



## **Failure Modes, Effects and Diagnostic Analysis**

Project:

Temperature transmitters TSP\*\*\*, TT\*200-\*H and TT\*3\*0-\*H  
with 4..20 mA output

Customer:

**ABB Automation Products GmbH**  
Alzenau  
Germany

Contract No.: ABB 06/05-29

Report No.: ABB 06/05-29 R029

Version V2, Revision R0; November 2009

Stephan Aschenbrenner, Alexander Dimov

## Management summary for TT\*200-\*H and TT\*3\*0-\*H, 4..20 mA output

This report summarizes the results of the hardware assessment according to IEC 61508 carried out on the temperature transmitters TT\*200-\*H and TT\*3\*0-\*H with 4..20 mA output.

The temperature transmitter TT\*200-\*H is a configurable single sensor channel (1 x RTD 2/3/4 wire, 1 x TE, 1 x mV ) analog 4..20mA device.

The temperature transmitter TT\*3\*0-\*H is a configurable single or dual sensor channel (1 or 2 x RTD 2/3/4 wire, 2 x TE, 2 x mV, 1 x RTD 2/3 and 1 x TE / mV) analog 4..20mA device output.

Table 1 gives an overview of the different types that belong to the considered temperature transmitters including hardware and software version

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	HW Version	SW Version
TTH200-*H	Head mounted temperature transmitter	1.06	1.00.06
TTR200-*H	Rail mounted temperature transmitter	1.01	1.00.06
TTH300-*H	Head mounted temperature transmitter	1.06	1.01.07
TTR300-*H	Rail mounted temperature transmitter	1.01	1.01.07
TTF300-*H	Field mounted temperature transmitter	1.06	1.01.07
TTF350-*H	Field mounted temperature transmitter	1.06	1.01.07

For safety applications only the 4..20 mA output was considered. All other possible output variants or electronics are not covered by this report.

The failure rates of the electronic components 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  $\geq 1,00E-03$  to  $< 1,00E-02$  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 35% of the total SIF  $PFD_{AVG}$  value is caused by the sensor part.

For a SIL 2 application operating in low demand mode the total  $PFD_{AVG}$  value of the SIF should be smaller than  $1,00E-02$ , hence the maximum allowable  $PFD_{AVG}$  value for the sensor part would then be  $3,50E-03$ .

The temperature transmitters TT\*200-\*H and TT\*3\*0-\*H with 4..20 mA output are considered to be Type B<sup>1</sup> subsystems with a hardware fault tolerance of 0.

The failure rates do not include failures resulting from incorrect use of the temperature transmitters TT\*200-\*H and TT\*3\*0-\*H with 4..20 mA output, in particular humidity entering through incompletely closed housings or inadequate cable feeding through the inlets.

<sup>1</sup> Type B subsystem: "Complex" subsystem (using micro controllers or programmable logic); for details see 7.4.3.1.3 of IEC 61508-2.

The listed 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 40°C. For a higher average temperature of 60°C, the failure rates should be multiplied with an experience based factor of 2,5. A similar multiplier should be used if frequent temperature fluctuation must be assumed.

It is assumed that the connected logic solver is configured per the NAMUR NE43 signal ranges, i.e. the temperature transmitters TT\*200-\*H and TT\*3\*0-\*H with 4..20 mA output communicate detected faults by an alarm output current  $\leq 3,6\text{mA}$  or  $\geq 21\text{mA}$ . Assuming that the application program in the safety logic solver does not automatically trip on these failures, these failures have been classified as dangerous detected failures. The following tables show how the above stated requirements are fulfilled.

**Table 2: Failure rates <sup>2</sup>**

Failure category	Failure rates (in FIT)
Fail Dangerous Detected	<b>327</b>
Fail dangerous detected (internal diagnostics or indirectly <sup>3</sup> )	227
Fail high (detected by the logic solver)	23
Fail low (detected by the logic solver)	77
Annunciation detected	0
Fail Dangerous Undetected	<b>41</b>
Fail dangerous undetected	39
Annunciation undetected	2
No Effect	<b>110</b>
Not part	<b>91</b>

**Table 3: IEC 61508 failure rates**

$\lambda_{SD}$	$\lambda_{SU}$ <sup>4</sup>	$\lambda_{DD}$	$\lambda_{DU}$	SFF <sup>5</sup>	DC <sub>s</sub> <sup>6</sup>	DC <sub>D</sub> <sup>8</sup>
0 FIT	110 FIT	327 FIT	41 FIT	91%	0%	88%

**Table 4: PFD<sub>AVG</sub> values**

T[Proof] = 1 year	T[Proof] = 5 years	T[Proof] = 10 years
PFD <sub>AVG</sub> = 1,79E-04	PFD <sub>AVG</sub> = 8,95E-04	PFD <sub>AVG</sub> = 1,79E-03

<sup>2</sup> It is assumed that practical fault insertion tests can demonstrate the correctness of the failure effects assumed during the FMEDAs.

<sup>3</sup> "indirectly" means that these failure are not necessarily detected by diagnostics but lead to either fail low or fail high failures depending on the transmitter setting and are therefore detectable.

<sup>4</sup> Note that the SU category includes failures that do not cause a spurious trip

<sup>5</sup> Note: SFF should be calculated for the sensor subsystem. This SFF is only for reference.

<sup>6</sup> DC means the diagnostic coverage (safe or dangerous) for the temperature transmitters by the safety logic solver.

A complete temperature sensor assembly consisting of the temperature transmitters TT\*200-\*H and TT\*3\*0-\*H and a thermocouple or RTD can be modeled by considering a series subsystem where a failure occurs if there is a failure in either component. For such a system, failure rates are added.

Appendix 3 gives typical failure rates and failure distributions for thermocouples and RTDs which were the basis for the following tables.

Assuming that the temperature transmitter TT\*200-\*H and TT\*3\*0-\*H will go to the pre-defined alarm state on detected failures of the thermocouple or RTD, the failure rate contribution or the  $PFD_{AVG}$  value ( $T[Proof] = 1$  year) for the thermocouple or RTD in a **low stress environment** is as follows:

**Table 5: TT\*200-\*H and TT\*3\*0-\*H with thermocouple (close coupled)**

$\lambda_{SD}$	$\lambda_{SU}$	$\lambda_{DD}$	$\lambda_{DU}$	SFF	$PFD_{AVG}$
0 FIT	110 FIT	422 FIT	46 FIT	92%	2,01E-04

**Table 6: TT\*3\*0-\*H with two thermocouples (close coupled)**

$\lambda_{SD}$	$\lambda_{SU}$	$\lambda_{DD}$	$\lambda_{DU}$	SFF	$PFD_{AVG}$
0 FIT	113 FIT	533 FIT	38 FIT	94%	1,68E-04

**Table 7: TT\*200-\*H and TT\*3\*0-\*H with 2/3-wire RTD (close coupled)**

$\lambda_{SD}$	$\lambda_{SU}$	$\lambda_{DD}$	$\lambda_{DU}$	SFF	$PFD_{AVG}$
0 FIT	110 FIT	366 FIT	50 FIT	90%	2,17E-04

**Table 8: TT\*3\*0-\*H with two 2/3-wire RTDs (close coupled)**

$\lambda_{SD}$	$\lambda_{SU}$	$\lambda_{DD}$	$\lambda_{DU}$	SFF	$PFD_{AVG}$
0 FIT	113 FIT	428 FIT	39 FIT	93%	1,70E-04

**Table 9: TT\*3\*0-\*H with thermocouple and 2/3-wire RTD (close coupled)**

$\lambda_{SD}$	$\lambda_{SU}$	$\lambda_{DD}$	$\lambda_{DU}$	SFF	$PFD_{AVG}$
0 FIT	113 FIT	481 FIT	43 FIT	93%	1,90E-04

**Table 10: TT\*200-\*H and TT\*3\*0-\*H with 4-wire RTD (close coupled)**

$\lambda_{SD}$	$\lambda_{SU}$	$\lambda_{DD}$	$\lambda_{DU}$	SFF	$PFD_{AVG}$
0 FIT	110 FIT	375 FIT	44 FIT	91%	1,90E-04

**Table 11: TT\*200-\*H and TT\*3\*0-\*H with thermocouple (with extension wire)**

$\lambda_{SD}$	$\lambda_{SU}$	$\lambda_{DD}$	$\lambda_{DU}$	SFF	$PFD_{AVG}$
0 FIT	110 FIT	1227 FIT	141 FIT	90%	6,17E-04

**Table 12: TT\*3\*0-\*H with two thermocouples (with extension wire)**

$\lambda_{SD}$	$\lambda_{SU}$	$\lambda_{DD}$	$\lambda_{DU}$	SFF	PFD <sub>AVG</sub>
0 FIT	113 FIT	2323FIT	48 FIT	98%	2,10E-04

**Table 13: TT\*200-\*H and TT\*3\*0-\*H with 2/3-wire RTD (with extension wire)**

$\lambda_{SD}$	$\lambda_{SU}$	$\lambda_{DD}$	$\lambda_{DU}$	SFF	PFD <sub>AVG</sub>
0 FIT	110 FIT	707 FIT	136 FIT	85%	5,95E-04

**Table 14: TT\*3\*0-\*H with two 2/3-wire RTDs (with extension wire)**

$\lambda_{SD}$	$\lambda_{SU}$	$\lambda_{DD}$	$\lambda_{DU}$	SFF	PFD <sub>AVG</sub>
0 FIT	113 FIT	1274 FIT	47 FIT	96%	2,08E-04

**Table 15: TT\*3\*0-\*H with thermocouple and 2/3-wire RTD (with extension wire)**

$\lambda_{SD}$	$\lambda_{SU}$	$\lambda_{DD}$	$\lambda_{DU}$	SFF	PFD <sub>AVG</sub>
0 FIT	113 FIT	1799 FIT	48 FIT	97%	2,09E-04

**Table 16: TT\*200-\*H and TT\*3\*0-\*H with 4-wire RTD (with extension wire)**

$\lambda_{SD}$	$\lambda_{SU}$	$\lambda_{DD}$	$\lambda_{DU}$	SFF	PFD <sub>AVG</sub>
0 FIT	110 FIT	822 FIT	46 FIT	95%	2,01E-04

Assuming that the temperature transmitters TT\*200-\*H and TT\*3\*0-\*H will go to the pre-defined alarm state on detected failures of the thermocouple or RTD, the failure rate contribution or the PFD<sub>AVG</sub> value (T[Proof] = 1 year) for the thermocouple or RTD in a **high stress environment** is as follows:

**Table 17: TT\*200-\*H and TT\*3\*0-\*H with thermocouple (close coupled)**

$\lambda_{SD}$	$\lambda_{SU}$	$\lambda_{DD}$	$\lambda_{DU}$	SFF	PFD <sub>AVG</sub>
0 FIT	110 FIT	2227 FIT	141 FIT	94%	6,17E-04

**Table 18: TT\*3\*0-\*H with two thermocouples (close coupled)**

$\lambda_{SD}$	$\lambda_{SU}$	$\lambda_{DD}$	$\lambda_{DU}$	SFF	PFD <sub>AVG</sub>
0 FIT	113 FIT	4323 FIT	48 FIT	98%	2,10E-04

**Table 19: TT\*200-\*H and TT\*3\*0-\*H with 2/3-wire RTD (close coupled)**

$\lambda_{SD}$	$\lambda_{SU}$	$\lambda_{DD}$	$\lambda_{DU}$	SFF	PFD <sub>AVG</sub>
0 FIT	110 FIT	1114 FIT	214 FIT	85%	9,36E-04

**Table 20: TT\*3\*0-\*H with two 2/3-wire RTDs (close coupled)**

$\lambda_{SD}$	$\lambda_{SU}$	$\lambda_{DD}$	$\lambda_{DU}$	SFF	PFD <sub>AVG</sub>
0 FIT	113 FIT	2236 FIT	55 FIT	97%	2,42E-04

**Table 21: TT\*3\*0-\*H with thermocouple and 2/3-wire RTD (close coupled)**

$\lambda_{SD}$	$\lambda_{SU}$	$\lambda_{DD}$	$\lambda_{DU}$	SFF	PFD <sub>AVG</sub>
0 FIT	113 FIT	3280 FIT	146 FIT	95%	6,38E-04

**Table 22: TT\*200-\*H and TT\*3\*0-\*H with 4-wire RTD (close coupled)**

$\lambda_{SD}$	$\lambda_{SU}$	$\lambda_{DD}$	$\lambda_{DU}$	SFF	PFD <sub>AVG</sub>
0 FIT	110 FIT	1277 FIT	91 FIT	93%	3,98E-04

**Table 23: TT\*200-\*H and TT\*3\*0-\*H with thermocouple (with extension wire)**

$\lambda_{SD}$	$\lambda_{SU}$	$\lambda_{DD}$	$\lambda_{DU}$	SFF	PFD <sub>AVG</sub>
0 FIT	110 FIT	18327 FIT	2041 FIT	90%	8,94E-03

**Table 24: TT\*3\*0-\*H with two thermocouples (with extension wire)**

$\lambda_{SD}$	$\lambda_{SU}$	$\lambda_{DD}$	$\lambda_{DU}$	SFF	PFD <sub>AVG</sub>
0 FIT	113 FIT	40133 FIT	238 FIT	99%	1,04E-03

**Table 25: TT\*200-\*H and TT\*3\*0-\*H with 2/3-wire RTD (with extension wire)**

$\lambda_{SD}$	$\lambda_{SU}$	$\lambda_{DD}$	$\lambda_{DU}$	SFF	PFD <sub>AVG</sub>
0 FIT	110 FIT	7927FIT	1941 FIT	80%	8,50E-03

**Table 26: TT\*3\*0-\*H with two 2/3-wire RTDs (with extension wire)**

$\lambda_{SD}$	$\lambda_{SU}$	$\lambda_{DD}$	$\lambda_{DU}$	SFF	PFD <sub>AVG</sub>
0 FIT	113 FIT	19143 FIT	228 FIT	98%	9,98E-04

**Table 27: TT\*3\*0-\*H with thermocouple and 2/3-wire RTD (with extension wire)**

$\lambda_{SD}$	$\lambda_{SU}$	$\lambda_{DD}$	$\lambda_{DU}$	SFF	PFD <sub>AVG</sub>
0 FIT	113 FIT	29638 FIT	233 FIT	99%	1,02E-03

**Table 28: TT\*200-\*H and TT\*3\*0-\*H with 4-wire RTD (with extension wire)**

$\lambda_{SD}$	$\lambda_{SU}$	$\lambda_{DD}$	$\lambda_{DU}$	SFF	PFD <sub>AVG</sub>
0 FIT	110 FIT	10227 FIT	141 FIT	98%	6,17E-04

The boxes marked in yellow (■) mean that the calculated PFD<sub>AVG</sub> 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 35% of this range, i.e. to be better than or equal to 3,50E-03. The boxes marked in green (■) mean that the calculated PFD<sub>AVG</sub> values are within the allowed range for SIL 2 according to table 2 of IEC 61508-1 and do fulfill the requirement to not claim more than 35% of this range, i.e. to be better than or equal to 3,50E-03.



A user of the temperature transmitters TT\*200-\*H and TT\*3\*0-\*H with 4..20 mA output 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 section 5.1 along with all assumptions.

It is important to realize that the “no effect” failures are included in the “safe undetected” failure category according to IEC 61508, Edition 2000. Note that these failures on its own will not affect system reliability or safety, and should not be included in spurious trip calculations.

The failure rates are valid for the useful life of the temperature transmitters TT\*200-\*H and TT\*3\*0-\*H with 4..20 mA output (see Appendix 2).