

# INCOBAT – Innovative COst efficient management system for next generation high voltage BATteries

19th International Forum on Advanced  
Microsystems for Automotive Applications  
(AMAA 2015)  
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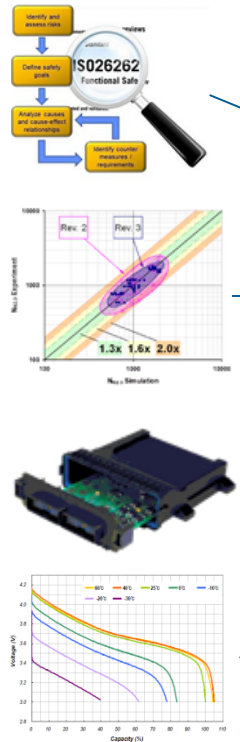
The research leading to these results has received funding from the European Union's Seventh Framework Programme (FP7/2007-2013) under grant agreement n° 608988

- INCOBAT project in a nutshell
- INCOBAT technical innovations
- INCOBAT smart E/E control platform
- Improved control strategy
  - Kalman filtering
  - Electrochemical impedance spectroscopy
- Security-Aware Safety Hazard Analysis and Risk Assessment
- Conclusion

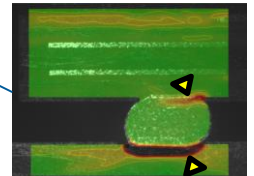
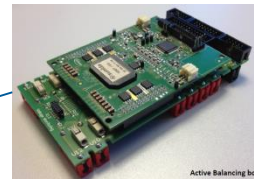
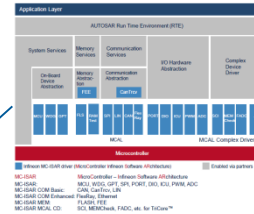
# INCOBAT project in a nutshell

- **Project Name:** INCOBAT - INnovative COst efficient management system for next generation high voltage BAtteries
- **Funding:** European research project ICT STREP (FP7)

- **Project Duration:** 36 months
- **Duration:** Oct. 2013 – Sept. 2016
- **Budget:** 5.8M€



Participant organization name	Country	Status
AVL List GmbH	AT	LE
Ideas&Motion	IT	SME
Fraunhofer Institute ENAS (Chemnitz)	DE	RE
Infineon Technologies Austria AG	AT	LE
Infineon Technologies AG	DE	LE
Impact Clean Power Technology S.A.	PL	SME
Kemet Electronics Italia SRL	IT	LE
Chemnitzer Werkstoffmechanik GmbH	DE	SME



The aim of INCOBAT is to provide **innovative and cost efficient battery management systems for next generation HV-batteries**. To that end, INCOBAT will propose a **platform concept** in order to achieve cost reduction, reduced complexity, increased reliability as well as flexibility and higher energy efficiency.

The main outcomes of the project will be:

- Very tight control of the cell function leading to **an increase of the driving range** of the FEV for current chemistry and by enabling the use of new cell chemistries such as LiS or even Li-air
- **Radical cost reduction** of battery management system
- Development of **modular concepts for system architecture and partitioning, safety, security, reliability** as well as **verification and validation**, thus enabling efficient integration into different vehicle platforms.
- INCOBAT is in the position to provide a 100% European value chain for the development of next generation HV battery management systems.

### Customer needs and integration aspect

1

Mission profiles

12

Car demonstrator / vehicle validation

### Transversal innovation: consistent concept and specification

2

Model-based systems engineering

3

System architecture – efficient partitioning of the functionalities

4

Integration of multiples functionalities (such as charging and billing)

### Technology innovation: E/E control system

5

TriCore AURIX platform for additional computing resources

6

Smart and integrated module management unit

7

Modular SW platform

8

Improved BMS control algorithms

### Transversal innovation: improving system maturity

9

Definition and integration of safety and security concepts

10

Design and validation plan including reliability consideration

11

Reliability and robustness assessment

# **INCOBAT technical innovations**

**Target:** ensures a correct identification of customer needs and enables an efficient integration into different platforms.

- **TI001: Identification and use of mission profiles for system definition and evaluation**

Identification of mission profiles (extracted from experimental data gathered on a real car - an hybrid vehicle) in order to provide complex situations similar to real vehicle behavior over different battery chemistries, mission profiles and algorithms

- **TI012 Car demonstrator / vehicle validation**

Setup of car demonstrator to evaluate the BMS module. This shall illustrate the feasibility of the proposed approach in realistic environment

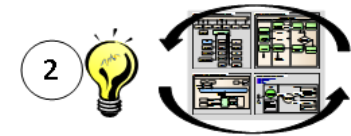




**Target:** optimization of the system architecture and its consistent description over the technologies and over the system hierarchies.

→ Aims at providing a consolidated basis in order to simplify later industrialization of the proposed technologies

- **TI002 “Model-based systems engineering”** to improve correctness / completeness / consistency of system specification
- **TI003 “System architecture - efficient partitioning of the functionalities”** for system optimization at BMS or even vehicle level
- **TI004 “Integration of multiple functionalities”** to reduce the number of electronic control units (and thus related costs) in the vehicle.



Model-based systems engineering

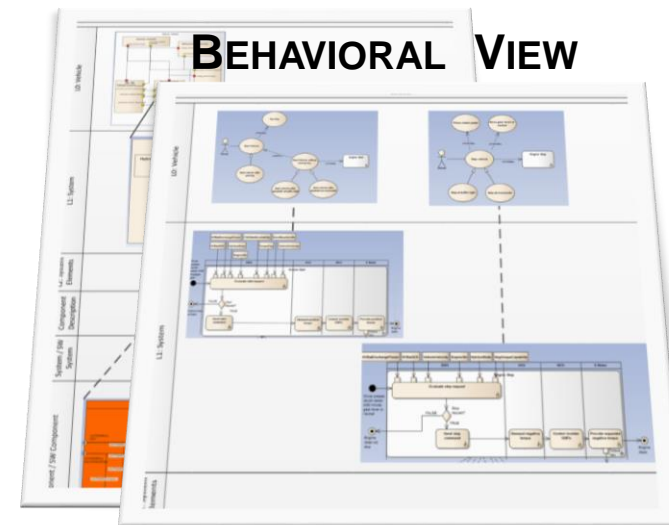


System architecture – efficient partitioning of the functionalities



Integration of multiples functionalities (such as charging and billing)

## TECHNICAL DEPENDENCIES

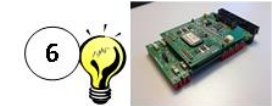


**Target:** Integration of innovative electronics components and innovative SW solutions to improve overall control efficiency

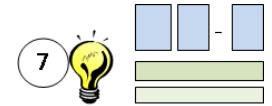
- **TI005 “TriCore AURIX™ Platform”** to provide more computing resources for integration of new functionalities and / or more complex algorithms as well as dependable computing
- **TI006 “Smart and integrated module management unit”** for higher measurement accuracy and assessment of additional physical parameters
- **TI007 “Modular SW platform”** based on the AutoSAR methodology to define the architecture in a flexible way
- **TI008 “Improved BMS control algorithms”** to provide improved algorithms taking full advantage of the BMS platform



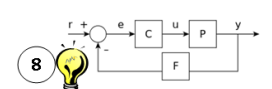
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TriCore AURIX platform for additional computing resources



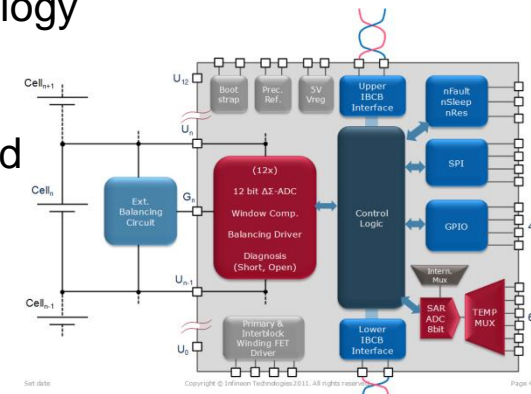
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Smart and integrated module management unit



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Modular SW platform



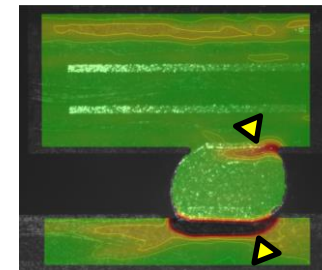
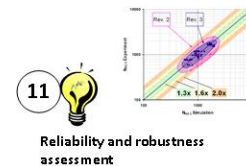
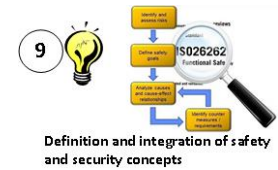
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Improved BMS control algorithms



**Target:** improve system maturity by early consideration of ISO26262, V&V, and reliability testing

→ Indicator for the maturity of the proposed technology and further provides information on the efforts required for proper integration and validation of the system.

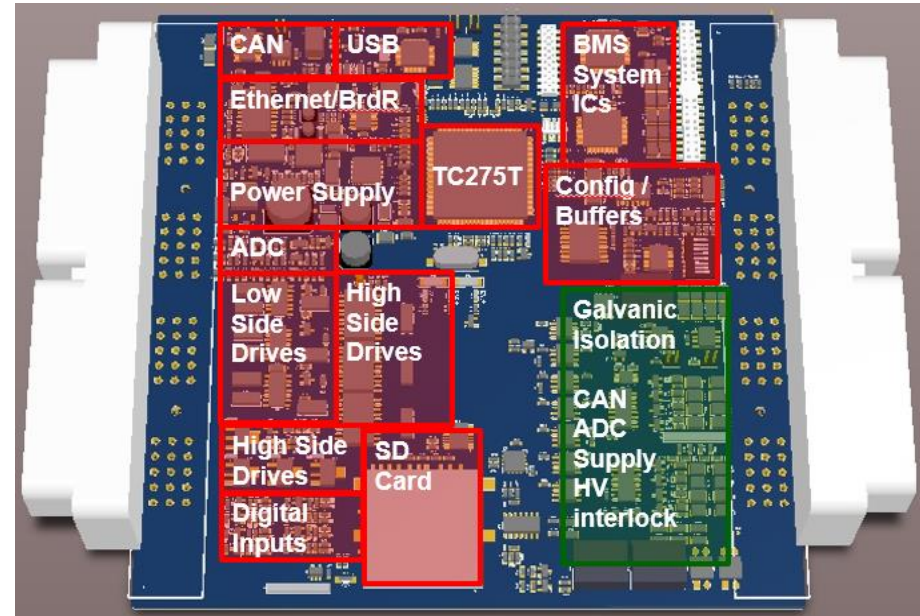
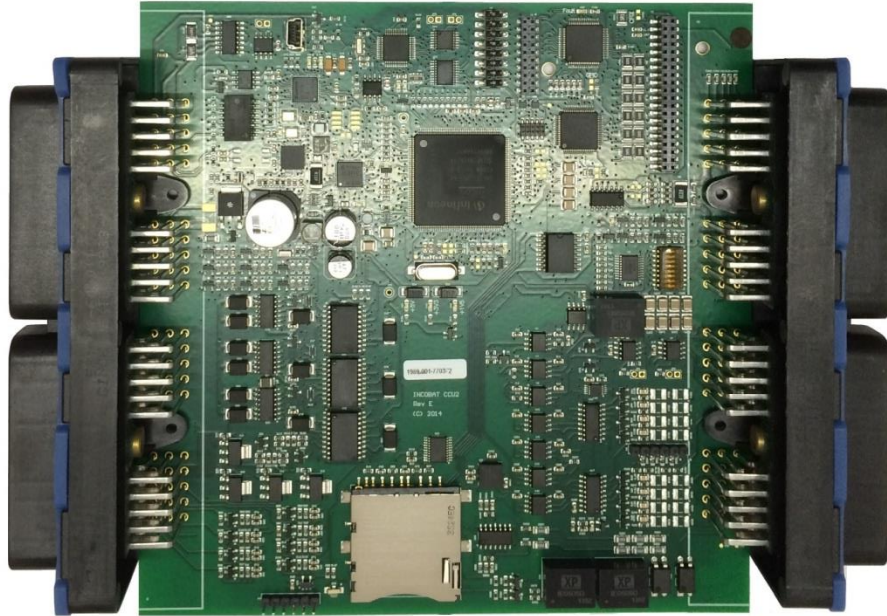
- **TI009 “Definition and integration of safety and security concept”** encompassing cost efficient functional safety support as well as robust mechanisms to support cyber security
- **TI010 “Design and validation plan including reliability consideration”** to provide an holistic view on the test plan and the test methods to be applied
- **TI011 “Reliability and robustness validation”** targeting the development of combined tests (accelerated lifetime tests applying combined loads) for accelerated lifetime assessment.



1. Vocabulary			
2-3 Overall safety management	2-6 Safety management during item development		2-7 Safety management after release for production
3. Concept phase			
3-1 Item definition	3-2 Allocation of safety	3-3 Allocation of the safety lifecycle	3-4 Failure analysis and risk determination
3-5 Functional safety	3-6 Functional safety		
4. Product development			
4-1 System design		4-2 System development	
4-3 Hardware architecture		4-4 Software architecture	
4-5 Hardware verification and validation		4-6 Software verification and validation	
4-7 Hardware integration and testing		4-8 Software integration and testing	
4-9 Hardware unit testing		4-10 Software unit testing	
4-11 Hardware integration and testing		4-12 Software integration and testing	
4-13 Hardware integration and testing		4-14 Software integration and testing	
5. Production and operation			
5-1 Production			
5-2 Operation, service, maintenance and repair, and			
5-3 End of life			
6. Supporting processes			
6-1 Communication			
6-2 Identification of software tools			
6-3 Identification of hardware components			
6-4 Identification of hardware components			
6-5 Process in use management			
6-6 Safety-oriented analysis			
6-7 Analysis of dependent failures			
6-8 Fault analysis			
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6-100 Fault analysis			

# Smart E/E Control Platform

- Available since spring 2015



- BMS specific hardware integrated
- Electrochemical impedance spectroscopy (EIS) daughterboard connectors
- Cover for HV area
- Metal Housing made of Aluminum (IP55)

- Lowest cost BMS system solution by fully integrating all main BMS functions into one ECU
- Close-to-production platform supporting the exploitation of advanced BMS approaches
- Reduced system installation space, high level of integration and of functional density
- AURIX multicore controller provides high compute performance and safety mechanisms
- Encapsulated processing with freedom from interference
- Modular software architecture

# Improved Control Strategy Relying on Multicore Computing Platform



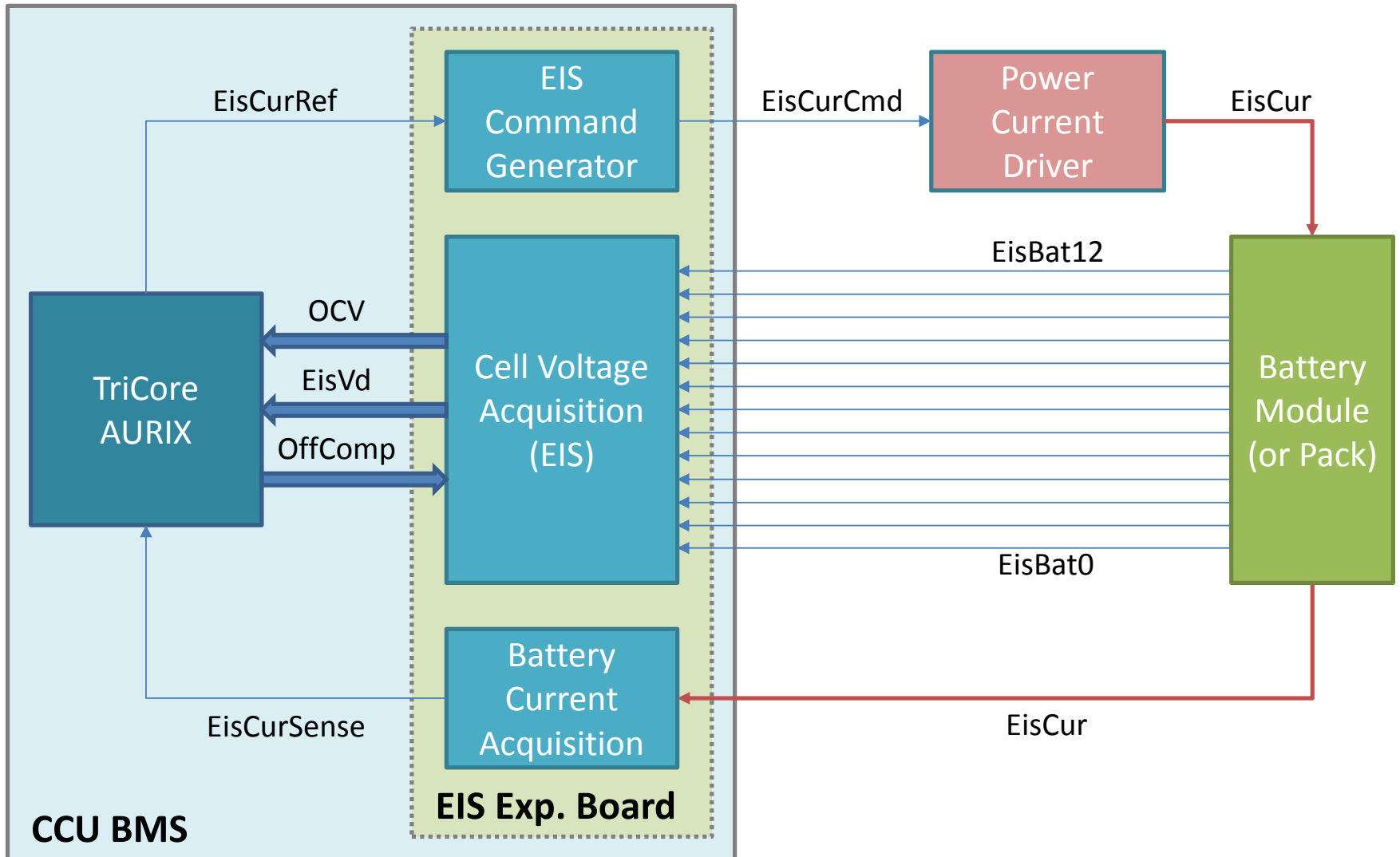
Providing a dedicated instance of existing model estimation algorithms for each single cell instead of for a group of cells

- State-of-the-Art SoC estimation algorithm (Kalman filtering)
- More accurate due to considering of process and measurement noises than Coulomb-counting technique
- Requires more computing power to run algorithms in parallel for cell-individual calculation
- Higher modelling accuracy provide more accurate status information of cells
- More accurate SoC, SoH, and SoF prediction increases range of vehicle and cycle life of the battery



The hardware architecture supporting the EIS functions consists of the following main modules:

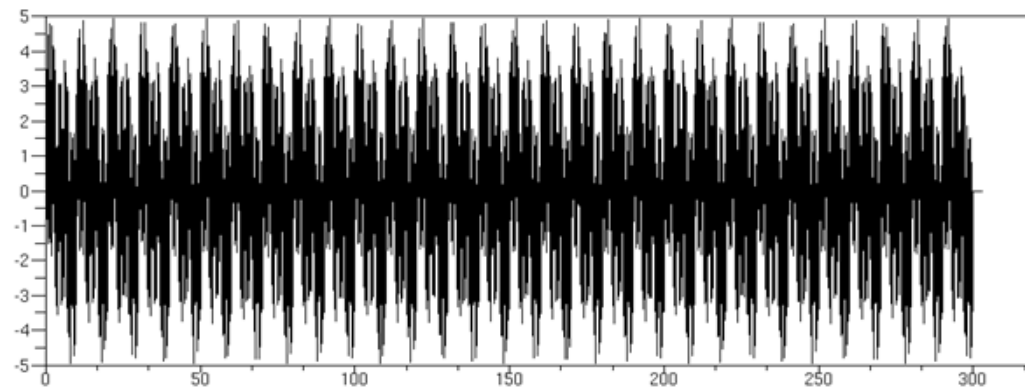
- EIS Command Generator: its purpose is to generate the proper EIS Command signal (voltage reference) representing the current stimulus to be forced into the battery pack.
- Power Current Driver amplifying the EIS command signal and providing the EIS current stimulus to the battery cells
- Battery Module/Pack, representing the load whose impedance has to be measured
- EIS Signals Acquisition Sub-system, for the coherent measurement of:
  - Cell voltages - both DC and AC (useful EIS signal) - for each battery cell
  - EIS current flowing in the battery module/pack
- Data Processing System for the calculation of the EIS spectrum (based on TriCore AURIX processor)



- The EIS sub-system is designed to manage 12 Li-Ion battery cells (60V max)
- The EIS Sub-System has been implemented by means of an EIS Daughter Board (by I&M) plugged on the CCU HW (by IFX)
- The CCU HW provides:
  - A computational core running on IFX AURIX microcontroller, which is responsible for EIS data acquisition, digital filtering, and running the EIS algorithm.
  - Expansion connectors for EIS daughter board, providing all needed signals, interconnections and power supplies
  - A low-impedance current shunt (20mOhm) with dual range op-amps for EIS current measurement
- The EIS daughter board integrates:
  - EIS Command Generator
  - 12x EIS cell voltage measurement circuitry (differential amplifier + OCV cancelling + 4<sup>th</sup> order Bessel anti-aliasing filter)
  - 2x EIS current measurement circuitry (4<sup>th</sup> order Bessel anti-aliasing filter)

- The approach is based on **heterodyne** and coherent demodulation
- The impedance is evaluated only at  $N$  discrete frequency values; therefore, the most efficient solution is to provide energy only at the frequencies of interest.
- A proper stimulus is the sum of sine waves, one for each frequency value that has to be evaluated

$$i(t) = \frac{1}{\sqrt{N}} \sum_{i=1}^N \sin(2\pi f_i t)$$

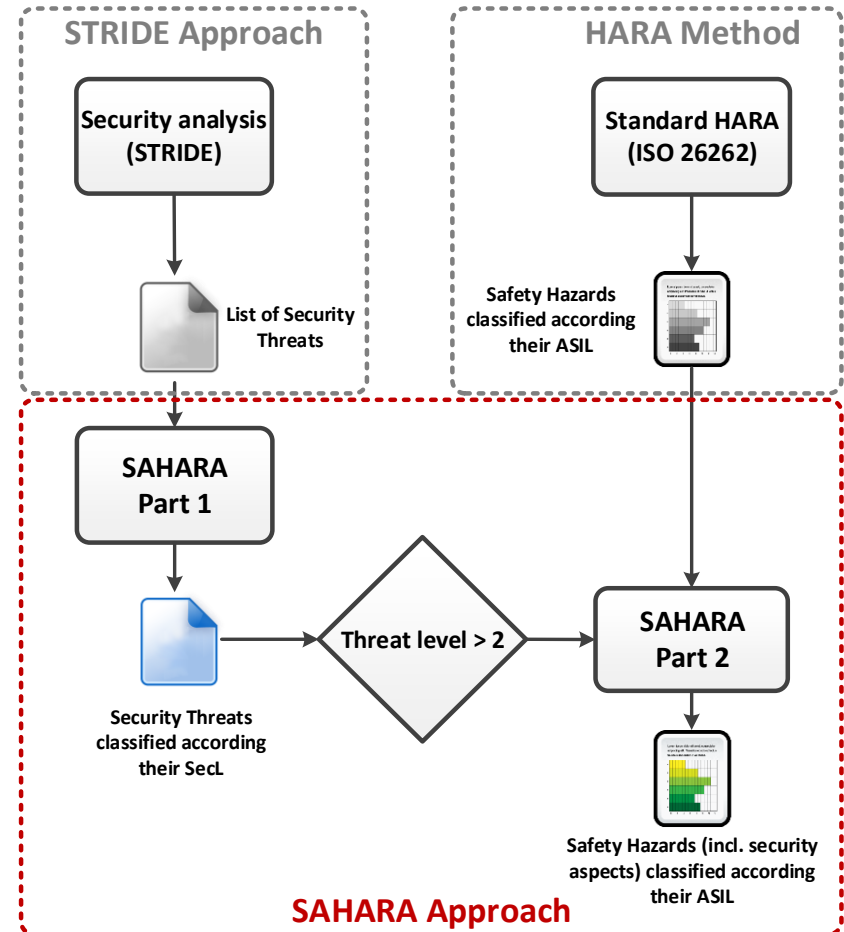


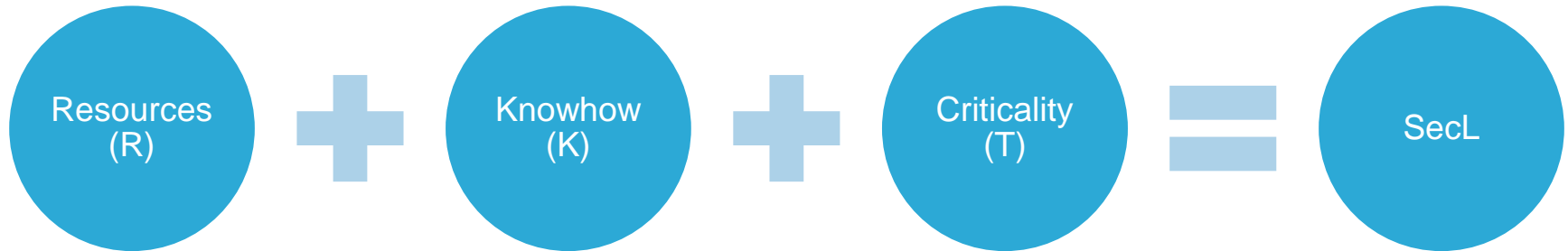
- Each input signal (the excitation current and the resulting voltage) is multiplied by a sine wave and a cosine wave at a certain frequency, and the convolution is calculated.
- As a result, the amplitude and phase (at that frequency) of the voltage and current signals can be calculated, and from their ratio the battery cell impedance may be calculated.
- It must be noted that the heterodyne approach is much less demanding than FFT in terms of processing power, and the convolution integrals may be easily calculated directly on-line by the cell monitoring module.

➔ cell measurement task (cooperation WP2 / WP4) has shown that heterodyne approach is a factor 100 more efficient with respect to the amount of data to process

# Security-Aware Safety Hazard Analysis and Risk Assessment

- Combined approach of STRIDE and HARA
- Considers security aspects having an impact on safety
- Classification of security threats aligned with HARA approach
- via:
  - required resources (R)
  - required know-how (K)
  - threat criticality (T)





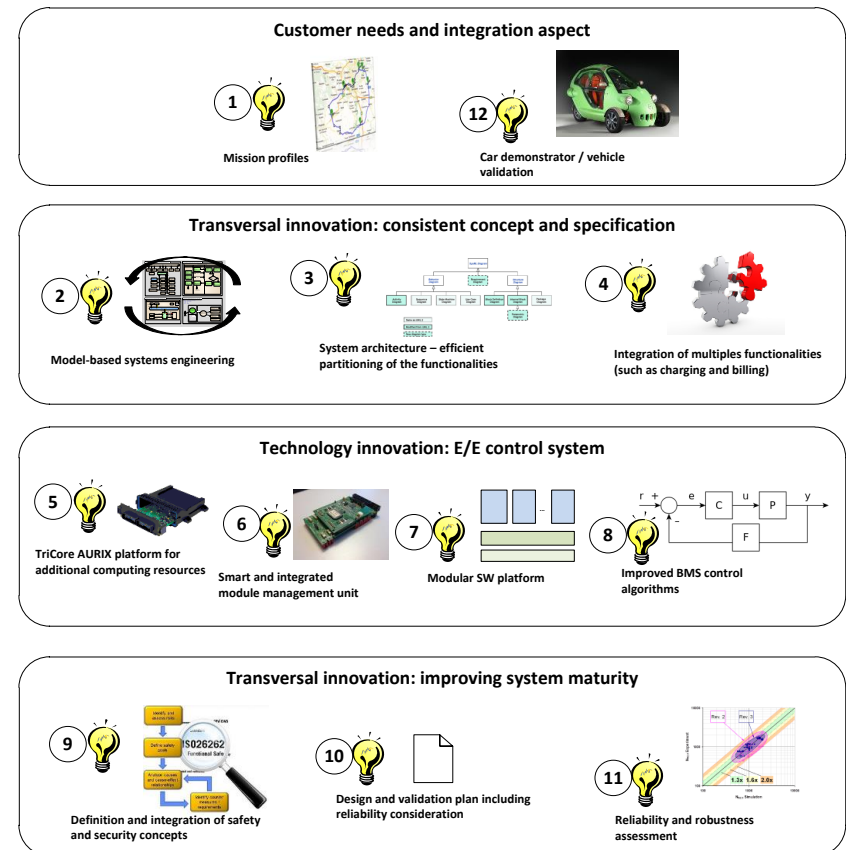
Level	Required Resource
0	no additional tool or everyday commodity
1	standard tool
2	simple tool
3	advanced tools

Level	Required Resources 'R'	Required Know-How 'K'	Threat Level 'T'				Criticality
			0	1	2	3	
0	0	0	0	3	4	4	impact security
		1	0	2	3	4	
1	0	2	0	1	2	3	ty rele-
		1	0	2	3	4	
2	1	1	0	1	2	3	ity and safety
		2	0	0	1	2	
3	2	0	0	1	2	3	
		1	0	0	1	2	
3	2	0	0	0	1	2	
		1	0	0	0	1	
3	2	0	0	0	0	1	
		1	0	0	0	1	



## INCOBAT project outcomes:

- smart dependable and modular computing multicore platform
- Discussion of impact of multicore platform on control strategies
- Additional computing power enables refinement of existing control strategies
- Advanced measurement approaches performable (EIS)
- Safety-critical application in connected context tackled



# Thank you for your attention!



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