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In Car rattle noise management

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Rattling is an audible and unwanted noise radiated by structures and objects mechanically or acoustically linked to the loudspeakers. The study presents a system of digital processes to prevent rattling that suppresses or reduces rattling whilst retaining the original perception of low frequency energy. The principle is to generate low frequency harmonics which are subsequently added to the original signal. The loudspeakers are able to reproduce the harmonics correctly, before the ‘rattling frequencies’ are removed. Thanks to the psychoacoustic effect known as the ‘missing fundamental’ principle, the listener perceives a good low frequency rendering without being disturbed by the rattles.By using this method, the bass rendering can be improved by avoiding rattle noise and pushing the loudspeaker into the low frequencies that the speaker or the doors cannot handle.

1 Introduction

Rattling is an audible and unwanted noise radiated by structures and objects mechanically or acoustically linked to the loudspeakers.

There are several ways to prevent this noise by focusing on the causes:

- mechanically decouple the loudspeakers from the car body, which can be achieved by adding “silent blocs” or foam rings or spacers.
- mechanically decouple individual parts of the car body that are likely to rattle. This can be achieved by inserting foam blocs or working on the mechanical links.
- change the mechanical properties of the structures, (e.g. stiffness and mass), in order to optimize the resonant frequencies of each part.
- remove or fix any object that may vibrate and radiate in the enclosures, when excited by the loudspeakers at resonant frequencies.

The study presents a digital signal process that increases the audio bass rendering in a car cabin.

In addition to increasing the sensation of bass, the system is also a new way to prevent rattling, by reproducing only the frequencies where rattling is low, and shifting the energy of frequencies where rattling is high to frequencies where rattling is low.

By using this method, the bass rendering can be improved by avoiding rattle noise and pushing the loudspeaker into the low frequencies that the speaker or the doors cannot handle.

2 Overview

The rattle noise management is a system of digital processes that suppresses or reduces rattling whilst retaining the original perception of low frequency energy.

The principle is to generate low frequency harmonics which are subsequently added to the original signal. The loudspeakers are able to render the harmonics correctly, before the ‘rattling frequencies’ are removed. Thanks to the psychoacoustic principle known as the ‘missing fundamental’ principle, the listener perceives a good low frequency rendering without being disturbed by the rattles.

The tasks are carried out in the following order:

- Identify the frequency band at which rattling occurs,
- Use a low-frequency band to generate harmonics (including the rattling frequencies),
- Add the harmonics to the original signal,
- Remove the energy at the frequencies which are at the source of the rattling.

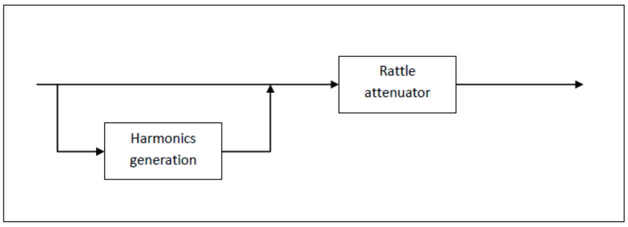


Figure 1: Audio signal processing path

3 Rattle detection

As the rattling is produced by structures and objects, the resulting sounds are not a harmonic like a musical note, but noises. This means that the frequency content of the rattling is not correlated with the acoustic source signal.

A slow constant sweep of the frequency spectrum is used to locate the bands at which the rattling occurs. The signal is reproduced over the speakers inside the vehicle and measured by a microphone placed at the driver’s listening position. By analyzing the time/frequency signal representation, any rattles will become apparent by way of their wide-band content.

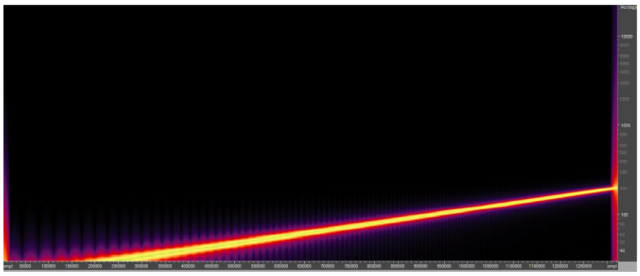


Figure 2: Original sweep signal

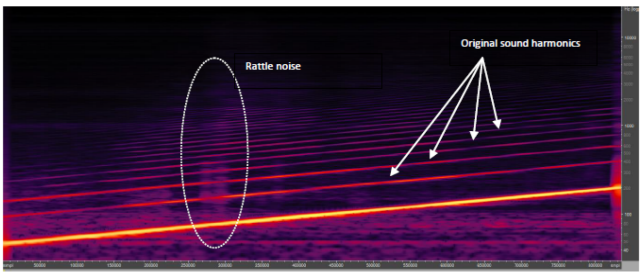


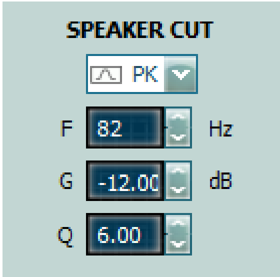
Figure 3: Rattle measurement

In the example (a Renault Clio), equipped with the standard 4-speaker system, the rattle band is [80-90] Hz. The original sweep signal is rendered with harmonics because of the system distortion (amplifier or speakers).

4 Rattle attenuation

A 'Speaker Cut' control is used to attenuate or remove the frequency band containing the rattles. Depending on the level of the unwanted rattle and its bandwidth, the filter can either be:

- a notch filter,
- a high pass filter.



For the Renault Clio example, a notch filter is set to [F:82Hz, Q:6, G:-12dB]. Figure 4 shows the notch activity.

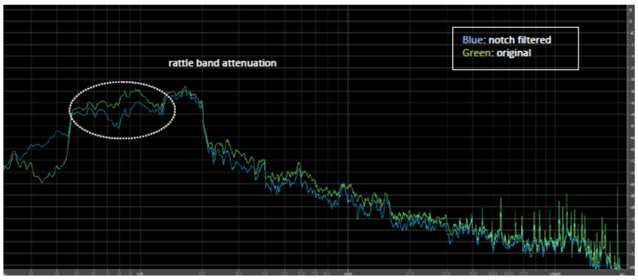


Figure 4: Notch attenuation example

The following graphs (Figure 5 and 6) show the suppression of rattles using the Speaker Cut filter. The frequency response measurement demonstrates the resonant (rattle) frequency at 82Hz, and the rattling noises it causes at higher frequencies. The filtered signal (red) shows that the fundamental and its harmonics have been attenuated, and the high frequency noise has disappeared.

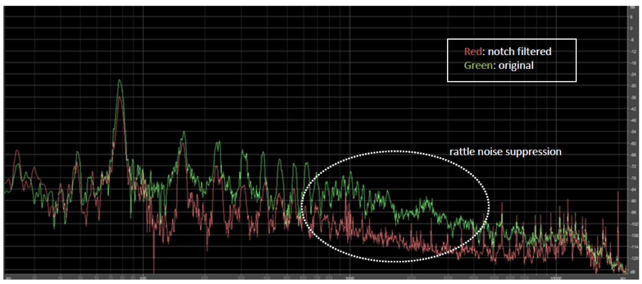


Figure 5: Rattle noise suppression

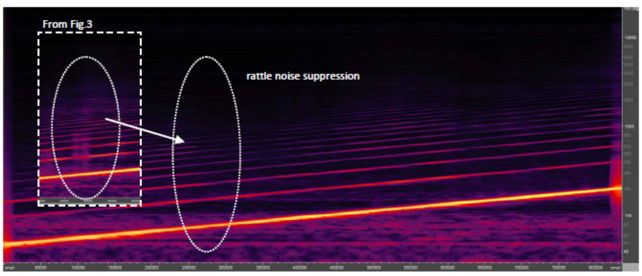


Figure 6: Rattle noise suppression

By using a filter to attenuate the frequency band responsible for the generation of rattles, it is possible to suppress the undesirable noises. Yet, the frequency response in the low frequencies will be impaired by the missing bandwidth attenuated to avoid the rattling noise.

Therefore a harmonic generator is used to compensate for this slight reduction in bass energy.

5 Harmonics compensation

The 'Speaker Cut' control is able to suppress the rattle but it is possible to hear that the processed audio signal lacks some bass energy. The method takes advantage of the 'missing fundamental' psychoacoustic principle to compensate for the reduced bass energy:

A sound is said to have a missing fundamental, a suppressed fundamental, or a phantom fundamental when its overtones suggest a fundamental frequency but the sound lacks a component at the fundamental frequency itself. However, the brain perceives the pitch of a tone not only by its fundamental frequency, but also by the ratio of the higher harmonics. Thus, we may perceive the same pitch (perhaps with a different timbre) even if the fundamental frequency is missing from a tone.

First, the pre-harmonizer selects a frequency band that includes the rattling to be analyzed. Harmonics are then generated from this part of the signal. The bandwidth of the generated harmonics is controlled using the post harmonizer filter to keep only the first and second harmonics.

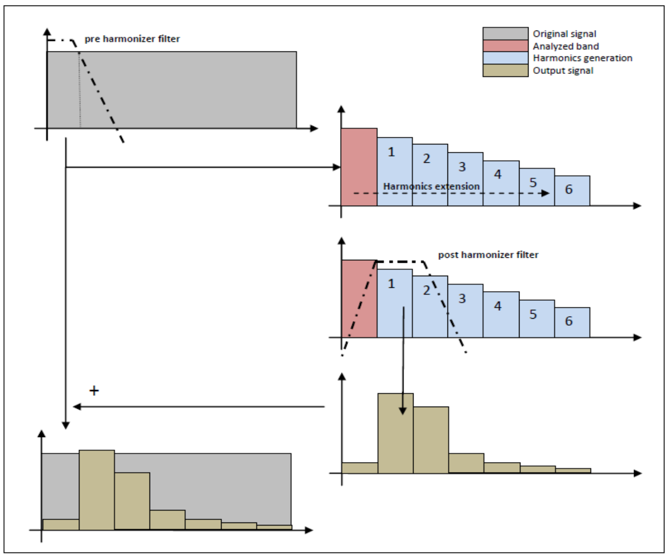


Figure 7: Method of harmonics generation

Ajouter methode de filtrage + generation harmonics

For the current Renault Clio example, the pre-harmonizer is set to 100Hz and the post harmonizer is set to [100, 400] Hz. The rattle band is then harmonized between 100Hz to 400Hz. The following graph shows the level difference of the harmonics between the notch-filtered signal and the harmonized one when the sweep signal is at 82Hz.

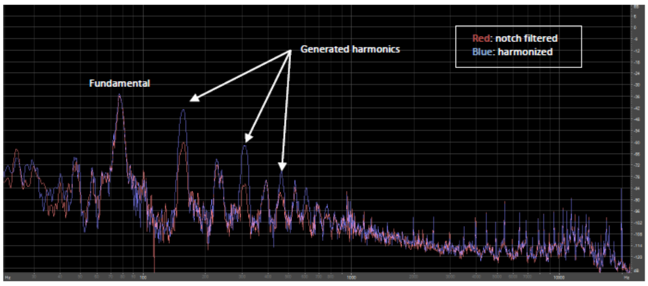


Figure 8: Harmonics level differences

6 Conclusion

The presented system allows the suppression of rattling by attenuating the energy in the fundamental frequency band. Despite the reduction of bass energy, the sensation of bass is retained by adding harmonics to the audio signal using the 'missing fundamental' principle. The fundamental frequency band that is the cause of the rattle is attenuated, but its harmonics are boosted, which gives the listener the sensation of deep (psychoacoustic) bass. The following frequency responses show the comparison between the original and the processed signal when the input signal is a sine tone at 82Hz (Renault Clio example). The processed signal clearly demonstrates that the rattle has been removed and the fundamental has been attenuated but the signal harmonics remain the same. The sensation of bass energy remains intact or can also be increased.

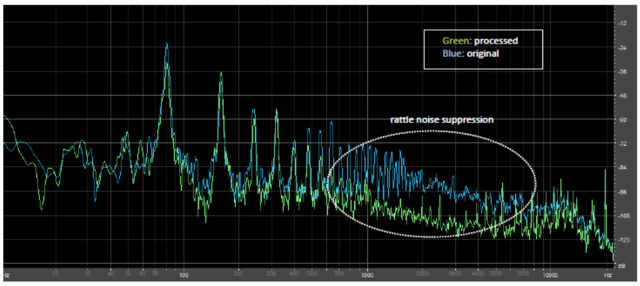


Figure 9: Rattle noise attenuation/suppression

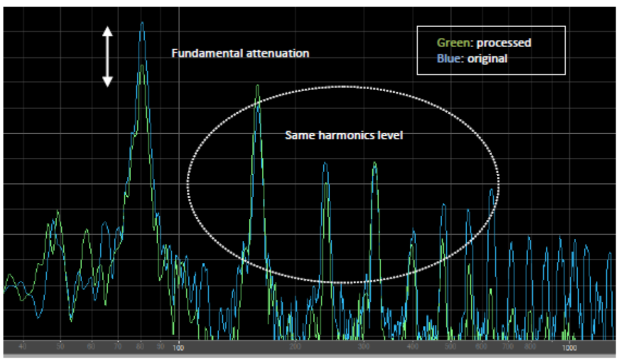


Figure 10: Comparison of fundamental and harmonics

7 Reference

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