A very simple way to simulate the timbre of flutter echoes in spatial audio

Tor Halmrast

A VERY SIMPLE WAY TO SIMULATE THE TIMBRE OF FLUTTER ECHOES IN SPATIAL AUDIO

Tor Halmrast
University of Oslo/Musicology
torhalm@online.no

ABSTRACT

The “strange” timbre of flutter echoes is often not included in spatial audio, auralisations and room simulations for video games etc., perhaps due to lack of knowledge, but also because a detailed simulation will be very heavy. In common room acoustic modelling only a relatively small number of reflections are used, and the later part of the decay is treated simply as diffuse reverberation. For rooms likely to give a flutter echo, this will not be sufficient. This paper will explain why a flutter echo gives the characteristic mid-/high frequency “tail” and show how this can be simulated adding a band pass filtering to a “ping-pong” echo between two loudspeakers.

1. INTRODUCTION

Flutter echoes are usually thought of as a defect one simply wants to avoid. The physics of flutter echoes is, however, not simple. Repetitive reflections with Δt [s] between each reflections give a perceived tone with a frequency of $fo=1/\Delta t$ [Hz] and multiples of this. Often this “Repetition Pitch”/“Repetition Tonety[1]” is used to explain the “tonal” character of a flutter echo in rooms with two parallel, reflecting surfaces and the other surfaces almost totally absorbing. However, $fo=1/\Delta t$ is in the low frequency range but the characteristic “almost tonal” character of a flutter echo is of mid/high frequency, typically around 1-2 kHz. Also sound engineers mix up these effects, and several plug-ins called “pong-echo” etc. forget this special timbre of real flutter echoes. This paper gives an overview on several ways to explain the special timbre of flutter echoes, by inspecting Diffraction, Mirror sources, Fresnel Zones, Transformation from spherical to plane waves etc. This knowledge about flutter was implemented as a sound effect not only in time but also frequency domain.

The paper shows measurements of flutter in actual rooms compared with simulations in room acoustics modelling software (Odeon), empirical evaluations, Fresnel-Kirchhoff approximations of diffraction and simulations in MatLab (Edge Diffraction Toolbox). Each of these methods does not fully describe the physics of flutter, but together they give interesting views on what is happening. For a deeper analysis, see [1] and [2]. This paper shows that the resulting characteristic mid/high frequency timbre of a flutter in ordinary rooms is not a “tone”, but a gradual band pass filtering of the broad banded impulsive signal, like a gradual subtractive synthesis. We find that this filtering is a combination of two filtering effects: Low frequency dampening due to the increasing source distance and diffraction, which gives that the sound field is transferred from spherical to plane waves, and High frequency dampening due to air absorption, as shown in the overview in figure 1.

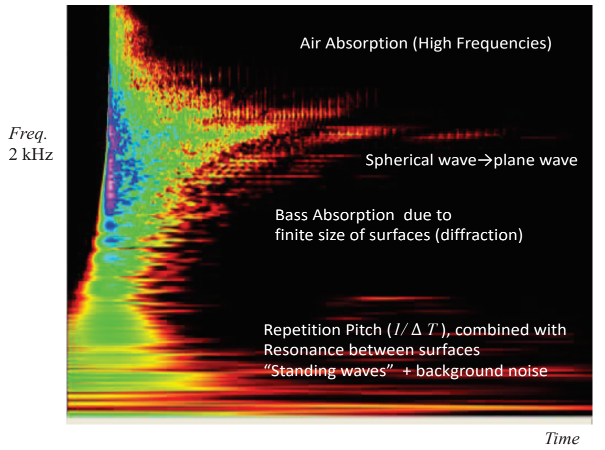

Figure 1. Overview of the timbre of flutter echoes

The sound pressure level of a plane wave is reduced only by air absorption and the absorption at the surfaces, while a spherical wave is reduced by 6 dB per doubling of distance. Together these two main filtering effects give the characteristic mid/high frequency “almost tonal” character of flutter, which we will call the “Flutter Band Tonety[1]” (or just “Flutter Tonety”), as a distinction from the “Repetition Tonety”. Depending on the amount of bass in the signal, its duration and especially the position of the sender/receiver with respect to the resonance peaks and nodes of the standing wave pattern of the room resonances between the surfaces (and “overtones” thereof) will appear, but for most positions between the reflecting surfaces, and especially for short sounds like handclaps, the “Flutter Band Tonety-tail” in mid/high frequencies will last longer.

[1] The word “Tonety” is chosen by the author for such “almost a tone” because Pure Tones, Pitch and Tonality have more precise definitions.

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2. MEASUREMENTS OF FLUTTER ECHOES

Measurements of several flutter echoes in real rooms and in anechoic chamber are given in [1]. A typical measurement of a flutter echo in a foyer with absorbent ceiling and two reflecting, parallel walls is shown in fig. 2.

We see that the decay ends up in a "tail" around 2 kHz, almost like a gradual subtractive synthesis. If the surfaces are somewhat absorbing for high frequencies, this "tail" appears at a somewhat lower frequency.

(PS! The distance between the walls was app. 12 m, giving a room resonance between the two surfaces of app. 14 Hz, which proves that the room resonance/Repetition "Tonety" is far away from the flutter tail of 2 kHz).

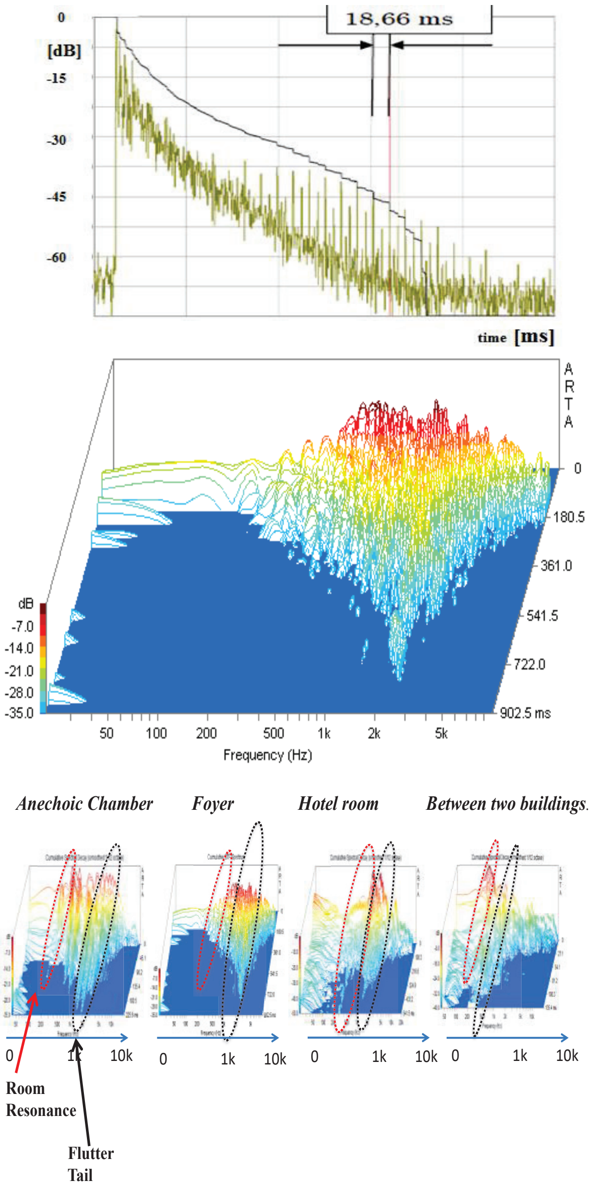

Figure 2. Upper panes: Measurement of typical flutter echo in a room: Impulse Response, and Waterfall. Lower pane: Waterfall curves of flutter echoes in several rooms.

3. SPERICAL TO PLANE WAVE

A very simple Odeon [3] room acoustics model with two parallel, reflecting surfaces was prepared (all other surfaces totally absorbing). Figure 3 shows the radiation from a point source (spherical wave). The receiver position is almost the same as the sender (as for a person clapping) and these are both positioned closer to the bottom of the surfaces, giving the possibility to inspect the situation both for a small surface (in the upper part of each figure) and a bigger surface (in the lower part of each figure).

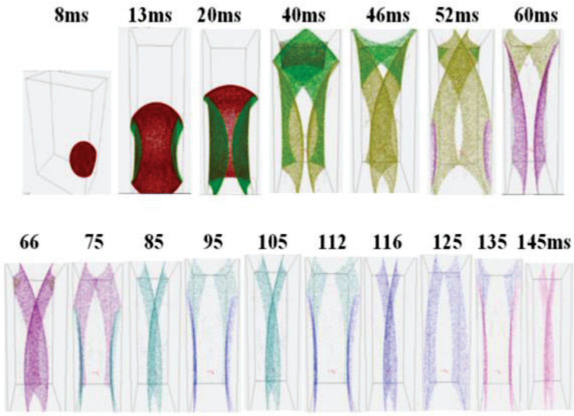

Figure 3. Odeon simulation of flutter between two parallel, reflecting surfaces, showing the transformation from spherical wav to plane wave.

Figure 4 shows similar Odeon simulation, where we see the diffraction from the edges more clearly (the small. "later" reflections, gradually decreasing).

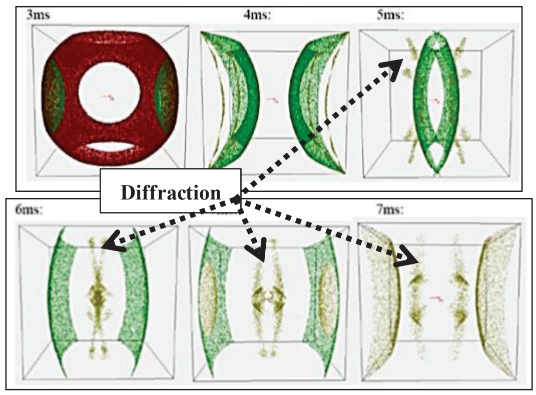

Figure 4. Odeon simulation showing the diffraction from the edges of the reflecting surfaces, which gradually combine in a destructive way, leaving the plane wave in the last part of fig.3.

4. SPERICAL TO PLANE WAVE

When you clap your hands at a distance from a surface, the result will be the combination not only of the direct sound and the reflected sound, but also the diffraction; which is the "reflection" from the edge of the surface. For some frequencies they arrive in phase and for other frequencies, one or two of them might arrive out-of-phase with another.

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A typical situation for one reflecting surface is shown in figure 5.

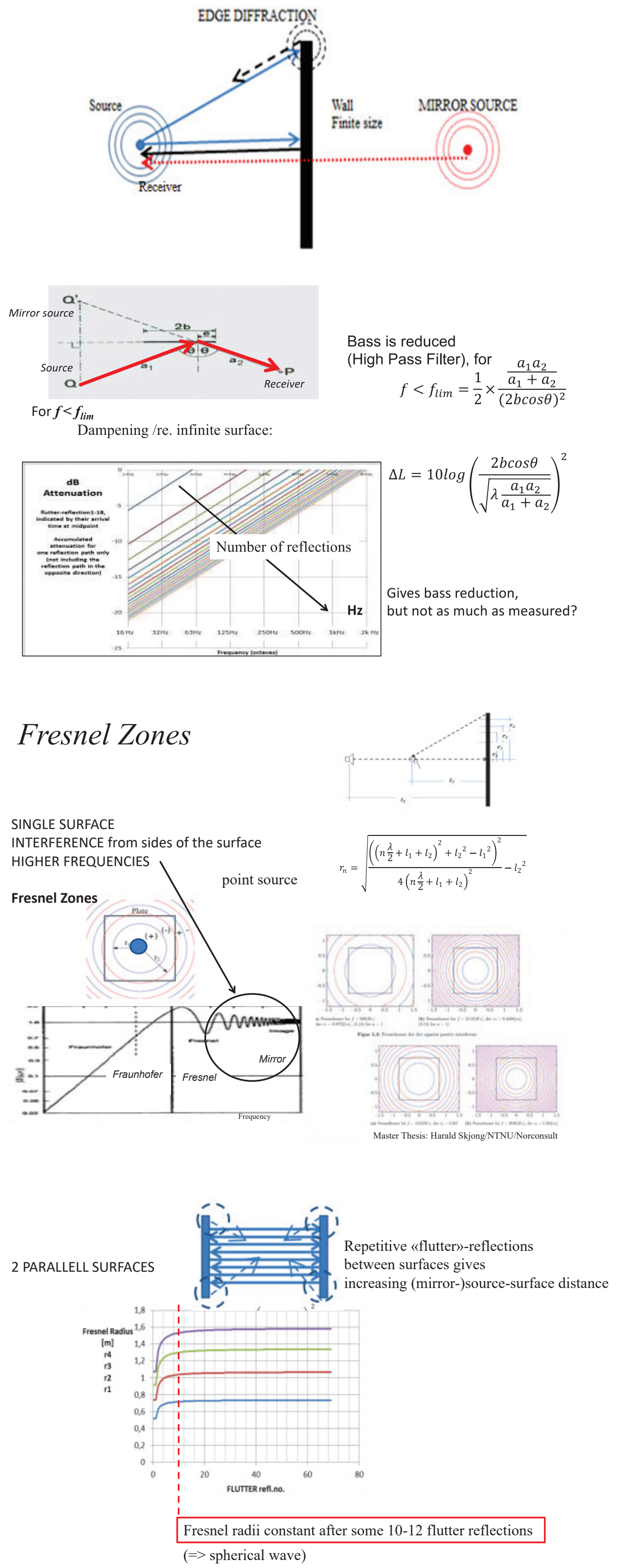

Figure 5. Mirror source and Diffraction from the edge of a finite surface. Receiver is at source position (as for a person listening to his own handclap). Middle and lower panes: Illustrations of diffraction. See [1] for discussions.

Fig. 4 showed how diffraction influenced the fluttering reflections between two walls. For our repetitive reflections the distance between mirror source(s) and its corresponding reflecting wall grows very rapidly, giving that, seen from the mirror source, the surface(s) appears smaller and smaller. The result is that they reflect gradually less and less in the bass and lower mid-frequencies. Several methods for calculations of diffraction are given in [1], and are beyond the scope of this paper. The results [1] from the analysis in MatLab (Edge Diffraction Toolbox by Peter Svensson [7]), iterative use of Rindel´s approximations of Fresnel/Kirchoff [8] etc. confirm the main conclusions about flutter echoes.

5. INFLUENCE OF DIMENSIONS AND ABSORPTION; KUHL´S EQUATION

Flutter was investigated by Maa [4], Krait et al. [5] and Kohl [6]. Both [5] and [6] states that for a plane wave between two surfaces ***S*** [m2] with distance ***l*** [m], the wave is dampened only by the absorption coefficients ***α*** at each surface and the air absorption, ***m***. (frequency dependent; ***4m*** is typically 0 for low frequencies, 0.01 for 1 kHz, rising to 0.03 for 4 kHz). More background for Kuhl´s equations is given in [1]. The frequency content of flutter can be looked upon as the "sum" of three reverberation "asymptotes" for the reverberation time versus frequency, ***f***.

1. Low Frequency damping due to finite surface area:

$$T_1 = \frac{0.041\ x\ 2fS}{c} \tag{1}$$

(where *c* is the velocity of sound, typically 343 m/s)

2. Damping due to absorption (α) on the surfaces:

$$T_2 = \frac{0.041 \times l}{\alpha} \tag{2}$$

3. Damping in the air (dissipation):

$$T_3 = \frac{0.041}{m} \tag{3}$$

The total reverberation time, T_{FL}, can be re-written *as*:

$$\frac{1}{T_{FL}} = \frac{1}{T_1} + \frac{1}{T_2} + \frac{1}{T_3} \tag{4}$$

Fig. 6 shows how these three "asymptotes" work together to get the total maximum reverberation for a mid/high frequency band, and how the different parameters influence on the position of the "peak" and, to a certain degree, how narrow this "tail" will be, (the "Q-factor" of the combined filter) (logarithmic freq.- and T-axis).

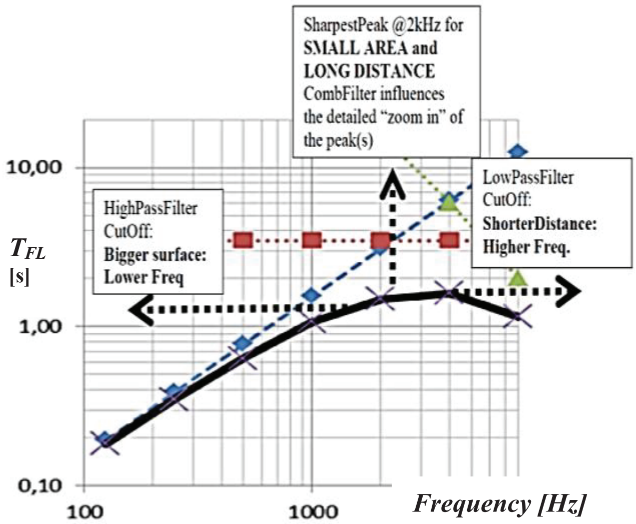

Figure 6. Illustration of Kuhl´s equation, showing how the different parameters influence the reverberation time of flutter echoes

6. LINKS BETWEEN ROOM RESONANCES AND FLUTTER TAIL

The waterfall curves in fig. 7 show the two main "tonalities" a flutter echo. The lowest "hill" (marked 1, red/dotted ellipse) indicates the "Repetition Tonety" (fo=1/Δt) between the surfaces. (Often disturbed by some background noise). For gradually higher frequencies we see the "harmonics" of this resonance (2fo, 3fo etc.) We see that the mid/high band (marked 2, black/solid line ellipses) last longer and one of these "overtones" will of course "win" in the competition of lasting the longest. The fact that a mid/high frequency band last longer than the fundamental of the Repetition Pitch/"Tonety" (fo), is therefore not a direct result of the fo-resonance itself, but as we only have the multiples of fo to choose from towards the "tail", there is of course a certain link between the two main "tonalities" of flutter. It is like a subtractive synthesis gradually resulting in one (or some) of the many higher overtones of the room resonances.

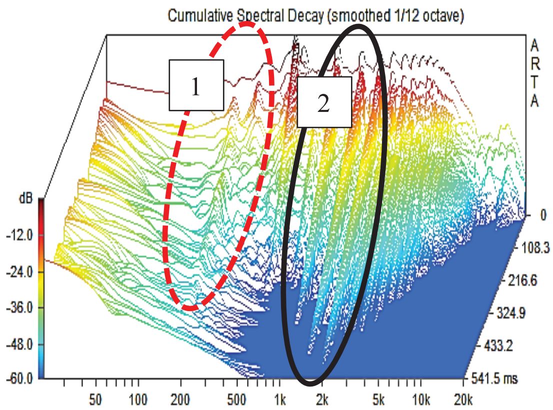

Figure 7. Waterfall curves of flutter "Resonance Tonety" (1, red/dotted), "Flutter Band Tonety" (2, black/solid line).

Fig. 8 shows an overview of these two main "tonalities" of flutter, now using a linear frequency axis. The equally spaced lines are the "overtones" of the "Resonance Tonety" fo. The overall filtering giving the mid/high frequency "tail" is the "Flutter-Band-Tonety" as a result of the High Pass Filter due to non-infinite surfaces and increasing distance between mirror source and surface for each flutter reflection, and the Low Pass filtering due to air absorption. The impact of the "Repetitive Tonety" (marked 1), combined with the room resonances is highly dependent on the signal and the positions of sender and receiver, but the flutter filtering towards the "tail"/"Flutter Tonety" (marked 2) is perceived much easier for all positions.

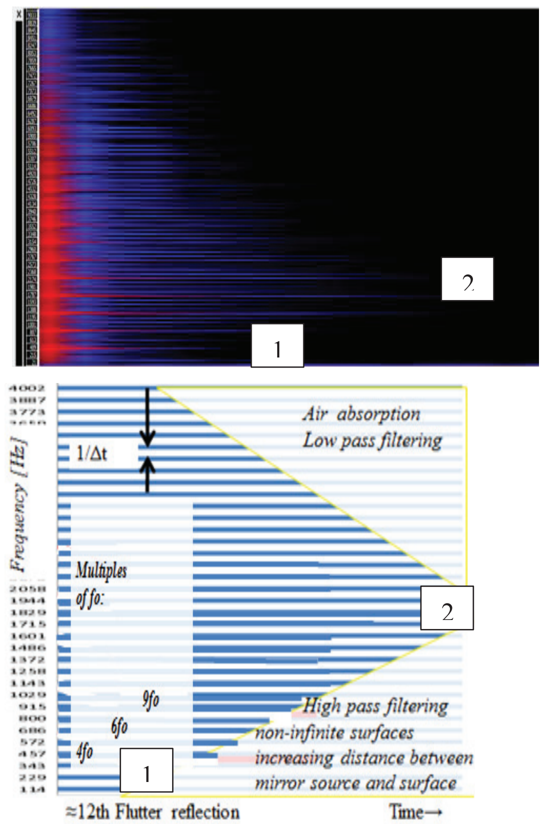

Figure 8. The two main "toneties" of flutter. Measurement and schematic overview

7. FLUTTER AS A SOUND EFFECT

For the composition FLUTR [9], the author used flutter as a major sound effect, of course for rhythmic effects, but also regarding timbre. Because Kuhl´s equations are given for reverberation time, and thus not directly a signal processing algorithm, several typical input parameters were chosen, and used in patches both in Max and Pure Data, and also transferred to plug-ins in Reaper.

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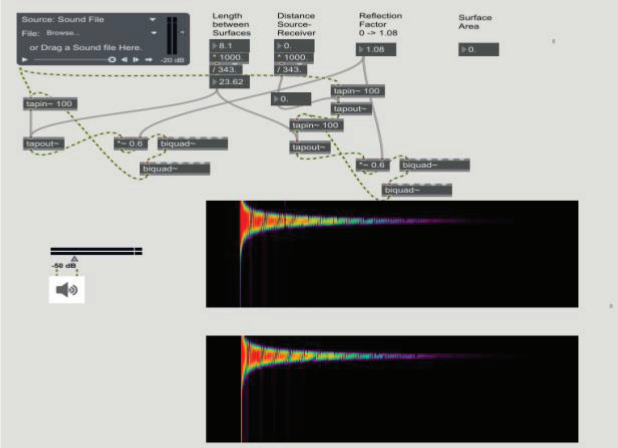

Figure 9. Extract from Max/msp patch for flutter echoes

To check the very simple patch, a Dirac pulse was used as signal and the result in fig. 10 shows good agreement with the measurements shown in the fig.1 and 2.

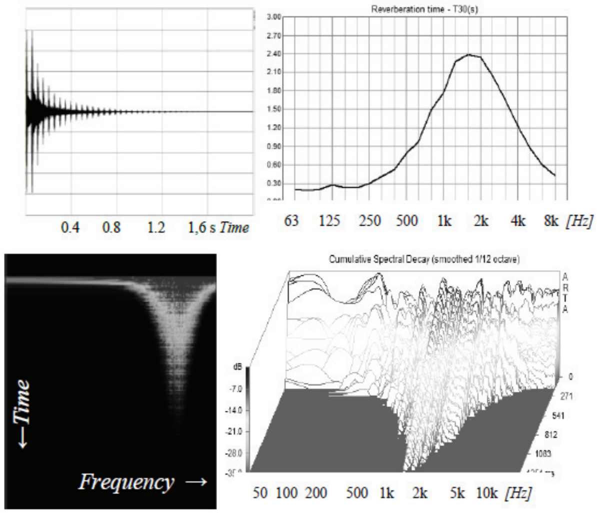

Figure 10. Dirac pulse sent through Max/Msp patch. Impulse Response, Reverberation Time, Spectrogram and Waterfall.

Tests indicate that for “common sized rooms”, an exact calculation of the peak frequency of the “flutter tail” is not really necessary. Both calculations using Kuhl´s equations and from the measurements in fig. 6, shows that for a quick simulation, it is sufficient to choose app. 1.5-2 kHz as the center frequency of the band pass filter in the loop. Another reason for not needing to be very precise in the calculation of the frequency of the “tail” is that the frequency is so high that we are over the common melodic range of frequencies.

8. CONCLUSION

This paper shows that the resulting characteristic mid/high frequency timbre of a flutter in ordinary rooms is not a “tone”, but a gradual band pass filtering of the broad banded impulsive signal, like a gradual subtractive synthesis. This filtering is a combination of two filtering effects: Low frequency dampening due to the increasing source distance and diffraction, which gives that the sound field is transferred from spherical to plane waves, and High frequency dampening due to air absorption. The result is the characteristic “tonety” mid/high frequency character of a flutter echo, as a “tail”, typically ending around 1-2 kHz. Flutter should not be explained by room resonances/ repetition “Tonety”, (but might actually be considered as a gradually filtering towards a very high harmonic of this).

We started out stating that flutter echoes had nothing to do with room resonances, but since the fluttering is filtering, the final “target” of the flutter tail actually will be the ***n***th harmonic of the room resonance, (where ***n*** might be typically in the order of 50-150). A more detailed simulation for which of these resonances that “win” could be interesting, but for a “real time” simulation, 2 kHz clearly gives the timbre of flutter. For practical use in room simulations and electro-acoustic music, it is found that a very simple way to simulate flutter echoes is to make repetitive repetitions between the two actual dimensions and make a gradual bandpass filtering to about 2 kHz. This has been implemented in Max/Pd and as a plug in.

9. REFERENCES

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