Sequential Muting of a Light Curtain with S7-1500

SIMATIC Safety Integrated for Factory Automation

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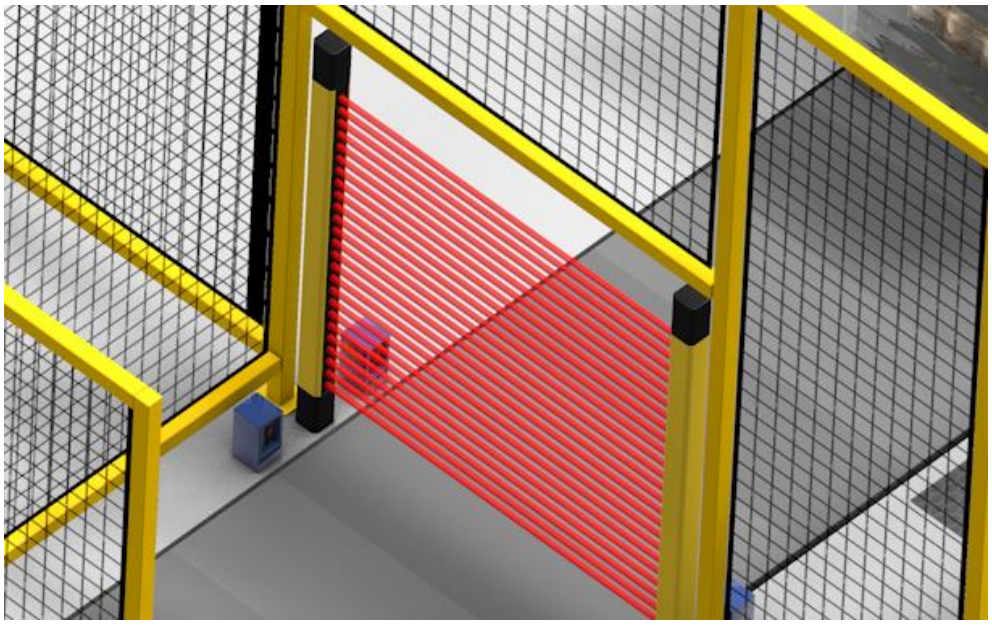
1 Task

1.1 Starting point

Workpieces are machined in an assembly cell. The assembly cell is surrounded by a fence to prevent personnel from entering the hazard area and has an access to transport workpieces on a conveyor inside.

Figure 1-1



1.2 Task

Access to the assembly cell is to be protected with a safety light curtain. When the protective field is violated (interruption of the light curtain), a distinction is to be made between the following situations:

- Transport of workpieces: do not stop the machine
- No transport of workpieces: stop the machine

For monitoring, a SICK safety light curtain is to be used in conjunction with a fail-safe SIMATIC S7 CPU (F-CPU).

2 Solution

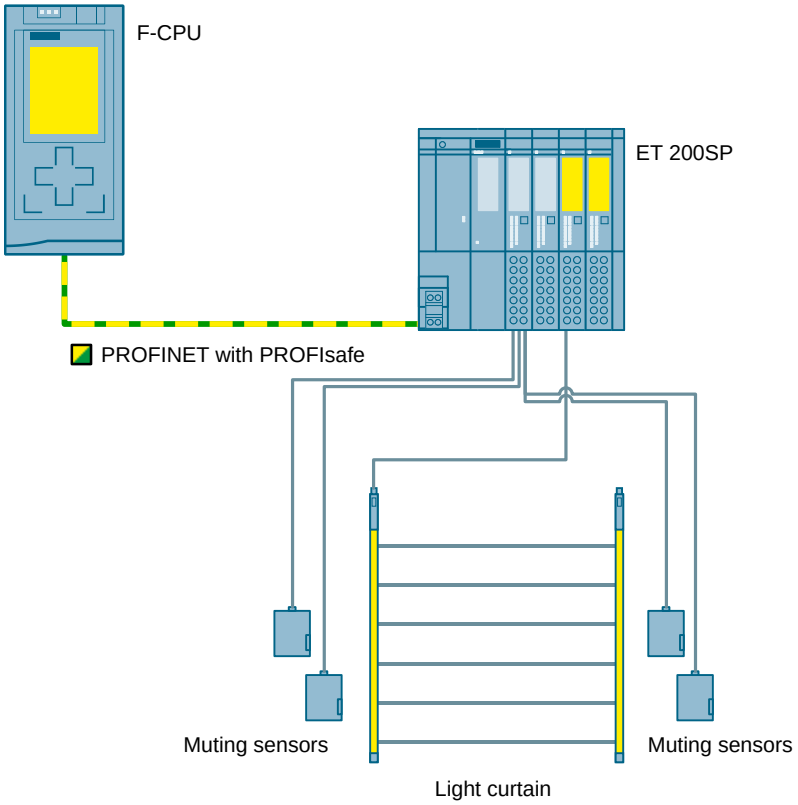
2.1 Overview

So-called “muting” is used to distinguish if the protective field is violated by the transport of workpieces or by other reasons. Muting is the intentional suppression of the protective function of light curtains – the light curtain is “muted” temporarily. For this purpose, muting sensors are installed on both sides of the light curtain which determine in which cases to activate muting. This allows transporting workpieces out of the work area without interrupting the production flow and at the same time monitoring access to the hazard area.

Figure 2-1 schematically shows the most important components of the application example:

- SIMATIC F-CPU (IO controller)
- Distributed I/O SIMATIC ET 200SP (IO device) with DI, DQ, F-DI, F-DQ
- SICK safety light curtain
- SICK photoelectric retro-reflective sensors as muting sensors

Figure 2-1



The actuators will not be elaborated on in this application example. Light indicators are used to represent the conveyor and the processing machine in the assembly cell. These are called “conveyor” and “machine” below.

2.2 Description of the core functionality

The following functions are implemented in the application example:

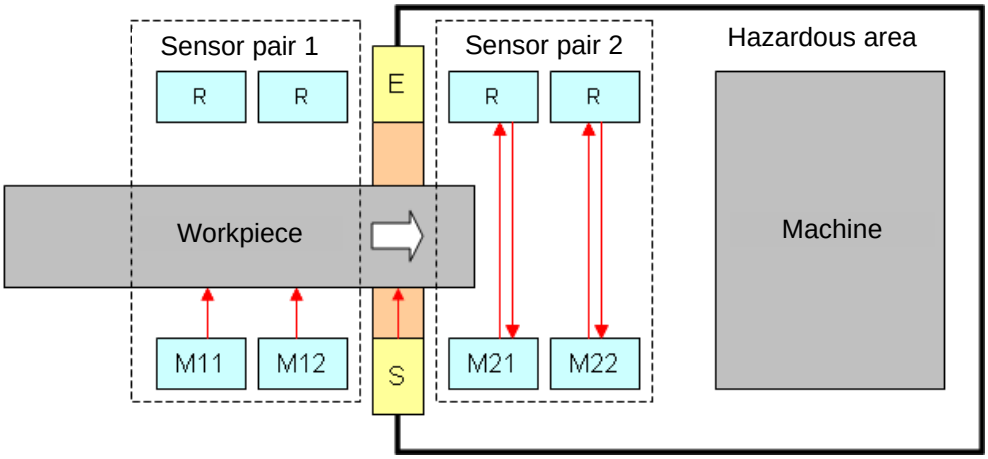
- Switching a conveyor and a machine
- Switching off the conveyor and the machine, when the detection zone of the light curtain is violated
- Muting the light curtain using F-CPU
- Freeing of workpieces

Sequential muting with 4 muting sensors (2 sensor pairs) is implemented in the application example. Photoelectric retro-reflective sensors are used as muting sensors.

For the transport direction of the workpiece, both directions are permitted:

- Transport into the assembly cell (“forward”)
- Transport out of the assembly cell (“reverse”)

Figure 2-2



Explanations

S: Light curtain sender

S: Light curtain receiver

Silhouetted in orange: Protective field of the light curtain

M: Muting sensor (photoelectric retro-reflective sensor)

R: Reflector of the photoelectric retro-reflective sensor

2.3 Hardware and software components

The application example was created with the following components.

Hardware components

Manufactured by Siemens

Table 2-1

Component	Type	Number	Article number
DIN rail	Length 482 mm	1	6ES7590-1AE80-0AA0
Fail-safe S7 CPU (F-CPU)	CPU 1516F-3 PN/DP	1	6ES7516-3FN00-0AB0
Memory Card	24 Mbytes	1	6ES7954-8LF02-0AA0
DIN rail	35 mm, length: 483 mm	1	6ES5710-8MA11
IM of the ET 200SP	IM 155-6PN ST incl. bus adapter 2xRJ45	1	6ES7155-6AA00-0BN0
DI	8x24VDC ST	1	6ES7131-6BF00-0BA0
DQ	8x24VDC/0.5A HF	1	6ES7132-6BF00-0CA0
F-DI	8x24VDC HF	1	6ES7136-6BA00-0CA0
F-DQ	4x24VDC/2A PM HF	1	6ES7136-6DB00-0CA0
Base unit for DI	Push-in, 10 AUX, supply terminals separated	1	6ES7193-6BP00-0DA0
Base unit for DQ, F-DI, F-DQ	Push-in, supply terminals bridged	3	6ES7193-6BP00-0BA0
Pushbutton for start, acknowledgment (NO)	SIRIUS pushbutton, indicator light	2	3SU1
Pushbutton for stop (NC)		1	
Indicator light		4	
Power supply	Load current supply PM 190W	1	6EP1333-4BA00

Manufactured by SICK

Table 2-2

Component	Type	Number	Article number
Safety light curtain SICK C4000 Eco Sender, M12	C40S-0303AA310	1	1027464
Safety light curtain SICK C4000 Eco Receiver, M12	C40E-0303AN310	1	1027465
Connecting cable with connector	DOL-1205-G02M	2	6008899
Retro-reflective sensor Red-emitting LED, with potentiometer, PNP, M12 connector, 4-pin	WL27-3P2431	4	1027982
Reflector	PL30A	4	1002314
Connecting cable	DOL-1204-G02M	4	6009382

Software components

Table 2-3

Component	Article number	Type
STEP 7 Professional	6ES7822-1AA03-0YA5	V13 SP1
STEP 7 Safety Advanced	6ES7833-1FA13-0YA5	V13 SP1

Sample files and projects

The following list includes all files and projects that are used in this example.

Table 2-4

File name	Content
58793869_Muting_Light_Curtain_DOC_V30_en.pdf	This document
58793869_Muting_Light_Curtain_PROJ_V30.zip	TIA Portal project
LMutSV20.zip	Library for realizing the muting function

2.4 Advantages

SIMATIC Safety Integrated for Factory Automation

In SIMATIC, standard applications and failsafe applications can be implemented with a single system (hardware and software).

This has the following advantages:

- One controller for both applications
- Uniform engineering for both applications
- One bus system for communication for both applications
- Uniform, centrally accessible diagnostics for both applications
- Easy connection of the safety program to the standard user program

Special instructions are available for programming safety-related applications. Examples: Two-hand monitoring, discrepancy analysis, muting, EMERGENCY STOP, safety door monitoring, feedback loop monitoring.

Safety light curtains by SICK (/11/)

SICK offers a wide range of safety light curtains:

- Cost-saving complete systems with integrated functions
- Rapid commissioning
- Individual adaptation using CDS user software or customer-specific presettings from the factory
- Can be used with large temperature fluctuations as well as in wet areas
- Reduced engineering and stock-holding costs due to a universal interface
- Integrated PSDI mode with defined PSDI window provides up to 30% higher productivity

2.5 Assumed knowledge

The application example shows the principle of how a light curtain can be operated on an F-CPU. It does not describe details. Therefore, basic knowledge of the following topics is required:

- Software for SIMATIC controllers:
  - STEP 7 Professional V13 SP1 (/10/)
  - STEP 7 Safety Advanced V13 SP1 (/7/)
- Modular Controller SIMATIC S7-1500 (/3/)
- SIMATIC Distributed I/O System ET 200SP (/5/)
- ET 200SP Fail-safe modules (/6/)
- Industrial Communication PROFINET (/9/)
- SICK Safety light curtain C4000 (/11/)
- SICK Photoelectric Retro-Reflective Sensor (/11/)

3 Basics

3.1 Muting

3.1.1 Definition

Muting is the intentional suppression of the protective function of light curtains.

Muting can, for example, be used to transport workpieces into the hazardous area monitored by a light curtain without stopping the machine.

Muting is initiated by signals from muting sensors.

DANGER

It must be ruled out that a person generates the same signal sequence as a transported object.

The position of the muting sensors and correct integration into the production process must ensure that no person can enter the hazardous area while muting is active.

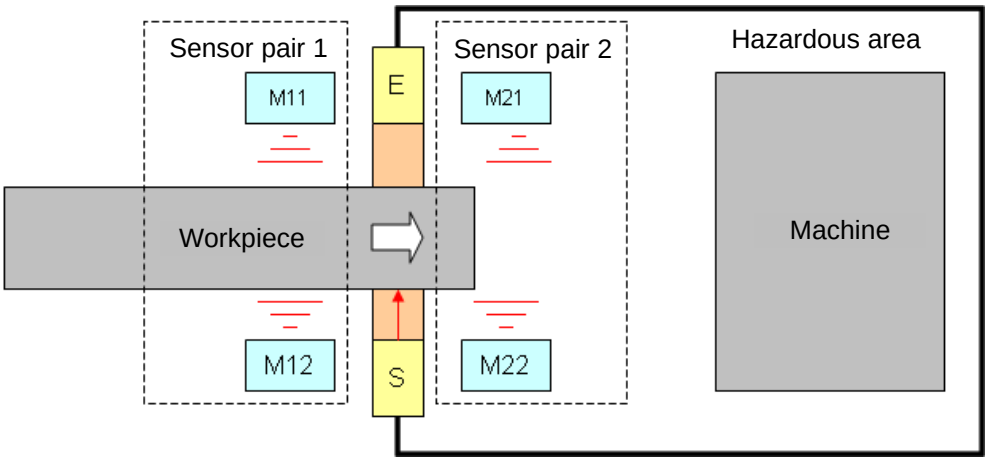
3.1.2 Alternative muting sensor arrangements

The muting function can be realized in different ways. Two alternatives for sequential muting are presented below. How sequential muting works is explained in detail in chapter 4.1.

Parallel muting with four sensors

Diffuse reflection light scanners or inductive proximity sensors can be used as an alternative to the photoelectric retro-reflective sensors. The two sensors of a sensor pair are then arranged opposite to one another. This offers advantages when there is limited space on the plant.

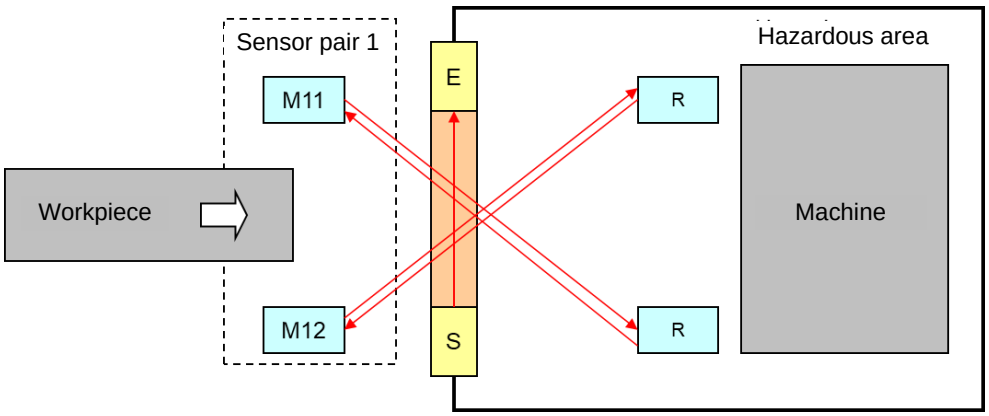
Figure 3-1



Two diagonally opposite muting sensors

Instead of four muting sensors, two crossed sensors are installed. This has the benefit of having to use fewer sensors. However, the correct arrangement is more complex, and the workpieces must have a minimum length and width. The intersection of the two sensors should be behind the protective device in the direction of the hazardous area to prevent triggering of the switching- or bridging function by unexpected material or persons. The distance between the protective field and the intersection should be as small as possible, so that an unrecognized access of a person following the transported material is not possible.

Figure 3-2



Muting sequence:

- When the two muting sensors M11 and M12 are activated by the workpiece (switch to “1” signal) within a configured discrepancy time, muting will start.
- As long as both muting sensors M11 and M12 are activated, muting remains active.
- Muting will only be terminated if one of the two muting sensors M11 and M12 is deactivated (switches to “0” signal).
- Muting must be terminated within the set maximum duration.

3.2 Safety light curtain SICK C4000 Eco

The application example focuses on the use of a safety light curtain for SIMATIC Safety Integrated for Factory Automation.

A safety light curtain from SICK is used as an example.

This chapter describes the basics of the SICK C4000 Eco safety light curtain (/11/).

Field of Application

The C4000 safety light curtain is electro-sensitive protective equipment. The device is suitable for:

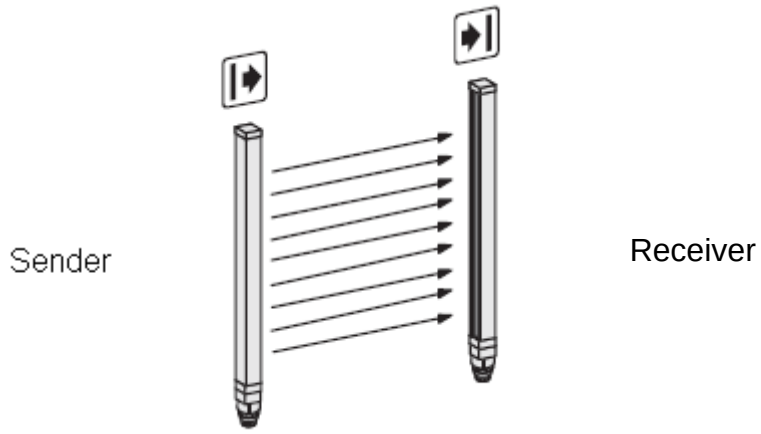
- Hazardous point protection (finger and hand protection)
- Hazardous area protection
- Access protection

Function Principle

The C4000 safety light curtain consists of a sender and a receiver (Figure 3-3). Between these two units is the protective field, defined by the protective field height and the protective field width.

Sender and receiver automatically synchronize themselves optically. An electrical connection between the two components is not necessary.

Figure 3-3



The receiver provides two safety-relevant switching outputs (OSSD1, OSSD2). When the protective field is violated, both switching outputs will switch off (“0” signal).

Connection to the F-CPU

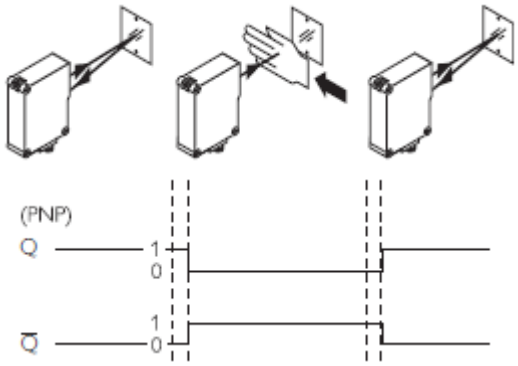
The receiver of the light curtain provides the fail-safe OSSD1 and OSSD2 signals. The signals are connected to a fail-safe digital input module (F-DI) of the ET 200S and evaluated in this module. The F-CPU reads in the result via the process input images.

If the detection zone is violated (the light curtain is interrupted), the F-CPU will read a “0” signal from the F-DI. The safety program in the F-CPU will then initiate that the machine is stopped.

3.3 Photoelectric retro-reflective sensor SICK WL27-3

SICK photoelectric retro-reflective sensors of the WL27-3 series are used as muting sensors. Figure 3-4 shows the function principle (/11/).

Figure 3-4



In the application example, the $\overline{Q}$ signal is evaluated:

- Light beam not interrupted:
  $\overline{Q}$ provides “0” signal (sensor inactive)
- Light beam interrupted:
  $\overline{Q}$ provides “1” signal (sensor active)

4 Function Principle

4.1 Functionality of the application example

Sequential muting with 4 muting sensors is implemented in the application example. Photoelectric retro-reflective sensors are used as muting sensors. The muting function is activated by the muting sensors once the correct switching order and the discrepancy times of the muting sensors have been met.

The muting function is designed for both transport directions:

- Transport into the assembly cell (“forward”)
- Transport out of the assembly cell (“reverse”)

Depending on the transport direction of the workpiece, the muting sensors must switch in the following sequence (light abeam is interrupted) to active and maintain the muting function:

- “forward”: M11 → M12 → M21 → M22
- “reverse”: M22 → M21 → M12 → M11

When the object leaves the detection zone, the muting sensors must be deactivated in the above-mentioned order (light beam no longer interrupted).

The detection of an incorrect switching sequence leads to the fail-safe shutdown of the conveyor and the machine.

4.1.1 Transporting a workpiece without active muting function

If the muting function is not activated when the workpiece enters the assembly cell or a person tries to enter it, the interruption of the light curtain will lead to a fail-safe shutdown of the conveyor and the machine.

Table 4-1

Signal	Hardware	Explanations	
START	Start button	Positive edge:	Start the machine
STOP	Stop button	“0” signal:	Shut down the machine
ACK	Acknowledgment button	Positive edge:	Acknowledgment
OSSD	Light curtain output	“0” signal:	Detection zone violation
ACTUATOR	Machine and conveyor	---	

Figure 4-1

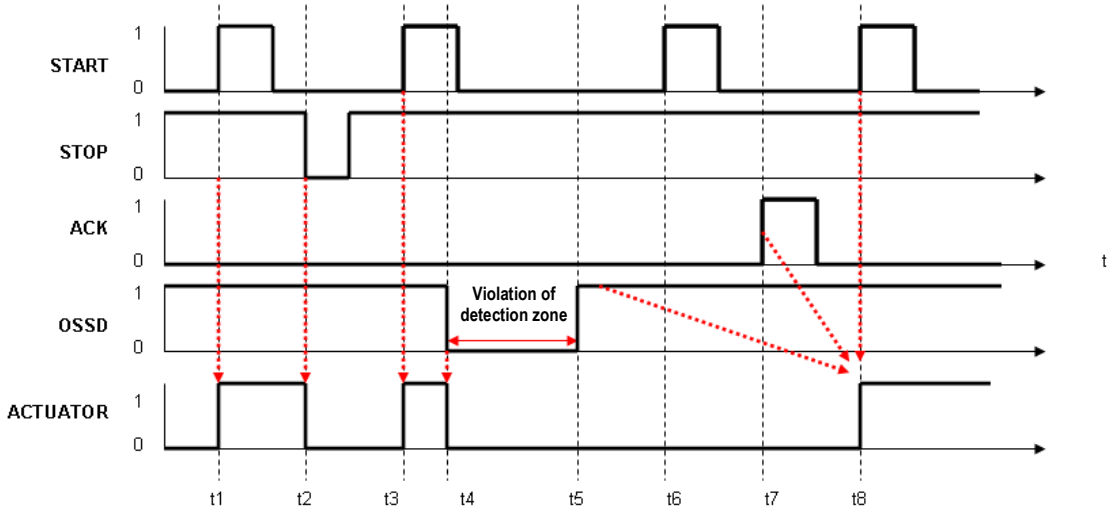


Table 4-2 Explanation of the times t from Figure 4-1

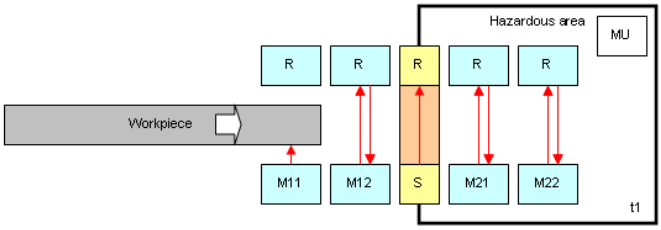
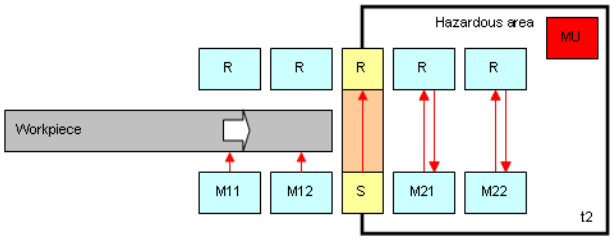
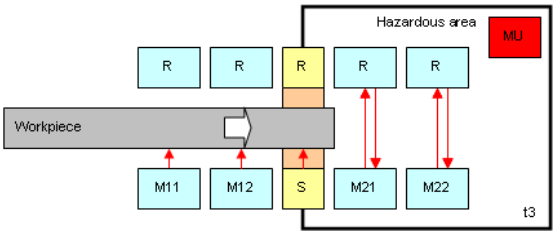
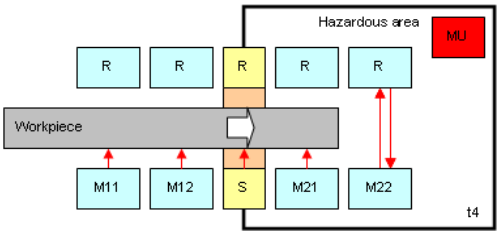
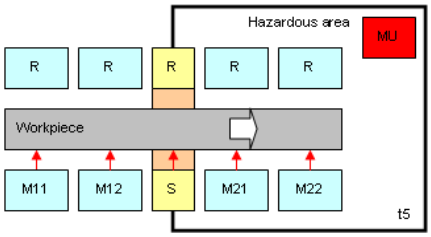
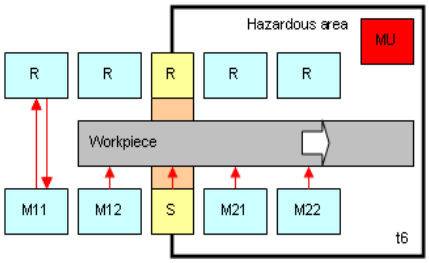
Time	Explanations
t1	Start the machine
t2	Stop the machine
t3	Start the machine
t4	Detection zone violation → Shutdown machine
t5	Protective field unoccupied again
t6	Machine cannot be started due to missing acknowledgment
t7	Acknowledgment
t8	Start the machine

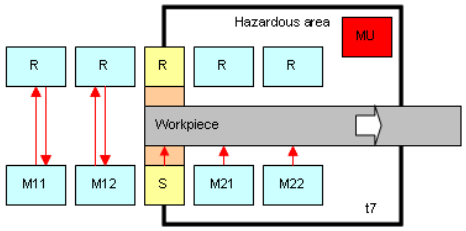
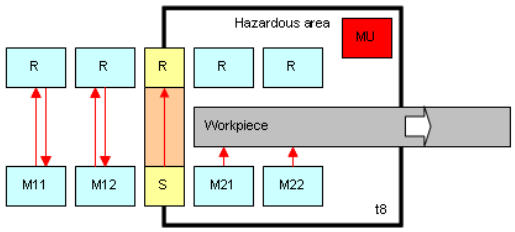
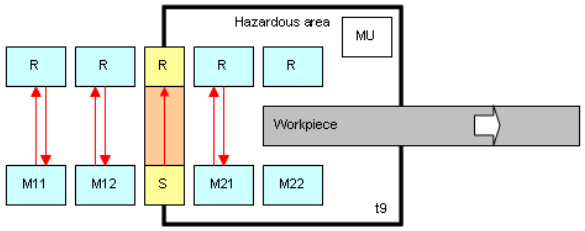
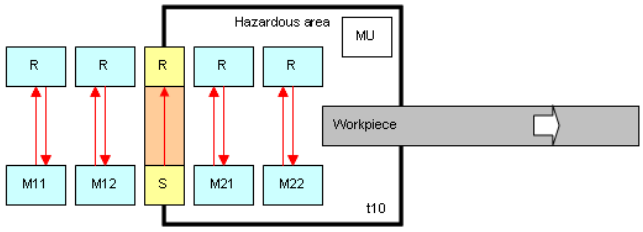
4.1.2 Transporting a workpiece with active muting function

The activation of the muting function by the transport of the workpiece into the assembly cell (“forward” transport direction) is described below.

Graphic representation of the muting function sequence

Table 4-3

tx	Workpiece position	Comments
t1		Muting is activated when both applies: • Sensor M11 is activated (light beam is interrupted) • Sensor M12 is also activated within the set discrepancy time.
t2		
t3		The workpiece violates the protective field, and the machine is not stopped.
t4		Muting is maintained when both applies: • The two sensors M21 and M22 are activated within the set discrepancy time • all four sensors were active simultaneously before M11 is deactivated
t5		
t6		

tx	Workpiece position	Comments
t7		
t8		
t9		Muting ends when sensor M21 is deactivated
t10		

Legend:

tx: Time x (Figure 4-2)

S: Light curtain sender

S: Light curtain receiver

M: Muting sensor (photoelectric retro-reflective sensor)

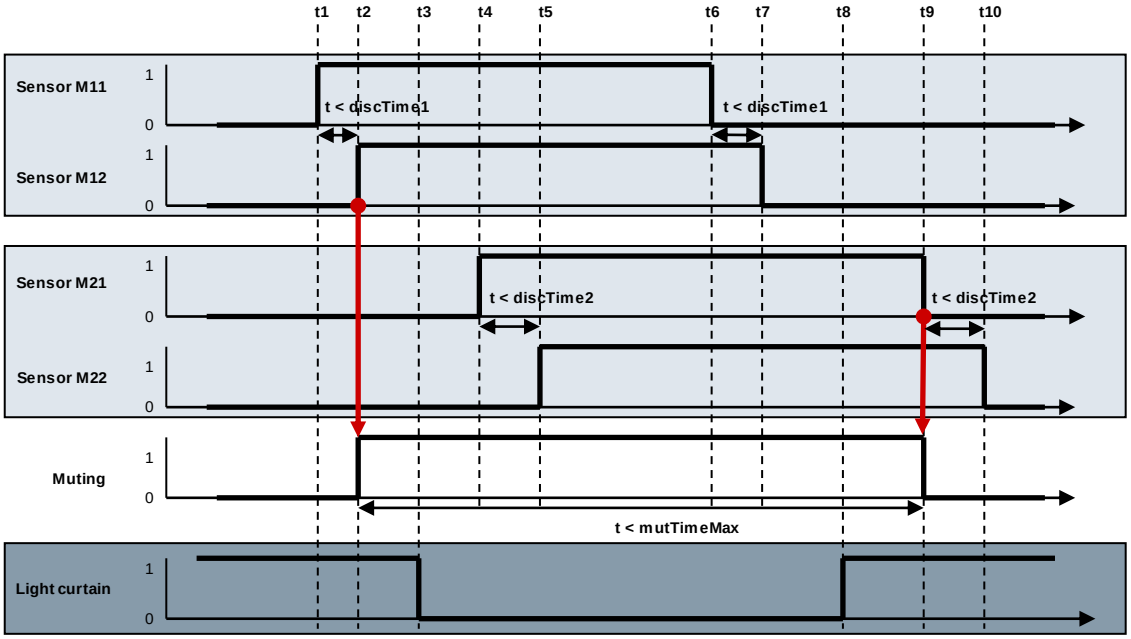
R: Reflector of the photoelectric retro-reflective sensor

MU: Muting indicator light (off: white background, on: red background)

Signal characteristics

Figure 4-2 shows the shows the signal characteristics when the workpiece is transported through the plant. Times t1 to t10 correspond to Table 4-3.

Figure 4-2



Monitoring times:

- discTime1: Discrepancy time for sensor pair 1 (M11, M12)
- discTime2: Discrepancy time for sensor pair 2 (M21, M22)
- mutTimeMax: Max. admissible duration of the muting function

"Reverse" transport direction

Muting is initiated, when sensor M22 is activated (light beam is interrupted) and sensor M21 is also activated within the configurable time (discrepancy time for sensor pair 2).

In error-free operation, muting ends when sensor M12 is deactivated (light beam no longer interrupted)

Muting light indicator

By being permanently illuminated, the indicator light signals to the operating staff that muting is active and therefore the protective function is bridged.

The muting light indicator is monitored for wire break by the F-DQ module. If a wire break is detected, muting will be terminated, and the conveyor and machine will be stopped.

Before the machine can be restarted, the workpiece must be retracted, the wire break must be corrected, and the acknowledgment pushbutton must be pressed.

Termination of muting

In case of errors, muting will be terminated, and the conveyor and machine will be switched off.

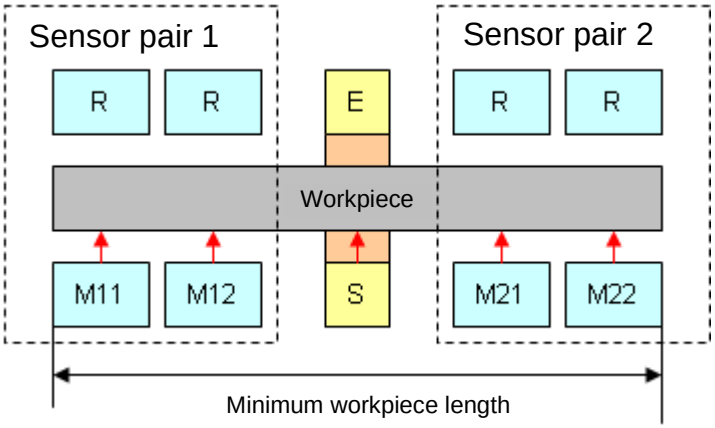
Errors that may occur during muting:

- Monitoring times are not complied with:
  - Discrepancy time for sensor pair 1 (M11, M12)
  - Discrepancy time for sensor pair 2 (M21, M22)
  - The maximum duration for active muting is exceeded
- The workpiece does not have the required minimum length (see next section).
- The muting sensors switch in an illogical order (e.g. M11 and M21)
- Hardware error (e.g. wire break)

Minimum length of the workpiece

For error-free muting, the minimum length of the workpiece must be at least the distance of the two outer muting sensors. If shorter workpieces are transported, the correct switching sequence is not maintained.

Figure 4-3



4.1.3 Free function

In case of error, the conveyor and the machine are shut down immediately and can only be switched on again, once the light curtain and the four muting sensors are unoccupied and the error has been acknowledged.

A free function has been implemented to be able to retract the workpiece from the detection zone in case of error.

The free function is activated by pressing the acknowledgment button twice within 4 seconds and holding it down. As long as the free function is active, the conveyor can be moved.

The free function is deactivated automatically under the following conditions:

- The acknowledgment pushbutton is released.
- All muting sensors are inactive.
- The maximum duration for active muting is exceeded.

After the workpiece has been successfully retracted, the error must be acknowledged with the acknowledgment button.

4.1.4 Reintegration of F-I/O

If an error occurs in a channel of the F-I/O (e.g. wire break), this results in the passivation of this channel. Once the error has been rectified, the passivated channel must be re-integrated. This is done with the ACK_GL command.

4.2 Description of the code (STEP 7 project)

4.2.1 Overview

The code (STEP 7 project) contains the user program for the F-CPU.
The user program consists of:

- Standard user program
- Safety program

Standard user program

Figure 4-4

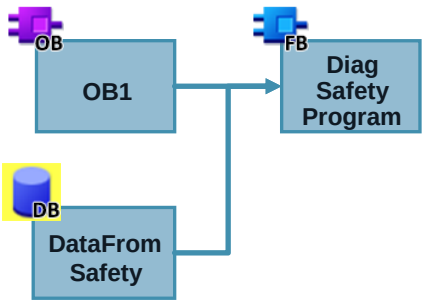


Table 4-4

Program block	Function
Main	Calling the “DiagSafetyProgram” block.
DataFromSafety	The diagnostics information of the “LMutS_Main” function block are stored in Word data type and evaluated by “DiagSafetyProgram”.
DiagSafetyProgram	This function block evaluates the diagnostics information in Word data type from “DataFromSafety”, stores it in the same data block as UDT and sets the non-failsafe outputs for the indicator lights.

Safety program

Figure 4-5

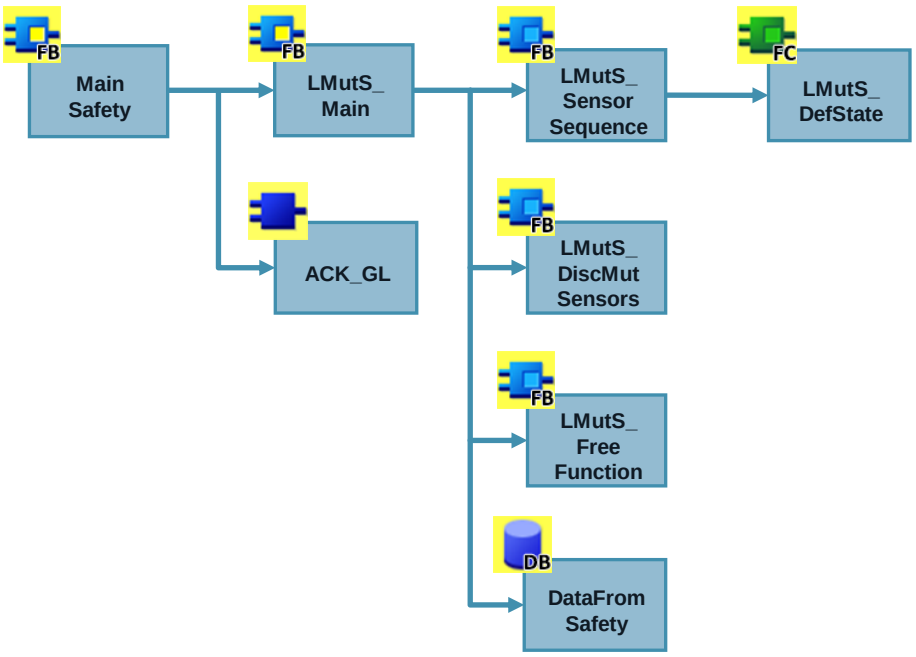


Table 4-5

Program block	Function
MainSafety	In this function block, “LMutS_Main” is called up and the outputs for the actuators for the conveyor and machine are set. Additionally, the “ACK_GL” command for the re-integration of passivated channels is executed.
LMutS_Main	This block realizes sequential muting and calls up the subordinate blocks.
DataFromSafety	The diagnostics information of the “LMutS_Main” function block is stored in Word data type in this data block.
ACK_GL	Reintegration of passivated channels.

4.2.2 Library LMutS

The library „LMutS“ realizes the sequential muting function and consists oft he following program blocks and data types.

Table 4-6 Program blocks of the library „LMutS“ V2.0.0 for STEP 7 V13 SP1

Name	Typ	Version	Beschreibung
LMutS_Main	FB	V1.1.0	Realizes sequential muting and calls up the subordinate blocks. User interface of the library.
LMutS_DefState	FC	V1.0.0	Sets and resets the states of the state machine in „LMutS_SensorSequence“.
LMutS_DiscMut Sensors	FB	V1.0.1	Monitoring of discrepancy time between the two muting sensors of a sensor pair.
LMutS_Sensor Sequence	FB	V2.0.0	Monitoring the switching sequence of the muting sensors for plausibility.
LMutS_FreeFunction	FB	V1.0.1	Provides a free function if the safety function has shut down the material transport equipment due to an error while the material is between the muting sensors.
LMutS_typeDiag	Datentyp	V1.0.0	Diagnoseinformationen des Bausteins „LMutS_Main“ in einzelnen Bits.

4.2.3 MainSafety

This block contains all safety-relevant block calls. In addition, the conveyor and machine are controlled, and passivated channels are re-integrated.

Conveyor and machine can be switched on with a start button as long as the enable signal of the safety function #Q from “LMutS_Main” is applied. In addition, the conveyor can be switched on if the free function is active.

Both functions can be switched off with a stop button.

In addition, the “ACK_GL” command for the simultaneous reintegration of all F I/Os/channels of the F I/Os of an F runtime group after communication errors or F I/O/channel errors.

Examples of events that cause passivation:

- Wire break on the F-DQ
- Missing power supply on the F-DI

Note If an error occurs on the hardware, it may take a couple of seconds until the module detects that the error has been removed (e.g. detected wire break). Only then is there an effect from pressing the acknowledgment button.

4.2.4 LMutS_Main

Function

The block monitors the light curtain and realizes sequential muting. In it, all other blocks involved in the safety function are called.

The block evaluated, when the muting function is activated and deactivated and evaluates possible errors.

Parameter

Figure 4-6

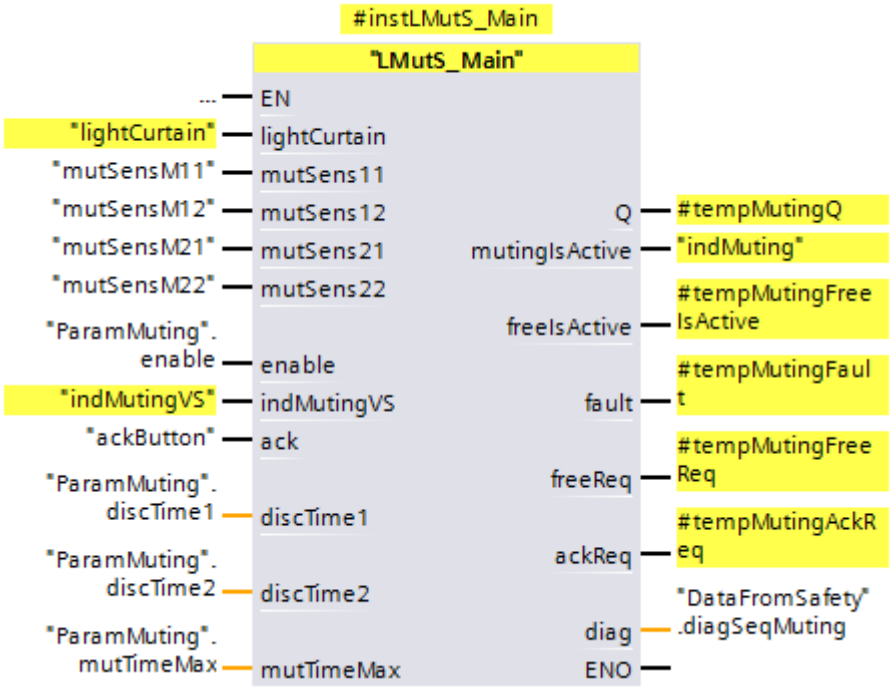


Table 4-7

Parameter	Declaration	Type	Description
lightCurtain	IN	Bool	Enable signal from light curtain. “1” signal: Detection zone not violated
mutSens11	IN	Bool	Sensor pair 1, muting sensor 1
mutSens12	IN	Bool	Sensor pair 1, muting sensor 2
mutSens21	IN	Bool	Sensor pair 2, muting sensor 1
mutSens22	IN	Bool	Sensor pair 2, muting sensor 2
enable	IN	Bool	Enabling the muting function. “0” signal: The muting sensors are not monitored. Muting is not activated.
indMutingVS	IN	Bool	Value status of the F-DQ channel to which the muting light is connected
ack	IN	Bool	Acknowledging errors
discTime1	IN	Time	Max. admissible discrepancy time for sensor pair 1

Parameter	Declaration	Type	Description
discTime2	IN	Time	Max. admissible discrepancy time for sensor pair 2
mutTimeMax	IN	Time	Max. admissible duration of the muting function
Q	OUT	Bool	Enable signal of the safety function
mutingIsActive	OUT	Bool	Muting function is active
freeIsActive	OUT	Bool	Free function is active
fault	OUT	Bool	Signal for a detected error in the safety program
freeReq	OUT	Bool	The workpiece must be retracted
ackReq	OUT	Bool	User acknowledgment required
diag	OUT	Word	Diagnostics information

Function Principle

At the beginning, the “LMutS_DiscMutSensors” function block is called up for each of the two sensor pairs. It monitors the time discrepancy of two muting sensors of a sensor pair. If the max. admissible discrepancy time is exceeded, an error bit is set which prevents /deactivates the muting function and safely shuts down the machine.

Then, the “LMutS_SensorSequence” function block is called which monitors the switching sequence with a state machine.

As the muting function shall be active for both directions of transport, there are two states in which the muting function is activated or deactivated.

Figure 4-7 Workpiece positions with activation of the muting function

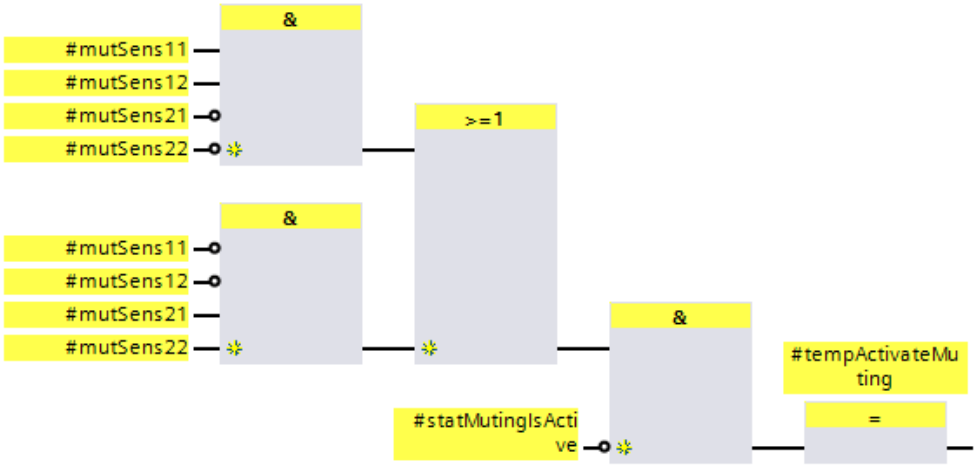
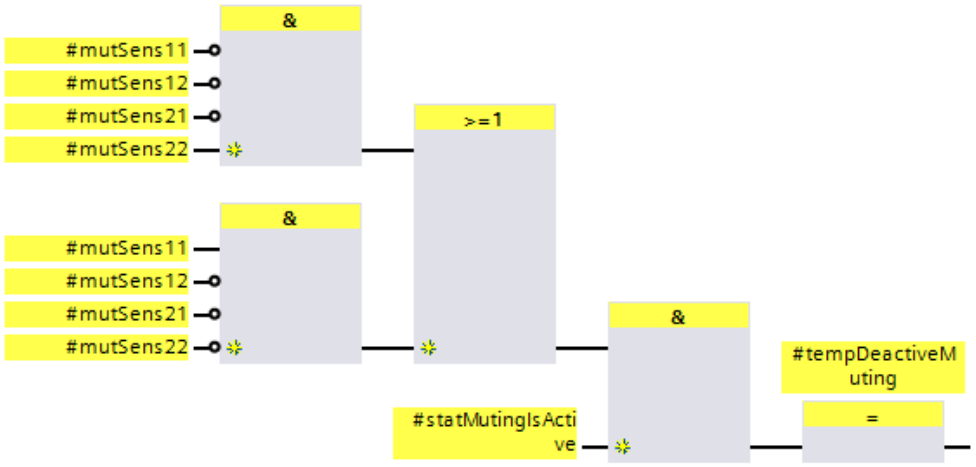
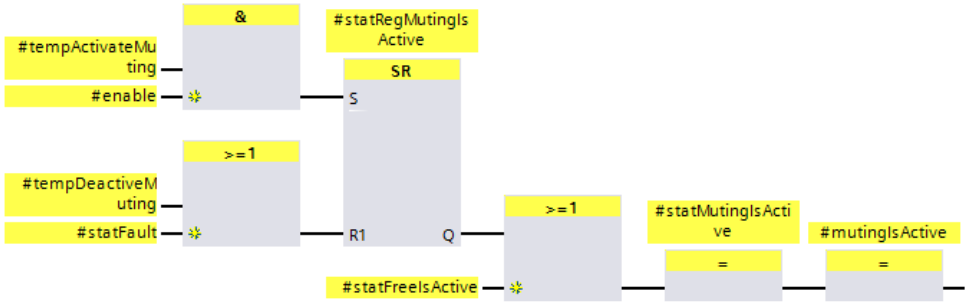


Figure 4-8 Workpiece positions with deactivation of the muting function



In addition to the normal activation of the muting function through the muting sensors, they are also activated when the free function is active.

Figure 4-9



Note

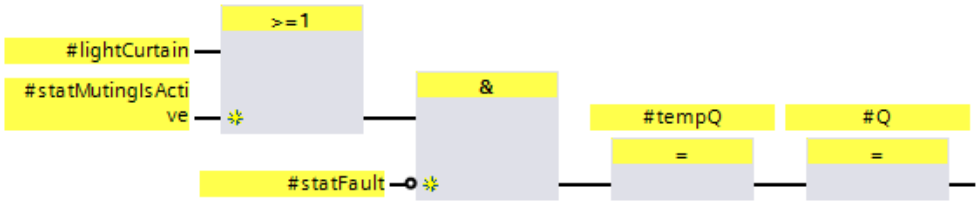
If the #enable input is FALSE, the muting function is blocked temporarily so it is not activated even if the muting function conditions are observed. During that time, the muting sensors will not be monitored for switching sequence and discrepancy.

The “LMutS_FreeFunction” function block is used to determine whether it is necessary to retract the workpiece and when to activate this function.

The enable signal of the safety function #Q is set if the following applies:

- light curtain is not interrupted or
- the muting function is active and
- no error has occurred

Figure 4-10



4.2.5 LMutS_DiscMutSensors

Function

In order to detect faulty muting sensors before the next muting function activation, both muting sensors of a sensor pair are monitored for discrepancy.

If the two muting sensors of a sensor pair have different states for a longer period of time than the max. admissible discrepancy time, this is detected as an error and leads to a fail-safe shutdown of the conveyor and the machine.

Parameter

Figure 4-11

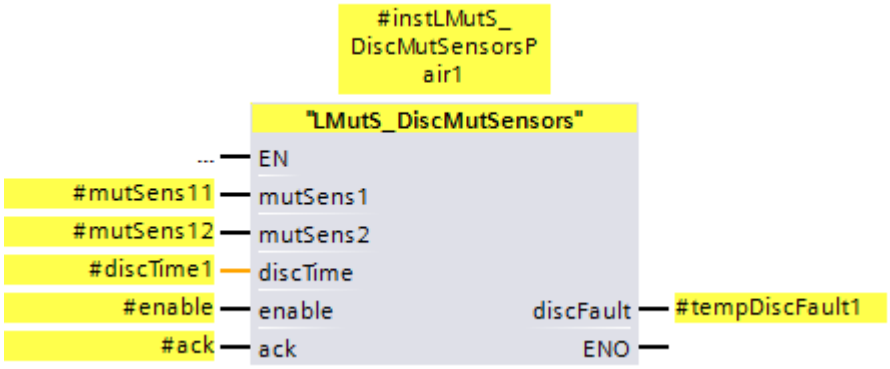


Table 4-8

Parameter	Declaration	Type	Description	
mutSens1	IN	Bool	Muting sensor 1 of a sensor pair	“1” signal: Sensor active (object detected)
mutSens2	IN	Bool	Muting sensor 2 of a sensor pair	
discTime	IN	TIME	Max. admissible discrepancy time	
enable	IN	Bool	Muting function is enabled. “0” signal: discrepancy time is not monitored.	
ack	IN	Bool	Acknowledging errors	
discFault	OUT	Bool	Error bit (“1”: max. admissible discrepancy time exceeded)	

4.2.6 LMutS_SensorSequence

Function

This program block monitors the switching sequence of the muting sensors. Depending on the direction from which the workpiece enters the light curtain, the following switching sequence of the muting sensors must be adhered to:

- “forward”: M11 → M12 → M21 → M22
- “reverse”: M22 → M21 → M12 → M11

When the object leaves the detection zone, the muting sensors must be deactivated in the above-mentioned order.

The detection of an incorrect switching sequence leads to the fail-safe shutdown of the conveyor and the machine.

Parameter

Figure 4-12

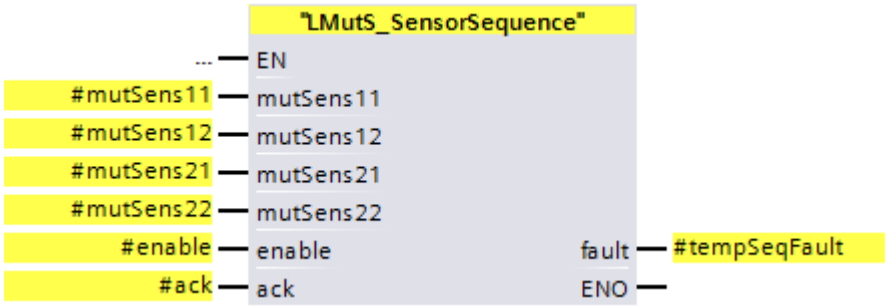


Table 4-9

Parameter	Declaration	Type	Description	
mutSens11	IN	Bool	Sensor pair 1, muting sensor 1	“1” signal: sensor active (object detected)
mutSens12	IN	Bool	Sensor pair 1, muting sensor 2	
mutSens21	IN	Bool	Sensor pair 2, muting sensor 1	
mutSens22	IN	Bool	Sensor pair 2, muting sensor 2	
enable	IN	Bool	Muting function is enabled. “0” signal: sequence is not monitored.	
ack	IN	Bool	Acknowledging errors	
fault	OUT	Bool	Error bit (“1”: wrong sequence of muting sensors)	

Function Principle

The correct switching sequence of the muting sensors is monitored with a state machine. The signals of the four muting sensors determine the state of the machine.

State 0 (no workpiece detected, all muting sensors output “0” signal) is the starting point. Depending from which side the workpiece is supplied, state F1 (“forward” direction) or state R1 (“reverse” direction) is output.

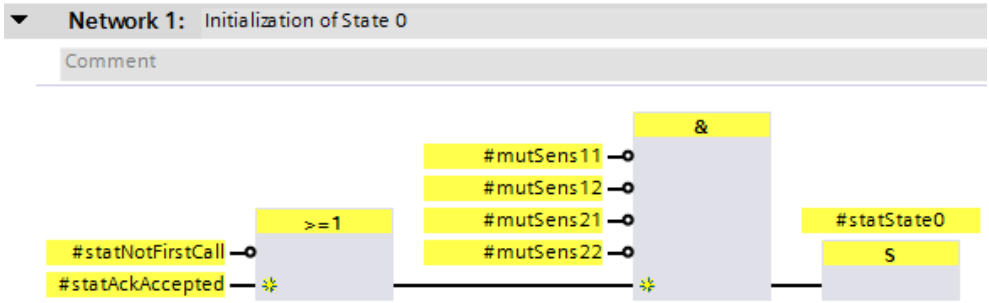
Only one of the 15 possible conditions at a time can be active. To change to another state, the next muting sensor needs to activate. The setting and resetting of the states is done in the function “LMutS_DefState”.

In an error-free situation, the state of the state machine changes along with every signal change of the muting sensors. If this is not the case, it is detected as a fault and the output #fault is set. This leads to the fail-safe shutdown of the conveyor and the machine.

Example

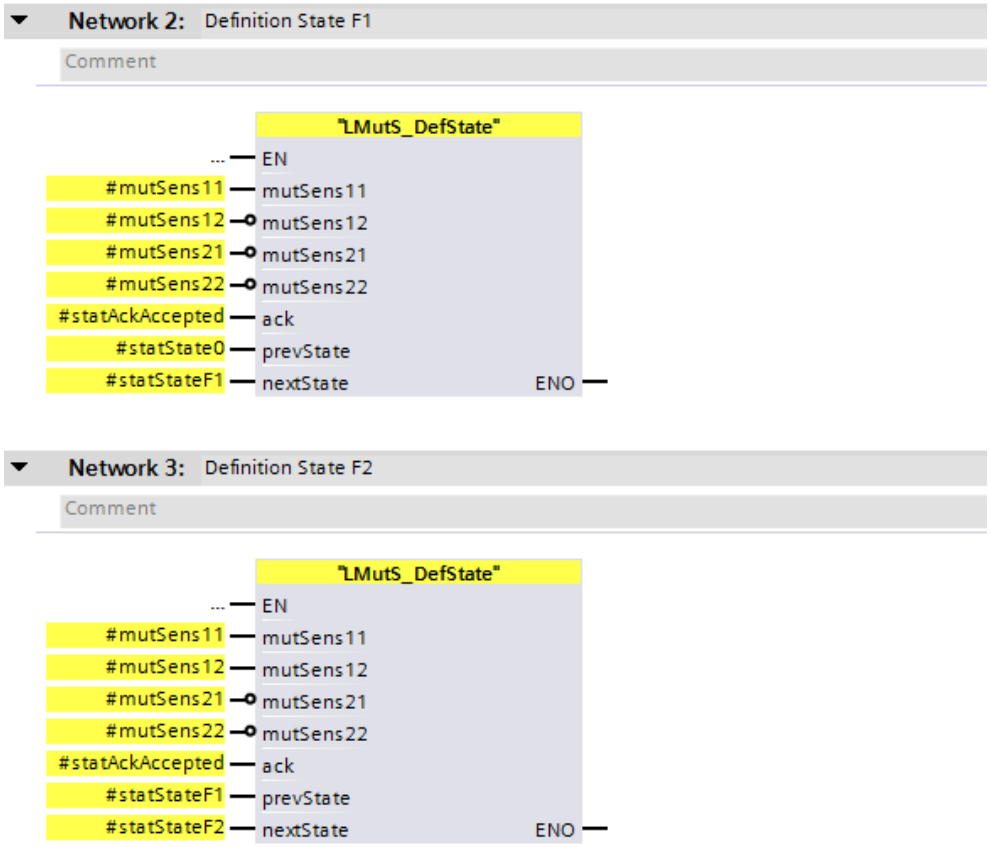
During the first program cycle #statState0 (state 0) is set if all four muting sensors are free.

Figure 4-13 Initialization of state 0



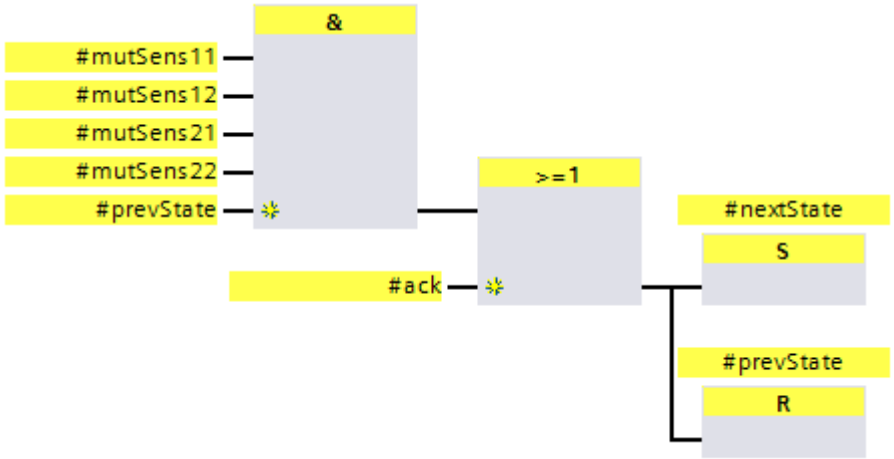
If the next network prescribes that the current state is 0 and only muting sensor 11 is active while the other three muting sensors are inactive, the step enabling condition is fulfilled, #statState1 is set and #statState0 reset.

Figure 4-14 Definition of the states F1 and F2



The following figure shows the only network of “LMutS_DefState”.

Figure 4-15 Program of “LMutS_DefState”



4.2.7 LMutS_FreeFunction

Function

The function block “LMutS_FreeFunction” realizes the free function described in chapter 4.1.3.

Parameter

Figure 4-16

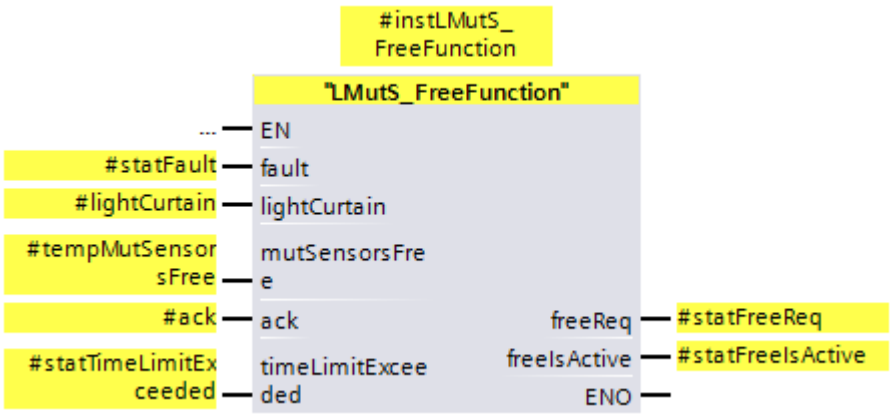


Table 4-10

Parameter	Declaration	Type	Description
fault	IN	Bool	The conveyor and machine were stopped due to an error.
lightCurtain	IN	Bool	Enable signal from light curtain. “1” signal: detection zone not violated
mutSensorsFree	IN	Bool	All four muting sensors are unoccupied.
ack	IN	Bool	Command for enabling the free function.
timeLimitExceeded	IN	Bool	Max. admissible duration of the muting function exceeded.
freeReq	OUT	Bool	The workpiece was stopped between the muting sensors and must be retracted.
freeIsActive	OUT	Bool	The free function is active.

Function Principle

The block recognizes that freeing is required, if an error occurs and the light curtain or at least one of the muting sensors is blocked. Then, the output is set to #freeReq.

If a positive edge is detected on the #ack input twice within 4 seconds, the free function is activated and the output is set to #freeIsActive.

The free function is deactivated automatically if one of the following conditions applies:

- The acknowledgment pushbutton is released.
- All muting sensors and the light curtain are unoccupied.
- The maximum duration for active muting is exceeded.

4.2.8 DiagSafetyProgram

Function

The function block evaluates the diagnostics information from the safety program and sets the respective light indicator outputs.

To make the diagnostics information of the muting function better readable, these information in Word data type are written in a UDT (User Data Type) “LMutS_typeDiag” back to “DataFromSafety”.

The meaning of the individual bits is described in chapter 8.1.

If an error in the muting function is detected, this is written on the output to the light indicator for error display.

The acknowledgment light indicator blinks with a frequency of 1 Hz, if user acknowledgment is required and is lit up continuously, if manual freeing of the workpiece by the user is required.

5 Configuration and Settings

The enclosed project does not require any further configuration. If you want to replicate the application example with other components, then the most important settings are shown in this chapter.

NOTICE	**The settings displayed below help to meet PL e / SIL 3. Changes on the settings may cause loss of the safety function.**

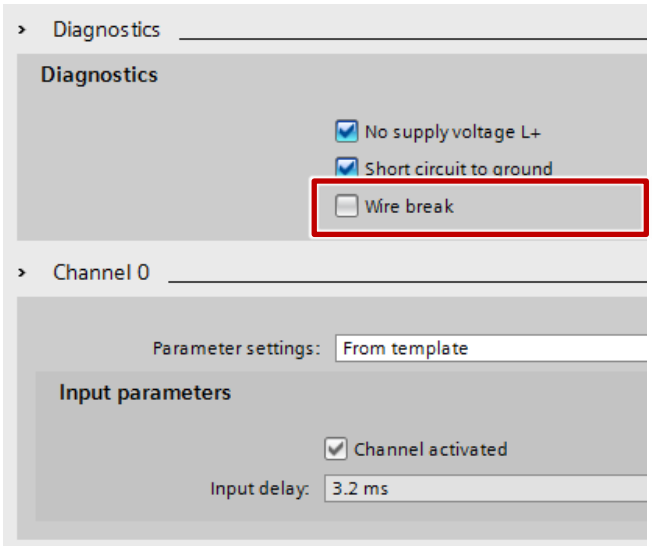
NOTICE	**The values used in the example projects may also differ from your individual requirements.**

5.1 Setting the DI

Diagnostics

Wire break diagnostics must be deactivated.

Figure 5-1



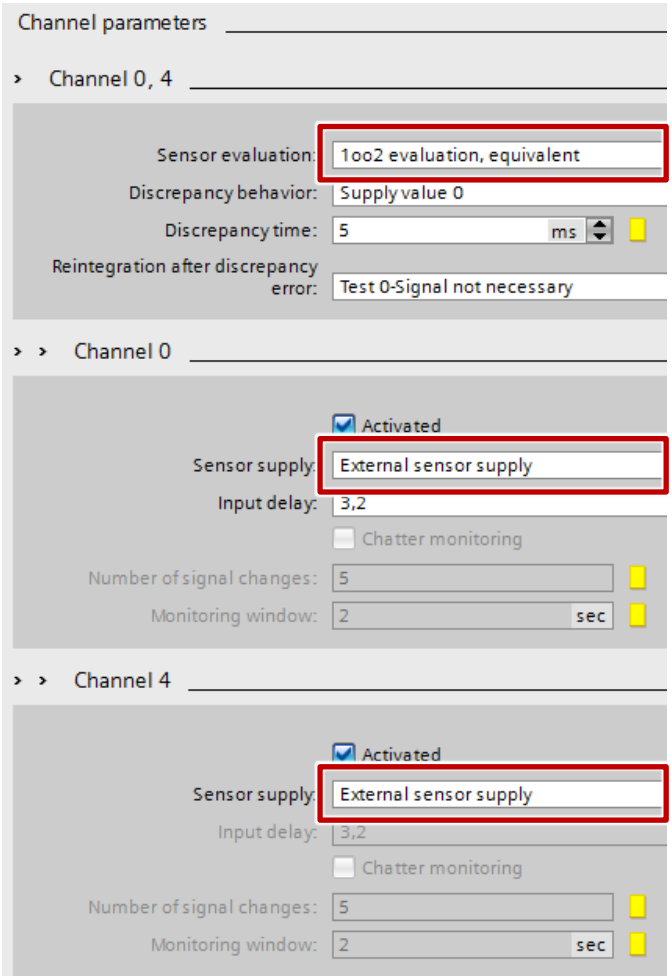
5.2 Settings of the F-DI

Channel parameters

The monitoring of the light curtain is via the channel pair 0, 4. The evaluation of the encoder has to be set to “1oo2 evaluation, equivalent” in order to detect discrepancies between the two channels and to therefore achieve the demanded safety level.

As the light curtain monitors its outputs for cross-circuits, it must be set as sensor supply “External sensor supply”.

Figure 5-2



Note Channels which are not used must be deactivated manually.

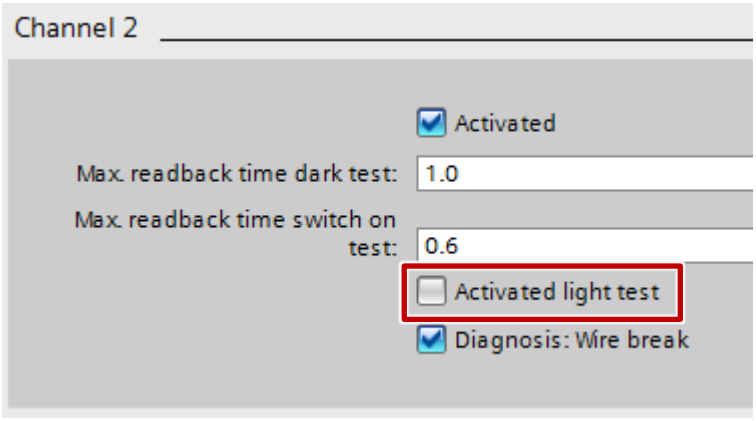
5.3 Setting the F-DQ

DQ parameters

The light test must be deactivated for outputs with light indicators connected, as light indicators are not slow enough and would otherwise light up during the tests.

As in this application example, the actuators are simulated by light indicators, the light test for channels 0 to 2 is deactivated.

Figure 5-3



Note Channels which are not used must be deactivated manually.

6 Installation and Commissioning

6.1 Installing the hardware

The required hardware components are listed in chapter 2.3.

NOTICE

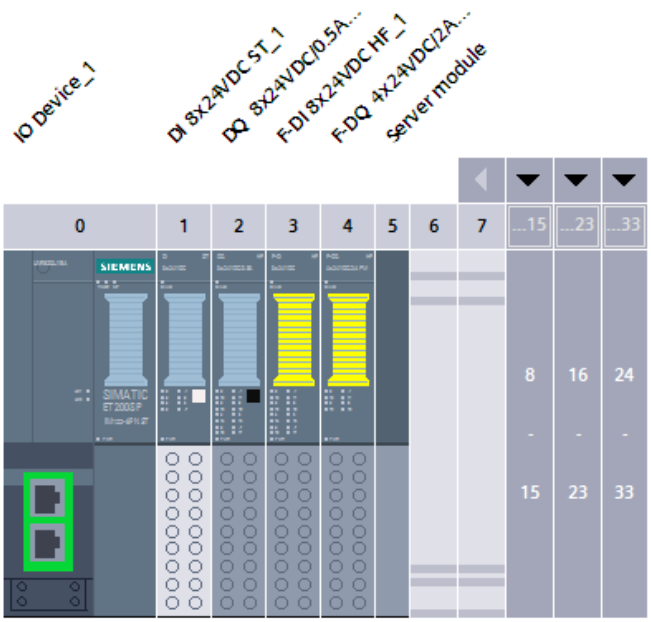
Follow the installation guidelines for PROFINET (/4/), SICK light curtain and photoelectric retro-reflective sensor (/11/), SIMATIC S7-300 (/3/) and SIMATIC ET 200SP (/5/).

Please refer to the corresponding device manuals.

6.1.1 Overview

Figure 6-1 shows the sequence of the distributed I/O modules. The wiring diagrams can be found in the following section.

Figure 6-1



Note

A separate power supply can be used for the safety light curtain to increase availability (EMC, voltage fluctuations, etc.).

Both power supplies require the same ground.

6.1.2 DI wiring

The figure and the table below show the wiring of the buttons and muting sensors on the DI module.

Figure 6-2

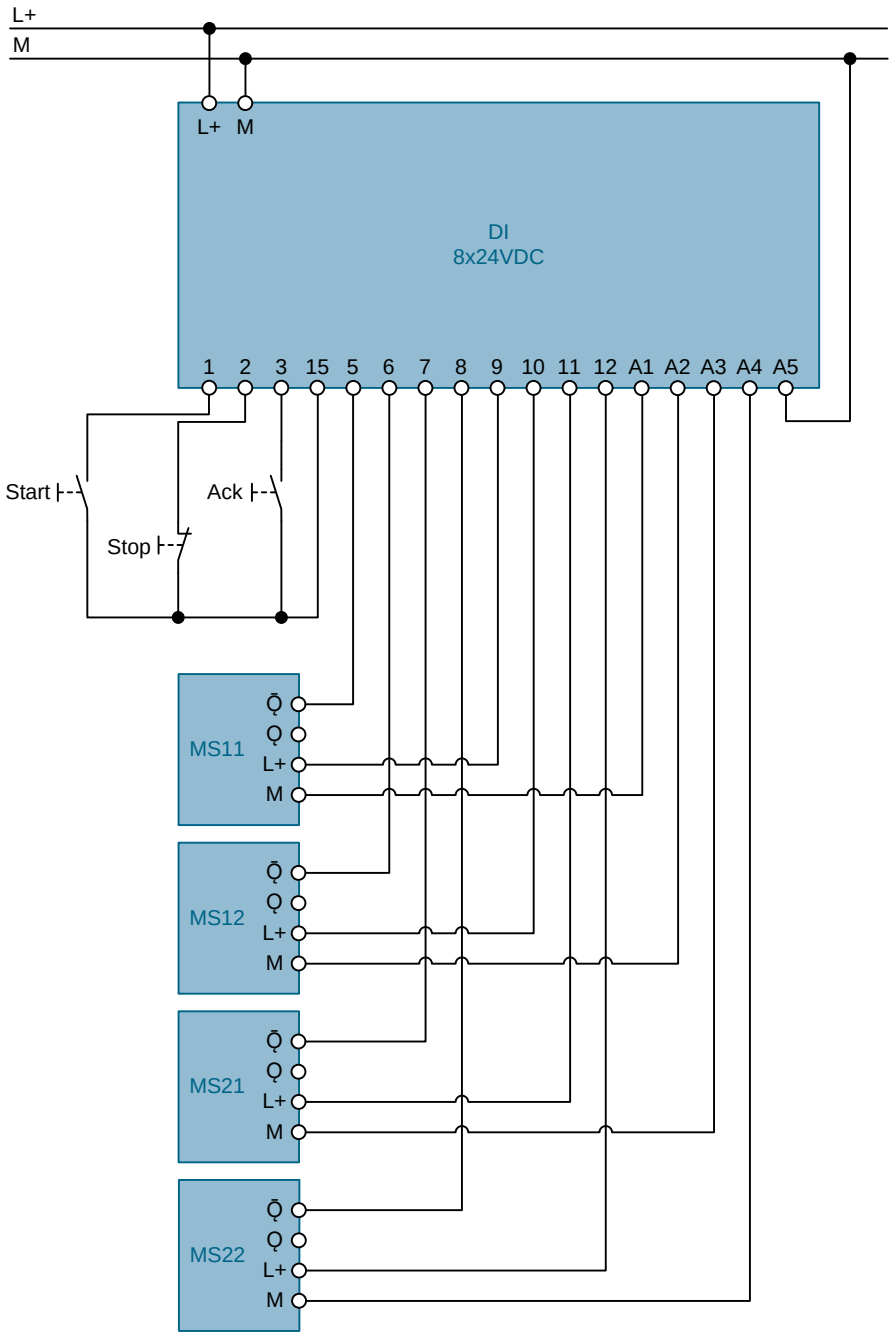


Table 6-1

Terminal	Module	Component connection
1 / 15	DI.0 / 24VDC	Start button (NO)
2 / 15	DI.1 / 24VDC	Stop button (NC)
3 / 15	DI.2 / 24VDC	Acknowledgment button (NO)
5	DI.0	$\overline{Q}$ Muting sensor 11
6	DI.1	$\overline{Q}$ Muting sensor 12
7	DI.2	$\overline{Q}$ Muting sensor 21
8	DI.3	$\overline{Q}$ Muting sensor 22
9	24VDC	L+ muting sensor 11
10	24VDC	L+ muting sensor 12
11	24VDC	L+ muting sensor 21
12	24VDC	L+ muting sensor 22
1A	AUX	M muting sensor 11
2A	AUX	M muting sensor 12
3A	AUX	M muting sensor 21
4A	AUX	M muting sensor 22
5A	AUX	M PM 190 W
L+	L+	L+ PM 190 W
M	M	M PM 190 W

Detecting hardware errors at the muting sensors

Possible errors:

- Short circuit on +24 V of the complete module:
  - Simultaneous switching of the four muting sensors is detected as an implausible switching sequence by the state machine in the function block “LMutS_SensorSequence”, which leads to a shutdown of the conveyor and machine.
- Short circuit on +24 V of a single channel:
  - If this affects one of the channels of the two outer muting sensors M11 or M22, this is detected as an error after the discrepancy time has elapsed, which leads to a conveyor and machine shutdown.
  - If this affects one of the channels of the two inner muting sensors M12 or M21, this is interpreted as an implausible state machine by “LMutS_SensorSequence” leads to an immediate shutdown of conveyor and machine.

6.1.3 DQ wiring

Table 6-2

Terminal	Module	Component connection
1	DQ.0	L+ LED acknowledgment button
2	DQ.1	L+ light indicator error
9	M	M LED acknowledgment button
10	M	M light indicator error

6.1.4 F-DI wiring

Figure 6-3

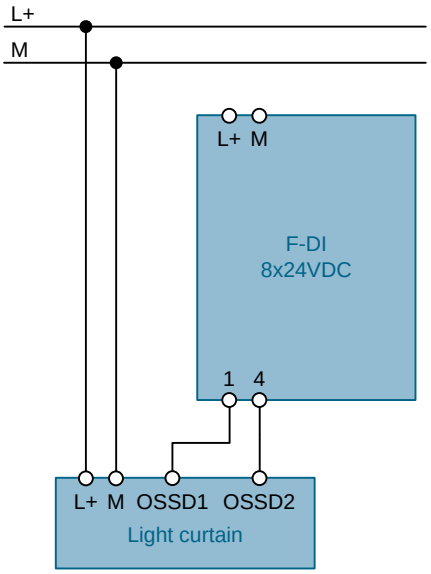


Table 6-3

Terminal	Module	Component connection
1	F-DI.0	OSSD1
5	F-DI.4	OSSD2

6.1.5 F-DQ wiring

Figure 6-4

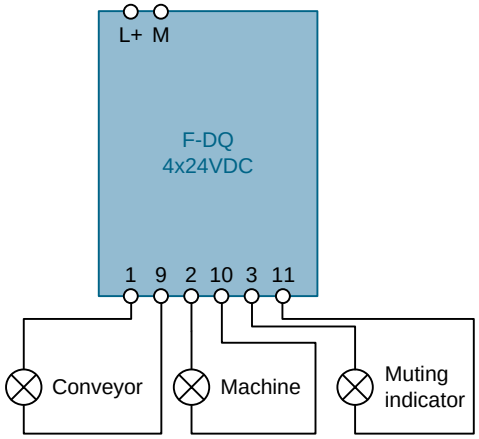


Table 6-4

Terminal	Module	Component connection
1	F-DQ.0	L+ conveyor
2	F-DQ.1	L+ machine
3	F-DQ.2	L+ light indicator muting
9	M.0	M conveyor
10	M.1	M machine
11	M.2	M light indicator muting

6.2 Commissioning

6.2.1 Preparation

1. Download the project file “58793869_Muting_Light_Curtain_PROJ_V21.zip“. The download link can be found under /2/.
2. Save the zip file in any directory on your computer and unzip it.
3. Set the IP address of the PG/PC in a way so that the PG/PC is located in the same subnet as the CPU.
4. Use an Ethernet cable to connect the PG/PC with the Ethernet interface of CPU S7-1516F.

For this application example, the following IP addresses were used:

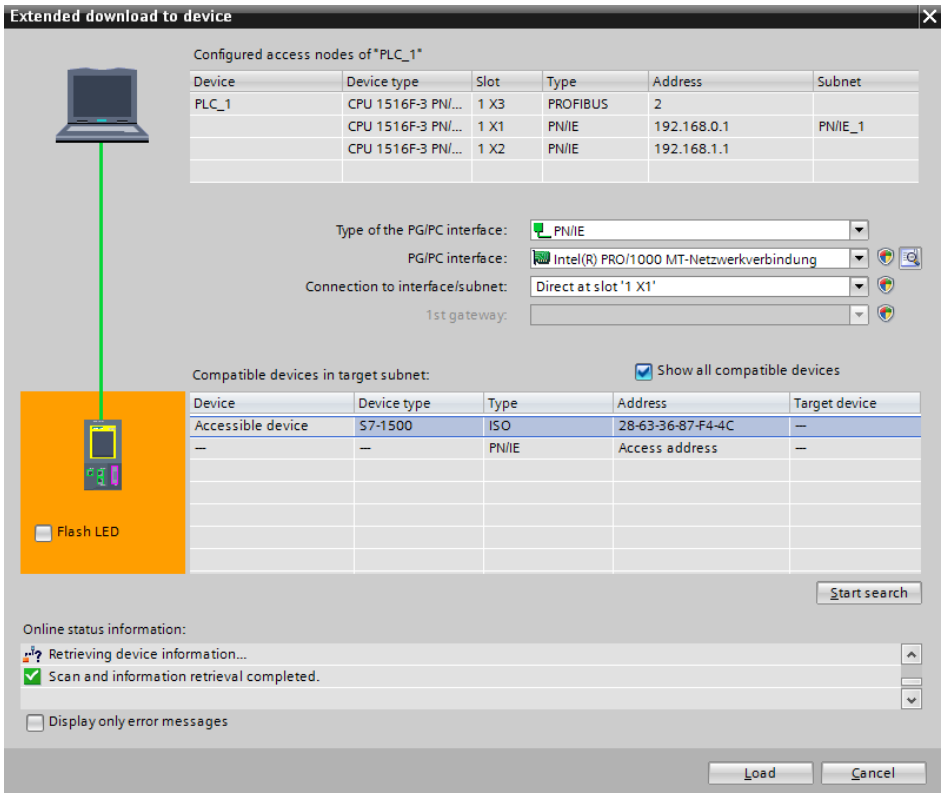
CPU S7-1516F
IP address: 192.168.0.1
Subnet mask: 255.255.255.0

IM 155-6PN
IP address: 192.168.0.2
Subnet mask: 255.255.255.0

6.2.2 Loading the S7 project into CPU S7-1516F

1. Open “TIA Portal V13”.
2. Go to the project view.
3. Click “Project > Open” in the menu bar in the TIA Portal.
4. Click “Browse” and open the unzipped project.
5. Set the CPU S7-1516F to STOP.
6. Right click “PLC_1 [CPU1516F-3 PN/DP]” and then “Download to device > Hardware and Software (only changes)”).
7. Select the respective interface and click “Start search”.

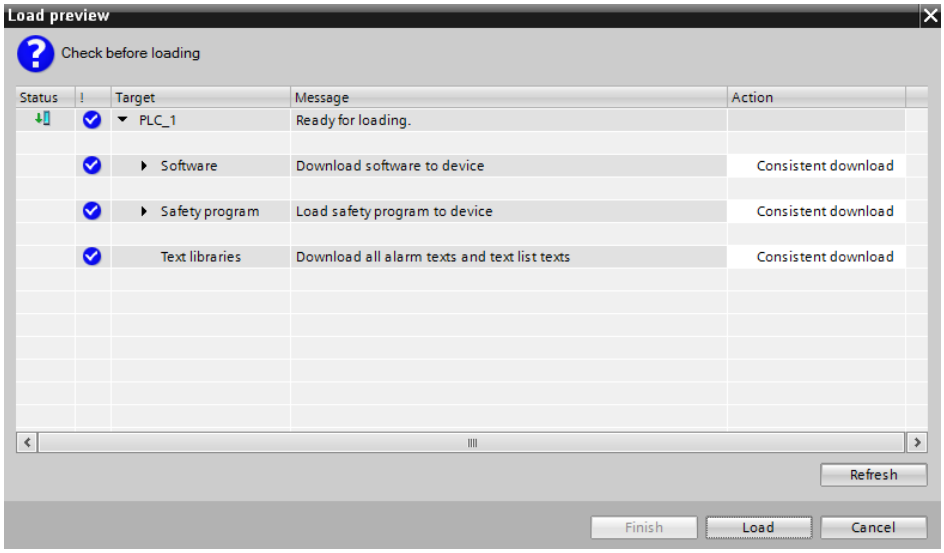
Figure 6-5



8. Select the CPU based on the MAC address and then click “Load”.

Note The IP address and the device name are automatically assigned when downloading the project into the CPU.

Figure 6-6



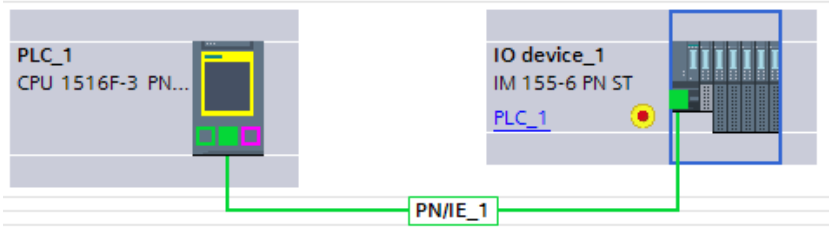
9. Confirm the dialog by clicking “Load”.
10. Click “Finish” when the loading process is completed.

6.2.3 Assigning device names

The device name of the CPU is automatically assigned during the loading process. The device name has to be assigned manually to the ET 200SP. To do this, proceed as follows:

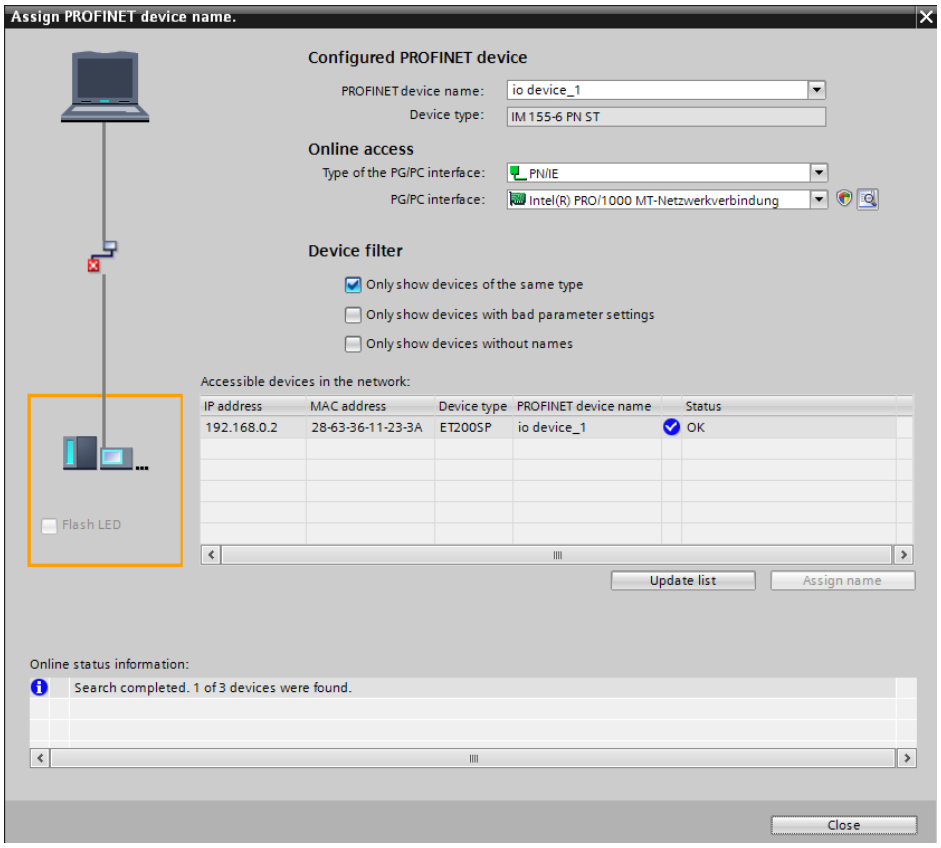
1. Open “Devices & networks” from the project tree.
2. Right click the ET 200SP and select “Assign device name”.

Figure 6-7 Devices & networks



3. Click on “Update list” and select the detected ET 200SP based on the MAC address.
4. Now click “Assign name” and close the window when the status is marked with “OK”.

Figure 6-8 Assigning device names



6.2.4 Assigning F target address

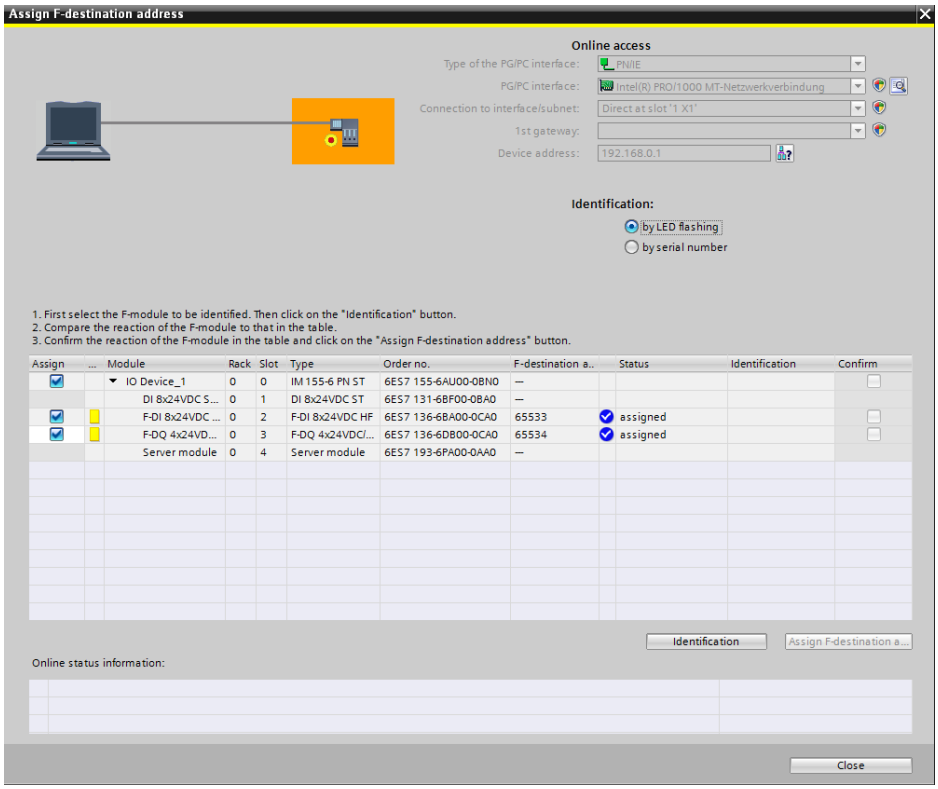
In order to establish a secure communication between the F-CPU and the fail-safe modules of the ET 200SP, the modules have to be assigned F target addresses.

Note

Since the F address is saved in the electronic coding element, the following steps are only required if the coding element has not previously been assigned an F address or another F address.

1. Open “Devices & networks” from the project tree.
2. Right click the ET 200SP station and select “Assign F-destination address”), see Figure 6-7.
3. Enable the checkbox of the first fail-safe module and click the “Identification” button.
4. When the LEDs of the F-DI are simultaneously flashing green, enable the “Confirm” checkbox.
5. Then click the “Assign F-destination address” button and confirm the dialog with “Yes”.

Figure 6-9



6. Repeat the steps for the other failsafe modules.
7. You can then close the window.

Note All red LEDs of the ET 200SP station should go out after assigning the F-target address. If this is not the case, there may be an error in the wiring.

8. Now set the CPU S7-1516F to RUN.

7 Operating the Application

7.1 Resetting to the initial state of the setup

Prerequisite

- No object in the sensing area of the light curtain.
- No object in the sensing area of the muting sensors.

Instruction

- Switch on the power supply.
- Set the F-CPU to RUN (mode selector switch to RUN).

Result

- Conveyor indicator light: off
- Machine indicator light: off
- Muting indicator light: off
- Error indicator light: on
- Acknowledgment button: blinks at 1 Hz
- Light curtain receiver: green LED on
- Muting sensor: green LED on, yellow LED on

For a description of the indicators on the light curtain and the muting sensor, please refer to chapter 8.2.

7.2 Operation in error-free mode

Prerequisite

- The setup is in the initial state (see chapter 7.1).

The actions in the table are used to simulate the transport of a workpiece into the assembly cell.

Note During operation, the monitoring times parameterized in the STEP 7 project must be complied with.

Table 7-1

	Action	Result / Note
1.	Press the acknowledgment button.	The error indicator light and the acknowledgment button go out.
2.	Press the start button.	The conveyor and machine indicator light are on.
3.	Move an object in front of muting sensors M11 and M12.	The muting function is activated. The muting light indicator lights up.

	Action	Result / Note
4.	Move the object through the light curtain and in front of muting sensors M21 and M22.	The conveyor and machine indicator lights remain on.
5.	Move on the object so that muting sensors M11, M12, M21 and the light curtain are unoccupied again.	The muting function is deactivated. The muting light indicator goes off. The conveyor and machine indicator lights remain on.
6.	Move on the object so that muting sensor M22 becomes unoccupied again as well. Be sure to observe the discrepancy time.	---
7.	Press the stop button.	The conveyor and machine indicator light go off.

7.3 Freeing

If an error is detected while the workpiece is transported through the detection zone of the muting sensors and the conveyor is switched off, the workpiece can be moved out of the detection zone with the free function.

The need for freeing is signaled by the constant light of the acknowledgment button.

To free the workpiece, proceed as follows:

Table 7-2

	Action	Result / Note
1.	Press the acknowledgment button twice within 4 seconds and keep it down.	The free function is activated. The muting light indicator lights up.
2.	Keep the acknowledgment button pressed and press the start button once.	The conveyor indicator light is activated.
3.	---	The muting function is deactivated once all muting sensors are unoccupied. The conveyor indicator light goes out. The acknowledgment button blinks at 1 Hz.
4.	Let go of the acknowledgment button.	
5.	Press the acknowledgment button again to acknowledge the error.	The error indicator light and the acknowledgment button go out.

8 Diagnostics

8.1 Diagnostics information of the application

The “LMutS_Main” function block provides diagnostics information in Word data type at the #diag output. These are stored in the global “DataFromSafety” data block and are evaluated in the standard user program. The “DiagSafetyProgram” function block divides the diagnostics information into the individual bits and stores them in the UDT (User Data Type) “LMutS_typeDiag” in the same global data block.

The meaning of the individual bits is shown in the following table.

Table 8-1

Bit	Name in UDT	Meaning
0	discTime1	The max. admissible discrepancy time of sensor pair 1 was exceeded.
1	discTime2	The max. admissible discrepancy time of sensor pair 2 was exceeded.
2	sequenceFault	The switching sequence of the muting sensors was violated.
3	maxTimeExceeded	Max. admissible duration of the muting function exceeded.
4	lightCurtainInterrupted	The light curtain is interrupted, although muting and free function are disabled.
5	indicatorBroken	The muting light indicator is defective.
6	fault	One of the above errors has occurred.
7	freeReq	The workpiece was stopped between the muting sensors and must be retracted.
8	ackReq	User acknowledgment required
9	Q	Enable signal of the safety function is applied.
10	mutingIsActive	The muting function is active.
11	freeIsActive	The free function is active.

The machine is switched off at the following events:

- The stop button is pressed.
- An error listed in the above table has occurred.
- An error was detected by the fail-safe modules:
  - Passivation of F-DI (e.g. discrepancy error for OSSD1 and OSSD2)
  - Passivation of F-DQ (e.g. muting indicator light wire break)

8.2 Indicators on light curtain and muting sensor

Note This chapter describes only indicators that are important for the application example.

Light curtain receiver ()

Figure 8-1

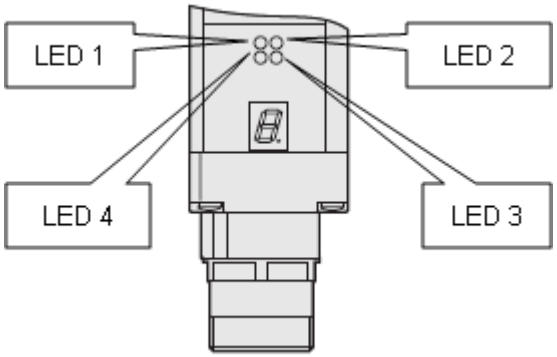


Table 8-2

LED	Color	Meaning	
LED 1	Orange	On:	Cleaning or realignment required
LED 2	red	On:	Object in the protective field (protective field violated)
LED 3	green	On:	No object in the protective field (protective field unoccupied)
LED 4	yellow	Blinking:	Reset required

Muting sensor ()

Figure 8-2

Table 8-3

LED	Color	Meaning	
LED 1	green	On:	Operating voltage active
LED 2	yellow	On: Off:	Light beam not interrupted (sensor inactive) Light beam interrupted (sensor active)

9 Evaluation of the Safety Function

9.1 Standards

For the evaluation of the safety function the following versions of the standards were used:

Table 9-1

Version	Mentioned below
EN ISO 13849-1:2006	ISO 13849-1
EN 62061:2005 + A1:2013	IEC 62061

9.2 Safety function

The following safety function is important for the further considerations:

“When the protective field of the light curtain is violated and when there is no muting, the machine must be stopped.”

Note The “reaction” subsystem is not described in this application example. The evaluation of the safety function is therefore incomplete.

9.3 Evaluation according to IEC 62061

Detection

The subsystem „Detection“ consists of the following safety-related parts:

- Safety light curtain
- DI module for detection of the muting signals
- Muting sensors where each pair is represented by one subsystem

The resulting failure rates of these four safety-related parts are accumulated.

Any fault is detected by means of the sequence and discrepancy monitoring within the safety program. Thus a diagnostic coverage of 99 % is used for the subsystems of the muting sensor and the DI module. The probability that an accumulation of faults results in the correct signal sequence can be disregarded.

The following table shows the parameters for evaluation of one pair of muting sensors.

Table 9-2

Parameter	Value	Explanation	Definition
MTTFd Retro-reflective sensor	632 years	Manufacturer information	SICK AG
T1 Lifetime	20 years	Manufacturer information	
Subsystem architecture	D	2 channels, 2 components: Single fault tolerance with diagnostic function	User
Actuations/ test interval	1/hour	Assumption	
β **(CCF factor)** Susceptibility to common cause failures	0.1 (10%)	For installations according to IEC 62061, a CCF factor of 0.1 (10%) is achieved.	
DC Diagnostic coverage	≥ 0.99 (99%)	Sequence monitoring by the controller	

The following table shows the parameters for evaluation of the DI module.

Table 9-3

Parameter	Value	Explanation	Definition
MTBF (Mean Time Between Failures) DI module 8x24VDC ST	302 years	Manufacturer information	SIEMENS AG
T1 Lifetime	20 years	Manufacturer information	
Rate of dangerous failures	50 %	The probability of a falsely detected signal to cause a dangerous failure is assumed to be 50 %.	User
Subsystem architecture	C	1 channel, 1 component: Zero fault tolerance with diagnostic function	
Actuations/ test interval	1/hour	Assumption	
DC Diagnostic coverage	≥ 0.99 (99%)	Sequence monitoring by the controller	

Table 9-4

Component	PFH_D	SILCL	Definition
Safety light curtain C400	$1.50 \cdot 10^{-8}$	SILCL 3	SICK AG
Muting sensors pair 1	$1.81 \cdot 10^{-8}$	SILCL 3	Calculation
Muting sensors pair 2	$1.81 \cdot 10^{-8}$	SILCL 3	Calculation
DI module	$1.88 \cdot 10^{-9}$	SILCL 3	Calculation
Total	$\mathbf{5.31 \cdot 10^{-8}}$	**SILCL 3**	**Calculation**

Evaluation

Table 9-5

Component	PFH_D	SILCL	Definition
CPU 1516F-3PN/DP incl. PROFIsafe	$2.00 \cdot 10^{-9}$	SILCL 3	SIEMENS AG
F-DI of the ET 200SP	$1.00 \cdot 10^{-9}$	SILCL 3	
F-DQ of the ET 200SP	$1.00 \cdot 10^{-9}$	SILCL 3	
Total	$\mathbf{4.00 \cdot 10^{-9}}$	**SILCL 3**	

Result

Table 9-6

Subsystem	PFH_D	SIL achieved
Detection	$5.31 \cdot 10^{-8}$	SILCL 3
Evaluation	$4.00 \cdot 10^{-9}$	SILCL 3
Reaction	---	---
Total	$\mathbf{5.71 \cdot 10^{-8}}$	**SILCL 3**
	SIL 3	

Note The “reaction” subsystem must fulfill SILCL 3 to achieve a SIL 3-rated safety function.

9.4 Evaluation according to ISO 13849-1

Detection

According to DIN ISO/TR 23849 and ISO 13849-1 it is permitted to evaluate subsystems according to another standard and to integrate them in the evaluation according to ISO 13849-1. For this application the results of the evaluation of the subsystem “Detection” according to IEC 62061 are integrated in the evaluation of the safety function according to ISO 13849-1. The resulting SIL 3 can be transferred to a PL e.

Table 9-7

Component	PFH_D	PL	Definition
Subsystem “Detection” according to IEC 62061	$5.31 \cdot 10^{-8}$	PL e	Calculation

Evaluation

Table 9-8

Component	PFH_D	PL	Definition
CPU 1516F-3PN/DP incl. PROFIsafe	$2.00 \cdot 10^{-9}$	PL e	SIEMENS AG
F-DI of the ET 200SP	$1.00 \cdot 10^{-9}$	PL e	
F-DQ of the ET 200SP	$1.00 \cdot 10^{-9}$	PL e	
Total	$\mathbf{4.00 \cdot 10^{-9}}$	**PL e**	

Result

Table 9-9

Subsystem	PFH_D	PL achieved
Detection	$5.31 \cdot 10^{-8}$	PL e
Evaluation	$4.00 \cdot 10^{-9}$	PL e
Reaction	**---**	---
Total	$\mathbf{5.71 \cdot 10^{-8}}$	**PL e**
	PL e	

Note The “reaction” subsystem must fulfill PL e to achieve a PL e-rated safety function.

10 Appendix

10.1 Service and support

Industry Online Support

Do you have any questions or need assistance?

Siemens Industry Online Support offers round the clock access to our entire service and support know-how and portfolio.

The Industry Online Support is the central address for information about our products, solutions and services.

Product information, manuals, downloads, FAQs, application examples and videos – all information is accessible with just a few mouse clicks:

support.industry.siemens.com

Technical Support

The Technical Support of Siemens Industry provides you fast and competent support regarding all technical queries with numerous tailor-made offers – ranging from basic support to individual support contracts.

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We support you with our globally available training courses for industry with practical experience, innovative learning methods and a concept that’s tailored to the customer’s specific needs.

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support.industry.siemens.com/cs/sc

Industry Online Support app

You will receive optimum support wherever you are with the "Siemens Industry Online Support" APP. The app is available for iOS and Android:

support.industry.siemens.com/cs/ww/en/sc/2067

10.2 Industry Mall

The Siemens Industry Mall is the platform on which the entire siemens Industry product portfolio is accessible. From the selection of products to the order and the delivery tracking, the Industry Mall enables the complete purchasing processing – directly and independently of time and location:
mall.industry.siemens.com

10.3 Links and literature

Notes with reference (/x/) in the document:

Table 10-1

	Topic
/1/	Siemens Industry Online Support https://support.industry.siemens.com
/2/	Download page of the entry https://support.industry.siemens.com/cs/ww/en/view/58793869
/3/	SIMATIC S7-1500/ET 200MP – Manual Collection https://support.industry.siemens.com/cs/ww/en/view/86140384
/4/	PROFINET – System Manual https://support.industry.siemens.com/cs/ww/en/view/19292127
/5/	SIMATIC Distributed I/O System ET 200SP – Operating Instructions https://support.industry.siemens.com/cs/ww/en/view/58649293
/6/	SIMATIC Distributed I/O System ET 200SP Fail-safe Modules https://support.industry.siemens.com/cs/ww/en/view/78361093
/7/	SIMATIC Industrial Software SIMATIC Safety – Configuring and Programming - Manual https://support.industry.siemens.com/cs/ww/en/view/54110126
/8/	Safety Evaluation with TIA Selection Tool http://www.siemens.com/safety-evaluation
/9/	PROFINET with STEP 7 V13 – Function Manual https://support.industry.siemens.com/cs/ww/en/view/49948856
/10/	STEP 7 Professional V13 SP1 – System Manual https://support.industry.siemens.com/cs/ww/en/view/109011420
/11/	SICK manufacturer's website www.sick.com

10.4 Change documentation

Table 10-2

Version	Date	Revisions
V1.0	04.2012	First version
	05.2012	Note on the power supply modified
V1.1	02.2014	Amendment of the “SensorSequence” function block for monitoring the switching sequence of the muting sensors Notes on wiring the muting sensors
V2.0	02.2016	Creating the S7 project for STEP 7 V13 SP1 Migrating the hardware to S7-1500 and ET 200SP Revision of the documentation
V2.1	05.2016	Update of the function block “LMutS_SensorSequence” in order to optimize performance