

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

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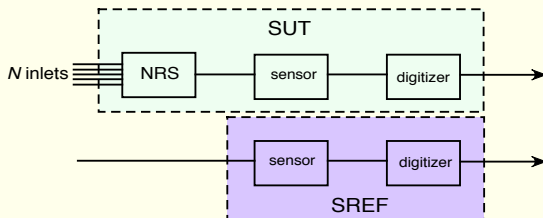
12 October, 2015

# 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.

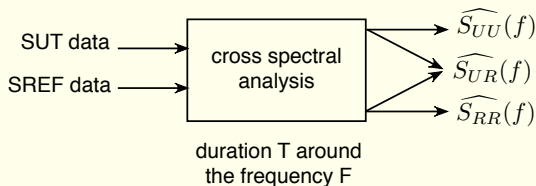
# Undetermined problem

The model of signals writes:

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

- 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



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

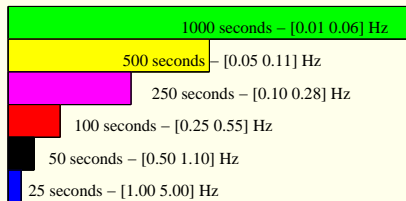
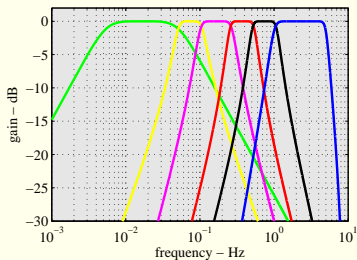
For stationary and “almost 0-noise” time segments we have:

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

if  $\alpha < 1$ , we underestimate  $G_{\text{sut}}$ .

## 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.

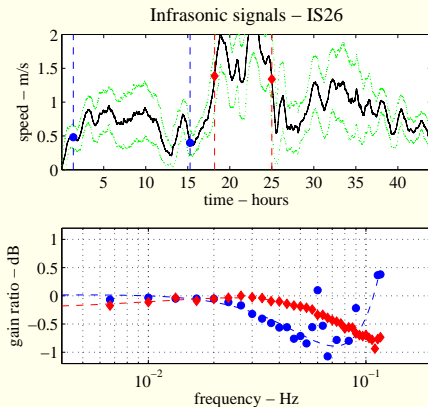


Sizing is empirically performed on real data; we have observed that the sizing is not critical.

# 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.

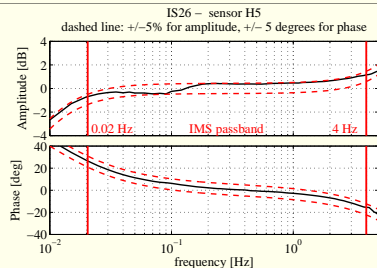
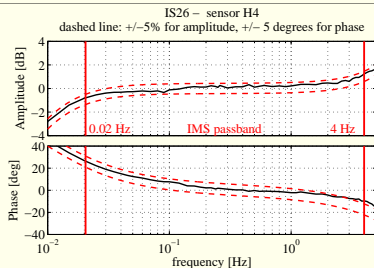
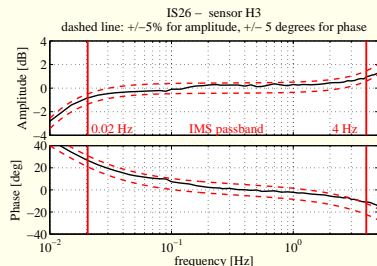
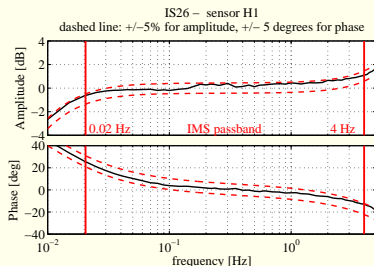


## PTS requirements

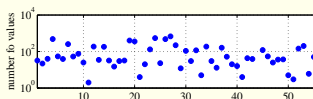
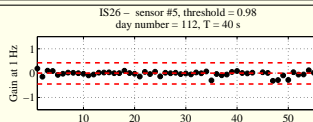
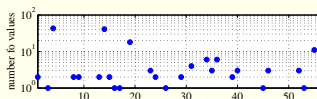
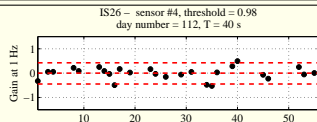
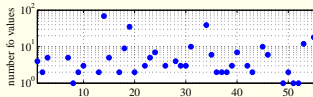
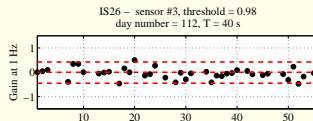
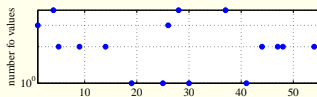
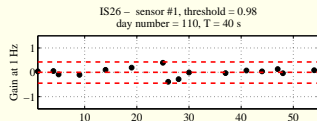
PTS specifications are:

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

## Averaging on a few months



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



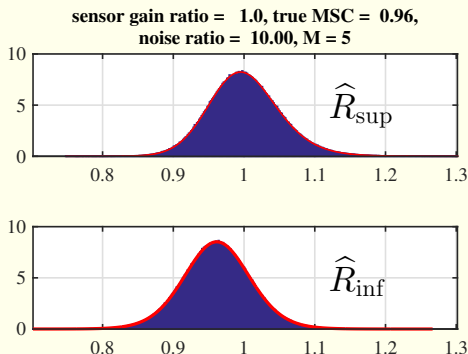
# Conclusions

## 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

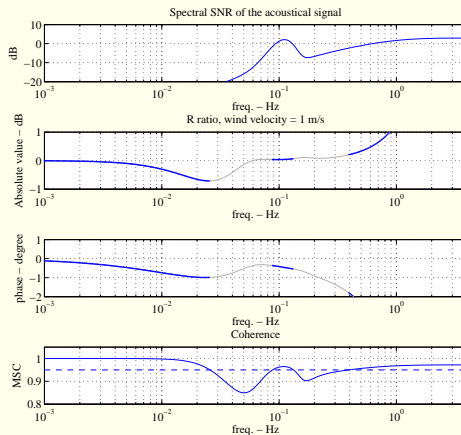


$$\hat{R}_{\text{sup}} = \frac{\hat{S}_{UU}}{\hat{S}_{RU}}$$

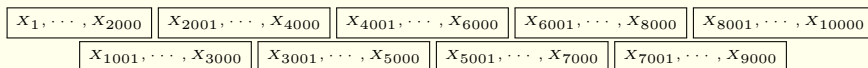
$$\hat{R}_{\text{inf}} = \frac{\hat{S}_{UR}}{\hat{S}_{RR}}$$

- the r.v.  $\hat{R}_{\text{sup}} \geq \hat{R}_{\text{inf}}$ , but no reason for the true ratio to be between them;
- the r.v.  $\hat{R}_{\text{sup}}$  and  $\hat{R}_{\text{inf}}$  are biased w.r.t. the true ratio;
- the r.v.  $\hat{R}_{\text{sup}}$  and  $\hat{R}_{\text{inf}}$  are not independent;
- the r.v.  $\alpha_1 \hat{R}_{\text{sup}} + \alpha_2 \hat{R}_{\text{inf}}$  is also biased; we have no way to chose  $\alpha_i$ ;

## NRS effect simulation



## Rks



- 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.