New ON/OFF Absorption Technology That Includes Low Frequencies

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ABSTRACT

Previous studies have shown that what distinguishes the best from the less well liked halls for pop and rock music is a short reverberation time in the 63, 125 and most importantly the 250 Hz octave band. Since a quite long reverberation time in these bands is needed in order to obtain warmth and enough strength at classical music concerts, variable acoustics must address these frequencies in order to obtain desirable acoustics in multipurpose music halls. A new, patented, variable broadband absorption technology is presented. Absorption coefficients measured are approx. 0.4 - 0.5 in the 63 – 1 kHz octave bands while decreasing at higher frequencies when in the ON position. In the OFF position the product attains absorption values close to 0.0. Since the product is placed in the entire ceiling area the T30 of a hall can be lowered by 40 – 50 % in all the most relevant octave bands of musical instruments at the push of a button. The technology, which is the only one to enable for variability at low frequencies, is meant to be used anywhere where both classical as well as amplified music is being played such as in music schools and performing arts centres.

1 INTRODUCTION

In [1] it was statistically proven, based on questionnaire responses, that what distinguishes the best from the less well-liked halls for pop and rock music is a shorter reverberation time in the 63, 125 and 250 Hz octave bands. This is not surprising referring to the fact that a pop or rock concert is as loud and rhythmically active in the 63 Hz to 250 Hz bands as at higher frequencies. The critical distance, \( r_{cr} \) is given by (1):

\[
r_{cr} = \sqrt{\frac{Q V}{100 \pi T (1 - a') N}}
\]  

(1)

where \( Q \) is the directivity of the sound source at a given frequency, \( V \) is the volume of the room, \( T \) is the reverberation time of the room at a given frequency, \( a' \) is the average absorption coefficient of the room at a given frequency and \( N \) is number of discrete loudspeaker clusters. It is inherent from the equation that since \( Q \) is close to 1 at low frequencies a big share of audiences will suffer from reverberant, undefined low frequency sound if not the reverberation time increases just as much with higher frequency as the directivity of the speaker system. The directivity at higher frequencies can easily be 10 and it is unlikely that the reverberation time of a room is a factor of 10 higher at high
frequencies than at low. Seen in that light, it is at least possible, that the reverberation time at higher frequencies in a room for amplified music can be somewhat longer at high frequencies than at low and that the critical distance will still be shortest in the bass domain. If the loudspeakers are correctly aimed towards the audience who absorbs more than 4-6 times as much mid-high frequency sound than bass this by itself will control the critical distance at mid-high frequencies. Surely, further studies lead to proposed acceptable tolerances of recommendable T30 in [3]. Due to the punchy, boomy nature of the 125 Hz band and to the fact that our hearing does not roll off as fast in this band with the decay of sound as in the 63 Hz band makes the 125 Hz band the most important to control. It seems that reverberant 125 Hz octave band sound is unfortunately a good and dominant masker.

![Graph showing acceptable tolerances of T30 in halls for amplified music in the 63 Hz to 4 kHz band domain proposed in [3].](image)

**Fig. 1:** Acceptable tolerances of T30 in halls for amplified music in the 63 Hz to 4 kHz band domain proposed in [3].

Also in [1] it was found that sound engineers preferred a very short T30, but musicians preferred a somewhat longer reverberation time. The reason for this is that the musicians prefer a sensation of envelopment and “togetherness” with each other and the audience while sound engineers in a quite dead room achieve of control over their out board gear including artificial reverberation tools. It is believed, but not proven, that the audience also has a desire for a sense of envelopment since they are not attending live concerts to experience a high fidelity sound quality adventure, but rather a social event. To achieve this, a certain level of reverberant sound at live pop and rock concerts is required, but evidently according to the above, not at low frequencies. Hence a design goal for pop and rock halls could be to allow for an amount of higher pitched reflections for a sensation of envelopment. In big halls such as arenas, this is probably not true due to the very big distances the sound is traveling [4]. Therefore extremely precise speaker coverage for all audiences is here needed.
2 INFLATABLE ABSORBER TECHNOLOGY

From our knowledge that a low T₃₀ at low frequencies is required for amplified music while warmth demands a higher value of low frequency T₃₀ at classical music concerts, attaining a high absorption coefficient over a broad spectrum at lower frequencies has been one aim in the development of this new variable absorber.

The basic technology of soft inflatable membranes as means for variability of reverberation time in multipurpose venues was presented in [2] and the first measurements on a practical embodiment of the technology was presented in [3]. This new product, the AqFlex™ absorber system, enables an inexpensive way to achieve enough absorption variability when installed in the ceiling to make it possible, for example, to present both symphonic music and rock concerts in the same venue with favorable acoustics. The product can be installed permanently for ON/OFF use as seen in figure 2, or, since it is extremely thin and light, it could potentially be installed temporarily in any hall. The figure shows how any number can be employed to reach a specific reverberation time as specified by an acoustic consultant.

Fig.2: A number of absorber-rows are mounted in the ceiling around ventilation ducts etc. For symphonic music and choir no absorbers are inflated. At pop and rock concerts all absorbers are activated. For chamber music only a portion are activated.

If the PA system is designed correctly, i.e. avoiding loudspeakers aimed directly against wall surfaces, suitable conditions for pop and rock concerts and rehearsals are obtained with all absorbers in their “on” position. Also, variable porous absorbers can be employed on the rear wall leaving the low-mid frequencies to be absorbed by the AqFlex system. A lowered acoustically transparent ceiling can be mounted underneath the absorbers for aesthetic or utility purposes. This may include attachment of lighting, ventilation, fire sprinklers etc. It takes approx. 5-15 min. to activate the system after the push of a button on a wall-mounted control unit. The air pressure of the system is automatically surveyed to ensure maximum absorption at all times. The absorber material is flame retardant to the European B,s1,d0 and US NFPA 701 and ASTM E 84 standards and is a specially engineered PVC with a high degree of inner damping. The dimension of the absorber is 4.1 ft. of height and when activated they come out to a maximum width of app. 28 inches. The absorption features of such an inflated absorber are given by its dimensions, material weight per area, its damping properties and the pressure which determines the stiffness of the membrane, etc.
3 ACOUSTIC TESTS ON THE AQFLEX ABSORBER AND SYSTEM

An AqFlex system is installed in a music school in Denmark. As a first case installation there was installed 15 absorber-rows each with a length of 27 feet in the hall that measures L x W x H = 63 x 28 x 18 ft.

The reason for installing the absorbers in the width-direction of the hall was that the roof is supported by a number of concrete slabs of considerable height in that same direction. There could have been many more absorbers installed but as a first test installation 15 absorbers spread, somewhat uniformly across the ceiling area, seemed to be sufficient to test the functionality. The average distance between absorber lines is hence 4.2 ft. T20 in the room with the system in it’s on and off positions was measured by Grontmij and a full report is available. The results are shown in figure 3. The differences achieved in the 63 and 125 Hz bands are believed to be some of the biggest ever encountered anywhere. The measurements lead to the absorption coefficients in Table 1 calculated from Sabines formula as a difference between on and off positions over the entire ceiling area. To simulate a denser spacing alpha in this table has been multiplied by a factor of 1.4 in the 3rd column of Table 1.

![T30[s] in the ON and OFF positions](image)

**Figure 3:** Certified measurements in Danish music school, with the system in its ON respectively OFF positions. The drop of T30 in the 63 and 125 Hz bands are notable.

T30 in the hall was also measured before the installation of the absorbers and there was no detectable, reliable difference between that value and T30 measured with the system in its off-position. This finding agrees somewhat with the measurements of emptied baffles in the reverberation chamber and is an important feature of the system.
Table 1: calculated absorption coefficient, $\alpha$, working in entire ceiling area of the case installation with absorbers mounted in average 4.2 ft. from each other. To estimate the highest achievable absorption coefficients in real case settings, based on results from reverberation chamber of denser placements of only 3.3 and 2.6 ft. (see below) the coefficients are multiplied with a factor 1.4 in 3rd column.

<table>
<thead>
<tr>
<th>$f$ [Hz]</th>
<th>$\alpha$</th>
<th>1.4 x $\alpha$</th>
</tr>
</thead>
<tbody>
<tr>
<td>63</td>
<td>0.25</td>
<td>0.36</td>
</tr>
<tr>
<td>125</td>
<td>0.33</td>
<td>0.47</td>
</tr>
<tr>
<td>250</td>
<td>0.37</td>
<td>0.52</td>
</tr>
<tr>
<td>500</td>
<td>0.37</td>
<td>0.52</td>
</tr>
<tr>
<td>1000</td>
<td>0.20</td>
<td>0.28</td>
</tr>
<tr>
<td>2000</td>
<td>0.11</td>
<td>0.16</td>
</tr>
<tr>
<td>4000</td>
<td>0.04</td>
<td>0.05</td>
</tr>
</tbody>
</table>

When certifying a sound baffle type product in Europe to the EN ISO 354:2003 standards the specimen must be placed inside a so called well. The well used in this case was made of plates of plywood of about 0.5 inch of thickness. 3 measurements have at the present been conducted in a well: 3 emptied absorbers and 3 respectively 4 activated absorbers. Since the absorbers contract some 10% in the length direction while inflating, the dimension of the well was changed to fit both the activated and emptied states of the absorbers. Dimensions of the well were: LxWxH: 11.81 x 9.84 x 3.28 ft. and 10.93 x 9.84 x 3.28 ft. The absorbers were in all cases spaced evenly in the well.

Unlike the real case measurement where there is a constant feed of air on the membranes from the fan, in the reverberation chamber the absorbers are inflated and then sealed hermetically. In real life situations a valve can also close the system if, against expectations, there is a detectable noise stemming from the air flow. In the reverberation chamber it is too complicated to install a complete fan system wherefore this has been avoided. Therefore it is difficult to determine the exact pressure inside the absorbers at the measurements and give a 100% true picture of the absorption properties. A certain pressure setting is recommended by the manufacturer. Once a system has been implemented this pressure can easily be fine-tuned. Also noise-measurements on the real life case have been carried out as seen later in this paper.

Evidently many configurations of the air supply can be implemented on real systems according to each customer’s needs. For instance in order to reach reverberation times in between the extreme cases of all absorbers ON respectively OFF a second air supply system can be employed to activate only a certain portion of the absorbers such as every third absorber. Since as mentioned the absorbers contract app. 10% in the length direction when inflated a small part of the ceiling opposite the point where the air supply is mounted is left without absorption. To avoid an absorption free column in one end of the hall the two subsystems should be attached at each end of the hall. It will be for the acoustical consultant to decide how the configuration should be to best fulfill the needs.
Measured $\alpha$ of 3 samples in well; ON and OFF positions

It is seen that alpha rolls off in the LF domain more in the well measurements, fig. 4 and fig. 5 than in the real life case, table 1. The well is used for baffle measurement in order to avoid the edge effect but also to create a mirror effect where the sound is reflected inside the well onto the absorbers. Baffles are traditionally made for MF and HF absorption. A well of $\frac{1}{2}$" thick plywood transmits rather than reflects the LF and the more pronounced roll off at LF in the well is believed to be caused by this.

No well was used for the measurement in figure 6. Here one single absorber was placed in the chamber. The projected area on the floor is given by the rectangle that the extremities of the absorber described. The corresponding absorption coefficient is seen to be app. 1 from 125 – 500 Hz. The roll off at HF is believed to be caused by a too high pressure in the absorber during this measurement.

Fig. 4: Measured absorption coefficient in well of 3 absorbers placed every 3.28 ft. (1m) in first OFF then ON positions.

Fig. 5: 4 samples in well placed at every 2.46 ft. (0.75 m) measured in only ON position.
It is seen from fig. 4 and 5 that by increasing the density by which the absorbers are mounted from 1 absorber per meter to one per 0.75 meter, $\alpha$ increases by app. 0.1 in the crucial frequencies 63 Hz – 500 Hz.

![Graph showing octaves bands and m² vs. Octave band [Hz]](image)

**Fig. 6:** Measurement of one single absorber in the reverberation chamber. The projected area on the floor, given by the rectangle that the extremities of the absorber described, was 2.24 m².

Certified measurements of the noise level of the air supply were carried out on the same installation as earlier mentioned. After the first minutes of inflation once the system has reached its operational mode the noise from the fan was measured to 38 dB(A) 3 feet away from the fan. During inflation the noise was measured to 57 dB(A). The fan can be installed in a sound attenuating box in the same room as the absorbers or, as in this present case, placed in an adjacent room. It was not possible to measure any noise from airflow or fan in the actual hall where the absorbers were mounted once the system had reached operational mode.

Not only does the technology enable for variation of the reverberation of the most important frequencies to a degree never formerly seen. It also has close to no impact on the reverberation time in its off position. Moreover does the system, when on, supply diffusion of higher frequency sound in the entire ceiling surface. The real case installation mentioned resembles very well a situation as it can often be encountered in other existing halls, where not the entire ceiling area is at the disposal because of existing installations. In the case of the music school in Denmark the system is in use every day. It is the hope that the product will be used to benefit amplified as well as classical music in music schools, recital halls, arts performance centers, multi-purpose halls etc. The technology is patented [5].

**REFERENCES**


