# SOUND TRANSMISSION BETWEEN MUSICIANS IN A SYMPHONY ORCHESTRA ON A CONCERT HALL STAGE

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## ABSTRACT

Mutual hearing among musicians playing in an orchestra is essential for their ability to play well. The degree of mutual hearing (also referred to as "hearing others") is assumed to depend on the quality of sound transmission from the musical instrument of one musician to the ears of a colleague musician. Further, this quality depends on several factors: The direct sound path (if not obstructed), the indirect sound paths via reflecting surfaces surrounding the orchestra, and the sound travelling through the orchestra in complex ways. Moreover, the quality of the sound that radiates from an instrument in the directions of the various paths varies with time and frequency due to properties of the instruments, the way they are played, and the music itself. This paper presents results from MLS-measurements of transmission through a symphony orchestra, and a discussion of the significance of some physical factors, e.g. seating arrangement, a canopy and of source directionality.

## INTRODUCTION

Mutual hearing among musicians playing in an orchestra is essential for their ability to play well. Knowledge of the sound transmission from the musical instrument of one musician to the ears of a colleague musician is important in the field of stage acoustics in general, but particularly to concert hall design and in efforts to improve acoustical conditions on stage. Room acoustic measurements and simulations are usually performed with an omni-directional source on empty stage. However, such measurements and simulations can not be expected to fully describe conditions for sound transmission inside an orchestra on stage, since directivity of musical instruments and obstruction of the direct sound path is not taken into account [1]. Orchestra members, music stands and instruments are assumed to represent significant sound barriers. This author performed MLS-measurements through Oslo Philharmonic Orchestra in Oslo Concert Hall in January 2007, obtaining impulse responses for further analysis. While Halmrast have analysed the measurements in order to study coloration effects [2], the intension of this paper is to report on how internal sound transmission on stage is affected by parameters like source-receiver height, free sound paths, (relevant to orchestra layout and use of risers), directivity, the effect of a canopy, and the sound barrier effect from the presence of the orchestra.

## MEASUREMENT

### Measurement description

Measurements through the orchestra have previously been suggested by Halmrast[i] [3]. Transmission through an orchestra ready for playing was measured by obtaining impulse responses with MLS technique. Further measurement description is given in Table 1:

[i] Denoted Through the Orchestra impulse Response measurements, abbreviated TOR measurements after the originaTOR.

Table 1: Measurement description

| | |
|---|---|
| Time | January 31, 2007 |
| Place | Oslo Concert Hall |
| Orchestra | Oslo Philharmonic Orchestra, 90 musicians, instruments, music stands |
| Source | Yamaha Monitor Speaker MS101 |
| Source Position | Instrument position leftmost 1. Violin |
| Receiver | AKG Condenser microphone (omnidirectional) |
| Receiver position | Ear position of rearmost Bassoon player |
| Software | winMLS 2004 |
| Number of measurements | 16 |

Measurement positions and direction is illustrated in Figure 1. The distance between source and receiver is 11.7 meters.

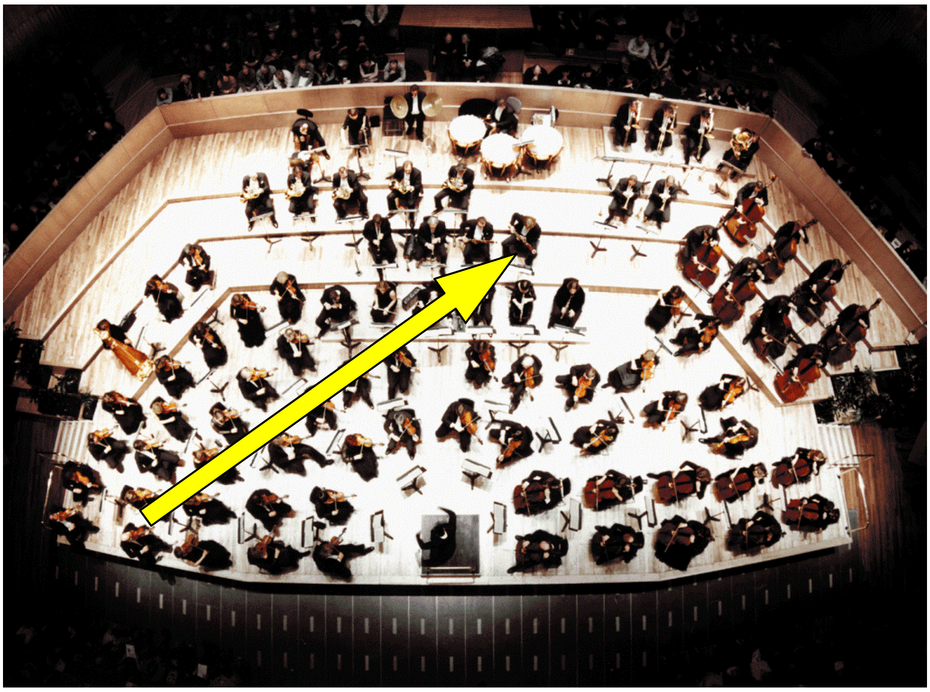


Figure 1. Transmission through an orchestra – from 1. Violin to Bassoon player.
(Image: http://www.mti.dmu.ac.uk/~ahugill/manual/seating.html)

**Physical parameters**
The physical parameters chosen for this investigation are given in Table 2. Combinations of varying parameter values formed a set of 16 measurement configurations. Heights in bold figures represent normal violin height and ear height, respectively. In the analysis, the average of the source height and the receiver height representing the height of the direct sound path was chosen as the physical parameter.

Table 2. Parameters and measured variables

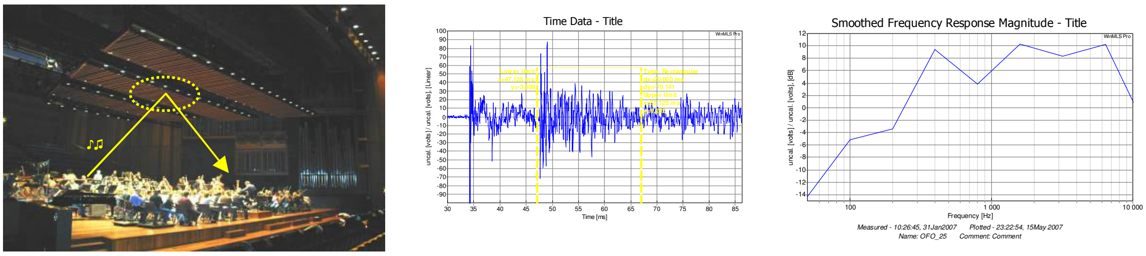
<table>
<tr><td>Source height</td><td colspan="2">65 cm</td><td colspan="2">103 cm</td><td colspan="2">150 cm</td></tr>
<tr><td>Receiver height</td><td colspan="3">125 cm</td><td colspan="3">170 cm</td></tr>
<tr><td>Directivity</td><td colspan="3">0 degrees (Towards receiver)</td><td colspan="3">140 degrees</td></tr>
<tr><td>Canopy reflector</td><td colspan="3">7.2m above stage floor</td><td colspan="3">Stored vertically in ceiling</td></tr>
<tr><td>Orchestra</td><td colspan="3">Present, ready to play</td><td colspan="3">Only chairs and stands</td></tr>
</table>

**A set of 16 impulse responses**

From 16 measurement configurations, 16 impulse responses were obtained from the 16 through-the-orchestra measurements with an MLS-signal feeding into the loudspeaker having an integrated amplifier.

**Data processing**

From the 16 impulse responses the winMLS software calculated the common room acoustical parameters in octave bands from 63Hz thru 16kHz. The calculated parameters were exported to Excel, and from the values of the parameter pair D50 and G, the values of the parameter G50 were calculated.




a b c

Figure 2. (a) Oslo Concert Hall, w Oslo Philharmonic Orchestra; (b) Impulse response; (c) Frequency Response.

**G50 – a hearing related acoustical parameter**

The initial energy of the interval 0-50ms after direct sound arrival is previously denoted E50, and previously presented [5] as a hearing related parameter taking in to account the 50ms merging of our auditory system. The use of this parameter is based on the common assumption that the auditory impression of a sound is a result of energy integration over a 50ms interval. An example of this merging effect is that two equal sound events that occurs within the same 50ms interval is on usually perceived as a single event having double sound energy. In particular, an echo must be at least 50ms delayed to be perceived as a separate sound event. Further, a periodic signal with period T< 50ms (frequency > 20Hz) is merged to the perception of a *tone* rather than a train of separate events. This knowledge must not be confused by the fact that we can distinguish between two sounds having different impulse-densities within 50ms intervals, for instance between rainfall of different drop-density.

G50=20·log(E50) is the sound energy level from the initial 50ms, with reference level 0dB related to free field measurement at 10m from the source. It is advantageous that G50 has the same reference level as the room acoustical G (strength) parameter. A similar parameter G80, with integration limits 0-80ms can be deduced from C80 and G. While this parameter may be adequate for tonal impression and intonation, it is less adequate for articulation and rhythmical information. For the purpose of this paper, G50 was chosen for measuring the effects of changes in physical stage conditions.

Figure 3. The author directing the orchestra. (Photo: Tor Halmrast)

## RESULTS

**Frequency dependant features**

An overview of the most typical tendencies of the results is presented in Figure 4. Legend synthax “0.46 ax NoCan Orch” means: Direct path **0.46**m above reference (1.14m), receiver is in loudspeaker **ax**is, there is **no can**opy, and the **Orch**estra is present.

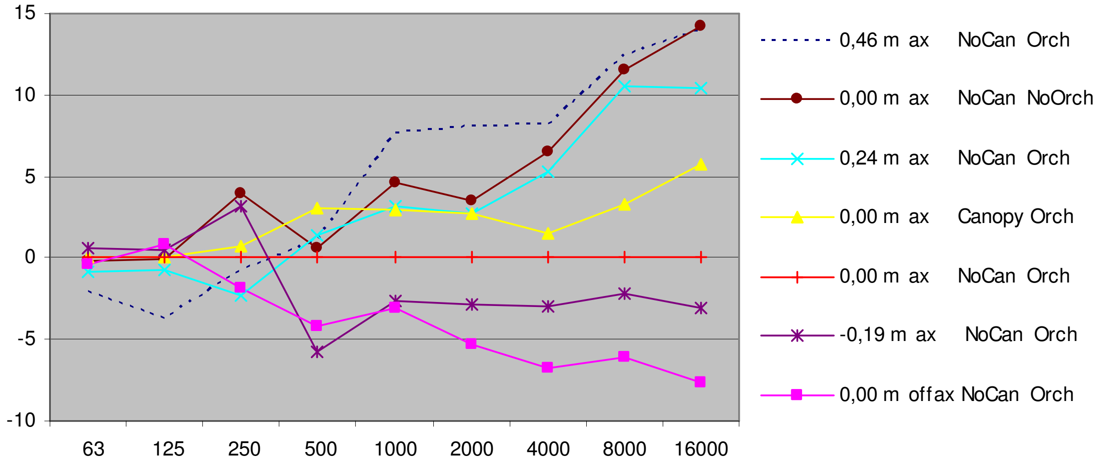



Figure 4. G50 (dB) vs octave bands (Hz). Typical measurements.

When the octave bands are grouped in the 3 categories 63-125Hz, 500-2kHz and 4-8kHz, the results may become more simple to read (Figure 5).

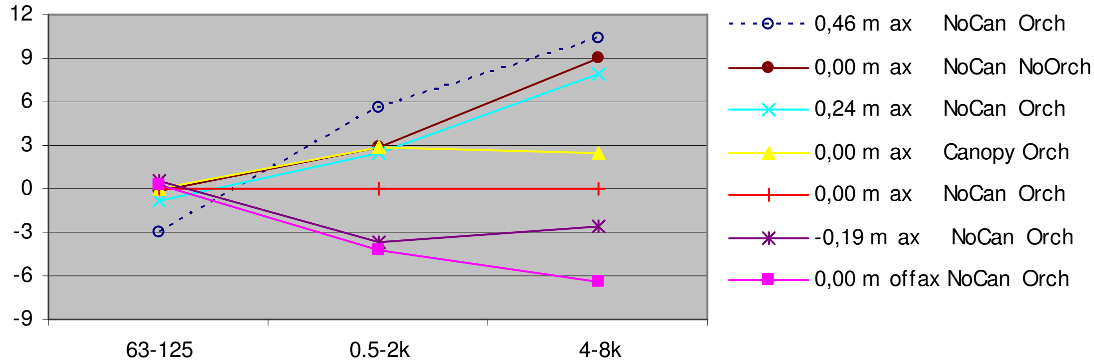



Figure 5. G50 (dB) vs 3 groups of octave bands.

The 500-2kHz bands have been assumed important to ensemble in stage acoustics [6]. Secondly, the 4-8kHz bands distinguish clearly between the measurements. Third, the negative level to height dependency in the bass is very clear when looking at 63-125Hz. The 250Hz octave appears to be of little significance, and the reason may be that interference between direct sound and floor reflection falls in this octave (and partly 500Hz) and the fact that interference is very sensitive to changes in height.

Another tendency seen from Figure 4 is that from 500Hz and upwards, the direct sound makes a difference: The lower -0.19m direct path as well as the “receiver **off ax**is” case suffer from weak direct sound transmission, while the higher +0.24m and +0.46 direct paths, together with the **no orch**estra case, benefits from having nearly free paths.

Studying the upper, dotted curve: Interestingly, by raising the direct path from +0.24m to +0.46m, the level gain is strongest in the mid high octaves 1-2kHz. Expressed differently, if lowering a path with free sight closer to acoustic barriers on stage, the 1-2kHz bands are more attenuated than the higher octave bands. This is assumed to be due to the fact that the lower frequencies, having wider Fresnel-Zone, requires wider clearance around the optical path then does the higher frequencies.

At 500Hz, there are little level differences in the height interval of 0.00 to +0.46m, or in the orchestra leaving the stage. A possible reason may be that a 500Hz wave may quite easily diffract around one head or two. The only factor that seems to boosts the 500Hz transmission is the canopy, which offers 3dB gain.

The canopy works from 500Hz and upwards, bringing approximately 3dB gain up to 8kHz.

Low frequency observation: Raising the source and/or the receiver results in weaker bass transmission, since the floor reflection effect decreases.

Source directivity makes a difference from 500Hz and upwards with significant off-axis attenuation. In the same frequency region, the lower (-0.19m) direct path is attenuated by the more obstacles.

## PARAMETER STUDY

The significance of the physical parameters has been studied in the 500Hz-4kHz octave bands in particular due to the importance in stage acoustics (Table 3).
If source and/or receiver is raised to higher positions, bass levels (63-125 octaves) fall by a tendency of -6dB per meter change in height.

Table 3. Results from parameter study

| Parameter | Significance to G50(dB), average in 500-4000Hz octave bands |
|---|---|
| Direct path height | +9 dB/m with canopy, +11 dB/m without canopy |
| Directivity | Directivity is 3dB stronger when path is raised 46cm above the reference |
| Canopy reflector | 3dB gain at normal sound-receiver height, 4-5dB at lower height |
| Orchestra | Without orchestra members on stage, the effect of the canopy is 2dB underestimated, possibly more so if stage floor is completely empty |

## FURTHER WORK

The musicians' sensitivity to directivity in combination with unreliable direct paths must lead to temporal changes in sound transmission from one instrument to an ear of a listener or a colleague musician. The G50 parameter should be tested for correlation with perception.

## CONCLUSIONS

Orchestra members, music stands, instruments and chairs are inherent obstacles in an orchestra, and it is shown that the presence of the musicians makes a difference to sound transmission internally on stage. This should be taken into account whenever measuring or predicting stage acoustics. The positive effect of the canopy was significantly underestimated by measurements without orchestra members on stage. Use of higher raisers may have some unwanted effects that need to be investigated further: Bass level drops as source and/or receiver raises. Free direct paths will lead to stronger peak level transmission from some instruments to some listeners' ears, but can this be evened out by ensemble effect from large instrument groups, or will it lead to unsatisfactory unevenness? The results show that inter-orchestral sound transmission is attenuated significantly from 500Hz and upwards. To compensate for this, canopy reflectors should operate effectively in this frequency range [4]. In this same frequency range, directivity of musical instruments makes direct sound radiation unreliable. This previous conclusion that good sound transmission on stage as well as from stage rely upon diffuse surroundings providing many sound paths [5], maintains.

**References**:


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Figure 6. The loudspeaker at 1st Violin position (Photo: Tor Halmrast)

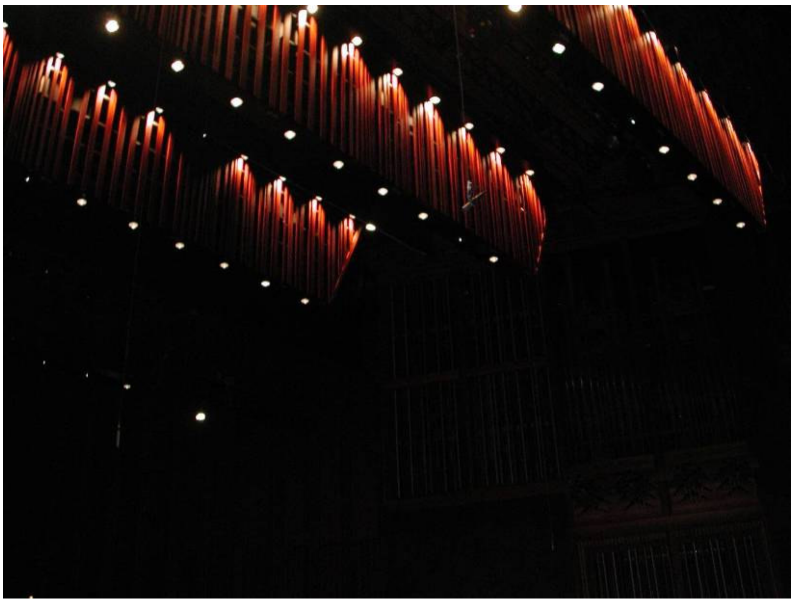

Figure 7. "NoCan" – the canopy stored under the ceiling. (Photo: Tor Halmrast)