ODEON APPLICATION NOTE
Detecting flutter echoes in Odeon

AR, GK, CLC – October 2021

1. Introduction

A flutter echo is a well-known acoustic phenomenon, in which a sound wave is reflected back and forth between two reflective surfaces. As little energy is absorbed by these two surfaces, flutter echoes can persist for a considerable amount of time. As a result, they can cause unfavourable colouration in the signal (speech, music), which disturbs conversations and leads to discomfort in acoustics. Therefore, they should generally be avoided. It can be useful to detect flutter echoes already in the design phase of projects in order to mitigate them. For that purpose, multiple features in ODEON can help the user to identify these flutter echoes.

The note shows that flutter echoes are included in Odeon simulations and demonstrates how we can detect them – other than auralisation.

Note: The features presented in this note are available in the Auditorium and Combined editions of ODEON.

2. ODEON model: a rectangular room

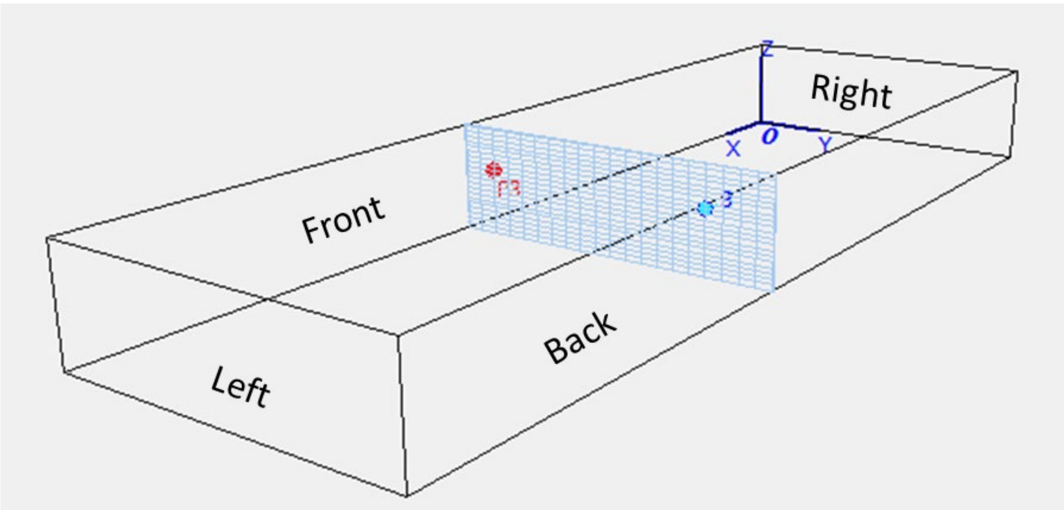

Figure 1: A rectangular room in ODEON with dimensions L*W*H = 30 m * 10 m * 3 m. A source and a receiver are placed in the same YZ plane to study flutter echoes. The walls are named according to the receiver, which is facing the source.

We consider a rectangular room with dimensions L*W*H = 30 m * 10 m * 3 m (see Figure 1). The room and its sound field have been investigated in another application note on rectangular rooms [1]. The room has several particularities:

- Simple geometry: parallel walls.
- Uneven dimensions: low height compared to the two other dimensions.
- Flat surfaces: scattering coefficient set to 1 % on all surfaces.

The presence of parallel walls with both low scattering and low absorption favours the presence of flutter echoes in the room. This is especially expected in the Y and Z directions, which are the smallest dimensions.

We consider two conditions in terms of absorption, as in [1]:

- **Condition 1:** Material 10 (10 % absorption) on all surfaces.
- **Condition 2:** Material 90 (90 % absorption) on the ceiling, Material 10 (10 % absorption) on the other surfaces.

These conditions are analysed in detail in [1], where Condition 1 leads to a relatively diffuse field far away from the source, whereas Condition 2 is a typical example of a room with a double decay. Condition 2 leads to a clear flutter echo in between the two side walls. In this note, we place a source and a receiver in the same YZ plane (see Figure 1) and we investigate echo phenomena in both conditions. The results are found in the *Single Point Response* menu from the *Job list.* A complete description of the content of this menu can be found in the contextual help of ODEON (keyboard shortcut: F1).

3. Sound intensity and energy decays

The *Decay curves* tab contains the *raw decay curves*, which are accessed by toggling the display (Keyboard shortcut: T). The corresponding graph shows the *simulated raw sound energy*, *the backwards integrated decay curve*, as well as its version *corrected for truncation* [2]. The graph also shows the decay of the *sound intensity norm* and its *backwards integrated* version. The curves are presented per octave band, navigating between the different bands is done with the up and down keys. By default, both the energy (mean-squared pressure) and the intensity vector are calculated in time slices of duration 1 ms.

Figure 2 and Figure 3 show the squared pressure decay and the intensity norm decay in Condition 1 (Reflective surfaces) and Condition 2 (Absorptive ceiling), respectively. We focus on the 1 kHz band, but the behaviour is similar in the other octave bands.

In both cases, the curves have a steep initial decay and a sharp increase at about 60 ms. This increase is attributed to the first strong reflection from the back wall. Afterwards, the curves decay more continuously. For both Energy and Intensity, Condition 1 leads to smoother curves than in Condition 2, because the sound field contains more reflections from different directions. The peaky aspect of the curves for Condition 2 is typical of flutter echoes, where the energy increases periodically during the decay, every time the flutter echo reaches the receiver position.

Note: in ODEON, variations in the simulated decay curves can also be the consequence of too few rays. However, in this case, we have already used a very large number of rays to account for the unevenness of the geometry, as explained in [1].

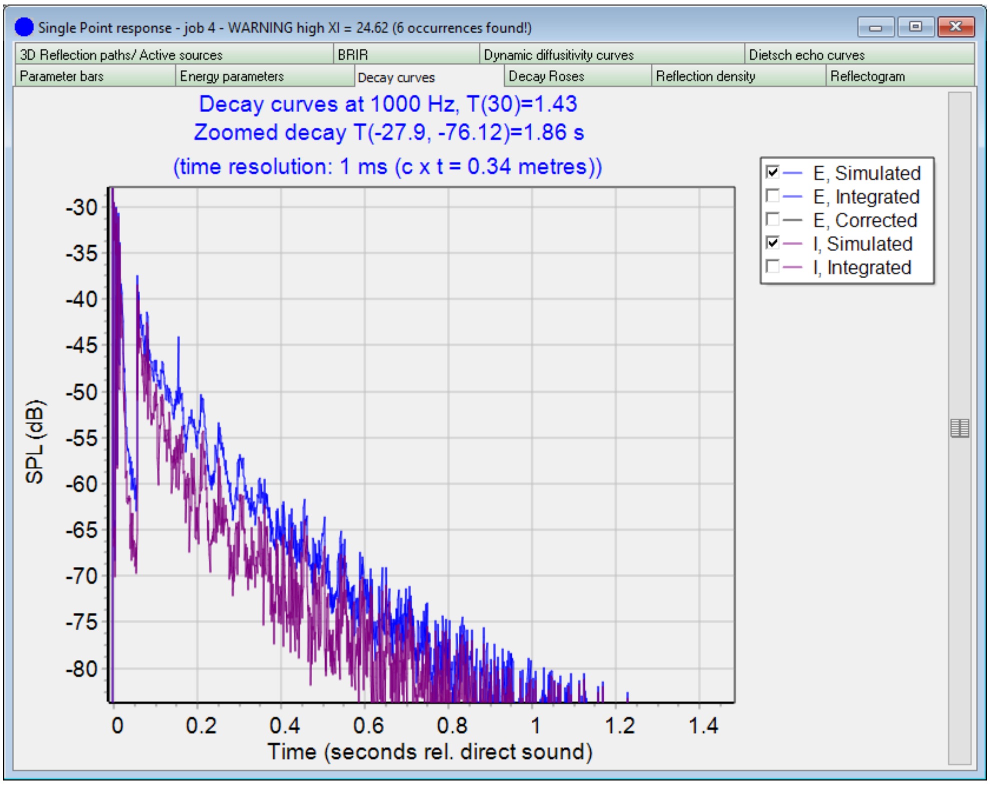

Figure 2: Energy and Intensity decay in Condition 1 (Reflective surfaces).

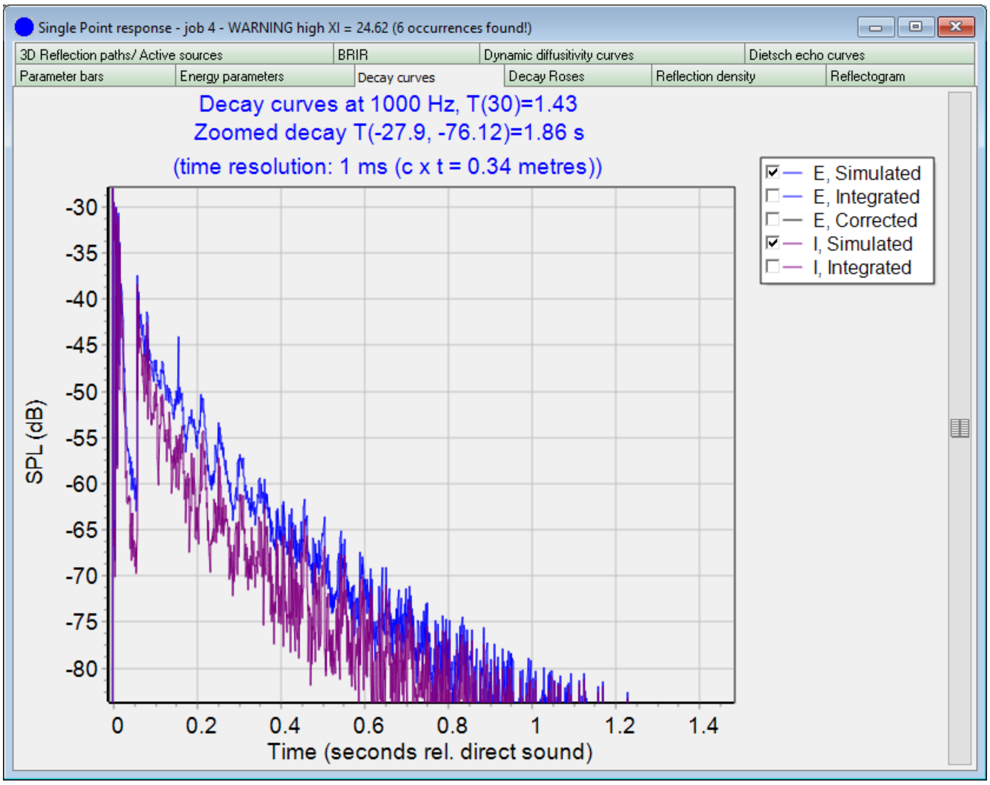

Figure 3: Energy and intensity decays in Condition 2 (Absorptive ceiling).

4. Intensity hedgehogs

From the intensity curve, ODEON can display an *intensity hedgehog*, by toggling the *3D geometry* (keyboard shortcut Ctrl+T).

As a reminder, the acoustic intensity is defined as the acoustic power per unit area at the receiver point, and it represents the flow of acoustic energy at this point. It is a vector quantity, calculated as the product of the pressure and the particle velocity. The direction of the vector represents the direction of the energy flow. It is common to average the intensity over a period of time. In ODEON, this period of time is the time resolution, which can be changed by the user (between 1 ms and 50 ms).

The intensity hedgehog is composed of spikes corresponding to local maxima of the intensity norm as a function of time. If only one reflection is detected in the time slice, the corresponding hedgehog spike points towards the direction of arrival of that reflection.

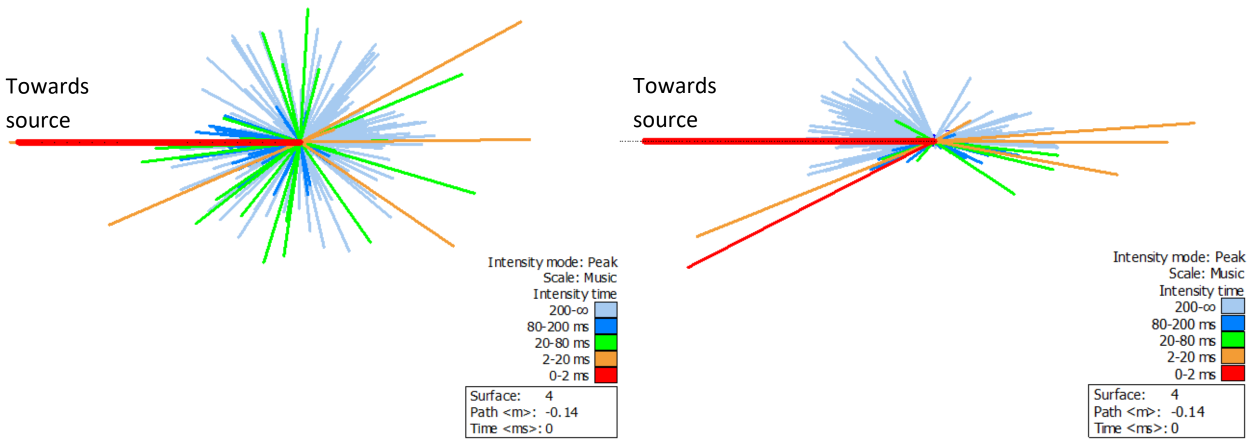

Figure 4: Intensity hedgehogs for Condition 1 (Left) and Condition 2 (Right). Side view: the source is located on the left of the receiver, as indicated by the dashed line.

Figure 4 shows a side view of the intensity hedgehogs in both conditions. Whereas some of the components of the hedgehogs are similar in both cases (direct sound, reflection from the right wall, reflection from the floor), the components with more vertical dimensions are attenuated in Condition 2, as expected. We also notice large differences in the later part (after 20 ms), where most vertical spikes are suppressed by the absorbing ceiling in Condition 2. The hedgehog for Condition 2 shows most components close to the source-receiver axis, which can be an indication of a strong flutter echo. Conversely, the late part of the hedgehog (after 200 ms) in Condition 1 contains more directions, indicating a more diffuse sound field.

Note: although hedgehogs can be very useful to detect reflections, they only show intensity maxima, which can also cluster several reflections. In that sense, they can differ from the *Reflection path analysis*, which is available in the *Reflectogram* tab of the *Single Point Response menu*. As an illustration, Figure 5 shows both the reflection path analysis and the hedgehog zoomed in around 6 ms, in Condition 2. At 6 ms, ODEON detects 3 reflections, all in the same vertical plane: a reflection from the front wall close to the source, a second order reflection from the ceiling and the floor, and a reflection from the floor and the ceiling arriving at the exact same time as the previous one. The corresponding spike in the hedgehog points towards the source, as the floor and ceiling reflections compensate each other.

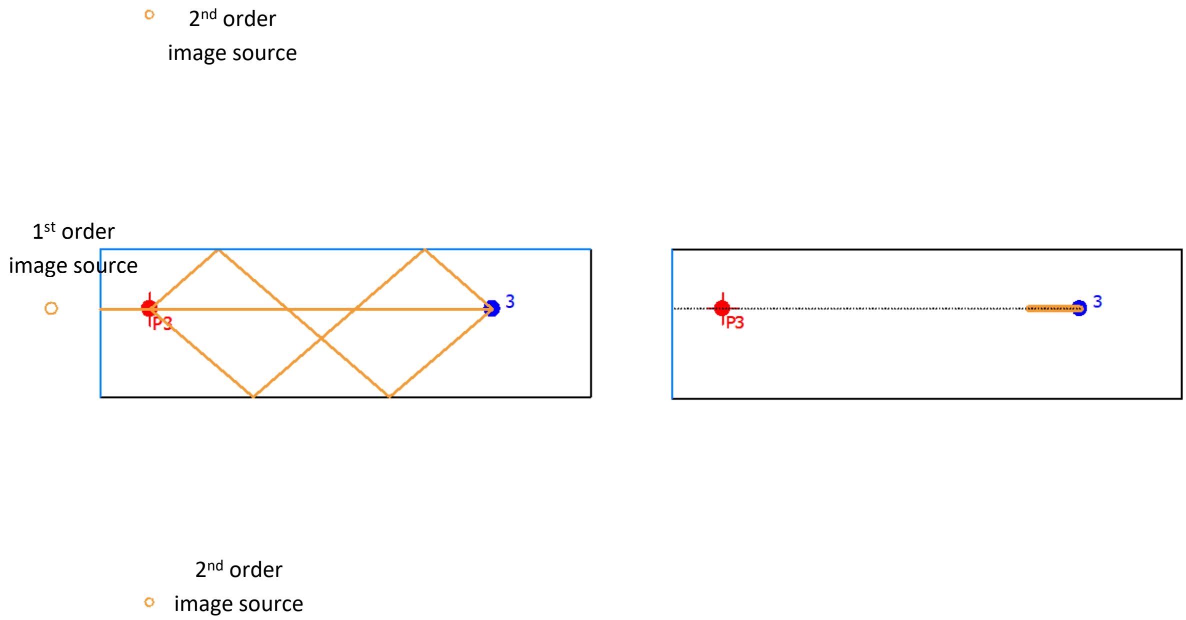

Figure 5: Reflection paths when the reflectogram is zoomed in at 6 ms after the direct sound (Left). Intensity hedgehog (Right). The two second order reflections cancel each other and are not visible in the hedgehog.

Another difference is that the reflectogram only shows the reflections from the early image source method, while the hedgehog covers the whole decay. This means that the hedgehog also includes the contribution of secondary sources, as well as higher order reflections calculated with the ray radiosity method. This is clear in our example between 17 ms and 58 ms, where no early reflection is detected in the reflectogram (see Figure 6). Indeed, in that time interval, the front/back and floor/ceiling reflections have reached the transition order, but the left/right reflections have not yet reached the receiver due to the large room length. As shown in Figure 7, the hedgehog still detects components in that interval, though with lower levels, which are due to late rays. The spikes are almost all located in the YZ plane containing the source and receiver, as no contribution from the left and right walls has reached the receiver.

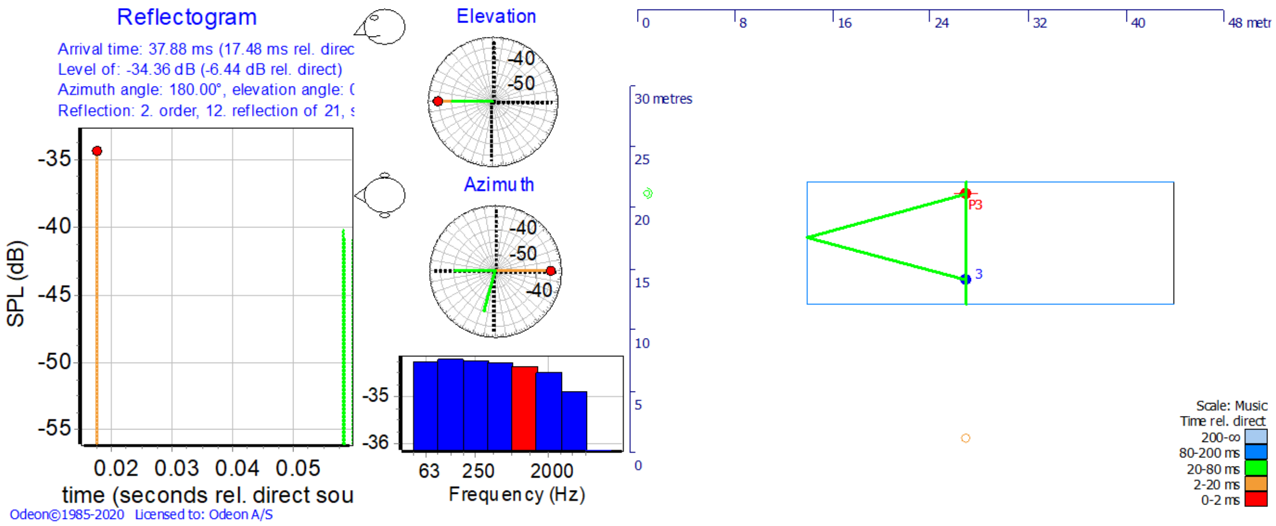

Figure 6: Reflectogram display between 17 ms and 58 ms. The orange peak corresponds to the last second order reflection detected in the YZ plane. The green peak is the first order reflection coming from the left wall, as shown in the right-hand side display.

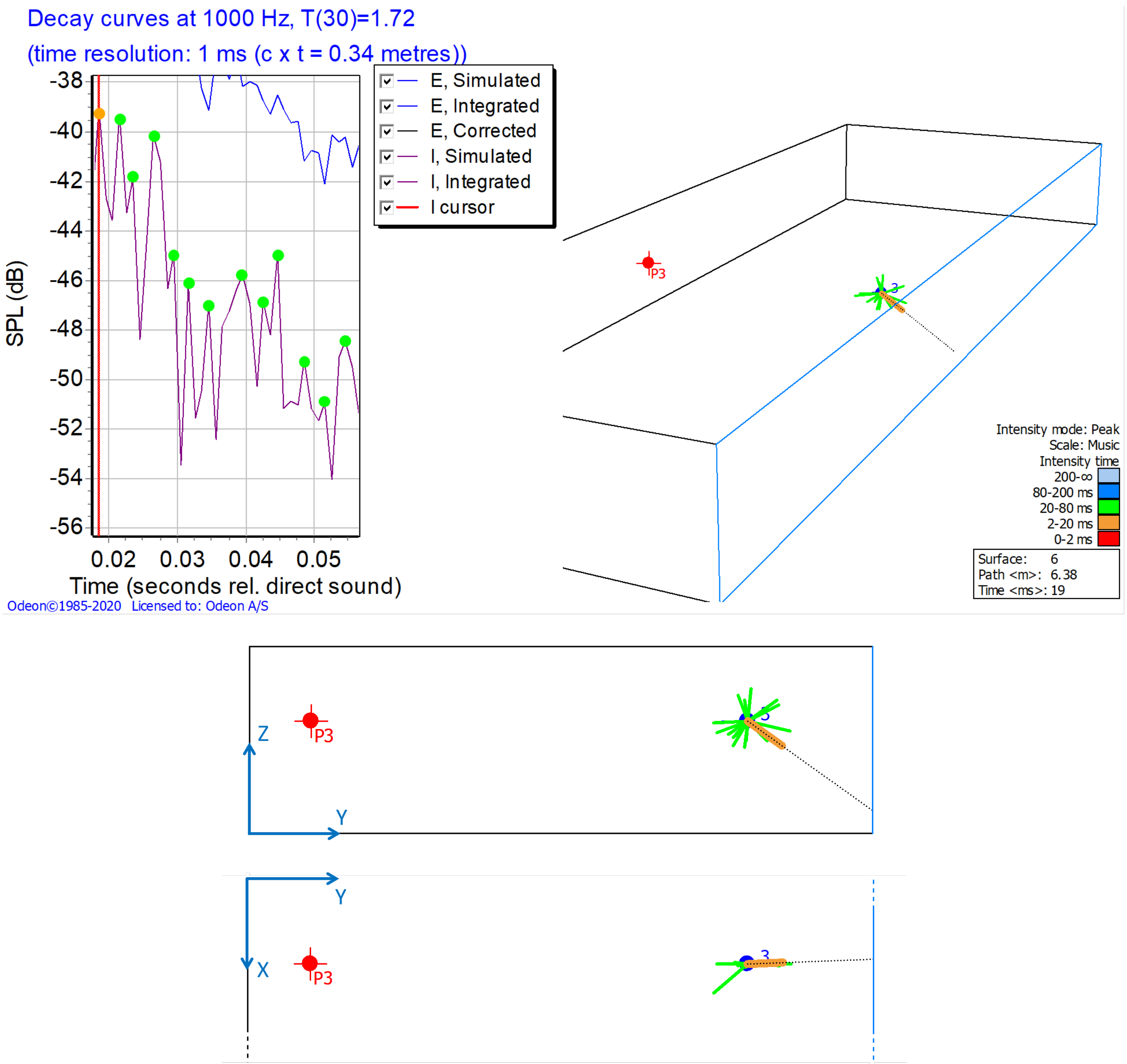

Figure 7: Intensity hedgehog display between 17 ms and 58 ms. Top left: decay curve graph. The local maxima are highlighted by dots. Top right: hedgehog view in the room. Bottom: hedgehog view in the YZ plane, containing the source and the receiver and in the XY plane (top view). All the peaks are located close to the YZ plane.

5. Dietsch echo curves

The Dietsch echo curves are a tool to detect if an echo will be perceived in reality [3]. They can be found in the *Dietsch echo curves* tab of the *Single Point Response* menu. For an echo to be perceivable, the curves should show values after the echo time limit 50 ms (displayed as a black vertical line) and above one of the horizontal lines. The higher the echo strength, the more subjects will perceive it.

Figure 8 and Figure 9 show the echo strength curves in both room conditions. In both graphs, the echo from the left side wall is visible, at about 65 ms after the direct sound. However, the echo strength only reaches 0.5 for Condition 1 and 0.6 for Condition 2, which is too weak to be properly perceived by most subjects, according to the Dietsch criterion. Nevertheless, the general aspect of the echo curves differs greatly between the two conditions. In Condition 2, the echo curves lead to a series of spikes, which are attributed to the flutter echo between the side walls. The curves are much smoother in Condition 1, as reflections travel in more directions.

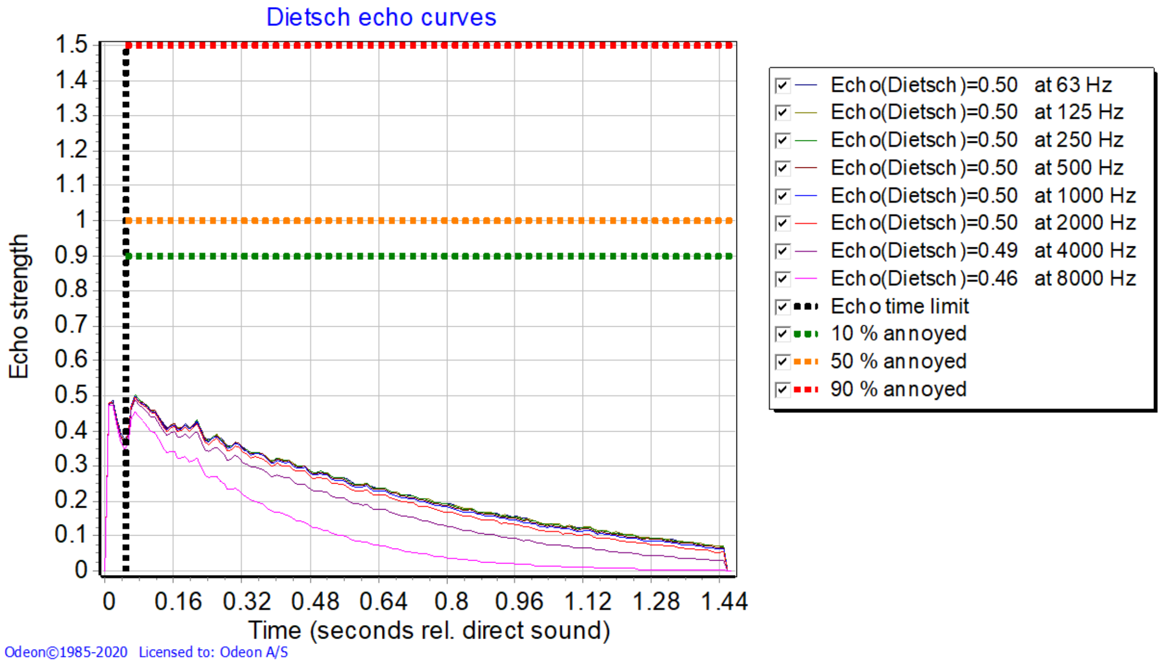

Figure 8: Dietsch echo curves in Conditon 1 (reflective surfaces).

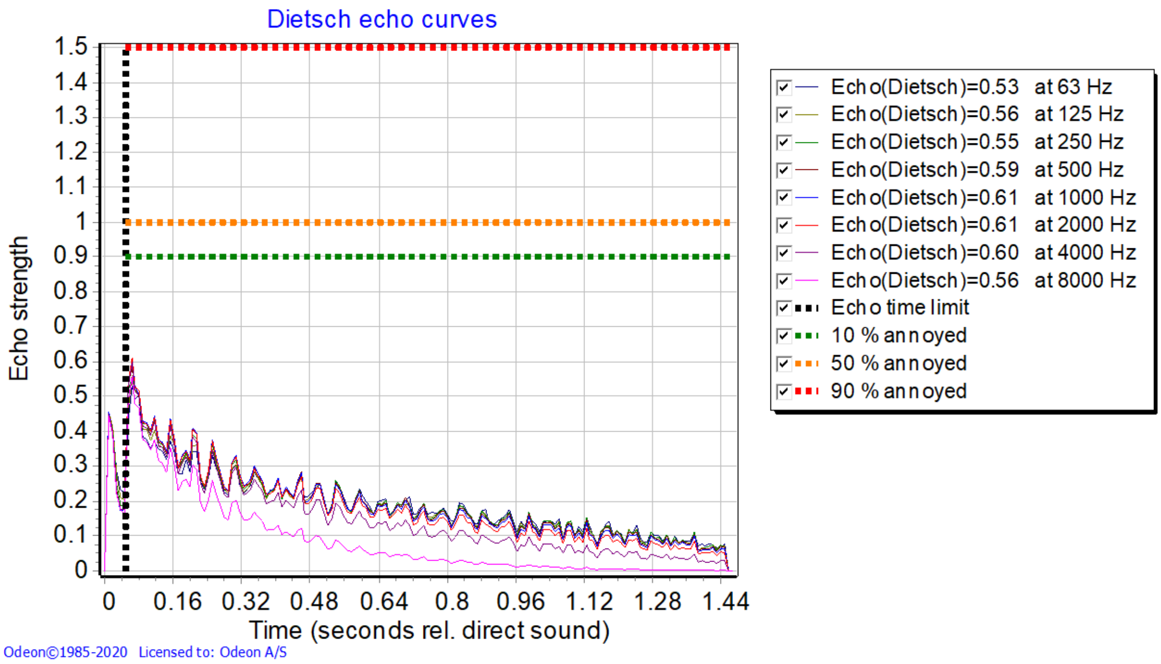

Figure 9: Dietsch echo curves in Condition 2 (absorptive ceiling).

This illustrates that even if no echo is detected according to Dietsch, there can still be flutter echo present in the room. The Dietsch method is indeed not entirely reliable, and should only serve as an indication of a strong echo. Moreover, the Dietsch method is designed to detect single echo events (called slapbacks in music), but not flutter echoes. Nevertheless, it is worth pointing out that the flutter echo clearly affects the echo curves.

6. Binaural impulse response and auralisation

If the corresponding option is activated in the *Auralisation setup*, ODEON calculates a Binaural Room Impulse Response (BRIR) for each single point response in the *Job list*. The binaural impulse responses can be visualised in the *BRIR* tab of the *Single Point Response* menu.

A quick inspection of the BRIR makes the flutter echo evident. Figure 10 compares the left channel of the BRIR in the two conditions (the same observations can be made with the right channel). The introduction of ceiling absorption leads to a peakier impulse response, which is more prone to the perception of a flutter echo. The decay is much smoother in Condition 1. Note that the echo from the left wall can clearly be seen at about 180 ms.

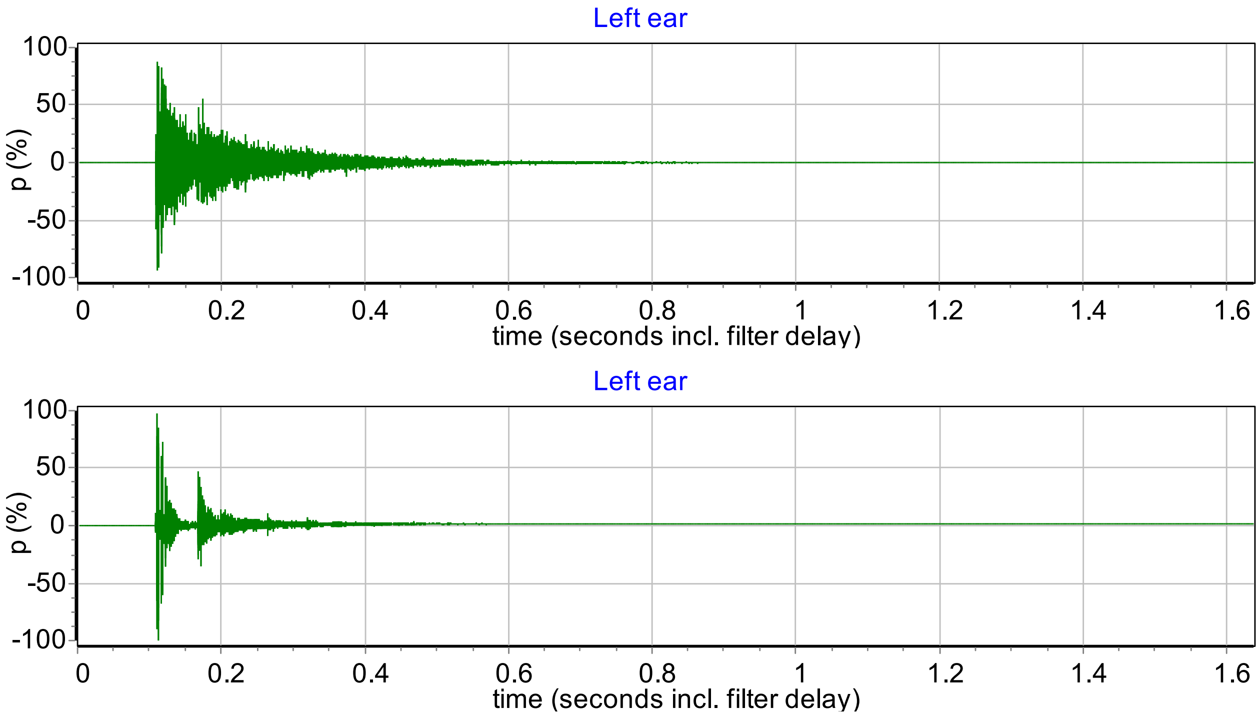

Figure 10: Left channel of the simulated Binaural Room Impulse Response (BRIR) in Condition 1 (Top) and Condition 2 (Bottom).

Convolving the BRIR with a sound signal, the difference between the two conditions can be experienced more subjectively. A first source file is the file “Clapping.wav” which is available with the ODEON installation. Both conditions lead to an echo, but they sound different. Condition 1 is more reverberant, with a continuous decay, whereas the flutter echo is clearly discernible in Condition 2. As a second example, a synthesised anechoic drum track was used as audio input [4]. An interesting effect is that in both conditions, the bass drum persists for a very long time, due to the echo in the length direction, which allows low frequencies to propagate and reflect almost unattenuated. The flutter echo is also clearly perceived in Condition 2, especially for the bass drum. These examples show two different natures of echo, depending on the attenuation of ceiling reflections. In a way, the flutter echo is also present in Condition 1 but it is masked by the other reflections involving the floor and the ceiling. Condition 2 simply makes it more perceivable.

7. Conclusion

The Single Point response menu in ODEON can be used to detect flutter echoes, which typically occur between two parallel flat walls. This section has shown different manifestations of the flutter echo in these results:

- **Decay curves:** periodic peaks in the raw squared pressure decay and the intensity norm;
- **Intensity hedgehog:** directional hedgehog, with most spikes close to the same axis;
- **Dietsch echo curves tab:** periodic peaks in the Dietsch echo curves;
- **BRIR:** peaks in the simulated BRIR;
- **Auralisations:** subjective examples in auralisation scenarios.

In general, flutter echoes should be avoided as they can create acoustic discomfort. This note has shown that in some cases, they can be masked by other reflections, in case of a high reflection density. However, avoiding large flat parallel surfaces in the design is a good practice to avoid this effect.

This note focuses on simulation cases, but similar results can also be obtained from measurements with an ambisonic probe, which captures spatial aspects of the decay.

References

[1] ODEON A/S, “Application Note: Modelling rectangular rooms in Odeon,” 2021.

[2] ISO 3382-1, “Acoustics - Measurement of room acoustic parameters - Part 1: Performance spcaes”.

[3] L. Dietsch and W. Kraak, “Ein objektives Kriterium zur Erfassung von Echostörungen bei Musik- und Sprachdarbietungen,” *Acustica,* vol. 60, pp. 205-216, 1986.

[4] D. Murphy and J. Rees-Jones, “Open AIR Library - Anechoic data,” [Online]. Available: https://www.openair.hosted.york.ac.uk/?page_id=310.