

INTERNATIONAL STANDARD

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**Industrial communication networks – Profiles –
Part 3-2: Functional safety fieldbuses – Additional specifications for CPF 2**

**Réseaux de communication industriels – Profils –
Partie 3-2: Bus de terrain de sécurité fonctionnelle – Spécifications
supplémentaires pour CPF 2**



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International Standard IEC 61784-3-2 has been prepared by subcommittee 65C: Industrial networks, of IEC technical committee 65: Industrial process measurement, control and automation.

This second edition cancels and replaces the first edition published in 2007. This edition constitutes a technical revision. The main changes with respect to the previous edition are listed below:

- updates in relation with changes in IEC 61784-3;
- addition or modification of the following subclauses to support the Extended Format:
 - 6.3.2.1, 6.3.3.4, 6.3.11, 6.6.7.5, 6.8.5.13, 6.8.5.14, 7.1.1, 7.5.5, 7.6.10.10, 7.6.10.12, 8.2, 8.10.2.4.4, 9.5.2;
- modification of all pseudo code in 7.5 to support Extended Format;
- addition of Attribute 15 in 6.7.3.1;

- addition of subclauses 8.11, 8.12 and 8.13 to clarify requirements for CP 2/2, CP 2/3 and CP 16/3 respectively.

This bilingual version published in 2011-12, corresponds to the English version published in 2010-06.

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FDIS	Report on voting
65C/591A/FDIS	65C/603/RVD

Full information on the voting for the approval of this standard can be found in the report on voting indicated in the above table.

The French version of this standard has not been voted upon.

This publication has been drafted in accordance with the ISO/IEC Directives, Part 2.

A list of all parts of the IEC 61784-3 series, published under the general title *Industrial communication networks – Profiles – Functional safety fieldbuses*, can be found on the IEC website.

The committee has decided that the contents of this publication will remain unchanged until the stability date indicated on the IEC web site under "<http://webstore.iec.ch>" in the data related to the specific publication. At this date, the publication will be

- reconfirmed,
- withdrawn,
- replaced by a revised edition, or
- amended.

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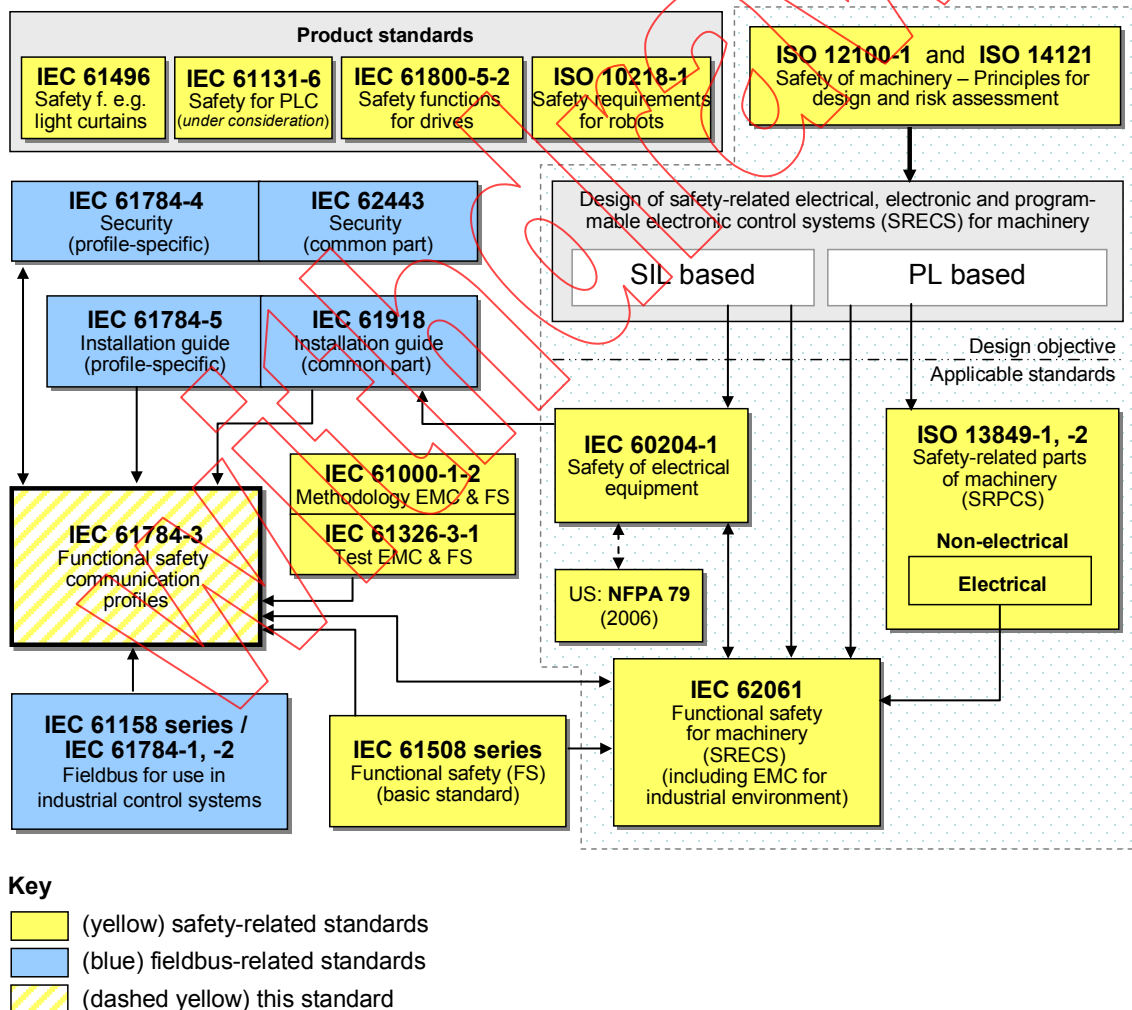
0 Introduction

0.1 General

The IEC 61158 fieldbus standard together with its companion standards IEC 61784-1 and IEC 61784-2 defines a set of communication protocols that enable distributed control of automation applications. Fieldbus technology is now considered well accepted and well proven. Thus many fieldbus enhancements are emerging, addressing not yet standardized areas such as real time, safety-related and security-related applications.

This standard explains the relevant principles for functional safety communications with reference to IEC 61508 series and specifies several safety communication layers (profiles and corresponding protocols) based on the communication profiles and protocol layers of IEC 61784-1, IEC 61784-2 and the IEC 61158 series. It does not cover electrical safety and intrinsic safety aspects.

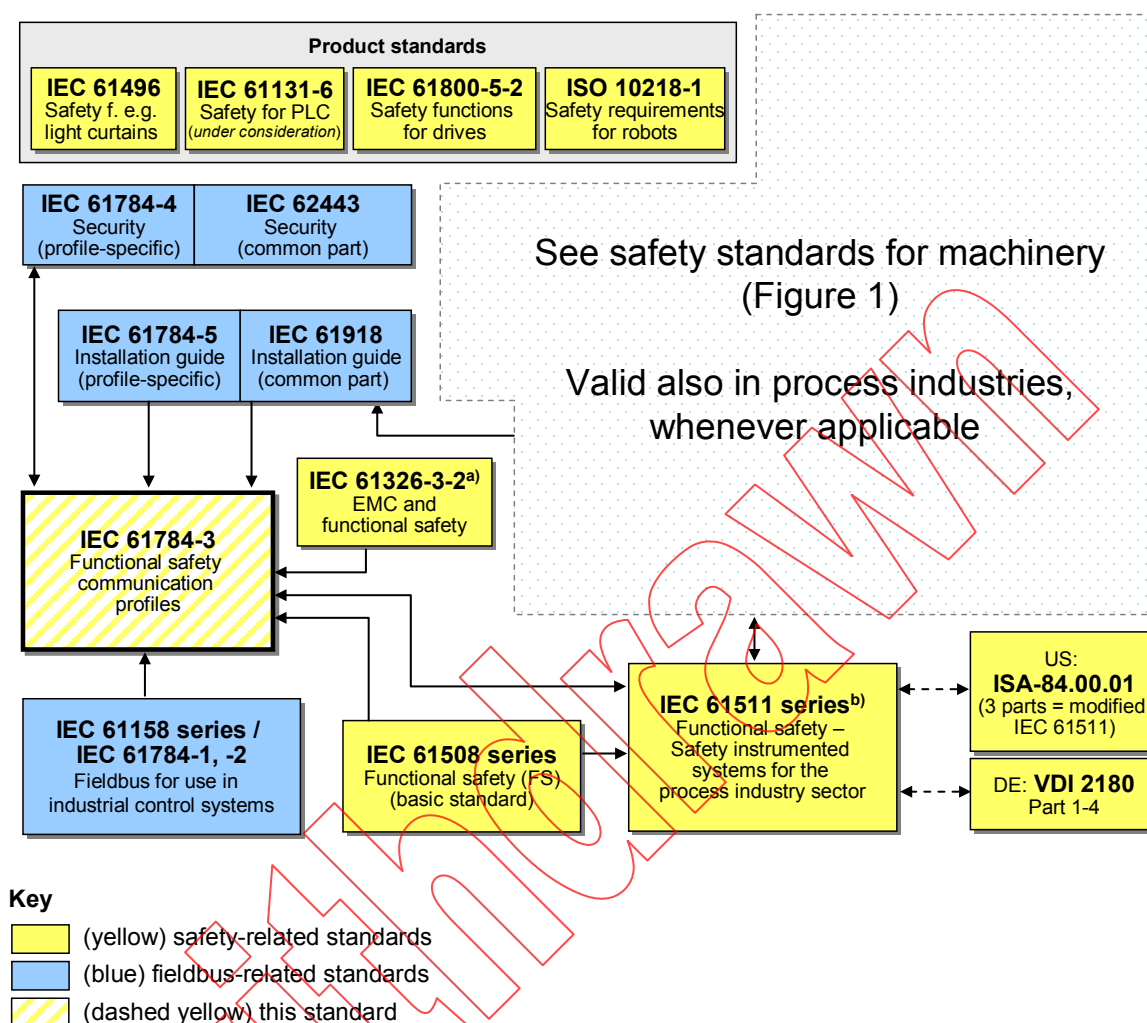
Figure 1 shows the relationships between this standard and relevant safety and fieldbus standards in a machinery environment.



NOTE Subclauses 6.7.6.4 (high complexity) and 6.7.8.1.6 (low complexity) of IEC 62061 specify the relationship between PL (Category) and SIL.

Figure 1 – Relationships of IEC 61784-3 with other standards (machinery)

Figure 2 shows the relationships between this standard and relevant safety and fieldbus standards in a process environment.



^a For specified electromagnetic environments; otherwise IEC 61326-3-1.

^b EN ratified.

Figure 2 – Relationships of IEC 61784-3 with other standards (process)

Safety communication layers which are implemented as parts of safety-related systems according to IEC 61508 series provide the necessary confidence in the transportation of messages (information) between two or more participants on a fieldbus in a safety-related system, or sufficient confidence of safe behaviour in the event of fieldbus errors or failures.

Safety communication layers specified in this standard do this in such a way that a fieldbus can be used for applications requiring functional safety up to the Safety Integrity Level (SIL) specified by its corresponding functional safety communication profile.

The resulting SIL claim of a system depends on the implementation of the selected functional safety communication profile within this system – implementation of a functional safety communication profile in a standard device is not sufficient to qualify it as a safety device.

This standard describes:

- basic principles for implementing the requirements of IEC 61508 series for safety-related data communications, including possible transmission faults, remedial measures and considerations affecting data integrity;
- individual description of functional safety profiles for several communication profile families in IEC 61784-1 and IEC 61784-2;
- safety layer extensions to the communication service and protocols sections of the IEC 61158 series.

0.2 Patent declaration

The International Electrotechnical Commission (IEC) draws attention to the fact that it is claimed that compliance with this document may involve the use of patents concerning the functional safety communication profiles for family 2 as follows, where the [xx] notation indicates the holder of the patent right:

US 6,631,476	[RA]	Safety network for industrial controller providing redundant connections on single media
US 6,701,198	[RA]	Safety network for industrial controller allowing initialization on standard networks
US 6,721,900	[RA]	Safety network for industrial controller having reduced bandwidth requirements
US 6,891,850	[RA]	Network independent safety protocol for industrial controller
US 6,915,444	[RA]	Network independent safety protocol for industrial controller using data manipulation techniques

IEC takes no position concerning the evidence, validity and scope of these patent rights.

The holders of these patents rights have assured the IEC that they are willing to negotiate licences under reasonable and non-discriminatory terms and conditions with applicants throughout the world. In this respect, the statement of the holders of these patent rights are registered with IEC.

Information may be obtained from:

[RA] Rockwell Automation, Inc.
1201 S. Second Street
Milwaukee, WI 53204
USA
Attention: Intellectual Property Dept.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights other than those identified above. IEC shall not be held responsible for identifying any or all such patent rights.

INDUSTRIAL COMMUNICATION NETWORKS – PROFILES –

Part 3-2: Functional safety fieldbuses – Additional specifications for CPF 2

1 Scope

This part of the IEC 61784-3 series specifies a safety communication layer (services and protocol) based on CPF 2 of IEC 61784-1, IEC 61784-2 and IEC 61158 Type 2. It identifies the principles for functional safety communications defined in IEC 61784-3 that are relevant for this safety communication layer.

NOTE 1 It does not cover electrical safety and intrinsic safety aspects. Electrical safety relates to hazards such as electrical shock. Intrinsic safety relates to hazards associated with potentially explosive atmospheres.

This part¹ defines mechanisms for the transmission of safety-relevant messages among participants within a distributed network using fieldbus technology in accordance with the requirements of IEC 61508 series² for functional safety. These mechanisms may be used in various industrial applications such as process control, manufacturing automation and machinery.

This part provides guidelines for both developers and assessors of compliant devices and systems.

NOTE 2 The resulting SIL claim of a system depends on the implementation of the selected functional safety communication profile within this system – implementation of a functional safety communication profile according to this part in a standard device is not sufficient to qualify it as a safety device.

2 Normative references

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

IEC 61131-2, *Programmable controllers – Part 2: Equipment requirements and tests*

IEC 61131-3, *Programmable controllers – Part 3: Programming languages*

IEC 61158-2, *Industrial communication networks – Fieldbus specifications – Part 2: Physical layer specification and service definition*

IEC 61158-3-2, *Industrial communication networks – Fieldbus specifications – Part 3-2: Data-link layer service definition – Type 2 elements*

IEC 61158-4-2, *Industrial communication networks – Fieldbus specifications – Part 4-2: Data-link layer protocol specification – Type 2 elements*

IEC 61158-5-2, *Industrial communication networks – Fieldbus specifications – Part 5-2: Application layer service definition – Type 2 elements*

¹ In the following pages of this standard, “this part” will be used for “this part of the IEC 61784-3 series”.

² In the following pages of this standard, “IEC 61508” will be used for “IEC 61508 series”.

IEC 61158-6-2, *Industrial communication networks – Fieldbus specifications – Part 6-2: Application layer protocol specification – Type 2 elements*

IEC 61326-3-1, *Electrical equipment for measurement, control and laboratory use – EMC requirements – Part 3-1: Immunity requirements for safety-related systems and for equipment intended to perform safety related functions (functional safety) – General industrial applications*

IEC 61326-3-2, *Electrical equipment for measurement, control and laboratory use – EMC requirements – Part 3-2: Immunity requirements for safety-related systems and for equipment intended to perform safety related functions (functional safety) – Industrial applications with specified electromagnetic environment*

IEC 61508 (all parts), *Functional safety of electrical/electronic/programmable electronic safety-related systems*

IEC 61784-1, *Industrial communication networks – Profiles – Part 1: Fieldbus profiles*

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

IEC 61784-3:2010³, *Industrial communication networks – Profiles – Part 3: Functional safety fieldbuses – General rules and profile definitions*

IEC 61784-5-2, *Industrial communication networks – Profiles – Part 5: Installation of fieldbuses – Installation profiles for CPF 2*

IEC 61918, *Industrial communication networks – Installation of communication networks in industrial premises*

IEC 62026-3, *Low-voltage switchgear and controlgear – Controller-device interfaces (CDIs) – Part 3: DeviceNet*

ISO 13849-1, *Safety of machinery – Safety-related parts of control systems – Part 1: General principles for design*

ISO 15745-2:2003, *Industrial automation systems and integration – Open systems application integration framework – Part 2: Reference description for ISO 11898-based control systems*

ISO 15745-3:2003, *Industrial automation systems and integration – Open systems application integration framework – Part 3: Reference description for IEC 61158-based control systems*

ISO 15745-4:2003, *Industrial automation systems and integration – Open systems application integration framework – Part 4: Reference description for Ethernet-based control systems*

3 Terms, definitions, symbols, abbreviated terms and conventions

3.1 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

³ To be published.

3.1.1 Common terms and definitions

3.1.1.1

availability

probability for an automated system that for a given period of time there are no unsatisfactory system conditions such as loss of production

3.1.1.2

black channel

communication channel without available evidence of design or validation according to IEC 61508

3.1.1.3

bridge

abstract device that connects multiple network segments along the data link layer

3.1.1.4

communication channel

logical connection between two end-points within a *communication system*

3.1.1.5

communication system

arrangement of hardware, software and propagation media to allow the transfer of *messages* (ISO/IEC 7498 application layer) from one application to another

3.1.1.6

connection

logical binding between two application objects within the same or different devices

3.1.1.7

Cyclic Redundancy Check (CRC)

<value> redundant data derived from, and stored or transmitted together with, a block of data in order to detect data corruption

<method> procedure used to calculate the redundant data

NOTE 1 Terms "CRC code" and "CRC signature", and labels such as CRC1, CRC2, may also be used in this standard to refer to the redundant data.

NOTE 2 See also [34], [35]⁴.

3.1.1.8

error

discrepancy between a computed, observed or measured value or condition and the true, specified or theoretically correct value or condition

[IEC 61508-4:2010⁵], [IEC 61158]

NOTE 1 Errors may be due to design mistakes within hardware/software and/or corrupted information due to electromagnetic interference and/or other effects.

NOTE 2 Errors do not necessarily result in a *failure* or a *fault*.

3.1.1.9

failure

termination of the ability of a functional unit to perform a required function or operation of a functional unit in any way other than as required

⁴ Figures in square brackets refer to the bibliography.

⁵ To be published.

NOTE 1 The definition in IEC 61508-4 is the same, with additional notes.

[IEC 61508-4:2010, modified], [ISO/IEC 2382-14.01.11, modified]

NOTE 2 Failure may be due to an *error* (for example, problem with hardware/software design or message disruption)

3.1.1.10

fault

abnormal condition that may cause a reduction in, or loss of, the capability of a functional unit to perform a required function

NOTE IEC 191-05-01 defines "fault" as a state characterized by the inability to perform a required function, excluding the inability during preventive maintenance or other planned actions, or due to lack of external resources.

[IEC 61508-4:2010, modified], [ISO/IEC 2382-14.01.10, modified]

3.1.1.11

fieldbus

communication system based on serial data transfer and used in industrial automation or process control applications

3.1.1.12

frame

denigrated synonym for DLPDU

3.1.1.13

hash function

(mathematical) function that maps values from a (possibly very) large set of values into a (usually) smaller range of values

NOTE 1 Hash functions can be used to detect data corruption.

NOTE 2 Common hash functions include parity, checksum or CRC.

[IEC/TR 62210, modified]

3.1.1.14

hazard

state or set of conditions of a system that, together with other related conditions will inevitably lead to harm to persons, property or environment

3.1.1.15

master

active communication entity able to initiate and schedule communication activities by other stations which may be masters or slaves

3.1.1.16

message

ordered series of octets intended to convey information

[ISO/IEC 2382-16.02.01, modified]

3.1.1.17

nuisance trip

spurious trip with no harmful effect

NOTE Internal abnormal errors can be caused in communication systems such as wireless transmission, for example by too many retries in the presence of interferences.

3.1.1.18**performance level (PL)**

discrete level used to specify the ability of safety-related parts of control systems to perform a safety function under foreseeable conditions
[ISO 13849-1]

3.1.1.19**redundancy**

existence of means, in addition to the means which would be sufficient for a functional unit to perform a required function or for data to represent information

NOTE The definition in IEC 61508-4 is the same, with additional example and notes.

[IEC 61508-4:2010, modified], [ISO/IEC 2382-14.01.12, modified]

3.1.1.20**reliability**

probability that an automated system can perform a required function under given conditions for a given time interval (t_1, t_2)

NOTE 1 It is generally assumed that the automated system is in a state to perform this required function at the beginning of the time interval.

NOTE 2 The term "reliability" is also used to denote the reliability performance quantified by this probability.

NOTE 3 Within the MTBF or MTTF period of time, the probability that an automated system will perform a required function under given conditions is decreasing.

NOTE 4 Reliability differs from availability.

[IEC 62059-11, modified]

3.1.1.21**risk**

combination of the probability of occurrence of harm and the severity of that harm

NOTE For more discussion on this concept see Annex A of IEC 61508-5:2010⁶.

[IEC 61508-4:2010], [ISO/IEC Guide 51:1999, definition 3.2]

3.1.1.22**safety communication layer (SCL)**

communication layer that includes all the necessary measures to ensure safe transmission of data in accordance with the requirements of IEC 61508

3.1.1.23**safety connection**

connection that utilizes the safety protocol for communications transactions

3.1.1.24**safety data**

data transmitted across a safety network using a safety protocol

NOTE The Safety Communication Layer does not ensure safety of the data itself, only that the data is transmitted safely.

3.1.1.25**safety device**

device designed in accordance with IEC 61508 and which implements the functional safety communication profile

⁶ To be published.

3.1.1.26

safety function

function to be implemented by an E/E/PE safety-related system or other risk reduction measures, that is intended to achieve or maintain a safe state for the EUC, in respect of a specific hazardous event

NOTE The definition in IEC 61508-4 is the same, with an additional example and reference.

[IEC 61508-4:2010, modified]

3.1.1.27

safety function response time

worst case elapsed time following an actuation of a safety sensor connected to a fieldbus, before the corresponding safe state of its safety actuator(s) is achieved in the presence of errors or failures in the safety function channel

NOTE This concept is introduced in IEC 61784-3:2010⁷, 5.2.4 and addressed by the functional safety communication profiles defined in this part.

3.1.1.28

safety integrity level (SIL)

discrete level (one out of a possible four), corresponding to a range of safety integrity values, where safety integrity level 4 has the highest level of safety integrity and safety integrity level 1 has the lowest

NOTE 1 The target failure measures (see IEC 61508-4:2010, 3.5.17) for the four safety integrity levels are specified in Tables 2 and 3 of IEC 61508-1:2010⁸.

NOTE 2 Safety integrity levels are used for specifying the safety integrity requirements of the safety functions to be allocated to the E/E/PE safety-related systems.

NOTE 3 A safety integrity level (SIL) is not a property of a system, subsystem, element or component. The correct interpretation of the phrase "SILn safety-related system" (where n is 1, 2, 3 or 4) is that the system is potentially capable of supporting safety functions with a safety integrity level up to n.

[IEC 61508-4:2010]

3.1.1.29

safety measure

<this standard> measure to control possible communication errors that is designed and implemented in compliance with the requirements of IEC 61508

NOTE 1 In practice, several safety measures are combined to achieve the required safety integrity level.

NOTE 2 Communication errors and related safety measures are detailed in IEC 61784-3:2010, 5.3 and 5.4.

3.1.1.30

safety-related application

programs designed in accordance with IEC 61508 to meet the SIL requirements of the application

3.1.1.31

safety-related system

system performing *safety functions* according to IEC 61508

3.1.1.32

slave

passive communication entity able to receive messages and send them in response to another communication entity which may be a master or a slave

⁷ In preparation.

⁸ To be published.

3.1.1.33**spurious trip**

trip caused by the safety system without a process demand

3.1.1.34**time stamp**

time information included in a *message*

3.1.2 CPF 2: Additional terms and definitions**3.1.2.1****base format**

format used for connection RPIs of less than 100 ms or for applications where dropped connections can be tolerated

3.1.2.2**extended format**

format used for connection RPIs of more than 100 ms or for applications where there is a need to avoid dropped connections

3.1.2.3**ping**

request for the consumer to acknowledge the reception of a message

3.1.2.4**ping response**

response to a ping

3.1.2.5**signature**

method of uniquely identifying a set of data

NOTE This could be by revision, checksum or some other method that is agreed upon by the originating and target devices.

3.2 Symbols and abbreviated terms**3.2.1 Common symbols and abbreviated terms**

CP	Communication Profile	[IEC 61784-1]
CPF	Communication Profile Family	[IEC 61784-1]
CRC	Cyclic Redundancy Check	
DLL	Data Link Layer	[ISO/IEC 7498-1]
DLPDU	Data Link Protocol Data Unit	
EMC	Electromagnetic Compatibility	
EUC	Equipment Under Control	[IEC 61508-4:2010]
E/E/PE	Electrical/Electronic/Programmable Electronic	[IEC 61508-4:2010]
FAL	Fieldbus Application Layer	[IEC 61158-5]
FS	Functional Safety	
FSCP	Functional Safety Communication Profile	
MTBF	Mean Time Between Failures	
MTTF	Mean Time To Failure	
PDU	Protocol Data Unit	[ISO/IEC 7498-1]

PFD	Probability of dangerous Failure on Demand	[IEC 61508-6:2010 ⁹]
PFH	Average frequency of dangerous failure [h ⁻¹] per hour	[IEC 61508-6:2010]
PhL	Physical Layer	[ISO/IEC 7498-1]
PL	Performance Level	[ISO 13849-1]
PLC	Programmable Logic Controller	
SCL	Safety Communication Layer	
SIL	Safety Integrity Level	[IEC 61508-4:2010]

3.2.2 CPF 2: Additional symbols and abbreviated terms

AIRS	Already In Requested Mode/State
BER	Bit Error Rate
BF	Base Format
CCO	Connection Configuration Object
CFUNID	Configuration UNID
CNP	Connection Point
CID	Consumer ID
CI TM 10	Common Industrial Protocol (application framework shared among CPF 2 communication profiles)
CPCRC	Connection Parameter CRC
CTM	Connection Timeout Multiplier
EDS	Electronic Data Sheet
EF	Extended Format
EPI	Expected Packet Interval
LED	Light Emitting Diode
MACID	Device physical address (CP 2/3) or IP Address (CP 2/2) on network
MOD	Module
NV	Non-Volatile
NVS	Non-Volatile Storage
OCPUNID	Output Connection Owner UNID
OSC	Object State Conflict
O-to-T	Originator to Target
OUNID	Originator UNID
PID	Producer Identifier
PS	Power Supply
Res.	Reserved
RPI	Requested Packet Interval
SCCRC	Safety Configuration Data CRC
SCID	Safety Configuration Identified
SCTS	Safety Configuration Time Stamp
SNCT	Safety Network Configuration Tool
SNN	Safety Network Number
T-to-O	Target to Originator
TBD	To Be Defined

⁹ To be published.

¹⁰ For trade name declaration, see Clause 4.

TNS	TUNID Not Set	
TUNID	Target UNID	
UML	Universal Modeling Language	[ISO/IEC 19501]
UNID	Unique Network Identifier	

3.3 Conventions

The conventions used for the descriptions of objects services and protocols are described in IEC 61158-3-2, IEC 61158-4-2, IEC 61158-5-2, and IEC 61158-6-2.

As appropriate this part uses flow charts, UML Sequence Diagrams and “C” pseudo-code to describe concepts.

4 Overview of FSCP 2/1 (CIP Safety™)

4.1 General

Communication Profile Family 2 (commonly known as CIP™¹¹) defines communication profiles based on IEC 61158-2 Type 2, IEC 61158-3-2, IEC 61158-4-2, IEC 61158-5-2, and IEC 61158-6-2.

The basic profiles CP 2/1, CP 2/2, and CP 2/3 are defined in IEC 61784-1 and IEC 61784-2. The CPF 2 functional safety communication profile FSCP 2/1 (CIP Safety™¹¹) is based on the CPF 2 basic profiles in IEC 61784-1 and IEC 61784-2 and the safety communication layer specifications defined in this part.

4.2 FSCP 2/1

FSCP 2/1 is based on the producer/consumer model of CPF 2. The pairing of producers and consumers is an important part of the relationship that provides the high integrity needed for safety-related applications.

The FSCP 2/1 safety communication layer is specified using a Safety Validator object. This object is responsible for managing the FSCP 2/1 safety connections and serves as the interface between the safety-related application objects and the link layer connections, as shown in Figure 3. The Safety Validator ensures the integrity of the safety data transfers.

¹¹ CIP™ (Common Industrial Protocol) and CIP Safety™ are trade names of the non-profit organization ODVA, Inc. This information is given for the convenience of users of this International Standard and does not constitute an endorsement by IEC of the trade name holder or any of its products. Compliance to this part does not require use of the trade names CIP™ or CIP Safety™. Use of the trade names CIP™ or CIP Safety™ requires permission of ODVA.

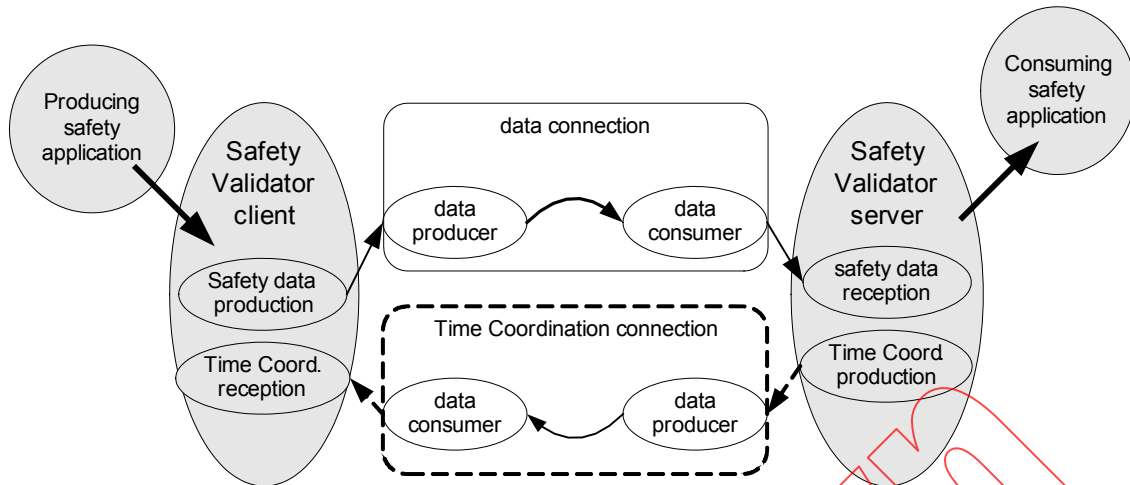


Figure 3 – Relationship of Safety Validators

The integrity of the safety data transfers is ensured as follows:

- the producing safety-related application uses an instance of a client Safety Validator to produce safety data and ensure time coordination;
- the client uses a link data producer to transmit the data and a link consumer to receive time coordination messages;
- the consuming safety-related application uses a server Safety Validator to receive and check data;
- the server uses a link consumer to receive data and a link producer to transmit time coordination messages.

FSCP 2/1 utilizes the black channel concept. The link producers and consumers have no knowledge of the safety packet and implement no safety function. The responsibility for high-integrity transfer and checking of safety data lies within the Safety Validators.

FSCP 2/1 uses the following measures to ensure the integrity of safety messaging:

- time stamp;
- connection authentication;
- data integrity assurance;
- redundancy with cross checking;
- different data integrity assurance systems.

Messages are produced with a timestamp that allows the consumer to verify the age of data being sent. Identification is encoded into each safety-related message to ensure that the correct consumer is using the message. All safety-related messages use a unique CRC. Safety-related data is sent redundantly. Diverse measures for producing safety-related messages are used to ensure that standard CPF 2 messages are not interpreted as safety messages.

5 General

5.1 External documents providing specifications for the profile

The following document is especially useful in understanding the design of FSCP 2/1 protocols:

- GS-ET-26 [33]

5.2 Safety functional requirements

The following requirements shall apply to the development of devices that implement the FSCP 2/1 protocol. The same requirements were used in the development of FSCP 2/1.

- The FSCP 2/1 protocol is designed to support Safety Integrity Level 3 (SIL3) (see IEC 61508), and PLe/category 4 (see ISO 13849-1).
- The safety state for discrete data is the unenergized state (0). For analog values the unenergized state shall be defined by the safety-related application.
- The basic requirements for the development of the FSCP 2/1 protocol are in IEC 61784-3.
- FSCP 2/1 protocol is implemented using a black channel approach; there is no safety related dependency on the standard CPF 2 communication profiles.
- Implementations of FSCP 2/1 shall comply with IEC 61508.
- Environmental conditions shall be according to IEC 61131-2 for the basic levels and IEC 61326-3-1, IEC 61326-3-2 for the safety margin tests, unless there are specific product standards.
- Safety communication and standard communication shall be independent. However, standard devices and safety devices shall be able to use the same communication channel.
- Unless specified in this part, the CPF 2 requirements shall be unchanged for safety.

5.3 Safety measures

Table 1 contains the measures used to detect communication errors and the coverage provided by each measure as used.

Table 1 – Communications errors and detection measures matrix

Communication errors	Safety measures							
	Sequence number	Time stamp	Time expectation	Connection authentication	Feedback message	Data integrity assurance	Redundancy with cross checking	Different data integrity assurance systems
Corruption						X	X	
Unintended repetition		X				X ^a	(X) ^e	
Incorrect sequence		X				X ^a	(X) ^e	
Loss			X ^c			X ^a	(X) ^e	
Unacceptable delay		(X) ^e	X					
Insertion		X ^d		X		X ^a	(X) ^e	
Masquerade		X ^d		X		X ^b	X ^f	X
Addressing				X		X ^b		
^a The safety related CRC provides additional protection for communication errors in messages. ^b Encoding the unique identifier into the safety related CRC prevent masquerade and addressing errors. ^c A message not received within the time expectation will be detected. ^d Masquerade or inserted messages will not have the expected time stamp. ^e Not claimed for FSCP 2/1. ^f Masquerade will likely not have redundant data and will fail the cross-check.								

5.4 Safety communication layer structure

The safety protocol is layered on top of the standard network protocol (the standard protocol stack is a black channel). Figure 4 shows how the safety communication layer is related to the existing CPF 2 layers.

The safety layers accept safety data from the safety-related application circuit. The safety layers then formulate a safety message, transmit the safety message, receive and decode the safety message. Once the safety message is decoded and verified, the data is presented to the receiving safety-related application circuit.

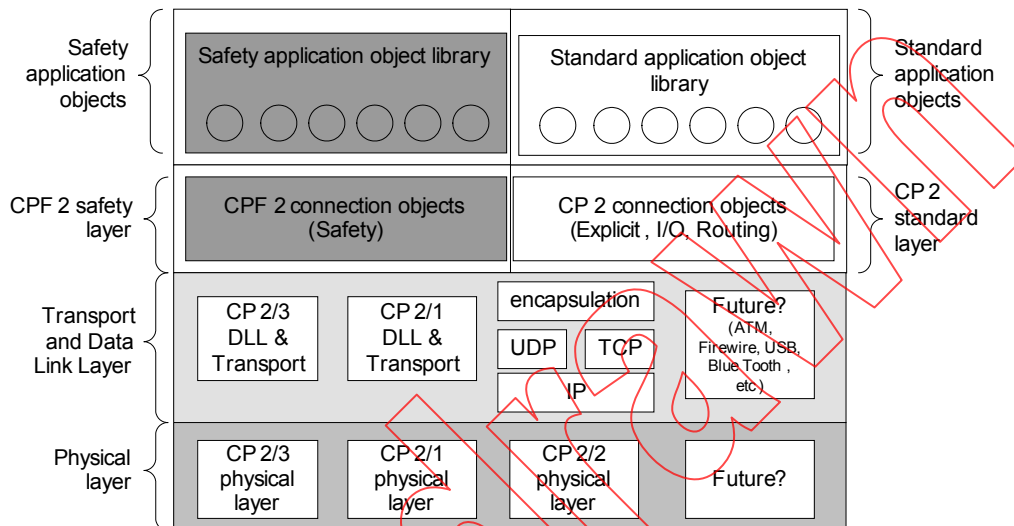


Figure 4 – Communication layers

5.5 Relationships with FAL (and DLL, PhL)

5.5.1 General

This safety communication layer shall only be used in conjunction with CPF 2 communication profiles (CP 2/3 (DeviceNet™¹²), CP 2/2 (EtherNet/IP™¹³)). There are no requirements of CPF 2 communications profiles other than those defined in this part.

5.5.2 Data types

Profiles defined in this part support all the CPF 2 data types as defined in IEC 61158-5-2.

¹² DeviceNet™ is a trade name of the non-profit organization ODVA, Inc. This information is given for the convenience of users of this International Standard and does not constitute an endorsement by IEC of the trade name holder or any of its products. Compliance to this part does not require use of the trade name DeviceNet™. Use of the trade name DeviceNet™ requires permission of ODVA.

¹³ EtherNet/IP™ is a trade name of ODVA, Inc. This information is given for the convenience of users of this International Standard and does not constitute an endorsement by IEC of the trade name holder or any of its products. Compliance to this part does not require use of the trade name EtherNet/IP™. Use of the trade name EtherNet/IP™ requires permission of ODVA.

6 Safety communication layer services

6.1 Introduction

This subclause defines the extensions to existing CPF 2 objects and new objects for Safety. Safety connections use Class 0 connections for I/O messages. Standard Explicit message connections are used for the establishment of Safety I/O connections.

6.2 Connection object

6.2.1 General

Several safety specific class attributes and services are defined to support safety. Safety nodes which reside on FSCP 2/1 shall implement the SafetyOpen and SafetyClose services of the Connection object.

6.2.2 Class attribute extensions

Table 2 defines the class attributes used by safety devices.

Table 2 – New class attributes

Attrib ID	Need in implementation	Access rule	N V	Name	Date type	Description of attribute
8	Optional	Get	V	Connection request error count	UINT	Diagnostic Counter that is a running count of SafetyOpen or SafetyClose faults ^a
9	Optional	Get	V	Safety connection counters	STRUCT of:	Status counters
				SafetyOpen request success count	UINT	Count of successful SafetyOpen requests issued from this node to another target
				SafetyOpen request failure count	UINT	Count of unsuccessful SafetyOpen requests issued from this node to another target
				SafetyClose request success count	UINT	Count of successful SafetyClose requests issued from this node to another target
				SafetyClose request failure count ^b	UINT	Count of unsuccessful SafetyClose requests issued from this node to another target
				SafetyOpen indication success count	UINT	Count of successful SafetyOpen requests issued from an external originator to this node
				SafetyOpen indication failure count ^b	UINT	Count of unsuccessful SafetyOpen requests issued from an external originator to this node
				SafetyClose indication success count	UINT	Count of successful SafetyClose requests issued from an external originator to this node
				SafetyClose indication failure count ^b	UINT	Count of unsuccessful SafetyClose requests issued from an external originator to this node

^a Attribute 8 is the sum of the 4 failure counters in attribute 9. Having this single attribute represent connection errors can be used in monitoring software to efficiently monitor errors without polling the additional attribute 9 structures. Once attribute 8 is non-zero then the monitoring software can examine attribute 9 for more details.

^b Included in class attribute 8.

6.2.3 Service extensions

Table 3 defines services for use by safety devices on FSCP 2/1. These services shall be supported by a target device on FSCP 2/1. The SafetyOpen and SafetyClose services, used in lieu of the ForwardOpen and ForwardClose services of the Connection Manager object, inherit the identical behavior from those Connection Manager services.

Table 3 – Service extensions

Service code	Need in implementation		Service name	Description of service
	Class	Instance		
4D _{hex}	Optional	N/A	Reset Counters	This service resets class attributes 8 and 9 to zero
4E _{hex}	Required	N/A	SafetyClose	Used to close a Safety I/O connection. See the ForwardClose service of the Connection Manager object 6.3.13
54 _{hex}	Required	N/A	SafetyOpen ^a	Used to establish a safety I/O connection. See the ForwardOpen service of the Connection Manager object 6.3.2
^a The SafetyOpen service data shall contain a Safety Network Segment in the Connection_Path field.				

6.2.4 Explicit message response format for SafetyOpen and SafetyClose

The SafetyOpen and SafetyClose service responses have a common response format. This format contains status information for both success and failure. If the service response is a success, response data specific to each service is returned. If the service response is an error, a successful FSCP 2/1 status indicated by the general error code FF_{hex} is returned, along with a variable amount of extended error information.

The response format for the SafetyOpen and SafetyClose object Specific services are defined in Table 4:

Table 4 – SafetyOpen and SafetyClose response format

Parameter name	Data type	Description of response parameter
Reserved	USINT	Reserved
General status	USINT	One of the general status codes listed in IEC 61158-6-2 (status codes)
Size of additional status	USINT	Number of 16 bit words in Additional status array
Additional status	ARRAY of UINT	Additional status
Response data	ARRAY of OCTET	Response data from request or additional error data if general status indicated an error

The Response Data and General/Additional Statuses for the SafetyOpen and SafetyClose services shall match the Response Data and General/Additional Statuses for the ForwardOpen and ForwardClose services of the Connection Manager object, respectively.

6.3 Connection Manager object

6.3.1 General

Safety devices shall use a ForwardOpen with a Safety Network Segment to establish safety connections. This segment uniquely identifies the ForwardOpen service as a safety ForwardOpen. Throughout this subclause, the term “SafetyOpen” shall refer to both the ForwardOpen service of the Connection Manager object (when containing a Safety Network Segment) and the SafetyOpen service of the Connection object.

6.3.2 ForwardOpen for safety

6.3.2.1 ForwardOpen for safety contents

The contents of the ForwardOpen service of the Connection Manager object, including the safety network segment, are outlined in Figure 5 below. The proper settings for the various parameters in the ForwardOpen are given in Figure 5.

Parameter Name		Data Type / Size	Target Destination and Semantics
Priority/Time_tick		OCTET	Connection manager servicing request
Time-out_ticks		USINT	Connection manager servicing request
O-to-T Network Connection ID		UDINT	Consuming connection instance:: CIP consumed connection ID
T-to-O Network Connection ID		UDINT	Producing connection instance:: CIP producing connection ID
Connection Serial Number		UINT	Value: Unique (to originator) 16-bit number. Destination: Connection manager servicing request
Originator Vendor ID		UINT	Connection manager servicing request
Originator Serial Number		UDINT	Connection manager servicing request
Connection Timeout Multiplier		USINT	Producing and consuming connection instance: Timeout Multiplier
Reserved		3 OCTETS	
O-to-T RPI		UDINT	Consuming connection instance: EPR
O-to-T Network Connection Parameters	Redundant Owner	WORD	Value: 0 (Safety Connections do not support redundancy); Destination: Connection Manager
	Connection Type		Value: Point-to-point; Destination: Connection Manager
	Priority		Value: High Priority; Destination: Connection Manager
	Fixed/Variable		Value: Fixed; Destination: Connection Manager
	Connection Size (in octets)		Value: Size of safety PDU including the Mode Octet, Actual, Complement, and Time stamp sections Destination: Consuming connection instance: Consumed connection size attribute
T-to-O RPI		UDINT	Producing connection instance: EPR
T to O Network Connection Parameters	Redundant Owner	WORD	Value: 0 (Safety connections do not support redundancy); Destination: Connection Manager
	Connection Type		Value: Point-to-point; Destination: Connection Manager
	Priority		Value: High Priority; Destination: Connection Manager
	Fixed/Variable		Value: Fixed; Destination: Connection Manager

Parameter Name		Data Type / Size	Target Destination and Semantics
	Connection Size (in octets)		Value: Size of safety PDU including the Mode Octet, Actual, Complement, and Time stamp sections. Destination: Producing Connection Instance: Produced connection size
Transport Type/Trigger		SWORD	Value: Safety single or multipoint. Destination: Validator instance. Trigger always set to Application. Client/Server: depending on direction
Connection_Path_Size		USINT	Number of 16 bit words in the Connection_Path field – destination is Connection Manager servicing request. NOTE Value included in CRC calculation does not include the words used for Network/Port segments.
Connection_Path (Padded EPATH)			
Path		Variable	Consumed by intermediate bridge connection manager(s). Each Router Format-safety Network Segment immediately follows the (CPF 2 - to-CPF 2) bridge for which it is intended
Logical Segment: Electronic Key	Vendor ID	UINT	Value: Electronic Key of required target. Servicing Connection Manager or Connection object
	Prod Type	UINT	
	Prod Code	UINT	
	Compatible/ Major Rev	SWORD	
	Minor Rev	USINT	
Application Path 1	Logical Segment: Class	Variable; 1 word typically	Refer to IEC 61158-6-2 for rules on setting/parsing these paths
	Logical Segment: Instance	Variable; 1 word typically	
Application Path 2	Logical Segment: Connection Point	Variable; 1 word typically	Refer to IEC 61158-6-2 for rules on setting/parsing these paths
Application Path 3	Logical Segment: Connection Point	Variable; 1 word typically	Refer to IEC 61158-6-2 for rules on setting/parsing these paths
Config Data	Data Segment: Simple Data	Variable	Configuration data to apply to the Safety-related application object identified by Config Path
Network Segment:	Safety Segment Name	50 _{hex}	Safety Network Segment
	Segment Size	USINT	Target format size = 54 octets
	Segment Format	USINT	Target format = 0
	Network Safety Data	ARRAY of OCTET	Safety Network Segment data

Key

- = Connection/Safety Validator fields covered by Connection Parameters CRC
- = Configuration Data Segment covered by SCCV

Figure 5 – ForwardOpen with safety network segment

6.3.2.2 ForwardOpen for safety for Extended Format

Safety Originators that support the Extended Format may connect to Targets with RPI's of 100 ms or less with either the Extended Format (EF) or the Base Format (BF).

Safety Originators that connect with a CP 2/2 target or a CP 2/3 target with a CP 2/2 hop within the path and have an RPI of greater than 100 ms shall use the Extended Format.

A variety of methods may be used to assure this. EDS files and configuration software can pre-configure the choice, or the originator can use a dynamic algorithm to make the determinations.

The mechanism used by the originator to indicate to a target that the Extended Format is being requested will be with a new Safety Network Segment Format as defined in 6.3.3.

6.3.3 Safety network segment

6.3.3.1 Common format

The Safety Connection Parameters Segment Type has been added to the CPF 2 Network Segment definition as segment type 10_{hex} (resulting in a segment value of 50_{hex}). The updated Network Segment definition is defined in Table 5.

Table 5 – Safety network segment identifier

Network segment type	Network segment name
50 _{hex}	Safety segment

The format of the Safety Network Segment is defined in Table 6. This segment type is in the range of Network Segment types, which contains a data size field. The Safety Segment Format parameter, the first parameter in the data area, indicates which data follows.

Table 6 – Safety network segment definition

Octet offset	Field name	Data type	description
0	Segment Type	SWORD	Indicates Safety Network Segment (50 _{hex})
1	Network Segment data length	SWORD	Length of segment data to follow (in words)
2	Safety Network Segment format	USINT	Indicates type of Safety Network Segment 0 = Target format 1 = Router format 2 – 255 = Reserved
3 - n	Safety Network Segment data	ARRAY of OCTET	Safety Network Segment data, defined by segment format

6.3.3.2 Safety network segment: target format (00_{hex})

The target format is directed at the target of the connection. The value of the Network Segment Data Length parameter shall be 27 (1b_{hex}) which corresponds to 27 WORDS. Figure 6 defines the safety network target format.

Field name	Data type	Description
Reserved	SWORD	Pad
Configuration CRC (SCCRC)	UDINT	CRC-S4 of target Config Data Segment. A value of 0 is an indicator that SCID check can be skipped
Configuration Time Stamp (SCTS)	DATE_AND_TIME	Time and Date stamp of the configuration. A value of 0 is an indicator that SCID check can be skipped. 6 octet value (Date: 2 octets, Time: 4 octets)
Time Correction EPI	UDINT	Not used: 0 When used: Time Correction Connection Instance:: EPI
Time Correction Network Connection Parameters	WORD	Network Connection Parameters for the Time Correction connection. This field uses the same definition as the Network Connection Parameter within the Connection Manager object. When not used: 0 (Null). When used: Fixed, High Priority, Multipoint
Target_UNID (TUNID)	STRUCT of: 10 OCTETS	UNID of the target device. This value is a 10 octet value consisting of the Safety Network Id (6 octets) and the Node Address (4 octet address)
Originator UNID (OUNID)	STRUCT of: 10 OCTETS	UNID of the Originator device. This value is a 10 octet value consisting of the Safety Network Id (6 octets) and the Node Address (4 octet address)
Ping_Interval_EPI_Multiplier	UINT	Number that defines the Ping_Count_Interval for the connection. Valid range of values is given in 7.6.5.10
Time_Coord_Msg_Min_Multiplier	UINT	For Producing Connection Instance. Valid range is 0 to 7 813
Network_Time_Expectation_Multiplier	UINT	For Consuming Connection Instance. Valid range is 0 to 42 969
Timeout_Multiplier	USINT	Used by producer and consumer to timeout connections. Valid range 1 to 4
Max_Consumer_Number	USINT	Value: 1 (Point-to-point), 2-15(Multipoint)
Connection Parameters CRC (CPCRC)	UDINT	CRC-S4 of target connection parameters in this request
Time Correction Connection ID	UDINT	Not Used: FFFFFFFF _{hex} When used: Time Correction Connection Instance:: Connection ID

Key

 = Safety Segment fields covered by Connection Parameters CRC

Figure 6 – Safety network target format

6.3.3.3 Safety network segment: router format (01_{hex})

The router format is directed at an intermediate router along the connection path when that router needs to know this is a Safety ForwardOpen. Currently, only CP 2/3 routers need this network segment directed to them. The Network Segment is applied to the subnet from which the connection request originated. Router Format Safety Network Segments only appear in the Path portion of the Connection_Path of a Safety ForwardOpen. The total segment length is 6 words. The safety network segment router format is defined in Table 7.

Table 7 – Safety network segment router format

Field name	Data type	Description
Reserved	SWORD	Reserved, value = 0
Time Correction Connection ID	UDINT	Not Used: FFFFFFFF _{hex} When used: Time Correction connection instance:: Connection ID
Time Correction EPI	UDINT	Not used: 0 When used: Time Correction connection instance:: EPI
Time Correction Network Connection Parameters	WORD	Network Connection Parameters for the Time Correction connection. This field uses the same definition as the Network Connection Parameter within the Connection Manager object. Not used: 0 (Null). When used: Fixed, High Priority, Multipoint

6.3.3.4 Safety network segment: Extended Format (0x02)

The Extended Format is directed at the target of the connection and shown in Table 8.

All EF safety connections shall be established using the EF safety network segment in a Forward Open (CP 2/2) or a SafetyOpen (CP 2/3).

Table 8 – Safety Network Segment Extended Format

Field Name	Data Type	Description
Reserved	octet	Pad
Configuration CRC (SCCRC)	UDINT	CRC-S32 of target Config Data Segment. A value of 0 is an indicator that SCID check can be skipped
Configuration TimeStamp (SCTS)	DATE_AND_TIME	Time and Date stamp of the configuration. A value of 0 is an indicator that SCID check can be skipped. 6 octet value (Date: 2 octets, Time: 4 octets)
Time Correction EPI	UDINT	Not used: 0 When used: Time Correction Connection Instance:: EPI
Time Correction Network Connection Parameters	WORD	Network Connection Parameters for the Time Correction connection. This field uses the same definition as the Network Connection Parameter within the Connection Manager object. When not used: 0 (Null). When used: Fixed, High Priority, Multipoint
Target_UNID (TUNID)	STRUCT of: UINT 10: octets	UNID of the target device. This value is a 10 octet value consisting of the Safety Network Id (6 octets) and the Node Address (4 octet address)
Originator UNID (OUNID)	STRUCT of: UINT 10: octets	UNID of the Originator device. This value is a 10 octet value consisting of the Safety Network Id (6 octets) and the Node Address (4 octet address)
Ping_Interval_EPI_Multiplier	UINT	Number that defines the Ping_Count_Interval for the connection. Valid range of values is given in 7.6.5.10
Time_Coord_Msg_Min_Multiplier	UINT	For Producing Connection Instance. Valid range is 0 to 7 813

Field Name	Data Type	Description
Network_Time_Expectation_Multiplier	UINT	For Consuming Connection Instance. Valid range is 0 to 42 969
Timeout_Multiplier	USINT	Used by producer and consumer to timeout connections. Valid range of 1 to 255 for HiAvailabilityFormat
Max_Consumer_Number	USINT	Value: 1 (Point to point), 2-15(Multipoint)
Max_Fault_Number	UINT	Used by both producers and consumers to determine how many erroneous packets can be dropped before a connection shall be closed. Default = 5. A value of 0 indicates connections shall be closed on any detected error
Connection Parameters CRC (CPCRC)	UDINT	CRC-S32 of target connection parameters in this request
Time Correction Connection ID1	UDINT	Not Used: 0xFFFFFFFF When used: Time Correction Connection Instance:: Connection ID
Initial Time Stamp1	UINT	Used by Consumer to initialize Last_Time_Stamp_for_Rollover. Consuming Originator sets to 0xFFFF
Initial Rollover Value1	UINT	Used by Consumer to initialize TS_Rollover_Count. Consuming Originator sets to 0xFFFF
^a These fields are NOT included in the CPCRC.		

6.3.4 Originator rules for calculating the connection parameter CRC

The Connection Parameter CRC (CPCRC) is only calculated when a connection is initially configured or when that connection configuration is changed. This value remains static in the originator otherwise.

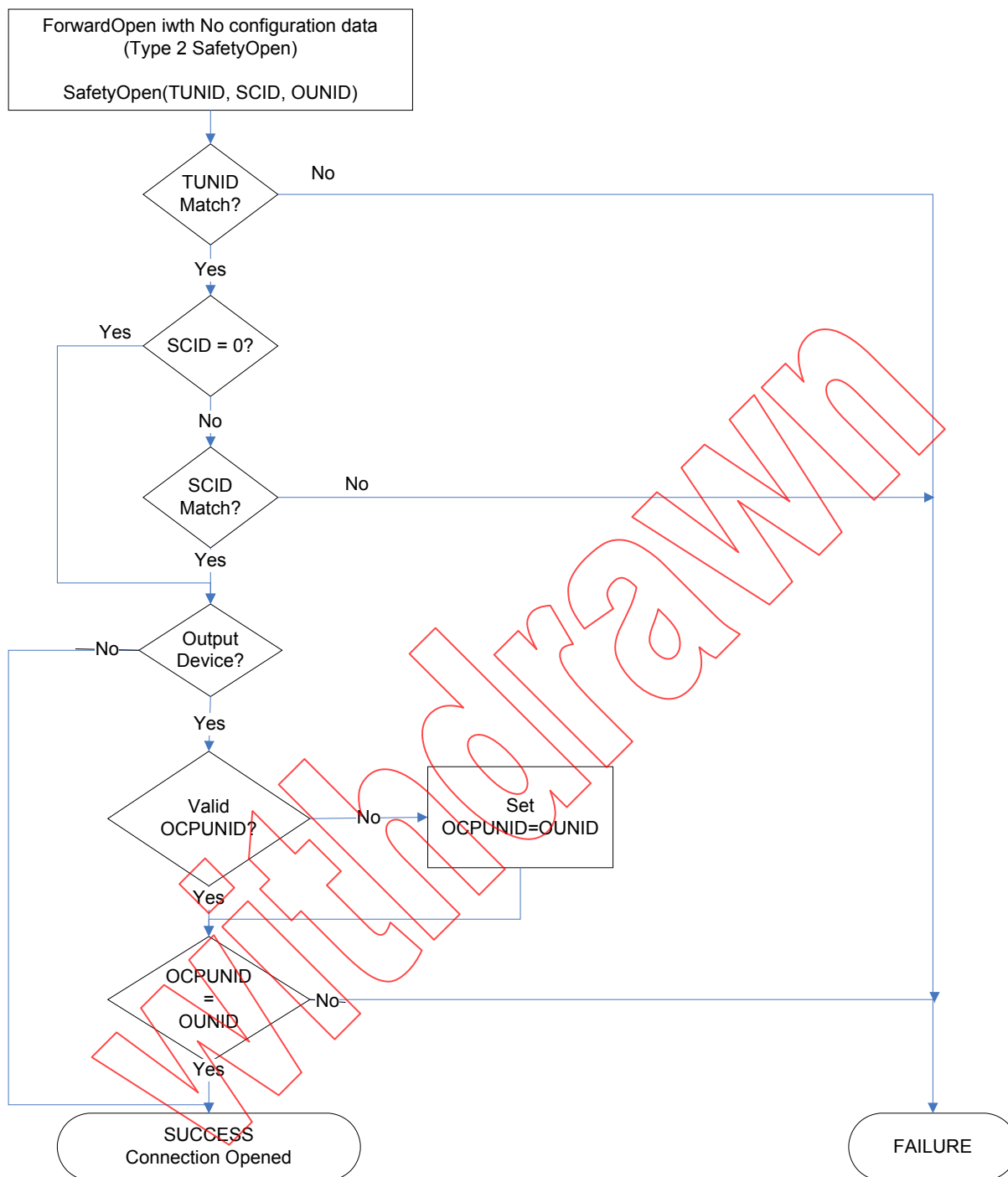
The connection path size in the SafetyOpen changes value depending on whether an originator is sending configuration data or not. Since this field is included in the CPCRC calculation, originators need to calculate and maintain two values when they support the SafetyOpen configuration function. One value is used when configuring a device while opening the connection and the other value is used when just opening the connection (no configuration data is included).

Also, the path size shall be “pre-adjusted” to remove the path entries that get stripped off by routers as the Safety ForwardOpen traverses each sub-net. The requirement is that the originator is responsible for calculating the CPCRC value based on what the SafetyOpen or ForwardOpen will be when the target receives it so that the target can perform a simple calculation in all cases.

6.3.5 SafetyOpen processing flowcharts

The following flowcharts outline the required behavior of a target upon receipt of a SafetyOpen:

- Verify the Connection Parameter CRC. As depicted in Figure 6, the connection parameter CRC covers the SafetyOpen fields that will be used by the target. Routers along the path shall not modify these fields;
- The target checks that the electronic key segment matches (see 6.3.7);
- Depending on the type of safety connection, the logic is defined in Figure 7 or Figure 8 shall be followed.

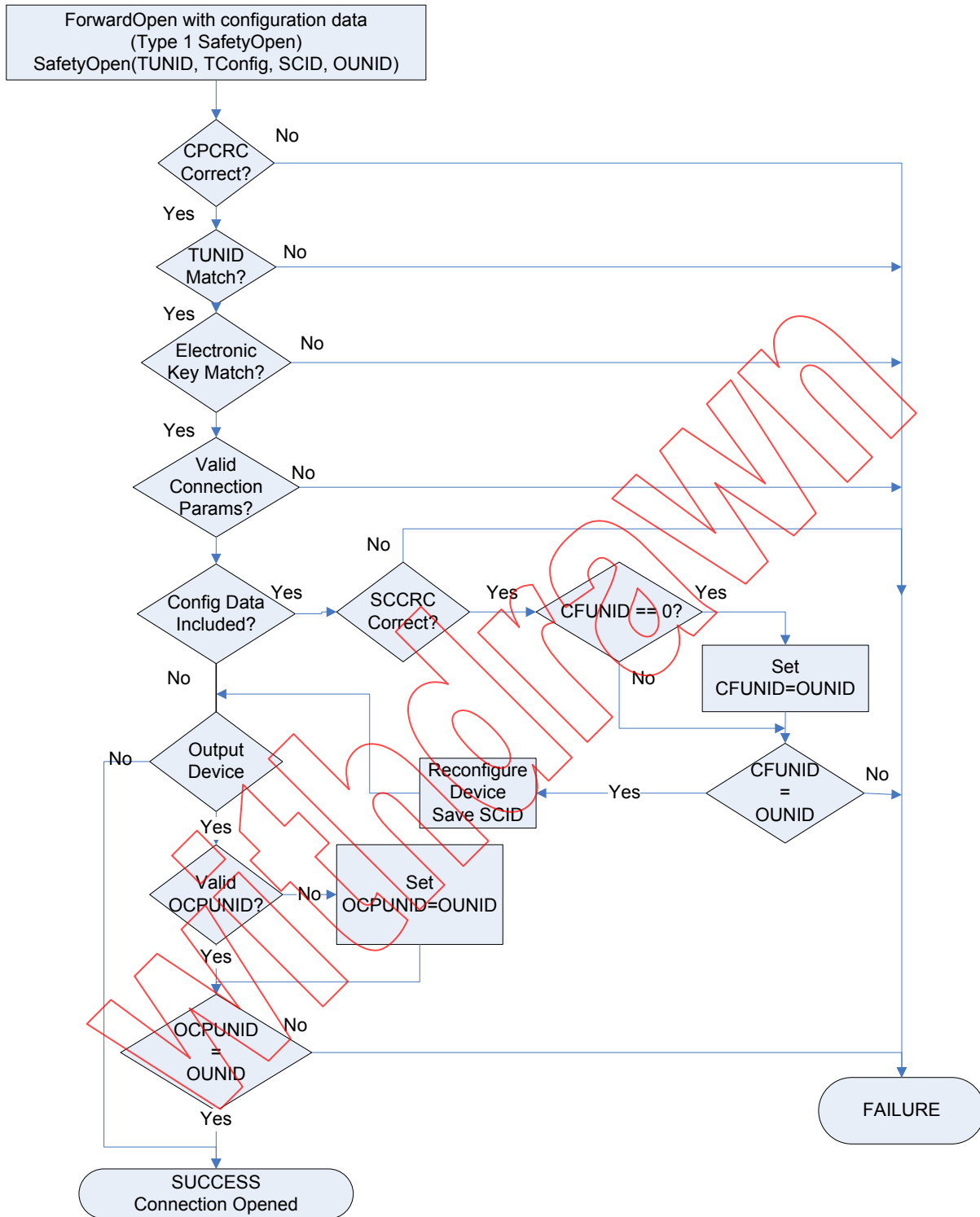


Key:

UNID = Unique Network Identifier
 SCID = Target's Safety Configuration ID
 OCP = Output Connection Point
 CFUNID = Configuration Owning UNID

TUNID = Target's Unique Network Identifier
 OUNID = Originator's Unique Network Identifier
 OCPUNID = Output Connection Owning UNID

**Figure 7 – Target Processing SafetyOpen with no configuration data
(Form 2 SafetyOpen)**



Key:

UNID = Unique Network Identifier
CPCRC = Connection Parameter CRC
SCCRC = CRC portion of the SCID
OCPUNID = Output Connection Owning UNID

TUNID = Target's Unique Network Identifier
SCID = Target's Safety Configuration ID
OUNID = Originator's Unique Network Identifier
CFUNID = Configuration Owning UNID

**Figure 8 – Target Processing for SafetyOpen with configuration data
(Form 1 SafetyOpen)**

Safety Originators that do not support any other means to determine which format to connect with can implement the logic shown in Figure 9 to dynamically determine the format.

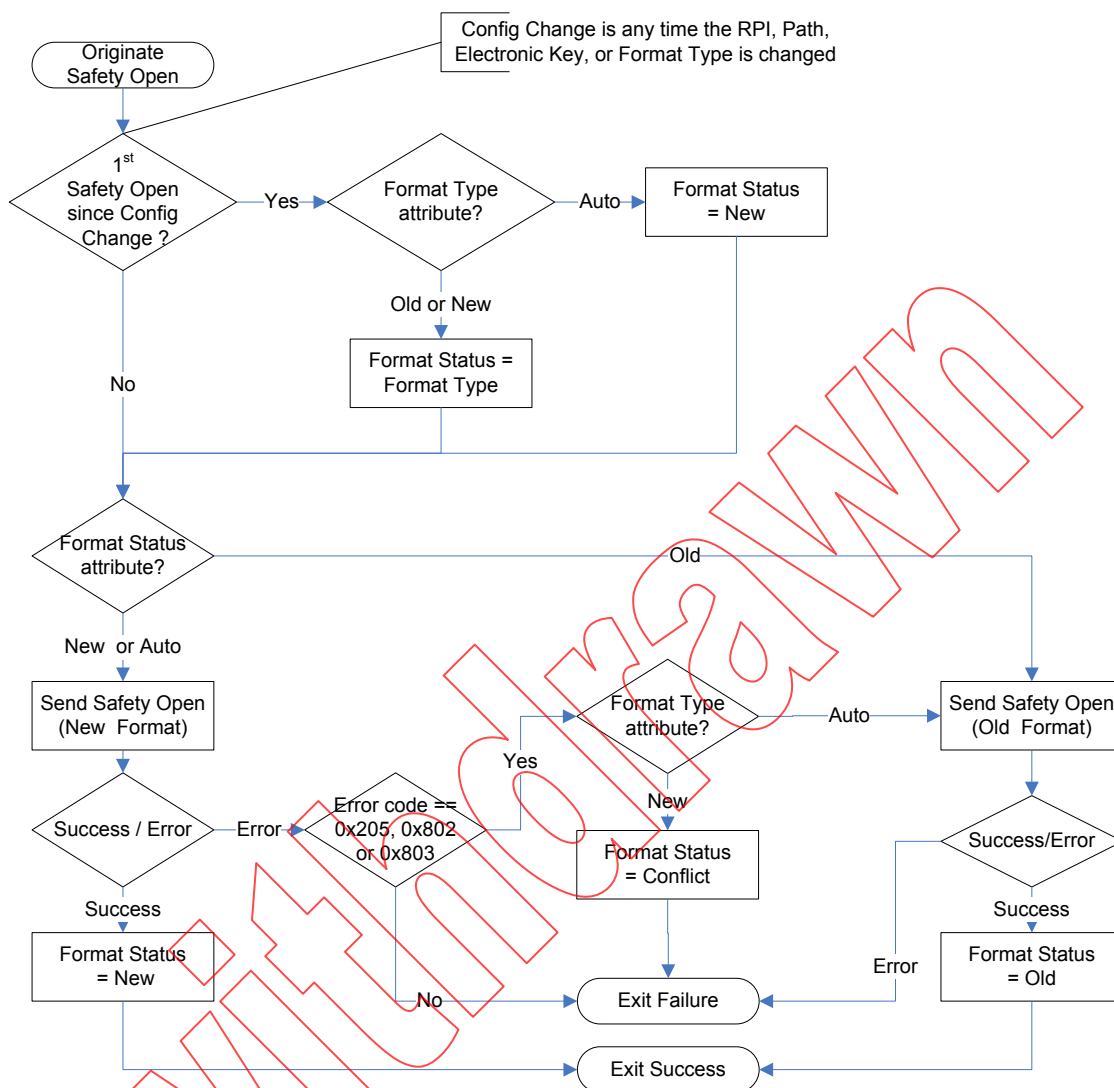


Figure 9 – Originator logic to determine which format to use

6.3.6 Checks required by Multipoint producers with existing connections

There is a distinct possibility that the safety parameters used in a ForwardOpen or SafetyOpen from various consuming originators will not always be the same. A consistent set of rules shall be used for how a Multipoint producing target evaluates these parameters when they conflict with other already established consuming connections. Table 9 defines the multipoint producer parameter evaluation rules.

Table 9 – Multipoint producer parameter evaluation rules

Safety parameter	Producer evaluation rule if connection exists	Error response ^a (if appropriate)	
		General	Extended
Ping_Interval EPI Multiplier	Shall match existing P.I.E.M.	01 _{hex} 00 _{hex}	0801 _{hex} 0012 _{hex}
Time Coord Msg Min Multiplier	Accept any (all can be different)	N/A	
Network Time Expectation Multiplier	Accept any (all can be different)	N/A	
Timeout_Multiplier	Accept any (all can be different)	N/A	
Max_Consumer_Number	Shall match existing Max_Consumer_Number	00 _{hex} 01 _{hex}	0801 _{hex} 002A _{hex}
T-to-O RPI, O-to-T RPI, and Time Correction RPI	Shall match existing connection RPIs	01 _{hex}	0111 _{hex}
Network Segment Type	Shall match existing connection format ^b	0x01	0x803
Max_Fault_Number	Accept any (all can be different)	N/A	
^a At the option of the device developer, another connection could also be opened rather than return an error response.			
^b Subsequent connection requests on an existing multi-point connection shall all be the same format as the existing connection			

6.3.7 Electronic key usage for safety

Safety originators and targets shall meet the following requirements for use of the Electronic Key segment within a SafetyOpen.

The Electronic Key segment shall be present in all SafetyOpen or Safety ForwardOpen service requests.

The Electronic Key shall always be processed by Target devices with integrity (cannot be confirmed externally).

The compatibility bit and behavior in the Electronic Key shall be supported as defined by safety originators and targets. Wildcards (fields set to 0) for individual fields within the Electronic Key shall not be supported.

6.3.8 RPI vs. API in safety connections

Safety devices do not have the ability to negotiate the RPI value. Safety Targets either accept the requested RPI because it can be supported, or it rejects it completely. The tolerance around an acceptable RPI request shall be $\pm 128 \mu s$.

The T-to-O API, O-to-T API, and Time Correction API in a success response shall always be the same value received in the SafetyOpen.

6.3.9 Application path construction for safety

IEC 61158-6-2 defines a method to construct an application path in a SafetyOpen for 3 references: one for configuration, one for consumed data and one for produced data.

The possible path types are identified as follows:

A. - [Class] [Assembly] [Instance] [Configuration-instance]

- B. - [Class] [Assembly] [Instance] [Producer-instance]
- C. - [Class] [Assembly] [Instance] [Consumer-instance]
- D. - [Class] [Assembly] [Instance] [Device-defined NULL instance])
- E. - [CNP] [Consumer CNP]
- F. - [CNP] [Producer CNP]
- G. - [CNP] [Device-defined NULL CNP]

When all 3 paths referenced the same class, they are often formatted in a compressed format: (CP stands for Connection Point).

[Class] [Class #] [Instance] [Instance #] [CNP] [Consumer CP] [CNP] [Producer CNP]

Since all three paths shall reference the same class, a NULL instance value shall be reserved in that class (by the device developers) to use the compressed form for safety. The NULL value will be used for the portion of the path that references the Time Coordination connection and configuration connection (in non-configuring originators). If a common class reference is not practical, the long form shall be used.

The following rules apply to SafetyOpen path construction:

- all devices shall support the long form at a minimum;
- a Null path or Null connection point shall be used to represent the Time Coordination connection;
- a Null path or Null connection point shall be used for the configuration path when no configuration data can ever be sent on the connection;
- on any connections, which can accept a Form 1 SafetyOpen, Originators shall always send a valid configuration path even if no configuration data is present (i.e. Form 2a).

The “Null” path or connection point used shall be one of the module’s choosing. The method of making this selection in an EDS file will be via the Data Path field in the Connection Manager section. Devices configured by configuration applet also shall provide this path.

Safety device designers can choose the path format to specify in their EDS files from the following options. The possible three-path combinations for Form 1, 2a SafetyOpen on connections, which will accept configuration are:

- [A, D, B] for the input connection;
- [A, G, F] compressed format for input connections;
- [A, C, D] for the output connection;
- [A, E, G] compressed format for output connections.

The possible three-path combinations for Form 2a, 2b SafetyOpen on connections, which will not accept configuration data are:

- [D, D, B] for the input connection;
- [D, G, F] compressed format for input connections;
- [D, C, D] for the output connection;
- [D, E, G] compressed format for output connections.

6.3.10 Safety Validator connection types

The Safety Validator function, depending on the safety connection type provided in the SafetyOpen, will always require between 2-3 connection resources. The SafetyOpen contains the connection information to allow a target to set up these connections appropriately. This

subclause will show how the connection types are determined by how the SafetyOpen shall be filled out.

One basic assumption is that connections for Time Coordination and Time Correction messages do not require a path entry since they have an implied path to the Safety Validator object coordinating the safety connection. The various connection scenarios are described in the Validator object in 6.7.

The Safety Validator function can determine which connection resources will be required by looking at the parameter in the SafetyOpen. The various SafetyOpen parameters as well as the key parameters that the safety function will need to determine the types of connections are defined in Table 10. Connection object instances may not be available due to target identifier capacity or limitations; there may be no unallocated connection identifiers. Or the device may not have the processing throughput to handle the additional connection; etc. Safety Connection objects requires resources similar to standard I/O connections.

Table 10 – ForwardOpen setting options for safety connections

O-to-T connection type	T-to-O connection type	Transport type/ trigger	App path 1	App path 2 ^a	App path 3 ^a	Max consumer number	Safety Validator connection type	Key decision factors	Target role
Point-to-point	Point-to-point	Application, Class 0, Client	Vendor defined Null Path ^b	Vendor defined Null Path	Safety Input App. object	1	Point-to-point Producer (Input)	2-point-to-point + Client	Producing connection: Safety data Consumer connection: Coordination
Point-to-point	Point-to-point	Application, Class 0, Server	Vendor defined Null Path	Safety Output App. object	Vendor defined Null Path	1	Point-to-point Consumer (Output)	2- point-to-point + Server	Consuming connection: Safety data Producing connection: coordination
Point-to-point	Multipoint	Application, Class 0, Client	Vendor defined Null Path	Vendor defined Null Path	Safety Input App. object	2-15	Multipoint Producer CP 2/3	2 – Multipoint + 1 point-to-point + Client	Producing connection: Safety data Producing connection: Correction Consuming connection: coordination
Point-to-point	Multipoint	Application, Class 0, Client	Vendor defined Null Path	Vendor defined Null Path	Safety input app. object	2-15	Multipoint Producer CP 2/2	1 – Multipoint + 1 point-to-point + Client	Producing connection: Safety data + correction Consuming connection: coordination

O-to-T connection type	T-to-O connection type	Transport type/ trigger	App path 1	App path 2 ^a	App path 3 ^a	Max consumer number	Safety Validator connection type	Key decision factors	Target role
Multipoint	Point-to-point	Application, Class 0, Server	Vendor defined Null Path	Safety output app. object	Vendor defined Null Path	2-15	Multipoint Consumer CP 2/3	2 – Multipoint + 1 point-to-point + Server	Consuming connection: Safety data Consuming connection: Correction Producing connection: coordination
Multipoint	Point-to-point	Application, Class 0, Server	Vendor defined Null Path	Safety output app. object	Vendor defined Null Path	2-15	Multipoint Consumer CP 2/2	1 – Multipoint + 1 point-to-point + Server	Consuming connection: Safety Data + correction Producing connection: coordination

^a Input and Output with respect to the network.

^b Devices configurable via EDS shall define an application Null Path in the EDS file.

Table 11 defines which network connection parameters to use for all three connections associated with each safety connection type.

Table 11 – Network connection parameters for safety connections

Target type	Network connection parameter	Proper parameter value	Description
Point-to-point producer	O-to-T	4406 _{hex}	Point-to-point high priority, fixed
	T-to-O	4408 _{hex}	Point-to-point high priority, fixed
	Time Correction	0000 _{hex}	Not used
Point-to-point producer	O-to-T	4408 _{hex}	Point-to-point high priority, fixed
	T-to-O	4406 _{hex}	Point-to-point high priority, fixed
	Time Correction	0000 _{hex}	Not used
Multipoint producer	O-to-T	4406 _{hex}	Point-to-point high priority, fixed
	T-to-O	240E _{hex}	Multipoint high priority, fixed
	Time Correction	2406 _{hex}	Multipoint high priority, fixed

Successful SafetyOpen responses shall return the connection identifiers used, as well as the Consumer_Number assigned to the originator (always FFFF_{hex} for point-to-point connections).

6.3.11 Application reply data in a successful SafetyOpen response

The format for a SafetyOpen response for Success is the same as the Forward_Open_Reply as defined in IEC 61158-6-2. The data return is defined in Table 12.

Table 12 – CP 2/3 Safety target application reply (size: 10 octets)

Parameter name	Data type	Description
Consumer_Number	UINT	
PID/CID	STRUCT of:	Target Identifier used to generate a PID or CID seed value
Target Vendor Id	UINT	Target's Vendor Id
Target Device Serial Number	UDINT	Target's Device Serial Number
Target Connection Serial Number	UINT	Connection Serial Number Target assigned to the connection. The Safety Validator instance Id shall be used

When the Target of a connection is using the Extended Format on CP 2/2 links, it shall use the 14 octet EF SafetyOpen Target Application reply defined in Table 13.

Table 13 – EF CP 2/3 Safety target application reply (size: 14 octets)

Parameter Name ^a	Data Type	Description
Consumer_Number	UINT	
PID/CID	STRUCT of:	Target Identifier used to generate a PID or CID seed value
Target Vendor Id	UINT	Target's Vendor Id
Target Device Serial Number	UDINT	Target's Device Serial Number
Target Connection Serial Number	UINT	Connection Serial Number Target assigned to the connection. The Safety Validator instance Id should be used
Initial Time Stamp ^b	UINT	Used by Consumer to initialize Last_Time_Stamp_for_Rollover
Initial Rollover Value ^b	UINT	Used by Consumer to initialize TS_Rollover_Count
^a These fields are always present in the Application Reply field. When a CP 2/3 Safety target receives a SafetyOpen that is not multipoint (thus no Time Correction connection is established) the Time_Correction_Connection_ID parameter shall be set to FFFF _{hex} . If the target is not a multipoint producer, the consumer number is set to FFFF _{hex} . ^b Consuming targets should echo back the values received in the SafetyOpen		

The target of a SafetyOpen shall return the data defined in Table 14 in the Application Reply field of the SafetyOpen response. The consumer number and PID reply data is only of significance when the originator is the consumer.

Table 14 – SafetyOpen target application reply (size: 18 octets)

Parameter name ^a	Data type	Description
Consumer_Number	UINT	
PID/CID	STRUCT of:	Target Identifier used to generate a PID or CID seed value
Target Vendor Id	UINT	Target's Vendor Id
Target Device Serial Number	UDINT	Target's Device Serial Number
Target Connection Serial Number	UINT	Connection Serial Number Target assigned to the connection. The Safety Validator instance Id shall be used
Time_Correction_Connection_ID	UDINT	Connection ID selected by the Target for the Time Correction connection. If chosen by the originator, then the value is echoed back
Time_Correction_API	UDINT	Returns same value received in the Request packet
^a These fields are always present in the Application Reply field. When a CP 2/3 Safety target receives a SafetyOpen that is not multipoint (thus no Time Correction connection is established) the Time_Correction_Connection_ID parameter shall be set to FFFF _{hex} . If the target is not a multipoint producer, the consumer number is set to FFFF _{hex} .		

When the Target of a connection is using the Extended Format on CP 2/3, it shall use the 22 octet EF SafetyOpen Target Application reply defined in Table 15.

Table 15 – EF SafetyOpen target application reply (size: 22 octets)

Parameter Name ^a	Data Type	Description
Consumer_Number	UINT	
PID/CID	STRUCT of:	Target Identifier used to generate a PID or CID seed value
Target Vendor Id	UINT	Target's Vendor Id
Target Device Serial Number	UDINT	Target's Device Serial Number
Target Connection Serial Number	UINT	Connection Serial Number Target assigned to the connection. The Safety Validator instance Id should be used
Time_Correction_Connection_ID	UDINT	Connection ID selected by the Target for the Time Correction connection. If chosen by the originator, then the value is echoed back
Time_Correction_API	UDINT	Returns same value received in the Request packet
Initial Time Stamp ^b	UINT	Used by Consumer to initialize Last_Time_Stamp_for_Rollover
Initial Rollover Value ^b	UINT	Used by Consumer to initialize TS_Rollover_Count
^a These fields are always present in the Application Reply field. When a CP 2/3 target receives a SafetyOpen that is not multipoint (thus no Time Correction connection is established) the Time_Correction_Connection_ID parameter shall be set to 0xFFFF. If the target is not a multipoint producer, the consumer number is set to 0xFFFF.		
^b Consuming targets should echo back the values received in the SafetyOpen.		

6.3.12 Unsuccessful SafetyOpen response

The SafetyOpen has some special error cases that do not map to the existing set of error codes, and extends the definition of existing error codes.

Table 16 defines new extended error codes for safety and shows the extended definition of existing error codes.

Table 16 – New and extended error codes for safety

General status	Extended status	Explanation
01 _{hex}	0105 _{hex}	Ownership conflict or OUNID mismatch. The configuration is already owned by another originator
01 _{hex}	0106 _{hex}	Ownership conflict or OUNID mismatch. The output connection was already owned by another originator
01 _{hex}	0205 _{hex}	Parameter Error in Unconnected Send service or Parameter Error in SafetyOpen or SafetyClose
01 _{hex}	801 _{hex}	Incompatible Multipoint RPI. An existing connection has been established at a different RPI
01 _{hex}	802 _{hex}	Invalid Safety Connection size
01 _{hex}	803 _{hex}	Invalid Safety Connection format
01 _{hex}	804 _{hex}	Invalid Time Correction Connection Parameters
01 _{hex}	805 _{hex}	Invalid Ping Interval EPI Multiplier
01 _{hex}	806 _{hex}	Time Coordination Msg Min Multiplier
01 _{hex}	807 _{hex}	Network Time Expectation Multiplier
01 _{hex}	808 _{hex}	Timeout Multiplier
01 _{hex}	809 _{hex}	Invalid Max Consumer Number
01 _{hex}	80A _{hex}	Invalid CPCRC
01 _{hex}	80B _{hex}	Time Correction Connection Id Invalid
01 _{hex}	80C _{hex}	SCID Mismatch. The SCID was non-zero and did not match the value in the target
01 _{hex}	80D _{hex}	TUNID not set. Device is out-of-box and TUNID has not been set, so connections are not allowed
01 _{hex}	80E _{hex}	TUNID Mismatch. The TUNID provided does not match. The message was likely routed to this node in error
01 _{hex}	80F _{hex}	Configuration operation not allowed

Event/Error Matrix Table 17 provides guidance for which error codes to use for possible errors detected in processing a SafetyOpen. This is not intended to be an exhaustive list.

Table 17 – SafetyOpen error event guidance table

Event	Error type	General status	Extended status
The target device received a SafetyOpen request in states of Safety Supervisor object other than Idle and Executing	Configuration operation not allowed	01 _{hex}	080F _{hex}
	Device not configured	01 _{hex}	110 _{hex}
Safety Connection Type (name) Invalid	Safety parameter error – Invalid Connection Type	01 _{hex}	315 _{hex}
Safety Connection Size Invalid	Safety parameter error – Invalid Safety Connection Size	01 _{hex}	0802 _{hex}

Event	Error type	General status	Extended status
Safety Connection Format Invalid	Safety parameter error – Invalid Safety Connection Format	01 _{hex}	0803 _{hex}
Time Correction Connection Parameters Invalid	Safety parameter error – Invalid Time Correction Connection Parameters	01 _{hex}	0804 _{hex}
Ping Interval EPI Multiplier was out of the range	Safety parameter error – Invalid Ping Interval EPI Multiplier	01 _{hex}	0805 _{hex}
Time Coordination Message Min Multiplier was out of the range	Safety parameter error – Time Coordination Msg Min Multiplier	01 _{hex}	0806 _{hex}
Time Expectation Multiplier was out of the range	Safety parameter error – Time Expectation Multiplier	01 _{hex}	0807 _{hex}
Timeout Multiplier was out of the range	Safety parameter error – Timeout Multiplier	01 _{hex}	0808 _{hex}
Max Consumer Number not within the limits in Multipoint Producer	Safety parameter error – Invalid Max Consumer Number	01 _{hex}	0809 _{hex}
CPCRC value in SafetyOpen and calculated CPCRC value	Safety parameter error – Invalid CPCRC	01 _{hex}	080A _{hex}
Time Correction Connection Id Invalid	Safety parameter error – Time Correction Connection Id invalid	01 _{hex}	080B _{hex}
RPI requested is incompatible with previously established multipoint connections	Incompatible multipoint RPI	01 _{hex}	801 _{hex}
O-to-T RPI, T-to-O RPI, or Time Correction RPI is not supported	RPI not supported	01 _{hex}	0111 _{hex}
All Safety Validator Instances are being used	Connection Manager or connection object cannot support any more connections	01 _{hex}	0113 _{hex}

6.3.13 ForwardClose for safety

There are no additional behaviors defined for the ForwardClose service when used to close a Safety connection. In the following Safety Requirements, the term “SafetyClose” refers to both the ForwardClose of the Connection Manager object and the SafetyClose of the Connection object.

The SafetyClose Service shall be used to close connections with a Safety Targets (and in the case of a ForwardClose all other nodes in the connection path).

The SafetyClose request shall remove a connection from all the nodes participating in the original connection.

The SafetyClose request shall cause all resources in all nodes participating in the connection to be deallocated, including connection IDs, bandwidth, and internal memory buffers.

Targets receiving the SafetyClose service request shall close the connection who's Originator Vendor ID, Connection Serial Number, and Originator Serial Number parameters match. Additional information provided by this service (ie, Connection Path) shall be ignored by the target.

A SafetyClose Success reply shall be returned after the connection has been deleted at the target.

When a SafetyClose success reply is received, the originator and each intermediate node along the path, closes the connection and releases resources associated with that connection. But the originator shall also close the connection if no response is received within a vendor selected wait period.

6.4 Identity object

6.4.1 General

Class Code: 01hex

This subclause describes changes to the Identity object to support safety.

All CPF 2 safety devices shall replace the Identity object state behavior with the behavior defined in the Safety Supervisor object.

6.4.2 Changes to common services

Table 18 defines the services of the Identity object that require updates.

Table 18 – Identity object common service changes

Service code	Need in implementation		Service name	Description of service
	Class	Instance		
05 _{hex}	Optional	Conditional ^a	Reset	Invokes the Reset Service for the device
^a Conditional – The Identity object Reset service shall not be supported in safety devices (reply to any requests with "Service Not Supported" error). The service shall be replaced by the Reset service defined by the Safety Supervisor.				

6.5 Link objects

6.5.1 DeviceNet object changes

6.5.1.1 Additional attribute for safety

Class Code: 03hex

This subclause defines the changes and additions required of the DeviceNet object to support safety. An attribute shall be added to allow the Safety Network Number (SNN) to be read. The definition for this attribute is defined in Table 19.

Table 19 – New DeviceNet object instance attribute

Attrib ID	Need in implem.	Access rule	Name	Data type	Description of attribute	Semantics of value
11	Required	Get	Safety Network Number	6 OCTETS	System-wide unique number for the subnet this device resides on	Attribute shall contain the SNN portion of the TUNID in the Safety Supervisor. See 8.2 for further definition of this attribute