networks – Profiles – Part 2: Additional fieldbus profiles for real-time networks based on ISO/IEC 8802-3

3 Terms, Definitions and Word Usage

3.1 Terms and Definitions

The terms and definitions of ETG.1000 series shall be fully valid, unless otherwise stated.

3.2 Word usage: shall, should, may, can

The word *shall* is used to indicate mandatory requirements strictly to be followed in order to conform to the standard and from which no deviation is permitted (*shall* equals *is required to*).

The word *should* is used to indicate that among several possibilities one is recommended as particularly suitable, without mentioning or excluding others; or that a certain course of action is preferred but not necessarily required; or that (in the negative form) a certain course of action is deprecated but not prohibited (*should* equals *is recommended that*).

The word *may* is used to indicate a course of action permissible within the limits of the standard (*may* equals *is permitted to*).

The word *can* is used for statements of possibility and capability, whether material, physical, or causal (*can* equals *is able to*).

4 Functional Description

This part of the modular device profiles describes the fieldbus integration of IO-Link.

The IO-Link system defines the communication between sensors, actors and I/O devices which can be used as fieldbus devices in different fieldbus systems.

As shown in Figure 2 the IO-Link-Hub is a normal EtherCAT slave device within an EtherCAT segment. One or more IO-Link masters with IO-Link ports are used as gateways between EtherCAT and IO-Link.

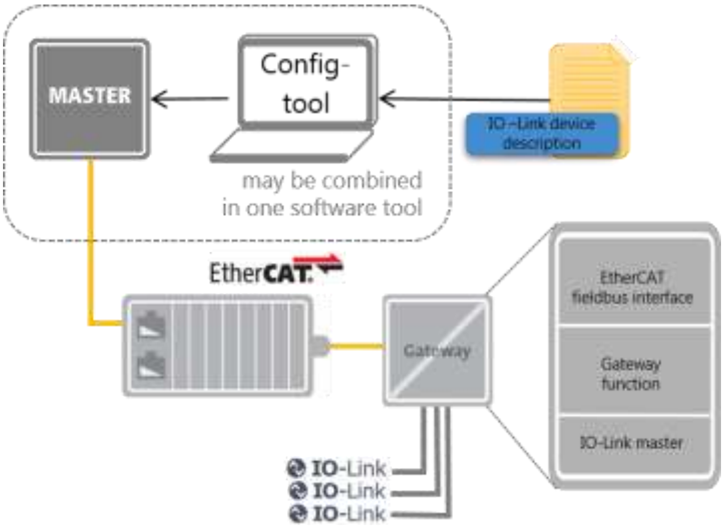

Figure 2: IO-Link Schematic configuration

The IO-Link Master gateway is based on the modular device profile (fieldbus gateway) with an object dictionary for each module (IO-Link Port respectively IO-Link Slave).

5 EtherCAT Communication Area

The objects in the EtherCAT Communication Area are defined in [5] and [6]. MDP specific content is defined in the document ETG.5001.1 ([9]) and following sub-clauses.

5.1 Diagnosis History (0x10F3)

To support enhanced IO-Link diagnosis information an IO-Link gateway should support the Diagnosis History object. The Diagnosis History is specified in [6].

6 Module Object Dictionary

The object dictionary of the device contains the following object areas as shown in Table 1: IO-Link Master Object Dictionary Structure.

Table 1: IO-Link Master Object Dictionary Structure

Index	Object Dictionary Area
0x0000…0x0FFF	Data Type Area
0x1000…0x1FFF	Communication Area
0x6000…0x6FFF	Input Area (TxPDOs of the IO-Link slaves)
0x7000…0x7FFF	Output Area (RxPDOs of the IO-Link slaves)
0x8000…0x8FFF	Configuration Area (Expected configuration of the IO-Link slaves)
0x9000…0x9FFF	Information Area (Detected configuration of the IO-Link slaves)
0xA000…0xAFFF	Diagnosis Data
0xF000…0xFFFF	Device Area

The index offset for each module (IO-Link slave) is 0x10.
E.g. 0x6000 for the first IO-Link slave

0x6010 for the second IO-Link slave

6.1 Input Data (0x6nnx)

The Input Data of the IO-Link master represent the TxPDOs of the IO-Link Slaves. Input Data is mandatory for an IO-Link Master if IO-Link slaves with TxPDOs are connected. The TxPDO data of an IO Link slave can either be defined as an OCTET-STRING (Table 2) or detailed (Table 3). The entry name in the table and slave implementation may differ.

Table 2: IO-Link Master Object 0x6nn0…0x6nn1: Input Data (OCTET-STRING)

Index	Subindex	Name	Data Type	Use	Access	Description / Value
0x6000	1	TxPDO 001	OCTET-STRING	C	RO	Represents TxPDO of the first IO-Link Slave Port0
	2 .. 255		*reserved*			

Table 3: IO-Link Master Object 0x6nn0…0x6nn1: Input Data (Detailed)

Index	Subindex	Name	Data Type	Use	Access	Description / Value
0x6000	1	TxPDO 001	Datatype first TxPDO	C	RO	Represents the first TxPDO of the first IO-Link Slave Port0
	2	TxPDO 002	Datatype second TxPDO	C	RO	Represents the second TxPDO of the first IO-Link Slave Port0
	3 .. 255					

6.2 Output Data (0x7nnx)

The Output Data of the IO-Link master represent the RxPDOs of the IO-Link Slaves. Output Data is mandatory for an IO-Link Master if IO-Link slaves with RxPDOs are connected. The RxPDO data of an IO Link slave can either be defined as an OCTET-STRING (Table 4) or detailed (Table 5). The entry name in the table and slave implementation may differ.

Table 4: IO-Link Master Object 0x7nn0…0x7nn1: Output Data (OCTET-STRING)

Index	Subindex	Name	Data Type	Use	Access	Description / Value
0x7000	1	RxPDO 001	OCTET-STRING	C	RO/RW	Represents RxPDO of the first IO-Link Slave Port0
	2 .. 255	*reserved*				

Table 5: IO-Link Master Object 0x7nn0…0x7nn1: Output Data (Detailed)

Index	Subindex	Name	Data Type	Use	Access	Description / Value
0x7000	1	RxPDO 001	Datatype first RxPDO	C	RO	Represents the first RxPDO of the first IO-Link Slave Port0
	2	RxPDO 002	Datatype second RxPDO	C	RO	Represents the second RxPDO of the first IO-Link Slave Port0
	3 .. 255					

6.3 Configuration Data of the Modules (0x8nnx)

During startup the EtherCAT master should write all configuration data for the IO-Link master in state transition from PREOP to SAFEOP. This is done by writing the objects 0x8nn0 of the EtherCAT slave device. To get the entry values the EtherCAT Configuration Tool can make use the IO-Link device description file (IODD) and/or user inputs.

Table 6: Configuration Data (0x8nn0)

Attribute	Value/Description
Index	0x8nn0
Name	Configuration Data
ObjectCode	RECORD
Use	M
SDO Access	If complete access is supported this object shall be accessible with complete access and optional entries shall either be supported or defined as a padding entries.

Table 7: Entries of Configuration Data (0x8nn0)

Sub-Index	Description	Data Type	Access	Use	Description/ DefaultValue
4	Device ID	UNSIGNED32	RW	M	Device ID of the IO-Link device. This unique IO-Link Device ID is allocated by the vendor The backup flag shall be set The setting flag shall be set
5	Vendor ID	UNSIGNED32	RW	M	Vendor ID of the IO-Link device This unique IO-Link Vendor ID is given by the IO-Link consortium. The backup flag shall be set The setting flag shall be set

Sub-Index	Description	Data Type	Access	Use	Description/ DefaultValue
32	IO-Link Revision	UNSIGNED8	RW	M	Version of the implemented IO-Link specification According to version 1.0 of IO-Link specification Bit 0…3: Minor Rev Bit4…7: Major Rev The backup flag shall be set The setting flag shall be set
33	Frame Capability	UNSIGNED8	RW	O	Information about implemented options in relation to frames and physical configuration of an IO-Link device, e.g. SPDU supported. According to version 1.0 of IO-Link specification Bit 0: SPDU Bit 1: Type1 Bit 2…6: reserved Bit 7: PHY1 The backup flag shall be set The setting flag shall be set
34	Cycle Time	UNSIGNED8	RW	O	Cycle time given to the IO-Link Master The IO-Link Master sends all data to the IO-Link device according to this configured cycle time. This value is transmitted in IO-Link format as "Min Cycle Time". This is a performance feature of the device and it is determined by its device function. According to version 1.0 of IO-Link specification Bit 0…5: Multiplier Bit 6..7: Time Base See also Appendix A The backup flag shall be set The setting flag shall be set

Sub-Index	Description	Data Type	Access	Use	Description/ DefaultValue
35	Offset Time	UNSIGNED8	RW	O	Time between start of cycle and point in time when process data is processed on the device. This value is transmitted in IO-Link format as "Offset Time". According to version 1.0 of IO-Link specification Bit 0…5: Multiplier Bit 6..7: Time Base See also Appendix A The backup flag shall be set The setting flag shall be set
36	Process Data In Length	UNSIGNED8	RW	M	Number and structure of input data This value is transmitted in IO-Link format as "Process Data In" According to version 1.0 of IO-Link specification Bit 0…4: Length Bit 5: reserved Bit 6: SIO Indictor, if device supports standard IO mode Bit 7: Byte Indicator, if value of length is interpreted as bit-length or as byte-length +1 The backup flag shall be set The setting flag shall be set
37	Process Data Out Length	UNSIGNED8	RW	M	Number and structure of output data This value is transmitted in IO-Link format as "Process Data Out" According to version 1.0 of IO-Link specification Bit 0…4: Length Bit 5: reserved Bit 6: SIO Indictor, if device supports standard IO mode Bit 7: Byte Indicator, if value of length is interpreted as bit-length or as byte-length +1 The backup flag shall be set The setting flag shall be set

Sub-Index	Description	Data Type	Access	Use	Description/ DefaultValue
38	Compatible ID	UNSIGNED16	RW	O	Ensure proper communication of an IO-Link device with older versions. This has to be defined in the IO-Link specification The backup flag shall be set The setting flag shall be set
39	reserved for future use	UNSIGNED16	RW	O	
40	Master Control	UNSIGNED16	RW	M	Control of the IO-Link master port and defines the different operating modes of the IO-Link master. Bits 0..3 0: Inactive 1: Digital Input Port 2: Digital Output Port 3: Communication over IO-Link Protocol 4: Communication over IO-Link Protocol. IO-Link State = CompStop (no cyclic communication, data exchange on demand Bits 4..15 2: DataStorage active 4: DataStorage disable upload The backup flag shall be set The setting flag shall be set

NOTE: In former slave implementations the entry “Cycle Time” may also be “Min Cycle Time”.

Examples for SDO Info and ESI file name values:
0x8000 => “IO Settings CH1” or “Config Data Module 1”

0x8010 => “IO Setting CH2” or “Config Data Module 2”

The Master Control (subindex 40) can be changed through the state of the EtherCAT slave internally, but the settings of the Master Control persist. If the EtherCAT state is not OP, then a modified Master Control will be send to the IO-Link Master. Table 8 shows the effects of the different EtherCAT states on the Master Control and the corresponding Master Command. Please refer to chapter 9 for details about the EtherCAT state machine.

Table 8: IO-Link Master Modified Master Controls

EtherCAT State	Master Control	Action	Master Command
INIT	0	-	-
PREOP	3 or 4	Master Control will be changed to "1", otherwise Master Control is unchanged	-

EtherCAT State	Master Control	Action	Master Command
SAFEOP	3 or 4	Write MasterCommand, otherwise Master Control is unchanged	0x99 (invalid output data)
OP	3 or 4	Write MasterCommand, otherwise Master Control is unchanged	0x98 (valid output data)

Table 9: Serial number (0x8nn1)

Attribute	Value/Description
Index	0x8nn1
Name	Serial number
ObjectCode	VARIABLE
Data Type	VISIBLE_STRING
Access	RW
Use	O

Examples for SDO Info and ESI file name values:
0x8001 => "IO Settings SerialNr Ch.1" or "Serial number Module 1"

0x8011 => "IO Settings SerialNr Ch.2" or "Serial number Module 2"

6.4 Information Data of the Modules (0x9nnx)

The object area 0x9nn0 contains all actual data. During startup of an IO-Link device this object shall be filled with data and is available for acyclic communication of EtherCAT. These parameters are neither backup objects nor setting objects. The format of all parameter is equal to the object area 0x8nn0 (see also 6.3).

Table 10: Information Data (0x9nn0)

Attribute	Value/Description
Index	0x9nn0
Name	Information Data
ObjectCode	RECORD
Use	M

Table 11: Entries of Information Data (0x9nn0)

Sub-Index	Description	Data Type	Access	Use	Description/ DefaultValue
4	Device ID	UNSIGNED32	R	M	see 0x8000.4

Sub-Index	Description	Data Type	Access	Use	Description/ DefaultValue
5	Vendor ID	UNSIGNED32	R	M	see 0x8000.5
32	IO-Link Revision	UNSIGNED8	R	M	see 0x8000.32
33	Frame Capability	UNSIGNED8	R	O	see 0x8000.33
34	Cycle Time	UNSIGNED8	R	O	see 0x8000.34
35	Offset Time	UNSIGNED8	R	O	see 0x8000.35
36	Process Data In Length	UNSIGNED8	R	M	see 0x8000.36
37	Process Data Out Length	UNSIGNED8	R	M	see 0x8000.37
38	reserved for future use	UNSIGNED16	R	O	
39	reserved for future use	UNSIGNED16	R	O	

NOTE: In former slave implementations the entry “Cycle Time” may also be “Min Cycle Time”.

Examples for SDO Info and ESI file name values:
0x9000 => “IO Info data CH1” or “Information Data Module 1”

0x9010 => “IO Info data CH2” or “Information Data Module 2”

Table 12: Serial number (0x9nn1)

Attribute	Value/Description
Index	0x9nn1
Name	Serial number
ObjectCode	VARIABLE
Data Type	VISIBLE_STRING
Access	R
Use	O

Examples for SDO Info and ESI file name values:

0x9001 => “IO Settings SerialNr Ch.1” or “Serial number Module 1”

0x9011 => “IO Settings SerialNr Ch.2” or “Serial number Module 2”

6.5 Diagnostic Data of the Modules (0xAnnx)

The Diagnosis Data specify the actual "IO-Link State" and "Lost Frames" counter of each IO-Link port.

Table 13: Diagnosis Data (0xAnn0)

Attribute	Value/Description
Index	0xAnn0
Name	Diagnosis Data
ObjectCode	RECORD
Use	O

Table 14: Entries of Diagnosis Data (0xAnn0)

Sub-Index	Description	Data Type	Access	Use	Description/ DefaultValue
1	IO-Link State	UNSIGNED8	R	O	State of the IO-Link Master (statemachine of IO-Link Port)
2	Lost Frames	UNSIGNED8	RW	M	Counter of lost IO-Link telegrams. Reset counter during startup. The entry may be writeable to reset the entry value.

Examples for SDO Info and ESI file name values:
0xA000 => “IO Diag data CH1” or “Diagnosis Data Module 1”

0xA010 => “IO Diag data CH2” or “Diagnosis Data Module 2”

7 Object Areas of the Device

7.1 Object 0xF100: Status Data

The status data object contains one entry for each IO-Link port status. This entry is divided into two nibbles. The lower part of the nibble contains the actual status of the Master Control. The higher part of the nibble contains an error code only when an error occurred.

This object is available for acyclic access. Additionally the object can be mapped into the input process data and transferred via process data.

Table 15: Device Status (0xF100)

Attribute	Value/Description
Index	0xF100
Name	Device Status
Use	M

Table 16: Entries of Device Status (0xF100)

Sub-Index	Description	Data Type	Access	Use	Description/ DefaultValue
1 ... 255	*not defined*	UNSIGNED8	R	C	[Mandatory if Module Si# matches profile] Status of IO-Link port n (n represents the Subindex/Module position) Bit 0…3 IO-Link State 0: Port Inactive 1: Siomode Digital In 2: Siomode Digital Out 3: Communication OP 4: Communication STOP Bit 4…7 ErrorCode 00: No Error 1: Watchdog Error 2: Buffer Overflow 3: Invalid Device ID 4: Invalid Vendo ID 5: Invalid IO-Link Revision 6: Invalid Frame Capability 7: Invalid Cycle Time 8: Invalid Length processdata In 9: Invalid Length processdata Out 10: No Device deteced 11: Error PreOP

8 Process data configuration

The PDO index increment per module (IO-Link slave) is 0x01.
E.g. 0x1600 : RxPDO for the first IO-Link slave

0x1601 : RxPDO for the second IO-Link slave

8.1 RxPDO Mapping (0x16nn)

For each IO-Link Slave one RxPDO Mapping object is reserved.

8.2 TxPDO Mapping (0x1Ann)

For each IO-Link Slave one TxPDO Mapping object is reserved.

The Status Data of all IO-Link Ports (object 0xF100) are mapped to object 0x1A80 as shown in Table 17.

Table 17: IO-Link Master Object 0x1A80: TxPDO Mapping of Status Data

Index	Subindex	Name	Data Type	Description / Value
0x1A80	1	Subindex 001	UINT32	Status Data of 1st IO-Link Slave Value : 0xF1000108
	2	Subindex 002	UINT32	Status Data of 2nd IO-Link Slave Value : 0xF1000208
	…			

The IO-Link Status Data mapping is optional for IO-Link Master.

NOTE: For legacy IO-Link Master it is also possible to use object 0x1A04 to Map “TxPDO Mapping of Status Data” if not more than 4 Ports are supported. This object could also be assigned at the beginning of process data.

9 EtherCAT State Machine

Table 18 describes the behavior of an IO-Link Gateway according to the EtherCAT states. Table 19 describes the IO-Link master action according to the EtherCAT states.

Table 18: EtherCAT state behavior for the modular devices

EtherCAT State	Behavior / Allowed Operations
INIT	Connected to the internal bus
PRE-OP	Connected to the internal bus Optional: download the expected modules configuration Optional: download of PDO Mapping Optional: download of PDO Assign Acyclic access to modules with CoE and AoE
SAFE-OP	Cyclic data transfer with modules Outputs are in the safe state Acyclic access to modules with CoE and AoE
OP	Cyclic data transfer with modules Outputs have process values Acyclic access to modules with CoE and AoE

Table 19: EtherCAT state and IO-Link Master Action

EtherCAT State	IO-Link Master Action
INIT	All IO-Link ports deactivated
PRE-OP	Download process data mapping Download IO-Link master configuration IO-Link ports in safe state Optional: Acyclic IO-Link communication may possible
SAFE-OP	Set IO-Link ports to configured mode Configuration of startup of IO-Link devices, output data invalid (MasterCommand: 0x99) Verification of target configuration with actual configuration Acyclic and cyclic communication possible, if configured
OP	Set IO-Link ports to configured mode Configuration of startup of IO-Link devices, output data valid (MasterCommand: 0x98) Acyclic and cyclic communication possible, if configured

10 Mailbox

The IO-Link Master should support the AoE services to have acyclic access to the IO-Link slaves. AoE (instead of CoE) is used because every IO-Link slave has a full independent object dictionary.

Each EtherCAT device gets an AMS NetID and a port for communication from the master. The AMS NetId is for communication with the EtherCAT slave only, not the IO-Link master. Therefore a second AMS NetId is generated by the EtherCAT master and for IO-Link communication only. The whole area of the ports, the IndexGroups and IndexOffsets of the Ads Telegram are available for the IO-Link Master.

Each IO-Link port obtains a port number beginning with 0x1000, e.g. IO-Link port 1 = portnumber 1001 and IO-Link port n = port number 1000+n.

IndexGroup 0xF302 is being used.

The IndexOffset shall be 32 Bit and is coded in the following syntax: 16 Bit Index, 8 Bit 0, 8 Bit Subindex.

The error code (32 Bit) consists of two parts:

- LoWord (16 Bit); contains error code. Error codes are generated by the IO-Link master and uses the error codes of the ADS communication.
- HiWord (16 Bit); contains additional info of the error code. Standard entry is "ads device error (0x0700)". If an IO-Link device sends "Index not available" (code 0x8011), then the following error code shall occur: 0x80110700.

11 Synchronization

No special synchronization requirements are needed.

Appendix A: Examples

Example for the Cycle Time calculation (0x8nn0.34)

Table 20 shows some calculation examples for Cycle Time (subindex 34). Usually the cycle time is equal to the minimum cycle time of the IO-Link device.

Table 20: IO-Link Cycle Time Calculation

Time Base	Meaning for Time Base	Calculation	Minimum Cycle Time
00b	0.100 ms	Multiplier * Time Base	0.000 ... 6.300 ms
01b	0.400 ms	6.400 ms + Multiplier * Time Base	6.400 ... 31.600 ms
10b	1.600 ms	32.000 ms + Multiplier * Time Base	32.000 ... 132.800 ms
11b	6.400 ms	134.400 ms + Multiplier * Time Base	134.000 ... 537.600 ms

Table 21 shows the Offset Time (subindex 35) calculation.

Table 21: IO-Link Offset Time Calculation

Time Base	Meaning for Time Base	Calculation	Minimum Cycle Time
00b	0.010 ms	Multiplier * Time Base	0.010 ... 0.630 ms
01b	0.040 ms	0.640 ms + Multiplier * Time Base	0.640 ... 3.160 ms
10b	0.640 ms	3.200 ms + Multiplier * Time Base	3.200 ... 43.520 ms
11b	10.240 ms	44.160 ms + Multiplier * Time Base	44.160 ... 689.208 ms