# Transient real-time load stepping on the basis of field meta models (FMOP) for electro-thermal-mechanical FE simulations


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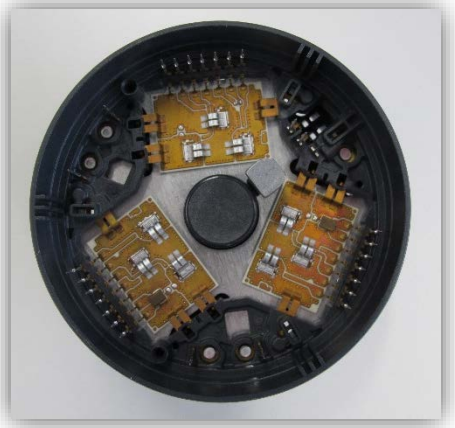
# Content

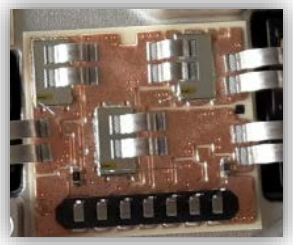
# Real-time load stepping on the basis of FMOP for electro-thermal-mechanical FE simulations

## Electronic power steering

Electronic power steering



Electronic control unit (ECU)



DBC

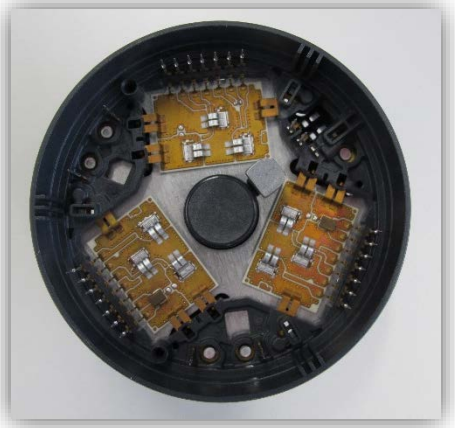
Power pack

# Electronic power steering

Environmental influences:

- Humidity
- Chemicals
- Vibration
- Thermal stresses
- …

Electronic power steering



Electronic control unit (ECU)

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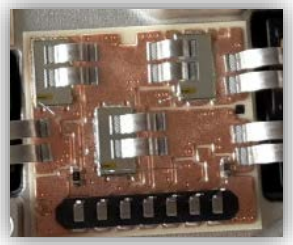
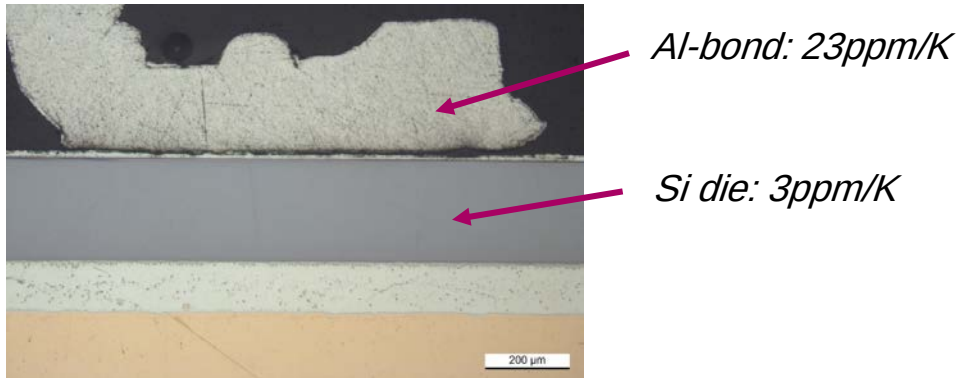
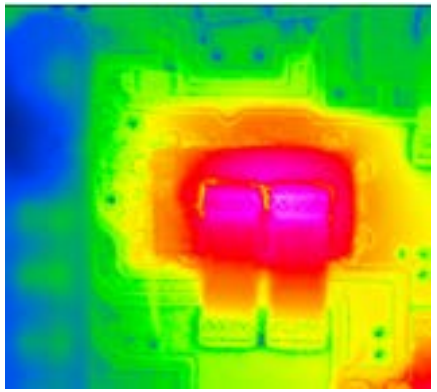


DBC

# Motivation

- Different environmental influences lead to fatigue during lifetime
- Typical fatigue failure mechanism on DBCs are bond cracks due to thermal mismatch between aluminum bonds and silicon dies

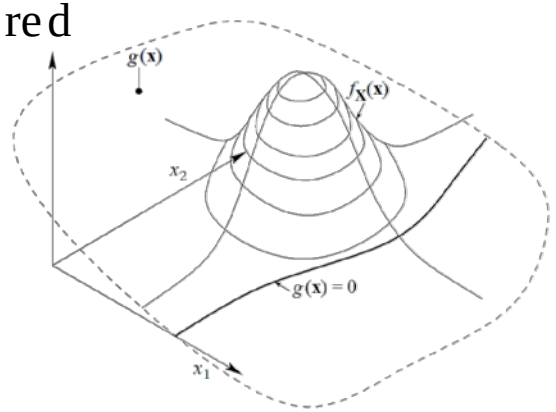


- Engineering goal: No fatigue failures during lifetime

# Motivation

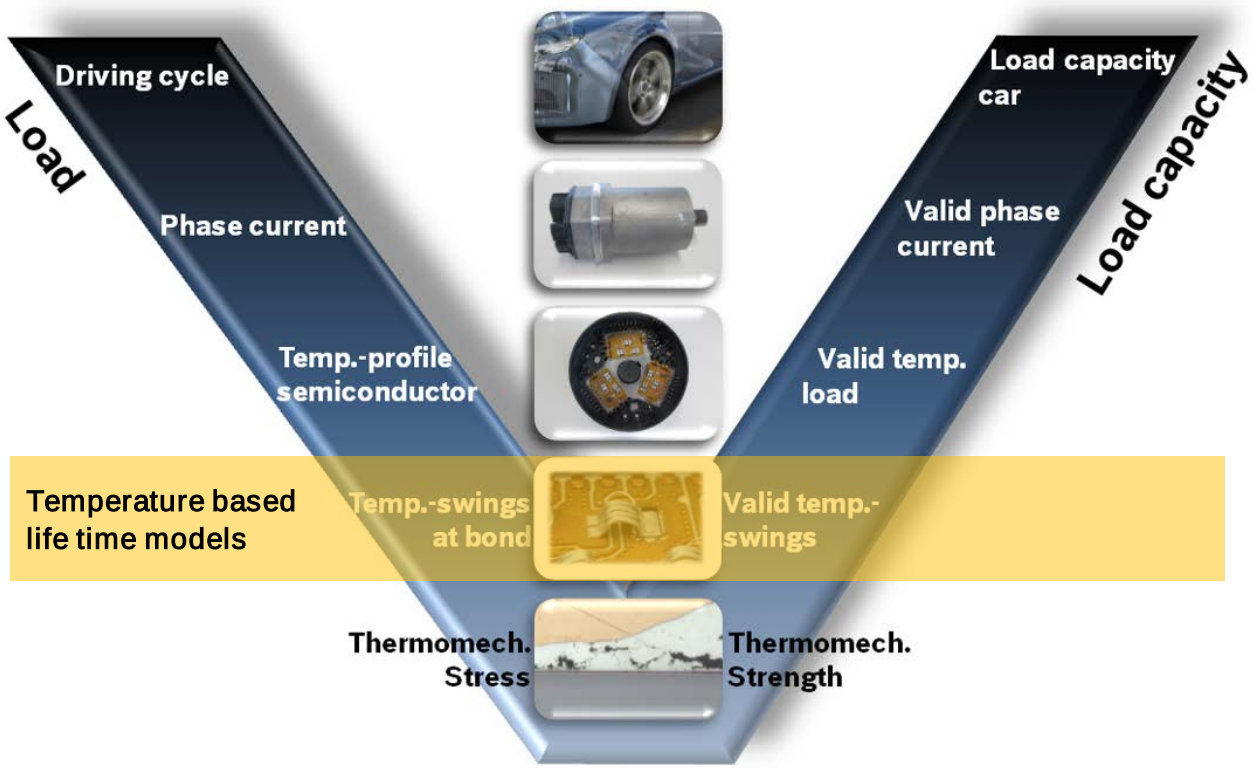
- Load and load capacity need to be compared




- State of the art reliability dimensioning and proofs are based on thermal based life time models, e.g.

$$N_f = A \cdot \left(\Delta T_{Global} + \boldsymbol{k} \cdot \rho \cdot J^2\right)^{-\alpha} \cdot \exp\left(\frac{\boldsymbol{Q}}{RT_m}\right)^{(*)}$$

(*)CIPS Presentation: Dürr, Faust-Ellsässer, Pröpper, Riester, 2016

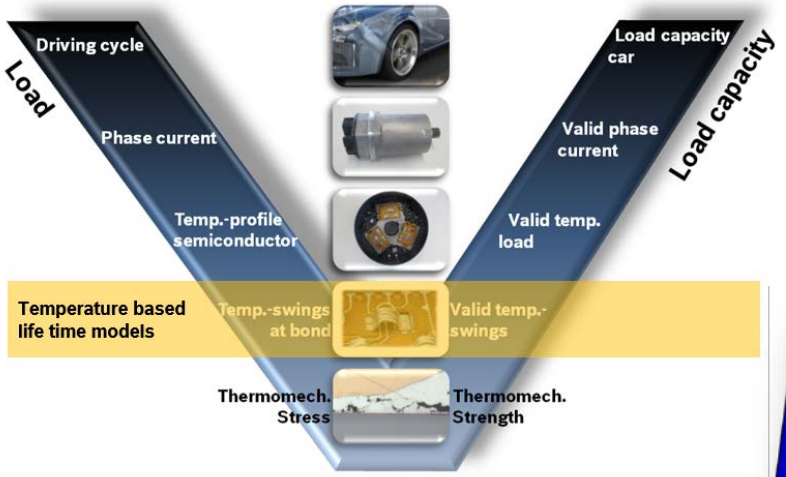



Advantage: Easy accessible parameter

Disadvantage: Geometry dependent parameter

# Real-time load stepping on the basis of FMOP for electro-thermal-mechanical FE simulations

## Motivation

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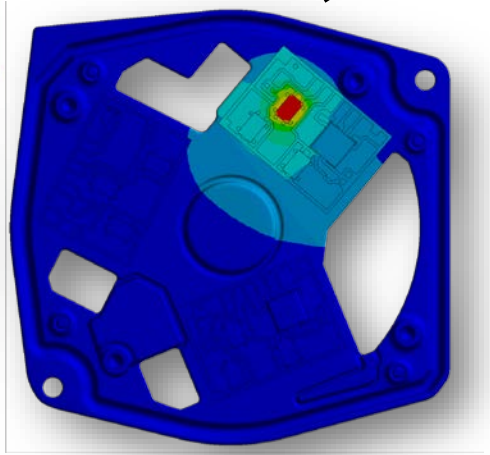
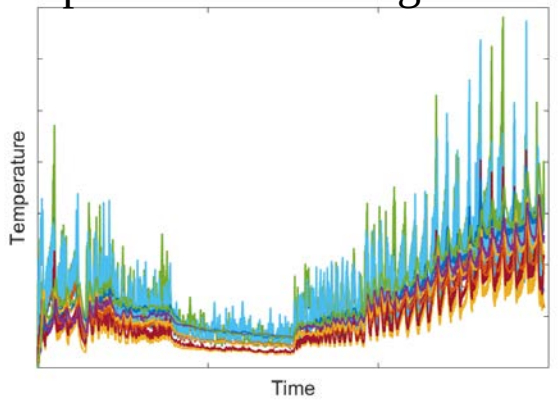
**Easy accessible parameter:**

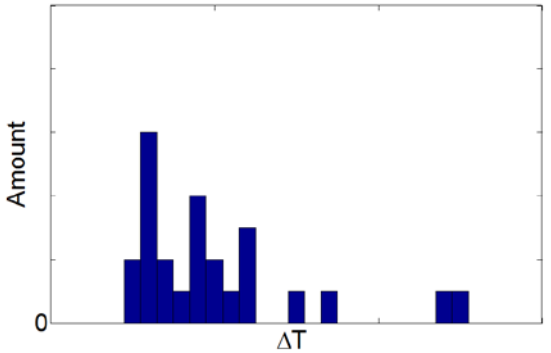


FEM Simulation

Temperature at design element




Rainflow counting



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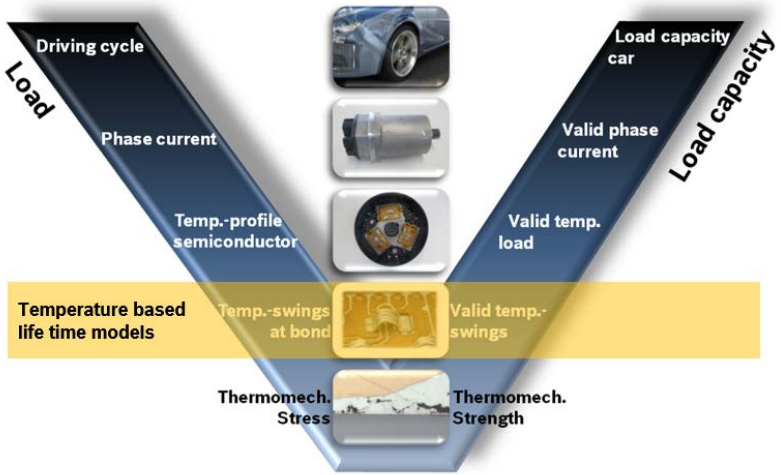


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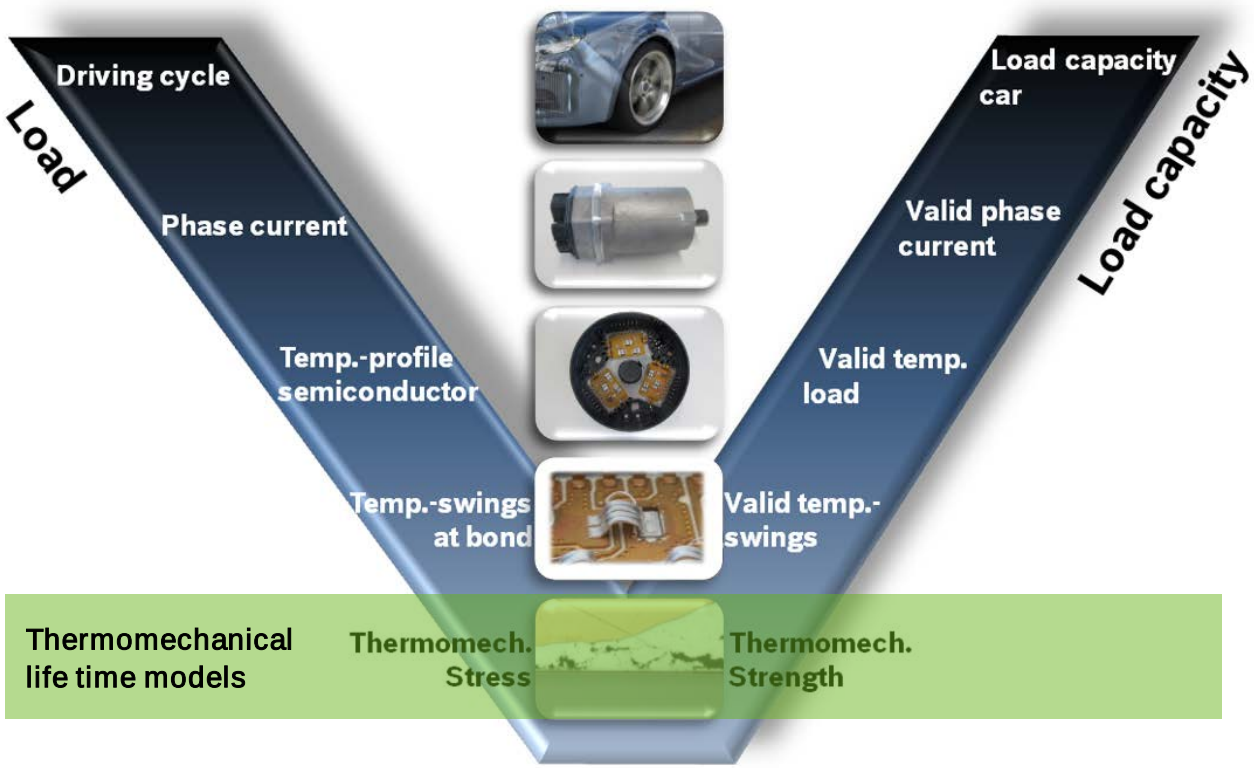


Advantage: Geometry independent parameter

Disadvantage: Elaborate accessible parameter

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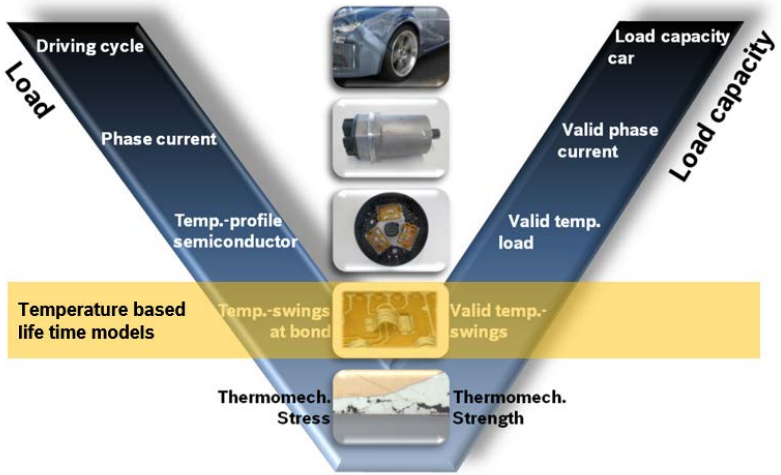


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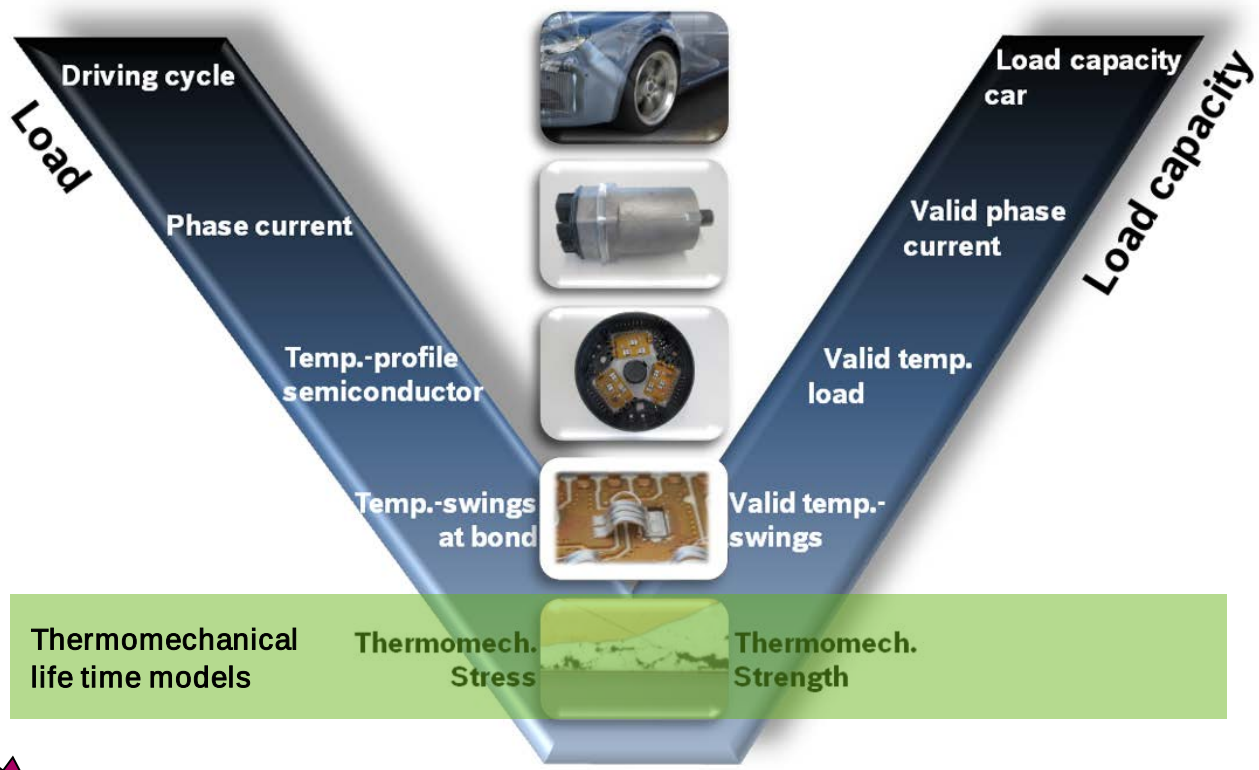
Disadvantage: Geometry dependent parameter

Allows earlier prognosis in development process on design element level

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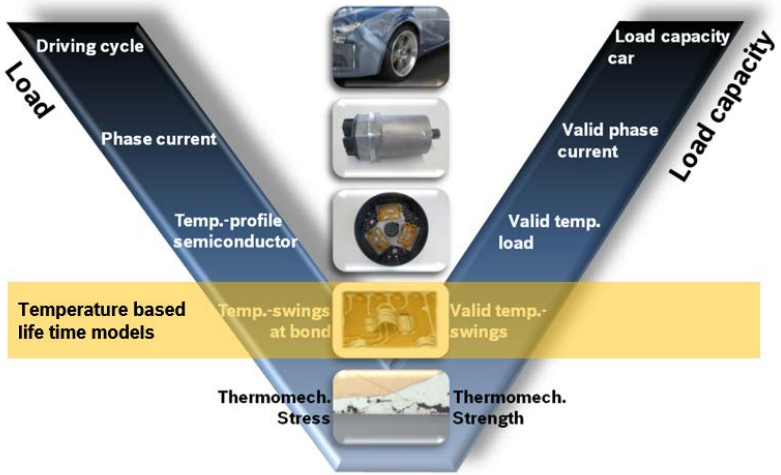


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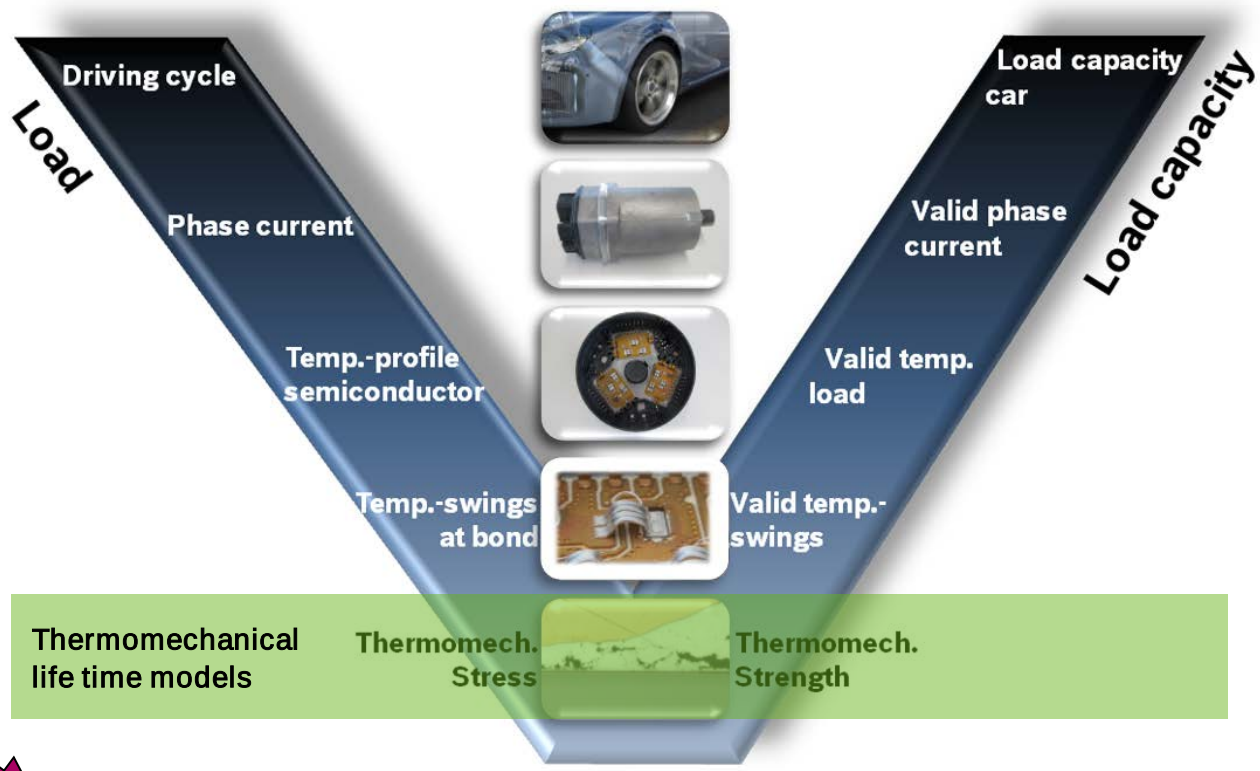


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# Real-time load stepping on the basis of FMOP for electro-thermal-mechanical FE simulations

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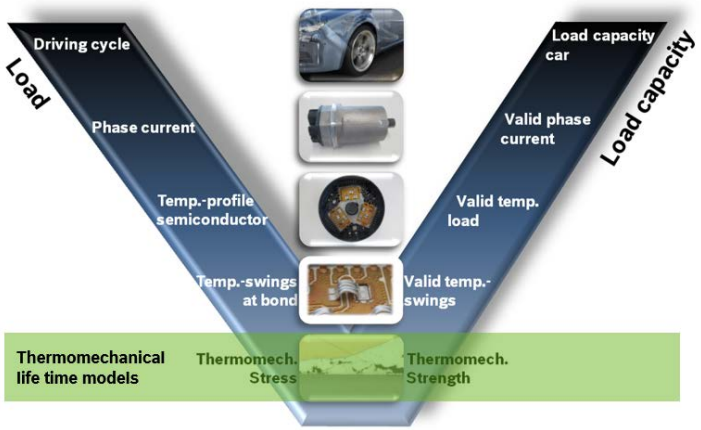
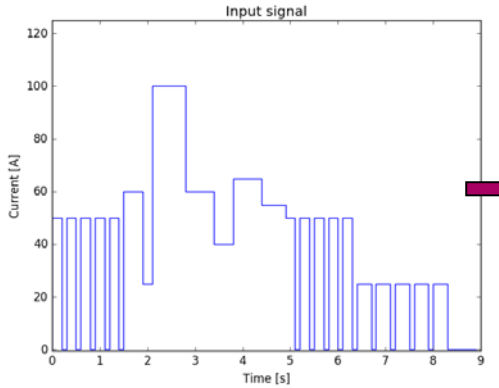
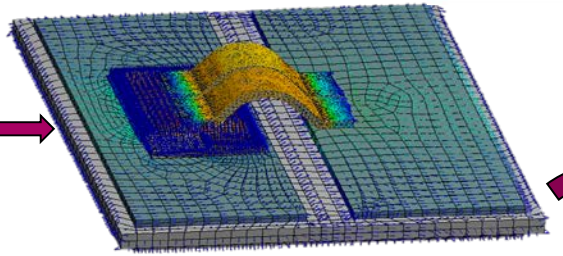
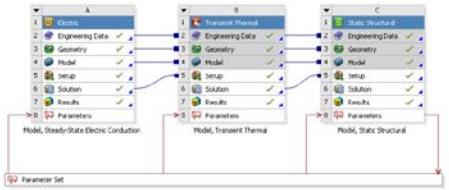



**Elaborate accessible parameter?**

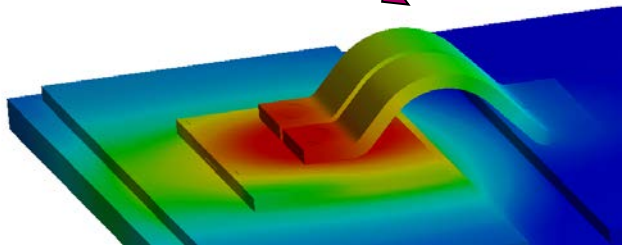
### Electrical Analysis

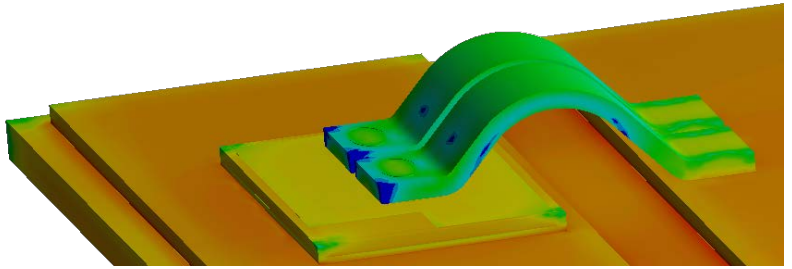




### Thermal Analysis

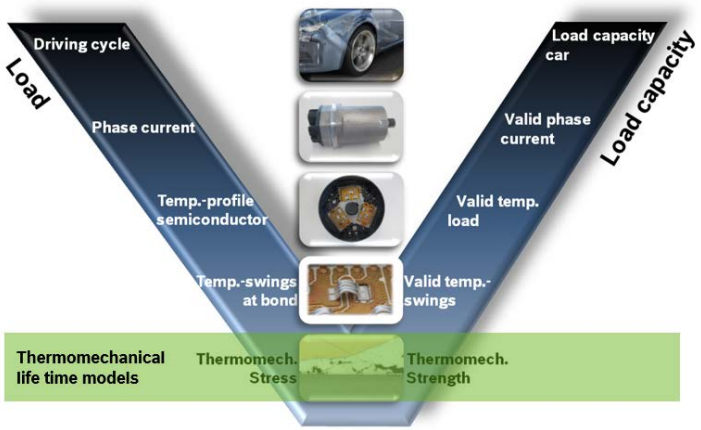




### Mechanical Analysis

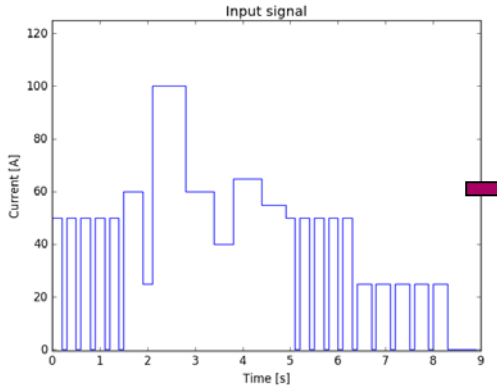
# Real-time load stepping on the basis of FMOP for electro-thermal-mechanical FE simulations

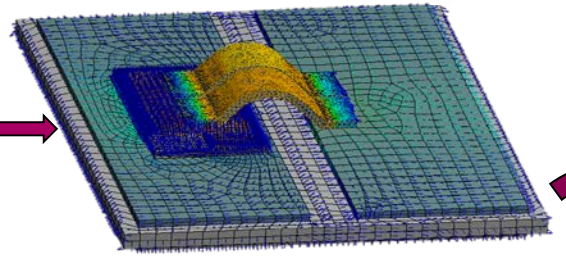
## Motivation

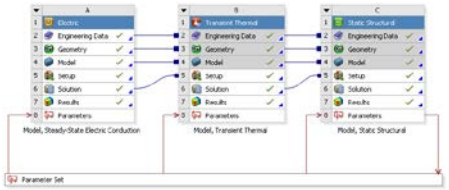



**Elaborate accessible parameter?**

### Electrical Analysis





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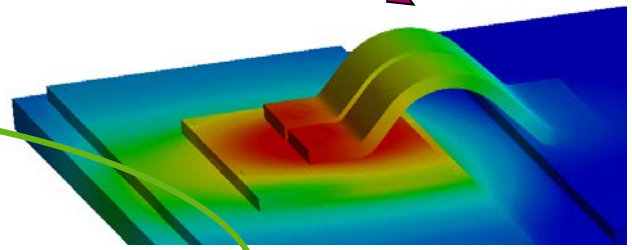
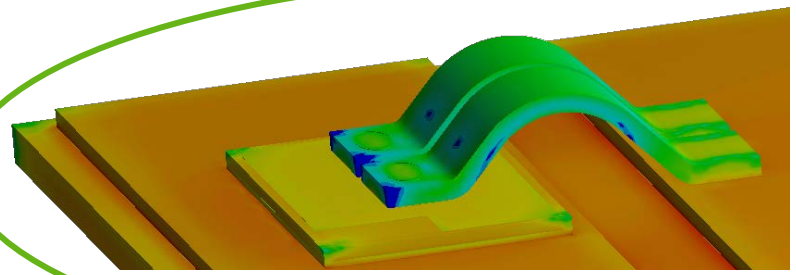
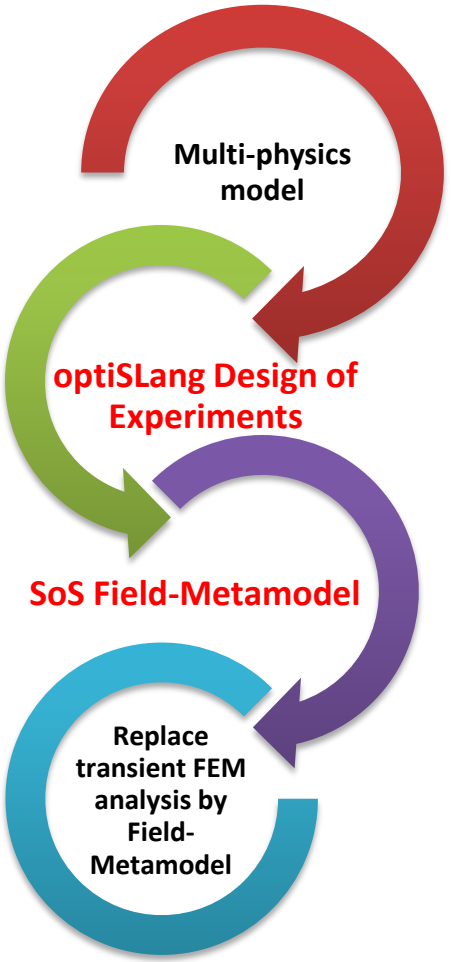




### Mechanical Analysis

**Nonlinear mechanical FEM simulation for transient load profile of whole ECU is not purposeful at the moment**

# Goal of the project




- The goal of the project is to produce an optiSLang SoS Field-Metamodel.
  - It can be used as a replacement for the coupled multi-physics simulation model.
- The Field-Metamodel is a surrogate model that can be used to **very rapidly assess new designs**.

# Real-time load stepping on the basis of FMOP for electro-thermal-mechanical FE simulations

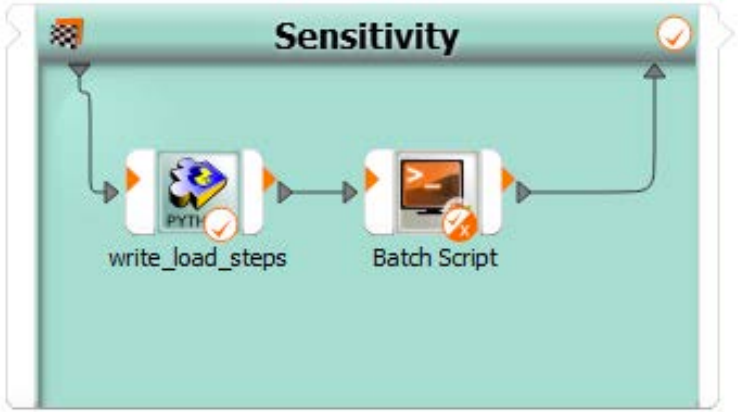
## optiSLang sensitvity analysis

- An optiSLang sensitivity analysis is used to generate a sampling data base.
- optiSLang SoS is then used to generate Field-Metamodels (FMOPs) for solution field quantities like temperature and stresses.

Sensitivity

Parameter | Start designs | Criteria | Dynamic sampling | Other | Result design

| | Name | Parameter type | rence v | onstar | alue typ | Resolution | Range | |
|---|---|---|---|---|---|---|---|---|
| 1 | t1 | Opt.+Stoch. | 0 | | REAL | Continuo... | 0 | 2 |
| 2 | t2 | Opt.+Stoch. | 0 | | REAL | Continuo... | 0 | 2 |
| 3 | t3 | Opt.+Stoch. | 0 | | REAL | Continuo... | 0 | 2 |
| 4 | t4 | Opt.+Stoch. | 0 | | REAL | Continuo... | 0 | 2 |
| 5 | t5 | Opt.+Stoch. | 0 | | REAL | Continuo... | 0 | 2 |
| 6 | A1 | Opt.+Stoch. | 0 | | REAL | Continuo... | -150 | 150 |
| 7 | A2 | Opt.+Stoch. | 0 | | REAL | Continuo... | -150 | 150 |
| 8 | A3 | Opt.+Stoch. | 0 | | REAL | Continuo... | -150 | 150 |
| 9 | A4 | Opt.+Stoch. | 0 | | REAL | Continuo... | -150 | 150 |
| 10 | A5 | Opt.+Stoch. | 0 | | REAL | Continuo... | -150 | 150 |
| 11 | Tm | Opt.+Stoch. | 0 | | REAL | Continuo... | 40 | 120 |




Parameter | Start designs | Criteria | Dynamic sampling | Other | Result designs

| | Id | Feasible | Duplicates | Status | A1 | A2 | A3 | A4 | A5 | Tm | t1 | t2 | t3 | t4 | t5 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 0.1 | true | | Succeeded | 8.75 | 28.75 | 98.75 | 0 | 0 | 78.3333 | 1.175 | 0.858333 | 1.375 | 1.675 | 0.341667 |
| 2 | 0.2 | true | | Succeeded | 0 | 0 | 18.75 | 0 | 11.25 | 79 | 1.44167 | 0.258333 | 1.94167 | 1.35833 | 1.19167 |
| 3 | 0.3 | true | | Succeeded | 0 | 148.75 | 46.25 | 0 | 63.75 | 115.667 | 0.958333 | 1.675 | 1.275 | 0.341667 | 1.44167 |
| 4 | 0.4 | true | | Succeeded | 0 | 0 | 0 | 33.75 | 131.25 | 62.3333 | 1.99167 | 0.108333 | 0.0416667 | 0.275 | 0.825 |

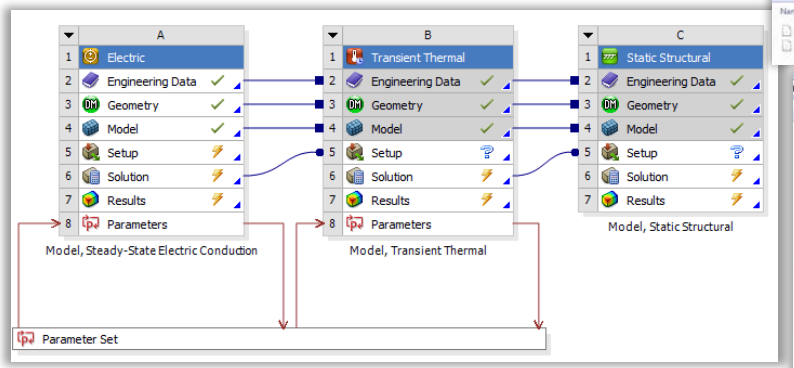
# Real-time load stepping on the basis of FMOP for electro-thermal-mechanical FE simulations

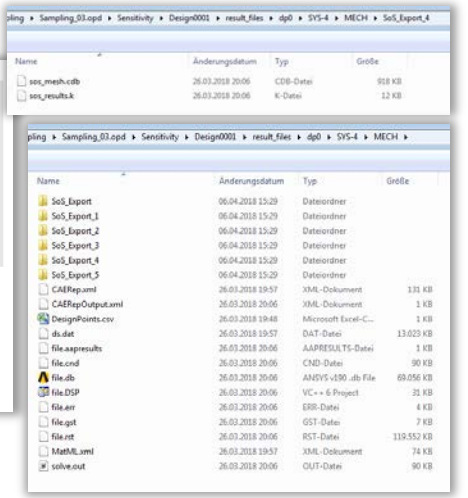
## ANSYS WB model

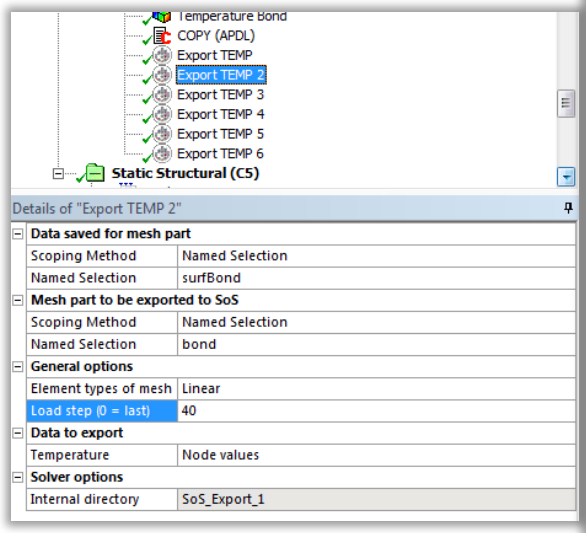
- **ANSYS WB**: connects 3 different physics and data transition between 3 ANSYS Mechanical models:
  Transient electrical loading leads to an increase in the temperature of the domain and, subsequently, to thermally induced stresses.

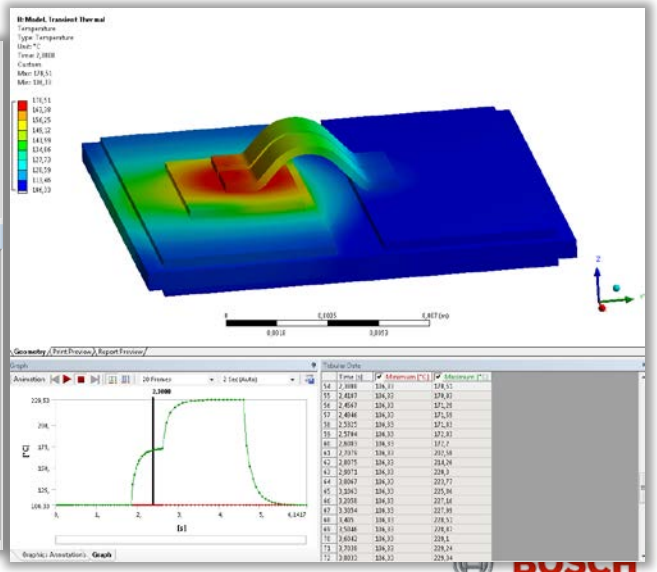
- **ANSYS APDL**: Define load transients based on external parameters

- **SoS for ANSYS**: Plugin for Mechanical exports result data directly to SoS for FMOP creation



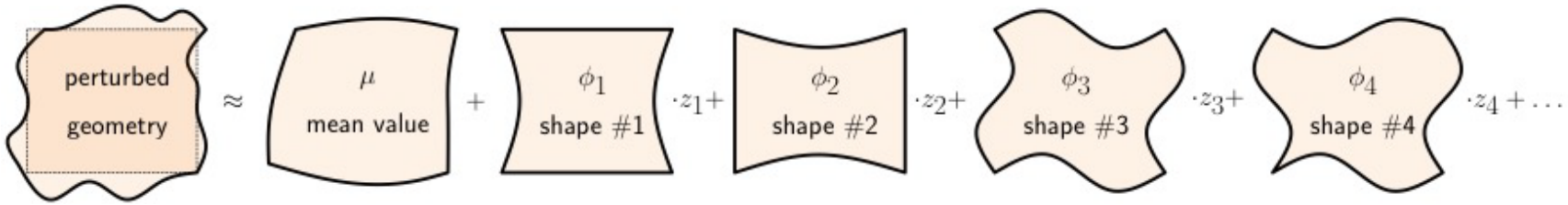





# SoS FMOP

- The Field-Metamodel is based on the non-linear combination of a random shape decompositioning of the solution fields.
- FMOP is an enhancement of the classical optiSLang metamodelling technique




- New input-parameter combinations can be used to approximate the full output field.

Inputs:
- Current amplitude signal
- Ambient temperature
- Transient temperature field


Outputs:
- TEMP,
- SX,
- SEQV,
- ...

# FMOP Approximation quality

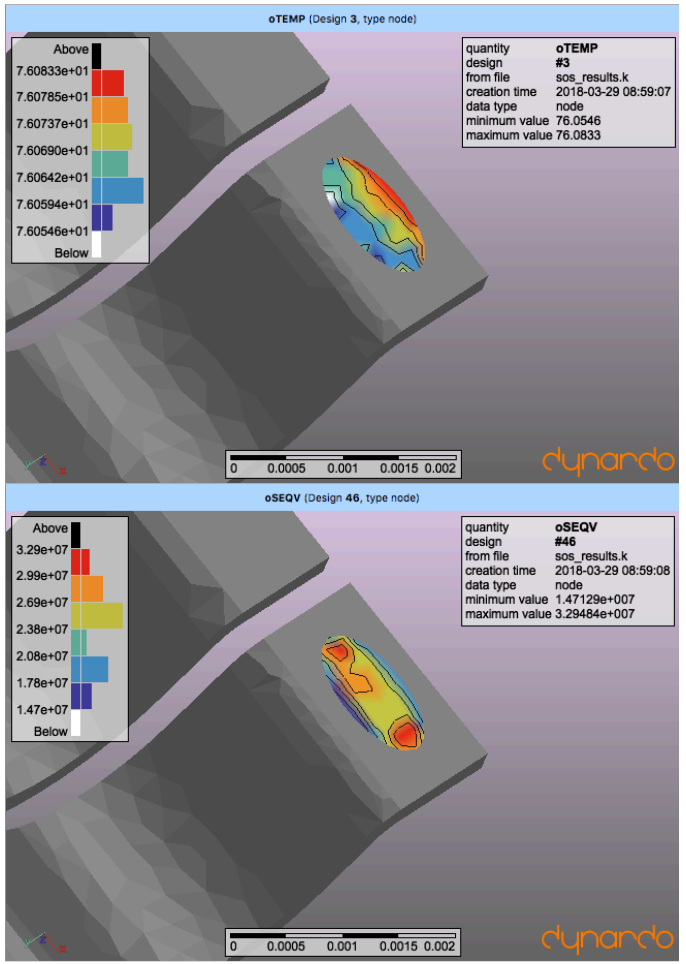
- Like for a classical optiSLang Metamodel, CoP values can be used to assess, whether the metamodel has a high approximation quality.

- For the generated Field-Metamodel the F-CoP (Total) values are very high (nonlinear thermal solution, linear mechanical)

- **The field metamodel has a very good approximation quality for all results** (stresses, temperatures)

| | iTEMP | oS1 | oS2 | oS3 | oSEQV | oSX | oSXY | oSXZ | oSY | oSYZ | oSZ | oTEMP |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| F-CoP[A] | | 71.15 % | 66.21 % | 68.33 % | 69.73 % | 64.84 % | 67.39 % | 67.64 % | 69.68 % | 73.72 % | 77.16 % | 73.58 % |
| F-CoP[Tm] | | 8.74 % | 5.64 % | 3.99 % | 7.43 % | 3.70 % | 0.44 % | 0.61 % | 4.93 % | 1.44 % | 6.68 % | 3.47 % |
| F-CoP[Total] | | 94.26 % | 94.28 % | 96.95 % | 96.62 % | 96.59 % | 96.73 % | 96.73 % | 97.37 % | 97.67 % | 98.33 % | 99.69 % |
| F-CoP[amp[iTEMP][node]_shape[1]] | | 31.86 % | 36.91 % | 34.47 % | 31.53 % | 38.35 % | 38.41 % | 38.73 % | 33.48 % | 32.19 % | 25.31 % | 17.49 % |
| F-CoP[dt] | | 12.80 % | 15.89 % | 16.53 % | 16.07 % | 17.88 % | 18.05 % | 18.28 % | 15.66 % | 15.16 % | 13.56 % | 12.01 % |

# Solution postprocessing in optiSLang/SoS

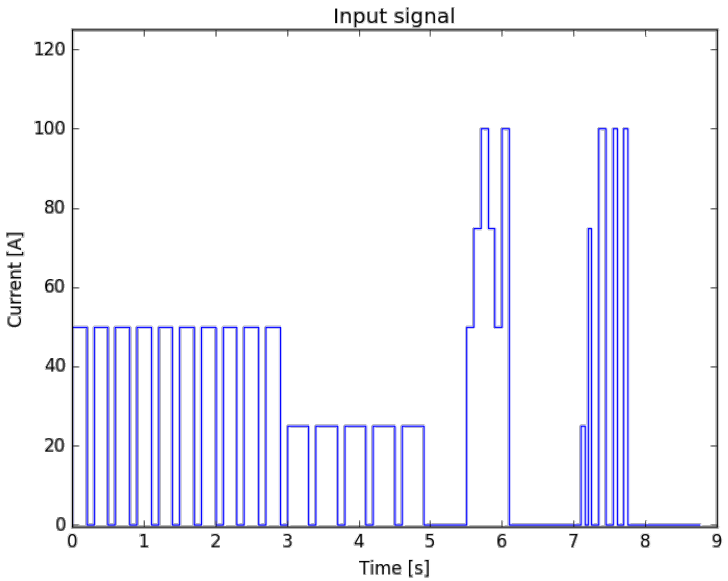



Visualized are solution fields for the temperature and the equivalent stress for the contact surface.

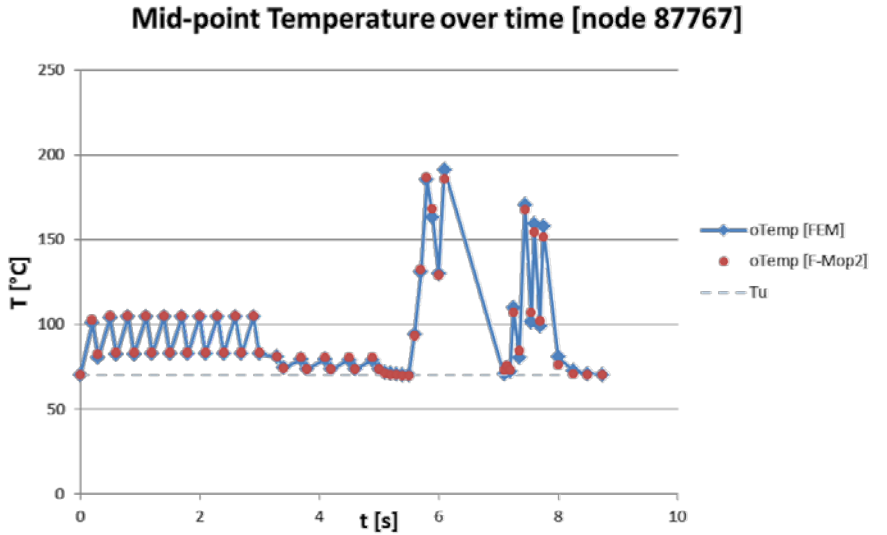
All field quantities are available for statistical postprocessing in SoS.

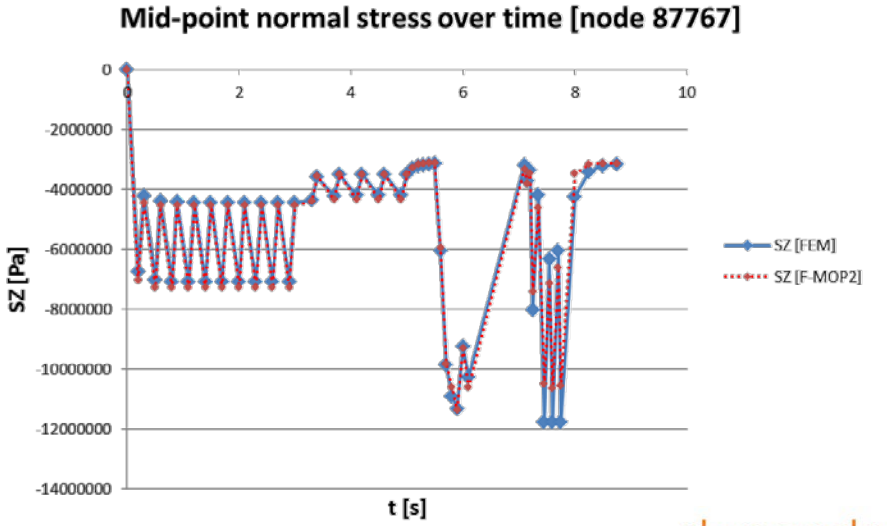
A Field-Metamodel (FMOP) can be produced for these result quantities.

# FMOP result validation




Field-MOP

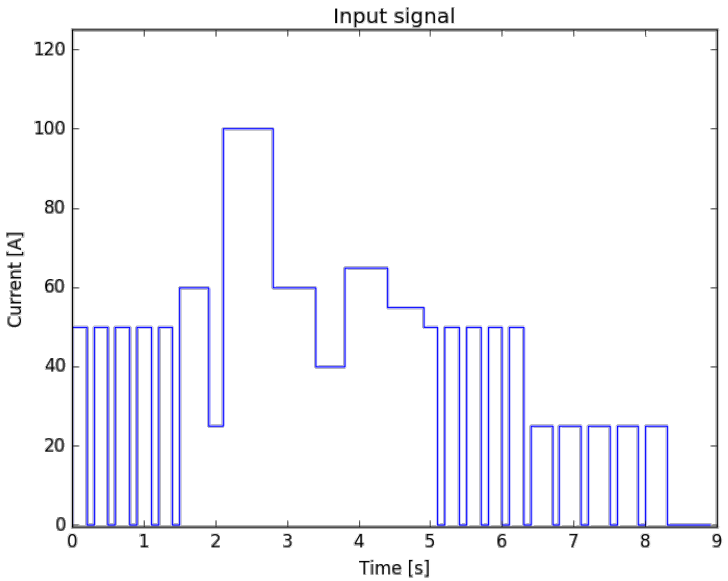


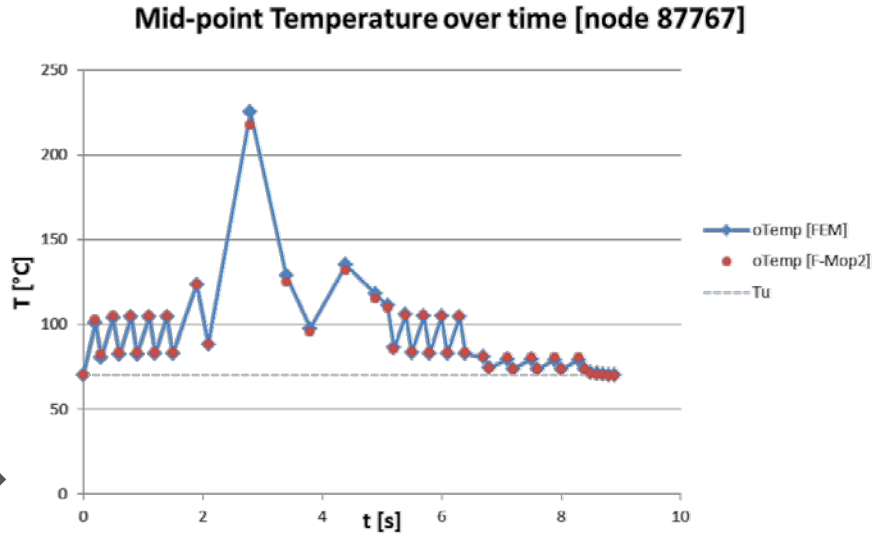

Output at point of the contact:

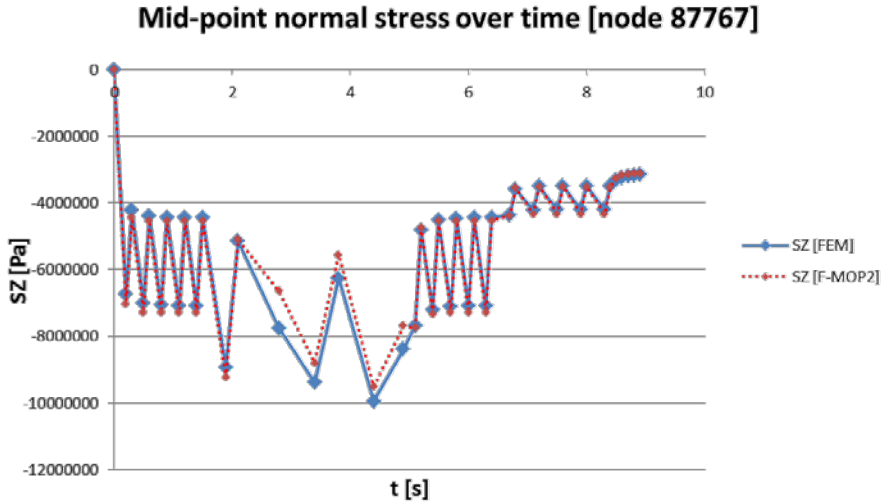
- Excellent approximation result for transient temperature and contact stresses.

# FMOP result validation




Field-MOP

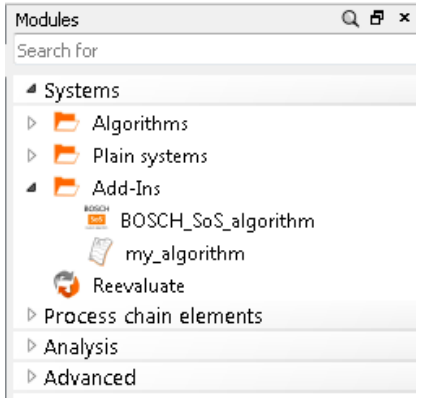


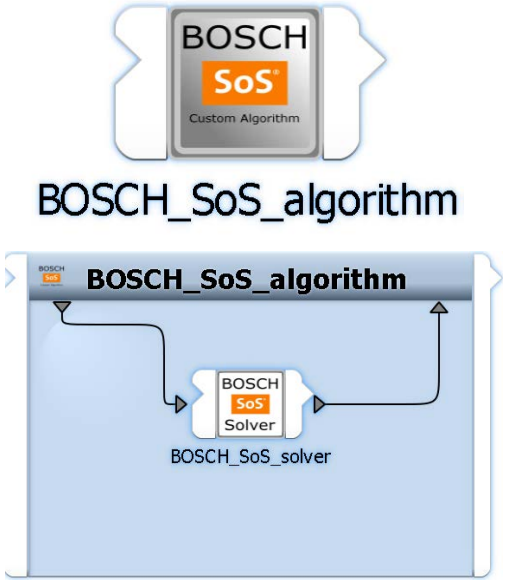

Output at point of the contact:

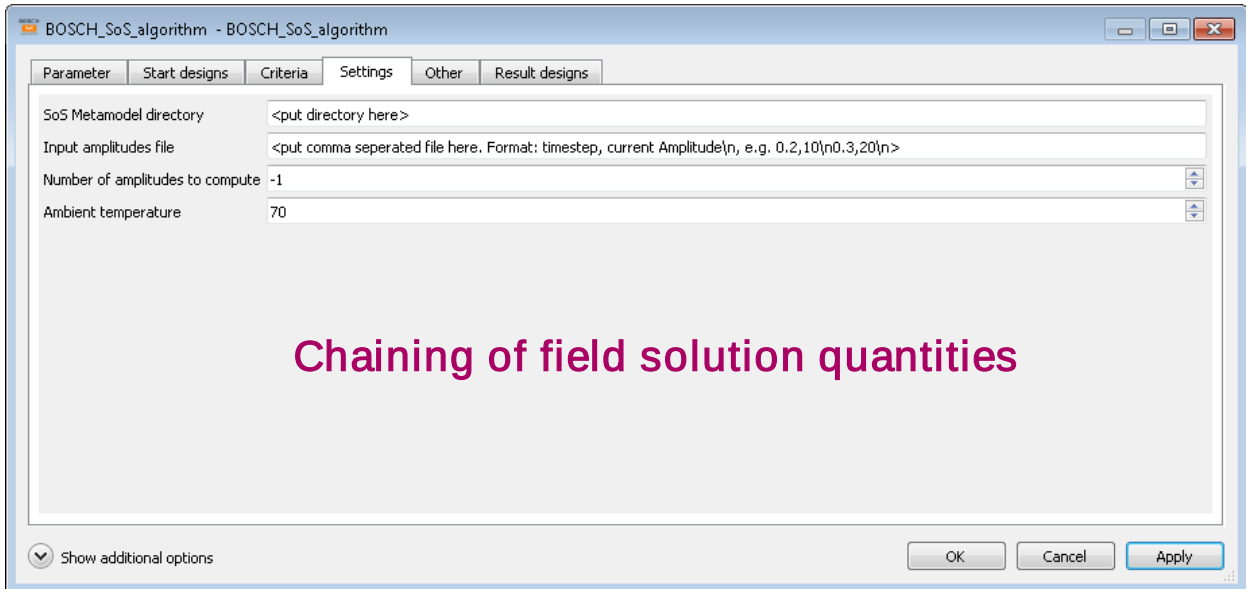
- Excellent approximation result for transient temperature and contact stresses.

# Transient solver: As optiSLang Custom Algorithm




- Based on the optiSLang Custom Algorithm interface, a custom user interface has been generated to **solve for transient field inputs/outputs**.
- Realized as custom node in optiSlang.

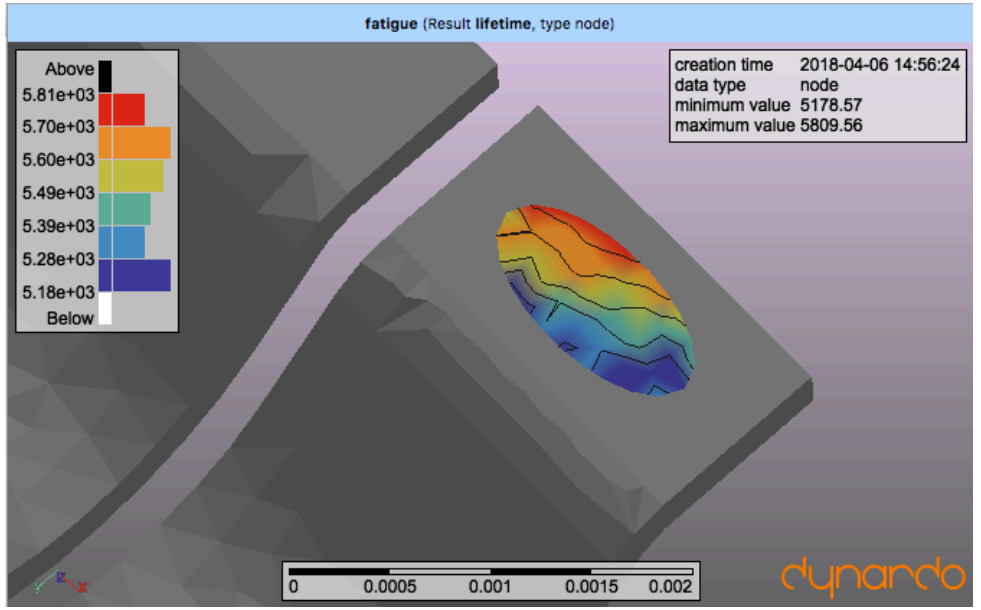


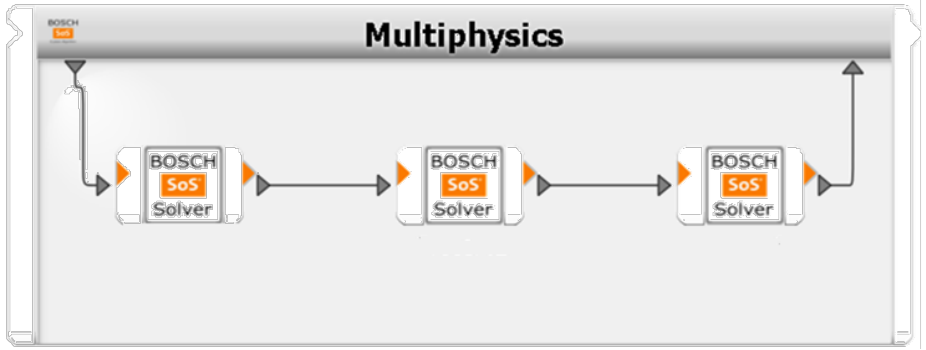
# Transient solver: As SoS script

- Based on SoS script API one can solve the system given a load transient directly from Windows Explorer

- Integrated rainflow counting to assess critical number of load cycles and visualization of expected lifetime in SoS:



# Résumé





Selective access:
- CAE expert
- Design engineer
- Project manager

- **The generation of the SoS FMOP was successful.**
- User-friendly export of data through ANSYS plugin
- Automatic FMOP generation and solution using pre-defined SoS scripts.

- FMOP allows the rapid evaluation of field quantities without the need to run a full simulation model.
- The field metamodel can be saved in a database (QM).
- Team based access can be organized on a high-level using optiSLang technology.

**CPU-time for validation 1**

**FEM: 24.85 h**

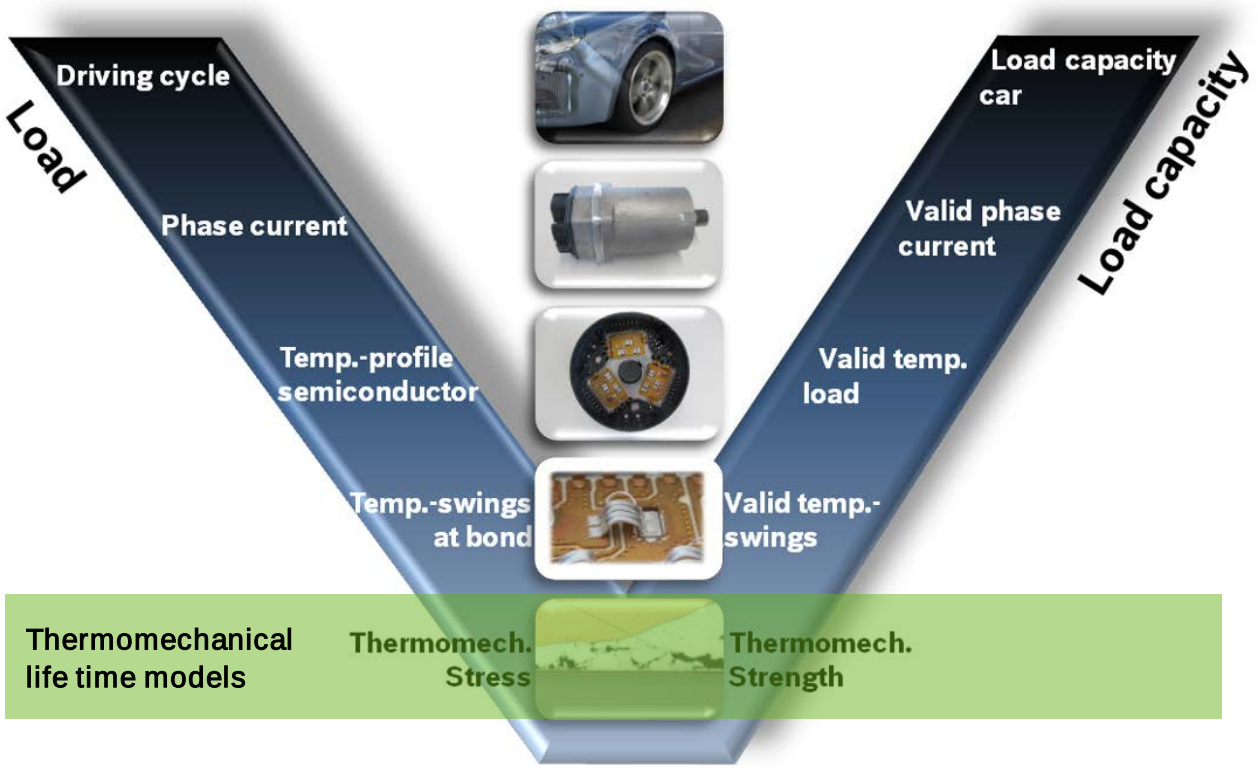
**SoS Field-MOP optiSlang Custom Algorithm: 130 s**

**SoS Field-MOP as script: 6 s**

# Conclusion / Outlook

- SoS FMOP enables to go one step deeper on the load side of the V model and reach a geometry independent parameter for comparing load and load capacity

- Outlook:
  - FMOP validation for different design elements is ongoing
  - FMOP could enable real time simulation to identify remaining life time of the ECU
  - Web access & Digital Twin application



# THANK YOU

## FOR YOUR ATTENTION

dynardo

BOSCH