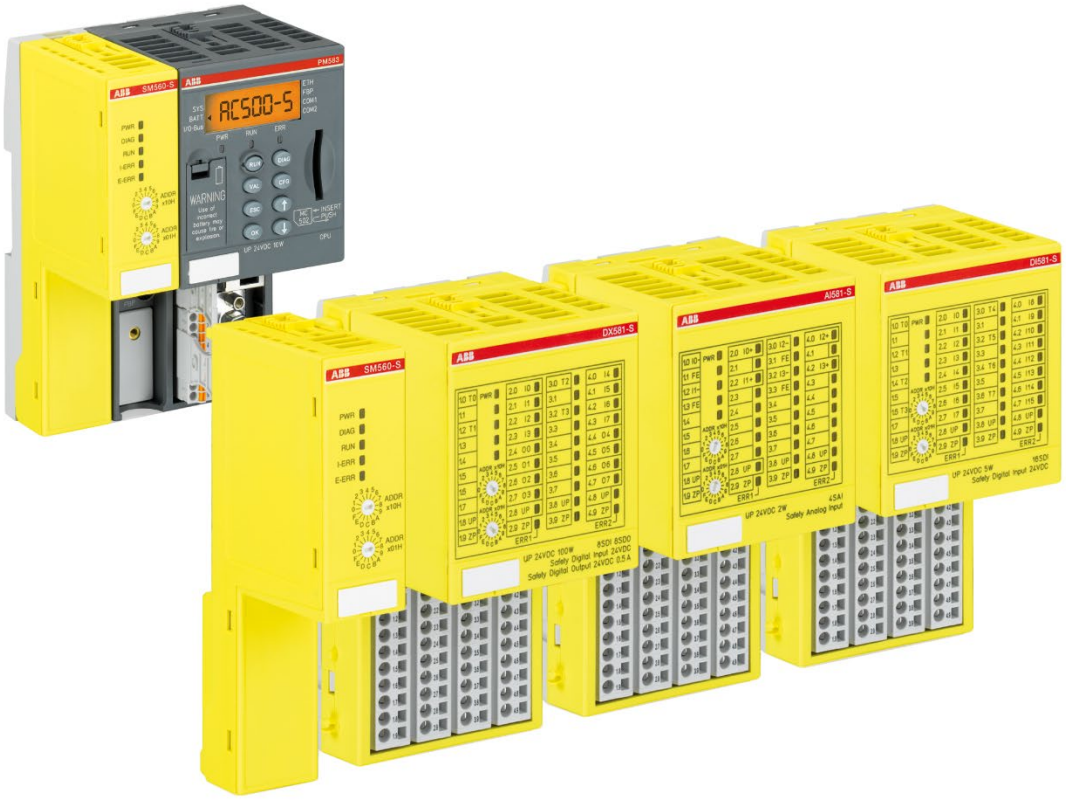
APPLICATION NOTE

AC500-S safety PLC

Usage of DX581-S safety digital outputs with up to 2 A (24 V DC) electrical loads



Contents

1. Introduction

1.1. Purpose

In some applications the current limit of 0.5 A per safety output channel on a DX581-S safety I/O module is not high enough to drive selected electrical loads, such as large electrical contactors. These applications usually require the use of external interface safety relays to drive electrical loads of more than 0.5 A (24 V DC).

This application note provides technical instructions on how to connect the safety output channels of the DX581-S safety I/O module in parallel to increase the output current supplied to electrical loads up to 2.0 A. In some cases, this can remove the need for an external safety relay.

Three types of electrical loads can potentially be connected to the DX581-S safety I/O module:

- A resistive load, such as electronics with no capacitance and inductance
- A capacitive load, such as electronics with internal capacitance
- An inductive load, such as components with inductance, for example magnetic valves with a coil

NOTICE

For resistive and capacitive loads, it is possible to connect the safety digital outputs of the DX581-S safety I/O module in parallel to produce supply currents of up to 2.0 A (24 V DC). For inductive loads, the maximum permitted electrical load remains at 0.5 A and an external safety relay is needed to drive loads with a greater current requirement. Refer to [3.] for information on how to use the DX581-S safety I/O module with inductive loads.

This application note includes examples with three devices (refer to Table 2 for more information), that can be used with the DX581-S safety I/O module:

- Two contactors
- One magnetic valve

1.2. Task

The application note describes a connection example of how to connect the safety digital outputs on the DX581-S safety I/O module in parallel to produce currents of up to 2.0 A (24 V DC) for functional safety applications up to PL e (ISO 13849-1).

The customer benefits of connecting safety digital outputs in parallel on the DX581-S safety I/O module are:

- Less space is required in control cabinets
- Cost savings as external safety relays are not required
- Wiring is simpler to implement

1.3. Document history

Rev.	Description of version / changes	Who	Date
C	Programming environment for safety devices was re-styled and renamed to "AC500-S Programming Tool".	ABB	26.04.2023
B	Company name was changed. Various typos were corrected and various improvements in the texts and illustrations were made.	ABB	15.09.2021
A (V1.0.0)	First release	ABB	30.09.2019

1.4. Validity

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1.5. Important user information

This documentation is intended for qualified personnel who are familiar with functional safety. You must read and understand the safety concepts and requirements presented in the AC500-S Safety User Manual [1.] and the other referenced documents before you operate the AC500-S safety PLC system.

The following special notices may appear throughout this documentation to warn of potential hazards or to call attention to specific information.

⚠ DANGER

The notices referring to your personal safety are highlighted in the manual by this safety alert symbol, which indicates that death or severe personal injury may result if proper precautions are not taken.

NOTICE

This symbol of importance identifies information that is critical for successful application and understanding of the product. It indicates that an unintended result can occur if the corresponding information is not considered.

1.6. Definitions, expressions, abbreviations

AC500	ABB PLC, refer also to www.abb.com/PLC for further details
AC500-S	ABB Safety PLC for applications up to SIL3 (IEC 61508), SILCL 3 (IEC 62061) and PL e (ISO 13849-1), refer also to www.abb.com/PLC for further details

AB	Automation Builder (ABB Automation Builder is the integrated software suite for machine builders and system integrators which covers the engineering of ABB AC500 PLC, AC500-S safety PLC, control panels, drives, motion and robots)
CPU	Central Processing Unit
FSDT	Functional Safety Design Tool (ABB tool for functional safety calculation according to ISO 13849-1 and/or IEC 62061)
IEC	International Electro-technical Commission Standard
I/O	Input/Output
Passivation	Passivation is a special state of safety I/O modules which leads to the delivery of safe substitute values, which are '0' values in AC500-S, to the Safety CPU.
PFHd	Average probability of dangerous failure per hour
PL	Performance Level according to ISO 13849-1
PLC	Programmable Logic Controller
S-DO	Safety digital output
SFRT	Safety Function Response Time
SIL	Safety Integrity Level (IEC 61508)
TÜV	Technischer Überwachungs-Verein (Technical Inspection Association)

1.7. References / related documents

[1.] AC500-S Safety User Manual, 3ADR025091M0207 (or newer)

[2.] AC500 Documentation, refer to www.abb.com/PLC and then navigate to "Downloads" area

[3.] Application Note – DX581-S Safety I/O Module with BSR23 Safety Relay, 3ADR010408

2. Usage of DX581-S outputs in parallel to increase the output current up to 2 A (24 V DC)

The DX581-S safety I/O module can supply a current of up to 0.5 A (24 V DC) to a load connected directly to a safety digital output, as shown in Fig. 1.

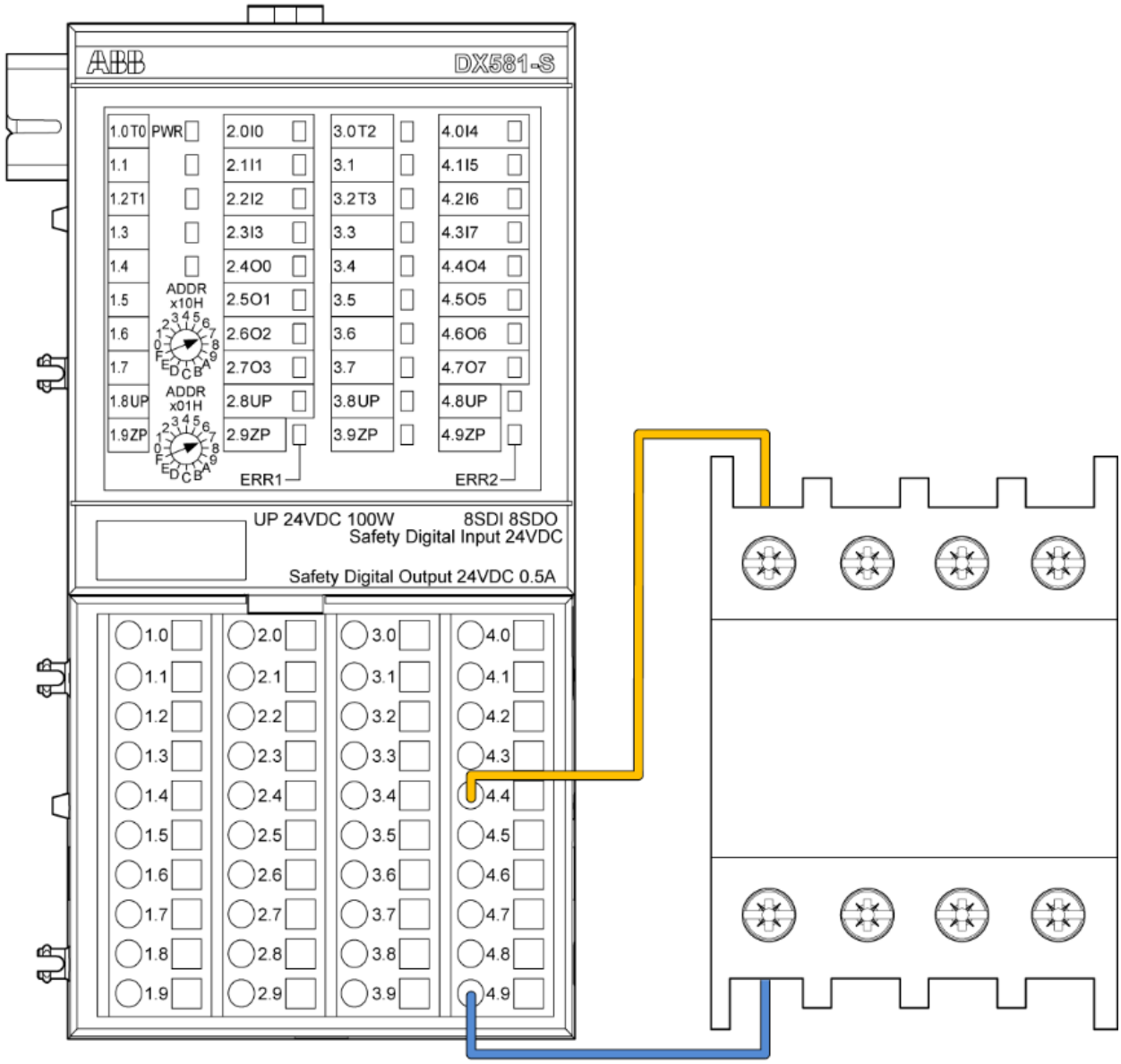

Fig. 1: The DX581-S safety I/O module supplies up to 0.5 A (24 V DC) from one safety digital output.

You can increase the output current by connecting up to four safety digital outputs in parallel. For example, when you connect two safety digital outputs in parallel to the same load, the maximum supply current increases to 1.0 A as shown in Fig. 2.

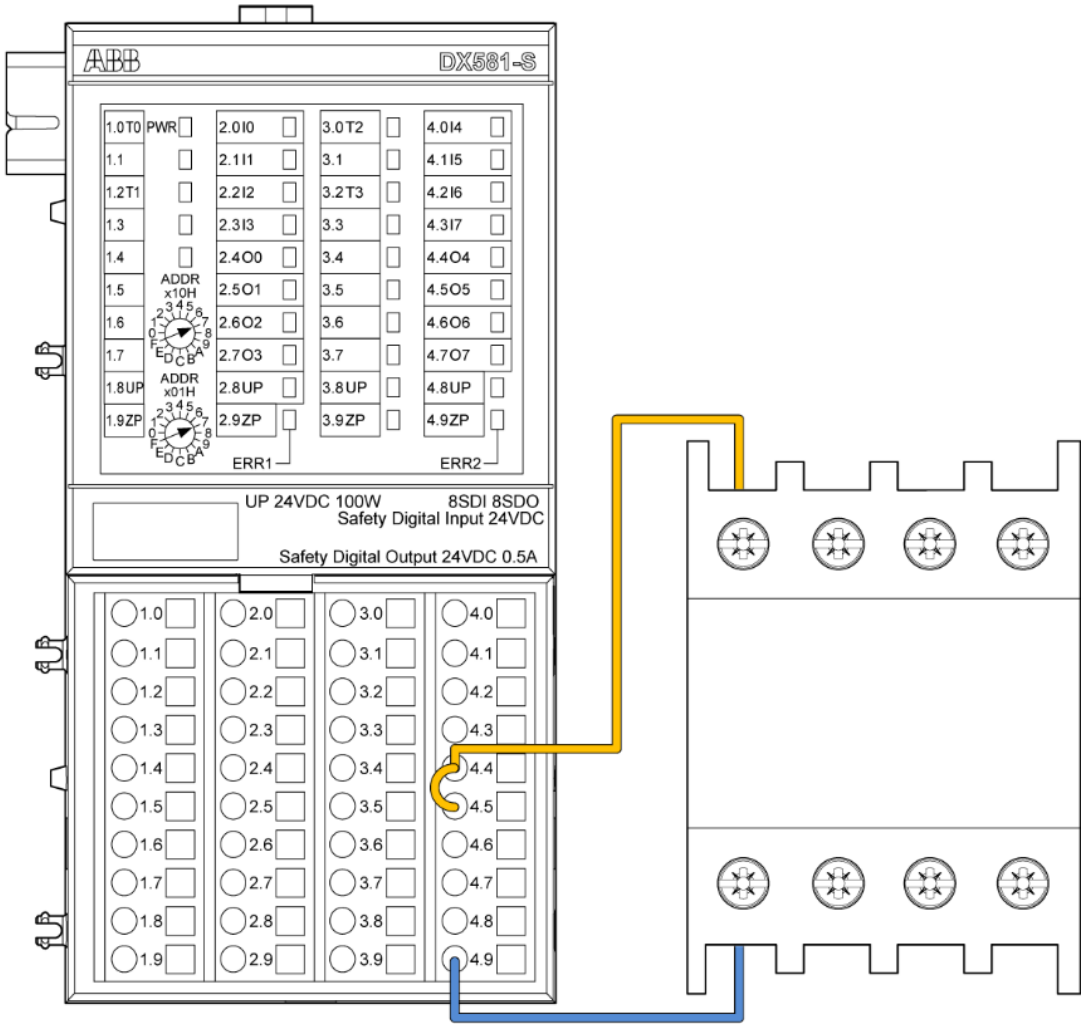

Fig. 2: Two safety digital outputs connected in parallel increases the maximum output current to 1.0 A.

You can increase the maximum output current even more by connecting three or four safety digital outputs in parallel.

Refer to Fig. 3 and Fig. 4 for examples of how to connect three and four safety digital outputs in parallel to produce maximum output currents of 1.5 A and 2.0 A, respectively.

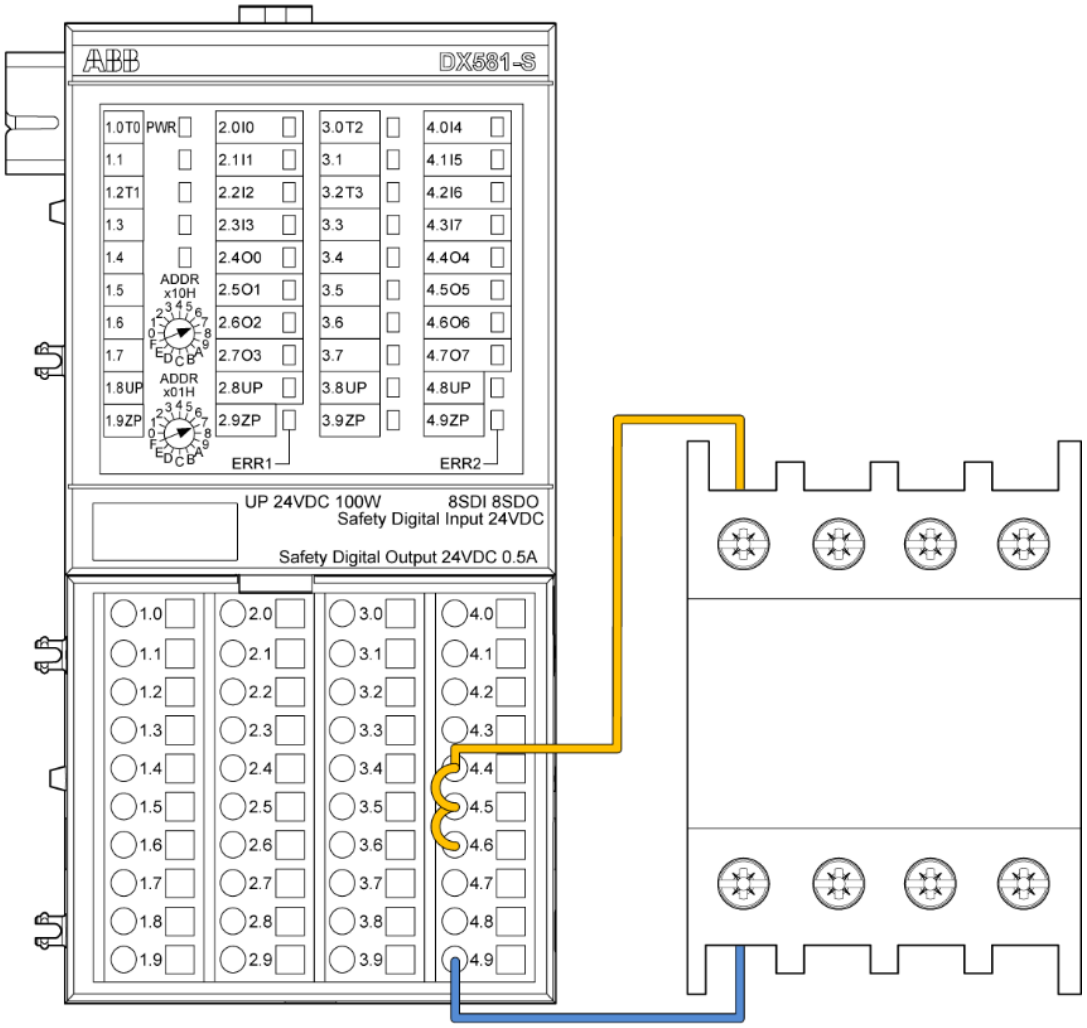

Fig. 3: The DX581-S safety I/O module can supply up to 1.5 A from three safety digital outputs connected in parallel.

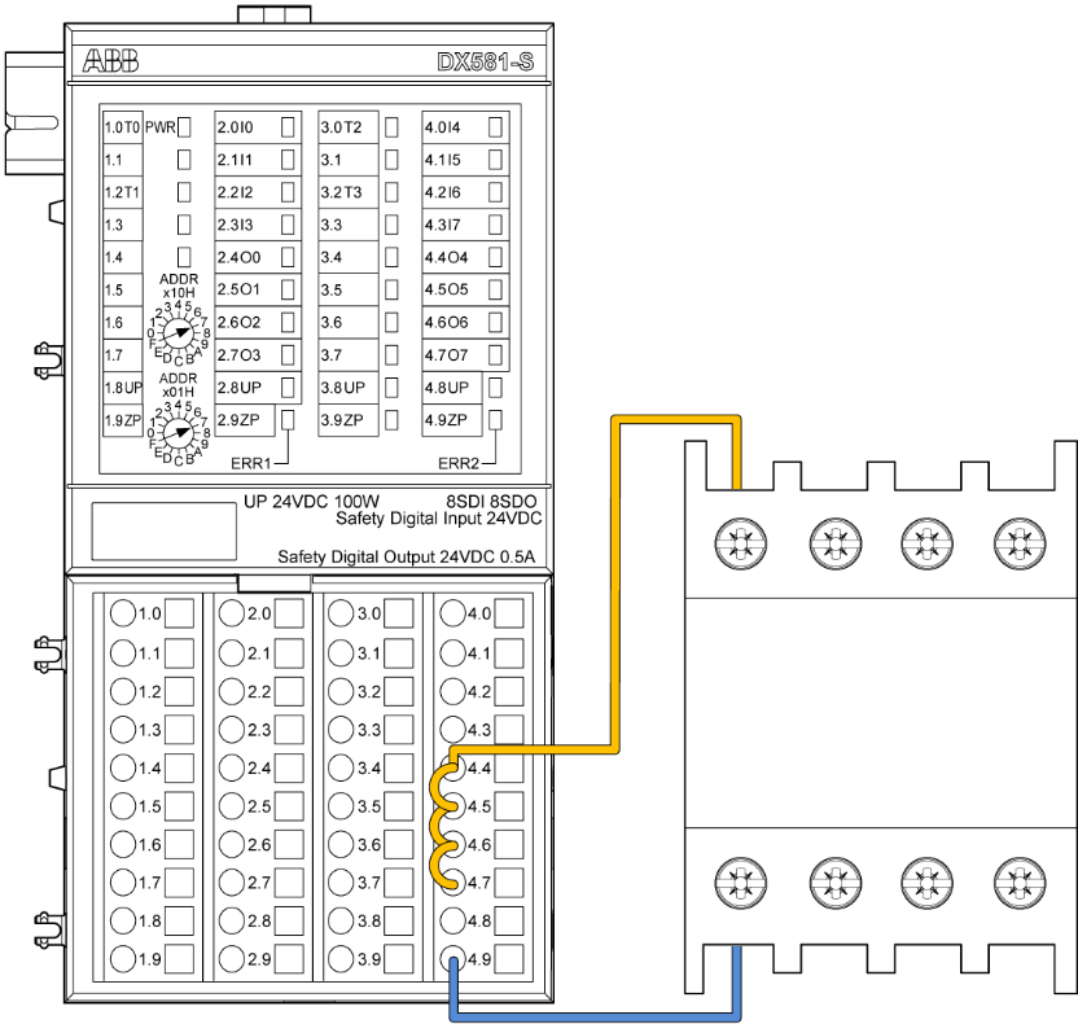

Fig. 4: The DX581-S safety I/O module can supply up to 2.0 A from four safety digital outputs connected in parallel.

Depending on the number of safety digital outputs that are connected in parallel, the DX581-S safety I/O module can supply a maximum current of:

- 0.5 A (24 V DC) from a single safety digital output
- 1.0 A (24 V DC) with two safety digital outputs connected in parallel
- 1.5 A (24 V DC) with three safety digital outputs connected in parallel
- 2.0 A (24 V DC) with four safety digital outputs connected in parallel

NOTICE

In the safety application with the DX581-S safety I/O module, the DX581-S safety digital outputs that are connected in parallel must be activated and deactivated simultaneously.

In addition, you can combine the control of different loads with the DX581-S safety I/O module: You can connect some loads to one safety digital output and some loads with parallel connections to safety digital outputs as shown in Fig. 5.

In the example in Fig. 5:

- Load A is controlled by three safety digital outputs in parallel (1.5 A maximum supply current)
- Load B is controlled directly from a single safety digital output (0.5 A maximum supply current)
- Load C is controlled by four safety digital outputs in parallel (2.0 A maximum supply current)

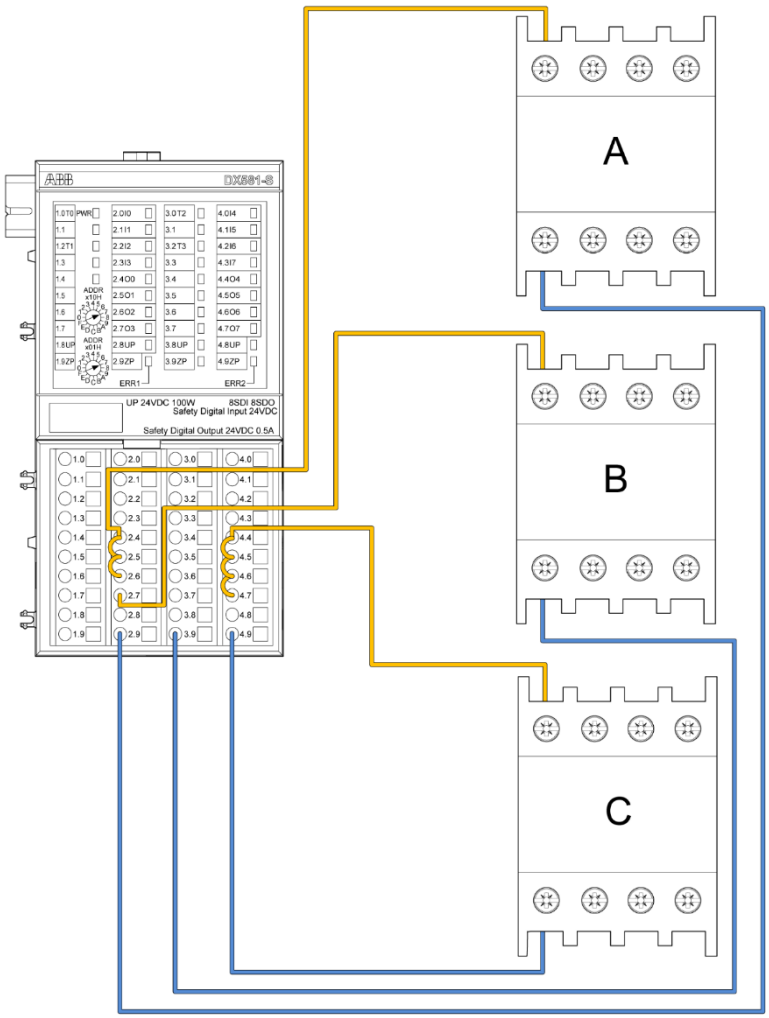

Fig. 5: The DX581-S safety I/O module controls three different loads that have differing current requirements.

NOTICE

Do not mix safety digital output groups O0...O3 and O4...O7 in the same parallel connection on the DX581-S safety I/O module. This can lead to channel passivation.

The DX581-S safety I/O module has internal cross-talk detection in the module but does not have cross-talk detection for the external wiring of electrical loads connected to the DX581-S terminals on the TU582-S. This permits the connection of DX581-S safety digital output wires to the terminals in parallel.

The output currents of the safety digital outputs are split equally, so that safety digital outputs O0, O1, O2 and O3 of the first group can be connected in parallel to a load. The safety digital outputs O4, O5, O6 and O7 of the second group can be connected in parallel to other loads. You cannot mix the outputs from these groups to the same load.

Table 1 shows the permitted parallel connections of safety digital outputs.

Table 1: Permitted and not permitted safety digital output parallel connections

Primary S-DO	Permitted S-DOs for parallel connections with the primary S-DO	Not permitted S-DOs for parallel connections with the primary S-DO (these can lead to channel passivation)
O0 with	O1, O2 and O3	O4, O5, O6 and O7
O1 with	O0, O2 and O3	O4, O5, O6 and O7
O2 with	O0, O1 and O3	O4, O5, O6 and O7
O3 with	O0, O1 and O2	O4, O5, O6 and O7
O4 with	O5, O6 and O7	O0, O1, O2 and O3
O5 with	O4, O6 and O7	O0, O1, O2 and O3
O6 with	O4, O5 and O7	O0, O1, O2 and O3
O7 with	O4, O5 and O6	O0, O1, O2 and O3

You can use the readback contact supervision as shown in the DX581-S safety I/O module connection examples [1.] in the same way as with single channel outputs.

2.1. Application example

The screenshots below show an application example with the AC500-S safety PLC for the combination of four safety digital outputs that are connected in parallel.

NOTICE

If one of the safety digital output channels connected in parallel shows a channel fault via related diagnostic bits, the safety application on the AC500-S safety CPU switches off all of the remaining parallel connected output channels (refer to Fig. 6 and output_ok signal usage).

If the safety application on the AC500-S safety CPU does not switch off all of the S-DO channels connected in parallel at the same time, the remaining S-DO channels can detect an overcurrent and cause channel passivation [1.].

	Safe diagnostic O0 - O7	%IB2	BYTE
IS_diag0	Safe_Diag - Output O0	%IX2.0	BOOL
IS_diag1	Safe_Diag - Output O1	%IX2.1	BOOL
IS_diag2	Safe_Diag - Output O2	%IX2.2	BOOL
IS_diag3	Safe_Diag - Output O3	%IX2.3	BOOL

	Safety digital outputs O0 - O7	%QB0	BYTE
OS_out0	Safety digital output O0	%QX0.0	BOOL
OS_out1	Safety digital output O1	%QX0.1	BOOL
OS_out2	Safety digital output O2	%QX0.2	BOOL
OS_out3	Safety digital output O3	%QX0.3	BOOL

PLC_PRG (PRG-ST)

```
0001 PROGRAM PLC_PRG
0002 VAR
0003     output_signal: BOOL;   (* signal for parallel output *)
0004     output_ok: BOOL;       (* consolidated channel diagnostic signal *)
0005 END_VAR
0006
```

```
0001 output_ok := IS_diag0 AND IS_diag1 AND IS_diag2 AND IS_diag3; (* ok = TRUE *)
0002
0003 OS_out0 := output_signal AND output_ok; (* Output on Channel 0 *)
0004 OS_out1 := output_signal AND output_ok; (* Output on Channel 1 *)
0005 OS_out2 := output_signal AND output_ok; (* Output on Channel 2 *)
0006 OS_out3 := output_signal AND output_ok; (* Output on Channel 3 *)
0007
0008
0009
0010
0011
0012
0013
0014
```

Fig. 6: Safety application example in AC500-S Programming Tool with AC500-S safety CPU variable declaration and safety program for four connected parallel safety digital outputs on one DX581-S safety I/O module

Table 2 lists the electrical loads that were tested with four DX581-S safety digital outputs connected in parallel as shown in Fig. 4 and using the safety application example in Fig. 6.

Table 2: Tested electrical loads with four DX581-S safety digital outputs connected in parallel

Type	Manufacturer	ID	Result
Contactor	ABB	AF12-30-01-11	The contactor with a current of 0.5 A to 2.0 A (24 V DC) can be used with the DX581-S safety I/O module and S-DO channels connected in parallel.

Contactor	ABB	AF80-22-00-11	The contactor with a current of 0.5 A to 2.0 A (24 V DC) cannot be used with the DX581-S safety I/O module and S-DO channels connected in parallel. Reason: Contact bouncing was observed in the contactor. This was caused by the “main switch test pulse” from the DX581-S S-DO channels. The contactor is not able to tolerate these pulses on S-DO channels. Solution: Use an interface safety relay as described in [3.].
Magnetic valve	Bürkert GmbH	00085299 2/2-Way-Magnetic Valve	The magnetic valve with a current of 0.5 A to 2.0 A (24 V DC) cannot be used with the DX581-S safety I/O module and S-DO channels connected in parallel. Reason: High inductance of the magnetic valve. Refer to Section 2.3 (“Electric load limitations”) for details. Solution: Use an interface safety relay as described in [3.].

2.2. Detection test pulses

⚠ DANGER

The reachable SILCL (IEC 62061), SIL (IEC 61508) and PL (ISO 13849-1) levels for the safety outputs of the DX581-S safety I/O module are valid only if the parameter “Detection is” set to “On”.

If parameter “Detection” is set to “Off”, contact ABB technical support for the correct reachable SILCL, SIL and PL levels.

Fig 7 shows the safety digital output settings including the “Detection” parameter for the DX581-S safety I/O module.

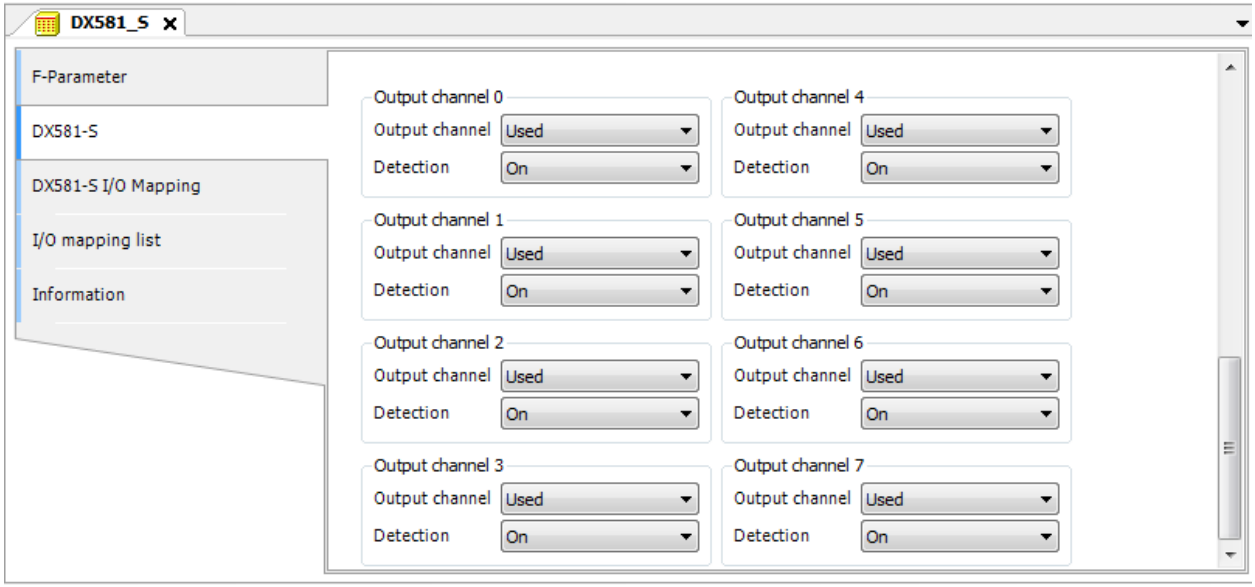

Fig 7. Settings for the DX581-S safety digital output channels in Automation Builder

On the safety digital outputs, the DX581-S safety I/O module uses two types of internal test pulses, the “main switch test pulse” [1] and “output channel test pulse”.

Due to the internal “main switch test pulse” all of the safety digital outputs of each group (O0...3 and O4...7, respectively) are periodically switched off for a time of slightly less than 1 ms simultaneously. The “main switch test pulse” on the DX581-S cannot be disabled.

NOTICE

Make sure that your load is not influenced by the “main switch test pulses” with a maximum length of less than 1 ms. The “main switch test pulses” can cause unexpected safe stop reactions of the actuators (refer to [1.] for more details).

The “output channel test pulse” is not visible on safety digital outputs that are connected in parallel, because only one of the four S-DO channels is switched off for a short time and the electrical current continues to flow through the other active parallel-connected safety digital outputs. Therefore, disabling the “output channel test pulse” by setting the “Detection” parameter to “Off” has no effect on the current flow through the electrical load.

2.3. Electrical load limitations

⚠ DANGER

The DX581-S safety I/O module is limited to an inductive load of 0.5 A even if all four channels are connected in parallel. If the inductive load current is more than 0.5 A, the internal suppressor diode gets too hot. This can lead to module damage.

[1] The “main switch” in the DX581-S electronics connects the process voltage to the output driver of each S-DO group (O0...3 and O4...7, respectively). In case of a fault, it safely interrupts the process voltage on the safety digital outputs to de-energize them in addition to the S-DO output driver.

Table 3 lists the electrical limit as Imax (maximum current) and Cmax (maximum capacitance) for connecting two, three or four DX581-S safety digital outputs in parallel to an electrical load.

Table 3: Electrical load limitations

Type of electrical load	Limit for 1 S-DO channel	Limit for 2 S-DO channels in parallel	Limit for 3 S-DO channels in parallel	Limit for 4 S-DO channels in parallel
Resistive [1)]	I_{max} = 0.5 A	I_{max} = 1.0 A	I_{max} = 1.5 A	I_{max} = 2.0 A
Capacitive	C_{max} = 300 µF	C_{max} = 600 µF	C_{max} = 900 µF	C_{max} = 1200 µF
Inductive [2)]	I_{max} = 0.5 A	I_{max} = 0.5 A	I_{max} = 0.5 A	I_{max} = 0.5 A

1) The maximum resistor value depends on the maximum voltage of the used DX581-S power supply.

2) The inductivity value is not relevant because the defined I_{max} is used as the electrical limit parameter.

The DX581-S safety I/O module reads the current state back to supervise each safety digital output. To do this, it measures the voltage level on the safety digital output 7.5 ms after setting the output to the active state and periodically after that. If the voltage is less than the specified level, the output is marked as unserviceable and is passivated by the DX581-S safety I/O module.

This behavior is related to electrical loads (for example, capacitive loads) which have an inrush current of more than 0.5 A for one output, 1.0 A for two parallel outputs, 1.5 A for three parallel outputs, and 2.0 A for four parallel outputs.

NOTICE

The DX581-S safety I/O module can drive a maximum capacitive load of 300 µF per S-DO channel without a series resistor. A higher capacitive load is possible with a series resistor. Contact ABB technical support for detailed instructions.

2.4. Faults and possible fault reactions

Table 4 lists the faults and possible fault reactions of the DX581-S safety I/O module that are related to safety digital output wiring.

Table 4: Fault models and possible fault reactions related to S-DO wiring on the DX581-S safety I/O module

Type of fault	Detection in DX581-S?	Fault reaction	Description
Short circuit of parallel connected outputs to ground (GND) in the ON (Active) state	Yes	Output passivation	The channel supervision passivates these safety digital outputs using overcurrent and short-circuit detection. The outputs have a current limitation.

Short circuit of parallel connected outputs to ground (GND) in the OFF state	No	-	Safe state because of de-energized safety digital outputs. The short circuit is detected as soon as the safety digital outputs are set to the ON state.
Short circuit of parallel connected outputs to +24 V DC or wire cross-talk	No	-	The outputs of the DX581-S safety I/O module are decoupled from the connected electrical load. This is necessary to avoid any influence of the connected electrical load on the internal test circuit and it guarantees high robustness (no occasional trips due to false error detection caused by unexpected changes in the electrical characteristics of the connected load). Because of this, wire cross-talk and short circuit to +24 V DC can be detected only up to the output clamp of the DX581-S safety digital output channel but not on the attached output wire. For more information, refer to chapter 2.16 in the AC500-S Safety User Manual [1.] “No detection of wire cross-talk or short circuit to +24 V DC for S-DOs of DX581-S …”.
Missing connection of one S-DO channel in a parallel connected group or Non-simultaneous switching of the outputs by the safety application on the safety CPU	Yes	Output passivation when overloaded	The load current is divided over the remaining S-DO channels. If the current is more than specified (0.5 A per channel), the remaining overloaded channels are passivated.
Unexpected activation of safety digital outputs because of internal faults	Yes	Safe state using the main switch in the DX581-S safety I/O module	Internal supervision in the DX581-S safety I/O module detects this condition and stops the outputs using main switch functionality.

2.5. Checklist for parallel connection of outputs

Table 5 shows the items to be verified by the application engineer, in addition to those listed in [1.], when they connect safety digital outputs in parallel.

Table 5: Checklist for connecting safety digital outputs in parallel with the DX581-S safety I/O module

No.	Item to check	Fulfilled (Yes/No)?	Comment
1	Make sure that you do not mix the S-DO channels from different groups (O0…O3 and O4…O7, respectively) in the same parallel connection.		
2	Make sure that the DX581-S configuration parameter “Detection” is set to “On” and done for all safety digital outputs of one parallel-connected group.		
3	Make sure that the safety application on the safety CPU controls all of safety digital outputs connected in parallel with the same safety application signal.		
4	Make sure that the safety application on the safety CPU switches off all of the safety digital outputs connected in parallel if a fault is detected on one output.		
5	Make sure that the capacitive load is not more than 300 µF per output, that is: One output ≤ 300 µF Two outputs in parallel ≤ 600 µF Three outputs in parallel ≤ 900 µF Four outputs in parallel ≤ 1200 µF		
6	Make sure that the current of the electrical load is not more than 0.5 A per safety digital output and, respectively, for: Two outputs in parallel ≤ 1.0 A Three outputs in parallel ≤ 1.5 A Four outputs in parallel ≤ 2.0 A		
7	Make sure that the current of the inductive load is not more than 0.5 A, independent of the number of safety digital outputs connected in parallel.		
8	Make sure that the test pulses on the S-DOs (with a duration of less than 1 ms) do not affect the load.		

2.6. Safety function response time (SFRT)

The safety function response time (SFRT), as defined in chapter 5 of [1.], is also valid and not changed for safety digital outputs connected in parallel, because each safety digital output still has a maximum output current of 0.5 A.

2.7. Calculation of the probability of failure according to PL (ISO 13849-1)

2.7.1. Safety loop

The safety loop for the AC500-S Safety PLC has three parts: sensors, Safety PLC and actuators. Fig. 8 shows the typical PFH distribution between the three parts in the safety loop.

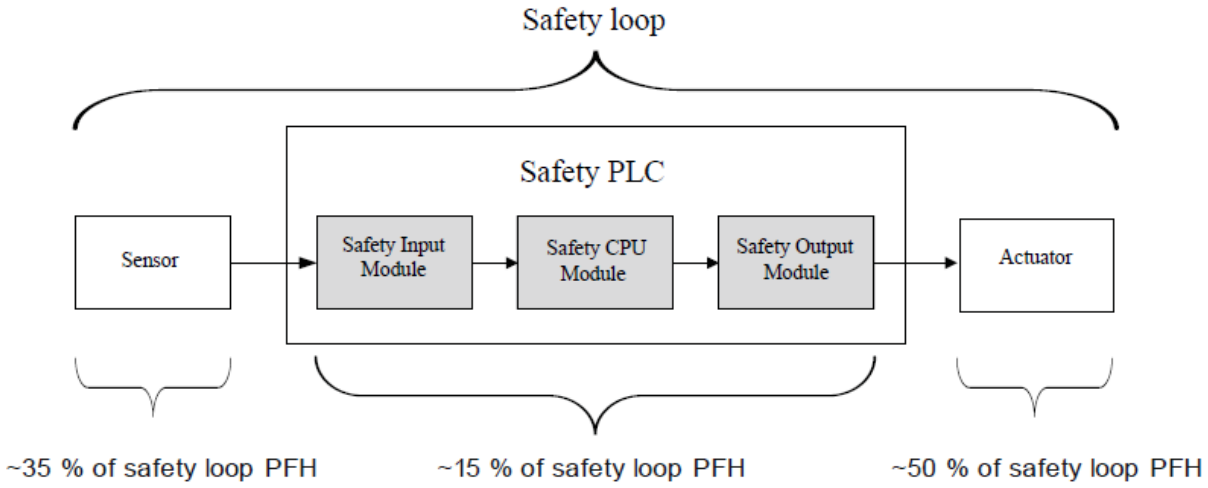

Fig. 8: Typical safety loop with AC500-S safety PLC

To calculate the probability of the dangerous failure per hour (PFHd) values of an example safety system, it is common to use a maximum value of 15 % for the Safety PLC. Section 2.7.2 shows how DX581-S safety digital outputs that are connected in parallel conform to PL e.

2.7.2. Safety values

Table 6 shows the Performance Level (PL) and probability of dangerous failure per hour (PFHd) for DX581-S safety digital outputs including those connected in parallel.

Table 6: PL and PFHd values for DX581-S safety digital outputs connected in parallel

Type	PL [1)]	PFHd [2)]
1 output of DX581-S(-XC) with parameter Detection set to “On”	e	1.17E-09
2 parallel outputs of DX581-S(-XC) with parameter Detection set to “On”	e	2.34E-09
3 parallel outputs of DX581-S(-XC) with parameter Detection set to “On”	e	3.51E-09
4 parallel outputs of DX581-S(-XC) with parameter Detection set to “On”	e	4.68E-09

1) PL (Performance Level) according to ISO 13849-1

2) Average probability of dangerous failure per hour according to ISO 13849-1

The 15 % limit of the safety loop for Safety PLC is 1.5E-08 for PL e.

The PFHd value of a setup with one safety input module, one safety CPU module and four DX581-S safety digital outputs (worst-case setup) connected in parallel is less than this limit. Table 7 shows a calculation example with a PFHd value of 9.01E-09, which is less than the required 1.5E-08 for PL e (ISO 13849).

Table 7: PFHd values of the typical AC500-S safety PLC setup with an AI581-S safety I/O module, safety CPU and four parallel connected DX581-S output channels

Type	PFHd
1 AI581-S (-XC) safety analog input module	2.53E-09
1 SM560-S (-XC) safety CPU	1.80E-09
4 parallel outputs on DX581-S (-XC) with parameter Detection set to “On”	4.68E-09
Total PFHd value	9.01E-09

2.7.3. Safety value calculation (PFHd)

The calculation of the probability of dangerous failure (PFHd) for the Safety PLC part is done with the ABB FSDT software (Functional Safety Design Tool, refer to www.abb.com).

To calculate the PFHd values for DX581-S safety I/O modules with safety digital outputs connected in parallel, add one additional DX581-S safety I/O module for each safety digital output connected in parallel.

For example, for four DX581-S safety digital outputs connected in parallel, the DX581-S safety I/O module must be added four times in the loop (refer to Fig. 9).

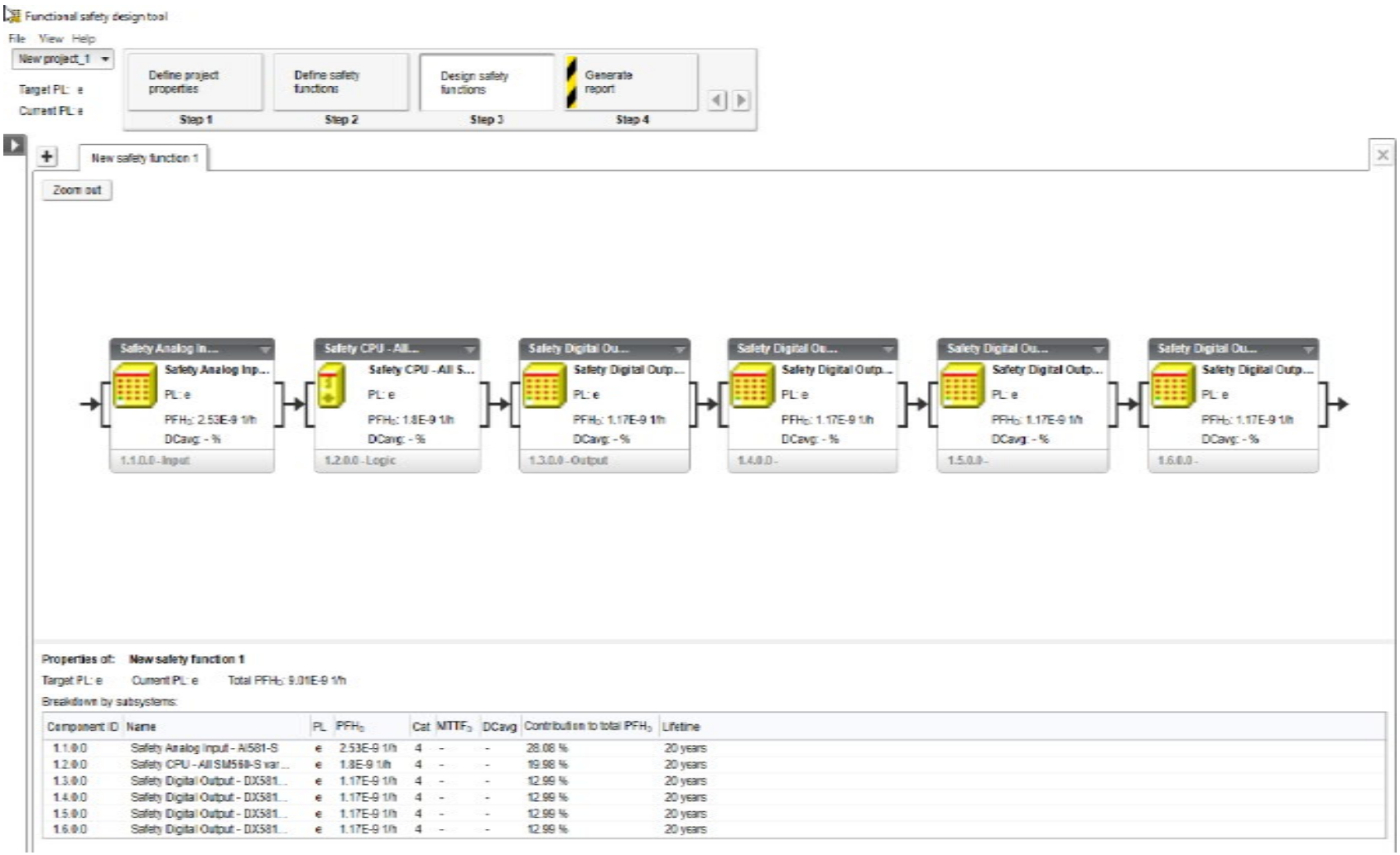

Fig. 9: Example of safety loop calculation for four DX581-S safety digital outputs connected in parallel in FSDT

3. Summary

DX581-S safety digital outputs can be used with up to 2 A (24 V DC) electrical loads in functional safety applications if the safety digital outputs are connected in parallel.

For resistive and capacitive electrical loads with the DX581-S safety I/O module, the permitted resistance and capacitance scales with the number of safety digital outputs connected in parallel on the DX581-S safety I/O module (refer to Table 3). Parallel connection of safety digital outputs can, therefore, be used to supply output currents of more than 0.5 A (24 V DC) to resistive and capacitive loads. For example, a current of up to 2.0 A (24 V DC) can be generated with four safety digital outputs connected in parallel on the DX581-S safety I/O module.

For inductive loads, the 0.5 A limit for the DX581-S safety I/O module does not increase by connecting channels in parallel. To control inductive loads of more than 0.5 A with the DX581-S, an external safety relay is required, as described in [3.]. An external safety relay is also required for resistive and capacitive loads that exceed the limits shown in Section 2.3.

3ADR010444, REV C, en_US, 2023/04/26

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