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Methods to Improve the Sound Reproduction of Limited Size Systems

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Three examples will be given to improve sound reproduction, which all have 'distortion' in common. First, we push a loudspeaker to its limits. In the second example we add some distortion. In the third example we create a very high distortion level by replacing the original signal with another.

I. INTRODUCTION

There is a longstanding interest in obtaining a high sound output from compact loudspeaker arrangements. Compact relates here to both the volume of the cabinet in which the loudspeaker is mounted as well as to the cone area of the loudspeaker. Loudspeakers can be built such that they properly reproduce the entire audible frequency spectrum, down to 20 Hz, but such systems would be both expensive and very bulky. In many sound reproduction applications it is not possible to use large loudspeaker systems because of size or cost constraints. Typical applications are mobile phones, portable audio, multimedia and (flat) TV-sets. Various signal-processing schemes have been proposed to equalize the response of small loudspeakers or to use psychoacoustic enhancement methods; see [1] for some overview. Three examples will be given, which all have 'distortion' in common. One usually sees distortion as a bad behavior of an audio system, but we will show that distortion can actually be useful, in particular for set-ups of compact arrangements. In the first example we push a loudspeaker to its limits in such a way that the loudspeaker does not get damaged, and at the same time that the distortion is kept at a low level. In the second example we *add* deliberately some distortion to increase the bass perception using a psycho-acoustic concept. The third example shows a method that electronically processes—in a strongly non-linear fashion—the audio signal, which is then sent to a special loudspeaker with high acoustical sensitivity.

II. PUSHING A LOUDSPEAKER TO ITS LIMITS

For systems equipped with small size loudspeakers usually one wants to increase the loudness of the audio. A drawback is that the loudspeaker can be damaged or the sound will be severely distorted. It is the aim of the present processing scheme to provide a loudspeaker protection system without unnecessarily affecting the full power range available for the loudspeaker, and at the same time taking care for a low perceived distortion level. To achieve this goal, the loudspeaker is preceded by a signal processing algorithm, shown in Fig. 1, which monitors the thermal condition and the mechanical displacement of the voice coil. The maximal signal level is monitored and limited within various frequency bands.

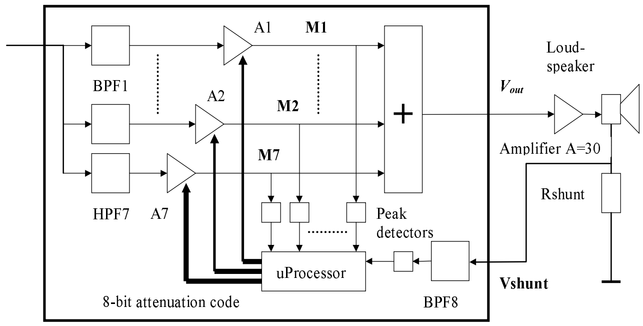

Fig. 1. Signal processing for loudspeaker protection.

III. SMALL LOUDSPEAKER WITH BASS PERCEPTION

Figure 2 shows the general processing scheme that we use for psychoacoustic bass enhancement. As the system is 'merely' based on a psychoacoustic model of pitch perception, and uses loudspeaker characteristics in a very general sense (it is only assumed that reproducing lower frequencies is less efficient than reproducing higher frequencies), the method can be employed for any kind and/or size of loudspeaker.

The non-linear device, or harmonics generator, 'shifts' signal components in a low frequency range to a higher frequency range. The pitch of the input signal is preserved, because the components in the higher frequency range are harmonics of the original components. The preservation of the original low pitch is due to the virtual pitch (or difference tone effect) of the harmonics signal. Because this element is a non-linear device, any single output component depends on all input components. Moreover, at the output, frequency components will be generated, which are not present at the input. This is a desired effect, since this is how the harmonics are obtained. However, it also leads to sum and difference components, which are not desired, because they are not harmonically related to the input signals. These undesirable distortions can be controlled by the use of sufficiently narrow band-pass filters ('BP' in Fig. 2).

IV. SMALL LOUDSPEAKERS WITH HIGH OUTPUT

In the past much effort has been spent regarding the efficiency of loudspeakers, see e.g. [2]. However, focus in that work was on designing systems with a reasonably broad bandwidth, while for the present application we are aiming for the highest efficiency, which implies a very small bandwidth [3], and hence a high quality factor. We discuss these special resonant loudspeakers which have a high SPL but require only a very small cone displacement. The dependence on the behavior of the transducer and its housing on

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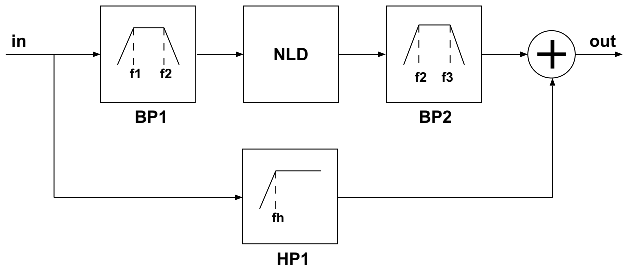

Fig. 2. Signal processing for psychoacoustic bass enhancement.The input signal is split and filtered to obtain the bass portion. Then harmonics are created by the non-linear device (NLD) and added to left and right output signals. In the direct path a high-pass filter is implemented.

various parameters, in particular the force factor Bl, and the consequences for the required signal processing is investigated. The loudspeaker driver can be made as a resonator, but also the driver mounted into a pipe can be brought into resonance. For both of these special loudspeakers (see Fig. 3), a practically relevant optimality criterion, involving the loudspeaker and pipe parameters, will be defined.

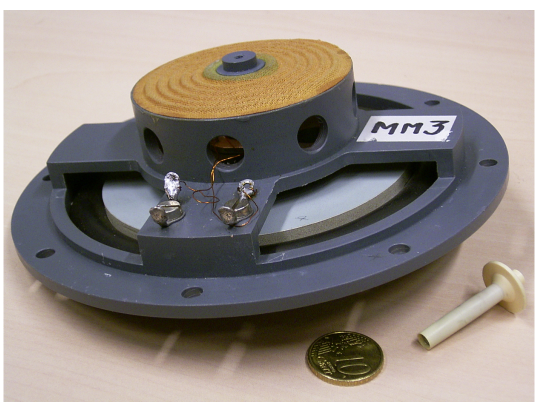

Fig. 3. Picture of the prototype driver (MM3c) with a ten Euro cents coin. At the position where a normal loudspeaker has its heavy and expensive magnet, the prototype driver has an almost empty cavity; only a small moving magnet is necessary which is shown in the right corner.

The desired characteristics are obtained at the expense of a decreased sound quality and the requirement of some additional electronics. An example of such a design is described and the performance of a working prototype is presented. Due to the typical high and narrow peak in the frequency response, the normal operating range of the driver decreases considerably. This makes the driver unsuitable for normal use. To overcome this, a second measure is applied: non-linear processing essentially compresses the bandwidth of a 20 to 120 Hz 2.5-octave bass signal down to a much narrower span, which is centered at the SPL peak of the system. This can be done with a set-up as depicted in Fig. 4 and will be discussed below.

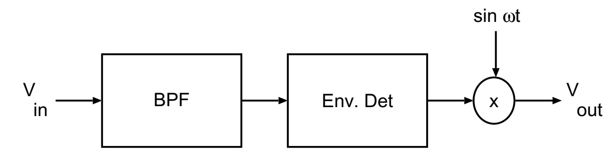

Fig. 4. Set-up of the mapping scheme. The boxes labeled 'BPF' and 'Env. Det.' are a band-pass filter and envelope detector, respectively. The sinusoid has a fixed frequency equal to f_{work}. The signal V_{out} is fed to the power amplifier and finally to the driver.

The band-pass filter takes the band of interest, typically 20–120 Hz, and the envelope detector determines the envelope $m(t)$ of this signal. Then $m(t)$ is multiplied with a sinusoid of fixed amplitude and fixed frequency f_{work}. The result is that the coarse structure $m(t)$ (the envelope) of the music signal after the compression or 'mapping' is the same as before the mapping. Only the fine structure has been changed to a sinusoid of fixed frequency f_{work} which coincides with the peak in the SPL response.

V. CONCLUSIONS

We have proposed three methods to enhance the perceived bass response of a loudspeaker. All have distortion and psycho acoustics in common. In the first example we push a loudspeaker to its limits in such a way that the loudspeaker does not get damaged, while at the same time the distortion is kept at a low level. In the second example we deliberately *add* some distortion to increase the bass perception using a psycho-acoustic concept. In the third example we create a very high distortion level, by replacing the original low-frequency content with another signal adapted to a special efficient loudspeaker. This leads to an improved listening experience. This new loudspeaker together with some additional electronics yields a low-cost, lightweight, compact, sensitive, and efficient loudspeaker system that is very suitable for low-frequency sound reproduction. These advancements provide a large increase in form-factor design freedom.

VI. REFERENCES

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