Spatial Energy Analysis for Room Acoustical Evaluation

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Introduction

Sound perception in a room is significantly influenced by the spatial distribution of early and late reflections [1].

A Spatial Impulse Response (SIR) is a detailed representation of all reflections within a room and as such it has a complex data set. There are different methods and tools for measuring and visualizing an SIR each with a unique approach for the challenges, advantages and disadvantages.

In general, the solutions consist of a detailed description of the SIR with most if not all information visible. This data set, however important, can be difficult to interpret and the overall distribution of energy in the room is hard to visualize (Figure 1).

The Spatial Decomposition Method (SDM) is one of the suitable options for analyzing the spatial distribution of sound [2]. A SDM Toolbox for MATLAB was released and with little effort a detailed description of the sound field in a room can be achieved.

The intention of this paper is to propose a simplified view for the SDM. A graphical representation where the fundamental information of the distribution of energy in the room can be analyzed in a quick and intuitive manner.

Method

In order to ease the understanding of the distribution of energy in a SIR, a set of simplification measures were undertaken.

The first simplification was to adjust the time-windows to run the SDM analysis. It was decided to split the impulse response into 3 main parts, direct sound, early reflections and late reflections to allow for direct comparisons with revised Strength theory [3].

The values were defined as follows:

- 0-5ms (Direct Sound);
- 5-80ms (Early Reflections);
- > 80ms (Late Reflections);

For visualization purposes the SDM analysis presents the spherical energy cosine weighed into 3 bidimensional representations, transverse, median and lateral [4]. Energy arriving on the lateral plane (horizontal plane) has a greater influence on Spatial Impression [5] and therefore, the second simplification is to consider only the lateral plane.

The third simplification in this method was the reduction of angular resolution, set to 60° (Figure 2).

The fourth, and final simplification, was to flatten the SDM Polar plot into a linear representation (Figure 3).

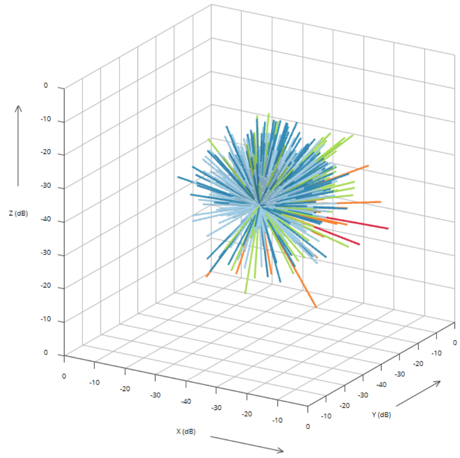

Figure 1: Example of an Hedgehog plot from Iris Measuring System.

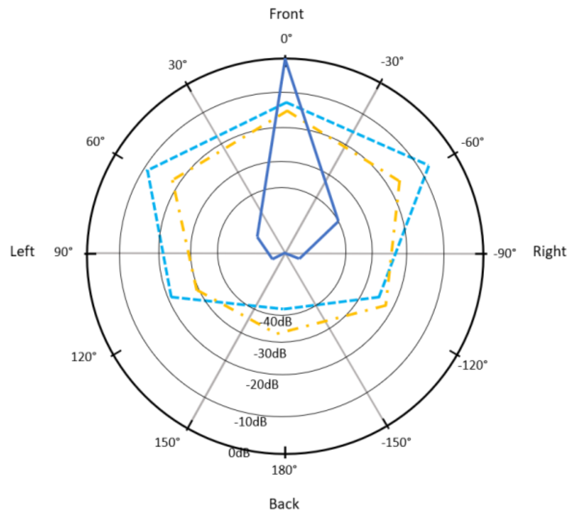

Figure 2: Simplified SDM Polar Plot (illustrative data).

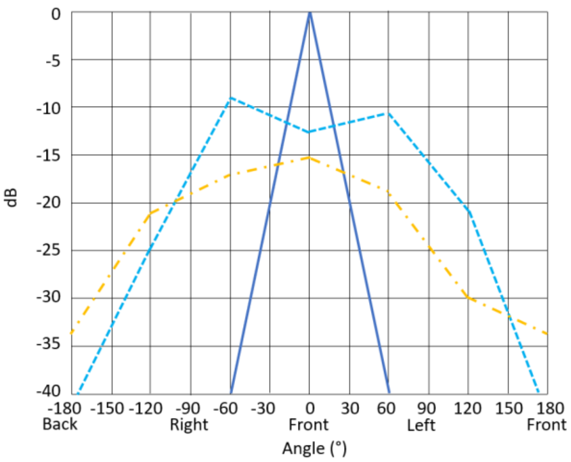

Figure 3: Linear representation of Figure 2.

Proof of concept

Experiment 1 – Analysis of a simplified model

This first experiment consisted in analyzing a simulated SIR of a small concert hall (Figure 4). The software used for the simulation was one of the industry standards, Odeon 15.15 Auditorium and the characteristics of the hall were as follows (occupied with audience):

Table 1: Room characteristics of the simplified model.

Volume (m^3)	Width (m)	Length (m)	Height (m)	T30 Average (s)
3860	14	28,6	10	1,6

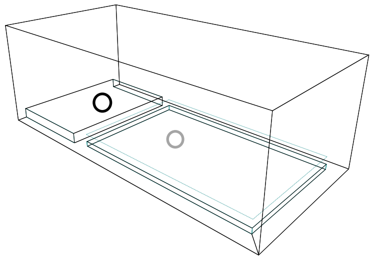

Figure 4: Simplified model for simulation.

The source was set as omnidirectional with a gain of 31dB and the receiver was placed at distance of 10m.

A so-called B-Format SIR of 1st order was generated by Odeon and analyzed with the SDM toolbox. The simplifications were applied and the results are displayed on Figure 5.

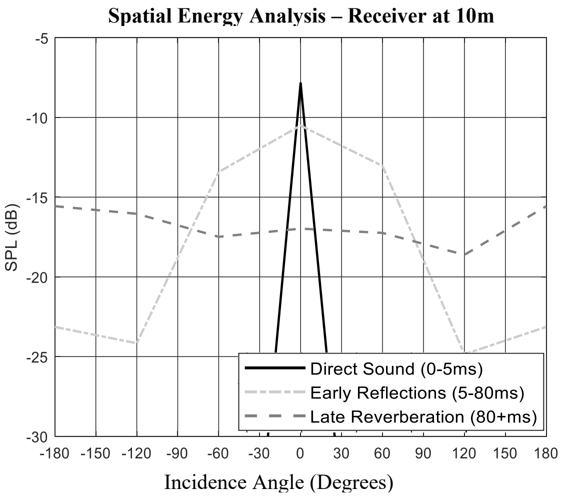

Figure 5: Spatial Energy Analysis of a simplified room. SIR generated via simulation.

From those curves, it is possible to have a preliminary evaluation of some characteristics of the particular receiver position in this room.

Direct Sound has a well-defined direction of arrival and has a higher sound power level than early and late reflections;

Early Reflections are dominated by strong energy from the front and sides with maxima in the range from -30° to 30° (front) and minima in the range 90° to 150° (rear left);

Late Reverberation has a small variation in level indicating high degree of diffuseness;

The relatively high difference in levels between early and late reflections on lateral energy could indicate that this room would have a high value for Apparent Source Width (ASW) but low Listener Envelopment (LEV) [6] [7].

This casual and intuitive analysis gives some important information about the room allowing the acoustician to design changes that could help to improve certain aspects of the room.

Experiment 2 – Analysis of a complex model

In order to validate the application of the method in concert halls design evaluation, it was important to verify if this simplistic approach could also be applied to a model with a complex structure.

For this task the model of the Konzerthaus Blaibach (Figure 6) in Germany was chosen and a set of simulations were conducted (occupied with audience).

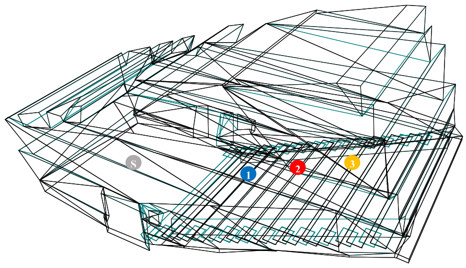

Figure 6: Complex model for simulation. Konzerthaus Blaibach, Germany.

The source was set as omnidirectional with a gain of 31dB. Three receivers were positioned at 7,4 m, 10,1m and 12,8m of distance from the source.

Table 2: Room characteristics of the complex model. Konzerthaus Blaibach, Germany

Volume (m^3)	Width (m)	Length (m)	Height (m)	T30 Average (s)
1260	9,8	21,5	11,5	1,4

For the present analysis, in order to compare the behavior of different seats in this room, the direct sound was left away from the analysis and the other two components, Early reflections and Late Reflections are displayed for each receiver in individual graphs Figure 7.

From the two graphs, it is possible to assess the distribution of sound within this room, as follows:

Early reflections:

- The spatial distribution in these seats indicates that the further the receiver is away from the source more energy arrives from behind;

- The maxima in all seats are in the range -30° to 30° (front);

- The higher energy of receiver 2 on angles ±60° when compared to the energy from the front, could indicate a wider ASW than the other two positions;

Late reflections:

- The similarity of the curves and the relatively small differences in level (less than 2dB) indicates that this hall has a consistent level of reverberance throughout the room;

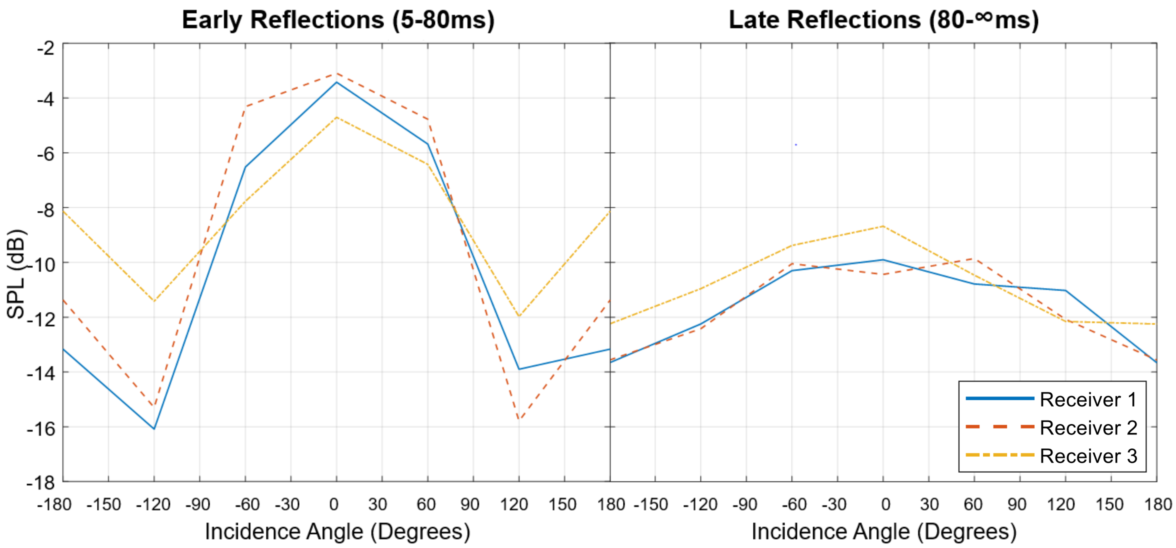

Figure 7: Spatial Energy Analysis of Konzerthaus Blaibach. SIR generated via simulation.

- A theoretical room with a fully diffuse sound field would be represented by a horizontal line. The late reflections deviate ±2dB from this theoretical line. This finding indicates that this room has a relatively diffuse late reflection field.

- Looking at both figures, the balance between early and late reflections for receiver 3 is significantly different than for the other two positions.

The presented view allows for direct comparisons between the different positions with a good overview of the hall. It is possible for the acoustician to determine necessary changes to the design of the hall ad hoc in order improve consistency of sound between different seats.

Experiment 3 – Analysis of a measurement

The two previous experiments were conducted on SIR rendered in simulations. The third and last experiment aims to validate if the observed results are also visible in properly measured SIR.

Three measured SIRs from different positions in the 980-seat concert hall of the Anneliese Brost Musikforum Ruhr (Figure 8) were analyzed with the proposed method.

Figure 8: Anneliese Brost Musikforum Ruhr, Bochum, Germany. Photo: Brigida Gonzalez.

The measurements of the SIR were made with a dodecahedron speaker and a sound field microphone from CoreSound, model TetraMic, within the Iris Measurement System. The SIRs were exported in B-Format and analysed accordingly.

The 3 receivers were positioned with increasing distances from the source, two in the stalls and one on the first balcony (Figure 9).

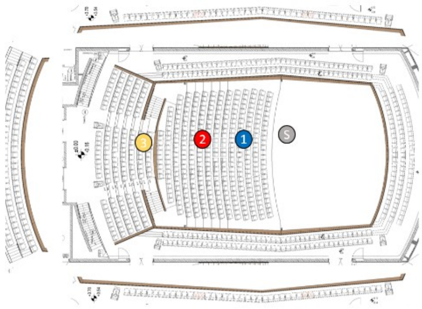

Figure 9: Floor plan of the Anneliese Brost Musikforum Ruhr, Bochum, Germany.

The analysis will also take advantage of the two-graph view, allowing for quick and intuitive observations about the distribution of sound throughout the different positions (Figure 10).

Early Reflections

- All positions show a similar energy distribution shape. However, receiver 3 has a large difference on the energy arriving at 180°. The energy arriving from this direction is the lowest for seat 3, in contrast to the other receivers with local minima at ±120° and a gain at 180°. The difference could be explained by the seating area of receiver 3, since the seats behind this position are inclining, thus absorbing more energy than the flat floor in the stalls;

- The higher energy from the sides ±60° indicates a high ASW for this room.

Late Reflections:

- The curves for receiver 1 and 2 are quite similar with maximum difference of about 2dB. Receiver 3 presents a wider dynamic range and significantly lower values.

- All receivers are ranging between 2dB and 3dB away from a theoretical horizontal line (diffuse sound field);

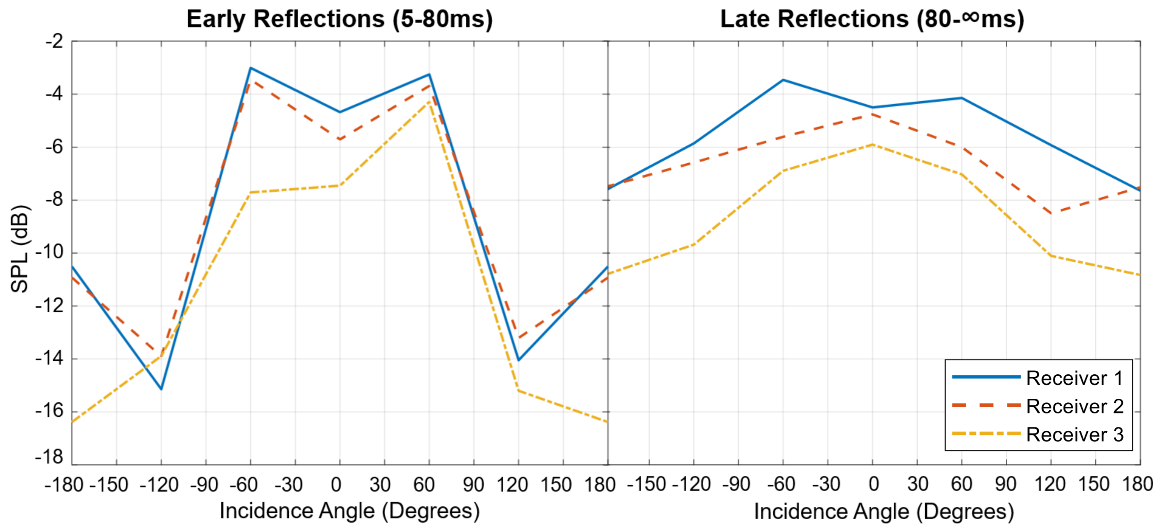

Figure 10: Spatial Energy Analysis of Anneliese Brost Musikforum Ruhr. Spatial Impulse Response measured on site.

- The positions also show consistently higher levels of energy from the front than from behind, albeit the differences are small;

Considering a grander perspective and observing the balance between early and late energy, it is clear that the levels for late reflections are much closer to the maxima of the early reflections than in the other observed rooms which is due to the larger size and longer reverberation time.

Conclusion

A simplified method for visualizing the spatial distribution of sound in a room was proposed. SDM was used to analyze SIRs of three distinctly different concert halls. The first two rooms had their SIRs generated via simulation with Odeon software and the third room had its SIRs measured on site by the use of the Iris Measurement System.

The simplified graphs give cues information on the behavior of sound distribution within a room. Furthermore, information on balance between direct, early and late energy can be easily assessed.

The versatility of this method allows for an acoustician to inspect a specific position in a room or to compare different receivers to evaluate the entire room. In addition, this method is fitted for comparisons between different rooms, allowing for direct comparisons of iterative steps during the design phase of a project.

However, it is important to remember the compromises that have been taken for such simplified display. A relevant shortcoming is that only the horizontal plane is being displayed and therefore overhead energy could be neglected.

The outlook for this research is to continue validating this approach as a tool for room acoustical design via a systematic investigation of different room shapes based on simulated and measured SIRs.

It would also be important to define a perceptually desirable curve/shape for early reflections and late reverberation in order to have a benchmark for further evaluations and to serve as a goal when designing a hall.

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