BUILDING AND ROOM ACOUSTICS MEASUREMENTS WITH SINE-SWEEP TECHNIQUE

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Introduction

In a classical measurement of reverberation time, the room is excited with a noise signal. The decay rate of the sound pressure level after the excitation is switched off, is used to determine the reverberation time. The decay will have a spread in the value due to the randomness of the excitation. Averaging is therefore normally required.

M.R. Schroeder [1] has shown that the expected decay may be obtained without averaging by processing the impulse response as observed between the excitation (loudspeaker signal) and the observation (microphone) directly. This holds as long as the system is linear and time-invariant. The theory may be extended and applied also to the transmission from the source to the receiver room.

If the noise is switched off at $t = 0$, the expected level $L(t)$ for $t \geq 0$, is given by:

$$L(t) = 10\log\left\{ N_0 \int_t^{\infty} h^2(\tau)d\tau \right\} \qquad (1)$$

where N_0 is a constant specifying the spectral density of the noise excitation and $h(t)$ is the impulse response. In addition to the reverberation time, also the level before the noise was switched off can be found by setting $t = 0$ in equation (1).

Traditionally, pulse excitation has been used as excitation to measure the impulse response. The impulse response is obtained directly as response to such excitation, but will normally have limited dynamic range due to background noise and limitation in the excitation level.

Correlation based techniques with maximum length sequence (MLS) or swept-sine as excitation signals brought further improvements in obtaining impulse response. In the 1980s, the popularity of MLS based techniques grow due to the ability to use computer features available at that time. Nice features, such as extended signal-to-noise ratio, could then be provided. The signal processing behind an MLS measurement is usually based on the Fast Hadamard Transform. MLS based techniques have some undesirable properties such as vulnerability to distortion and time variance.

All those facts as well as the efforts of International Organization for Standardization (ISO) to standardize the method for applications in building acoustics [3], motivated the implementation of swept-sine method based measurement as a feature of a sound analyser.

Swept-Sine Method

Generally speaking, any kind of excitation signal can be used to determine the impulse response and the respective frequency response function of any linear and time-invariant system, provided that it contains enough energy at every frequency of interest. The impulse response can be obtained from the response to the excitation by deconvolution, or the frequency response function can be obtained by dividing the output spectrum of the system under test by the spectrum of the input. The last implies Fourier-transformation of the input- and output-signal in order to perform the division in the spectral domain.

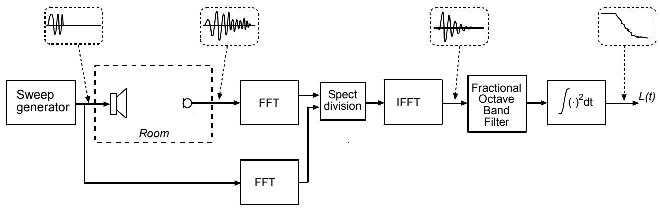

***Figure 1:** Block diagram of the processing of signals to obtain the level and the reverberation time for a single room based on the new method using sinusoidal sweep for the excitation.*

Using sinusoidal sweeps as the excitation signals offers a couple of crucial advantages compared to most other excitation signals such as: reduced sensitivity to environmental stability and elimination of the deterioration of the effective signal-to-noise ratio due to harmonic distortions. As all harmonic distortion may be deleted from the results, the sinusoidal excitation signal can be fed with substantially more power than MLS-signals. At quiet sites, sweep measurements can provide signal-to-noise ratios in excess of 100 dB.

Measurements with sweeps are less vulnerable to the deleterious effects of time variance. In outdoor measurements, these frequently occur due to air movement. Under windy weather conditions, sweeps are sometimes the only viable option when measuring impulse responses over long distances.

The sweep also makes it possible to control the shape of the spectrum by modifying the sweep-speed. The exponentially swept-sine is suitable for measurements in building and

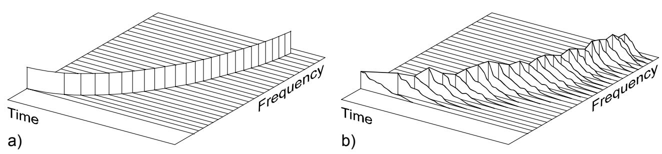

***Figure 2:** Illustration of the time-frequency distribution for an exponential sinusoidal sweep: excitation a) and response b). The received frequency components are delayed due to reverberation.*

room acoustics as it provides the same energy in each fractional-octave band. The spectral response will then have a spectral shape as a pink noise, which normally, by the classical method, is used for excitation.

Increasing the sweep duration feeds more acoustic energy into the room to be measured, and thus increases the effective signal-to-noise ratio. In room and building acoustics, the reverberation time is normally longest for the lower frequencies. When very long sweeps (many seconds) are being used, the final gap only has to accommodate the reverberation at the highest frequencies, which generally is short. This holds because all the lower frequency components arrive while the excitation signal is still sweeping upwards, as illustrated in figure 2. Therefore, an exponential upward sweep provides a shorter gap i.e. shorter overall measurement time than sweeping in the other direction. But an even more important feature of upward sweeps is that this gives the ability to separate harmonic distortion components from the measured impulse response, [2].

Comparison of MLS and swept-sine performance

The MLS technique has been widely used in acoustical measurements due to its positive features compared to classical methods, such as reduced statistical spread of results, enhanced signal-to-noise ratio and an reduced lower limit for the measured reverberation time. Periodic deterministic noise sequences (such as MLS) are extremely vulnerable to even a slight time variance. Increased measurement length is often used in order to further increase signal-to-noise ratio in an MLS measurement. Unfortunately this also increases vulnerability to time variance. Excitation with a single sweep demonstrates a considerable less sensitivity to the time variations.

Since harmonic components may be removed from the response to a sweep, higher loudspeaker output levels can be used. This will result in an increased signal-to-noise ratio. In an MLS measured response, the distortion will appear as spurious peaks that hardly can be removed. This reduces the signal-to-noise ratio and may deteriorate the measured impulse response.

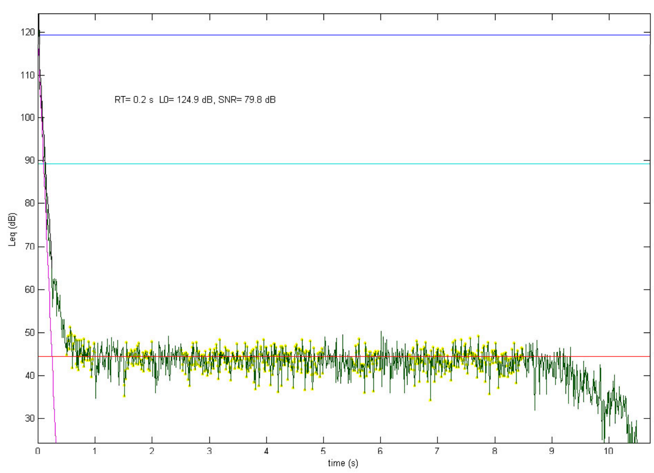

Figure 3*: Example of a result obtained by a swept-sine based measurement for the 1000 Hz third-octave band. The level and reverberation time is calculated from the response. The estimated reverberation time for 30 dB dynamic range is indicated by a straight line.*

Figure 4*: The swept-sine method may be implemented in a sound level meter like Nor121.*

Another advantage is that the swept-sine method is more tolerant to clock synchronization error between the excitation and the measured response compared to an MLS based system.

Implementation in sound level meter *Nor121*

The swept-sine method has been implemented in the sound level meter Norsonic *Nor121*. The sound analyser with its 120 dB dynamic range and widely used building acoustics measurement mode was a logical choice as a platform for the implementation. The existing user-interface in the building acoustic mode has been kept with small extensions. The sine sweep generator and the whole measurement algorithm are installed in the instrument as a software option.

For building acoustic applications, a filtered impulse-response is measured for each octave- or third-octave band. The sweep starts from a frequency below the lower band-edge frequency for the lowest band and continues to above the upper band-edge frequency for the upper band to be measured. Filters satisfy the requirements to a class 1 filter according to IEC 61260 and have a short virtual reverberation time.

The Nor121 based implementation contains an automatic detection of the start of the sweep. This allows the use of a pre-recorded excitation signal or a signal generated by another instrument.

With present implementation, it is possible to measure in octave or third-octave bands within the frequency range 50 Hz to 20 kHz i.e. 9 octaves or 27 third-octave bands. Sweep durations are 19.2 s for octave and 38.4 s for third-octave bands. The measured signal-to-noise ratio may exceed 100 dB. The length of the measured impulse response is more than 10 s at 50 Hz to more than 2 s at 20 kHz.

References

[1] Schroeder, M.R., "New Method of Measuring Reverberation Time". J. Acoust. Soc. Am., vol. 37 (1965) pp. 409 – 412.

[2] Müller, S. and Massarini, P.: “Transfer-Function Measurement with Sweeps”. J. Audio Eng. Soc., vol. 49 (2001) pp. 443-471.

[3] ISO/1CD 18233 Acoustics - Application of new measurement methods in building acoustics (First committee draft).