ACOUSTIC NOISE EMISSION LIMITING ALGORITHMS: TAXONOMY AND PROPOSALS

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Garrido-Sánchez Pablo, Almagro Pastor José Antonio, Roldán Aranda Andrés
Dept. of Electronics and Computer Technology.
Universidad de Granada
Granada
Spain
Tel: 637981626
E-Mail: pablogs@ugr.es

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ABSTRACT

This paper presents a detailed taxonomy of acoustic noise emission limiting algorithms. First, concepts and market-available solutions are explained and compared in qualitative and quantitative terms. These algorithms approaches are analyzed taking into account spectral and time-domain signal effects. Moreover, digital and analog versions of these procedures are also discussed.

After that, new approaches are presented as results. These acoustical noise-limiting algorithms proposals rely on an acoustic monitoring and real-time audio processing platform. This platform gives versatility and a rapid prototyping approach to the algorithm test and validation phases, enabling a fast iteration through new acoustical noise controlling concepts and ideas.

INTRODUCTION

Audio signal conditioning and acoustic environment measurements are becoming increasingly important in environmental noise control systems.

Due to the great computing power available on most general-purpose devices, a high-performance signal processing and conditioning is possible using low-cost processors. Continuous noise measuring is also possible using this architectures [1].

On most public venues, devices in an audio line [2] (audio player, processing chain and power amplifiers plus loud speakers) are the main source of environmental noise. Thus, acting over this audio line is the first response for controlling acoustic noise emissions. This kind of proceeding directly adjusts the audio line system into the allowed and safe acoustic emission range.
Multiple sorts of interventions over the audio line can be implemented in order to limit acoustic emissions. The intervention could range from something as simple as a volume control using a

PID controller, to a spectral processing that measures which part of the analyzed noise is noise floor and which is an audio line contribution.

Thus, this document explains the basis of this sort of procedures, shows a taxonomy based on the most common solution with respect to noise limiting architectures, and presents some new approaches and ideas that aim to improve the current state of tecnology.
Most of the available solutions rely on a device inserted just before the power amplifiers and the loud speakers, as shown in Figure 1. The first requirement for this device is to maintain the acoustic emission inside a certain range. For this purpose, the device must act over the eletrical audio line and can sense the acoustical environment.

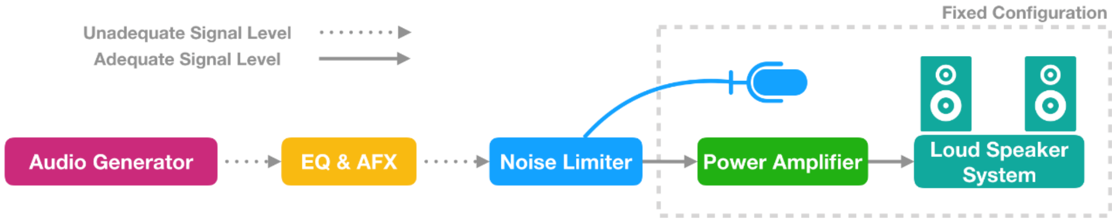


FIGURE 1. Acoustical noise limited audio chain.

This way, acoustic environmental health can be guaranteed by mantaining noise emission levels bounded. This kind of architectures can be implemented in many different forms: by using digital signal processors or analog signal attenuating topologies; taking into account the spectral componentes of the acoustical noise or just measuring its global values; or using an electrical calibrated device or relying on a sensing microphones signal. Each of them has pros and cons, such as delay times, digital noise, or spectral distortions inherents to frequency filtering mechanisms. Costs and system complexity are also critical milestones for control and limiting acoustical noise devices because of its ubiquitous nature.

ELECTROACOUSTICAL TESTBENCH

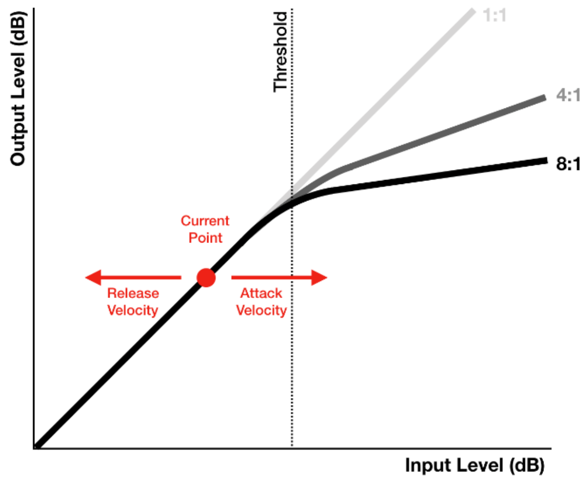
All acoustic noise limiting procedures analyzed in this document have been tested with a black-box oriented approach [3]. This way, a specifically designed audio signal set is injected in the device being tested and the output is recorded. A post-processing stage can determine common audio figures of merit like frequency response, total harmonic distortion, or signal to noise ratios [4].

Furthermore, non-linear temporal and spectral effects can be obtained using proposed input-output analysis. Thanks to these procedures and analysis, different products can be tested.

INFERED ALGORITHMS

Most of current acoustic noise limiting algorithms are based on a dynamics compression operation. A dynamics compressor acts as non-linear signal processing block where an output depends on the input amplitude. An amplitude threshold is set and when the input amplitude is lower than this threshold, it is driven to the output with no modification. If the input amplitude overtakes the defined threshold, an attenuation is applied. This attenuation is described by a gain function which may not be linear. This attenuating or compressing procedure is represented in Figure 2a.

Beyond this variable attenuation function over the amplitude, a dynamics compressor responds to two temporal parameters. Attack time defines how long it takes the attenuation to be applied once the input amplitude overtakes the threshold. Release time defines how this attenuation is removed when the input signal amplitude goes below the threshold. These two parameters are exposed in Figure 2b.



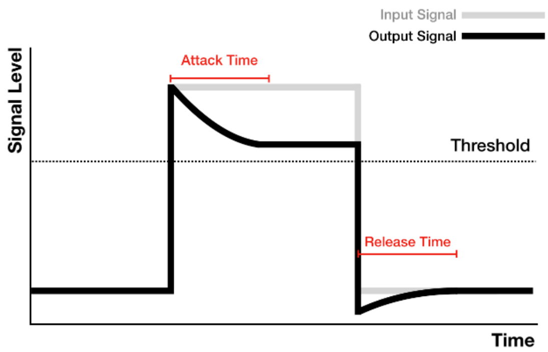


FIGURE 2a. Compressor input-output diagram. **FIGURE 2b.** Compressor temporal behaviour.

As previously stated, applying this kind of algorithms in the middle of an audio chain (assuming a calibrated voltage to acoustic emission reference) an acoustical noise emission limiter can be implemented. However, depending on the attenuation function and the attack and release times, the acoustic perception can be poor.

Taking into account that the main purpose of noise limiting algorithms is to adequate the acoustic environment to healthy levels, some other considerations must be taken into account. First of all, two types of subjects are exposed to the acoustic emissions: the active and the passive ones. Active subjects are those who are directly exposed to the noise focus and their exposure must be adequate in global terms.

On the other hand, passive subjects are indirectly exposed to the noise focus, usually through walls or architectural objects. In this case, architectural noise and vibrations transmissions must be taken into account. These kind of noise transmissions through architectural objects apply strong high pass filtering to the acoustical signal, and this directly impacts on how low, middle and high components of the spectrum are perceived by passive subjects. Specifically, low frequencies are able to reach easily distant points within an architecture, so they usually must be controlled carefully.

This way, the spectral dynamics compressor applies the same explained operation to defined sections of the spectrum. For example, as mentioned before, the lower frequencies have a better transmission through building structure.In this set of frequencies, the spectral noise emission limiter must apply a lower threshold. At this point, two key points of this process plus one consideration can be exposed:

- How does the acoustical noise limiter know how much noise there is? This sensing process can be solved by two approaches: using a sensing microphone or through an acoustical to electrical calibration of the output line. It should be noted that the second approach assumes that the audio chain is the only noise focus and there is no external noise focus.

- How does the acoustical noise limiter act against an excessively acoustical noise? This limiting process can attenuate the whole audio spectrum in the same way, henceforth this action will be named global attenuation. Moreover, the limiter can distinguish which audio spectrum bands exceed the emission limit and act over them individually.
- As a consideration, it must be said that the sensing process has not much to do with the limiting action. A global spectrum noise emission analysis can act over a fixed spectrum-corrected limiting action, and on the other hand, a spectral noise emission analysis can perform a global attenuation process (taking into account the worst case, for example).

These two key points expose a first organization which talks about the main blocks that a noise limiting device could have: a spectral or RMS global level noise analizer and a spectral or RMS global attenuating processor. Both of them and their functional combinations are exposed in Figure 3.

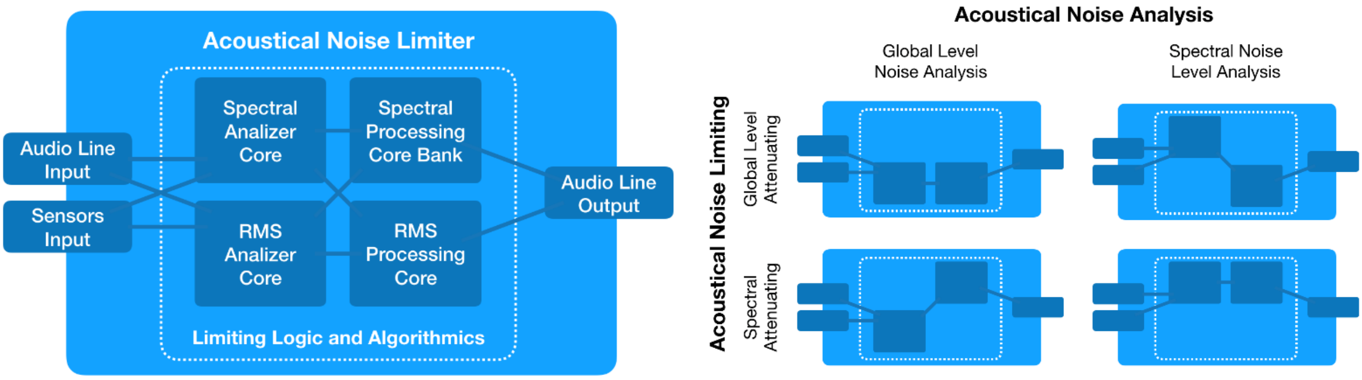


FIGURE 3. Acoustical noise limiter key blocks and basic configurations.

After exposing the main configuration and topologies, some commercial devices are analyzed from a behavioral point of view. Figure 4 shows attack time of a digital noise limiter.

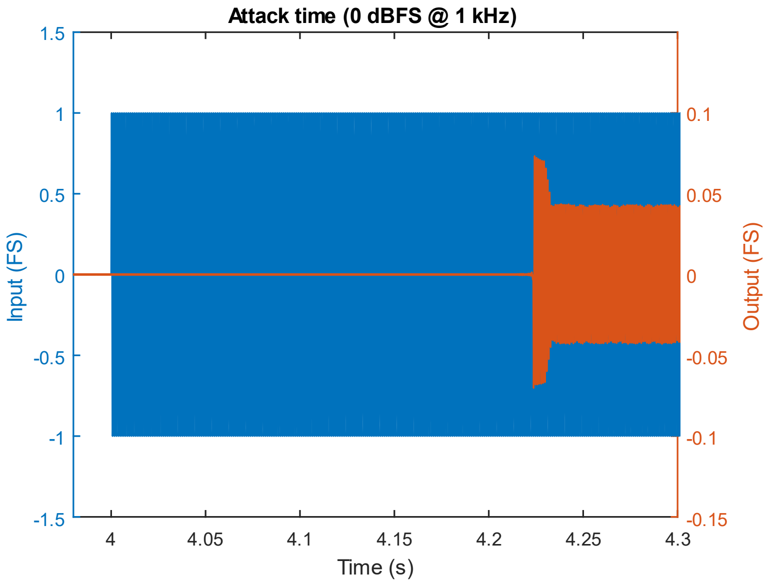


FIGURE 4. Attack time and input to output delay measured on a digital acoustical noise limiter.

Some non-desired effect appears in Figure 4 digital signal processing. They can be seen in Figure 5 both in temporal and spectral domain. As it is shown, within a simple spectral analysis, total harmonic distortion and signal to noise floor ratio can be estimated.

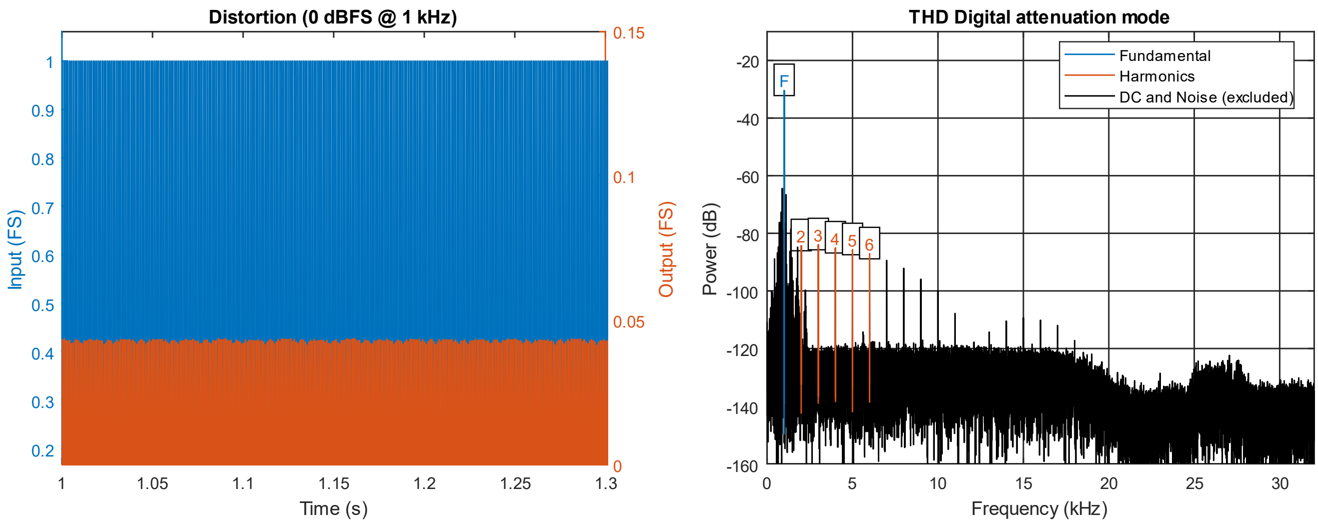


FIGURE 5. Digital signal processing distortions on digital acoustical noise limiter.

Due to the nature of this kind of algorithms, based on digital third octave filter banks (foreseeably implemented using FIR filters), there are differences between the limiting and non-limiting behaviors of the same device. Figure 6 shows how both noise floor and harmonics distortions differ in the mentioned states.

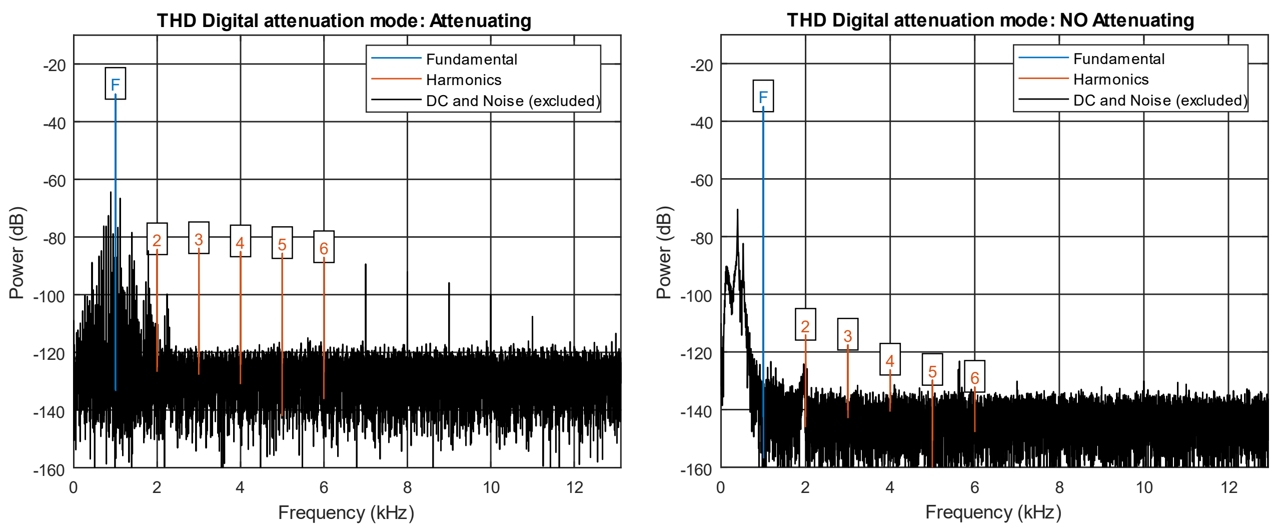


FIGURE 6. Signal to Noise Ratio (SNR) and Total Harmonic Distortions (THD) on a digital limiter implementation with filters acting and not acting on the audio signal.

In order to compare this digital noise limiting architecture with an analog global noise attenuating one, Figure 7 shows both temporal and spectral response of an analog acoustic noise limiter. This device uses a digital spectral audio signal analysis and an analogic global level attenuation.

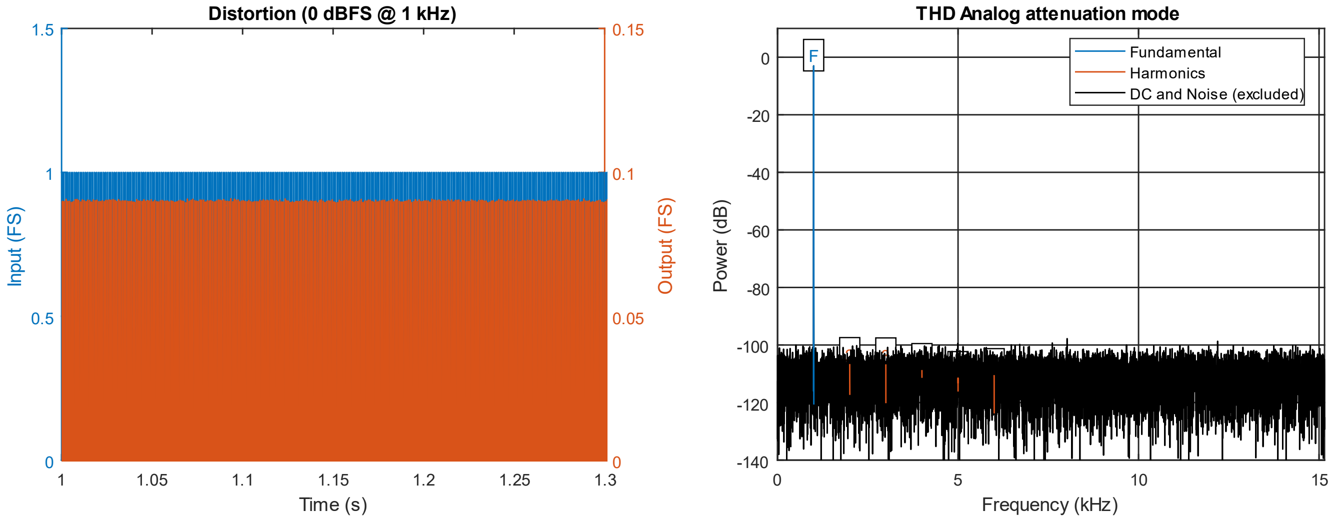


FIGURE 7. Distortions on digital analisys and analogic attenuation acoustical noise limiter.

TAXONOMY

After last section's dissertation about noise emission controlling architectures, a taxonomy is exposed henceforward.

An acoustic emission limiter can follow two approaches with regard to audio line limiting action. It can perform like a **dynamics compressor** where noise emission overcomes are attenuated in accordance to a threshold, an attenuation function, and attack and release time. It can also act like a **noise emission adequation device** where it takes into account the maximum noise level allowed, senses the current noise level and takes a certain strategy to maintain it under the limit.

This signal process can be done using **digital signal processors**. This option enables a flexible algorithmic operation that can be updated by software and can take advantage of high performance and low cost commercial devices. Despite this, a digital signal processing has the intrinsic digitalization and dedigitalization problems such as delay and digitalization noise. On the other hand, a less flexible **analog filter bank** can perform the needed signal process with no delay and (depending on the implementation) less noise and distortion. However, this can be achieved at the expense of design simplicity and component cost.

Both of these solutions can apply to global or spectral approaches. **Global attenuation** ensures that the limiter device only modifies the acoustic emission level and guarantees the same audio equalization in the device input and output. It must be noticed that this kind of attenuation usually impacts directly over the volume perception, minimizing it. On the other hand, **spectral attenuation** deals with each frequency group individually. This way, attenuation is only applied where it is needed in order to keep the noise emissions and transmissions through buildings controlled. Its drawbacks are that it does not guarantee an unmodified equalization through the device, which impacts directly over the audio quality perception.

Similarly, the device can sense the environmental acoustical noise level by retrieving a **global noise level** or by processing a **spectral analysis** of the noise environment. First option provides enough information for estimating the acoustical noise level by using simple circuitry: an RSM integrator plus a slow analog to digital converter is a possible setup. However, retrieving the whole acoustical signal not only provides spectral information but it also allows to discriminate the noise generated by the audio chain from the noise floor generated by other sources.

The limiting algorithm's input parameters can be both the sensing signal from a **room measurement microphone** and just a **calibrated state of the output line**. The limiting algorithm's operation using a room microphone checks the acoustical noise level and adequates the output signal to the threshold level. On the other hand, by providing a multipoint calibration on the electrical output line, the device should be able to interpolate how much noise level will produce a certain electrical signal, being also able to limit the acoustical noise emission.

When talking about attenuation timing control, the device can act as a compressor by limiting noise peaks. This reaches a **continuous emission control with no peak tolerance** at the expense of compressing the audio signal by adding non-linear behaviors. On the other side, the device can be **tolerant to noise peaks** not applying instant noise level correction but at the cost of regulating the **long-term threshold to an adequate level**.

PROPOSED CONCEPTS

On the basis of the exposed operation of most devices some other concepts are exposed.

One common approach to noise control and acoustical healthiness are Noise Criteria Curves [5]. By measuring an acoustical noise spectrum and comparing it to a set of standardized curves, a NC rate can be calculated. By this industry standard method (ANSI S12.2-2008) it can be said for example that a school should have 25-35 NC rate and a shop can go up to a 50-60 NC rate. This way, considering that the main purpose of an acoustical noise emission limiter is to maintain a comfortable acoustical environment, a device that can analyze the room's noise spectrum and globally attenuate the audio line emissions in a grade in which the result accomplishes a certain noise criterion is proposed.

Moreover, if passive subjects that may be harmed by noise emissions are taken into account, a multipoint noise sensing system can be suggested. By using noise sensors both in the room with noise emission systems and in the place where said noise emissions are being transmitted through architectural objects, a real time approach of these transmissions' behavior can be retrieved. Both sensed environments must be correlated in order to isolate the controlled noise focus contribution to the passive subject location. By using these multipoint sensing systems an acoustical noise limiting system can have features for active annoyances detection.

On the same line, by a analyzing the noise profiles of a public venue, a penalty system can be implemented. Having as reference how a noise chain is used, the main noise focus can be isolated from the noise floor produced by other items in the place. This could be useful in order to adapt in a smart way how the limited sound line behaves. For example, although a maximum acoustical noise limit could be set up, this limit can be penalized in cases when other noise sources (people noise, machinery noise…) overcome certain levels. That way, the acoustic noise management system can act according to the noise profile and control the acoustical environment with different approaches depending on the nature of the noise.

Focusing on the signal that goes through the audio line, some of its features can be extracted in order to adapt the compressing/limiting algorithm to minimize the impact of the processing over the perceptual quality of the signal. For example, analyzing the dynamic range and the beat per minute, attack and release of the limiting algorithm can be tailored to go unnoticed. This audio analysis can be extended by using complex statistical models such as probability functions analyses of the audio line magnitude and predicting its behavior by modelling its characteristics. These advanced noise profile analysis and modeling approach can be implemented by using Hidden Markov Chains or Kalman filters.

SUMMARY

Along this paper, basic concepts of how audio compressor/limiters are used in order to adequate the acoustical noise environment. First of all, common topologies and device integration within the audio line are exposed togetherwith sensing mechanism.

Second, most common inner architectures and fundamental blocks of noise limiters are discussed. Next, an early taxonomy of how the noise limiting process splits in sensing and environment analyzing and acoustical noise limiting is presented. This explanation is followed by measurements of how different kind of commercial devices performs in terms of signal to noise ratio and total harmonic distortions.

After that this document presents a detailed taxonomy of acoustic noise emission limiting devices and algorithms. This taxonomy includes considerations and comparisons about limiting and sensing process along with sound perception considerations. Finally, new approaches are presented as innovative ideas of how noise control procedures can be improved.

ACKNOWLEDGMENTS

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