# Ride Comfort Transfer Function for the MAGLEV Vehicle Transrapid

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# 1. Introduction: Prognosis of Ride Comfort previous to Detailed Design of Vehicle/Guideway

- Problem: How to predict the ride comfort for high velocities before the detailed design of a new vehicle and guideway?
- Method:
  - The 3D motion of a MAGLEV vehicle can be split up into the traveling, the heave-pitch, and the lateral-yaw motion and can be investigated by considering 2D models as substitutes
  - For driving straight ahead with constant velocity, the heave-roll-lateral motion remains as the essential motion
  - For ride comfort analysis, the amplitudes of the vehicle motion are small
    → The mechanical system dynamics can be considered as linear
- Suggestion:
  Approximation by a transfer function from guideway excitations to accelerations of the passengers (RCTF)

**Goals of this work:**

**Calculate a transfer function for the ride comfort**

**Is the transfer function independent of the vehicle speed?** ✓

**Prognosis of ride comfort for higher vehicle speeds than hitherto travelled (600 km/h)**



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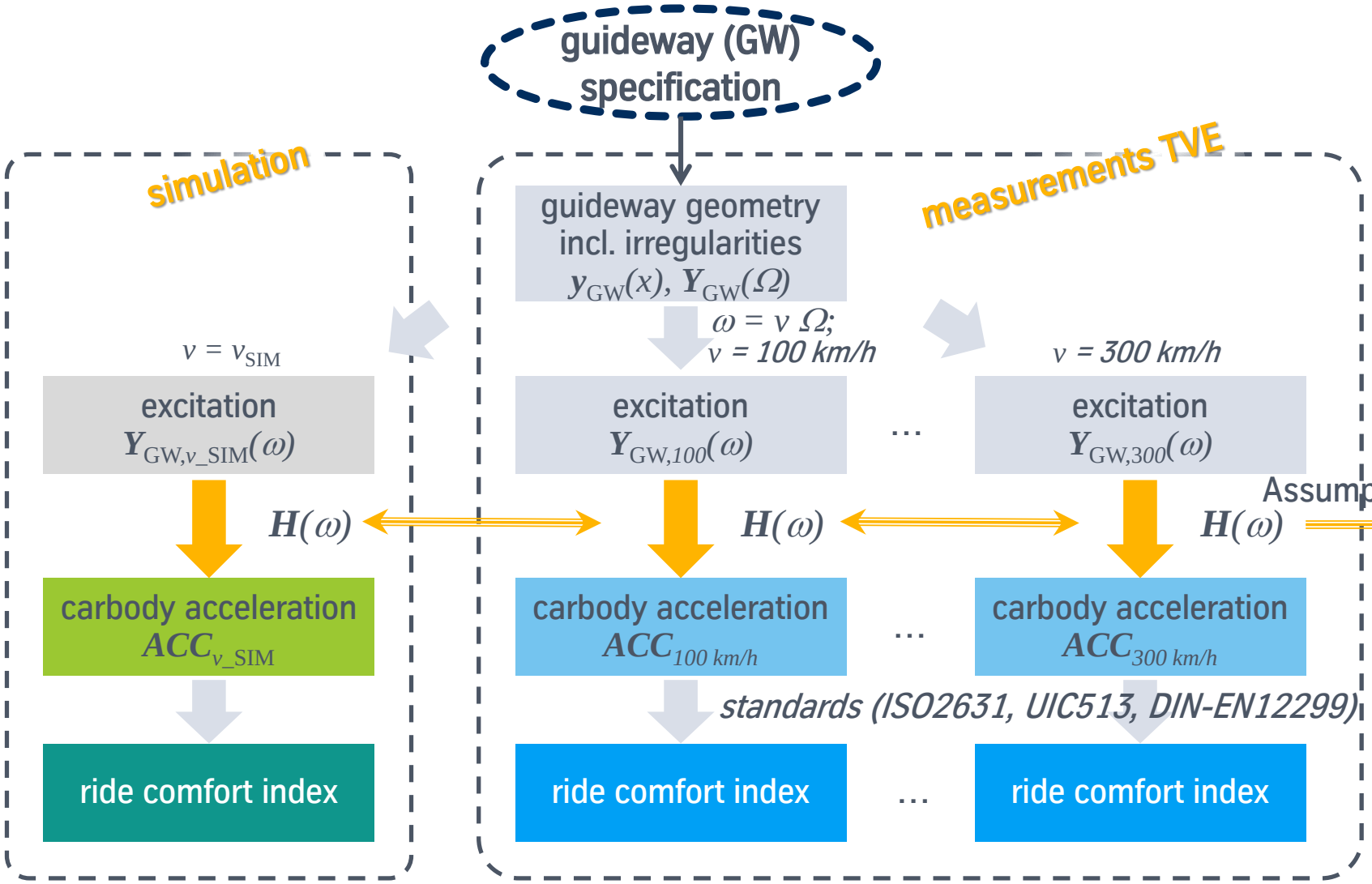
# 1. Introduction: Prognosis of Ride Comfort previous to Detailed Design of Vehicle/Guideway




Assumption: $H(\omega)$ does not dep. on velocity

$H(\omega) =: RCTF(\omega)$

$RCTF$…Ride Comfort Transfer Function

$v$… vehicle velocity

$x$… longitudinal position along the track

$y_{GW}$, $Y_{GW}$…degrees of freedom of the GW

$\Omega$…space frequency

$\omega$…frequency



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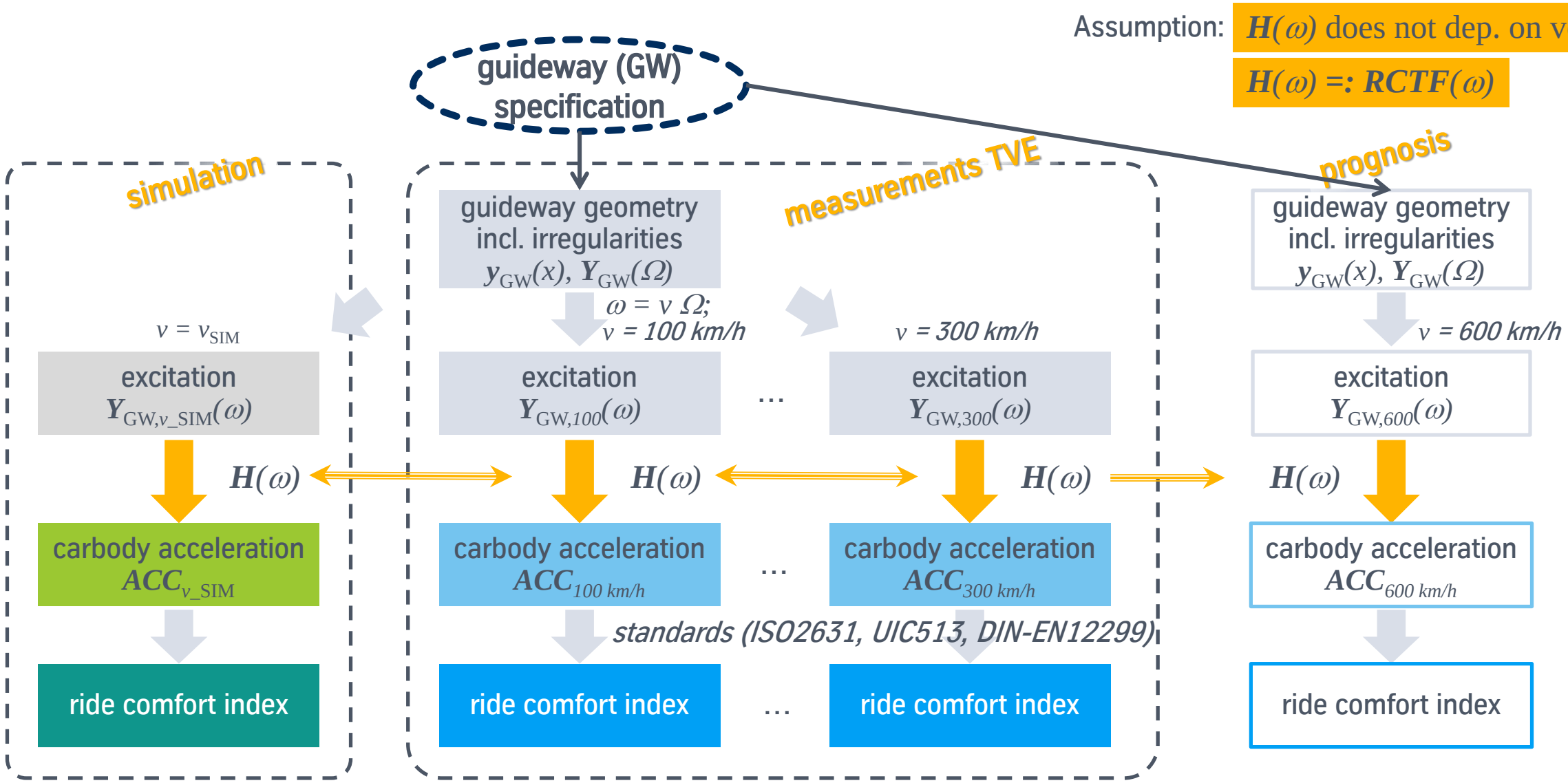




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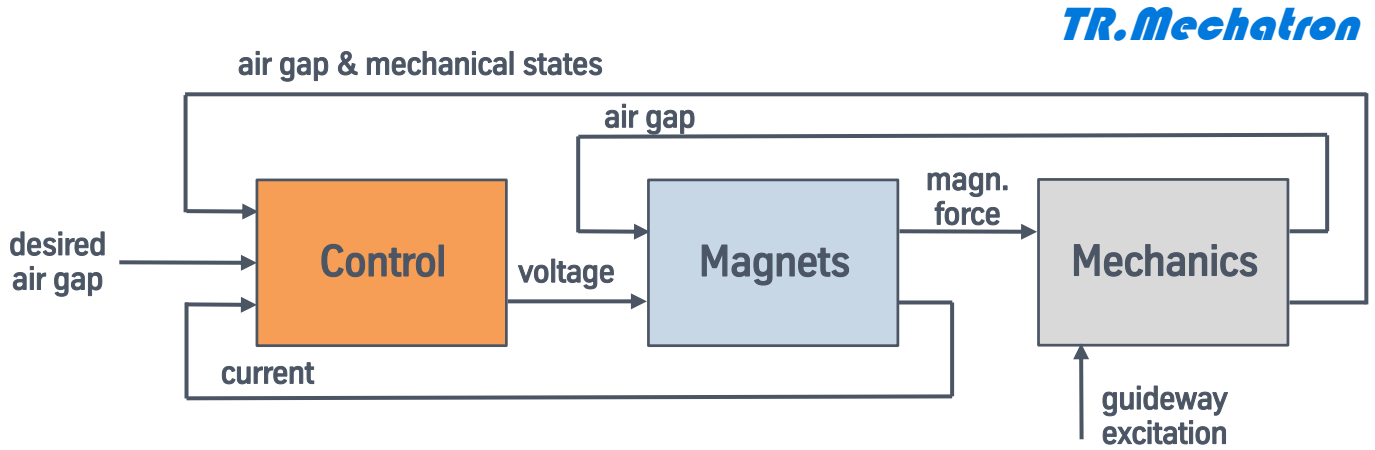
# 2. Mechatronic Multibody Simulation Model of TR09

For details see [DellnitzEtAl12]

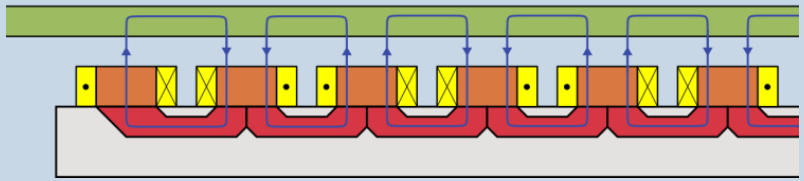



## Control

- The magnet control units regulate the size of the air gap by adjusting the magnets' input voltages
- Representation of the authentic C-Code of the control laws used within the TR09

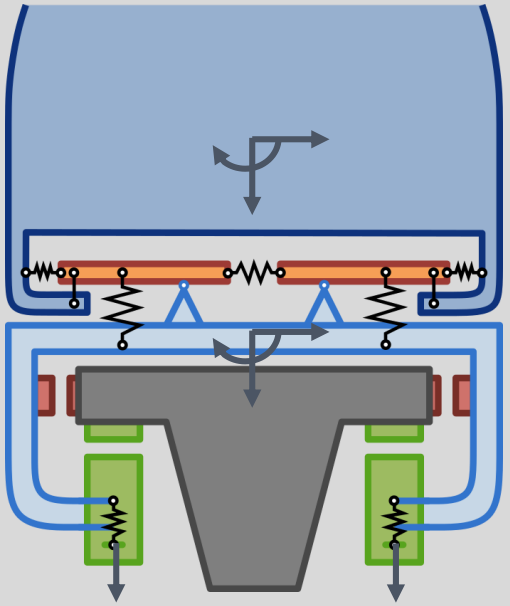
## Magnets

- Two guidance and two levitation magnets
- Flux-based dynamics are derived by the magnet's electro-magnetic networks

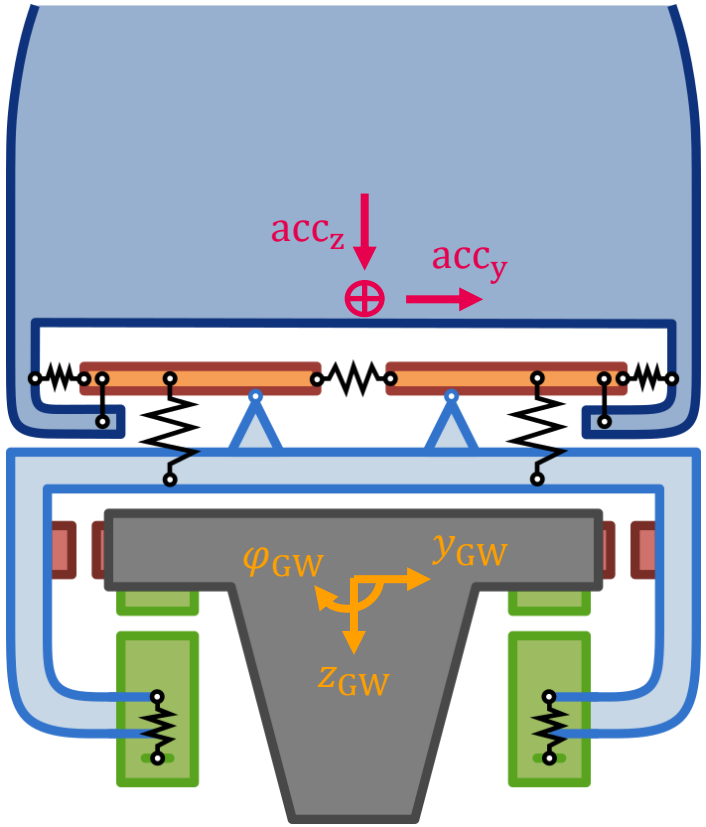


## Mechanics (using Neweul-M²)

- Rigid multibody system
- 2D lateral cross section
- 8 degrees of freedom



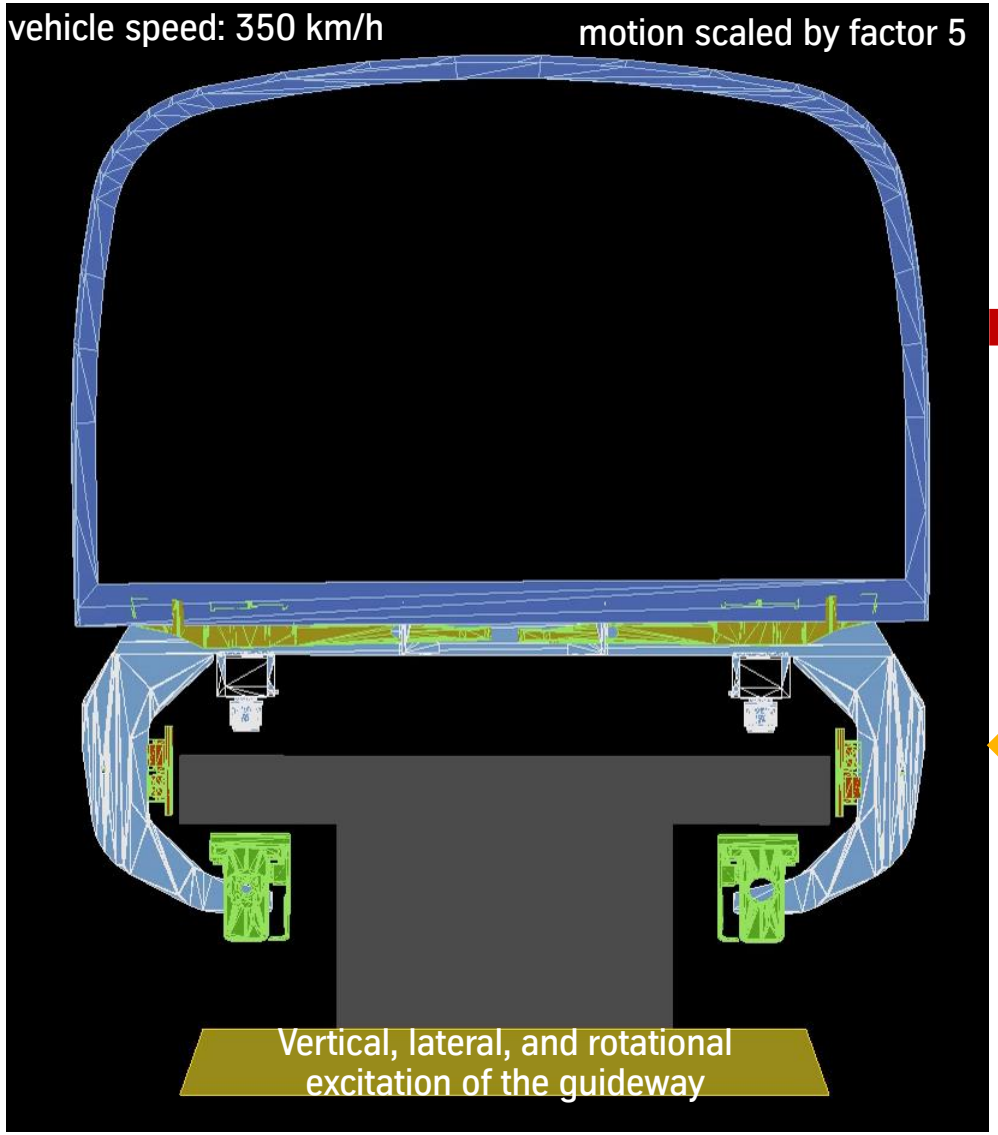
# 2. Mechatronic Multibody Simulation Model



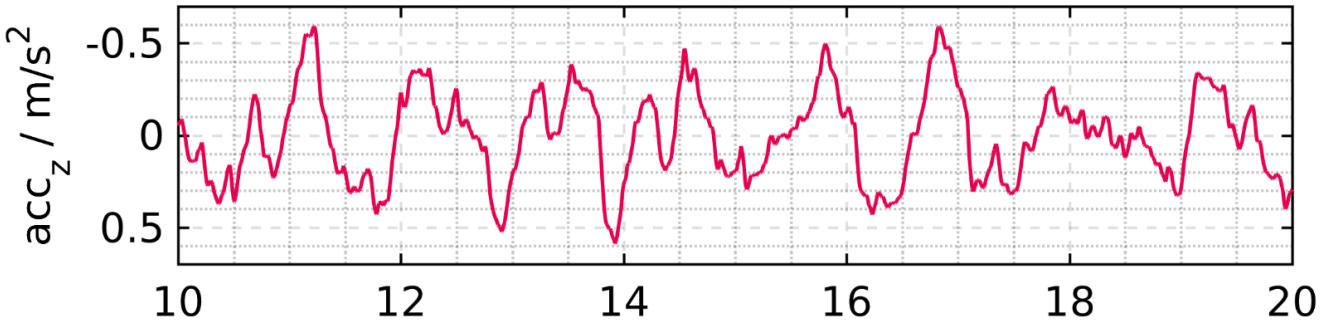

Absolute accelerations in the car body, calculated at the sensor position for the measurement of the ride comfort

Vertical, lateral, and rotational excitation of the guideway

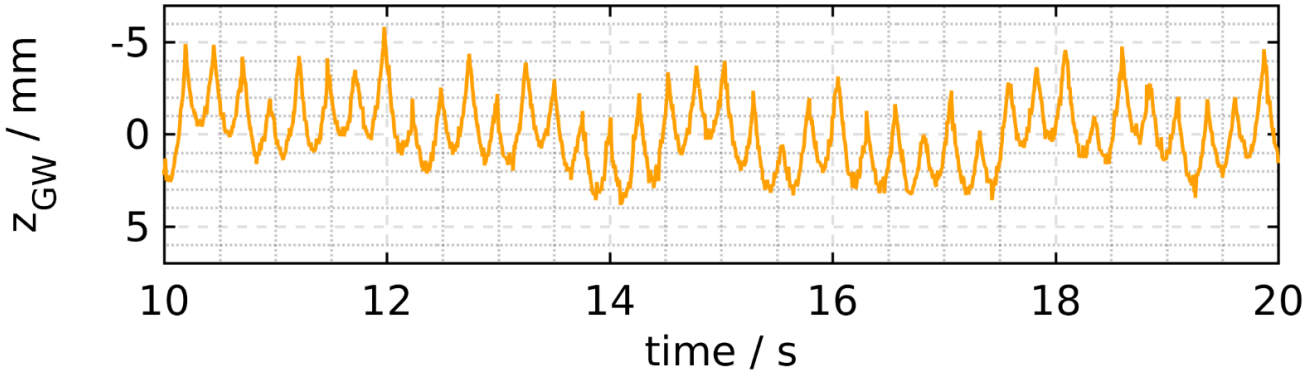
# 2. Mechatronic Multibody Simulation Model




Absolute accelerations in the car body, at the sensor position




Vertical excitation of the guideway



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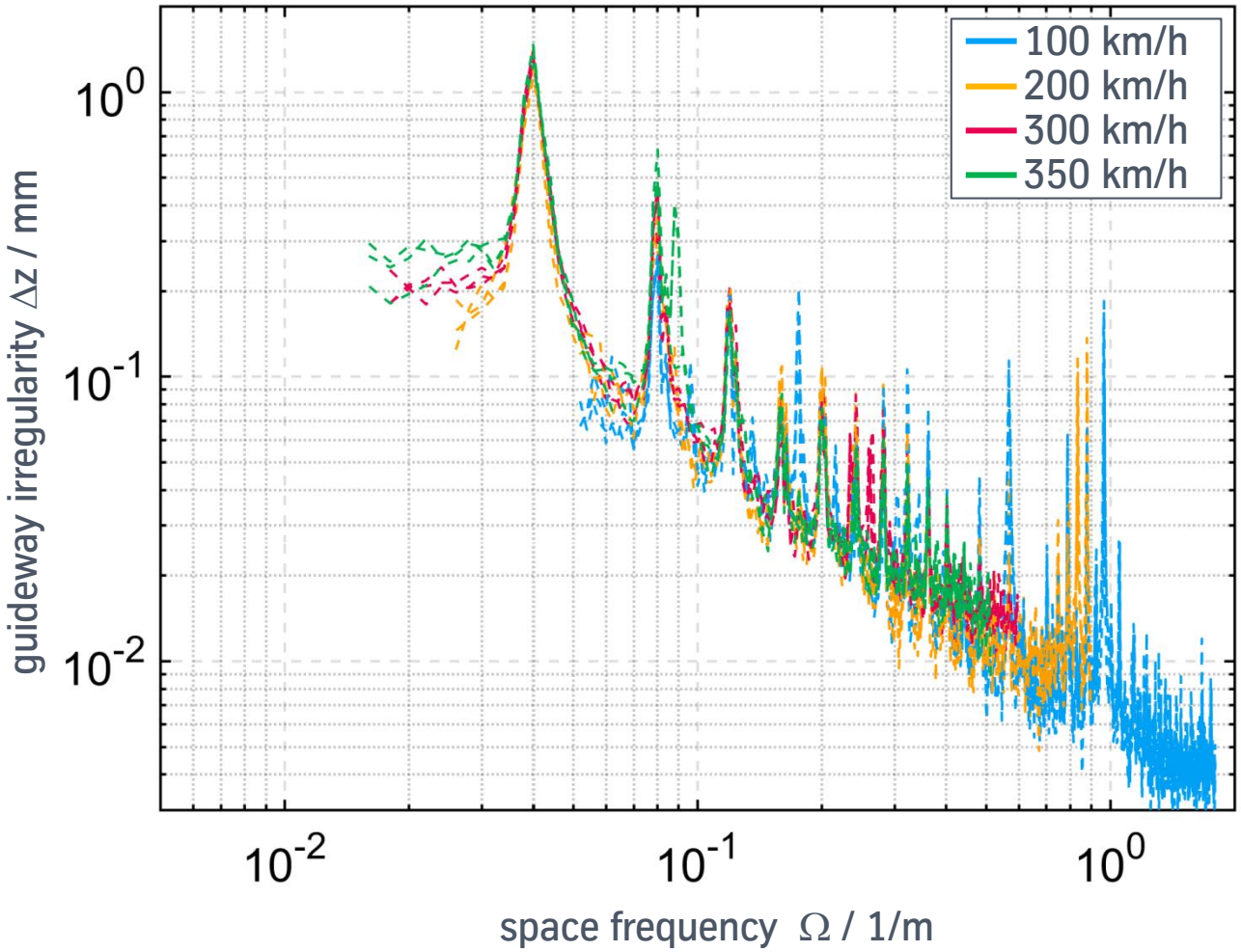
# 3. Measurements on Test Track TVE

- Measurements of vehicle dynamics at the 30 km Test Track in Northern Germany (TVE) in 2009&2010
- Reconstruction of absolute magnet positions by integration of magnet accelerations
- Reconstruction of guideway irregularities from magnet positions and gap signals
- Method is very similar to the method in
  *[Shi et al., Measurements and analysis of track irregularities…, Journal of Zhejiang University, 2014]*



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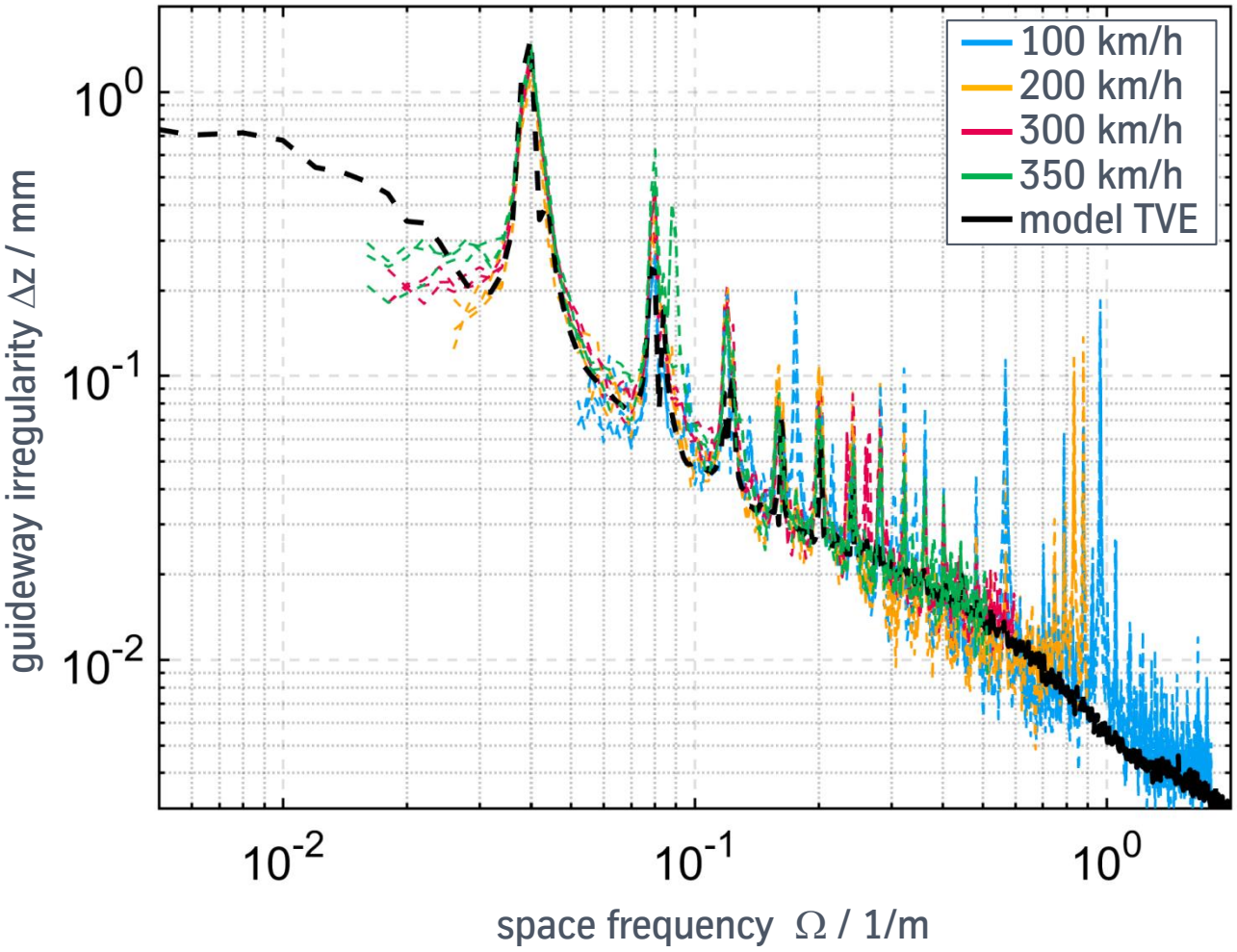
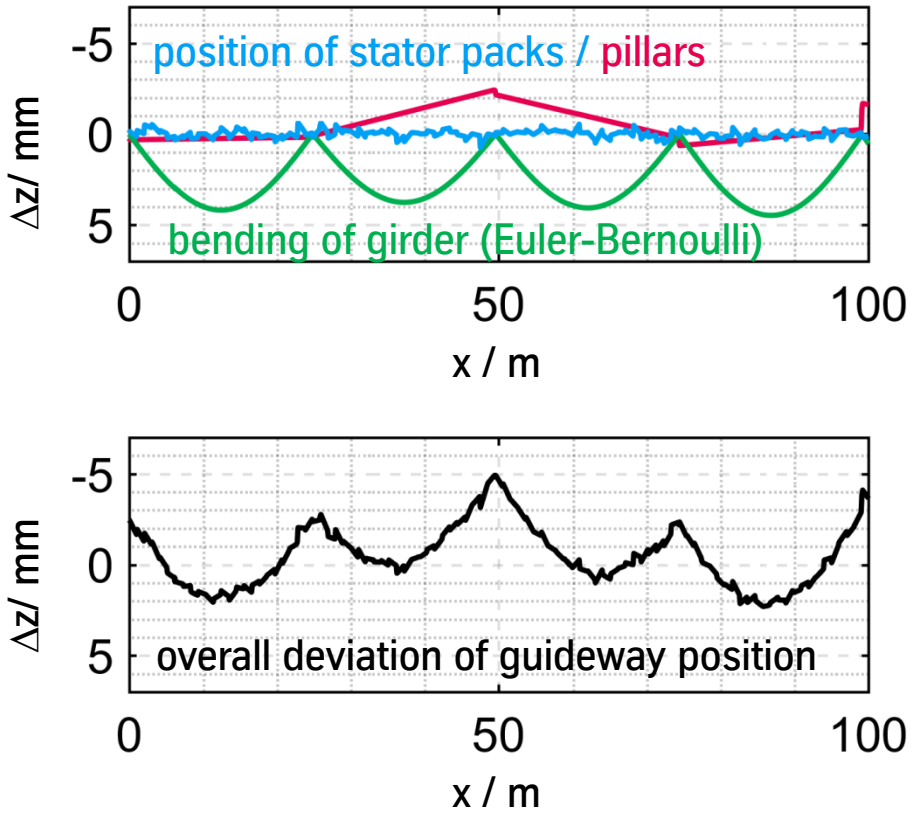
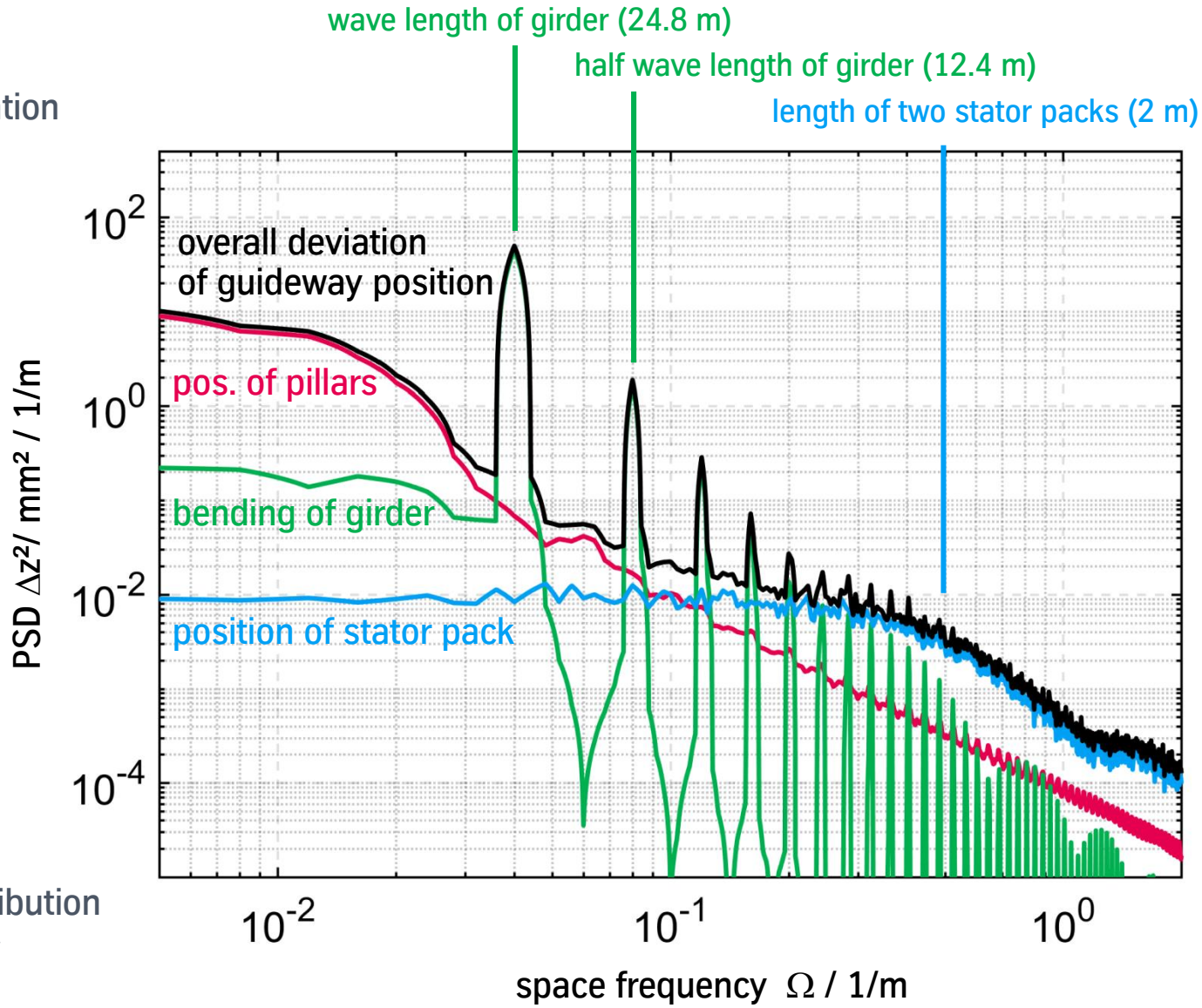


# 3. Measurements on Test Track TVE

- Construction of guideway irregularities from specification




Tolerances from specification as 3-σ limit of normal distribution

*[EBA: Design Principles High-speed Maglev System (MSB) 2007]*

→ Suggested reference guideway REF

# 4. Ride Comfort Transfer Function (RCTF)

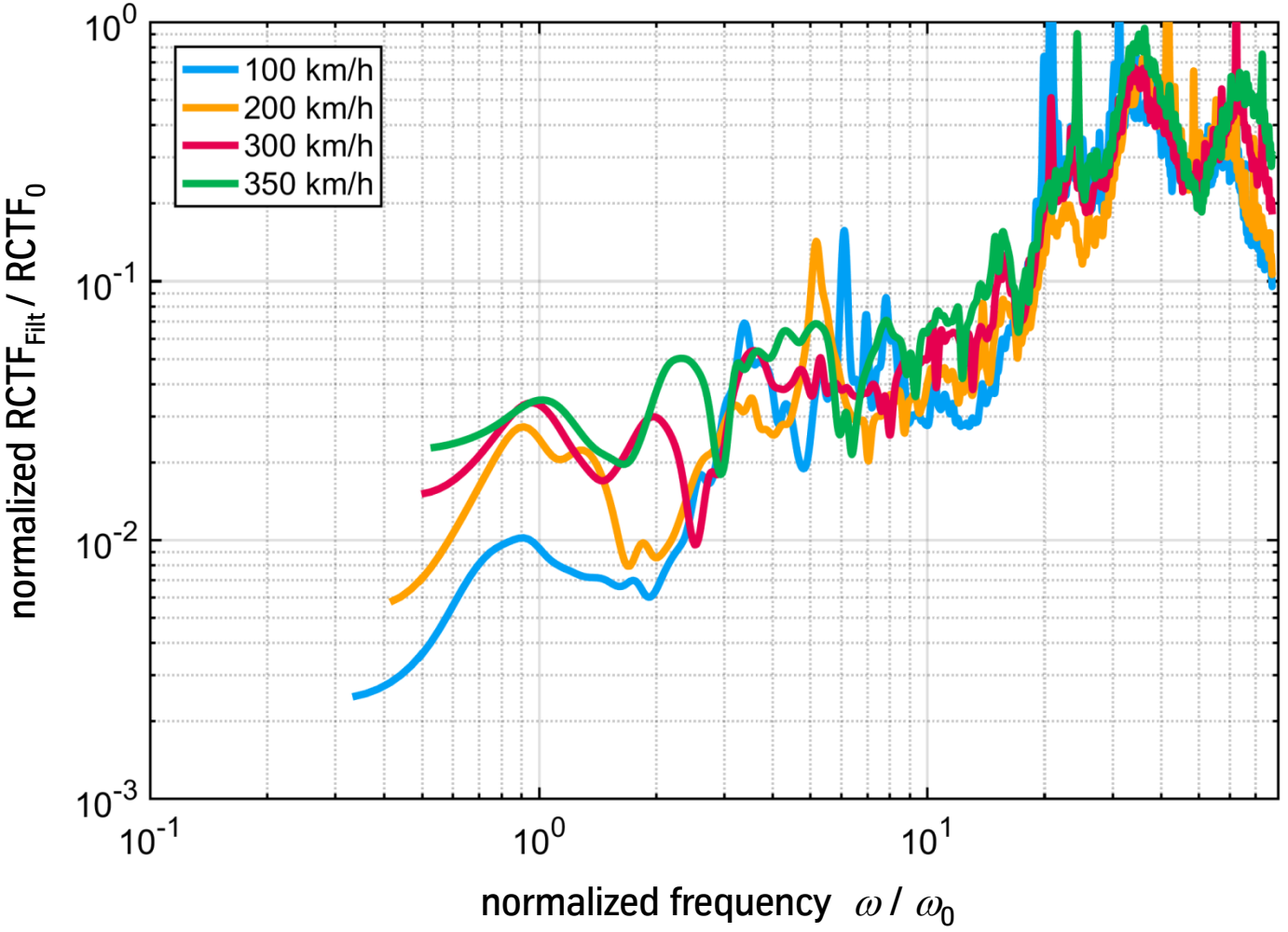
$acc_{z,v}(t)$ → FFT → $ACC_{z,v}(\omega)$

$z_{GW}(t)$ → FFT → $Z_{GW,v}(\omega)$

(for segments of 500 m)

$$RCTF = ACC_{z,v}(\omega) / Z_{GW,v}(\omega)$$

Calculated from Measurements



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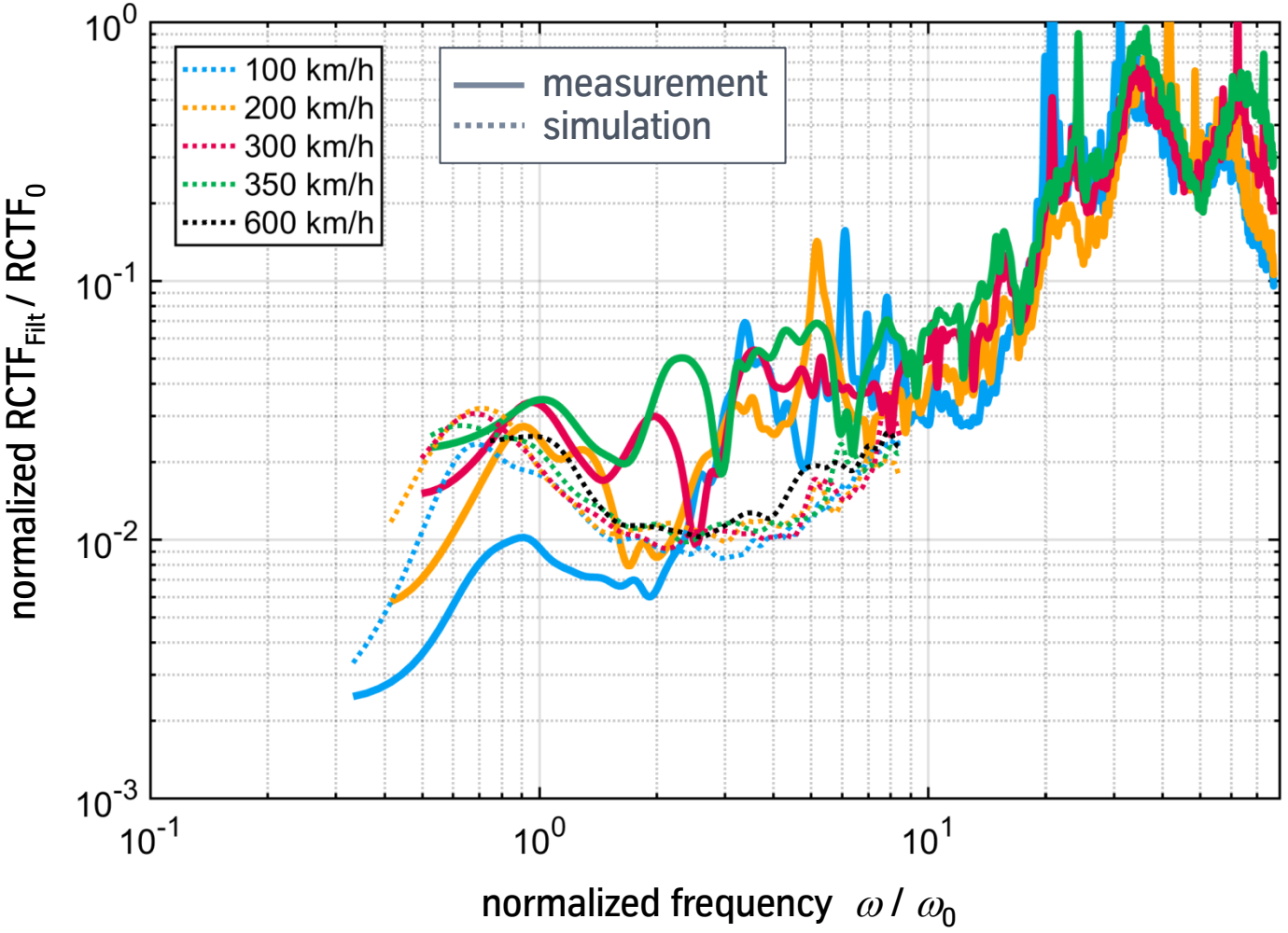
(for segments of 500 m)

$$RCTF = ACC_{z,v}(\omega) / Z_{GW,v}(\omega)$$

Calculated from Measurements & Simulation



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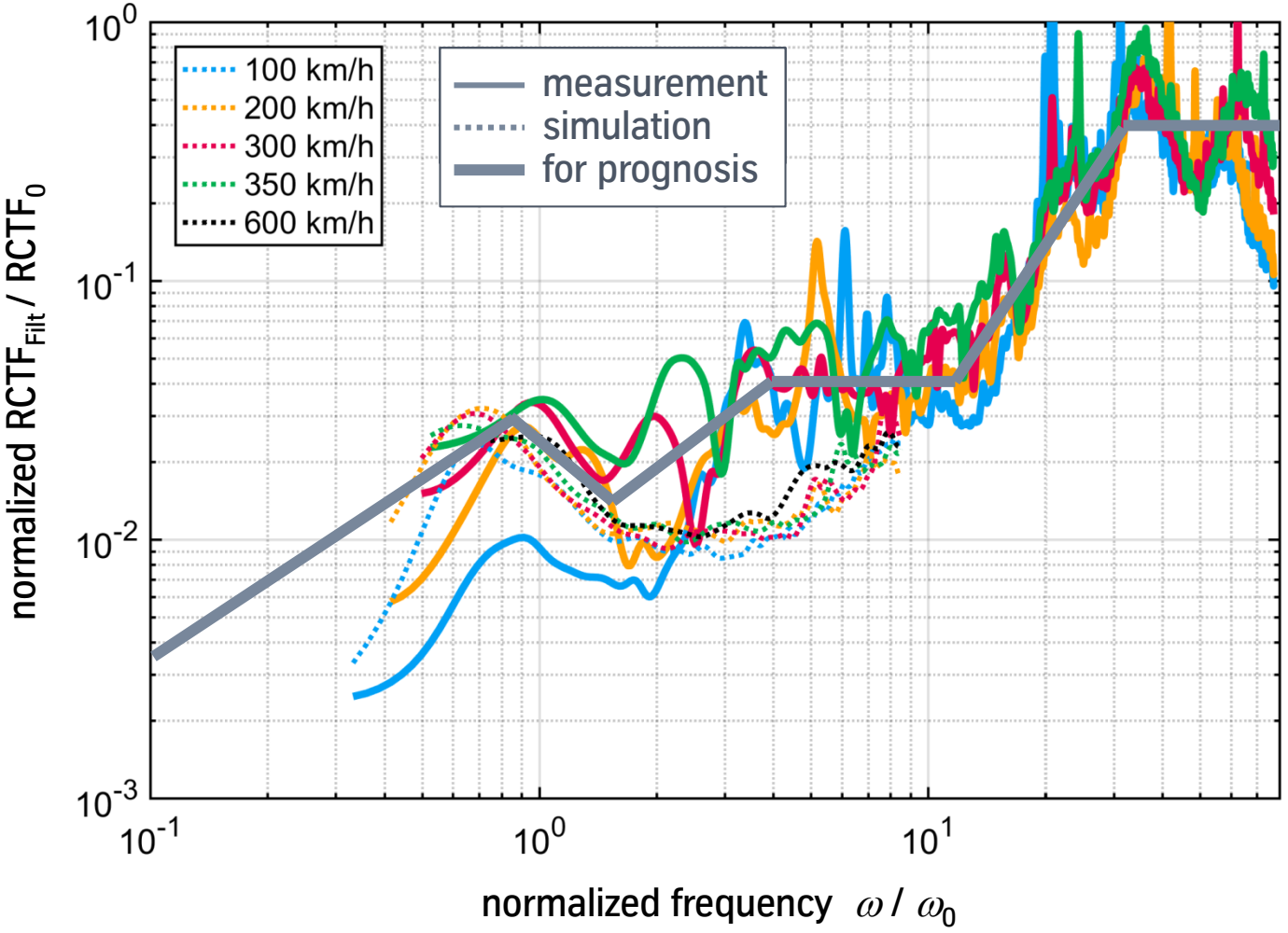
# 4. Ride Comfort Transfer Function (RCTF)

- Polygon approximation used for prognosis
- RCTF calculated from Measurements & Simulation and Approximated for Prognosis



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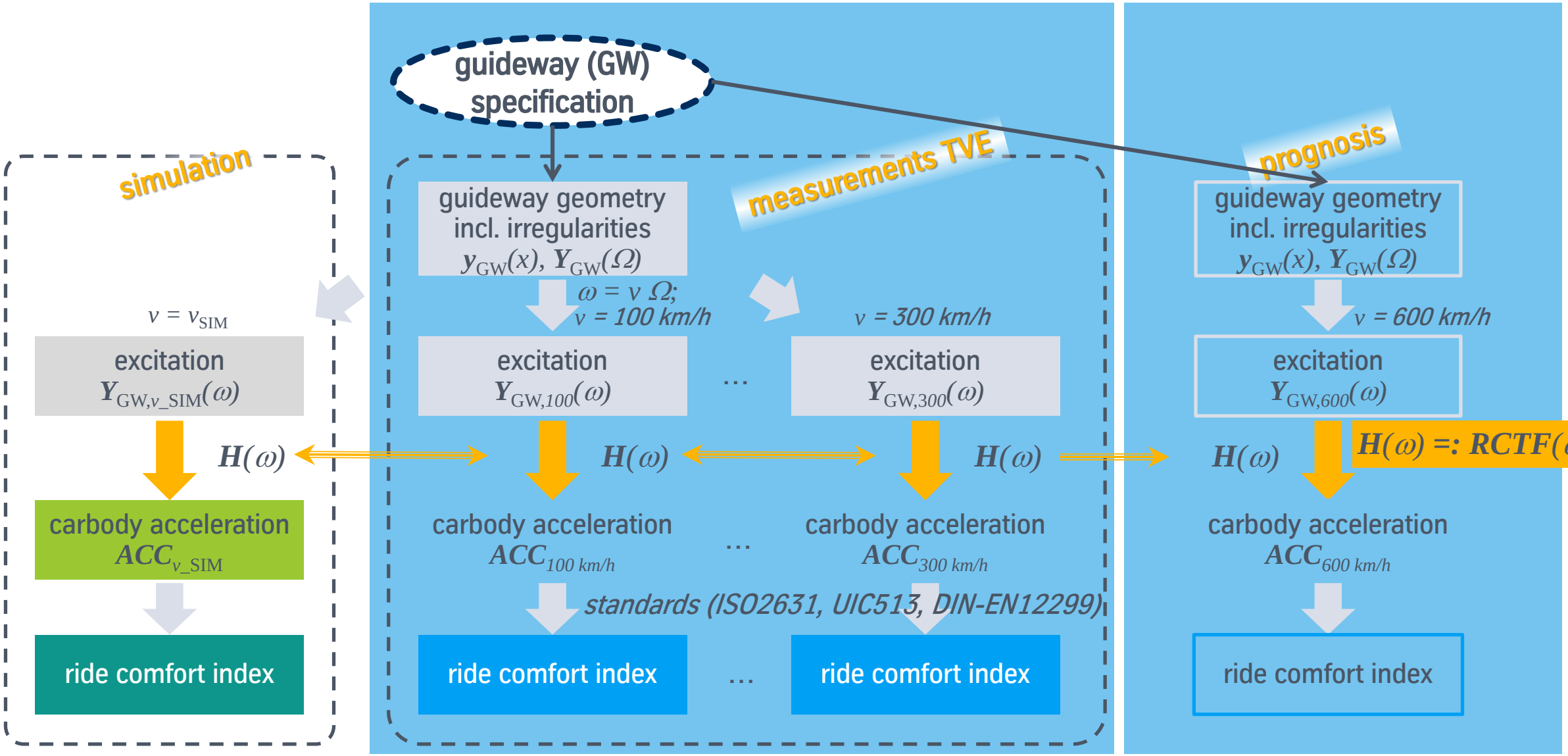
# 5. Prognosis of Ride Comfort for 600 km/h



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# 5. Prognosis of Ride Comfort for 600 km/h

$z_{GW}(t)$

FFT (for segments of 500 m)

$Z_{GW,\,v}(\omega)$

RCTF

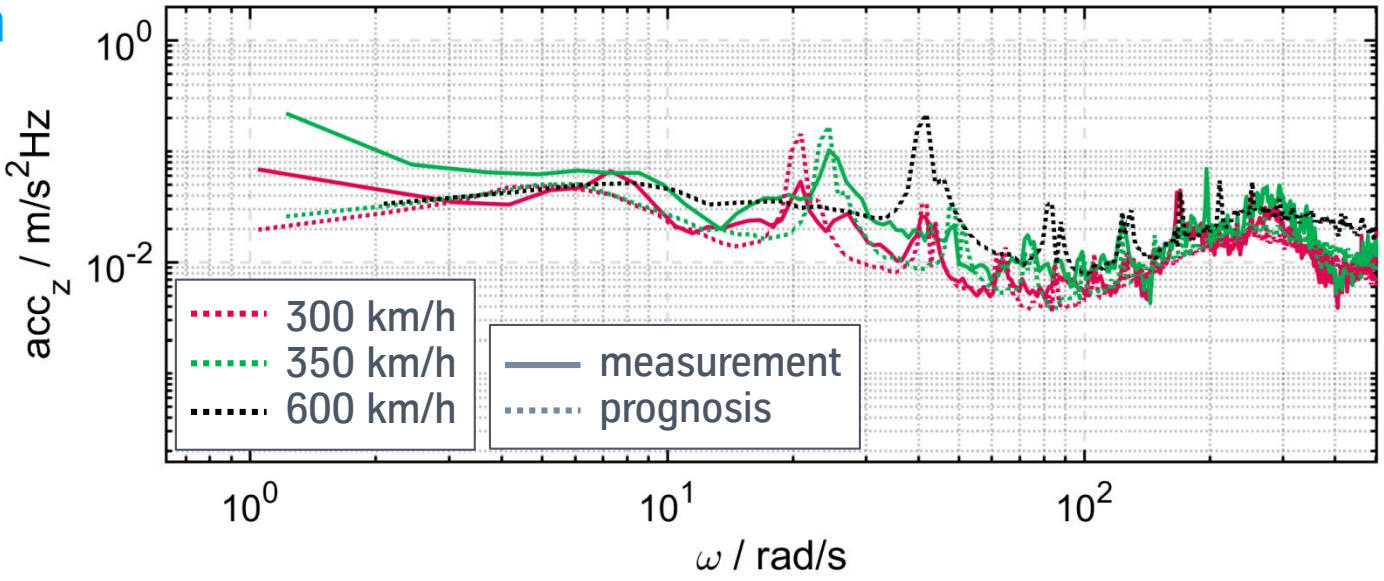
$$ACC_{z,\,v}(\omega) = RCTF * Z_{GW,\,v}(\omega)$$

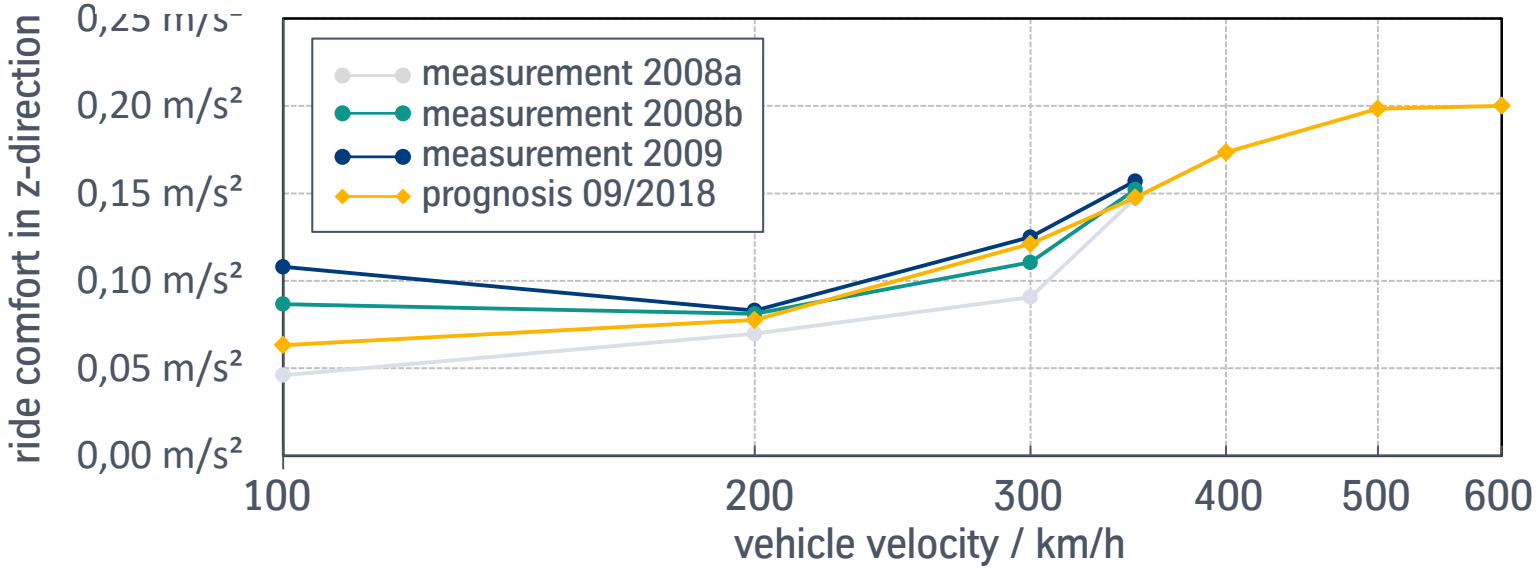
iFFT (for random phase angles)

$acc_{z,\,v}(t)$

(DIN ISO 2631, DIN-EN 12299)

ride comfort index



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# Summary

- Guideway irregularities calculated from measurements
  - REFerence guideway set-up based on specification published by the German Federal Railway Authority (EBA)
- Ride Comfort Transfer Function RCTF calculated from simulation model and from measurements
  - The RCTF can be approximated independent of the vehicle speed
  - Simulation and measurement match (→validation of the simulation model and the method)
- The RCTF is a measure of the vehicle quality
- The RCTF can be used for a prognosis of the ride comfort for higher speeds
- The predicted ride comfort is „a little uncomfortable“ at 600 km/h for a vehicle similar to the TR09 using the reference guideway