Time Selective Measurements with a Logarithmically Swept Sine

A time selective measurement of a frequency response is (directly or indirectly) based on a measurement of the impulse response, where a well-defined time window is applied to the impulse response. The frequency response is simply the Fourier transform of the impulse response. Time selective measurements are often used in electro acoustics to make simulated free-field measurements of transducers. This is to isolate the directly transmitted, “free-field” sound from reflections due to the surroundings. By using a time window applied to the impulse response, it is possible to obtain results similar to those obtained in a non-echoic environment.

The accuracy of such measurements depends on several factors. Some basic properties apply generally to all implementations, while some others relate to the actual algorithm and specific implementation.

The most basic requirement for simulated free-field measurements is that the reflections must not arrive so early that they overlap the impulse response of the direct sound. If the reflections arrive so early that they overlap the direct sound, the time window will cut away some of the impulse response of the direct sound, and the measurement will loose accuracy. This applies to all time selective methods.

If the system is perfectly linear then the impulse response can be obtained by a direct measurement, simply by applying a short pulse and recording the resulting “impulse response”. In practice, however, such measurements will usually suffer from either a poor S/N ratio due to the low energy in the short pulse or suffer from overloading if the pulse is increased to improve the S/N ratio. The crest factor of the excitation is simply too high for practical use.

Various types of noise signals have a much lower crest factor and combined with cross spectrum or cross correlation analysis, the response of the linear behavior can be measured. Most systems, however, are not perfectly linear. The non-linearity not only set limits for which test signals can be used, but also introduces the need for characterizing this non-linearity, i.e. measuring the distortion.

The Time Delay Spectrometry (TDS) introduced by Heyser uses a linear swept sine for Time selective measurements. Like most other swept sine algorithms, it is based on the assumption that the response at a certain point in time represents the response to just one particular frequency. That is approximately correct if the sweep rate is low enough. A delay in the system under test, however, will result in a frequency shift (proportional to the delay) of the measured response. If the signal follows different paths with different delays (e.g. direct and reflected sound from a loudspeaker), the signal measured will contain slightly different frequencies. Tracking the response with a narrow bandpass filter therefore makes it possible to isolate one path (e.g. just the direct sound from a loudspeaker) from the others. It is proven that such a tracking bandpass filter is simply equivalent to applying a time window to the impulse response. In addition, a tracking bandpass filter can also be used to track the harmonics of the swept signal, thereby measure harmonic distortion as well (and still in a time selective way). However, the sweep rate must be limited in order to measure the fundamental correctly, measuring harmonics at low frequencies put further constraints on the maximum sweep rate.

The Time Selective Response (TSR) introduced by Brüel & Kjær also uses a linear swept sine, but removes the limitation on the sweep rate (by mathematical refinement of the algorithm) so the fundamental response is measured correctly even with very fast sweeps. For measuring distortion at low frequencies, the same constraints still applies to the maximum sweep rate for TSR, as for TDS.

Both TDS and TSR, with the tracking bandpass filter approach, are linked to using a linear sweep. The linear sweep, however, is not very ideal, if the measurements shall cover a broad frequency range:

- Often the S/N ratio at low frequencies is critical, but the linear sweep has relatively little energy at low frequencies: Half of the time (and thereby half of the energy) is used in the highest octave, only one fourth of the time (and of the energy) is used in the second highest octave, etc. In order to achieve a sufficient S/N ratio at low frequencies a very slow sweep has to be used, wasting time (and energy) at high frequencies.

- The linear sweep also becomes very slow, if the sweep rate has to be kept very low in order to measure distortion at low frequencies – eventually even slower than required for a sufficient S/N ratio.

The “log TSR” implemented in SoundCheck uses a logarithmically swept sine for fast time selective measurements of both the fundamental response and of distortion. The logarithmically swept sine is much more suitable for electro acoustical measurements:

- The logarithmic sweep uses the same time (and energy) for every octave, which is much more suitable achieving a good S/N ration for all frequencies in typical electro acoustical measurements.
- The logarithmic sweep also provides a sweep rate, which is low at low frequencies but increases with the frequency. That makes it possible to measure distortion also at low frequencies without making the whole sweep very slow.

As a logarithmically swept sine is used the “tracking bandpass filter“ method is not applicable for the analysis. Instead, cross correlation analysis is used. By doing the cross correlation of the response signal with a special energy weighted version of the excitation signal, the impulse response is found directly, and from that the frequency response is easily calculated as well.

It is thereby possible to obtain a unique combination of features:

- Time selectivity.
- The very suitable energy distribution of the logarithmic sweep (increased energy at low frequencies).
- The capability of measuring distortion due to the sine based nature of the signal.
- ... and in a effective way measure distortion even at low frequencies due to the sweep rate of the logarithmic sweep being low only at low frequencies just where it is needed.