Evaluation of a Nonlinear Auditory Filterbank with Instantaneous Frequency Control

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Introduction

Models of basilar membrane motion have a long tradition and a wide range of applications. They usually take stapes vibration as input and provide the excitation of different sections of the basilar membrane as output. For this purpose filterbank models with a dual-resonance nonlinear (DRNL) filter approach have been suggested recently [1]. This approach was extended by Hohmann and Kollmeier [2] with an instantaneous frequency based control mechanism for the nonlinear compression.

An important psychophysical effect for the evaluation of a nonlinear auditory filter model are suppression and "upward spread of masking". These effects are closely related and are possibly based on the a common mechanism [3]. Hohmann and Kollmeier [2] showed that the nonlinear auditory filterbank with instantaneous frequency control can simulate suppression experiments with a suppressor spectrally below the signal frequency quite well. However, psychoacoustical studies suggest that the increase in suppression as a function of suppressor level is greater for a suppressor spectrally below than above the signal frequency (see [4]). These different types of suppression are termed low- and high-side suppression, respectively. Results of high-side suppression studies are not yet used to evaluate the filterbank with instantaneous frequency control and may give reason to an enhancement of the model.

Suppression data in the literature is partially limited in terms of number of subjects. E.g., [4] used only a few subjects and did not show mean results. Furthermore, the simulation results of the DRNL model for this type of experiments are not known yet.

A general weakness of the dual-resonance approach, where the output of two filter paths are added, is that phase differences between the outputs may cause unwanted cancellations (notches) in the summed response.

This study investigates the effects of low- and high-side suppression for a tonal signal with the pulsation threshold method. An enhanced nonlinear auditory filterbank with instantaneous frequency control is suggested. The enhancements of the model address the problem of phase cancellations and improve the simulations of high-side suppression. The enhanced model and the DRNL model are used to simulate the experimental data presented in the current study and literature data on upward spread of masking [5].

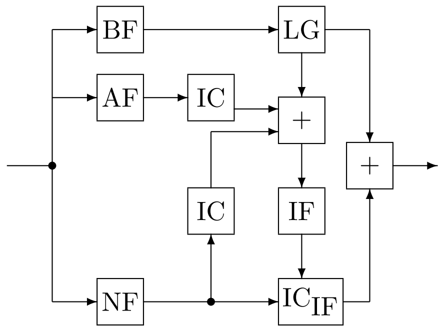

Figure 1: Block diagram of one frequency channel of the model. BF: Broadband filter, NF: Narrowband filter, AF: Additional narrowband filter, LG: Linear gain, IC: Instantaneous compression, IF: Instantaneous frequency estimation

Description of the models

The nonlinear auditory filterbank with instantaneous frequency control suggested here is based on a dual-resonance filter approach [1, 2]. A block diagram of one frequency channel of the filterbank model is presented in Figure 1. The main concept is to control the ammount of gain applied in the nonlinear filterpath (NF and IC_{IF}) by a comparison of the estimated instantaneous frequency (IF) of a feedforward result of the filter output (summation in the middle of the block diagram) and the center (natural) frequency of the filter. Most gain (mimicking the cochlear amplifier) is applied when the instantaneous frequency matches the center frequency. The control is realized by calculating a factor depending on the deviation of the instantaneous frequency of the feedforward result and the center frequency of the filterbank channel. The gain of the instantaneous compression IC_{IF} is then multipied by this factor (see Figure 2). In this way a reduced gain is applied in the nonlinear path of the model when the current frequency deviates from the center frequency of the filter.

In order to achieve better simulations of high-side suppression a third pathway with a narrowband filter (AF) and an instantaneous compression (IC next to AF) is introduced in this study. The bandwidths of the filters NF and AF are approximately equal. However, the center frequency of the filter AF is about 2 Erb higher than the center frequency of the filter NF. The instantaneous compression (IC) of this feedforward pathway of the model uses the maximum possible gain of the instantaneous compression IC_{IF}.

The filter impulse responses of BF and NF are derived from the same chirp (see Figure 3) by temporal window-

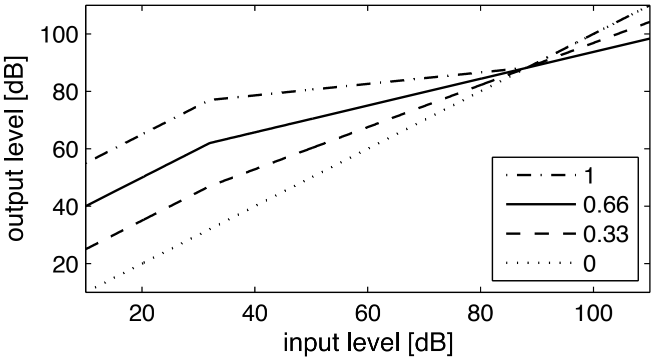

Figure 2: Compressive functions of IC_{IF} for different factors that are calculated from the deviation between instantaneous frequency and frequency of the filterbank channel.

ing of two parts of the impulse response. This method minimizes phase cancellations when the outputs of the two filter paths are added. See [6] for an example of chirp based auditory filter design and [7] for psysiological data of frequency glides in auditory filter impulse responses.

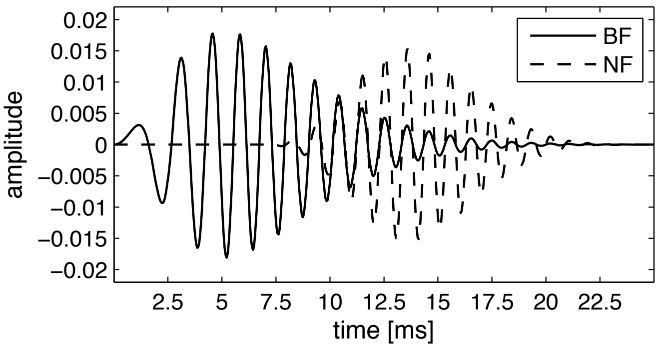

Figure 3: Impulse responses of the filters BF and NF.

For comparison, the DRNL model as described in [1] was also used to predict the data in the current study. The model parameters used here were taken from [8].

Method

The experimental method was the pulsation threshold technique [4] that was used in a two-tone suppression paradigm with suppressor frequencies below and above the signal frequency of 1 kHz. The term suppressor thereby reffers to the sinusoidal tone that suppresses the tone at the signal frequency, referred to as suppressee. Suppressor frequencies of 400 and 1200 Hz and suppressee levels of 40 and 60 dB SPL were applied. A method of adjustment was used in order to determine the level of the probe at pulsation threshold. The level of the probe at threshold reflects the supression effect on the suppresee. 10 subjects participated in the experiment.

The measured data of the two-tone suppression experiment was simulated by the models decribed above. The model outputs of the frequency channel that corresponded to the frequency of the suppressee were calculated for different signals. These signals consisted either of suppressor and suppressee or of the probe. Different probe levels were processed by the model and the level that yielded the same model output as suppressor and suppressee was taken as simulated probe level at pulsation threshold.

The literature data of [5] was simulated with a corresponding method. Again, the filter centered at the probe frequency was used. A certain ratio criterion for the model output of the masker alone and masker plus probe was used to calculate the level of the probe at threshold. The ratio criterion differed for simultaneous and nonsimultaneous masking.

Results

Figure 4 shows the measured and simulated data of the two-tone suppression experiment indicated by the symbols and lines, respectively. The probe level of the measured data decreases up to a certain suppressor level with increasing suppressor level. The suppression effect is defined as the difference between suppressee level and probe level. The suppression growth functions are different for the different suppressor frequencies.

These different high- and low-side suppression effects are simulated by the instantaneous frequency based model (solid line). On the contrary, the DRNL model (dashed line) is only able to simulate a suppression effect in the condition with a suppressor frequency of 1200 Hz and a suppressee level of 40 dB SPL.

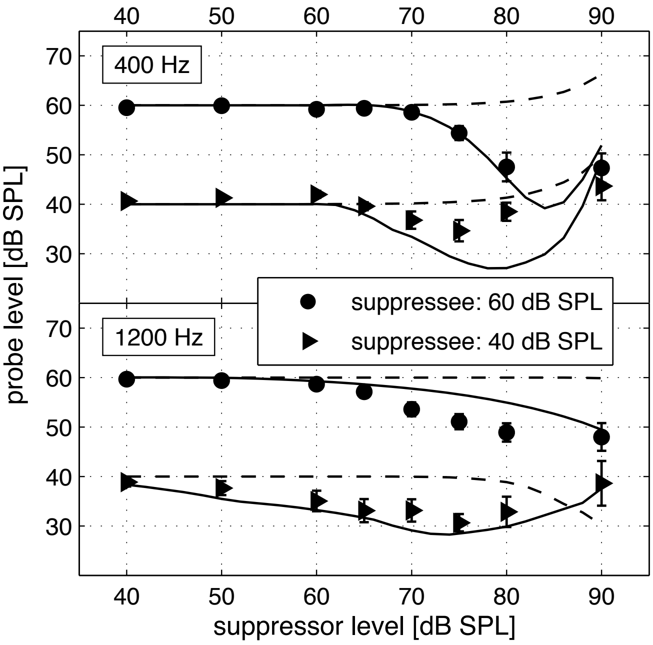

Figure 4: Experimental pulsation threshold results (symbols) and model simulations (lines). The different symbols stand for different values of suppressor frequency and suppressee level. The different line styles represent the instantaneous frequency based model (solid) and the DRNL model (dashed).

Figure 5 shows upward spread of masking data taken from [5] indicated by the symbols and model simulations (lines). The instantaneous frequency based model (solid lines) is able to simulate upward spread of masking with slopes greater than 1 dB/dB. The difference between simultaneous and nonsimultaneous masking in the data can also be described. The simulation results of the DRNL model (dashed lines) have mostly slopes of 1 dB/dB. This is a major difference to the literature data.

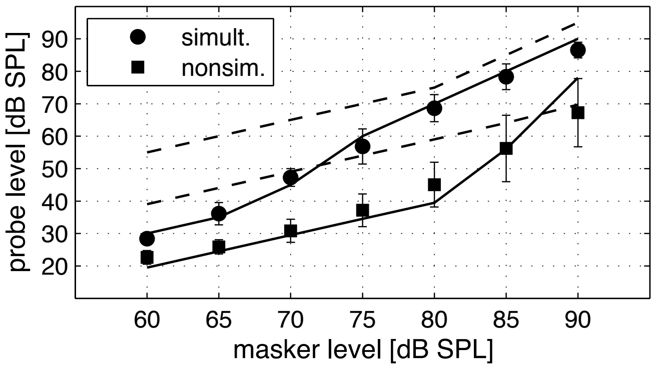

Figure 5: Upward spread of masking data taken from [5] (symbols) and model simulations (lines). The legend refers to simultaneous- or forward-masked thresholds. The different lines represent the instantaneous frequency based model (solid) and the DRNL model (dashed).

Discussion

The results of the experiment are consistent with [4] and the hypothesis of different suppression growth functions for the different frequency regions. The nonlinear auditory filter with instantaneous frequency control is able to simulate the different suppression characteristics. The additional filter path centered above the center frequency of the filter which modifies the instantaneous frequency estimation and thus the supression characteristics for high-side supression is crucial for the success of the model. The instantaneous frequency controlled model by Hohmann and Kollmeier [2], without this enhancement introduced here, cannot account for the data. Likewise, the DRNL model cannot account for the supression data.

The literature data for the upward spread of masking experiment from [5] can also be accounted for by the model suggested here. The differences between measured and simulated data of the DRNL model are considerably bigger.

Acknowledgments

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