Noise Diagnostics of Stationary and Non-Stationary Reactor Processes

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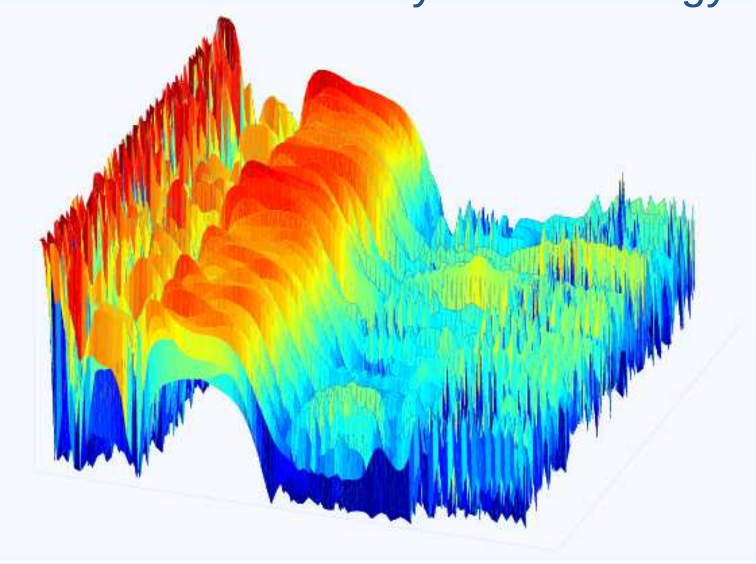


Erata

Figure 2.2 page 6: *dotted* should read *dashed*

In section 7.2 pages 50-51: $e^{\frac{|\mathbf{r}-\mathbf{r}'|}{l}}$ should read $e^{\frac{|\mathbf{r}'-\mathbf{r}''|}{l}}$

Part 1, wavelets analysis

This thesis is an introduction to and a summary of the work published in the following papers:

- PAPER I
  C. Sunde, S. Avdić and I. Pázsit, ”Classification of two-phase flow regimes via image analysis and a neuro-wavelet approach”
  Progress in Nuclear Energy, **46**, 348 (2005).
- PAPER II
  C. Sunde and I. Pázsit, ”Investigation of detector tube impacting in the Ringhals-1 BWR”
  International Journal of Nuclear Energy Science and Technology, **2**, 189 (2006).
- PAPER III
  C. Sunde and I. Pázsit, ”Wavelet techniques for the determination of the decay ratio in boiling water reactors”
  Kerntechnik, **72**, 7 (2007).

Part 2, core barrel vibrations

- PAPER IV

  C. Sunde, C. Demazière and I. Pázsit , ”Calculations of the neutron noise induced by shell-mode core-barrel vibrations in a 1-D, two-group, two-region slab reactor model”

  Nuclear Technology, **154**, 129 (2006).

- PAPER V

  C. Sunde, C. Demazière and I. Pázsit , ”Investigation of the neutron noise induced by shell-mode core-barrel vibrations in a reflected reactor”

  Proc. Int. Top. Mtg. on Mathematics and Computing, Supercomputing, Reactor Physics and Nuclear and Biological Applications (M&C2005), September 12-15, 2005.

- PAPER VI

  M. Pázsit, C. Sunde and I. Pázsit, ”Beam mode core-barrel vibrations in the PWRs Ringhals 2-4”, *Proc. Int. Top. Mtg. on Advances in Nuclear Analysis and Simulations (PHYSOR2006)*, September 10-14, 2006.

Part 3, break-frequency method

- Paper VII

  C. Sunde, C. Demazière and I. Pázsit, ”Investigation of the validity of the point-kinetics approximation and of the break-frequency method in 2-D subcritical systems”, *Proc. Joint Int. Top. Mtg. on Mathematics and Computing and Supercomputing in Nuclear Applications (M&C + SNA 2007)*, Monterey, California, April 15-19, 2007, American Nuclear Society (2007)

Noise diagnostics

- Noise is the time-dependent fluctuation from the mean value of the neutron flux.
- Power reactor noise can be induced by technological processes, vibrations of core components, or temperature or density variations.
- Fluctuations of the cross-sections leads to fluctuations of the neutron flux, noise.
- The noise can be used to identify deteriorating or malfunctioning components, parameter estimation (e.g. reactivity, moderator temperature coefficient and decay ratio)

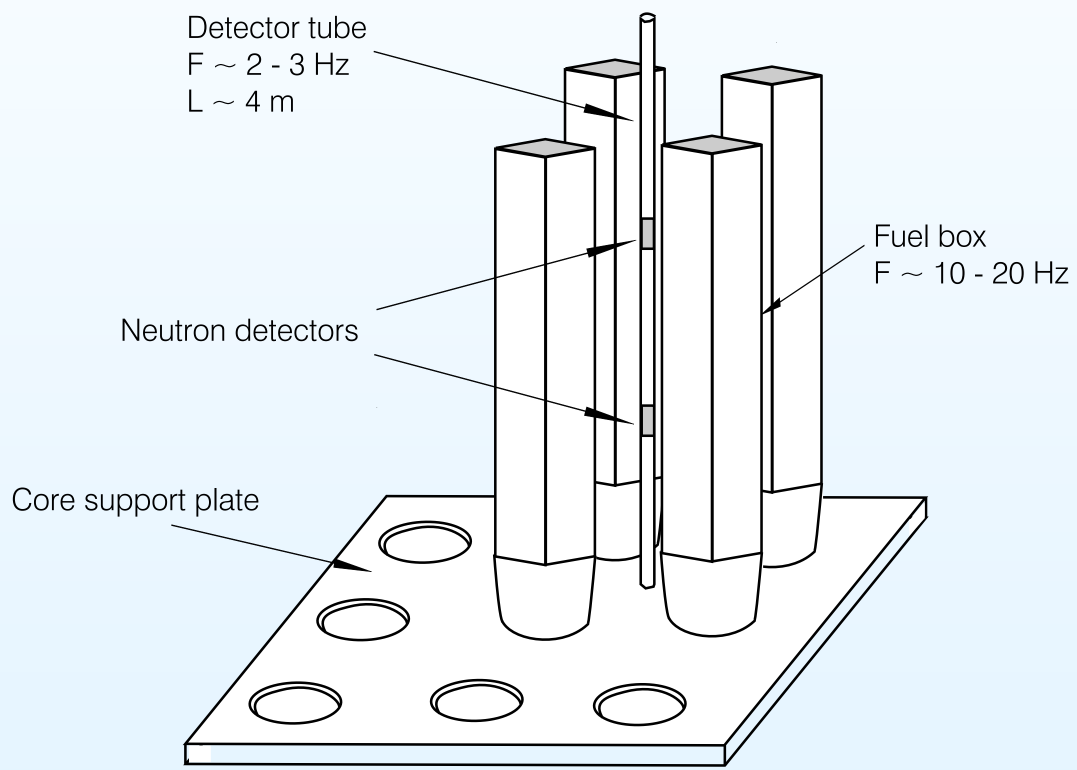
Stationary and Non-Stationary

- Stationary processes are uniform in time (frequencies do not change)
  Beam-mode core barrel vibration or detector tube vibrations

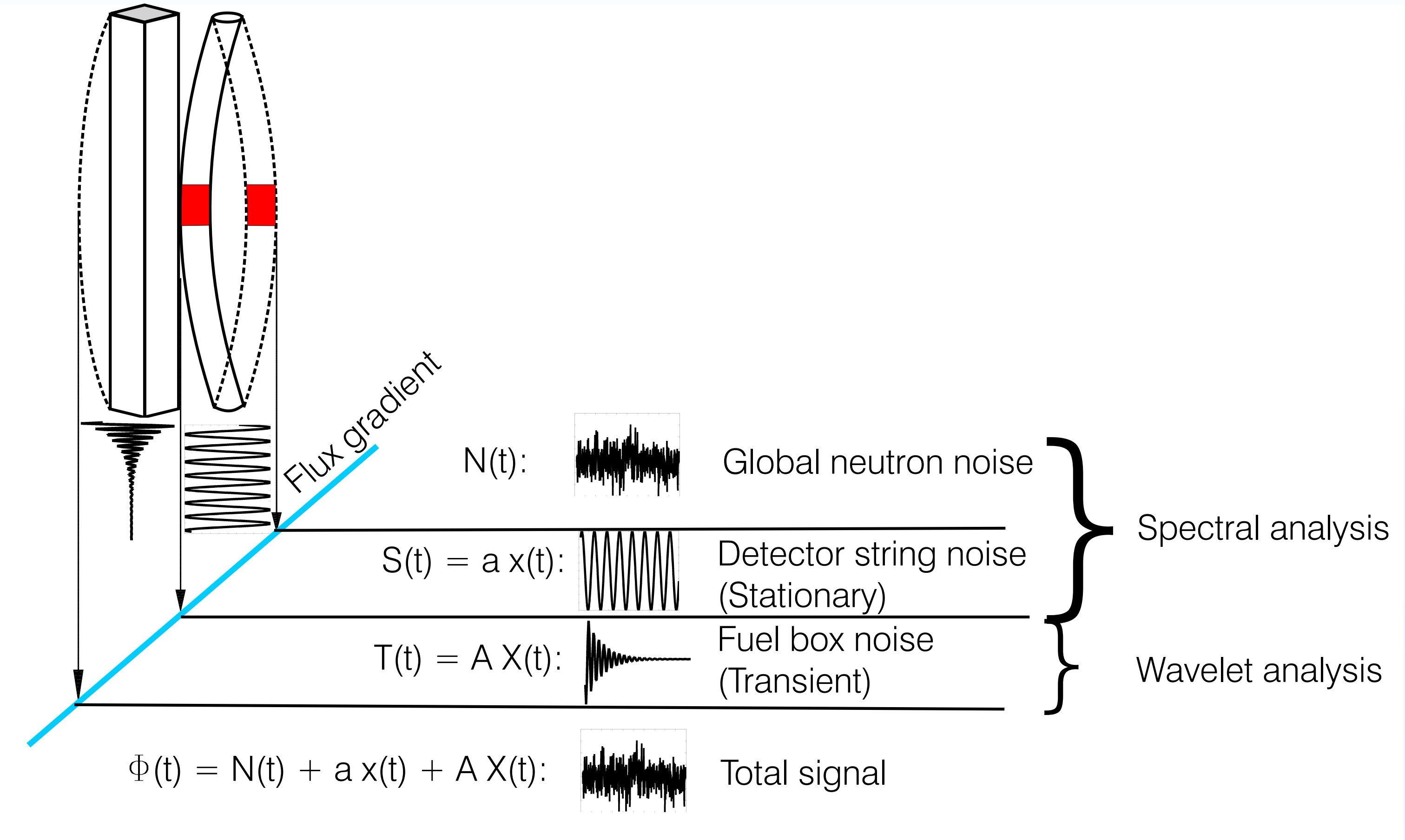
- Non-Stationary processes are intermittent or transient
  Fuel assembly vibrations due to detector impacting

Detector tube vibrations

- Stationary and Non-stationary processes
- Spectral and Wavelet analysis

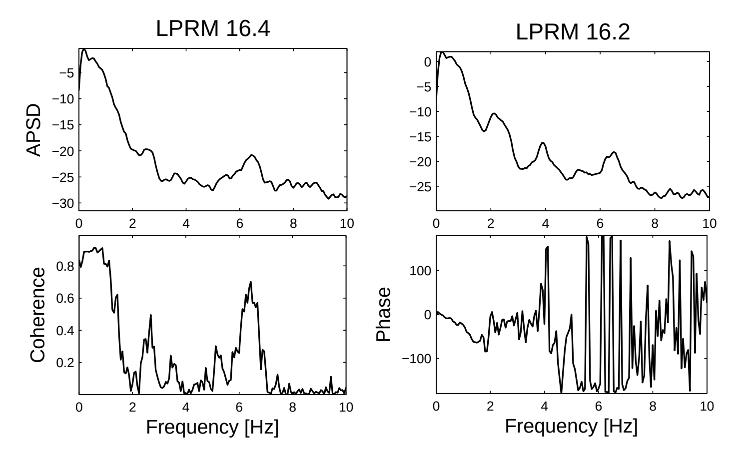


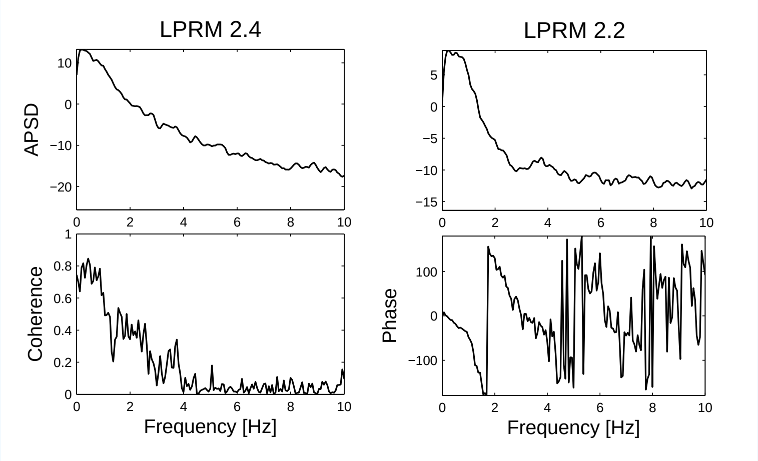
Signals


Flux gradient
N(t):
Global neutron noise
S(t) = a x(t):
Detector string noise (Stationary)
T(t) = A X(t):
Fuel box noise (Transient)
Φ(t) = N(t) + a x(t) + A X(t):
Total signal
Spectral analysis
Wavelet analysis

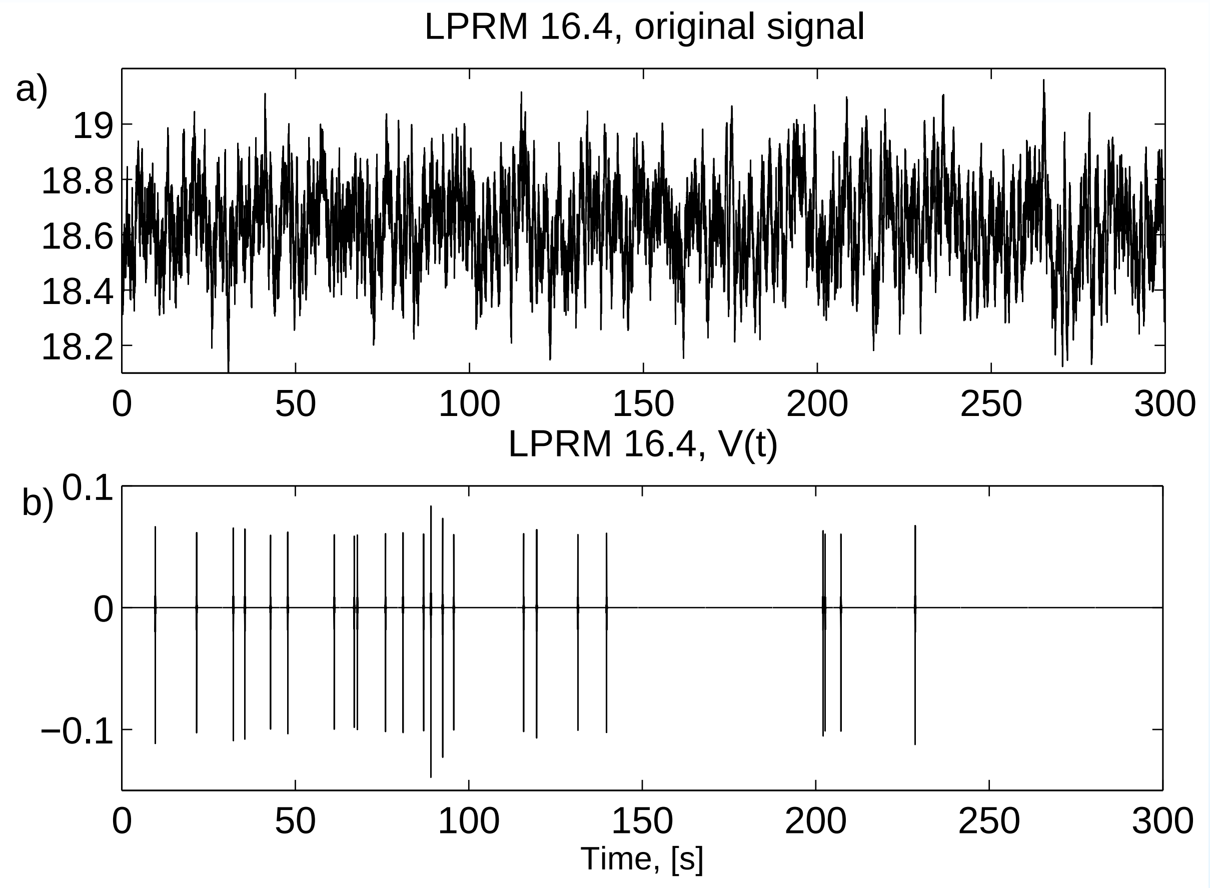
Spectral analysis

- Broad vibration peak at the eigenfrequency
- multiple peaks at double and triple frequencies
- zero phase around the eigenfrequency
- high coherence around the eigenfrequency



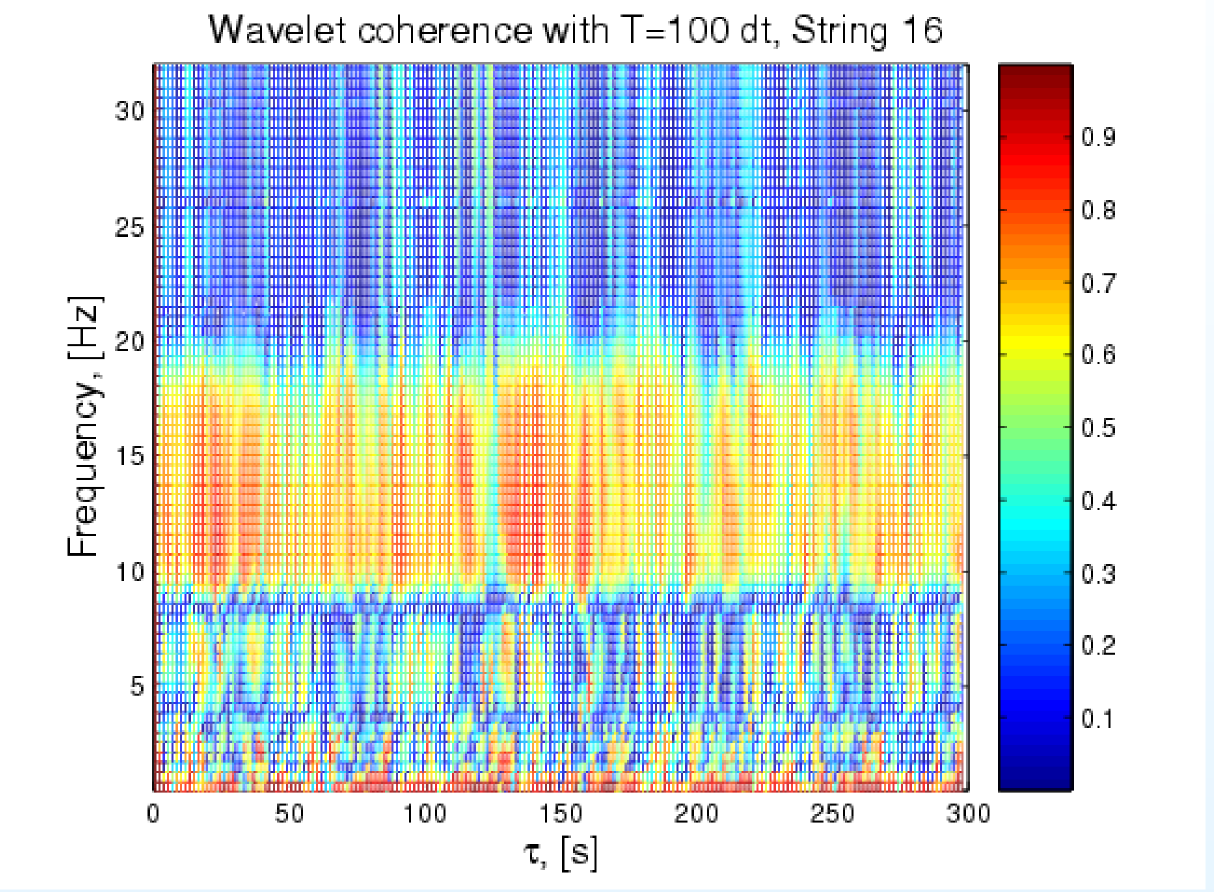


Discrete wavelet analysis



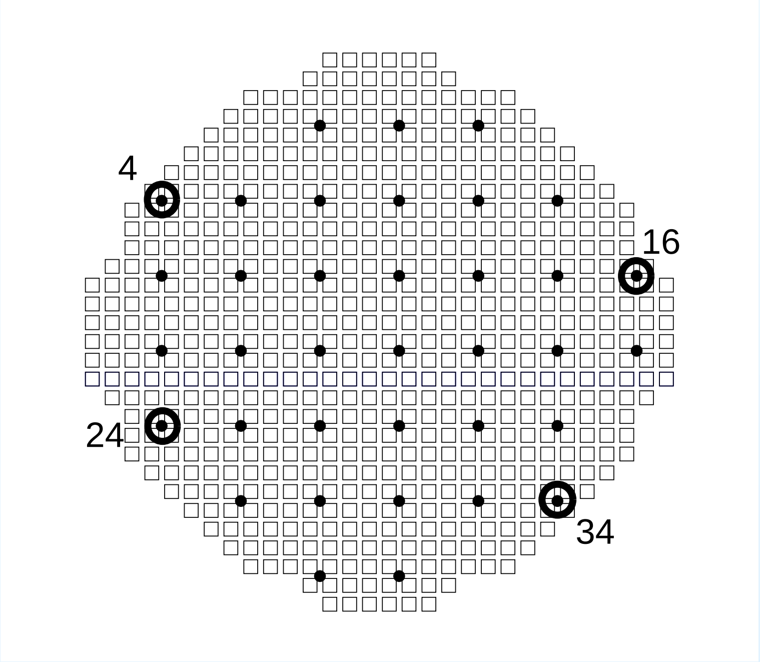
$$x(t) = x_M(t) + \sum_{n=1}^{n=M} d_n(t) \tag{1}$$

Continuous wavelet analysis



Results

- Four measurements at BOC 2002-2005 from the BWR Ringhals-1 have been analysed
- All with spectral and three with wavelet methods due to low sampling frequency in the first measurement
- four detector tubes are suspected for impacting in all or all but one of the measurements
- visual inspection in 2007 and analysis of measurement from 2006

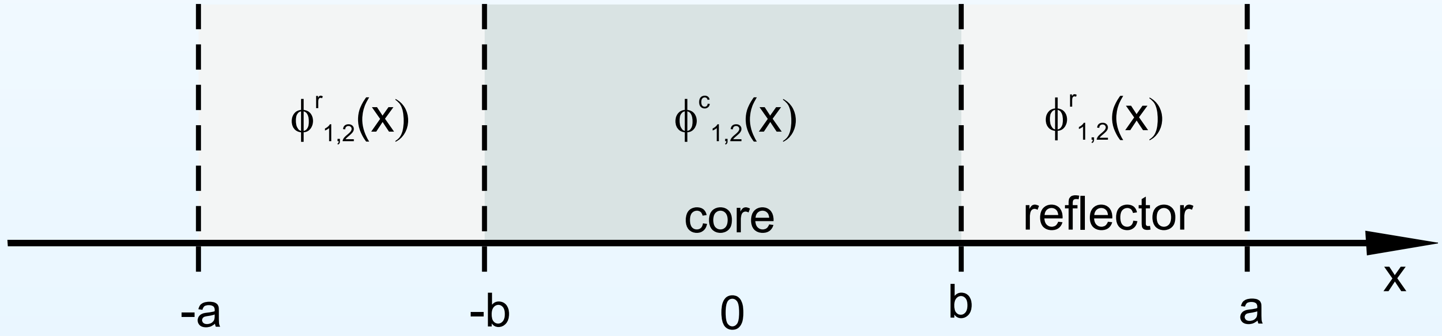


Core-barrel vibrations

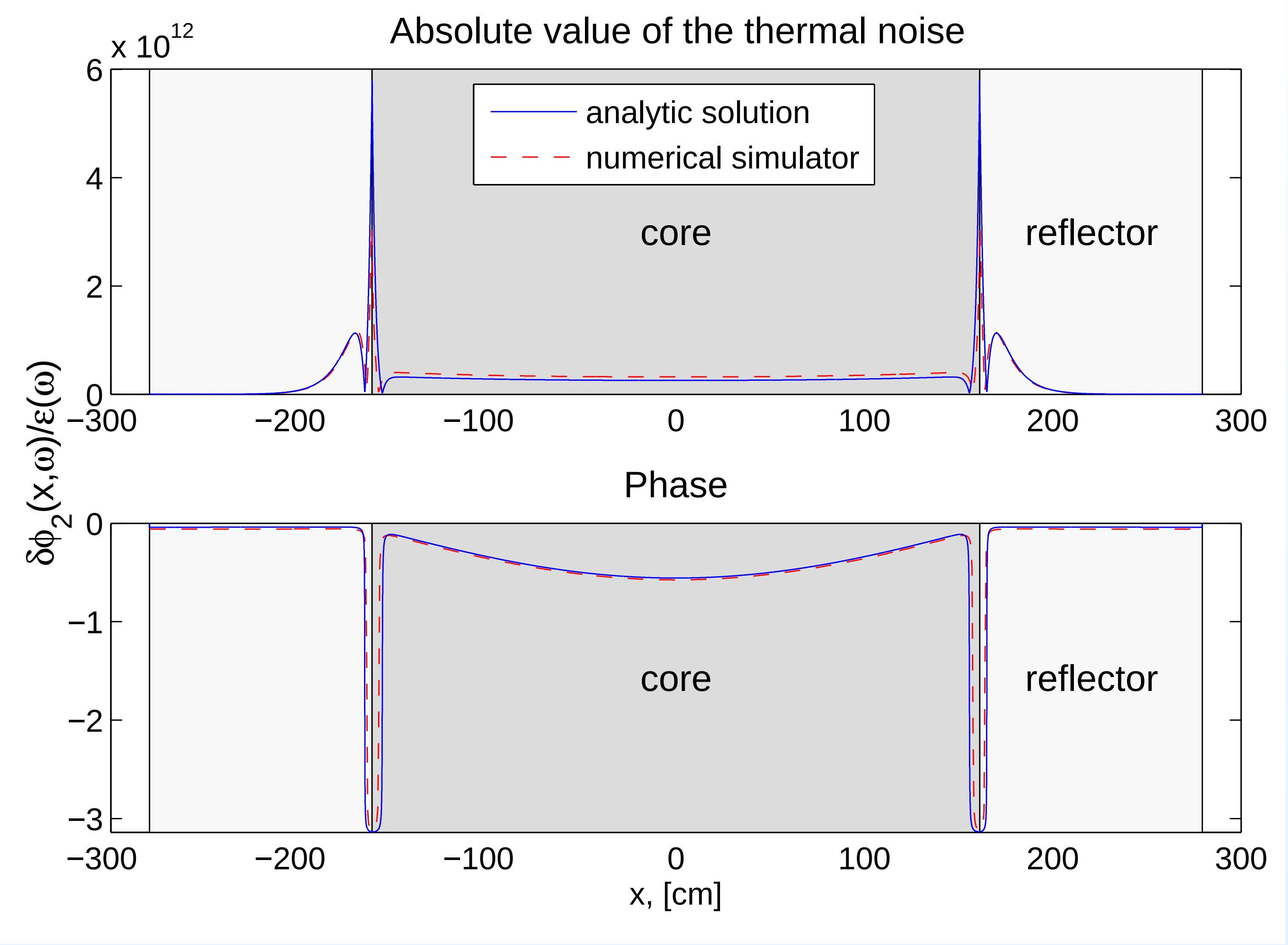
Shell mode vibration, in-core noise used to classify the vibration?

Model of the vibrations

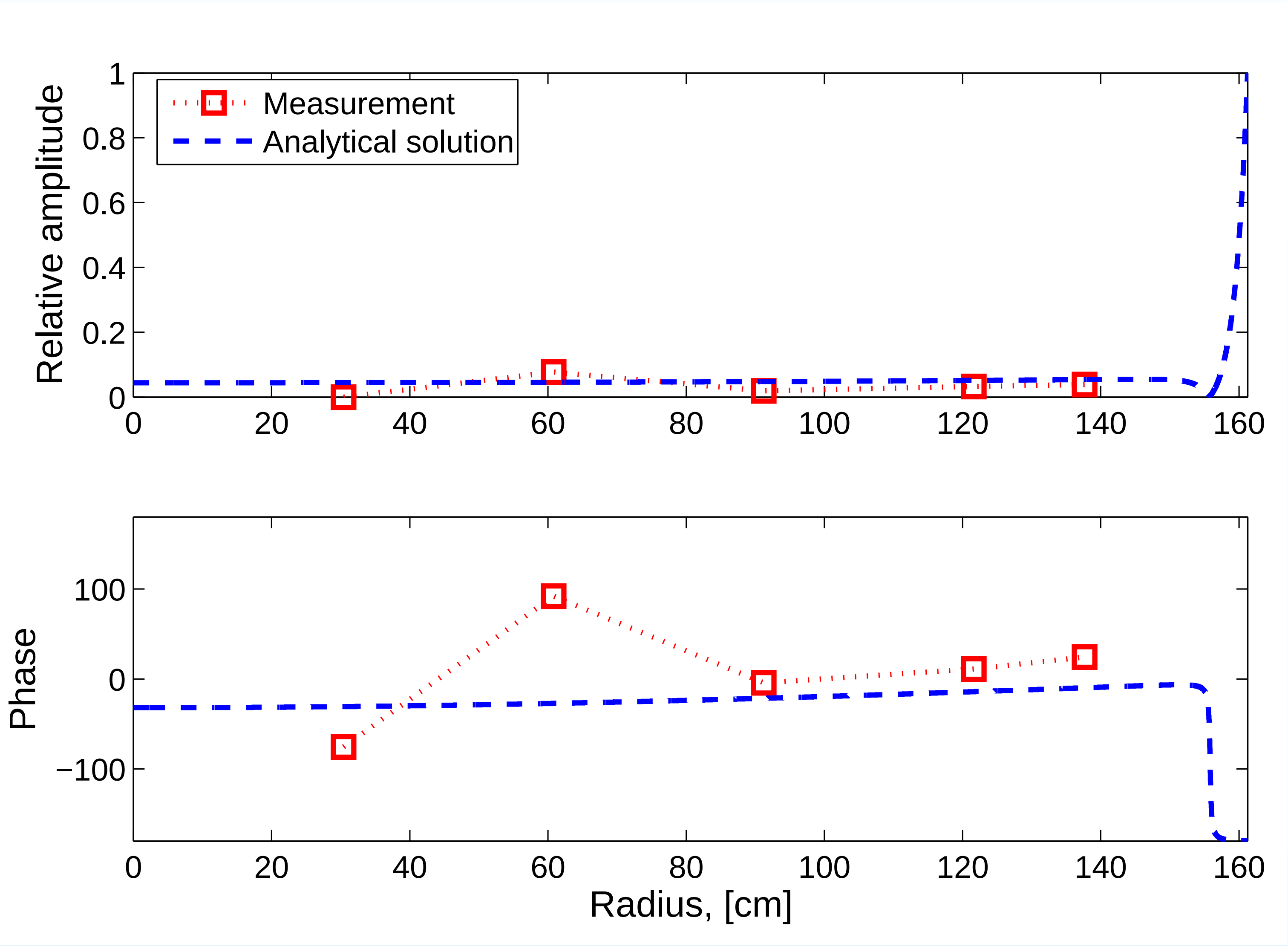
- 1-D analytical calculation of the induced in-core noise (2-group diffusion model)
- 1-D numerical calculation of the induce in-core noise (2-group diffusion model)
- comparison with measurement



Analytical and numerical results



Comparison with measurements



Conclusions

- Important to have access to real measurements and data from nuclear power plants
- In four of the five research areas the algorithms have been tested on real measurements and data with success.
- Wavelets can be of use in some applications but they are not a magic tool which solves all problems in signal processing.
- Some of the methods and algorithms elaborated in this thesis are in routinely use for diagnosing operating power reactors