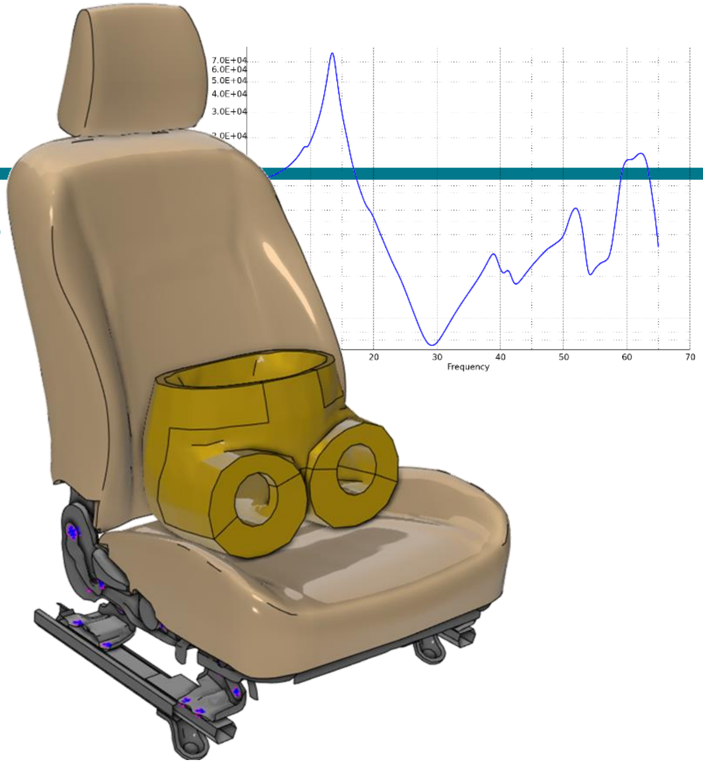
Webinar

Frequency domain analyses in LS-DYNA



Anders Jonsson, DYNAmore Nordic AB

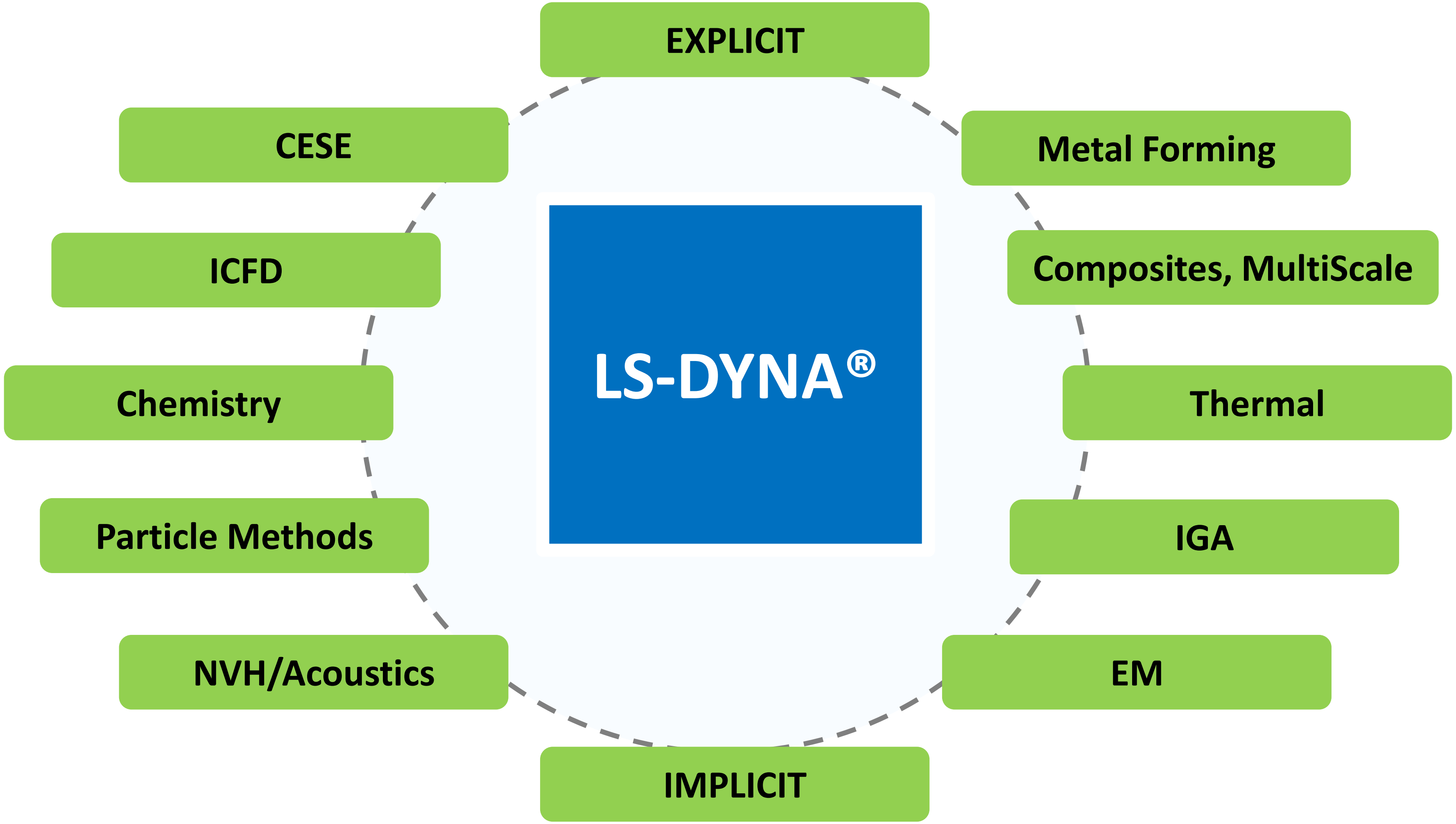
Overview

Frequency domain

- The One Code Strategy
- Case studies
  - Steady state dynamics (SSD)
  - Frequency domain acoustics (BEM or FEM)
  - Random vibration
- Analysis types
  - Frequency response function (FRF)
- Model set-up for frequency domain analyses
  - Postprocessing in META
- Summary

Frequency domain analyses in LS-DYNA

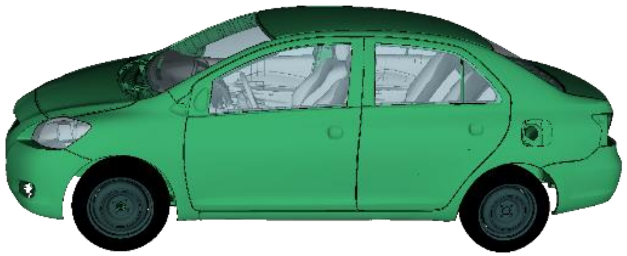
The One Code strategy



Frequency domain analyses in LS-DYNA

The One Code strategy

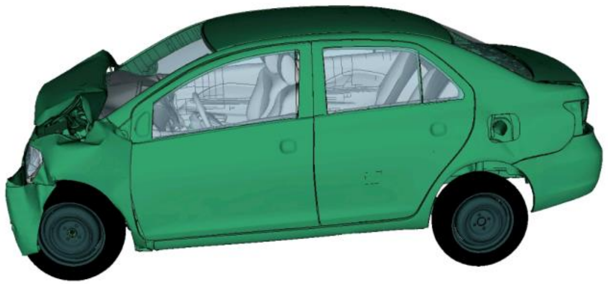
- Providing solutions for many applications



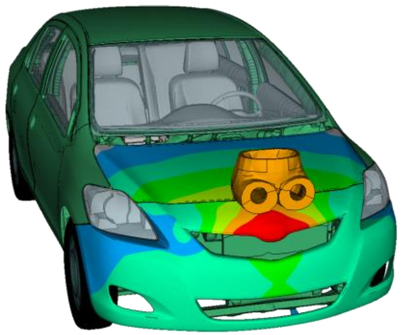
FE-Model

LS-DYNA®

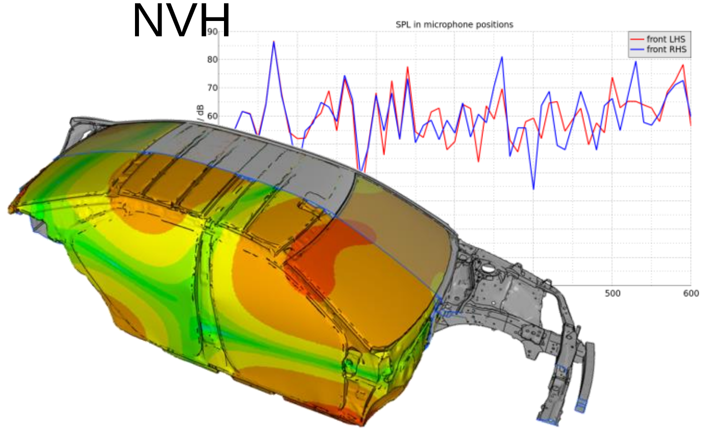
Crash /
occupant safety



Static /
durability



NVH

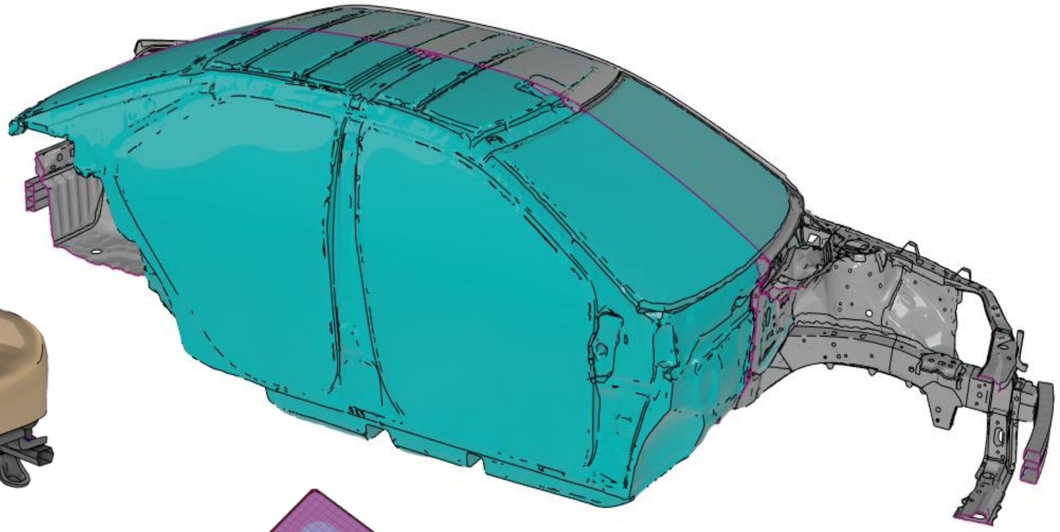


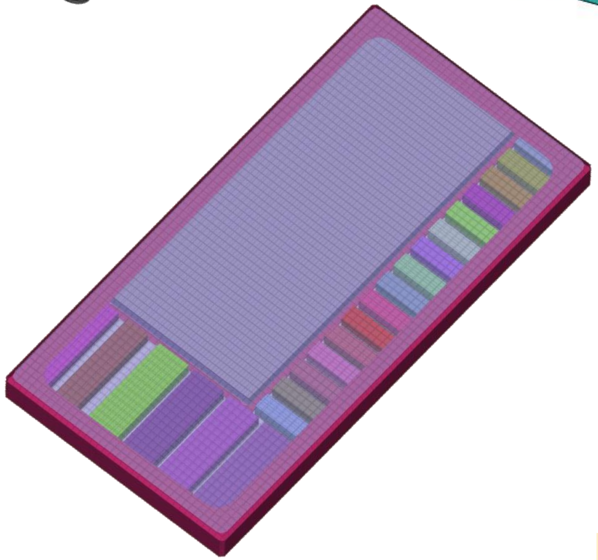
Case studies

Some examples and applications of frequency domain analyses

Case studies

- Seat comfort analysis
  - Steady state dynamics
- Acoustic analysis of a car
  - FEM Acoustics
- Electronic device
  - BEM Acoustics
  - Random vibration fatigue





Seat comfort analysis

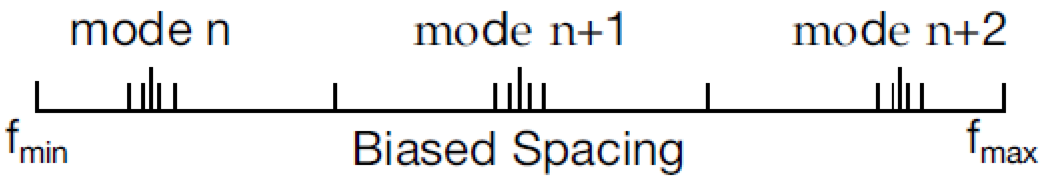
Setup

- Estimate seat comfort for a car seat
- Determine transfer functions from attachment points to seat cushion
- Estimate transfer function from attachment points to passenger
- Pre-loading
  - Non-linear implicit seating analysis
  - Add mass and constraints to partial dummy
  - Apply gravity loading
  - Evaluate contact pressure

Seat comfort analysis

Setup

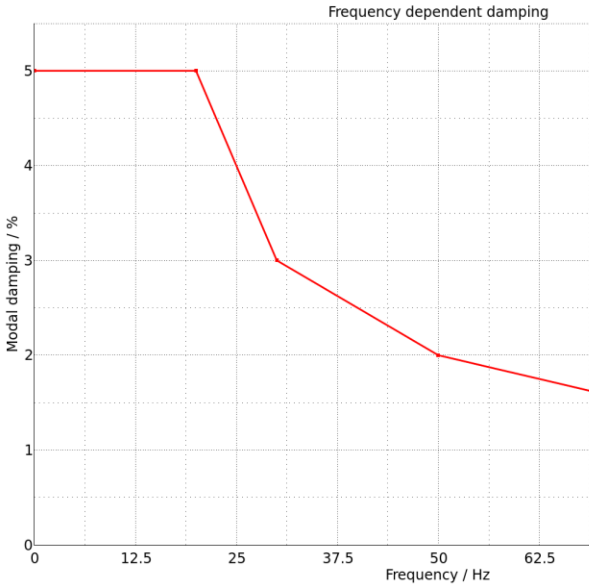
- Estimate seat comfort for a car seat
- Determine transfer functions from attachment points to seat cushion
- Estimate transfer function from attachment points to passenger
- Pre-loading
- Steady state dynamics analysis
  - Sine sweep
    - 1g loading, 1 – 65 Hz
    - Biased evaluation frequencies



Seat comfort analysis

Setup: Steady state dynamics

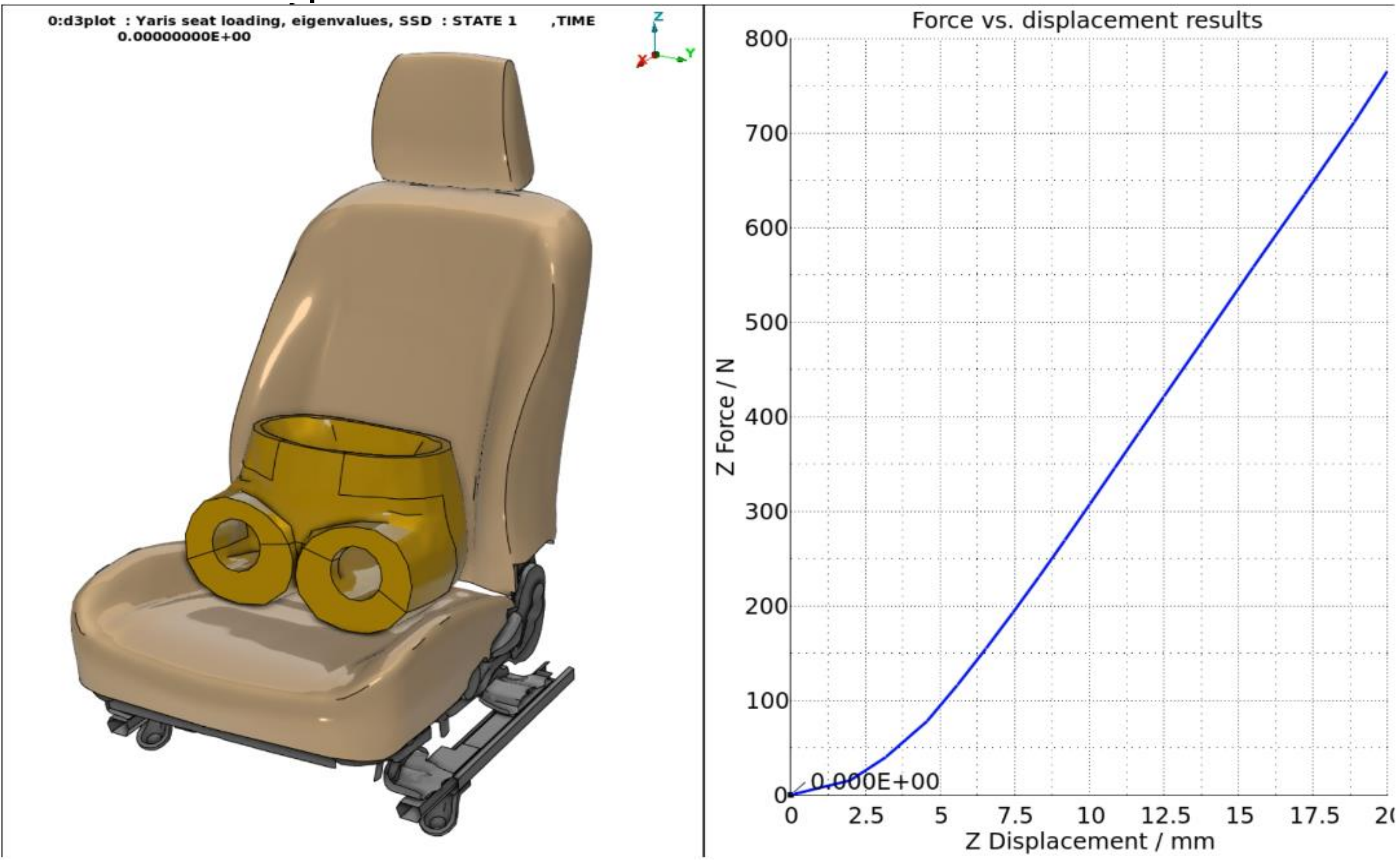
- Excitation at attachment points
  - Base acceleration in the Z-direction
- Response points for evaluations
  - Seat
  - Dummy
- Frequency dependent damping
  - 5 to 1 %



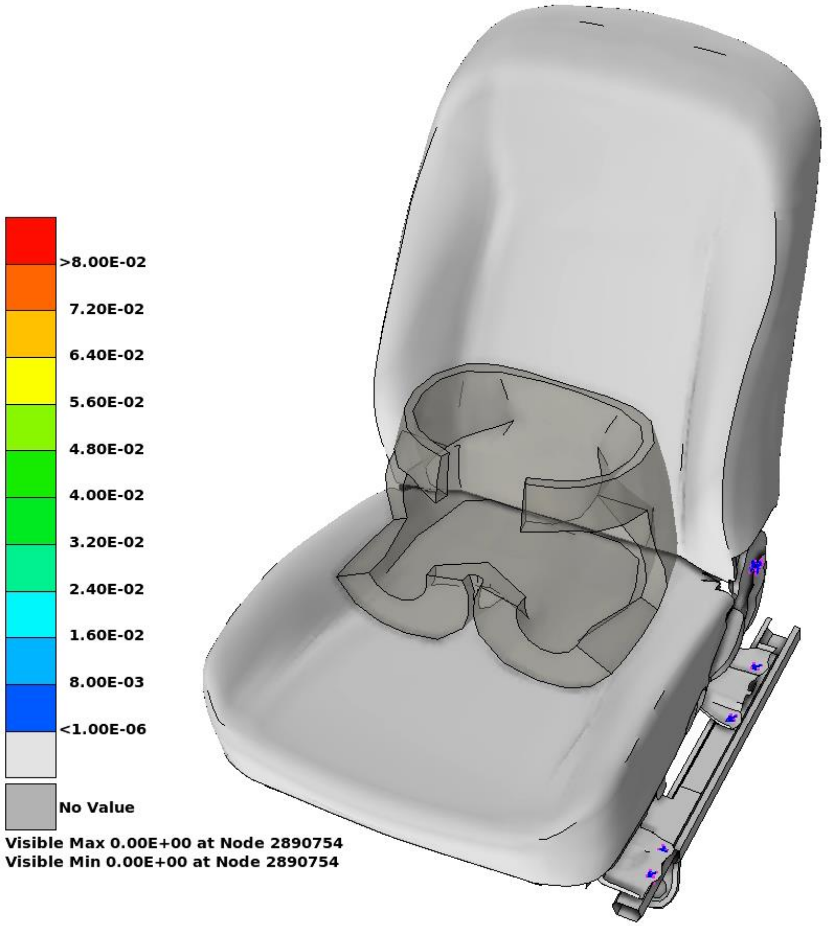
Seat comfort analysis

Results: Non-linear implicit preload

- Force - displacement



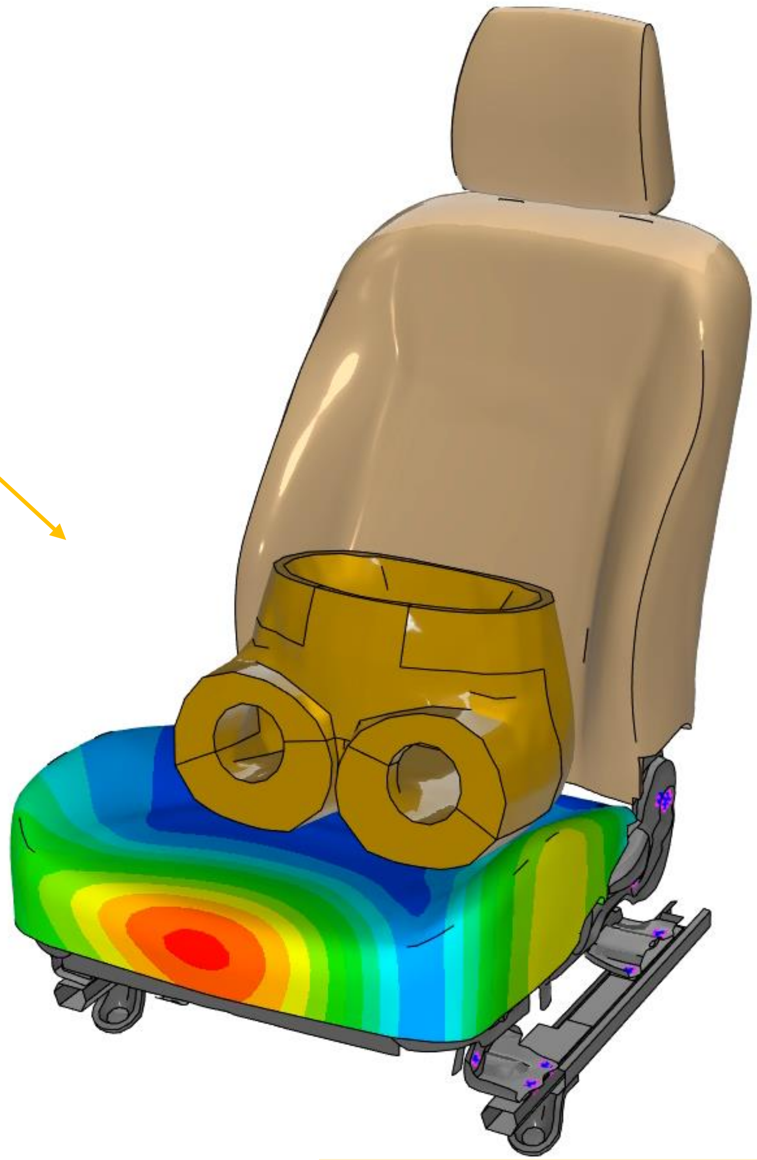
Contact pressure



Seat comfort analysis

Results: Steady state dynamics

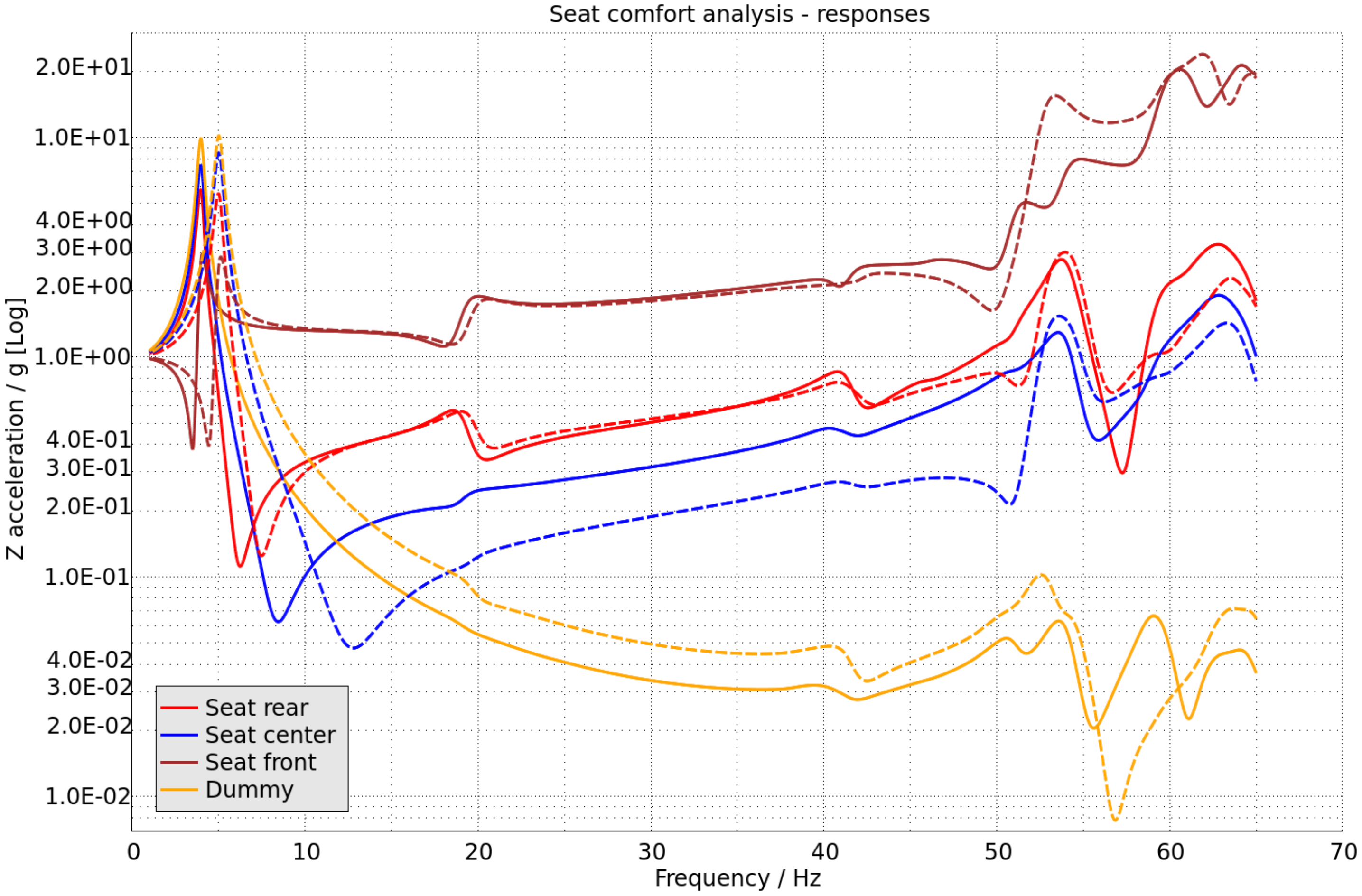
- Responses: Z-accelerations in seat and dummy



Seat comfort analysis

Results: Steady state dynamics

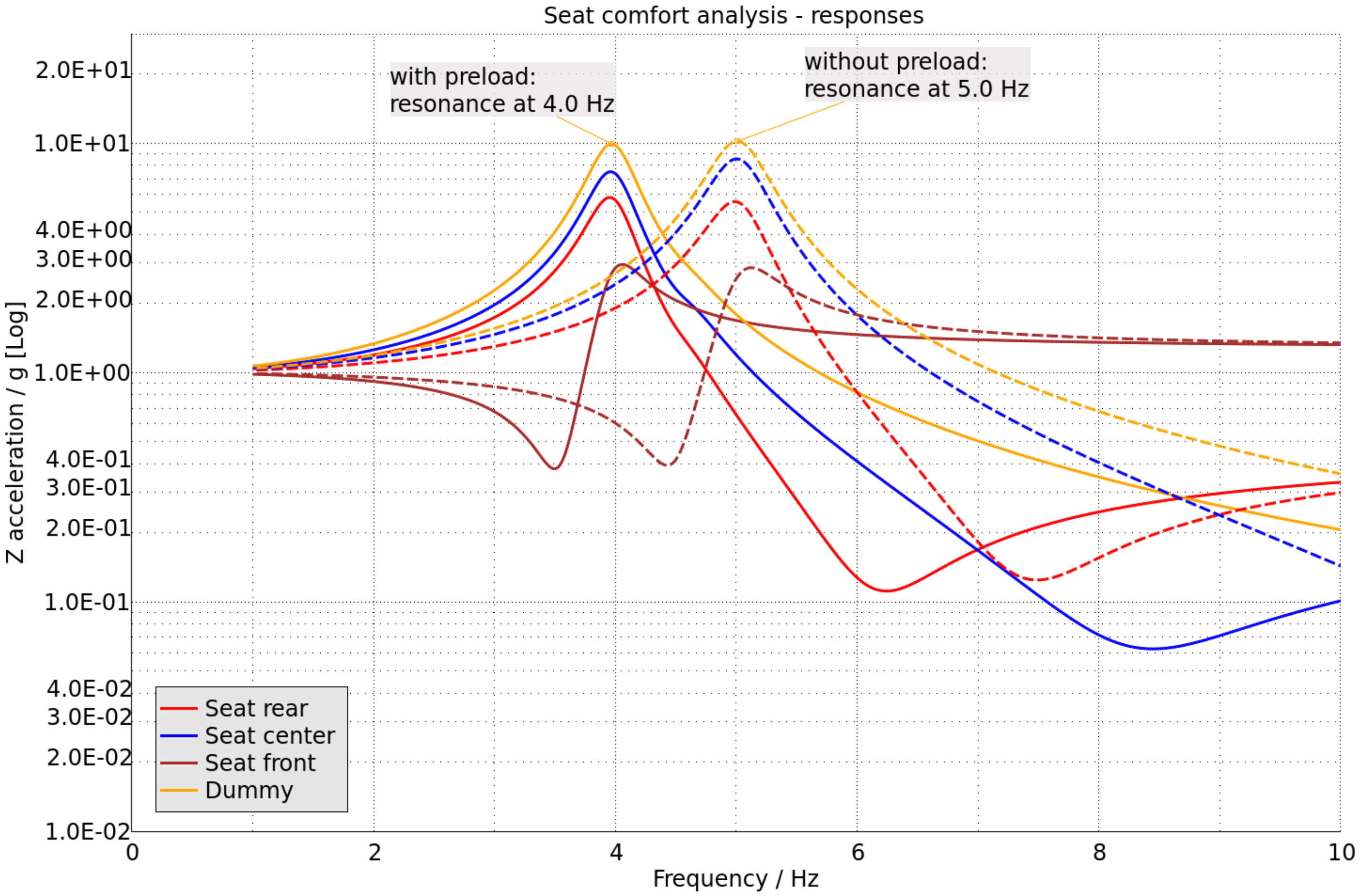
- Responses: Effect of pre-loading



Seat comfort analysis

Results: Steady state dynamics

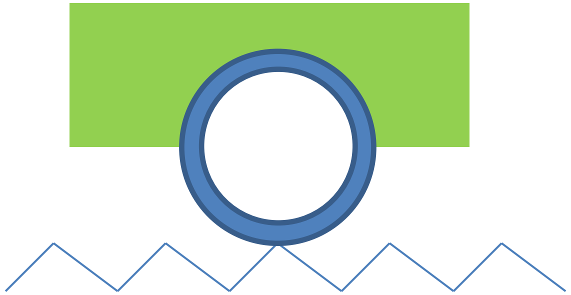
- Responses: Effect of pre-loading



Steady State Dynamics

Frequency domain analysis types

- Determine the response in the whole structure due to harmonic excitation
- Harmonic excitation is often encountered in engineering systems.
  - Unbalance in rotating machinery.
  - Periodic load, e.g., in fatigue test.
  - Uneven base, e.g., the force on tires running on a zig-zag road (rough road shake test)
- Fundamental assumptions:
  - Transient effects are negligible, and the time-dependent nature of the loads can be expressed purely in terms of harmonic forcing functions.
  - Response occurs at the same frequency as the harmonic loads, and in proportion to the magnitude of the applied loads.
- Also known as
  - Harmonic vibration
  - Frequency response (SOL 108, 111)
  - *DYNAMIC, STEADY STATE

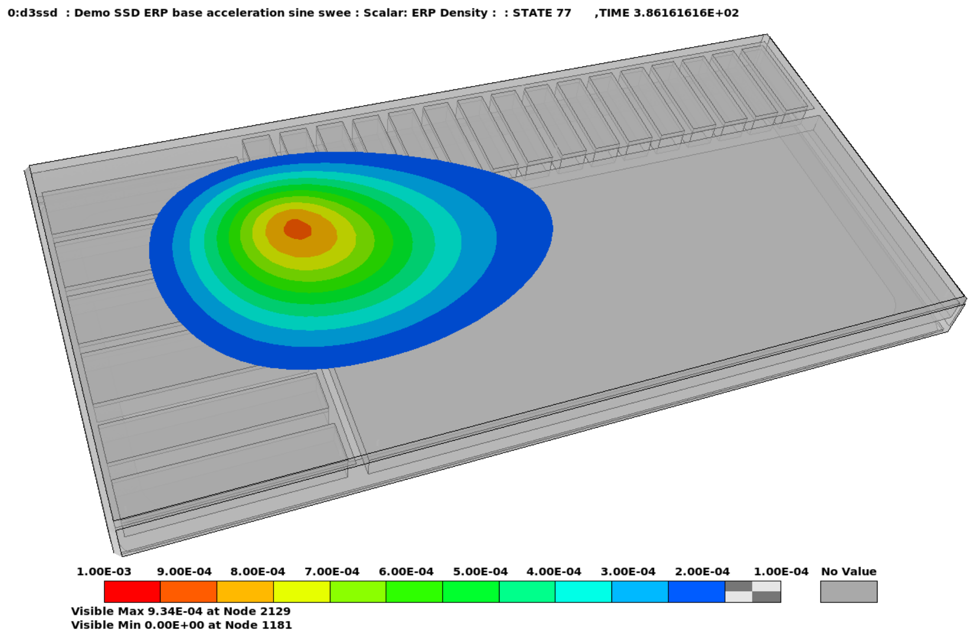


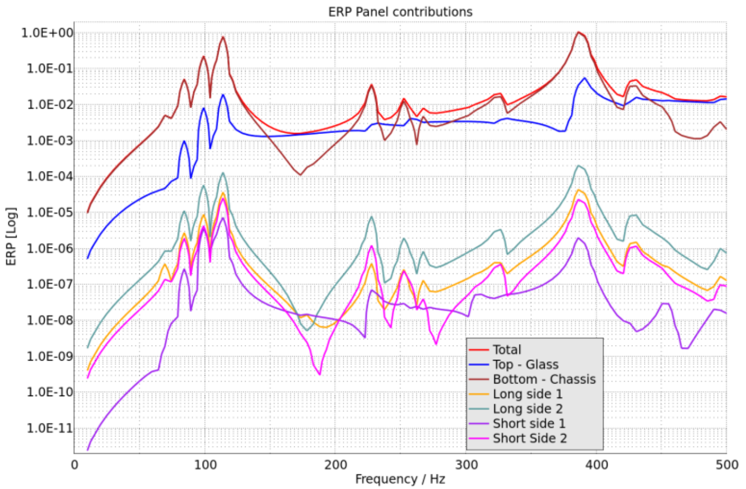
$$F(t) = F_0 \sin(\omega t + \phi)$$

Steady State Dynamics

Frequency domain analysis types

- LS-DYNA offers mode-based solution
- **`*FREQUENCY_DOMAIN_SSD`**
- or direct solution
- **`*FREQUENCY_DOMAIN_SSD_DIRECT`**
- with optional calculation of Equivalent Radiated Power
- **`*FREQUENCY_DOMAIN_SSD_ERP`**
- or integrated fatigue analysis
- **`*FREQUENCY_DOMAIN_SSD_FATIGUE`**
  - Fatigue properties from `*MAT_ADD_FATIGUE`

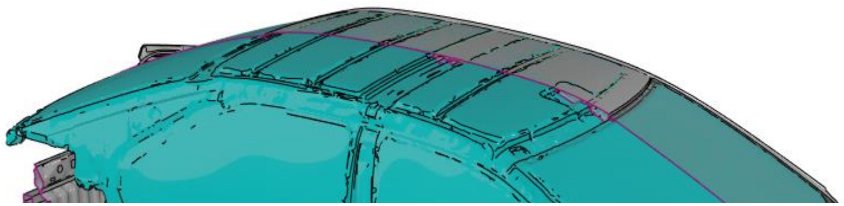


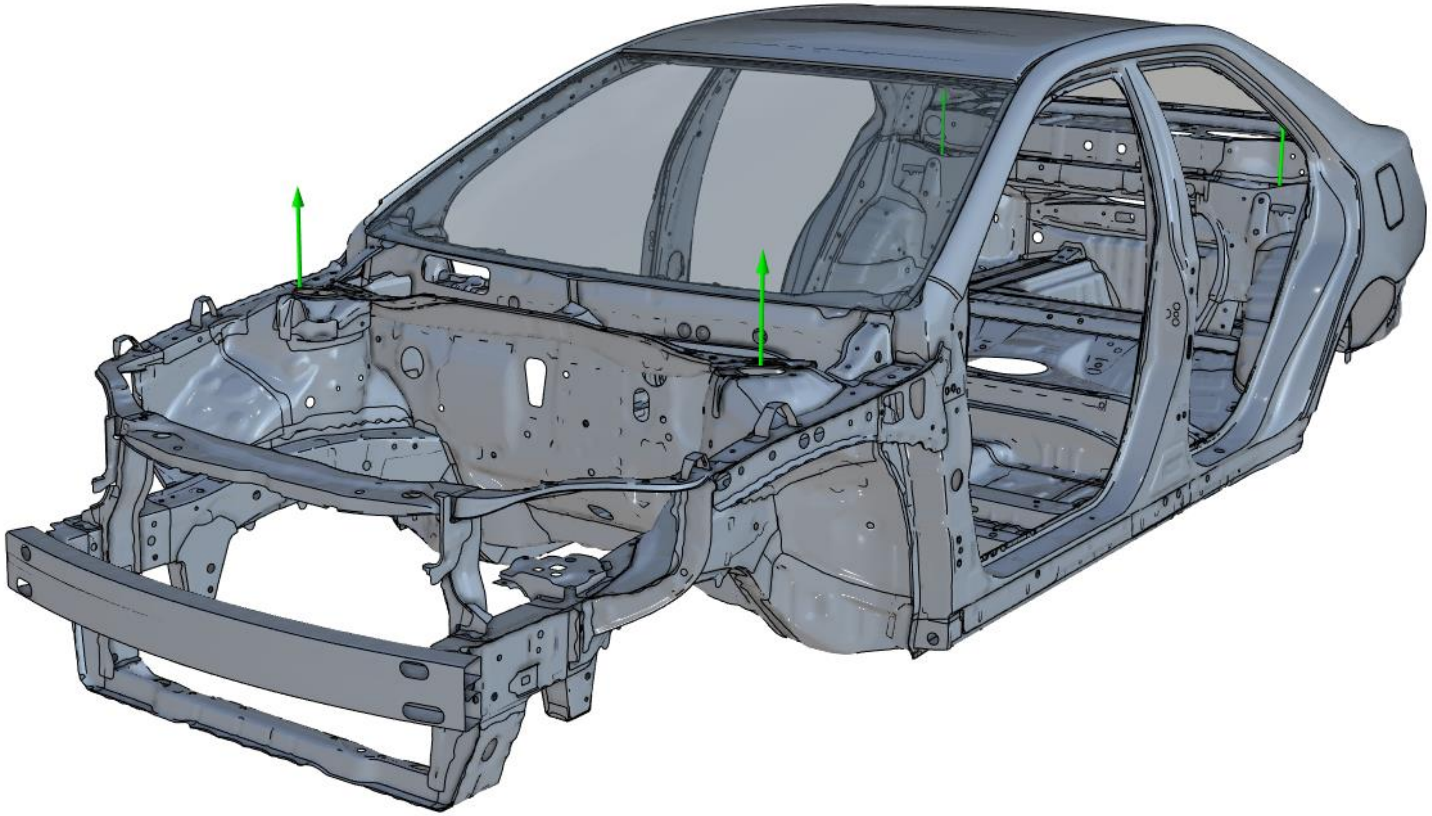


Acoustic analysis of car compartment

Setup

- Interior acoustics analysis
  - Evaluate SPL up to 600 Hz
- Compute all eigenmodes up to 1200 Hz
  - MCMS, all modes up to 1200 Hz: 7195
  - Solution time: 6 hours
- SSD analysis
  - Sine sweep, unit loading
  - Z-excitation at suspension towers
- FEM acoustics
  - Cavity mesh coupled by tied contact
  - Mesh size ~10 mm, should be OK up to 600 Hz ($\lambda/6 \approx 94$ mm)

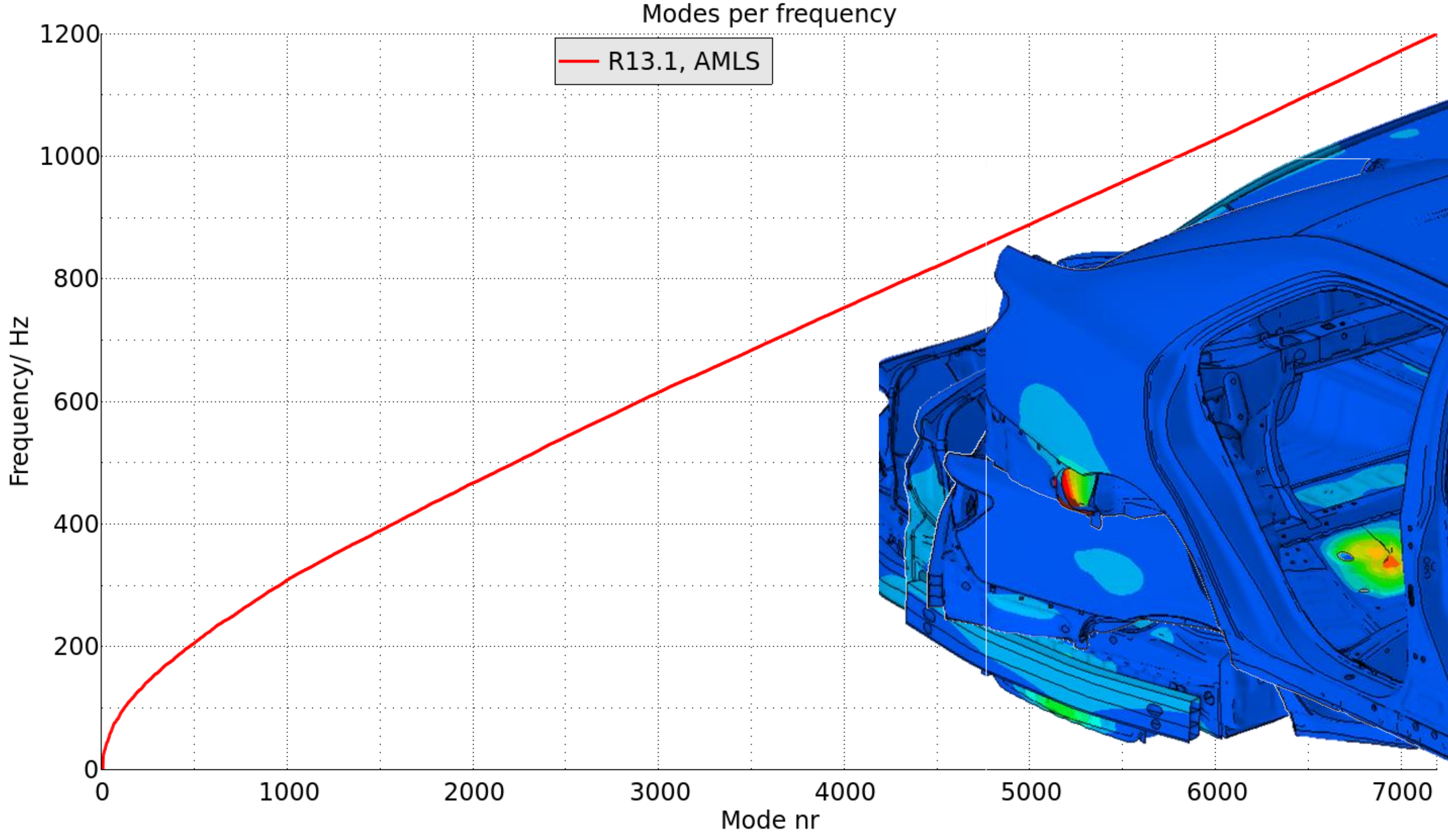


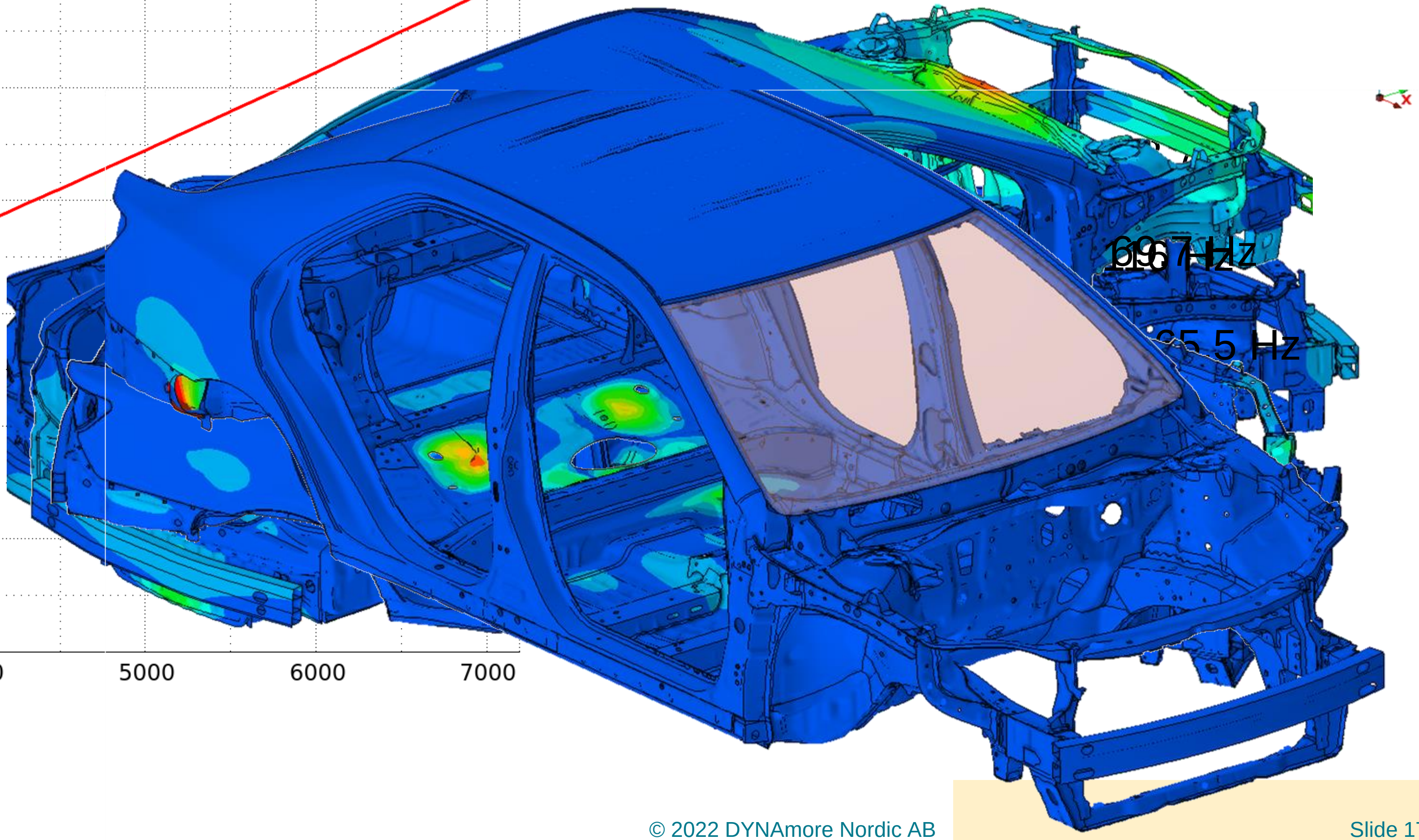


Acoustic analysis of car compartment

Results: Eigenvalues

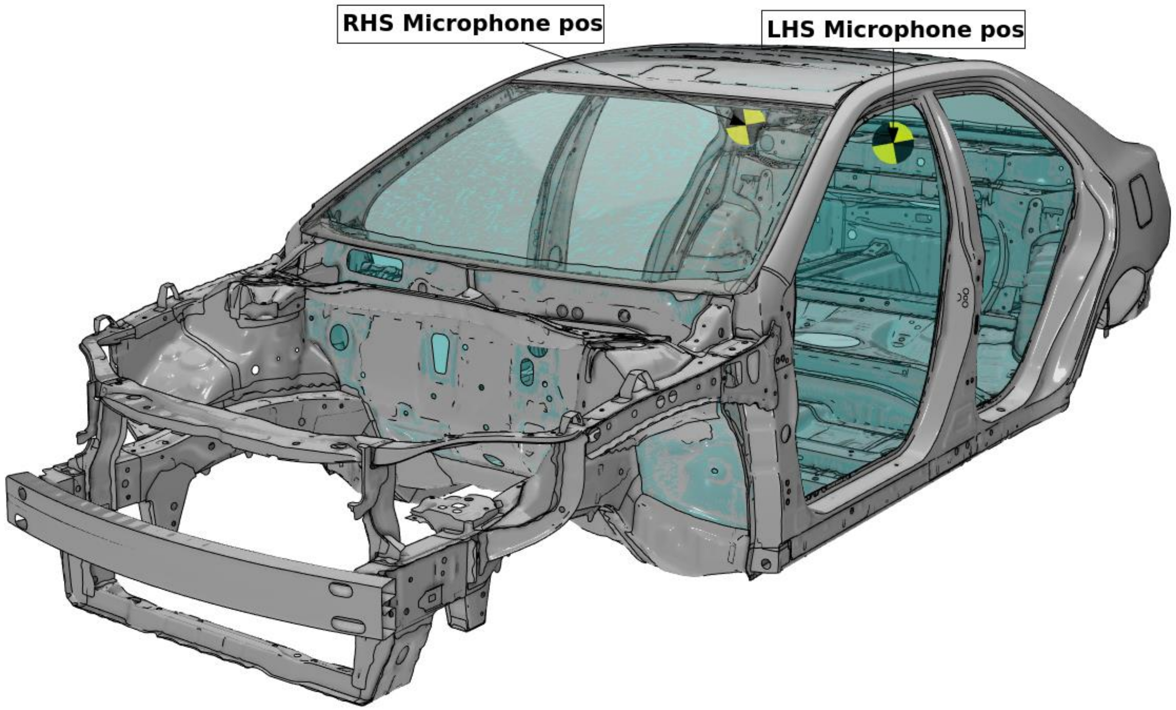
- Modes per frequency

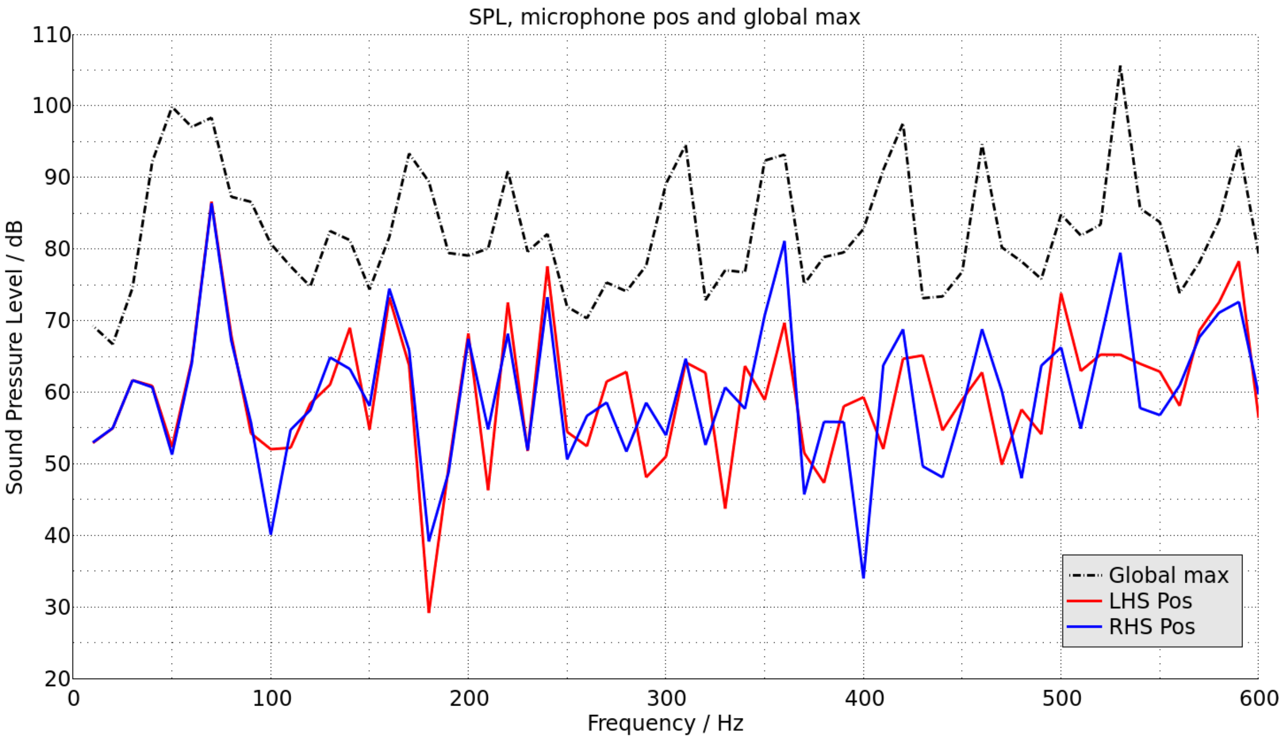




Acoustic analysis of car compartment

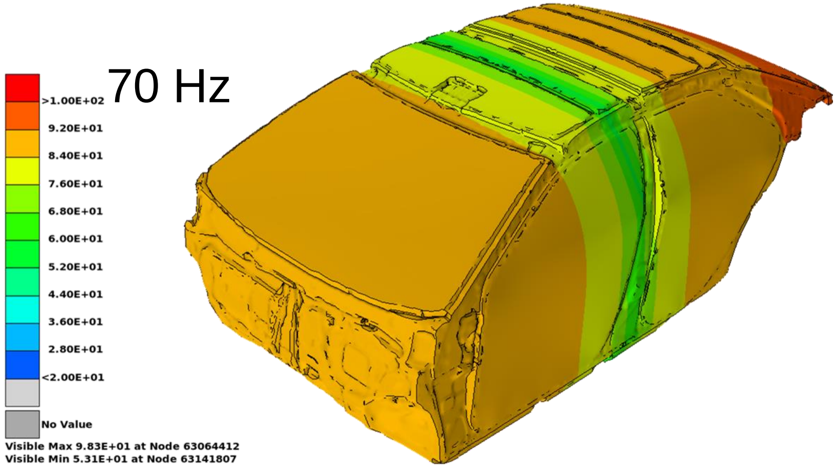
Results: SPL in microphone positions

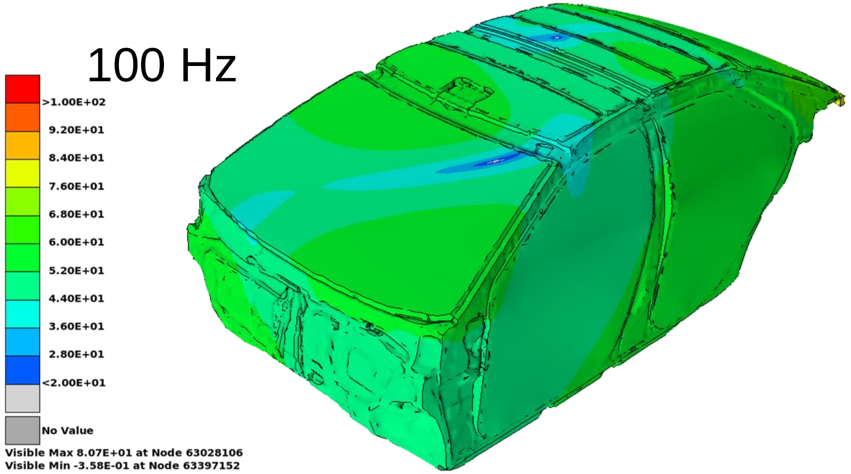


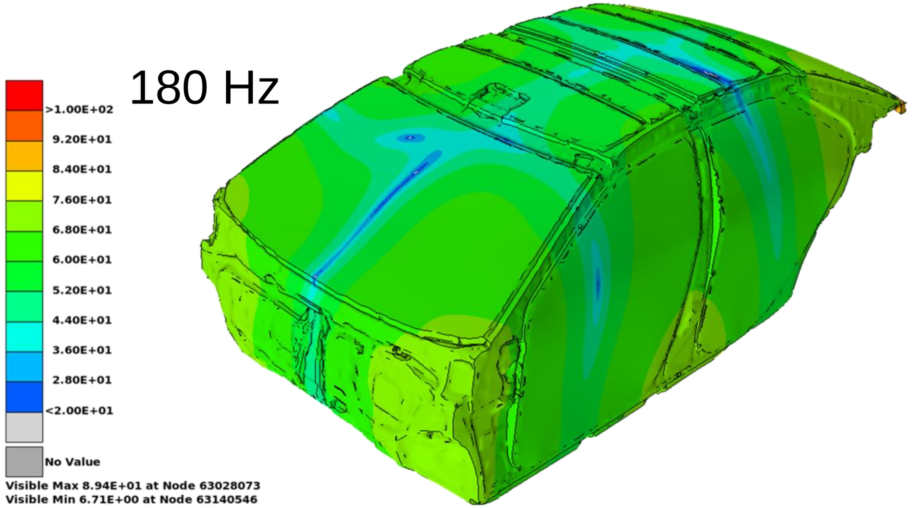


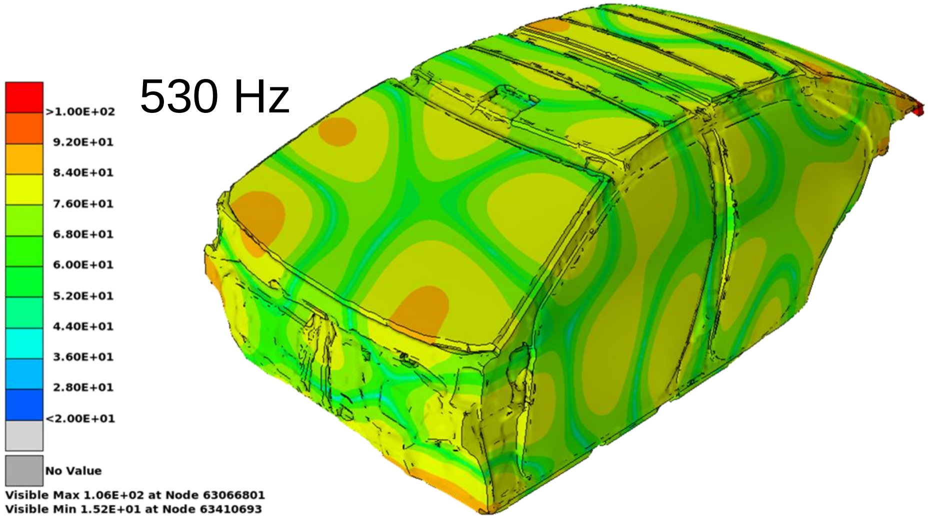
Acoustic analysis of car compartment

Results: SPL (dB)





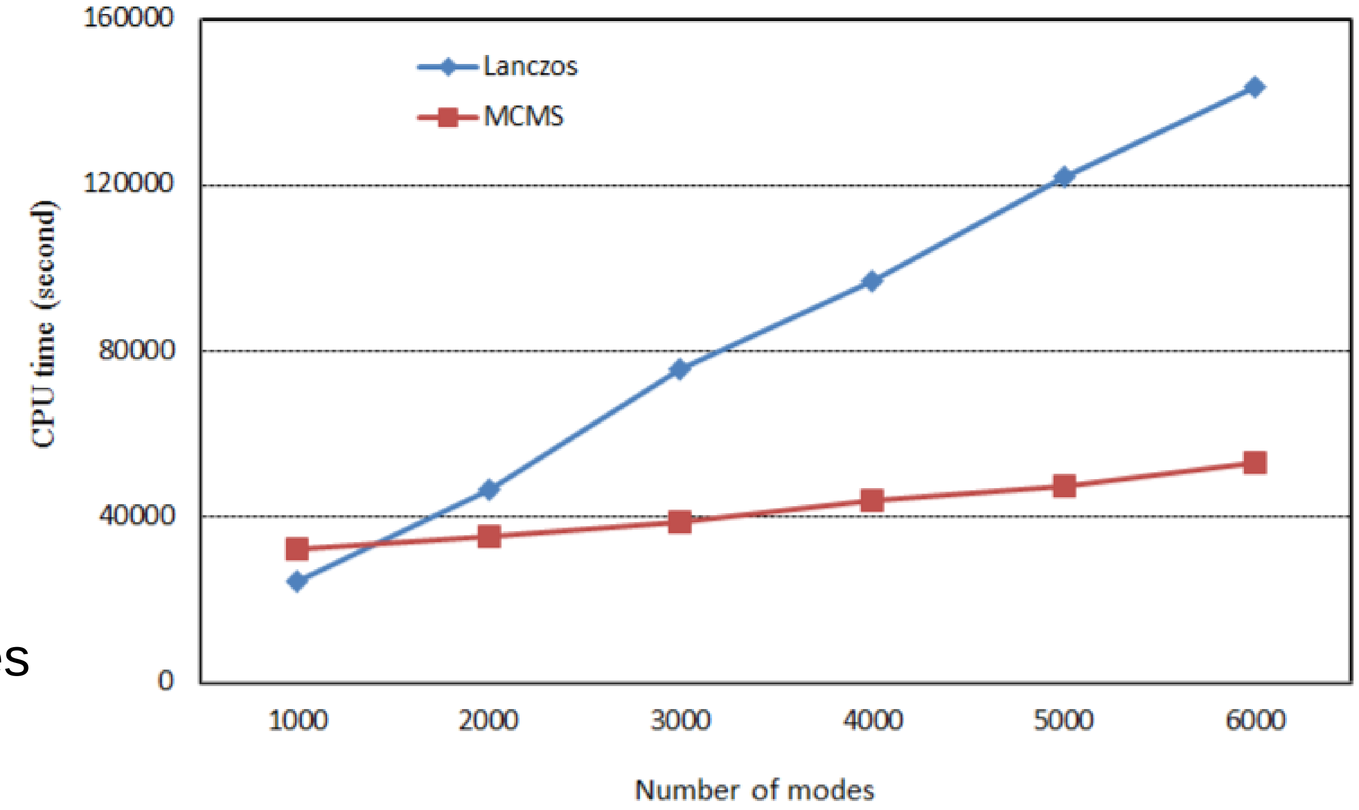




Modal analysis

Frequency domain analysis types

- *CONTROL_IMPLICIT_EIGENVALUE
- Block Shift and Invert Lanczos Method is the default option
- Nonsymmetric eigenvalues optional
  - Damped eigenvalues
  - Non-symmetric stiffness matrix
- MCMS for > 1000 eigenmodes of big models
  - LS-DYNA's implementation of AMLS
  - Typical application: Automotive NVH analyses
  - Set *EIGMTH* = 101
  - Not efficient for ~ 100 eigenmodes



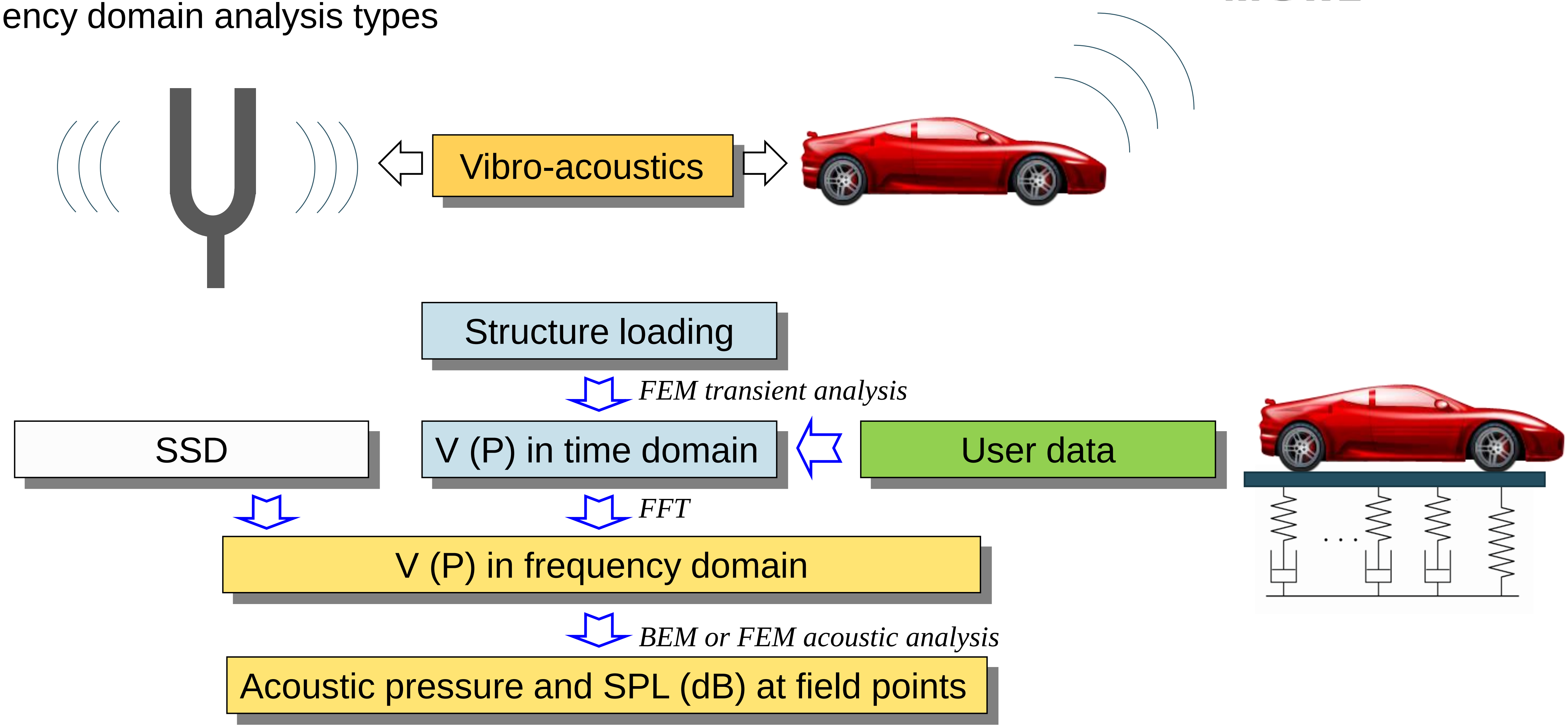
BEM and FEM Acoustics

Frequency domain analysis types

- Acoustic evaluations are commonly performed as frequency domain analyses
- The Boundary Element Method (BEM) is often used for exterior problems
  - Sound radiation in an anechoic chamber
- The Finite Element Method is often applied for interior problems
  - Sound Pressure Level evaluation in a car cabin
- LS-DYNA offers both solution methods
- **`*FREQUENCY_DOMAIN_ACOUSTIC_FEM`**
- or
- **`*FREQUENCY_DOMAIN_ACOUSTIC_BEM`**
  - Exact or Approximate solutions (Rayleigh, Kirchhoff)
  - Optional calculation of panel contributions

BEM and FEM Acoustics

Frequency domain analysis types



Electronic device

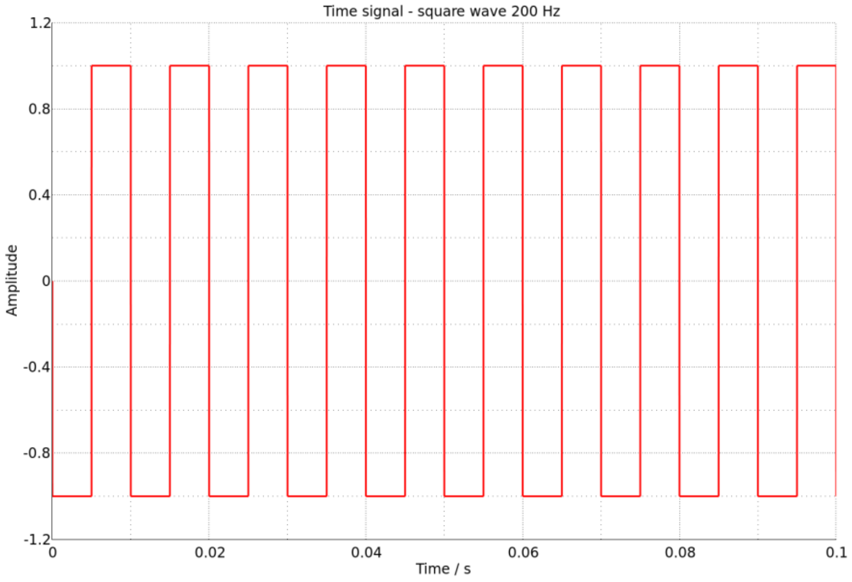
Setup

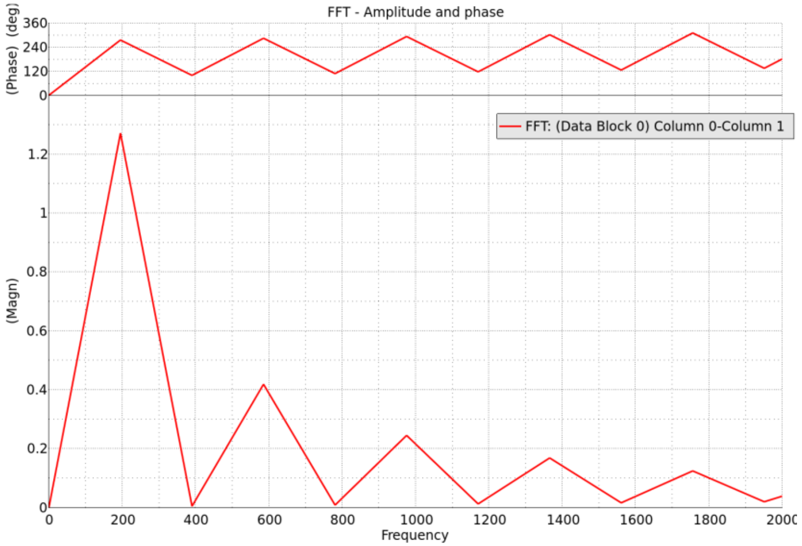
- Noise evaluation of buzzer
  - SSD with square wave excitation, 200 Hz
  - BEM Acoustics, 50 – 400 Hz
  - Device placed on a reflecting half-plane
  - Comparison to ERP result
- Shaker table test
  - Random vibration fatigue
  - Steinberg’s three-band method

Electronic device

Setup – Noise evaluation

- Noise evaluation of buzzer
  - SSD with square wave excitation, 200 Hz

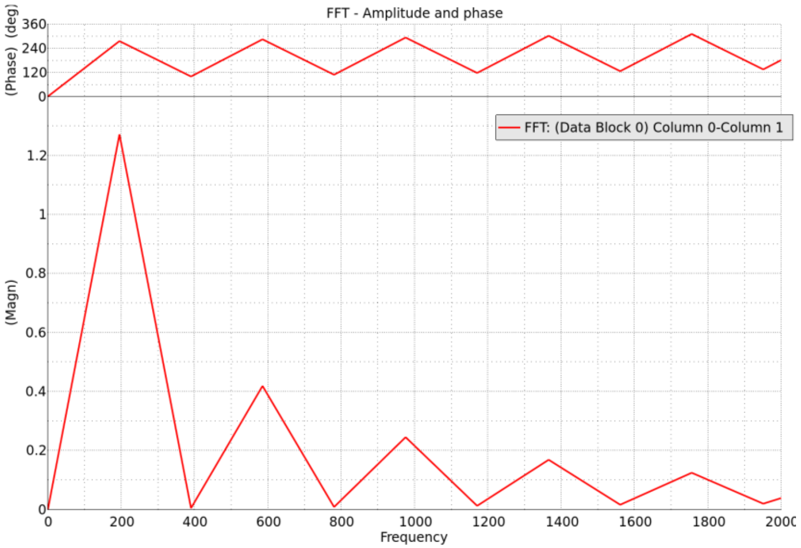


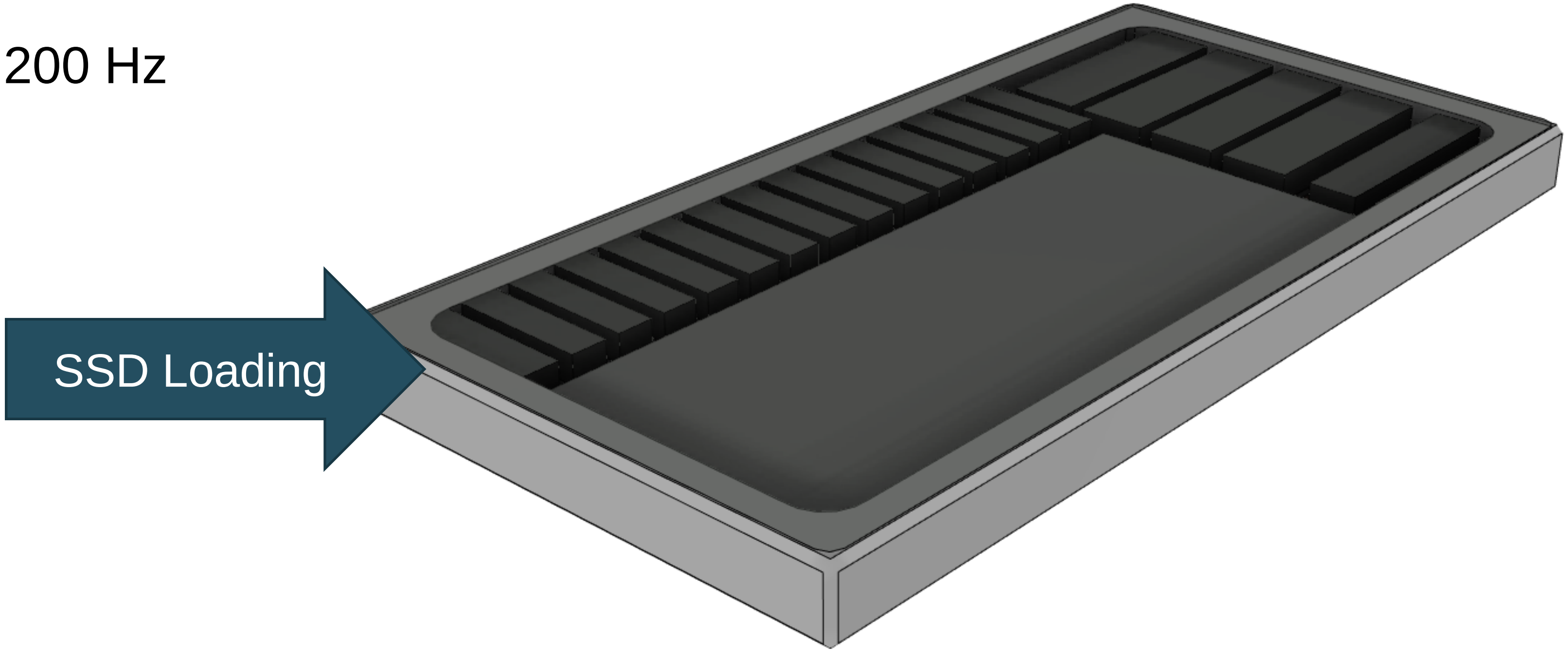


Electronic device

Setup – Noise evaluation

- Noise evaluation of buzzer
  - SSD with square wave excitation, 200 Hz

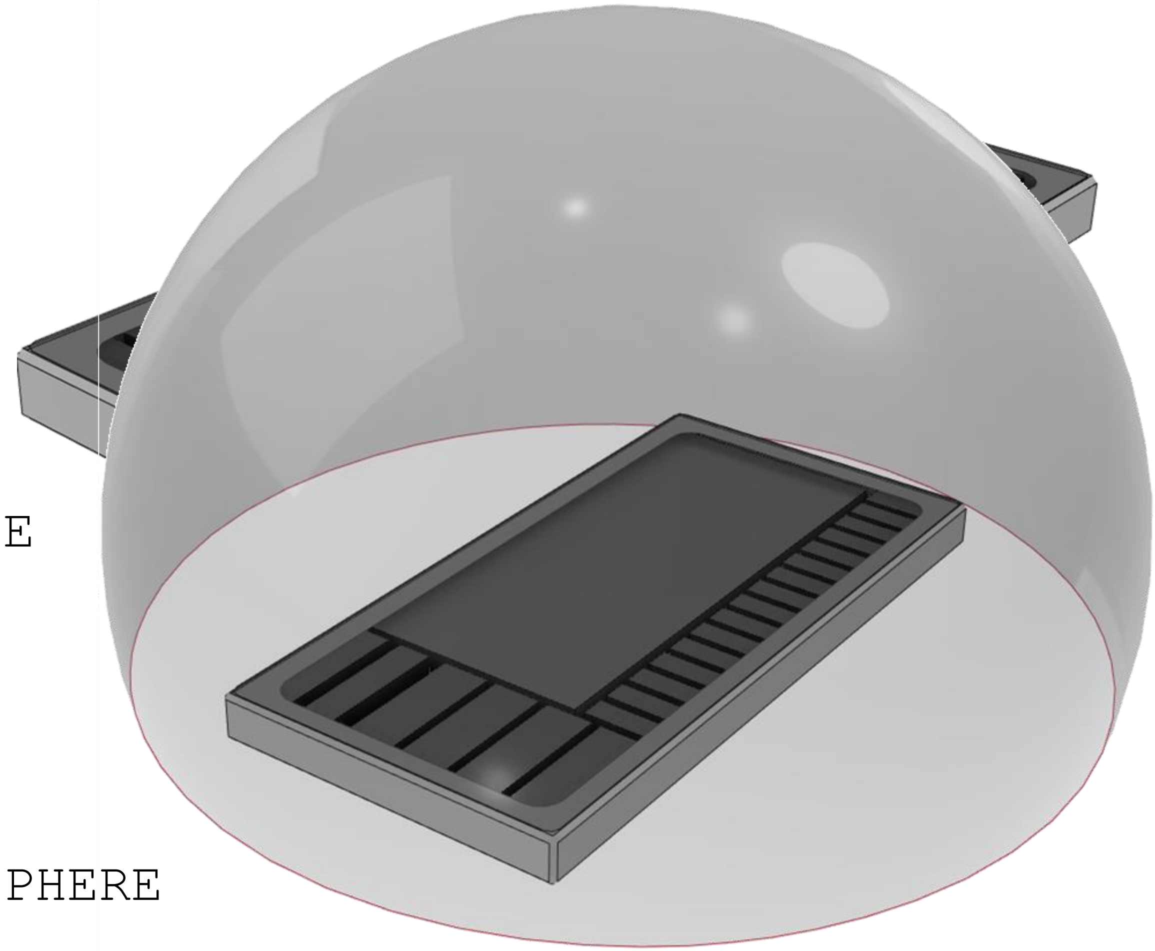




Electronic device

Setup – Noise evaluation

- Noise evaluation of buzzer
  - SSD with square wave excitation, 200 Hz
  - *FREQUENCY_DOMAIN_SSD_ERP
  - BEM Acoustics, 50 – 400 Hz
  - *DEFINE_PLANE
  - *FREQUENCY_DOMAIN_ACOUSTIC_BEM_HALF_SPACE



  - Evaluation for fringe plotting of SPL in field points
  - *FREQUENCY_DOMAIN_ACOUSTIC_FRINGE_PLOT_SPHERE

Electronic device

Some eigenmodes

#2, 84.5 Hz

#3, 98.5 Hz

#5, 175 Hz

#11, 327 Hz

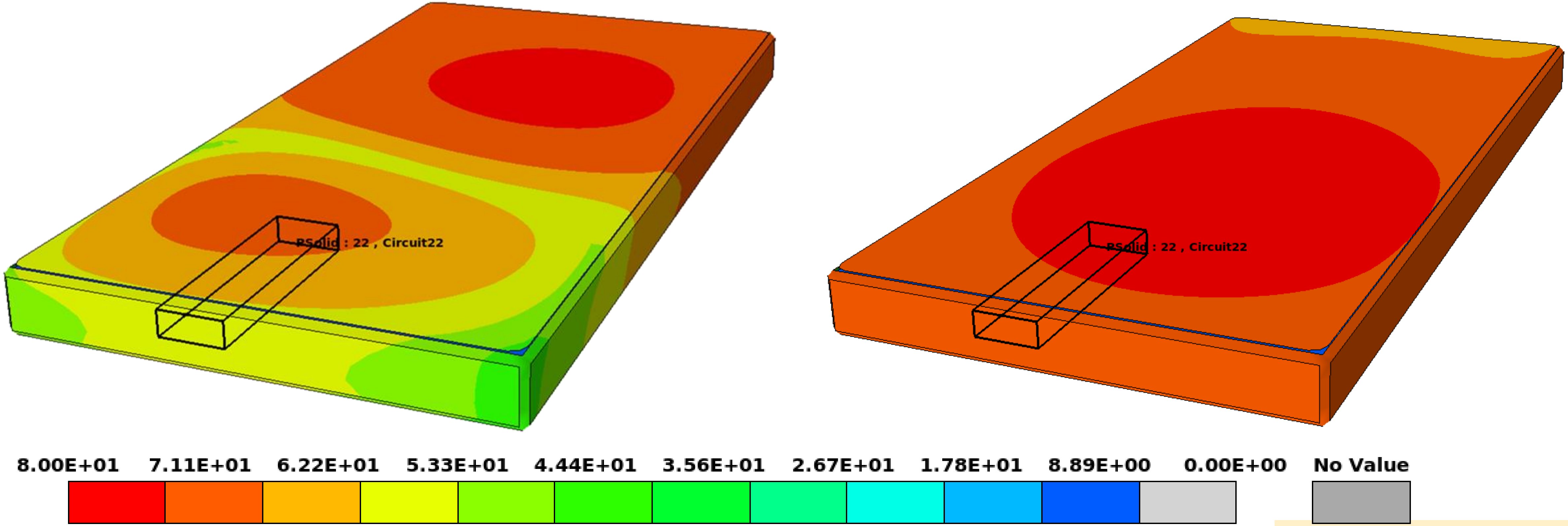
Electronic device

BEM Acoustics results

- Sound pressure level

175 Hz

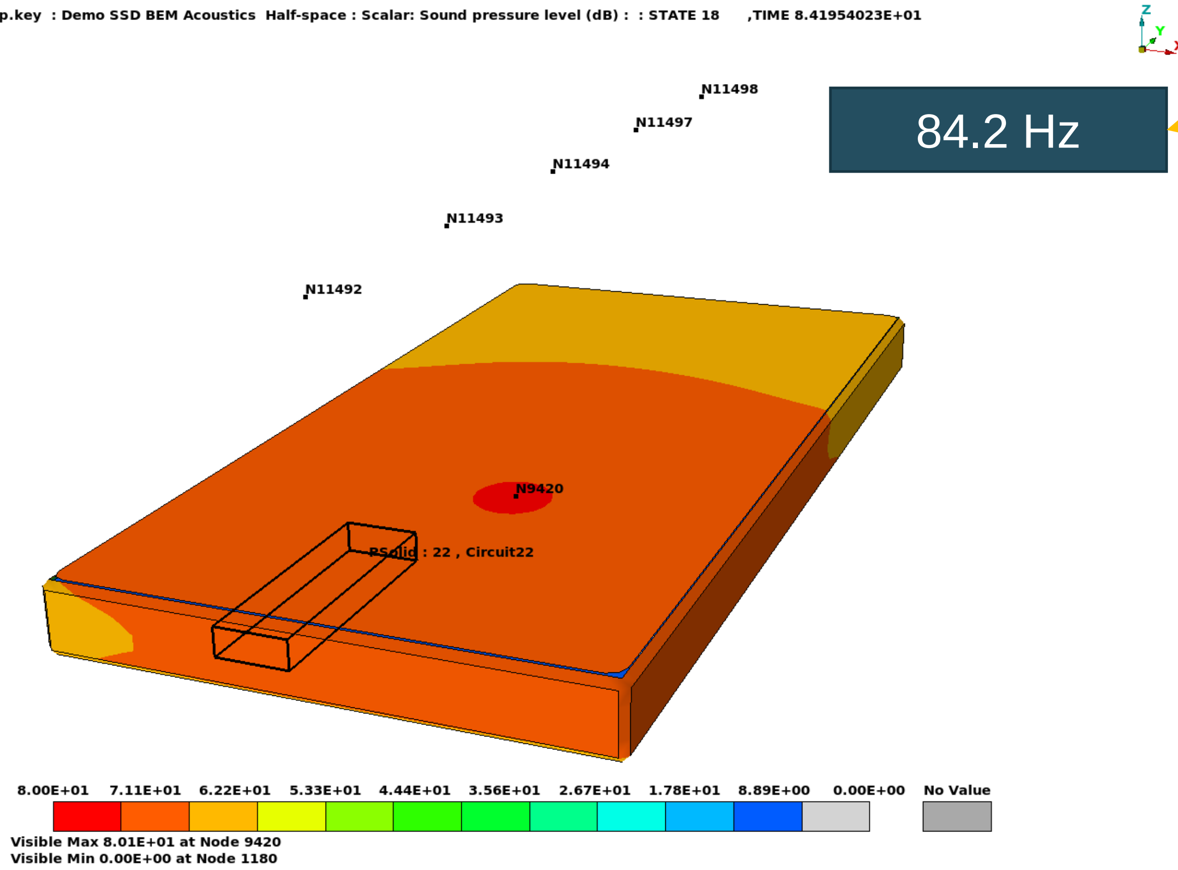
328 Hz

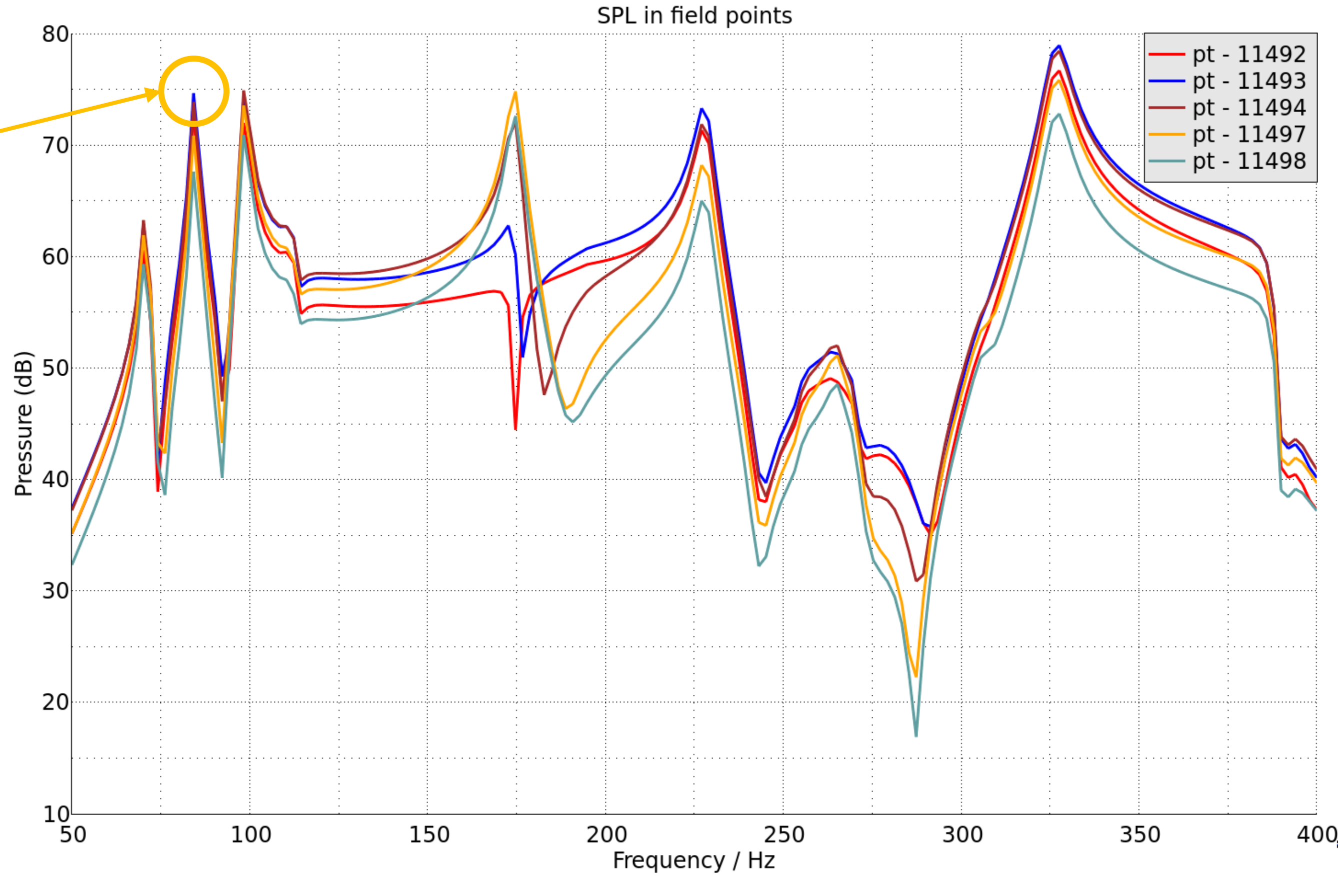


Electronic device

BEM Acoustics results

- Sound pressure level in field points

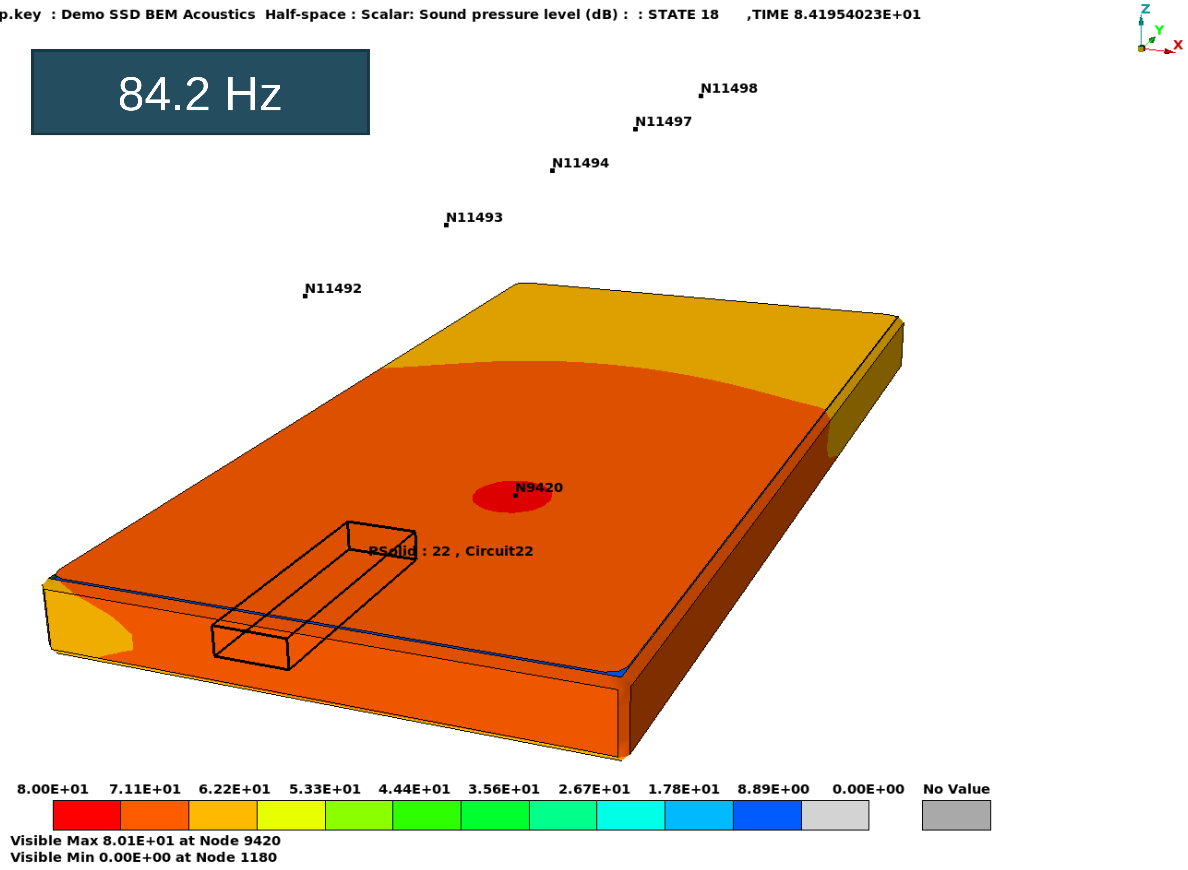


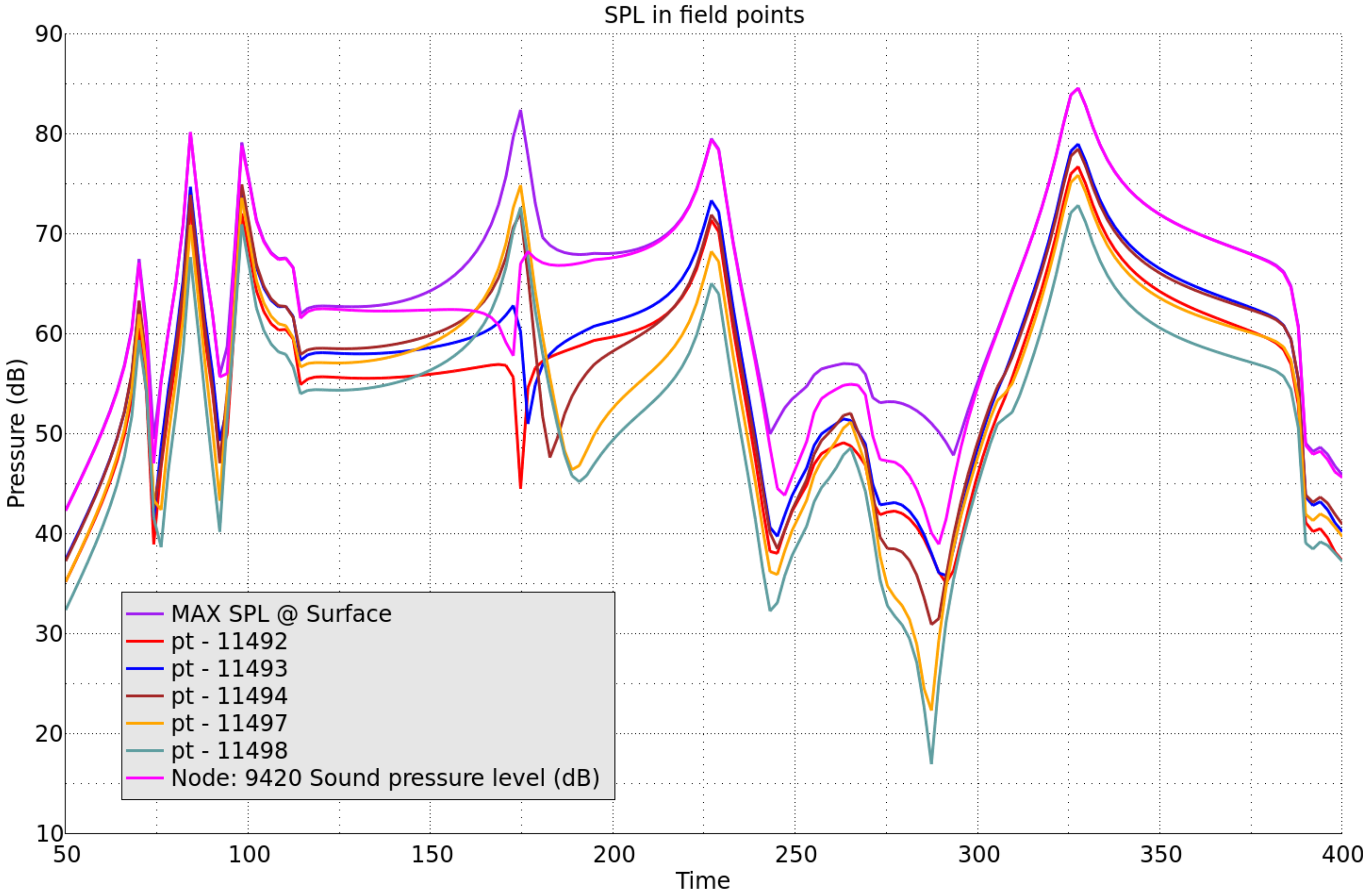


Electronic device

BEM Acoustics results

- Sound pressure level in field points

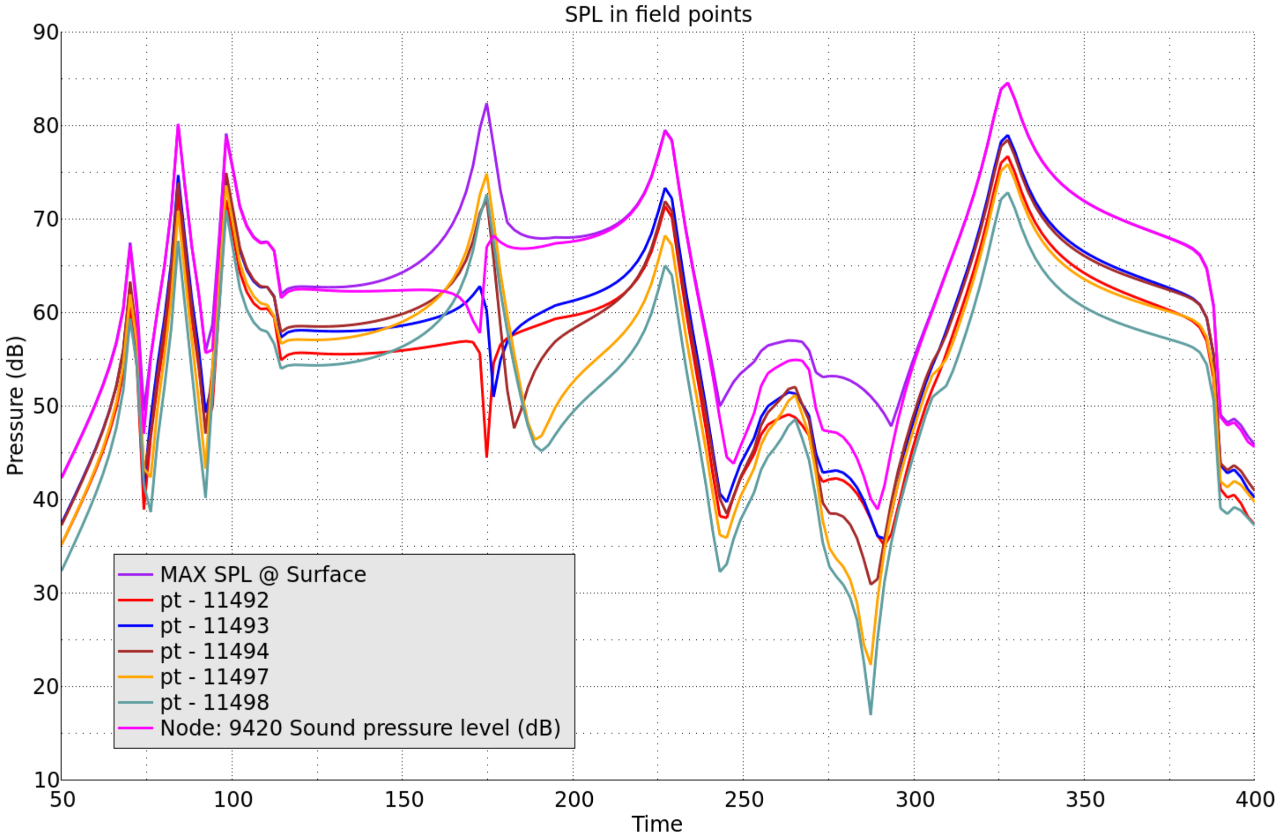


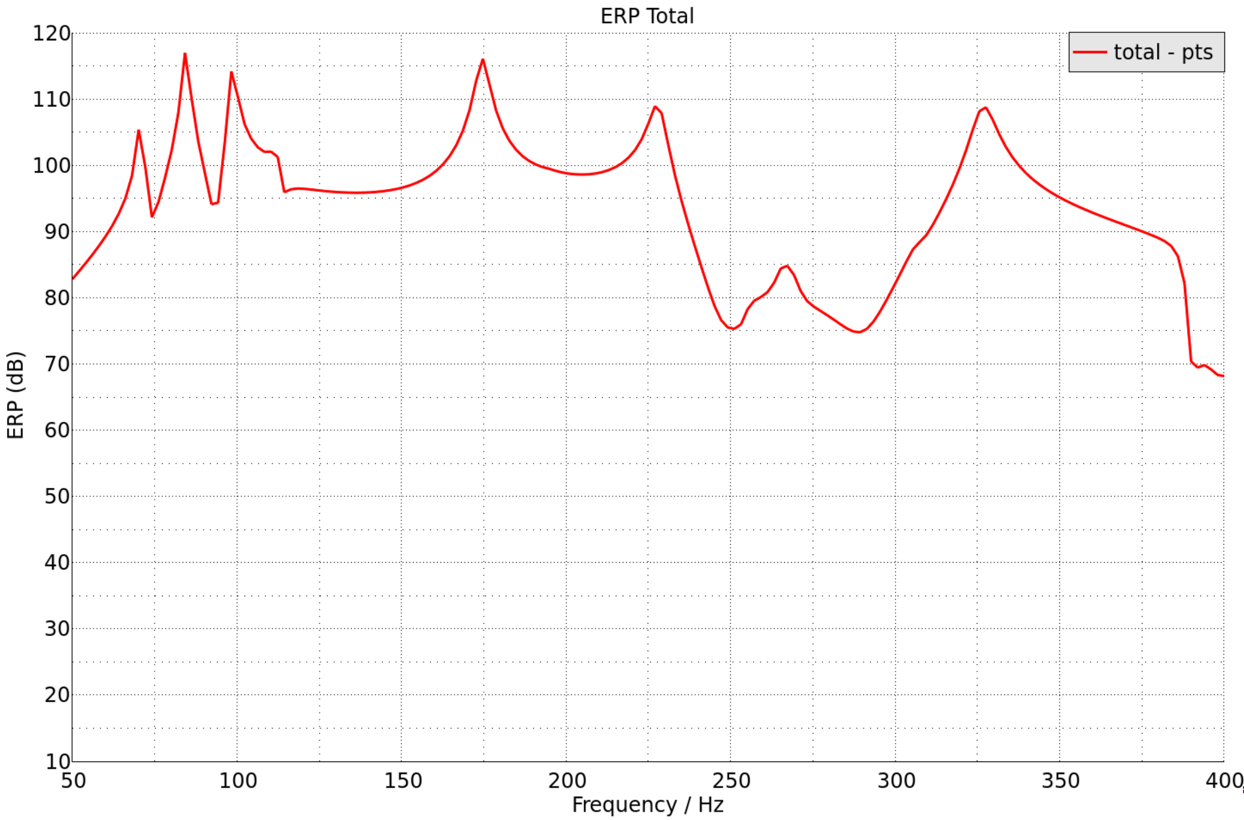


Electronic device

BEM Acoustics results

- Sound pressure level in field points vs. ERP evaluation

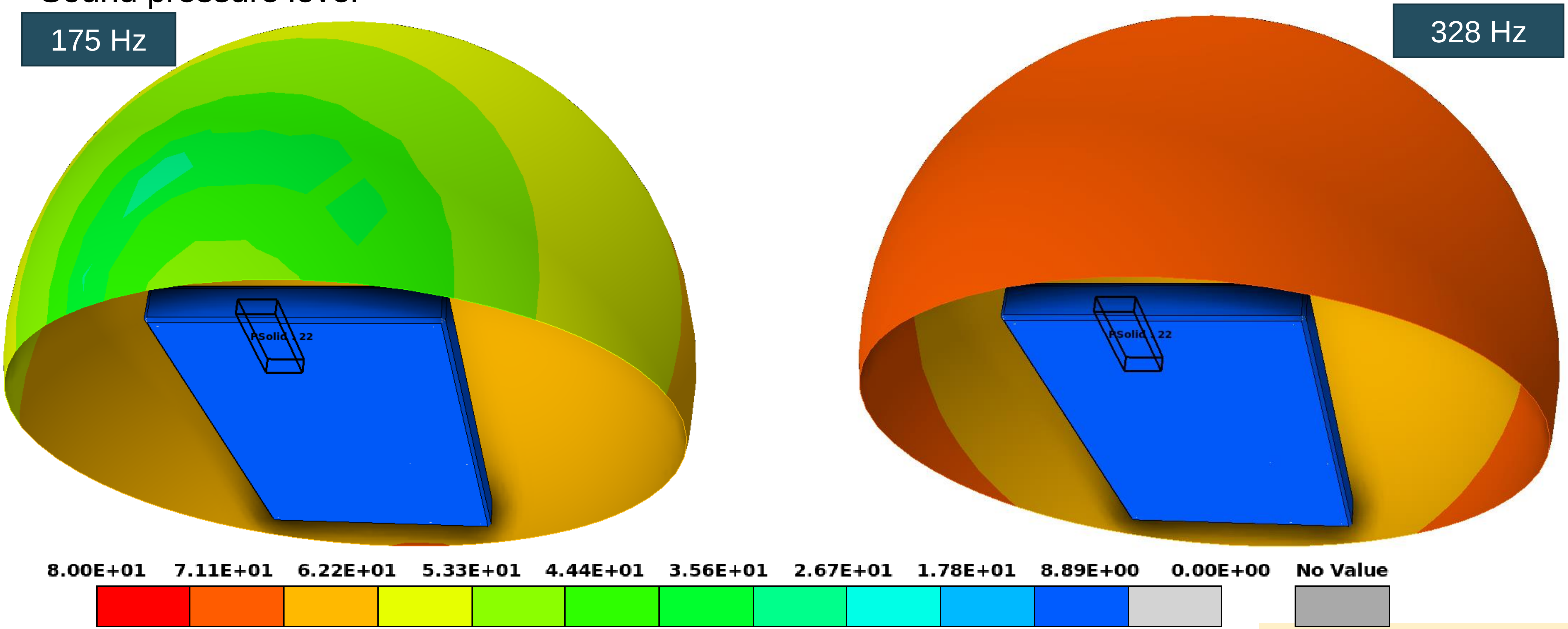




Electronic device

BEM Acoustics results – Fringe plot

- Sound pressure level

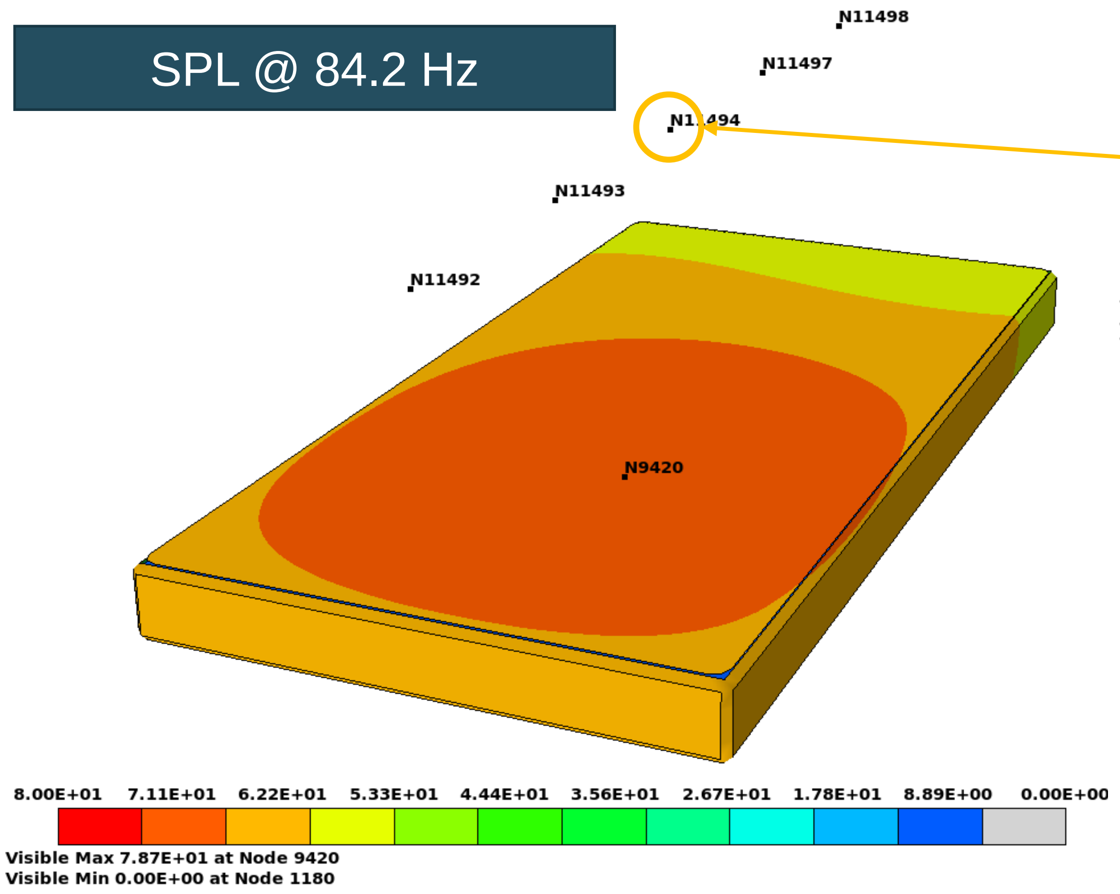


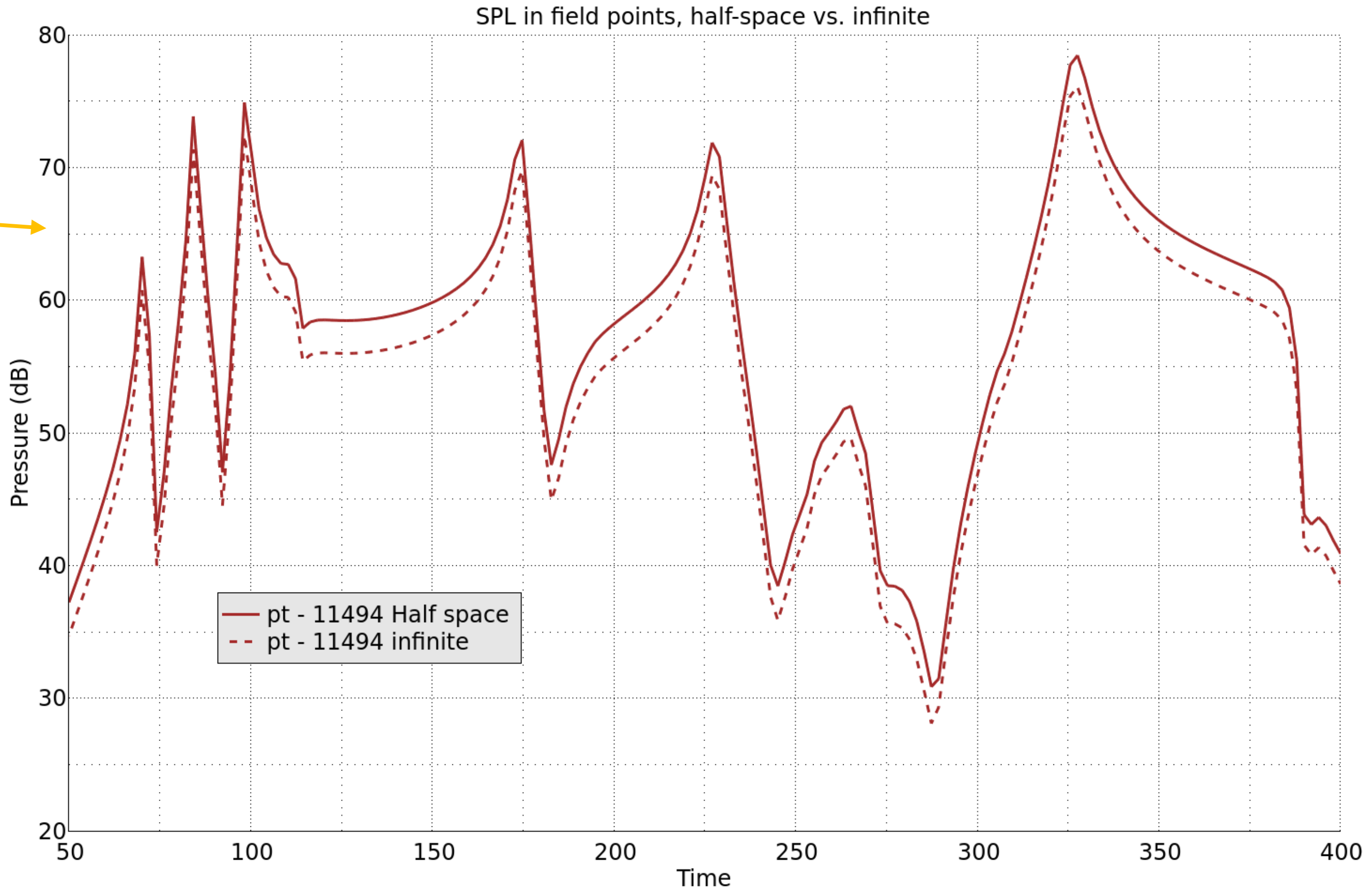
Electronic device

BEM Acoustics results – Half space vs. infinite domain

- Sound pressure level in field points

SPL @ 84.2 Hz

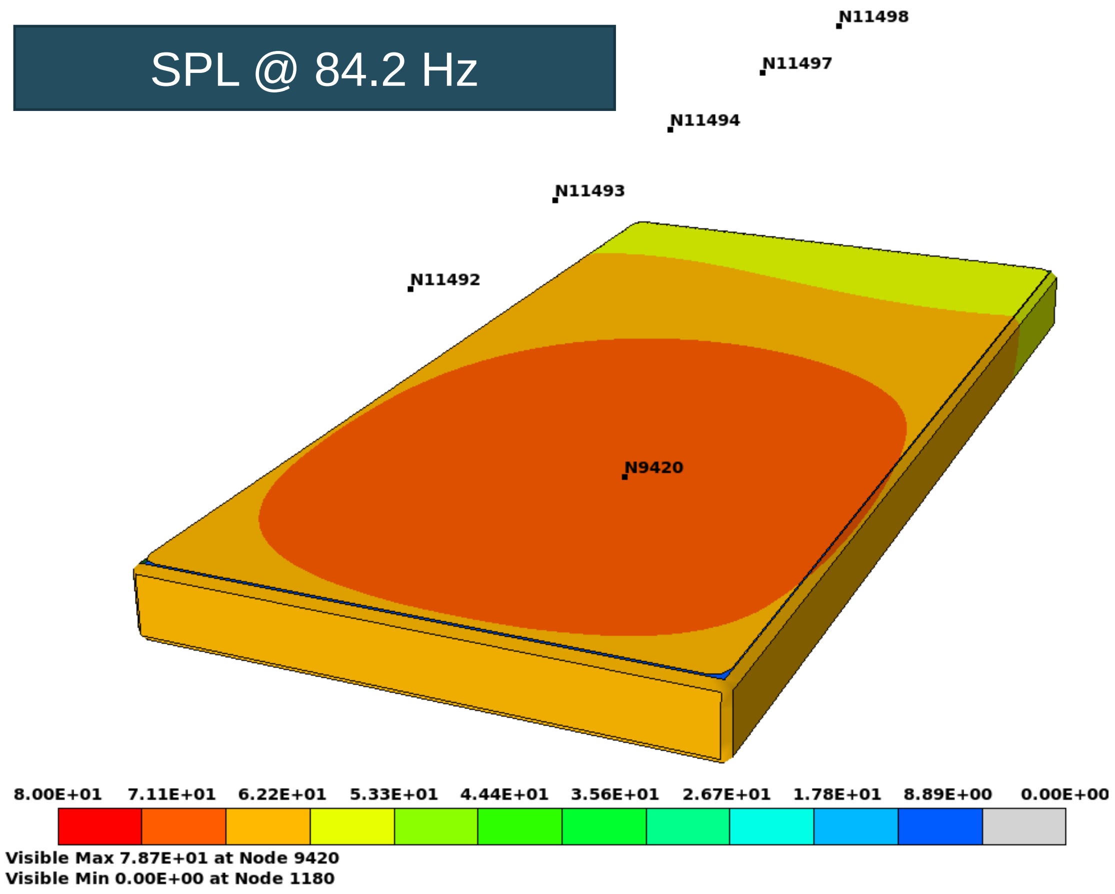


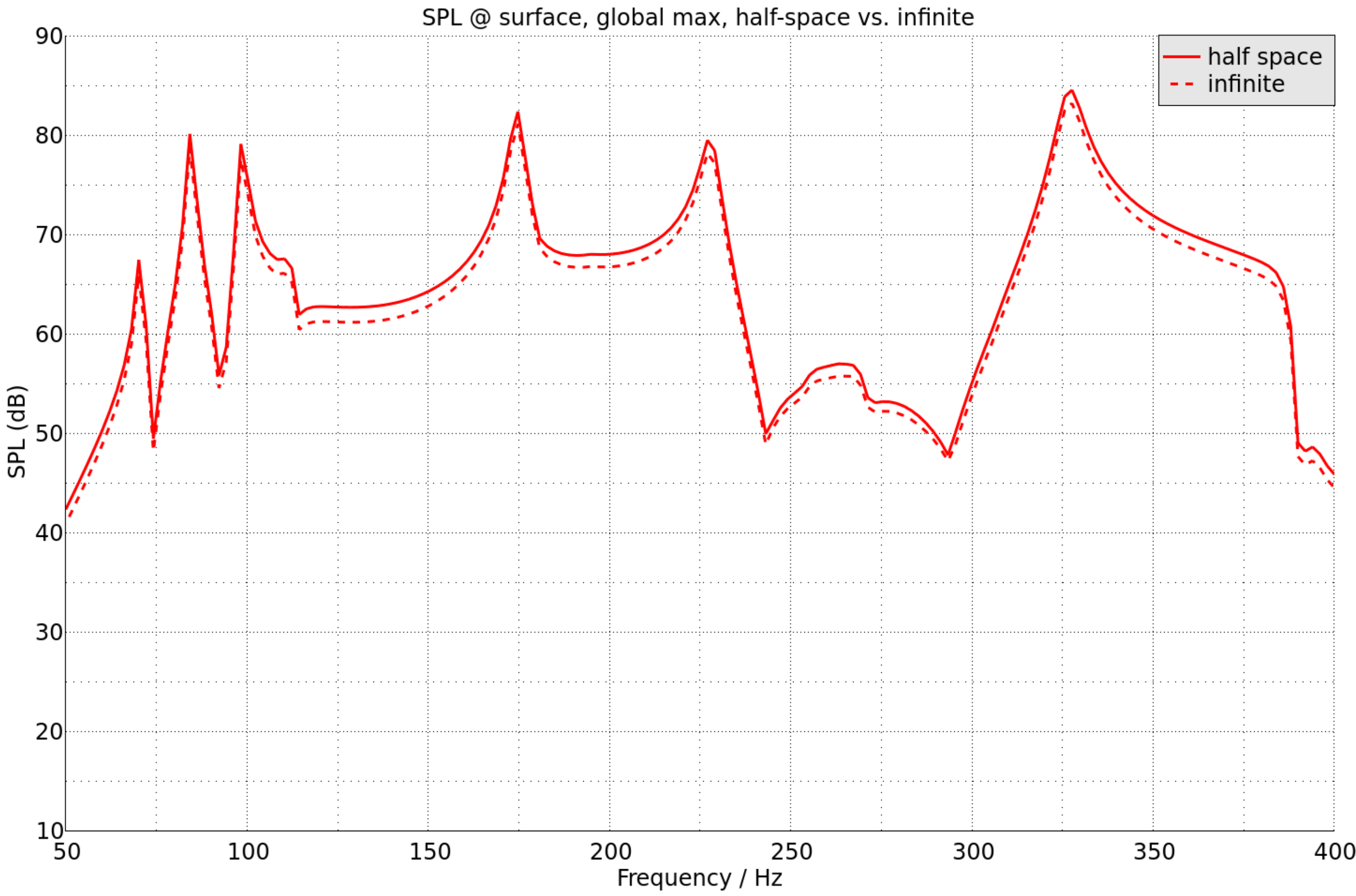


Electronic device

BEM Acoustics results – Half space vs. infinite domain

- Sound pressure level in field points

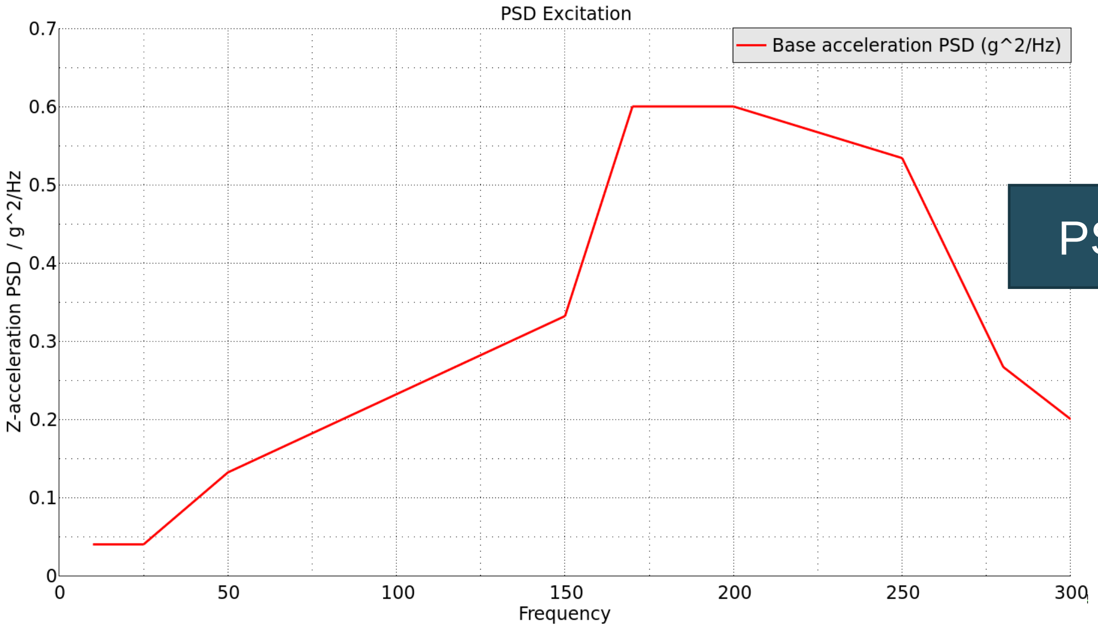


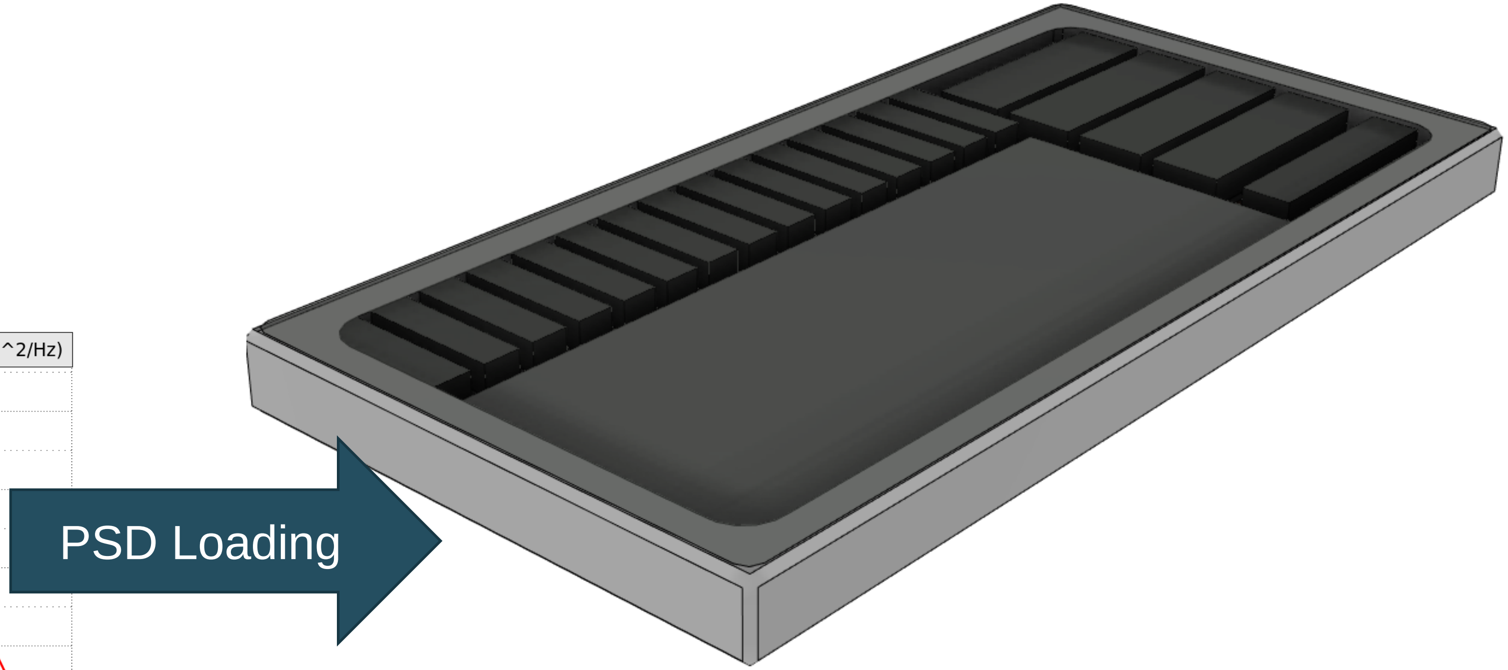


Electronic device

Setup – random vibration fatigue

- Shaker table test
  - PSD excitation – base acceleration Z
  - Material data for fatigue evaluation
    - `*MAT_ADD_FATIGUE`

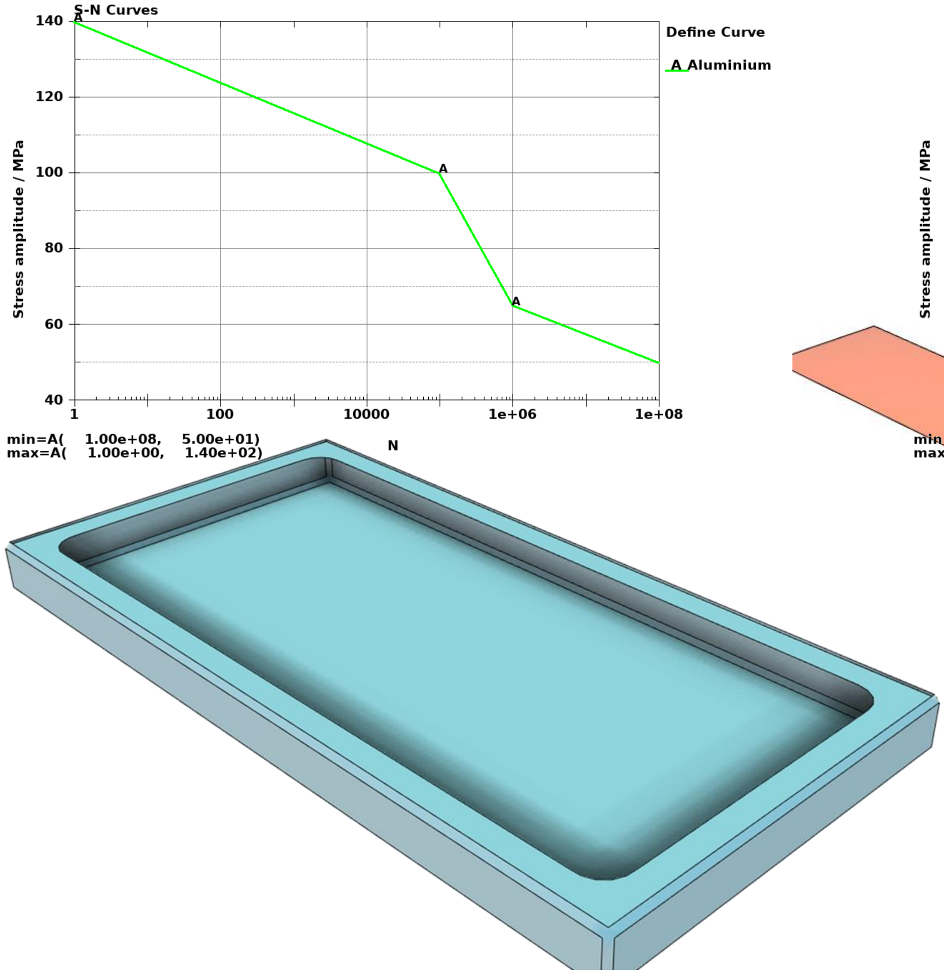




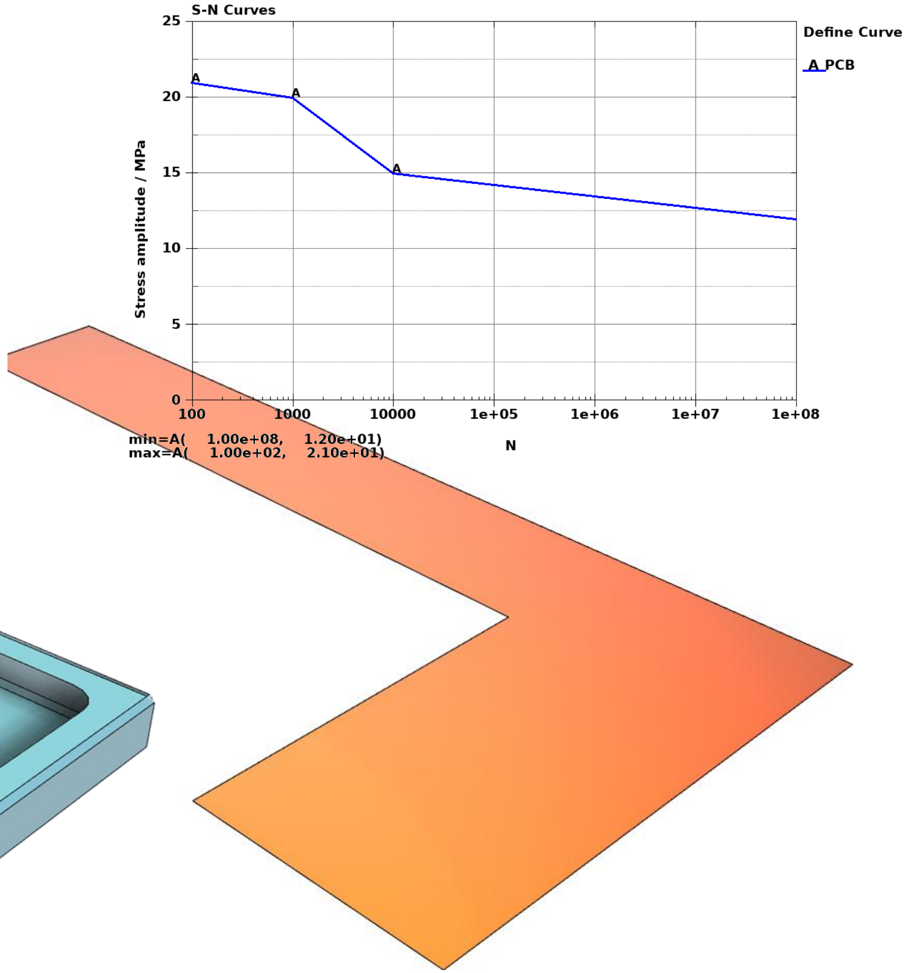
LS-DYNA for frequency domain analyses

Fatigue data

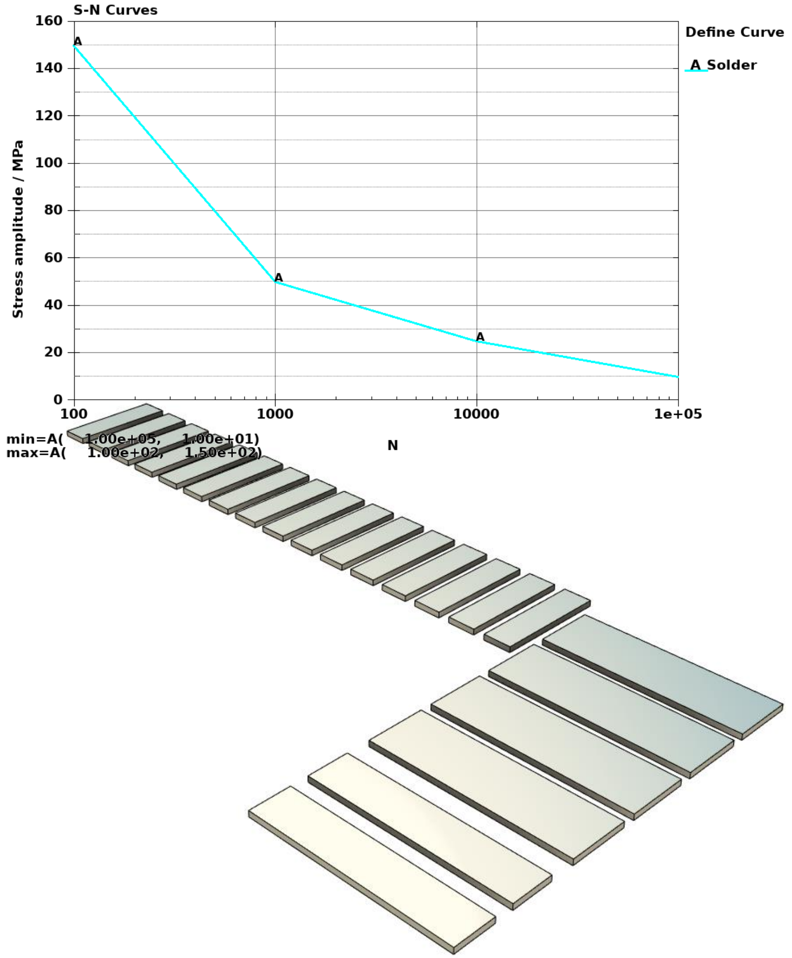
Housing



PCB



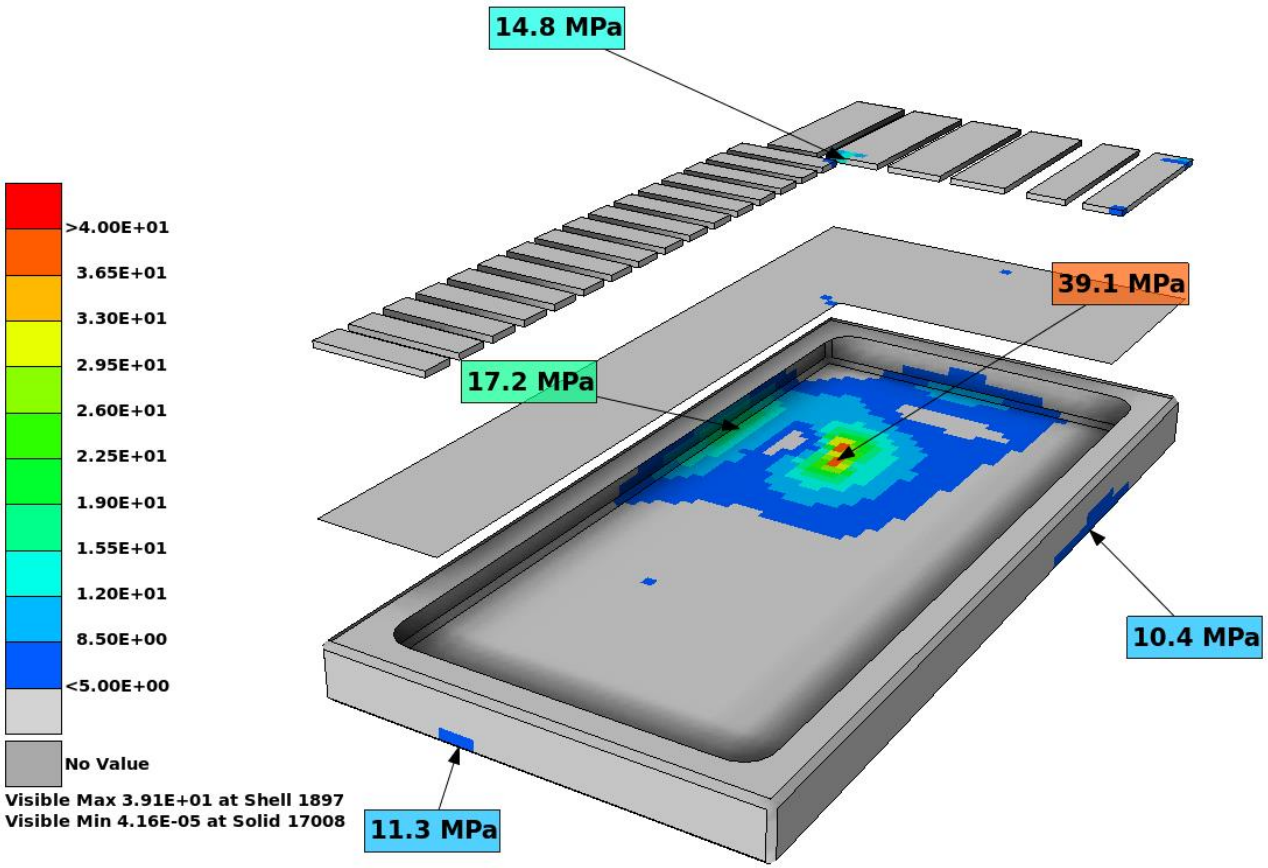
Solder



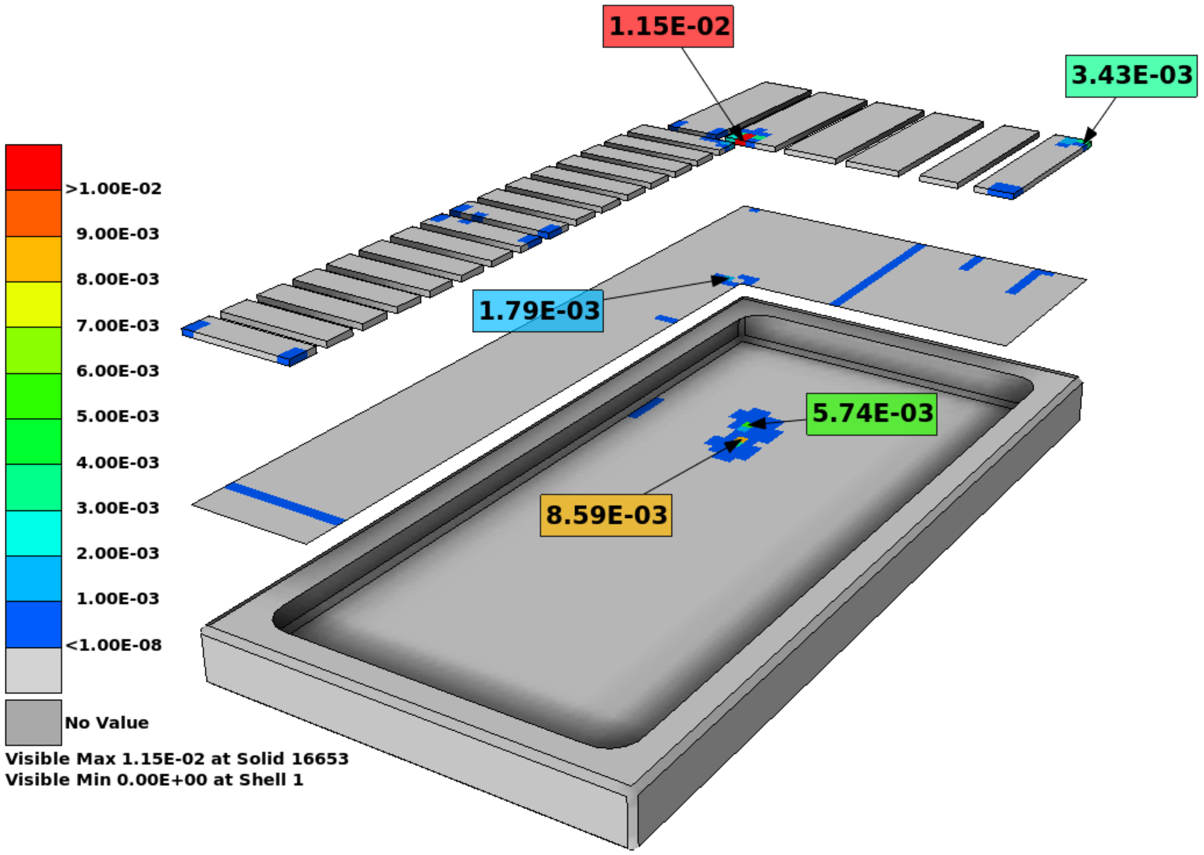
Electronic device

Random vibration fatigue results

RMS($\sigma_{e,vM}$)



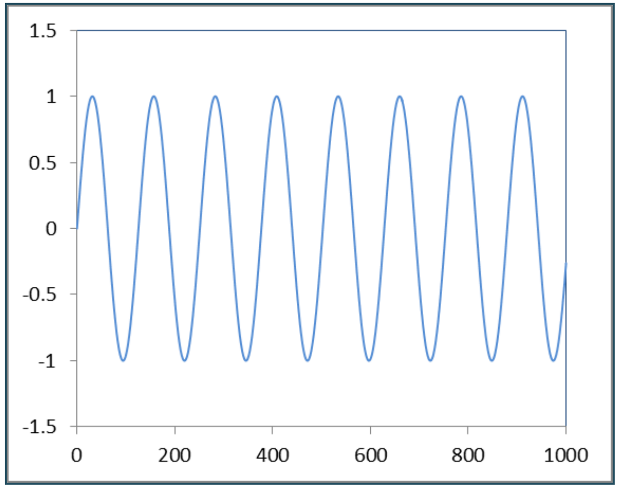
Cumulative damage ratio



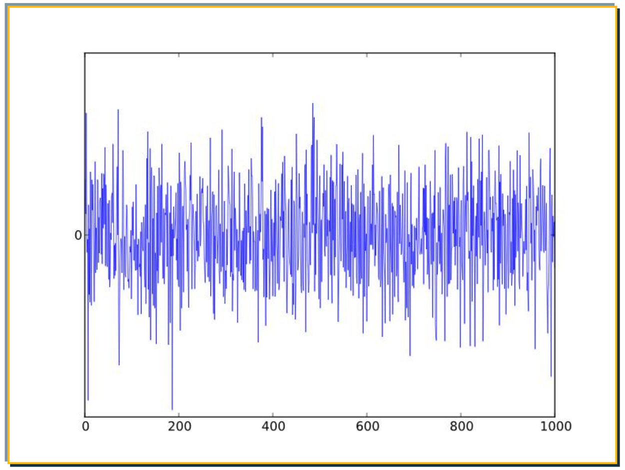
Random Vibration

Frequency domain analysis types

- Random vibration is motion which is non-deterministic
  - Vehicles riding on a rough road
  - Wind or wave loading
- The exact future behaviour cannot be predicted
- But excitation and responses can be described using a statistic or probabilistic approach
- Signals are often characterized by their Power Spectral Density (PSD)
  - A measure of the signal’s power content per frequency unit, as a function of frequency
  - Phase angle is neglected
- The Root Mean Square of a signal is the square root of the area under the PSD curve



Deterministic motion



Non-deterministic motion

Random Vibration

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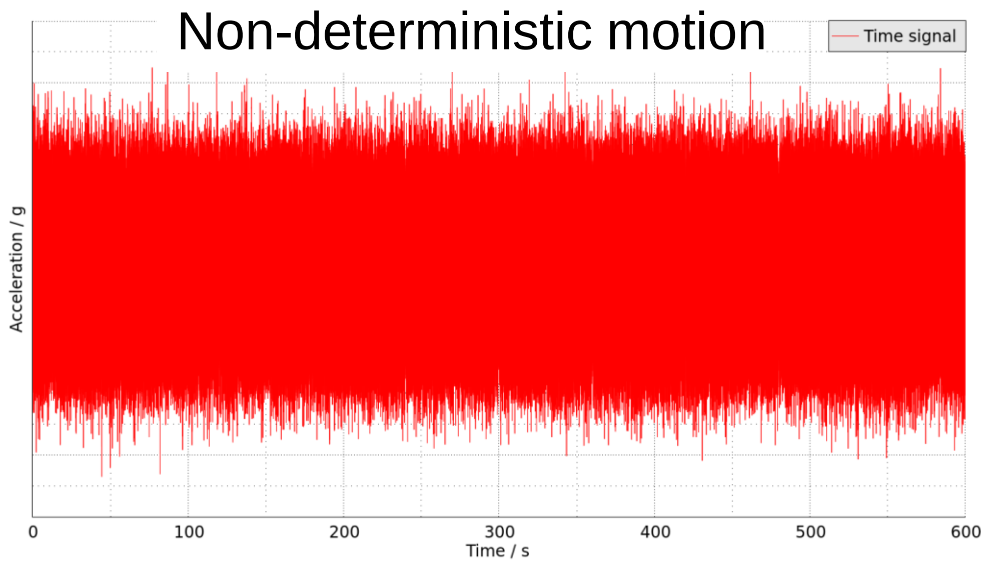
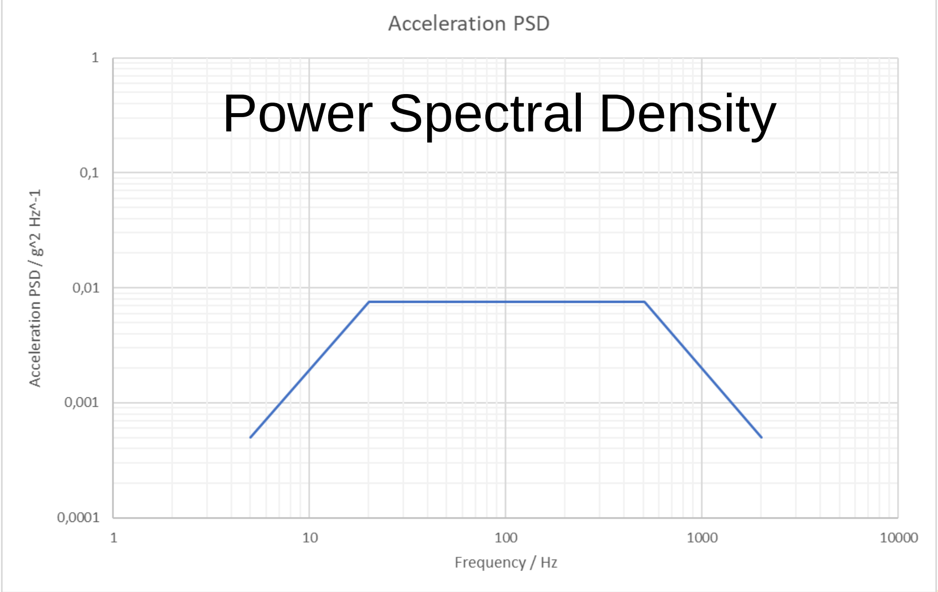
- But excitation and responses can be described using a statistic or probabilistic approach
- Signals are often characterized by their Power Spectral Density (PSD)
  - A measure of the signal's power content per frequency unit, as a function of frequency
  - Phase angle is neglected
- The Root Mean Square of a signal is the square root of the area under the PSD curve

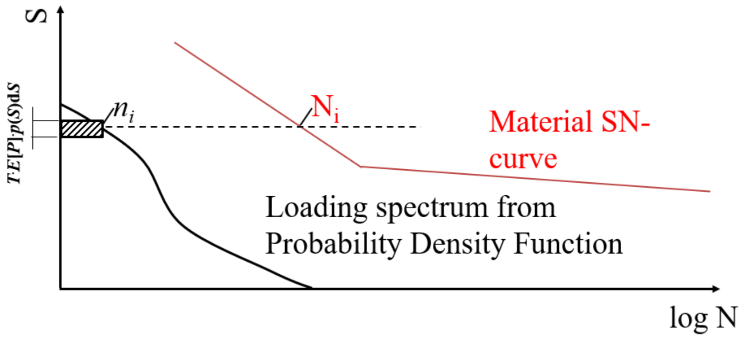


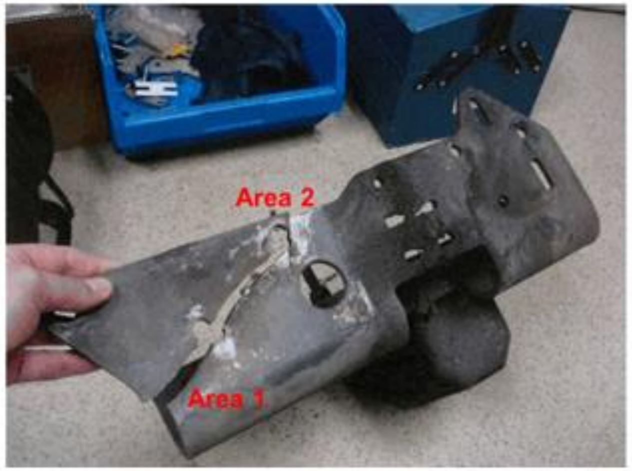


Random Vibration

Frequency domain analysis types

- LS-DYNA offers mode-based solution
- **`*FREQUENCY_DOMAIN_RANDOM_VIBRATON`**
- with optional integrated fatigue analysis
- **`*FREQUENCY_DOMAIN_RANDOM_VIBRATION_FATIGUE`**
  - Fatigue properties from `*MAT_ADD_FATIGUE`



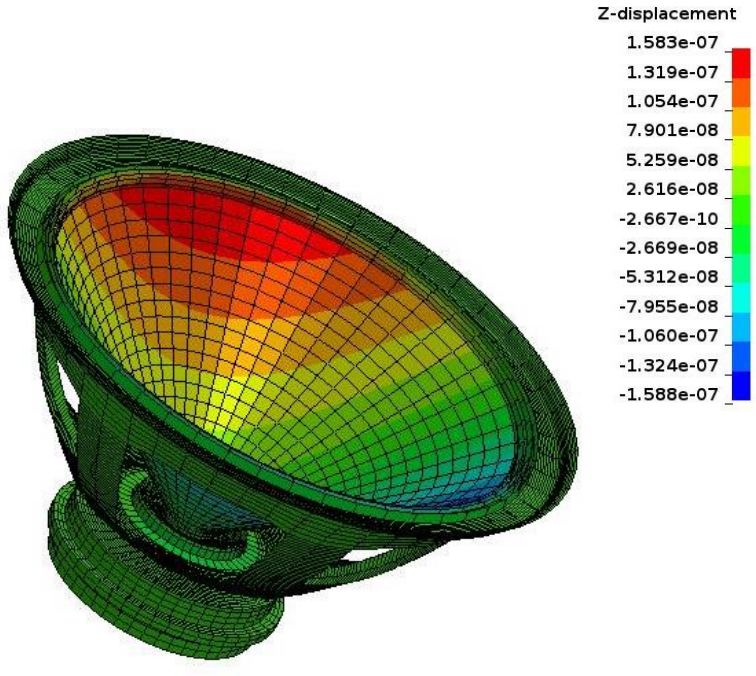


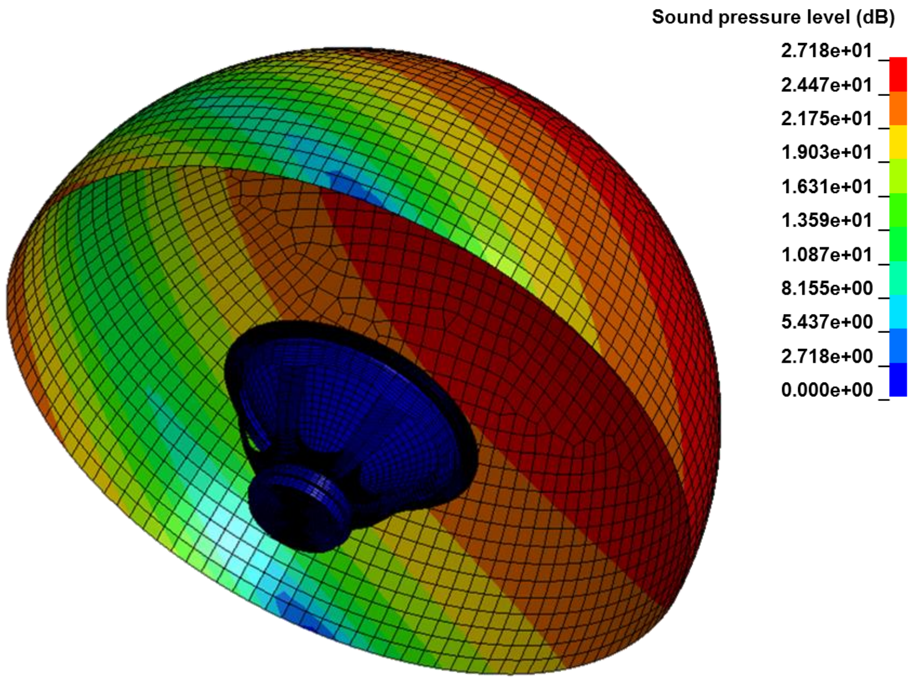
Area 2 - damage ratio = 3.45

Area 1 - damage ratio = 25.5

Frequency domain analyses

Summary of analysis types in LS-DYNA





Frequency Response Function

Frequency domain analysis types

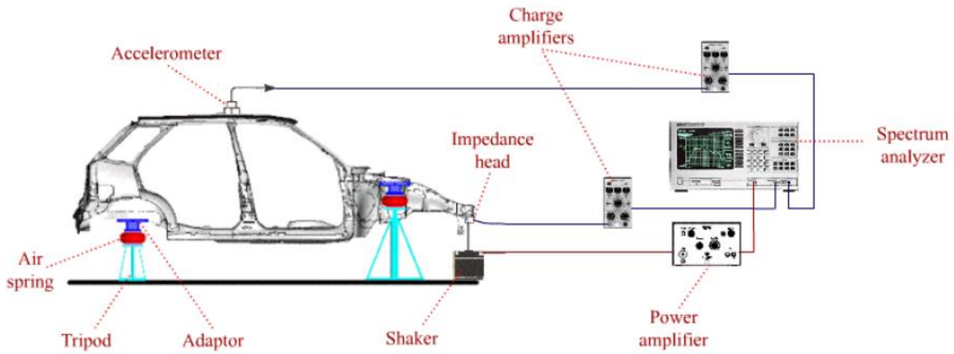
- Determine the transfer function of a system, from excitation to response, as a function of frequency

Load → Transfer function H(ω) → Response

F(ω) X(ω)

$$H(\omega) = \frac{X(\omega)}{F(\omega)}$$

- Similar to experimental modal analysis (Impact hammer)
- Can be used for
  - Load identification analysis
  - Energy transfer path analysis
  - Mode management – separate system eigenmodes from source input
  - Provide guidance for experimental set-up
  - Help interpret experimental findings



Frequency Response Function

Frequency domain analysis types

- LS-DYNA offers mode-based solution
- ***FREQUENCY_DOMAIN_FRF**
- Including pre-defined unit loading

Accelerance, Inertance	$\frac{\text{Acceleration}}{\text{Force}}$
Effective Mass, Apparent Mass, Dynamic Mass	$\frac{\text{Force}}{\text{Acceleration}}$
Mobility	$\frac{\text{Velocity}}{\text{Force}}$
Impedance	$\frac{\text{Force}}{\text{Velocity}}$
Dynamic Compliance, Admittance, Receptance	$\frac{\text{Displacement}}{\text{Force}}$
Dynamic Stiffness	$\frac{\text{Force}}{\text{Displacement}}$

Frequency domain analyses in LS-DYNA

Keywords and functionality

- Frequency domain analyses are always linear in LS-DYNA
- The keywords are
- ***FREQUENCY_DOMAIN_...**
- for selecting
  - analysis type
  - eigenmodes (or direct solution)
- and
  - specifying damping
  - excitations
  - ...

- The LS-DYNA keywords are
- ***DATABASE_FREQUENCY_{BINARY/ASCII}_...**
- for specifying
  - Output requests, and
  - Which frequencies to be analysed

Summary of keywords

Frequency domain analysis types

- Frequency response function
- Steady state dynamics
- Random vibrations
- FEM Acoustics
- BEM Acoustics
- Response spectrum analysis
- Binary database for 3D - visualization
- ASCII database for 2D (curve plotting)

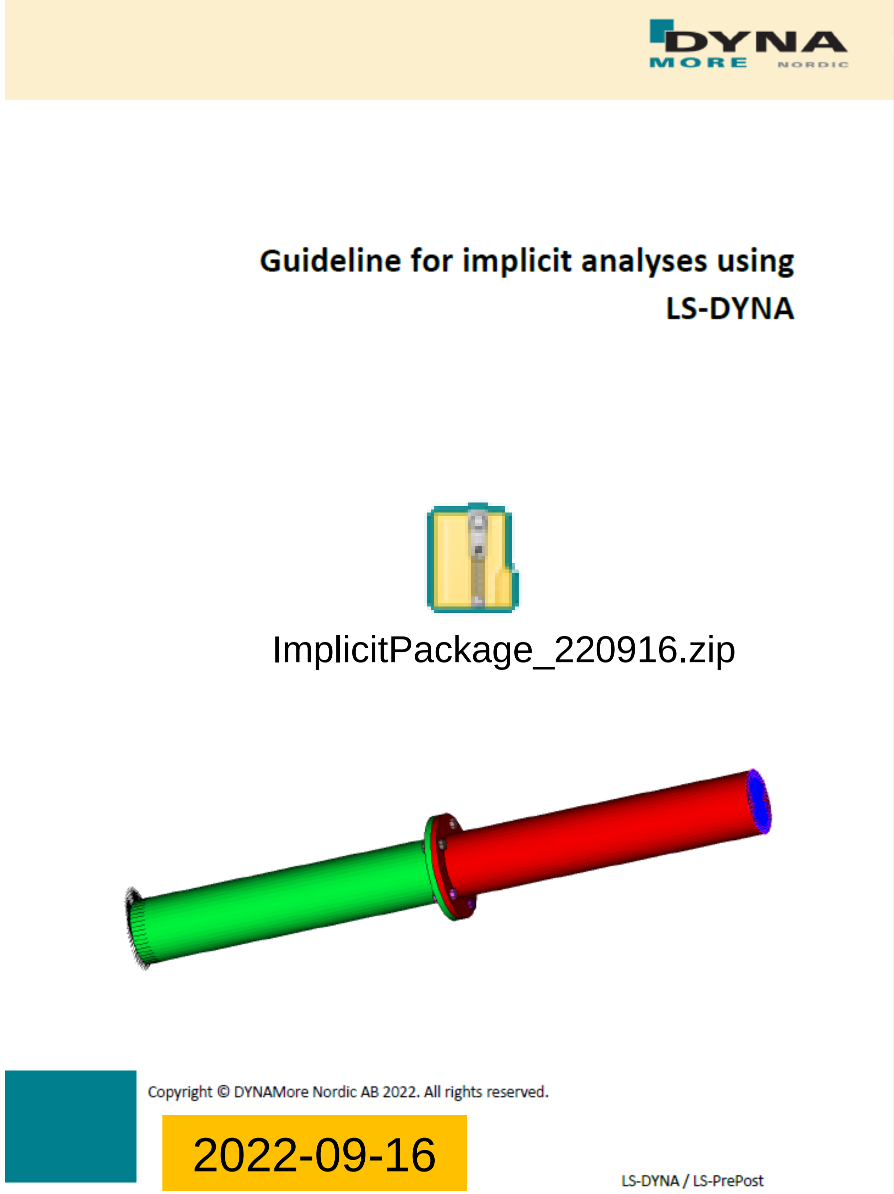
- **`*FREQUENCY_DOMAIN_FRF`**
- **`*FREQUENCY_DOMAIN_SSD`**
- **`*FREQUENCY_DOMAIN_RANDOM_VIBRATION`**
- **`*FREQUENCY_DOMAIN_ACOUSTIC_FEM`**
- **`*FREQUENCY_DOMAIN_ACOUSTIC_BEM`**
- **`*FREQUENCY_DOMAIN_RESPONSE_SPECTRUM`**
- **`*DATABASE_FREQUENCY_BINARY_...`**
- **`*DATABASE_FREQUENCY_ASCII_...`**

Model setup

Workflow for frequency domain analyses

Guideline for implicit analyses in LS-DYNA

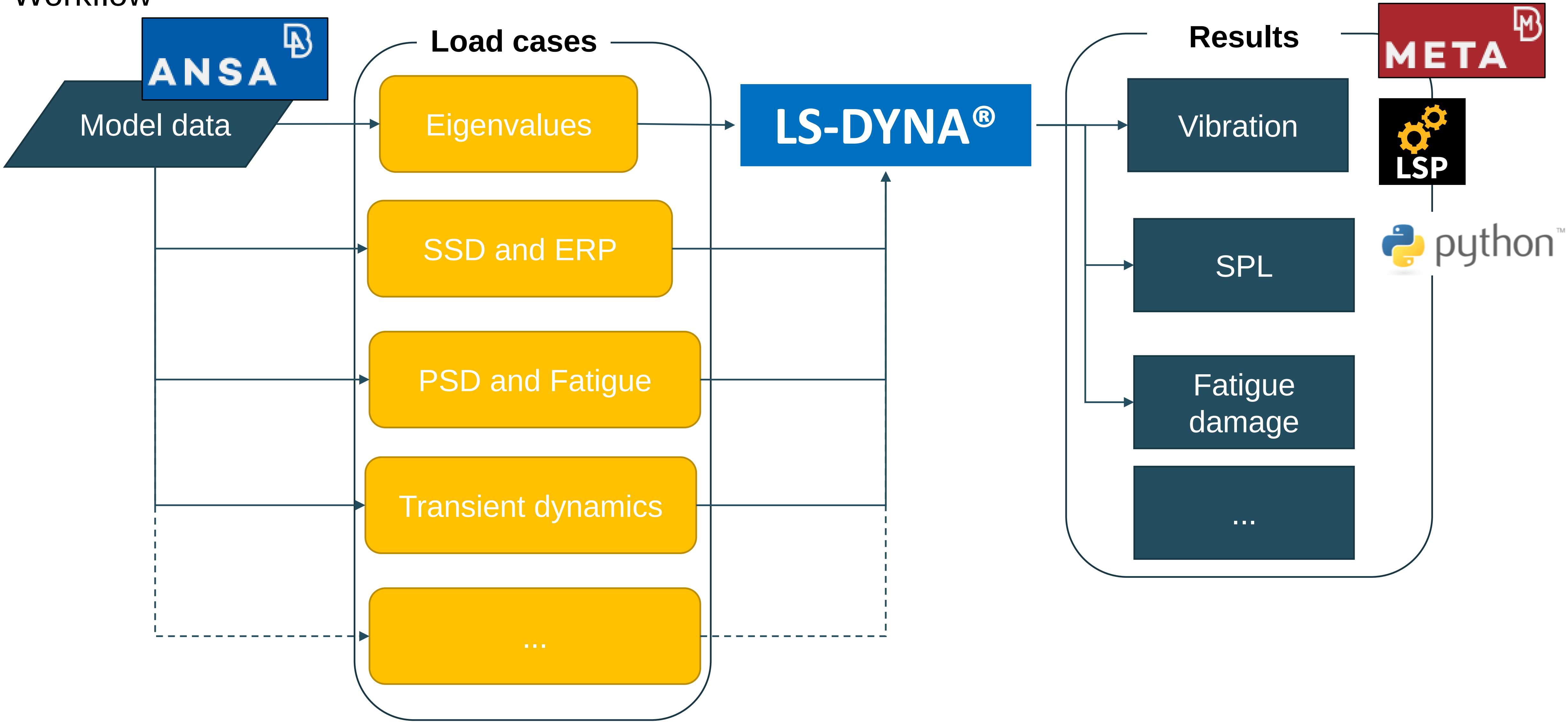
- 1 Background
- 2 Overview
- 3 LS-DYNA database cards for different analysis types
- 4 Set-up of some common implicit analysis types
  - 4.1 Linear static analysis
  - 4.2 Non-linear static analysis
  - 4.3 Linear buckling analysis
  - 4.4 Non-linear analysis using the arc-length method
  - 4.5 Eigenfrequency analysis
  - 4.6 Linear transient modal dynamic analysis
  - 4.7 Frequency domain analyses
  - 4.8 Non-linear implicit dynamic analysis
  - 4.9 Rotational dynamics
  - 4.10 Thermal analyses
- 5 Element types
- 6 Contacts for implicit analyses
- 7 Material models
- 8 Loads and boundary conditions
- 9 Other implicit analysis types
- 10 Modifications of control card settings
- 19 Appendix G: Some comments on control card settings



- Help for getting started with LS-DYNA Implicit
  - Reference guide in everyday work
- How to set up common analysis types
  - Including frequency domain analyses
- Recommended element types, contacts etc.
- Small example models
- Recommended control cards prepared in keyword files for direct use via `*INCLUDE`

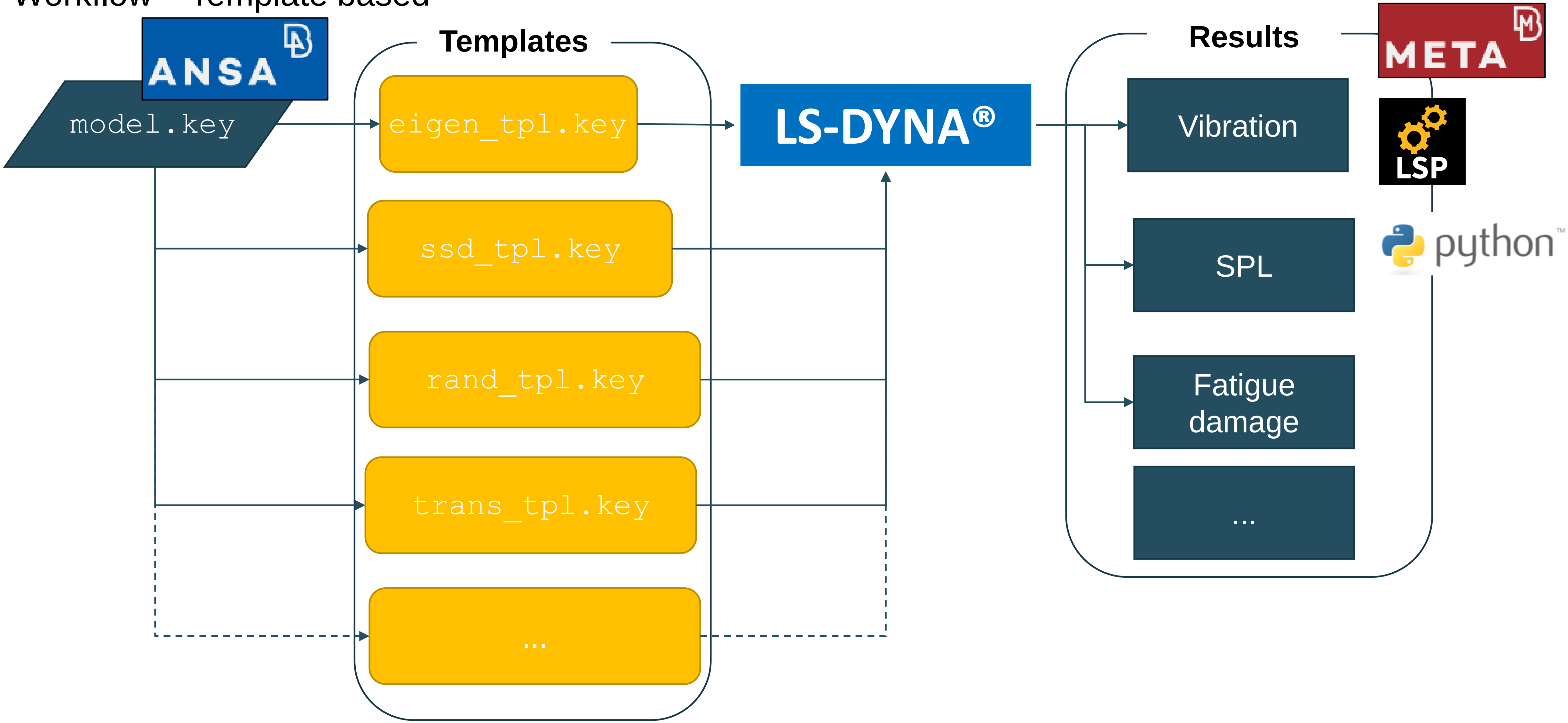
Frequency domain analyses in LS-DYNA

Workflow



Frequency domain analyses in LS-DYNA

Workflow – Template based



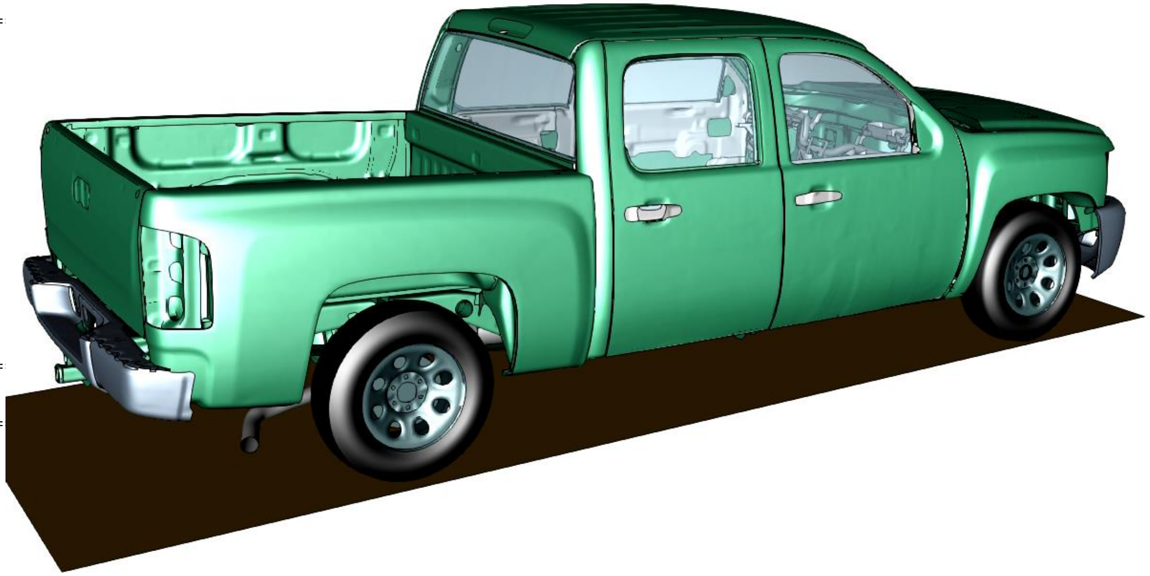
LS-DYNA for frequency domain analyses

Template based workflow – modal analysis

model.key → eig_template.key → LS-DYNA® → Eigenmodes → Modal report / Model check

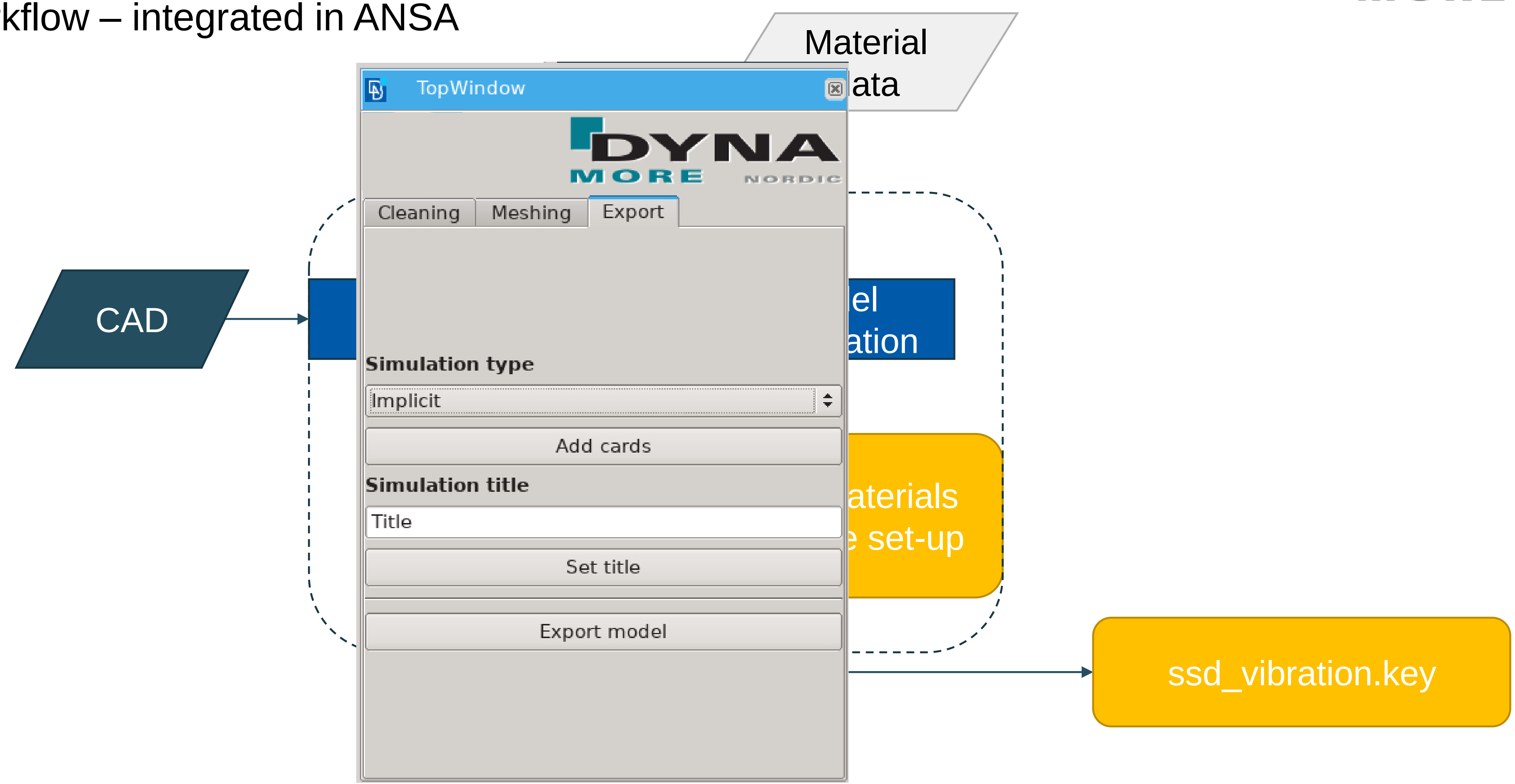
META

```
KEYWORD
$===============================================================================
$ Geometry
$===============================================================================
*INCLUDE
model.key
*INCLUDE
materials.key
$===============================================================================
$ Control and output cards
$======================================================================
*INCLUDE
control_cards_linear.key
*INCLUDE
database_cards_static.key
*CONTROL_TERMINATION
$    ENDTIM    ENDCYC     DTMIN    ENDENG    ENDMAS
        1.
*CONTROL_IMPLICIT_EIGENVALUE
       100
                                                 1
*CONTROL_MPP_IO_NODUMP
$======================================================================
$ Contacts
$======================================================================
*CONTACT_TIED_SHELL_EDGE_TO_SURFACE_CONSTRAINED_OFFSET_ID
2010      Global tie contact
       101       102         4         2
```



LS-DYNA for frequency domain analyses

Workflow – integrated in ANSA



Postprocessing in META

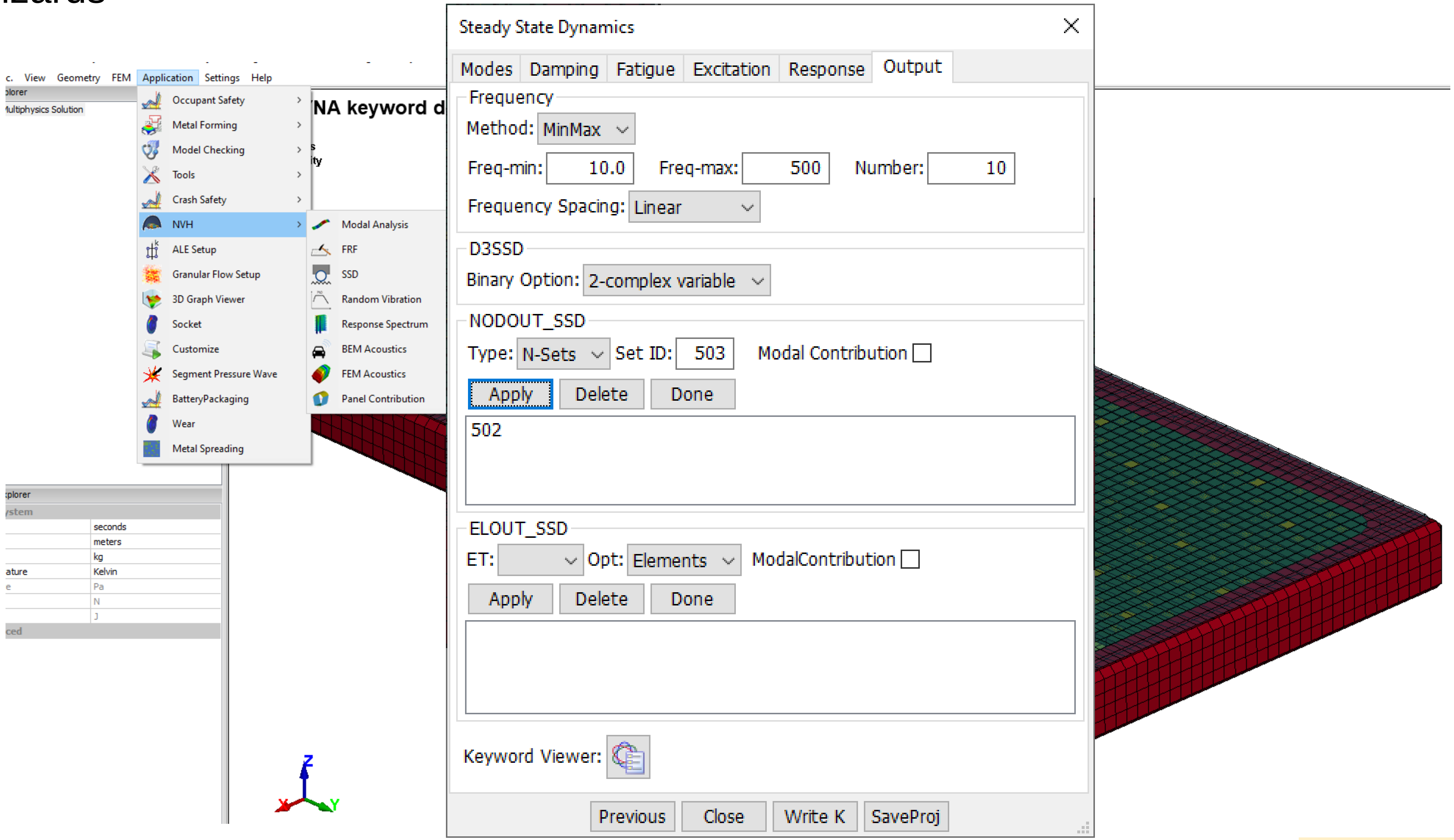
3D results from `*FREQUENCY_DOMAIN_...`

Database	Results	META[1] Support
d3psd	PSD of responses, random vibration analysis	Full
d3rms	RMS results, random vibration analysis	Full
d3ssd	Steady State Dynamic results (displacements, stresses, etc.)	Full
d3ftg	Fatigue analysis	Toolbar for reading available
d3acs	Acoustics results	
d3erp	Equivalent Radiated Power	
d3acp	Acoustics results	
d3eigv_ac	FE-Acoustic eigenvalues	
d3atv	Acoustic transfer vectors	
d3acc	Acoustic contribution results	

Notes: (1) Up to version 23.0. More support in coming versions

NVH Setup in LS-PrePost

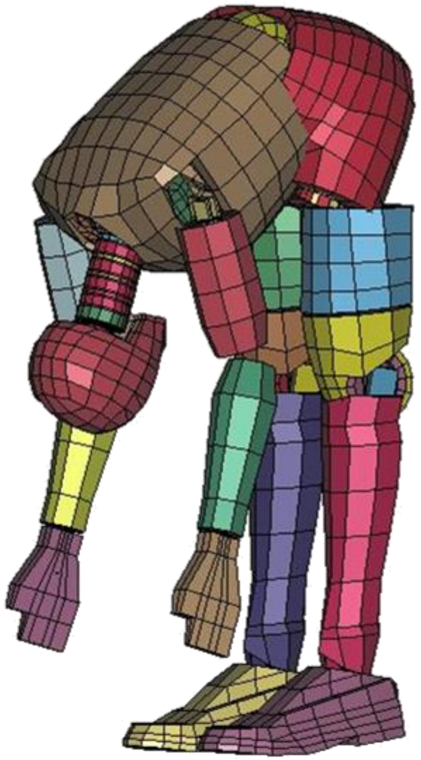
Using Wizards



Summary

- LS-DYNA provides many possibilities for linear dynamic analyses in the frequency domain
  - Vibrations
  - Acoustics
  - Fatigue
- Powerful eigensolver
  - Nonsymmetric eigenvalues
  - MCMS for many ($\gtrsim$1000) modes of big models
- Basic examples
  - www.dynaexamples.com/nvh
- Seminar: NVH & Frequency domain analyses in LS-DYNA
  - DYNAmore Nordic: A. Jonsson
  - DYNAmore Germany: Yun Huang

Thank You



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