Nonlinear Phase Separation Testing of an Experimental Wing-Engine Structure

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Outline

NL phase resonance & NL phase separation

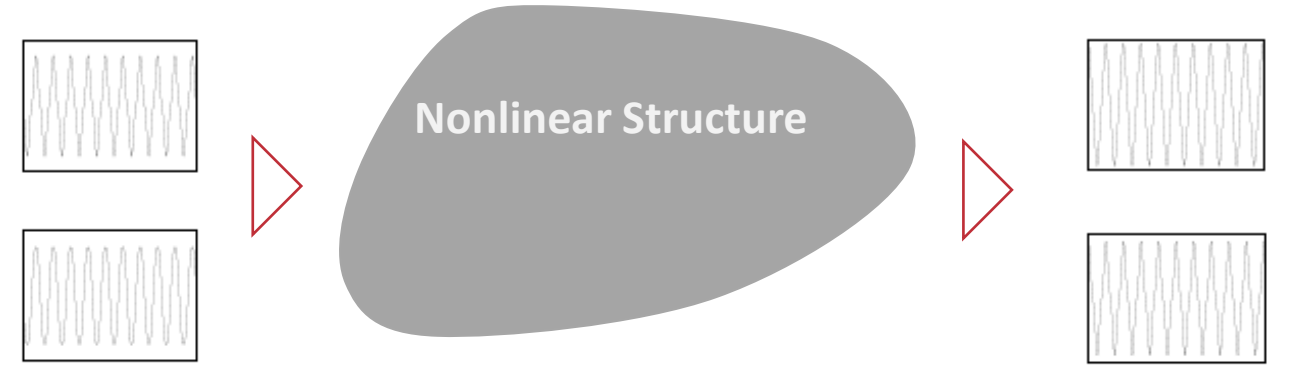
Numerical demonstration on a beam

Experimental set-up

Applied excitation

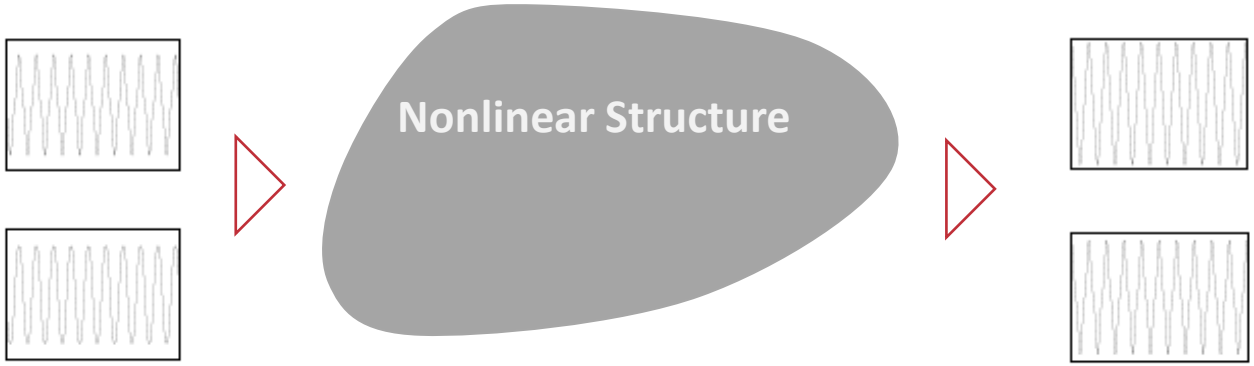
Experimentally identified NNMs

Phase Resonance for Nonlinear Systems



Harmonic input → Phase quadrature ? (90°) ← Steady-state output

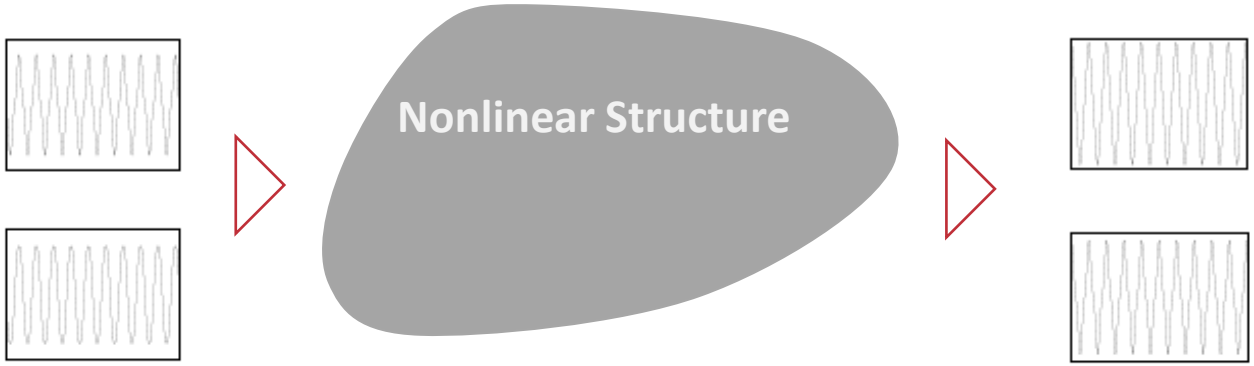
Backbone Curve Captured Through Free Response



Harmonic input → Phase quadrature ? (90°) ← Steady-state output

→ Free decay + time-freq. analysis

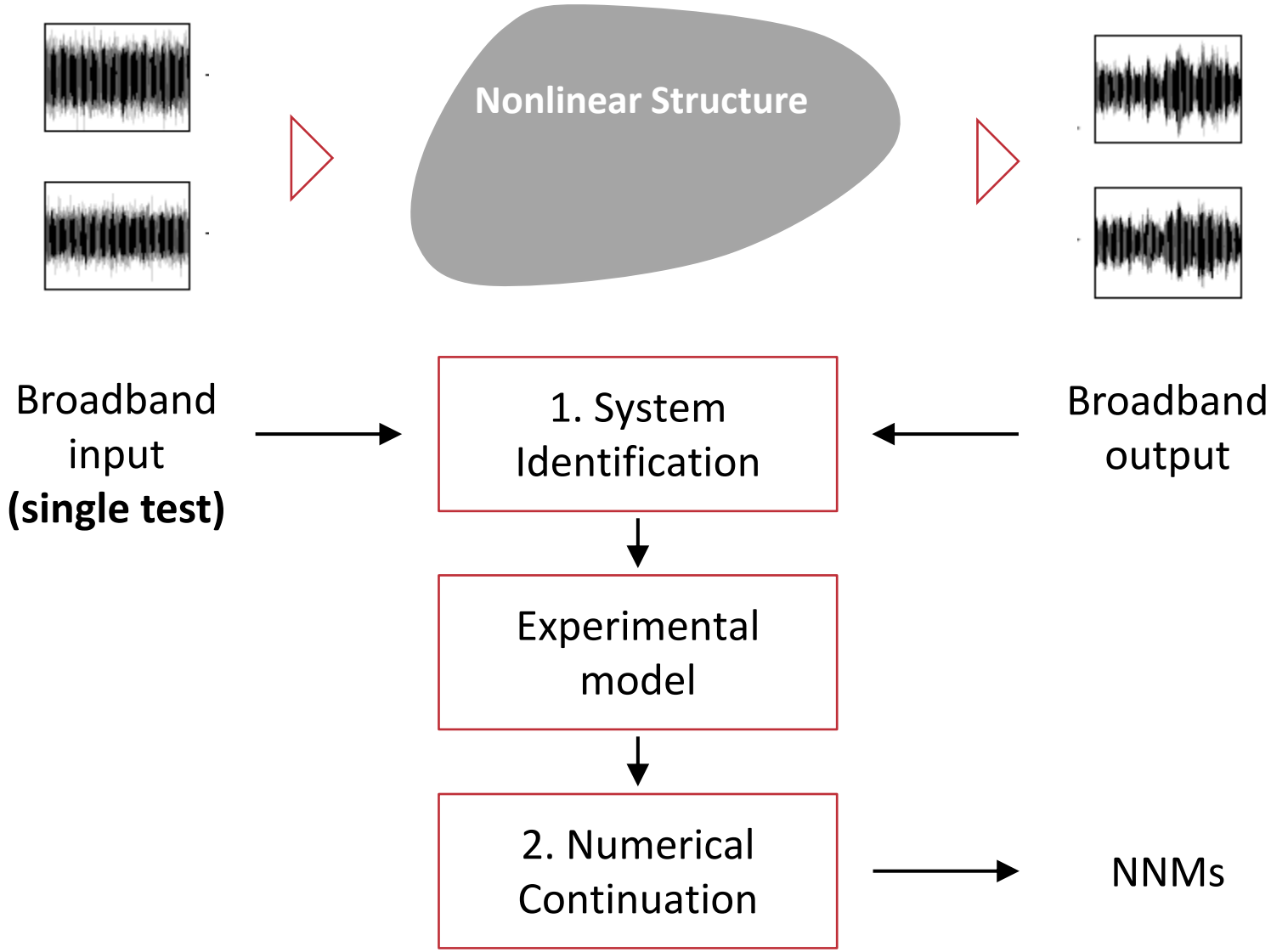
Reach & Track NNMs Using Feedback Control



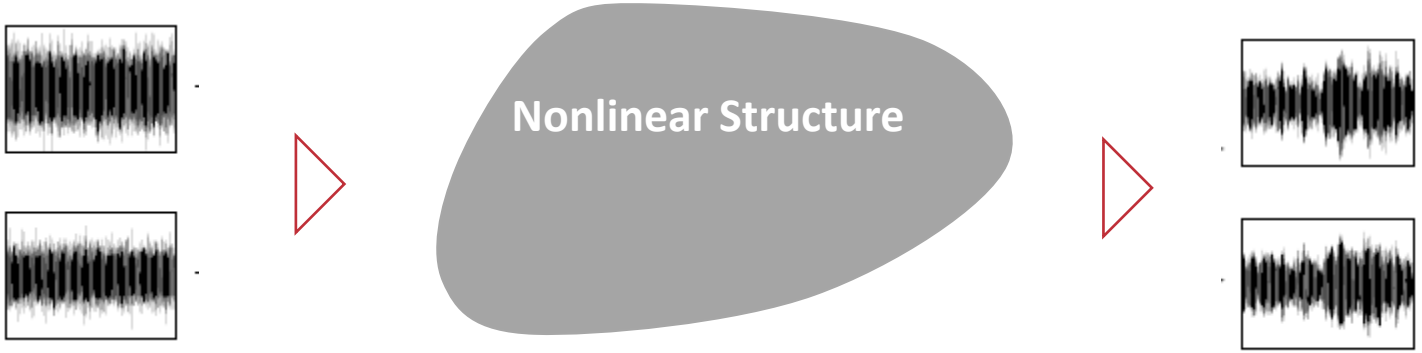
Harmonic input → Phase quadrature ? (90°) ← Steady-state output

- Free decay + time-freq. analysis
- Track for increasing excitation amplitude (Control-based continuation, Phase-locked loops)

Two-step Methodology for NL Phase Separation



Two-step Methodology for NL Phase Separation



Broadband input **(single test)**

FNSI

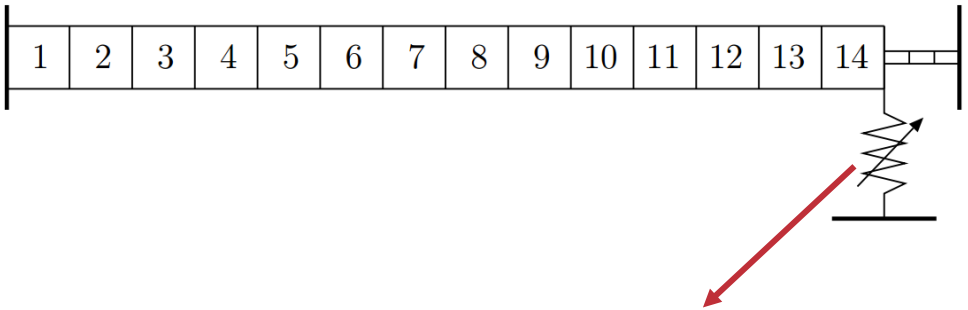
Broadband output

$$\ddot{\bar{q}} + \bar{K}\,\bar{q} + k_{nl}\,\Phi^{T}\,f_{nl}(q) = 0$$

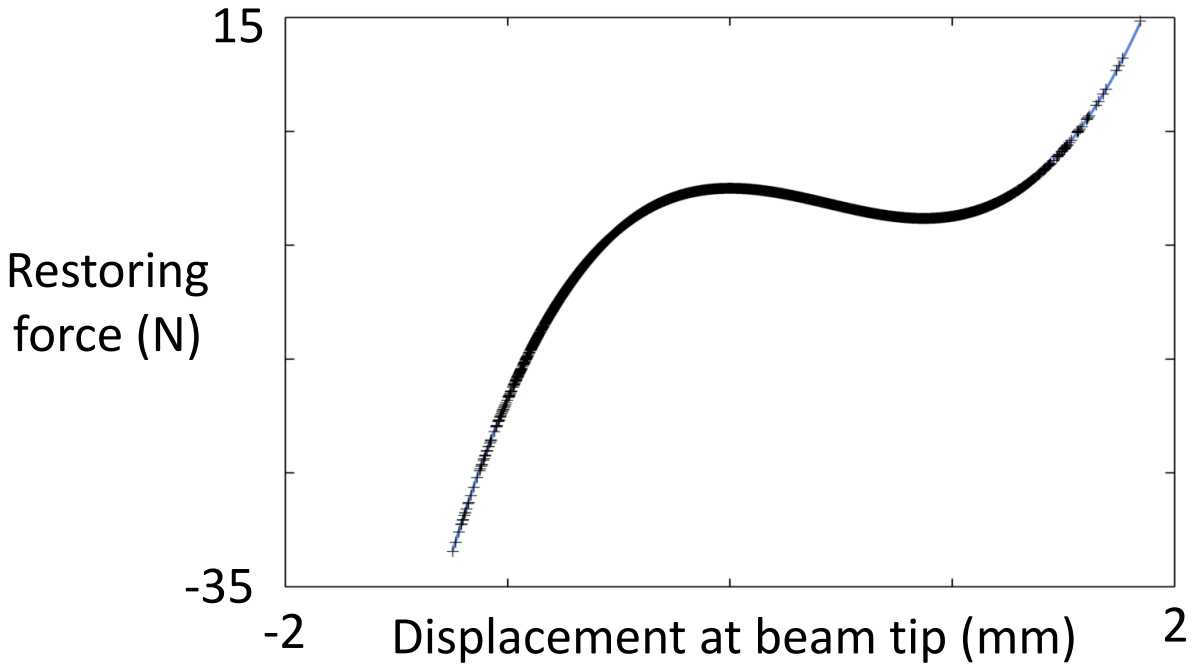
Shooting + pseudo-arclength cont.

NNMs

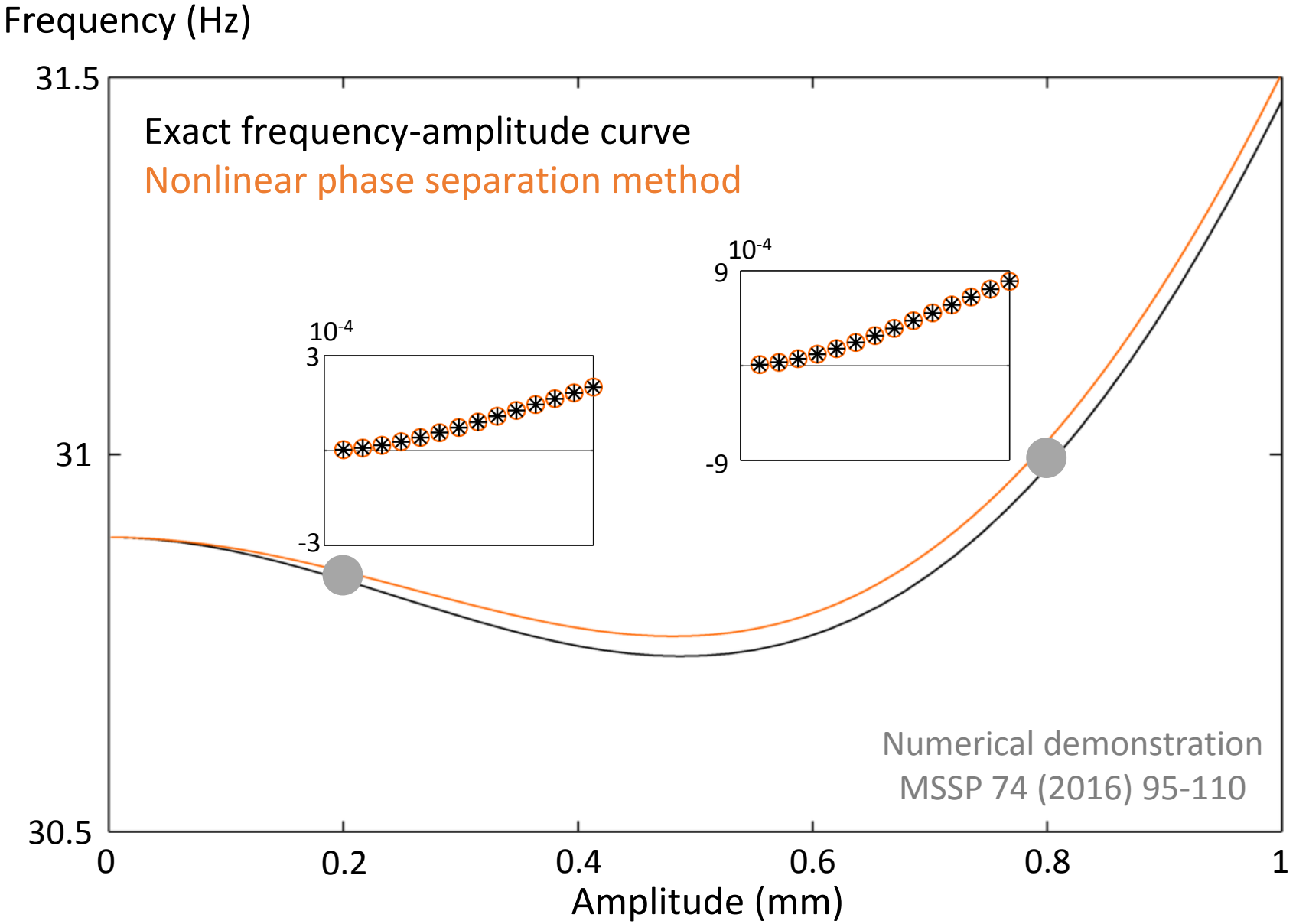
Numerical Demonstration on a Beam with NL Spring



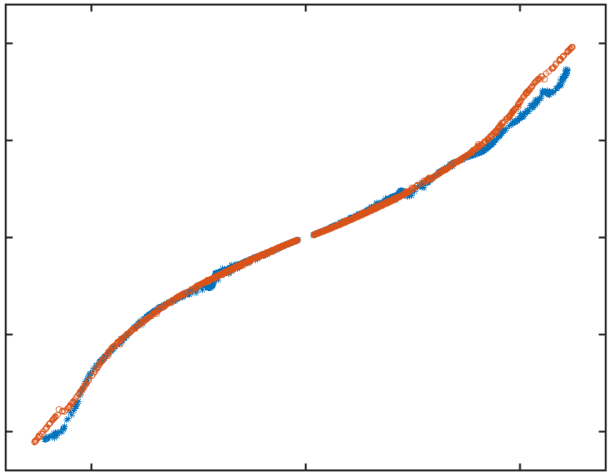
Softening-hardening



Exact and Identified NNMs Match Very Well



Exp. Demonstration on a Wing-Engine Structure



Smooth stiffness nonlinearities

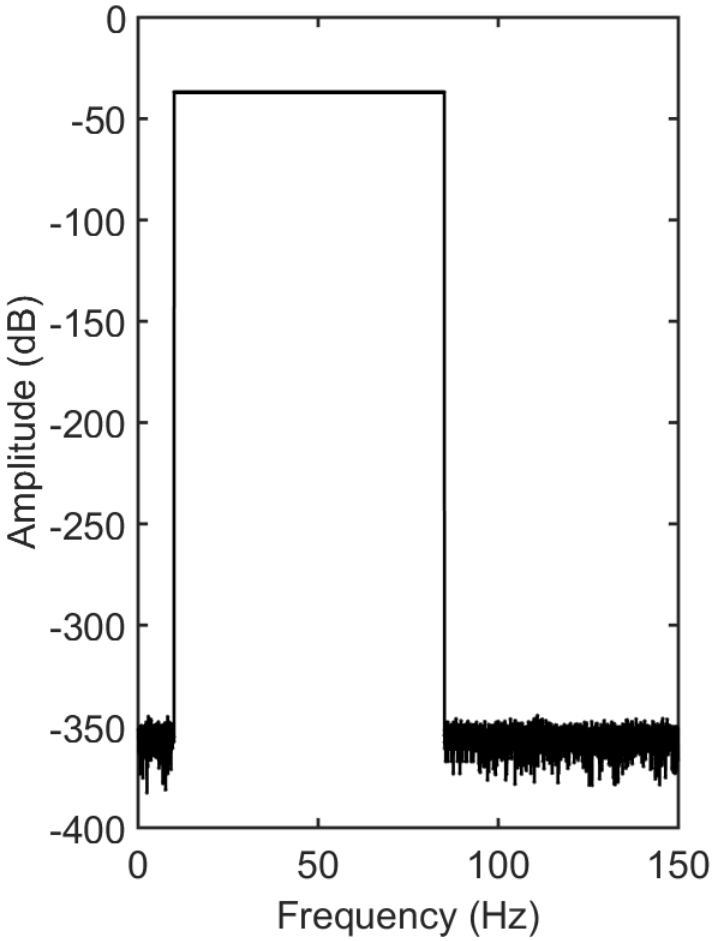
Identification carried out with quadratic + cubic

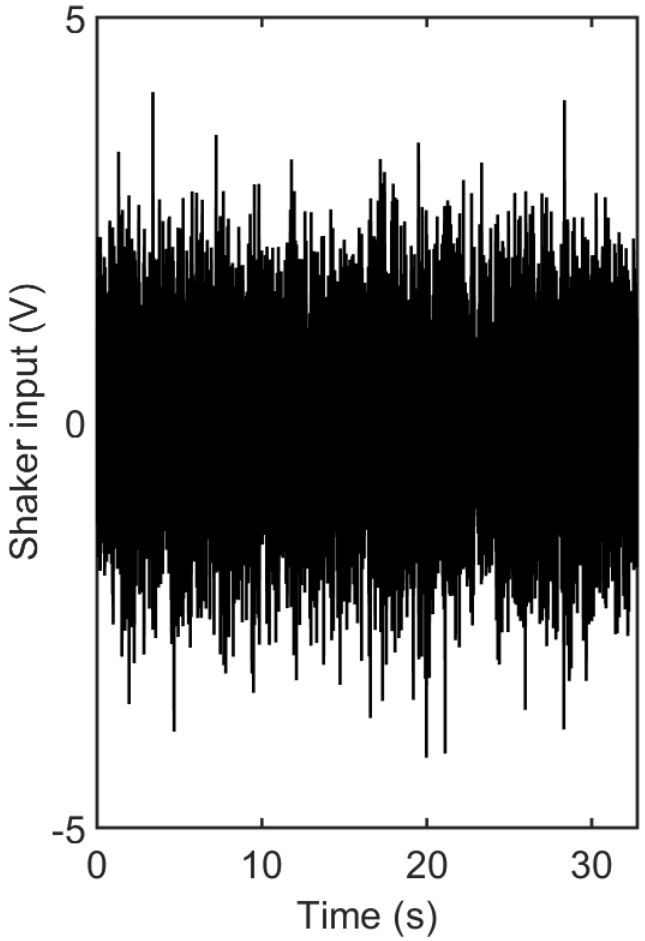
Limited Excitation of the Nonlinearities Using Broadband

$$u(t) = \sum_{k=1}^{F} A_k \cos(2\pi f_k t + \varphi_k)$$

uniform

random

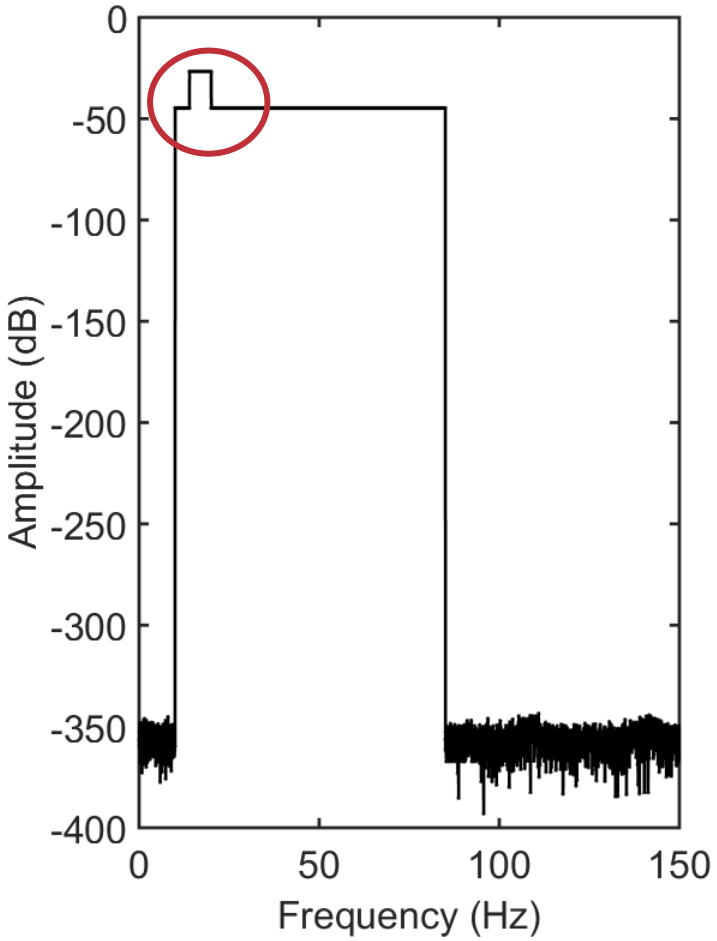


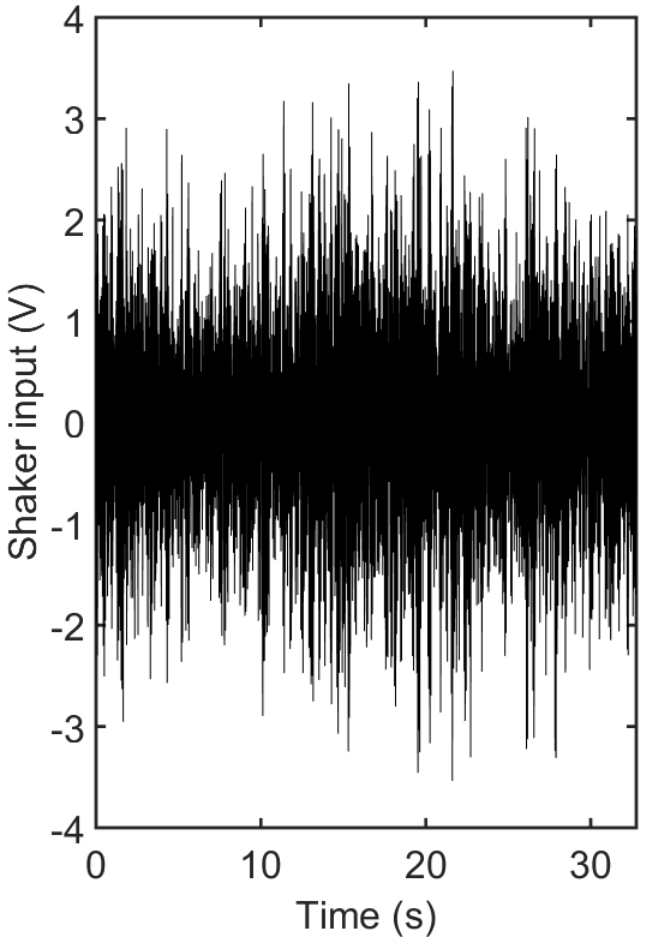


Crest factor ≈ 4

Large Crest Factor Signals are Difficult to Realise Exp.

Increase spectrum amplitude (x8) around NL modes

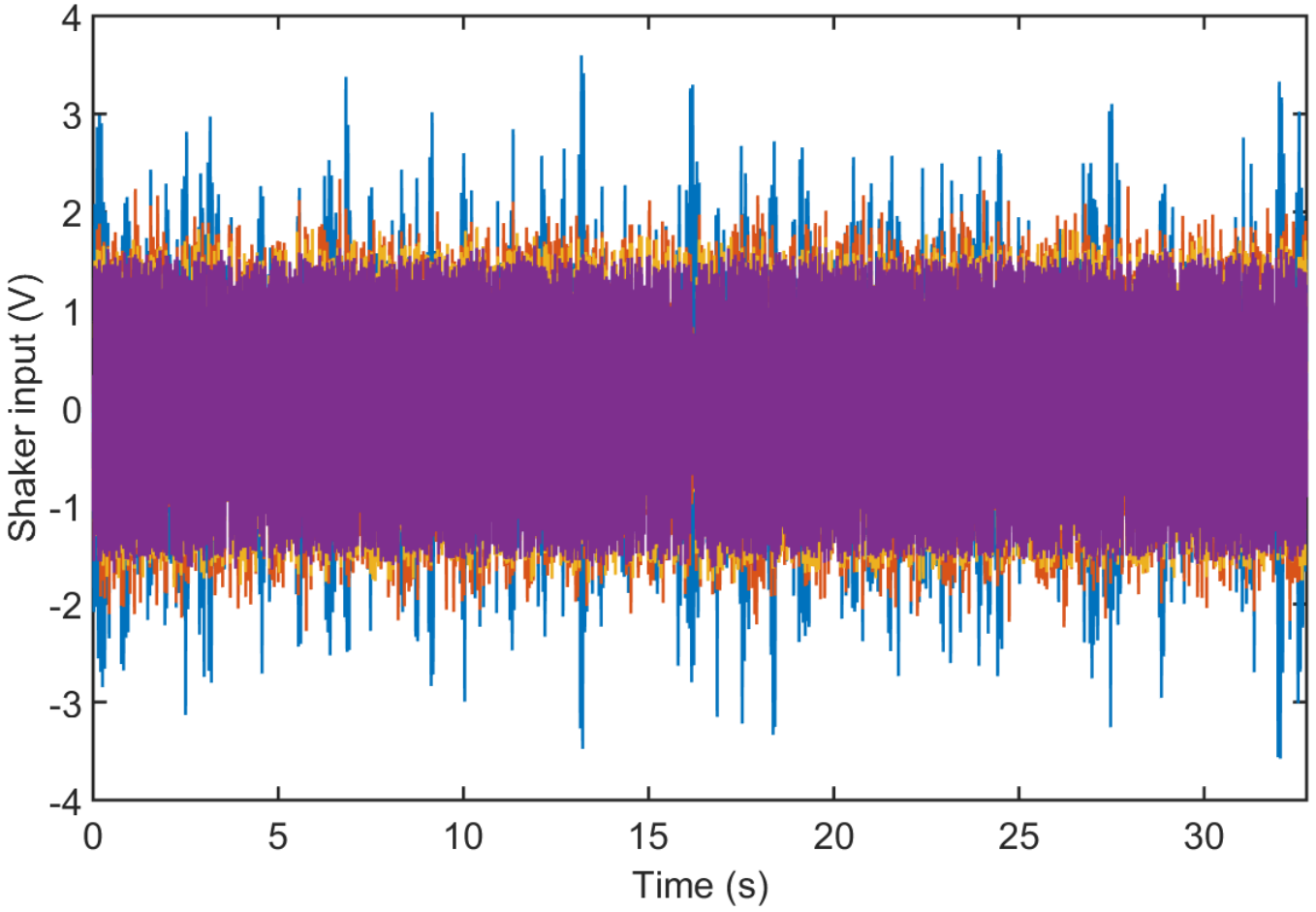




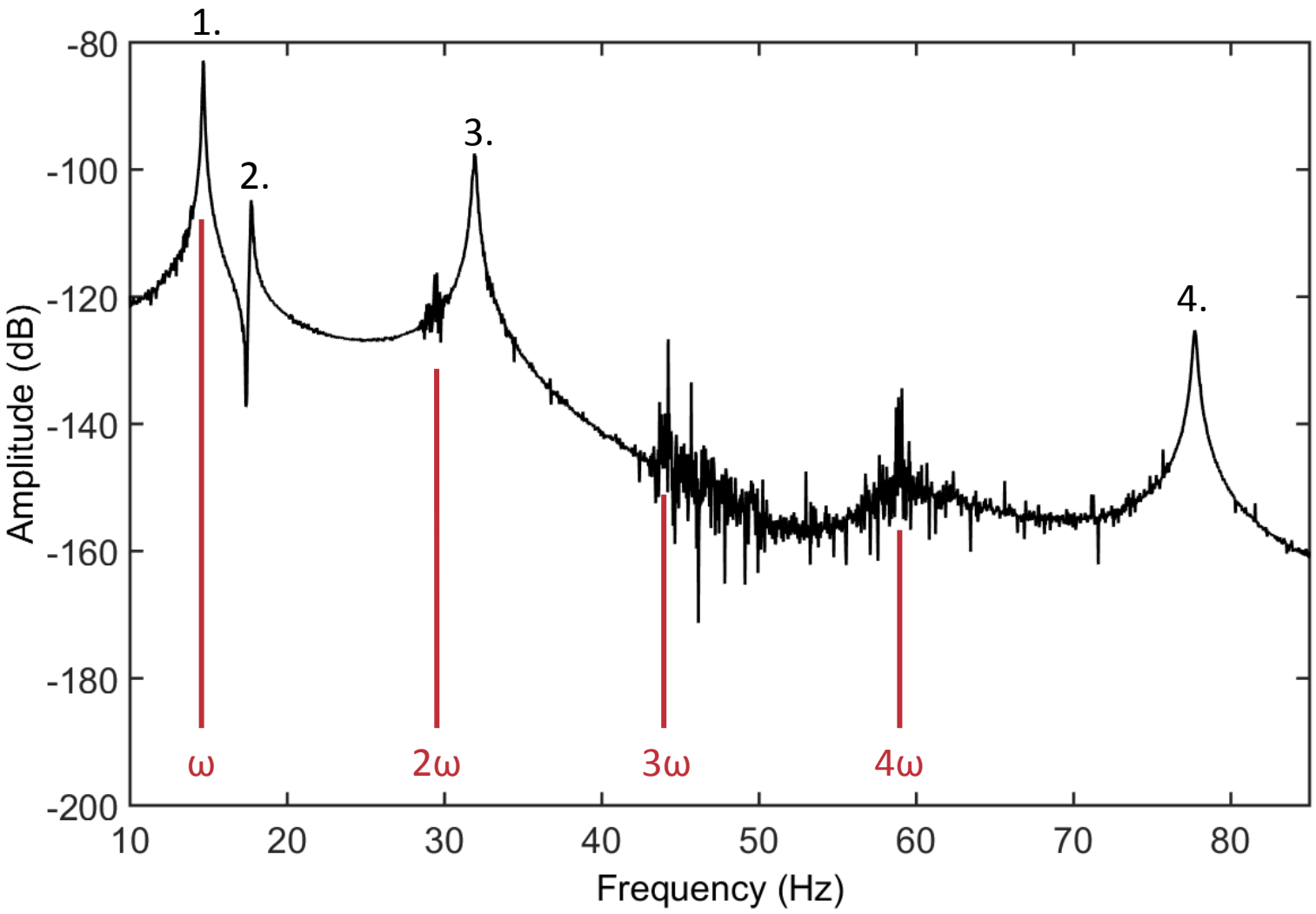
Crest factor
≈ 4

Phase Components Optimised to Reduce Crest Factor

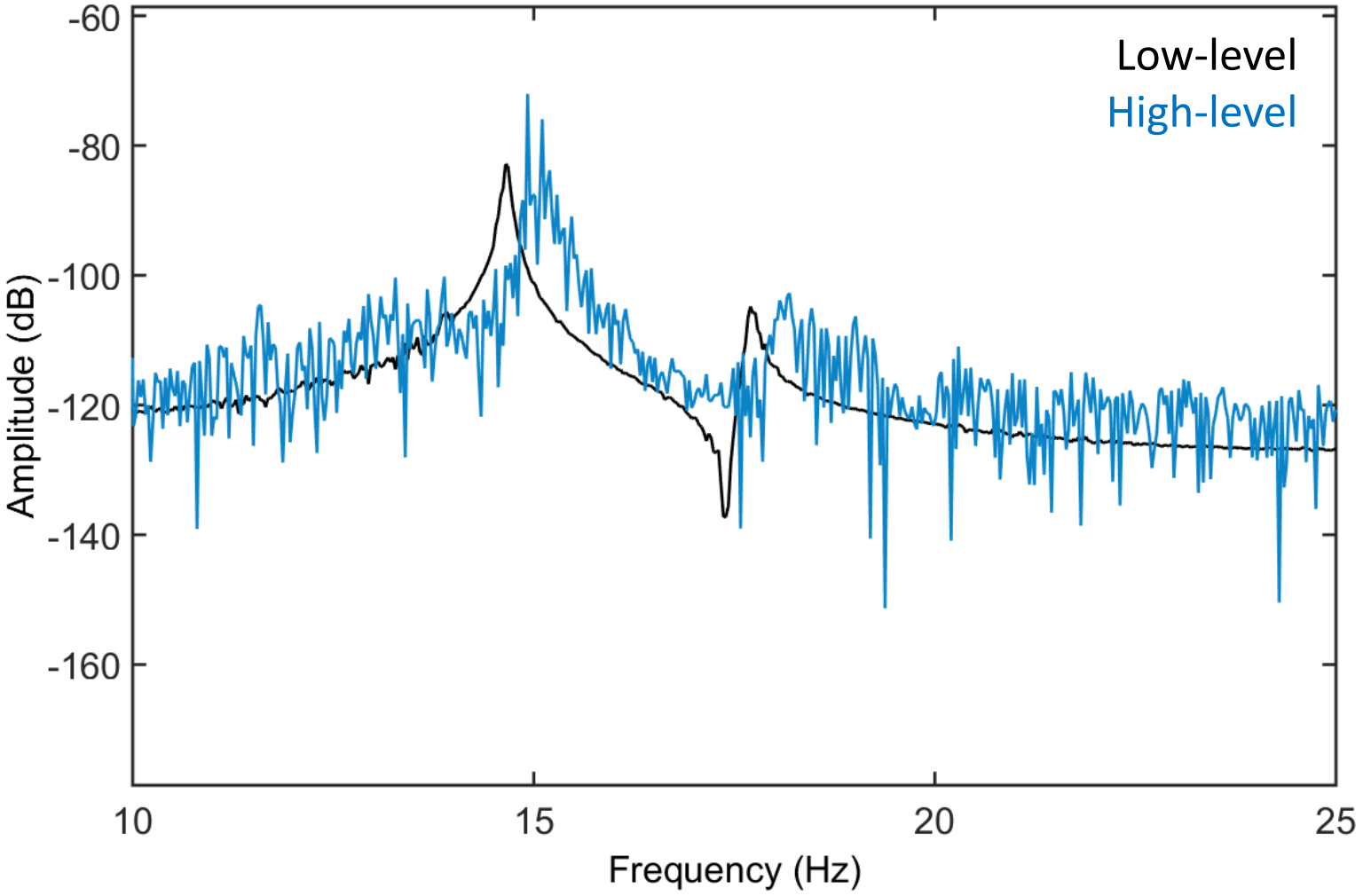
Minimise l_{2p}-norm of the input signal $u(t)$



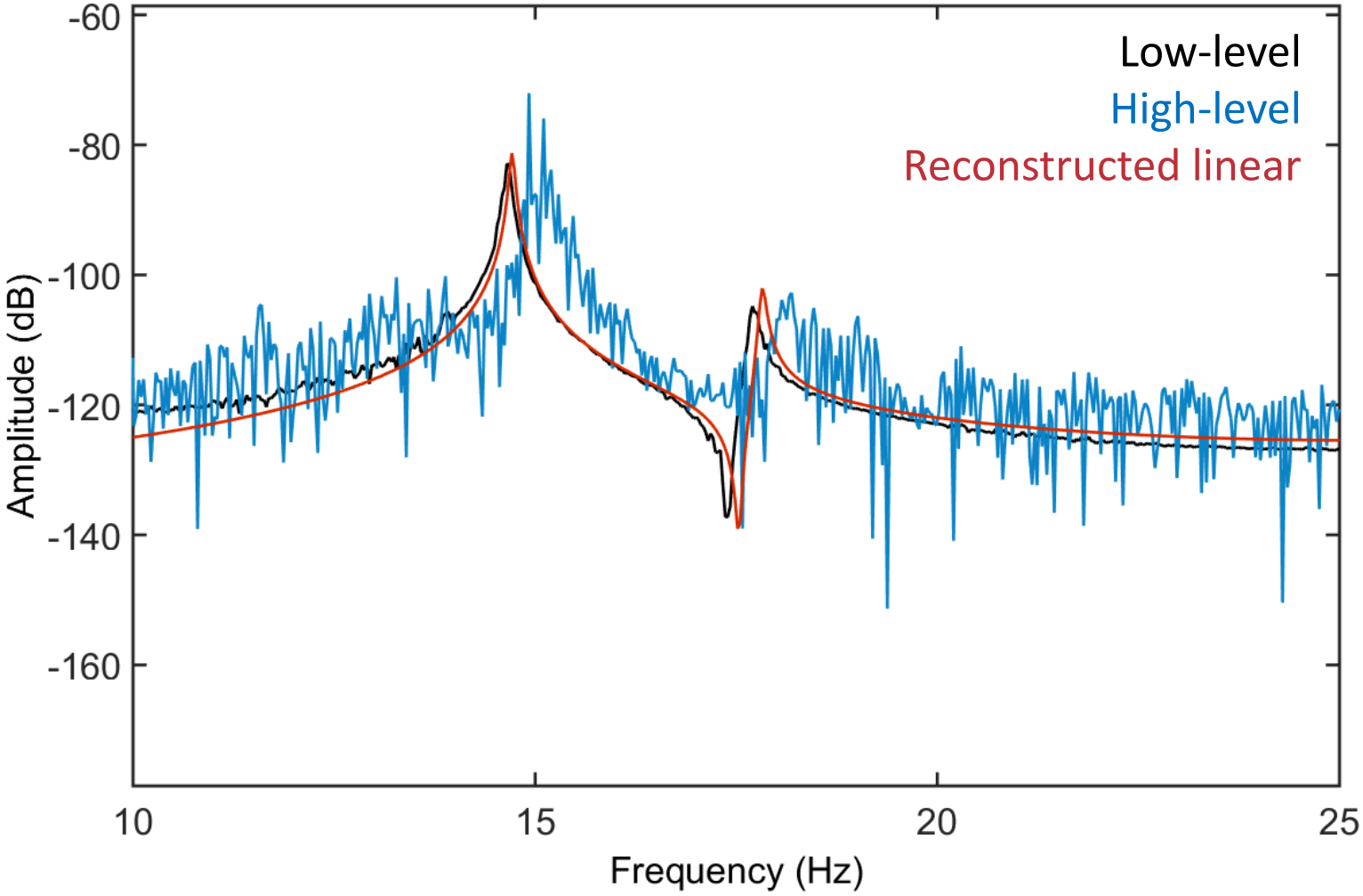
Low-level FRF Shows Signs of Nonlinearity (Harmonics)



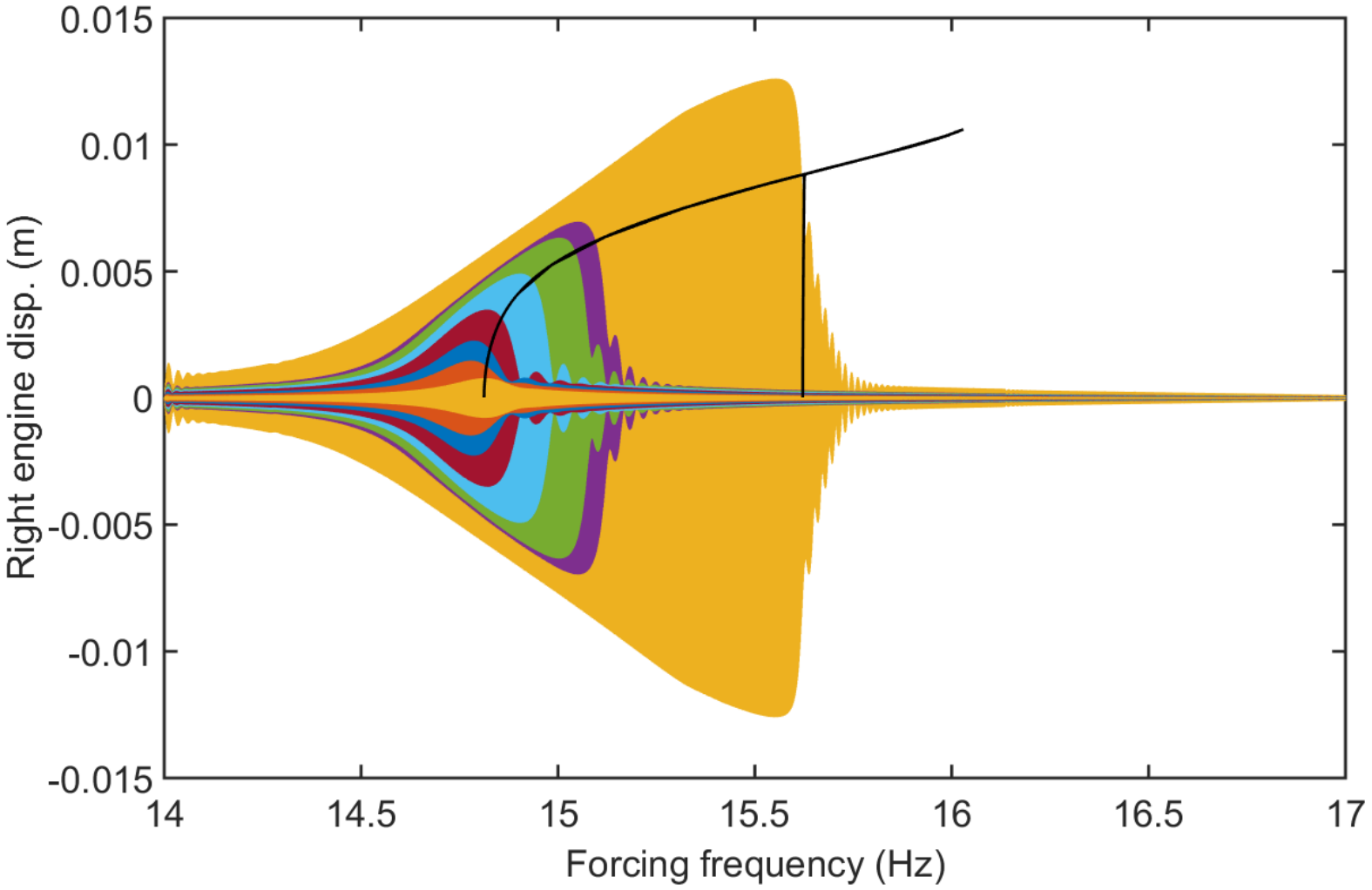
Clear Nonlinear Distortions at High-level



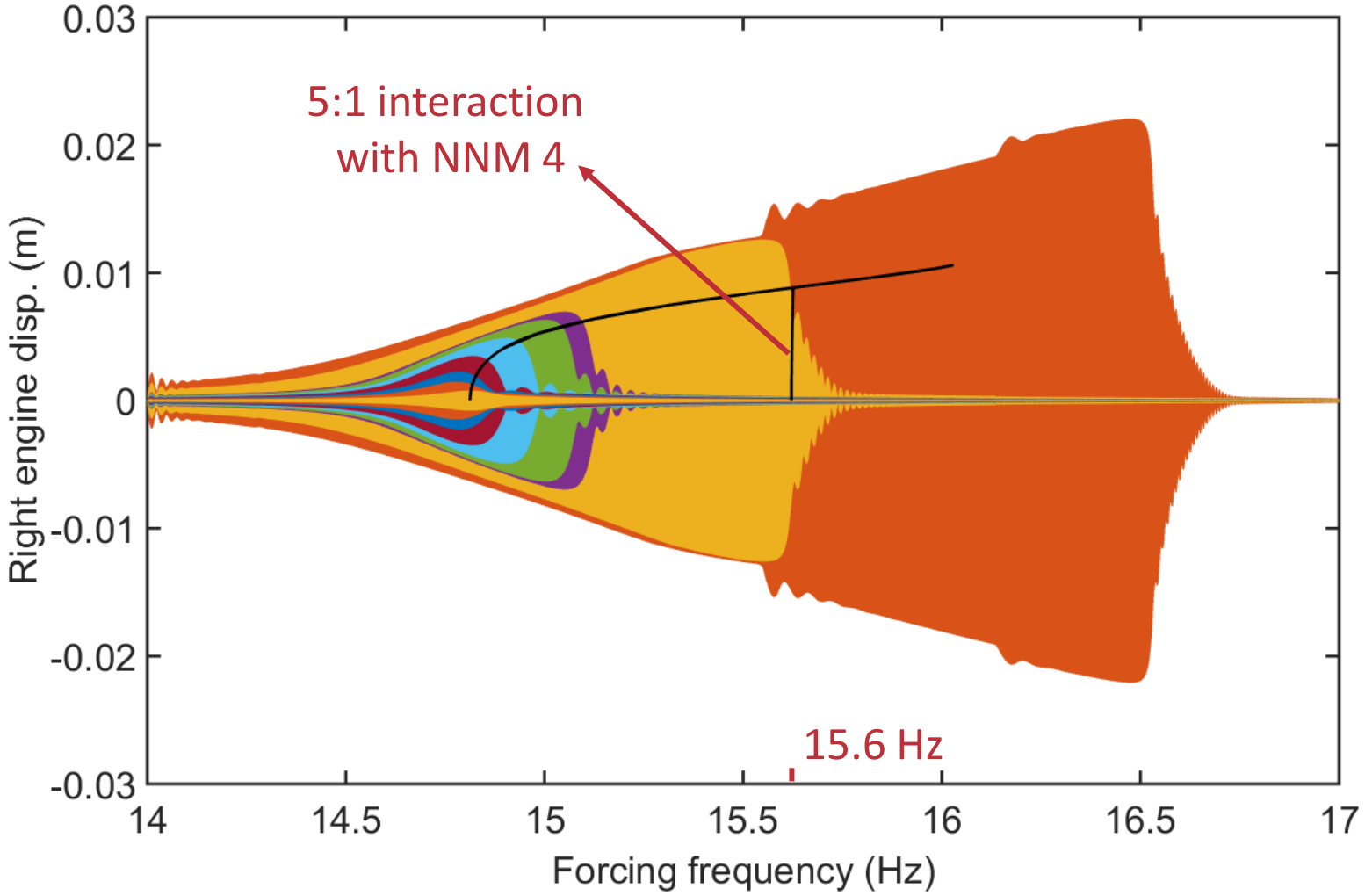
Small Errors on the Reconstructed FRF after NL ID



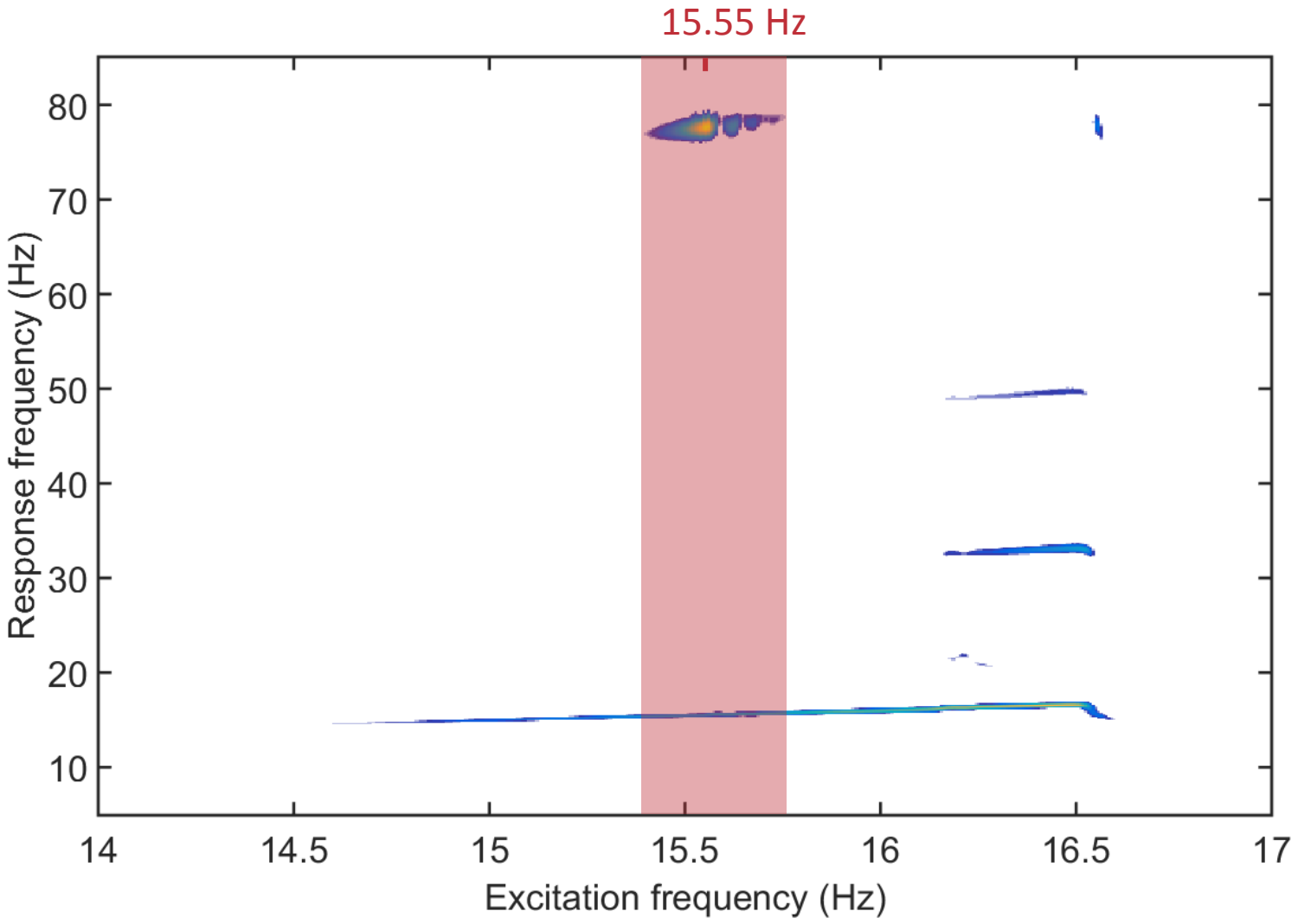
Comparison Between First NNM and Sine-sweep Data



A Modal Interaction Is Captured by the Model



Modal Interaction Clearly Visible in the Sweeps



Conclusions

Challenging application requiring a careful excitation

Linear frequencies & frequency-amplitude dependence well captured
→ modal interaction reproduced by the model

Accuracy depends on experimental model

Future Work

Improve experimental model (increase complexity)

- More physical insight
- Grey-box models (splines)
- Black-box models

Directly work on the identified model (instead of modal space)

Thank you!

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NNMs Identified Using NPS