IO-Link Safety Integration into FSCP

Exemplary integration into FSCP-3 (IEC 61784-3-3)

White Paper

Draft Version 0.9.0
February 2019

Order No: 10.102

File name: **IOL-Safety_IntegrationIntoFSCP_10102_V10_Feb19.doc**

This specification has been prepared by the IO-Link Safety technology subgroup. This version incorporates now the Standardized Master Interface (SMI) and created minor changes to the SPDU format.

Any comments, proposals, requests on this document are appreciated through the IO-Link CR database www.io-link-projects.com. Please provide name and email address.
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Important notes:

NOTE 1 The IO-Link Community Rules shall be observed prior to the development and marketing of IO-Link products. The document can be downloaded from the www.io-link.com portal.

NOTE 2 Any IO-Link device shall provide an associated IODD file. Easy access to the file and potential updates shall be possible. It is the responsibility of the IO-Link device manufacturer to test the IODD file with the help of the IODD-Checker tool available per download from www.io-link.com.

NOTE 3 Any IO-Link devices shall provide an associated manufacturer declaration on the conformity of the device with this specification, its related IODD, and test documents, available per download from www.io-link.com.

Conventions:

In this specification the following key words (in **bold** text) will be used:
may: indicates flexibility of choice with no implied preference.
should: indicates flexibility of choice with a strongly preferred implementation.
shall: indicates a mandatory requirement. Designers **shall** implement such mandatory requirements to ensure interoperability and to claim conformity with this specification.

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0 Introduction

0.1 Functional safety applications

So far, many functional safety applications are still using basic electromechanical equipment such as E-Stop buttons or switches and relays connected to functional safety input and output modules in remote I/O that are communicating with functional safety PLCs. Thus, digitalization is already realized within the safety world, but not for the "last" meter.

On the other hand, new applications such as autonomous systems like automated guided vehicles and manufacturing cells as well as service or collaborative robotics in industries (Cobots) show an increasing demand for example in

- new sensor technologies (e.g. Radar, Lidar, distance, strain, torque, stress);
- new kind of sensor functions (e.g. classification of objects, position of an object);
- combination of different sensor technologies in one sensor system.

IO-Link and IO-Link Safety provide the necessary technologies to meet the requirements of such use cases in an elegant and cheap manner.

0.2 IO-Link Safety

The base technology of IO-Link™ [1] is subject matter of the international standard IEC 61131-9 (see [1]). The IO-Link Safety specification describes a conceptual model for functional safe communication across IO-Link communication serving as "black channel" together with the necessary infrastructure for parameterization of the safety communication layer and the technology of FS-Devices using IODD safety extensions and dedicated tools.

The IO-Link Safety specification has been developed by a working group with engineers of renowned companies within the IO-Link Community, which in turn is an independent subdivision of the legal entity PROFIBUS Nutzerorganisation e.V.

It describes a simple and efficient functional safety communication for safety sensors, actuators, and mechatronic components requiring safety input and output data. Unshielded flexible cables with signal and power supply lines allow for smallest size solutions.

0.3 Functional Safety Communication Profiles (FSCP)

IEC 61158 specifies many fieldbus solutions for industrial automation all over the world. In the meantime, quite a number of them provide functional safety communication profiles (FSCP) running on top of those fieldbuses. They are standardized within the IEC 61784-3 series.

The IO-Link Safety solution is a point-to-point communication solution and not designed for a particular fieldbus. It requires individual integration into these FSCPs if requested. This document covers integration into CPF3 and FSCP-3.

0.4 Patents

Patents in [5], [2], and [3] apply.

1 Objectives and management summary

1.1 IO-Link (Safety) integration into CPF3/FSCP-3

Figure 1 shows the entire IO-Link system environment for CPF3 and FSCP-3. The new Standardized Master Interface (SMI) on top of the FS-Master simplifies the integration effort and illustrates the "Black Channel" approach of IO-Link Safety. Only a few non-safety related modifications of the standard Master are building the basis for the integration into CPF3 and FSCP-3 (see [3]):

[1] IO-Link™ is a trade name of the "IO-Link Community". This information is given for the convenience of users of this specification and does not constitute an endorsement by the IO-Link Community of the trade name holder or any of its products. Compliance to this standard does not require use of the registered logos for IO-Link™. Use of the registered logos for IO-Link™ requires permission of the "IO-Link Community".

- Detection of the READY pulse prior to the Wake-up, and
- Splitter / Composer of the process data message (safety / non-safety).

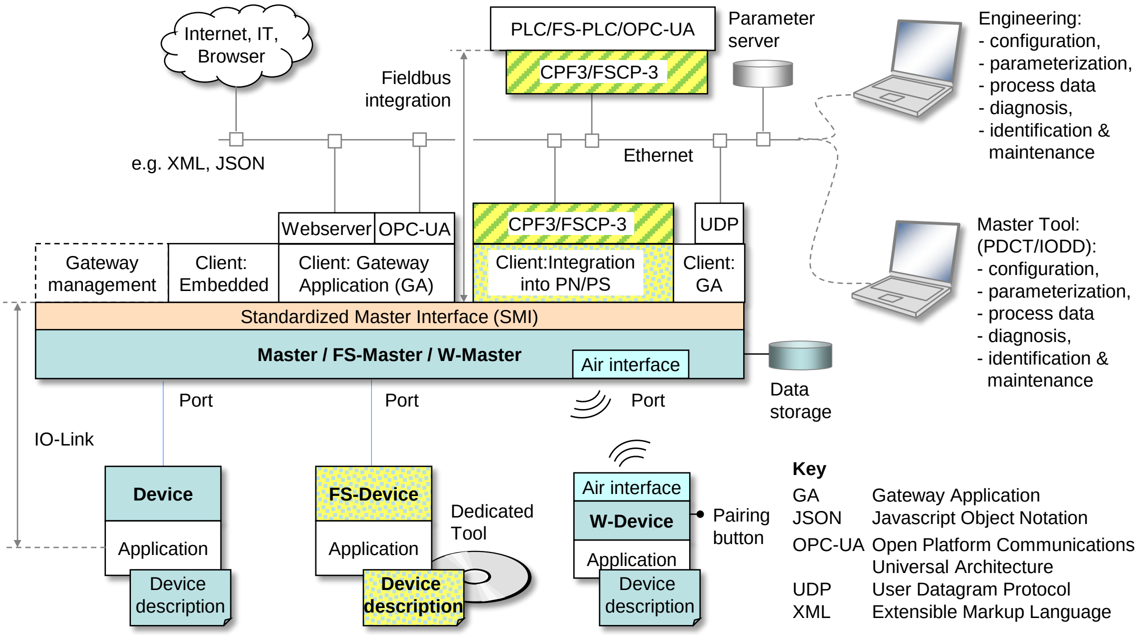

Figure 1 – IO-Link (Safety) integration into CPF3/FSCP-3

IO-Link Safety integration is based on definitions in clause 5.2 of [4] and thus uses the Linking Module concept type "B" as specified in clause 3 within this document.

Version 1.1 of IO-Link Safety is only suitable for wired Port communication.

Content of this document follows the structure of clause 6 "Model of the Linking Module" and clause 7 "Mapping Application" in [4].

In case of FS-Master with Port capability "OSSDe", a separate "FS-DI"-unit is required within the gateway layer (see Figure 2).

1.2 Gateway from IO-Link Safety to FSCP-3

Figure 2 illustrates via the yellow marked fields, how the Mapping Application layer in [4] is extended by the safety-related integration parts "FSCP-3 driver", "FS-IO mapping", "IO-Link Safety driver", and the optional "FS-DI driver" for support of safety devices using the OSSDe interface.

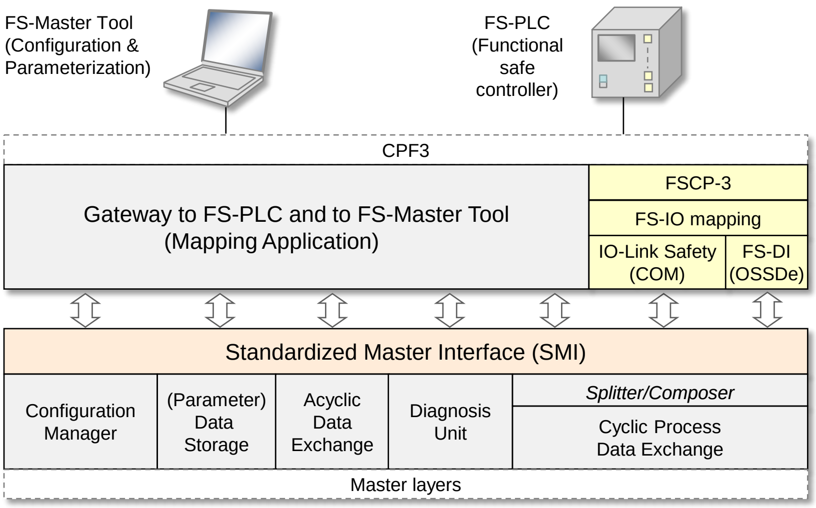

Figure 2 – Gateway from IO-Link Safety to FSCP-3

NOTE It should be noted that the above mentioned safety-related parts do not represent a complete stack for implementation. In order to perform an IO-Link Safety protocol test, a so-called Upper Tester layer shall be considered for the design according to [6].

Four different FS-IO mapping configurations for FS-Masters are possible and specified in this document (see 4.4):

- Non-safety operations (FS-Master Port with standard Device);
- IO-Link Safety communication with FS-Device (submodule passivation);
- IO-Link Safety communication with FS-IO-Hub (channel specific passivation);
- FS-DI operation (channel specific passivation).

1.3 Uniform basic system behavior

It was one of the intentions of the new Standadized Master Interface within the

- "IO-Link Interface and System" specification [2],
- "IO-Link Safety – System Extensions with SMI" specification [3], and
- "IO-Link Integration for CPF3" specification, Edition 2, dV1.1 [4]

to achieve a higher degree of uniform basic system behavior and to provide means for the integration of IO-Link Safety allowing for safety assessments already early at specification stage for all projects and not at the implementation stage. This will reduce effort and time.

"Basic" means a specified level of functionality all FS-Master and CPF3/FSCP-3-Gateway systems shall provide. There is room for manufacturers/vendors beyond this common level for individual features to meet customer requirements.

1.4 Reference model for other integrations

It is an objective for IO-Link Safety to achieve a worldwide acceptance in automation. Thus, it is obvious that integrations into other fieldbuses and FSCPs are essential. This document is meant to be a design guideline for CPF3/FSCP-3 integration designers and to be a reference model for designers of integration documents for other fieldbuses and FSCPs.

1.5 Responsibilities

1.5.1 Organizations

It is the responsibility of PNO to take care of an efficient and correct integration concept, especially through the IO-Link integration working group and the FSCP-3 working group. The IO-Link integration working group takes the lead of the necessary activities. It is planned to transfer most of the content of this document to Annex A in [4].

It is the responsibility of the IO-Link Community to consider efficient integratability and to provide the necessary support.

1.5.2 Assessment

It is the joint responsibility of the FSCP-3 working group and the IO-Link Safety working group to arrange for a concept assessment of this document by an assessment body. Corresponding activities are funded by PNO.

2 Status of safety layers

2.1 FSCP-3

Basis for the designs in this document is the "FSCP-3" specification in [5]. FSCP-3 driver stacks are available from several vendors (see www.profibus.com).

2.2 IO-Link Safety with SMI

Basis for the designs in this document is the "IO-Link Safety" specification in [3]. IO-Link Safety driver stacks are available from different vendors (see www.io-link.com).

3 Extensions of the "Linking module" model

3.1 System requirements of IO-Link Safety

Figure 3 illustrates the components and technologies involved in this integration project.

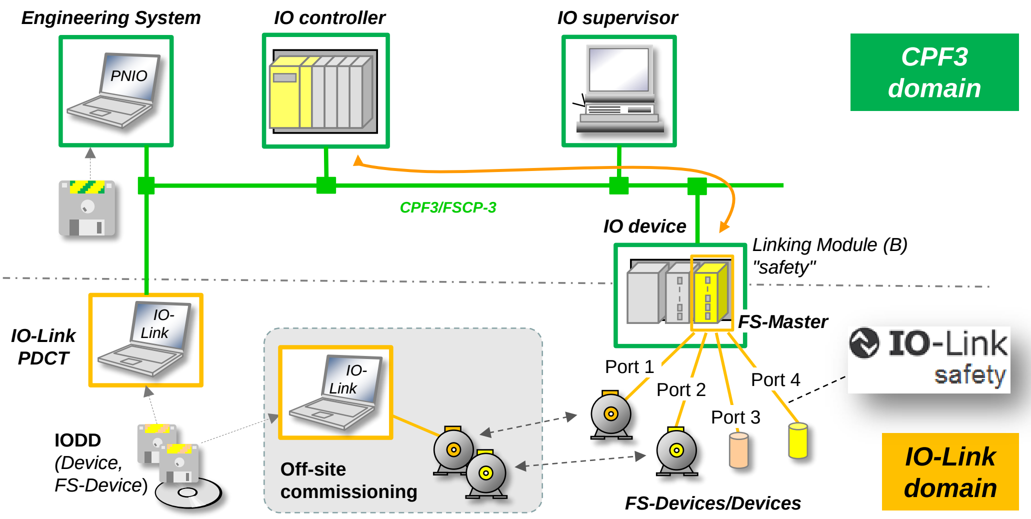

Figure 3 – System overview

The CPF3 domain comprises safety IO controller supporting FSCP-3 communications and engineering systems using GSD for safety IO devices. A particular class of IO devices are safety Linking Modules (B) that build "links" (gateway) to the IO-Link Safety system consisting of FS-Master and FS-Devices as well as non-safety Devices.

Thus, IO-Link Safety provides mixed messages with a Safety PDU (SPDU) as first transmitted part and an attached non-safety related IO data part. For example in case of a received message, a splitter cares for separation of the two parts and storage of the SPDU within an "FSInBuffer" and the non-safety data within the "InBuffer" as shown in Figure 4 and already specified in [3].

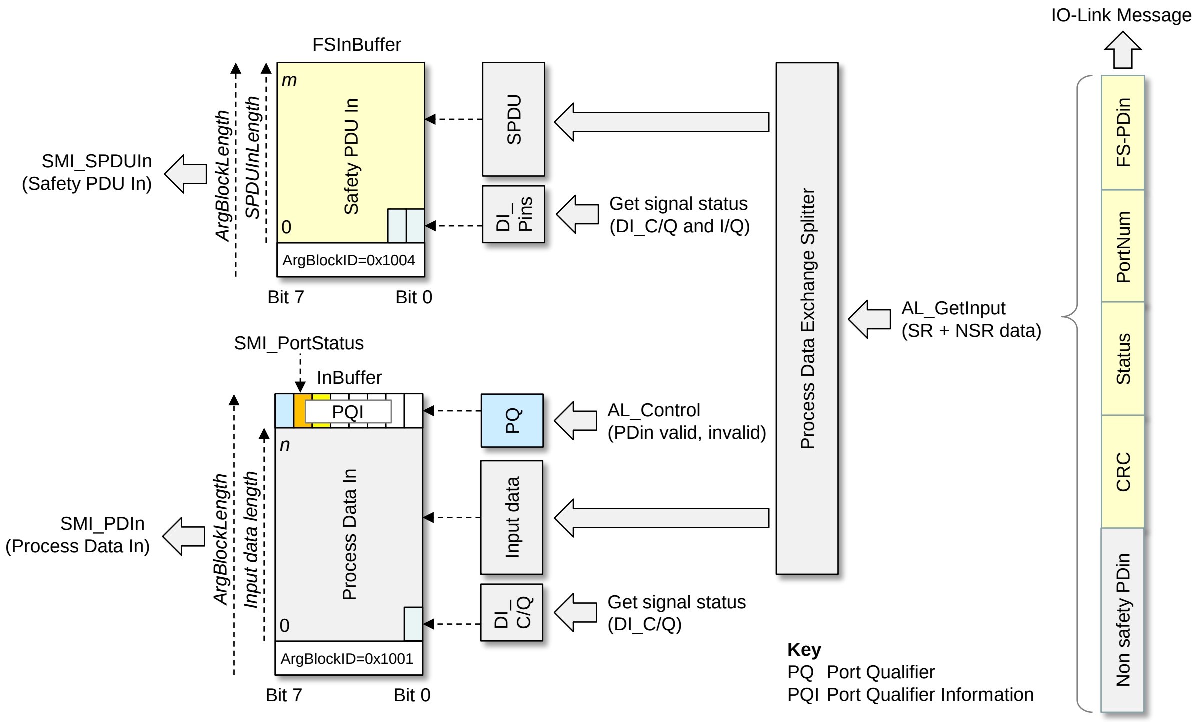

Figure 4 – InBuffer and FSInBuffer

Additional SMI services and extended ArgBlocks for existing SMI services such as for Port configuration are defined for IO-Link Safety to care for these augmented features (see [2] for details).

3.2 Linking Module (B) for IO-Link Safety

The basic "Linking Module (A)" concept is specified in [4]. The "Linking Module (B)" concept encapsulates the entire IO-Link safety-related (SR) and non safety-related (NSR) data objects and functions of an IO-Link FS-Master system into one CPF3 slot but not in one subslot.

As a consequence, this means for the top level concept:

- The entire IO-Link FS-Master system shall be mapped into one slot k with k = 1 to 32767.
- The FS-Master itself shall be mapped into two appropriate IOLM proxy submodules, one in subslot x of slot k as defined in [4] and a second one in subslot x+1 for single bit FS-signals + Qualifiers such as from Ports with single bit Inputs or OSSDe operation.
- The FS-Devices shall be mapped each into two appropriate IOLD proxy submodules, one in subslot x+2, x+4, and etc. of slot k as defined in [4] and a second one in subslot x+3, x+5, and etc. for safety PDin and safety PDout.

Figure 4 demonstrates the mapping of IO-Link Safety system data objects and functions into CPF3 slot and subslots. Each IOLM/IOLD proxy can have up to two submodules.

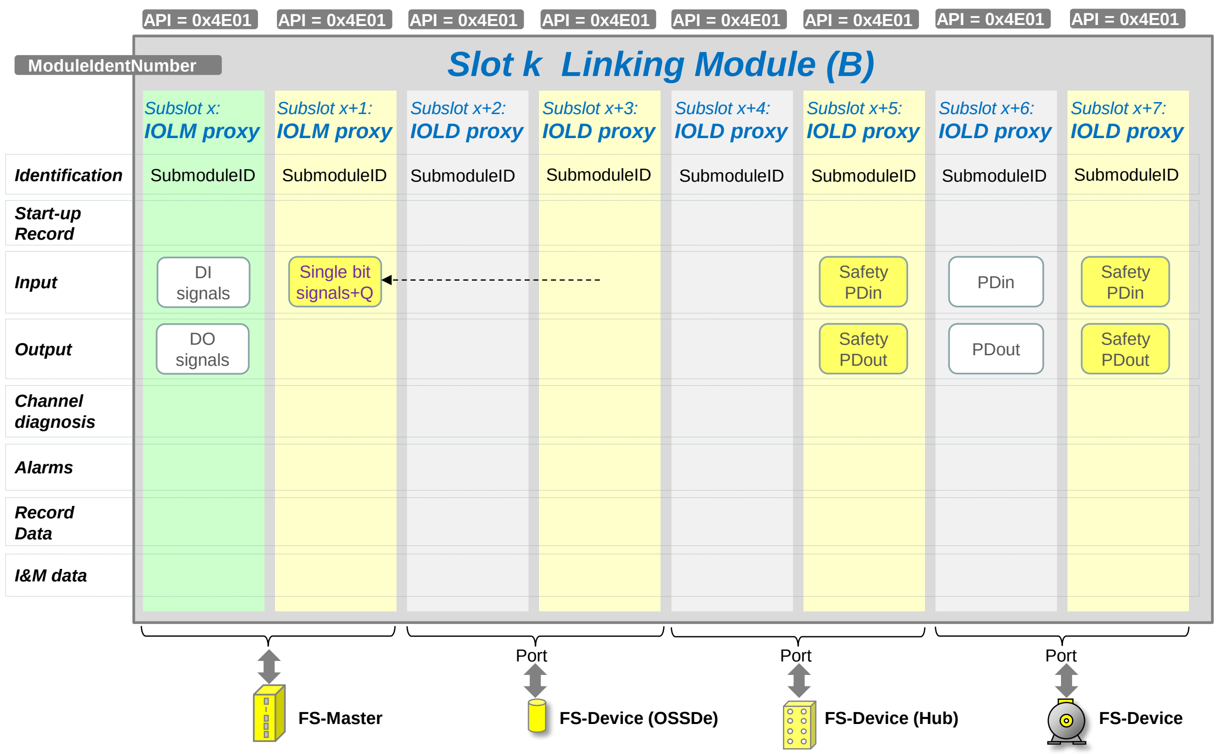

Figure 5 – Linking Module (B) for IO-Link Safety

In general, the rules in [4] apply. Additional or modified rules apply for Linking Modules (B):

- It is manufacturer's/vendor's responsibility to assign subslots. However, it is recommended to start with subslot "x" and "x+1" for the IOLM proxies followed by *n* subslots representing the IO-Link Ports.
- The IOLM proxy "x" represents the FS-Master functionality and the access point of the PDCT interface as defined in [4].
- The IOLM proxy "x+1" represents all single safety signal bits from Ports with OSSDe support ("FS-DI") or safety communication. These signals together with Qualifier bits are mapped to one FSCP-3 instance with its unique Codename (message) in a fixed order: signal bit 1 to Port 1, signal bit "*p*" to Port "*p*". Rules for Qualifiers are specified in 4.5.

- The IOLD submodules in slots x+2, x+4, and etc. represent the proxy for the FS-Device/ Device and NSR IO data are mapped as defined in [4].
- The IOLD submodules in slots x+3, x+5, and etc. represent the proxy for the safety part of an FS-Device. SR IO data are mapped to one FSCP-3 instance with its unique Codename (message).

Clause 7 in [4] provides more details of the individual CPF3 aspects such as identification, input/output data, channel diagnosis, alarms, start-up, and I&M.

3.3 Classification and identification

VendorID, DeviceID, ModuleIdentNumber, and SubmoduleIdentNumber are used for the identification of Linking Modules. All of them are manufacturer/vendor specific as defined in [4]. However, recommendations exist for the classification of IOLM and IOLD proxies with identical characteristics of IO data structures, diagnosis, and start-up parameters.

Table 1 shows the coding for functional safety Devices with mapping to FSCP-3.

Table 1 – SubmoduleIdentNumbers for IOLD_proxy (Safety)

SubmoduleIdentNumber	Coding	IOLD proxy submodule
Octet 2,3	0x5000 to 0x5FFF	Tools shall display the following groups within their Device libraries: ♦ IOL FS-Proxies (COM) ♦ IOL FS-Proxies (1 In)
Octet 1	0x00 to 0x20	Output length of IOLD proxy Submodule (0 to 32 octets)
	0x81	Reserved
	All other	Reserved
Octet 0	0x00 to 0x21	Input length of IOLD proxy Submodule (0 to 33 octets)
	0x81	Digital Input (FS-DI)
	All other	Reserved

3.4 IOLM proxy (safety)

Features of the basic IOLM proxy are defined in clause 6.4 of [4]. The IOLM safety proxy provides an extended catalog display to the user (see Figure 11):

- Collection of Ports with single bit safety signals via OSSD or safety COM.

Mapping method is illustrated in Figure 11.

3.5 IOLD proxy (safety)

Features of the basic IOLD proxy are defined in clause 6.5 of [4]. The IOLD safety proxy provides an extended catalog display to the user (see Figure 9):

- Ports with safety IO data > 1 single bit.

Mapping method is illustrated in Figure 9.

3.6 Start-up record (GSD parameter)

3.6.1 FSCP-3 F-Parameter

The F-Parameters of the (safety) Linking Module (B) are layed down in its GSD file. It contains also possible F-IO data structure containers for the mapping of IO-Link Safety IO data. A designer is responsible for the coding according to the rules specified in [5].

3.6.2 IO-Link Safety Port configuration

A Dedicated Tool is required for the configuration and parameterization of FS-Master and FS-Device. Thus, GSD based support as provided in [4] for a non safety-related operation is not defined yet.

3.7 Port configuration

3.7.1 Concept

IO-Link Safety integration follows the concept specified in [4]. Figure 6 shows the data paths within this concept.

The safety-related Submodules within the IOLM proxy and the IOLD proxy receive the FSCP-3 F-Parameters at start-up from the IO-Controller. The FSCP-3 specification in [5] describes the F-IO data structure within the GSD and secures this description by the F-Parameter "F_IO_StructureDescCRC". The GSD for the "Linking Module" shall provide a number of reasonable F-IO container ("FS_Struct*x*", see Figure 9 and Figure 11) the user can chose from.

Due to the restrictions mentioned in 3.6.2, Port configuration (safety) via GSD and start-up from IO controller ① is not possible or not yet defined.

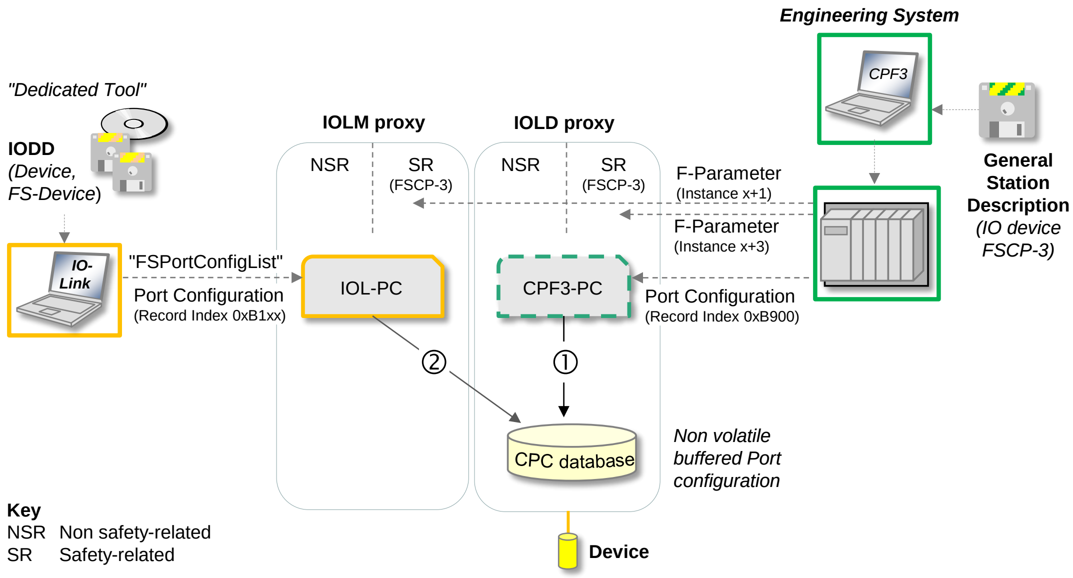

Figure 6 – Restricted Port configuration paths for safety

3.7.2 CPF3 Port configuration (PN-PC)

The parameter "PortConfigurationMode" shall be set to "Tool based configuration" within the PN-PC record to prevent from further activities.

3.7.3 IO-Link tool based Port configuration (IOL-PC)

The SMI service "SMI_PortConfiguration" uses ArgBlockID 0x8001 for FS-Masters and the definitions in clause 10.3.3 of [2]. Table 2 shows the corresponding "FSPortConfigList" adapted to FSCP-3.

Table 2 – FSPortConfigList for FSCP-3 mapping

Off set	Element name	Definition	Data type	Range
0	ArgBlockID	0x8001	Unsigned16	–
2	PortMode	This element contains the port mode expected by the SMI client, e.g. gateway application. All modes are mandatory. They shall be mapped to the Target Modes of "SM_SetPortConfig" (see 9.2.2.2 in [2]) 0: DEACTIVATED (SM: INACTIVE → Port is deactivated; input and output Process Data are "0"; Master shall not perform activities at this port) 1: IOL_MANUAL	Unsigned8 (enum)	0 to 255

Off set	Element name	Definition	Data type	Range
		(SM: CFGCOM → Target Mode based on user defined configuration including validation of RID, VID, DID) 2: IOL_AUTOSTART [a] (SM: AUTOCOM →Target Mode w/o configuration and w/o validation of VID/DID; RID gets highest revision the Master is supporting; Validation: NO_CHECK) 3: DI_C/Q (Pin4 at M12) [b] (SM: DI → Port in input mode SIO) 4: DO_ C/Q (Pin4 at M12) [b] (SM: DO → Port in output mode SIO) 5 to 48: Reserved for future versions 49: SAFETYCOM (implying IOL_MANUAL behavior) 50: MIXEDSAFETYCOM (implying IOL_MANUAL behavior) 51: OSSDE (Values in offset 15 to 36 are don't care; SPDUInLength in offset 38 = 1 octet; value in offset 39 is don't care) 52 to 96: Reserved for extensions such as Safety or Wireless) 97 to 255: Manufacturer specific		
3	Validation&Backup	This element contains the InspectionLevel to be performed by the Device and the Backup/Restore behavior. 0: No Device check 1: Type compatible Device V1.0 2: Type compatible Device V1.1 3: Type compatible Device V1.1, Backup + Restore 4: Type compatible Device V1.1, Restore 5 to 255: Reserved	Unsigned8	0 to 255
4	I/Q behavior (manufacturer or profile specific)	This element defines the behavior of the I/Q signal (Pin2 at M12 connector). 0: Not supported 1 to 4: Not permitted with FS-Master 5: Power 2 (Port Class B) 6 to 255: Reserved	Unsigned8	0 to 255
5	PortCycleTime	This element contains the port cycle time expected by the SMI client. Both modes are not mandatory. They shall be mapped to the ConfiguredCycleTime of "SM_SetPortConfig" (see 9.2.2.2 in [2]) 0: AFAP (As fast as possible – SM: FreeRunning → Port cycle timing is not restricted. Default value in port mode IOL_MANUAL) 1 to 255: TIME (SM: For coding see Table B.3 in [2]. Device shall achieve the indicated port cycle time. An error shall be created if this value is below MinCycleTime of the Device or in case of other misfits)	Unsigned8	0 to 255
6	VendorID	This element contains the 2 octets long VendorID expected by the SMI client (see [2])	Unsigned16	1 to 65535
8	DeviceID	This element contains the 3 octets long DeviceID expected by the SMI client (see [2])	Unsigned32	1 to 16777215
12	InputDataLength	This element contains in Bit 0 to 5 the total size	Unsigned8	0 to (32 – *m*)

Off set	Element name	Definition	Data type	Range
		(*n*) of the InBuffer required for the input Process Data of the Device (NSR data, see 10.5 in [3]). Size can be ≥ input Process Data length (see [2]). Bit 6 and 7 shall contain "0".		octets
13	OutputDataLength	This element contains in Bit 0 to 5 the size (*p*) of the OutBuffer required for the output Process Data of the Device (NSR data, see 10.5 in [3]). Size can be ≥ output Process Data length. Bit 6 and 7 shall contain "0".	Unsigned8	0 to (32 – *o)* octets
14	FSCP_Authenticity1	FSCP-3 Codename part1 (see [5])	Unsigned32	–
18	FSCP_Authenticity2	FSCP-3 Codename part2 (see [5])	Unsigned32	–
22	FSP_Port	Port number	Unsigned8	1 to 255
23	FSP_AuthentCRC	CRC signature across complete authentication	Unsigned16	–
25	FSP_ProtVersion	Version of the IO-Link Safety protocol	Unsigned8	1 to 255
26	FSP_ProtMode	IO-Link Safety protocol mode	Unsigned8	–
27	FSP_WatchdogTime	Watchdog time of FS-Master and FS-Device	Unsigned16	1 to 65535
29	FSP_IO_StructCRC	CRC signature across FS IO data description	Unsigned16	–
31	FSP_TechParCRC	CRC signature across technology parameter	Unsigned32	–
35	FSP_ProtParCRC	CRC signature across protocol parameter	Unsigned16	–
37	IO_DescVersion	Version of this generic structure description	Unsigned8	1
38	SPDUInLength	OSSDe data (1 octet) or length of incoming SPDU (*m*); see 10.5 and Table 4 in [3]	Unsigned8	1 or 5 to (32 – *n)* octets
39	TotalOfInBits	Set of input BooleanT (bits)	Unsigned8	0 to 255
40	TotalOfInOctets	Set of input BooleanT (octets, also partly filled)	Unsigned8	–
41	TotalOfInInt16	Input IntegerT(16)	Unsigned8	–
42	TotalOfInInt32	Input IntegerT(32)	Unsigned8	–
43	SPDUOutLength	Length of outgoing SPDU (*o*); see 10.5 and Table 4 in [3]	Unsigned8	5 to (32 – *p)* octets
44	TotalOfOutBits	Set of output BooleanT (bits)	Unsigned8	0 to 255
45	TotalOfOutOctets	Set of output BooleanT (octets, also partly filled)	Unsigned8	–
46	TotalOfOutInt16	Output IntegerT(16)	Unsigned8	–
47	TotalOfOutInt32	Output IntegerT(32)	Unsigned8	–

a In PortMode "IOL_Autostart" parameters VendorID, DeviceID, and Validation&Backup are treated don't care.

b In PortModes "DI_C/Q" and "DO_C/Q" all parameters are don't care except for "InputDataLength" and "Output DataLength".

3.8 Extended Port start-up

No modifications to [4] could be identified.

3.9 Exceptional operations

No modifications to [4] could be identified.

4 Mapping Application

4.1 General

Figure 7 shows the entire structure of the Linking Module.

In its upper part it contains the Slot, Subslot, IOLM and IOLD proxy structure as already shown in 3.2 and Figure 5. For simplicity reasons it is depicted without the safety Submodules.

A set of FAL services according to IEC 61158-6-10 within the CPF3 domain and a set of SMI services according to [2] are used for the center part of the Linking Module. This center part is called Mapping Application.

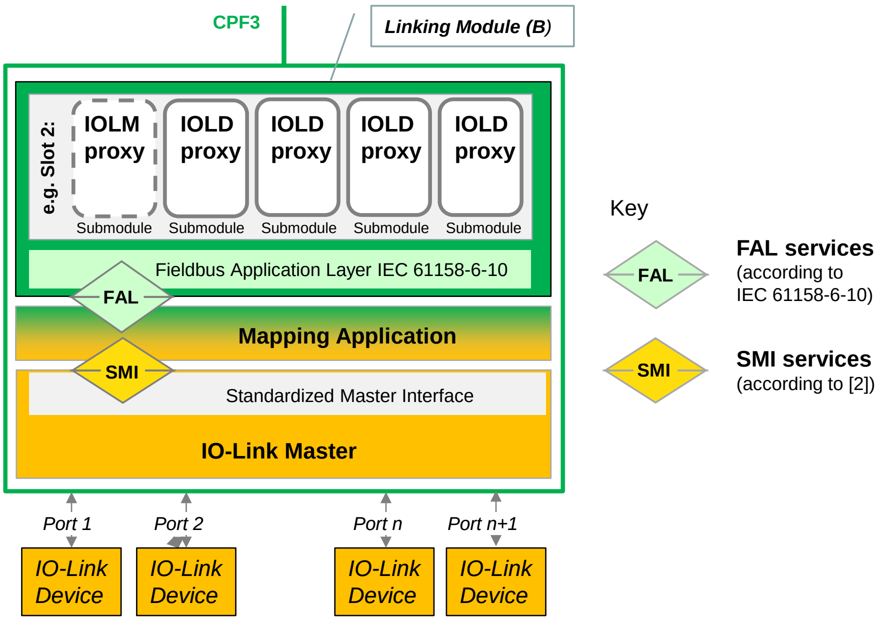

Figure 7 – Overview of entire Linking Module

Figure 8 shows the structure of the Mapping Application. It contains all the functions to be implemented for integration. The function "Port Suspend & Release" for FS-Master is reserved for future versions and will not be specified in this version of integration.

Boxes of functions that require modifications or extensions for IO-Link Safety are marked by blue colored lines. The functions of other boxes are specified in [4].

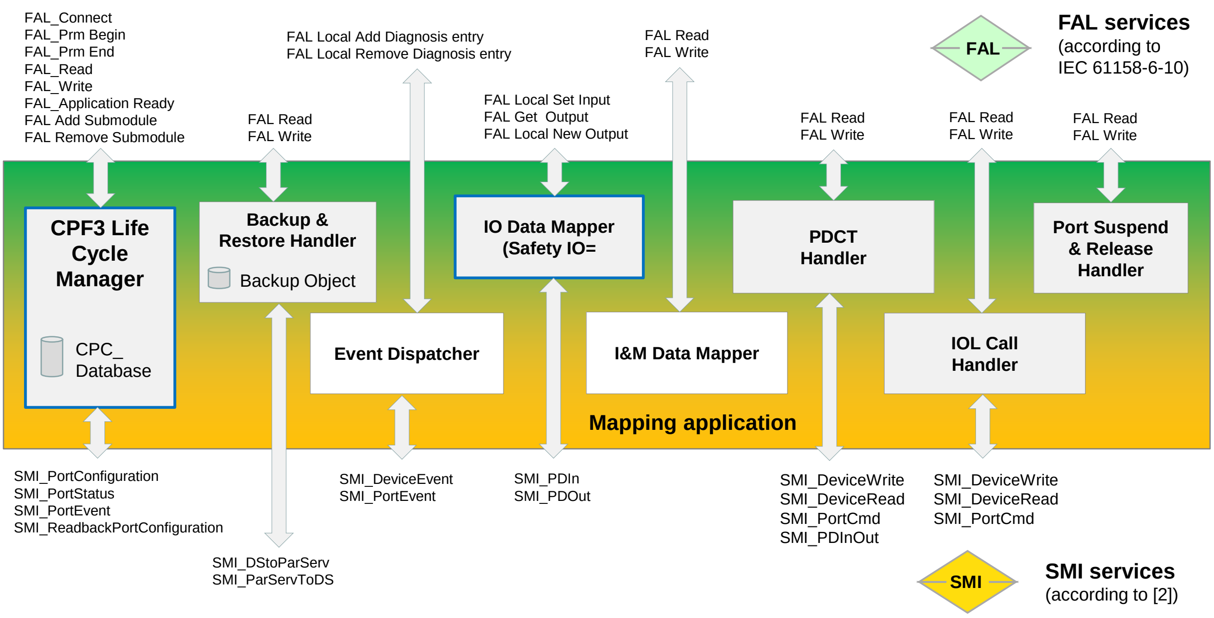

Figure 8 – Structure of the Mapping Application

4.2 CPF3 Life Cycle Manager

Basic extensions are described in 3.7, for example supplying safety-related proxies with FSCP-3 F-Parameters. Other modifications to [4] could not be identified.

4.3 Safety Process Data mapping

4.3.1 FSCP-3 Codename assignment

Each safety proxy such as IOLM proxy "x+1" and IOLD proxies "x+3", "x+5" to "x+*n*" are assigned to one FSCP-3 (driver) instance. It is the first FSCP-3 instance that shall be assigned a unique (Authenticity) Codename "CN" as specified in [5]. Subsequent FSCP-3 instancies shall be assigned "CN+1", "CN+2", and etc.

4.3.2 Multi FSCP-3 instance

Figure 9 shows the concept of multi FSCP-3 instance mapping where each port is directly mapped into a FSCP-3 message (instance). The Device catalog window of the Engineering Tool shows IOL FS-Proxies (COM) with a number of different IO data containers together with IOL FS-Data Structures. This information is derived from GSD data for this particular Linking Module.

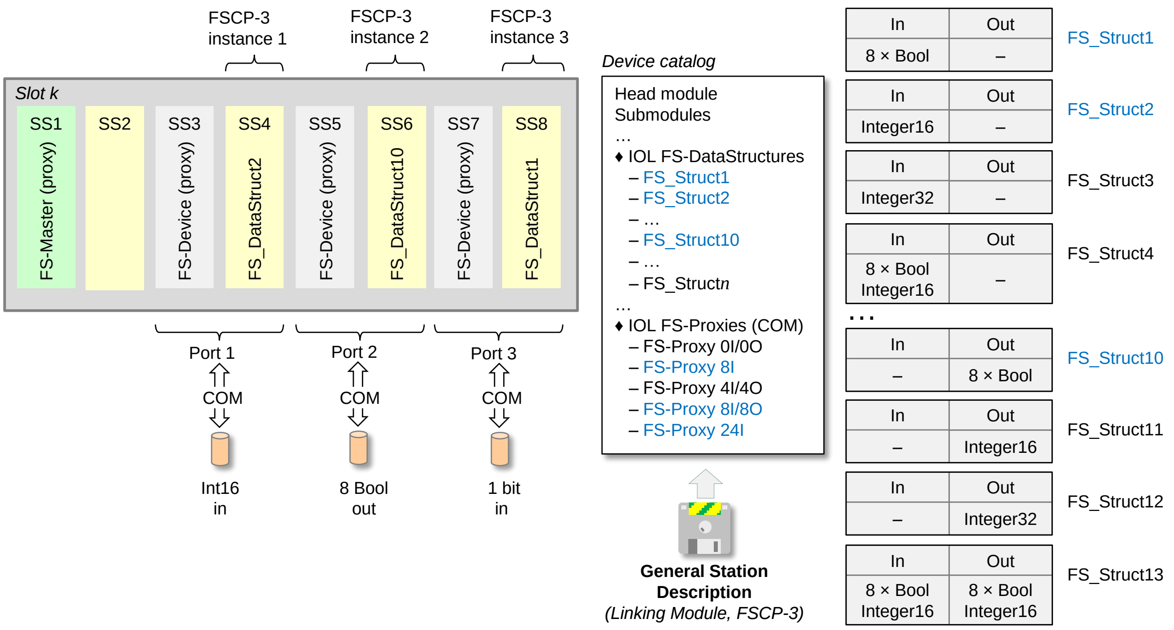

Figure 9 – Concept of multi FSCP-3 instance mapping

4.3.3 Single FSCP-3 instance

Figure 10 illustrates the motivation for single FSCP-3 instance mapping by means of the comparison with a classic FS-DI input module of a remote IO.

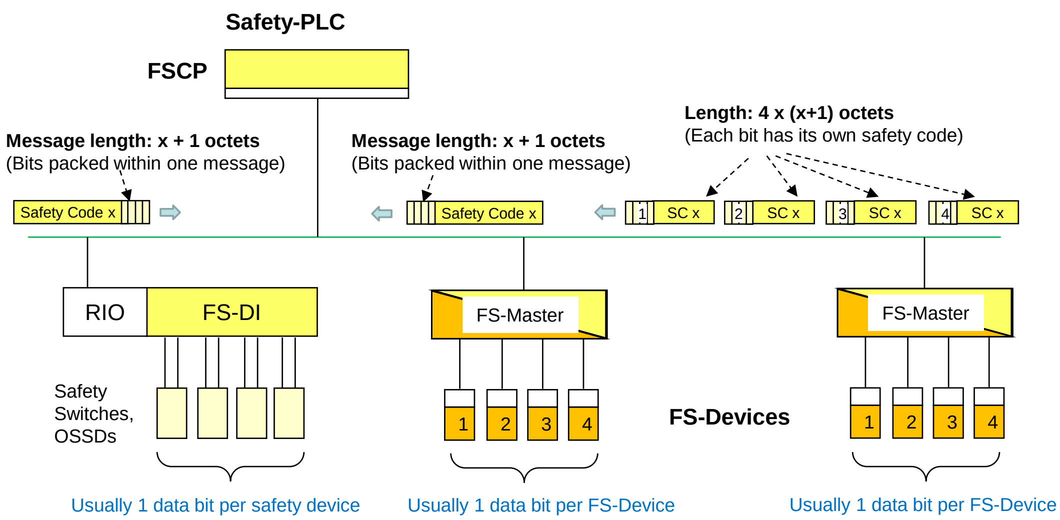

Figure 10 – Motivation for single FSCP-3 instance mapping

Figure 11 shows the concept of single FSCP-3 instance mapping where each port with single safety signals (BOOL) is mapped into one FSCP-3 message. Each bit position within the data structure corresponds to the Port number. Each bit is accompanied by a Qualifier bit. See 4.4.4 for details.

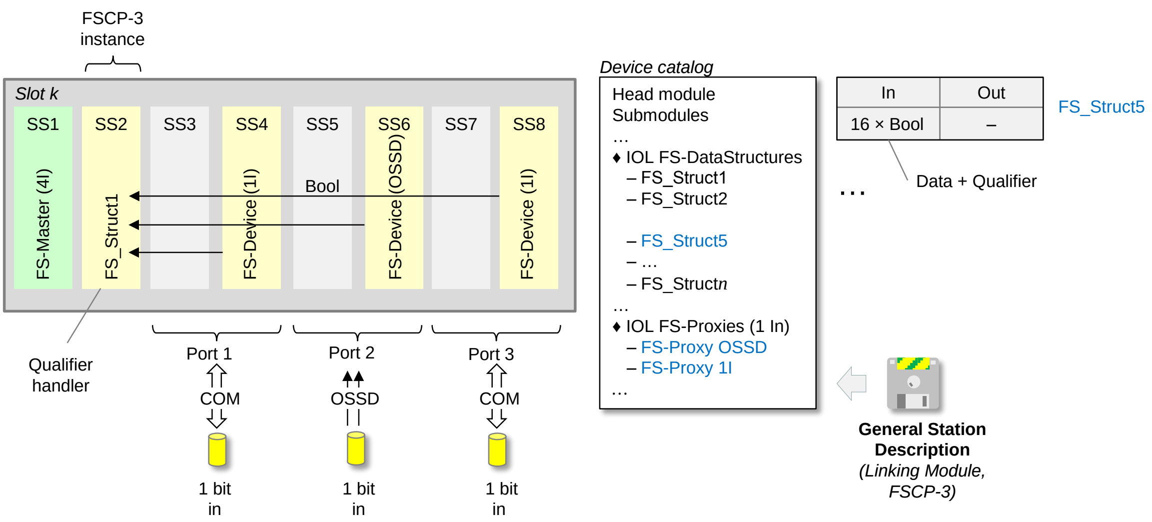

Figure 11 – Concept of single FSCP-3 instance mapping

An FS-Master can support either an FS-Device (safety) or Device (non-safety) at a port. "Non-safety" bits are mapped to the non-safety IOLM proxy submodule (see [4]).

4.3.4 Predefined FSCP-3 I/O data container (FS_Struct)

Figure 9 and Figure 11 show examples of FSCP-3 I/O data container (FS_Structs) manufacturers of Linking Module IO devices can provide within the associated GSD file. The final list of recommended FS_Structs will be defined by the IO-Link Safety and FSCP-3 working groups.

4.4 Mapping of Safety Communication Layers (SCL)

4.4.1 Overview

Two SCLs are involved in the mapping: the FSCP-3 SCL and the IO-Link Safety SCL as shown in Figure 12. See [5] for the service diagram of FSCP-3 (IOLD proxy) marked in orange color and [3] for that of IO-Link Safety marked in blue color.

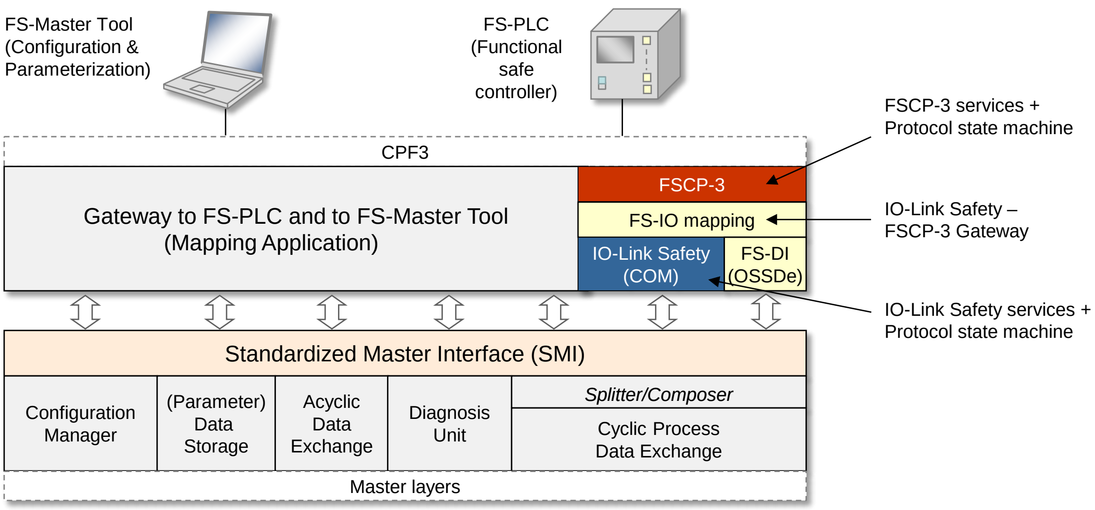

Figure 12 – Location of FSCP-3 and IO-Link Safety SCLs

Three kinds of mapping combinations of these SCLs have been identified: General FS-Device, HUB FS-Device, and OSSD FS-Device.

4.4.2 General FS-Device

Figure 13 illustrates the general SCL combination for FS-Devices in case of multi FSCP-3 instance mapping. Fault acknowledgment is performed on FSCP-3 level.

In this case, the Qualifier Handler is simply connecting the control and status signals of both SCLs. Any faults (FAULT_S) of the IO-Link Safety SCL driver are logical ORed with the SDset_S status signal.

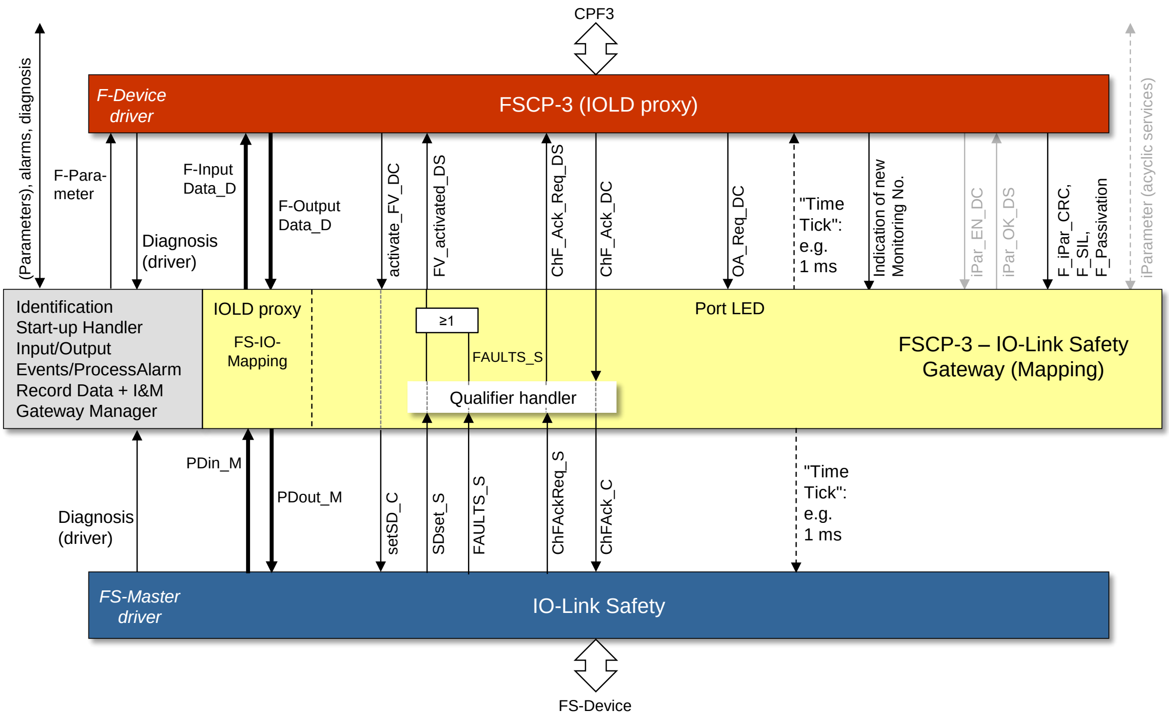

Figure 13 – General SCL combination for FS-Devices

4.4.3 HUB FS-Device

Figure 14 illustrates the SCL combination for HUB FS-Devices (multi FSCP-3 instance).

A HUB FS-Device is a terminal connected to an FS-Master Port using IO-Link Safety communication and which is acting like a remote FS-DI. Classic switching safety devices can be connected to this remote FS-DI using for example OSSD signals (see Figure 14 and its lower right corner).

The Safety HUB subfigure shows the principle architecture of such a terminal. The sensor signal is processed and mapped to the IO data of the IO-Link Safety SPDU ("D"). A "Test" unit examines the redundant input signals from the sensor for validity (e.g. wire brake) and sets a Qualifier bit ("Q") in case.

Both signal bits and Qualifier bits are transmitted as IO Data to the IOLD proxy of the Linking Module and directly mapped to FSCP-3 IO Data.

In this case, the Qualifier Handler within the FSCP-3 – IO-Link Safety Gateway is also simply connecting the control and status signals of both SCLs.

Any faults (FAULT_S) of the IO-Link Safety SCL driver are logical ORed with the SDset_S status signal.

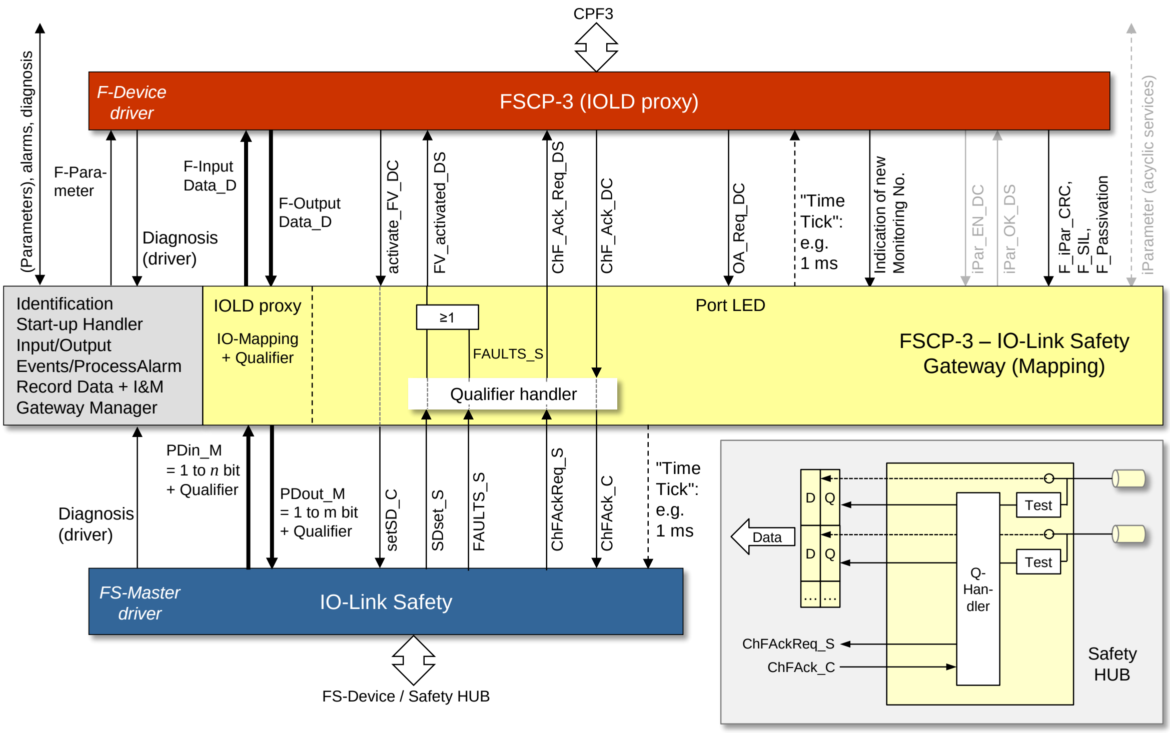

Figure 14 – SCL combination for HUB FS-Devices

4.4.4 OSSD FS-Device

Figure 15 illustrates the SCL combination for OSSD FS-Devices.

In this case the single safety signal bits are mapped to the IOLM proxy (single FSCP-3 instance) and the Qualifier handler is responsible for setting/resetting the Qualifier bits and for the acknowledegment as specified in [3].

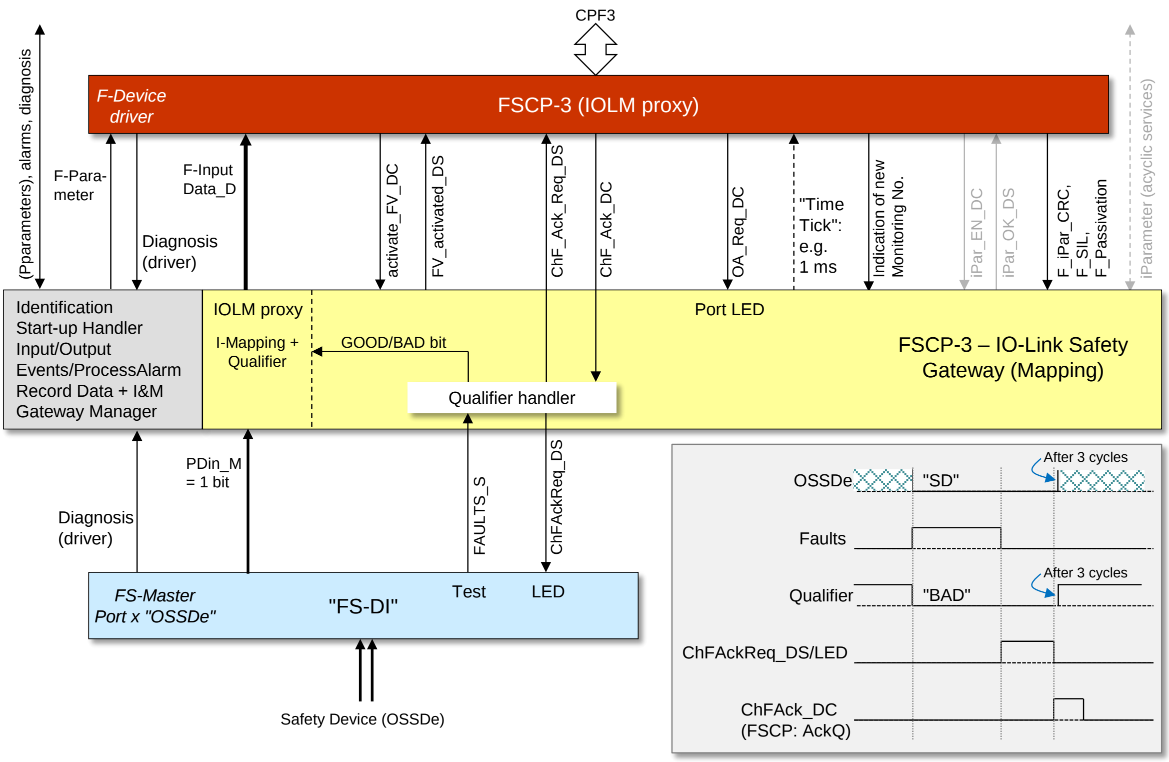

Figure 15 – SCL combination for OSSD FS-Devices

The behavior of the signals OSSDe, Faults, Qualifier, ChFAckReq_DS, and ChFAck_DC is demonstrated in Figure 15 within the lower right corner. This behavior is defined by the state machine in clause 11.11.5 of [3].

4.5 Qualifier

4.5.1 Motivation

Figure 16 illustrates, why Port specific passivation matters for industrial automation. In this Figure it is assumed for each Port to be connected to an emergency stop button that belongs to a particular safety function to stop the associated manufacturer cell with a robot. In this case this would mean 8 different and independent safety functions. If the FS-Master (in "FS-DI" mode) fails, the entire 8 safety functions will trip and a large area of production would stop even if only one Port is impacted, for example a wire break to the safety sensor.

Additional Port depended bits (called "Qualifier") associated with the input signals can be used to indicate for a certain class of faults the validity of this input signal. The user can extend the safety PLC program and thus determine the behavior of the safety function reaction individually.

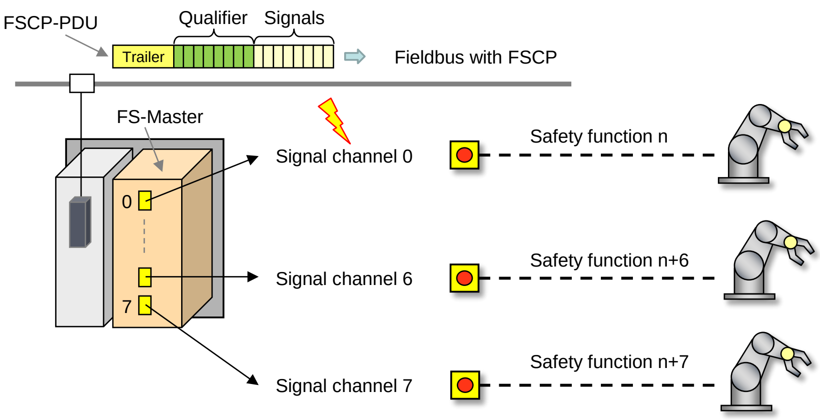

Figure 16 – FS-Master with Ports for several safety functions

4.5.2 Coding and overall acknowledgment mechanisms

Figure 17 shows examples on how the Qualifiers are arranged for different IO data structures. Details will be specified within the final document.

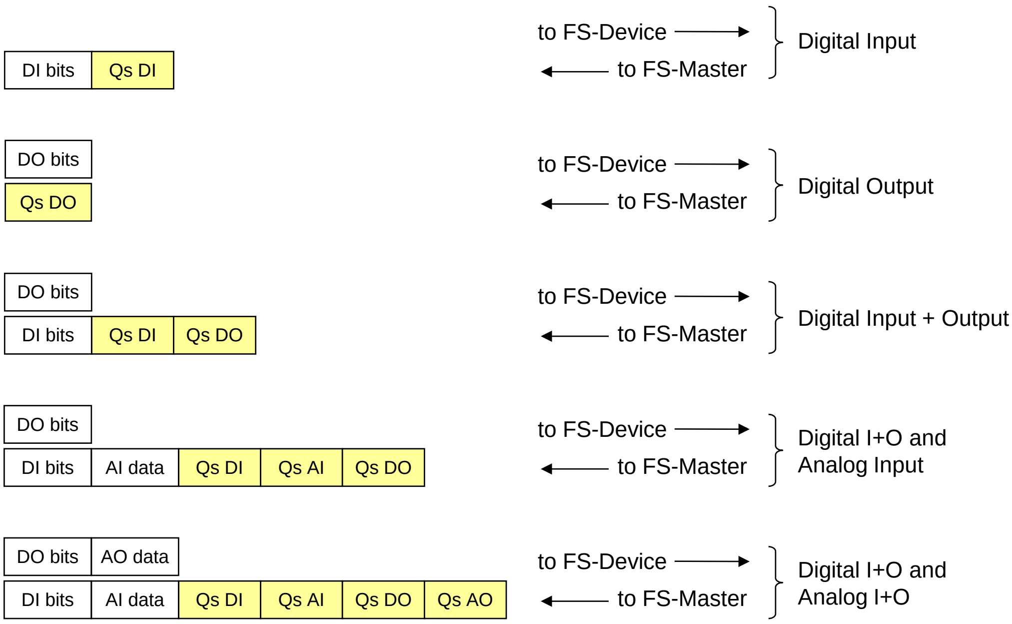

Figure 17 – Arrangement of Qualifiers for different IO data structures

Figure 18 shows where acknowledgment requests are set and acknowledgments are handled within a FSCP-3 communication system.

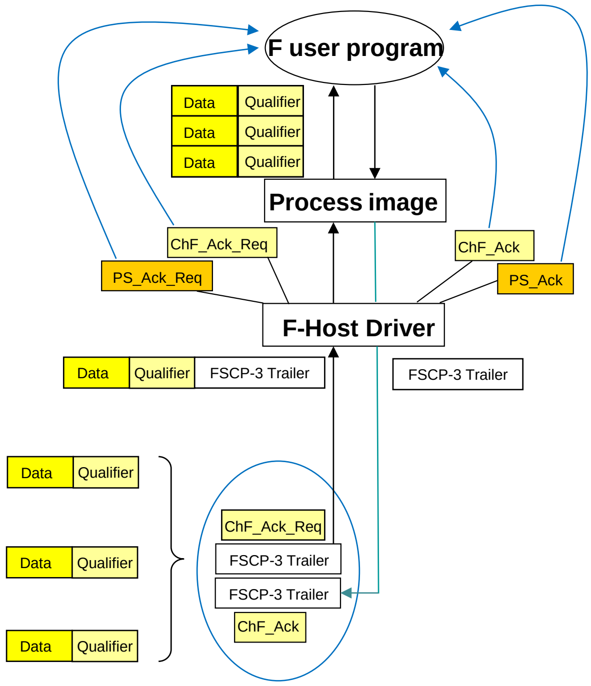

Figure 18 – Overall ChannelFault Acknowledgment

4.6 Timeliness (watchdog timer and mapping)

FSCP-3 and IO-Link Safety are both responsible for timeliness of their protocols. Thus, it is the responsibility of mapping concepts and implementations to guarantee latest data updates in time.

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[4] PI Specification, *IO-Link Integration for PROFINET – Edition 2*, Draft V1.1, February 25th 2019, WG distribution

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