Auralization and Assessment of Loudspeaker Distortion

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Introduction

Loudspeaker distortions influence the reproduced sound quality. Metrics that are used by the department of engineering may not be suitable to describe sound quality for the departments of management or marketing, which often prefer personal impressions before physical metrics. An improvement of a product's sound quality is always desired, but the connected costs have to be justified between the engineers and management/marketing.

Loudspeaker distortions can be separated in different components - a signal flow plan is shown in Figure 1. Regular linear distortions (e.g. frequency response, room modes) are present in small and large signal domain. The influence of regular nonlinear distortions (e.g. nonlinear force factor and stiffness of transducer) is negligible in small signal domain and grows as the stimulus amplitude increases. The probability to excite defects (e.g. rubbing voice coil, loose particles and parasitic vibrations) increases with higher amplitudes as well. Noise is not dependent on the stimulus.

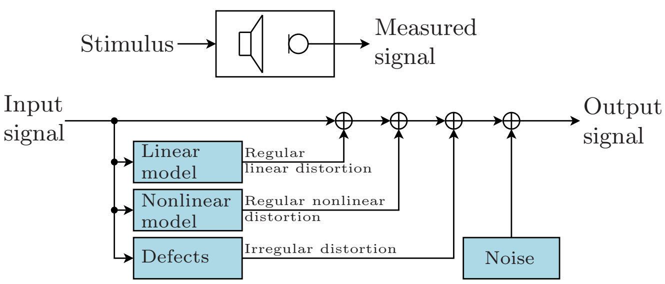

Figure 1: Signal flow plan of generation of distortion in loudspeakers (adopted from [1])

Objective measurement techniques are able to detect defects reliably and fast. However, PASS/FAIL limits often deliver no information, whether the defects are audible or not. A perceptual evaluation can predict the audibility of defects, but is only meaningful, if the loudspeaker performs in its final application and critical stimuli, as well as the usage situation (e.g. rolling and propulsion noise in automobile applications) are defined.

The definition of quality limits at the end of the assembly line is often a trade-off between costs and quality. The associated dialog between the departments of management, marketing and development is assisted with the presented *Perceptual Assessment Module*. Current production and long-term production goals can be compared without the need to perform listening tests at the end of the production line. The *Auralization* is performed by scaling the distortion signal (attenuation or enhancement).

Distortion Isolation and Auralization

The distortion isolation is based on decomposition: All signal components, that are present in the test signal y_{test}, but not in the reference signal y_{ref} are judged as distortions y_{err} (difference signal)

$$y_{\text{err}}(t) = y_{\text{test}}(t) - y_{\text{ref}}(t). \tag{1}$$

The distortions are scaled with the *Distortion Scaling Factor* S_{dis} (in decibel) and added to the reference signal to obtain responses with enhanced or attenuated distortions (Figure 2):

$$y_{\text{test},S\text{dis}}(t) = y_{\text{ref}}(t) + y_{\text{err}}(t) \cdot 10^{S_{\text{dis}}/20}. \tag{2}$$

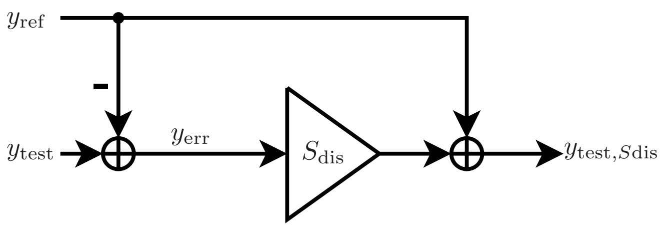

Figure 2: Distortion isolation and *Auralization*

The distortion signal comprises distortion components defined by the choice of reference and test signal. Table 1 shows exemplary combinations. An example for the response simulation with a digital model is given in [5].

Table 1: Definition of distortion signal ("output" refers to the response of a transducer or digital model to a stimulus)

Difference	Test	Reference
Regular linear distortion	Transducer output at small amplitudes	Stimulus
Regular nonlinear distortion	Total output of digital model	Linear output of digital model
Irregular nonlinear distortion	Transducer output at high amplitudes	Total output of digital model
Regular linear and regular nonlinear distortion	Total output of digital model	Stimulus
Regular linear and regular nonlinear distortion	Transducer output at high amplitudes	Transducer output at small amplitudes
All distortion	Transducer output at high amplitudes	Stimulus

One example for a simple measurement technique is shown in Figure 3. The influence of noise is assumed to be small.

Regular linear distortions are included in both responses and thus excluded from the distortion signal (second last line in Table 1). Nonlinear distortions (regular and irregular) are assumed to be present only in the large signal domain response (test signal).

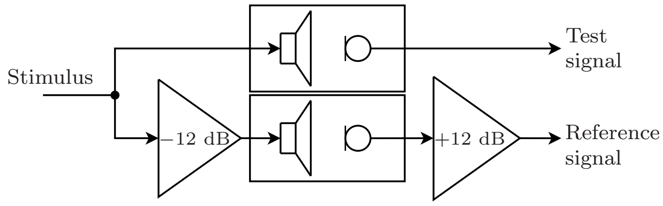

Figure 3: Measurement of small and large signal domain response

The reference signal and the synthesized test signal are fed into the perceptual objective assessment and exported as audio files. These files can be used for subjective evaluations.

Perceptual Objective Assessment

The perceptual objective assessment is based on ITU-R BS.1387-1 "PEAQ" ([2]), which was developed for the perceptual assessment of distortions caused by codecs. The auditory model and the calculation of representative excitation, masking and specific loudness patterns is adopted. The calculation of descriptive metrics (Model Output Variables, or "MOVs") is only partly adopted, because some MOVs are not suitable for the assessment of loudspeaker distortions. An overall quality metric cannot be calculated reliably at the current state of research. The perceptual objective assessment delivers a "descriptive vocabulary" for the subjective sensations when performing listening tests with the exported audio files. Adopted MOVs are *Distortion to Mask Ratio*[1] DMR, and the *Modulation Difference* $ModDiff$.

Additional MOVs *Discoloration* V, *Treble Stressing* TS and *General Bass Enhancement* B are adopted from [3] to increase the descriptive vocabulary. These measures were proposed mainly for the assessment of linear distortions.

The modulation patterns, that are obtained with the basic version of PEAQ, are sensitive to artifacts from the FOURIER-Transformation, the modulation frequency and phase. The *Modulation Difference* and the modulation patterns show poor performance for modulated signals and are worthy of improvement.

Figure 4 shows the *Discoloration* and the *Distortion to Mask Ratio* versus time for a *Distortion Scaling Factor* $S_{\text{dis}} = -20$ dB for a musical stimulus. Both curves show high peaks for points of time, where the stimulus is dominated by the bass-drum and bass-tones, which excite irregular distortions.

[1] The original notation *Noise to Mask Ratio* NMR was renamed.

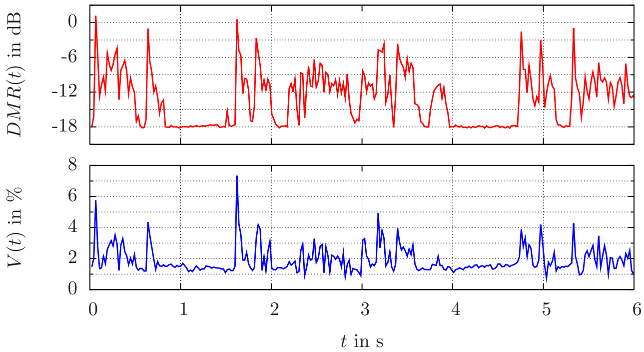

Figure 4: The MOVs *Distortion to Mask Ratio* DMR and *Discoloration* V versus time

Summary

The *Perceptual Assessment Module* isolates distortions from given reference and test signals. The distortion isolation and *Auralization* is based on decomposition, no mathematical model is used. New test signals are synthesized by scaling the distortion signal with the *Distortion Scaling Factor* S_{dis}. Thereby, the choice of reference and test signal defines the distortion signal. Exported audio files are used in listening tests. Acceptable *Distortion Scaling Factors* can help determining the target sound quality of a product. The dialog between the departments of management, marketing and engineering, as well as the definition of production limits is assisted with the exported audio files.

The measurement in large and small signal domain is only one possibility to obtain input signals for the *Perceptual Assessment Module*. Digital models of loudspeakers and simulation tools can be employed as well.

Future work will increase the descriptive vocabulary. The description of modulated signals has to be improved and metrics for the sensations of roughness and fluctuation strength have to be developed. Listening tests will determine if critical thresholds for individual MOVs can be formulated. An orthogonal and rich descriptive vocabulary for the investigated distortions is required, before a calculation of an overall quality metric can be considered.

References

[1] Klippel, W; Irrgang, S; Seidel, U: *Loudspeaker Testing at the Production Line*

[2] International Telecommunication Union: *Recommendation ITU-R BS.1387-1, Method for objective measurement of perceived audio quality*

[3] Klippel, W: *Multidimensional relationship between subjective listening impression and objective loudspeaker parameters*, Acustica, 70(1):45–54, 1990.

[4] Klippel, W: *Loudspeaker Nonlinearities - Causes, Parameters, Symptoms*. Klippel GmbH

[5] *S5 - Auralization (AUR)*, Klippel GmbH, Specification, October 2009