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Enhanced Bass Reinforcement Algorithm for Small-sized Transducer

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ABSTRACT

Nowadays, it is very popular that mobile devices such as cell phones or mp3 players are using small-sized speaker systems to supply sound event to users. The reason why they are using small-sized transducers is mainly restrictions due to the design and the size of the devices. Unfortunately, their design and size restrain the transducers from high quality of low frequency performance. To breakthrough this physical barrier of poor low frequency generation, well-know psycho-acoustical background, "missing fundamental illusion" is exploited. In this paper, the method of enhancing bass perception using virtual pitch is presented. With the presented method, listeners can feel the deep bass with fewer artefacts.

1. INTRODUCTION

Small-sized transducers such as earphones or cell phone built-in speakers cannot reproduce high-quality bass sound because of the physical limitation such as the light mass of the speaker unit and size constraints. Figure 1 shows a typical ear-bud speaker frequency response. Clearly the bass frequency response is highly attenuated. The response drops below -20 dB for deep bass frequencies. As matter of fact, poor bass response can be improved easily by enlarging the diaphragm of the transducer. But this solution is not applicable on the mobile devices due to the design and the size of the devices. As a second best method to solve this problem, signal processing approach with psycho-acoustical background, the missing fundamental illusion, is often exploited [1]-[3].

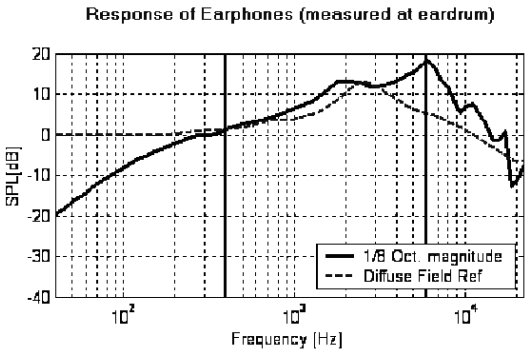

Figure 1 Earphone frequency response

With this background, a method to make listeners feel the bass effect can be designed. While new developments are being made in the areas of physical design and materials, the techniques of deceiving human perception or giving them the bass illusion are being popularly researched [4]-[6]. Our work uses similar psycho-acoustical background to enhance the bass signal reproduction and to give the listeners virtual pitch illusion. However, we used new harmonic generation method which induces very small amount of hearing artifacts. In this paper, the new method to generate virtual pitch is presented. Chapter 2 describes the missing fundamental effect and the existing methods on the basis of psycho-acoustics to enhance the bass perception. Chapter 3 describes new developed virtual pitch generation method followed by spectral and listening test results in Chapter 4 and conclusions in Chapter 5.

2. PSYCHOACOUSTICAL BACKGROUND

2.1. Missing Fundamental Illusion

A sound is said to have a missing fundamental, suppressed fundamental, or phantom fundamental when its overtones suggest a fundamental frequency but the sound lacks a component at the fundamental frequency itself. Every periodic sound has a fundamental frequency. For example, when a note has a pitch of 100 Hz, it will consist of frequency components that are close to integer multiples of that value (e.g. 100, 200, 300, 400, 500.... Hz). However, smaller loudspeakers will not produce low frequencies, and so in our example, the 100 Hz component may be missing. Nevertheless, a pitch corresponding to the fundamental may still be heard.

It was once thought that this effect was because the missing fundamental was replaced by distortions, introduced by the physics of the ear. However, experiments subsequently showed that when a noise was added, which would have masked these distortions had they been present, listeners still heard a pitch corresponding to the missing fundamental. It is now widely accepted that the brain processes the information present in the overtones to calculate the fundamental frequency. The precise way in which it does so is still a matter of hot debate, but the processing seems to be based on an autocorrelation involving the timing of neural impulses in the auditory nerve.

This very concept of 'missing fundamental' being reproduced based on the overtones in the tone is nowadays used to create the illusion of bass. By processing certain overtones selectively, a rich bass effect can be created using the small speakers which can not produce lower frequency components below 100 Hz. While speakers produce tones above 100 Hz, the processed bass overtones compel the brain to replace the missing fundamental bass signals, creating the illusion of bass.

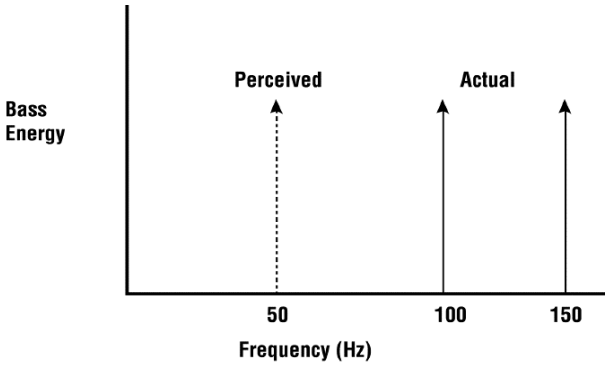

Figure 2 Psycho-acoustical background

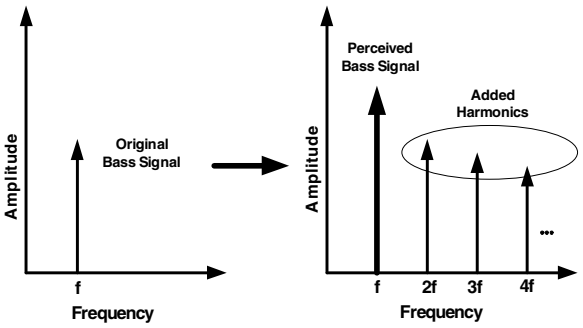

Figure 3 Pitch perception of a complex tone (Missing fundamental effect)

2.2. Psychoacoustic Bass Enhancement Methods

Psycho-acoustical bass enhancement methods involve extracting the low frequency signal below the speaker cut-off frequency, generating harmonics for each frequency component in the low frequency signal and adding it back to the original signal. The original signal is usually high pass filtered above the speaker cut-off frequency to remove the low frequency component

because it is anyway not reproduced acoustically by the transducer. The approach is depicted in figure 4 [5]. The simplest method to produce harmonics of an input signal is to perform a non-linear operation on the signal. All non linear operations produce harmonic frequencies, the amplitude of harmonics depending on the type of non linearity used. The filters HFIL in figure 4 are high pass filters. The left and right channels are added together and the low frequency signal is extracted from the combined data using FIL1. The NLD portion is the nonlinear harmonic generation portion. The FIL2 is used to filter out DC and harmonics or distortion created in the bass frequency range. FIL2 can also be used to shape the harmonic structure produced by the NLD. After that a gain is applied and the harmonic signal is added to the high pass filtered signal.

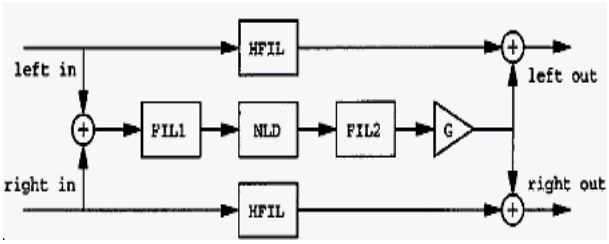

Figure 4 Psychoacoustic bass enhancement method

The method used to generate the harmonics i.e. the non linearity used is a topic of research and various methods have been proposed. Amongst the simplest methods used is the full wave rectification of the input signal [5]. Full wave rectification produces harmonic components at 2f, 4f, 6f and so on for the input frequency f. Although this method is very simple but the pitch perceived is 2f rather than f because only even harmonics are produced [5]. To solve this problem, several other methods were proposed [6].

3. ALGORITHMIC DESCRIPTION

To enhance bass signal component psycho-acoustically, generating a fine set of partials of the fundamental is very essential. Imitating a set of overtones of the fundamental frequency requires two very important steps. The first step is to estimate the bass region and to decide bass frequency range to be enhanced. And the second step is to generate a set of harmonics which can induce virtual pitch by the missing fundamental illusion.

In this paper, autocorrelation based pitch detection technique [7] is proposed to decide which frequency range is to be enhanced in the first step and single sideband modulation [8] is exploited to make a set of overtones in the second step.

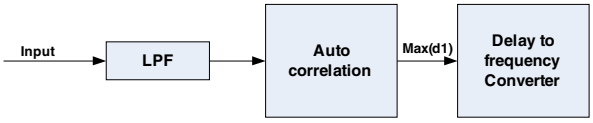

Figure 5 Fundamental frequency in bass region estimator

The first step of the algorithm is illustrated in figure 5. The input audio signal is low-pass-filtered to select only the bass region. Then, the autocorrelation of the signal with the filtered signal is evaluated. The fundamental frequency to be enhanced can be inferred from the maximum of this autocorrelation value by the delay-frequency converter [7]. Then the estimated frequency as the fundamental is enhanced with virtual pitch by generating a set of its partials in harmonic generator. Single sideband modulation method is used to make overtones in harmonic generator.

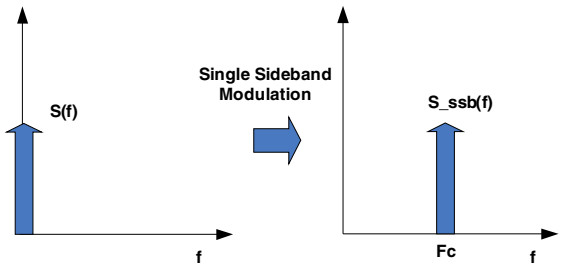

Figure 6 Single sideband modulation

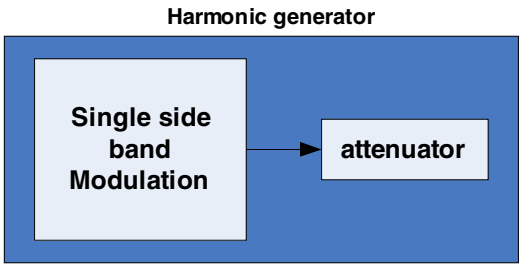

Figure 7 Harmonic generator

Figure 6 shows the process of single sideband

modulation of baseband signal S(f) schematically. The baseband signal S(f) is modulated by the modulation frequency fc. Then, the resulting frequency of the signal is altered into S(f+fc). To consist of the harmonic components of the original fundamental signal, the modulation frequency, fc, is set to 2f, 3f, 4f, and so on. After making the harmonic components, each harmonic component is attenuated to be more natural partial set.
The schematic diagram of harmonic generator is depicted in figure 7.

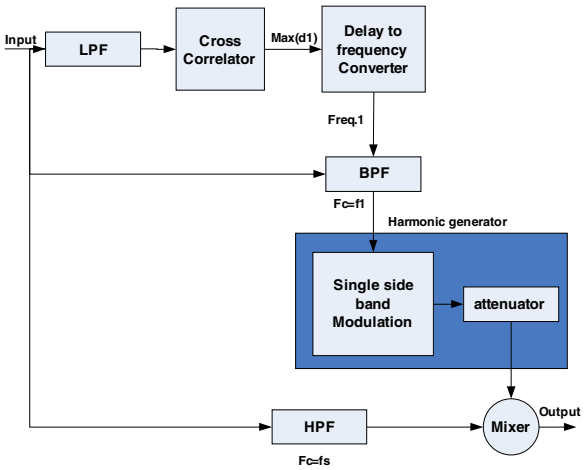

Figure 8 Schematic diagram of the proposed method

The overall algorithm is illustrated in figure 8. As the first step, the fundamental frequency to be enhanced is estimated. Then, the input signal is filtered with band pass filter whose center frequency is set by the first step. The filtered component is modulated to make the harmonics. Finally, the enhanced overtones are added back to high pass filtered input signal.

4. PERFORMANCE EVALUATION

4.1. Objective evaluation

The input and output signal spectrum of proposed algorithm is shown in figure 9. As shown in the figure, there are several partials in the output spectrum and the partials have a slope to imitate pseudo pitch of the fundamental naturally. Comparing both spectrums, the output spectrum doesn't include fundamental frequency of the input signal. This is the result of high pass filtering of the input signal before the enhanced signal is added back to the input.

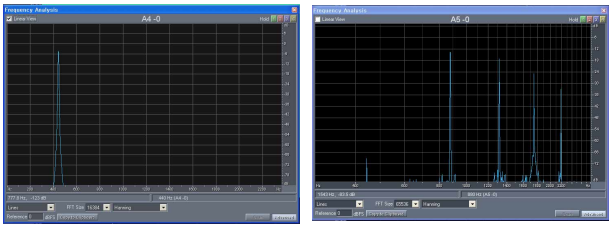

Figure 9 Estimated fundamental & enhanced harmonics

Blocking the deep bass components of input signal enables small-sized transducers to move more effectively. Moreover, the possibility of evoking excursion error is reduced by lessening the energy of real bass part. Accordingly, the proposed method can prevent deterioration of reproduced quality of small-sized transducers due to the physical barrier. Figure 10 shows the bass levels of input and output signals. In this figure, It is clear that the bass energy of the enhanced signal with proposed method has less level that that of the original signal.

Figure 10 Bass level comparison of the original and the enhanced signals

4.2. Subjective evaluation

For the subjective assessment, five test signals with deep bass portions are used. The test signals were played with earphone and small sized speaker system. The cut-off frequency of earphone is 150Hz and that of speaker system is 200Hz. Therefore, Fc of HPF was set to 180Hz. For comparison, test signals were processed

to enhance the harmonic components by conventional method and by proposed method. 15 testees participated in the subjective test. 4 test results were screened out during the training process. Among 11 trained listeners, 9 listeners preferred the enhanced test vectors with the proposed method to those of the conventional method [4]. The 9 listeners expressed their opinion that test signals with the proposed algorithm seems to give less artifacts than those with the conventional method.

5. CONCLUSION

This paper proposes new method to give listeners missing fundamental illusion with the help of psycho-acoustical background. The proposed algorithm approaches the solution with two steps to make a virtual pitch. The first step of estimating fundamental frequency is embodied with autocorrelation based pitch detection algorithm. The second step of constructing a set of partials is embodied with single sideband modulation and attenuation of each partial. To compare the proposed algorithm with the conventional method, 5 test music streams which have deep bass portion were used as the test contents. Among the valid 11 subjective testees, 9 listeners preferred the proposed method to the conventional. They reported that the new one made fewer side effects than the conventional one.

6. REFERENCES

[1] J. F. Schouten, R. J. Ritsma, and B. Lopes Cardozo "Pitch of the residue", J. Acoust. Soc. Am., 34(8(Part 2)):1418-1424, 1962.

[2] R. J. Ritsma. "Existence region of the tonal residue I", J. *Acoust. Sot. Am., 34(9):* 1224-1229, 1962.

[3] R. J. Ritsma. Existence region of the tonal residue II", J. *Acoust. Sot. Am., 35(8):* 1241-1245, 1963.

[4] D. Ben-Tzur and M. Colloms. "The effect of MaxxBass psychoacoustic bass enhancement on loudspeaker design", *in preprint 4892(F3) of the 106th AES Convention Munic,.* Audio Eng. Soc., May 1999.

[5] Erik Larsen and Ronald M. Aarts, "Reproducing Low-Pitched Signals through Small Loudspeakers", *J. Audio Eng. Soc.* vol. 50, no. 3, 2002.

[6] M. Arora and H. Moon "Low Complextity Virtual Bass Enhancement Algorithm for Portable Multimedia Device", *in proceeding of the 27th AES international conference Seoul*, Audio Eng. Soc., Sep 2006"

[7] L. R. Rabiner, "On the Use of Autocorrelation Analysis for Pitch Detection," IEEE Trans. Acoust., Speech, and Signal Processing 1977.

[8] Lawrence L. Feth, Richard V. Wolf, and Robert C. Bilger "Frequency Modulation and the Difference Limen for Frequency", J. Acoust. Soc. Am., vol. 45, no. 6, 1969.