PROCESS AUTOMATION

SAFETY MANUAL SIL

SURGE PROTECTION BARRIERS

K-LB-*.*

F*-LB-I

P-LB-*.*.*

SIL
IEC 61508/61511

ISO9001

CE

SIL3

PEPPERL+FUCHS
PROTECTING YOUR PROCESS

1 Introduction

1.1 General Information

This manual contains information for application of the device in functional safety related loops.

The corresponding data sheets, the operating instructions, the system description, the Declaration of Conformity, the EC-Type-Examination Certificate, the Functional Safety Assessment and applicable Certificates (see data sheet) are integral parts of this document.

The documents mentioned are available from **www.pepperl-fuchs.com** or by contacting your local Pepperl+Fuchs representative.

Assembly, commissioning, operation, maintenance and dismounting of any devices may only be carried out by trained, qualified personnel who have read and understood the instruction manual.

When it is not possible to correct faults, the devices must be taken out of service and action taken to protect against accidental use. Devices should only be repaired directly by the manufacturer. De-activating or bypassing safety functions or failure to follow the advice given in this manual (causing disturbances or impairment of safety functions) may cause damage to property, environment or persons for which Pepperl+Fuchs GmbH will not be liable.

The devices are developed, manufactured and tested according to the relevant safety standards. They must only be used for the applications described in the instructions and with specified environmental conditions, and only in connection with approved external devices.

1.2 Intended Use

General Considerations – Safety Loops with Surge Protection

A Surge Protection Barrier is used to protect a connected field device or control system against lightning induced signals and high transient voltages. This is achieved by diverting the transient current to ground and limiting the signal line voltage to a safe level for the duration of the surge. Therefore a Surge Protection Barrier is always the enhancement of an existing application or the device which shall be protected – it is not intended to use this device as a standalone, since its only purpose is to protect the connected device. For a proper understanding of a safety loop and its devices the most important step is to define the desired safety function and the safe state of the whole construction.

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1.3 Devices covered in this Safety Manual

The whole series of Pepperl+Fuchs Surge Protection Barriers is covered in this safety manual.

DIN Rail Mount Modules

K-LB-*.*

This barrier provides low line-to-line clamping voltage and 500 V line-to-ground clamping voltage for the protected instruments. It can be used to protect instruments **that have more than 500 V** isolation-to-ground, such as intrinsic safety isolated barriers, signal conditioners and most field devices.

K-LB-*.*G

This barrier provides a low line-to-line clamping voltage and line-to-ground clamping voltage for the protected instrument. It can be used to protect instruments **that have less than 500 V** isolation-to-ground, such as Zener Barriers, standard I/O cards, and some field devices.

Plug-In Modules

P-LB-*.*.*

This barrier is designed for use with K-System (KF modules). By simply snapping the barriers into a standard KF module, the modules are safely protected. The end digits of the model designation correspond to the protected terminals of the respective KF module.

Field Mount Modules

F*-LB-I

This barrier provides 85 V line-to-line and 500 V line-to-ground clamping voltage for the protected instruments. It also protects instruments that have less than 500 V isolation-to-ground. It is installed in an available conduit or cable gland opening like those found on most process transmitters.

1.4 Manufacturer Information

Pepperl+Fuchs GmbH

Lilienthalstrasse 200
68307 Mannheim/Germany

K-LB-*.**
F*-LB-I
P-LB-*.*.*

Up to SIL3

The stars replace a combination of characters, depending on the product.

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1.5 Relevant Standards and Directives

Device specific standards and directives

- Functional safety IEC 61508 part 2, edition 2000:
  Standard of functional safety of electrical/electronic/programmable electronic safety-related systems (product manufacturer)
- Electromagnetic compatibility:
  - EN 61326-1:2006
  - NE 21:2006

System specific standards and directives

- Functional safety IEC 61511 part 1, edition 2003:
  Standard of functional safety: safety instrumented systems for the process industry sector (user)

2 Planning

2.1 System Structure

2.1.1 Low Demand Mode

If there are two loops, one for the standard operation and another one for the functional safety, then usually the demand rate for the safety loop is assumed to be less than once per year.

The relevant safety parameters to be verified are:

- the PFD_{avg} value (average **P**robability of **F**ailure on **D**emand) and T_{proof} (proof test interval that has a direct impact on the PFD_{avg})
- the SFF value (**S**afe **F**ailure **F**raction)
- the HFT architecture (**H**ardware **F**ault **T**olerance architecture)

2.1.2 High Demand Mode

If there is only one loop, which combines the standard operation and safety related operation, then usually the demand rate for this loop is assumed to be higher than once per year.

The relevant safety parameters to be verified are:

- PFH (**P**robability of dangerous **F**ailure per **H**our)
- Fault reaction time of the safety system
- the SFF value (**S**afe **F**ailure **F**raction)
- the HFT architecture (**H**ardware **F**ault **T**olerance architecture)

2.2 Assumptions

The following assumptions have been made during the FMEDA analysis:

- Failure rates are constant, wear out mechanisms are not included.
- The stress levels are average for an industrial environment and the assumed environment is similar to IEC 60654-1 Class C (sheltered location) with temperature limits within the manufacturer's rating and an average temperature over a long period of time of 40 °C. Humidity levels are assumed within manufacturer's rating.
- The listed failure rates are valid for operating stress conditions typical of an industrial field environment similar to IEC 60654-1 Class C with an average temperature over a long period of time of 40 °C. For a higher average temperature of 60 °C, the failure rates should be multiplied with an experience based factor of 2.5. A similar multiplier should be used if frequent temperature fluctuation must be assumed.
- Failure rate based on the Siemens SN29500 data base.
- It was assumed that the appearance of a safe error (e. g. output in safe state) would be repaired within 8 hours (e. g. remove sensor burnout).
- During the absence of the device for repairing, measures have to be taken to ensure the safety function (for example: substitution by an equivalent device).
- The circuit has a Hardware Fault Tolerance of **0** and it is a type **A** component. A SFF for this device is not given, since this value has to be calculated in conjunction with the connected field device, as described in the following chapter (see chapter 5).

Application Information

The Surge Protection Barrier and the connected device (field device, interface device or actuator) have to be considered together. The PFD_{avg}/PFH budget of the device categories in the entire loop is (→ view Figure 5.1 on page 25):

- Actuator (valve) 40 %
- Transmitter (sensor) 25 %
- Interface device 10 %

As an overview for SIL2/SIL3 loop this means:

	SIL2		**SIL3**	
	PFH	**PFD_{avg}**	**PFH**	**PFD_{avg}**
Total	10^{-6}	10^{-2}	10^{-7}	10^{-3}
Actuator (40 %)	4×10^{-7}	4×10^{-3}	4×10^{-8}	4×10^{-4}
Transmitter (25 %)	2.5×10^{-7}	2.5×10^{-3}	2.5×10^{-8}	2.5×10^{-4}
Interface device (10 %)	10^{-7}	10^{-3}	10^{-8}	10^{-4}

Table 2.1: Overview PFD_{avg}/PFH budget

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2.3 Safety Function and Safe State

A Surge Protection Barrier has to be considered in conjunction with the connected field device. The safety function of the Surge Protection Barrier is defined by the signals and settings of the connected device (e. g. interface module, DCS input, output, field device).

Safety Function

The safety function of a Surge Protection Barrier in the sense of IEC 61508 is to behave like a piece of copper wire, passing through the process signal without being altered. In case of a 0/4 mA ... 20 mA signal the maximum additional loop current error of the Surge Protection Barrier is maximum ±1 % full scale.

Safe State

The safe state is defined as the Surge Protection Barrier interrupting the input signal.

Reaction Time

The reaction time is < 20 ms.

2.4 Characteristic Safety Values

The following tables contain no data for the SFF, since this performance value has to be calculated with consideration of the connected field device.

DIN Rail Mount Modules

K-LB-1.30, K-LB-2.30, K-LB-1.6, K-LB-2.6 (1oo1 structure)

Parameters acc. to IEC 61508	**Variables**			
Assessment type and documentation	Hardware FMEDA			
Pepperl+Fuchs FMEDA report [1]	FS-0019PF-20			
Device type	A			
Demand mode	Low Demand Mode or High Demand Mode			
Safety function [2]	Pass through the signal			
HFT	0			
SIL [3]	2 or 3			
Signal type [2]	AI	AO	DI	DO
Safe state [2]	I_{in} < 4 mA Signal line interrupted	I_{out} < 4 mA Signal line interrupted	I_{out} = 0 mA U_{out} = 0 V Signal line interrupted	I_{out} = 0 mA U_{out} = 0 V Signal line interrupted
Loop error detection [4]	< 4 mA and > 20 mA can be detected	No error detection since < 4 mA is safe state of the loop	SC and LB detection of the loop	No error detection
$\lambda_{sd} + \lambda_{su}$	16 FIT	16 FIT	16 FIT	16 FIT
λ_{dd}	0 FIT	0 FIT	0 FIT	0 FIT
λ_{du}	0 FIT	0 FIT	0 FIT	0 FIT
$\lambda_{no\ effect}$	41.1 FIT	41.1 FIT	41.1 FIT	41.1 FIT
$\lambda_{not\ part}$	0 FIT	0 FIT	0 FIT	0 FIT
$\lambda_{total\ (safety\ function)}$	57 FIT	57 FIT	57 FIT	57 FIT
MTBF [5]	2002 years (1-channel device), 1001 years (2-channel device)			
PFH	0 1/h	0 1/h	0 1/h	0 1/h
PFD_{avg} for T_1 = 1 year	0	0	0	0

[1] Pepperl+Fuchs documentation number

[2] The safe state of a Surge Protection Barrier depend on the application.

[3] The maximum safety integrity level of the safety loop in which the device might be used depends on the performance values of the whole loop and the connected field devices in the application.

[4] This error detection has to be provided by the safety loop architecture (e. g. NAMUR signal – lead breakage and short circuit detection, current loop > 20 mA).

[5] acc. to SN29500. This value includes failures which are not part of the safety function/MTTR = 8 h.

K-LB-1.30G, K-LB-2.30G, K-LB-1.6G, K-LB-2.6G (1oo1 structure)

Parameters acc. to IEC 61508	**Variables**			
Assessment type and documentation	Hardware FMEDA			
Pepperl+Fuchs FMEDA report [1]	FS-0019PF-20			
Device type	A			
Demand mode	Low Demand Mode or High Demand Mode			
Safety function [2]	Pass through the signal			
HFT	0			
SIL [3]	2 or 3			
Signal type [2]	AI	AO	DI	DO
Safe state [2]	I_{in} < 4 mA Signal line interrupted	I_{out} < 4 mA Signal line interrupted	I_{out} = 0 mA U_{out} = 0 V Signal line interrupted	I_{out} = 0 mA U_{out} = 0 V Signal line interrupted
Loop error detection [4]	< 4 mA and > 20 mA can be detected	No error detection since < 4 mA is safe state of the loop	SC and LB detection of the loop	No error detection
$\lambda_{sd} + \lambda_{su}$	15 FIT	15 FIT	15 FIT	26.9 FIT
λ_{dd}	0 FIT	0 FIT	0 FIT	0 FIT
λ_{du}	11.9 FIT	11.9 FIT	11.9 FIT	0 FIT
$\lambda_{no\ effect}$	24.2 FIT	24.2 FIT	24.2 FIT	24.2 FIT
$\lambda_{not\ part}$	0 FIT	0 FIT	0 FIT	0 FIT
$\lambda_{total\ (safety\ function)}$	51 FIT	51 FIT	51 FIT	51 FIT
MTBF [5]	2238 years (1-channel device), 1119 years (2-channel device)			
PFH	1.19×10^{-8} 1/h	1.19×10^{-8} 1/h	1.19×10^{-8} 1/h	0 1/h
PFD_{avg} for T_1 = 1 year	4.81×10^{-5}	4.81×10^{-5}	4.81×10^{-5}	0

[1] Pepperl+Fuchs documentation number

[2] The safe state of a Surge Protection Barrier depend on the application.

[3] The maximum safety integrity level of the safety loop in which the device might be used depends on the performance values of the whole loop and the connected field devices in the application.

[4] This error detection has to be provided by the safety loop architecture (e. g. NAMUR signal – lead breakage and short circuit detection, current loop > 20 mA).

[5] acc. to SN29500. This value includes failures which are not part of the safety function/MTTR = 8 h.

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Field Mount Modules

FN-LB-I, FS-LB-I, FP-LB-I (1oo1 structure)

Parameters acc. to IEC 61508	Variables			
Assessment type and documentation	Hardware FMEDA			
Pepperl+Fuchs FMEDA report [1]	FS-0019PF-20			
Device type	A			
Demand mode	Low Demand Mode or High Demand Mode			
Safety function [2]	Pass through the signal			
HFT	0			
SIL [3]	2 or 3			
Signal type [2]	AI	AO	DI	DO
Safe state [2]	I_{in} < 4 mA Signal line interrupted	I_{out} < 4 mA Signal line interrupted	I_{out} = 0 mA U_{out} = 0 V Signal line interrupted	I_{out} = 0 mA U_{out} = 0 V Signal line interrupted
Loop error detection [4]	< 4 mA and > 20 mA can be detected	No error detection since < 4 mA is safe state of the loop	SC and LB detection of the loop	No error detection
$\lambda_{sd} + \lambda_{su}$	6.95 FIT	6.95 FIT	6.95 FIT	9.45 FIT
λ_{dd}	0 FIT	0 FIT	0 FIT	0 FIT
λ_{du}	5 FIT	5 FIT	5 FIT	2.5 FIT
$\lambda_{no\ effect}$	25.1 FIT	25.1 FIT	25.1 FIT	25.1 FIT
$\lambda_{not\ part}$	0 FIT	0 FIT	0 FIT	0 FIT
$\lambda_{total\ (safety\ function)}$	37 FIT	37 FIT	37 FIT	37 FIT
MTBF [5]	3085 years (all components of the device)			
PFH	0.5×10^{-8} 1/h	0.5×10^{-8} 1/h	0.5×10^{-8} 1/h	0.25×10^{-8} 1/h
PFD_{avg} for T_1 = 1 year	2.19×10^{-5}	2.19×10^{-5}	2.19×10^{-5}	1.09×10^{-5}

[1] Pepperl+Fuchs documentation number

[2] The safe state of a Surge Protection Barrier depend on the application.

[3] The maximum safety integrity level of the safety loop in which the device might be used depends on the performance values of the whole loop and the connected field devices in the application.

[4] This error detection has to be provided by the safety loop architecture (e. g. NAMUR signal – lead breakage and short circuit detection, current loop > 20 mA).

[5] acc. to SN29500. This value includes failures which are not part of the safety function/MTTR = 8 h.

Plug-In Modules

P-LB-1.D.*, P-LB-1.F.* (1oo1 structure)

Parameters acc. to IEC 61508	Variables			
Assessment type and documentation	Hardware FMEDA			
Pepperl+Fuchs FMEDA report [1]	FS-0019PF-20			
Device type	A			
Demand mode	Low Demand Mode or High Demand Mode			
Safety function [2]	Pass through the signal			
HFT	0			
SIL [3]	2 or 3			
Signal type [2]	AI	AO	DI	DO
Safe state [2]	I_{in} < 4 mA Signal line interrupted	I_{out} < 4 mA Signal line interrupted	I_{out} = 0 mA U_{out} = 0 V Signal line interrupted	I_{out} = 0 mA U_{out} = 0 V Signal line interrupted
Loop error detection [4]	< 4 mA and > 20 mA can be detected	No error detection since < 4 mA is safe state of the loop	SC and LB detection of the loop	No error detection
$\lambda_{sd} + \lambda_{su}$	16 FIT	16 FIT	16 FIT	27.9 FIT
λ_{dd}	0 FIT	0 FIT	0 FIT	0 FIT
λ_{du}	17.9 FIT	17.9 FIT	17.9 FIT	5.95 FIT
$\lambda_{no\ effect}$	44.2 FIT	44.2 FIT	44.2 FIT	44.2 FIT
$\lambda_{not\ part}$	124 FIT	124 FIT	124 FIT	124 FIT
$\lambda_{total\ (safety\ function)}$	78 FIT	78 FIT	78 FIT	78 FIT
MTBF [5]	565 years (all components of the device)			
PFH	1.79×10^{-8} 1/h	1.79×10^{-8} 1/h	1.79×10^{-8} 1/h	0.59×10^{-8} 1/h
PFD_{avg} for T_1 = 1 year	7.84×10^{-5}	7.84×10^{-5}	7.84×10^{-5}	2.6×10^{-5}

[1] Pepperl+Fuchs documentation number

[2] The safe state of a Surge Protection Barrier depend on the application.

[3] The maximum safety integrity level of the safety loop in which the device might be used depends on the performance values of the whole loop and the connected field devices in the application.

[4] This error detection has to be provided by the safety loop architecture (e. g. NAMUR signal – lead breakage and short circuit detection, current loop > 20 mA).

[5] acc. to SN29500. This value includes failures which are not part of the safety function/MTTR = 8 h.

P-LB-1.A.*, P-LB-2.A.* (1oo1 structure)

Parameters acc. to IEC 61508	**Variables**			
Assessment type and documentation	Hardware FMEDA			
Pepperl+Fuchs FMEDA report [1]	FS-0019PF-20			
Device type	A			
Demand mode	Low Demand Mode or High Demand Mode			
Safety function [2]	Pass through the signal			
HFT	0			
SIL [3]	2 or 3			
Signal type [2]	AI	AO	DI	DO
Safe state [2]	I_{in} < 4 mA Signal line interrupted	I_{out} < 4 mA Signal line interrupted	I_{out} = 0 mA U_{out} = 0 V Signal line interrupted	I_{out} = 0 mA U_{out} = 0 V Signal line interrupted
Loop error detection [4]	< 4 mA and > 20 mA can be detected	No error detection since < 4 mA is safe state of the loop	SC and LB detection of the loop	No error detection
$\lambda_{sd} + \lambda_{su}$	16 FIT	16 FIT	16 FIT	16 FIT
λ_{dd}	0 FIT	0 FIT	0 FIT	0 FIT
λ_{du}	0 FIT	0 FIT	0 FIT	0 FIT
$\lambda_{no\ effect}$	41.1 FIT	41.1 FIT	41.1 FIT	41.1 FIT
$\lambda_{not\ part}$	0 FIT	0 FIT	0 FIT	0 FIT
$\lambda_{total\ (safety\ function)}$	57 FIT	57 FIT	57 FIT	57 FIT
MTBF [5]	2002 years (1-channel device), 1001 years (2-channel device)			
PFH	0 1/h	0 1/h	0 1/h	0 1/h
PFD_{avg} for T_1 = 1 year	0	0	0	0

[1] Pepperl+Fuchs documentation number

[2] The safe state of a Surge Protection Barrier depend on the application.

[3] The maximum safety integrity level of the safety loop in which the device might be used depends on the performance values of the whole loop and the connected field devices in the application.

[4] This error detection has to be provided by the safety loop architecture (e. g. NAMUR signal – lead breakage and short circuit detection, current loop > 20 mA).

[5] acc. to SN29500. This value includes failures which are not part of the safety function/MTTR = 8 h.

P-LB-1.B.*, P-LB-2.B.*, P-LB-1.C.*, P-LB-2.C.*, P-LB-2.D.*, P-LB-1.E.* (1oo1 structure)

Parameters acc. to IEC 61508	**Variables**			
Assessment type and documentation	Hardware FMEDA			
Pepperl+Fuchs FMEDA report [1]	FS-0019PF-20			
Device type	A			
Demand mode	Low Demand Mode or High Demand Mode			
Safety function [2]	Pass through the signal			
HFT	0			
SIL [3]	2 or 3			
Signal type [2]	AI	AO	DI	DO
Safe state [2]	I_{in} < 4 mA Signal line interrupted	I_{out} < 4 mA Signal line interrupted	I_{out} = 0 mA U_{out} = 0 V Signal line interrupted	I_{out} = 0 mA U_{out} = 0 V Signal line interrupted
Loop error detection [4]	< 4 mA and > 20 mA can be detected	No error detection since < 4 mA is safe state of the loop	SC and LB detection of the loop	No error detection
$\lambda_{sd} + \lambda_{su}$	16 FIT	16 FIT	16 FIT	16 FIT
λ_{dd}	0 FIT	0 FIT	0 FIT	0 FIT
λ_{du}	5.95 FIT	5.95 FIT	5.95 FIT	5.95 FIT
$\lambda_{no\ effect}$	42.1 FIT	42.1 FIT	42.1 FIT	42.1 FIT
$\lambda_{not\ part}$	52 FIT	52 FIT	52 FIT	52 FIT
$\lambda_{total\ (safety\ function)}$	64 FIT	64 FIT	64 FIT	64 FIT
MTBF [5]	984 years (1-channel device), 492 years (2-channel device)			
PFH	0.59×10^{-8} 1/h	0.59×10^{-8} 1/h	0.59×10^{-8} 1/h	0.59×10^{-8} 1/h
PFD_{avg} for T_1 = 1 year	2.60×10^{-5}	2.60×10^{-5}	2.60×10^{-5}	2.60×10^{-5}

[1] Pepperl+Fuchs documentation number

[2] The safe state of a Surge Protection Barrier depend on the application.

[3] The maximum safety integrity level of the safety loop in which the device might be used depends on the performance values of the whole loop and the connected field devices in the application.

[4] This error detection has to be provided by the safety loop architecture (e. g. NAMUR signal – lead breakage and short circuit detection, current loop > 20 mA).

[5] acc. to SN29500. This value includes failures which are not part of the safety function/MTTR = 8 h.

The characteristic safety values like PFD/PFH, SFF, HFT and T_{proof} are taken from the SIL report/FMEDA report. Please note, PFD and T_{proof} are related to each other.

The function of the devices has to be checked within the proof test interval (T_{proof}).

3 Safety Recommendation

3.1 Interfaces

The device has the following interfaces. For corresponding terminals see data sheet.

- Safety relevant interfaces: input and output

3.2 Configuration

A configuration of the device is not necessary and not possible.

3.3 Useful Life Time

Although a constant failure rate is assumed by the probabilistic estimation this only applies provided that the useful life time of components is not exceeded. Beyond this useful life time, the result of the probabilistic calculation is meaningless as the probability of failure significantly increases with time. The useful life time is highly dependent on the component itself and its operating conditions – temperature in particular (for example, the electrolytic capacitors can be very sensitive to the working temperature).

This assumption of a constant failure rate is based on the bathtub curve, which shows the typical behavior for electronic components.

Therefore it is obvious that failure calculation is only valid for components that have this constant domain and that the validity of the calculation is limited to the useful life time of each component.

It is assumed that early failures are detected to a huge percentage during the installation period and therefore the assumption of a constant failure rate during the useful life time is valid.

However, according to IEC 61508-2, a useful life time, based on experience, should be assumed. Experience has shown that the useful life time often lies within a range period of about 8 ... 12 years.

Our experience has shown that the useful life time of a Pepperl+Fuchs product can be higher

- if there are no components with reduced life time in the safety path (like electrolytic capacitors, relays, flash memory, opto coupler) which can produce dangerous undetected failures and
- if the ambient temperature is significantly below 60 °C.

Please note that the useful life time refers to the (constant) failure rate of the device. The effective life time can be higher.

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3.4 Installation and Commissioning

Installation has to consider all aspects regarding the SIL level of the loop. During installation or replacement of the device the loop has to shut down. Devices have to be replaced by the same type of devices.

4 Proof Test

4.1 Proof Test Procedure

According to IEC 61508-2 a recurring proof test shall be undertaken to reveal potential dangerous fails that are otherwise not detected by diagnostic test.

The functionality of the subsystem must be verified at periodic intervals depending on the applied PFD_{avg} in accordance with the data provided in see chapter 2.4.

It is under the responsibility of the operator to define the type of proof test and the interval time period.

The ancillary equipment required on the tested Surge Protection Barrier:

- Two digital multimeter providing the possibility to measure current voltage and resistance with an accuracy of ±1 %.
- Power supply with a selectable voltage of 0 V DC ... 50 V DC and current limitation.

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DIN Rail Mount Modules

The following pictures show examples of Surge Protection Barriers K-LB-2.30 and K-LB-2.30G, the other devices of this device family have to be tested accordingly.

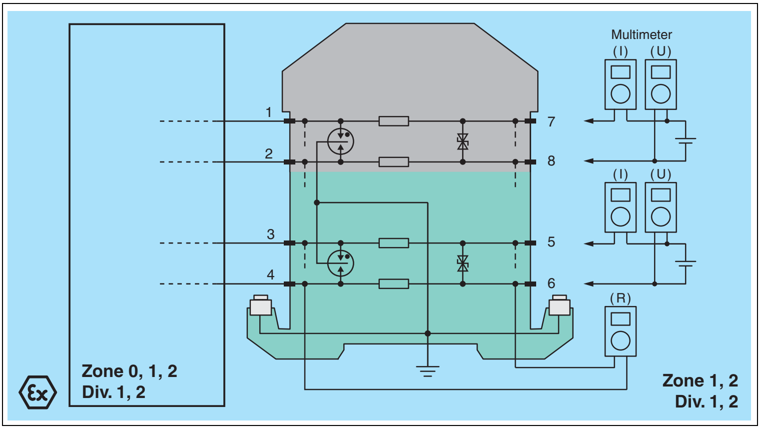

Figure 4.1: Proof test set-up for K-LB-*.* (example Surge Protection Barrier K-LB-2.30)

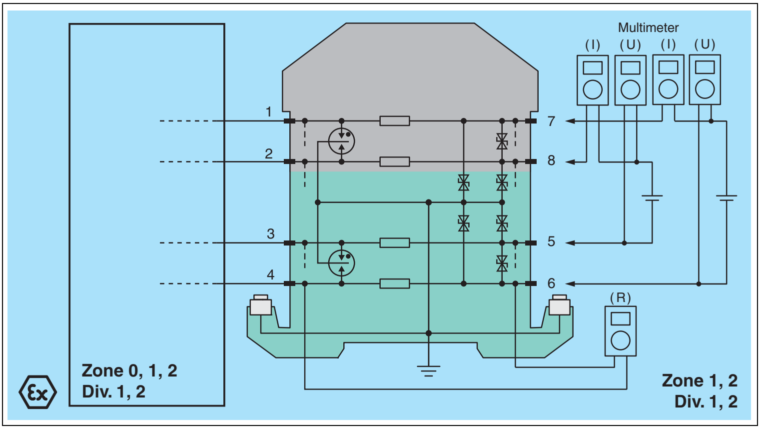

Figure 4.2: Proof test set-up for K-LB-*.*G (example Surge Protection Barrier K-LB-2.30G)

Current and Voltage Measurement

Device	Step No.	Rated Voltage	Leakage Current	Comment
K-LB-1.30 K-LB-1.30G	1	30 V between Pins 7, 8	< 50 µA	Test passed if leakage current is below 200 µA.
K-LB-2.30	1 2	30 V between Pins 7, 8 30 V between Pins 5, 6	< 50 µA	Test passed if leakage current is below 200 µA.
K-LB-2.30G	1 2 3 4	30 V between Pins 7, 8 30 V between Pins 5, 6 30 V between Pins 5, 7 30 V between Pins 5, 8	< 50 µA	Test passed if leakage current is below 200 µA.

Device	Step No.	Rated Voltage	Leakage Current	Comment
K-LB-1.6 K-LB-1.6G	1	6 V between Pins 7, 8	< 50 µA	Test passed if leakage current is below 200 µA.
K-LB-2.6	1 2	6 V between Pins 7, 8 6 V between Pins 5, 6	< 50 µA	Test passed if leakage current is below 200 µA.
K-LB-2.6G	1 2 3 4	6 V between Pins 7, 8 6 V between Pins 5, 6 6 V between Pins 5, 7 6 V between Pins 5, 8	< 50 µA	Test passed if leakage current is below 200 µA.

Resistance Measurement

Device	Step No.	Measurement	Comment
K-LB-1.6 K-LB-1.30 K-LB-1.6G K-LB-1.30G	1 2	Resistance between Pins 1, 7 Resistance between Pins 2, 8	Test passed if resistance is below 2 Ω
K-LB-2.6 K-LB-2.30 K-LB-2.6G K-LB-2.30G	1 2 3 4	Resistance between Pins 1, 7 Resistance between Pins 2, 8 Resistance between Pins 3, 5 Resistance between Pins 4, 6	Test passed if resistance is below 2 Ω

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Field Mount Modules

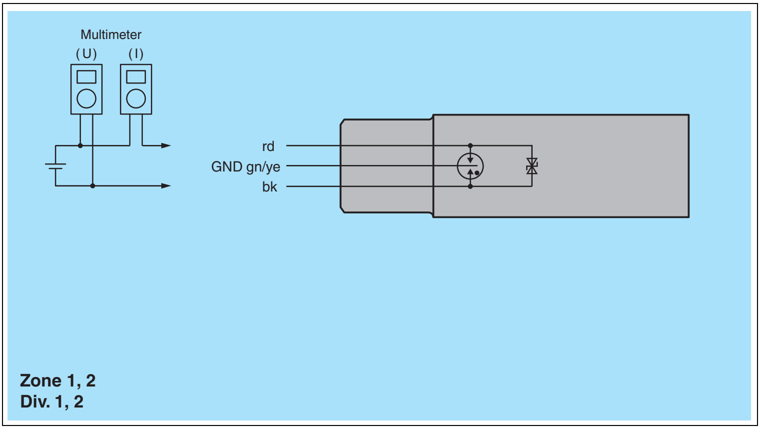

Figure 4.3: Proof test set-up for F*-LB-I

Device	Step No.	Rated Voltage	Leakage Current	Comment
F*-LB-I	1	45 V between red (rd) and black (bk) cable	< 50 μA	Test passed if leakage current is below 200 μA.

Plug-In Modules

The following picture shows an example of P-LB-1.C.123, the other devices of this device family have to be tested accordingly.

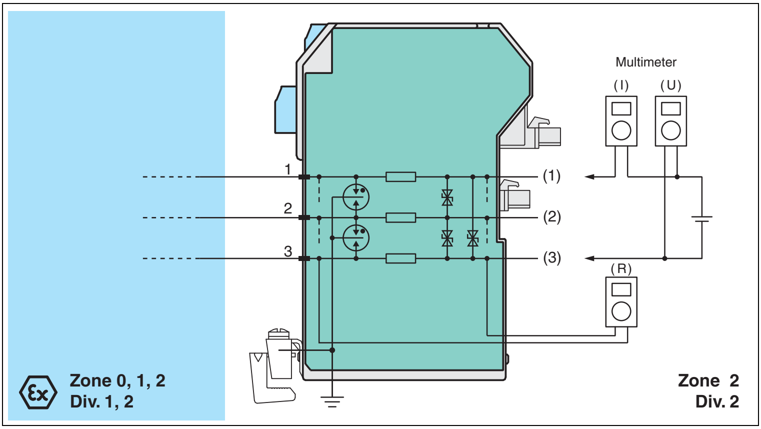

Figure 4.4: Proof test set-up for P-LB-*.*.* (example Surge Protection Barrier P-LB-1.C.123)

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Current and Voltage Measurement

Device	Step No.	Rated Voltage	Leakage Current	Comment
P-LB-1.A.13	1	30 V between Pins 1, 3	< 50 µA	Test passed if leakage current is below 200 µA.
P-LB-2.A.1346	1 2	30 V between Pins 1, 3 30 V between Pins 4, 6	< 50 µA	Test passed if leakage current is below 200 µA.
P-LB-1.B.12	1	30 V between Pins 1, 2	< 50 µA	Test passed if leakage current is below 200 µA.
P-LB-2.B.1245	1 2	30 V between Pins 1, 2 30 V between Pins 4, 5	< 50 µA	Test passed if leakage current is below 200 µA.
P-LB-1.C.123	1 2 3	30 V between Pins 1, 2 30 V between Pins 2, 3 30 V between Pins 1, 3	< 50 µA	Test passed if leakage current is below 200 µA.
P-LB-2.D.123456	1 2 3 4 5 6	30 V between Pins 1, 2 30 V between Pins 2, 3 30 V between Pins 1, 3 30 V between Pins 4, 5 30 V between Pins 5, 6 30 V between Pins 4, 6	< 50 µA	Test passed if leakage current is below 200 µA.
P-LB-1.E.23	1	30 V between Pins 2, 3	< 50 µA	Test passed if leakage current is below 200 µA.
P-LB-2.C.2356	1 2	30 V between Pins 2, 3 30 V between Pins 5, 6	< 50 µA	Test passed if leakage current is below 200 µA.
P-LB-1.D.1234	1 2 3 4 5 6	30 V between Pins 1, 2 30 V between Pins 1, 3 30 V between Pins 1, 4 30 V between Pins 2, 3 30 V between Pins 2, 4 30 V between Pins 3, 4	< 50 µA	Test passed if leakage current is below 200 µA.
P-LB-1.F.1236	1 2 3 4 5 6	30 V between Pins 1, 2 30 V between Pins 1, 3 30 V between Pins 1, 6 30 V between Pins 2, 3 30 V between Pins 2, 6 30 V between Pins 3, 6	< 50 µA	Test passed if leakage current is below 200 µA.

Resistance Measurement

Device	Step No.	Rated Voltage	Comment
P-LB-1.A.13	1 2	Resistance between Pins 1, (1) Resistance between Pins 3, (3)	Test passed if resistance is below 2 Ω
P-LB-2.A.1346	1 2 3 4	Resistance between Pins 1, (1) Resistance between Pins 3, (3) Resistance between Pins 4, (4) Resistance between Pins 6, (6)	Test passed if resistance is below 2 Ω
P-LB-1.B.12	1 2	Resistance between Pins 1, (1) Resistance between Pins 2, (2)	Test passed if resistance is below 2 Ω
P-LB-2.B.1245	1 2 3 4	Resistance between Pins 1, (1) Resistance between Pins 2, (2) Resistance between Pins 4, (4) Resistance between Pins 5, (5)	Test passed if resistance is below 2 Ω
P-LB-1.C.123	1 2 3	Resistance between Pins 1, (1) Resistance between Pins 2, (2) Resistance between Pins 3, (3)	Test passed if resistance is below 2 Ω
P-LB-2.D.123456	1 2 3 4 5 6	Resistance between Pins 1, (1) Resistance between Pins 2, (2) Resistance between Pins 3, (3) Resistance between Pins 4, (4) Resistance between Pins 5, (5) Resistance between Pins 6, (6)	Test passed if resistance is below 2 Ω
P-LB-1.E.23	1 2	Resistance between Pins 2, (2) Resistance between Pins 3, (3)	Test passed if resistance is below 2 Ω
P-LB-2.C.2356	1 2 3 4	Resistance between Pins 2, (2) Resistance between Pins 3, (3) Resistance between Pins 5, (5) Resistance between Pins 5, (5)	Test passed if resistance is below 2 Ω
P-LB-1.D.1234	1 2 3 4	Resistance between Pins 1, (1) Resistance between Pins 2, (2) Resistance between Pins 3, (3) Resistance between Pins 4, (4)	Test passed if resistance is below 2 Ω
P-LB-1.F.1236	1 2 3 4	Resistance between Pins 1, (1) Resistance between Pins 2, (2) Resistance between Pins 3, (3) Resistance between Pins 6, (6)	Test passed if resistance is below 2 Ω

Only if all tests are successfully done, the proof test is successful.

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5 Application Examples

All performance parameters used in the following chapter were actual when this safety manual was released but may vary. The main purpose of this section is to show how to include a surge protected device into a safety loop.

How to include a Surge Protection Barrier into a Safety Loop

The general considerations given above lead to the conclusion that it is mandatory before starting any loop calculation to have a clear understanding of:

1. the signal characteristic of the safety loop (analog, digital),
2. the signal direction of the safety loop as seen from the perspective of the safety
   DCS-System (input or output),
3. the safe state of the field device allocated to the Surge Protection Barrier,
4. the desired SIL level of the safety loop.

After the safety loop under consideration is defined, a Surge Protection Barrier can be integrated into this safety loop by allocating it to a field device. It should be possible to get a principled overview as shown below.

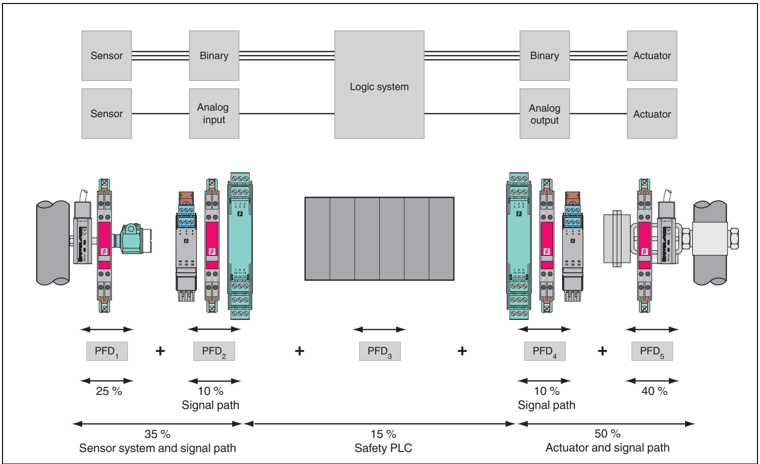

Figure 5.1: Example of a complete safety loop with allocated Surge Protection Barriers

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In principle the IEC 61508 performance values of the Surge Protection Barriers have to be added to the IEC 61508 performance values of the field device. By doing so it is assumed that the Surge Protection Barrier becomes an integral part of this device. After that the Probability of Failure on Demand (PFD_{avg}) and the Safe Failure Fraction (SFF) have to be recalculated. With these new values it can be verified if the desired SIL level can be reached.

Basically the calculations are always very similar. Nevertheless it is important to understand the application completely and to interpret the figure above correctly. The calculation has to show that the subpart of the safety loop under consideration allows the overall safety loop to get into the range given in the following table:

SIL Level	PFD_{avg}	SFF
SIL2	$\geq 10^{-2}$ to $< 10^{-1}$	≥ 60 %
SIL3	$\geq 10^{-3}$ to $< 10^{-2}$	≥ 90 %

Table 5.1: IEC 61508 performance values for type A subcomponents

SIL Level	PFD_{avg}	SFF
SIL2	$\geq 10^{-3}$ to $< 10^{-2}$	≥ 90 %
SIL3	$\geq 10^{-4}$ to $< 10^{-3}$	≥ 99 %

Table 5.2: IEC 61508 performance values for type B subcomponents

Examples of various combinations are given in the following text.

Example 1 - Digital Input - NAMUR NE22 Signals

When using a standard switch amplifier from Pepperl+Fuchs it is possible to implement safety loops up to SIL2 with a standard NAMUR NE22 digital input signal. A sample configuration of a surge protected device would be KCD2-SR-Ex1.LB and K-LB-*.**.

The questions listed above lead to the following answers:

1. Signal characteristic of the safety loop = digital
2. Signal direction of the safety loop as seen from the perspective of the safety DCS-System = input
3. Safe state of the field device allocated to the Surge Protection Barrier = de-energized
4. Desired SIL level of the safety loop = SIL2

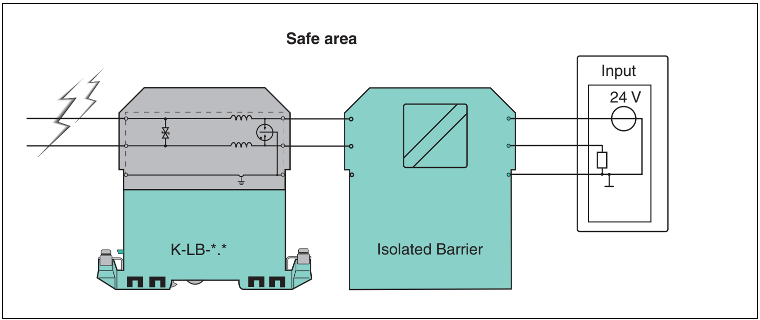

Figure 5.2: Combination of K-LB-1.30 and an isolated barrier, e. g. KCD2-SR-Ex1.LB

Has the Safety Loop SIL2 after the Surge Protection Barrier is inserted?

- SFF of the loop is as demanded for type A components > 60 %
- As an optimum the combination of Surge Protection Barrier and field barrier claims 10 % of the overall PFD_{avg} maximum 1 x 10^{-2} and therefore has a PFD_{avg} <1 x 10^{-3}

The IEC 61508 performance values of the KCD2-SR-Ex1.LB are:

Total failure rate	254 FIT
PFD_{avg} for T_1 = 1 year	2.05 x 10^{-4}
SFF	81.5 %

Table 5.3: Performance values of isolated barrier KCD2-SR-Ex1.LB

For further calculation λ_{du} of the KCD2-SR-Ex1.LB has to be calculated by using the PFD_{avg} formula given in IEC 61508:

- $PFD_{avg} = 1/2 \times \lambda_{du} \times T_{proof}$ (1)
- $\lambda_{du} = 2 \times PFD_{avg} / T_{proof} = 2 \times 2.05 \times 10^{-4} / 8760$ [h] = 47 FIT

The failure rates in this operating condition for K-LB-1.30 from the Safety Manual are:

Total failure rate	57 FIT
Dangerous undetected failure rate	0 FIT

Table 5.4: Failure rates of Surge Protection Barrier K-LB-1.30

The next step is to allocate the Surge Protection Barrier to the device by adding the total failure rates of both components.

- $\Sigma\lambda_{total} = \lambda_{Isolated\ Barrier} + \ldots + \lambda_{Surge\ Protection\ Barrier}$ (2)
- $\Sigma\lambda_{total}$ = 254 FIT + 57 FIT = 311 FIT

The same has to be done for the dangerous undetected failure rates of both devices.

- $\Sigma\lambda_{du} = \lambda_{du/Isolated\ Barrier} + \ldots + \lambda_{du/Surge\ Protection\ Barrier}$ (3)
- $\Sigma\lambda_{du}$ = 47 FIT + 0 FIT = 47 FIT

These values allow calculating the SFF and PFD_{avg} for the combination of both devices.

- SFF = $1 - (\lambda_{du} / \lambda_{total})$ (4)
- SFF = 1 – (47 FIT / 311 FIT) = 84 %
- $PFD_{avg\_1y} = 1/2 \times \lambda_{du} \times 8760$ [h] (5)
- PFD_{avg_1y} = 1/2 x 47 FIT x 8760 [h] = 2.05×10^{-4}

The following table summarizes the results of the calculations:

Total failure rate	311 FIT
Dangerous undetected failure rate	47 FIT
PFD_{avg} for T_1 = 1 year	2.05×10^{-4}
SFF	84 %

Table 5.5: Sum of failure rates of isolated barrier KCD2-SR-Ex1.LB and Surge Protection Barrier K-LB-1.30

This means that for this specific combination the requirements for a SIL2 loop are still fulfilled.

Example 2 - Digital Output – Solenoid Drivers

The Pepperl+Fuchs digital output modules can be categorized into two groups – loop powered devices and bus powered devices.

Bus powered Solenoid Drivers

If a bus powered Solenoid Driver from Pepperl+Fuchs is considered it is possible to use virtually the same calculation method as used for NAMUR NE22 inputs described above.

1. Signal characteristic of the safety loop = digital
2. Signal direction of the safety loop as seen from the perspective of the safety DCS-System = output
3. Safe state of the field device allocated to the Surge Protection Barrier = de-energized
4. Desired SIL level of the safety loop = SIL2

A standard KFD2-SL2-Ex1.LK device has the following performance values:

Total failure rate	714 FIT
Dangerous undetected failure rate	10.3 FIT
PFD_{avg} for T_1 = 1 year	4.51×10^{-5}
SFF	98.5 %

Table 5.6: Performance values of isolated barrier KFD2-SL2-Ex1.LK

For the corresponding Surge Protection Barrier P-LB-1.A the following values are given:

Total failure rate	57 FIT
Dangerous undetected failures	0 FIT

Table 5.7: Failure rates of Surge Protection Barrier P-LB-1.A

The combination of both devices is done by simply adding the values again as before. The SFF and PFD_{avg} values can be calculated by using the equations given above.

Total failure rate	771 FIT
Dangerous undetected failure rate	10.3 FIT
PFD_{avg} for T_1 = 1 year	4.51×10^{-5}
SFF	98.6 %

Table 5.8: Sum of failure rates of isolated barrier KFD2-SL2-Ex1.LK and Surge Protection Barrier P-LB-1.A

This means that if compared with table 1 for this specific combination the requirements for a SIL2 loop are still easily fulfilled.

Example 3 - Analog Inputs – 4 mA ... 20 mA Signals

The basic characteristics are:

1. Signal characteristic of the safety loop = analog
2. Signal direction of the safety loop as seen from the perspective of the safety DCS-System = input
3. Safe state of the field device allocated to the Surge Protection Barrier = output signal < 4 mA or respectively > 20 mA
4. Desired SIL level of the safety loop = SIL3

A standard KCD2-STC-Ex1 device has the following performance values:

Total failure rate	348 FIT
Dangerous undetected failure rate	67 FIT
PFD_{avg} for T_1 = 1 year	2.93×10^{-4}
SFF	80.8 %

Table 5.9: Performance values of isolated barrier KCD2-STC-Ex1

For the corresponding Surge Protection Barrier P-LB-1.A the following values are given:

Total failure rate	57 FIT
Dangerous undetected failures	0 FIT

Table 5.10: Failure rates of Surge Protection Barrier P-LB-1.A

The combination of both devices is done by simply adding the values again as before. The SFF and PFD_{avg} values can be calculated by using the equations given above.

Total failure rate	405 FIT
Dangerous undetected failure rate	67 FIT
PFD_{avg} for T_1 = 1 year	2.93×10^{-4}
SFF	83.4 %

Table 5.11: Sum of failure rates of isolated barrier KCD2-STC-Ex1 and Surge Protection Barrier P-LB-1.A

This means that if compared with table 1 for this specific combination the requirements for a SIL2 loop are still easily fulfilled.

Example 4 - Surge Protection Barriers and Field Devices

The same method can be applied when the DIN rail variant K-LB-*.** or the field mount module F*-LB-I has to be combined with any other field device.

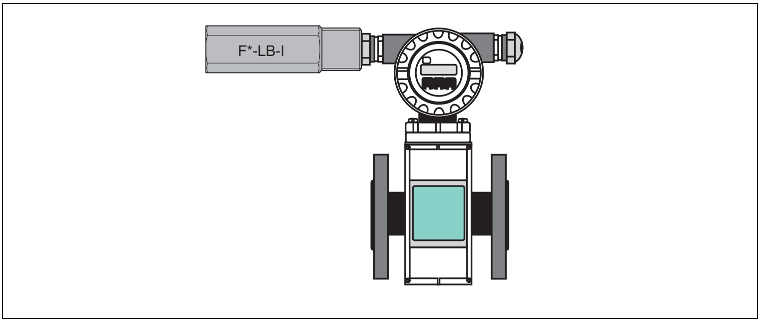

Figure 5.3: Combination of F*-LB-I and a transmitter

The basic characteristics are:

1. Signal characteristic of the safety loop = analog
2. Signal direction of the safety loop as seen from the perspective of the safety DCS-System = input
3. Safe state of the field device allocated to the Surge Protection Barrier = output signal < 4 mA or respectively > 20 mA

Since the availability of SIL3 field devices is very limited, it is most likely that the end user wants to know wether he can integrate a Surge Protection Barrier into his SIL2 application.

The following example deals with a differential pressure transmitter Rosemount 3051S_C getting combined with a Surge Protection Barrier F*-LB-I.

Total failure rate	536 FIT
MTBF	213 years
Safe undetected failure rate	143 FIT
Safe detected failure rate	0 FIT
Dangerous undetected failure rate	37 FIT
Dangerous detected failure rate	356 FIT
SFF	93 %

Table 5.12: Performance values of isolated barrier KCD2-SCD-Ex1

Combined with the values for the Surge Protection Barrier F*-LB-I the result is:

Total failure rate	536 FIT + 37 FIT = 573 FIT
MTBF	199 years
Safe undetected failure rate	143 FIT + 6.95 FIT = 150 FIT
Safe detected failure rate	0 FIT
Dangerous undetected failure rate	57 FIT + 5 FIT = 62 FIT
Dangerous detected failure rate	356 FIT
SFF	89 %

Table 5.13: Sum of failure rates of Rosemount 3051S_C and Surge Protection Barrier F*-LB-I

Derived from this results using equation 4:

T_1	1 year	2 years	5 years
PFD_{avg}	2.74×10^{-4}	5.43×10^{-4}	1.35×10^{-3}

Table 5.14: PFD_{avg} values of the combination of Rosemount 3051S_C and Surge Protection Barrier F*-LB-I

The proof that the transmitter is still feasible for IEC 61508 SIL2 safety loops is done, since SFF and PFD_{avg} values are still sufficient.

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6 Abbreviations

FMEDA	**F**ailure **M**ode, **E**ffects and **D**iagnostics **A**nalysis
HFT	**H**ardware **F**ault **T**olerance
PFD_{avg}	Average **P**robability of **F**ailure on **D**emand
PFH	**P**robability of dangerous **F**ailure per **H**our
PTC	**P**roof **T**est **C**overage
SFF	**S**afe **F**ailure **F**raction
SIF	**S**afety **I**nstrumented **F**unction
SIL	**S**afety **I**ntegrity **L**evel
SIS	**S**afety **I**nstrumented **S**ystem
T_{proof}	Proof Test Interval

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