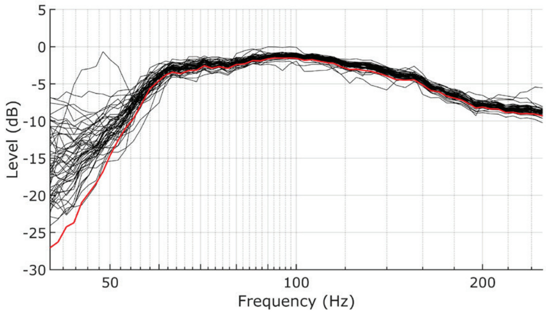
HOW TO IMPROVE MEASUREMENT QUALITY AT LOW FREQUENCIES?

- **Number of sweeps is the parameter to consider: use 8 outdoor and 4 indoor**
- **Duration of sweep has little influence**
- **Sweep level should be representative of the operating level of the loudspeaker system**

MEASUREMENT QUALITY AT LOW FREQUENCIES

Background noise affects the quality of measured frequency responses* of a loudspeaker system. Repeated measurements can reveal very different results, especially at low frequencies*, compromising optimal system tuning decisions (EQ*, quality of summation for time alignment, etc.).

Combination of multiple acquisitions with appropriate test signal parameters can help getting more consistent and qualitative measurements at low frequencies.



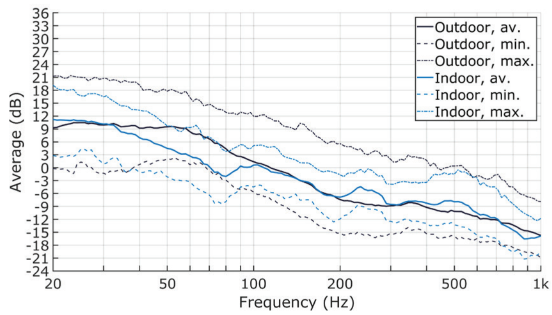
RECOMMENDATIONS TO IMPROVE MEASUREMENT QUALITY

Noise spectrum and variability over time

Typical noise spectrum has low-pass characteristic with a slope of -6 dB per octave.

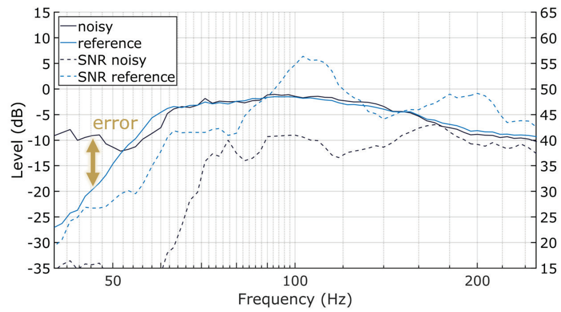
It is typically generated by workers (speech and impulsive noise), environmental noise and wind in microphones (outdoor), heating, ventilation and air-conditioning systems (indoor).

By nature, background noise in measurements is very unstable, with level varying by up to 20 dB outdoor and 12 dB indoor at a given frequency.



Measurement error and relation to Signal-to-Noise Ratio

The presence of background noise in a measurement may degrade the quality of the captured frequency response. In the low-frequency range, the measurement error is likely to increase around the cutoff frequency (-10 dB)* of the loudspeaker system. It is typically the lower cutoff frequency for a full-range system, as displayed here, but it can be either the lower or the higher cutoff frequency when measuring a subwoofer system. Indeed, when the useful signal level is dropping but the noise level remains high, the latter corrupts the measurements. The error is indirectly assessed through the Signal-to-Noise Ratio* (SNR, see Annex 2).



Measurement quality improvement by multiplying the number of sweeps

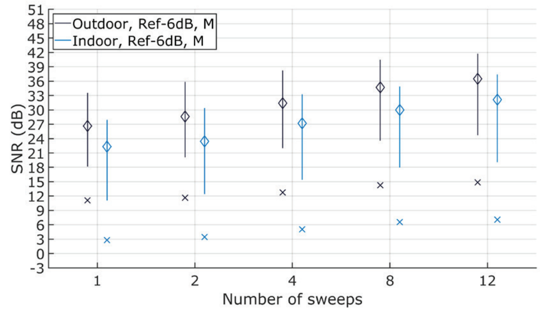
Combining multiple acquisitions of sweeps as a test signal is the recommended solution to improve the measurement quality and consistency. This is possible in the M1 tool.

To verify the effect of number of sweeps, sweep duration and sweep level on measurement quality and consistency, multiple series of 50 sweeps* were acquired, both indoor and outdoor. The sweeps are combined in consecutive groups of 1, 2, 4, 8 or 12 sweeps to form measurements, as in the M1 tool. The measurements are analyzed in terms of SNR, measurement error (indicator of quality) and measurement instability (indicator of consistency, see Annex 3). A statistical analysis is performed for each criterion using all measurements and focusing around the lower cutoff frequency of the corresponding loudspeaker systems (40 to 110 Hz outdoor, KARA; 25 to 70 Hz indoor, K1).

Effect on SNR

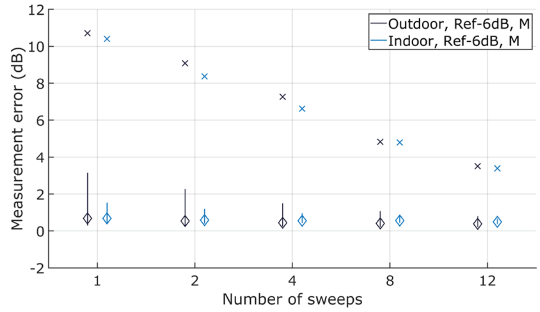
Increasing the number of sweeps from 1 to 8 improves the average SNR (diamond) by as much as 8 to 9 dB in the lower cutoff frequency region.

The improvement is not as significant for extreme low SNR values (x), which only improve 4 to 5 dB outdoor. These SNR values typically correspond to frequencies below the lower cutoff frequency where the signal level is very low.



Effect on magnitude error

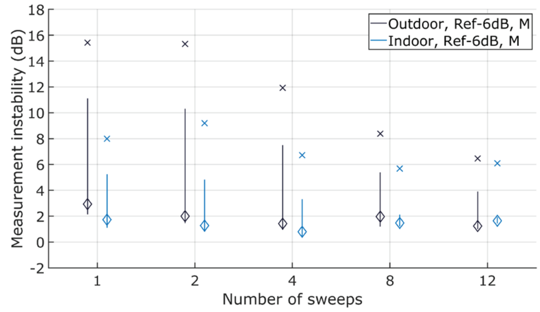
The average magnitude error (diamond) in the lower cutoff frequency region is small for all settings. Extreme values (x) reach up to 10 dB for 1 sweep and are reduced by approximately 2 dB per each doubling of the number of sweeps. High values (upper point of the vertical lines) are reduced as well. Overall, measurement quality is improved by increasing number of sweeps both indoor and outdoor.



Effect on measurement instability

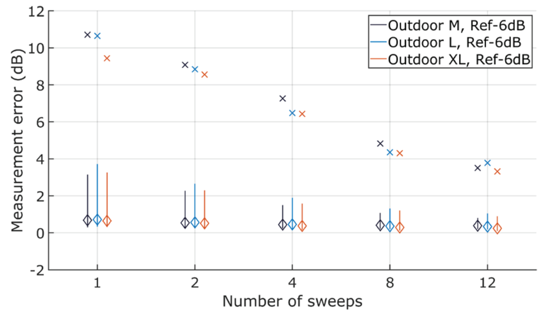
The measurement instability is an indicator of the consistency of the measurement from one take to the other (see Annex 3 for details of calculation).

Measurement instability is generally lower indoor than outdoor, and is reduced by multiplying the number of sweeps. Measurements performed at a few minutes' interval are more similar when computed from 4 sweeps indoor or 8 sweeps outdoor than from 1 sweep only.



Effect of sweep duration

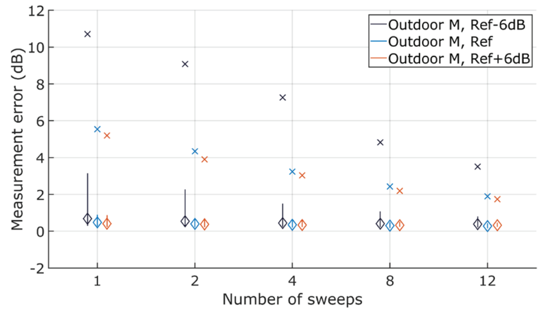
There is no clear influence of sweep duration on measurement error and therefore quality (see Annex 4 for details). However, the error reduction due to the increase of the number of sweeps is very consistent and does not depend on sweep duration.



Effect of sweep level

Increasing the sweep level may reduce the measurement error but is not always bringing the expected benefit (see Annex 4 for details). Increasing the level should also be used with care to avoid limitation and introduce non-linearities.

The multiplication of the number of sweeps tends to reduce the measurement error for all sweep levels.



GLOSSARY

Cutoff frequency (- x dB): Frequency at which the level is x dB lower than the maximum level in the magnitude response of a system, thereby defining the lower or upper limit of the operating frequency range.

EQ / Equalization: Tool or process aimed at electronically adjusting the frequency response of an audio system.

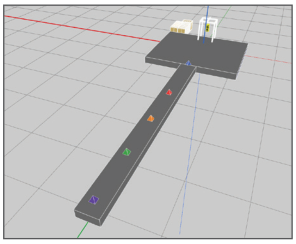
Frequency response: Characterization of the frequency-dependent variations induced by an element of the system on the signal.

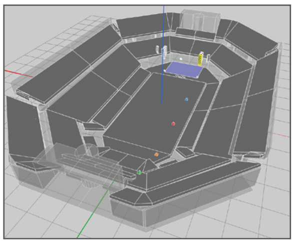
Low frequencies: Frequencies under 250 Hz when the hearing frequency range is split into three (low/medium/high).

Sweep: Short for logarithmic sine sweep: sine wave with frequency that increases at an exponential rate, covering the entire hearing frequency range over the duration of the signal.

ANNEX 1: MEASUREMENTS SETUP AND CONDITIONS

Measurements were performed both indoor and outdoor. Microphones were placed at regular distances, between 20 m and 75 m depending on the loudspeaker system coverage, although only measurements at 40 m are used in this study. Series of 50 sweeps were recorded using three sweep durations (M = 1.36s, L = 2.73s, XL = 5.46s), and three sweep gains (Reference level, Ref. -6dB, Ref. +6dB). The reference level is set to correspond to normal operating conditions of the system.

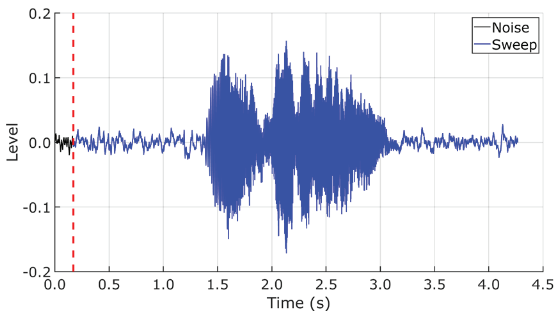




Outdoor: L-Acoustics, Paris, France	**Indoor:** AccorHotels Arena, Paris, France
8 KARA	12 K1 + 4 K2 down

ANNEX 2: ESTIMATION OF SNR IN M1 TOOL

The SNR is evaluated by comparing the energy of the background noise with the energy of the recorded signal while playing the sweep. It is however not possible to extract the background noise during the playback of the sweep. Therefore, the M1 tool records a small snapshot of the noise before starting the sweep.



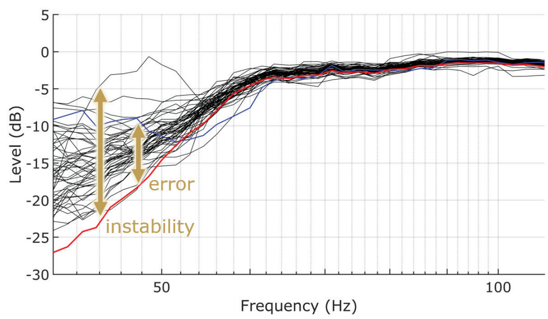
The M1 tool compares the level of the recorded sweep (including the background noise) with the level of the noise snapshot (normalized to the length of the recording). The SNR can either be calculated broadband or for a given frequency using FFT on both noise snapshot and recorded signal.

Note that the SNR estimation in the M1 tool corresponds to an estimation of signal+noise over noise ratio, which explains why negative values are seldom. A 0 dB value would only be observed if there is no signal and the noise is identical between the snapshot and the recording.

ANNEX 3: CALCULATION OF MEASUREMENT ERROR AND INSTABILITY

Measurements are combinations of N=1, 2, 4, 8, or 12 consecutive sweeps (amplitude average at low frequencies). Therefore, 50, 49, 47, 43 and 39 measurements are obtained for each series of 50 sweeps recording respectively.

A reference frequency response is calculated for each series of 50 sweeps as the linear average of all sweeps. Throughout the white paper, 1/3rd octave smoothing is used. It corresponds to auditory bandwidth at low frequencies.



The **measurement error** is calculated at each frequency as the difference, in dB, between a given measurement, in blue, and the reference frequency response, in red.

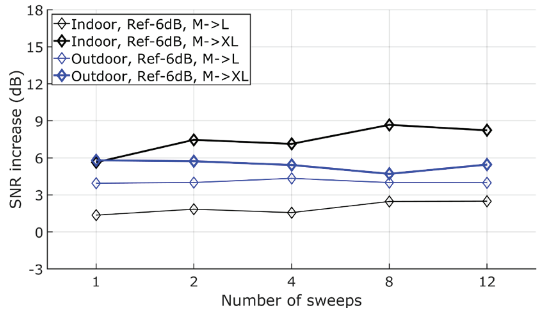
The **measurement instability** is calculated as the spread, in dB, of all measurements.

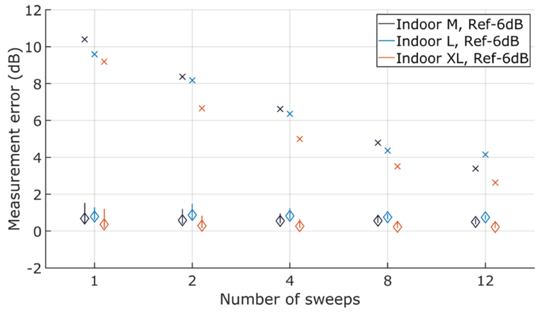
Measurement error and instability are calculated around the lower cutoff frequency of the loudspeaker system, half an octave below and an octave above, as shown in the previous figure for KARA (40 to 110 Hz).

In the figures, we use the following display:

- Diamond: median, referred to as "average" value,
- vertical bar: 25th to 75th percentile, referred to as "low" and "high" values,
- x: 5th or 95th percentile depending on metric, referred to as "extreme" values.

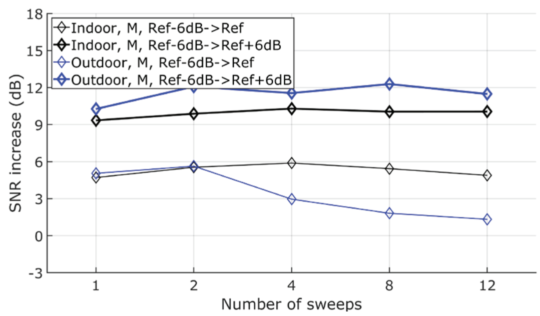
ANNEX 4: LEVEL AND SWEEP DURATION INFLUENCE ON MEASUREMENT ERROR

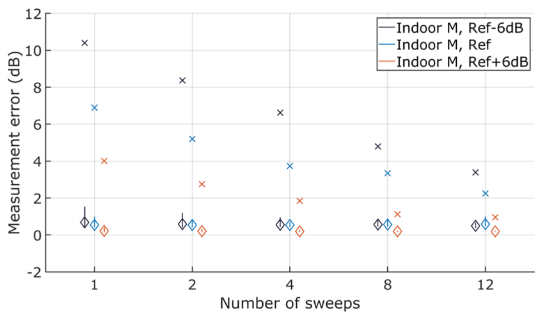




The theoretical SNR increase is 3 dB when doubling sweep duration, if the background noise is perfectly decorrelated from the signal. This tendency can be globally observed in measurements with an increase of 3 dB from M to L (double length) and about 6 dB in average from M to XL (quadruple length).

However, the reduction of measurement error is at best limited. Increasing the duration of the sweep increases not only the duration of the measurement session but also the chance of capturing intermittent noises, to the detriment of the measurement quality.





There is an obvious benefit of sweep level increase in terms of SNR. Theoretically, any level change should automatically translate into an equivalent SNR variation. However, because of the variable nature of background, this effect is not always observed. A level increase may reduce the measurement error, but a plateau can be reached where the measurement error does not decrease any longer unless the number of sweeps is increased.