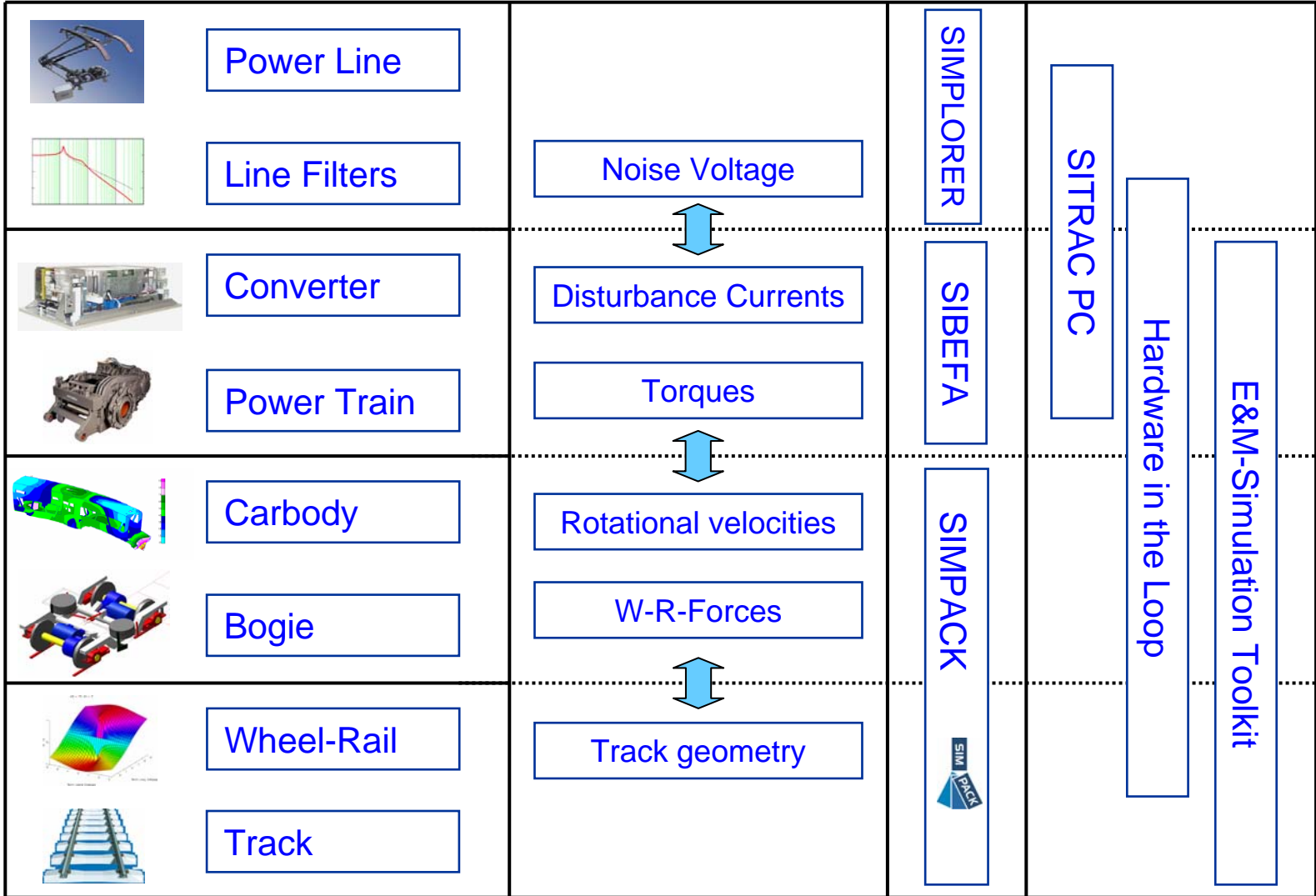


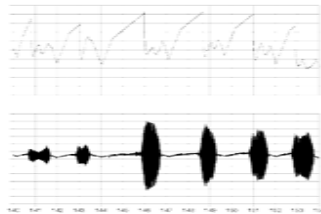
# Linear Analysis of Railway Vehicle as Mechatronic System

Dr. Heinz-Peter Kotz  
TS BG EN

# Separated worlds ... and how to reunify them

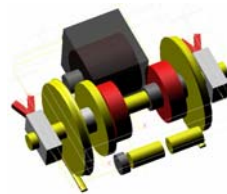


# The Simulation Toolkit



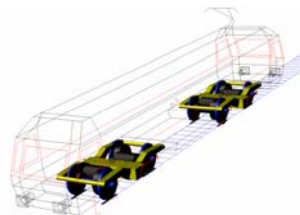
## Focus

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



## Models

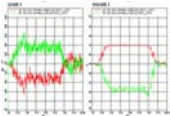
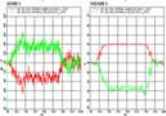
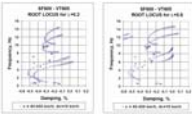
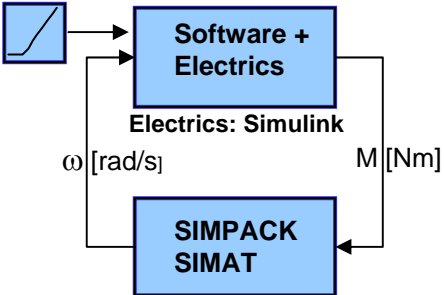
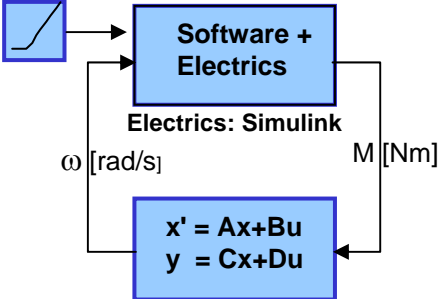
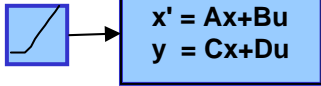
Mechanics: Drive train - Bogie - Vehicle  
 Electrics: Converter – Induction motor – Tachometer dynamics  
 Software: ASG – Slip control - GSS -  $dn/dt$



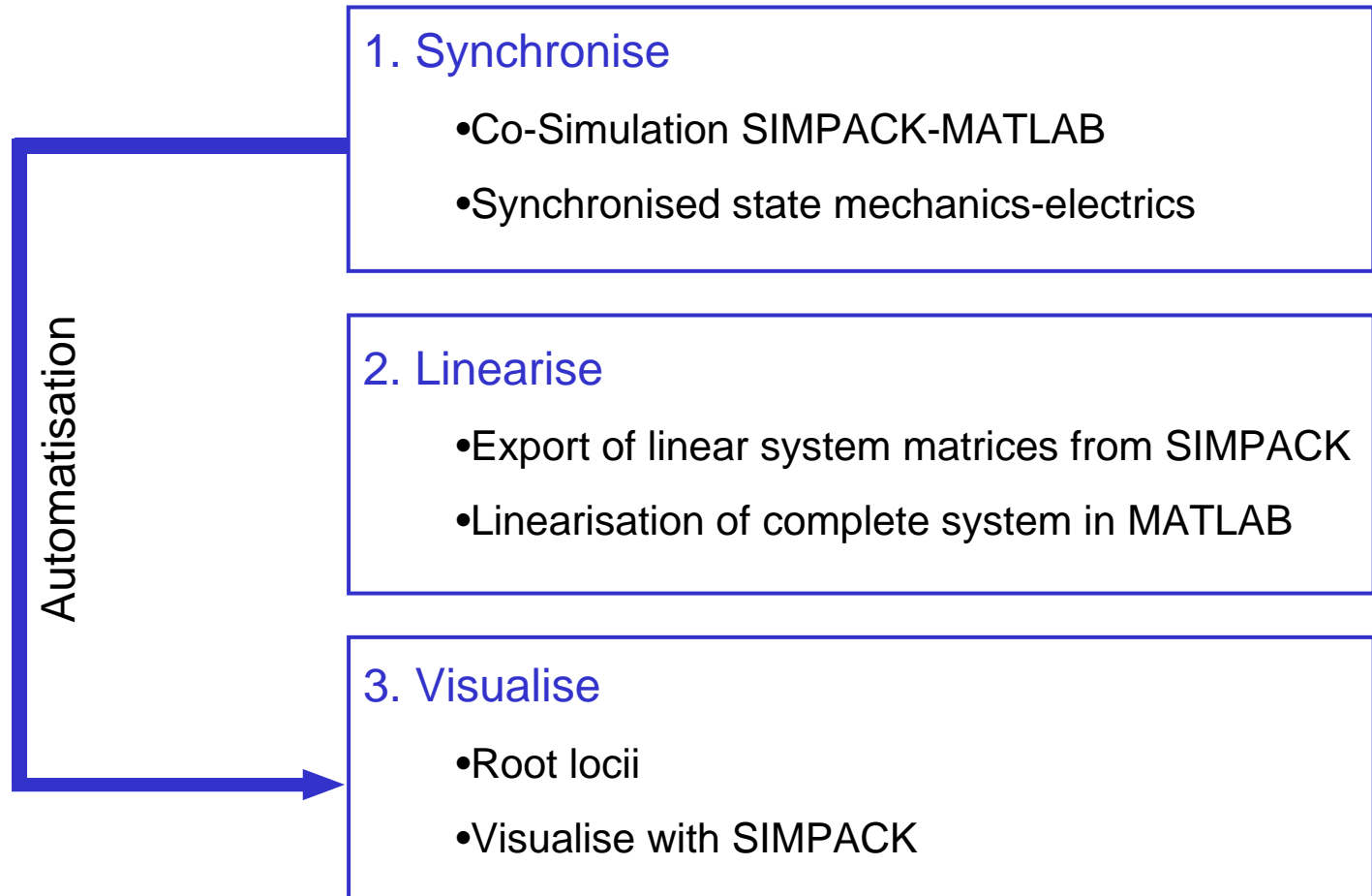
## Applications

Drive train vibrations  
 Vehicle vibrations  
 Shock-loads

# Methods of Simulation

<p>Time-Integration Non-Linear-System</p> 	<p>Time-Integration Linear-System</p> 	<p>Linear System Analysis</p> 
<p>Traction force</p>  <p>Electrics: Simulink</p> <p>Mechanics: Co-Simulation SIMPACK</p>	<p>Traction force</p>  <p>Electrics: Simulink</p> <p>Mechanics: Co-Simulation SIMPACK</p>	<p>Traction force</p>  <p>Electrics &amp; Mechanics: Linear System Matrices</p>
<p>Simulation of the entire system Electrics – Mechanics – Software including track geometry and track irregularities</p>	<p>Stand-alone-simulation in MATLAB</p>	<p>Fundamental insight into the behaviour of the linear system</p>
<p>Various applications: Shock Loads Torsional vibrations Vehicle vibrations</p>	<p>Used for verification of system-matrix-export</p>	<p>Implemented, validation and first applications</p>

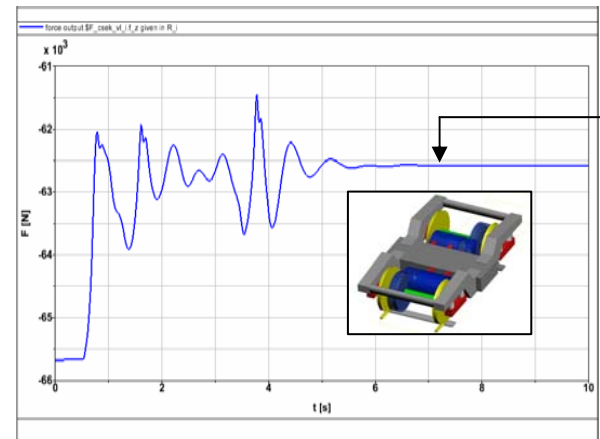
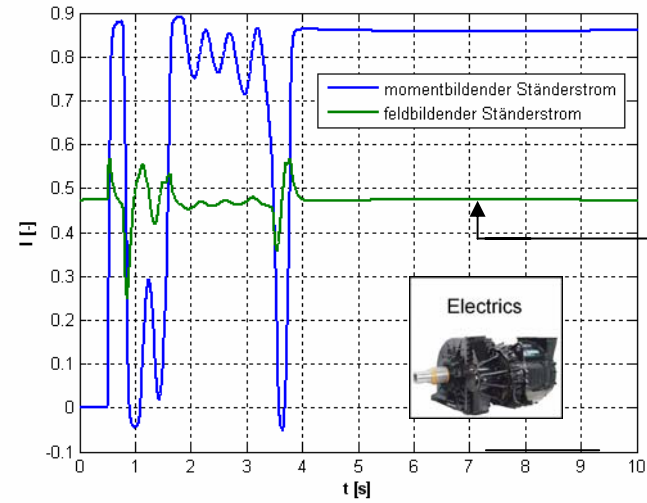
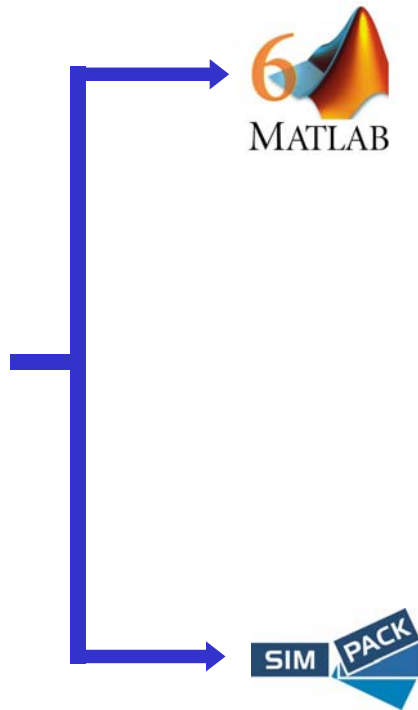
## The Linearisation Recipe





# Synchronise

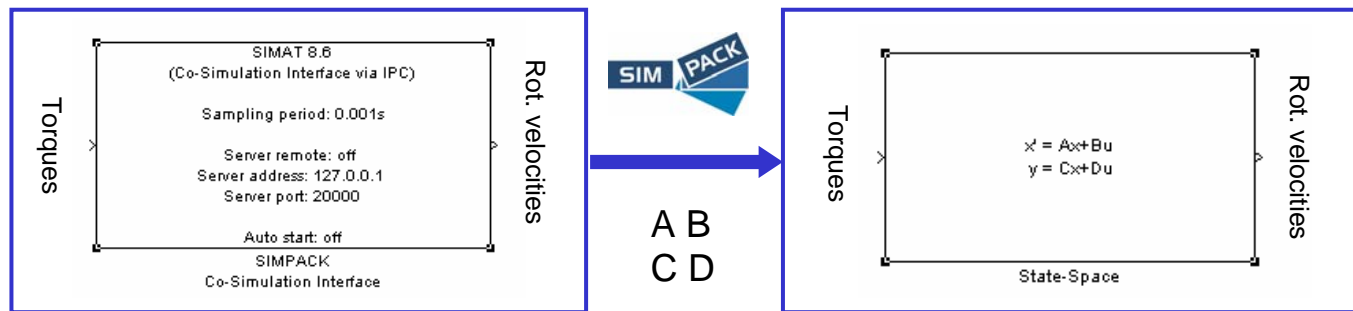
Co-Simulation  
in time domain



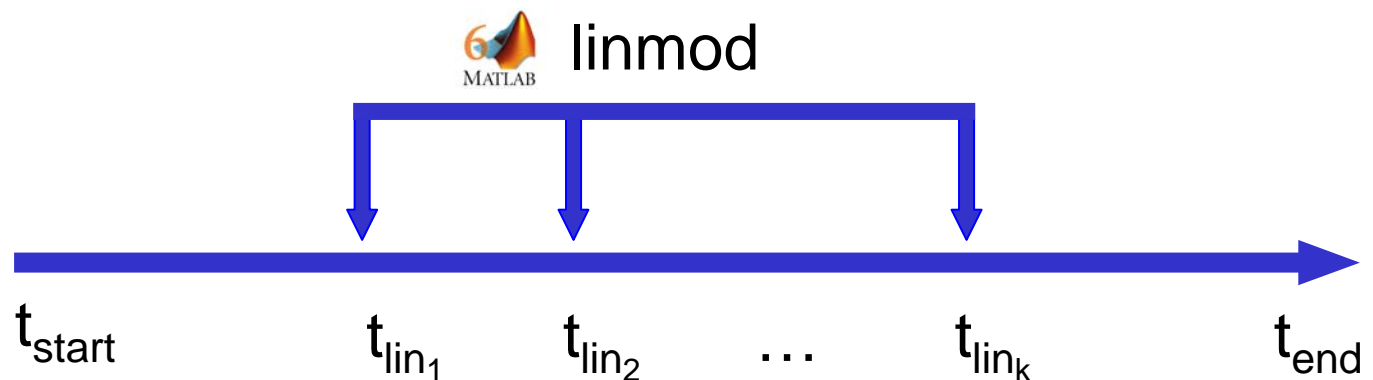
Synchronised state

# Linearise

## 1. Exchange SIMAT – System Matrix Block



## 2. Linearise the complete system at given times



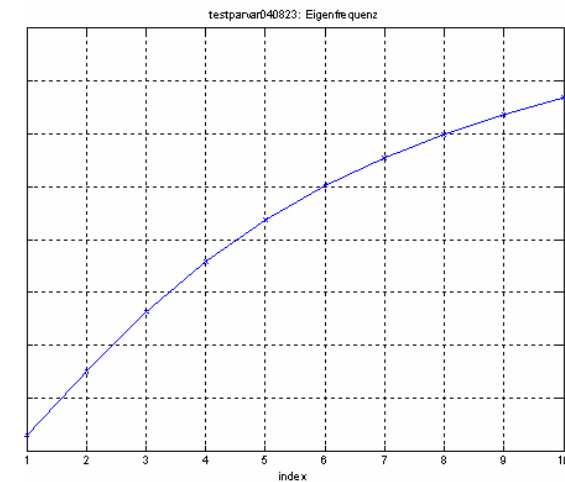
## Visualise

## Plot Eigenvalues

Ew	fmin	fmax	max(real)
1	0	0	-4263.0451
2	0	0	-3546.5929
3	0	0	-2748.8071
4	0	0	-1352.9142
5	0	0	-1351.9446
6	0	0	-883.8595
7	0	0	-875.64044
8	0	0	-655.65964
9	0	0	-665.56437
10	0	0	500
11	0	0	-481.28609
12	0	0	-333.33333
13	0	0	-200
14	0	0	-200
15	0	0	-196.34521
16	0	0	-111.17178
17	0	0	-100
18	0	0	-100
19	0	0	-74.25903
20	0	0	-50.024578
21	0	0	-49.371954
22	0	0	-21.421871

Select all

Ok Cancel



## Generate SIMPACK aew-file

Auswahl Linearisierungspunkt(e)

Durchlauf 1, tlin = 1.0001
Durchlauf 1, tlin = 2
Durchlauf 2, tlin = 1.0001
Durchlauf 2, tlin = 2
Durchlauf 3, tlin = 1.0001
Durchlauf 3, tlin = 2
Durchlauf 4, tlin = 1.0001
Durchlauf 4, tlin = 2

Select all

Ok quit

```

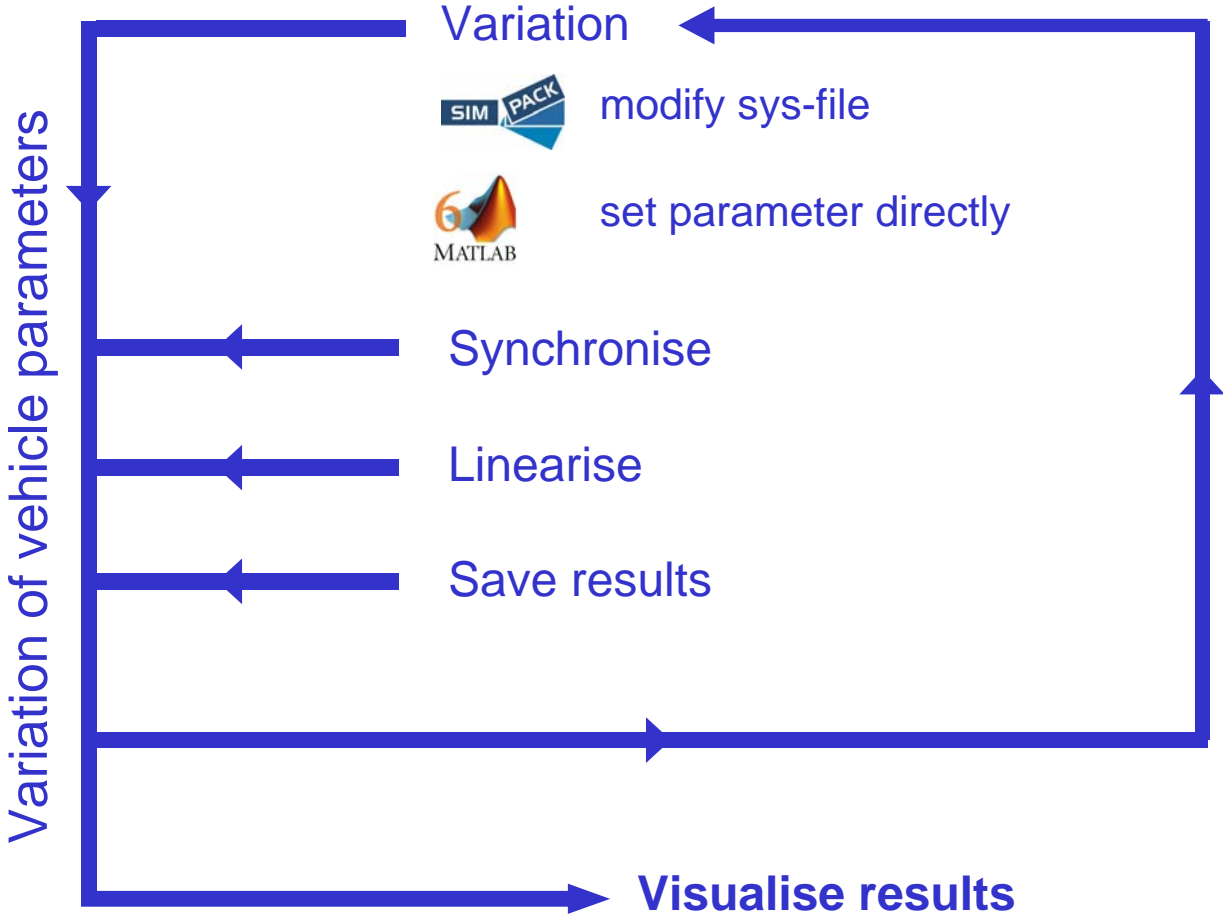
Editor - D:\Simulationsumgebung\v04.0.02\resource\aeawschreiben.m*
File Edit Text Cell Tools Debug Desktop Window Help
Stack: Base
1 function [message]=main( S, xname, fmax, filename )
2 %aeawschreiben: Erzeugung von Simpack-aew-Dateien
3 %Aufruf:
4 % [message]=aeawschreiben( S, xname, fmax, [ filename ] )
5 % S: Datenstruktur mit Systemmatrizen/Eigenwerten/StateNames
6 % xname: Name des zu extrahierenden Subsystems oder Indizes der Eigenwerte,
7 %       Default: xname = [], entspricht 'Grundmodell_1fz/Mechanik/Mechanik Sim'
8 % fmax: Maximalfrequenz (Imaginaerteil/2/pi) der extrahierten Eigenwerte
9 % filename (optional): Pfad/Modellname (ohne Endung ".aew"); Wird kein
10 % Modellname vorgegeben, so erfolgt die Ausgabe auf stdout

```

main Ln 8 Col 30 OVR



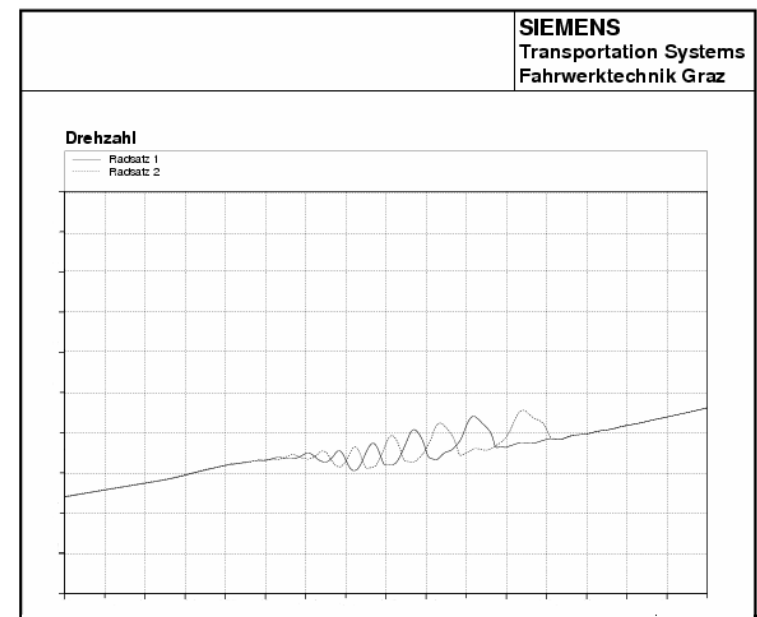
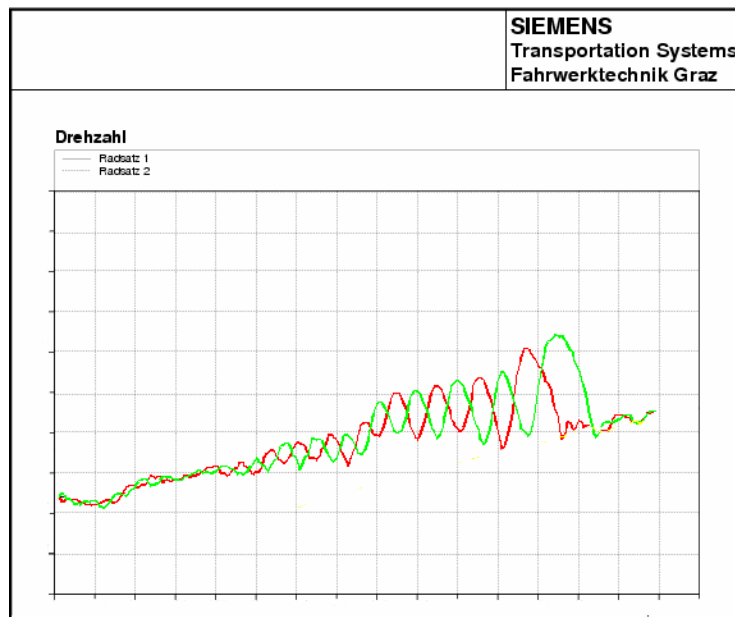
# Automatisation



## Example – Step 1

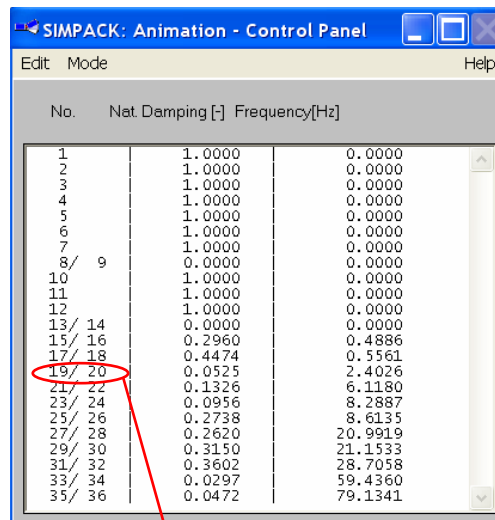
Vibration effect due to interaction  
mechanics-electrics-software  
is found on the real vehicle

Co-simulation in time domain  
can reproduce the behaviour



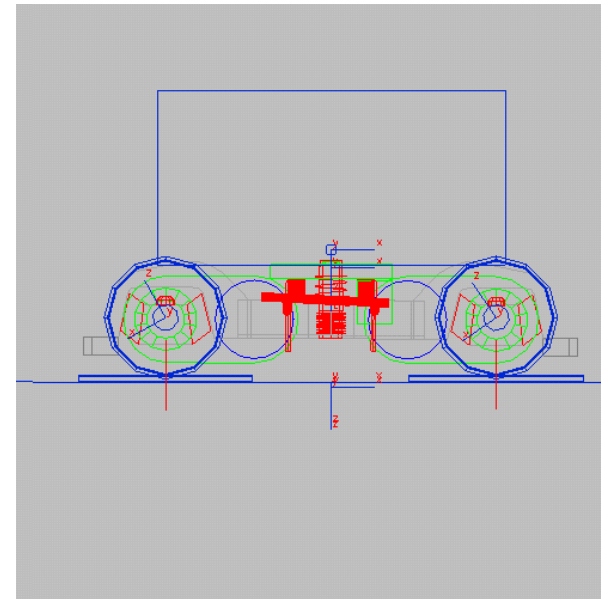
## Example – Step 2

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



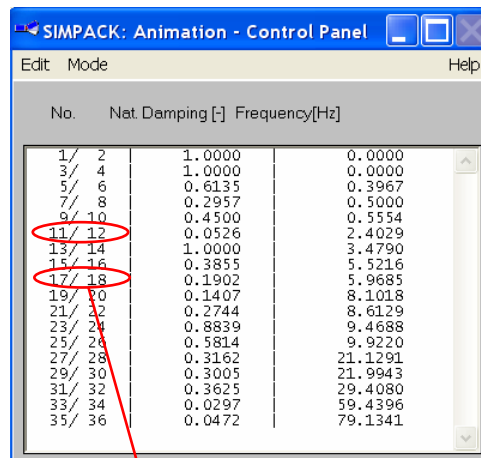
No.	Nat. Damping [-]	Frequency[Hz]
1	1.0000	0.0000
2	1.0000	0.0000
3	1.0000	0.0000
4	1.0000	0.0000
5	1.0000	0.0000
6	1.0000	0.0000
7	1.0000	0.0000
8/ 9	0.0000	0.0000
10	1.0000	0.0000
11	1.0000	0.0000
12	1.0000	0.0000
13/ 14	0.0000	0.0000
15/ 16	0.2960	0.4886
17/ 18	0.4474	0.5561
19/ 20	0.0525	2.4026
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



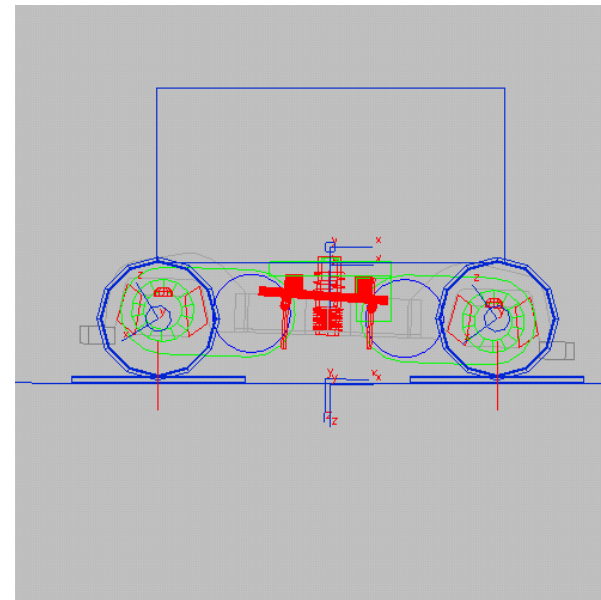
## Example – Step 3

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