

SPATIAL ANALYSIS OF THE ACOUSTICS OF ROCK CLUBS AND NIGHTCLUBS

S Tervo Dept. of Computer Science, Aalto University, Helsinki, Finland
J Saarelma Dept. of Computer Science, Aalto University, Helsinki, Finland
J Pätynen Dept. of Computer Science, Aalto University, Helsinki, Finland
I Huhtakallio Dept. of Signal Processing and Acoustics, Aalto University, Helsinki, Finland
P Laukkanen Ramboll UK, London, UK

1 INTRODUCTION

Rock venues and nightclubs are important spaces for experiencing amplified live music. As discussed by Adelman-Larsen⁴, the research on acoustics has focused on concert halls and rock and pop halls acoustics has been somewhat neglected. This paper aims to increase the knowledge by presenting practical measurements and analysis of the acoustics of rock venues and nightclubs.

Previously, the acoustics of rock and pop venues has been studied in terms of standard single microphone acoustic parameters^{1,2,3,4}. A study from 2010⁴ finds appropriate reverberation times for rock and pop venues by correlating the musicians' and sound engineers' preferences of several venues to measured standard acoustic parameters. In addition, it is also found that clarity is important for the general impression⁴. Other study elaborates the acceptable limits for the reverberation times and proposes a broadband absorption device to reduce the reverberation³. A book¹ describes the acoustics and other features of several halls and binds together the current research on the acoustics of halls for rock and pop music. Moreover, acoustic parameters of several halls are also reported in a recent article².

A paper from Støfringsdal¹⁰, which is partially based on the results of Adelman-Larsen *et al.* summarizes recommendations for the stage and the audience area acoustics. Besides the recommendations listed in the above studies for the audience area, the paper suggests that the walls should be diffusive, low frequency response should have good control (in terms of reverberation time), and listening conditions should be even in the main audience area.

Nowadays, directional sound field analysis is often employed in room acoustic studies. Examples of this trend are the increasing number of audio cameras⁸ and several spatial analysis tools such as the one we introduced in a recent article⁹. Directional analysis can reveal more about the acoustics of space than the standard single microphone measurements. Previously, we have applied the so-called spatiotemporal visualizations to investigate the spatial properties of concert hall acoustics⁹. In this paper, we demonstrate the method in the analysis of rock and nightclubs. We use the in-house Sound Reinforcement (SR) system as the sound source to study the acoustics in the audience area and record the room impulse response in the audience area with a microphone array. The in-house SR system is applied in the measurements since we are interested the acoustics that the audience perceive.

2 EXPERIMENTS

2.1 Methods

The spatial analysis is performed to spatial impulse responses measured from a source to a microphone array. The microphone array applied in this paper is the SPS200 SoundField microphone, which has four cardioid microphones in each corner of a tetrahedron where the radius 2.4 cm.

Table 1 Measured halls, the loudspeaker system, approximate volume, and the maximum audience capacity reported by the venue.

Hall	Function	Main loudspeakers	V [m ³]	Cap. [persons]
A	Rock club & Nightclub	Point source	800 (+ 3000)*	500
B	Nightclub	Point source	300 (+400) *	250
C	Multi-purpose	Line Array	2800	400
D	Multi-purpose	Line Array	2000	600
E	Nightclub	Point source	400 (+200) *	250
F	Rock club & Nightclub	Point source	300 (+300) *	250
G	Rock club & Nightclub	Line Array	2500 (+1000) *	700

* Connected to another space (bar etc.) via corridors or openings. Cap. Maximum capacity

The recorded spatial impulse responses are analyzed with Spatial Decomposition Method (SDM)¹¹ and visualized using the spatiotemporal and time-frequency visualizations⁹. SDM estimates the direction of arrival and the sound pressure in the center of a microphone array from the recorded spatial impulse response at each time moment in a small time window. Here, we apply a 0.33 ms Hanning window in the analysis. Consequently, the sound field is presented as pressure and direction of arrival values. In the visualization technique, the sound energy is integrated beginning from a certain time moment until the end of the impulse response, and the energy is presented w.r.t. the estimated direction of arrival.

Direction of arrival \mathbf{n} at each time moment t is estimated using the least squares solution for plane-waves from time difference of arrival estimates¹¹:

$$\mathbf{n}(t) = V^+ \hat{\boldsymbol{\tau}}, \quad (1)$$

where V^+ is the pseudo-inverse of the microphone positions difference matrix and $\hat{\boldsymbol{\tau}}$ are the time difference of arrival estimates, evaluated via cross-correlation. For four microphones there are six different microphone pairs.

For estimating the pressure $p_o(t)$ in the center of the array, we use the maximum pressure over all the microphones of the array at each time moment t :

$$i = \arg \max_m (|p_m(t)|), m = 1, \dots, 4 \quad (2)$$

$$p_o(t) = p_i(t), \forall t \quad (3)$$

where $p_m(t)$ are the microphone signals in the array.

Spatiotemporal visualizations are created by calculating the directional energy distribution w.r.t the estimated direction of arrival. The energy is integrated over five different time windows, from 0, 5, 20, 50, and 200 ms after the arrival time of the direct sound, until the end of the impulse response. The same integration limits are applied in the time-frequency visualizations. For more information and details on the analysis and visualization, the reader is referred to publications (Tervo *et al.* 2013) and (Pätynen *et al.* 2013)

2.2 Measurements

Measurements were conducted in seven different halls, located in Southern Finland. The halls have various functions. Two halls operate mainly as nightclubs and have live performances of electronic music performed by Disk Jockeys. Three halls operate most of the time as nightclubs but still have live performances with rock bands occasionally. Two other halls host mainly live performances but may be used also in various other purposes. For example, Hall G is sometimes used for theater performances.

All halls were equipped with a multi-way main speaker system and separate subwoofers. The main speakers were either line arrays or traditional point source speakers. Sound systems in nightclubs

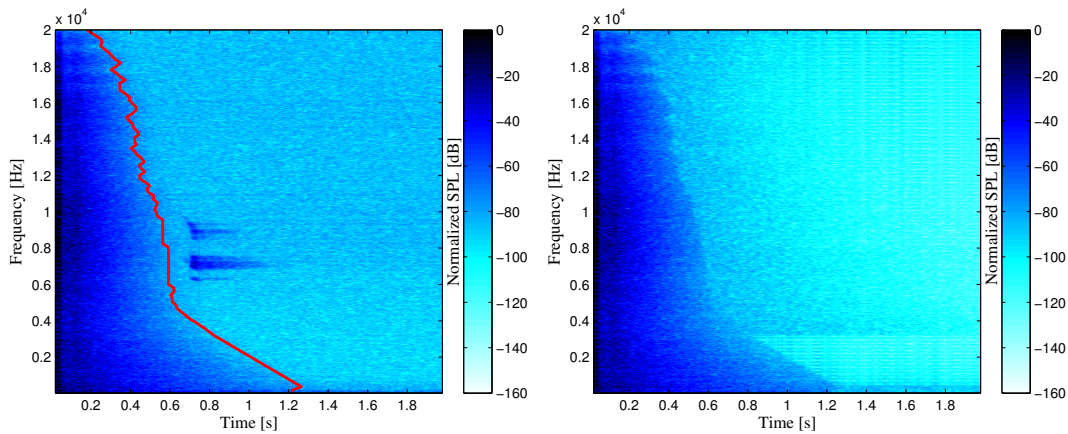


Figure 1 Subharmonic distortion of a line array is visible in the original impulse response in the left panel at 0.7 s in frequency range [6.5 10] kHz. The curve on the left panel is the estimated time for the beginning of the noise and the right panel shows the impulse response after compensation.

have usually more than two distributed sources as opposed to typical 2.1. left-right-subwoofer configuration used in rock clubs. For example, the studied nightclubs have two additional loudspeakers in the back of the audience area. However, in this paper we are interested in the acoustics of these halls when live amplified music, such as rock, is performed. Therefore, we only investigate the 2.1. systems in the halls. Table 1 shows an overall description and naming of the halls.

Spatial impulse responses were measured from the left and right channel of each in-house SR system to three receiver locations. All impulse responses were measured without the audience. The main loudspeakers are located in the front of the stage in all the halls. The receiver was located at a distance of $2/3 \times D$ from the stage front, where D is the length of the main audience area. All the receiver locations were in the middle of the audience area, i.e., on the axis between the SR-system, and the height of the microphone array was 1.70 m. The responses were measured using an SPS200 SoundField microphone and B&K 4192 pressure-field microphone.

The main loudspeakers were calibrated with pink noise such that the A-weighted SPL was 80 dB in the measurement point. Six seconds long logarithmic sine-sweep from 20 Hz to 24 kHz at a sampling rate of 192 kHz was used as the excitation signal in the measurements⁶. The sine-sweep signal causes a particular problem for the line arrays. Namely, compression drivers introduce subharmonic distortion when they are excited with an oscillator⁵. Here it is assumed, that this distortion does not occur when music is amplified via the SR system. Therefore, the distortion is removed from the measurements using a moderate sound pressure level (SPL) and digital signal processing. Figure 1 shows an example in Hall G, where the subharmonic distortion is suppressed from the signal using the noise slope compensation⁷ proposed by Jot *et al.* Similar subharmonic distortion was observed with all the line arrays and consequently the distortion was compensated for.

Room acoustic parameters were calculated for each hall as the average of the left and right channel, and they are shown in Table 2. Lateral energy fraction (LEF), Definition, D_{50} ; Clarity, C_{50} ; Reverberation time, T_{30} ; and early decay time (EDT) are calculated for low frequencies (B) as the average of 62.5 Hz and 125 Hz octave bands, in the mid frequencies (M) as the average of 250 Hz, 500 Hz, 1 kHz, and 2 kHz octave bands, and in wide-band (W) as the average of all the above octave bands. All parameters are calculated from the omni-directional microphone in a standard manner, except LEF, which is estimated from the SDM coefficients.

Table 2 Acoustic parameters for each hall. The parameters are averaged over left and right loud-speaker channel response, measured with an omni-directional microphone. The measurement point was in the back of the main audience area, at a distance of two thirds of the total length.

	LEF _W [dB]	D _{50,B} [-]	D _{50,M} [-]	D _{50,W} [-]	C _{50,B} [dB]	C _{50,M} [dB]	C _{50,W} [dB]
A	-8.98	0.53	0.80	0.72	0.50	6.81	5.74
B	-7.65	0.49	0.76	0.68	0.26	5.90	4.88
C	-9.45	0.54	0.86	0.77	1.42	9.18	8.00
D	-8.25	0.43	0.67	0.60	-1.17	4.28	3.29
E	-7.62	0.77	0.89	0.86	5.93	9.90	9.09
F	-8.77	0.68	0.93	0.86	3.36	12.79	11.52
G	-8.31	0.67	0.80	0.76	3.07	6.67	5.91
	T _{30,B} [s]	T _{30,M} [s]	T _{30,W} [s]	EDT _B [s]	EDT _M [s]	EDT _W [s]	
A	1.30	1.14	1.19	0.84	0.61	0.68	
B	1.14	0.81	0.90	1.20	0.56	0.74	
C	1.48	0.57	0.83	1.05	0.46	0.63	
D	1.95	1.29	1.48	1.34	1.13	1.19	
E	0.72	0.51	0.57	0.56	0.38	0.43	
F	0.61	0.50	0.53	0.77	0.29	0.43	
G	1.32	0.74	0.91	0.93	0.56	0.66	

B: Octave bands 62.5 Hz and 125 Hz, M: Octave bands 250 Hz - 2 kHz, W: Octave bands 62.5 Hz - 2 kHz

3 RESULTS

3.1 Spatiotemporal visualizations

Figures 2 and 3 show the spatiotemporal visualizations in the lateral and median plane, respectively. In general, the localization of the direct sound is accurate, since the main direction of the first directional energy distribution (shown in red), points towards the loudspeakers. In the halls which are equipped with line arrays, the localization is more ambiguous than in those ones which have point sources. This can be seen when comparing for example halls C and B in Figure 3. The direct sound (red) from the loudspeaker is spread to several directions in Hall C, whereas in B it is concentrated in a single direction. This is caused by the fact that the line arrays are constructed of several loudspeakers, and each loudspeaker contributes to the overall direct sound.

Since there was no audience present during the measurements, all halls, except Hall C, have a strong floor reflection present in the visualization. This is visible in Figs. 2 and 3 in the yellow area (5 ms - 20 ms). In Hall C the inclining audience area is made of light wood material, which can also be folded back, and the audience area consists of seats. These materials effectively reduce the strength of the floor reflection. In addition, the floor reflections in Halls B and G are not as strong as in other halls, since the loudspeakers are only not as much tilted towards the floor w.r.t. to the measurement point compared o SR systems in other halls. Moreover, in Hall G, the floor reflection is also less pronounced.

As can be seen from Figs. 2 and 3, a large part of the total energy arrives during the first 50 ms from the direction of the loudspeakers. The visualization in Fig. 2, and the high C_{50,W} values in Table 2, indicate that the perceived clarity is high. When the audience is present, the amplitude of the floor reflection will decrease in the wide-band case. When the the audience is present C_{50,W} values will probably slightly decrease, since the early field will lose more energy than the late field due to the absorptive walls and ceilings.

In addition to floor reflection, strong reflections are visible in Halls D, F, and G. In Hall D, the strong reflections are arriving via multiple routes from the sidewalls and back walls, and the floor. For example, as shown in Figs. 2 and 3 with green color, reflections arrive between 20 and 50 ms from the back wall. The back wall material in Hall D is painted concrete and curtains cover most of the back wall, except the area where the reflections are arriving. Also the curved balcony front in Hall D introduces some reflections which are visible in green and yellow colors. In Hall F, the back wall, the corners,

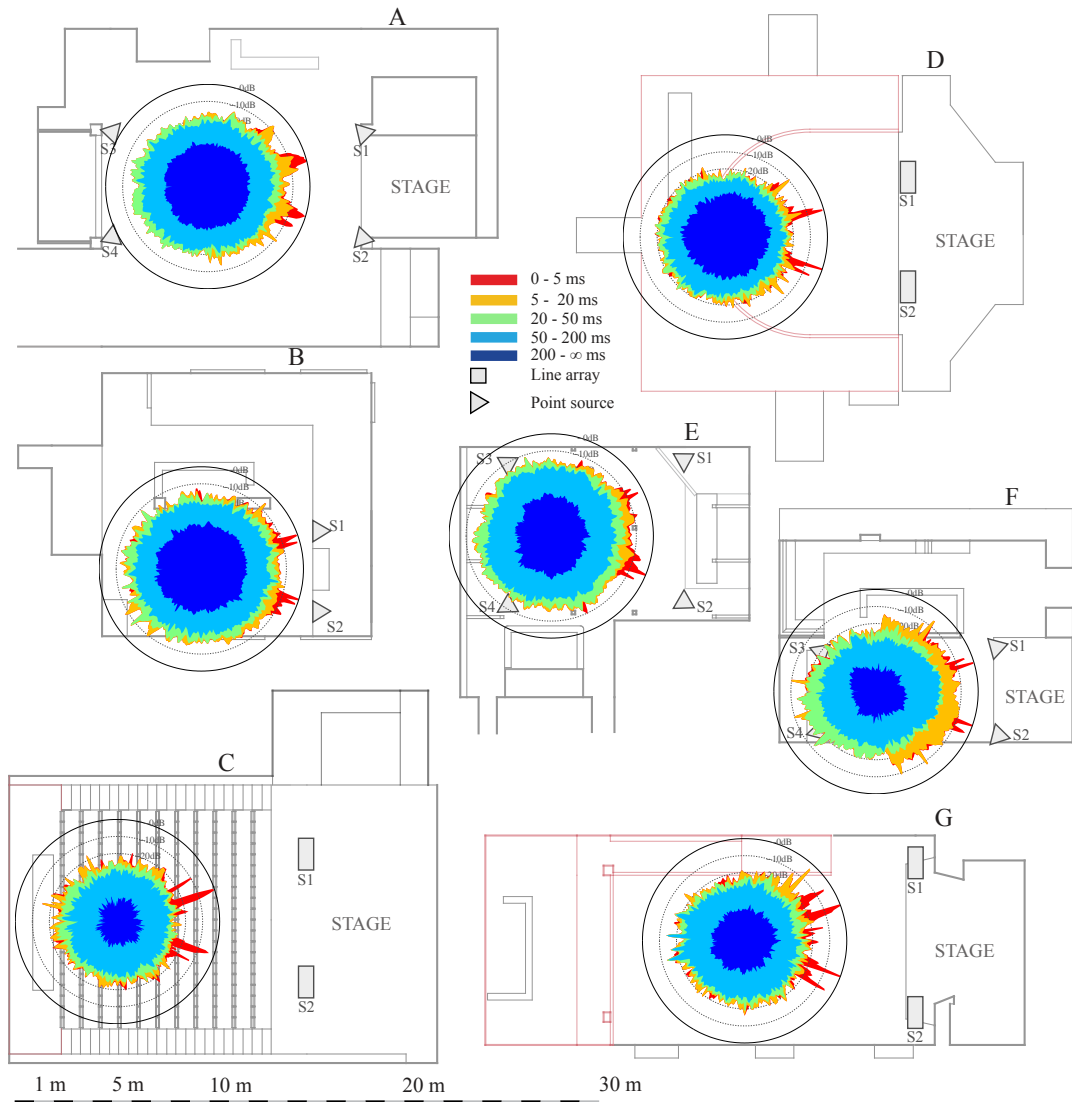


Figure 2 Spatio-temporal visualization of the sound energy in the lateral plane.

and the mixing table, located close to the back wall, cause energy to be reflected from the back of the listener between 20 and 50 ms, as shown with green color in Figure 2. Moreover, in Hall F, the left wall is made of reflective material, whereas the right wall is treated with absorptive material. The left wall clearly produces strong reflections between 5 and 20 ms, as shown in Fig. 2 with yellow color. In addition, in Hall F, more energy is arriving from the left side in overall, even though there are two large openings to the bar in the left wall. In Hall G, strong reflections arrive from the left side wall and from the mixing table and back wall, which are behind the measurement point.

The amount of late reverberation can be inspected from the dark blue area in Figures 2 and 3. The order according to the size of the dark blue area (200 ms - ∞) is the same as the wide-band reverberation time $T_{30,W}$ in Table 2. Moreover, the light green, red and yellow areas (0 ms - 50 ms) versus the light blue area (50 ms - 200 ms) are directly related to the acoustic parameters definition $D_{50,W}$ and clarity $C_{50,W}$. The light blue area is smaller in the halls which have a high clarity $C_{50,W}$ value.

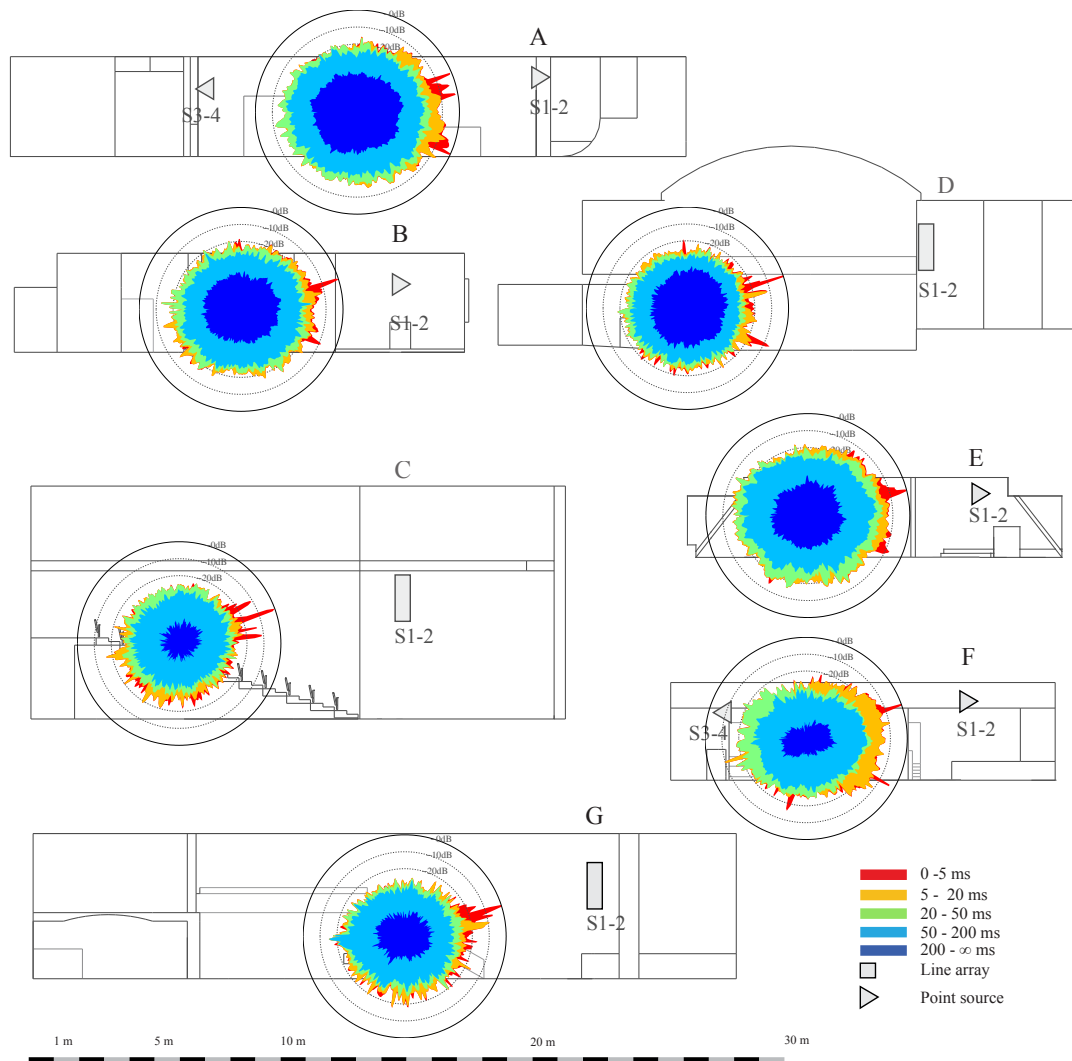


Figure 3 Spatio-temporal visualization of the sound energy in the median plane.

3.2 Time-frequency visualizations

Figure 4 shows the time-frequency visualizations with the same colors and integration limits as in the spatiotemporal visualizations. In overall, the line arrays provide a smoother magnitude response in the measurement point. This is mainly due to the strong floor reflection, and partly by the directivity of the point sources and also by the fact that all the halls that have point sources are smaller than the ones with the line arrays. The point source emits more sound to the principal radiation direction, which is reflected back a few times, whereas the line arrays emit sound more to the sides and cause more reflections in overall. Several strong reflections cause a noticeable comb filtering effect in the frequency response more easily than many reflections with lower amplitudes and different delays. As observed from Figs. 2 and 3, in Halls E and F, the early sound field has several strong reflections. These reflections are the cause for the comb filtering effect in the magnitude response. The comb-filtering effect reduces as time moves onward in the integration, since the reflection is no longer included in the time window. This is demonstrated in Fig. 4 for Halls E and F.

The magnitude response is declining towards high frequencies, resembling a pink noise spectrum. When the two magnitude responses at 0 ms and 200 ms are compared, we can observe that sound is absorbed more in the higher frequencies, as the air absorption is the highest in that region. In Halls

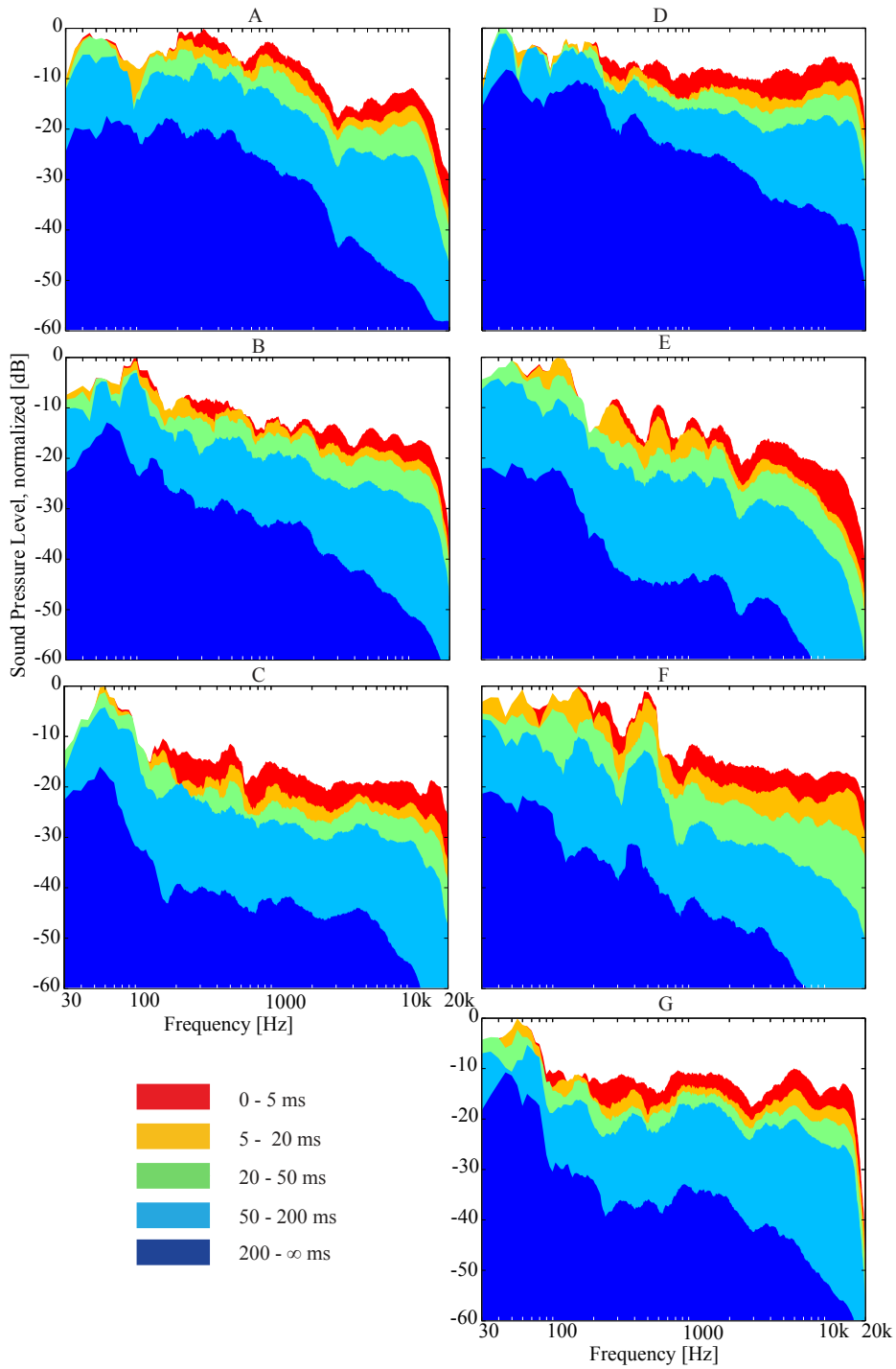


Figure 4 Magnitude response in the measurement point in different time windows. The responses are 1/3-octave band smoothed.

C, E, and F the mid-frequencies are attenuated more than in other halls. From 200 Hz to 2 kHz, the mid-frequencies are attenuated on average about 30 dB in Halls E and C, and elsewhere from 15 to 20 dB. E and F are quite low spaces, and the ceiling has been treated with absorptive material to avoid

ceiling reflections. This absorption effectively reduces the reverberation in mid frequencies. Hall C is one of the largest places in this study, and all the walls are treated with absorptive material, which explains the lack of reverberation on mid and high frequencies.

Adelman-Larsen *et al.*³ have recommended appropriate T_{30} in octave bands in octave bands for empty halls of size 1000 m³ - 7000 m³. Out of the studied halls, the volumes of Halls A, C, D, G are within these values. Compared to the recommended values, Hall C has too short reverberation time in mid and high frequency octave bands, but too long low frequency reverberation time. Moreover, the mid and high frequency reverberation times in Hall G are within the recommended values. In halls C and D the reverberation times exceed the recommendation in mid frequencies, but is too short in high frequencies. Moreover, the low frequency reverberation time in all the halls exceeds the proposed tolerances. The time-frequency visualization in Fig. 4 characterizes the low frequency response of the halls. For example in Hall D, there is a strong mode around 40 Hz, in Hall C around 50 Hz, and in Hall G around 50 Hz. This affects the low frequency reverberation time, shown in Table 2 and is the cause for the long reverberation time in low frequencies. It should be noted that in this paper the reverberation time was measured with in-house SR systems, whereas the original paper³ used an omni-directional source.

4 CONCLUSIONS AND FUTURE WORK

This paper presented the spatial analysis of the acoustics of seven rooms which operate as rock and nightclubs. The spatial analysis was implemented by measuring spatial room impulse response using a microphone array and the in-house SR systems. Spatial analysis revealed that in most of the studied halls, the main direction of sound is the loudspeaker, and reflections from walls and ceilings are attenuated. The most prominent reflection in all the halls arrives via floor, but when audience is present in the hall this reflection will be highly attenuated in the mid and high frequencies.

Future work on this topic includes listening tests with sound engineers and common rock and pop concert-goers, measurements in other halls, as well as measurements in occupied halls.

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