



Science Arts & Métiers (SAM)

is an open access repository that collects the work of Arts et Métiers Institute of Technology researchers and makes it freely available over the web where possible.

This is an author-deposited version published in: <https://sam.ensam.eu>
Handle ID: <http://hdl.handle.net/10985/10369>

To cite this version :

Kerem EGE, Maxime GALLO, Jérôme ANTONI, Marc RÉBILLAT - Exponential sine sweeps for the autonomous estimation of nonlinearities and errors assessment by bootstrap Application to thin vibrating structures - Journal of Manufacturing Science and Engineering p.1007-1018 - 2015

Any correspondence concerning this service should be sent to the repository

Administrator : scienceouverte@ensam.eu





Exponential sine sweeps for the autonomous estimation of nonlinearities and errors assessment by bootstrap Application to thin vibrating structures

Marc Rébillat¹, Kerem Ege², Maxime Gallo², Jérôme Antoni²

A linear behavior in vibroacoustics ?

- Geometrically nonlinear vibrations of plates, shells:

when the amplitude of the transverse displacement w
exceeds the plate/shell thickness h



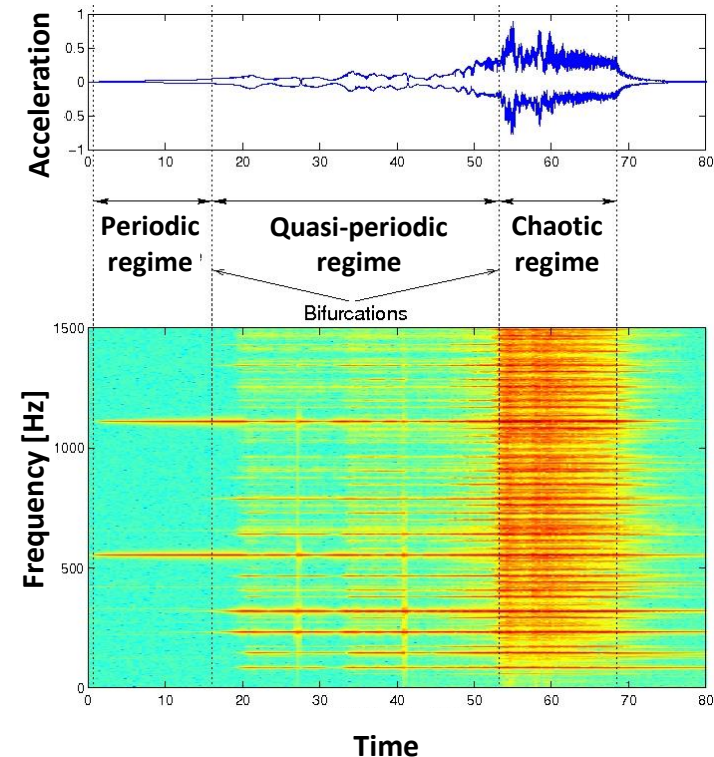
→ *jump phenomenon, hysteresis,
internal resonance*

- Boundary conditions, joints, contacts...



Example : Gong

Cyril Touzé, Olivier Thomas

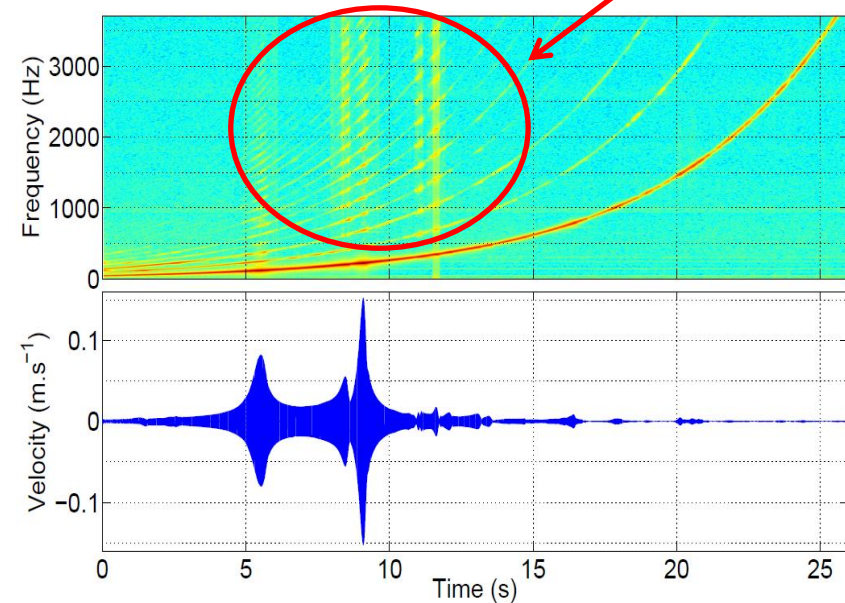


A linear vibroacoustic measurement ?

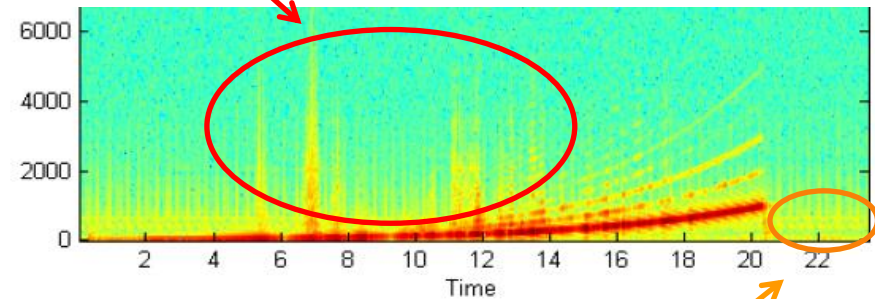
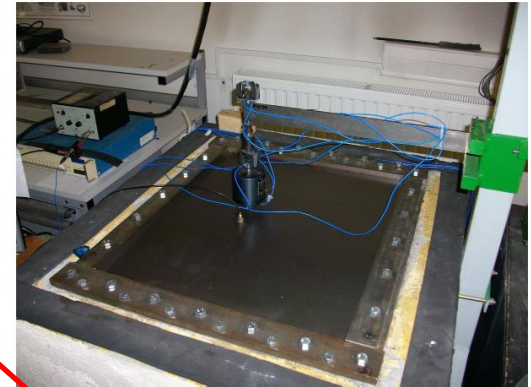
Acoustical excitation



How to extract the linear/nonlinear parts of a typical vibroacoustic measurement ?



Vibrational excitation

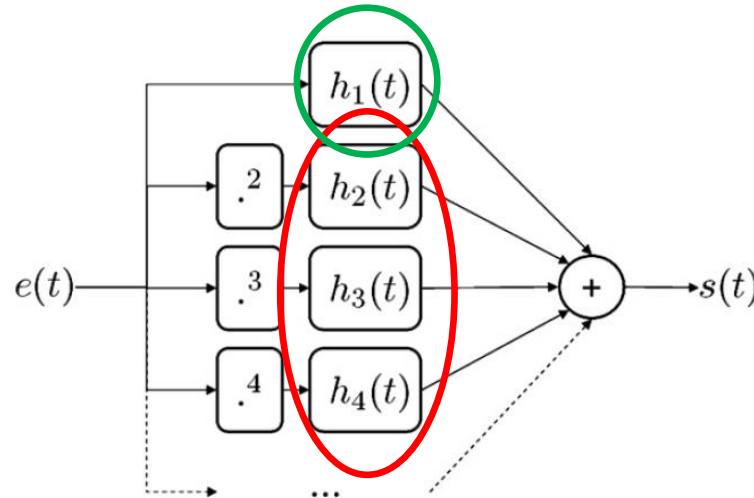


How to estimate the effects of experimental noise ?

- Estimation of Parallel Hammerstein models
 - Theory
 - Application to a vibrating plate
 - Separation of the intrinsic nonlinear contributions
- Improvements of the method (sweep repetition)
 - Theory
 - Noise estimation by synchronous averaging
 - Uncertainty estimation by bootstrap
 - Autonomous kernel order estimation
- Conclusion and perspectives

Parallel Hammerstein models estimation

⇒ Slightly nonlinear system modeled as **parallel Hammerstein models**

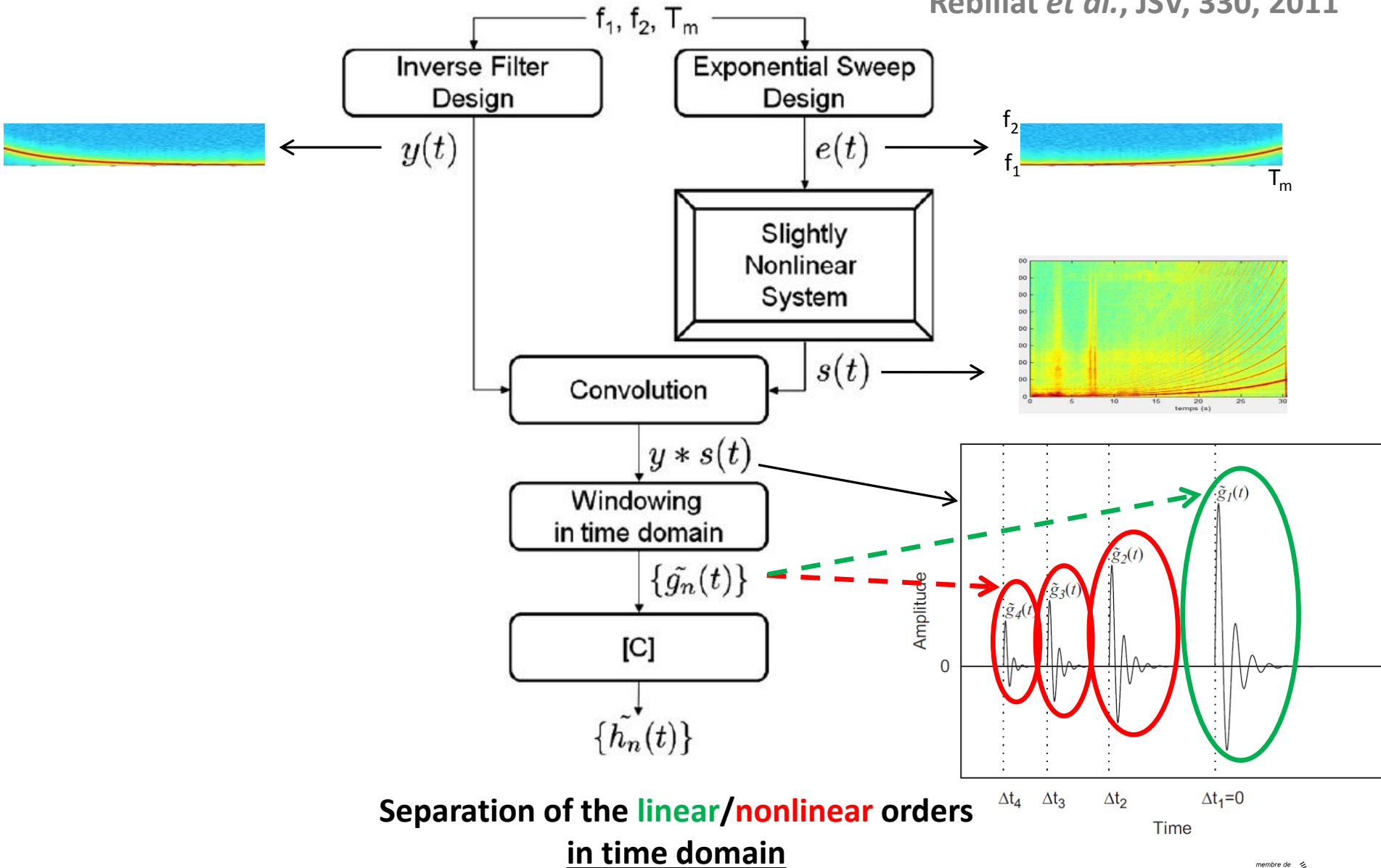


⇒ Kernels easily estimated using **exponential sine sweeps**
(see [Farina, AES, 2000], [Rébillat, JSV, 2011] or [Novak, IEEE Instrumentation, 2011] for example)

→ Separation of the **linear**/**nonlinear** orders

Parallel Hammerstein models estimation

Rébillat *et al.*, JSV, 330, 2011

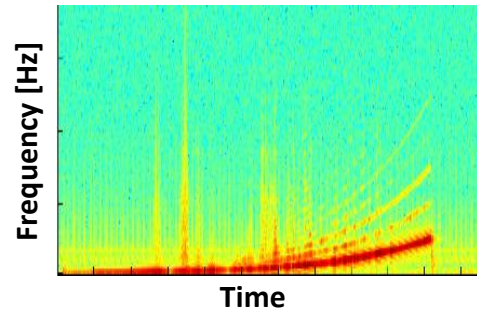


Separation of the **linear/nonlinear** orders
in time domain

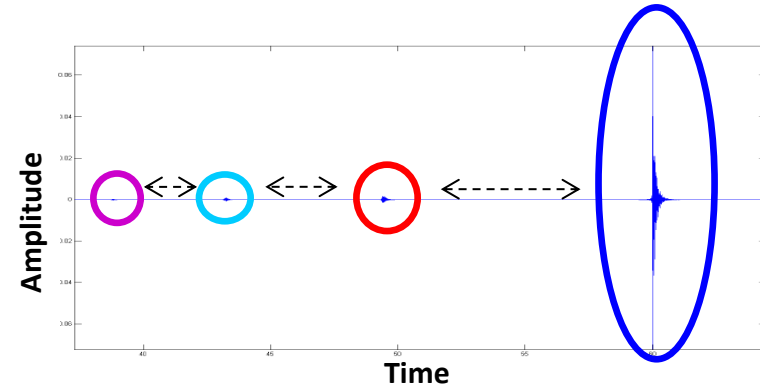
Application to a vibrating plate

- Clamped Steel plate (1mm)
- Shaker + Accelerometer

One sweep of **20 seconds**
[20Hz-1kHz]

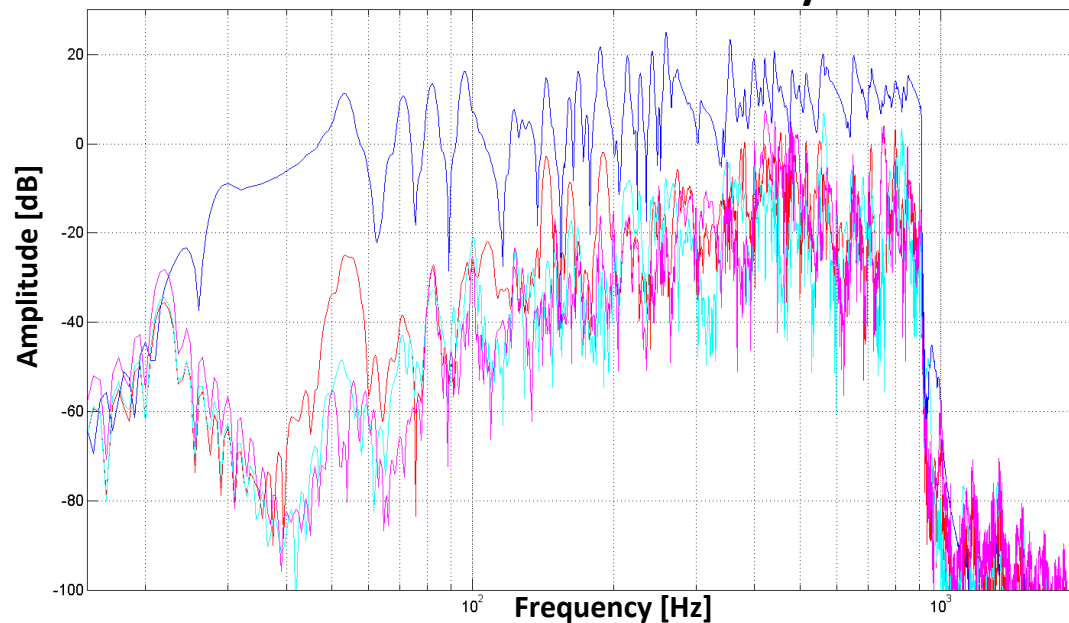


After deconvolution:



Importance of the **length of the sweep** for
time domain separation

Identified Kernels of the system

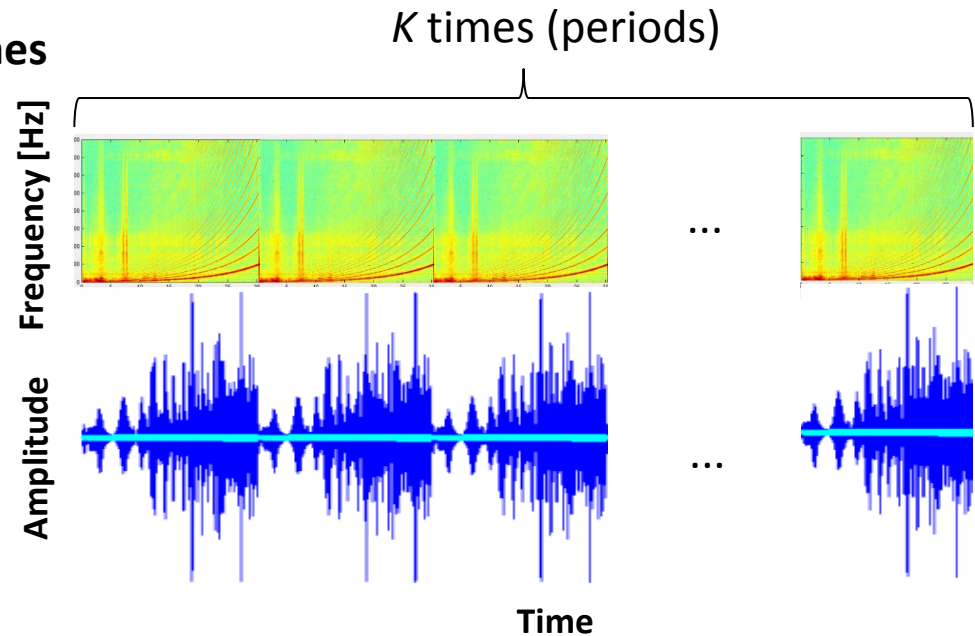


- Kernel h_1 (linear part)
- Kernel h_2
- Kernel h_3
- Kernel h_4

Improvement of the method: Sweep repetition & Noise estimation

- Measured signal = system response + experimental noise $x(t) = s(t) + n(t)$

- Repetition of the same sweep K times



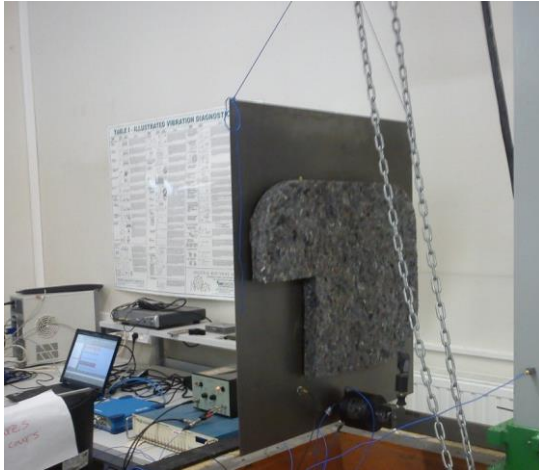
- Estimation of the noise $\bar{n}(t) = x(t) - \bar{s}(t)$

using the time synchronous averaging $\bar{s}(t)$
of the system response $x(t)$

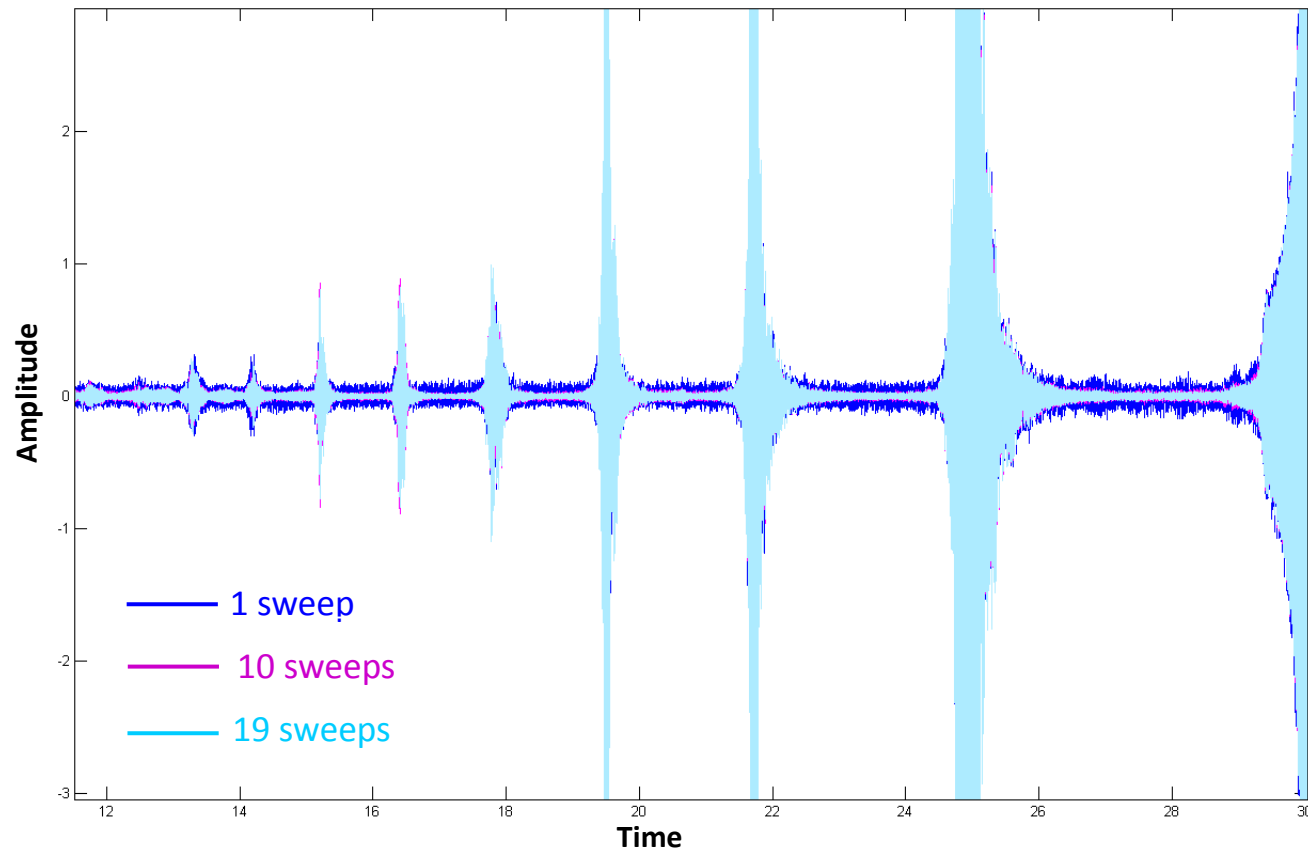
$$\bar{s}(t) = \frac{1}{K} \sum_{k=0}^{K-1} [x(t - kT)]$$

Application to a vibrating plate – Noise estimation

- Free-free damped steel plate (1mm)
- Shaker + Accelerometer



Influence of sweep repetitions (number of periods K)



Increase of K



Synchronous averaging
on **more periods**

$$\bar{s}(t) = \frac{1}{K} \sum_{k=0}^{K-1} [x(t - kT)]$$

→ Better extraction
of the noise

→ More precise estimations of
the kernels of high orders

Uncertainty of measurement using Bootstrap

How to study the
variability of the measurements ?



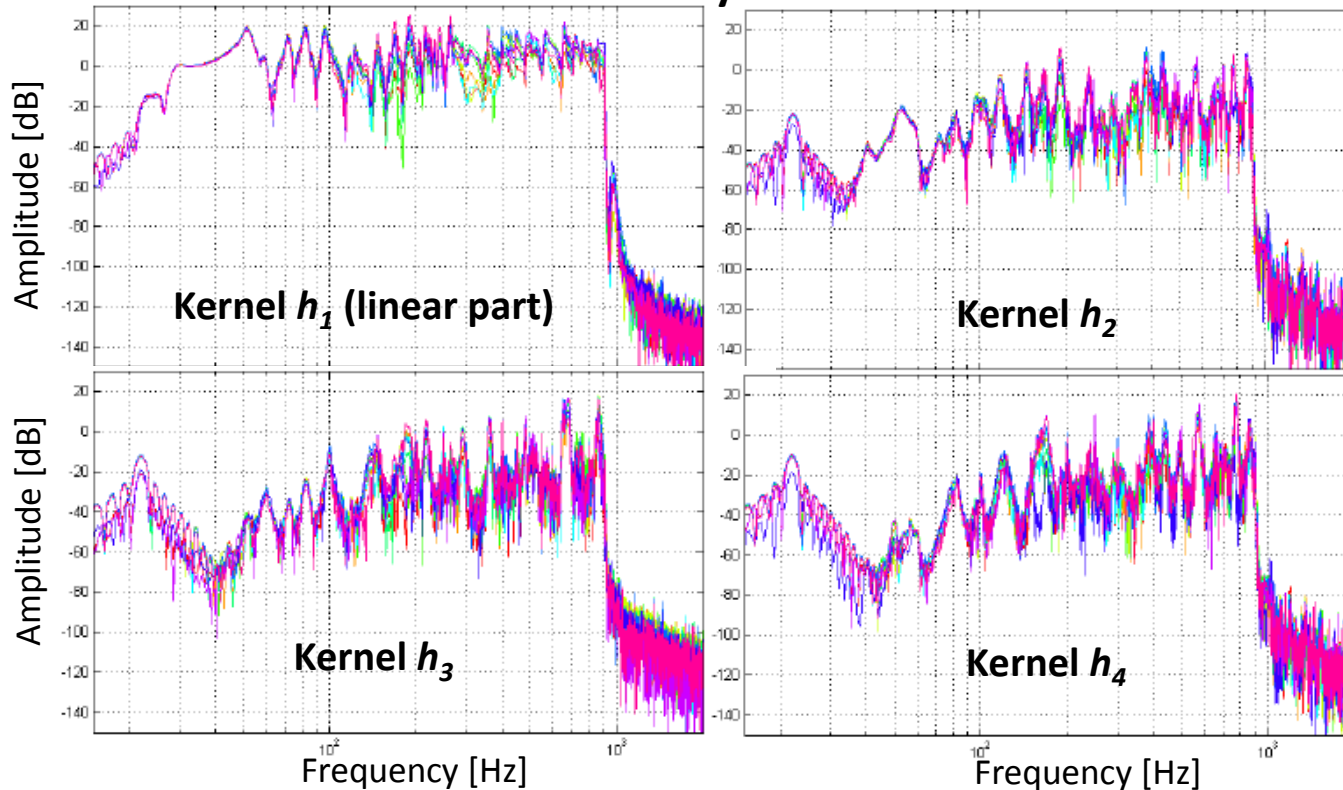
Bootstrap method

B random sample with replacement (of K sweeps each time)
Synchronous averaging on K repetitions



B different
kernel estimations

Identified Kernels of the system for $B=10$ and $K=19$



Way to identify and
quantify variability
(uncertainty) of plate
nonlinearities
estimations

Uncertainty of quantification

Synchronous averaging on K
random draw with replacements
(performed B times)

Estimation of parallel
Hammerstein model
(performed B times)

Mean over the B
estimations

K repetitions of
exponential sine
sweeps (ESS)

B estimations
of the response

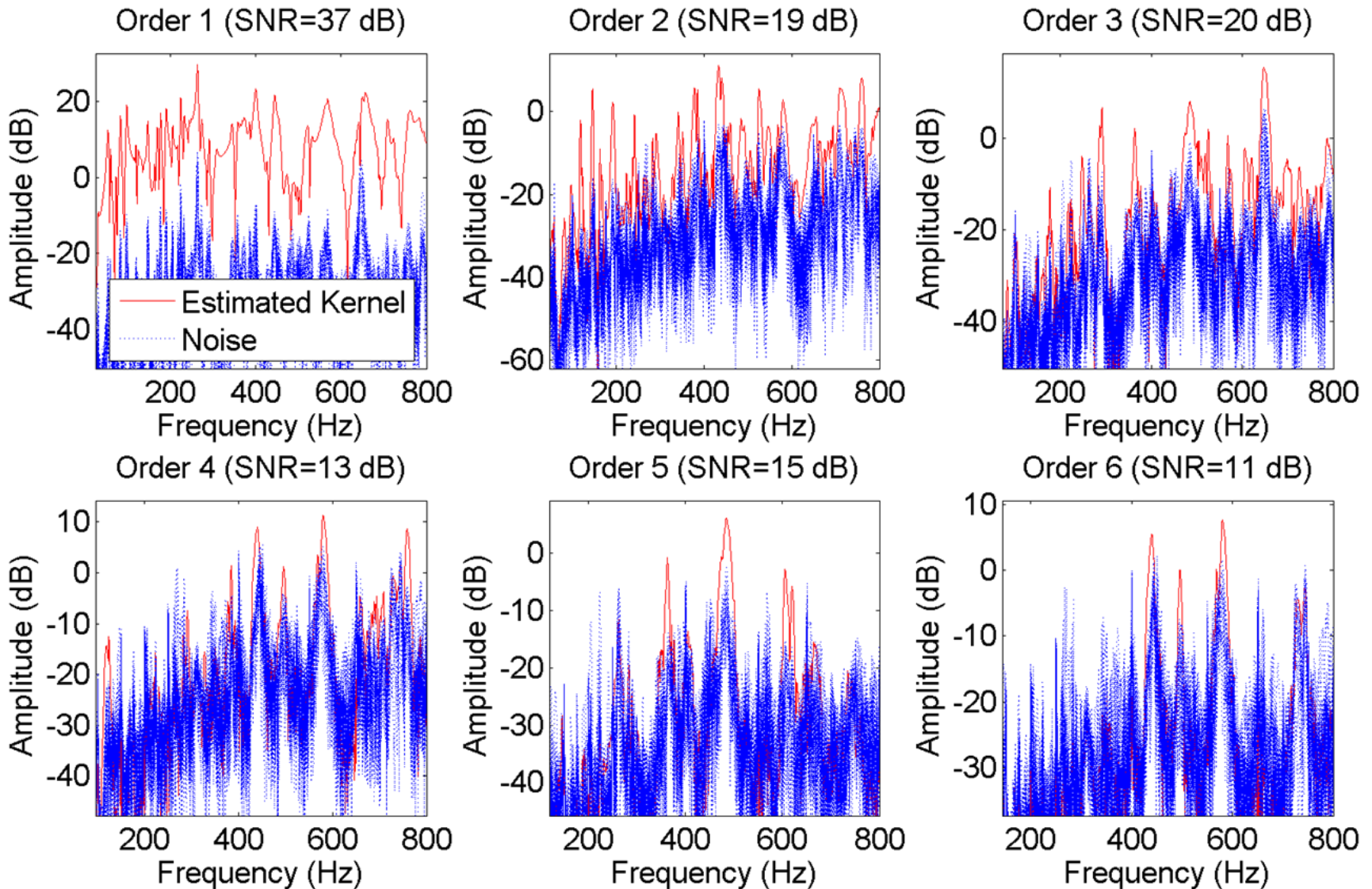
B estimations
of the N kernels

1 mean
estimation
of the N
Kernels

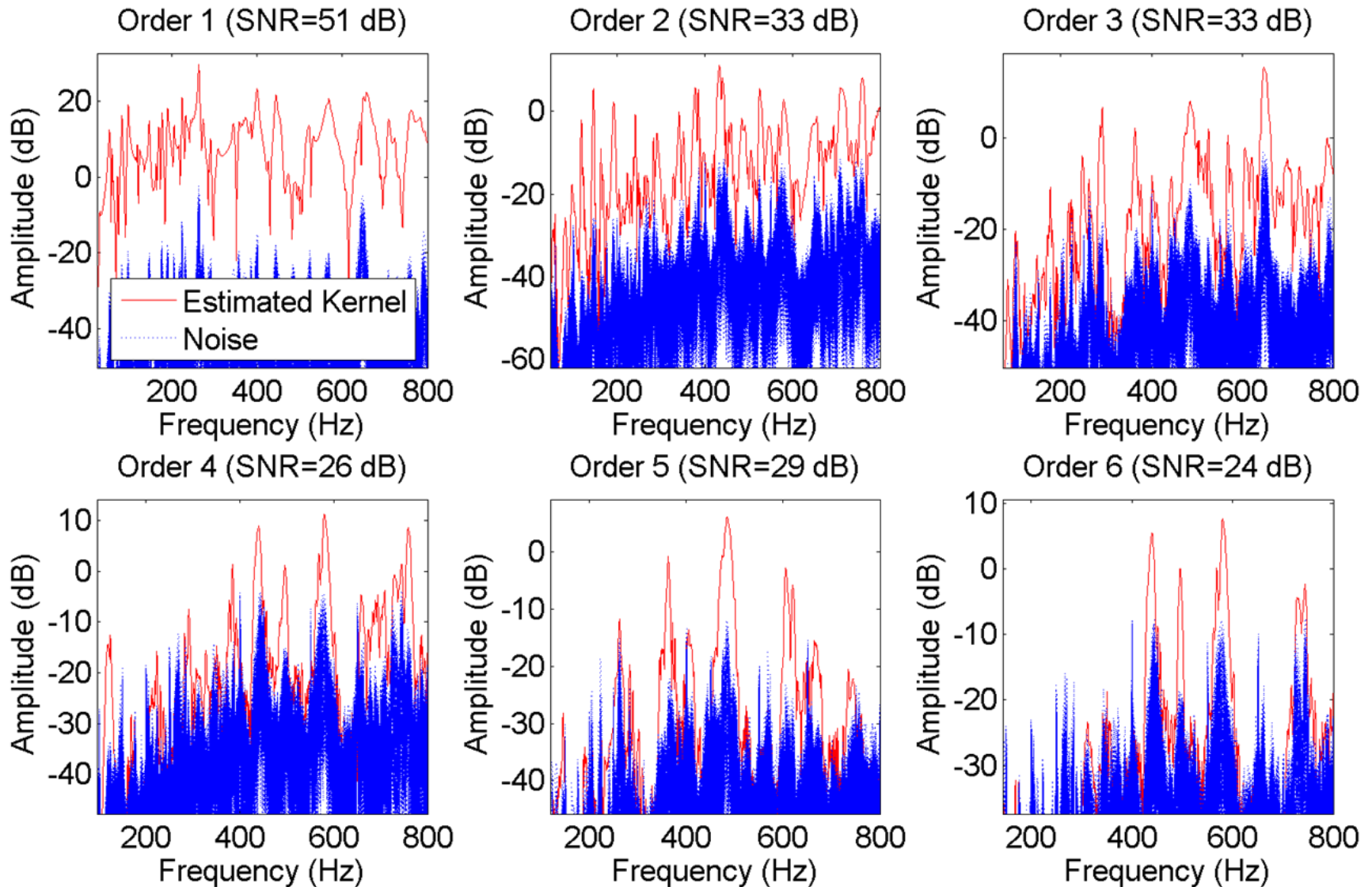


B estimations of
the « estimation
noise » on the N
kernels

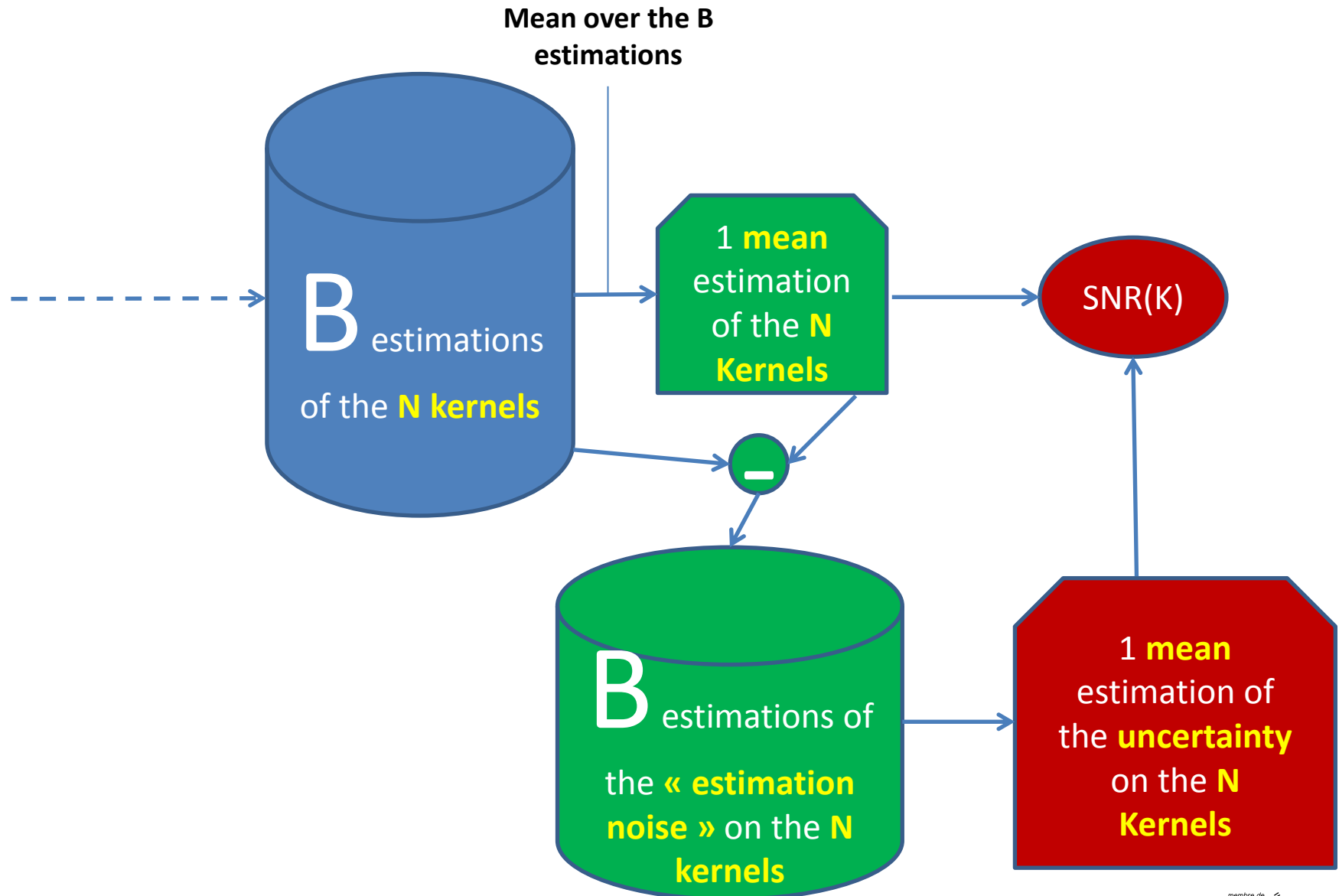
No averaging (K=1, B=150)



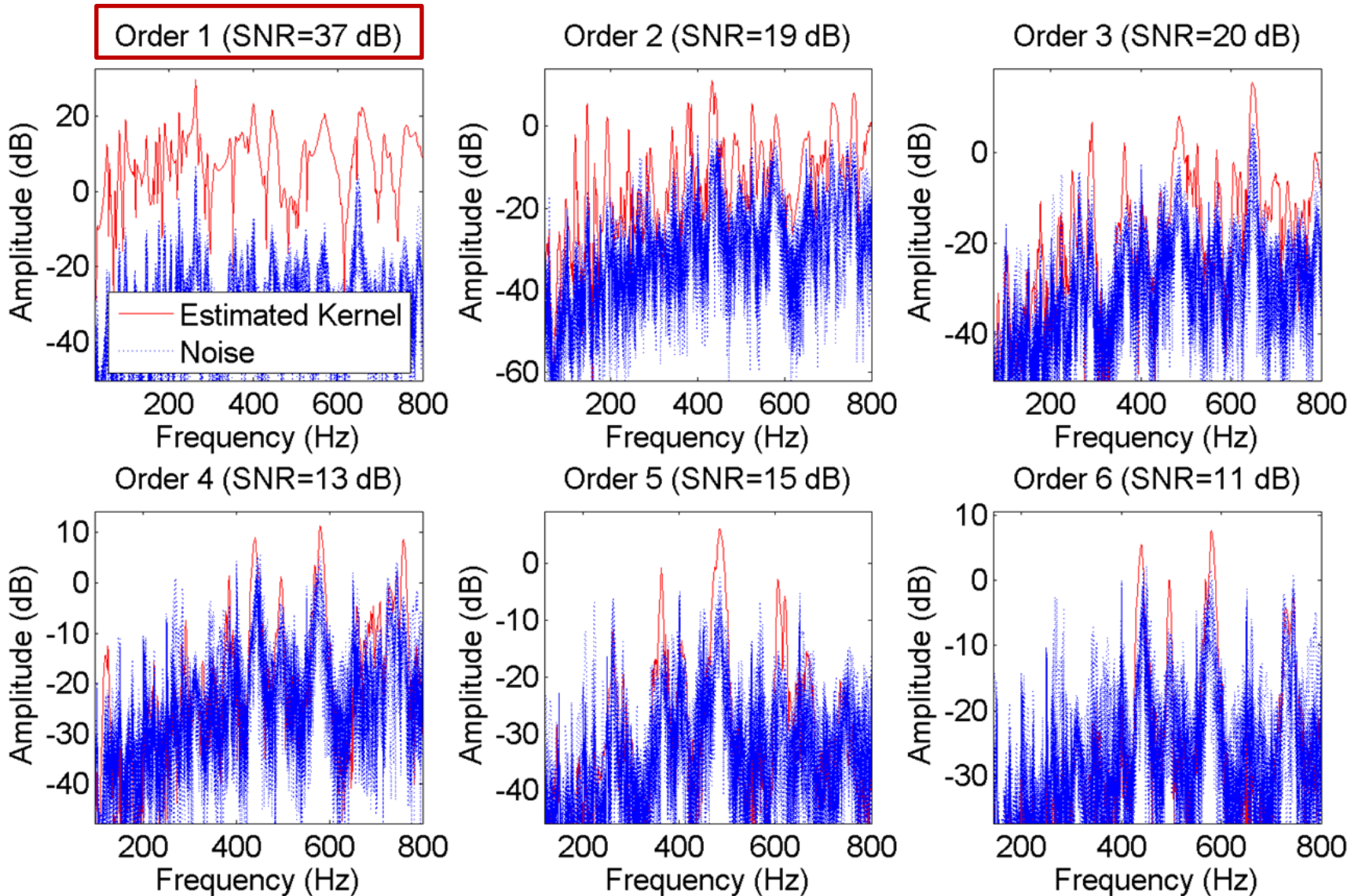
Averaging (K=19, B=150)



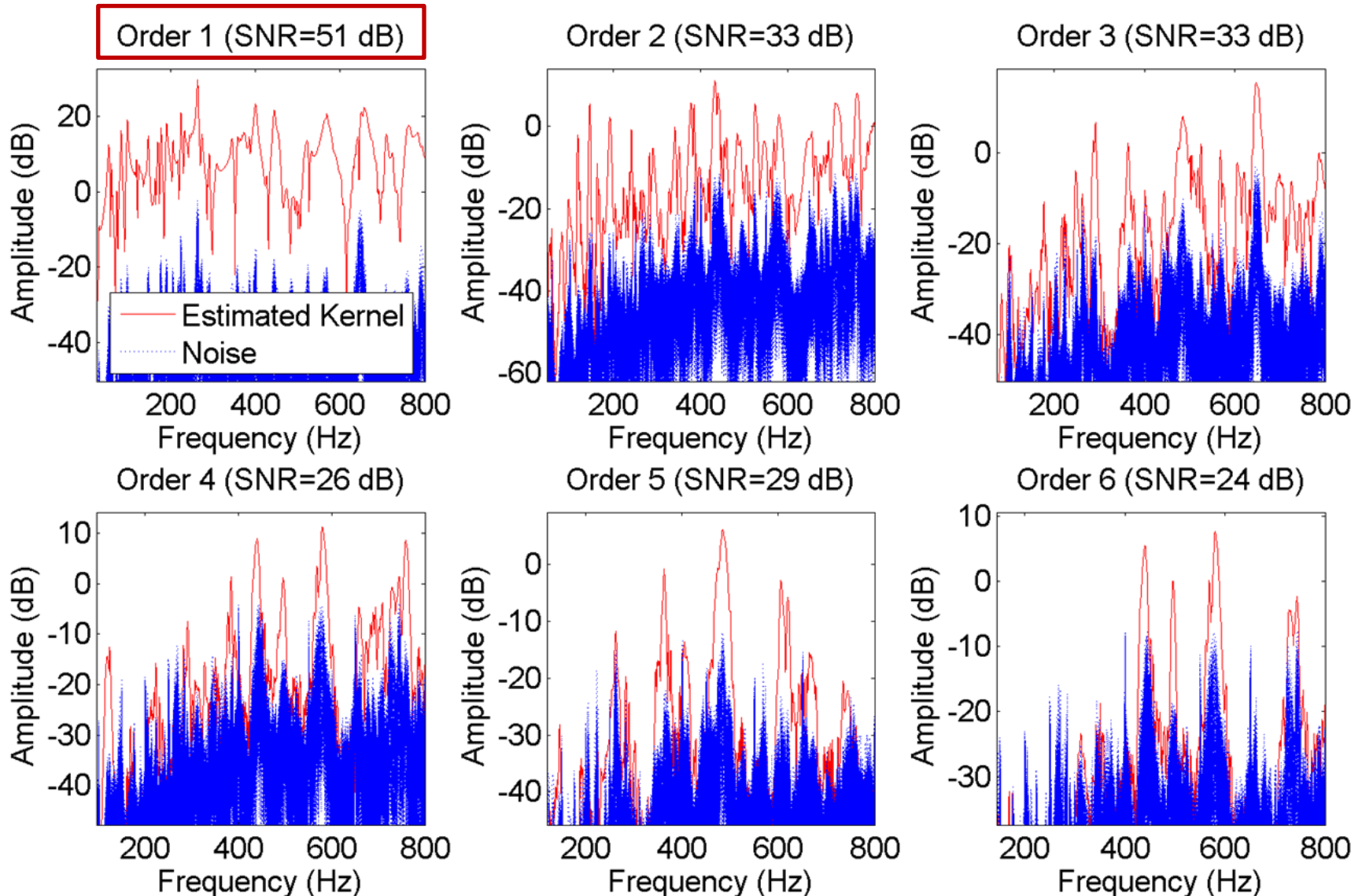
Uncertainty of quantification



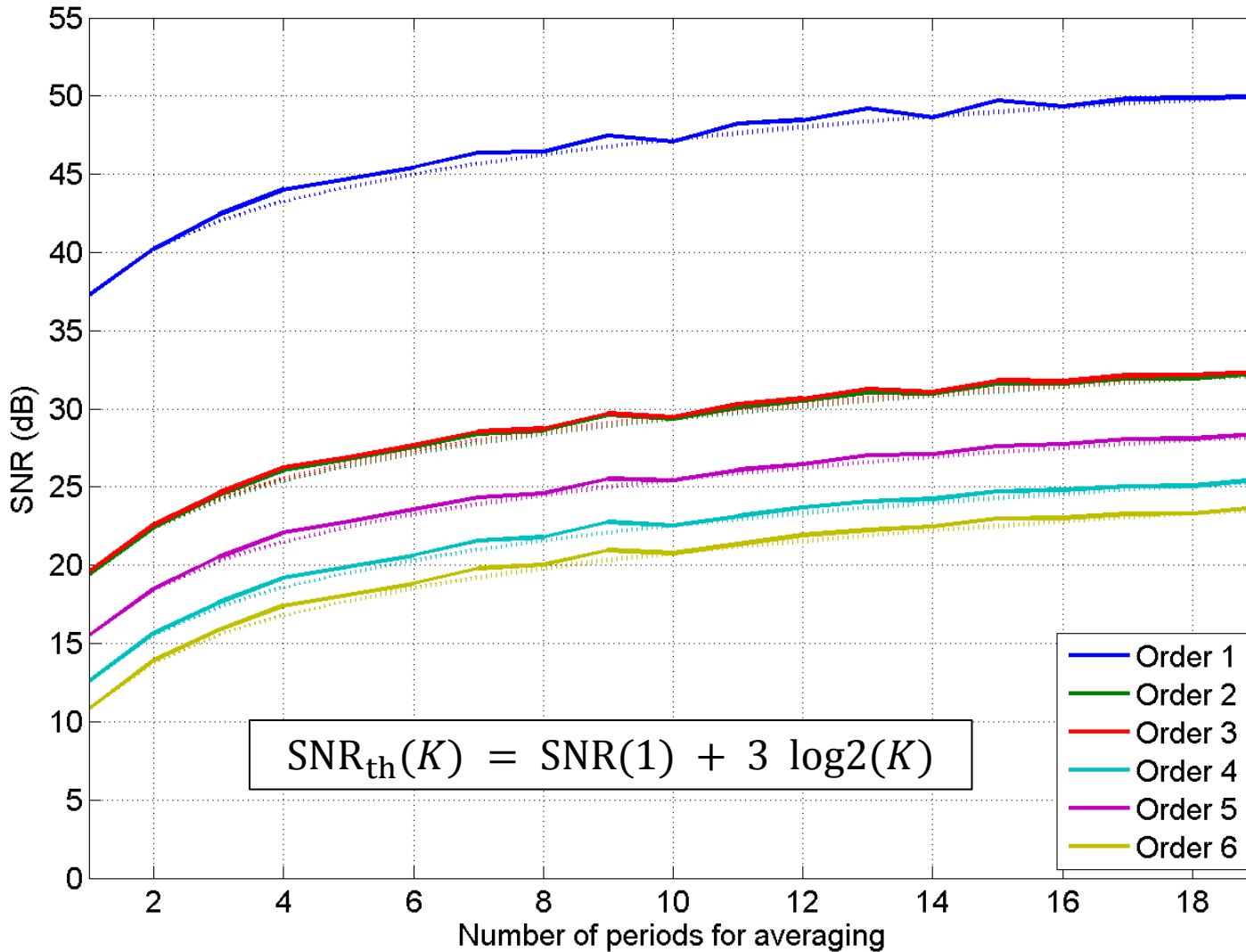
No averaging (K=1, B=150)



Averaging (K=19, B=150)

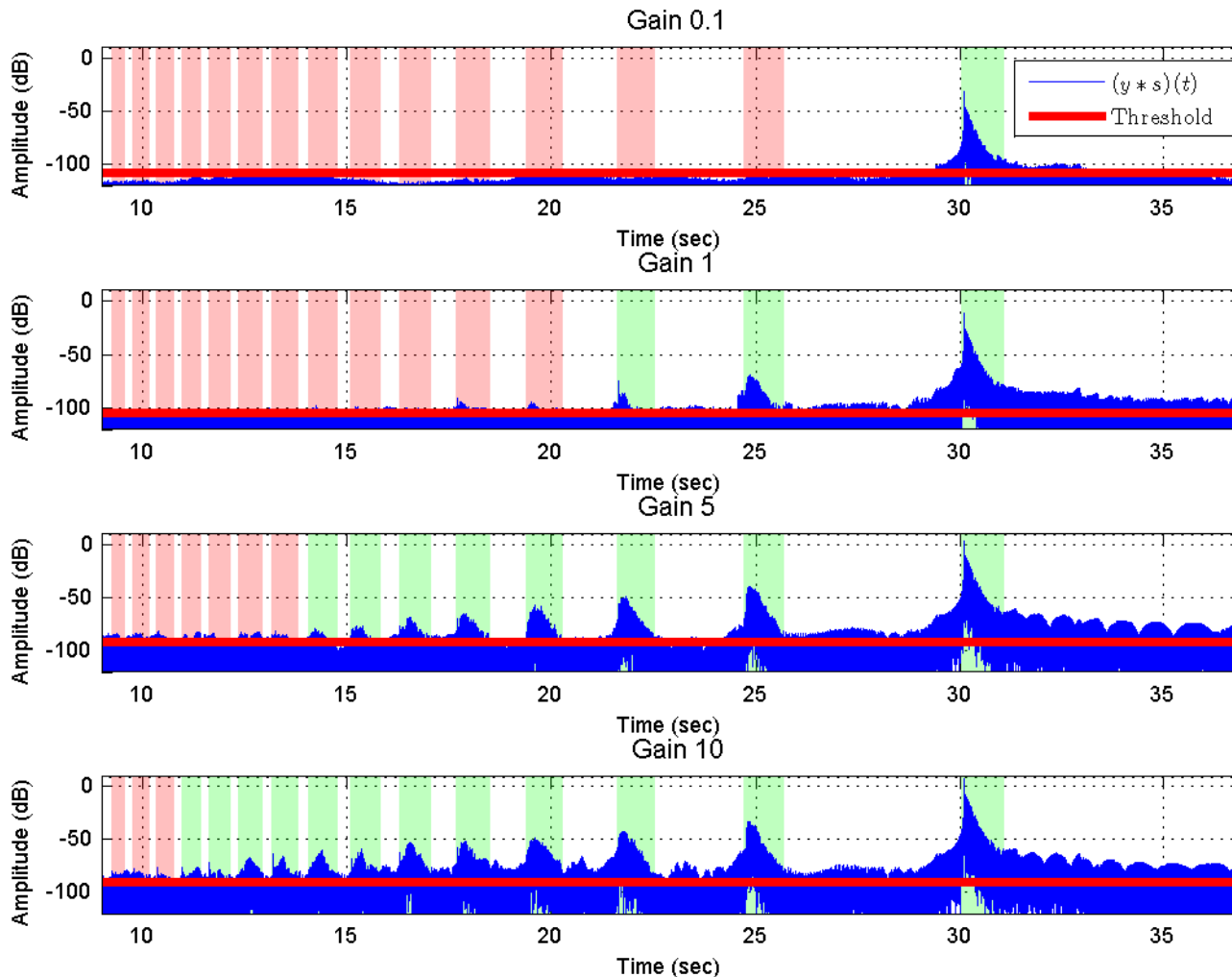


Effect of repetition number K on SNRs



Autonomous kernel order estimation

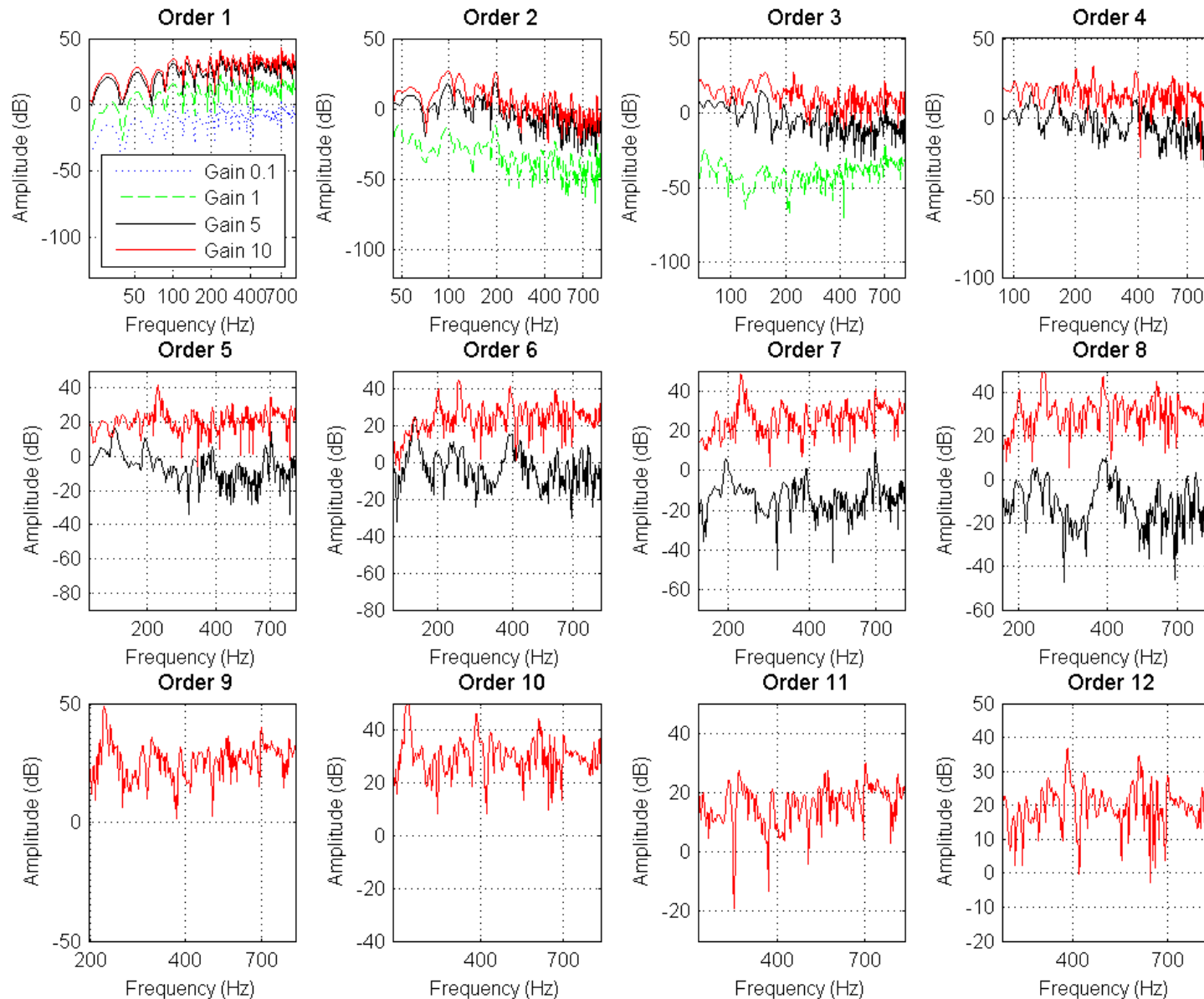
→ Example on the suspended damped plate (5 different gains)



Estimation of the proper kernel order N to identify

Threshold defined following a statistical F-test (Fisher)

Example of autonomous Kernel estimation



Conclusion & Perspectives

- Original method to **estimate the nonlinearities** of a vibro-acoustical structure
 - Slightly nonlinear systems modelled as **parallel Hammerstein models**
 - Kernels easily estimated using **exponential sine sweeps**
- **Improvements** of the sine sweep method
 - **Repetition of the excitation signal** – K sweeps
 - **Extraction of the noise** through time synchronous averaging
 - **Uncertainty estimation** by bootstrap
 - **Autonomous kernel order estimation**
- **Perspectives**
 - **Comparisons** with other methods (spectral domains): **periodic multisines...**