Failure Modes, Effects and Diagnostic Analysis

Project:
Ex NAMUR Isolating Amplifiers
MACX MCR-(EX)-SL-xNAM-yRO
MACX MCR-(EX)-SL-xNAM-yRO-SP

Customer:

Phoenix Contact GmbH & Co. KG
Blomberg
Germany

Contract No.: Phoenix Contact 07/06-39r1
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Management summary

This report summarizes the results of the hardware assessment carried out on the Ex NAMUR Isolating Amplifier MACX MCR-(EX)-SL-xNAM-yRO resp. MACX MCR-(EX)-SL-xNAM-yRO-SP. Table 1 gives an overview of the different versions.

The hardware assessment consists of a Failure Modes, Effects and Diagnostics Analysis (FMEDA). A FMEDA is one of the steps taken to achieve functional safety assessment of a device per IEC 61508. From the FMEDA, failure rates are determined and consequently the Safe Failure Fraction (SFF) is calculated for the device. For full assessment purposes all requirements of IEC 61508 must be considered.

Table 1: Module overview

Ex - Variant	Non Ex - Variant	Description
MACX MCR-EX-SL-NAM-R (N) Art.-No: 28 65 434	MACX MCR-SL-NAM-R (N) Art.-No: 28 65 997	One input channel module with one output relay and standard switching behavior.
MACX MCR-EX-SL-NAM-R (I) Art.-No: 28 65 434	MACX MCR-SL-NAM-R (I) Art.-No: 28 65 997	One input channel module with one output relay and inverted switching behavior.
MACX MCR-EX-SL-NAM-R-SP (N) Art.-No: 29 24 045	MACX MCR-SL-NAM-R-SP (N) Art.-No: 29 24 252	One input channel module with one output relay, standard switching behavior and spring pressure clamp.
MACX MCR-EX-SL-NAM-R-SP (I) Art.-No: 29 24 045	MACX MCR-SL-NAM-R-SP (I) Art.-No: 29 24 252	One input channel module with one output relay, inverted switching behavior and spring pressure clamp.
MACX MCR-EX-SL-NAM-2RO (N) Art.-No: 28 65 450	MACX MCR-SL-NAM-2RO (N) Art.-No: 28 65 010	One input channel module with two output relays and standard switching behavior.

MACX MCR-EX-SL-NAM-2RO (I) Art.-No: 28 65 450	MACX MCR-SL-NAM-2RO (I) Art.-No: 28 65 010	One input channel module with two output relays and inverted switching behavior.
MACX MCR-EX-SL-NAM-2RO-SP (N) Art.-No: 29 24 061	MACX MCR-SL-NAM-2RO-SP (N) Art.-No: 29 24 265	One input channel module with two output relays, standard switching behavior and spring pressure clamp.
MACX MCR-EX-SL-NAM-2RO-SP (I) Art.-No: 29 24 061	MACX MCR-SL-NAM-2RO-SP (I) Art.-No: 29 24 265	One input channel module with two output relays, inverted switching behavior and spring pressure clamp.
MACX MCR-EX-SL-2NAM-RO (N) Art.-No: 28 65 476	MACX MCR-SL-2NAM-RO (N) Art.-No: 28 65 049	Two input channel module with two output relays and standard switching behavior.
MACX MCR-EX-SL-2NAM-RO (I) Art.-No: 28 65 476	MACX MCR-SL-2NAM-RO (I) Art.-No: 28 65 049	Two input channel module with two output relays and inverted switching behavior.
MACX MCR-EX-SL-2NAM-RO-SP (N) Art.-No: 29 24 087	MACX MCR-SL-2NAM-RO-SP (N) Art.-No: 29 24 294	Two input channel module with two output relays, standard switching behavior and spring pressure clamp.

MACX MCR-EX-SL-2NAM-RO-SP (I) Art.-No: 29 24 087	MACX MCR-SL-2NAM-RO-SP (I) Art.-No: 29 24 294	Two input channel module with two output relays, inverted switching behavior and spring pressure clamp.

For safety applications only the relay output was considered. All other possible output variants or electronics are not covered by this report.

The module MACX MCR-EX-SL-2NAM-R0 might be brand labelled as BTD277-E0 for the company ABB.

The modules with the letter N do have the standard switching behavior, the one with I do have the inverted switching behavior. For the safety function with the letter N the relay at the output will be open as long as there is no input signal, with the letter I the relay will be open as long as there is an input signal.

The failure rates used in this analysis are the basic failure rates from the Siemens standard SN 29500.

According to table 2 of IEC 61508-1 the average PFD for systems operating in low demand mode has to be $\geq 10^{-3}$ to $< 10^{-2}$ for SIL 2 safety functions. A generally accepted distribution of PFD_{AVG} values of a SIF over the sensor part, logic solver part, and final element part assumes that 10% of the total SIF PFD_{AVG} value is caused by the logic solver part. However, as the module under consideration is only one part of an entire safety function it should not claim more than 10% of this range, i.e. they should be better than or equal to 1.0×10^{-3} for SIL 2.

The Ex NAMUR Isolating Amplifier is considered to be a Type A[1] subsystem with a hardware fault tolerance of 0. For Type A subsystems with a hardware fault tolerance of 0 the SFF shall be 60% - < 90 % according to table 2 of IEC 61508-2 for SIL 2 (sub-) systems.

The listed SN29500 failure rates are valid for operating stress conditions typical of an industrial field environment similar to IEC 60654-1 class C (sheltered location) with an average temperature over a long period of time of 40ºC (25°C ambient temperature plus internal self heating). 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 (daily fluctuation of > 15°C) must be assumed.

[1] Type A subsystem: simple devices without microprocessors; for details see 7.4.3.1.3 of IEC 61508-2.

Table 2: Summary of MACX MCR-(EX)-SL-NAM-R (N/I) / MACX MCR-(EX)-SL-NAM-R-SP (N/I)

Failure category	Failure rates (in FIT) MACX MCR-(EX)-SL-NAM-R N MACX MCR-(EX)-SL-NAM-R-SP N	Failure rates (in FIT) MACX MCR-(EX)-SL-NAM-R I MACX MCR-(EX)-SL-NAM-R-SP I
Fail Safe Detected (λ_{SD})	**6**	**1**
Fail safe detected	6	1
Fail Safe Undetected (λ_{SU})	**242**	**249**
Fail safe undetected	158	160
Residual	76	81
Annunciation undetected (95%)	8	8
Fail Dangerous Detected (λ_{DD})	**7**	**6**
Fail dangerous detected	7	6
Annunciation detected	0	0
Fail Dangerous Undetected (λ_{DU})	**60**	**64**
Fail dangerous undetected	59	63
Annunciation undetected (5%)	1	1
No part	72	66

Total failure rate (safety function)	**315 FIT**	**320 FIT**
SFF	**78,89 %**	**78,00 %**
DC_D	**10 %**	**8 %**

Table 3: Summary of MACX MCR-(EX)-SL-NAM-R (N/I) / MACX MCR-(EX)-SL-NAM-R-SP (N/I)

Name	T[Proof] = 1 year	T[Proof] = 2 years	T[Proof] = 5 years	SFF
MACX MCR-(EX)-SL-NAM-R N MACX MCR-(EX)-SL-NAM-R-SP N	**PFD_{AVG} = 2.90 E-4**	**PFD_{AVG} = 5,79E-04**	**PFD_{AVG} = 1,45E-03**	78%
MACX MCR-(EX)-SL-NAM-R I MACX MCR-(EX)-SL-NAM-R-SP I	**PFD_{AVG} = 3,08E-04**	**PFD_{AVG} = 6,15E-04**	**PFD_{AVG} = 1,54E-03**	78%

The boxes marked in yellow (☐) mean that the calculated PFD values are within the allowed range for SIL 2 according to table 2 of IEC 61508-1 but do not fulfill the requirement to not claim more than 10% of this range, i.e. to be better than or equal to 1.0 x 10^{-3}. The boxes marked in green (☐) mean that the calculated PFD values fulfill this requirement to be better than 1.0 x 10^{-3}.

Table 4: Summary of MACX MCR-(EX)-SL-NAM-2RO (N/I) / MACX MCR-(EX)-SL-NAM-2RO-SP (N/I)

Failure category	**Failure rates (in FIT)** MACX MCR-(EX)-SL-NAM-2RO N MACX MCR-(EX)-SL-NAM-2RO-SP N	**Failure rates (in FIT)** MACX MCR-(EX)-SL-NAM-2RO I MACX MCR-(EX)-SL-NAM-2RO-SP I
Fail Safe Detected (λ_{SD})	**6**	**1**
Fail safe detected	6	1
Fail Safe Undetected (λ_{SU})	**244**	**251**
Fail safe undetected	159	161
Residual	77	82
Annunciation undetected (95%)	8	8
Fail Dangerous Detected (λ_{DD})	**7**	**6**
Fail dangerous detected	7	6
Annunciation detected	0	0
Fail Dangerous Undetected (λ_{DU})	**57**	**64**
Fail dangerous undetected	56	63
Annunciation undetected (5%)	1	1
No part	72	66

Total failure rate (safety function)	**314 FIT**	**322 FIT**
SFF	**79,42 %**	**77,98 %**
DC_D	**10 %**	**8 %**

Table 5: Summary of MACX MCR-(EX)-SL-NAM-2RO (N/I) / MACX MCR-(EX)-SL-NAM-2RO-SP (N/I)

Name	T[Proof] = 1 year	T[Proof] = 2 years	T[Proof] = 5 years	SFF
MACX MCR-(EX)-SL-NAM-2RO N MACX MCR-(EX)-SL-NAM-2RO-SP N	**PFD_{AVG} = 2,83E-04**	**PFD_{AVG} = 5,65E-04**	**PFD_{AVG} = 1,41E-03**	79%
MACX MCR-(EX)-SL-NAM-2RO I MACX MCR-(EX)-SL-NAM-2RO-SP I	**PFD_{AVG} = 3,09 E-04**	**PFD_{AVG} = 6,12 E-04**	**PFD_{AVG} = 1,54 E-03**	77%

The boxes marked in yellow ( ) mean that the calculated PFD values are within the allowed range for SIL 2 according to table 2 of IEC 61508-1 but do not fulfill the requirement to not claim more than 10% of this range, i.e. to be better than or equal to 1.0 x 10^{-3}. The boxes marked in green ( ) mean that the calculated PFD values fulfill this requirement to be better than 1.0 x 10^{-3}.

Table 6: Summary of MACX MCR-(EX)-SL-2NAM-RO (N/I) / MACX MCR-(EX)-SL-2NAM-RO-SP (N/I)

Failure category	**Failure rates (in FIT)** MACX MCR-(EX)-SL-2NAM-RO N MACX MCR-(EX)-SL-2NAM-RO-SP N	**Failure rates (in FIT)** MACX MCR-(EX)-SL-2NAM-RO I MACX MCR-(EX)-SL-2NAM-RO-SP I
Fail Safe Detected (λ_{SD})	**6**	**1**
Fail safe detected	6	1
Fail Safe Undetected (λ_{SU})	**249**	**248**
Fail safe undetected	167	160
Residual	74	80
Annunciation undetected (95%)	8	8
Fail Dangerous Detected (λ_{DD})	**7**	**6**
Fail dangerous detected	7	6
Annunciation detected	0	0
Fail Dangerous Undetected (λ_{DU})	**64**	**62**
Fail dangerous undetected	63	61
Annunciation undetected (5%)	1	1
No part	272	378

Total failure rate (safety function)	**326 FIT**	**317 FIT**
SFF	**78,33 %**	**78,27 %**
DC_D	**9 %**	**8 %**

Table 7: Summary of MACX MCR-(EX)-SL-2NAM-RO (N/I) / MACX MCR-(EX)-SL-2NAM-RO-SP (N/I)

Name	T[Proof] = 1 year	T[Proof] = 2 years	T[Proof] = 5 years	SFF
MACX MCR-(EX)-SL-2NAM-RO N MACX MCR-(EX)-SL-2NAM-RO-SP N	**PFD_{AVG} = 3,09E-04**	**PFD_{AVG} = 6,17E-04**	**PFD_{AVG} = 1,54E-03**	78 %
MACX MCR-(EX)-SL-2NAM-RO I MACX MCR-(EX)-SL-2NAM-RO-SP I	**PFD_{AVG} = 3,01E-04**	**PFD_{AVG} = 6,02E-04**	**PFD_{AVG} = 1,50E-03**	78%

The boxes marked in yellow ( ) mean that the calculated PFD values are within the allowed range for SIL 2 according to table 2 of IEC 61508-1 but do not fulfill the requirement to not claim more than 10% of this range, i.e. to be better than or equal to 1.0 x 10^{-3}. The boxes marked in green ( ) mean that the calculated PFD values fulfill this requirement to be better than 1.0 x 10^{-3}.

A user of the Ex NAMUR Isolating Amplifier can utilize these failure rates in a probabilistic model of a safety instrumented function (SIF) to determine suitability in part for safety instrumented system (SIS) usage in a particular safety integrity level (SIL). A full table of failure rates for different operating conditions is presented in section 5.1 to 5.6 along with all assumptions.

The two channels on the MACX MCR-(EX)-SL-2NAM-RO-(SP) (N/I) modules should not be used for one safety function as they contain common components.

The failure rates are valid for the useful life of the MACX MCR-(EX)-SL-2NAM-RO-(SP) (N/I) (see Appendix 2).

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1 Purpose and Scope

Generally three options exist when doing an assessment of sensors, interfaces and/or final elements.

Option 1: Hardware assessment according to IEC 61508

Option 1 is a hardware assessment by *exida* according to the relevant functional safety standard(s) like IEC 61508 or EN 954-1. The hardware assessment consists of a FMEDA to determine the fault behavior and the failure rates of the device, which are then used to calculate the Safe Failure Fraction (SFF) and the average Probability of Failure on Demand (PFD_{AVG}). When appropriate, fault injection testing will be used to confirm the effectiveness of any self-diagnostics.

This option provides the safety instrumentation engineer with the required failure data as per IEC 61508 / IEC 61511. This option does not include an assessment of the development process.

Option 2: Hardware assessment with proven-in-use consideration according to IEC 61508 / IEC 61511

Option 2 extends Option 1 with an assessment of the proven-in-use documentation of the device including the modification process.

This option for pre-existing programmable electronic devices provides the safety instrumentation engineer with the required failure data as per IEC 61508 / IEC 61511. When combined with plant specific proven-in-use records, it may help with prior-use justification per IEC 61511 for sensors, final elements and other PE field devices.

Option 3: Full assessment according to IEC 61508

Option 3 is a full assessment by *exida* according to the relevant application standard(s) like IEC 61511 or EN 298 and the necessary functional safety standard(s) like IEC 61508 or EN 954-1. The full assessment extends option 1 by an assessment of all fault avoidance and fault control measures during hardware and software development.

This option provides the safety instrumentation engineer with the required failure data as per IEC 61508 / IEC 61511 and confidence that sufficient attention has been given to systematic failures during the development process of the device.

This assessment shall be done according to option 1.

This document shall describe the results of hardware assessment according to IEC 61508 carried out on the Ex NAMUR Isolating Amplifier. Table 1 gives an overview of the different modules of the Ex NAMUR Isolating Amplifier which have been assessed.

The information in this report can be used to evaluate whether the Ex NAMUR Isolating Amplifier meets the average Probability of Failure on Demand (PFD_{AVG}) requirements and the architectural constraints / minimum hardware fault tolerance requirements per IEC 61508. It **does not** consider any calculations necessary for proving intrinsic safety.

2 Project management

2.1 *exida*

exida is one of the world's leading knowledge companies specializing in automation system safety and availability with over 300 years of cumulative experience in functional safety. Founded by several of the world's top reliability and safety experts from assessment organizations like TUV and manufacturers, *exida* is a partnership with offices around the world. *exida* offers training, coaching, project oriented consulting services, internet based safety engineering tools, detail product assurance and certification analysis and a collection of on-line safety and reliability resources. *exida* maintains a comprehensive failure rate and failure mode database on process equipment.

2.2 Roles of the parties involved

Phoenix Contact GmbH & Co. KG	Manufacturer of the Ex NAMUR Isolating Amplifier. Performed the hardware assessment according to option 1 (see section 1).
exida	reviewed the FEMDA's and issued the report.

Phoenix Contact GmbH & Co. KG contracted *exida* in August 2007 to review the existing FMEDA's and to issue the report the above mentioned modules.

2.3 Standards / Literature used

The services delivered by *exida* were performed based on the following standards / literature.

[N1]	IEC 61508-2:2000	Functional Safety of Electrical/Electronic/Programmable Electronic Safety-Related Systems
[N2]	ISBN: 0471133019 John Wiley & Sons	Electronic Components: Selection and Application Guidelines by Victor Meeldijk
[N3]	FMD-91, RAC 1991	Failure Mode / Mechanism Distributions
[N4]	FMD-97, RAC 1997	Failure Mode / Mechanism Distributions
[N5]	SN 29500	Failure rates of components
[N6]	IEC 60654-1:1993-02, second edition	Industrial-process measurement and control equipment – Operating conditions – Part 1: Climatic condition

2.4 Reference documents

2.4.1 Documentation provided by the customer

[D1]	FMEDA MACX MCR-EX-SL-NAM-R N R01.xls, received on August 31, 2007	FMEDA of the 1 input Ex NAMUR Isolating Amplifier with standard switching behavior.
[D2]	FMEDA MACX MCR-EX-SL-NAM-R N R01.xls, received on August 31, 2007	FMEDA of the 1 input Ex NAMUR Isolating Amplifier with inverted switching behavior.
[D3]	FMEDA MACX MCR-EX-SL-NAM-2RO N 2S R01.xls, received on August 31, 2007	FMEDA of the 1 input with 2 outputs Ex NAMUR Isolating Amplifier with standard switching behavior.
[D4]	FMEDA MACX MCR-EX-SL-NAM-2RO I 2S R01, received on August 31, 2007	FMEDA of the 1 input with 2 outputs Ex NAMUR Isolating Amplifier with inverted switching behavior.
[D5]	FMEDA MACX MCR-EX-SL-2NAM-RO N R02.xls, received on August 31, 2007	FMEDA of the 2 inputs and 2 outputs Ex NAMUR Isolating Amplifier with standard switching behavior.
[D6]	FMEDA MACX MCR-EX-SL-2NAM-RO I R02.xls, received on August 31, 2007	FMEDA of the 2 inputs and 2 outputs Ex NAMUR Isolating Amplifier with inverted switching behavior.
[D7]	Ex Description MACX MCR-Ex-SL-NAM-RO 300507.pdf	Description of the different modules.
[D8]	STR MACX MCR-EX-SL-2NAM - RO_01.pdf	Circuit diagram, 9779873_01, 16.01.07
[D9]	Namur Trennschaltverstärker SIL.doc	Information from Mr. Teuber, dated Nov. 9, 2007
[D10]	Antwort Überarbeiteter Bericht	e-mail, dated Nov. 27,2007
[D11]	Information brand labeling	e-mail, dated Nov. 29, 2007
[D12]	Ergänzung des Assessment für die MACX MCR-EX-SL-xNAM-yR(O).msg	e-mail, Knut Teuber, Apr. 08, 2008
[D13]	Antwort WG Anfrage.msg	e-mail, Knut Teuber, Apr. 08, 2008
[D14]	Unser Telefongespräch, Erweiterung des Typenschlüssels.msg	e-mail, Knut Teuber, Feb. 20, 2009
[D15]	Tabelle Ex - NichtEx Varianten.doc	Overview of the variants, Feb 20, 2009

2.4.2 Documentation generated by *exida*

[R1]	FMEDA MACX MCR-EX-SL-NAM-R N R02.xls, dated Nov. 15, 2007 provided from Phoenix and reviewed by Exida
[R2]	FMEDA MACX MCR-EX-SL-NAM-R I R02.xls, dated Nov. 15, 2007 provided from Phoenix and reviewed by Exida
[R3]	FMEDA MACX MCR-EX-SL-2NAM-RO N R02.xls, dated Nov. 15, 2007 provided from Phoenix and reviewed by Exida
[R4]	FMEDA MACX MCR-EX-SL-2NAM-RO I R02.xls, dated Nov. 15, 2007 provided from Phoenix and reviewed by Exida
[R5]	FMEDA MACX MCR-EX-SL-2NAM-RO N R04.xls, dated Nov. 13, 2007 provided from Phoenix and reviewed by Exida
[R6]	FMEDA MACX MCR-EX-SL-2NAM-RO I R04.xls, dated Nov. 15, 2007 provided from Phoenix and reviewed by exida
[R7]	e-mail „MACX MCR-EX-SL-NAM-RO FMEDA's“, dated Aug. 7, 2007

3 Description of the analyzed modules

3.1 System description

The Modules MACX MCR-EX-SL-xNAM-yRO are isolating amplifiers. They have intrinsically safe input circuits and are designed for the operation of proximity switches with Namur – behaviour.

The non-Ex-Versions MACX MCR-SL-xNAM-yRO, have the same components and circuit diagram as the Ex-Versions MACX MCR-EX-SL-xNAM-yRO.

The Module MACX MCR-EX-SL-NAM-R is the one channel version, which is able to operate only one proximity switch. The module has only one relay output.

The module MACX MCR-EX-SL-NAM-2RO is as well a one input channel version for the connection of a single proximity switch, but it has two independent relay outputs.

The module MACX MCR-EX-SL-2NAM-RO is the two input channel version for the connection of two proximity switches with two relay outputs. The two intrinsically safe circuits are not galvanically separated. The signals from the proximity switches will be transferred via relays to the plc.

All three version are available with screw clamps and with combicon spring pressure clamps. The spring pressure variants are labelled MACX MCR-EX-SL-xNAM-yRO-SP.

The modules with the letter 'N' do have the standard switching behavior the one with 'I' do have the inverted switching behavior.

The isolating amplifiers are supplied with a galvanic isolation between input and output circuit and between input circuit and supply.

The modules are supplied with a circuit for the detection of line faults, which can be switched on or off depending on the application. Detected line faults are available as an additional signal on contacts in the bottom of the module. The module can be supplied via other contacts in this area alternatively.

The switching behaviour (standard or inverted) of the modules can be selected via DIP - switches in their front.

The isolating amplifiers are designed for an operating voltage range of 20 to 30 V and an operating temperature range of -20 to 60 °C.

The following modules have been analyzed.

Ex - Variant	**Non Ex - Variant**	**Description**
MACX MCR-EX-SL-NAM-R (N) Art.-No: 28 65 434	MACX MCR-SL-NAM-R (N) Art.-No: 28 65 997	One input channel module with one output relay and standard switching behavior.

MACX MCR-EX-SL-NAM-R (I) Art.-No: 28 65 434	MACX MCR-SL-NAM-R (I) Art.-No: 28 65 997	One input channel module with one output relay and inverted switching behavior.
MACX MCR-EX-SL-NAM-R-SP (N) Art.-No: 29 24 045	MACX MCR-SL-NAM-R-SP (N) Art.-No: 29 24 252	One input channel module with one output relay, standard switching behavior and spring pressure clamp.
MACX MCR-EX-SL-NAM-R-SP (I) Art.-No: 29 24 045	MACX MCR-SL-NAM-R-SP (I) Art.-No: 29 24 252	One input channel module with one output relay, inverted switching behavior and spring pressure clamp.
MACX MCR-EX-SL-NAM-2RO (N) Art.-No: 28 65 450	MACX MCR-SL-NAM-2RO (N) Art.-No: 28 65 010	One input channel module with two output relays and standard switching behavior.
MACX MCR-EX-SL-NAM-2RO (I) Art.-No: 28 65 450	MACX MCR-SL-NAM-2RO (I) Art.-No: 28 65 010	One input channel module with two output relays and inverted switching behavior.
MACX MCR-EX-SL-NAM-2RO-SP (N) Art.-No: 29 24 061	MACX MCR-SL-NAM-2RO-SP (N) Art.-No: 29 24 265	One input channel module with two output relays, standard switching behavior and spring pressure clamp.

MACX MCR-EX-SL-NAM-2RO-SP (I) Art.-No: 29 24 061	MACX MCR-SL-NAM-2RO-SP (I) Art.-No: 29 24 265	One input channel module with two output relays, inverted switching behavior and spring pressure clamp.
MACX MCR-EX-SL-2NAM-RO (N) Art.-No: 28 65 476	MACX MCR-SL-2NAM-RO (N) Art.-No: 28 65 049	Two input channel module with two output relays and standard switching behavior.
MACX MCR-EX-SL-2NAM-RO (I) Art.-No: 28 65 476	MACX MCR-SL-2NAM-RO (I) Art.-No: 28 65 049	Two input channel module with two output relays and inverted switching behavior.
MACX MCR-EX-SL-2NAM-RO-SP (N) Art.-No: 29 24 087	MACX MCR-SL-2NAM-RO-SP (N) Art.-No: 29 24 294	Two input channel module with two output relays, standard switching behavior and spring pressure clamp.
MACX MCR-EX-SL-2NAM-RO-SP (I) Art.-No: 29 24 087	MACX MCR-SL-2NAM-RO-SP (I) Art.-No: 29 24 294	Two input channel module with two output relays, inverted switching behavior and spring pressure clamp.

The Ex NAMUR Isolating Amplifier is considered to be a Type A subsystem with a hardware fault tolerance of 0.

The following figures show the hardware structure of the isolating amplifiers.

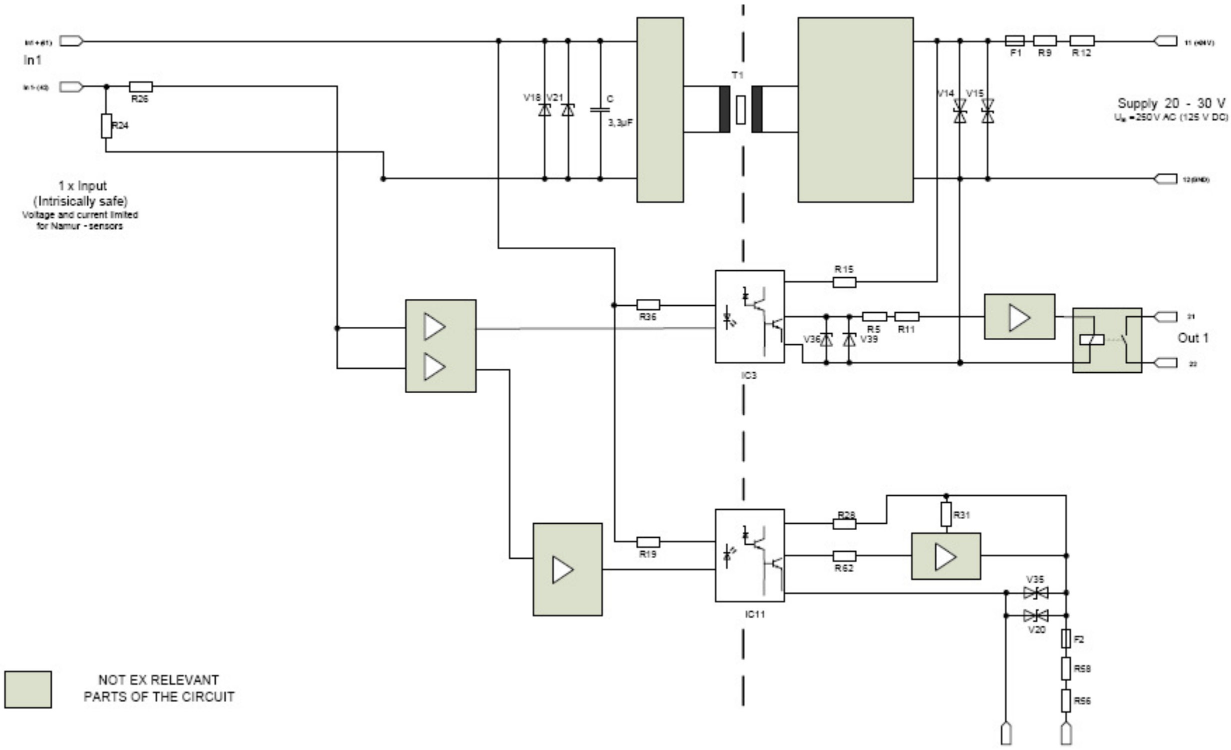


Figure 1: MACX MCR-(EX)-SL-NAM-R / : MACX MCR-(EX)-SL-NAM-R-SP

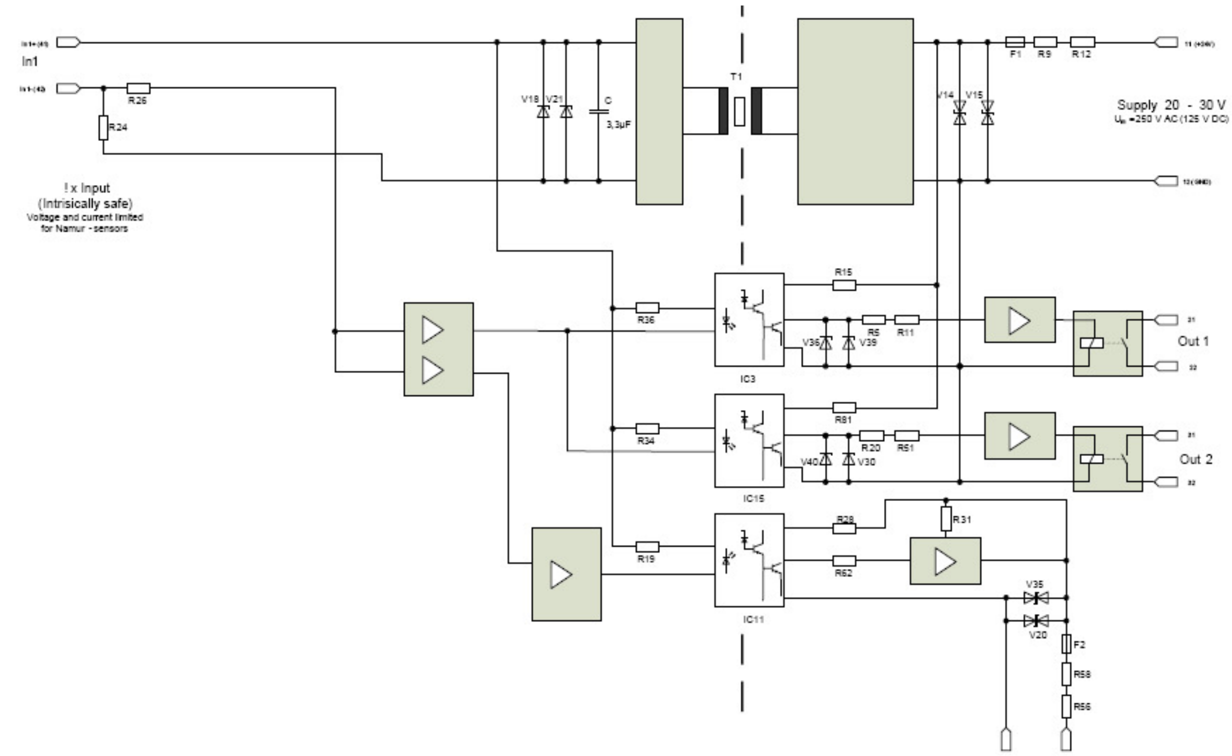


Figure 2: MACX MCR-(EX)-SL-NAM-2RO / MACX MCR-(EX)-SL-NAM-2RO-SP

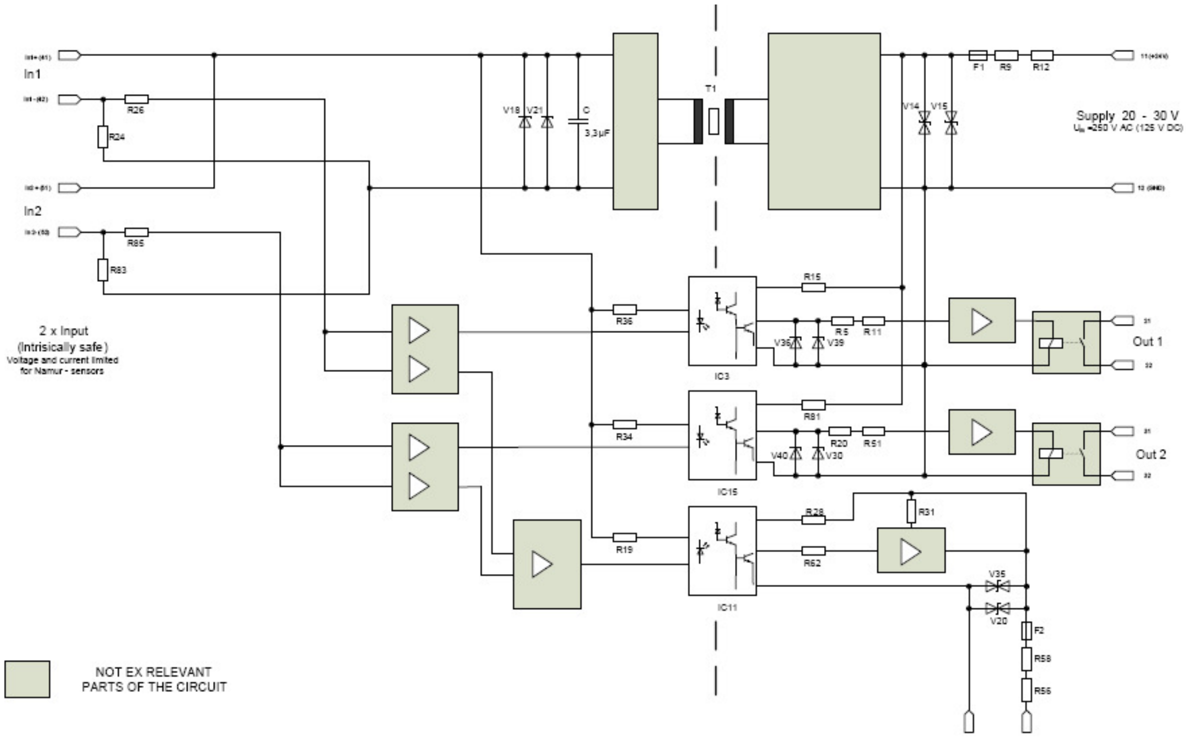


Figure 3: MACX MCR-(EX)-SL-2NAM-RO / MACX MCR-(EX)-SL-2NAM-RO-SP

4 Failure Modes, Effects, and Diagnostic Analysis

The Failure Modes, Effects, and Diagnostic Analysis were done by Phoenix Contact and reviewed by Exida and are documented in [R1] to [R6]. Failures have been classified according to the following failure categories and are described in the document [D9] provided by the customer.

4.1 Description of the failure categories

In order to judge the failure behavior of the Ex NAMUR Isolating Amplifier MACX MCR-(EX)-SL-xNAM-yRO / MACX MCR-(EX)-SL-xNAM-yRO-SP, the following definitions for the failure of the product were considered.

Fail-Safe State	The fail-safe state is defined as the relay output being open for the standard switching behavior (letter N) and the inverted switching behavior (letter I).
Fail Dangerous	Failure that does not respond to a demand from the process (i.e. being unable to go to the defined fail-safe state).
Fail Dangerous Undetected	Failure that is dangerous and that is not being diagnosed by internal diagnostics.
Fail Dangerous Detected	Failure that is dangerous but is detected by internal diagnostics (These failures may be converted to the selected fail-safe state).
Annunciation	Failure that does not directly impact safety but does impact the ability to detect a future fault (such as a fault in a diagnostic circuit). Annunciation failures are divided into annunciation detected (AD) and annunciation undetected (AU) failures. For the calculation of the SFF they are treated to 5% as a dangerous failure and to 95% as a residual failure. These failures are used for the diagnostic to detect either an interruption or a short circuit at the input.
Residual	Failure mode of a component that plays a part in implementing the safety function but is neither a safe failure nor a dangerous failure. For the calculation of the SFF it is treated like a safe undetected failure.
No part	Component that plays no part in implementing the safety function but is part of the circuit diagram and is listed for completeness. When calculating the SFF this failure mode is not taken into account. It is also not part of the total failure rate.

The “Residual” and “Annunciation” failures are provided for those who wish to do reliability modeling more detailed than required by IEC 61508. The “Residual” failures are defined as safe undetected failures even though they will not cause the safety function to go to a safe state. Therefore they need to be considered in the Safe Failure Fraction calculation.

4.2 Methodology – FMEDA, Failure rates

4.2.1 FMEDA

A Failure Modes and Effects Analysis (FMEA) is a systematic way to identify and evaluate the effects of different component failure modes, to determine what could eliminate or reduce the chance of failure, and to document the system under consideration.

An FMEDA (Failure Mode Effect and Diagnostic Analysis) is an FMEA extension. It combines standard FMEA techniques with extensions to identify online diagnostics techniques and the failure modes relevant to safety instrumented system design. It is a technique recommended to generate failure rates for each important category (safe detected, safe undetected, dangerous detected, dangerous undetected, fail high, fail low) in the safety models. The format for the FMEDA is an extension of the standard FMEA format from MIL STD 1629A, Failure Modes and Effects Analysis.

4.2.2 Failure rates

The failure rate data used by *exida* in this FMEDA are from the Siemens SN 29500 failure rate database. The rates were chosen in a way that is appropriate for safety integrity level verification calculations. The rates were chosen to match operating stress conditions typical of an industrial field environment similar to IEC 60654-1, class C. It is expected that the actual number of field failures will be less than the number predicted by these failure rates.

The user of these numbers is responsible for determining their applicability to any particular environment. Accurate plant specific data may be used for this purpose. If a user has data collected from a good proof test reporting system that indicates higher failure rates, the higher numbers shall be used. Some industrial plant sites have high levels of stress. Under those conditions the failure rate data is adjusted to a higher value to account for the specific conditions of the plant.

4.2.3 Assumptions

The following assumptions have been made during the Failure Modes, Effects, and Diagnostic Analysis of the Ex NAMUR Isolating Amplifier MACX MCR-(EX)-SL-xNAM-yRO / MACX MCR-(EX)-SL-xNAM-yRO-SP.

- Failure rates are constant, wear out mechanisms are not included.
- Propagation of failures is not relevant.
- Failures during parameterization are not considered.
- Complete practical fault insertion tests can demonstrate that the diagnostic coverage (DC) corresponds to the assumed DC in the FMEDAs.
- Sufficient tests are performed prior to shipment to verify the absence of vendor and/or manufacturing defects that prevent proper operation of specified functionality to product specifications or cause operation different from the design analyzed.
- The time to restoration after a safe failure is 8 hours.
- All modules are operated in the low demand mode of operation.
- Only the output relay contact is used for safety applications.
- External power supply failure rates are not included.

- The listed SN29500 failure rates are valid for operating stress conditions typical of an industrial field environment 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 (25°C ambient temperature plus internal self heating). 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 (daily fluctuation of > 15°C) must be assumed. Humidity levels are assumed within manufacturer's rating.
- Only the described versions are used for safety applications.
- All relay outputs are protected by a fuse which initiates at 60% of the rated current to avoid contact welding.

5 Results of the assessment

Phoenix Contact GmbH & Co. KG conducted the FMEDA

exida reviewed the FMEDAs and issued the report

For the calculation of the Safe Failure Fraction (SFF) the following must be noted:

λ_{total} consists of the sum of all component failure rates. This means:

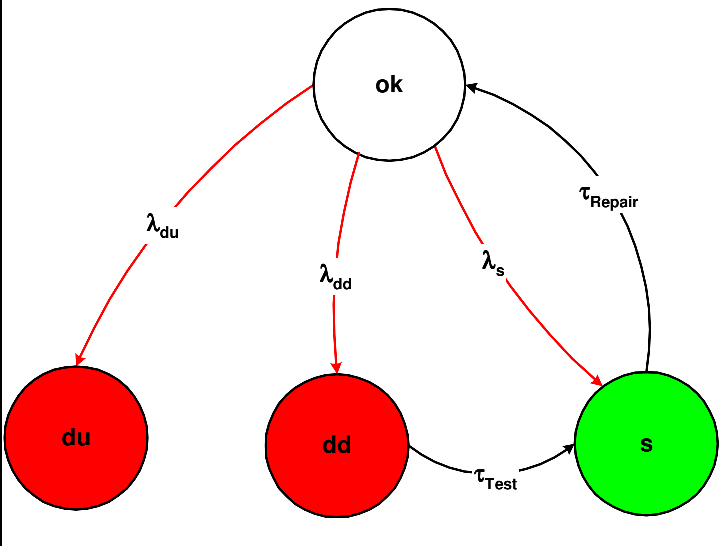
$\lambda_{total} = \lambda_{safe} + \lambda_{dangerous} + \lambda_{residual} + \lambda_{annunciation}$

$SFF = 1 - \lambda_{DU} / \lambda_{total}$

For the FMEDAs failure modes and distributions were used based on information gained from [N3] to [N5].

For the calculation of the PFD_{AVG} the following Markov model for a 1oo1D system was used. As after a complete proof test all states are going back to the OK state no proof test rate is shown in the Markov models but included in the calculation.

The proof test time was changed using the FMEDA tool of *exida* as a simulation tool. The results are documented in the following sections.



Abbreviations:

du	The system has failed dangerous undetected
dd	The system has failed dangerous detected
s	The system has failed safe
λ_{du}	Failure rate of dangerous undetected failures
λ_{dd}	Failure rate of dangerous detected failures
λ_{s}	Failure rate of safe failures
T_{Test}	Test time
τ_{Test}	Test rate ($1 / T_{Test}$)
T_{Repair}	Repair time
τ_{Repair}	Repair rate ($1 / T_{Repair}$)

Figure 4: Markov model for a 1oo1D structure

5.1 MACX MCR-(EX)-SL-NAM-R N / MACX MCR-(EX)-SL-NAM-R-SP N

The FMEDA carried out on the MACX MCR-(EX)-SL-NAM-R(-SP) N module leads under the assumptions described in section 4.2.3 and 5 to the following failure rates and SFF:

Failure category	**Failure rates (in FIT)**
Fail Safe Detected (λ_{SD})	**6**
Fail safe detected	6
Fail Safe Undetected (λ_{SU})	**242**
Fail safe undetected	158
Residual	76
Annunciation undetected (95%)	8
Fail Dangerous Detected (λ_{DD})	**7**
Fail dangerous detected	7
Annunciation detected	0
Fail Dangerous Undetected (λ_{DU})	**60**
Fail dangerous undetected	59
Annunciation undetected (5%)	1
No part	72

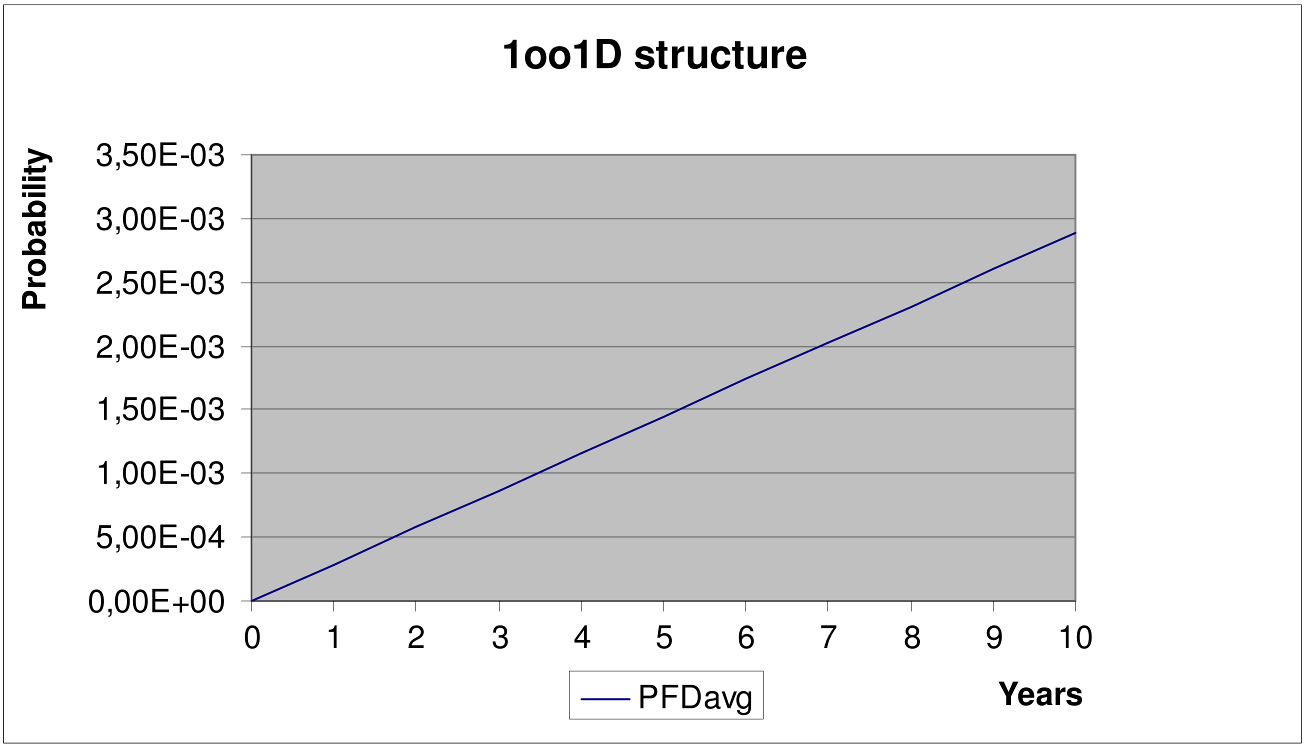
Total failure rate (safety function)	**315 FIT**
SFF	**78,89 %**
DC_D	**10 %**

The PFD_{AVG} was calculated for three different proof test intervals using the Markov model as described in Figure 4.

Name	T[Proof] = 1 year	T[Proof] = 2 years	T[Proof] = 5 years
MACX MCR-(EX)-SL-NAM-R N MACX MCR-(EX)-SL-NAM-R-SP N	**PFD_{AVG} = 2.90 E-4**	**PFD_{AVG} = 5,79E-04**	**PFD_{AVG} = 1,45E-03**

The boxes marked in yellow ( ) mean that the calculated PFD values are within the allowed range for SIL 2 according to table 2 of IEC 61508-1 but do not fulfill the requirement to not claim more than 10% of this range, i.e. to be better than or equal to 1.0 x 10^{-3}. The boxes marked in green ( ) mean that the calculated PFD values fulfill this requirement to be better than 1.0 x 10^{-3}.

Figure 5 shows the time dependent curve of PFD_{AVG}.



5.2 MACX MCR-(EX)-SL-NAM-R I / MACX MCR-(EX)-SL-NAM-R-SP I

The FMEDA carried out on the MACX MCR-(EX)-SL-NAM-R(-SP) I module leads under the assumptions described in section 4.2.3 and 5 to the following failure rates and SFF:

Failure category	**Failure rates (in FIT)**
Fail Safe Detected (λ_{SD})	**1**
Fail safe detected	1
Fail Safe Undetected (λ_{SU})	**249**
Fail safe undetected	160
Residual	81
Annunciation undetected (95%)	8
Fail Dangerous Detected (λ_{DD})	**6**
Fail dangerous detected	6
Annunciation detected	0
Fail Dangerous Undetected (λ_{DU})	**64**
Fail dangerous undetected	63
Annunciation undetected (5%)	1
No part	66

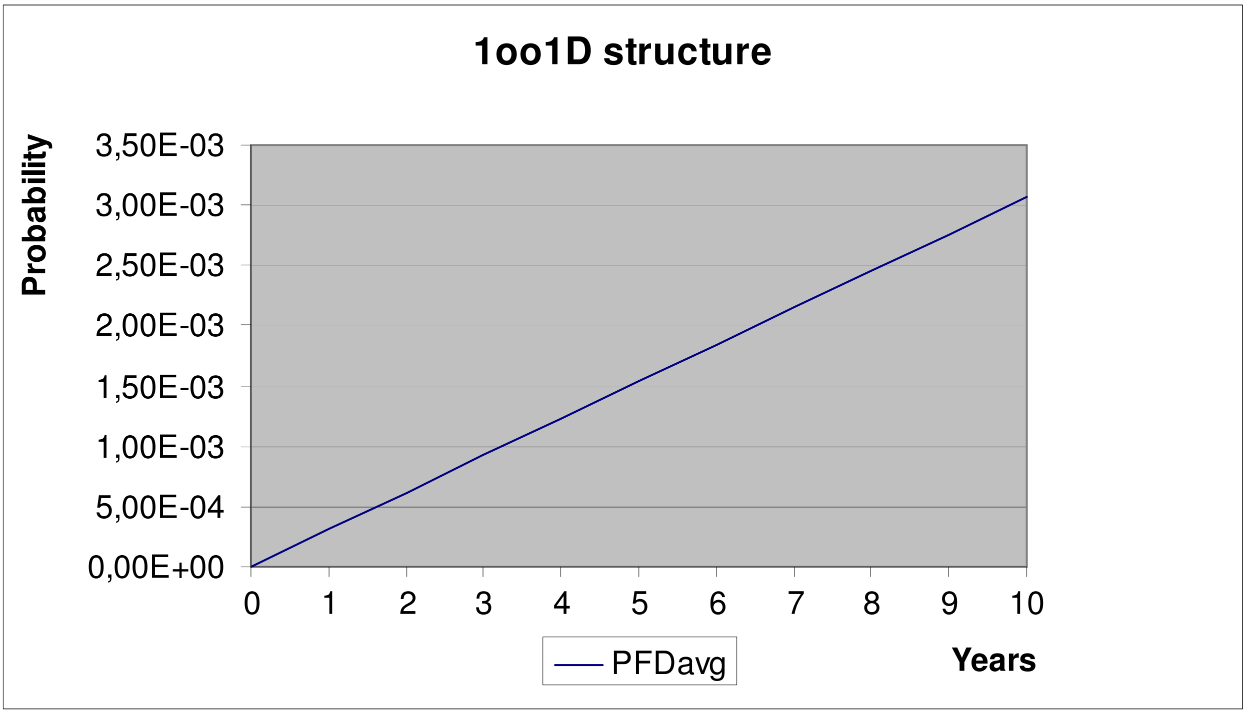
Total failure rate (safety function)	**320 FIT**
SFF	**78,00 %**
DC_D	**8 %**

The PFD_{AVG} was calculated for three different proof test intervals using the Markov model as described in Figure 4.

Name	T[Proof] = 1 year	T[Proof] = 2 years	T[Proof] = 5 years
MACX MCR-(EX)-SL-NAM-R I MACX MCR-(EX)-SL-NAM-R-SP I	**PFD_{AVG} = 3,08E-04**	**PFD_{AVG} = 6,15E-04**	**PFD_{AVG} = 1,54E-03**

The boxes marked in yellow ( ) mean that the calculated PFD values are within the allowed range for SIL 2 according to table 2 of IEC 61508-1 but do not fulfill the requirement to not claim more than 10% of this range, i.e. to be better than or equal to 1.0 x 10^{-3}. The boxes marked in green ( ) mean that the calculated PFD values fulfill this requirement to be better than 1.0 x 10^{-3}.

Figure 6 shows the time dependent curve of PFD_{AVG}.



5.3 MACX MCR-(EX)-SL-NAM-2R0 N / MACX MCR-(EX)-SL-NAM-2R0-SP N

The FMEDA carried out on the MACX MCR-(EX)-SL-NAM-R(-SP) N module leads under the assumptions described in section 4.2.3 and 5 to the following failure rates and SFF:

Failure category	Failure rates (in FIT)
Fail Safe Detected (λ_{SD})	**6**
Fail safe detected	6
Fail Safe Undetected (λ_{SU})	**244**
Fail safe undetected	159
Residual	77
Annunciation undetected (95%)	8
Fail Dangerous Detected (λ_{DD})	**7**
Fail dangerous detected	7
Annunciation detected	0
Fail Dangerous Undetected (λ_{DU})	**57**
Fail dangerous undetected	57
Annunciation undetected (5%)	1
No part	72

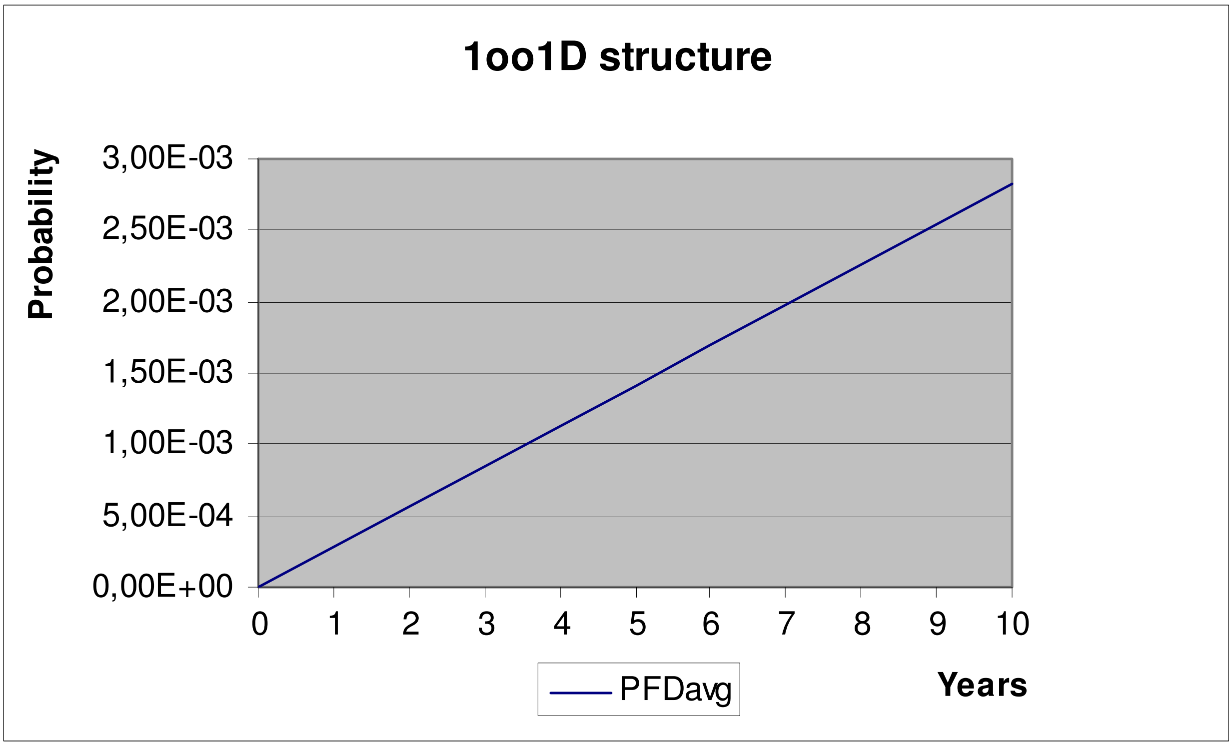
Total failure rate (safety function)	**314 FIT**
SFF	**79,42 %**
DC_D	**10 %**

The PFD_{AVG} was calculated for three different proof test intervals using the Markov model as described in Figure 4.

Name	T[Proof] = 1 year	T[Proof] = 2 years	T[Proof] = 5 years
MACX MCR-(EX)-SL-NAM-2RO N MACX MCR-(EX)-SL-NAM-2RO-SP N	**PFD_{AVG} = 2,83E-04**	**PFD_{AVG} = 5,65E-04**	**PFD_{AVG} = 1,41E-03**

The boxes marked in yellow ( ) mean that the calculated PFD values are within the allowed range for SIL 2 according to table 2 of IEC 61508-1 but do not fulfill the requirement to not claim more than 10% of this range, i.e. to be better than or equal to 1.0 x 10^{-3}. The boxes marked in green ( ) mean that the calculated PFD values fulfill this requirement to be better than 1.0 x 10^{-3}.

Figure 7 shows the time dependent curve of PFD_{AVG}.



5.4 MACX MCR-(EX)-SL-NAM-2R0 I / MACX MCR-(EX)-SL-NAM-2R0-SP I

The FMEDA carried out on the MACX MCR-(EX)-SL-NAM-R(-SP) I module leads under the assumptions described in section 4.2.3 and 5 to the following failure rates and SFF:

Failure category	Failure rates (in FIT)
Fail Safe Detected (λ_{SD})	**1**
Fail safe detected	1
Fail Safe Undetected (λ_{SU})	**251**
Fail safe undetected	161
Residual	82
Annunciation undetected (95%)	8
Fail Dangerous Detected (λ_{DD})	**6**
Fail dangerous detected	6
Annunciation detected	0
Fail Dangerous Undetected (λ_{DU})	**64**
Fail dangerous undetected	63
Annunciation undetected (5%)	1
No part	66

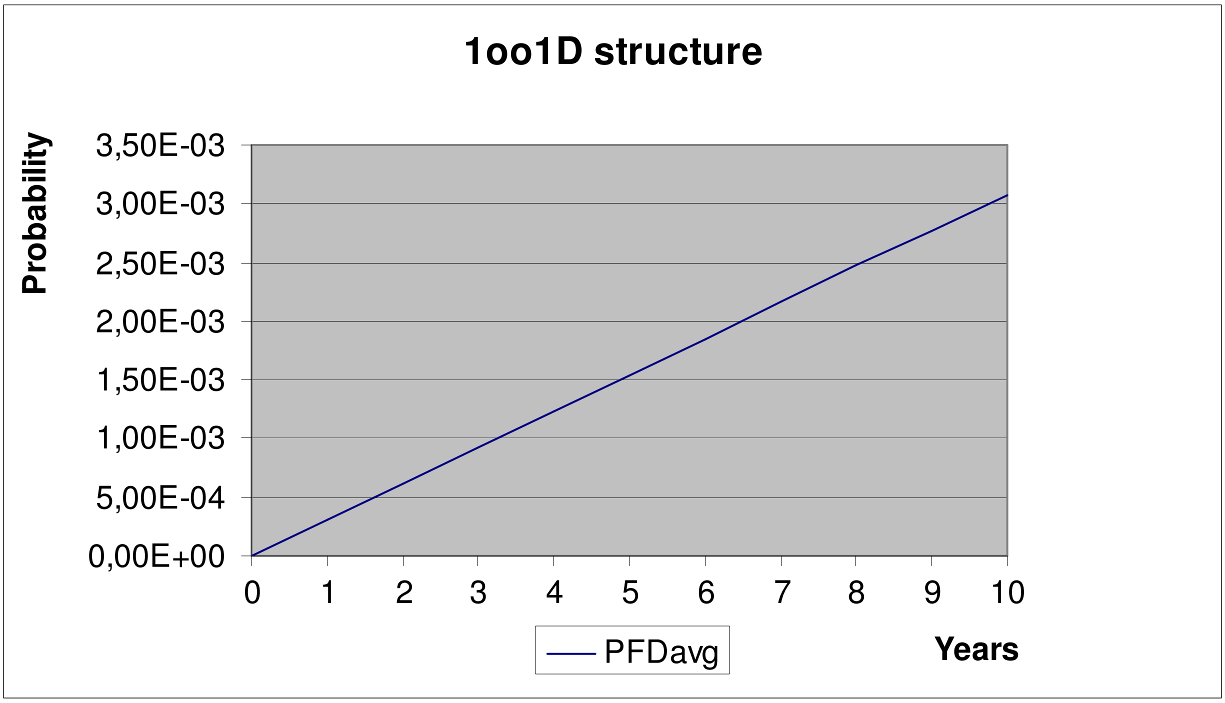
Total failure rate (safety function)	**322 FIT**
SFF	**77,98 %**
DC_D	**8 %**

The PFD_{AVG} was calculated for three different proof test intervals using the Markov model as described in Figure 4.

Name	T[Proof] = 1 year	T[Proof] = 2 years	T[Proof] = 5 years
MACX MCR-(EX)-SL-NAM-2RO I MACX MCR-(EX)-SL-NAM-2RO-SP I	**PFD_{AVG} = 3,09 E-04**	**PFD_{AVG} = 6,12 E-04**	**PFD_{AVG} = 1,54 E-03**

The boxes marked in yellow ( ) mean that the calculated PFD values are within the allowed range for SIL 2 according to table 2 of IEC 61508-1 but do not fulfill the requirement to not claim more than 10% of this range, i.e. to be better than or equal to 1.0 x 10^{-3}. The boxes marked in green ( ) mean that the calculated PFD values fulfill this requirement to be better than 1.0 x 10^{-3}.

Figure 8 shows the time dependent curve of PFD_{AVG}.



5.5 MACX MCR-(EX)-SL-2NAM-R0 N / MACX MCR-(EX)-SL-2NAM-R0-SP N

The FMEDA carried out on the MACX MCR-(EX)-SL-2NAM-R0(-SP) N module leads under the assumptions described in section 4.2.3 and 5 to the following failure rates and SFF:

Failure category	**Failure rates (in FIT)**
Fail Safe Detected (λ_{SD})	**6**
Fail safe detected	6
Fail Safe Undetected (λ_{SU})	**249**
Fail safe undetected	167
Residual	74
Annunciation undetected (95%)	8
Fail Dangerous Detected (λ_{DD})	**7**
Fail dangerous detected	7
Annunciation detected	0
Fail Dangerous Undetected (λ_{DU})	**64**
Fail dangerous undetected	63
Annunciation undetected (5%)	1
No part	272

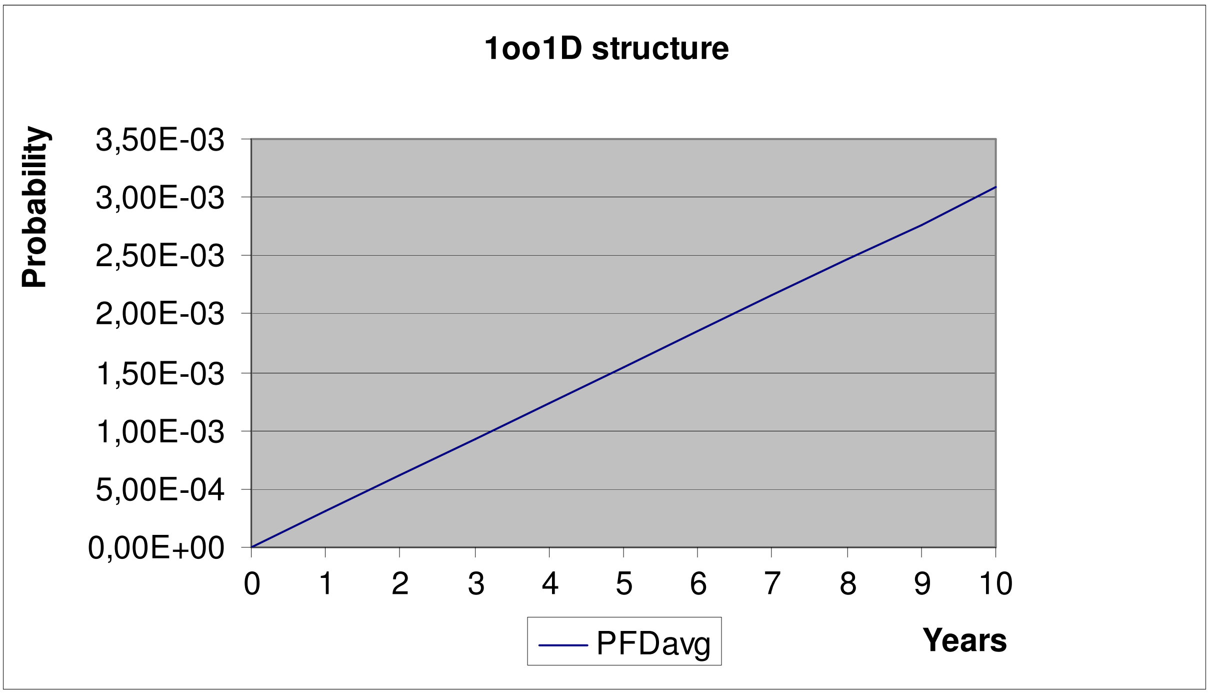
Total failure rate (safety function)	**326 FIT**
SFF	**78,33 %**
DC_D	**9 %**

The PFD_{AVG} was calculated for three different proof test intervals using the Markov model as described in Figure 4.

Name	T[Proof] = 1 year	T[Proof] = 2 years	T[Proof] = 5 years
MACX MCR-(EX)-SL-2NAM-RO N MACX MCR-(EX)-SL-2NAM-RO-SP N	**PFD_{AVG} = 3,09E-04**	**PFD_{AVG} = 6,17E-04**	**PFD_{AVG} = 1,54E-03**

The boxes marked in yellow ( ) mean that the calculated PFD values are within the allowed range for SIL 2 according to table 2 of IEC 61508-1 but do not fulfill the requirement to not claim more than 10% of this range, i.e. to be better than or equal to 1.0 x 10^{-3}. The boxes marked in green ( ) mean that the calculated PFD values fulfill this requirement to be better than 1.0 x 10^{-3}.

Figure 9 shows the time dependent curve of PFD_{AVG}.



5.6 MACX MCR-(EX)-SL-2NAM-R0 I / MACX MCR-(EX)-SL-2NAM-R0-SP I

The FMEDA carried out on the MACX MCR-(EX)-SL-NAM-R(-SP) I module leads under the assumptions described in section 4.2.3 and 5 to the following failure rates and SFF:

Failure category	Failure rates (in FIT)
Fail Safe Detected (λ_{SD})	**1**
Fail safe detected	1
Fail Safe Undetected (λ_{SU})	**248**
Fail safe undetected	160
Residual	80
Annunciation undetected (95%)	8
Fail Dangerous Detected (λ_{DD})	**6**
Fail dangerous detected	6
Annunciation detected	0
Fail Dangerous Undetected (λ_{DU})	**62**
Fail dangerous undetected	61
Annunciation undetected (5%)	1
No part	378

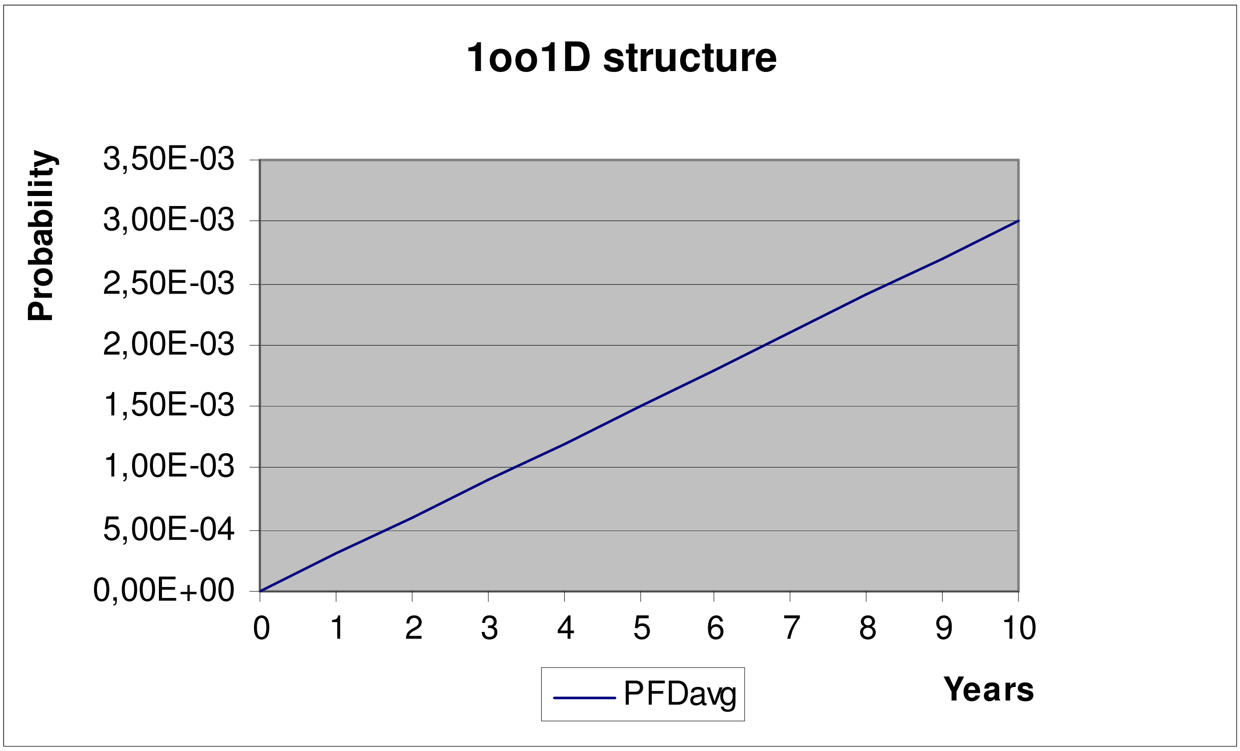
Total failure rate (safety function)	**317 FIT**
SFF	**78,27 %**
DC_D	**8 %**

The PFD_{AVG} was calculated for three different proof test intervals using the Markov model as described in Figure 4.

Name	T[Proof] = 1 year	T[Proof] = 2 years	T[Proof] = 5 years
MACX MCR-(EX)-SL-2NAM-RO I MACX MCR-(EX)-SL-2NAM-RO-SP I	**PFD_{AVG} = 3,01E-04**	**PFD_{AVG} = 6,02E-04**	**PFD_{AVG} = 1,50E-03**

The boxes marked in yellow ( ) mean that the calculated PFD values are within the allowed range for SIL 2 according to table 2 of IEC 61508-1 but do not fulfill the requirement to not claim more than 10% of this range, i.e. to be better than or equal to 1.0 x 10^{-3}. The boxes marked in green ( ) mean that the calculated PFD values fulfill this requirement to be better than 1.0 x 10^{-3}.

Figure 10 shows the time dependent curve of PFD_{AVG}.



6 Terms and Definitions

DC_S	Diagnostic Coverage of safe failures ($DC_S = \lambda_{sd} / (\lambda_{sd} + \lambda_{su})$)
DC_D	Diagnostic Coverage of dangerous failures ($DC_D = \lambda_{dd} / (\lambda_{dd} + \lambda_{du})$)
FIT	Failure In Time ($1x10^{-9}$ failures per hour)
FMEDA	Failure Modes, Effects, and Diagnostic Analysis
HFT	Hardware Fault Tolerance
Low demand mode	Mode where the frequency of demands for operation made on a safety-related system is no greater than one per year and no greater than twice the proof test frequency.
PFD_{AVG}	Average Probability of Failure on Demand
SFF	Safe Failure Fraction summarizes the fraction of failures which lead to a safe state and the fraction of failures which will be detected by diagnostic measures and lead to a defined safety action.
SIF	Safety Instrumented Function
SIL	Safety Integrity Level
Type A subsystem	Simple subsystem (without micro controllers or programmable logic); for details see 7.4.3.1.3 of IEC 61508-2
T[Proof]	Proof Test Interval

7 Status of the document

7.1 Liability

exida prepares reports based on methods advocated in International standards. Failure rates are obtained from a collection of industrial databases. *exida* accepts no liability whatsoever for the use of these numbers or for the correctness of the standards on which the general calculation methods are based.

Due to future potential changes in the standards, best available information and best practices, the current FMEDA results presented in this report may not be fully consistent with results that would be presented for the identical product at some future time. As a leader in the functional safety market place, *exida* is actively involved in evolving best practices prior to official release of updated standards so that our reports effectively anticipate any known changes. In addition, most changes are anticipated to be incremental in nature and results reported within the previous three year period should be sufficient for current usage without significant question.

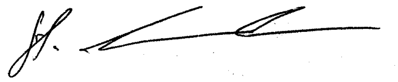
Most products also tend to undergo incremental changes over time. If an exida FMEDA has not been updated within the last three years and the exact results are critical to the SIL verification you may wish to contact the product vendor to verify the current validity of the results.

7.2 Releases

Version:	V2	
Release	R1	
Version History:	V1, R1:	Reviewed version, November 27, 2007
	V1, R2:	addition of the brand labeling in the management summary, November 30, 2007
	V2, R0:	Philipp Neumeier, Added spring pressure clamp modules MACX MCR-EX-SL-xNAM-yR(O)-SP, April 11, 2008
	V2, R1	Philipp Neumeier, Review comments incorporated, April 14, 2008
	V2, R2	Philipp Neumeier, added non-Ex Versions, February 26, 2009
Authors:		Otto Walch, Philipp Neumeier
Review:	V1, R1	Stephan Aschenbrenner, November 27, 2007
	V2, R0	Knut Teuber, Phoenix Contact, April 14, 2008
Release status:	Released to Phoenix Contact GmbH & Co. KG	

7.3 Release Signatures

Dipl.-Ing. (FH) Otto Walch, Manager Hazardous Locations



Dipl.-Ing. (Univ.) Stephan Aschenbrenner, Partner

Appendix 1: Possibilities to reveal dangerous undetected faults during the proof test

According to section 7.4.3.2.2 f) of IEC 61508-2 proof tests shall be undertaken to reveal dangerous faults which are undetected by diagnostic tests.

This means that it is necessary to specify how dangerous undetected faults which have been noted during the FMEDA can be detected during proof testing.

Table 8 to Table 13 show an importance analysis of the ten most critical dangerous undetected faults and indicate how these faults can be detected during proof testing.

Appendix 1 shall be considered when writing the safety manual as it contains important safety related information.

Table 8: Importance Analysis for MACX MCR-(EX)-SL-NAM-R(-SP) N

Component	% of total λ_{du}	Detection through
K2, (K3)	68,28%	100% functional test with monitoring of the relay output
IC3, (IC15)	7,68%	100% functional test with monitoring of the relay output
V23, (V25)	4,27%	100% functional test with monitoring of the relay output
V9, (V39	4,27%	100% functional test with monitoring of the relay output
IC2-1, (IC9-1)	2,56%	100% functional test with monitoring of the relay output
V29, V36, (V30, V40)	1,88%	100% functional test with monitoring of the relay output
V22	1,71%	100% functional test with monitoring of the relay output
IC4	1,71%	100% functional test with monitoring of the relay output
IC14	1,02%	100% functional test with monitoring of the relay output
IC2-2, (IC12-1)	1,02%	100% functional test with monitoring of the relay output

Table 9: Importance Analysis for MACX MCR-(EX)-SL-NAM-R(-SP) I

Component	% of total λ_{du}	Detection through
K2, (K3)	63,79%	100% functional test with monitoring of the relay output
IC3, (IC15)	7,18%	100% functional test with monitoring of the relay output
IC2-2,(IC12-1)	4,78%	100% functional test with monitoring of the relay output
V23, (V25)	3,99%	100% functional test with monitoring of the relay output
V9, (V39)	3,99%	100% functional test with monitoring of the relay output
V2, (V31)	2,39%	100% functional test with monitoring of the relay output
IC2-1, (IC9-1)	2,39%	100% functional test with monitoring of the relay output
V29, V36, (V30, V40)	1,75%	100% functional test with monitoring of the relay output
V22	1,59%	100% functional test with monitoring of the relay output
IC14	0,96%	100% functional test with monitoring of the relay output

Table 10: Importance Analysis for MACX MCR-(EX)-SL-NAM-2R0(-SP) N

Component	% of total λ_{du}	Detection through
K2, (K3)	70,20%	100% functional test with monitoring of the relay output
IC3, (IC15)	7,90%	100% functional test with monitoring of the relay output
V23, (V25)	4,39%	100% functional test with monitoring of the relay output
V9, (V39)	4,39%	100% functional test with monitoring of the relay output
IC2-1, (IC9-1)	2,63%	100% functional test with monitoring of the relay output
V29, V36, (V30, V40)	1,93%	100% functional test with monitoring of the relay output
V22	1,76%	100% functional test with monitoring of the relay output
IC14	1,05%	100% functional test with monitoring of the relay output
V4	0,88%	100% functional test with monitoring of the relay output
V8	0,88%	100% functional test with monitoring of the relay output

Table 11: Importance Analysis for MACX MCR-(EX)-SL-NAM-2R0(-SP) I

Component	% of total λ_{du}	Detection through
K2, (K3)	63,79%	100% functional test with monitoring of the relay output
IC3, (IC15)	7,18%	100% functional test with monitoring of the relay output
IC2-2,(IC12-1)	4,78%	100% functional test with monitoring of the relay output
V23, (V25)	3,99%	100% functional test with monitoring of the relay output
V9, (V39)	3,99%	100% functional test with monitoring of the relay output
V2, (V31)	2,39%	100% functional test with monitoring of the relay output
IC2-1, (IC9-1)	2,39%	100% functional test with monitoring of the relay output
V29, V36, (V30, V40)	1,75%	100% functional test with monitoring of the relay output
V22	1,59%	100% functional test with monitoring of the relay output
IC14	0,96%	100% functional test with monitoring of the relay output

Table 12: Importance Analysis for MACX MCR-(EX)-SL-2NAM-R0(-SP) N

Component	% of total λ_{du}	Detection through
K2	63,51%	100% functional test with monitoring of the relay output
IC3	14,29%	100% functional test with monitoring of the relay output
V23	3,97%	100% functional test with monitoring of the relay output
V9	3,97%	100% functional test with monitoring of the relay output
IC2-1	2,38%	100% functional test with monitoring of the relay output
IC2-2	2,38%	100% functional test with monitoring of the relay output
V29, V36	1,75%	100% functional test with monitoring of the relay output
V22	1,59%	100% functional test with monitoring of the relay output
V17	0,95%	100% functional test with monitoring of the relay output
IC14	0,79%	100% functional test with monitoring of the relay output

Table 13: Importance Analysis for MACX MCR-(EX)-SL-2NAM-R0(-SP) I

Component	% of total λ_{du}	Detection through
K2	65,35%	100% functional test with monitoring of the relay output
IC3	7,35%	100% functional test with monitoring of the relay output
V23	4,08%	100% functional test with monitoring of the relay output
V9	4,08%	100% functional test with monitoring of the relay output
V2	2,45%	100% functional test with monitoring of the relay output
IC2-1	2,45%	100% functional test with monitoring of the relay output
IC2-2	2,45%	100% functional test with monitoring of the relay output
V29, V36	1,80%	100% functional test with monitoring of the relay output
V10	1,63%	100% functional test with monitoring of the relay output
V22	0,98%	100% functional test with monitoring of the relay output

Appendix 2: Impact of lifetime of critical components on the failure rate

According to section 7.4.7.4 of IEC 61508-2, a useful lifetime, based on experience, should be assumed.

Although a constant failure rate is assumed by the probabilistic estimation method (see section 4.2.3) this only applies provided that the useful lifetime[2] of components is not exceeded. Beyond their useful lifetime the result of the probabilistic calculation method is therefore meaningless, as the probability of failure significantly increases with time. The useful lifetime is highly dependent on the component itself and its operating conditions – temperature in particular (for example, electrolytic capacitors can be very sensitive).

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 the PFD_{AVG} calculation is only valid for components which have this constant domain and that the validity of the calculation is limited to the useful lifetime 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 lifetime is valid.

Assuming one demand per year for low demand mode applications and additional switching cycles during installation and proof testing, the relays do not have a real impact on the useful lifetime.

The circuit of the Ex NAMUR Isolating Amplifier MACX MCR-(EX)-SL-xNAM-yRO(-SP) does not contain any components with reduced useful lifetime that are contributing to the dangerous undetected failure rate. Therefore there is no limiting factor with regard to the useful lifetime of the system.

[2] Useful lifetime is a reliability engineering term that describes the operational time interval where the failure rate of a device is relatively constant. It is not a term which covers product obsolescence, warranty, or other commercial issues.

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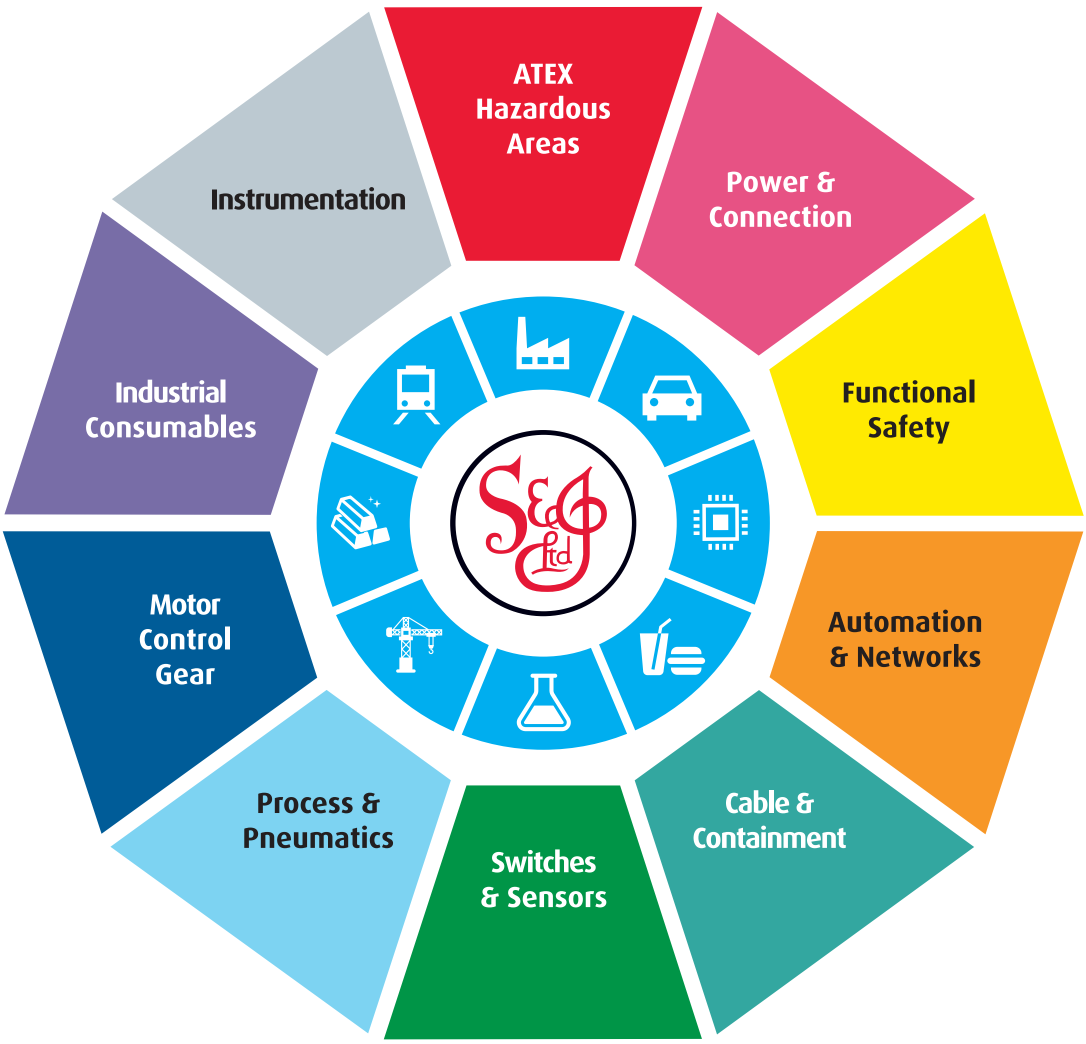

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