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# EFFECTS OF DIFFUSION ON EARLY REFLECTED ENERGY ON ORCHESTRA PLATFORMS

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## 1. INTRODUCTION

The subject of this study consists of investigating how some changes in the design of a stage in a concert hall affect the early reflected energy on the orchestra platform. These changes are especially related to the amount of diffusion. Diffuse and specular reflections are not perceived the same way by musicians, and at the present time there is no agreement conceming the optimum amount of diffuse and specular reflected energy which has to be sent back to the players. Experiments take place in a tenth scale model of a concert hall; by that way, changing the design of the stage and simulating the scattering of diffusers with accuracy is possible. Finding adequate transducers for the measurement of impulse response in a scale model is often difficult, and problems arise when both transducers are close to each other, as it is the case for measurements on orchestra platforms.

## 2. PREVIOUS WORK

### 2.1 Musician's Needs

It has been seen in the literature that an efficient transmission of direct sound and early reflections is vital for the possibility of musicians hearing each other. According to Marshall [1], reflection delays should lie between 17 and 35 ms relative to the direct sound, while the relative level of these reflections should be about - 14 dB. It has been shown later that the temporal window for these reflections depends on the tempo of the music and on the amplitude of reflections [2]. High frequency components of reflections are the most important to musicians playing in an ensemble: most of the musical information necessary for musicians is contained in the attack transients which are cues for rhythm and expression. The important ensemble bandwidth is 500 - 2000 Hz. In addition, a loss of information occurs if the direct sound is below 10 dB when compared to the statistical sound field. To achieve a correct balance among players, reflection level differences between instruments must not exceed 4 dB.

Gade [3, 4] defined two parameters, "Support" (ST) and "Early Ensemble Level" (EEL) which seem to be well correlated with musicians' requirements. "Support" corresponds to the amount of reflected energy related to the energy emitted and is intended as a measure of how much early reflections assist performers. The optimum ST range for ensemble in symphony orchestras is about -12dB, but for smaller groups higher values may be allowed. The "EEL" describes the possibility of two players to hear each other; it seems to be the most important quality to the majority of conductors and orchestra members. EEL is also related to the calculation of fractions of early energy within certain time intervals in impulse responses recorded on the orchestra platform.

A musician playing in a group receives at least two signals: a signal from his own instrument, typically referred to as the "self" signal, and another one coming from the players he is trying to get ensemble information from, known as the "other" signal. In addition there will also often be musical parts which render little or no useful ensemble information, termed the "interference" signal by Naylor [5]. According to his work [6], the relative levels of different signals a musician hears are more important for ensemble than temporal details of the impulse response; this is especially true for the hearing of the "self" signal. Concerning the hearing of "other", high early to late energy ratios are preferred.

## 2.2 General Comments on the Design of the Stage Area

Sometimes this early energy is lacking and a device has to be set on the stage to provide stronger reflections, but great care has to be taken not to cause tonal distortion. The presence of suspended panels over the orchestra improves the sense of response of string and woodwind instruments by increasing the early reflected energy which would be reflected out towards the audience. However, colouration and comb filtering effects often appear for reflections arriving between 8 and 25 ms after the direct sound. Indeed, problems caused by false localisation, colouration, acoustic glare, comb filtering effects and harshness could be partly solved by the utilization of diffusing devices. Diffusers can also provide a mellow sound by diffusing the high frequencies, and can reduce the phenomenon of focussed energy by diffusing the late part of the energy. Diffusers can also give a uniform coverage over a wide angular range and a broad frequency bandwidth, which is necessary for good ensemble playing conditions. Various types of sidewalls and stage canopies exist in the literature, but there are no agreements concerning their effectiveness, particularly with respect to the optimum amount of diffuse reflected energy and specular reflected energy. The current work is aimed at producing design guidelines for diffuse reflections on stages. This paper is a spot of progress to date.

# 3. EXPERIMENTAL PROCEDURE

## 3.1 Equipment used for Measurements

Finding adequate transducers for measurements of the impulse response in a tenth scale model can be difficult due to the fact that the sound source and the receiver have to be small sized and as omnidirectional as possible for up to 40 kHz spectral range. Usually spark sources are used despite the fact that the energy emitted is not always repeatable. This is why our experiments are carried out using MLSSA, a system analyser that can work for up to 40 kHz and employs a maximum-length sequence as a source signal. The receiver is a quarter inch pressure microphone B&K 4136. Choosing the sound source is harder: most of the loudspeakers become directional at high frequencies. Two sound sources are employed to cover the whole frequency range, a 5" driver (KEF B200) for 630 Hz, 1250 Hz and 2500 Hz measurements, and another source for 5 kHz, 10 kHz, 20 kHz, and 40 kHz measurements. Several high frequencies sources are tested, all have advantages and drawbacks: a ribbon tweeter, a plasma source, a piezo tweeter Motorolla type KSN1038A, and a half inch microphone B&K type 4133. A measuring amplifier B&K type 2610 is connected to the microphone and a power amplifier QUAD 303 to the loudspeaker. To limit the background noise, each impulse response is computed using 16 preaverages followed by three averages in the MLSSA process.

## 3.2 Design of the Scale Model

The work is restricted to the orchestra platform only, this is why simulating the audience area very accurately is not necessary. Then, the only requirement as far as the audience area is concerned is to have acceptable acoustic conditions in it. The scale model has a simple rectangular shape made of varnished plywood. Its volume is approximately11 $m^3$, which corresponds to a medium sized hall. A surface of 5.4$m^2$ of pegboard boxes and a surface of approximately 2 $m^2$ of pyrosorb-s foam have been set in the audience area to attenuate the low and medium frequencies respectively. Three simple tilted wood panels have been hung from the ceiling in the audience area to get a more diffuse sound field. A diagram is enclosed.

To establish whether the sound field in the scale model is realistic and close to the one of most concert halls, the impulse response is measured in the audience area at five microphone positions with the plasma source. The reverberation time is measured over some linear portion of the Schroeder plot decay curve for each frequency band from 630 Hz to 40000 Hz. The range of optimum values of reverberation time given in the literature [7] is about 1.6s/2.1s at mid frequencies for an occupied concert hall. It is satisfactory to see that values measured at mid frequencies in the scale model belong to that range. The reverberation time found at 63 Hz, 125 Hz and 250 Hz full scale is about 2.3 s, which is rather high for a medium sized concert hall. Absorbing the frequency bands of 630 Hz, 1250 Hz, 2500 Hz, and 5000 Hz without absorbing the frequency bands of 20 kHz and 40 kHz is a difficult task to achieve. The use of pegboard boxes does not affect the high frequencies, but is not very effective at 2500 Hz, their resonant frequency being 400 Hz. The pyrosorb-s foam is much more effective at this frequency range, but absorbs the higher frequencies as well. The reverberation time measured at 4 kHz is about 0.9 s and reaches 1.3 s full scale after compensation due to air absorption [8]. Values of the clarity are rather high. They are about 3 dB for measurements conducted using with a low frequencies source, and of about 4 dB for high frequencies. Schroeder decay curves are linear over a long period, this means that the amount of diffusion is reasonable in the audience area. Values of EDT at mid frequencies are about 1.9 s full scale, which is realistic. In conclusion, the acoustic conditions in the audience area are not too far from the ones in a real concert hall, and seem satisfactory enough regarding the work that will be done in it.

# 4. RESULTS OF PRELIMINARY MEASUREMENTS

## 4.1 Characteristics of the Sound Field measured on a Stage

For measurements on the orchestra platform, the source and the receiver being at close proximity, 60 cm or less, the impulse response becomes very sensitive to the signal emitted. This depends on the directionality of the source, its distance and orientation to the microphone and on the level of the signal emitted. That is why for same positions of transducers values of the reverberation time can vary so much from one source to the other, especially for measurements at 20 kHz and 40 kHz. In a real hall the situation must be fairly different in the way that an omnidirectional source can easily be found, then the reverberant field is not as overpowered by the direct sound. In addition measurements are made on an empty stage which makes the direct sound dominate the rest of the sound field. Indeed, the room cannot be fully excited if the source is not omnidirectional enough, which makes values of the reverberation time smaller than what they should be, and Schroeder decay curves nonlinear. In addition, when the microphone is surrounded by the side walls of the stage, it picks up many strong early reflections, very close in time to the direct sound. The reverberant field predominates after a certain time, when the early energy has decreased enough. Then, the Schroeder decay curves consist of a double slope separated by a plateau. The first slope corresponds to the decay of the direct sound followed by early reflections and the second one to the decay of the reverberant field. It is unlikely that the double slope is due to a phenomenon of coupled rooms caused by the geometry of the hall. Therefore, it is not possible to achieve straight Schroeder decay curves when both transducers stand on the orchestra platform, and regardless of the amount of diffusion. Besides, none of the sources can produce enough reverberant field at 20 kHz and 40 kHz for measurements on stage once absorbing materials are set in the audience area: at high frequencies Schroeder decay curves correspond to the decay of early reflections only.

## 4.2 Comparison between Various Sources

Values of reverberation time and shape of Schroeder decay curve depend on the source used and on the orientation of the microphone. At high frequencies, a vertical position of the microphone enables it to pick up a greater amount of the reverberant field. In cases where a directional source is employed, the angle between the transducers influences the impulse response, that is due to the close proximity of the microphone to the source. The ribbon tweeter for instance becomes too directional above 10 kHz. The room is not fully excited at such frequencies and any value of the reverberation time can be calculated over the Schroeder decay curve. The room is much better excited with the piezo tweeter: Schroeder decay curves are linear over a long temporal period up to 40 kHz. Its main disadvantage is that the orientation of the source to the microphone has a great influence on the impulse response. Indeed, the reverberation time at 40 kHz, without any absorbing materials set in the audience area can vary from 0.14 s with an angle of 90° to 0.18 s at an angle of 45°, but the reverberation time is impossible to deduce for an angle of 0°. Moreover, the frequency response is not flat. The plasma source is larger and its frequency response increases in level between 4 kHz and 40kHz but its advantage is to be omnidirectional in the horizontal plane up to 40 kHz, while less energy is emitted above though. However, the Schroeder decay curve is not quite linear at high frequencies, especially when the transducers are set close to each other. In addition, values of reverberation time change with the level of the emitted signal. Surprisingly, the piezo tweeter gives longer values of the reverberation time (i.e., about 0.1 s when no absorbing material is set in the audience area) and Schroeder decay curves are linear over a longer period at high frequencies than the plasma source: the room seems to be better excited although the source is less omnidirectional. The last source tested is a half inch microphone B&K type 4133. The microphone is the only source found that is small enough and directional above a higher frequency than a normal tweeter, in spite of the fact that it is a free field microphone. A pressure microphone would have been preferable but no B&K half inch pressure microphone can operate at up to 40 kHz. It is found that this source cannot be used because of poor signal to noise ratio, even after completing many averages in the MLSSA process. In conclusion, the only sources that provide useful measurements are the plasma source and the piezo tweeter, though they are far from ideal: the reverberant field becomes overpowered by the direct one at 20 kHz and 40 kHz.

# 5. EFFECTS OF THE DIFFUSION ON THE SOUND FIELD

## 5.1 Testing Procedure

Two types of diffusers affecting two different frequency bands have been designed. They are made of a sequence of varnished MDF wells having various depth and placed in random order. The maximum diffuse area that can be set on the stage represents roughly 60% of the side walls and ceiling surface. The same procedure was applied to three stage configurations: with no diffusers, with 30% of diffusing surfaces applied on the stage walls, and with 60%.

The plasma source is finally chosen in spite of its size and the lack of omnidirectionality at high frequencies. The microphone is successively positioned at seven key positions: at the soloist's position, in the middle of the violins' section, in the middle of the celli's section, at the oboe position, at the percussion's position, in the middle of the left wind instruments, and in the middle of the right wind instruments. Measurements of the impulse response are also carried out at one position in the front of the audience area. The procedure was repeated at five source positions corresponding to the one of the soloist, the middle of the violins' section, the oboe, the middle of the left wind instruments, and the percussion. For each source position one measurement was made with the microphone 10 cm model scale away from the source to derive the parameters ST and EEL.

## 5.2 Results and Discussion

This study focuses on the effects of diffusers on early reflected energy only, that part of the signal being the most significant one to musicians. As expected, the first slope of Schroeder decay curves tends to be more linear in presence of diffusers, in particular at high frequencies where echoes are strong. It can be seen on the figures 1 and 2 representing the impulse response that, with a greater amount of diffusion echoes patterns are spread over a longer period, shifted in time and reduced in amplitude. The standard deviation of clarity and EEL has been calculated over all transducer positions for each stage configuration. Surprisingly, it is found that 60% of diffusing surfaces do not reduce the standard deviation, though the difference between maximum and minimum values of EEL or clarity is not reduced by a greater amount of diffusion. Consequently, the distribution of energy does not seem to be improved.

Values of EEL and ST stay roughly the same when increasing the amount of diffusion, while values of reverberation time decrease and values of Clarity increase, this is probably because of the absorbing properties of the diffusers. EEL, ST and Clarity are not appropriate to report on the quality of the diffusion. It is found that values of these parameters vary more with the distance between the transducers than in with the amount of diffusion. As expected, clarity and EEL increase with smaller distances. Differences up to 8 dB for EEL and up to 12 dB for Clarity are measured among various distances between transducers. Such differences can be clearly perceived by musicians. In the future, effects of diffusion on the early sound field will have to be investigated using specific parameters. Indeed, acoustic indices based on the irregularity of the frequency response that are intended to evaluate the quality of diffusion have been defined in previous works [9,10]. Parameters based on the autocorrelation function appear to be appropriate to deal with colouration phenomenons [11]. The next step would be to investigate the variation of these parameters with the amount of diffusion.

## 6. CONCLUSION

One of the important conclusions of this study is that carrying out measurements on the orchestra platform of a tenth scale model concert hall leads to many difficulties regarding the choice of the source. The impulse response varies considerably from one source to the other when transducers are close to each other. A small sized source which remains omnidirectional up to 40 kHz would be required, but no sources that fulfill these conditions have been found. Contrary to measurements carried out in the audience area, the distance and orientation between the transducers have a great influence on the impulse response especially if a directional source is used. The amount of diffusion seems to have a smaller effect on acoustic parameters such as Clarity, ST, or EEL than the source used, or the distance and the orientation between the transducers. In future work, the influence of diffusion on the early energy will be investigated using parameters based on the frequency response.

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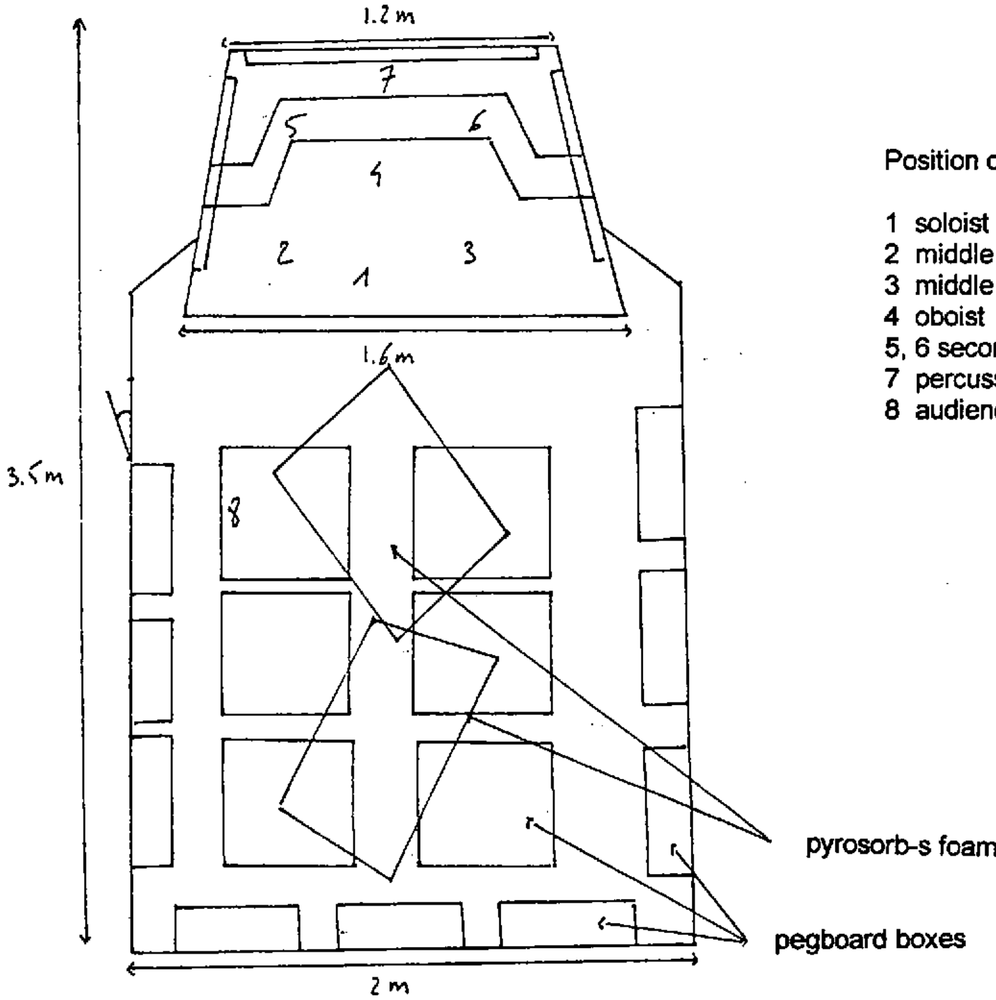
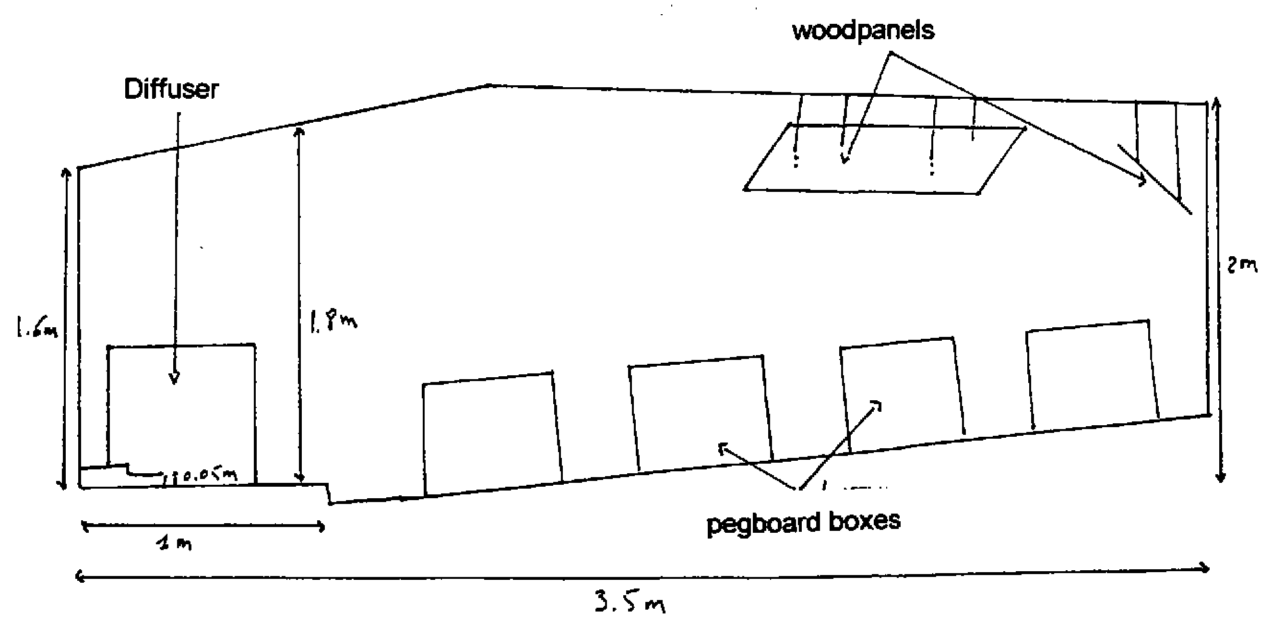
Diagram of the scale model:




Position of transducers:

1 soloist
2 middle of violins
3 middle of celli
4 oboist
5, 6 second row of winds
7 percussions
8 audience



**Effect of diffusion on the impulse response for same position of transducers:**

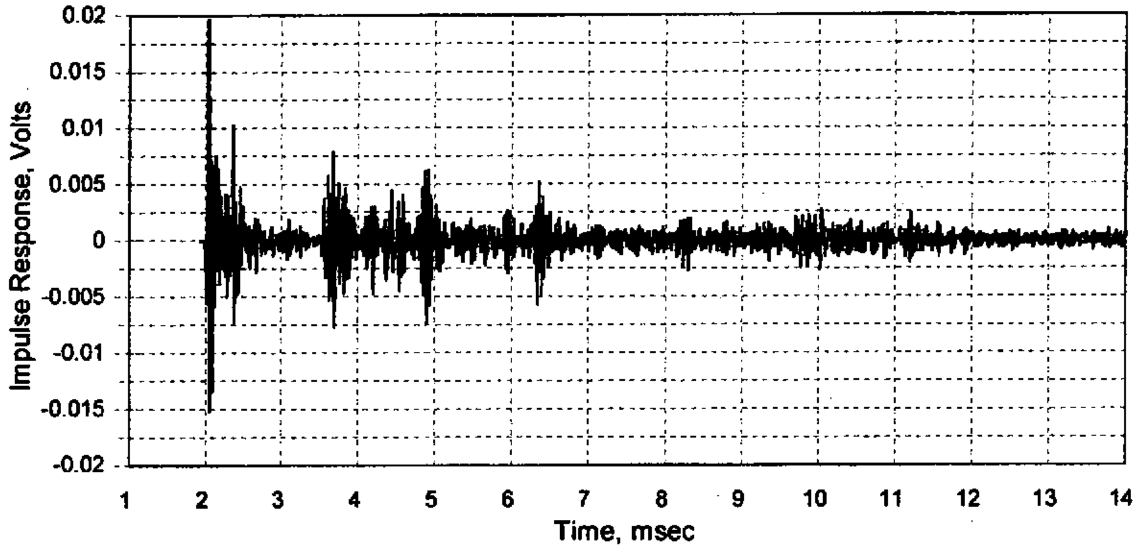



Fig.1. With 60% of diffusing surface set in the audience area.

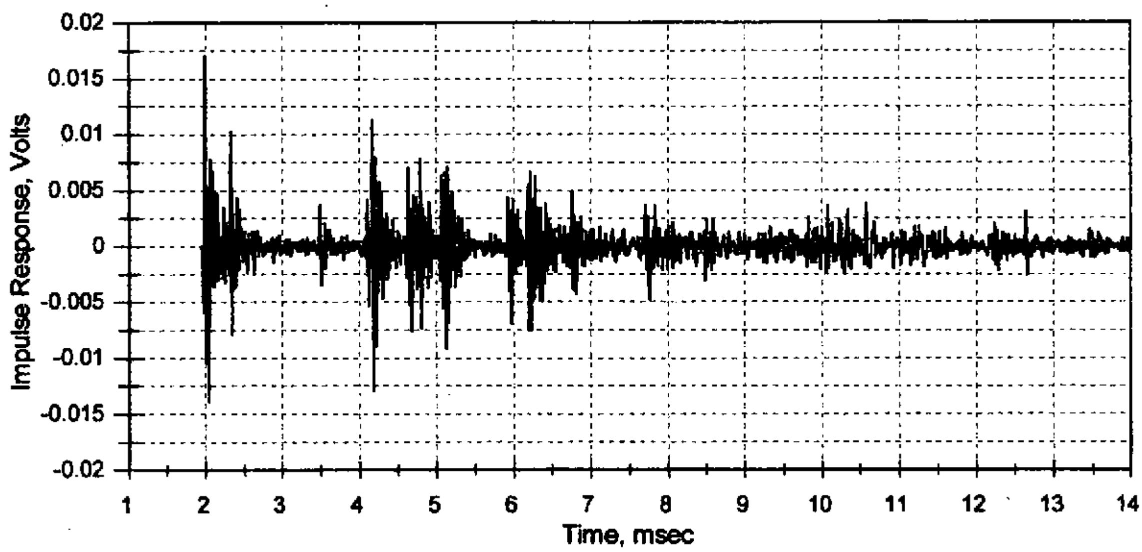



Fig.2. With no diffusing surface set in the audience area.