Evaluation of infrasound in-situ calibration method on a 3-month measurement campaign

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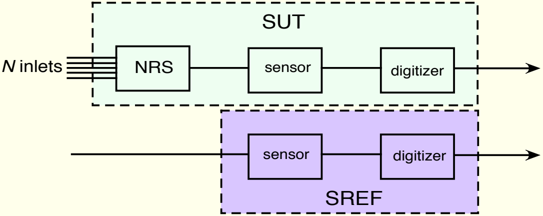
IMS study

In the framework of the calibration program, a study was conducted with the following theoretical and practical results:

- closed form expression for the asymptotic probability distributions of the spectrum ratio which is the base of the estimation;
- sizing the statistic of test for the **magnitude square coherence (MSC)** level;
- introducing a weighted estimator of the **system under test (SUT)** response based on the estimated value of the MSC;
- proposal of a filter bank analysis for the SUT estimation;
- providing a simple wind coherence model which explains an observed artefact of the **noise reduction system** (NRS), in relation with the wind velocity;
- **Evaluation on a measurement campaign at station IS26 during several months.**

Measurement chain [Kramer and al., ITW2015]



- the objective is the calibration of the SUT, which consists of the NRS, the sensor and a digitizer, based on the knowledge of the **system of reference (SREF)**;
- 2 kinds of signals: acoustic and non acoustic (typically wind) with different ranges of velocity;
- non spatially coherent signals are called "noise";
- acoustic signal is spatially coherent, in all frequency band of interest, regarding the size of the SUT.

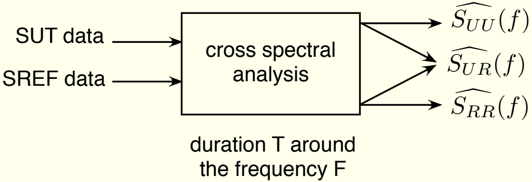
Undetermined problem

The model of signals writes:

$$\left\{\begin{array}{lcl} s_{\text{sut}}(t) & = & g_{\text{sut}}(t) \star (s(t) + w_{\text{sut}}(t)) \\ s_{\text{sref}}(t) & = & g_{\text{sref}}(t) \star (s(t) + w_{\text{sref}}(t)) \end{array}\right.$$

- problem is underdetermined: 4 unknowns for 2 observations;
- but with stationarity, uncorrelated noises, and "almost 0-noise" time segments, the problem is well-determined
- the MSC provides a way to test "almost 0-noise" time segments;
- theoretical results show that, to get an accuracy of $\pm 5\%$ on the gain, we need an MSC value greater than 0.96;
- but because only an estimate of the MSC is available, we have to threshold at about 0.98.

Performing process



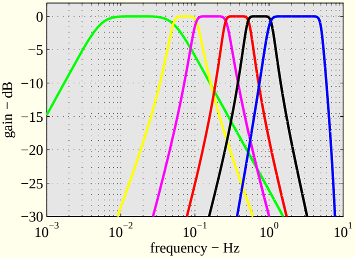
$$\begin{cases} s_{\text{sut}}(t) & \approx & g_{\text{sut}}(t) \star s(t) \\ s_{\text{sref}}(t) & \approx & g_{\text{sref}}(t) \star s(t) \end{cases}$$

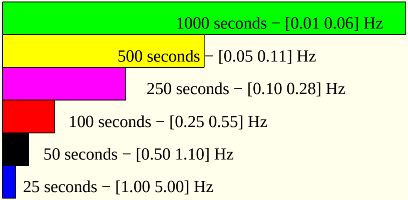
For stationary and “almost 0-noise” time segments we have:

$$\widehat{G_{\text{sut}}}(f) \approx G_{\text{sref}}(f) \times \frac{\widehat{S_{\text{UU}}}(f)}{\widehat{S_{\text{UR}}}(f)}$$

Manage the stationarity

- In relationship with the resolution but also to take into account the lack of stationarity on real dataset, we have considered a sequence of 6 durations in decreasing order with the frequency. A pre-filtering is also performed.



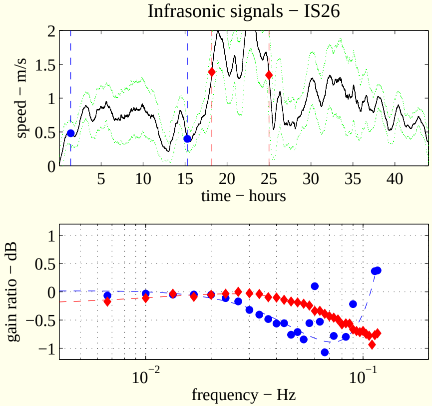


Sizing is empirically performed on real data; we have observed that the sizing is not critical.

NRS effect

If v denotes the wind velocity, the ratio $\frac{v}{f}$ can be interpreted as a "wavelength" [Alcoverro, al., JASA, 2002]. Therefore

- at very low frequency, the wind appears as spatially coherent for all SUT/SREF inlets. Therefore everything occurs as there is NO noise, and the MSC is almost 1,
- at high frequency, the wind appears as spatially NON coherent. Therefore the NRS plays its role to reduce the noise,
- around 0.8 Hz, a small part of the wind appears as spatially coherent for a few NRS inlets. Therefore a small dip artefact is observed.



Deployment [A.Kramer, al., ITW2015]

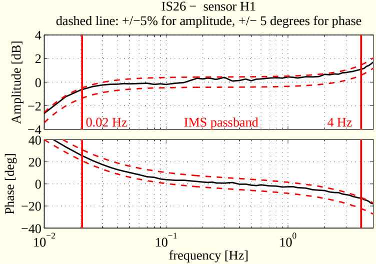
- 8 SUTs with 18 meter wind noise reduction system, each of them with 96 inlets;
- 8 SREFs have been deployed on May 2015;
- each reference sensor has been calibrated in the lab;
- wind velocity and direction are available at H1.

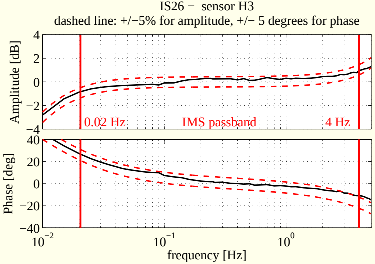
PTS requirements

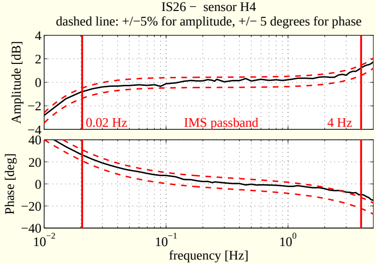
PTS specifications are:

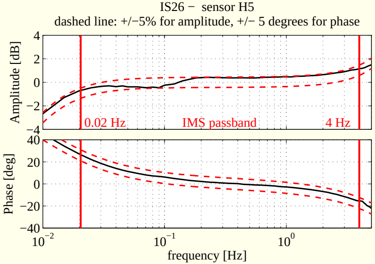
- bandwidth $[0.02 - 4]$ Hz;
- $\pm 5\%$ on the response magnitude, i.e. ± 0.43 in dB scale;
- the calibration is required at least once a year;
- no requirement on the phase but ... $\pm 5^\circ$ as for seismic requirements.

Averaging on a few months

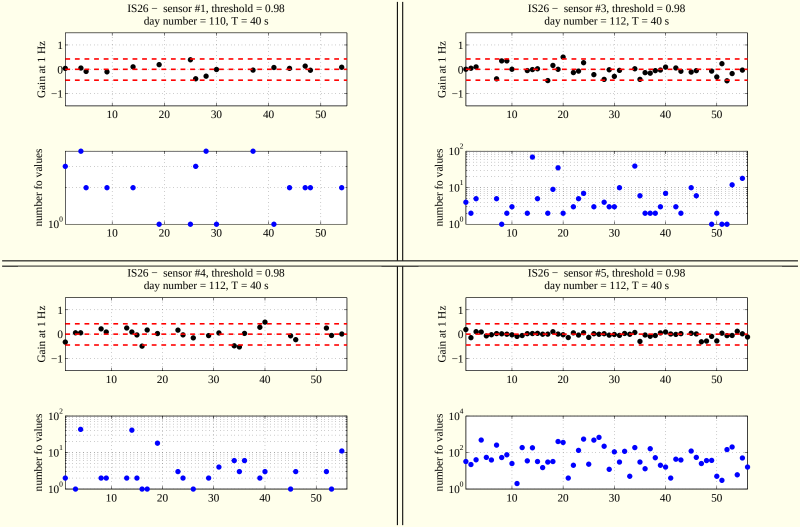








Temporal stability of successive gains at 1 Hz averaged on 2 days



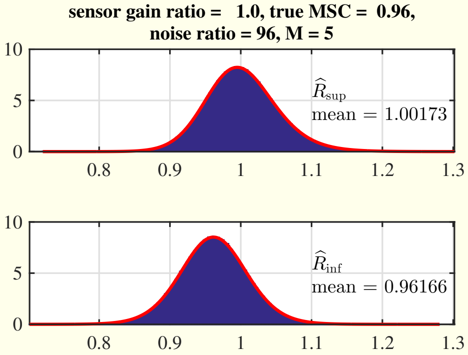
Conclusions

Conclusions:

- The numerical results obtained on a large campaign of measurements fully validate the calibration method;
- The experimental results obtained by couples of 2 days show a high stability in full agreement with the PTS requirements;

THANKS FOR YOUR ATTENTION

Ratio probability distribution



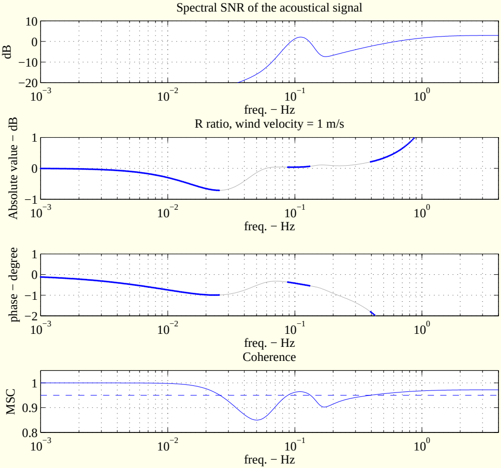
$$\widehat{R}_{\text{sup}} = \frac{\widehat{S}_{UU}}{|\widehat{S}_{RU}|}$$

$$\widehat{R}_{\text{inf}} = \frac{|\widehat{S}_{UR}|}{\widehat{S}_{RR}}$$

- True spectrum ratio : 1
- Power noise ratio: 96

- the r.v. $\widehat{R}_{\text{sup}} \geq \widehat{R}_{\text{inf}}$, but the true ratio could be outside ...;
- the r.v. $\widehat{R}_{\text{sup}}$ and $\widehat{R}_{\text{inf}}$ are biased w.r.t. the true ratio;
- the r.v. $\widehat{R}_{\text{sup}}$ and $\widehat{R}_{\text{inf}}$ are not independent;
- the r.v. $\alpha_1\widehat{R}_{\text{sup}} + \alpha_2\widehat{R}_{\text{inf}}$ is also biased; we have no way to chose α_i, except if we know the true power ratio.

NRS effect simulation



Rks

$\boxed{x_1,\cdots,x_{2000}}$ $\boxed{x_{2001},\cdots,x_{4000}}$ $\boxed{x_{4001},\cdots,x_{6000}}$ $\boxed{x_{6001},\cdots,x_{8000}}$ $\boxed{x_{8001},\cdots,x_{10000}}$

$\boxed{x_{1001},\cdots,x_{3000}}$ $\boxed{x_{3001},\cdots,x_{5000}}$ $\boxed{x_{5001},\cdots,x_{7000}}$ $\boxed{x_{7001},\cdots,x_{9000}}$

- If we have $N = 2000$ samples the resolution is $F_s/N = 0.01$ Hz. Therefore there is a possibility to decimate if the bandwidth is $B < 0.01$. But for sake of simplicity, we keep the common value F_s to all filters of the bank (no decimation).
- For each frequency bin, an averaging is applied on the $L = 9$ segments. If a few number of bins is required the fft algorithm is not needed.