A Novel Crossfeed Audio Plugin: Supplement

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The theory and implementation of the novel audio plugin X Feed, intended to improve the listening experience when using headphones, were covered in the author's paper [1], which this paper supplements. The supplement describes the enhancements and new features of the new crossfeed plugin X Feed II, including an adjustable head size, an additional HRTF-based equalizer mode, and increased accuracy of the interaural transfer function. Additionally, the manufacturer Beyerdynamic's new audio plugin, Headphone Lab, is thoroughly examined.

The plugin X Feed II is available for free on the author's website. It has the JSFX plugin format and operates natively in the digital audio workstation Reaper. Furthermore, with the assistance of the YSFX bridge plugin released by Joep Vanlier, it can run on nearly every audio plugin host. YSFX is also available for free as a VST3, AU, or CLAP plugin for Windows, Mac OS, and Linux.

1. Introduction

This paper assumes some of the information presented in the author's paper [1], which describes the creation of the crossfeed plugin X Feed. The features and enhancements of the author's new crossfeed plugin, X Feed II, are the subject of the current paper.

At the same time, the manufacturer Beyerdynamic's Headphone Lab plugin and the author's X Feed plugin were released. This competing plugin's crossfeed feature is also thoroughly examined. Consequently, a thorough review of both historical and modern crossfeed algorithms is provided (in conjunction with [1]).

2. Interaural transfer function with higher accuracy

The minimum phase filter's order is raised to eight in X Feed II. The approximation is now very accurate, as seen in **Fig. 1**. The picture shows the mean value of measurements of an artificial head (thin red lines), of 48 subjects (bold red lines), and the approximation (bold black lines). However, as was already anticipated in [1], comparing X Feed II with X Feed with the same equalizer and head size only slightly improves spatial perception.

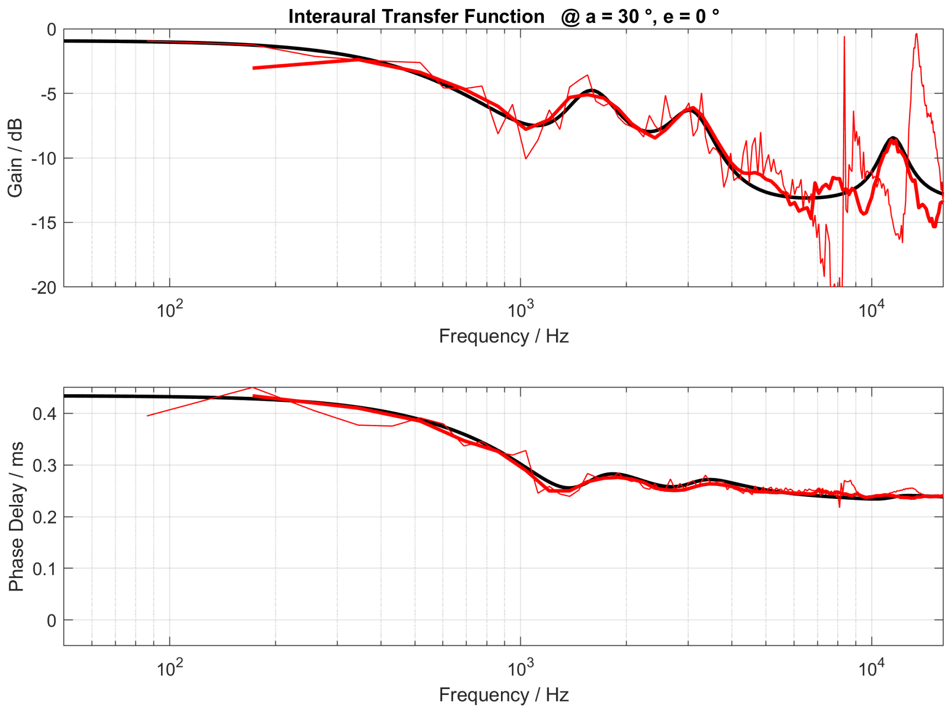

Fig. 1: Interaural transfer function of X Feed II

3. HRTF-based equalizer mode

For his plugin X Feed the author developed a unique equalizer that made it possible to smoothly blend between a flat direct signal and 100% mono compatibility. There is very little change in the perceived color of the sound of normal stereo recordings when the plugin is activated, especially when this equalizer is set to roughly 60%. Utilizing the head related transfer functions (HRTFs) from equations (1) and (2) in [1] directly in the circuit depicted in Fig. 1 from [1] is a more straightforward method. We must make a decision regarding the HRTFs' normalization for this strategy.

HRTFs normalized to the free field have a unity HRTF at an azimuth and elevation angle of zero degrees. This is one of two common types of HRTF normalization. The average of the squared magnitudes for each direction is unity for diffuse field normalized HRTFs.

It is possible to equalize headphones for both the free and diffuse field as well. A flat diffuse field response is a goal shared by many headphone manufacturers since Günther Theile's work in 1986 [2]. However, remember that this is simply an objective, and it is frequently only accomplished with notable deviations. However, we may anticipate that the diffuse field frequency response of contemporary headphones will typically be flatter than the free field frequency response. As a result, we choose to employ HRTFs normalized to the diffuse field.

If we assume perfectly diffuse field equalized headphones driven by a cross field circuit with diffuse field normalized HRTFs and flat frequency response loudspeakers in a reflection-free environment, we can expect the perceived sound color and spatial perception to be very similar in both listening conditions. However, we can no longer anticipate the color of sound to remain constant when we activate the crossfeed circuit.

The author approximated the HRTF of the direct ear H_{direct} using a minimum phase filter of order ten. The upper left plot of **Fig. 2** shows the approximation (strong black lines) and the mean value of 48 subjects (thin black lines). The same image depicts the frequency response of the equalizer previously employed in X Feed (bold blue, red, and yellow lines) as well as the derived transfer functions H_{cross}, H_{mono}, H_{side}, and H_{ind} as stated in [1].

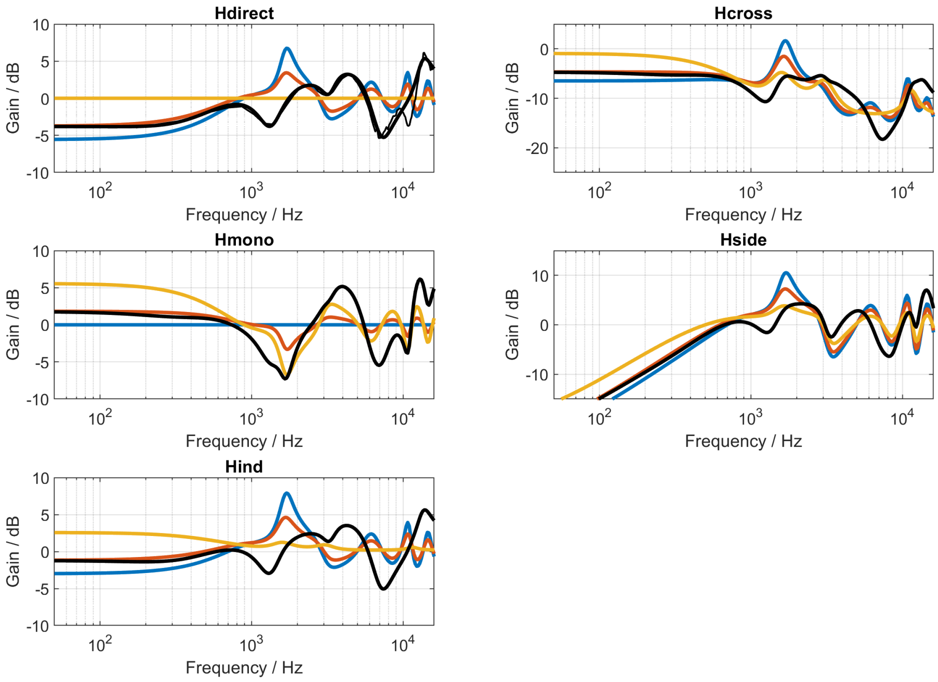

Fig. 2: H_{direct} and derived transfer functions of X Feed II

The HRTF-based equalization improves spatial perception more than the author assumed. The spectral clues offered by a genuine H_{direct} are clearly more relevant than anticipated. When the plugin is active, the changes in sound color are more noticeable than with the original X Feed equalizer. However, a similar color of sound is likely perceived while listening through flat frequency response loudspeakers in a reflection-free environment.

X Feed II retains the equalization from its predecessor. **Fig. 3** depicts the implementation's block diagram.

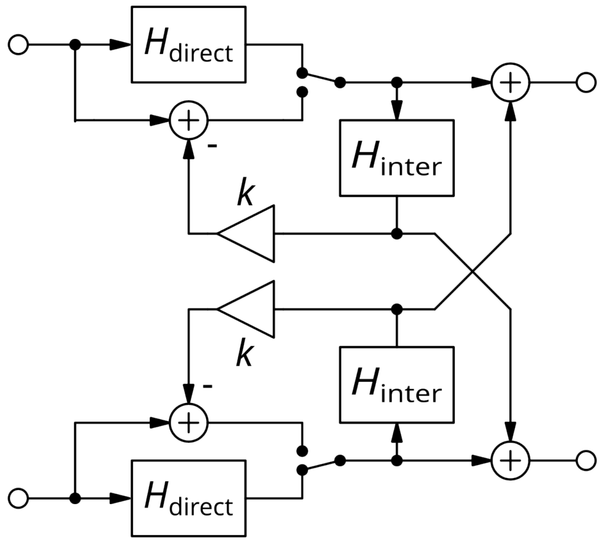

Fig. 3: Block diagram of X Feed II

4. Adjustable head size

Because the HRTFs utilized in this research are the mean values of 48 adult subjects (35 men, 13 females), and variances between subjects may be significant, it is reasonable to provide some means of individualizing the HRTFs. If we assume that the mean HRTFs are valid for the 48 participants' average head size, we can scale the HRTFs to other relative head sizes.

In an initial approximation, multiply the interaural delay time by the relative head size and divide all pole and zero frequencies by the relative head size. This method is used for relative head sizes ranging from 65 to 135%. A head size of 100% uses the original HRTFs and represents the average head size of the 48 individuals. Because the head size can be adjusted on the fly, the author employs digital state variable filters with parameter smoothing, as described in [3], rather than direct form digital filers.

Fig. 4 shows the GUI of the X Feed II plugin.

Fig. 4: GUI of X Feed II

The author suggests adjusting the head size while listening to sharply panned sounds. The setting with the most distinct direction sensation is likely the best suit for the listener's head size. After adjusting the head size properly, spatial perception should improve slightly.

5. Beyerdyamic's Headphone Lab

Beyerdynamic's free audio plugin Headphone Lab [4], as well as the author's plugin X Feed, were launched simultaneously. Headphone Lab includes an equalization for Beyerdynamic headphones, a crossfeed feature, and an ambience simulator. The crossfeed function can be employed independently, bypassing the headphone equalizer and totally attenuating the ambient signal.

The crossfeed function appears to use diffuse field normalized HRTFs too, however they are most likely sourced from a different data base. The HRTFs are implemented as FIR filters with 4096 samples (measured at 48 kHz sample rate). The azimuth angle of the virtual loudspeakers can be adjusted to +/- 20, 30, or 40 degrees, while the author's plugin has a fixed value of +/- 30 degrees. The head circumference is adjustable between 37.1 and 70.5 cm, with a default value of 53.8 cm.

Fig. 5 depicts the interaural transfer function of Headphone Lab for the +/- 30° setting and the default head size in black. The mean transfer functions for an artificial head and 48 subjects are displayed in red. The magnitude of the crossfeed signal is clearly too high at most frequencies. More noticeable is the fact that the phase delay time is too low in general, but especially so at low frequencies. The phase delay is even negative below 150 Hz. It appears that the developer has modified the phase response of the original HRTFs at low frequencies in an unnatural manner.

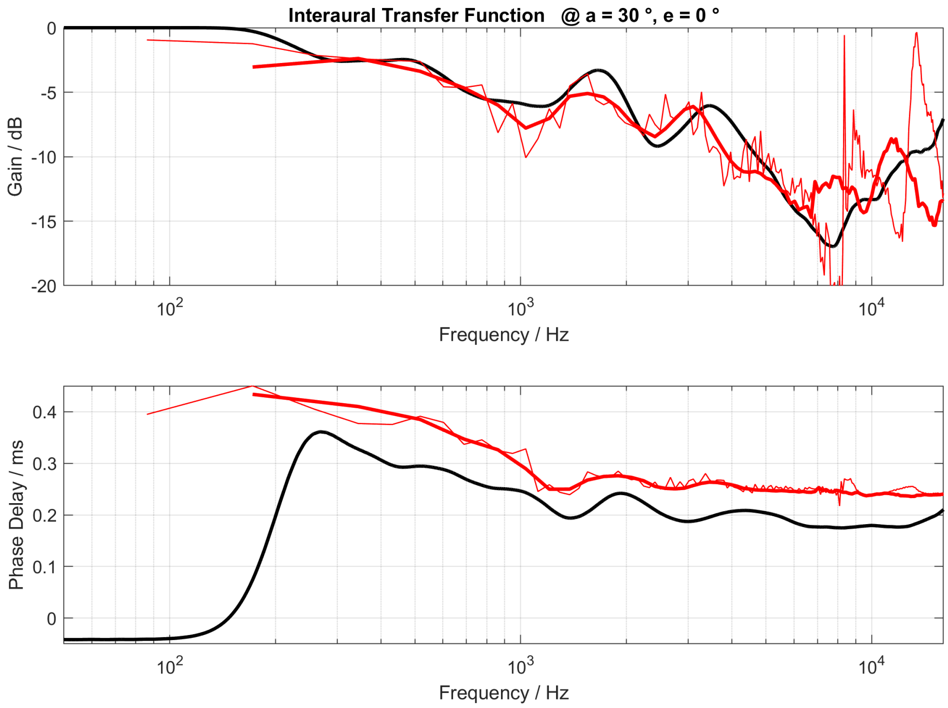

Fig. 4: Interaural transfer function of Headphone Lab

Only a variable delay time is used to modify the head size. As a result, the entire phase delay time curve shifts upward for larger head sizes and downward for smaller head sizes. The head size does not affect the resonance and notch frequencies of $H_{inter,}$ H_{direct} and H_{cross}.

Fig.6 illustrates H_{direct} and various derived transfer functions for the +/- 30° setting and Headphone Lab's default head size. In comparison to X Feed II, H_{momo} and H_{ind} have a 1 dB higher gain at low frequencies and more pronounced deviations from a flat response. As a result, Headphone Lab is louder and has a greater impact on sound color than X Feed II.

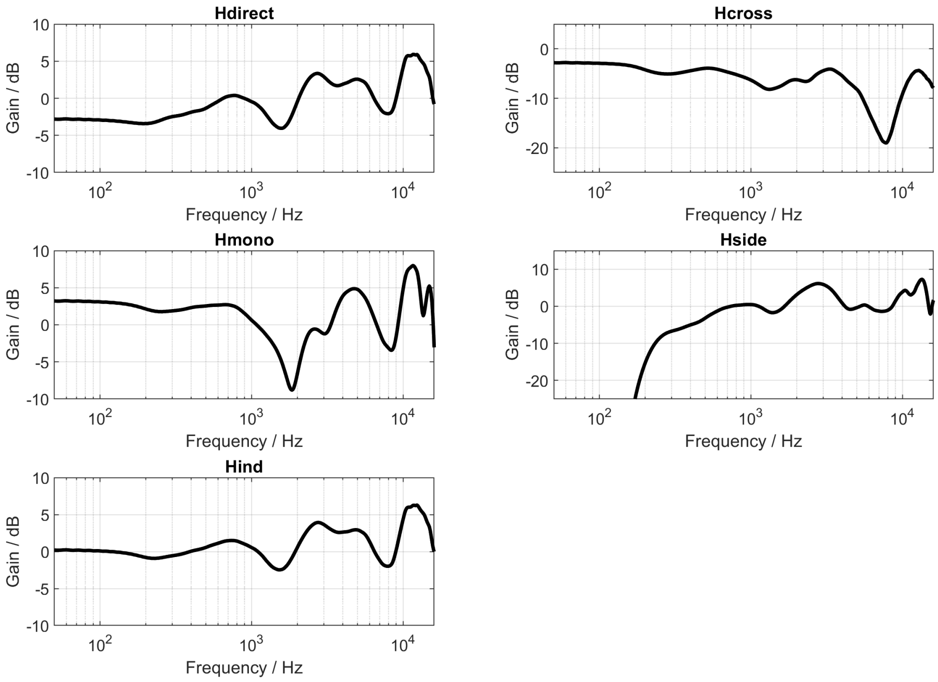

Fig.6: H_{direct} and derived transfer functions of Headphone Lab.

The author's website [5] includes a web player for an audio file containing raw (O), Headphone Lab (H), and author's plugin (K) signal samples. Both plugins have been reset to their default settings, and Headphone Lab's ambience effect has been disabled. To maintain a consistent loudness, the Headphone Lab samples were attenuated by 1 dB. For each signal sample, you will hear the following sequence: O-H-K.

The first signal is pink noise that pans continually from left to right. The second signal is composed of two independent pink noise signals: a mid-signal and a side-signal with a 6 dB lower strength. This signal approximates the characteristics of a normal stereo recording. The final three signals are brief snippets from popular stereo records.

The reader is invited to check out these demos!

6. Summary

The author's new crossfeed plugin X Feed II has been discussed in detail. In comparison to the predecessor X Feed, the interaural transfer function has been increased, and an adjustable head size has been included. Both elements slightly boost the effect's spatial perception. The adoption of a

HRTF-based equalization, on the other hand, improved the spatial perception more than anticipated. Even when listening with diffuse field equalized headphones, the perception of sound color is closer to that of a normal loudspeaker configuration.

Beyerdynamic’s plugin Headphone Lab has been thoroughly tested. The author's ears perceive X Feed II as more authentic in terms of sound color, with just a modest improvement in spatial impression.

Because X Feed II does not use head tracking or individual HRTFs, the spatial impression remains less realistic than it could be. The sound can still be heard inside the head, on a stage in front of the head's center. This is, however, far superior to the perception on a line merely between the two ears that we get when listening to headphones without a crossfeed circuit.

7. Links

[1] Helmut Keller: “A Novel Crossfeed Audio Plugin For An Improved Headphone Listening Experience”
https://www.helmutkelleraudio.de/_downloads/a08c6264f50e006db56f52474f678928

[2] Günther Theile: “On the Standardization of the Frequency Response of High-Quality Studio Headphones”
https://hauptmikrofon.de/theile/1986-3_Standardization-of-studio-headphones_JAES-1986.pdf

[3] Helmut Keller: “Digital State Variable Filters”
https://www.helmutkelleraudio.de/_downloads/bd50cee15835a4a58882d022a0ddc079

[4] Beyerdynamic: Download link for Headphhone Lab
https://www.beyerdynamic.de/headphone-lab-registration?cid=lp_header_hl

[5] Helmut Keller: The authors website
https://www.helmutkelleraudio.de/