Combining Subjective and Objective Assessment of Loudspeaker Distortion

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Abstract

To reproduce an artist's performance, the loudspeakers' influence on the reproduced sound shall be negligible and thus inaudible. An assessment of loudspeaker distortion or defects is often performed either subjectively or objectively, with a lack of common vocabulary. This paper suggests a method for combining these two methods by using a *differential auralization technique*. The human response to the auralization's output is simulated with a perceptual model, which helps explaining subjective sensations and predicting an audible impact, e.g. of loudspeaker defects.

1. Introduction

During the design of a sound-reproducing product (loudspeaker or loudspeaker application), several design choices have to be made, influencing the final sound quality and, of course the costs for development and production. Often, these choices are made in dialogs between engineering and the departments of management and marketing. The involved parties usually prefer different methods to assess the quality of reproduced sound. Managers for example, will prefer listening to prototypes rather than looking at curves of distortion measurements for the assessment.

The definition of target performance (and thus the definition of production quality limits) is always a trade-off between costs and quality. The connecting part between objective measurements and perceptual evaluation (e.g. subjective assessment of sound quality) is the prototype of the product, respectively the recorded response of the prototype.

To reduce the number of built prototypes the responses can be predicted with auralization techniques. In [1] an auralization technique is presented that is based on a precise loudspeaker model. In general, auralization is a simulation that has two major objectives:

- Sensitizing the listener to the investigated distortion components (by enhancing them) and thus defining "what to listen for".
- Determining the detection threshold (or an acceptable level) of the distortion components.

These two applications clearly show a demand to the employed auralization technique: the investigated distortion component must be scaled (enhanced or attenuated).

In loudspeaker applications, the input signal is altered by generated distortions. Figure 1 shows the distortion components generated in the complete signal chain from source audio material to sound pressure at the receiving position.

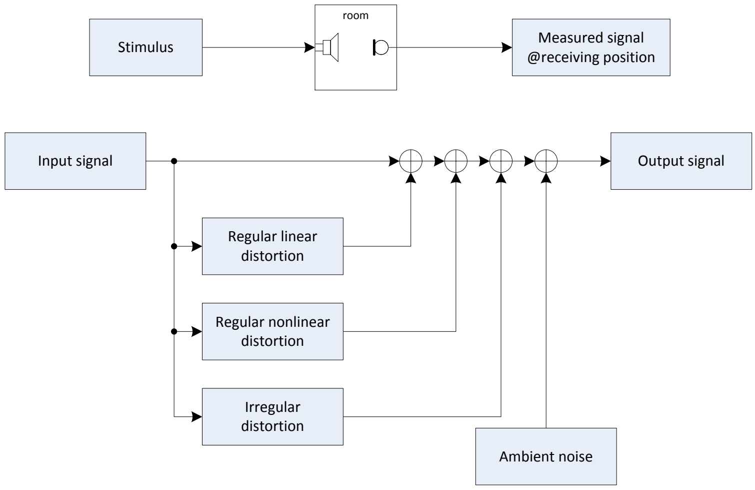

Figure 1: Signal flow plan showing the generation of signal distortion in a loudspeaker application.

The individual signal components are influenced by design choices and the final target application:

- Regular linear distortions are generated by equalizers, room acoustics and the linear transfer functions of the loudspeaker system.
- Regular nonlinear distortions are generated by the loudspeakers' non-linearities (e.g. motor and suspension).
- Irregular distortions show strong nonlinear characteristics. They are caused by loudspeaker defects (e.g. rubbing voice coil), but also by parasitic vibrations, that are excited by structure- and air-borne sound (e.g. vibrating panels).
- Ambient noise is highly dependent on the application situation (listening situations in audiophile listening rooms compared to listening through ear plugs while biking or in-car audio while driving).

Model-based auralization techniques rely on mathematical modeling of the response. Due to their (semi-) random characteristics [2], irregular distortion caused by defects cannot be modeled reliably. The same applies to the ambient noise component.
To be able to communicate the impact of all components on the subjective assessment, an auralization technique is required that can provide a scaling for all signal components.

2. Differential Auralization Technique

The presented *differential auralization technique* is solely based on decomposition of input signals with different distortion components. The input signals are called reference and test signal, the reference input signal is considered as the ideal response. The test signal contains additional distortion components.

2.1. Input signals

Considering the signal flow chart in Figure 1, various combinations for the selection of reference and test input signal exist. An example could be the response from a defective product as test signal and the response to the same stimulus from a good product as reference signal. Assuming that ambient noise is negligible, the additional distortion component in the test input signal would be irregular distortions.

In general, input signals can be the stimulus and simulated or recorded responses.

2.2. Distortion Isolation and Scaling

For the auralization of a distortion component, it is necessary to isolate and scale that component individually. Furthermore, the scaled distortion signal must be used to synthesize a virtual response. The *differential auralization technique* uses a simple subtraction, multiplication and addition for that task. Figure 2 shows a simplified signal flow plan. The scaling is specified with the *distortion scaling factor* S_{DIS}.

Before the distortion can be isolated, both input signals have to be aligned in time and level.

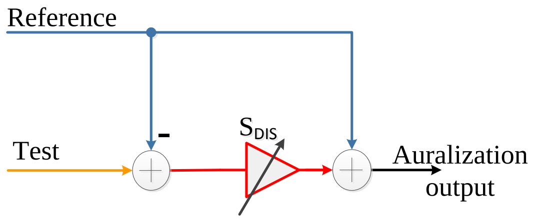

Figure 2: Simplified differential auralization technique

Figure 3 shows the resulting signal flow plan for the choice of input signals from Section 2.1 (responses of good and defective product). The isolated distortion component comprises irregular distortion, only.

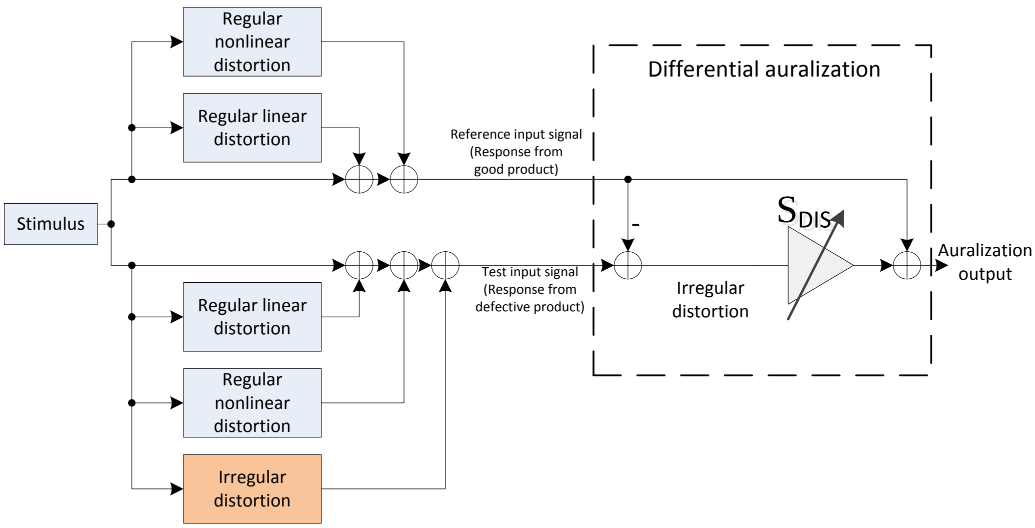

Figure 3. Signal flow plan for the differential auralization technique with individual distortion components

The isolated distortion component is defined by the choice of input signals. Table 1 shows typical applications for the *differential auralization technique.* Simulation output (auralization with digital model) and measured responses are employed.

Table 1: Selected choices of input signals for the differential auralization technique (all signals aligned in time/level)

Difference signal	**Test input signal**	**Reference input signal**
Regular linear distortion	Transducer output at small amplitudes	Stimulus
Regular nonlinear distortion	Total output of auralization with digital model	Linear output of auralization with digital model
Irregular distortion	Transducer output at high amplitudes	Total output of auralization with digital model
Regular linear and regular nonlinear distortion	Total output of auralization with digital model	Stimulus
Regular (motor) and irregular (defects) distortion	Transducer output at high amplitudes	Transducer output at small amplitudes
All distortion components (regular linear, regular nonlinear, irregular/defects)	Transducer output at high amplitudes	Stimulus

2.3. Determination of Threshold of Audibility or Acceptable Production Quality

The auralization output for multiple *distortion scaling factors* can be used in listening tests (e.g. blind A/B comparison) to detect the threshold of audibility for the investigated distortion component. A distortion scaling of $S_{\mathrm{DIS}} = 0$ dB represents the sound quality of actual product sample, since the original test signal is synthesized. A higher scaling generates an auralization output with enhanced distortion components; a lower scaling reduces the distortion components until the original reference signal is generated with a scaling of $S_{\mathrm{DIS}} = -\infty$ dB.

If the threshold of audibility is not desired due to high production costs, an acceptable distortion scaling can be determined by the management with the same listening test.

The used stimulus must expose the investigated distortion component that wants to be communicated. Thus, critical stimuli and levels have to be used to obtain the responses that are used as input signals for the *differential auralization technique.* This means low frequency excitation at high levels for most cases. Furthermore, critical stimuli have, where the symptoms of the excited defect occur, few or no frequency components at all, because the symptoms could be masked.

The necessary (or acceptable) scaling of the distortion components to become audible or unacceptable is called *safety headroom* of the investigated product.

3. Perceptual Modeling

To support the preparation of the listening test, a psycho-acoustic model from ITU-R BS.1387-1 ("PEAQ", [3]) simulates basic peculiarities of the human auditory system:

- Simultaneous masking,
- temporary masking
- calculation of excitation patterns and

- calculation of masking patterns.

As the masking effects are stimulus and level dependent a perceptual model can only be meaningful if the input signals represent signals at receiving position in the final target application.

The perceptive measures that are proposed in PEAQ were developed to assess the perceived impact of audio codecs and not loudspeaker applications. Therefore, not all metrics from this recommendation can be employed for assessing loudspeaker distortion. The overall quality measure is not meaningful for loudspeaker applications, either [4].

The main objectives of meaningful perceptive measures are:

1. Help finding critical stimuli that excite distortion which wants to be communicated.
2. Visualize how different design choices influence the perceived sound quality.
3. Predicting the audibility for distortions depending on the *distortion scaling factor* S_{DIS}.

Figure 4 shows an example of masking and distortion patterns for a music stimulus of a product with parasitic vibrations as irregular distortions. The masking pattern is the estimated masking threshold that is caused by the reference signal for a point of time. The distortion pattern represents all additional components that are present in the synthesized auralization output (depending on S_{DIS}). The noise floor is the model internal threshold of hearing in quiet.

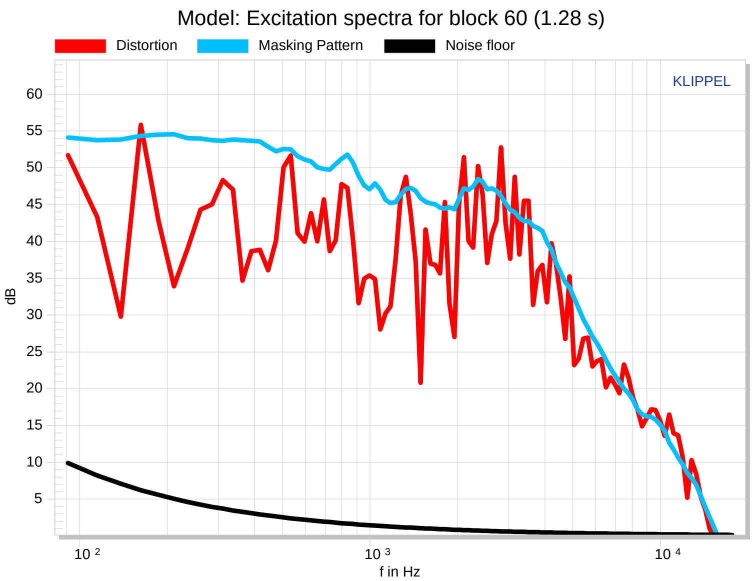

Figure 4: Masking pattern, distortion pattern and noise floor of the perceptual model for a point of time

4. Listening Test

The playback system used for the listening test should not produce any significant distortion. Headphones are the best choice, since room acoustics should not interfere with the played back audio material. Depending on the choice of input signals, the listening room's response (final target application) may already be included in the audio material for the listening test.

The weighted up-down method [5] is an example for an inexpensive listening test. Figure 5 shows an example for an interactive listening test with scaled distortions. Listening test examples with the output of the *differential auralization technique* will be published at www.klippel.de in the near future.

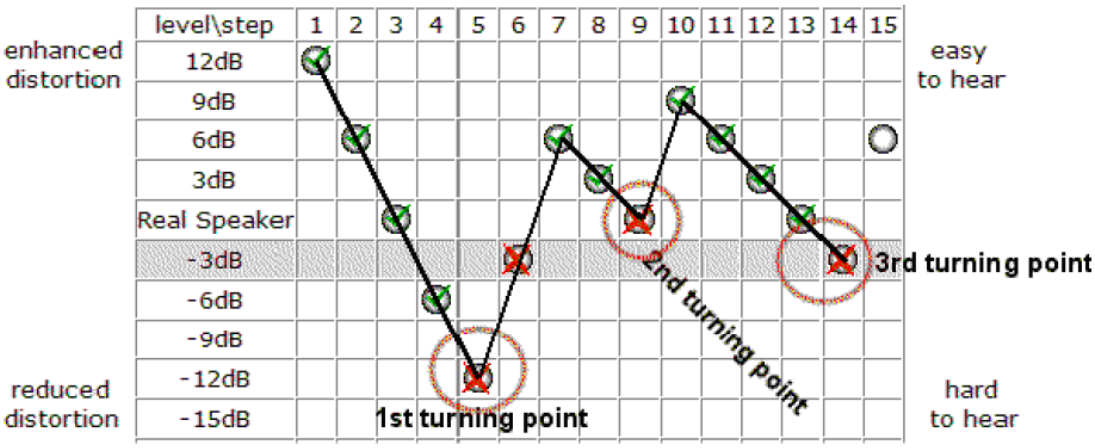

Figure 5: Example for weighted up-down method

5. Relation Product – Auralization

The auralization must represent the final target application. Otherwise detection thresholds, defined quality limits and perceptual simulation cannot be related to reality. An application example is explained below.

Figure 6 shows a possible relationship between prototype measurements and the calculation of production limits:

1. Quality limits are set for that production. Due to strict quality limits many products fail the quality control. The questions is raised, whether the limits could be widened or nor. Management and marketing must be involved in this decision.
2. A representative product that shows distortions (e.g. from parasitic vibrations) is selected. In the final target application the response to a music stimulus is measured at listening position. Thereby, it is essential that the level and characteristics of the stimulus excite and expose the investigated distortion in a similar way the sweep-measurement does.
3. The responses (reference: good response, test: response that comprises additional distortion) are used in the *differential auralization* with multiple *distortion scaling factors*.
4. The resulting *safety headroom* from the listening test and the measurement results of the prototype can be used for the calculation of new quality limits.

For a positive *safety headroom*, the limits could be widened, if the defects can be considered as stable.

This scheme could be extended by an automated classification algorithm [6] to find a representative measurement from a pool of measurements.

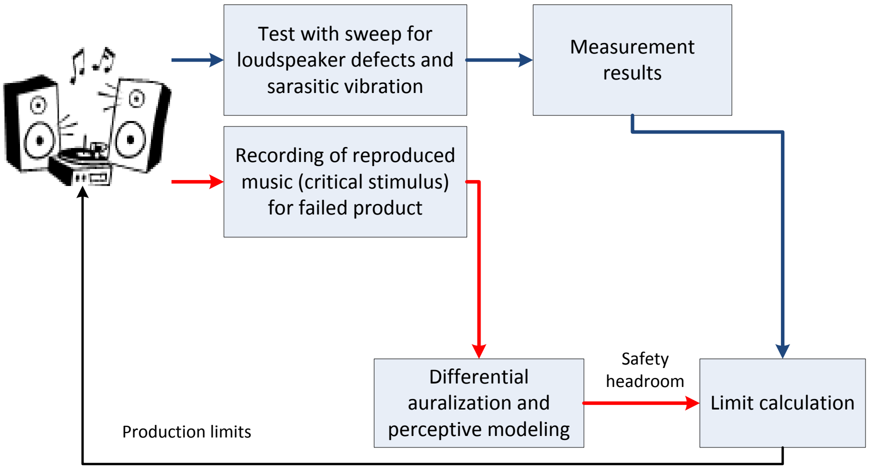

Figure 6: Prototype - production limits relationship

6. Summary

Auralization techniques are important for the dialog between engineering, marketing and management representatives. The *differential auralization technique* represents a method for isolating and scaling distortion components without using a mathematical model. The listening room's response and irregular distortions can be included in the auralized signals. The choice of input signals defines the isolated distortion component.
The auralization output can be used to evaluate the sound quality subjectively and objectively. Furthermore, objective measurements (e.g. with continuous sweep technology) result in objective data as well. Detection thresholds or acceptable production quality limits (*safety headroom*) can be defined by listening tests.
Perceptual modeling and distortion analysis help finding critical stimuli, critical points of time for the auralization. The impact of different design choices on the average listener can be estimated before performing listening tests. For the listening tests and perceptual modeling the auralization output must represent the sound at the listening position on the final target application.

7. References

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[6] Klippel GmbH: "S38 – Automatic Defect Classification", Preliminary specification. November 2012