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TURCK

IM33-...-HI/24VDC Isolating Transducers

Safety Manual

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1 About this safety manual

This safety manual contains instructions on the use of devices in safety instrumented systems (SIS). The consideration of safety-related values is based on IEC 61508. The safety manual describes the values determined for the SIL assessment and is only applicable in conjunction with the attached EXIDA FMEDA report Turck 04/07-14 R001. Read this document carefully before using the device. This will prevent the risk of personal injury or damage to property or equipment. Keep this manual safe during the service life of the device. If the device is passed on, hand over this safety manual as well.



DANGER

Malfunction caused by operating errors

Danger to life if safety function fails!

- Observe the instructions contained in this safety manual without fail if the device is to be used in safety-related applications.

1.1 Target groups

This safety manual is designed for use by suitably qualified or trained personnel. It must be read and understood by anyone entrusted with any of the following tasks:

- Unpacking and mounting
- Commissioning
- Testing and maintenance
- Troubleshooting
- Disassembly and disposal

1.2 Explanation of symbols

The following symbols are used in this safety manual:



DANGER

DANGER indicates an immediate hazardous situation that, if not avoided, will result in death or serious injury.



NOTE

NOTE indicates tips, recommendations and important information. The notes contain information, particular operating steps that facilitate work and possibly help to avoid additional work resulting from incorrect procedures.

➤ **MANDATORY ACTION**

This symbol denotes actions that the user must carry out.

➡ **RESULT OF ACTION**

This symbol denotes the relevant results of actions and procedures.

1.3 Abbreviations and terms

Definition of terms, see IEC 61508-4

DC	diagnostic coverage	
E/E/PE system	electrical/electronic/programmable electronic system	
EUC	equipment under control	
	dangerous failure	
	no effect failure	
	no part failure	
	safe failure	
	safe state	
HFT	hardware fault tolerance	
	high demand mode	
	low demand mode	
MooN	M out of N channel architecture	
MTBF	mean time between failures	
MTR	mean time to restoration	
PF	probability of dangerous failure on demand	
PFDAVG	average probability of dangerous failure on demand	
PFH	probability of a dangerous failure per hour	
SFF	safe failure fraction	
SIF	safety instrumented function	Safety function
SIS	safety instrumented system	
SIL	safety integrity level	
	proof test	
	proof test interval	

1.4 Document history

Rev.	Description	Date
1.0.0	First edition	02.04.2015
1.1.0	Useful lifetime updated	17.08.2022

The German version shall be considered the definitive document. Every care was taken in the production of the translations of this document. If there is any uncertainty in its interpretation, refer to the German version of the safety manual or contact Turck directly.



NOTE

In all cases use the latest version of this safety manual. Check whether a newer version is available.

2 Notes on devices

2.1 Device variants

This safety manual applies to the following Turck isolating transducers:

IM33-11EX-HI/24VDC	IM33-22EX-HI/24VDC
IM33-11-HI/24VDC	IM33-22-HI/24VDC
IM33-12EX-HI/24VDC	

2.2 Scope of delivery

The device is supplied with the SIL registration card.

2.3 Manufacturer and service

Turck supports you in your projects – from the initial analysis right through to the commissioning of your application. The Turck product database offers you several software tools for programming, configuring or commissioning, as well as data sheets and CAD files in many export formats. You can access the Product Database directly via the following address:
www.turck.de/products

For further inquiries in Germany contact the Sales and Service Team on:

Sales: +49 208 4952-380

Technical: +49 208 4952-390

For overseas inquiries contact your national Turck representative.

Hans Turck GmbH & Co. KG
45466 Mülheim an der Ruhr
Germany

3 For your safety

The device is designed according to the latest state-of-the-art technology. Residual hazards, however, still exist.

Observe the following warnings and safety regulations in order to prevent danger to persons and property. Turck accepts no liability for damage caused by failure to observe regulations.

3.1 Intended use

Isolating transducers are used to operate (intrinsically safe) active or passive 2-wire or passive 3-wire transmitters. The galvanically isolated (intrinsically safe) analog measuring signal is transmitted from the field to the controller. Besides the analog signal, HART signals can also be transmitted bidirectionally. The devices are designed for input/output circuits of 0/4...20 mA. The input signals are transmitted 1:1. A wire break is detected at an input current < 3.6 mA and a short circuit at an input current > 21.5 mA in accordance with NE requirements, and indicated accordingly as an output value.

These devices also enable the creation of safety-related systems up to and including SIL2 according to IEC 61508 (hardware fault tolerance HFT = 0). The devices must only be used in safety-related systems if all requirements stated in this safety manual and the EXIDA report are strictly observed. The information in the EXIDA report applies when IEC 61508 is used for applications with a low demand mode (device type A for low demand mode). When used in safety systems, the probability of dangerous failure (PFD) for the entire circuit must be determined and given due consideration.

3.2 Obvious misuse

When using dual-channel devices in safety circuits, the second channel must not be used to increase the hardware fault tolerance and thus achieve a higher SIL level.

The IM33-...EX-HI/24VDC isolating transducers can be installed in zone 2 in accordance with the ATEX Directive; the IM33-11-HI/24VDC and IM33-22-HI/24VDC isolating transducers must not be installed in explosion hazardous areas in accordance with the ATEX Directive.

3.3 SIL registration card



NOTE

With safety-related applications, the SIL registration card enclosed with the device must be filled in completely by the user and returned to Turck without fail.

3.4 General safety regulations

- It is the responsibility of the user to ensure that the device is used in compliance with the applicable regulations, standards and laws.
- The suitability for specific applications must be assessed by considering the particular overall safety-related system with regard to the requirements of IEC 61508.
- The device must only be carried out by trained and qualified personnel.
- The device must only be commissioned and operated by trained and qualified personnel.
- A function test must be completed prior to initial operation, after repair and replacement, as well as at the stipulated interval T[Proof]
- When the device is in operation, ensure that the power supply is within the specified voltage range.
- Ensure that the plug connections and cables are always in good condition.
- Special application-specific factors such as chemical and physical stresses may cause the premature wear of the devices and must be taken into consideration when planning systems; take special measures to compensate for a lack of experience based values, e.g. through the implementation of shorter test intervals.
- If faults occur in the device that cause a switch to the defined safe state, measures must be taken to maintain the safe state during the further operation of the overall control system.
- Turck must be notified of dangerous failures immediately.
- A faulty device must be replaced immediately and must not be repaired.
- The device must be replaced immediately if the terminals are faulty or the device has any visible faults.
- Interventions and conversions on the device are not permissible. Repairs must only be carried out by Turck. Return the device to Turck for this (see section "Repair").
- Before using the product in safety-related applications, the suitability of the specifications stated in this safety manual for the particular application (e.g. particular branch-specific requirements and practices) must always be checked. In cases of doubt please contact the stated manufacturer's address.

4 Device specific information on safety applications

4.1 Safety function

- Normal operation: The device transmits the 4...20 mA current signals with a tolerance of 2 % of the end value from the input to the output.
- Low trip (on wire break): The device switches to the safe state at an input current of < 3.6 mA: A current of < 3.6 mA is output.
- High trip (on short circuit): The device switches to the safe state at an input current of > 21.5 mA: A current of > 21.5 mA is output.



DANGER

The characteristic values determined apply to the use of an output in safety-related functions. The second output must not be used for the safety function with signal doubling.

Danger to life due to misuse!

- Only use one output for the safety function with signal doubling.

4.2 Safe state

The safe state is defined as follows:

- "fail low" status: Output < 3.6 mA
- "fail high" status: Output > 21.5 mA

4.3 Functions and operating modes

4.3.1 Supply of transmitters

The device supplies transmitters with a supply voltage of $\geq 17\text{ V}/20\text{ mA}$.

4.3.2 Signal transmission

Signal transmission on 2-channel devices: The input signal is transmitted 1:1 to the associated output.

4.3.3 Signal doubling

Signal doubling: The input signal of channel 1 is transmitted 1:1 at both outputs.

4.3.4 Line monitoring

A wire break is detected at an input current $< 3.6\text{ mA}$ and a short circuit at an input current $> 21.5\text{ mA}$ in accordance with NE requirements, and indicated accordingly as an output value.

4.3.5 Fault acknowledgement

Faults do not have to be acknowledged. If the fault is rectified, the device automatically resumes operation.

4.4 Types of faults and failures

Failures must be classified in conjunction with the application into safe (non-hazardous) and unsafe (hazardous) failures. You as the operator are responsible for this.



NOTE

Turck must be notified immediately of all damage that was caused by a dangerous undetected failure.

A dangerous failure is present if an internal error has caused

- the device not to respond when required by the process (e.g. does not switch to the defined safe state) or
- the output current – as opposed to the input current – changes by more than 2 % of the end value.

4.5 Safety characteristic values

4.5.1 FMEDA assumptions

The safety-related characteristic values were determined based on an FMEDA in accordance with IEC 61508. The FMEDA is based on the following assumptions:

- The failure rates are constant.
- The mechanical wear is not considered.
- The propagation of failures is not relevant.
- The MTTR repair time after a safe failure is 8 hours (replacement of the device).
- The device is operated in low demand mode.
- The failure rates of an external power supply are not considered.
- The HART protocol is not used during normal operation but only for the setup, calibration and diagnostics of the field devices and is not part of the safety function
- Only one input and one output are part of the safety function.
- The failure rates used are the Siemens standards SN 29500 at 40 °C .
- The second channel of a device cannot be used to increase the HFT hardware fault tolerance.
- The ambient conditions correspond to an average industrial environment, as defined in MIL-HNBK-217-F or IEC 60654-1, Class C (sheltered location).
 - The ambient temperature is normally 40 °C.
 - A safety factor of 2.5 must be applied for ambient temperatures of 60 °C and frequent temperature fluctuations
- The user program in the safety controller is designed so that a wire break (fail low failure) and short circuit (fail high failure) are detected irrespective of whether it is a safe or dangerous failure in relation to the safety function.

4.5.2 Hardware architecture

The device is considered as a Type A component (non complex). The hardware fault tolerance HFT is 0.

4.5.3 Characteristic values for IM33-... isolating transducers

The device can be used for applications up to SIL 2.
 MTBF = MTTF + MTTR = $1/(\lambda_{total} + \lambda_{not\ part}) + 8\ h = 159\ years$

Fail-safe state = fail high

Failure category	λ_{sd}	λ_{su}	λ_{dd}	λ_{du}	SFF	DC _S ²	DC _D ²
$\lambda_{low} = \lambda_{sd}$ $\lambda_{high} = \lambda_{dd}$	233 FIT	315 FIT	73 FIT	44 FIT	93 %	42 %	62 %
$\lambda_{low} = \lambda_{dd}$ $\lambda_{high} = \lambda_{sd}$	73 FIT	315 FIT	233 FIT	44 FIT	93 %	18 %	84 %

Fail-safe state = fail low

Failure category	λ_{sd}	λ_{su}	λ_{dd}	λ_{du}	SFF	DC _S ²	DC _D ²
$\lambda_{low} = \lambda_{sd}$ $\lambda_{high} = \lambda_{dd}$	239 FIT	315 FIT	67 FIT	44 FIT	93 %	43 %	60 %
$\lambda_{low} = \lambda_{dd}$ $\lambda_{high} = \lambda_{sd}$	67 FIT	315 FIT	239 FIT	44 FIT	93 %	17 %	84 %

IM33-... – Average probability of failure on demand

T[Proof] = 1 year	T[Proof] = 5 years	T[Proof] = 10 years
PFDAVG = 1.92×10^{-4}	PFDAVG = 9.60×10^{-4}	PFDAVG = 1.92×10^{-3}



NOTE

The PFDAVG value of the isolating transducers should be designed to be max. 10% of the total permissible PFDAVG value for the safety integrity level SIL2. A PFDAVG value marked in green means that the PFD value is within the range of SIL2 in accordance with IEC 61508-1 and is less than 10% of the total value for SIL2. A PFDAVG value marked in yellow indicates that the PFD value is within the range of SIL2 in accordance with IEC 61508-1 but is more than 10% of the total value for SIL2.

4.6 Recurrent function tests

A function test must be completed prior to initial operation, after each parameter setting, after repair and replacement, as well as at the stipulated interval T[Proof]:

- ▶ Ensure that the function test is only carried out by qualified personnel.
- ▶ Think first about your safety and the safety of your environment. If in doubt, replace the device.
- ▶ Bridge the isolating transducer in the safety controller (process control system) and ensure that safety is maintained. You as the operator are responsible for ensuring that safety is maintained.
- ▶ Check the transmission behavior of the device with a suitable transducer and measuring device in 1 mA steps.
- ▶ With intrinsically safe device variants follow the regulations for Ex protection.
- ▶ If all checks have been completed and no faults found, restart the safety circuit.
- ▶ Once the test has been completed, document and archive the results.



NOTE

The function test detects more than 90 % of the undetected dangerous failures (Du) of the device

4.7 Useful life

The calculated failure rates of the device are valid for a useful lifetime of 8...12 years.

4.8 Special regulations and restrictions



NOTE

Each application has its particular conditions of use and ambient requirements. For this reason, the safety-related assessment of a system must always take the actual process into account – in addition to the general statements concerning probability of failure, tolerances and failure rates of the components. Special application-specific factors such as chemical and physical stresses may thus cause the premature wear of the devices and must therefore be taken into consideration when planning systems. Take special measures to compensate for a lack of experience based values, e.g. through the implementation of shorter test intervals. The estimation of the diagnostic coverage (DC) can vary from application to application. The estimation of the hardware fault tolerance (HFT) can only take place if the use of the compliant object is restricted.

5 Installation and commissioning



DANGER

Failure caused by commissioning and operating errors

Danger to life if safety function fails!

- Ensure that the product is only fitted, installed, operated and maintained by trained and qualified personnel.
-

5.1 Mounting

Observe the mounting instructions in the user manual.

5.2 Connection

Observe the mounting instructions in the user manual.

5.2.1 Wiring diagrams

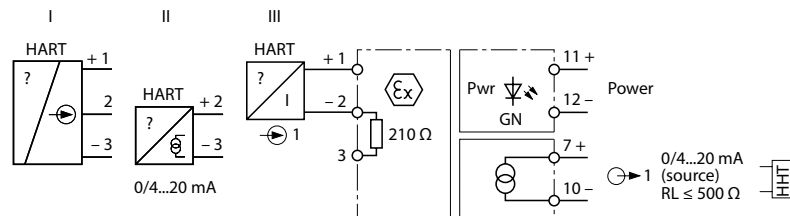


Fig. 1: Block diagram of the IM33-11EX-HI/24VDC

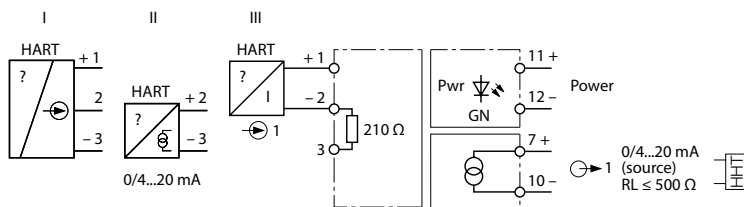


Fig. 2: Block diagram of the IM33-11-HI/24VDC

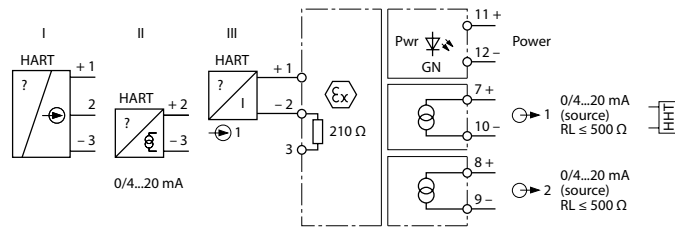


Fig. 3: Block diagram of the IM33-12EX-HI/24VDC

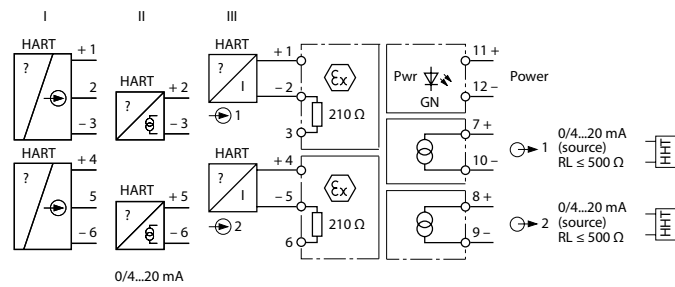


Fig. 4: Block diagram of the IM33-22EX-HI/24VDC

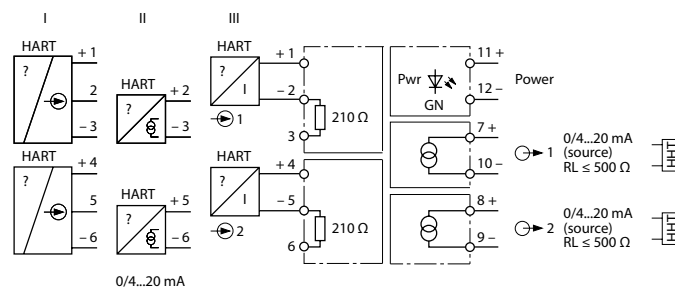


Fig. 5: Block diagram of the IM33-22-HI/24VDC

5.3 Commissioning

When the device is in operation, ensure that the power supply is within the specified voltage range. Commissioning is described in the operating instructions for the particular device.



DANGER

Malfunction caused by operating errors

Danger to life if safety function fails!

- A function test must be completed prior to initial operation, after repair and replacement, as well as at the stipulated interval T[Proof].

5.3.1 Selecting transmitters

The transmitters must be suitable for use in safety circuits.

Ensure that the devices and the housing materials are suitable for the application. For this refer also to the applicable data sheets of the Turck devices at www.turck.com.

6 Operation, maintenance and repair

The information is valid for the operating stress conditions in an industrial environment as per IEC 606541-1 Class C (sheltered location) with an ambient temperature of 40 °C over a long period of time.

6.1 Troubleshooting

The rectification of faults is described in the operating instructions for the particular device.



NOTE

The user must notify Turck immediately of any faults on the device which occur when it is used in safety instrumented applications.

6.2 Maintenance

Ensure that the plug connections and cables are always in good condition.

The devices are maintenance-free, clean dry if required.



DANGER

Malfunction caused by conductive media or static charge

Danger to life if safety function fails!

- When cleaning do not use any liquid media or statically charging cleaning agent.

6.3 Repair



DANGER

The device must not be repaired.

Danger to life due to malfunction!

- Send the device to Turck for repair. Observe here the specific warranty conditions agreed with the shipment.

6.3.1 Returning devices

If a device has to be returned, bear in mind that only devices with a decontamination declaration will be accepted. This is available for download at https://www.turck.de/static/media/downloads/01_Declaration_of_decontamination_EN.pdf and must be completely filled in, and affixed securely and weather-proof to the outside of the packaging.

7 Decommissioning and withdrawal from service

7.1 Decommissioning

Decommissioning is described in the operating instructions for the particular device.

7.2 Withdrawing from service

After the useful lifetime of 8...12 years has expired, the devices must be taken out of service. The devices are designed for installation in large-scale industrial installations and equipment. The relevant laws and regulations must be observed for the disposal of these installations and tools. They must not be included in normal household garbage.

8 Appendix – EXIDA FMEDA Report Turck 04/07-14 R001



Failure Modes, Effects and Diagnostic Analysis

Project:

Isolating Transducers IM33-**(Ex)-Hi/24VDC and Analog Signal
Transmitters IM35-**Ex-Hi/24VDC

Customer:

Hans Turck GmbH & Co. KG
Mühlheim
Germany

Contract No.: TURCK 04/07-14

Report No.: TURCK 04/07-14 R001

Version V2, Revision R0, February 2013

Stephan Aschenbrenner

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Management summary

This report summarizes the results of the hardware assessment carried out on the Isolating Transducers IM33-**(Ex)-Hi/24VDC and Analog Signal Transmitters IM35-**Ex-Hi/24VDC.

Table 1 gives an overview of the different versions that belong to the considered devices.

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: Version overview

Type	Description	Parts List / Circuit Diagram
IM33-11Ex-Hi/24VDC IM33-11-Hi/24VDC	1 input / 1 output	12260705 / 2260700 Ind. A of 28.06.04
IM33-12Ex-Hi/24VDC	1 input / 2 outputs	12260704 and 12263704 / 12260700 Ind. A of 28.06.04
IM33-22Ex-Hi/24VDC IM33-22-Hi/24VDC	2 inputs / 2 outputs	12260703 and 12263703 / 12260700 Ind. A of 28.06.04
IM35-11Ex-Hi/24VDC	1 input / 1 output	12280003 / 12280000 Ind. – of 17.10.03
IM35-22Ex-Hi/24VDC	2 inputs / 2 outputs	12280001 and 12280101 / 12280000 Ind. – of 17.10.03

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. However, as the modules under consideration are only one part of an entire safety function they should not claim more than 10% of this range, i.e. they should be better than or equal to $1,00E-03$.

The Isolating Transducers IM33-**(Ex)-Hi/24VDC and Analog Signal Transmitters IM35-**Ex-Hi/24VDC are considered to be Type A¹ components with a hardware fault tolerance of 0.

For Type A components the SFF has to be 60% to $< 90\%$ according to table 2 of IEC 61508-2 for SIL 2 (sub-) systems with a hardware fault tolerance of 0.

Assuming that a connected safety logic solver to the Isolating Transducers IM33-**(Ex)-Hi/24VDC can detect both over-range (fail high) and under-range (fail low), high and low failures can be classified as safe detected failures or dangerous detected failures depending on the application (see section 4.2.4). The following tables show how the above stated requirements are fulfilled based on the different applications.

¹ Type A component: "Non-complex" component (all failure modes are well defined); for details see 7.4.3.1.2 of IEC 61508-2.



Table 2: Summary for IM33-(Ex)-Hi/24VDC – Failure rates**

Fail-safe state = “fail high”

Failure Category	λ_{sd}	λ_{su}	λ_{dd}	λ_{du}	SFF	DC _S ²	DC _D ²
$\lambda_{low} = \lambda_{sd}$ $\lambda_{high} = \lambda_{dd}$	233 FIT	315 FIT	73 FIT	44 FIT	93%	42%	62%
$\lambda_{low} = \lambda_{dd}$ $\lambda_{high} = \lambda_{sd}$	73 FIT	315 FIT	233 FIT	44 FIT	93%	18%	84%

Fail-safe state = “fail low”

Failure Category	λ_{sd}	λ_{su}	λ_{dd}	λ_{du}	SFF	DC _S ²	DC _D ²
$\lambda_{low} = \lambda_{sd}$ $\lambda_{high} = \lambda_{dd}$	239 FIT	315 FIT	67 FIT	44 FIT	93%	43%	60%
$\lambda_{low} = \lambda_{dd}$ $\lambda_{high} = \lambda_{sd}$	67 FIT	315 FIT	239 FIT	44 FIT	93%	17%	84%

Table 3: Summary for IM33-(Ex)-Hi/24VDC – PFD_{AVG} values**

T[Proof] = 1 year	T[Proof] = 5 years	T[Proof] = 10 years
PFD _{AVG} = 1,92E-04	PFD _{AVG} = 9,60E-04	PFD _{AVG} = 1,92E-03

Table 4: Summary for IM35-Ex-Hi/24VDC – Failure rates**

λ_{safe}	$\lambda_{dangerous}$	SFF
583 FIT	103 FIT	85%

Table 5: Summary for IM35-Ex-Hi/24VDC – PFD_{AVG} values**

T[Proof] = 1 year	T[Proof] = 5 years	T[Proof] = 10 years
PFD _{AVG} = 4,50E-04	PFD _{AVG} = 2,25E-03	PFD _{AVG} = 4,48E-03

The boxes marked in yellow () mean that the calculated PFD_{AVG} 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 1,00E-03. The boxes marked in green () mean that the calculated PFD_{AVG} values are within the allowed range for SIL 2 according to table 2 of IEC 61508-1 and table 3.1 of ANSI/ISA–84.01–1996 and do fulfill the requirement to not claim more than 10% of this range, i.e. to be better than or equal to 1,00E-03.

Because the Safe Failure Fraction (SFF) is above 60%, also the architectural constraints requirements of table 2 of IEC 61508-2 for Type A subsystems with a Hardware Fault Tolerance (HFT) of 0 are fulfilled.

² DC means the diagnostic coverage (safe or dangerous) of the safety logic solver for the Isolating Transducers IM33-**Ex-Hi/24VDC.



The two channels on a redundant board shall not be used to increase the hardware fault tolerance needed for a higher SIL as they contain common components.

A user of the Isolating Transducers IM33-**(Ex)-Hi/24VDC and Analog Signal Transmitters IM35-**(Ex)-Hi/24VDC 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 is presented in sections 5.1 and 5.2 along with all assumptions.

The failure rates are valid for the useful life of the Isolating Transducers IM33-**(Ex)-Hi/24VDC and Analog Signal Transmitters IM35-**(Ex)-Hi/24VDC, which is estimated to be between 8 and 12 years (see Appendix 2).

It is important to realize that the “no effect” failures are included in the “safe undetected” failure category according to IEC 61508. Note that these failures on its own will not affect system reliability or safety, and should not be included in spurious trip calculations.



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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.com* according to the relevant functional safety standard(s) like DIN V VDE 0801, 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}).

This option for pre-existing hardware devices shall provide the safety instrumentation engineer with the required failure data as per IEC 61508 / IEC 61511 and does not consist of an assessment of the software development process

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

Option 2 is an assessment by *exida.com* according to the relevant functional safety standard(s) like DIN V VDE 0801, 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}). In addition this option consists of an assessment of the proven-in-use documentation of the device and its software including the modification process.

This option for pre-existing programmable electronic devices shall provide the safety instrumentation engineer with the required failure data as per IEC 61508 / IEC 61511 and justify the reduced fault tolerance requirements of 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.com* according to the relevant application standard(s) like IEC 61511 or EN 298 and the necessary functional safety standard(s) like DIN V VDE 0801, 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 is most suitable for newly developed software based field devices and programmable controllers to demonstrate full compliance with IEC 61508 to the end-user.

This assessment shall be done according to option 1.

This document shall describe the results of the hardware assessment carried out on the Isolating Transducers IM33-**(Ex)-Hi/24VDC and Analog Signal Transmitters IM35-**Ex-Hi/24VDC.

It shall be assessed whether the described Isolating Transducers and Analog Signal Transmitters meet the average Probability of Failure on Demand (PFD_{AVG}) requirements and the architectural constraints for SIL 2 sub-systems according to IEC 61508.

It **does not** consider any calculations necessary for proving intrinsic safety.



2 Project management

2.1 exida.com

exida.com is one of the world's leading knowledge companies specializing in automation system safety and availability with over 100 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.com is a partnership with offices around the world. exida.com 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.com maintains a comprehensive failure rate and failure mode database on process equipment.

2.2 Roles of the parties involved

Werner Turck GmbH & Co. KG Manufacturer of the considered Isolating Transducers and Analog Signal Transmitters.

exida.com Performed the hardware assessment according to option 1 (see section 1).

Werner Turck GmbH & Co. KG contracted exida.com in August 2004 with the FMEDA and PFD_{AVG} calculation of the above mentioned device.

2.3 Standards / Literature used

The services delivered by exida.com 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]	NPRD-95, RAC	Non-electronic Parts – Reliability Data 1995
[N6]	SN 29500	Failure rates of components



2.4 Reference documents

2.4.1 Documentation provided by the customer

[D1]	im33_12Ex_Hi.pdf	Description of the working principle
[D2]	im35_12Ex_Hi.pdf	Description of the working principle
[D3]	Datenblatt IM33.pdf	Data sheet
[D4]	Datenblatt IM35.pdf	Data sheet
[D5]	IM33_Blockschr.pdf	Page 7 of circuit diagram "IM33-22-Ex0-Hi/24DC 12260700 Ind. A"
[D6]	NetzteilIM33.pdf	Page 8 of circuit diagram "IM33-22-Ex0-Hi/24DC 12260700 Ind. A"
[D7]	IM33_E1_Basis.pdf	Page 9 of circuit diagram "IM33-22-Ex0-Hi/24DC 12260700 Ind. A"
[D8]	IM33_E2_Modul.pdf	Page 8 of circuit diagram "IM33-22 Modul 12263700 Ind. A"
[D9]	IM33_A1_Basis.pdf	Page 10 of circuit diagram "IM33-22-Ex0-Hi/24DC 12260700 Ind. A"
[D10]	IM33_A2_Modul.pdf	Page 7 of circuit diagram "IM33-22 Modul 12263700 Ind. A"
[D11]	IM35_Blockschr.pdf	Page 7 of circuit diagram "IM35-22-Ex0-Hi(U)/24DC 12280000"
[D12]	NetzteilIM35.pdf	Page 10 of circuit diagram "IM35-22-Ex0-Hi(U)/24DC 12280000"
[D13]	IM35_E1_Basis.pdf	Page 9 of circuit diagram "IM35-22-Ex0-Hi(U)/24DC 12280000"
[D14]	IM35_E2_Modul.pdf	Page 7 of circuit diagram "IM35-22 Modul 12280100"
[D15]	IM35_A1_Basis.pdf	Page 8 of circuit diagram "IM35-22-Ex0-Hi(U)/24DC 12280000"
[D16]	IM35_A2_Modul.pdf	Page 8 of circuit diagram "IM35-22 Modul 12280100"

2.4.2 Documentation generated by exida.com

[R1]	FMEDA V6 IM33-22-Ex0-Hi-24DC V0 R1.2.xls of 04.11.04
[R2]	FMEDA V6 IM35-22Ex0-HiU-24DC V0 R1.2.xls of 04.11.04



3 Description of the analyzed module

3.1 Isolating Transducers IM33-22Ex-Hi/24VDC

The isolating transducer IM33-22Ex-Hi/24VDC is used to energize intrinsically safe 2-wire HART® transducers in the hazardous area and to transmit the measuring signals to the non-hazardous area.

In addition to analog signals, digital HART® communication signals can be transferred bidirectional.

Further it is possible to connect active 2-wire (II) and passive 3-wire (I) transmitters. The device features two channels with 0/4...20 mA input and output circuits.

The input circuits are galvanically isolated from the output circuits, the supply voltage and from each other.

The input signals are transferred without attenuation (1:1 transfer) to the output circuits in the non-hazardous area. Due to the 1:1 transmission characteristic, wire-break or short-circuit conditions in the transducer circuit are indicated by an output current of 0 mA or > 22.5 mA, respectively.

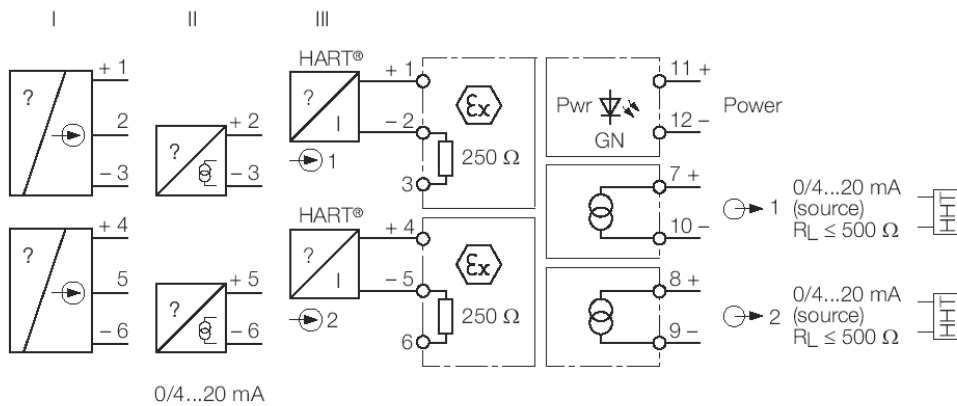


Figure 1: Block diagram of the Isolating Transducer IM33-22Ex-Hi/24VDC

The Isolating Transducers IM33-22Ex-Hi/24VDC are considered to be Type A components with a hardware fault tolerance of 0.

The description above is valid for all versions of the isolating transducer with the exception that this version has two input and two output channels. The differences between the versions are described in Table 1.



3.2 Analog Signal Transmitter IM35-22Ex-Hi/24VDC

The two-channel data transmitter IM35-22Ex-Hi/24VDC is designed to transfer standard galvanically isolated current signals from the safe area to the explosion hazardous area in a 1:1 transmission mode.

In addition to the analogue signal, digital HART® communication signals can be transferred bidirectional.

Typical applications are the control of I/P converters (e.g. at control valves / actuators) or of indicator displays in explosion hazardous areas.

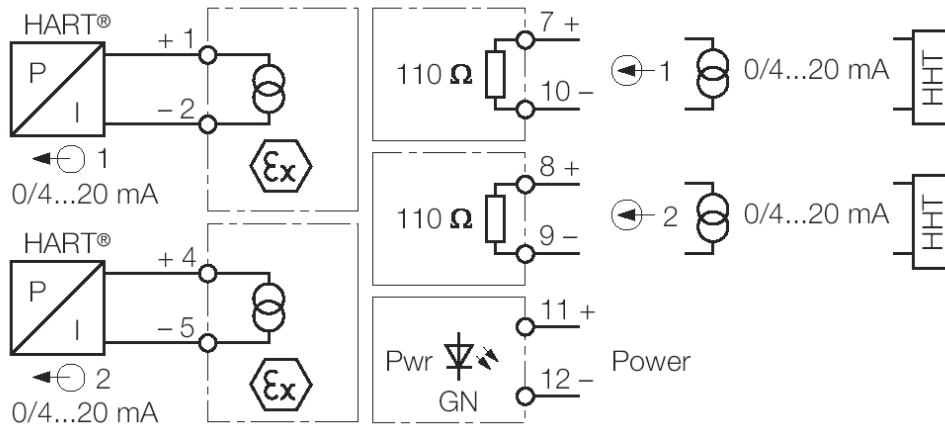


Figure 2: Block diagram of the Analog Signal Transmitter IM35-22Ex-Hi/24VDC

The Analog Signal Transmitters IM35-22Ex-Hi/24VDC are considered to be Type A components with a hardware fault tolerance of 0.

The description above is valid for all versions of the analog signal transmitter with the exception that this version has two input and two output channels. The differences between the versions are described in Table 1.



4 Failure Modes, Effects, and Diagnostic Analysis

The Failure Modes, Effects, and Diagnostic Analysis was done together with Werner Turck GmbH & Co. KG and is documented in [R1] and [R2]. When the effect of a certain failure mode could not be analyzed theoretically, the failure modes were introduced on component level and the effects of these failure modes were examined on system level. This resulted in failures that can be classified according to the following failure categories.

4.1 Description of the failure categories

In order to judge the failure behavior of the Isolating Transducers IM33-**(Ex)-Hi/24VDC and Analog Signal Transmitters IM35-**Ex-Hi/24VDC, the following definitions for the failure of the product were considered.

Fail Safe	Failure that causes the module / (sub)system to go to the defined fail-safe state without a demand from the process or has no effect on the safety function.
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) or deviates the output current by more than 2% full scale (+/-0.32mA).
Fail High	Failure that causes the output signal to go to the maximum output current (> 21 mA)
Fail Low	Failure that causes the output signal to go to the minimum output current (< 3.6 mA)
Fail No Effect	Failure of a component that is part of the safety function but that has no effect on the safety function or deviates the output current by not more than 2% full scale. For the calculation of the SFF it is treated like a safe undetected failure.
Not part	Failures of a component which is not part of the safety function but 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.

IM33-(Ex)-Hi/24VDC**

Fail-Safe State	Depending on the application the fail-safe state is defined as the output going to "fail-low" or "fail high".
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IM35-Ex-Hi/24VDC**

Fail-Safe State	The fail-safe state is defined as the output going to "fail-low".
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The "no effect" failures are provided for those who wish to do reliability modeling more detailed than required by IEC 61508. In IEC 61508 the "no effect" 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 in consideration.

A FMEDA (Failure Modes, Effects, and Diagnostic Analysis) is a FMEA extension. It combines standard FMEA techniques with extension 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.com* in this FMEDA are the basic failure rates from the Siemens SN 29500 failure rate database. The rates are considered to be appropriate for safety integrity level verification calculations. The rates match operating stress conditions typical of an industrial field environment similar to IEC 645-1, 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 Isolating Transducers IM33-**(Ex)-Hi/24VDC and Analog Signal Transmitters IM35-**Ex-Hi/24VDC.

- Failure rates are constant, wear out mechanisms are not included.
- Propagation of failures is not relevant.
- The time to restoration after a safe failure is 8 hours.
- All modules are operated in the low demand mode of operation.
- External power supply failure rates are not included.
- The HART protocol is only used for setup, calibration, and diagnostics purposes, not during normal operation.
- The two channels on a redundant board are not used to increase the hardware fault tolerance needed for a higher SIL as they contain common components.
- The stress levels are average for an industrial environment and can be compared to the Ground Fixed classification of MIL-HNBK-217F. Alternatively, the assumed environment is similar to:
 - IEC 645-1, 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.



- Only the current output 4..20mA is used for safety applications.
- The application program in the safety logic solver is constructed in such a way that fail low and fail high failures are detected regardless of the effect, safe or dangerous, on the safety function³.

4.2.4 Example explaining the behavior of the safety logic solver

For IM33-**(Ex)-Hi/24VDC, the following scenarios are possible:

- Low Trip: the safety function will go to the predefined fail-safe state when the process value is below a predefined low set value. A current < 3.6mA (Fail Low) is below the specified trip-point.
- High Trip: the safety function will go to the predefined fail-safe state when the process value exceeds a predefined high set value. A current > 21mA (Fail High) is above the specified trip-point.

The Fail Low and Fail High failures can either be detected or undetected by a connected logic solver. The SPLC Detection Behavior in Table 6 represents the under-range and over-range detection capability of the connected safety logic solver.

Table 6 Application example

Application	SPLC Detection Behavior	λ_{low}	λ_{high}
Low trip	< 4mA ⁴	= λ_{sd}	= λ_{du}
Low trip	> 20mA ⁵	= λ_{su}	= λ_{dd}
Low trip	< 4mA and > 20mA	= λ_{sd}	= λ_{dd}
High trip	< 4mA	= λ_{dd}	= λ_{su}
High trip	> 20mA	= λ_{du}	= λ_{sd}
High trip	< 4mA and > 20mA	= λ_{dd}	= λ_{sd}

In this analysis it is assumed that the safety logic solver is able to detect under-range and over-range currents, therefore the yellow highlighted behavior is assumed.

³ For further explanations see section 4.2.4 of this report.

⁴ The exact “low alarm” current is specified in section 4.1.

⁵ The exact “high alarm” current is specified in section 4.1.



5 Results of the assessment

exida.com did the FMEDAs together with Werner Turck GmbH & Co. KG.

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

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

$$\lambda_{total} = \lambda_{safe} + \lambda_{dangerous} + \lambda_{no\ effect}$$

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

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 models for a 1oo1D and a 1oo1 system were 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 Microsoft® Excel 2000 based FMEDA tool of exida.com as a simulation tool. The results are documented in the following sections.

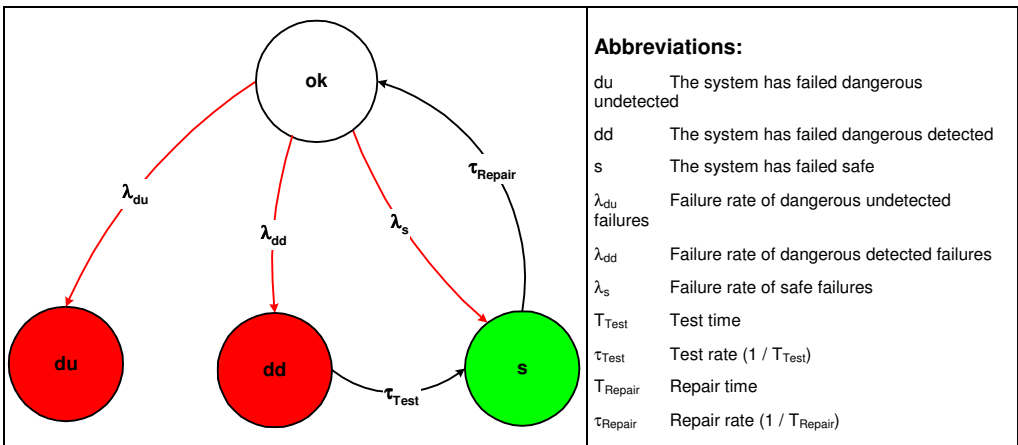


Figure 3: Markov model for a 1oo1D structure

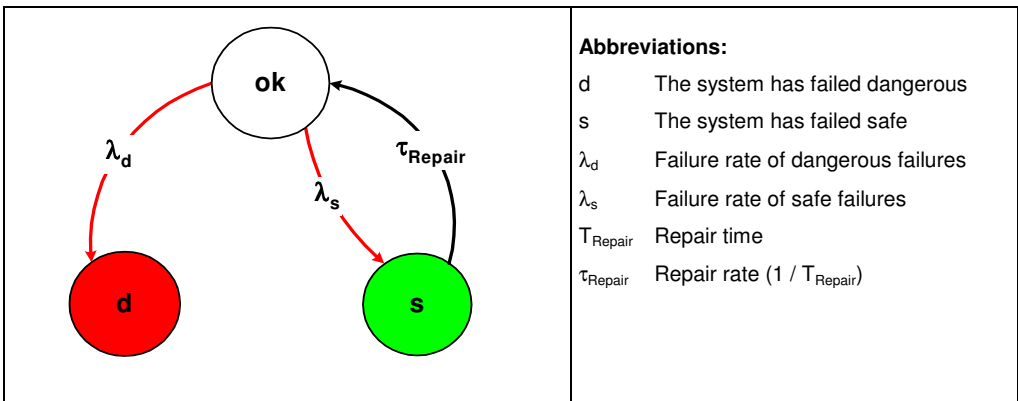


Figure 4: Markov model for a 1oo1 structure



5.1 Isolating Transducers IM33-(Ex)-Hi/24VDC**

The FMEDA carried out on the Isolating Transducer IM33-22Ex-Hi/24VDC leads under the assumptions described in sections 4.2.3 and 5 to the following failure rates:

$\lambda_{sd} = 0,00E-00$ 1/h

$\lambda_{su} = 6,00E-09$ 1/h

$\lambda_{dd} = 0,00E-00$ 1/h

$\lambda_{du} = 4,39E-08$ 1/h

$\lambda_{high} = 6,71E-08$ 1/h

$\lambda_{low} = 2,33E-07$ 1/h

$\lambda_{no\ effect} = 3,15E-07$ 1/h

$\lambda_{total} = 6,65E-07$ 1/h

$\lambda_{not\ part} = 5,28E-08$ 1/h

$MTBF = MTTF + MTTR = 1 / (\lambda_{total} + \lambda_{not\ part}) + 8\ h = 159\ years$

These failure rates can be turned over into the following typical failure rates:

Failure category (Failure rates in FIT)	Fail-safe state = "fail high"	Fail-safe state = "fail low"
Fail High (detected by the logic solver)	73	
Fail detected (int. diag.) = $\lambda_{sd} + \lambda_{su}^6 + \lambda_{dd}$	6	
Fail high (inherently) = λ_{high}	67	67
Fail Low (detected by the logic solver)		239
Fail detected (int. diag.) = $\lambda_{sd} + \lambda_{su} + \lambda_{dd}$	6	
Fail low (inherently) = λ_{low}	233	233
Fail Dangerous Undetected	44	44
No Effect	315	315
Not part	53	53
MTBF = MTTF + MTTR	159 years	159 years

Under the assumptions described in section 4.2.4 and 5 the following tables show the failure rates according to IEC 61508 depending on whether fail low / fail high was considered to be dangerous detected or safe detected to:

⁶ These failures are not detected by internal diagnostics but because they lead to the safe state (e.g. by reaching the user defined trip point) they are detected by the logic solver independent of the user defined fail-safe state ("fail low" or "fail high").



Fail-safe state = “fail high”

Failure Category	λ_{sd}	λ_{su}	λ_{dd}	λ_{du}	SFF	DC _S	DC _D
$\lambda_{low} = \lambda_{sd}$ $\lambda_{high} = \lambda_{dd}$	233 FIT	315 FIT	73 FIT	44 FIT	93,40%	42,52%	62,39%
$\lambda_{low} = \lambda_{dd}$ $\lambda_{high} = \lambda_{sd}$	73 FIT	315 FIT	233 FIT	44 FIT	93,40%	18,81%	84,12%

Fail-safe state = “fail low”

Failure Category	λ_{sd}	λ_{su}	λ_{dd}	λ_{du}	SFF	DC _S	DC _D
$\lambda_{low} = \lambda_{sd}$ $\lambda_{high} = \lambda_{dd}$	239 FIT	315 FIT	67 FIT	44 FIT	93,40%	43,14%	60,36%
$\lambda_{low} = \lambda_{dd}$ $\lambda_{high} = \lambda_{sd}$	67 FIT	315 FIT	239 FIT	44 FIT	93,40%	17,54%	84,45%

The PFD_{AVG} was calculated for three different proof test times using the Markov model as described in Figure 3.

T[Proof] = 1 year	T[Proof] = 5 years	T[Proof] = 10 years
PFD _{AVG} = 1,92E-04	PFD _{AVG} = 9,60E-04	PFD _{AVG} = 1,92E-03

The boxes marked in yellow () mean that the calculated PFD_{AVG} values are within the allowed range for SIL 2 according to table 2 of IEC 61508-1 and table 3.1 of ANSI/ISA–84.01–1996 but do not fulfill the requirement to not claim more than 10% of this range, i.e. to be better than or equal to 1,00E-03. The boxes marked in green () mean that the calculated PFD_{AVG} values are within the allowed range for SIL 2 according to table 2 of IEC 61508-1 and table 3.1 of ANSI/ISA–84.01–1996 and do fulfill the requirement to not claim more than 10% of this range, i.e. to be better than or equal to 1,00E-03. Figure 5 shows the time dependent curve of PFD_{AVG}.

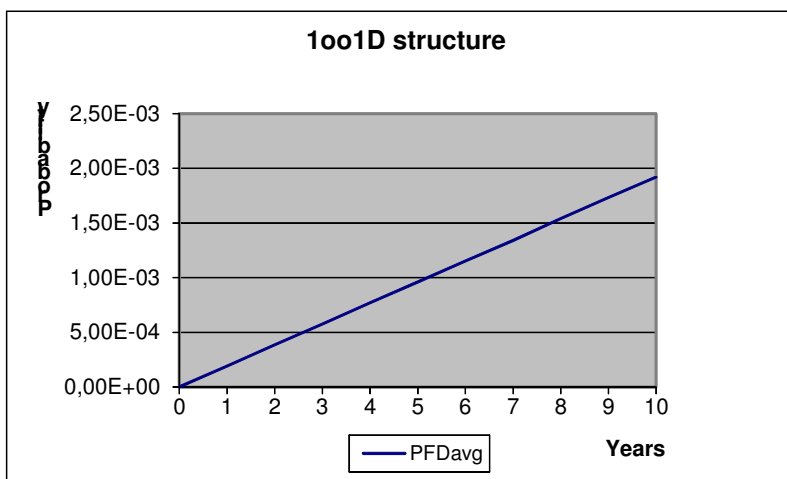


Figure 5: PFD_{AVG}(t)



5.2 Analog Signal Transmitters IM35-Ex-Hi/24VDC**

The FMEDA carried out on the Analog Signal Transmitter IM35-22Ex-Hi/24VDC leads under the assumptions described in section 4.2.3 and 5 to the following failure rates:

$\lambda_{sd} = 0,00E-00 \text{ 1/h}$

$\lambda_{su} = 4,60E-09 \text{ 1/h}$

$\lambda_{dd} = 0,00E-00 \text{ 1/h}$

$\lambda_{du} = 4,09E-08 \text{ 1/h}$

$\lambda_{high} = 6,18E-08 \text{ 1/h}$

$\lambda_{low} = 2,53E-07 \text{ 1/h}$

$\lambda_{no \text{ effect}} = 3,25E-07 \text{ 1/h}$

$\lambda_{total} = 6,85E-07 \text{ 1/h}$

$\lambda_{not \text{ part}} = 2,02E-08 \text{ 1/h}$

$MTBF = MTTF + MTTR = 1 / (\lambda_{total} + \lambda_{not \text{ part}}) + 8 \text{ h} = 162 \text{ years}$

Under the assumptions described in section 5 and the definitions given in section 4.1 the following tables show the failure rates according to IEC 61508:

λ_{safe}	$\lambda_{dangerous}$	SFF
583 FIT	103 FIT	85,01%

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

T[Proof] = 1 year	T[Proof] = 5 years	T[Proof] = 10 years
$PFD_{AVG} = 4,50E-04$	$PFD_{AVG} = 2,25E-03$	$PFD_{AVG} = 4,48E-03$

The boxes marked in yellow () mean that the calculated PFD_{AVG} values are within the allowed range for SIL 2 according to table 2 of IEC 61508-1 and table 3.1 of ANSI/ISA-84.01-1996 but do not fulfill the requirement to not claim more than 10% of this range, i.e. to be better than or equal to $1,00E-03$. The boxes marked in green () mean that the calculated PFD_{AVG} values are within the allowed range for SIL 2 according to table 2 of IEC 61508-1 and table 3.1 of ANSI/ISA-84.01-1996 and do fulfill the requirement to not claim more than 10% of this range, i.e. to be better than or equal to $1,00E-03$. Figure 6 shows the time dependent curve of PFD_{AVG} .

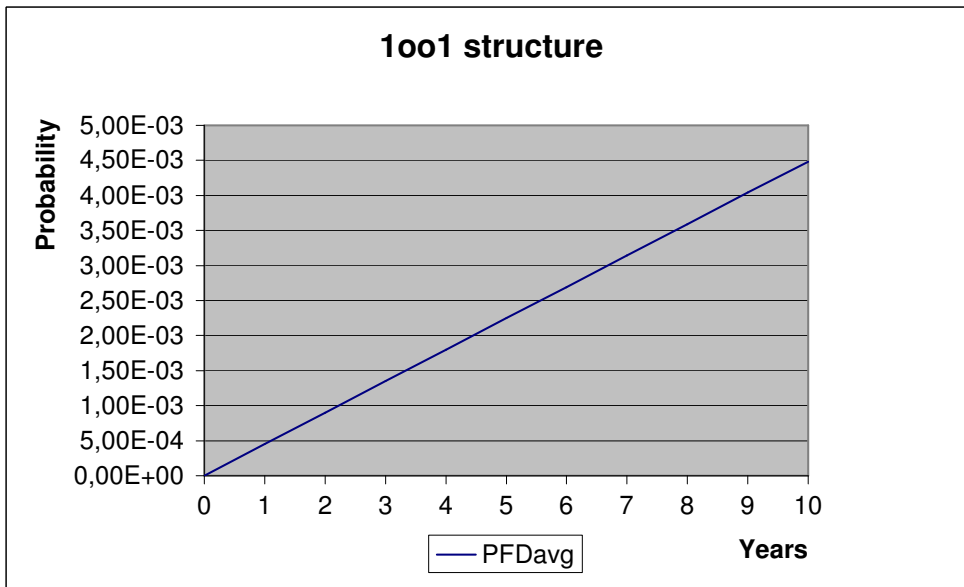


Figure 6: PFD_{AVG}(t)



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 (1×10^{-9} failures per hour)
FMEDA	Failure Modes, Effects, and Diagnostic Analysis
HART	Highway Addressable Remote Transducer
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 component	“Non-complex” component (all failure modes are well defined); for details see 7.4.3.1.2 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 History: V2R0: IM33-11-Hi/24VDC / IM33-22-Hi/24VDC added; February 8, 2013
V1, R1.0: Review comments integrated; November 15, 2004
V0, R1.0: Initial version; October 27, 2004
Authors: Stephan Aschenbrenner
Review: V0, R1.0: Rachel Amkreutz (*exida.com*); October 29, 2004
Release status: Released to Werner Turck GmbH & Co. KG

7.3 Release Signatures

A handwritten signature in black ink, appearing to read "S. Aschenbrenner", written over a horizontal line.

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

A handwritten signature in black ink, appearing to read "R. Faller", written over a horizontal line.

Dipl.-Ing. (Univ.) Rainer Faller, Principal 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 7 and Table 8 show a sensitivity 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 7: Sensitivity Analysis of dangerous undetected faults of IM33-(Ex)-Hi/24VDC**

Component	% of total λ_{du}	Detection through
T8	24,11%	100% functional test with monitoring of the expected output signal
IC6	8,44%	100% functional test with monitoring of the expected output signal
IC3	4,82%	100% functional test with monitoring of the expected output signal
IC4	4,82%	100% functional test with monitoring of the expected output signal
IC8	4,82%	100% functional test with monitoring of the expected output signal
IC13	4,82%	100% functional test with monitoring of the expected output signal
IC2	4,34%	100% functional test with monitoring of the expected output signal
IC9	2,89%	100% functional test with monitoring of the expected output signal
IC7	2,89%	100% functional test with monitoring of the expected output signal
C23	2,41%	100% functional test with monitoring of the expected output signal



Table 8: Sensitivity Analysis of dangerous undetected faults of IM35-**Ex-Hi/24VDC

Component	% of total λ_{du}	Detection through
T1	25,99%	100% functional test with monitoring of the expected output signal
C25	7,80%	100% functional test with monitoring of the expected output signal
IC4	5,20%	100% functional test with monitoring of the expected output signal
IC5	5,20%	100% functional test with monitoring of the expected output signal
IC8	5,20%	100% functional test with monitoring of the expected output signal
IC13	5,20%	100% functional test with monitoring of the expected output signal
IC3	4,68%	100% functional test with monitoring of the expected output signal
IC10	3,12%	100% functional test with monitoring of the expected output signal
IC7	3,12%	100% functional test with monitoring of the expected output signal
C67	2,60%	100% functional test with monitoring of the expected output signal



Appendix 1.1: Possible proof tests to detect dangerous undetected faults

Isolating Transducers

Proof test 1 consists of the following steps, as described in Table 9.

Table 9 Steps for Proof Test 1

Step	Action
1	Bypass the safety PLC or take other appropriate action to avoid a false trip
2	Send a HART command to the Isolating Transducers to go to the high alarm current output and verify that the analog current reaches that value. This tests for compliance voltage problems such as a low loop power supply voltage or increased wiring resistance. This also tests for other possible failures.
3	Send a HART command to the Isolating Transducers to go to the low alarm current output and verify that the analog current reaches that value. This tests for possible quiescent current related failures
4	Restore the loop to full operation
5	Remove the bypass from the safety PLC or otherwise restore normal operation

This test will detect approximately 50% of possible “du” failures in the Isolating Transducers.

Proof test 2 consists of the following steps, as described in Table 10.

Table 10 Steps for Proof Test 2

Step	Action
1	Bypass the safety PLC or take other appropriate action to avoid a false trip
2	Perform Proof Test 1
3	Perform a two-point calibration of the connected transmitter This requires that the transmitter has already been tested without the Isolating Transducers and does not contain any dangerous undetected faults anymore.
4	Restore the loop to full operation
5	Remove the bypass from the safety PLC or otherwise restore normal operation

This test will detect approximately 99% of possible “du” failures in the Isolating Transducers.



Analog Signal Transmitter

Proof test 1 consists of the following steps, as described in Table 9.

Table 11 Steps for Proof Test 1

Step	Action
1	Take appropriate action to avoid a false trip
2	Provide a 4mA control signal to the Analog Signal Transmitter to open/close the valve and verify that the valve is open/closed. This tests for compliance voltage problems such as a low loop power supply voltage or increased wiring resistance. This also tests for other possible failures. It requires, however, that the valve has already been tested without the Analog Signal Transmitter and does not contain any dangerous undetected faults anymore.
3	Restore the loop to full operation
4	Restore normal operation

This test will detect approximately 70% of possible “du” failures in the Analog Signal Transmitter.

Proof test 2 consists of the following steps, as described in Table 10.

Table 12 Steps for Proof Test 2

Step	Action
1	Take appropriate action to avoid a false trip
2	Perform Proof Test 1
3	Provide a 4..20 mA control signal in steps of 1 mA to the Analog Signal Transmitter to open/close the valve and verify that the valve opens/closes accordingly. This requires that the valve has already been tested without the repeater and does not contain any dangerous undetected faults anymore.
4	Restore the loop to full operation
5	Restore normal operation

This test will detect approximately 95% of possible “du” failures in the Analog Signal Transmitter.



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

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 of components is not exceeded. Beyond their useful lifetime, the result of the probabilistic calculation method is 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, electrolyte 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.

Table 13 shows which components are contributing to the dangerous undetected failure rate and therefore to the PFD_{AVG} calculation and what their estimated useful lifetime is.

Table 13: Useful lifetime of components contributing to λ_{du}

Type	Name	Useful life
Capacitor (electrolytic) - Tantalum electrolytic, solid electrolyte	C38 (IM33-**(Ex)-Hi/24VDC)	Appr. 500 000 hours

As there are no aluminium electrolytic capacitors used the only limiting factor are the Tantalum electrolytic capacitors with regard to the useful lifetime of the system, which have a useful lifetime of about 57 years.

However, according to section 7.4.7.4 of IEC 61508-2, a useful lifetime, based on experience, should be assumed. According to section 7.4.7.4 note 3 of IEC 61508-2 experience has shown that the useful lifetime often lies within a range of 8 to 12 years.

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