Experimental Data for SEA Modeling and Validation

Robert Unglenieks,
Johnson Controls, Inc.

Overview

Two Tasks:

Parameter Measurement

- Damping Loss Factors,
- Modal Density (Mode Count),
- Coupling Loss Factors
- Power Inputs

Model Validation

- Reverberation Times
- Transfer Functions
- *In situ* Operation

General Guidelines

- Choose a test that focuses on your issue
- Take enough data to get good averages
- Select points for a good space average
- Never assume the data is correct
- Your intuition is a valuable tool

Direct Parameter Measurement

Useful to obtain insight in “new” systems encountered for the first time

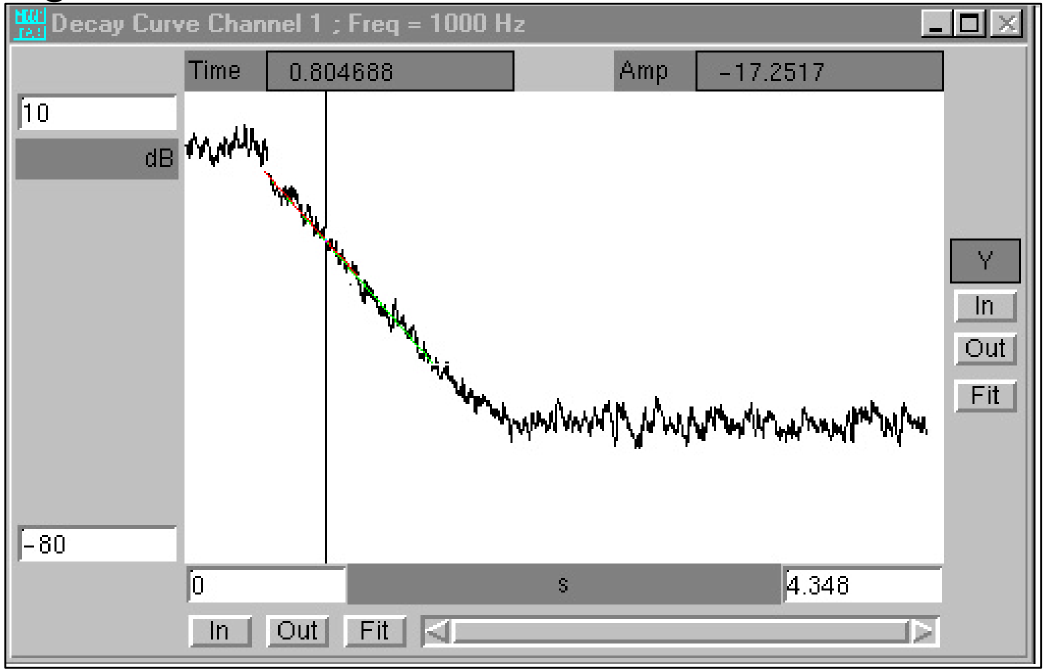
- Is this tunnel acting like a flat plate or a curved shell?
  - *Modal density*
- How much damping does the carpet add to the floor?
  - *Damping loss factor*
- Are spot welds a rigid or a simply supported connection?
  - *Coupling loss factor*
- How much sound is the engine generating?
  - *Input power*

Damping Parameter Measurement: Reverberation Time

- Most commonly used method

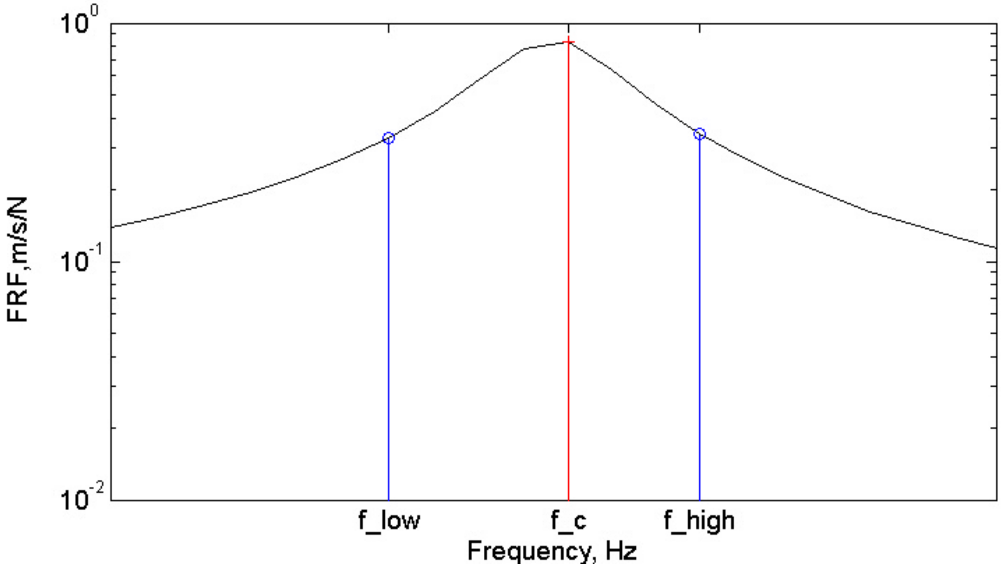
$$h = \frac{DR}{27.3\,f}$$

- Source should not act as an energy sink (absorber,damper)
- All modes should be responding approximately equal
- Be sure to average

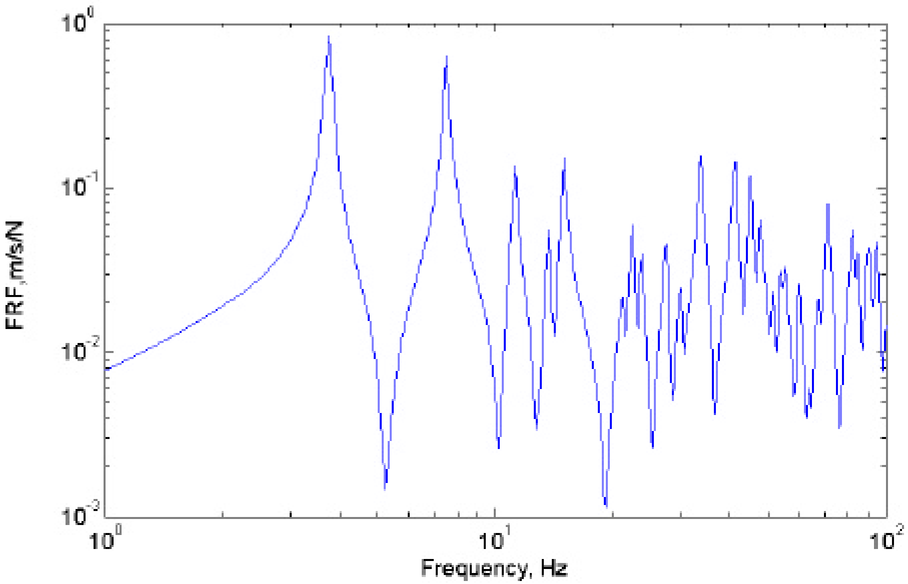


Damping Parameter Measurement: Modal Bandwidth

$$h = \frac{\Delta f}{f_c}$$



- Not a commonly used method
- Too many modes/too much overlap can be a problem
- Must be sure to excite the mode



Damping Parameter Measurement: Power Injection Method

- A commonly used method
- Usually assumes that a system of elements are weakly coupled
- Some physical properties must be known (mass, volume)

$$h = \frac{\Pi_{in}}{wE_{tot}}$$

$$E_{tot} = \frac{V\langle p^2 \rangle}{rc^2}, \quad M\langle v^2 \rangle$$

Parameter Measurement: Damping

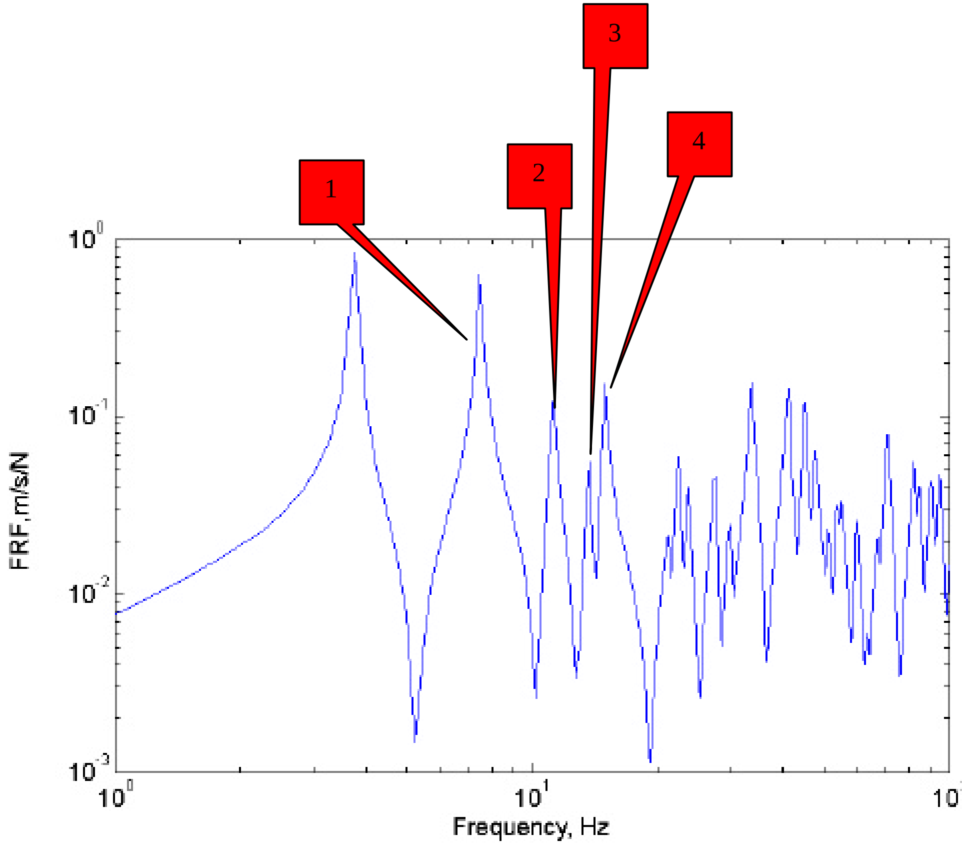
Key Points to Remember

- Measurements are actually for the total energy loss from the system, i.e., damping, boundary and coupling losses
    - *we assume damping losses >> coupling losses*
- Measurements do have a degree of variability associated with them; need to average
- Be sure that all modes are being excited equally
- Be sure that the response of all modes are being measured

Mode Count Parameter Measurement: Direct Counting

- Not a commonly used method***
- High modal overlap hides modes
- Must be sure to excite the modes enough to be counted
- Requires the modal spacing to be at least 3 times the modal bandwidth

$$\overline{df} \geq 3\frac{\eta f}{2}$$



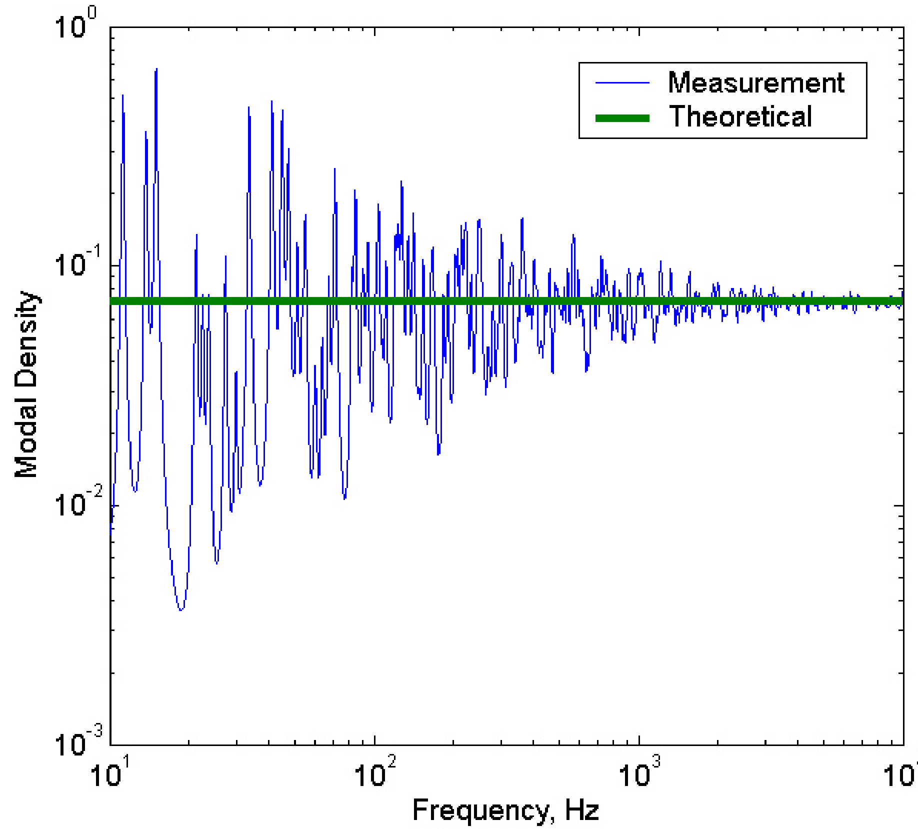
*** Can be used easily with FEA models! Find the number of modal frequencies in each frequency band.

Mode Count Parameter Measurement: Mobility Functions

For Structural Subsystems:

Conductance - *Real Part of Mobility*

$$\overline{G} = \frac{\pi n(\omega)}{2M}$$



For Acoustic Subsystems:

Resistance – *Real Part of Impedance*

$$\overline{R} = \frac{\rho c^2 \pi n(\omega)}{2V}$$

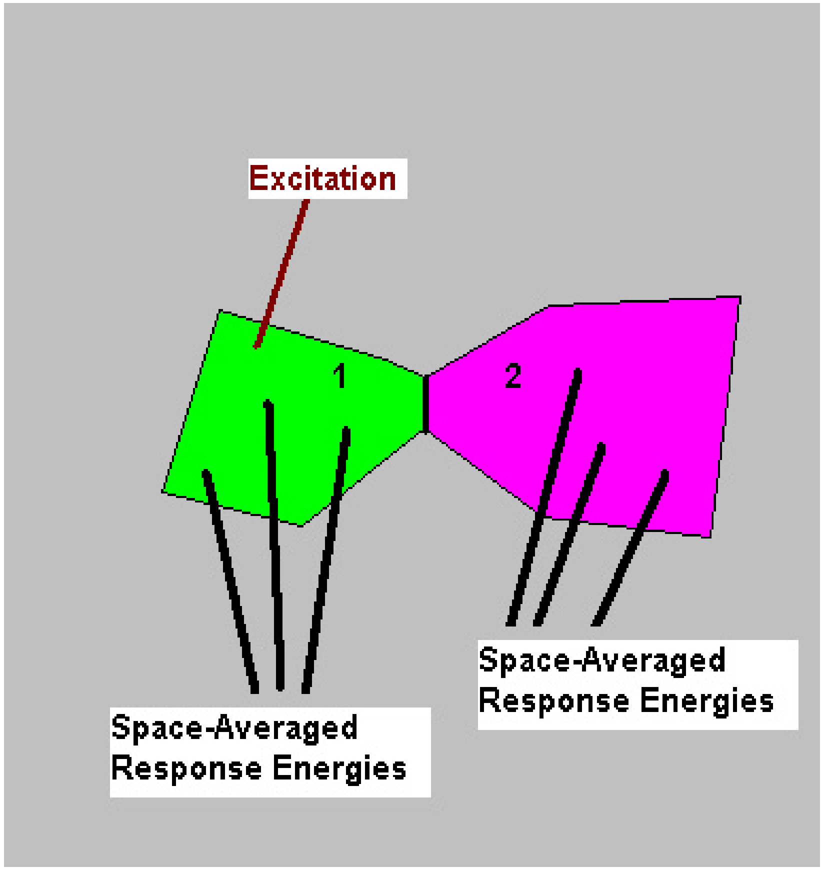
- Most commonly used method

Coupling Loss Factor Measurement: 2 Subsystems

- Apply an input(s) to a subsystem
- Measure the responses of the source and receiver
- Solve for the coupling loss factor

$$h_{12} = \frac{h_2 E_2}{E_1 - \frac{n_1(w)}{n_2(w)} E_2}$$

- Need an accurate estimate of the damping loss factor, mode counts, system parameters (mass, volume)
- For two systems this is fairly straightforward



Coupling Loss Factor Measurement*: >2 Subsystems

- Apply input(s) to most subsystems
  - *Create a matrix of power input vectors*
- Measure the responses of the subsystems
  - *Create a matrix of modal energies*
- Solve for the entire loss factor matrix

$$\begin{bmatrix} Loss \\ Factors \end{bmatrix} = [\Pi][e]^{-1}$$

Coupling Loss Factor Measurement*: >2 Subsystems

$$\begin{bmatrix} Loss \\ Factors \end{bmatrix} = [\Pi][e]^{-1}$$

- Is very sensitive to errors
  - *Measurement errors and parameter assumptions*
- Difficult to measure some of the subsystem energies and power inputs
  - *in-plane vibration*

Software to automate the collection and solution process is available

- Vibro-Acoustic Sciences
- LMS

Input Power Measurement

Direct Measurement

- Structural systems
  - impedance head (or accelerometer and force transducer)
  - structural intensity measurement (near the source but not too close)
- Acoustical systems
  - Measured with an acoustic intensity probe

A well calibrated, well executed measurement is required

Indirect Measurement

- Measure the energy in the system with the source on
- From previous measurements you can infer the power

$$h = \frac{\Pi_{in}}{wE_{tot}} \Rightarrow \Pi_{in} = wE_{tot}h$$

Parameter Measurements: Summary

Properly executed tests can be performed to obtain the modal densities, damping loss, and coupling loss factors, and power inputs

There are limitations and assumptions built into the measurements that must be understood

Model Validation

In-Vehicle Reverberation Time

Transfer Functions

- Transparency
- Ideal Noise Sources
- Transmission Loss

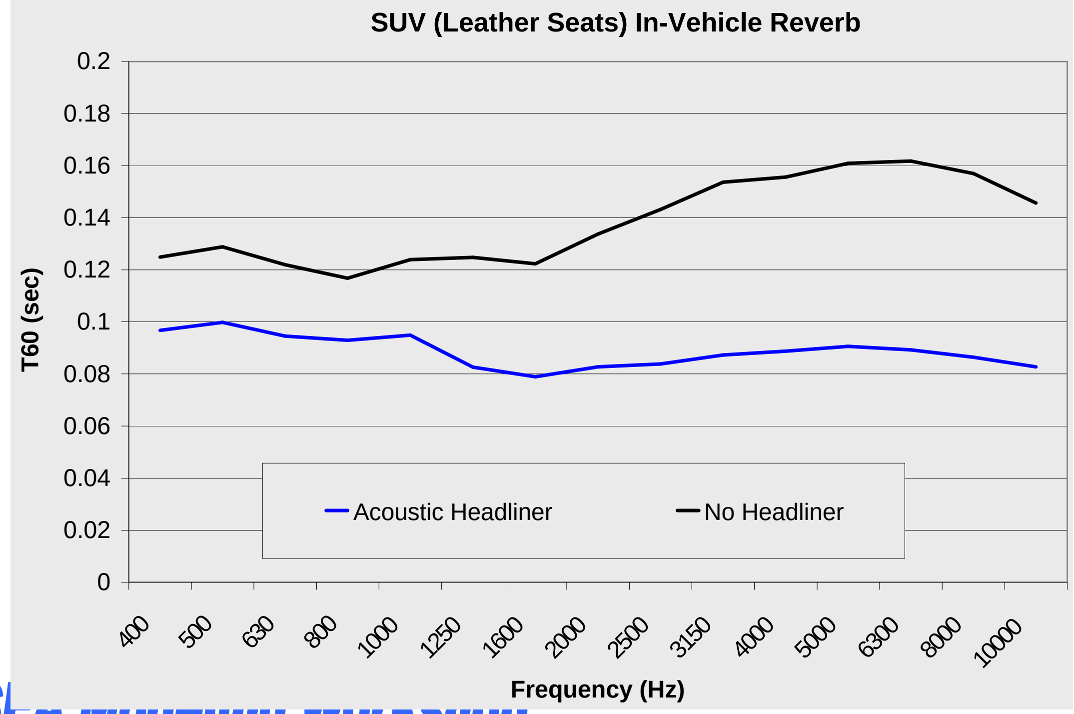
In Situ Operating Conditions

- Responses

Model Validation: In-Vehicle Reverb

Can be used to verify that the treatments applied in the model are correct

Can be used to experimentally set the damping loss factor if individual treatments cannot be measured



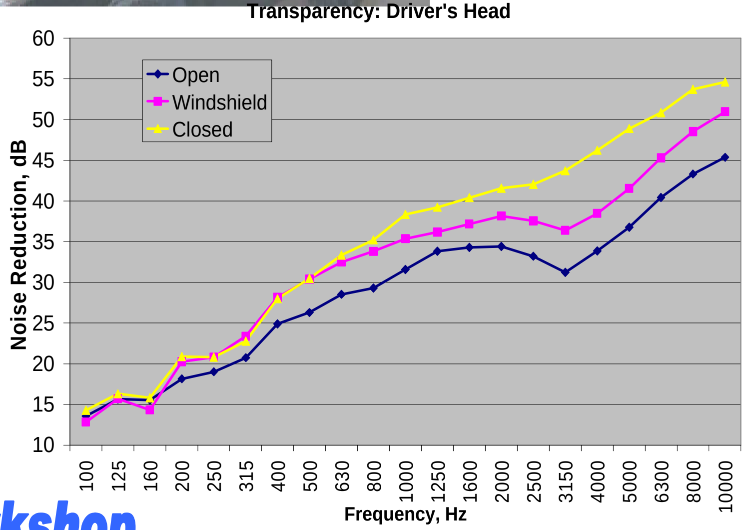
- May be difficult to avoid certain modes dominating the response, high decay rates, *etc.*

Model Validation: Transfer Functions Transparency

Vehicle is placed in a reverberation room

Exterior and interior response are measured

Various paths can be turned off with barriers, e.g., windshield



- Less ambiguity of noise source
- Easy to model
- Easy to test

Model Validation: Transfer Functions
Ideal Sources

Speakers

- Level?
- Directivity?

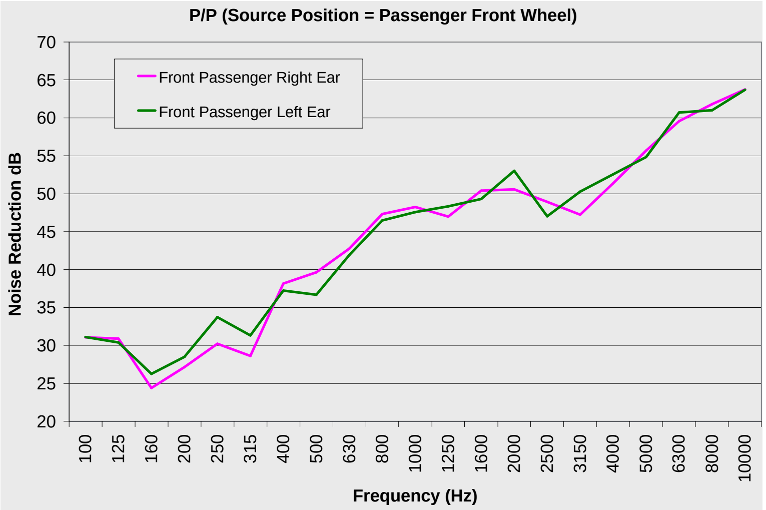
Can evaluate many different paths

Easy to test

Easy to model

- Directivity?

Pressure/Pressure



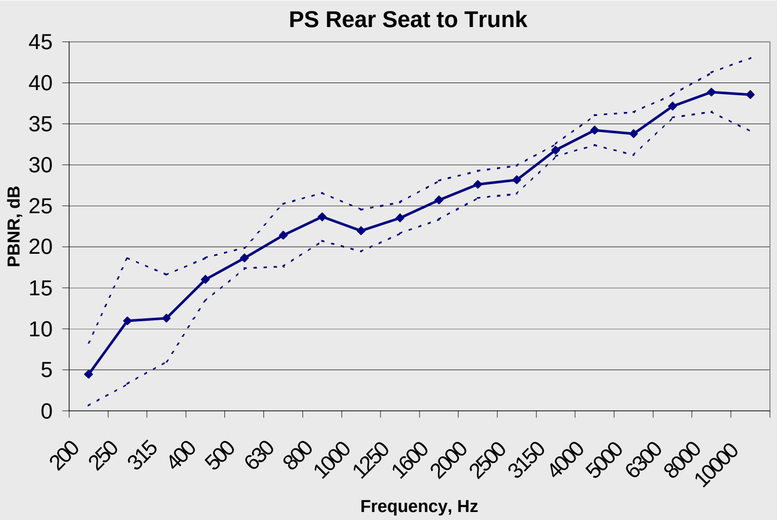
Model Validation: Transfer Functions
Ideal Sources

Pressure/Power

Point Sources

- LMS
- ISVR
- Do-it-yourself

Can evaluate many different paths

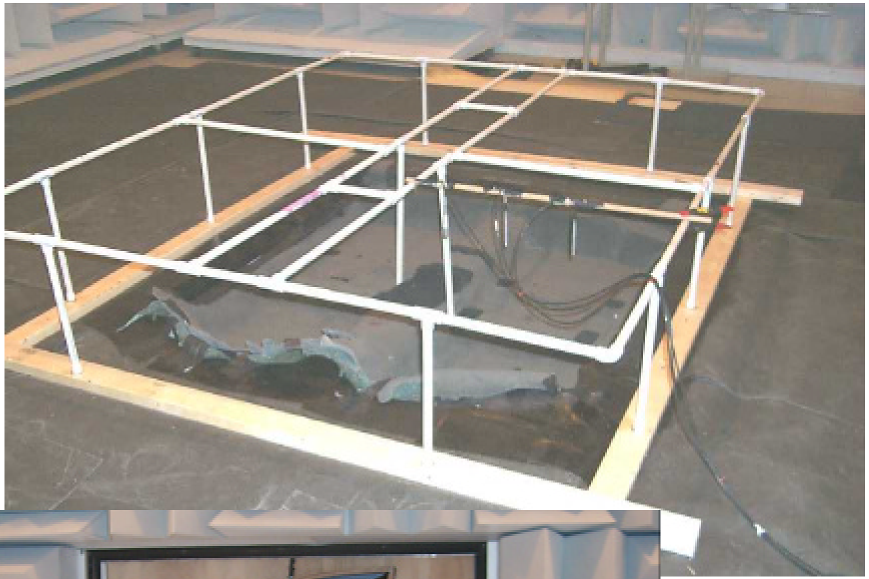


Easy to test

Easy to model

- Directivity?

Model Validation: Transmission Loss



Useful for verification of design and implementation

Easy to test

- Once it is set up

Easy to model?

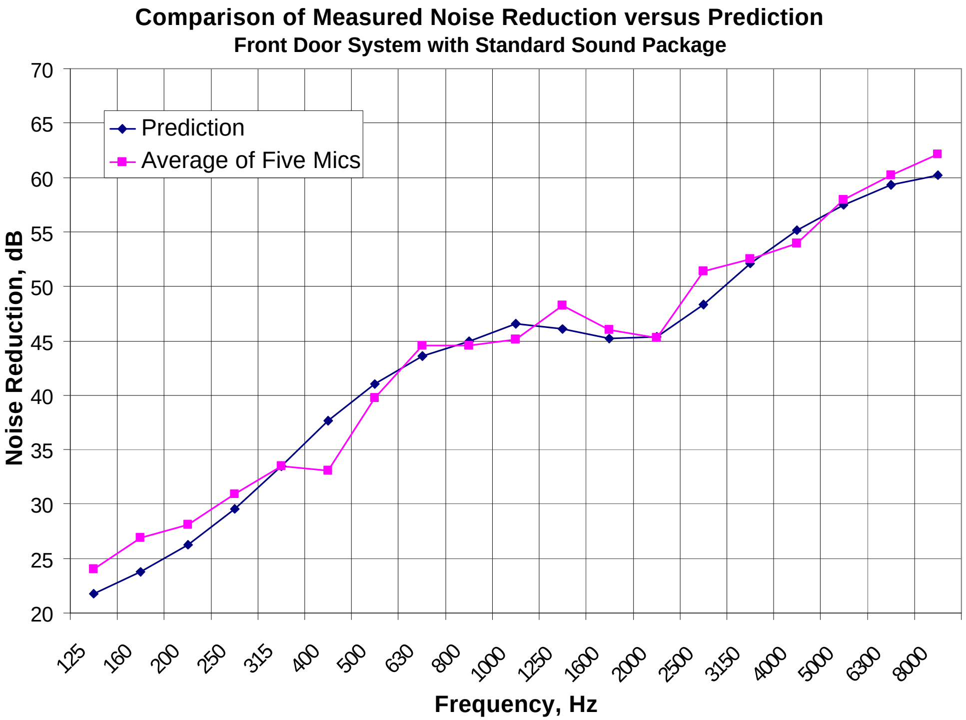
- Need to set-up the model exactly like the test
  - *Lab-to-lab differences in fixturing can make transferring results difficult*

Model Validation: Transmission Loss

Proper space-averaging is still required!

Some differences from model and test should be expected

- *Modal densities*
- *Finite-sized apertures*
- *Boundary conditions*
- *Flanking paths*



The real trick is to translate the data from the component model to the full model

Model Validation: Responses

Uses any number of loadcases

- Chassis rolls
- On-road

Responses, and sometimes sources, are measured

Can be used to estimate loadcases

<u>Most often, this is the final step!</u>

Useful References

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