APPLICATION NOTE

AC500-S safety PLC
Usage of DX581-S safety digital outputs with up to 2 A (24 V DC) electrical loads
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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

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

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.

<table>
<thead>
<tr>
<th><strong>DANGER</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>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.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>NOTICE</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>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.</td>
</tr>
</tbody>
</table>

1.6. Definitions, expressions, abbreviations

| AC500 | ABB PLC, refer also to [www.abb.com/PLC](http://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](http://www.abb.com/PLC) for further details |
### 1.7. References / related documents

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

[2.] AC500 Documentation, refer to [www.abb.com/PLC](http://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.

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

<table>
<thead>
<tr>
<th>Primary S-DO</th>
<th>Permitted S-DOs for parallel connections with the primary S-DO</th>
<th>Not permitted S-DOs for parallel connections with the primary S-DO (these can lead to channel passivation)</th>
</tr>
</thead>
<tbody>
<tr>
<td>O0 with O1, O2 and O3</td>
<td></td>
<td>O4, O5, O6 and O7</td>
</tr>
<tr>
<td>O1 with O0, O2 and O3</td>
<td></td>
<td>O4, O5, O6 and O7</td>
</tr>
<tr>
<td>O2 with O0, O1 and O3</td>
<td></td>
<td>O4, O5, O6 and O7</td>
</tr>
<tr>
<td>O3 with O0, O1 and O2</td>
<td></td>
<td>O4, O5, O6 and O7</td>
</tr>
<tr>
<td>O4 with O5, O6 and O7</td>
<td></td>
<td>O0, O1, O2 and O3</td>
</tr>
<tr>
<td>O5 with O4, O6 and O7</td>
<td></td>
<td>O0, O1, O2 and O3</td>
</tr>
<tr>
<td>O6 with O4, O5 and O7</td>
<td></td>
<td>O0, O1, O2 and O3</td>
</tr>
<tr>
<td>O7 with O4, O5 and O6</td>
<td></td>
<td>O0, O1, O2 and O3</td>
</tr>
</tbody>
</table>

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.

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**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.].
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**

<table>
<thead>
<tr>
<th>Type</th>
<th>Manufacturer</th>
<th>ID</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>Contactor</td>
<td>ABB</td>
<td>AF12-30-01-11</td>
<td>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.</td>
</tr>
</tbody>
</table>
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” 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.

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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 $I_{\text{max}}$ (maximum current) and $C_{\text{max}}$ (maximum capacitance) for connecting two, three or four DX581-S safety digital outputs in parallel to an electrical load.

Table 3: Electrical load limitations

<table>
<thead>
<tr>
<th>Type of electrical load</th>
<th>Limit for 1 S-DO channel</th>
<th>Limit for 2 S-DO channels in parallel</th>
<th>Limit for 3 S-DO channels in parallel</th>
<th>Limit for 4 S-DO channels in parallel</th>
</tr>
</thead>
<tbody>
<tr>
<td>Resistive $^1)$</td>
<td>$I_{\text{max}} = 0.5$ A</td>
<td>$I_{\text{max}} = 1.0$ A</td>
<td>$I_{\text{max}} = 1.5$ A</td>
<td>$I_{\text{max}} = 2.0$ A</td>
</tr>
<tr>
<td>Capacitive</td>
<td>$C_{\text{max}} = 300$ μF</td>
<td>$C_{\text{max}} = 600$ μF</td>
<td>$C_{\text{max}} = 900$ μF</td>
<td>$C_{\text{max}} = 1200$ μF</td>
</tr>
<tr>
<td>Inductive $^2)$</td>
<td>$I_{\text{max}} = 0.5$ A</td>
<td>$I_{\text{max}} = 0.5$ A</td>
<td>$I_{\text{max}} = 0.5$ A</td>
<td>$I_{\text{max}} = 0.5$ A</td>
</tr>
</tbody>
</table>

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 $I_{\text{max}}$ 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

<table>
<thead>
<tr>
<th>Type of fault</th>
<th>Detection in DX581-S?</th>
<th>Fault reaction</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Short circuit of parallel connected outputs to ground (GND) in the ON (Active) state</td>
<td>Yes</td>
<td>Output passivation</td>
<td>The channel supervision passivates these safety digital outputs using over-current and short-circuit detection. The outputs have a current limitation.</td>
</tr>
</tbody>
</table>
### 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>
<thead>
<tr>
<th>Condition</th>
<th>Yes/No</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Short circuit of parallel connected outputs to ground (GND) in the OFF state</td>
<td>No</td>
<td>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.</td>
</tr>
<tr>
<td>Short circuit of parallel connected outputs to +24 V DC or wire cross-talk</td>
<td>No</td>
<td>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.] &quot;No detection of wire cross-talk or short circuit to +24 V DC for S-DOs of DX581-S ...&quot;.</td>
</tr>
<tr>
<td>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</td>
<td>Yes</td>
<td>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.</td>
</tr>
<tr>
<td>Unexpected activation of safety digital outputs because of internal faults</td>
<td>Yes</td>
<td>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.</td>
</tr>
</tbody>
</table>
Table 5: Checklist for connecting safety digital outputs in parallel with the DX581-S safety I/O module

<table>
<thead>
<tr>
<th>No.</th>
<th>Item to check</th>
<th>Fulfilled (Yes/No)?</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>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.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Make sure that the DX581-S configuration parameter &quot;Detection&quot; is set to &quot;On&quot; and done for all safety digital outputs of one parallel-connected group.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>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.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>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.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>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</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>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</td>
<td></td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>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.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>Make sure that the test pulses on the S-DOs (with a duration of less than 1 ms) do not affect the load.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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.
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>
<thead>
<tr>
<th>Type</th>
<th>PL</th>
<th>PFHd</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 output of DX581-S(-XC) with parameter Detection set to “On”</td>
<td>e</td>
<td>1.17E-09</td>
</tr>
<tr>
<td>2 parallel outputs of DX581-S(-XC) with parameter Detection set to “On”</td>
<td>e</td>
<td>2.34E-09</td>
</tr>
<tr>
<td>3 parallel outputs of DX581-S(-XC) with parameter Detection set to “On”</td>
<td>e</td>
<td>3.51E-09</td>
</tr>
<tr>
<td>4 parallel outputs of DX581-S(-XC) with parameter Detection set to “On”</td>
<td>e</td>
<td>4.68E-09</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Type</th>
<th>PFHd</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 AI581-S (-XC) safety analog input module</td>
<td>2.53E-09</td>
</tr>
<tr>
<td>1 SM560-S (-XC) safety CPU</td>
<td>1.80E-09</td>
</tr>
<tr>
<td>4 parallel outputs on DX581-S (-XC) with parameter Detection set to “On”</td>
<td>4.68E-09</td>
</tr>
<tr>
<td>Total PFHd value</td>
<td>9.01E-09</td>
</tr>
</tbody>
</table>
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.
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