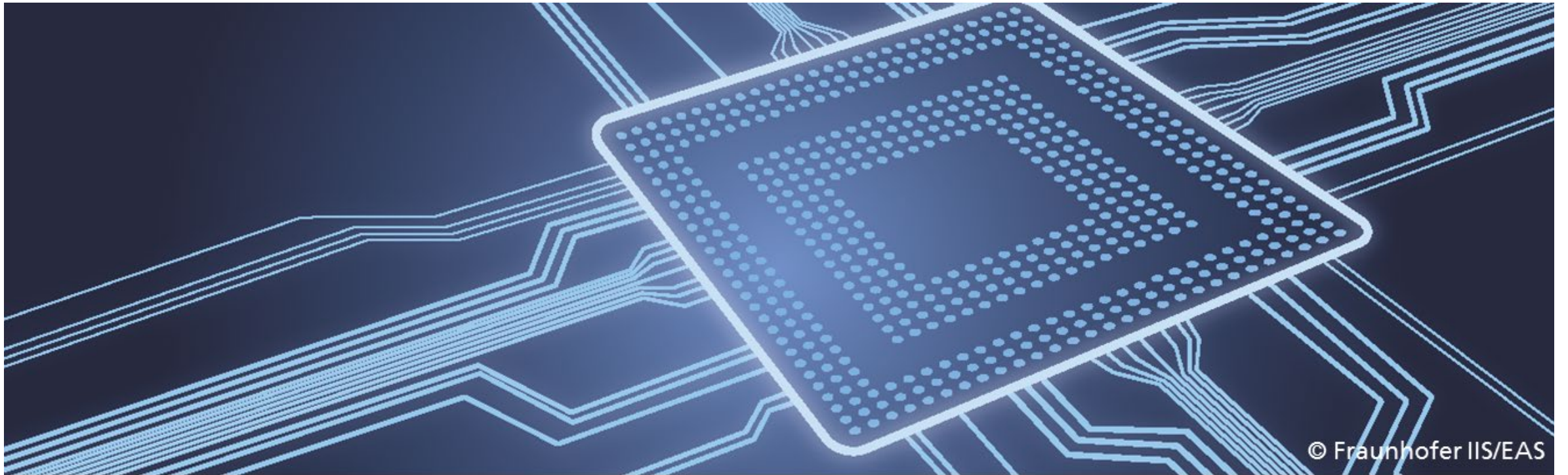

DYNAMIC FAULT INJECTION WITH SYSTEMC AMS FOR QUANTITATIVE SAFETY VERIFICATION

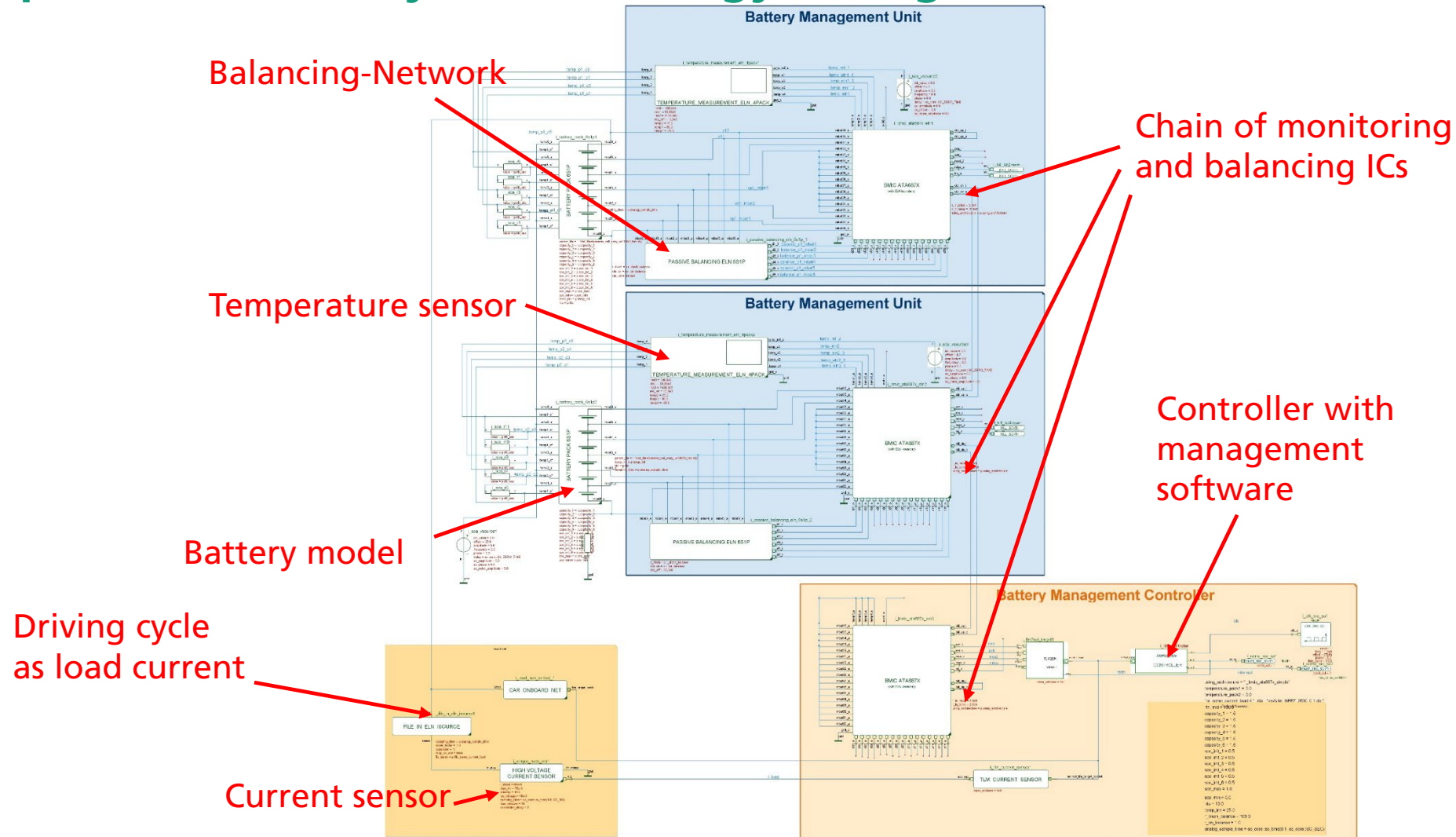
Fraunhofer Institute for Integrated Circuits IIS, Division Engineering of Adaptive Systems EAS
Department Design Methodology



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Battery management system (BMS)

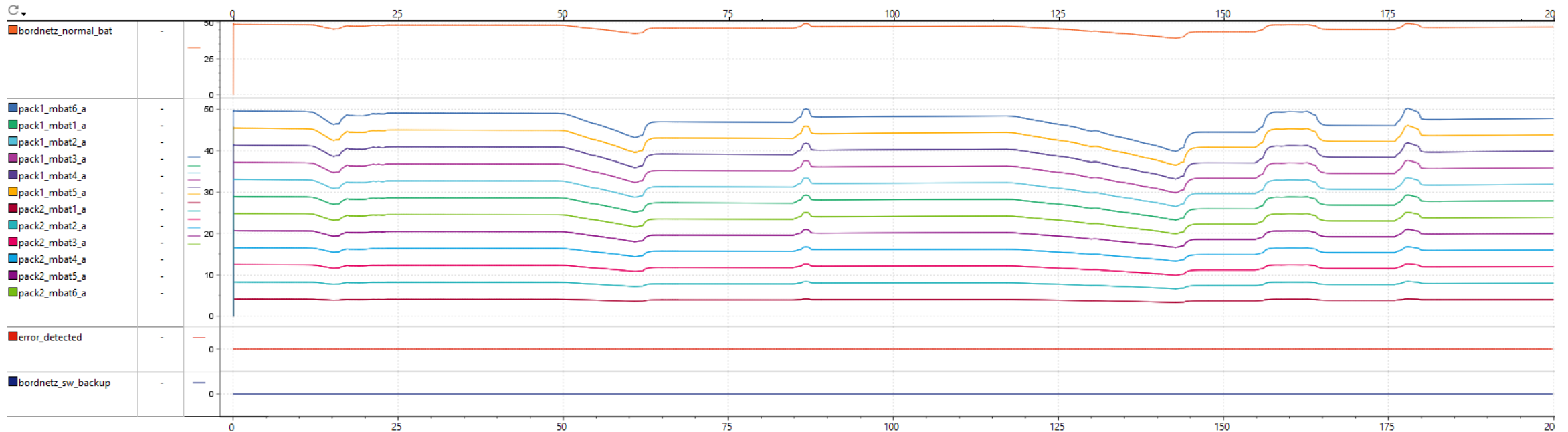
As part of the safety critical energy storage item



Battery management system (BMS)

As part of the safety critical energy storage item

- Nominal simulation: based on driving cycle, provided by a project partner
 - No fault occurs
 - Battery cell voltages depend on SOC and load current



Diagnostic Coverage Determination

FMEDA

- Investigations under Fusa aspects have to be done after functional verification

	Failure rate [FIT]	Safety Relevance Component	Failure Modes	Failure Mode Distribution D_{FMI} [%]	Failure Mode can Violate Safety Goal Directly	Failure Rate λ_i	Coverage by Safety Mechanism	Failure Mode Coverage K_{FMCi} [%]	Single Point Failure Rate $\lambda_{SPF,i}$ [FIT]	Residual Failure Rate $\lambda_{RF,i}$ [FIT]
Battery pack	10	x	Overvoltage	20	x	2	SM1	90	0	0,2
			Undervoltage	30	x	3	SM2	?	0	0
			Voltage changes too fast	10	x	1	SM3	99	0	0,01
			Temperature too low	20	x	2	SM4	95	0	0,1
			Temperature too high	20	x	2	SM4	95	0	0,1
Plug-Connector to main line	15	x	Open	30	x	4,5	SM5	99	0	0,045
			Short to ground	10	x	1,5	SM5	99	0	0,015
			Intermittent contact	60	x	9	SM5	99	0	0,09
Sum total [FIT]	123						Sum total [FIT]	2,2	6,085	
Sum safety-relevant [FIT]	123						SPFM [%]		93,3	
Sum not-safety-relevant [FIT]	0									

- Safety mechanism 2: Measure battery voltage and if a drop occurs connect redundant battery

Battery management system (BMS)

Example board net with safety critical loads

- Goal: Assessment of safety concepts (e.g. supply of safety critical board net loads)
- Switch to backup voltage in case of under voltage
- Under-voltage condition provoked by dynamic fault injection
- ISO26262 compliance proved on time metrics

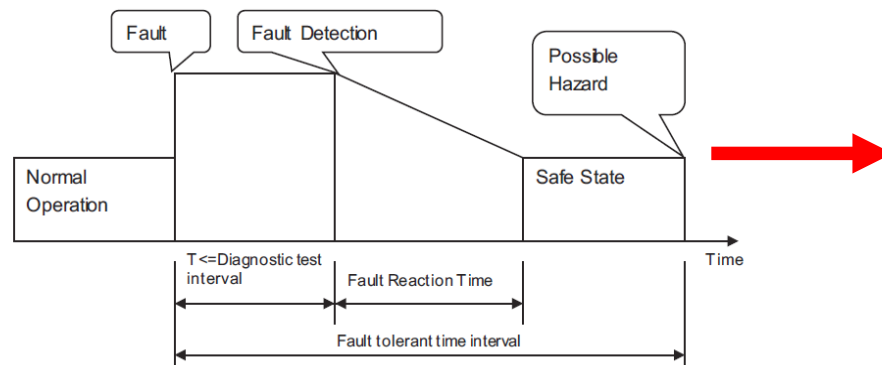
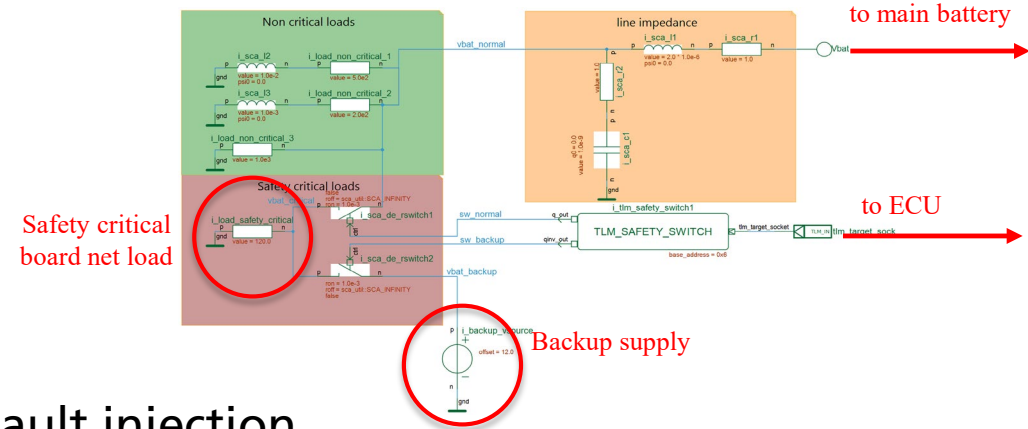
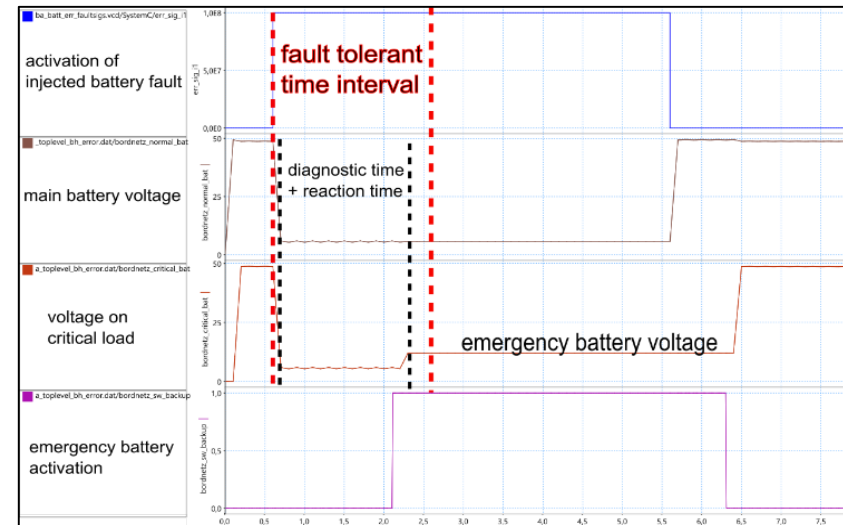


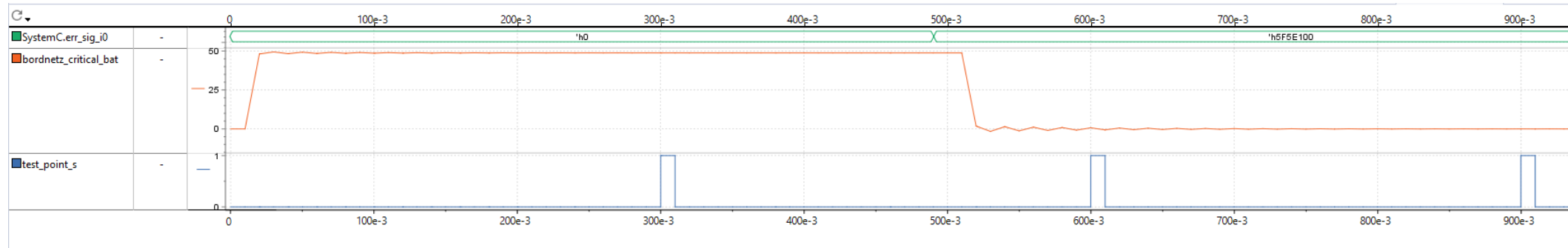
Figure 4 — Fault reaction time and fault tolerant time interval



Set up a fault injection scenario

Definition of the fault simulation scenario

■ Scenario:

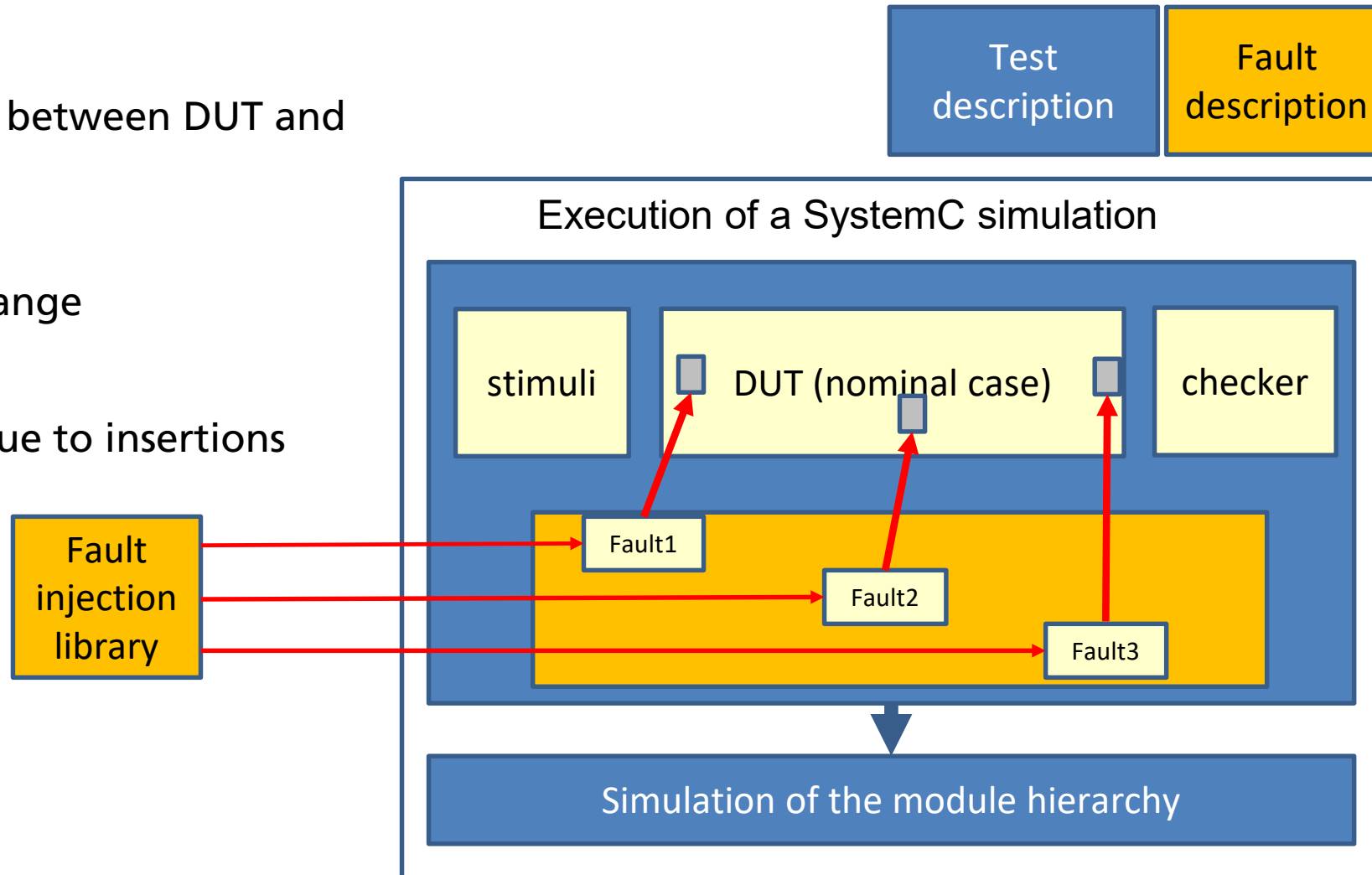


- Suddenly, main battery cannot supply safety critical loads anymore
- The provider defined a fault tolerant time interval
- It has to be proven that safety mechanism is able to bring system in stability again fast enough
- E.g. Check influence of fault occurrence time to this requirement

Fault injection approach for SystemC/ SystemC AMS

Principle of the dynamical fault injection

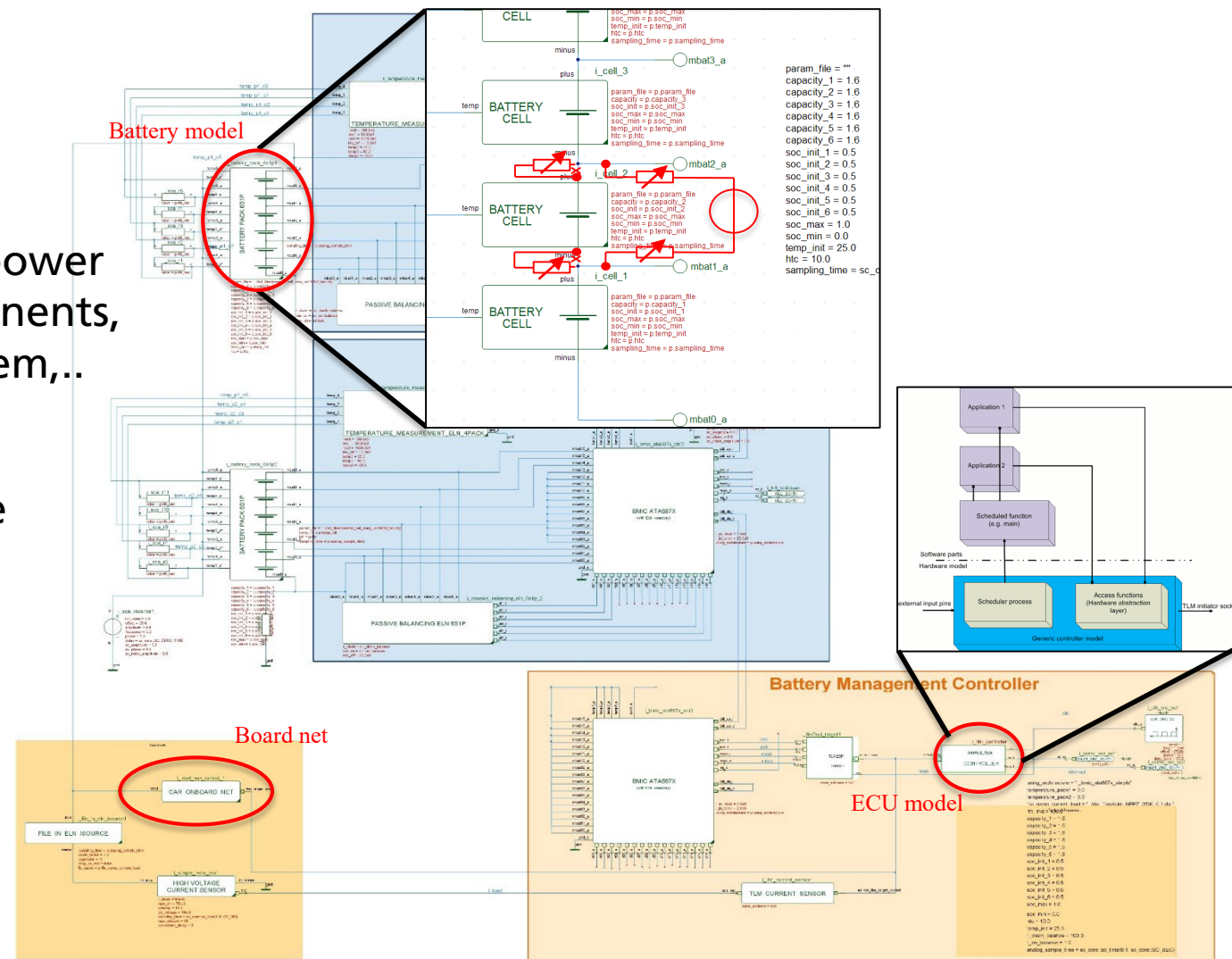
- Clear separation between DUT and test description
- No DUT code change
- Avoiding bugs due to insertions of test artifacts



Battery management system (BMS)

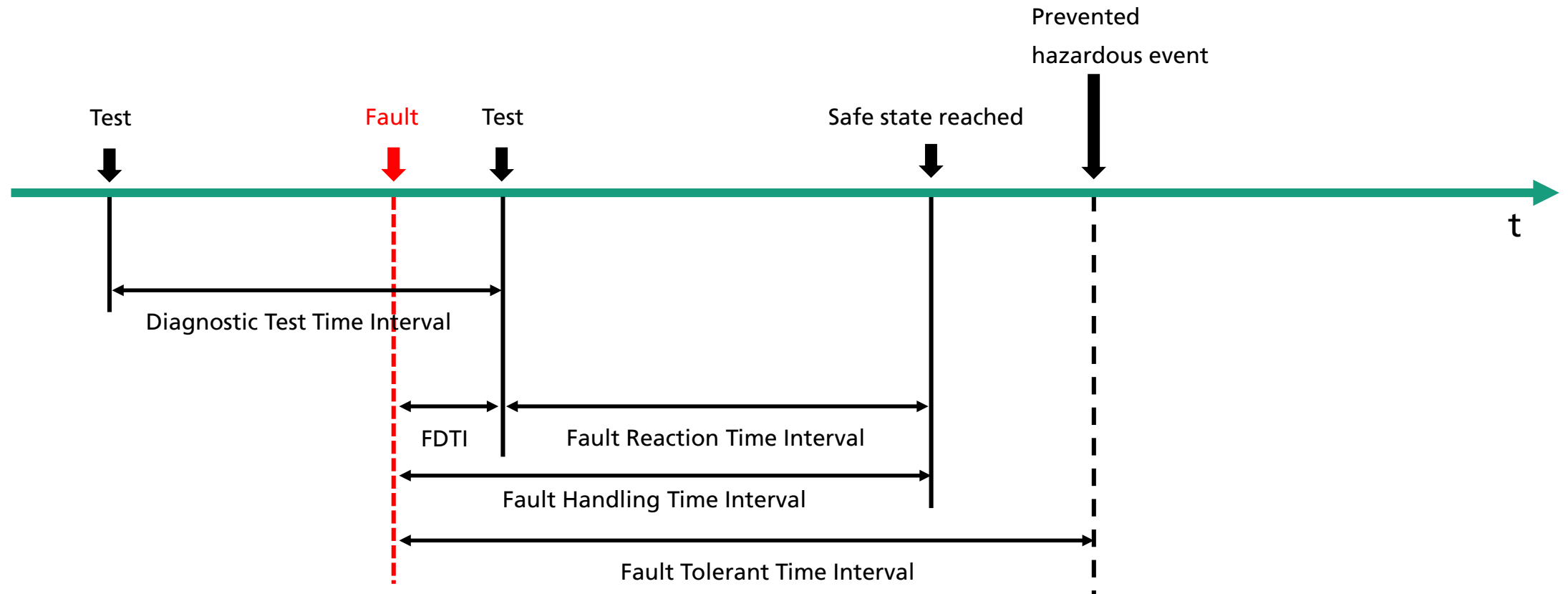
Battery fault injection

- Board net as part of a safety-critical system
- Safety concept requires stable power supply for safety critical components, e.g. ABS, Airbag, breaking system,...
- Safety mechanism is part of the software application



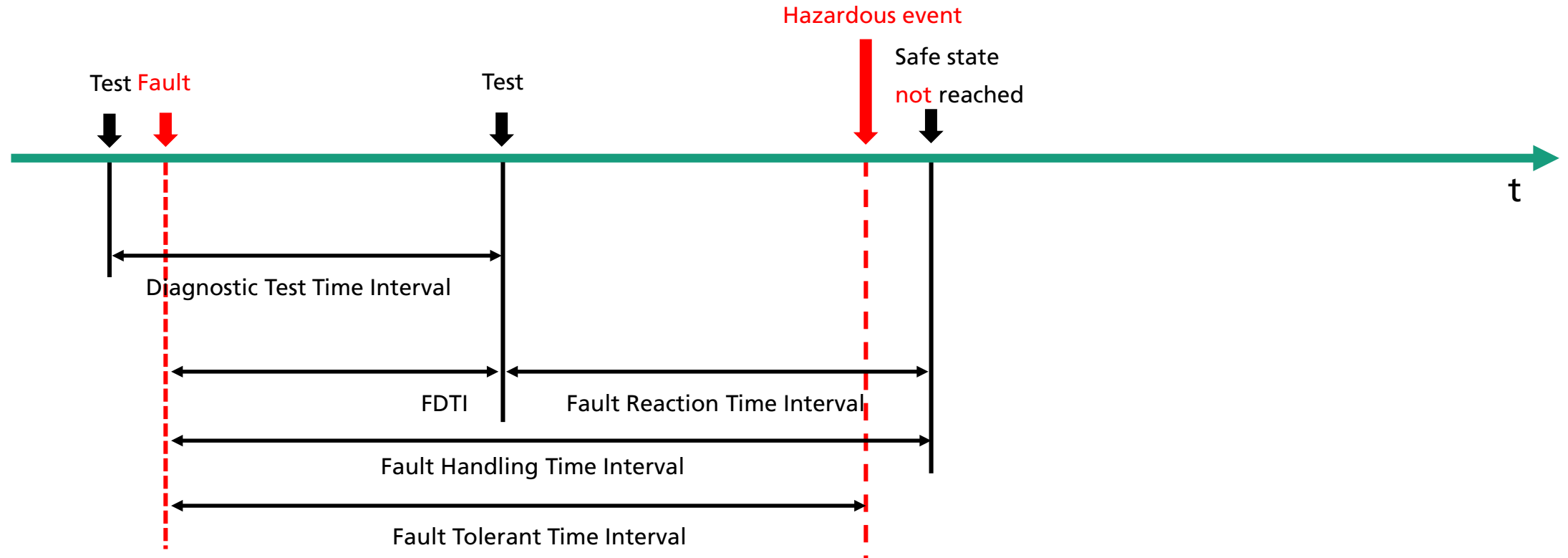
Diagnostic Coverage Determination

Timing limitations for DC



Diagnostic Coverage Determination

Timing limitations for DC



Battery management system (BMS)

Fault description embedded into structured generation flow

- Automated injection flow
 - Safety concept specified in requirement management tool
 - Requirement for fault simulation defined
 - Automated source code and testcase generation
 - Regression

FAULT ACTIVATION:
The fault occurrence time is calculated by using the exponential distribution function from the statistics_libraries and the definition of the mean time value
Which fault location is activated during a certain fault occurrence is calculated by using the fault_location distribution function from the statistics_libraries.
The fault duration comes from the battery cell fault duration value defined in the global test environment

Fault Injection Stimuli details

Unique name: **Battery bridging**

Injection Target kind: **Direct Target Definit.**

Injection Target(s):
"!_battery_pack_6s1p2_i_cell_1.plus" "!_battery_pack_6s1p2_i_cell_1.minus"
"!_battery_pack_6s1p2_i_cell_2.plus" "!_battery_pack_6s1p2_i_cell_2.minus"
"!_battery_pack_6s1p2_i_cell_3.plus" "!_battery_pack_6s1p2_i_cell_3.minus"
"!_battery_pack_6s1p2_i_cell_4.plus" "!_battery_pack_6s1p2_i_cell_4.minus"
"!_battery_pack_6s1p2_i_cell_5.plus" "!_battery_pack_6s1p2_i_cell_5.minus"
"!_battery_pack_6s1p2_i_cell_6.plus" "!_battery_pack_6s1p2_i_cell_6.minus"

Fault Model: **FAULT_BRIDGING**

Derivation Functions: statistics_libraries::exponential, statistics_libraries::fault_location

Mean Fault Occurrence Time: **FaultBatteryCellOccurrenceMeanTime**

Fault Duration Time: **FaultBatteryCellDurationTime**

Comments

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#3 stimuli can be used for different investigations by Thomas Markwirth on 2020-11-10 15:57

bridging voltages are definable separately by using the prepared vector type

```
// constructor
battery_bridging_fault_injection(sc_core::sc_module_name nm, params pa = params()) : p(pa)
{
    // definition of fault injection targets
    port.push_back("!_battery_pack_6s1p2_i_cell_1.plus");
    port.push_back("!_battery_pack_6s1p2_i_cell_2.plus");
    port.push_back("!_battery_pack_6s1p2_i_cell_3.plus");
    port.push_back("!_battery_pack_6s1p2_i_cell_4.plus");
    port.push_back("!_battery_pack_6s1p2_i_cell_5.plus");

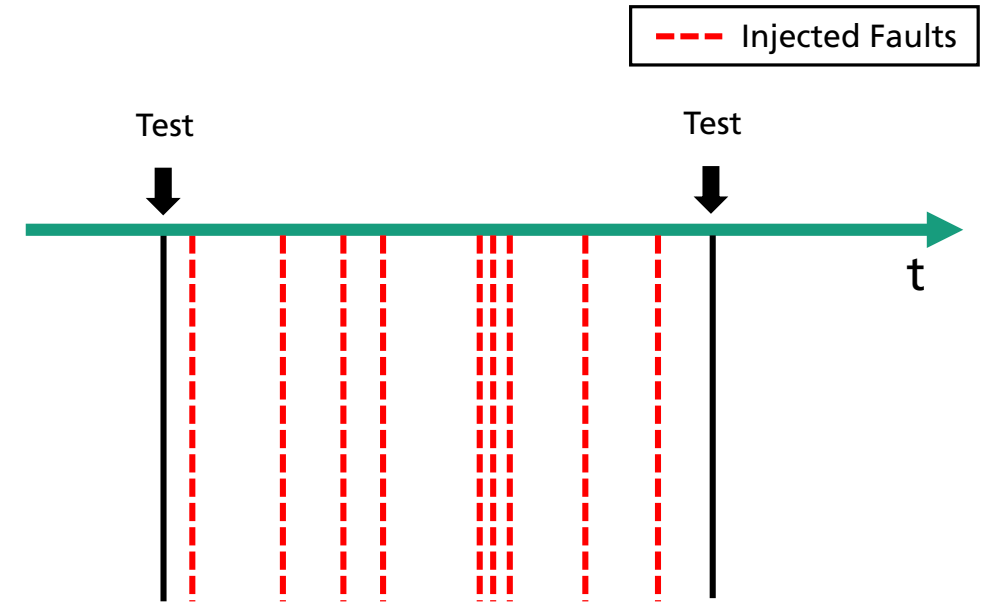
    port_b.push_back("!_battery_pack_6s1p2_i_cell_1.minus");
    port_b.push_back("!_battery_pack_6s1p2_i_cell_2.minus");
    port_b.push_back("!_battery_pack_6s1p2_i_cell_3.minus");
    port_b.push_back("!_battery_pack_6s1p2_i_cell_4.minus");
    port_b.push_back("!_battery_pack_6s1p2_i_cell_5.minus");

    // vector of fault models instances
    szenario1 = new fault_scenario_template<double>(>std::make_pair(port, port_b), fault_injection_base::FAULT_BRIDGING);
    szenario1->stat_failure_time_function = exponential;
    szenario1->location_function = fault_location;
    szenario1->set_mean_fault_occurrence( sc_core::sc_time(5000.0, SC_NS) );
    szenario1->set_fault_duration( sc_core::sc_time(5000.0, SC_NS) );
}
```

Diagnostic Coverage Determination

Monte-Carlo Simulations

- Define parameter space(s) – e.g. DTTI
- Inject fault at random points
- Estimate DC from ratio of faults with prevented hazardous event to all injected faults
- Advantages:
 - Best efficiency for many parameter spaces
 - Can map whole parameter space
- Disadvantages:
 - Normally not sensible for one parameter space and required accuracy
 - Complicated to set up compared to other approaches

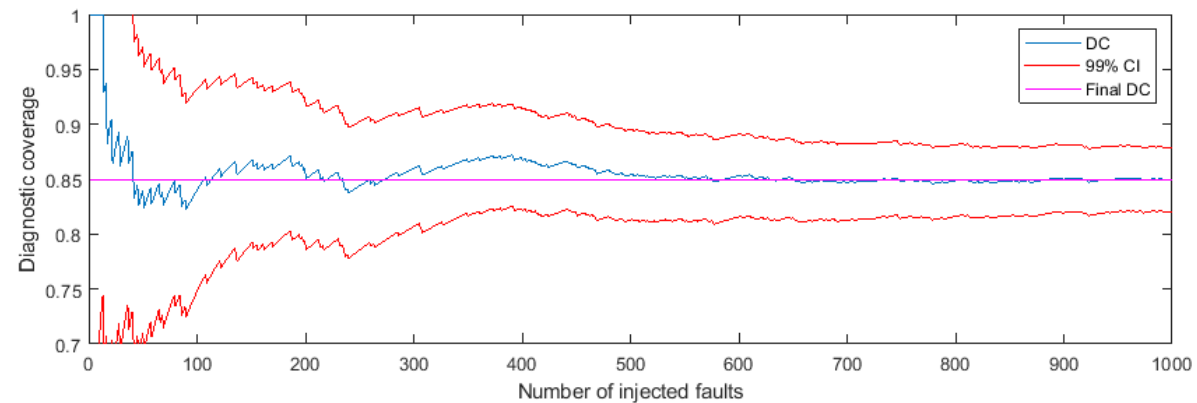
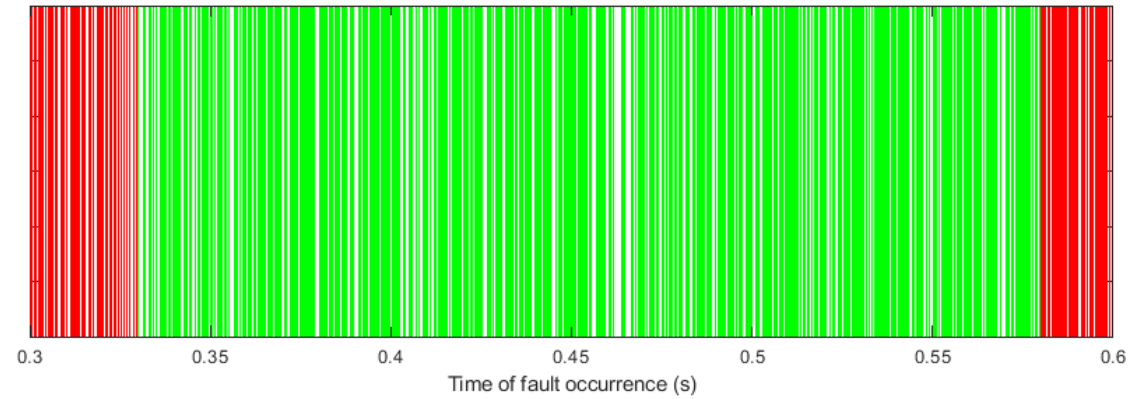


Example: 9 randomly injected faults – low accuracy

Diagnostic Coverage Determination

Monte-Carlo Simulations - Results

DC = 85% \pm 3%



Diagnostic Coverage Determination

FMEDA

	Failure rate [FIT]	Safety Relevance Component	Failure Modes	Failure Mode Distribution D_{FMI} [%]	Failure Mode can Violate Safety Goal Directly	Failure Rate λ_i	Coverage by Safety Mechanism	Failure Mode Coverage K_{FMCi} [%]	Single Point Failure Rate $\lambda_{SPF,i}$ [FIT]	Residual Failure Rate $\lambda_{RF,i}$ [FIT]
Battery pack	10	x	Overvoltage	20	x	2	SM1	99	0	0,2
			Undervoltage	30	x	3	SM2	85	0	0,45
			Voltage changes too fast	10	x	1	SM3	99	0	0,01
			Temperature too low	20	x	2	SM4	95	0	0,1
			Temperature too high	20	x	2	SM4	95	0	0,1
Plug-Connector to main line	15	x	Open	30	x	4,5	SM5	99	0	0,045
			Short to ground	10	x	1,5	SM5	99	0	0,015
			Intermittent contact	60	x	9	SM5	99	0	0,09
Sum total [FIT]	123						Sum total [FIT]	2,2	6,535	
Sum safety-relevant [FIT]	123						SPFM [%]		92,9	
Sum not-safety-relevant [FIT]	0									

- Safety mechanism 2: Measure battery voltage and if a drop occurs connect redundant battery

Diagnostic Coverage Determination

Sum up

- SystemC/ SystemC AMS is usable for a quantitative safety verification
- Could be demonstrated, that dynamic fault injection approach is very efficient for this task
- But...
 - No standardized interchange formats, e.g. for fault descriptions, metrics, ... ,simulation results as e.g. FMEDA input
 - Mainly “own” libraries for fault injection, statistics, interfaces... used

THANK YOU FOR YOUR ATTENTION

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