UM1741
User manual

STM32F0 series safety manual

Introduction

This document describes how to use the microcontrollers of STM32F0 series in the context of a safety-related system, specifying the user's responsibilities for installation and operation in order to reach the targeted safety integrity level.

This manual applies to the microcontrollers of the STM32F0 series and to STM32-SafeSIL part number.

If the STM32F0 series microcontrollers are used in adherence to this manual, system designers can avoid going into the details of the functional safety design and validation to give an estimation about the impact to the overall safety function.

This manual is written in compliance with IEC 61508. It indicates how to use the STM32F0 series microcontrollers in the context of other functional safety standards such as safety machine directives ISO 13849. This manual and FMEDA data were developed in cooperation with the safety expertise company YOGITECH using their faultRobust Methodology (fRMethodology).

The safety analysis summarized in this manual takes into account the variation in terms of memory size, internal peripheral number and presence and package between the different part numbers of the ARM® Cortex®-M0 based STM32F0 series microcontrollers.

This manual has to be read along with the technical documentation on related part numbers (such as Reference Manuals and Datasheets) available on *www.st.com*.

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1 About this document

1.1 Purpose and scope

This document describes how to use the STM32F0 series microcontrollers in the context of a safety-related system, specifying the user's responsibilities for installation and operation, in order to reach the desired safety integrity level.

This document is useful to system designers willing evaluate the safety of their solution.

1.2 Terms and abbreviations

Table 1. Terms and abbreviations

Acronym	Definition
ADAS	Advanced Driver Assistance System
CCF	Common Cause Failure
CM	Continuous Mode
COTS	Commercial Off-the-Shelf
CoU	Conditions of Use
CPU	Central Processing Unit
CRC	Cyclic Redundancy Check
DC	Diagnostic Coverage
DMA	Direct Memory Access
DTI	Diagnostic Test Interval
ECM	Engine Control Module
ECU	Electronic Control Unit
EHSR	Essential Health and Safety Requirement
EUC	Equipment Under Control
FE	Final Element (that is generalized actuator)
FIT	Failure In Time
FMEA	Failure Mode Effect Analysis
FMEDA	Failure Mode Effect Diagnostic Analysis
FPU	Floating Processing Unit
HD	High Demand
HFT	Hardware Fault Tolerance
HW	Hardware
INTC	Interrupt Controller
ITRS	International Technology Roadmap for Semiconductors
LD	Low Demand

Table 1. Terms and abbreviations (continued)

Acronym	Definition
MCU	Microcontroller Unit
MTBF	Mean Time Between Failure
MTTFd	Mean Time to Failure
OC	Output Circuit
PDS(SR)	Power Drive System (Safety Related)
PEc	Programmable Electronics - core
PEd	Programmable Electronics - diagnostic
PFH	Probability of Failure per Hour
PL	Performance Level
PST	Process Safety Time
SE	Sensor Element
SFF	Safe Failure Fraction
SIL	Safety Integrity level
SRCF	Safety-Related Control Function
SRECS	Safety-Related Electrical Control Systems
SRP/CS	Safety-Related Parts of Control Systems
SW	Software

1.3 Reference normative

This document is written in compliance with the IEC 61508 international norm for functional safety of electrical/electronic/programmable electronic safety-related systems.

The version used as reference is IEC 61508:1-7 © IEC:2010.

The other functional safety standards considered in this manual are the following:

- ISO 26262-1, 2, 3, 4, 5, 6, 7, 8, 9: 2011(E) / ISO 26262-10: 2012(E),
- ISO 13849-1:2006 / ISO 13849-2:2010,
- IEC 62061:2012-11, ed. 1.1,
- IEC 61800-5-2:2007, ed.1.0,
- IEC 60730-1:2010, ed. 4.0.

Table 2 reports the mapping of this document content with respect to the requirements listed in the IEC 61508-2 Annex D.

Table 2. Mapping between this document content and IEC 61508-2 Annex D requirements

IEC 61508 requirement (part 2 annex D)	Reference
D2.1 a) a functional specification of the functions capable of being performed	*Section 3*
D2.1 b) identification of the hardware and/or software configuration of the compliant item	*Section 3.2*
D2.1 c) constraints on the use of the compliant item and/or assumptions on which analysis of the behavior or failure rates of the item are based	*Section 3.2*
D2.2 a) the failure modes of the compliant item due to random hardware failures, that result in a failure of the function and that are not detected by diagnostics internal to the compliant item;	*Section 3.7*
D2.2 b) for every failure mode in a), an estimated failure rate;	
D2.2 c) the failure modes of the compliant item due to random hardware failures, that result in a failure of the function and that are detected by diagnostics internal to the compliant item;	
D2.2 d) the failure modes of the diagnostics, internal to the compliant item due to random hardware failures, that result in a failure of the diagnostics to detect failures of the function;	
D2.2 e) for every failure mode in c) and d), the estimated failure rate;	
D2.2 f) for every failure mode in c) that is detected by diagnostics internal to the compliant item, the diagnostic test interval;	*Section 3.2.2*
D2.2 g) for every failure mode in c) the outputs of the compliant item initiated by the internal diagnostics;	*Appendix B*
D2.2 h) any periodic proof test and/or maintenance requirements;	*Section 3.7*
D2.2 i) for those failure modes, in respect of a specified function, that are capable of being detected by external diagnostics, sufficient information shall be provided to facilitate the development of an external diagnostics capability.	
D2.2 j) the hardware fault tolerance;	*Section 3*
D2.2 k) the classification as type A or type B of that part of the compliant item that provides the function (see 7.4.4.1.2 and 7.4.4.1.3);	

The safe failure fraction reported in this manual has been computed under the assumptions described in this document and especially according to the conditions of use described in *Section 3.7: Conditions of use*.

2 STM32F0 series microcontroller development process

The development process of a microelectronic device that is used in safety critical application takes into account the adequate management to reduce the probability of systematic faults introduced during the design phase.

IEC 61508:2 in Annex F (Techniques and measures for ASICs - avoidance of systematic failures) act as a guidance in tailoring the microcontroller standard design and manufacturer process to the compliance of the IEC 61508 requirements. The checklist reported in the named Annex F helps to collect all related evidences of a given real process.

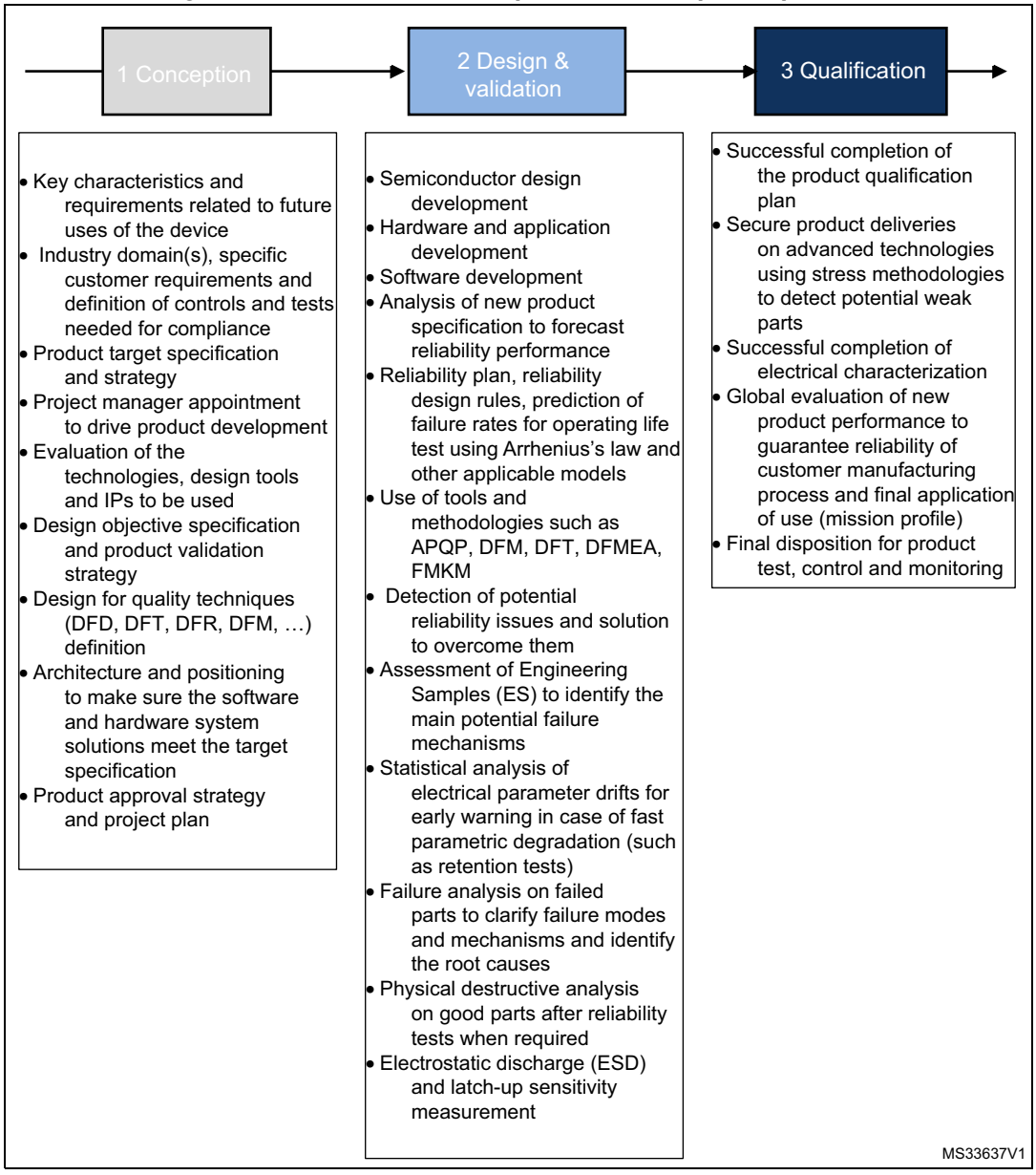
2.1 STMicroelectronics standard development process

STMicroelectronics (ST) serves four industry domains:

1. Standard products,
2. Automotive products: ST automotive products are AEC-Q100 compliant. They are subject to specific stress testing and processing instructions in order to achieve the required quality levels and product stability.
3. Automotive safety: a subset of the automotive domain. ST uses as a reference the ISO 26262 Road vehicles Functional safety standard. ST supports customer inquiries regarding product failure rates and FMEDA to support hardware system compliance to established safety goals. ST provides products that are safe in their intended use, working in cooperation with customers to understand the mission profile, adopt common methods and define countermeasures for residual risks.
4. Medical products: ST complies with applicable regulations for medical products and applies due diligence in the development and validation of these products.

STMicroelectronics product development process, compliant with the ISO/TS 16949 standard, is a set of interrelated activities dedicated to transform customer specification and market or industry domain requirements into a semiconductor device and all its associated elements (package, module, sub-system, application, hardware, software and documentation), qualified respecting ST internal procedures and able to be manufactured using ST internal or subcontracted technologies.

Figure 1. STMicroelectronics product development process



2.2 Yogitech fRMethodology process

Yogitech fRMethodology is the “white-box” approach for safety design exploration proprietary of Yogitech, including tools and methodology to FMEA/FTA analysis and fault injection of integrated circuits. *Appendix A: Overview of fRMethodology* reports additional informations.

Yogitech contribution to IEC 61508 compliance of STMicroelectronics development process can be summarized in these key elements:

- Failure rate estimation based on multiple industry standards as well as STMicroelectronics manufacturing data,
- Application of Yogitech fault injection techniques/tools to validate the safety metrics claimed for STMicroelectronics devices belonging to STM32 program.

3 Reference safety architecture

3.1 Introduction

The STM32F0 series microcontrollers described in this document is a Safety Element out of Context (SEooC), that is, the intent is to describe a compliant item that can be used within different safety applications.

The aim of this section is to identify such compliant item and therefore to define the context of the analysis in terms of assumptions with respect to a reference concept definition, that is with respect to reference safety requirements as also assumptions with respect to the design external to that compliant item.

As a consequence of the SEooC approach, the goal is not to provide an exhaustive hazard and risk analysis of the system around the microcontroller, but rather to list the system-related information - such as the application-related assumptions for dangerousness factors, frequency of failures and diagnostic coverage already guaranteed by the application - that have been considered during the following steps of the analysis.

Additional details on the reference safety architecture are given in *Appendix B: Examples of safety architectures – Informative*.

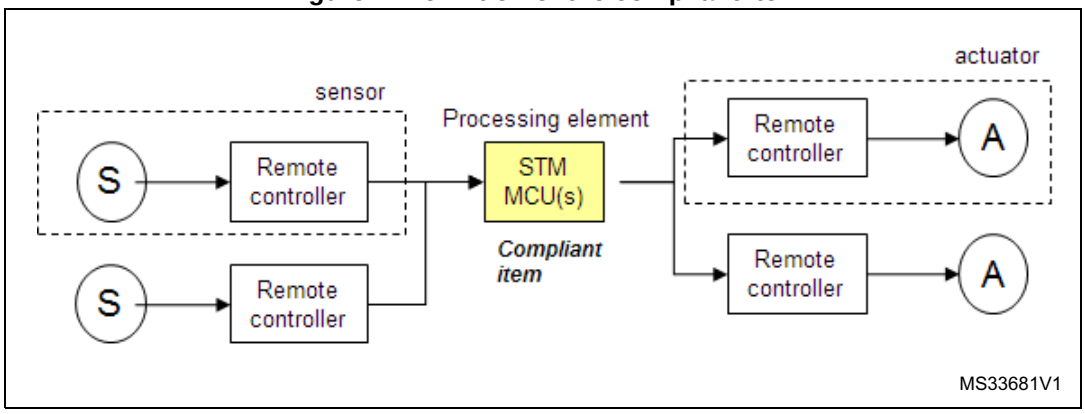
3.2 Compliant item

3.2.1 Definition of the compliant item

According to IEC 61508:1 clause 8.2.12, a compliant item is any item (for example an element) on which a claim is being made with respect to the clauses of IEC 61508 series. With respect to its user, at the end of its development the compliant item shall be described by a safety manual.

In this document, the compliant item is defined as a system including one or two STM32 microcontrollers (MCU) (see *Figure 2*). The communication bus is directly or indirectly connected to sensors and actuators.

Figure 2. Definition of the compliant item



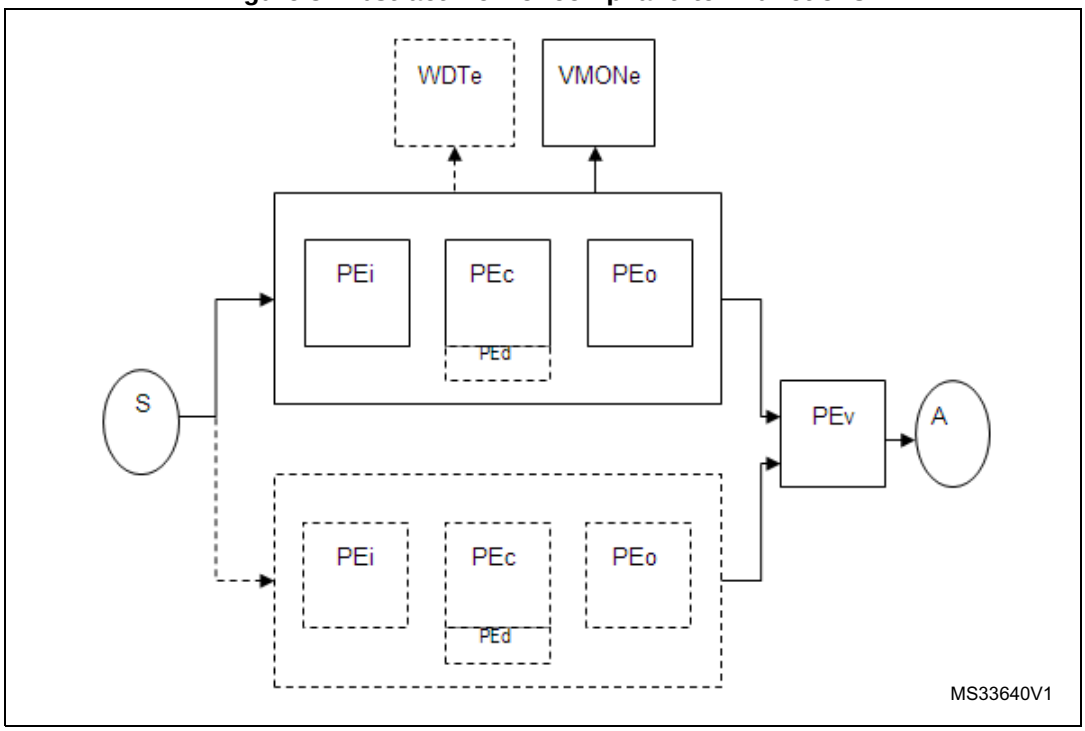
Other components might be related to the compliant item, like the external HW components needed to guarantee either the functionality of the STM32F0 (external memory, clock quartz etc) or its safety (for example the external watchdog, voltage supervisors).

3.2.2 Safety functions performed by the compliant item

In essence, the compliant item architecture can be represented as composed by the following processes performing the safety function or part of it:

- Input processing elements (PEi) reading safety related data from the remote controller connected to the sensor(s) and transferring them to the following computation elements;
- Computation processing elements (PEc) performing the algorithm required by the safety function and transferring the results to the following output elements;
- Output processing elements (PEo) transferring safety related data to the remote controller connected to the actuator;
- in the case of the 1oo2, 1oo2d or 2oo2 architecture (see *Appendix B: Examples of safety architectures – Informative*), a further voting processing element (PEv) can be present;
- in the 1oo2d case (see again *Appendix B: Examples of safety architectures – Informative*), the abstract view is the same as 1oo2 but with the addition of diagnostic processing elements (PEd), having the role of performing cross-diagnostic functions and contributing to the decision of the voter PEv;
- processes external to the compliant item are considered to guarantee functional safety, such as a watchdog (WDTe) and voltage monitors (VMONe).

Figure 3. Abstract view of compliant item functions



The role of the PEv and of the external processes WDTe and VMONe is clarified in the sections where the CoU (definition of safety mechanism) are detailed:

- WDTe: refer to *Independent watchdog – VSUP_SM_2*, *Control flow monitoring in application software – CPU_SM_1*,
- VMONe: refer to *Supply Voltage Monitoring – VSUP_SM_1*.

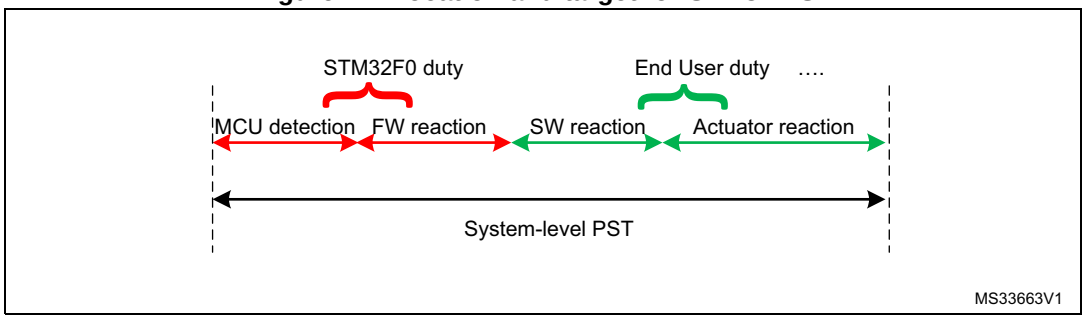
3.3 Assumed requirements

3.3.1 Assumed safety requirements

It is assumed that the concept specification, the hazard and risk analysis, the overall safety requirement specification and the consequent allocation has determined the following requirements for the compliant item (assumed safety requirements):

- The compliant item can be used for four kinds of safety functions:
  - A continuous mode / high-demand SIL3 safety function (CM3), or
  - A low-demand SIL3 safety function (LD3), or
  - A continuous mode / high-demand SIL2 safety function (CM2), or
  - A low-demand SIL2 safety function (LD2).
- The compliant item is used in a safety function with a worst case budget of 10 ms for the STM32 MCU to detect and react to a failure, which corresponds to the portion of the Process Safety Time[a] allocated to the STM32F0 MCU ("STM32F0 duty" in *Figure 4*)

Figure 4. Allocation and target for STM32 PST



- The compliant item is used in a safety function powered-on for a long time. It is assumed to not require any proof test and the lifetime of the product is considered to be not less than 10 years.
- The safe state of the compliant item is the one in which either:
  - the operating system (OS) is informed by the presence of a fault and a reaction is possible, or
  - if the OS cannot be informed or the OS is not able to execute a reaction[b]:

    in case of a 1oo2 or 1oo2D architecture, the PEv shall be directly informed so that the PEv itself is able to achieve or maintain the safe state of the system or,

    in case of 1oo1 and 1oo2/1oo2D high demand or continuous mode architectures, the safe state of the electronic system is "de-energize".
- The compliant item is assumed to be analyzed according to routes 1H and 1S of IEC 61508:2.

a. As explained in the following section, for the HFT=1 computations the value of the process safety time is not as stringent as it is for HFT=0 architectures (that is clarified further in the document).

b. The end user shall take into account that hardware random failures affecting the STM32 can compromise the MCU capability of operating properly (for example failure modes affecting the program counter prevent the correct execution of software).

The base assumptions about the de-energize state and the repair conditions, in the computation of the PFD/PFH, are as follows;

- In the 1oo1 mode:
  - The system is de-energized as soon as a fault is identified by the HW or SW diagnostics.
  - If the fault has been identified as a transient fault, the compliant item can be reset and the safety function can continue after reset.
  - If the fault has been identified as a permanent fault or if it has not been identified, the compliant item is assumed to be kept de-energized.
- In the 1oo2 / 1oo2D low-demand modes:
  - The 1oo2 system is NOT de-energized if a fault is identified in one of the two channels.
  - The faulty compliant item can be repaired, that is the faulty STM32F0 MCU can be replaced or one of the external components might be replaced.
- In the 1oo2 / 1oo2D high-demand or continuous modes:
  - The system is de-energized as soon as a fault is identified in one of the two channels or in the shared logic.
  - If the fault has been identified as a transient fault, the compliant item can be reset and the safety function can continue after reset.
  - If the fault has been identified as a permanent fault or if it has not been identified, the compliant item is assumed to be kept de-energized, and the compliant item cannot be repaired, that is the faulty STM32F0 MCU cannot be replaced or one of the external components cannot be replaced.

3.4 Electrical specifications and environment limits

The user must not exceed the electrical specification and the environmental limits defined in the below list as reported in the STM32F0 user manual in order to guarantee the STM32F0 safety integrity:

- Absolute maximum rating,
- Capacity,
- Operating conditions.

Due to the large number of STM32F0 part numbers, the related user manuals/datasheets are not listed in this document; users are responsible to carefully check the above reported limits in the technical documentation on the related part number available on *www.st.com*.

3.5 Systematic safety integrity

According to the requirements of IEC 61508 -2, 7.4.2.2, the Route 1s has been considered in the STM32F0 development and the techniques and measures given in IEC 61508-2 Annex F have been applied. The Safety Case Database (*Section 5: List of evidences*) maintains the evidences of the compliance to the norm.

3.6 Description of hardware and software diagnostics

This section lists all the safety mechanisms (hardware, software and application level) considered in the safety analysis of the microcontrollers of the STM32F0 series. It is expected that users are familiar with the STM32F0 architecture, and that this document is used in conjunction with the related device datasheet, user manual and reference information. Therefore, to avoid the eventuality of mistakes and reduce the amount of informations to be shown, no functional details are included in this document.

Note that the part numbers of the STM32F0 series represent different combinations of peripherals (for instance, some of them are not equipped with USB peripheral). To reduce the number of documents and avoid information-less repetitions, the current safety manual (and therefore this section) addresses the overall possible peripherals available in the targeted part numbers. Users have to select which peripherals are really available on their devices, and discard the meaningless recommendations accordingly.

The implementation guidelines reported in the following section are for reference only. The safety verification executed by Yogitech and related coverage figures reported in this manual are based on such guidelines.

Please read the following definitions:

- **end user:** the final user of STM32F0 that is in charge of integrating the MCU in a real application (for example an electronic control board).
- **application software**: the real software that runs on the STM32F0 and that is used to implement the safety function.

3.6.1 Cortex®-M0 CPU

Periodical core self test software - CPU_SM_0

Permanent faults affecting the CPU Core ARM® Cortex®-M0 are addressed through a dedicated software test executing a sequence of instructions and data transfers.

The software test is built around well-known techniques already addressed by IEC 61508:7, A.3.2 (Self-test by software: walking bit one-channel). A detailed safety analysis has shown that a self-test software based only on software testing operation is not able to reach the required values of coverage due to the complexity of the CPU. Therefore, in order to reach the required values of coverage, the self-test software has to be specified by means of a detailed analysis of all the CPU failure modes and related failure modes distribution. Moreover, it has to be verified by means of fault injection (according to ISO 26262:10, Annex A - the state of the art in terms of safety analysis applied to integrated circuits - fault injection is the recommended method for the verification of failure modes coverage in modern and complex microprocessor like Cortex®-M0).

The overall test software suite is assumed to be periodically executed with a time period compatible with the IEC 61508 requirements for the relationship between PST and the diagnostic test interval.

Control flow monitoring in application software – CPU_SM_1

A significant part of the failure distribution of ARM® Cortex®-M0 core for permanent faults is related to failure modes directly related to program counter loss of control or hang-up. Due to their intrinsic nature, such failure modes are not addressed by a standard software test method based on the execution of sequences of instruction/data access and consequent checks. Therefore it is necessary to implement a run-time control of the application software flow, in order to monitor and detect deviation from the expected behavior due to such faults. Linking this mechanism to watchdog firing assures that severe loss of control (or, in the worst case, a program counter hang-up) will be detected within DTI.

This diagnostic measure also contributes to the transient fault detection affecting the program counter and branch execution subpart in ARM® Cortex®-M0.

The guidelines for the implementation of the method are the following:

- The different internal states of the application software is well documented and described (the use of a dynamic state transition graph is encouraged).
- The monitoring of the correctness of each transition between different states of the application software is implemented.
- The transition through all expected states during the normal application software program loop is checked.
- The function in charge of triggering the system watchdog is implemented in order to constrain the triggering (preventing the watchdog reset) also to the correct execution of the above-described method for program flow monitoring.

The use of the window feature of the independent watchdog (IWDG) (or an external one) helps to implement a more robust control flow mechanism fed by a different clock source. In any case the safety metrics do not depend on the watchdog in use (the adoption of independent or external watchdog contributes to the mitigation of dependent failures, see *Section 4.2.2: Clock*).

Double computation in application software – CPU_SM_2

A timing redundancy for safety-related computation is considered to detect transient faults affecting the ARM® Cortex®-M0 CPU subparts devoted to mathematical computations and data access.

The guidelines for the implementation of the method are the following:

- The requirement needs be applied only to safety-relevant computation, that is to the computations that in case of wrong result could interfere with the system safety

functions. Such computation shall be therefore carefully identified in the original application software source code.

- Both mathematical operation and comparison are intended as computation.
- The redundant computation for comparison could be implemented according to the following template:
  - Original code:

```
If (VarA > VarB) then { ( execute function) }
```

  - Modified code:

```
copyVarA:=VarA;
copyVarB:=VarB;
If (VarA > VarB) then {
If (copyVarA <= copyVarB) then { (signal_error);  break }
( execute function)
}
```

- The redundant computation for mathematical computation is implemented by using copies of the original data for second computation, and by using an equivalent formula if possible.
- End users are responsible to carefully avoid that the intervention of optimization features of the used compiler removes the timing redundancy introduced according to this current condition of use.

ARM® Cortex®-M0 HardFault exceptions – CPU_SM_3

HardFault exception raise is an intrinsic safety mechanism implemented in ARM® Cortex®-M0 core, mainly devoted to intercept systematic faults due to software limitations and/or error in software design, leading for example to execution of undefined operations, unaligned address access. This safety mechanism is therefore able to detect hardware random faults inside the CPU bringing to such described abnormal operations.

Stack hardening for application software – CPU_SM_4

The stack hardening method is required to address faults affecting the CPU register bank. This method is based on source code modification, introducing information redundancy in register-passed information to the called functions.

The guidelines for the implementation of the method are the following:

- Pass also the redundant copy of the passed parameters values (possibly inverted) and execute a coherence check in the function.
- Pass also the redundant copy of the passed pointers and execute a coherence check in the function.
- For the parameters that are not protected by redundancy, implement defensive programming techniques (plausibility check of passed values). For example enumerated fields are to be checked for consistency.

External watchdog – CPU_SM_5

Using an external watchdog for the control flow monitoring method (CPU_SM_1) contributes to further reduce potential common cause failures, because the external watchdog will be clocked and supplied independently from the STM32F0.

3.6.2 System FLASH memory

Periodical software test for Flash memory – FLASH_SM_0

Permanent faults affecting the system Flash memory (that is the memory cells and address decoder) are addressed through a dedicated software test that checks the memory cell contents versus the expected value, using signature-based techniques. According to IEC 61508:2 Table A.5, the effective diagnostic coverage of such techniques depends on the width of the signature in relation to the block length of the information to be protected - therefore the signature computation method is to be carefully selected. Note that the simple signature method (IEC 61508:7 - A.4.2 Modified checksum) is inadequate as it only achieves a low value of coverage.

The information block does not need to be addressed with this test as it is not used during normal operation (no data/program fetch).

Without information over the frequency of usage of different occupied Flash sections, in principle, all used Flash area are assumed to be tested with a time period compatible with the IEC 61508 requirements for the relationship between PST and the diagnostic test interval.

Control flow monitoring in application software – FLASH_SM_1

Permanent and transient faults affecting the system Flash memory (that is the memory cells and address decoder) can interfere with the access operation by the CPU, leading to wrong data or instruction fetches. Such wrong data and operation, if able to heavily interfere with the expected flow of the application software, are detected by strong control flow mechanism linked to a system watchdog. For more detailed implementation guidelines for such technique refer to safety mechanism CPU_SM_1 in *Control flow monitoring in application software – CPU_SM_1*.

ARM® Cortex®-M0 Hardfault exceptions – FLASH_SM_2

Hardfault exception raise is an intrinsic safety mechanism implemented in ARM® Cortex®-M0 core, mainly devoted to intercept systematic faults that are due to software limitations and/or error in software design, leading for example to the execution of undefined operations, unaligned address access. This safety mechanism is therefore able to detect hardware random faults (both permanent and transient) that affect the system Flash memory (cells and address decoder) bringing to such described abnormal operations.

Option byte write protection – FLASH_SM_3

This safety mechanism prevents unintended writes on the option byte; it addresses therefore systematic faults in software application and not hardware random faults affecting the option byte value during running time. The use of this method is encouraged to enhance end application robustness for systematic faults.

3.6.3 System SRAM memory

Periodical software test for SRAM memory – RAM_SM_0

To enhance the coverage on SRAM data cells and to ensure adequate coverage for permanent faults affecting the address decoder it is required to execute a periodical software test on the system RAM memory. The selection of the algorithm ensures the target SFF coverage for both the RAM cells and the address decoder. The end user provides also evidences of the effectiveness of the coverage of the selected method.

The overall test software suite is assumed to be periodically executed with a time period compatible with the IEC 61508 requirements for the relationship between PST and the diagnostic test interval.

Parity bit check – RAM_SM_1

The Parity check on the system SRAM provides a relevant contribution to the detection of hardware random faults (both permanent and transient) that affect the RAM data cells (no expected contribution is expected for address decoder faults detection). This option is assumed to be enabled by the user after the boot.

Stack hardening for application software – RAM_SM_2

The stack hardening method is used to enhance the application software robustness to SRAM faults that affect the address decoder. The method is based on source code modification, introducing information redundancy in the stack-passed information to the called functions. This method is relevant in case the combination between the final application software structure and the compiler settings requires a significant use of the stack for passing function parameters.

The guidelines for the implementation of the method are the following:

- Pass also the redundant copy of the passed parameters values (possibly inverted) and execute a coherence check in the function.
- Pass also the redundant copy of the passed pointers and execute a coherence check in the function.
- For parameters that are not protected by redundancy, implement defensive programming techniques such as the plausibility check of the passed values for example to check the consistency of enumerated fields.

Information redundancy for safety-related variables in application software – RAM_SM_3

To address transient faults affecting SRAM controller, it is required to implement information redundancy on the safety-related system variables stored in the RAM.

The guidelines for the implementation of this method are the following:

- The system variables that are safety-related (in the sense that a wrong value due to a failure in reading on the RAM affects the safety functions) are well-identified and documented.
- The arithmetic computation and/or decision based on such variables are/is executed twice and the two final results are compared.

Note that the implementation of this safety method shows a partial overlap with an already foreseen method for Cortex®-M0 (CPU_SM_1); optimizations in implementing both

methods are therefore possible (see *Control flow monitoring in application software – CPU_SM_1*).

3.6.4 System bus interconnect

Periodical software test for interconnections – BUS_SM_0

The intra-chip connection resources (Bus Matrix, AHB/APB bridges) needs to be periodically tested for permanent faults detection. Note that STM32F0 series MCUs have no hardware safety mechanism to protect these structures. The test executes a connectivity test of these shared resources, including the testing of the arbitration mechanisms between peripherals. This method which is based on the periodical execution of software-based tests is executed at least once per DTI.

According to IEC 61508:2 Table A.8, A.7.4 the above-described method is considered able to achieve high levels of coverage (and it has to be verified by means of fault injection).

Information redundancy in intra-chip data exchanges – BUS_SM_1

Both permanent and transient fault affecting the intra-chip connection features (Bus Matrix, AHB/APB bridges) are addressed by information redundancy techniques implemented over the messages exchanged inside the MCU.

Lock mechanism for configuration options – LOCK_SM_0

The STM32F0 series MCUs feature spread protection to prevent unintended configuration changes for some peripherals and system registers (for example PVD_LOCK, timers); the spread protection detects systematic faults in software application and transient faults such as soft errors, that cause some bit-flip on registers during running time. The use of this method is encouraged to enhance the end application robustness to systematic faults.

The method described in this section provides a marginal protection against permanent and transient faults affecting system interconnect bus.

3.6.5 NVIC and EXTI controller

Periodical read-back of configuration registers – NVIC_SM_0

This diagnostic measure that is typically referred to as “Read Back Periodic by Software of Configuration Registers” is implemented by executing a periodical check of the configuration registers of each used system peripheral against its expected value that was previously stored in RAM and adequately updated after each configuration change. It mainly addresses the transient faults that affect the configuration registers, by detecting bit flips in the registers due to these transient faults. The register test is executed at least once per DTI in order to be able to claim the related diagnostic coverage.

Expected and unexpected interrupt check – NVIC_SM_1

According to IEC 61508:2 Table A.1 recommendations, a diagnostic measure for continuous, absence or cross-over of interrupt must be implemented. The method of expected and unexpected interrupt check is implemented at application software level. It contributes to detecting both permanent and transient fault for all the above-reported failure modes affecting interrupt handling.

The guidelines for the implementation of the method are the following:

- The list of the implemented interrupt for the MCU are well documented, reporting also the expected frequency of each request when possible (for example the interrupts related to ADC conversion completion, therefore coming on a deterministic way).
- Individual counters are maintained for each interrupt request served, in order to detect in a given time frame the cases of a) no interrupt at all b) too many interrupt requests ("babbling idiot" interrupt source). The control of the time frame duration shall be regulated according to the individual interrupt expected frequency.
- Interrupt vectors related to unused interrupt source point to a default handler that will report, in case of triggering, a faulty condition (unexpected interrupt).
- In case an interrupt service routine is shared between different sources, a plausibility check on the caller identity is implemented.
- Interrupt requests related to not-safety-relevant peripherals are handled with the same method here described, despite their originator safety classification; in order to decrease the complexity of this method implementation, the use of polling instead of interrupt for not-safety-relevant peripherals is suggested.

3.6.6 DMA

Periodical read-back of configuration registers – DMA_SM_0

This diagnostic measure that is typically referred to as "Read Back Periodic by Software of Configuration Registers" is implemented by executing a periodical check of the configuration registers of the DMA peripheral against its expected value that was previously stored in RAM and adequately updated after each configuration change. It mainly addresses the transient faults that affect the configuration registers, by detecting bit flips in the registers due to these transient faults. The register test is executed at least once per DTI in order to be able to claim the related diagnostic coverage.

Information redundancy on data packet transferred via DMA – DMA_SM_1

The information redundancy required on the DMA data transfer cannot be implemented, in line with the DMA concept, with multiple transfers of the same data block. Therefore, this method is implemented by constraining the use of DMA to the transfer of data packed covered by a redundancy check (like CRC, or similar techniques). Note that other diagnostic measures on data communication peripherals (potential DMA sources or destinations) already foresee the implementation of information redundancy at message level – therefore the overlap with those measures could reduce the potential complexity in the referred-method implementation.

Information redundancy including sender/receiver identifier on data packet transferred via DMA – DMA_SM_2

This method requires that the information redundancy introduced at message level (therefore adding a checksum field to the message) helps to identify inside the MCU the source and the originator of the message exchange (that is which peripherals dialogs with the RAM or the CPU). This is implemented by adding an additional field to the protected message, with a coding convention for message type identification fixed at MCU level. That is, this method implements some "virtual channel" between the peripheral and the target.

Periodical software test for DMA – DMA_SM_3

This method requires the periodical testing of the DMA basic functionality, implemented through a deterministic transfer of a data packet from one source to another (for example from memory to memory) and the checking of the correct transfer of the message on the target. The data packets are composed by not-trivial patterns (avoid the use of 0x0000, 0xFFFF values) and organized in order to allow the detection during the check of the following failures:

- Incomplete packed transfer,
- Errors in single transferred word,
- Wrong order in packed transmitted data.

The use of CRC packet protection is a way to simplify such checking operations.

3.6.7 CAN

Periodical read-back of configuration registers – CAN_SM_0

This diagnostic measure that is typically referred to as “Read Back Periodic by Software of Configuration Registers” executes a periodical check of the configuration registers of CAN peripheral against its expected value that is previously stored in the RAM and adequately updated after each configuration change. It mainly addresses the transient faults affecting the configuration registers, detecting bit flips in the registers due to transient faults. The register test is executed at least once per DTI in order to be able to claim the related diagnostic coverage.

Protocol error signals – CAN_SM_1

The CAN protocol error counters, which are entirely managed by the module at hardware level despite being conceived to detect network-related abnormal conditions, are able to contribute to the detection of the faults that lead to error messages generation.

The handling at application level of such error signals is a common technique in embedded applications. Their use is highly recommended.

Information redundancy techniques on messages, including End to End safing – CAN_SM_2

The CAN communications are protected by addressing both the permanent and transient faults with the redundant information technique that includes the End to End Safing.

For the implementation of redundant information, it is possible to adopt a different approach:

- Multiple sending of the same message, with comparison of the received results.
- Addition by the sender of a checksum field to the message to be verified by the receiver.

In case the checksum field approach is adopted, the selection of the algorithm for checksum computation shall ensure a similar protection against message corruption as the one ensured by a full redundancy.

For End to End Safing, additional measures are implemented:

- Additional field in payload allowing the unique identification of sender/receiver, and coherence check by receiver side.
- Timing monitoring of the message exchange (for example check the message arrival within the expected time window)
- Check of the message consistence using a message counter in the additional payload field and checking the right sequence of messages on the receiver side.

The use of a safe communication protocol such as ProfiSAFE is recommended for the correct implementation of this safety mechanism.

3.6.8 USART 1/2/3/4

Periodical read-back of configuration registers – UART_SM_0

This diagnostic measure that is typically referred to as “Read Back Periodic by Software of Configuration Registers” executes a periodical check of the configuration registers of USART against their expected value (previously stored in RAM and adequately updated after each configuration change). It mainly addresses transient faults affecting the configuration registers, detecting bit flips in the registers due to transient faults. The registers test is executed at least once per DTI in order to be able to claim the related diagnostic coverage.

Protocol error signals – UART_SM_1

The UART protocol errors signals (if used) despite being conceived to detect physical layer related abnormal conditions, are able to contribute to the detection to faults leading to error messages generation. For instance, option parity bit in data byte frame, overrun error.

The handling at application level of such error signals is a common technique in embedded applications. Their use is highly recommended.

Information redundancy techniques on messages – UART_SM_2

The redundant information technique is used to protect the USART communications by detecting both the permanent and transient faults. There are two different approaches to implement this technique:

- Multiple sending of the same message, with comparison of the received results.
- Addition by the sender of a checksum field to the message to be verified by the receiver.

In case the checksum field approach is adopted, the selection of the algorithm for checksum computation shall ensure a similar protection against message corruption as the one ensured by a full redundancy. Theoretic demonstrations on coverage capability are admitted – the use of CRC coding is anyway suggested.

The above-reported approaches are equivalent; an additional criteria for the selection of the approach is the availability of a quick hardware support on the MCU platform, and the evaluation of the computation capability of the external device with which the STM32F0 will exchange data.

Note that if the message is transferred by the DMA, the implementation of this safety mechanism takes into account also the overlap of DMA-related safety mechanism related to the message exchange inside the MCU and already declared as highly recommended.

3.6.9 I2C 1/2

Periodical read-back of configuration registers – IIC_SM_0

This diagnostic measure that is typically referred to as “Read Back Periodic by Software of Configuration Registers” executes a periodical check of the configuration registers of I2C against their expected value (previously stored in RAM and adequately updated after each configuration change). It mainly addresses transient faults affecting the configuration registers, detecting bit flips in the registers due to transient faults. The registers test is executed at least once per DTI in order to be able to claim the related diagnostic coverage.

Protocol error signals – IIC_SM_1

The I2C protocol errors signals, despite being conceived to detect physical layer related abnormal conditions, are able to contribute to the detection of faults leading to error messages generation such as for instance the ACK assertion phase, and related checks.

The handling at application level of such error signals being a common technique in embedded applications, their use is highly recommended.

Note: the adoption of SMBus protocol, if available on the selected I2C module and compatible with the external connected devices, is a way to get available additional hardware-based error checking mechanisms.

Information redundancy techniques on messages – IIC_SM_2

The redundant information technique is used to protect the I2C communications by detecting both the permanent and transient faults. There are two different approaches to implement this method:

- Multiple sending of the same message, with comparison of the received results
- Addition by the sender of a checksum field to the message to be verified by the receiver.

In case the checksum field approach is adopted, the selection of the algorithm for checksum computation shall ensure a similar protection against message corruption as the one ensured by a full redundancy. Theoretic demonstrations on coverage capability are admitted – the use of CRC coding is anyway suggested (also looking to the availability of a quick hardware support on the MCU platform).

The above-reported approaches are equivalent; an additional criteria for the selection is the evaluation of the computation capability of the external device with which the STM32F0 will exchange data.

If the message is transferred by the DMA, the implementation of this safety mechanism takes into account also the overlap of DMA-related safety mechanism related to the message exchange inside the MCU and therefore its use is highly recommended.

Note: The adoption of SMBus protocol (if available on selected I2C module and compatible with the external connected devices) is a way to simplify the implementation of this safety mechanism.

3.6.10 SPI 1/2

Periodical read-back of configuration registers – SPI_SM_0

This diagnostic measure that is typically referred to as “Read Back Periodic by Software of Configuration Registers” executes a periodical check of the configuration registers of SPI against their expected value that was previously stored in RAM and adequately updated after each configuration change. It mainly addresses transient faults affecting the configuration registers, detecting bit flips in the registers due to transient faults. The registers test is executed at least once per DTI in order to be able to claim the related diagnostic coverage.

Protocol error signals -SPI_SM_1

The SPI protocol errors signals, despite being conceived to detect physical layer related abnormal conditions, are able to contribute to the detection to faults leading to error messages generation such as for instance FIFO overrun and Mode error flags.

The handling at application level of such error signals being a common technique in embedded applications, their use is highly recommended.

Information redundancy techniques on messages – SPI_SM_2

The redundant information technique is used to protect the SPI communications by detecting both the permanent and transient faults. There are two different approaches to implement this method:

- Multiple sending of the same message, with comparison of the received results.
- Addition by the sender of a checksum field to the message to be verified by the receiver.

In case the checksum field approach is adopted, the selection of the algorithm for checksum computation shall ensure a similar protection against message corruption as the one ensured by a full redundancy. Theoretic demonstrations on coverage capability are admitted – the use of the hardware CRC computation unit built into SPI module is highly suggested).

The above-reported approaches are equivalent; an additional criteria for the selection is the evaluation of the computation capability of the external device with which the STM32F0 will exchange data.

If the message is transferred by the DMA, the implementation of this safety mechanism takes into account also the overlap of DMA-related safety mechanism related to the message exchange inside the MCU and therefore its use is highly recommended.

3.6.11 USB - 2.0 Universal Serial Bus interface FS module

Periodical read-back of configuration registers – USB_SM_0

This diagnostic measure that is typically referred to as “Read Back Periodic by Software of Configuration Registers” executes a periodical check of the configuration registers of USB against their expected value that was previously stored in the RAM and adequately updated after each configuration change. It mainly addresses transient faults affecting the configuration registers, detecting bit flips in the registers due to transient faults. The registers test is executed at least once per DTI in order to be able to claim the related diagnostic coverage.

Protocol error signals – USB_SM_1

The USB protocol errors signals, despite being conceived to detect physical layer related abnormal conditions, are able to contribute to the detection to faults leading to error messages generation. The errors are those entirely handled by hardware. that is buffer overruns, bit stuffing, frame format violations, CRC errors. End users must take care of the system availability by managing adequately the protocol errors that are not related to random hardware faults but to transmission issues that can be recovered with a repetition of the message transmission.

The handling at application level of such error signals being a common technique in embedded applications, their use is highly recommended.

Information redundancy techniques on messages – USB_SM_2

The redundant information technique is used to protect the USB communications by detecting both the permanent and transient faults. There are two different approaches to implement this method:

- Multiple sending of the same message, with comparison of the received results
- Addition by the sender of a checksum field to the message to be verified by the receiver.

In case the checksum field approach is adopted, the selection of the algorithm for checksum computation shall ensure a similar protection against message corruption as the one ensured by a full redundancy. Theoretic demonstrations on coverage capability are admitted – the use of CRC coding is anyway suggested (also looking to the availability of a quick hardware support on the MCU platform).

The above-reported approaches are equivalent; an additional criteria for the selection is the evaluation of the computation capability of the external device with which the STM32F0 will exchange data.

If the message is transferred by the DMA, the implementation of this safety mechanism takes into account also the overlap of DMA-related safety mechanism related to the message exchange inside the MCU and therefore its use is highly recommended.

3.6.12 HDMI CEC module

Periodical read-back of configuration registers – HDMI_SM_0

This diagnostic measure that is typically referred to as “Read Back Periodic by Software of Configuration Registers” executes a periodical check of the configuration registers of HDMI module against their expected value that was previously stored in RAM and adequately updated after each configuration change. It mainly addresses the transient faults affecting the configuration registers, detecting bit flips in the registers due to transient faults. The registers test is executed at least once per DTI in order to be able to claim the related diagnostic coverage.

Protocol error signals – HDMI_SM_1

HDMI protocol errors signals, despite being conceived to detect physical layer related abnormal conditions, are able to contribute to the detection to faults leading to error messages generation, for instance reception, transmission and arbitration error flags, transmission and reception under-run.

Information redundancy techniques on messages – HDMI_SM_2

The redundant information technique is used to protect the HDMI communications by detecting both the permanent and transient faults. There are two different approaches to implement this method:

- Multiple sending of the same message, with comparison of the received results
- Addition by the sender of a checksum field to the message to be verified by the receiver.

In case the checksum field approach is adopted, the selection of the algorithm for checksum computation shall ensure a similar protection against message corruption as the one ensured by a full redundancy. Theoretic demonstrations on coverage capability are admitted – the use of CRC coding is anyway suggested (also looking to the availability of a quick hardware support on the MCU platform).

The above-reported approaches are equivalent; an additional criteria for the selection is the evaluation of the computation capability of the external device with which the STM32F0 will exchange data.

3.6.13 Touch Sensing Controller (TSC)

Periodical read-back of configuration registers – TSC_SM_0

This diagnostic measure that is typically referred to as “Read Back Periodic by Software of Configuration Registers” executes a periodical check of the configuration registers of TSC against their expected value that was previously stored in RAM and adequately updated after each configuration change. It mainly addresses transient faults affecting the configuration registers, detecting bit flips in the registers due to transient faults. The registers test is executed at least once per DTI in order to be able to claim the related diagnostic coverage.

Multiple acquisition by application software – TSC_SM_1

To address transient faults affecting the TSC module it is required to implement a timing information redundancy by executing multiple acquisitions on TSC input data. This method overlaps on the native features of the TSC module of counting events in order to ensure a stable acquisition.

3.6.14 Analog to Digital Converters (ADC)

Periodical read-back of configuration registers – ADC_SM_0

This diagnostic measure that is typically referred to as “Read Back Periodic by Software of Configuration Registers” executes a periodical check of the configuration registers of ADC against their expected value that was previously stored in RAM and adequately updated after each configuration change. It mainly addresses transient faults affecting the configuration registers, detecting bit flips in the registers due to transient faults. The registers test is executed at least once per DTI in order to be able to claim the related diagnostic coverage.

Multiple acquisition by application software - ADC_SM_1

To address the transient faults that affect the ADC module, it is required to implement a timing information redundancy scheme that executes multiple acquisitions of the same

signal. This recommendation will most probably be satisfied by design by the end user application software. The usage of multiple acquisitions followed by average operations is a common technique in industrial applications where it is needed to survive with spurious EMI disturbs on sensor lines.

Range check by application software – ADC_SM_2

To address permanent faults affecting ADC module, and also to address failure modes affecting the analogue section, it is required that the application software executes a range of check/plausibility checks on the measures coming from ADC acquisitions.

The guidelines for the implementation of the method are the following:

- The expected range of the data to be acquired are investigated and adequately documented. Note that in a well-designed application it is improbable that during normal operation an input signal has a very near or over the upper and lower rail limit (saturation in signal acquisition).
- If the application software is aware of the state of the system, this information is to be used in the range check implementation. For example, if the ADC value is the measurement of a current through a power load, reading an abnormal value such as a a current flowing in opposite direction versus the load supply may indicate a fault in the acquisition module.
- As the ADC module is shared between different possible external sources, the combination of plausibility checks on the different signals acquired helps to cover the whole input range in a very efficient way.

Note: The implementation of this safety mechanism is strongly application-dependent.

Periodical software test for ADC – ADC_SM_3

To address permanent faults affecting ADC module, and also to address failure modes affecting the analogue section, it is required to execute a periodical test on the ADC acquisition section. The method is implemented by acquiring either the internal reference voltage or, alternatively, a reference voltage coming from the external (board) and connected to an input pin, and comparing to the expected value. This test is executed periodically at least once per DTI.

3.6.15 DAC

Periodical read-back of configuration registers – DAC_SM_0

This diagnostic measure that is typically referred to as “Read Back Periodic by Software of Configuration Registers” executes a periodical check of the configuration registers of DAC module against their expected value that was previously stored in RAM and adequately updated after each configuration change. It mainly addresses transient faults affecting the configuration registers, detecting bit flips in the registers due to transient faults. The registers test is executed at least once per DTI in order to be able to claim the related diagnostic coverage.

DAC output loopback on ADC channel – DAC_SM_1

To address permanent faults affecting DAC modules, and also to address failure modes affecting the analogue section, it is required to implement a loopback scheme where the output analogue value of DAC is acquired by one channel of the ADC and checked versus

its expected value. This test is executed periodically, each time the DAC value is updated and at least once per DTI.

3.6.16 Comparator

Periodical read-back of configuration registers – COMP_SM_0

This diagnostic measure that is typically referred to as “Read Back Periodic by Software of Configuration Registers” executes a periodical check of the configuration registers of the comparator against their expected value that was previously stored in RAM and adequately updated after each configuration change. It mainly addresses transient faults affecting the configuration registers, detecting bit flips in the registers due to transient faults. The registers test is executed at least once per DTI in order to be able to claim the related diagnostic coverage.

1oo2 scheme for comparator – COMP_SM_1

This safety mechanism is implemented using the two internal comparators to take the same decision. It requires that the comparator voting is handled accordingly.

Note: this safety mechanism ensure a high level of coverage against both permanent and transient faults but it is not compatible with the “window” comparator feature.

Plausibility check on inputs – COMP_SM_2

To address permanent faults affecting comparator module, it is needed to redundantly acquire, on the ADC channels, the analog inputs that are subjected to comparator function, and periodically check the coherence of the comparator output on the measured values. This method addresses only the permanent faults and with a medium level of efficiency. This test is executed periodically at least once per DTI.

Multiple acquisition by application software – COMP_SM_3

To address transient faults affecting comparator module, it is required that the application software makes a decision not on the basis of a single-shot transition, but with multiple events. This recommendation will most probably be satisfied by design by the end user application software. The usage of multiple acquisitions is a common technique in industrial applications where it is needed to survive with spurious EMI disturbs on sensor lines.

Comparator LOCK mechanism – COMP_SM_4

This safety mechanism prevents configuration changes for comparator control and status registers; it addresses therefore systematic faults in the software application and not transient faults (soft errors) possibly causing bit-flip on registers during running time. The use of this method is encouraged to enhance the end-application robustness for systematic faults.

3.6.17 TIM 6/7

Periodical read-back of configuration registers - GTIM_SM_0

This diagnostic measure that is typically referred to as “Read Back Periodic by Software of Configuration Registers” executes a periodical check of the configuration registers of TIMER against their expected value that was previously stored in RAM and adequately updated after each configuration change. It mainly addresses transient faults affecting the

configuration registers, detecting bit flips in the registers due to transient faults. The registers test is executed at least once per DTI in order to be able to claim the related diagnostic coverage.

1oo2 for counting timers – GTIM_SM_1

This method provides a high level of coverage for both permanent and transient faults on the addressed timers. The method is conceived to protect the timers used for counting features, for example the timers dedicated to maintain a system time base and/or to generate a timed interrupt for the execution of service routines (like for instance general timing counters update/increase).

The guidelines for the implementation of the method are the following:

- In case of timer use as a time base, use in the application software one of the timer as timebase source, and the other one just for check. In that case the coherence check for the 1oo2 will be done at application level.
- In case of interrupt generation usage, use the first timer as main interrupt source for the service routines, and use the second timer to activate a “checking routine” that cross-checks the coherence between the timers.

3.6.18 TIM1/2/3/14/15/16/17

Note: as the advanced timers are equipped with many different channels, each independent from the others, and possibly programmed to realize different features, the safety mechanism is selected individually for each channel.

Periodical read-back of configuration registers – ATIM_SM_0

This diagnostic measure that is typically referred to as “Read Back Periodic by Software of Configuration Registers” executes a periodical check of the configuration registers of TIMERS against their expected value that was previously stored in RAM and adequately updated after each configuration change. It mainly addresses transient faults affecting the configuration registers, detecting bit flips in the registers due to transient faults. The registers test is executed at least once per DTI in order to be able to claim the related diagnostic coverage.

1oo2 for counting timers – ATIM_SM_1

This method provides a high level of coverage for both the permanent and transient faults on the addressed timers. The method is conceived to protect the timers used for counting features, for example the timers dedicated to maintain a system time base and/or to generate a timed interrupt for the execution of service routines (like for instance general timing counters update/increase).

The guidelines for the implementation of the method are the following:

- In case of timer use as a time base, use in the application software one of the timer as timebase source, and the other timer just for check. In that case the coherence check for the 1oo2 is done at application level.
- In case of interrupt generation usage, use the first timer as main interrupt source for the service routines, and use the second timer to activate a “checking routine” that cross-checks the coherence between timers.

1oo2 for input capture timers - ATIM_SM_2

This method, based on 1oo2 scheme, provides a high level of coverage for both the permanent and transient faults on the addressed timers. It is conceived to protect the timers used for external signal acquisition and measurement, like “input capture” and “encoder reading”. The implementation is easy as it simply requires to connect the external signals also to the redundant timer, and perform a coherence check on the measured data at application level. To reduce the potential effect of the common cause failure, it is suggested, for the redundant check, to use a channel belonging to a different timer module and mapped to not-adjacent pins on the device package.

Loopback scheme for PWM outputs – ATIM_SM_3

This method uses a loopback scheme to detect permanent and transient faults on the timer channels used for wave generations (PWM). It is implemented by connecting the PWM to a separate channel, either in the same or in another timer, to acquire the generated waveform characteristics.

The guidelines for the implementation of the method are the following:

- Both frequency and duty cycle of PWM are measured and checked versus the expected value.
- To reduce the potential effect of common cause failure, it is suggested to use for the loopback check a channel belonging to a different timer module and mapped to not-adjacent pins on the device package.

This measure can be replaced under the end-user responsibility by different loopback schemes already in place in the final application and rated as equivalent. For example if the PWM is used to drive an external power load, the reading of the on-line current value can be used instead of the PWM frequency measurement.

3.6.19 GPIO – PORT A/B/C/D/E/F

Periodical read-back of configuration registers – GPIO_SM_0

This diagnostic measure that is typically referred to as “Read Back Periodic by Software of Configuration Registers” executes a periodical check of the configuration registers of GPIO against their expected value that was previously stored in RAM and adequately updated after each configuration change. It mainly addresses transient faults affecting the configuration registers, detecting bit flips in the registers due to transient faults. The registers test is executed at least once per DTI in order to be able to claim the related diagnostic coverage.

1oo2 for input GPIO lines – GPIO_SM_1

To address both permanent and transient faults on GPIO lines used as input, it is required to implement a 1oo2 scheme by connecting the external safety-relevant signal to two independent GPIO lines. To reduce the potential impact of common cause failure, it is suggested to use GPIO lines belonging to different i/o ports (for example PORT A and B) and mapped to not-adjacent pins on the device package.

Loopback scheme for output GPIO lines – GPIO_SM_2

To address both permanent and transient faults on GPIO lines used as output, it is required to implement a loopback scheme, connecting the output to a different GPIO line programmed as input and used to check the expected value on output port. To reduce the

potential impact of common cause failure, it is suggested to use GPIO lines belonging to different i/o ports (for example PORT A and B) and mapped to not-adjacent pins on the device package.

GPIO port configuration lock register – GPIO_SM_3

This safety mechanism prevents configuration changes for GPIO registers; it addresses therefore systematic faults in software application and not transient faults (soft errors) that can possibly cause bit-flip on registers during running time. The use of this method is encouraged to enhance the end-application robustness for systematic faults.

3.6.20 Real Time Clock module (RTC)

Periodical read-back of configuration registers – RTC_SM_0

This diagnostic measure that is typically referred to as “Read Back Periodic by Software of Configuration Registers” executes a periodical check of the configuration registers of RTC module against their expected value that was previously stored in RAM and adequately updated after each configuration change. It mainly addresses transient faults affecting the configuration registers, detecting bit flips in the registers due to transient faults. The registers test shall be executed at least once per DTI in order to be able to claim the related diagnostic coverage.

Application check of running RTC – RTC_SM_1

The application software implements some plausibility check on RTC calendar/timing data, mainly after a power-up and further date reading by RTC.

The guidelines for the implementation of the method are the following:

- RTC backup registers are used to store the coded information and detect the absence of V_{BAT} during power-off period.
- RTC backup registers are used to periodically store compressed information on date/time, and allow the application software to execute minimal consistence checks for date reading after power-on (that is detect “past” date/time retrieve).

3.6.21 Supply voltage system

Periodical read-back of configuration registers – VSUP_SM_0

This diagnostic measure that is typically referred to as “Read Back Periodic by Software of Configuration Registers” executes a periodical check of the configuration registers of the Power Control logic against their expected value that was previously stored in RAM and adequately updated after each configuration change. It mainly addresses transient faults affecting the configuration registers, detecting bit flips in the registers due to transient faults. The registers test is executed at least once per DTI in order to be able to claim the related diagnostic coverage.

Supply Voltage Monitoring – VSUP_SM_1

It is required to detect early the under voltage and overvoltage conditions that are potential sources of failure at MCU level. The power supply values close to the operating limits reported in device datasheet are considered at the same level as hardware faults and lead to similar recovery actions by the application software.

The use of internal Programmable Voltage Detector (PVD) helps to implement this method. The adoption of an external monitoring power supply device outside the MCU ensures additional protection against potential common cause failures.

Caution: the internal PVD will have limited efficiency in detecting an overvoltage condition – therefore it is highlighted recommended the end users respect the absolute maximum ratings for voltage (see *Section 3.4: Electrical specifications and environment limits*).

Independent watchdog – VSUP_SM_2

The independent watchdog is fed directly by V_{DD}; therefore, major failures in the 1.8 V supply for digital logic (core/peripherals) will not affect its behavior but may lead to a violation of the IDWG window for the key value write by the application software, leading to a system reset.

Internal temperature sensor check – VSUP_SM_3

The internal temperature sensor shall be periodically tested in order to detect abnormal increase of the die temperature – hardware faults in supply voltage system may cause excessive power consumption and consequent temperature rise. This method also mitigates the eventuality of common-cause affecting the MCU and due to too high temperature.

Refer to the device datasheet to set the threshold temperature.

3.6.22 Reset and clock control subsystem

Periodical read-back of configuration registers – CLK_SM_0

This diagnostic measure that is typically referred to as “Read Back Periodic by Software of Configuration Registers” executes a periodical check of the configuration registers of the Reset and Clock Control logic against their expected value (previously stored in RAM and adequately updated after each configuration change). It mainly addresses transient faults affecting the configuration registers, detecting bit flips in the registers due to transient faults. The registers test is executed at least once per DTI in order to be able to claim the related diagnostic coverage.

Clock Security System (CSS) – CLK_SM_1

The Clock Security System (CSS) detects the loss of HSE clock activity and executes the corresponding recovery action, such as switch-off HSE and commute on the HSI. For this reason it is able to detect potential abnormal situations:

- Loss of external clock,
- Abnormal activation of HSE despite being disabled by design.

The CSS detection of HSE abnormal condition is considered as equivalent to hardware faults and brings to similar recovery actions by the application software.

As these two above situations are potential source of common cause failure, the adoption of this method is highly recommended.

Independent watchdog – CLK_SM_2

The independent watchdog is fed by a dedicated oscillator; therefore, major failures on clock generation at system level will not affect its behavior but may lead to a violation of the IDWG window for the key value write by the application software, leading to a system reset.

Note that the efficiency of this safety mechanism is strongly dependent on the correct window setting and handling for the IDWG. The refresh of the IDWG should be implemented in order to bring alteration of the program flow able to bypass the time window limit.

Internal clock cross-measure – CLK_SM_3

This method is implemented using TIM14 capabilities to be fed by the 32KHz RTC clock or an external clock source (if available). This way a dedicated software routine is able to cross-measure the internal clock and detect any abnormal value of oscillation frequency. This method, despite its complexity, only provides medium efficiency in clock-related failure mode coverage.

3.6.23 Watchdogs (IWDG, WWDG)

Periodical read-back of configuration registers – WDG_SM_0

This diagnostic measure that is typically referred to as “Read Back Periodic by Software of Configuration Registers” executes a periodical check of the configuration registers of the watchdogs against their expected value (previously stored in RAM and adequately updated after each configuration change). It mainly addresses transient faults affecting the configuration registers, detecting bit flips in the registers due to transient faults. The registers test is executed at least once per DTI in order to be able to claim the related diagnostic coverage.

Software test for watchdog at startup – WDG_SM_1

This safety mechanism ensures the right functionality of the internal watchdogs in use. At startup, the software test programs the watchdog with the required expiration timeout, stores a specific flag in the RAM and waits for the reset signal. After the watchdog reset, the software understands that the watchdog has correctly triggered, and does not execute the procedure again.

3.6.24 Debug

Independent watchdog – DBG_SM_0

The debug unintentional activation due to hardware random fault will result in the massive disturbance of the independent watchdog or alternately, the other system watchdog WWGDG or an external one.

3.6.25 Cyclic Redundancy Check module (CRC)

CRC self-coverage – CRC_SM_0

The CRC algorithm implemented in this module (CRC-32 Ethernet polynomial: 0x4C11DB7) offers excellent features in terms of error detection in the message. Therefore the permanent and transient faults affecting CRC computations are easily detected by each operations using the module to recomputed the expected signature.

3.6.26 Dual MCU architecture

Cross-checking between two STM32F0 microcontrollers – DUAL_SM_0

In a dual MCU safety architecture, the previously defined diagnostics are complemented by a cross-check between the two MCUs. The rationale behind this safety mechanism is to involve in the cross-check both the self-check testing for each MCUs and the control flow / result checks for the running application software.

The guidelines for the implementation of this method are the following:

- The two microcontrollers receive the same input data at the same time and individually execute the mission algorithm, that is the application software. It is important that the input data received from the external world is protected by the most robust methods already described in this safety manual for the system peripherals in terms of data message protection - refer to safety mechanism like *Information redundancy techniques on messages, including End to End safing – CAN_SM_2*, or *Information redundancy techniques on messages – UART_SM_2*.
- During the execution of the mission algorithm, at every fixed time (referenced here as “tick”), each CPU interrupts the normal execution flow and executes a self-test aimed at the detection of permanent faults. The results are exchanged between the two MCUs by means of an external peripheral interface, like USART or SPI. The most efficient related safety mechanisms described in this safety manual are implemented for the peripherals used for the inter-MCU informations exchange.

Moreover, with the aim of detecting transient faults, the exchange of compressed results of the algorithm steps executed in the “tick” is performed according to the following steps:

- MCU2 compares the result of algorithm steps of MCU2 with the result of algorithm steps of MCU1.
- MCU1 compares the result of algorithm steps of MCU1 with the result of algorithm steps of MCU2.

The above referred “algorithm steps” are used to record intermediate safety-related computation data and tracking information on the internal state of the application software/algorithm. Note that the latter can be derived from the available data already computed by the safety mechanism linked to control flow monitoring (refer to *Control flow monitoring in application software – CPU_SM_1*).

3.6.27 Latent fault detection

This safety manual is based on a safety analysis according to IEC 61508.

ISO 26262 – the reference for integrated circuit safety analysis - considers also a metric for “latent” faults. The latent fault is a multiple-point fault which presence is not detected by a safety mechanism nor perceived by the driver within the multiple-point fault detection interval. In practical words, the latent fault is a combination of a fault in a safety mechanism - that by itself will NOT cause the violation of the safety goal (function) - and a fault in the mission logic supervised by that safety mechanism. Despite the lack of definition for latent fault metrics in IEC 61508, the robustness of a design against latent is considered as a key point in the safety community.

The following reported methods mainly address latent fault for the foreseen safety mechanism at MCU level.

CRC self-coverage – LAT_SM_0

The intrinsic high-level of self-coverage of the CRC computation unit is computed as a safety mechanism for latent fault for all STM32F0 series peripherals/modules covered by the safety mechanism implemented as software check based on CRC computations.

Independent Watchdog – LAT_SM_1

Each safety mechanism implemented as periodical software testing runs on the CPU. Possible faults in the safety mechanism are therefore faults in the “support” for the execution that is the CPU. The independent watchdog is considered here as safety mechanism addressing the program counter failures due to the CPU hardware random faults.

Periodical core self test software – LAT_SM_2

As the major part of the safety mechanism described in this safety manual is implemented by software, the periodical core self-test software execution able to detect faults in the ARM® Cortex®-M0 CPU acts as safety mechanism for latent faults. For implementation details refer to the description reported in *Periodical core self test software - CPU_SM_0* for CPU_SM_0.

3.6.28 Disable and periodic cross-check of unintentional activation of unused peripherals

This section reports the safety mechanism that addresses peripherals not used by the safety application, or not used at all. Note that it is possible to use these methods to manage application where the end user completely disables the DMA (using therefore polling techniques) in order to avoid the implementation of DMA-related safety measures.

Unused peripherals disable – FFI_SM_0

This method contributes to the reduction of the probability of cross-interferences caused by peripherals not used by the software application. It is implemented by end users, taking care of disabling by software (for instance during the system boot) each peripheral that is not used.

Periodical read-back of interference avoidance registers – FFI_SM_1

This method contributes to the reduction of the probability of cross-interferences between peripherals that can potentially conflict on the same output pins, including for instance unused peripherals (refer to *Unused peripherals disable – FFI_SM_0*). This diagnostic measure executes a periodical check of the below described registers against their expected value (previously stored in RAM and adequately updated after each configuration change). The register test is executed at least once per DTI.

The configuration registers to be tested with this method are those related to clock disabling features for peripherals and those related to the enabling of alternate functions on I/O pins.

3.7 Conditions of use

Table 3 provides a summary of the safety concept recommendations reported in *Section 3.6: Description of hardware and software diagnostics*. The conditions of use to be applied to STM32F0 series MCUs are reported in the form of safety mechanism requirements.

The single MCU/dual MCU columns address the related architecture and have the following meaning:

- **M** = this safety mechanism is always operating during normal operations – no end user activity can deactivate it.
- ++ = Highly recommended being a common practice and considered in this safety manual for the computation of the safety metrics.
- + = Recommended as additional safety measure, but not considered in this safety manual for the computation of safety metrics. Users of the STM32F0 series can skip the mechanism in case it is in contradiction with functional requirements.
- o = optional, not needed

The “X” marker in the “Perm” and “Trans” columns in *Table 3*, indicates that the related safety mechanism is effective for such fault model.

Table 3. List of safety mechanisms

STM32F0 function	Diagnostic	Description	Single MCU	Dual MCU	Perm	Trans
ARM® Cortex®-M0 CPU	CPU_SM_0	Periodical software test addressing permanent faults in ARM Cortex-M0 CPU core	++	++	X	-
	CPU_SM_1	Control flow monitoring in application software	++	++	X	X
	CPU_SM_2	Double computation in application software	++	++	-	X
	CPU_SM_3	ARM® Cortex®-M0 HardFault exceptions	M	M	X	X
	CPU_SM_4	Stack hardening for application software	+	+	X	X
	CPU_SM_5	External watchdog	o	o	X	X
System Flash	FLASH_SM_0	Periodical software test for Flash memory	++	++	X	-
	FLASH_SM_1	Control flow monitoring in application software	+	+	X	X
	FLASH_SM_2	ARM® Cortex®-M0 HardFault exceptions	M	M	X	X
	FLASH_SM_3	Option byte write protection	M	M	-	-
System SRAM	RAM_SM_0	Periodical software test for SRAM memory	++	++	X	-
	RAM_SM_1	Parity bit check	++	++	X	X
	RAM_SM_2	Stack hardening for application software	+	+	X	X
	RAM_SM_3	Information redundancy for system variables in application software	++	++	X	X

Table 3. List of safety mechanisms (continued)

STM32F0 function	Diagnostic	Description	Single MCU	Dual MCU	Perm	Trans
System interconnect	BUS_SM_0	Periodical software test for interconnections	++	++	X	-
	BUS_SM_1	Information redundancy in intra-chip data exchanges	++	++	X	X
NVIC	NVIC_SM_0	Periodical read-back of configuration registers	++	++	X	X
	NVIC_SM_1	Expected and unexpected interrupt check by application software	++	++	X	X
CAN	CAN_SM_0	Periodical read-back of configuration registers	++	++	X	X
	CAN_SM_1	Protocol error signals	+	+	X	X
	CAN_SM_2	Information redundancy techniques on messages, including End to End safing	++	++	X	X
UART	UART_SM_0	Periodical read-back of configuration registers	++	++	X	X
	UART_SM_1	Protocol error signals	+	+	X	X
	UART_SM_2	Information redundancy techniques on messages	++	++	X	X
I2C	IIC_SM_0	Periodical read-back of configuration registers	++	++	X	X
	IIC_SM_1	Protocol error signals	+	+	X	X
	IIC_SM_2	Information redundancy techniques on messages	++	++	X	X
SPI	SPI_SM_0	Periodical read-back of configuration registers	++	++	X	X
	SPI_SM_1	Protocol error signals	+	+	X	X
	SPI_SM_2	Information redundancy techniques on messages	++	++	X	X
USB	USB_SM_0	Periodical read-back of configuration registers	++	++	X	X
	USB_SM_1	Protocol error signals	+	+	X	X
	USB_SM_2	Information redundancy techniques on messages	++	++	X	X
HDMI	HDMI_SM_0	Periodical read-back of configuration registers	++	++	X	X
	HDMI_SM_1	Protocol error signals	+	+	X	X
	HDMI_SM_2	Information redundancy techniques on messages	++	++	X	X

Table 3. List of safety mechanisms (continued)

STM32F0 function	Diagnostic	Description	Single MCU	Dual MCU	Perm	Trans
TSC	TSC_SM_0	Periodical read-back of configuration registers	++	++	X	X
	TSC_SM_1	Multiple acquisition by application software	++	++	-	X
ADC	ADC_SM_0	Periodical read-back of configuration registers	++	++	X	X
	ADC_SM_1	Multiple acquisition by application software	++	++	-	X
	ADC_SM_2	Range check by application software	++	++	X	X
	ADC_SM_3	Periodical software test for ADC	+	+	X	-
DAC	DAC_SM_0	Periodical read-back of configuration registers	++	++	X	X
	DAC_SM_1	DAC output loopback on ADC channel	++	++	X	X
COMP	COMP_SM_0	Periodical read-back of configuration registers	++	++	X	X
	COMP_SM_1	1oo2 scheme for comparator	++	++	X	X
	COMP_SM_2	Plausibility check on inputs	+	+	X	-
	COMP_SM_3	Multiple acquisition by application software	+	+	-	X
	COMP_SM_4	Comparator LOCK mechanism	+	+	-	-
DMA	DMA_SM_0	Periodical read-back of configuration registers	++	++	X	X
	DMA_SM_1	Information redundancy on data packet transferred via DMA	++	++	X	X
	DMA_SM_2	Information redundancy including sender/receiver identifier on data packet transferred via DMA	++	++	X	X
	DMA_SM_3	Periodical software test for DMA	++	++	X	-
TIM6/7	GTIM_SM_0	Periodical read-back of configuration registers	++	++	X	X
	GTIM_SM_1	1oo2 for counting timers	++	++	X	X
TIM1/2/3/14/15/16/17	ATIM_SM_0	Periodical read-back of configuration registers	++	++	X	X
	ATIM_SM_1	1oo2 for counting timers	++	++	X	X
	ATIM_SM_2	1oo2 for input capture timers	++	++	X	X
	ATIM_SM_3	Loopback scheme for PWM outputs	++	++	X	X
CRC	CRC_SM_0	CRC self-coverage	++	++	X	X

Table 3. List of safety mechanisms (continued)

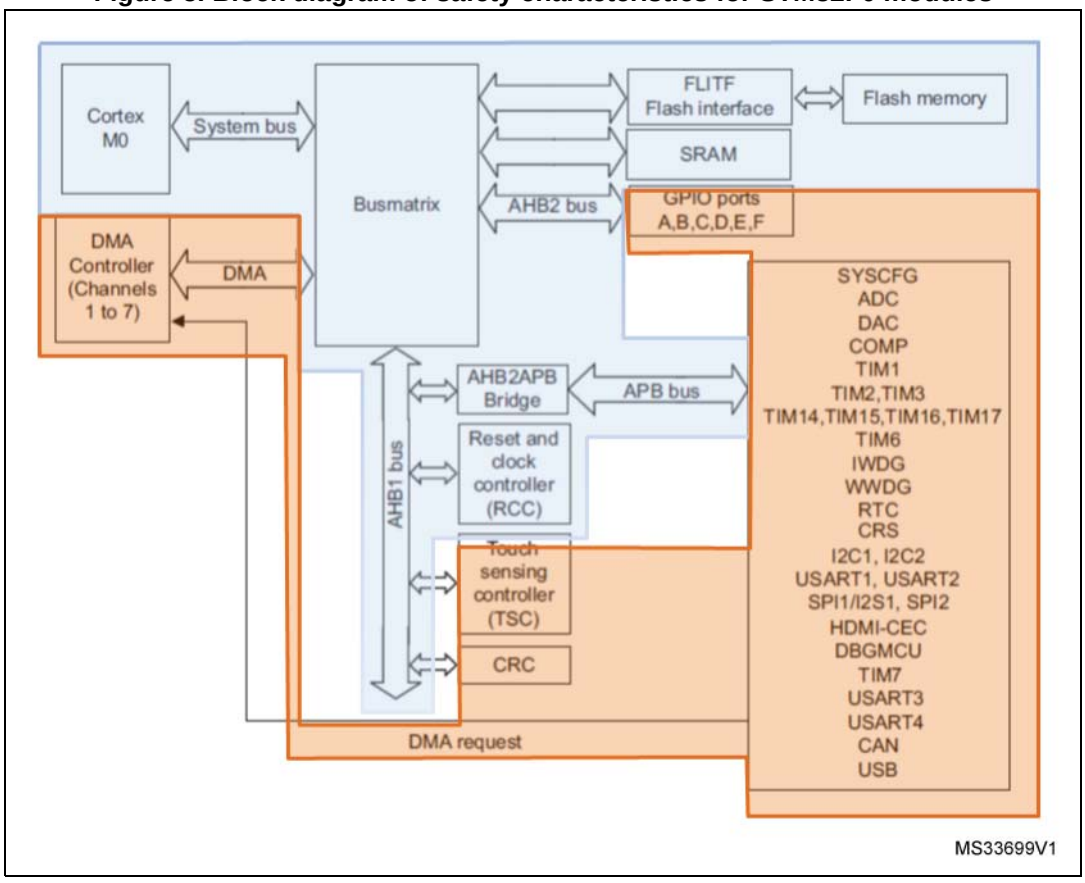
STM32F0 function	Diagnostic	Description	Single MCU	Dual MCU	Perm	Trans
GPIO	GPIO_SM_0	Periodical read-back of configuration registers	++	++	X	X
	GPIO_SM_1	1oo2 for input GPIO lines	++	++	X	X
	GPIO_SM_2	Loopback scheme for output GPIO lines	++	++	X	X
	GPIO_SM_3	GPIO port configuration lock register	+	+	-	-
RTC	RTC_SM_0	Periodical read-back of configuration registers	++	++	X	X
	RTC_SM_1	Application check of running RTC	++	++	X	X
Supply system	VSUP_SM_0	Periodical read-back of configuration registers	++	++	X	X
	VSUP_SM_1	Supply voltage monitoring	++	++	X	-
	VSUP_SM_2	Independent Watchdog	++	++	X	-
	VSUP_SM_3	Internal temperature sensor check	o	o	-	-
Clock and Reset	CLK_SM_0	Periodical read-back of configuration registers	++	++	X	X
	CLK_SM_1	CSS Clock Security System	++	++	X	-
	CLK_SM_2	Independent Watchdog	++	++	X	-
	CLK_SM_3	Internal clock cross-measure	+	+	X	-
Watchdogs	WDG_SM_0	Periodical read-back of configuration registers	++	++	X	X
	WDG_SM_1	Software test for watchdog at startup	o	o	X	-
Debug	DBG_SM_0	Independent watchdog	++	++	X	X
Dual MCU	DUAL_SM_0	Cross-checking between two STM32F0 microcontrollers	-	++	X	X
Software-based safety mechanism using hardware CRC	LAT_SM_0	CRC self-coverage	+	+	X	-
Software-based safety mechanism	LAT_SM_1	Independent Watchdog	+	+	X	-
	LAT_SM_2	Periodical core self test software	+	+	X	-
System / peripherals control	LOCK_SM_0	Lock mechanism for configuration options	+	+	-	-
Part separation (no interference)	FFI_SM_0	Unused peripherals disable	+	+	-	-
	FFI_SM_1	Periodical read-back of interference avoidance registers	+	+	-	-

The above-described safety mechanism/conditions of use are implemented with different levels of abstraction depending on their nature: the more a safety mechanism is implemented as application-independent, the wider is its possible use on a large range of end-user applications.

The safety analysis highlights two major areas inside the MCU, illustrated in *Figure 5*:

- The light blue area includes all MCU modules that are system-critical, meaning that each end-user application will be affected from a safety point of view by an issue on these modules. Each safety application addresses these modules with the adequate methods (according to the safety analysis reported above). Furthermore, these modules being commonly used by each end user application, the related methods/safety mechanism as described above are mainly implemented to be application-independent.
- The orange area includes peripheral modules that could be not used by the end-user application, or that were used for not-safety relevant tasks. The related safety methods are therefore implemented mainly at application level, as application software solutions and/or architectural solutions.

Figure 5. Block diagram of safety characteristics for STM32F0 modules



4 Safety results

This section reports the results of the safety analysis of the STM32F0 series MCU, according to IEC 61508 and to the Yogitech fRMethodology flow, related to the hardware random and dependent failures.

4.1 Hardware random failure safety results

The analysis for random hardware failures of STM32F0 series devices reported in this safety manual is executed according to Yogitech fRMethodology flow. The main advantages of this flow, described in details in Appendix A, are the following:

- the component is split into elementary parts and the analysis is executed at such level of detail, therefore with a more accurate granularity than typical approaches based on IEC 61508 tables (where granularity is the subpart level);
- verification of safety results by means of fault injection for both permanent and transient faults executed on the real netlist and RTL of real device;
- comparison of safety results coming from fault injection validation with those coming from estimation phase, allowing a redundant double check.

In summary, with the adoptions of the safety mechanism and conditions of use reported in *Section 3.7: Conditions of use*, it is possible to achieve the integrity levels summarized in *Table 4*.

Table 4. Overall achievable safety integrity levels

MCUs used	Safety architecture	Target	Safety analysis result
1	1oo1/1oo1D	SIL2 LD	Achievable
		SIL2 HD/CM	Achievable with potential performance impact(1)
2	1oo2	SIL3 LD	Achievable
		SIL3 HD/CM	Achievable with potential performance impact(1)
	1oo2D	SIL3 LD	Achievable
		SIL3 HD/CM	Achievable with potential performance impact(1)
	2oo2	SIL3 LD	Achievable
		SIL3 HD/CM	Achievable with potential performance impact(1)

1. Note that the potential performance impact related to some above-reported target achievements is mainly related to the need of execution of periodical software-based diagnostics (refer to safety mechanism description for details). The impact is therefore strictly related to how “aggressive” the system level PST is (see *Section 3.3.1: Assumed safety requirements*).

The resulting metrics (DC and SFF) are not reported in this section but in the FMEDA, and the same happens for absolute metrics (PFH, PFD), due to

- the large number of STM32F0 series devices,
- the possibility to declare not-safety-relevant unused peripherals, and
- the possibility to enable or not the different available safety mechanism.

The FMEDA calculation sheet can be provided on demand, please refer to your local ST sales contact.

4.1.1 Safety analysis result customization

The safety analysis executed for STM32F0 series devices and contained in this safety manual are considered to be safety relevant, that is able to interfere with the safety function, to all microcontroller parts, with no exclusion. This is in line with the conservative approach to be followed during the analysis of a general-purpose microcontroller, in order to be agnostic versus the final application. This means that no STM32F0 series device has been declared as “no part” nor “no effect” and therefore all STM32F0 series devices are included in SFF computations.

In end-user applications, not all the STM32F0 series parts/modules are used for the implementation of the safety function. Requiring the implementation of the respective safety mechanism for those parts could result in an overkill; as a consequence, a dedicated analysis has been done. According to this analysis, the end user can define the selected STM32F0 series parts as “not safety relevant” under the following conditions:

- Collect rationales and evidences that the parts play no role in safety function implementation (user responsibility).
- Collect rationales and evidences that the parts do not interfere with the safety function during normal operation.
- Fulfillment of the below-reported general condition for the mitigation of the intra-MCU interferences (*Table 5*).

The end user is allowed for “not safety relevant” parts to do the following:

- Disable the part contribution from metrics computations in FMEDA;
- Not implement the related safety mechanisms listed in *Table 3: List of safety mechanisms*.

4.1.2 General requirements for Freedom From Interferences (FFI)

A dedicated analysis has highlighted a list of general requirements to be followed by end users in order to be authorized to declare selected STM32F0 series parts as “not safety relevant”. The analysis considers two situations: the part that is not used at all (disabled) or the part is used for a function that is not safety-related (for example a GPIO port driving a “power-on” signaling led on the electronic board), and considers the possible interferences due to hardware random faults affecting not-safety-relevant parts.

The requirement for the end user is to implement the safety mechanism detailed in *Section 3.6: Description of hardware and software diagnostics* despite any evaluation about their contribution for the safety metrics computations. Those safety mechanisms are reported in *Table 6*.

Table 5. List of general requirements for FFI

Diagnostic	Description
FFI_SM_0	Unused peripheral disable
FFI_SM_1	Periodical read-back of interference avoidance registers
BUS_SM_0	Periodical software test for interconnections
NVIC_SM_0	Periodical read-back of configuration registers
NVIC_SM_1	Expected and unexpected interrupt check by application software
DMA_SM_0	Periodical read-back of configuration registers

Table 5. List of general requirements for FFI (continued)

Diagnostic	Description
DMA_SM_1	Information redundancy on data packet transferred via DMA
DMA_SM_2	Information redundancy including sender/receiver identifier on data packet transferred via DMA
GPIO_SM_0	Periodical read-back of configuration registers

4.2 Dependent failures analysis

The analysis of dependent failures is important for microcontrollers. The main sub-classes of dependent failures are the Common Cause Failures (CCF). Their analysis is ruled by the IEC 61508:2 annex E that lists the design requirements to be verified to allow the use of on-chip redundancy for ICs with one common semiconductor substrate. However, based on an agreement discussed by Yogitech with TÜV Sud Automotive in the past, the annexes E.1 and E.2 apply for HFT=1 while the Annex E.3 shall be applied to every on-chip redundancy, intended also in terms of diagnostic implemented on the same silicon.

As there are no on-chip redundancy on STM32F0 series devices, the CCF quantification through the BetaIC computation method is not required. Note that in the case of Dual-MCU architectures implementing for instance1oo2 safety architecture, the end user is required to evaluate the parameter βD, which is the measure of the common-cause between the two channels) used in PFH computation.

The STM32F0 series device architecture and structure are potential sources of dependent failures. These are analyzed in the following sections. The referred safety mechanisms are described in detail in *Section 3.6: Description of hardware and software diagnostics*.

4.2.1 Power supply

Power supply is a potential source of dependent failures, because any alteration of the power the supply can affect many parts, leading to not-independent failures. The following safety mechanisms address and mitigate those dependent failures:

- VSUP_SM_1: detection of abnormal value of supply voltage;
- VSUP_SM_2: the independent watchdog has a different supply source from the digital core of the MCU, and this diversity helps to mitigate dependent failures related to the main supply alterations.

The adoption of such safety mechanisms is therefore strongly recommended despite their minor contribution to the safety metrics to reach the required safety integrity level. Refer to *Section 3.6.21: Supply voltage system* for the detailed safety mechanism descriptions.

4.2.2 Clock

System clocks are a potential source of dependent failures, because alterations in the clock characteristics (frequency, jitter) can affect many parts, leading to not-independent failures. The following safety mechanisms address and mitigate those dependent failures:

- CLK_SM_1: the clock security system is able to detect hard alterations (stop) of system clock and activate the adequate recovery actions.
- CLK_SM_2: the independent watchdog has a dedicated clock source. The frequency alteration of the system clock leads to the watchdog window violations by the triggering routine on the application software, leading to the MCU reset by watchdog.

The adoption of such safety mechanism is therefore strongly recommended despite their minor contribution to the safety metrics to reach the required safety integrity level. Refer to *Section 3.6.22: Reset and clock control subsystem* for detailed safety mechanisms description.

4.2.3 DMA

DMA is a widely shared resource involved in data transfers operated mainly by all peripherals. Failures of DMA interfere with the behavior of the system peripherals, leading to not independent failures. The safety mechanism addressing such independent failures, which are described in *Section 4.1.2: General requirements for Freedom From Interferences (FFI)*, guarantee the Freedom from Interference:

- DMA_SM_0,
- DMA_SM_1,
- DMA_SM_2.

The adoption of such safety mechanism is therefore strongly recommended despite their minor contribution to the safety metrics to reach the required safety integrity level. Refer to *Section 3.6.6: DMA* for detailed safety mechanisms description.

4.2.4 Internal temperature

The abnormal increase of the internal temperature is a potential source of dependent failures, because it can affect many MCU parts and therefore lead to not-independent failures. The safety mechanism to be used to mitigate this potential effect is the following:

- VSUP_SM_3: the internal temperature read and check allow the user to quickly detect potential risky conditions before they lead to a series of internal failures. Refer to *Section 3.6.21: Supply voltage system* for the detailed safety mechanism descriptions.

5 List of evidences

The Safety Case Database stores all the informations related to the safety analysis performed to derive the results and conclusions reported in this safety manual.

In detail, the Safety Case Database is composed of the following:

- Safety Case with the full list of all safety analysis related documents;
- Yogitech internal FMEDA tool database for the computation of the safety metrics, including the estimated and measured values;
- Safety Report, the document that describes in detail the safety analysis executed on STM32F0 series devices and the clause-by-clause compliance to IEC 61508;
- All paper works, academic studies and Yogitech internal white papers/application notes quoted in the Safety Report to support the analysis;
- Yogitech internal fault injection campaign database including Safety Verifier settings, injection logs and results.

The above-described contents are not publicly available and are available for possible competent bodies audit and inspections.

Appendix A Overview of fRMethodology

This section provides an overview of Yogitech faultRobust Methodology (fRMethodology).

A.1 The essence of fRMethodology

The quality and completeness of the safety analysis is necessary to

- identify the failure modes of a microcontroller,
- plan the corresponding mitigations, and
- establish their effectiveness, that is their diagnostic coverage.

These are key points to consider for the functional safety applied to integrated circuits.

A typical black-box functional safety analysis is based on the collection of data from block diagrams and component user manuals. It assumes the following:

1. an equal failure mode distribution,
2. an equal split between dangerous and safe failures, and
3. it claims a diagnostic coverage higher than 60% without a detailed quantitative analysis and accurate safety verification.

However, the complexity of modern integrated circuits in terms of number of transistors, CPU features, bus architecture, memory size and the complexity of the safety application are such that the adoption of a black-box approach is no longer realistic. A functional safety analysis exclusively based on the aforementioned items leads to an unacceptable gap between the estimated and measured safety integrity levels (A/SIL).

In stark contrast to the “black-box” approach, Yogitech enables the highest safety integrity levels for integrated circuits to be achieved by means of its fRMethodology. The Yogitech fRMethodology is a patented white-box approach to perform and verify/validate functional safety analyses and safety-oriented design exploration of integrated circuits, according to different functional safety standards.

In essence, fRMethodology consists of:

- Dividing the component into elementary parts by using automatic tools to guarantee the completeness of the analysis;
- Computing the safety metrics by looking to the fault models of each elementary part, attributing the failure rate, the dangerousness and estimating the diagnostic coverage of the planned HW or SW safety mechanisms;
- Verifying/Validating the safety metrics by an extensive fault injection campaign simulating permanent, transient and common cause faults.

A.2 fRMethodology and its flow

fRMethodology is approved by TÜV SÜD as the flow to assess and validate the safe failure fraction of given integrated circuit in adherence to IEC 61508 (statement included in the certificate of Yogitech’ fRMEM product, Z10 06 11 61674 001). fRMethodology has been extended by Yogitech to ISO 26262, benefiting from Yogitech active role as member of the ISO-TC22-SC3-WG16 (ISO 26262) international working group. In the ISO 26262 international working group, Yogitech is a leading author of the Annex A of part 10, that is

about how to deal with microcontrollers in the context of an ISO 26262 application. Moreover, Yogitech extended both IEC 61508 and ISO 26262 requirements to analogue circuits thanks to its consolidated experience in analogue design and analogue verification.

In essence, the fRMethodology flow is intended to assist engineers in making the safety case for their designs with regard to the functional safety standards ISO 26262 and IEC 61508. It comprises:

- Splitting the component or system into elementary parts;
- Identifying the respective fault models and failure modes;
- Estimating the failure modes distribution;
- Using the relevant failure mode data to compute safety metrics;
- Performing sensitivity analyses by changing architectural and/or technology parameters;
- Verifying the results by fault injection.

Figure 6 summarizes the flow and *Table 6* shows the level of detail of the analysis required at each phase.

Figure 6. The fRMethodology flow for IEC 61508

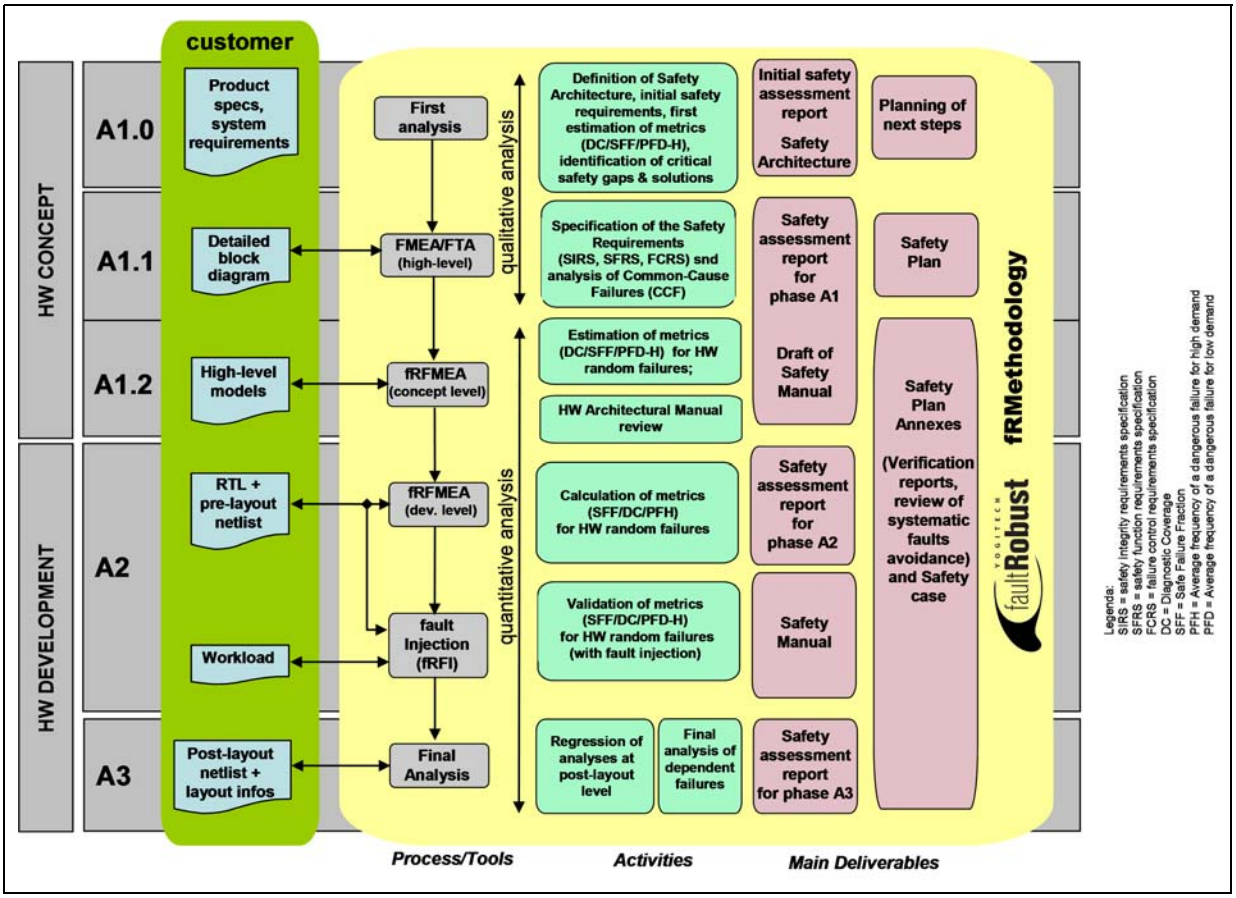


Table 6. Level of detail in fRMethodology

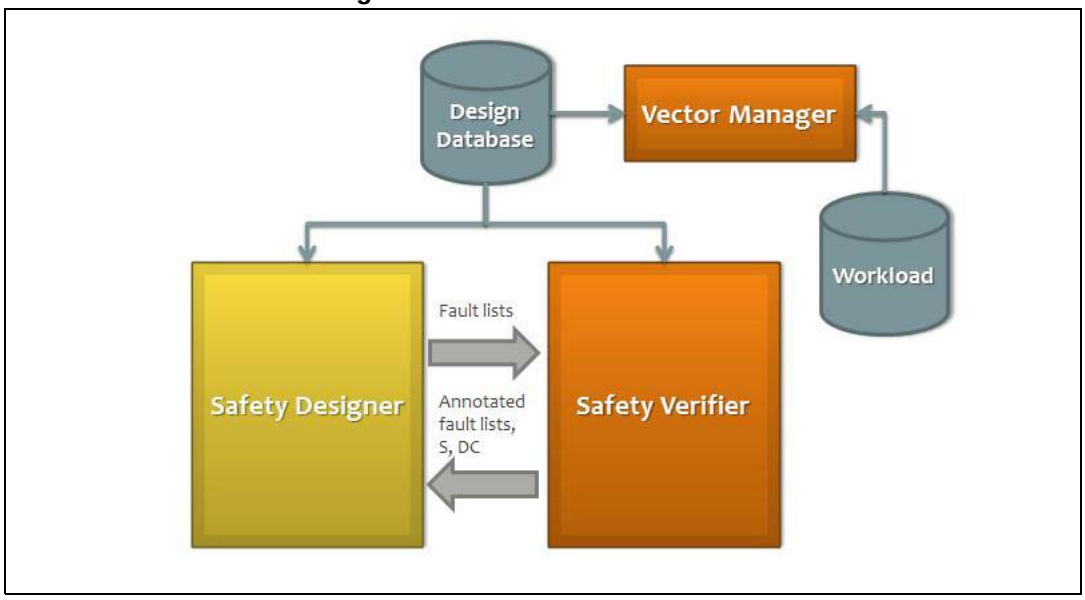
Phase	Input from customer	Level of detail	Accuracy of metrics	Verification type
A1.0	Block diagrams, preliminary gate / flip-flop count	Part-level	Initial Estimated figures driven by info from standard and experience with similar architectures	Inspection
A1.1 A1.2	+ detailed specifications of the component or IP, and detailed gate / flip-flop count estimation	Sub-part-level	More detailed estimation based on initial design database	
A2.1	+ RTL and pre-layout netlist	Gate-level	Accurate estimation on concrete design data	Inspection
A2.2			Measured at pre-layout level	Fault injection
A3	+ post-layout information	Gate-level	Measured at post-layout level	Fault injection

A.3 fRTools

Due to the complexity of modern integrated circuits, as recognized by functional safety standards like ISO 26262, the completeness of the analysis can be guaranteed only through automation. For this reason, fRMethodology is supported by a set of EDA tools:

- **Safety Designer**, a cockpit to determine failure rates, failure modes and failure modes distribution of integrated circuits. This tool is specific for integrated circuits and supports the safety engineer all the way through the safety analyses, from FMEA to FMEDA and FTA, including dependent failure analysis.
- **Safety Verifier**, a tool that covers the validation of the safety metrics (safeness and diagnostic coverage of HW and SW mechanisms) by managing a fault injection campaign on a device (or part of it). The Safety Verifier allows the user to partition the campaign according to the steps defined by the methodology and to the needs of complexity of the design. It manages all the necessary simulations (run by an external fault or functional simulator, depending on the fault model) and integrates the results into a comprehensive view for the portions of hardware injected. Permanent, transient and bridging fault models are supported.
- **Vector Manager**, a tool that supports the fault simulation flow, on which the Safety Verifier is based, decoupling it from the actual verification environment. The fault manager plugs into the customer's verification suite and allows the user to extract all the vectors being fed into the design, whatever is the language used. These vectors will be then used by the fault injector for the fault simulation.

Figure 7. Overview of the fRTools



Appendix B Examples of safety architectures – Informative

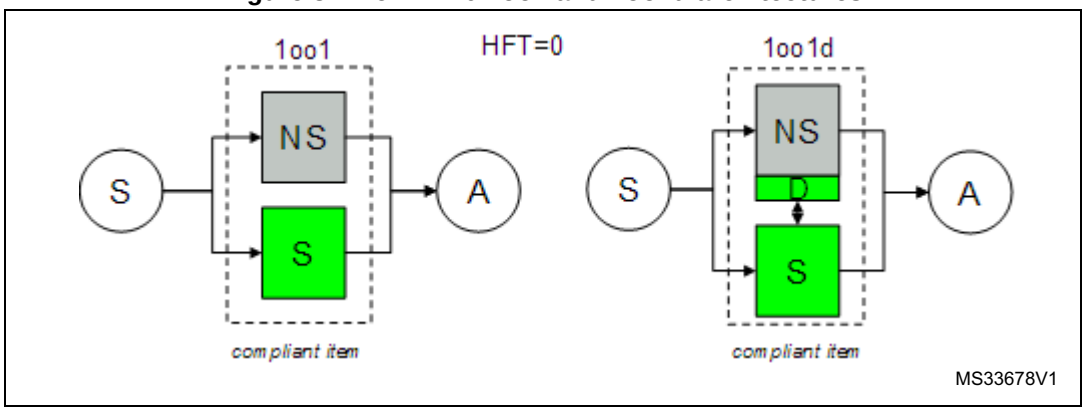
This section includes complementary information to *Section 3*.

Note: This section is informative only, and the proposed architectures and/or solution are to be considered just as an example.

B.1 Conceptual block diagrams of the target safety architectures

From a principle point of view, the safety architectures targeted in this document can be represented with one of the following block diagrams – depending if an HFT=0 (1oo1, 1oo1d) or HFT=1 (1oo2 or 1oo2d) architecture is selected, as further detailed in the following sections of this document. In the block diagrams: “S” represents the part of the compliant item performing the safety function, “D” the one performing a separate “diagnostic” function and “NS” the non-safety related function(s). For the 1oo2 architecture, SC1 and SC2 represent the same safety function but redundant(c).

Figure 8. The HFT=0 1oo1 and 1oo1d architectures



c. As shown further in this document, the redundancy can/shall be implemented by means of diverse functions. But they still perform the same safety function.

Figure 9. The HFT=1 1oo2 and 1oo2d architectures

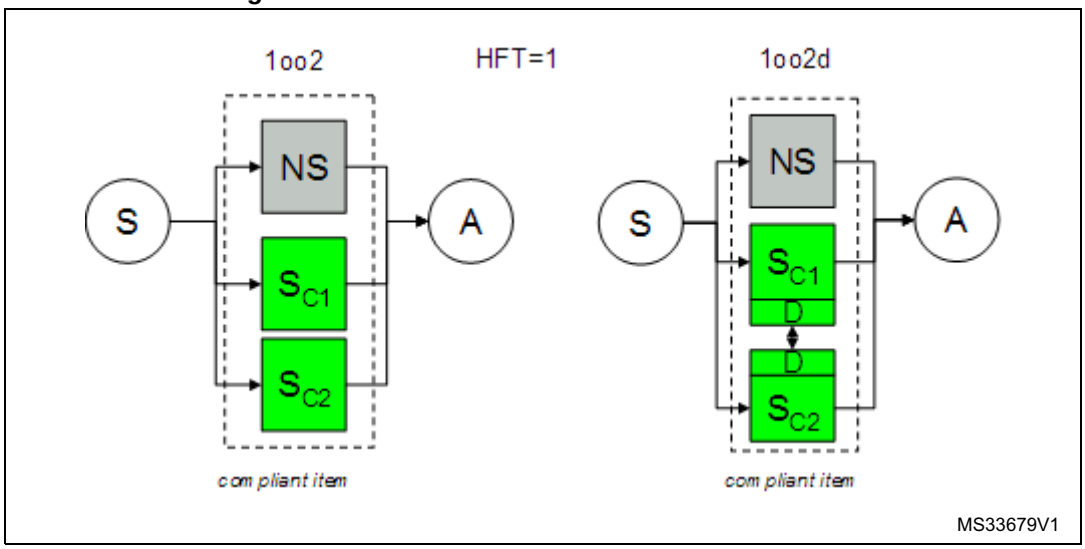
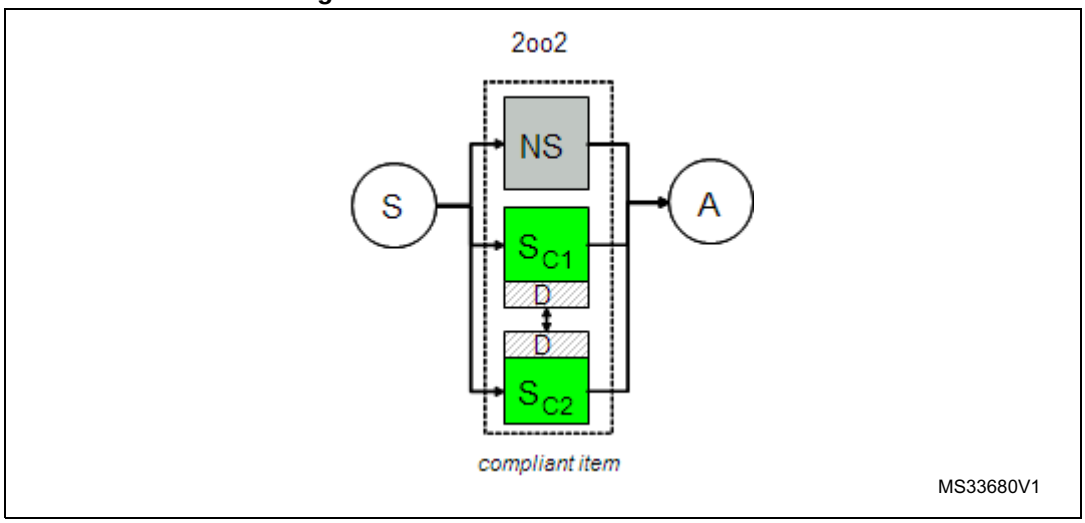


Figure 10. The HFT=1 2oo2 architecture



The following considerations apply:

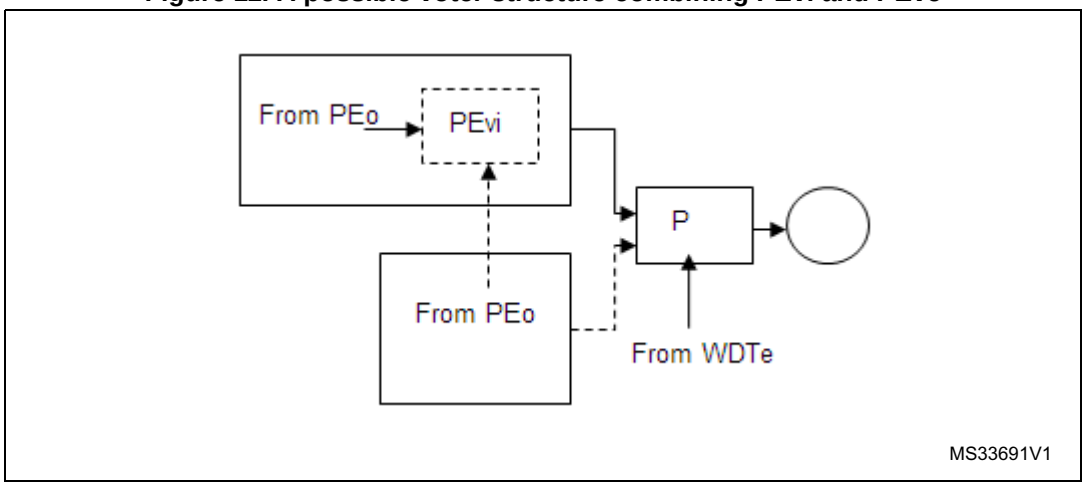
- It is assumed that only one safety function is performed or if many, all functions are classified with the same SIL and therefore they are not distinguishable in terms of their safety requirements;
- The “D” functions can be implemented using a “level” or “layered” approach, as further discussed in the following of this document;
- It is assumed that there are no “not safety relevant” functions mixed with the safety functions.
- The voter is not shown in 1oo2/1oo2D/2oo2 architectures. Note that in 1oo2D voter is affected by the diagnostic result
- In 2oo2 the diagnostic section is optional

B.2 Considerations about voter implementation

The general concept of the compliant item shown in *Section 3.2.2: Safety functions performed by the compliant item* foresees the presence of a voter/actuator PEv, that could be implemented by a combination of internal voter (PEvi) and external voter (PEve).

In absence of a dedicated piece of HW inside the STM32F0 series device that can take the role of PEvi, the structure of the voter can be organized as shown in *Figure 11*. This is still a general structure in the sense that the partitioning of voting functions between PEvi and PEve shall be decided by the end-customer based on the complexity of the voting algorithm to be performed.

Figure 11. A possible voter structure combining PEvi and PEve



The advantages of the internal PEvi are the following:

- Possibility to operate more elaborate types of voting (for example dynamic principles) and/or to provide conditioning signals (for example synchronization signals) to ease PEve process of the PEo output, and simplify the external circuit that implements the PEve.
- Possibility to cooperate to guarantee the needed coverage of the external PEve, by means of partially redundant decisions. As a consequence of the requirement in IEC 61508:2 Annex E.2.b, those external “measures shall achieve medium effectiveness (see also A.3) as minimum”, that is they must be implemented by means of “Tests by redundant hardware”, “Monitored redundancy”, etc…

The disadvantages of having an internal PEvi are:

- the possibly of more I/Os to be exchanged between MCU and the PEve;
- the need for a separation between the software functionalities related to PEc/PEo and PEvi.

On the other hand, the advantages of not having an internal PEv, that is just using the PEo outputs to drive the PEve, are:

- a simpler overall voting mechanism;
- the possibly of less I/Os to be exchanged.

The disadvantages of having just one external PEve are:

- this architecture is possible only if the voting algorithm is relatively simple – like a continuous comparison between few static signals;
- it is more difficult to implement tests or redundancy to reach the coverage requirements for the voter itself.

In general, with respect to the assumed requirement on the safe state described in *Section 3.3.1: Assumed safety requirements*, one role of the PEvi and PEve shall also be to achieve or maintain the safe state of the system in case the OS cannot be informed or cannot properly react.

Since the safe state of the system is not very well defined, it is not possible to define some standard and precise requirements about the structure of the voter in order to achieve or maintain the safe state. Therefore, only general Conditions of Use (CoU) can be defined.

Examples of such generic CoUs are given hereafter:

- provide a mean to inform the PEvi and then the PEve about the error conditions that cannot be resolved by the OS;
- provide a mean for the WDTe to communicate with the PEve in order to achieve or maintain the safe state in case of a common-cause failure in the SC logic.

Appendix C Change impact analysis for other safety standards

The safety analysis reported in this user manual is executed according to IEC 61508 safety norm. In this appendix a change impact analysis with respect to different safety standard is executed. The following topics are considered for each addressed safety norm:

- Differences in the suggested hardware architecture (architectural categories), and how to map what is foreseen in the new safety norm on the standard safety architectures of IEC 61508.
- Differences in the safety integrity level definitions and metrics computation methods, and how to recompute and judge the safety performances of STM32F0 series devices according to the new standard.
- Work products required by the new safety norms, and how to remap or rework if needed existing ones resulting as output of the IEC 61508 compliance activity.

The safety standards examined within this change impact analysis are the followings:

- ISO 13849-1:2006, ISO 13849-2:2010 – Safety of machinery / Safety-related parts of control systems,
- IEC 62061:2012-11, ed. 1.1 –Safety of machinery / Functional safety of safety-related electrical, electronic and programmable electronic control systems,
- IEC 61800-5-2:2007, ed.1.0 –Adjustable speed electrical power drive systems – Part 5-2: Safety requirements – Functional,
- IEC 60730-1:2010, ed. 4.0 –Automatic electrical controls for household and similar use – Part 1: General requirements,
- ISO 26262:2010 – Road vehicles - Electrical and/or electronic (E/E) systems.

C.1 ISO 13849-1 / ISO 13849-2

The ISO 13849-1 is a Type B1 standard. It offers applicable solutions for the machinery domain of those safety general aspects outlined in the IEC 61508 standard.

This ISO standard provides a guideline for the development of safety-related parts of control systems (SRP/CS) including programmable electronics, hardware and software, requirements here supplied are compatible with the methodology of design defined in IEC 62061.

Table 1 in ISO 13849-1 standard identifies the technologies which are used for the implementation of control systems for machines in the scope of ISO 13849-1 or IEC 62061. It results that complex electronics is restricted to those architectures defined in §6.2 of the ISO standard and with the achievable integrity level, here defined as Performance Level (PL) up to PLr = d, that is SIL2 HD/CM. On the contrary, complex electronics in the scope of IEC 62061 is suitable up to SIL 3 HD/CM since this standard is properly focused on the electrical/electronic part of controls.

The §6.2 of ISO 13849 identifies five categories for the basic parameters, DC, MTTFd and CCF, reflecting the expected resistance to faults of SRP/CS under design and needed to achieve the required PLr. For each category, the standard suggests a typical architecture that meets the related requirements.

C.1.1 Architectural categories

The section §6.2 of ISO 13849 identifies five categories for the basic parameters, DC, MTTFd and CCF, reflecting the expected resistance to faults of SRP/CS under design and needed for achieving the required PLr. For each category, the standard suggests a typical architecture that meets the related requirements.

Considering the ISO 13849 architectural categories defined in §6.2 and focusing on microcontrollers, *Table 7* presents a summary for end users willing to develop Logic Solver units suitable for safety critical channels and performing a defined safety function.

The assumptions are listed hereafter:

1. The safety function is realized by combining in series the elements (SRP/CS) input system, signal processing unit, output system.
2. The SRP/CSs elements may be assigned to one and/or different categories and different PLs.
3. The safety function is completely in the scope of the end user application.
4. The STM32F0 series MCU with the adoption of safety mechanism described in this safety manual as single compliant item is by itself suitable for CM application up to PLd (SIL2).

The ISO 13849 architectural categories for Logic Solver are shown in *Table 7*.

Table 7. IEC 13849 architectural categories

Cat.	Ref. §	Summary	Designated architecture of Logic	Block diagram
B	6.2.3	The main category; occurrence of one fault can lead to the loss of the safety function. No need of DC and CCF (usually single channel), MTTFd is low/medium. Highest achievable is PL = b	Single channel architecture, one MCU in 1oo1 Refer to *Section 3* Compliant item's MTTFd = high	*Figure 12*
1	6.2.4	Enforcing category B requirements by adopting solutions based on "well tried components" for safety critical application and "well tried" safety principles. A microprocessor is not classified as a "well tried" component. No need of DC and CCF (usually single channel), MTTFd is high. Highest achievable is PL = c.	Single channel architecture, one MCU in 1oo1 Refer to *Section 3* Compliant item's MTTFd = high	*Figure 12*
2	6.2.5	With respect to category 1, it is expected to include in the architecture a test equipment performing checks on the safety function and reporting its loss. Overall DC is low, CCF shall be evaluated, MTTFd can range from low to high allowing up to PL = d.	Single channel architecture, one MCU in 1oo1d Refer to *Section 3* Compliant item's MTTFd = high TE is in charge of End User, PL = d	*Figure 13*

Table 7. IEC 13849 architectural categories (continued)

Cat.	Ref. §	Summary	Designated architecture of Logic	Block diagram
3	6.2.6	With respect to category 1, it is expected to have fault detection mechanisms and any single fault occurrence does not lead the loss of the safety function.Overall DC is low, CCF shall be evaluated for the channels, MTTFd can range from low to high allowing up to PL = d	Double channel architecture, two identical MCUs in 1oo2 or 2oo2d Refer to *Section 3* Continuous testing / monitoring Compliant item's MTTFd = high	*Figure 14*
4	6.2.7	With respect to category 1, it is expected to have fault detection mechanisms and any single fault occurrence does not lead the loss of the safety function. Overall DC is high, CCF shall be evaluated for the channels, MTTFd is high allowing PL = e	Double channel architecture, two identical MCUs in 1oo2 or 2oo2d Refer to *Section 3* Continuous testing / monitoring Compliant item's MTTFd = high PLe achievable	*Figure 14*

Figure 12. Block diagram for IEC 13849 Cat. B and Cat. 1

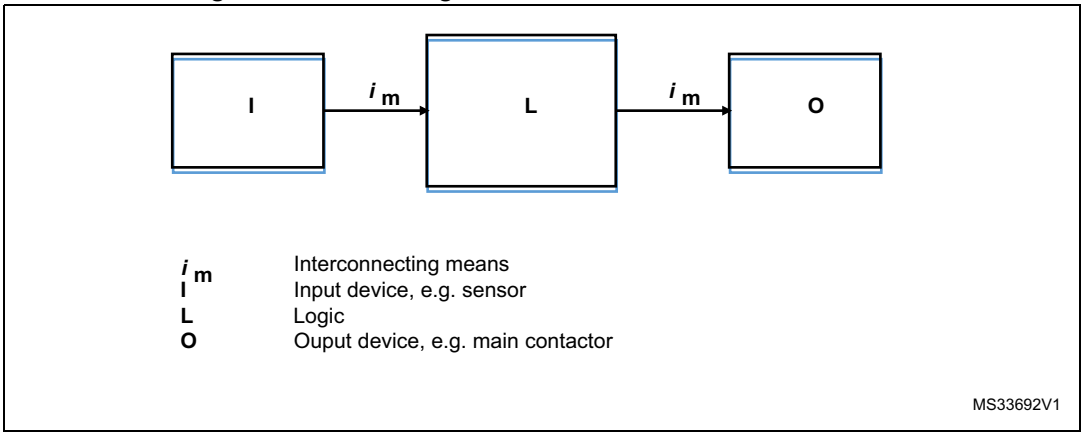
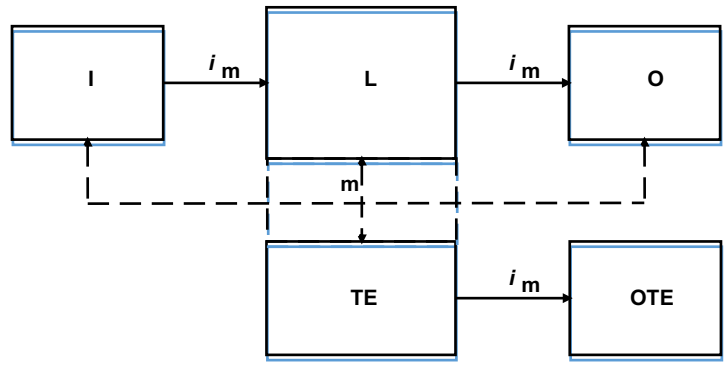


Figure 13. Block diagram for IEC 13849 Cat. 2



i_m	Interconnecting means
I	Input device, e.g. sensor
L	Logic
O	Output device, e.g. main contactor
m	monitoring
TE	Test equipment
OTE	Output of TE

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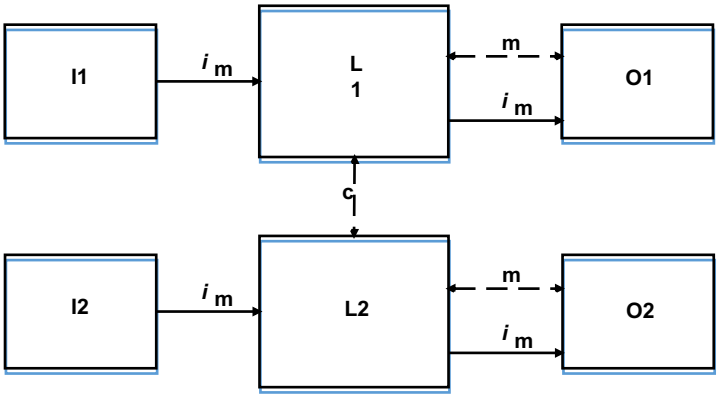
Figure 14. Block diagram for IEC 13849 Cat. 3 and Cat. 4



Im	Interconnecting means
I1, I2	Input device, e.g. sensor
L1, L2	Logic
O1, O2	Output device, e.g. main contactor
m	monitoring
cm	cross monitoring

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C.1.2 Safety metrics recomputation

Appendix C of ISO 13849 presents tables of standardized MTTFd for the various electric/electronics components. However, table C.3 in ISO 13849 points to ICs manufacturer's data while attempting to classify MTTFd for programmable ICs. As a consequence, Yogitech fRMethodology results even if native for IEC 61508 but definitely more and more accurate in the definition of dangerous failures identification can be re-mapped in ISO 13849 domain.

When for a certain component PFH << 1 we can assume that PFH is the opposite of MTTFd, that is MTTFd = 1 / PFH [years].

In IEC 61508, part 6 B.2.3.2 it is stated “the system is made of components completely and quickly repairable with constant failure and repair rates (for example dangerous detected failures)”. This is not aligned with the assumptions of the report “No repair, not de-energizing in case in case of a dangerous detected failure”.

From the reliability theory, MTTF (the inverse of λ and PFH) is a metric applicable only to not reparable systems. Nowadays it is a common practice to use MTBF also for not reparable systems where MTBF has to be understood as the average time for the first (and only) failure of the equipment; in this case MTBF is equal to MTTF.

Moreover the standard definition of diagnostic coverage §3.1.26 warrants the previously performed estimations for DC, refer to §3.1.1.7 of this report, obtained from fRMethodology application are still valid in the scope of ISO 13849-1. The DC for each single component has the same meaning of the IEC 61508 metric. However, this standard defines the concept of DC_{avg} applicable to the whole SRP/CS in the form of the equation defined in Annex E, formula E.1, where the contribution of each part of the control system is weighted with respect to MTTF of the various subsystems of the channel. The standard denies any possibility of fault exclusion while calculating DC_{avg} (ISO13849-2 Tab.D.21 no exclusion allowed) and this is the same assumption of fRMethodology. Application of fRMethodology to STM32F0 produces a complete classification of all possible failure modes without any exclusion being compliant to the standard’s requirements.

It is necessary to calculate the DC_{avg} only for subsystem made of a 2 MCUs architecture by applying the formula:

$$DC_{avg} = \frac{\frac{DC_{MCU1}}{MTTF_{MCU1}} + \frac{DC_{MCU2}}{MTTF_{MCU2}}}{\frac{1}{MTTF_{MCU1}} + \frac{1}{MTTF_{MCU2}}}$$

For two identical MCUs, that is devices having the same DC and MTTF, DC_{avg} = DC.

An evaluation of the possible common failure modes is required for any architectural solution implemented with two channels. This standard defines a simplified approach with respect to IEC 61508 approach.

Table 7 of the IEC 13849 standard provides a simplified procedure for PL evaluation of SRP/CS based on category, DC_{avg} and MTTFd. Each architectural solution analyzed by Yogitech with fRMethodology results in PFH producing high values of MTTF.

C.1.3 Work products

Table 8 lists the work products required by the IEC 13849, and how to map these into available work products from IEC 61508 compliance activity:

Table 8. IEC 13849 work product grid

ISO 13849-1		STM32F0 series IEC 61508 document
Information to be provided	**ISO 13849-1 Part-Clause**	
Safety functions provided by the SRP/CS	10 Technical documentation	End user responsibility
Characteristics of each safety function		
Exact points at which the safety-related part(s) start and end		
Environmental conditions		
Performance level (PL)		
Category or categories selected		
Parameters relevant to the reliability (MTTFd, DC, CCF and mission time)	10 Technical documentation	STM32F0 safety manual
Measures against systematic failure		
Technology or technologies used;		
All safety-relevant faults considered		
Justification for fault exclusions (see ISO 13849-2)	10 Technical documentation	End user responsibility
Design rationale (e.g. faults considered, faults excluded)	10 Technical documentation	STM32F0 safety manual
Measures against reasonably foreseeable misuse		
Dated reference to this part of ISO 13849 (that is “ISO 13849-1:2006”);	11 Information for use	
Category (B, 1, 2, 3, or 4)		
Performance level (a, b, c, d, or e)		
Use of de-energization (see ISO 13849-2)	G.2 Measures for the control of systematic failures	
Measures for controlling the effects of voltage breakdown, voltage variations, overvoltage, under voltage		
Measures for controlling or avoiding the effects of the physical environment (for example, temperature, humidity, water, vibration, dust, corrosive substances, electromagnetic interference and its effects)	G.2 Measures for the control of systematic failures	End user responsibility
Program sequence monitoring shall be used with SRP/CS containing software to detect defective program sequences		
Measures for controlling the effects of errors and other effects arising from any data communication process (see IEC 61508-2:2000, 7.4.8)		
Failure detection by automatic tests	G.2 Measures for the control of systematic failures	STM32F0 safety manual

Table 8. IEC 13849 work product grid (continued)

ISO 13849-1		STM32F0 series IEC 61508 document
Information to be provided	**ISO 13849-1 Part-Clause**	
Computer-aided design tools capable of simulation or analysis	G.3 Measures for avoidance of systematic failures	End user responsibility
Simulation	-	
Safety-related specification for machine control	App. J, tab.J.1 (SW)	End user responsibility
Definition of the control architecture		
Software descriptions	App. J, tab.J.1 (SW)	Software User Guide (End User responsibility because in charge of implementing software-based diagnostics)
Function block modeling	App. J, tab.J.1 (SW)	SW requirements specification (End User responsibility because in charge of implementing software-based diagnostics)
Encoding comments in the code	App. J, tab.J.1 (SW)	Code inspection results (End User responsibility because in charge of implementing software-based diagnostics)
Encoding re-reading sheets		
Correspondence matrix	App. J, tab.J.1 (SW)	Software module test specification Software system integration test specification Programmable electronic hardware and software integration tests specification (End User responsibility because in charge of implementing software-based diagnostics)
Test sheets	App. J, tab.J.1 (SW)	Software module test report Software system integration test report Programmable electronic hardware and software integration tests report SW verification report (End User responsibility because in charge of implementing software-based diagnostics)

C.2 IEC 62061:2012-11

This standard is applicable in the specification, design and verification/validation of Safety-Related Electrical Control Systems (SRECS) of machines. SRECS is the electrical/electronic control system of the machine which failure could lead to reduction/loss of safety. SRECS implements a Safety-Related Control Function (SRCF) to prevent any increase of the risk.

With respect of the safety lifecycle, the scope of this standard is limited from safety requirements allocation to safety validation.

IEC 62061 is the special standard for the machine domain within the framework of the more generic IEC 61508:2010. Since it is just an application standard, IEC 62061 is not strict with respect to the technical solutions. Moreover it is focused on electrical, electronic and programmable electronic parts of safety-related control systems.

Note that §3.2.26 and §3.2.27 in IEC 62061 apply only to SRECS in HD/CM, suitable for the machines domain. LD equipment are still ruled by IEC 61508 requirements.

The close relationship with IEC 61508:2010 is synthesized by the main assumption that the design of complex electronic components as subsystems or elements of subsystems has to be compliant with requirements of IEC 61508:2010 part 2, Route 1H, ref. to §7.4.4.2. Coming from the IEC 62061 definition §3.2.8, natively a microprocessor has to be considered as a complex component.

For this reason, the previously obtained results of the application of fRMethodology for the STM32F0 series item (refer to *Section 4: Safety results*), in the scope of IEC 61508 are still applicable also in the machines context ruled by IEC 62061.

End-users can effectively adopt the STM32F0 series compliant item to design SRECS suitable for the achievement of SIL2 or SIL3 (by adopting two STM32F0 series MCUs) machines control loops.

The standard defines as “subsystem” (refer to §3.2.5) the level of parts for a system architecture where a dangerous failure could lead to the loss of the safety function.

Concerning the integrity levels achievable for subsystems, the standard suggests a classification based on HFT and SFF as shown in *Table 9*.

Table 9. SIL classification versus HFT

SFF	HFT		
	0	1	2
<60%	Not allowed	SIL1	SIL2
60% - <90%	SIL1	SIL2	SIL3
60% - <99%	SIL2	SIL3	SIL3
≥90%	SIL3	SIL3	SIL3

SIL 3 is the highest requirement for SRCF in this context. SIL 4 is out of scope since the final outcome of the development is a control system for one machine only.

For the designer, the SIL values listed in the table has to be seen as the SILCL for the subsystem where SILCL is the maximum SIL claimable for a SRECS subsystem, as defined in IEC 62061, §3.2.24.

C.2.1 Architectural categories

The standard in §6.7.8.2 defines a set of basic system architectures to be used for the design of SRECS implementing their SRCFs. A key point is the definition of “subsystem”, refer to §3.2.5, as the level of parts for a system architecture where a dangerous failure could lead to the loss of the safety function.

Focusing on the microcontrollers, IEC 62061 proposed architectures are here quickly summarized for supporting end users in the development of their Logic Solver units usable as subsystems for the implementation of a SRCF.

The assumptions for the correct understanding of the architectures are listed hereafter:

1. The SRCF is completely in the scope of the end user.
2. The STM32F0 series device with the adoption of safety mechanism described in this safety manual as single compliant item is by itself suitable for applications up to SILCL 2.
3. Two identical STM32F0 series devices with the adoption of safety mechanism described in this Manual shall be used for achieving HFT ≠ 0, when required by basic architectures.
4. For a microcontroller, the parameter T1, mentioned in the standard as the minimum between service life or proof test, is intended as the lifetime (mission time) assumed equal to 20 years, as per *Section 3.3.1: Assumed safety requirements* of this Manual.

Table 10. IEC 62061 architectural categories

Cat.	Ref. §	Summary	Basic architecture of Logic	Block diagram
A	6.7.8.2.2	Equivalent of 1oo1, with HFT = 0, no diagnostic function(s). Overall PFH_{DssA} is the probability of dangerous failure of MCU	Single channel architecture, one MCU in 1oo1, n=1 $PFH_{DssA} = \lambda_{De1}\left[\frac{1}{Hours}\right]$ – SILCL = 1 if SFF < 90% – SILCL = 2 if 90 ≤ SFF < 99% – SILCL = 3 if SFF ≥ 99%	*Figure 15*
B	6.7.8.2.3	Equivalent to 1oo2 with HFT = 1, a single failure does not lead to the loss of SRCF. No diagnostic function(s).	Dual channel architecture with two identical MCUs – SILCL = 1 if SFF < 60% – SILCL = 2 if 60% ≤ SFF < 90% – SILCL = 3 if SFF ≥ 90% In this case: $\lambda_{De1} = \lambda_{De2} = \lambda_{De}$ $\lambda_{DssB} = (1-\beta)^2 \times \lambda_{De}^{\,2} \times T_1 + \beta \times \lambda_{De}$ For β factor see *Section 4.2*	*Figure*

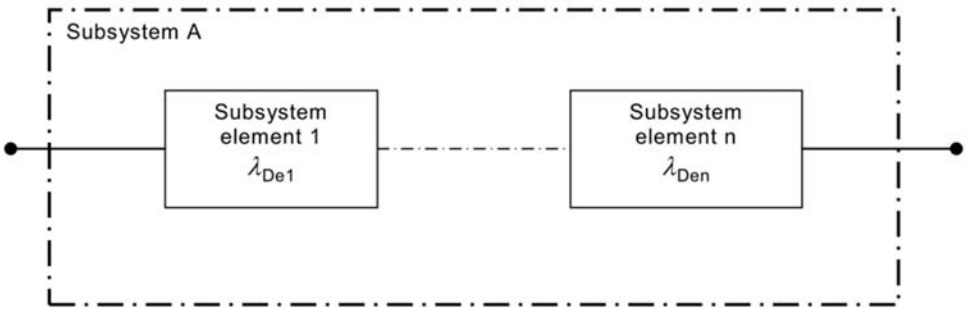
Table 10. IEC 62061 architectural categories (continued)

Cat.	Ref. §	Summary	Basic architecture of Logic	Block diagram
C	6.7.8.2.4	It is the equivalent of 1oo1d with a diagnostic function that initiates a reaction function as a dangerous failure happens on SRCF. NOTE: diagnostic function provides the Logic Solver with a diagnosis of an external subsystem, e.g. the actuator	Single channel architecture, one MCU in 1oo1, n=1 Diagnostic function is in charge of End User – SILCL = 1 if SFF < 90% – SILCL = 2 if 90 < SFF < 99% – SILCL = 3 if SFF ≥ 99% $\lambda_{DssC} = \lambda_{De1}(1 - DC_1)$ DC (Diagnostic Coverage) as resulting from FMEDA $PFH_{DssC} = \lambda_{DssC}\left[\frac{1}{Hours}\right]$	*Figure 17*
D	6.7.8.2.5	Any single failure does not lead to a loss of the SRCF; it is equivalent to 1oo2d with HFT = 1, with diagnostic function(s). NOTE: diagnostic function provides the Logic Solver with a diagnosis of an external subsystem, e.g. the actuator	Dual channel architecture with two identical MCUs Diagnostic function is in charge of End User – SILCL = 1 if SFF < 60% – SILCL = 2 if 60% ≤ SFF < 90% – SILCL = 3 if SFF ≥ 90% For β factor see *Section 4.2* DC (Diagnostic Coverage) as resulting from FMEDA In this case: – $\lambda_{De1} = \lambda_{De2} = \lambda_{De}$ – T2 has to be defined at Logic Solver level by End User	*Figure 18*

Figure 15. Block diagram for IEC 62061 Cat. A

$$\lambda_{DssA} = \lambda_{De1} + \ldots + \lambda_{Den} \qquad (A)$$

$$PFH_{DssA} = \lambda_{DssA} \times 1h$$



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$$\lambda_{DssB} = (1-\beta)^2 \times \lambda_{De1} \times \lambda_{De2} \times T_1 + \beta x \cdot (\lambda_{De1} + \lambda_{De2})/2 \qquad (B)$$

$$PFH_{DssB} = \lambda_{DssB} \times 1h$$

T_1 is the proof test interval of lifetime, whichever is the smaller

β is the susceptibility to common cause failures

Figure 16. Block diagram for IEC 62061 Cat. B

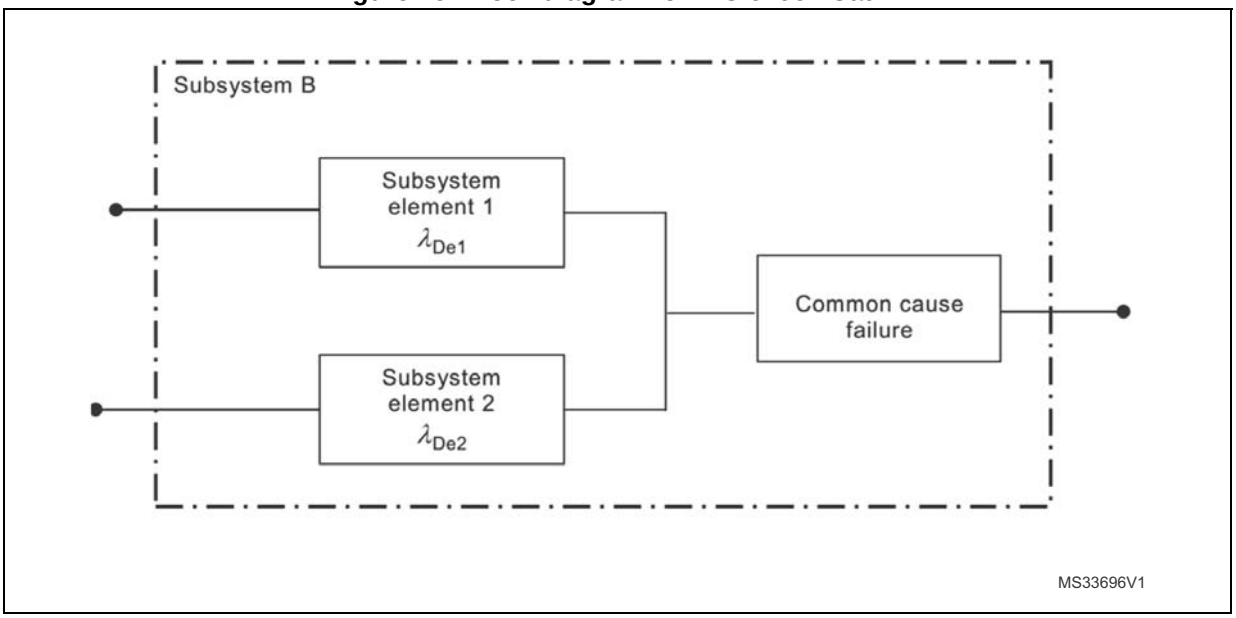
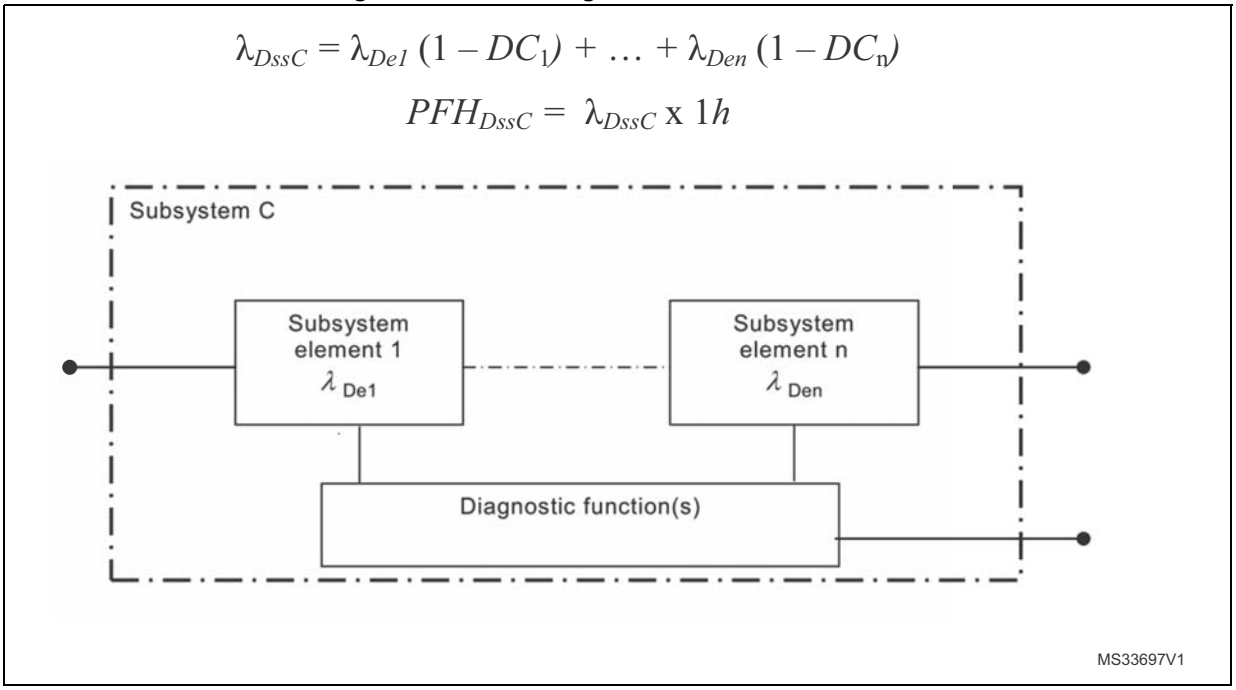


Figure 17. Block diagram for IEC 62061 Cat. C

$$\lambda_{DssC} = \lambda_{De1}(1 - DC_1) + \ldots + \lambda_{Den}(1 - DC_n)$$

$$PFH_{DssC} = \lambda_{DssC} \text{ x } 1h$$



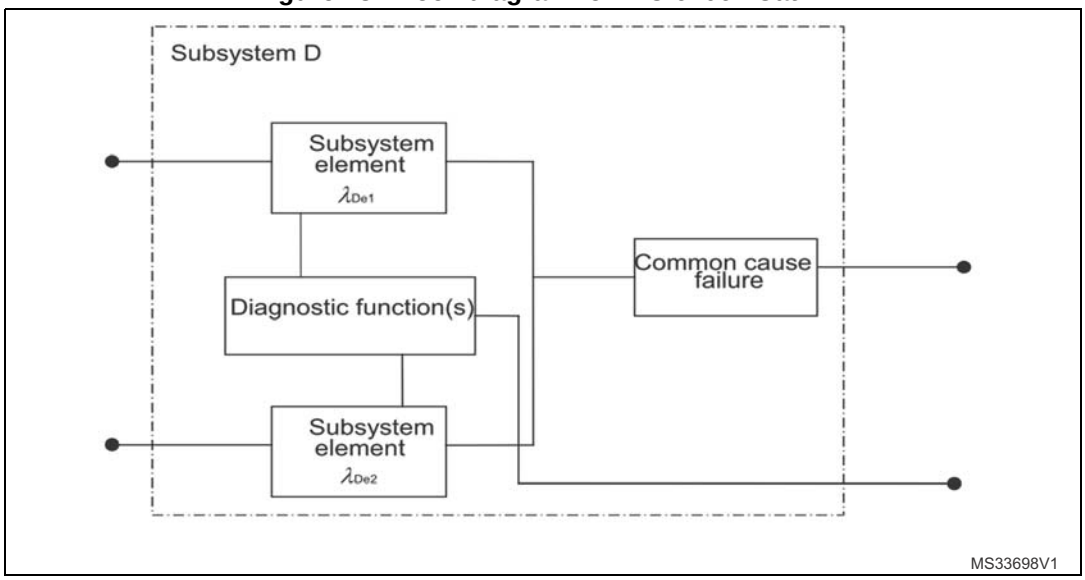
$$\lambda_{DssD} = (1-\beta)^2 \cdot \{[\lambda_{De}^2 \times 2 \times DC] \times T_2/2 + [\lambda_{De}^2 \times (1-DC) \times T_1]\} + x\lambda_{De}$$

$$PFH_{DssD} = \lambda_{DssD} \times 1h$$

λ_{De} is the dangerous failure rate of subsystem element 1 or 2

DC is the diagnostic coverage of subsystem element 1 or 2

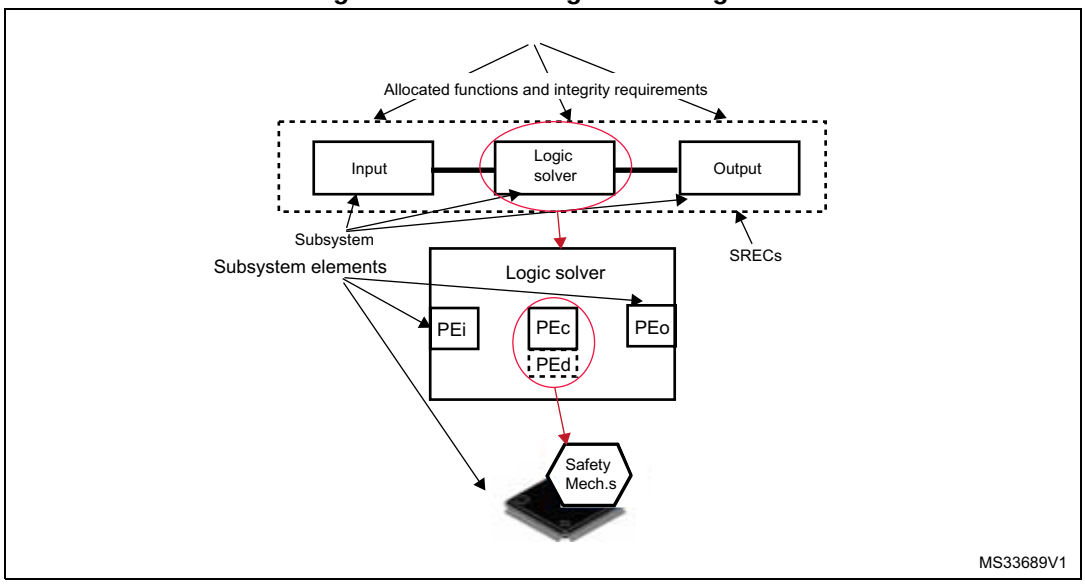
Figure 18. Block diagram for IEC 62061 Cat. D



Note: The "subsystem element" mentioned in Figure 15, Figure , Figure 17 and Figure 18 is the STM32F0 series device.

Based on IEC 62061 §6, *Figure 19* shows how to proceed with the development of SRECS implementing the generic control architecture depicted in figure B.1 of the standard.

Figure 19. SRECS high-level diagram



Where the microprocessor here presented is an STM32F0 series device with the adoption of the safety mechanisms as defined in *Section 3.7: Conditions of use*.

C.2.2 Safety metrics recomputation

Again, as already seen in ISO13849, is still considered valid the approximation §6.7.8.2.1 NOTE2:

$$\lambda = \frac{1}{MTTF}$$

Where is assumed to be:

$$1 \gg \lambda \times T$$

The failure rate (λ) in T is the smaller proof test interval or the life time of the subsystem. But from being:

$$PFH_D = \lambda_D \times 1h$$

again:

$$PFH_D = \frac{1}{MTTF_D}$$

Yogitech fRMethodology provides end-users with results for the STM32F0 series even if native for IEC 61508 but definitely more and more accurate for the definition of dangerous failure identifications that can be re-mapped in IEC 62061 domain. Thus, values of λ and PFHD that are reported in the FMEDA (refer to *Section 4: Safety results*), are still valid and can be used into formulas of the previous paragraph.

There is no need for re-computation for the SFF of a microcontroller. The end-user uses the same value resulting from the performed safety analysis with Yogitech fRMethodology.

As previously discussed in *Section 4.2: Dependent failures analysis*, in evaluating CCF for those basic architectures with an HFT = 1, the end-user uses the same result, if available, as achieved by the IEC 61508 approach (refer to IEC 61508:2010-6 Annex D). Alternatively,

the end-user can apply the simplified approach from the standard (refer to Annex F) to calculate the β factor value to be used in formulas for PFHD.

C.2.3 Work products

Table 11 lists the work products required by the IEC 62061 standard and their mapping with the work products from IEC 61508 compliance activity:

Table 11. IEC 62061 work product grid

IEC 62061 1.1 Tab.8		STM32F0 series IEC 61508 document
Information to be provided	**IEC 62061-1.1 Clause**	
Functional safety plan	4.2.1	End User responsibility
Specification of requirements for SRCFs	5.2	
Functional safety requirements specification for SRCFs	5.2.3	
Safety integrity requirements specification for SRCFs	5.2.4	
SRECS design	6.2.5	STM32F0 series safety manual
Structured design process	6.6.1.2	End User responsibility
SRECS design documentation	6.6.1.8	
Structure of function blocks	6.6.2.1.1	
SRECS architecture	6.6.2.1.5	STM32F0 series safety manual
Subsystem safety requirements specification	6.6.2.1.7	End User responsibility
Subsystem realization	6.7.2.2	
Subsystem architecture (elements & their interrelationships)	6.7.4.3.1.2	STM32F0 series safety manual
Fault exclusions claimed when estimating fault tolerance/SFF	6.7.6.1c / 6.7.7.3	End User responsibility
Software safety requirements specification	6.10.1	
Software based parameterization	6.11.2.4	
Software configuration management items	6.11.3.2.2	
Suitability of software development tools	6.11.3.4.1	
Documentation of the application program	6.11.3.4.5	
Results of application software module testing	6.11.3.7.4	
Results of application software integration testing	6.11.3.8.2	
Documentation of SRECS integration testing	6.12.1.3	
Documentation of SRECS installation	6.13.2.2	
Documentation for installation, use and maintenance	7.2	
Documentation of SRECS validation testing	8.2.4	
Documentation for SRECS configuration management	9.3.1	

C.3 IEC 61800-5-2:2007

The scope of this standard is the functional safety of adjustable speed electric drive systems. Part 5.2 of the IEC 61800 defines the requirements for the design, development, integration and validation of the safety related parts for power drive speed applications, PDS(SR), within the framework of IEC 61508 first edition. More precisely, this part of IEC 61800 just limits its application to those PSD(RS) operating in HD/CM, ref. to §3.10 NOTE1, implementing safety functions with a target integrity up to SIL 3.

Form the architectural point of view, this limitation is reflected in two tables, §6.2.2.3 Tab. 3 and Tab. 4, for the two different types of classified devices. The CPU or the whole microcontroller, since these are complex electronics parts, is classified as Type B. Also the concept of HFT is derived from IEC 61508 as it is.

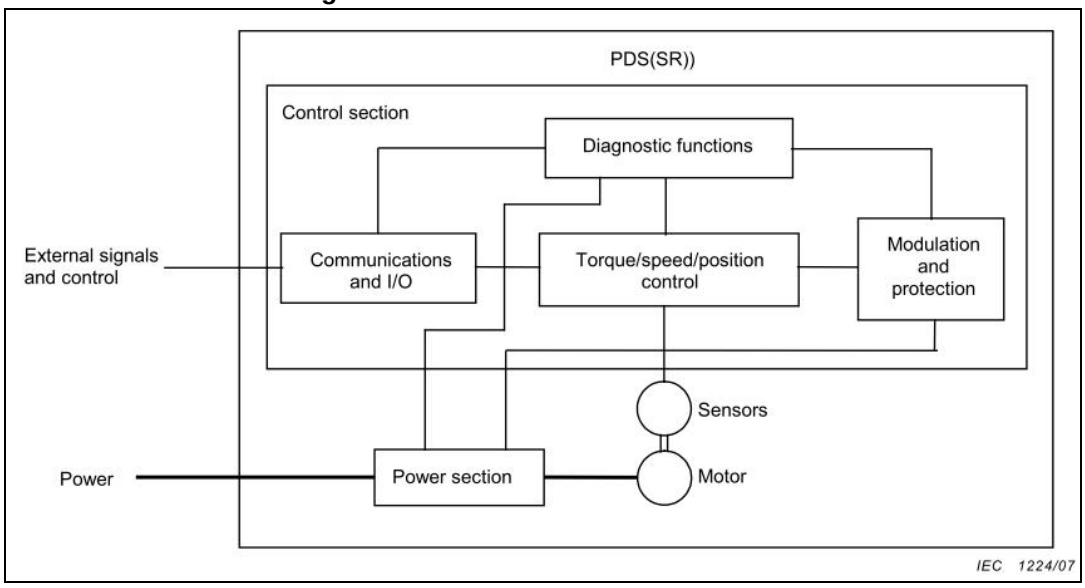
The development lifecycle depicted in §5.2 fig.2, matches with the realization phase, phase 10, of the overall safety lifecycle IEC 61508 (refer to part 1, figure 2). Annex A holds a cross reference table of the ISO 61800-5-2 produced document set in order to match the information content with respect to IEC 61508 requirements.

The strong link with the norm IEC 61508 is reflected also by the adoption in IEC 61800-5-2 of the same relevant metrics PFH, ref. to §6.2.1, and SFF, ref. to §6.2.3.

C.3.1 Architectural categories

The IEC 61800 standard provides an architectural view of PDS(SR) (refer to figure 1), that is duplicated below in *Figure 20*.

Figure 20. IEC 61800 architectural view



The purpose of this logic representation is to introduce the basic elements used to design PDS(SR) and it is deployed into a real system in the Annex B of the standard as an example of implementation of the standard safety function Safe Torque Off STO and related metrics.

C.3.2 Safety metrics recomputation

The PFH of a safety function performed by PDS(SR) is evaluated by the application of IEC 61508-2. So, Yogitech fRMethodology results can be re-mapped in this domain.

Yogitech fRMethodology has an intrinsic high accuracy in catching the failures modes for a certain CPU since the powerful analysis performed at the design level identifies a very detailed list of them. This detailed list of failures is more representative for STM32F0 series faults than the partial and arbitrary list provided in Table D.15 of this standard.

Moreover, the definition of the diagnostic coverage reported in IEC 61800-5.2 §3.3 indicates that the estimations for DC computed from fRMethodology (refer to Appendix A in this document) remain still valid in the scope of this standard. The same applies for SFF (refer to IEC 61800-5.2 §3.15). End users can directly apply results coming from Yogitech fRMethodology, refer to *Section 4.1: Hardware random failure safety results* and FMEDA.

C.3.3 Work products

Table 12 lists the work products required by the IEC 61800-5-2 standard and their mapping with the work products from IEC 61508 compliance activity.

Table 12. IEC 61800 work product grid

IEC 618000 5.2		STM32F0 series IEC 61508 document
Information to be provided	**IEC 61800-5.2 Part-Clause**	
Safety requirements specification (SRS) for PDS(SR) including safety function requirements and safety integrity requirements	5.4	End user responsibility
Verification of PDS(SR) safety requirements specification	8.2	
Hardware design on an architectural level	6	
Software design on an architectural level	IEC 61508-3	
Pre estimation of the probability of failure of safety functions due to random hardware failures on a level of functional block diagrams	IEC 61508-2	STM32F0 series safety manual
Reviews of system design	8.2	End User responsibility
Detailed planning of the validation of safety related PDS(SR).	8.3	
Hardware design	6	
Software design		
Reliability Prediction	6	STM32F0 series safety manual

Table 12. IEC 61800 work product grid (continued)

IEC 618000 5.2		STM32F0 series IEC 61508 document
Information to be provided	**IEC 61800-5.2 Part-Clause**	
Reviews of the system design	8.2	End user responsibility
Functional tests on module level		
Integration and test of the safety related PDS(SR).	6.5	
Review of HW/SW integration test results and documentation	8.2	
Develop user documentation describing PDS(SR) installation, commissioning, operation and maintenance.	7	
Complete software and appropriate documentation	8.3	
Documentation of the results of the validation tests		
Validation tests and procedures according to the validation plan		
Documentation of the results of the validation tests		
Subsystem testing plan	6.2.4.1.4	
Integration testing plan		
Validation testing plan		
Configuration testing plan		
Detailed results of each test	9.2.g)	
Any discrepancy between expected and actual results	9.2.h)	
Conclusion of the test: either it has been passed or the reasons for failure	9.2.i)	

C.4 IEC 60730-1:2010

This IEC 60730-1:2010 version.4.0 standard is applicable to the electrical/electronics control systems for household equipment/building automation/appliances that have a rated power supply voltage ≤ 690 V and a current ≤ 63 A that guarantee safety and reliability. Electrical and\or electronic devices intended for the public usage but not in normal households are out of scope of this standard.

Nowadays these control systems are largely based on complex electronics parts, such as embedded systems with microcontrollers and software implemented control functions.

Annex H of the standard defines specific requirements for electronics controls (HW and SW) which are mandatory when designing safe compliant electronics parts of control systems.

C.4.1 Architectural categories

In this standard the proposed architectures (refer to § H.11.12.1) are mainly classified on software basis, where specific suggestions are given at software level to avoid systematic faults.

IEC 60730-1:2010 §H.2.22 defines three classes of compliance for the performed control functions:

- Class A (§H.2.22.1): control functions which are not intended to be relied upon for the safety of the application. Room temperature control is a typical Class A control function.
- Class B (§H.2.22.2): control functions which are intended to prevent an unsafe state of the controlled equipment. Failure of the control function will not lead directly to a hazardous situation. A pressure limiting and a door lock control are Class B control functions.
- Class C (§H.2.22.3): control functions which are intended to prevent special hazards such as explosion or which failure could directly cause a hazard in the appliance. Automatic burner controllers are one example of Class C functions.

For those systems implementing their control function by software, the standard in §H.2.16 defines the set of applicable architectures. The following list summarizes typical solutions for the design of Class B control functions.

- Single channel with functional test (§H.2.16.5). A single CPU executes the software control functions as required. A functional test is performed as the software starts. It guarantees that all critical features are properly working.
- Single channel with periodic self test (§H.2.16.6). A single CPU executes the software control functions, but embedded periodical tests check the various critical functions of the system without impacting the performance of the fully planned control tasks.
- Dual channel (homogeneous) with comparison (§H.2.16.3): The software is designed to execute identical control functions on two independent CPUs. Both CPUs compare internal signals for fault detection before starting any safety critical task.

An example of Class B control function is the prevention of the overheating for an electrical motor. The control system can be implemented by dual-channel architecture with two STM32F0 series devices. One channel monitors the temperature from the embedded sensor in the coils; the other channel constantly measures the current of the rotor. In case one channel fails the other channel is still able to perform its control function and stop the motor when overheated.

For Class C control functions, the adequate architectural solutions are listed hereafter. The comparison can be achieved by a comparator or by software.

- Single-channel with periodic self-test and monitoring (§H.2.16.7),
- Dual-channel (homogeneous) with comparison (§H.2.16.3),
- Dual-channel (diverse) with comparison (§H.2.16.2).

Implementing a Class-C control system based on a single-channel architecture that comprises one single STM32F0 series device is possible but it requires to introduce some robust diagnostic measures to ensure that the software control function works properly. Monitoring the software control function to prevent any fault is required to avoid the occurrence of the hazardous event.

The standard states the need for control measures (see §H.11.12.2), and explains how to avoid faults/errors for Class B or Class C software control functions (see §H.11.12.3).

C.4.2 Safety metrics recomputation

This safety standard does not mention safety metrics, therefore there it is no need to recompute anything.

The possibility for a system to achieve Class B or Class C ranking is related to the adoption of a certain set of methods; the qualitative table (see Table H.1) in the standard lists the respective types of safety mechanism that need to be present in a Class B or C system.

Table 13 lists the requirements of the standard versus the target ranking (B or C) for the various parts/functions of the STM32F0 series device, that are detailed in *Section 3.6: Description of hardware and software diagnostics*. In case the IEC 60730 requires a safety method not yet foreseen in the framework of the IEC 61508 safety analysis, the gap is reported in the related field. For sake of clarity the original text of the standard requirement is omitted in the table (refer to standard).

Table 13. IEC 60730 required safety mechanism for Class B/C compliance

Component(1)	Fault/ error	Software class		Definitions	SM for Class B(2)	SM for Class C(3)	Gaps/Notes
		B	C				
1. CPU 1.1 Registers	Stuck at	X	-	H.2.16.5 H.2.16.6 H.2.19.6 H.2.19.8.2	CPU_SM_0	-	None
	DC fault	-	X	H.2.18.15 H.2.18.3 H.2.18.9 H.2.19.5 H.2.19.7 H.2.19.1 H.2.19.2.1 H.2.19.8.1 H.2.19.6 H.2.20.8.2	-	CPU_SM_1 CPU_SM_5 or DUAL_SM_0	None
1.2 Instruction decoding and execution	Wrong decoding and execution	-	X	H.2.18.15 H.2.18.3 H.2.18.9 H.2.18.5	-	DUAL_SM_0	In case of single-MCU architecture the safety mechanism CPU_SM_0 described in the Manual could be used but it shall explicitly implement also the “equivalent class test” as described in H.2.18.5 (this test it is not needed for IEC 61508)

Table 13. IEC 60730 required safety mechanism for Class B/C compliance (continued)

Component[1]	Fault/ error	Software class		Definitions	SM for Class B[2]	SM for Class C[3]	Gaps/Notes
		B	C				
1.3 Program counter	Stuck at	X	-	H.2.16.5 H.2.16.6 H.2.18.10.4 H.2.18.10.2	CPU_SM_0	-	None
	DC fault	-	X	H.2.16.7 H.2.18.10.3 H.2.18.9 H.2.18.15 H.2.18.3	-	CPU_SM_1 CPU_SM_5 or DUAL_SM_0	None
1.4 Addressing	DC fault	-	X	H.2.18.15 H.2.18.3 H.2.18.9 H.2.16.7 H.2.18.22 H.2.18.1.1 H.2.18.1.2	-	DUAL_SM_0 or BUS_SM_0	None
1.5 Data paths instruction decoding	DC fault and execution	-	X	H.2.18.15 H.2.18.3 H.2.18.9 H.2.16.7 H.2.18.22 H.2.18.1.2	-	DUAL_SM_0 or CPU_SM_0	None
2. Interrupt handling and execution	No interrupt or too frequent interrupts	X	-	H.2.16.5 H.2.18.10.4	NVIC_SM_1	-	None
	No interrupt or too frequent interrupts related to different sources	-	X	H.2.18.15 H.2.18.3 H.2.18.10.3	-	NVIC_SM_1 or DUAL_SM_0	None
3. Clock	Wrong frequency (for quartz synchronized clock: harmonics/ subharmonics only)	X	-	H.2.18.10.1 H.2.18.10.4	CPU_SM_1	-	None
		-	X	H.2.18.10.1 H.2.18.10.4 H.2.18.15 H.2.18.3	-	CPU_SM_1 or DUAL_SM_0	None

Table 13. IEC 60730 required safety mechanism for Class B/C compliance (continued)

Component(1)	Fault/ error	Software class		Definitions	SM for Class B(2)	SM for Class C(3)	Gaps/Notes
		B	C				
4. Memory 4.1 Invariable memory	All single bit faults	X	-	H.2.19.3.1 H.2.19.3.2 H.2.19.8.2	FLASH_SM_0	-	None
	99,6% coverage of all information errors	-	X	H.2.18.15 H.2.18.3 H.2.19.5 H.2.19.4.1 H.2.19.4.2 H.2.19.8.1	-	DUAL_SM_0 or FLASH_SM_0	In case of adoption of FLASH_SM_0 evidences shall be given about the 99,6% target of information errors
4.2 Variable memory	DC fault	X	-	H.2.19.6 H.2.19.8.2	RAM_SM_0	-	None
	DC fault and dynamic cross links	-	X	H.2.18.15 H.2.18.3 H.2.19.5 H.2.19.7 H.2.19.1 H.2.19.2.1 H.2.19.8.1	-	DUAL_SM_0	For single-MCU solution the RAM_SM_0 proposed for IEC 61508 needs to be enriched to add features like Abraham/GALPAT
4.3 Addressing (relevant for variable and invariable memory)	Stuck at	X	-	H.2.19.18.2	FLASH_SM_0 RAM_SM_0 or DUAL_SM_0	-	None
	DC fault	-	X	H.2.18.15 H.2.18.3 H.2.18.1.1 H.2.18.22 H.2.19.4.1 H.2.19.4.2 H.2.19.8.1	-	FLASH_SM_0 RAM_SM_0 or DUAL_SM_0	None
5. Internal data path 5.1 Data	Stuck at	X	-	H.2.19.8.2	BUS_SM_1	-	None
	DC fault	-	X	H.2.18.15 H.2.18.3 H.2.19.8.1 H.2.18.2.1 H.2.18.22 H.2.18.14	-	DUAL_SM_0 or DMA_SM_1 DMA_SM_3 BUS_SM_0 BUS_SM_1	None
5.2 Addressing	Wrong address	X	-	H.2.19.8.2	BUS_SM_1	-	None
	Wrong address and multiple addressing	-	X	H.2.18.15 H.2.18.3 H.2.19.8.1 H.2.18.1.1 H.2.18.22	-	DUAL_SM_0 or BUS_SM_0 BUS_SM_1	None

Table 13. IEC 60730 required safety mechanism for Class B/C compliance (continued)

Component[1]	Fault/ error	Software class		Definitions	SM for Class B[2]	SM for Class C[3]	Gaps/Notes
		B	C				
6. External communication 6.1 Data	Hamming distance 3	X	-	H.2.19.8.1 H.2.19.4.1 H.2.18.2.2 H.2.18.14	CAN_SM_2 UART_SM_2 IIC_SM_2 SPI_SM_2 USB_SM_2 HDMI_SM_2	-	None
	Hamming distance 4	-	X	H.2.19.4.2 H.2.18.2.1 H.2.18.15 H.2.18.3	-	DUAL_SM_0 or CAN_SM_2 UART_SM_2 IIC_SM_2 SPI_SM_2 USB_SM_2 HDMI_SM_2	In case of adoption of DUAL_SM_0 the communications are managed by both cores In case of adoption of individual safety mechanism for peripherals, the use of CRC32 is mandatory
6.2 Addressing	Wrong address	X	-	H.2.19.8.1 H.2.19.4.1 H.2.18.2.2 H.2.18.14	CAN_SM_2 UART_SM_2 IIC_SM_2 SPI_SM_2 USB_SM_2 HDMI_SM_2 DMA_SM_2	-	None
	Wrong and multiple addressing	-	X	H.2.19.4.2 H.2.18.1.1 H.2.18.15 H.2.18.3	-	DUAL_SM_0	In case of adoption of DUAL_SM_0 the communications are managed by both cores
6.3 Timing	Wrong point in time	X	-	H.2.18.10.4 H.2.18.18	CPU_SM_1	-	None
	Wrong point in time	-	X	H.2.18.10.3 H.2.18.15 H.2.18.3	-	CPU_SM_1 or DUAL_SM_0	None
	Wrong sequence	X	-	H.2.18.10.2 H.2.18.10.4 H.2.18.18	CPU_SM_1	-	None
	Wrong sequence	-	X	H.2.18.10.3 H.2.18.15 H.2.18.3	-	CPU_SM_1 or DUAL_SM_0	None

Table 13. IEC 60730 required safety mechanism for Class B/C compliance (continued)

Component(1)	Fault/ error	Software class		Definitions	SM for Class B(2)	SM for Class C(3)	Gaps/Notes
		B	C				
7. Input/output periphery 7.1 Digital I/O	Fault conditions specified in H.27	X	-	H.2.18.13	GPIO_SM_1 GPIO_SM_2	-	None
		-	X	H.2.18.15 H.2.18.3 H.2.18.8 H.2.18.11 H.2.18.12 H.2.18.22 H.2.18.2	-	GPIO_SM_1 GPIO_SM_2	None
7.2 Analog I/O 7.2.1 A/D-and D/A- converter	Fault conditions specified in H.27	X	-	H.2.18.13	ADC_SM_2	-	None
		-	X	H.2.18.15 H.2.18.3 H.2.18.8 H.2.18.11 H.2.18.12 H.2.18.22	-	ADC_SM_1 ADC_SM_3 DAC_SM_1 or DUAL_SM_0	In case of adoption of DUAL_SM_0 the analog values are acquired by both MCUs
7.2.2 Analog multiplexer	Wrong addressing	X	-	H.2.18.13	ADC_SM_2	-	None
		-	X	H.2.18.15 H.2.18.3 H.2.18.8 H.2.18.22	-	ADC_SM_1 ADC_SM_3 or DUAL_SM_0	In case of adoption of DUAL_SM_0 the analog values needs to be acquired by both MCUs
8. Monitoring devices and comparators	Any output outside the static and dynamic functional specification	-	X	H.2.18.21 H.2.18.17 H.2.18.6	-	WDG_SM_1 CPU_SM_5	None
9. Custom chips 5) for example. ASIC, GAL, Gate array	Any output outside the static and dynamic functional specification	X	-	H.2.16.6	N/A	N/A	Not applicable
		-	X	H.2.16.7 H.2.16.2 H.2.18.6	N/A	N/A	Not applicable

1. For fault/error assessment, some components are divided into their sub functions
2. It is recognized that some of the addressed measures provide a higher level of assurance than required by this standard for Class B.
3. For each sub function in the table, the software class C measure will cover the software class B fault/error

Note: Safety mechanisms separated by "or" word are alternative; safety mechanism listed together are intended to be applied all together.

C.4.3 Work products

Table 14 provides the list of work products that are required by the IEC 60730standard and their mapping with the work products from the IEC 61508 compliance activity:

Table 14. IEC 60730 work product grid

IEC 60730 5.2		STM32F0 series IEC 61508 document
Information to be provided	**IEC 60730 Part-Clause**	
Purpose of control	Tab.1 - 6	End user responsibility
Construction of control and whether the control is electronic	Tab.1 - 6a	
Which of the terminals for external conductors are for a wider range of conductor sizes than those indicated in the table of 10.1.4.	Tab.1 - 18	
For screw-less terminals the method of connection and disconnection	Tab.1 - 19	
Details of any special conductors which are intended to be connected to the terminals for internal conductors	Tab.1 - 20	
Method of mounting control	Tab.1 - 31	
Method of providing earthing of control	Tab.1 - 31a	
Method of attachment for non-detachable cords	Tab.1 - 32	
Details of any limitation of operating time	Tab.1 - 34	STM32F0 series safety manual
Type 1 or Type 2 action	Tab.1 - 39	End user responsibility
Additional features of Type 1 or Type 2 actions	Tab.1 - 40	
Reset characteristics for cut-out action	Tab.1 - 43	
Any limitation to the number or distribution of flat push-on receptacles which can be fitted	Tab.1 - 45	
Any Type 2 action shall be designed so that manufacturing deviation and drift of its operating value, operating time or operating sequence is within the limit declared in requirements 41, 42 and 46 of Table 1 (7.2 of the previous edition)	Tab.1 - 46	
Extent of any sensing element	Tab.1 - 47	
Operating value (or values) or operating time	Tab.1 - 48	STM32F0 series safety manual
Control pollution degree	Tab.1 - 49	End user responsibility
Rated impulse voltage	Tab.1 - 75	
Temperature for the ball pressure test	Tab.1 - 76	
Maximum declared torque on single bush mounting using thermoplastic material	Tab.1 - 78	

Table 14. IEC 60730 work product grid (continued)

IEC 60730 5.2		STM32F0 series IEC 61508 document
Information to be provided	**IEC 60730 Part-Clause**	
Pollution degree in the micro-environment of the creepage or clearance if cleaner than that of the control, and how this is designed	Tab.1 - 79	End user responsibility
Rated impulse voltage for the creepage or clearance if different from that of the control, and how this is ensured	Tab.1 - 80	
The values designed for tolerances of distances for which the exclusion from fault mode “short” is claimed	Tab.1 - 81	
For SELV or PELV circuits, the ELV limits realized	Tab.1 - 86	
Value of accessible voltage of SELV/PELV circuit, if different from 8.1.1, product standard referred to for the application of the control, in which standard(s) the accessible SELV/PELV level(s) is (are) given	Tab.1 - 87	
The minimum parameters of any heat dissipater (for example heat sink) not provided with an electronic control but essential to its correct operation	H.7 - 52	
Software sequence documentation	H.7 - 66	
Program documentation	H.7 - 67	
Software fault analysis	H.7 - 68	
Software class(es) and structure	H.7 - 69	
Analytical measures and fault/error control techniques employed	H.7 - 70	
Software fault/error detection time(s) for controls with software classes B or C	H.7 - 71	STM32F0 safety manual and End User Responsibility
Control response(s) in case of detected fault/error	H.7 - 72	End user responsibility
Software safety requirements	H.11.12.3.2.1	
Software architecture	H.11.12.3.2.2	
Module design and coding	H.11.12.3.2.3	
Design and coding standards	H.11.12.3.2.4	
Testing	H.11.12.3.3	
Inspection	H.2.17.5	
Walk-through	H.2.17.9	
Static analysis	H.2.17.7.1	
Dynamic analysis	H.2.17.1	
Hardware analysis	H.2.17.3	
Hardware simulation	H.2.17.4	
Failure rate calculation	H.2.17.2	STM32F0 series safety manual

Table 14. IEC 60730 work product grid (continued)

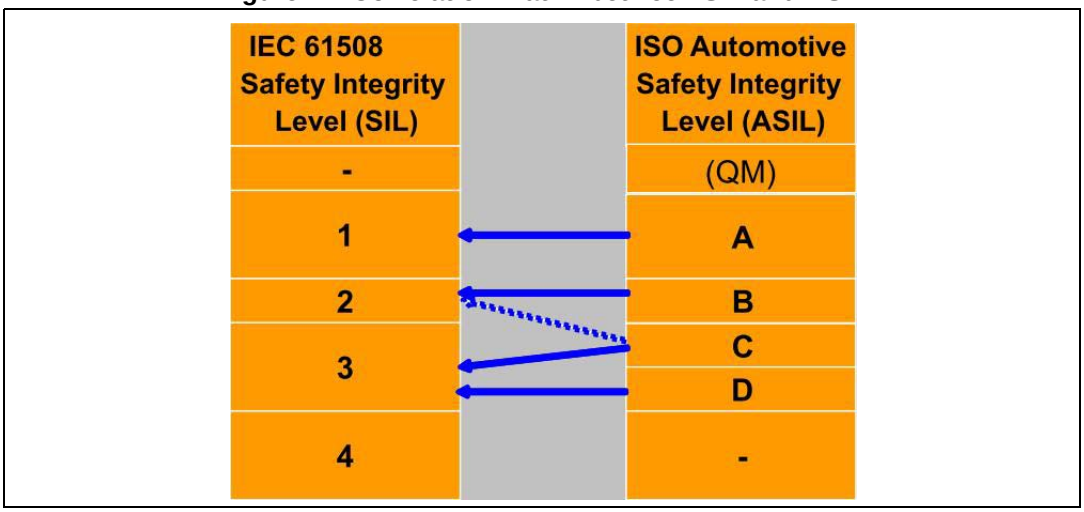
IEC 60730 5.2		STM32F0 series IEC 61508 document
Information to be provided	IEC 60730 Part-Clause	
FMEA	H.2.20.2	STM32F0 safety manual
Operational test	H.2.17.6	End User responsibility

C.5 ISO 26262:2010

This international standard, with a contribution from Yogitech in ISO working groups (WGs) – ref. to *Section A.2: fRMethodology and its flow* - is the reference for the functional safety for the automotive domain. It derives from IEC 61508 standard, and includes relevant modifications. Since the automotive is a mass production industry, the safety validation is usually performed at a sample C/D level, that is close to the pre-series version of the item. Only the positively assessed design of the item, from the functional safety point of view, shall be made ready for the production in a large number of copies.

ISO 26262 redefines the safety integrity levels in term of Automotive SIL (ASIL) with a scale from A, the lowest level, to D, the highest level. A correlation matrix between SIL and ASIL values has been empirically identified by TÜV SÜD and is illustrated in *Figure 21*.

Figure 21. Correlation matrix between SIL and ASIL



In the ISO 26262 scope, end-users can rely on ASIL decomposition to define system architectures where the highest ASIL requirements are fulfilled by using lower ASILs redundant sub systems but respecting the requirements in part 9 §5. Following the rules, an ASIL D safety goal can be decomposed leading to an item made of two ASIL B independent elements. Thus, end-users can positively match SEooC assumptions, in the form of STM32F0 series CoU (refer to *Section 3.7: Conditions of use*). Then the safety requirements of the system under development can integrate the STM32F0 series MCU together with the related safety mechanism defined in this manual, in items performing up to ASIL D safety functions.

In the automotive domain, hardware architectures that implement loops with two identical MCUs are rare. When challenged with the highest ASIL requirements, that is ASIL C and/or ASIL D, automotive safety designers usually adopt a multi core MCU solution. A practical

application of this principle is the ECM implementing E-GAS control strategy that relies on a dual-core lock-step MCU.

C.5.1 Architectural categories

Not Applicable - since ISO 26262 does not define any category.

C.5.2 Safety metrics recomputation

Hardware metrics in ISO 26262 standard have been defined with a slightly different perspective that is mainly focused on the capability of identification of the following:

- Single Point Failures (SPF): those failures which occurrence leads to the violation of a safety goal;
- Dual/multiple point failures: a chain of two subsequent or more independent failures is required for the violation of the safety goal;
- Latent faults: those multiple point failures are not completely covered by the defined safety mechanisms and are usually not perceived by the driver.

Moreover, these failures that are classified in IEC 61508 standard as no-parts/no-effect, are classified as “safe failures” as they do not affect results.

Considering the metrics computation, the main differences between IEC 61508 and ISO 26262 are related to how the safe faults are computed and how the failure rate of diagnostic is computed with the mission. The differences in failure rates related to hardware diagnostics are assumed to be negligible; hardware-native safety failures in STM32F0 series devices are very few, and with very little weight in terms of gate counts. Therefore, the safety analysis already performed for SFF target can be reused for the SPF targets in ISO.

For such kind of Commercial Off-the-Shelf (COTS) microcontroller, the natural target in ISO scenario is ASIL B (90% is the SPF target for permanent and transient, and 60% for latent). As these are the same targets as for 1oo1 SIL2 case, one can assume that the same set of conditions of use/safety mechanisms apply. Metrics computations are detailed into the FMEDA for microcontrollers of the STM32F0 series; note that the resulting PMHF values comply with the expectations for an ASIL B MCU.

We can conclude that the ASIL B target is reachable with some constraints for the final application. Note that safety diagnostic measures based on periodical execution of software are executed at least once each FTTI. As in the automotive domain this condition is easily achievable, the STM32F0 series devices are an effective solution for many applications.

Some typical automotive ASIL-B examples are listed below:

- Electronics door closure: failures affecting the Electronic Control Unit (ECU) normally generate ASIL A safety goals.
- Lighting ECU: faults on lighting functions such as failure on driving or braking lights lead to safety goals ranked as ASIL B.
- Forward collision warning (Advanced Driver Assistance System: ADAS): the safety goal of avoiding unattended deceleration can reasonably be ranked as ASIL B, if decomposition is applied.

For the STM32F0 series device, the fulfillment of ASIL B latent faults metrics (60%) is achieved (according to Yogitech fRMethodology analysis results) with the adoption of the same safety mechanism combination as the one that guarantees the microcontroller to be suitable for SIL2 applications.

C.5.3 Work products

Table 15 lists the work products required by the ISO 26262 standard and their mapping with the work products from IEC 61508 compliance activity:

Table 15. IEC 26262 work product grid

IEC 26262		STM32F0 series IEC 61508 document
Information to be provided	**IEC 26262 Part-Clause**	
Technical safety requirements specification	4-6.5.1	STM32F0 series safety manual
Technical safety concept	4-7.5.1	
Safety analysis reports resulting from requirement	4-7.5.6	
Hardware safety requirements verification report	5-6.5.3	
Hardware safety analysis report	5-7.5.2	
Analysis of the effectiveness of the architecture of the item to cope with the random hardware failures	5-8.5.1	
Review report of evaluation of the effectiveness of the architecture of the item to cope with the random hardware failures	5-8.5.2	
Analysis of safety goal violations due to random hardware failures	5-9.5.1	
Review report of evaluation of safety goal violations due to random hardware failures	5-9.5.3	
Software safety requirements specification	6-6.5.1	End user Responsibility
Software architectural design specification	6-7.5.1	
Software verification report (refined)	6-11.5.3	
Results of safety analyses	9-8.5.1	STM32F0 series safety manual

Appendix D fRSTL_STM32F0_SIL2(3) product and its use in the framework of this manual

From the list of safety mechanisms that end users implement to reach the SIL2 safety integrity level for STM32F0 series (see *Table 3* and *Section 3.7: Conditions of use*), we can extract a subset of mechanisms with the following characteristics:

- The safety mechanisms can be implemented with dedicated periodical software test.
- The safety mechanisms are inherently application-independent: they can be implemented independently of the specific application software that runs on the STM32F0 series final use.

Yogitech have developed a specific suite of fRSTL (fault-robust Software Test Libraries) for the STM32F0 series devices. The software product implements a software-based diagnostics. This dedicated version eases the implementation of the required safety mechanism for the STM32F0 series.

Table 16 lists the five main key differentiation factors of fRSTLs with other possible alternatives.

Table 16. fRSTLs differentiation factors

Compliant with IEC 61508	Both the diagnostic coverage and the development process (systematic capability) are compliant with the IEC 61508 2nd edition
Yogitech enabled	The SW test Libraries are developed and validated according to Yogitech fRMethodology,. This is a patented white-box approach which performs functional safety analyses and safety-oriented design exploration of integrated circuits
Optimized	The SW Test Libraries are optimized in code size and run-time for real time operation.
Application independent	The diagnostic coverage and conditions of use are not tied to any specific application
Modular	The SW Test Libraries are composed by a number of independent test segments that user can selectively run according to specific needs, thus facilitating integration with application software

The main advantages for end users who adopt fRSTL_STM32F0_SIL2(3) are the following:

- no need to prove that the software diagnostics are developed according to IEC 61508 requirement. The end user only refers to fRSTL_STM32F0_SIL2(3) safety manual for all the applicable safety measures. In general, when targeting different safety standards, end users can save time by consulting the available IEC 61508 work products documentation related to the fRSTL libraries development.
- no need to provide evidences on the claimed diagnostic coverage. The end user simply refers to fRSTL_STM32F0_SIL2(3) safety manual for the coverage of all the applicable safety measures.
- easy integration of the diagnostic with the end user application software. The fRSTL product architecture and implementation ease the integration and implementation of

the flow control when integrating the execution of the safety measures together with the mission software.

- mitigation of the software diagnostic impact on system performances (code size, execution time) because fRSTL are optimized. Optimization comes from the application of the fRMethodology that allows the removal of redundant and overlapping checks. Only the safety diagnostics that have a measurable and quantifiable incremental output in terms of coverage are implemented.

Table 17 presents the safety mechanisms based on fRSTL_STM32_SIL2(3) that can apply to the STM32F0 series functions detailed in *Section 3.7: Conditions of use*.

Table 17. List of STM32F0 series safety mechanism overlapped by fRSTL_STM32F0_SIL2(3)

STM32F0 series function	Diagnostic	Description
ARM® Cortex®-M0 CPU	CPU_SM_0	Periodical software test addressing permanent faults in Cortex-M0 CPU inner core
System Flash	FLASH_SM_0	Periodical software test for Flash memory cells
System SRAM	RAM_SM_0	Periodical software test for SRAM memory cells
System interconnect	BUS_SM_0	Periodical software test for interconnections
NVIC	NVIC_SM_0	Periodical read-back of configuration registers
CAN	CAN_SM_0	
UART	UART_SM_0	
I2C	IIC_SM_0	
SPI	SPI_SM_0	
USB	USB_SM_0	
HDMI	HDMI_SM_0	
TSC	TSC_SM_0	
ADC	ADC_SM_0	
DAC	DAC_SM_0	
DMA	DMA_SM_0	
COMP	COMP_SM_0	
TIM6/7	GTIM_SM_0	
TIM1/2/3/14/15/16/17	ATIM_SM_0	
GPIO	GPIO_SM_0	
RTC	RTC_SM_0	
Supply system	VSUP_SM_0	
Clock and Reset	CLK_SM_0	
Watchdogs	WDG_SM_0	
Part separation (no interference)	FFI_SM_0	Periodical read-back of interference avoidance registers

For further information about fRSTL_STM32F0_SIL2(3) products (documentation, user guide, software licensing) visit Yogitech website.

Revision history

Table 18. Document revision history

Date	Revision	Changes
19-Jun-2014	1	Initial release.
30-Jan-2015	2	Extended the user manual applicability to STM32F0 series and to STM32-SafeSIL part number. Updated: – *Figure 1: STMicroelectronics product development process*, – *Figure 16: Block diagram for IEC 62061 Cat. B*, – *Figure 18: Block diagram for IEC 62061 Cat. D*.
03-Mar-2015	3	Replaced all NVC occurrences with NVIC in *Table 3: List of safety mechanisms* and in *Table 17: List of STM32F0 series safety mechanism overlapped by fRSTL_STM32F0_SIL2(3)*.