SIEMENS

Transportation Systems

# Linear Analysis of Railway Vehicle as Mechatronic System

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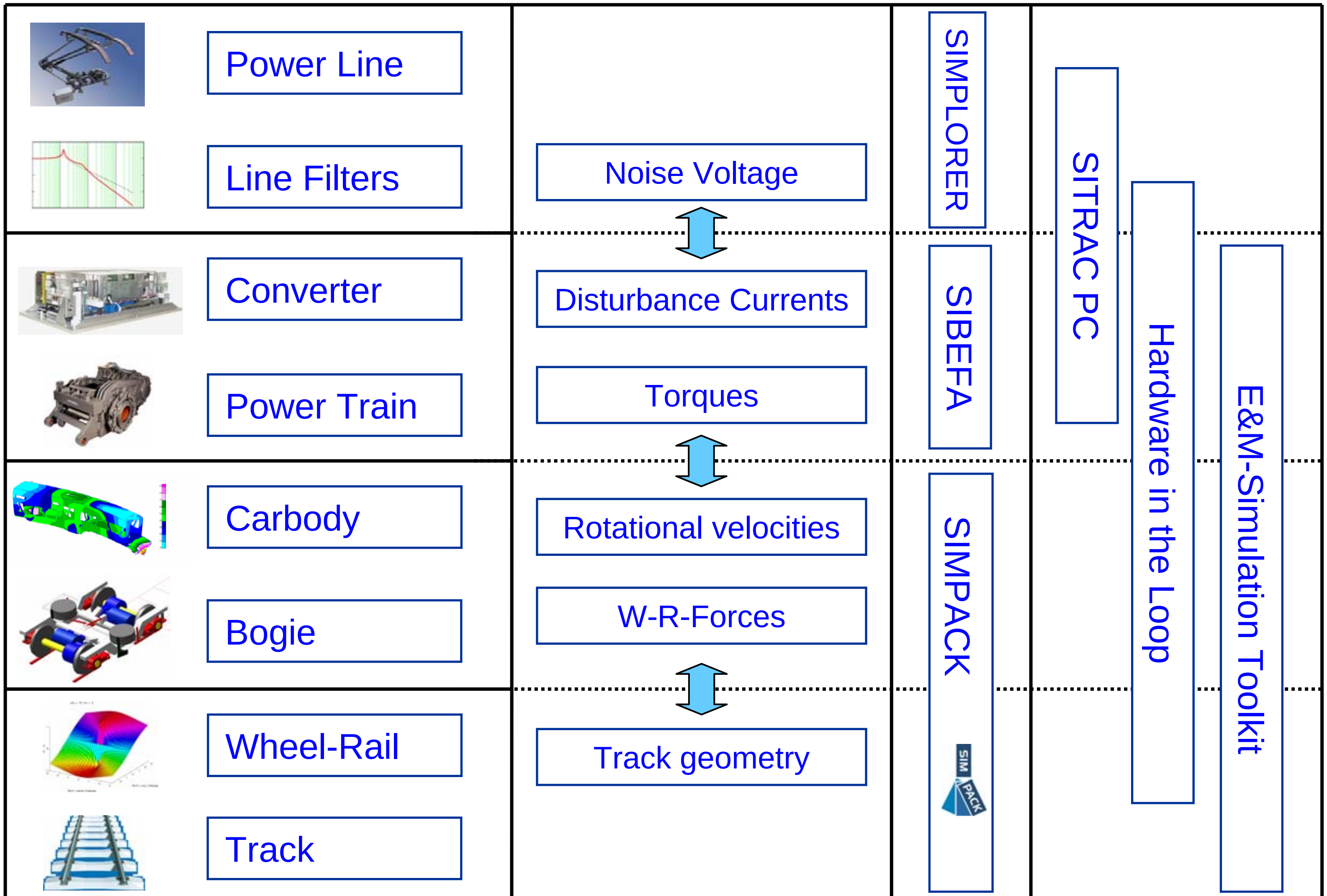
TS BG EN

# Separated worlds … and how to reunify them

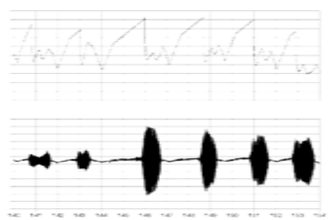


SIEMENS

Transportation Systems

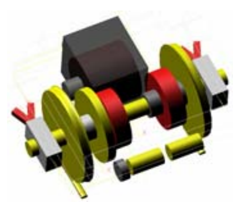
# The Simulation Toolkit

| 2002 | 2003 | 2004 | 2005 |
|---|---|---|---|
| Implementation | | Validation and first Applications | Linear System Analysis |



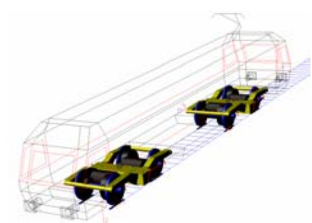
Focus

- Analysis of Interaction Mechanics – Electrics – Software
- Methods: Co-Simulation & Linear System Analysis
- Established Software Platforms



Models

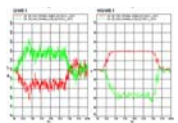
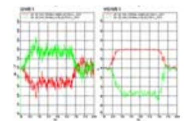
- Mechanics: Drive train - Bogie - Vehicle
- Electrics: Converter – Induction motor – Tachometer dynamics
- Software: ASG – Slip control - GSS - dn/dt



Applications

- Drive train vibrations
- Vehicle vibrations
- Shock-loads

# Methods of Simulation

<table>
<tr>
<td>Time-Integration<br>Non-Linear-System </td>
<td>Time-Integration<br>Linear-System </td>
<td>Linear System<br>Analysis </td>
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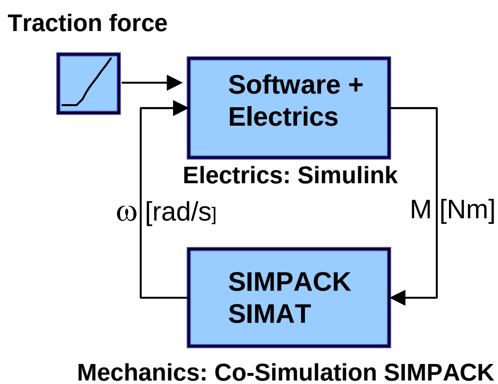
<td>
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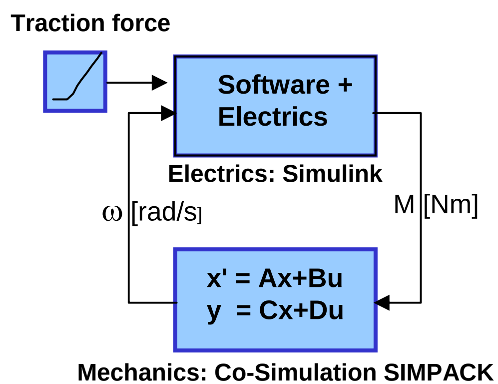
<td>
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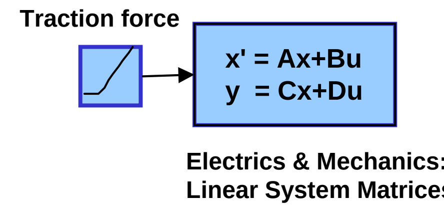
<td>
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</tr>
<tr>
<td>Simulation of the entire system<br>Electrics – Mechanics – Software<br>including track geometry and<br>track irregularities</td>
<td>Stand-alone-simulation<br>in MATLAB</td>
<td>Fundamental insight into<br>the behaviour of the<br>linear system</td>
</tr>
<tr>
<td>Various applications:<br>Shock Loads<br>Torsional vibrations<br>Vehicle vibrations</td>
<td>Used for verification of<br>system-matrix-export</td>
<td>Implemented, validation<br>and first applications</td>
</tr>
</table>



# The Linearisation Recipe

Automatisation

## 1. Synchronise

- Co-Simulation SIMPACK-MATLAB
- Synchronised state mechanics-electrics

## 2. Linearise

- Export of linear system matrices from SIMPACK
- Linearisation of complete system in MATLAB

## 3. Visualise

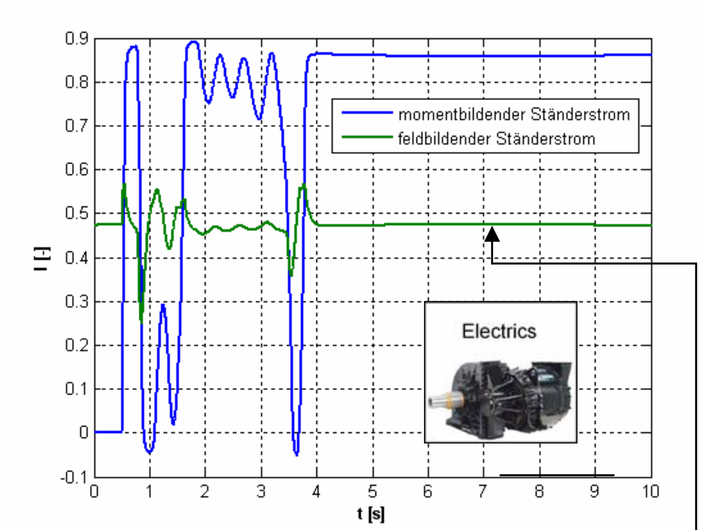
- Root locii
- Visualise with SIMPACK

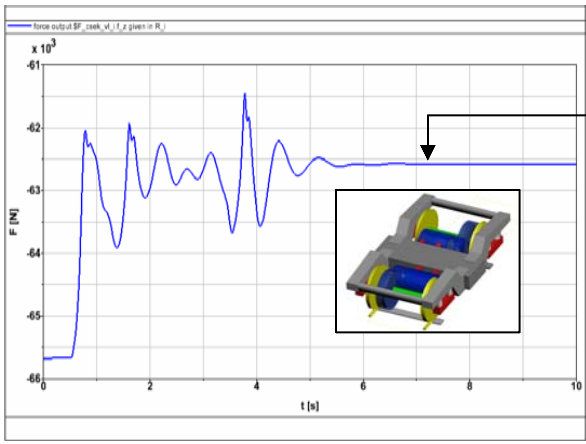
# Synchronise

Co-Simulation in time domain

MATLAB

SIMPACK

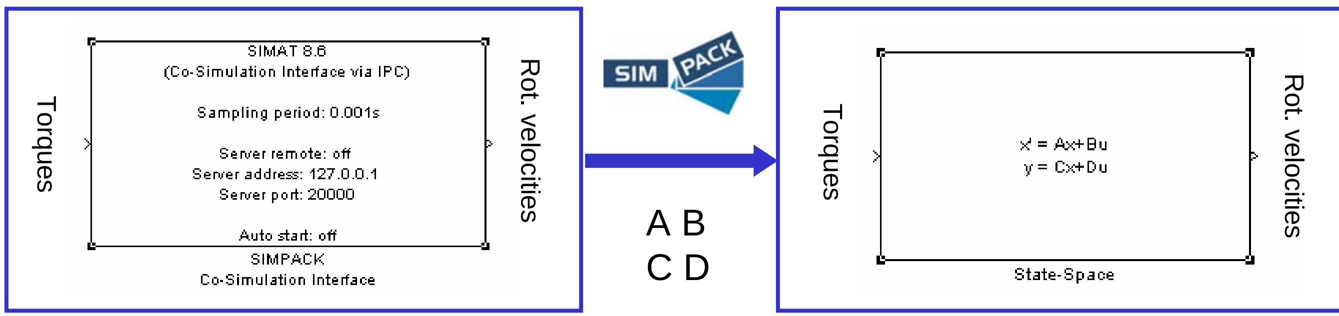


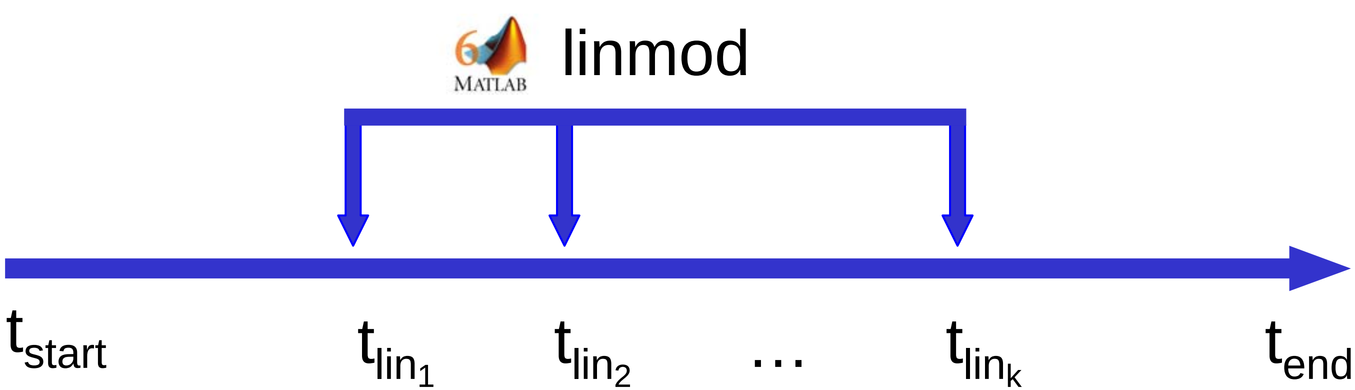

Synchronised state

# Linearise

## 1. Exchange SIMAT – System Matrix Block

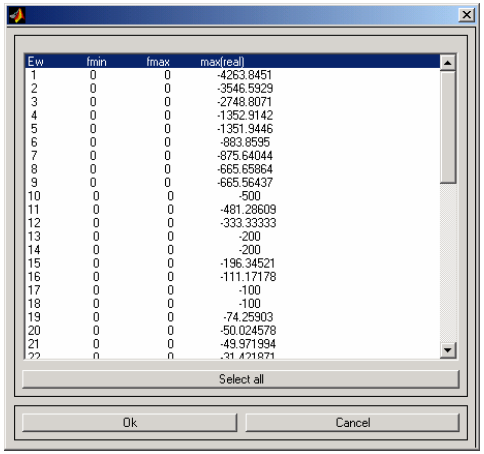


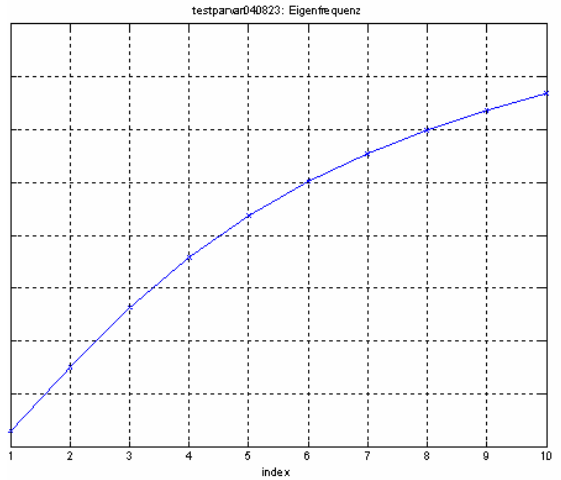

## 2. Linearise the complete system at given times



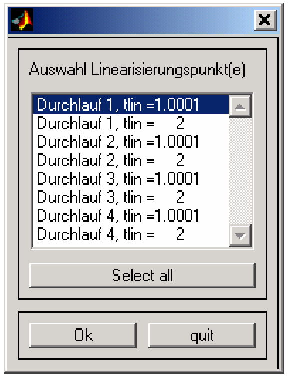
# Visualise

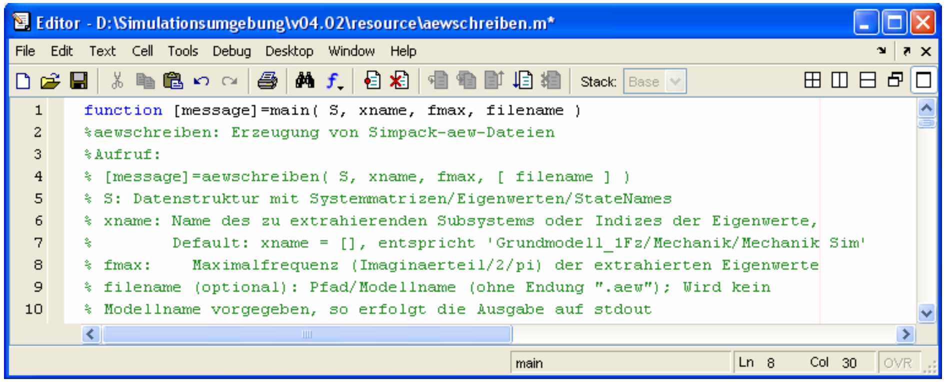
## Plot Eigenvalues



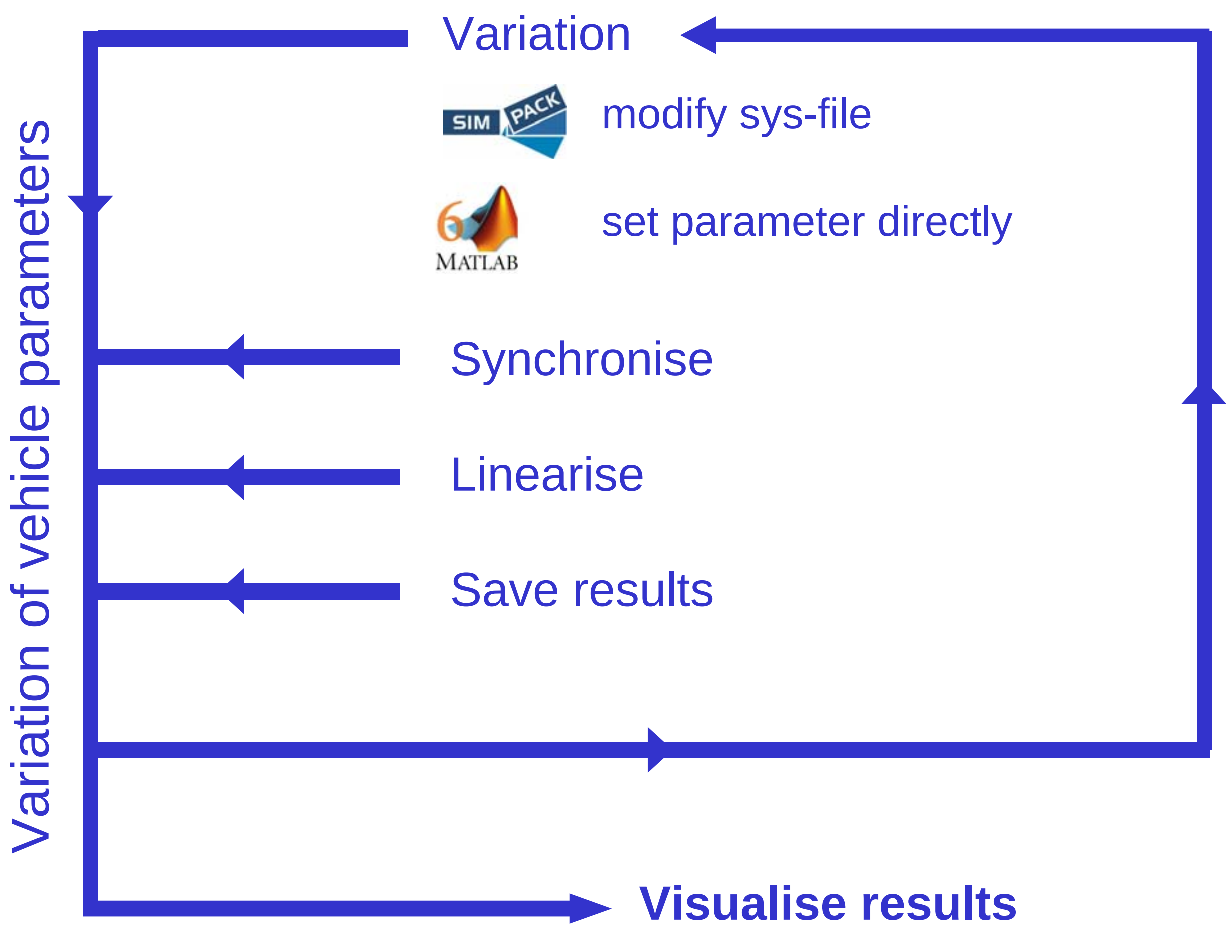




## Generate SIMPACK aew-file



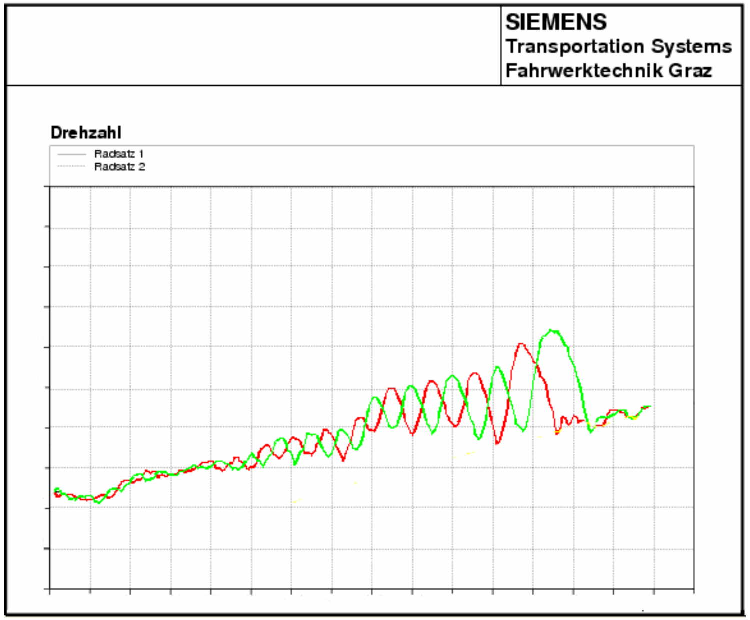
# Automatisation

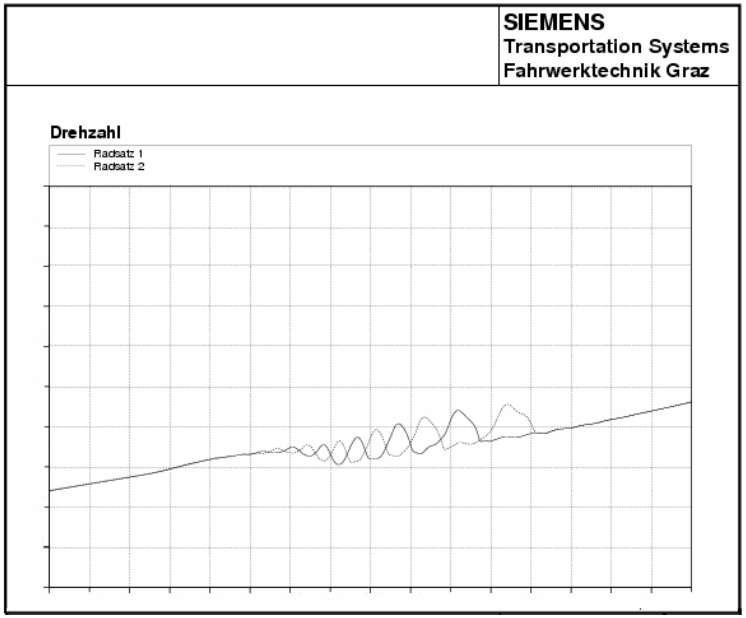


# Example – Step 1

Vibration effect due to interaction mechanics-electrics-software is found on the real vehicle

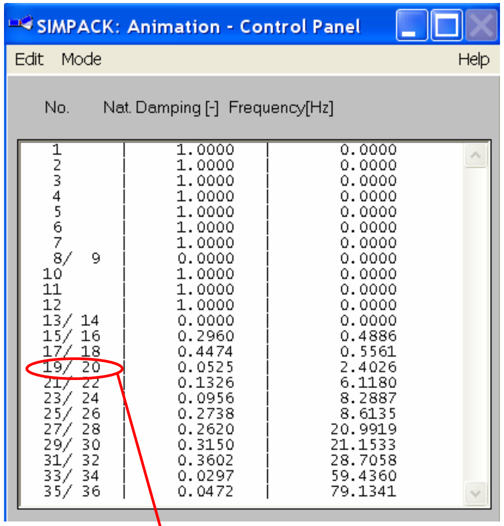
Co-simulation in time domain can reproduce the behaviour



# Example – Step 2

## Linear analysis - mechanics only (without E&M-coupling)



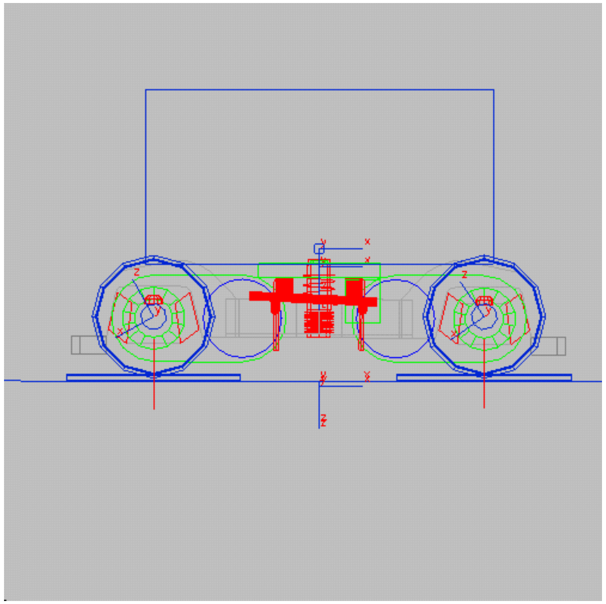
SIMPACK: Animation - Control Panel

Edit Mode Help

| No. | Nat. Damping [-] | Frequency[Hz] |
|---|---|---|
| 1 | 1.0000 | 0.0000 |
| 2 | 1.0000 | 0.0000 |
| 3 | 1.0000 | 0.0000 |
| 4 | 1.0000 | 0.0000 |
| 5 | 1.0000 | 0.0000 |
| 6 | 1.0000 | 0.0000 |
| 7 | 1.0000 | 0.0000 |
| 8/ 9 | 0.0000 | 0.0000 |
| 10 | 1.0000 | 0.0000 |
| 11 | 1.0000 | 0.0000 |
| 12 | 1.0000 | 0.0000 |
| 13/ 14 | 0.0000 | 0.0000 |
| 15/ 16 | 0.2960 | 0.4886 |
| 17/ 18 | 0.4474 | 0.5561 |
| 19/ 20 | 0.0525 | 2.4026 |
| 21/ 22 | 0.1326 | 6.1180 |
| 23/ 24 | 0.0956 | 8.2887 |
| 25/ 26 | 0.2738 | 8.6135 |
| 27/ 28 | 0.2620 | 20.9919 |
| 29/ 30 | 0.3150 | 21.1533 |
| 31/ 32 | 0.3602 | 28.7058 |
| 33/ 34 | 0.0297 | 59.4360 |
| 35/ 36 | 0.0472 | 79.1341 |

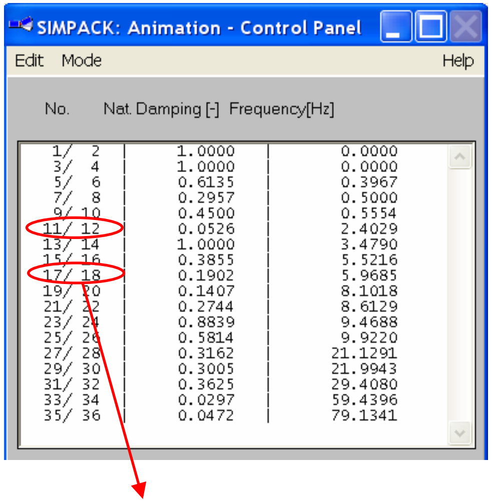
„Traditional“ mode shapes

from mechanics

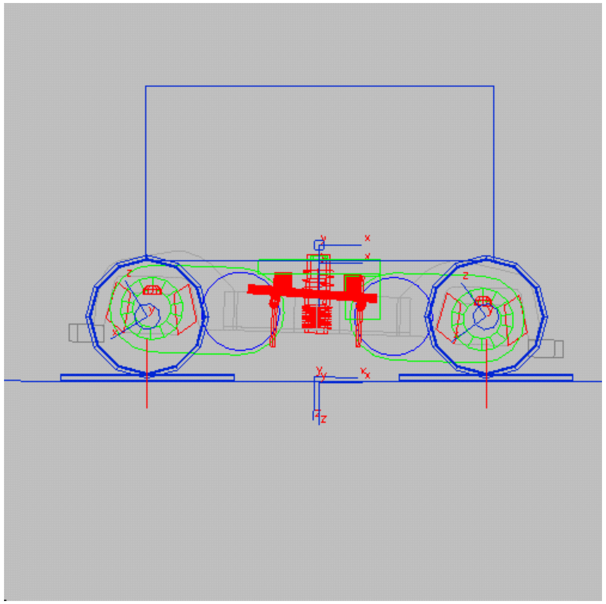


# Example – Step 3

## Linear analysis - complete system (with E&M-coupling)




| No. | Nat. Damping [-] | Frequency[Hz] |
|---|---|---|
| 1/ 2 | 1.0000 | 0.0000 |
| 3/ 4 | 1.0000 | 0.0000 |
| 5/ 6 | 0.6135 | 0.3967 |
| 7/ 8 | 0.2957 | 0.5000 |
| 9/ 10 | 0.4500 | 0.5554 |
| 11/ 12 | 0.0526 | 2.4029 |
| 13/ 14 | 1.0000 | 3.4790 |
| 15/ 16 | 0.3855 | 5.5216 |
| 17/ 18 | 0.1902 | 5.9685 |
| 19/ 20 | 0.1407 | 8.1018 |
| 21/ 22 | 0.2744 | 8.6129 |
| 23/ 24 | 0.8839 | 9.4688 |
| 25/ 26 | 0.5814 | 9.9220 |
| 27/ 28 | 0.3162 | 21.1291 |
| 29/ 30 | 0.3005 | 21.9943 |
| 31/ 32 | 0.3625 | 29.4080 |
| 33/ 34 | 0.0297 | 59.4396 |
| 35/ 36 | 0.0472 | 79.1341 |



Additional mode shapes

from interaction mechanics-electrics

with correct frequency are found



# Summary

## Intention

Apply methods of linear system analysis to models of railway vehicles as mechatronic system

## Method

Find a synchronised state electrics-mechanics by co-simulation
Exchange SIMAT-block by system-matrix-block
Import system matrices from SIMPACK
Linearise the complete system in MATLAB
Visualise results in SIMPACK

## Results

Method has been applied to sample models
Basic technical functionality is provided

## Outlook

Validation and testing is in progress