ELECTRO-ACOUSTIC SYSTEMS FOR THE NEW OPERA HOUSE IN OSLO

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ABSTRACT

In this paper the requirements, design and some measurements of the sound reinforcement system for the main auditorium in the new opera house in Oslo is presented. The extensive variable acoustic system for adjusting the room for amplified performances and minimizing problems with disturbing echoes is presented. The reinforcement system has been designed for highest level of fidelity. This includes the possibility of preserving correct localisation of singers on stage by using a delayed matrix which is automatically controlled by a tracking system. Furthermore, almost all of the loudspeakers are hidden which further increase the audience's belief in the "illusion" on stage. Additionally, the general paging and voice alarm system is shortly described.

1 INTRODUCTION

The new Opera House in Oslo was opened in April 2008. The house has a main hall with 1358 seats and a flexible small hall with 440 seats. Both halls have extensive variable acoustics and advanced sound reinforcement systems. In the main auditorium there is also a large induction loop system (Super Loop System) for people wearing hearing aid and a IR system mainly for visual description for the blind and interpretation. There are many other sound systems in the house such as sound reinforcement systems in the large rehearsal hall and foyer, intercom systems, fold back systems, sound effect play-back systems, paging sound system for live monitoring from stages, calling and voice alarm, AV-systems in lecture halls, play-back systems in small rooms and recording and sound effect production systems. The sound system for reinforcement and production use a fully digital Stagetec Nexus distribution system with sound and control mainly on fibre. Four Stagetec Aurus control surfaces are connected to this system. In this paper we will concentrate on the fixed loudspeaker system for the audience in the main auditorium.

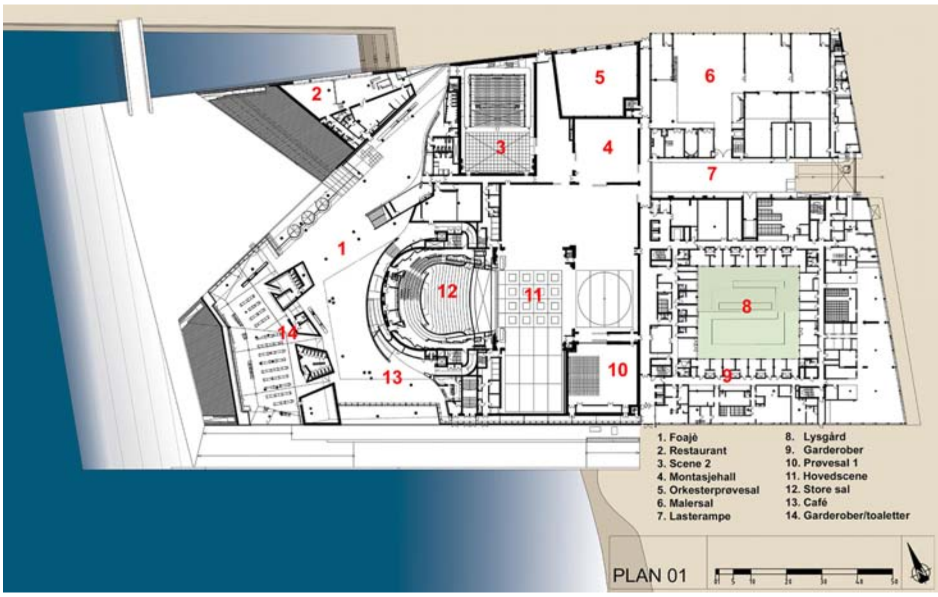

Figure 1.
Plan of the first floor of the opera house. The foyer is to the left, the large and small hall in the middle and BOH to the right (rehearsal rooms, workshops, administration etc).

2 VARIABLE ACOUSTICS

Variable acoustics is very important for adjusting a hall for different type of performances. Already in the program it was determined that electro-acoustic enhancement system should not be used for prolonging the reverberation time. It was later decided that the variable acoustics should be passive and motorized. The variable acoustics in the main auditorium is designed to enable high quality and intelligibility of amplified sound and to give the sound engineers the possibility for good control of the sound. For loudspeakers, when often higher levels are used, avoiding disturbing echoes is at least as important as low reverberation time. Reflections back to stage good for singer support can cause disturbing echoes from high level loudspeakers. Furthermore, the surfaces near the loudspeakers shall not cause audible colouring from comb filtering.

The performances in this house will be acoustic opera without sound reinforcement, operettas and musicals. Operas by Wagner, Richard Strauss etc will use the longest reverberation time that was specified in the program to be approximately 1.7 s for the mid frequencies. Modern rock operas and rock musicals will require the shortest reverberation time. With variable absorbents extended in the hall it was required that the minimum mid-frequency reverberation time should be adjustable down to approximately 1.2 s.

During the planning the acoustic consultant used ODEON[1] and the electro-acoustic consultant used CATT-Acoustics[2] for computer calculations. In the beginning of the planning the ODEON model and all given surface properties were converted to CATT format and verified by calculating room acoustical parameters in 36 positions spatially averaged. The differences between the two programs were very small (within subjective difference limen of appr. 5% for RT, EDT and D_{50}) except in the low frequency region (octave bands 125 Hz and 250 Hz) where the reverberation time etc predicted by ODEON was much longer. Of course, geometrical acoustics has a limited validity in the low frequency region but this holds for both the programs.

A difficulty in specifying reverberation time and other acoustical parameters for theatres is that the conditions on stage may have a large influence. The main stage volume (with shutters to rear and side stages closed) in the Oslo opera house is approximately the same as the auditorium volume. It is therefore likely that the stage conditions will have a large influence, especially on the reverberation time T30 and with sources on stage. Preliminary measurements indicate that the stage absorption used in the calculations was slightly higher than the measured condition and the box model of the stage probably too simple. For verification of the CATT model of the auditorium (converted from the room acoustical ODEON model) we therefore compared calculations with measurements (performed by the acoustic consultant) with the fire curtain closed. Figure 2 show averaged T30 with pit source and approximately 20 measurement positions and 36 calculation receiver positions. The results show clearly the high influence of the surface diffusion, especially for the mid frequency region. Even with a complex model as this with around 1250 planes estimating realistic values is crucial for the calculated results. However, the diffusion used in the calculations give good agreement with measured T30, especially in the mid frequency region.

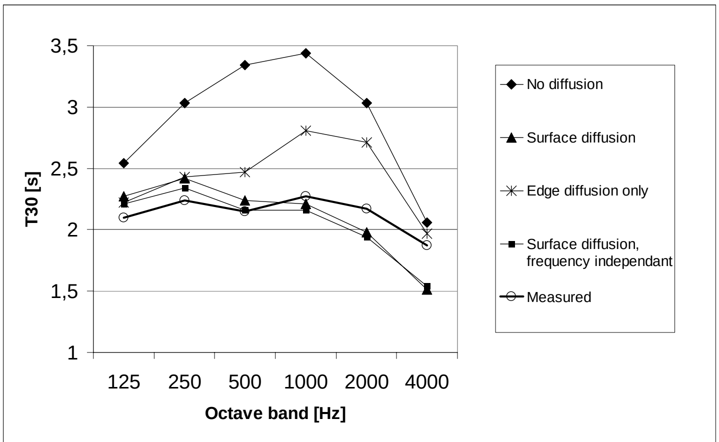

Figure 2.
CATT-predicted and measured reverberation time T_{30} in the main hall with the fire curtain down and with different surface diffusion modelling.

With the variable absorbents extended the remaining reflecting surfaces may cause disturbing echoes. Besides echograms both auralisation and calculation of the echo criterion proposed by Dietsch and Kraak [3] was used in the design process for detecting disturbing echoes from loudspeakers and transient sources in the pit. It was clear that the Dietsch and Kraak echo criterion was not enough and that auralisation was a necessary tool.

The variable acoustics consists mainly of movable auditorium towers, on each side of the pit, adjusting the width of the hall and of absorptive textiles in front of the walls around the auditorium. Almost all of the vertical walls can be covered by textiles. The textiles consists of two layers of velour, each layer surface mass ≥450 g/m2. Across the proscenium header and around 3rd balcony and technical gallery they are hung in folds (50-100% overdrape). All variable absorption are hung in motorized tracks and stored in closed boxes.

3 SOUND REINFORCEMENT SYSTEM IN THE MAIN AUDITORIUM

3.1 Requirements

The sound reinforcement systems for the audience and the variable acoustics in the main auditorium are designed for high quality amplification and play-back in operas, operettas and musicals. The usage in the standard repertoire operas will be very limited while musicals will demand all the more advanced functions.

The sound reinforcement system for the audience in the main auditorium is designed for the following functions mainly:

- Source oriented reinforcement (SOR) of artists on the stage i.e. amplifying sound while localising it back to its source.
- Natural sounding reinforcement (“inaudible PA”) for speech (and sometimes singing) in operettas etc.
- Reinforcement of orchestra and instruments.
- Play-back of recorded music.
- Live reproduction of choir from other rooms.
- Sound effects from mobile loudspeakers on stage.
- Advanced surround effects in the hall with 3D source imaging.

Requirements for localisation, intelligibility (STI[4]), maximum sound pressure level, sound pressure level coverage and maximum noise level were set.

3.1.1 Localisation

In theatres today it is common that the basic requirements for “good sound” such as low noise, low distortion, feedback prevention, adequate sound pressure level and coverage are fulfilled. However, the localisation of the sound sources (usually the singers) on stage is often wrong. This leads to reduced intelligibility and transparency, difficulty to differentiate between different actor’s dialogue, confusion and increased listener stress due to loss of correlation between visual and auditory perspective and undermining of the audience’s suspension of disbelief. Wrong auditory localisation means that the hearing gives wrong impression of direction and/or distance compared with the reality (sight). Since the actors are moving on stage (mostly) the sound system must be able to create multiple virtual sources which can change positions independently of each other. Moreover, the localisation should work for most of the spectators not only in a “hot spot” in the middle.

The auditory localisation is mainly tied to our binaural abilities and the precedence effect. In the free field the localisation in the horizontal plane is dependent on the inter-aural level, phase and time differences. In the median plane the pinnae (outer ear) give spectral cues. Head movements are important for resolving ambiguities between front, back and up. In real rooms with reflections the precedence effect (also called the "law of the first wave front") gives us the possibility to perceive the direction of the source. We hear a sound as coming from the direction from which it first reaches us.

3.1.2 Intelligibility, maximum sound pressure level and coverage

In performances of rock musicals etc, when high levels are used, it is no point in trying to achieve source localisation since the sound image anyway is unnatural. Therefore, a "high level system mode" was defined for which the system shall be adjusted for even coverage.

There are some standards on max SPL but there is no one widely used internationally. Therefore, a clear definition was developed for this project. One attempt in standardising is the so called "Common Loudspeaker Format" [5] which may be the future standard for presenting loudspeaker data. In this context the NORDTEST method NT ACOU 108 [6] should be mentioned. This method is one of very few standards for validating system requirements in situ.

Requirements were formulated for the voice system and the orchestra system separately and with variable acoustics in its max and min settings. Requirements for STI, maximum SPL and level coverage were set for a given percentage of the area of coverage.

3.1.3 Maximum noise level

Requirement for electronic noise from the loudspeakers were set to be maximum 14 dBA / PNC-9 by the acoustic consultant. It is very important to define the prerequisites for this type of requirement. We therefore clearly defined the frequency range, percentage of the area of coverage, number of channels routed, source impedance, groups of loudspeakers used, gain and acoustical conditions.

3.2 Design

Several CATT-calculations were performed in the design process. Three different types of main proscenium loudspeakers were calculated: normal point sources (clusters or individual boxes), curved line-arrays and straight line-arrays. The simulation of line-arrays in CATT consists of distance dependent directivity. The source position is still a point. Therefore, long arrays should be divided and added in phase. This is still an approximation but the influence of reflections near the loudspeakers will be more accurate.

3.2.1 Source oriented reinforcement

For controlling the SOR function a matrix mixer with adjustable gain and delay in the cross-points is needed. Every source (or group of sources in the same position) that shall be localisable simultaneously require one separate input in the matrix mixer. Every loudspeaker group which needs adjustable delay or level needs a separate output. The stage will be divided in minimum 15 localisation zones (five left-right and three front-back). Eight inputs and 16 outputs turned out to be sufficient. In the installed TTA system there will be 16 inputs and 16 outputs upgradeable to 32x32.

Since SOR was an important requirement it was decided to use normal point source loudspeakers. High directivity loudspeakers, such as line-arrays, are often used to get an even coverage and high intelligibility. However, there are several draw-backs in this case. A too even coverage is not the optimum for a natural sound image. High directivity often gives an impression of an unnatural close sound since the distance to the source is mainly determined by the relation between direct and reverberant sound level. In this hall there was also a risk for disturbing echoes.

In order to get maximum amplification with correct localisation the loudspeaker sound shall be delayed approximately 10-30 ms after the direct sound (Haas-zone). Around 10 ms is the preferred delay. With this delay the loudspeaker sound can be at least 4-5 dB louder than the direct sound. With weak voices or high amplification it will be necessary to amplify the direct sound. Therefore, four loudspeakers are hidden in the stage front edge for creating virtual sound sources on stage. When SOR is not used they can be used for normal front fill and image shift. CATT-calculations showed that SOR will not work on the sides furthest towards the stage on the first and second balcony. In these positions the level difference between the loudspeakers in the SOR-system will be too high. It was also clear that it was necessary to have four delay zones for the lowest under balcony fill loudspeakers on the sides (two zones on each side).

3.2.2 Loudspeaker systems

All loudspeakers except the central proscenium overhead cluster are hidden. Figure 3 show the loudspeakers included in the design for the SOR system and orchestra system in the CATT-model. Only the lowest level of the under balcony side fill loudspeakers are shown. E0-E3 are in the stage front edge. C3 and C6 are the orchestra loudspeakers in the loudspeaker towers, C1 and C5 are the voice loudspeakers in the loudspeaker towers, C2 is the central hanging voice loudspeaker. C4 and C7 are mainly for voice covering the front third of the stalls and are not included in the SOR system. D0-D7 are the side fill loudspeakers under the 1st balcony. A6-A9 are the 3rd balcony fill loudspeakers (A6 and A9 are hidden in the back of the follow spot room).

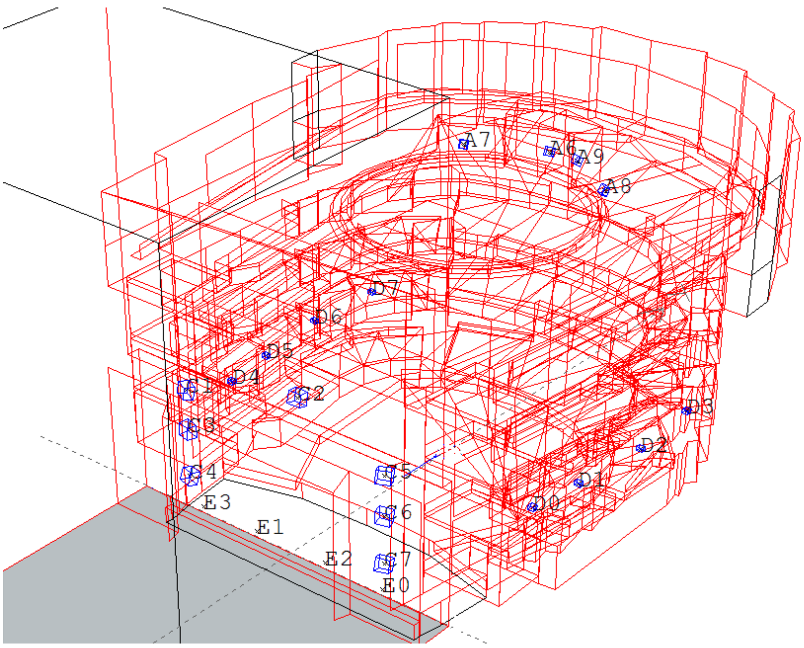

Figure 3.
CATT-model with SOR loudspeakers indicated (for clearness only side fills under the 1st balcony are shown)

The loudspeakers for the audience can be divided in the following functions:

- SOR system with delayed matrix controlled by tracking
  Consist of four stage front edge loudspeakers, three main proscenium loudspeakers (left and right in mobile loudspeaker towers, centre hanging in a hoist) and 28 balcony fill loudspeakers grouped in nine zones.

- Normal voice reinforcement system
  The same loudspeakers and groups as for the SOR system but the lower fill systems (2.5 m) in the loudspeaker towers are added (C4 and C7 in figure 3). A fixed delayed matrix in one of the sound processors is used for level and delay tuning of the loudspeakers to a

centre source position on stage.

- Orchestra system
  The orchestra loudspeakers consist of main systems (6 m over the stage floor) in the loudspeaker towers (left and right). Additionally, there are four (two left and two right) sub woofers hidden in the auditorium towers next to the loudspeaker towers. The balcony fill loudspeakers are used as well. The left and right channel are added with separate delay to give a better “stereo” image in the fill zones.

- Surround system
  There are totally 50 fixed speakers which can be used for surround. All are hidden except for the 3rd balcony. Under the first balcony ten surround loudspeakers are aimed towards the stalls. The rest are be used for under balcony seats (of which 24 are used for fill as well).

- Mobile sound effect loudspeakers
  Six active mobile loudspeakers and two sub woofers (woofers normally placed on the technical gallery).

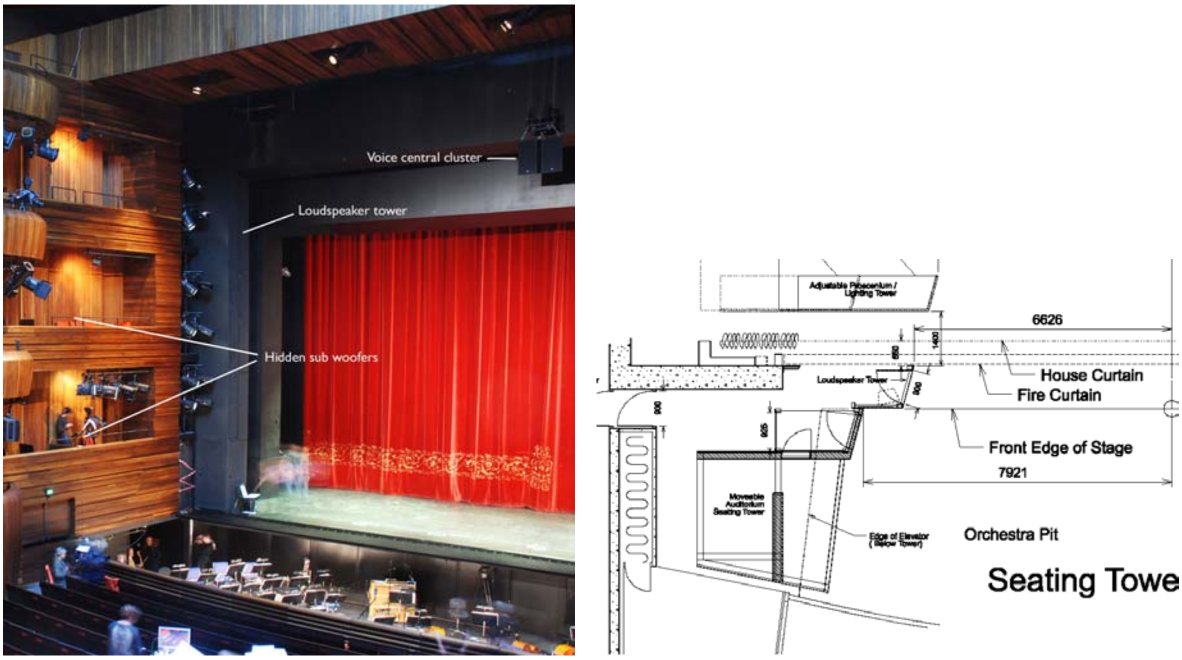

Figure 4. *Picture of proscenium and plan showing the movable loudspeaker and auditorium towers.*

3.3 Installed system

The loudspeakers installed in the fixed system are from Renkus-Heinz:
3 pcs ST4/4-2 active clusters for voice. Left and right in the loudspeaker towers and center hanging in hoist.
2 pcs ST4 active speakers for voice front fill left and right in the loudspeaker towers.
2 pcs ST4/4-2 active clusters for orchestra left and right in the loudspeaker towers.
4 pcs DR18-2 active sub-woofers (2 pcs left and 2 pcs right) hidden in the auditorium towers.
4 pcs PN61 active speakers hidden in the stage front edge.
54 pcs PNX61 passive speakers for fill and Surround

There are two delayed mixer systems. The voice SOR system is Stagetracker from TTA (Track the Actors) which automatically control the delay and level by tracking of singers position on stage. The TTA matrix in/out is 16/16 expandable to 32x32. There are two so called radio eyes above the main stage. The other system is a TiMax Imagemaker 16 which will be used for 3D sound effects.

There are two Yamaha DME64 processors used for tuning the loudspeakers with EQ, fixed delay, limiters, filtering etc.

Preliminary measurements of the orchestra system in 36 positions show a mean value STI=0.66 with a standard deviation of 0.046 with absorbents and STI=0.61 with standard deviation 0.054 without absorbents. These measurements are done with a “lightly damped” stage condition resulting in a mid frequency reverberation time of appr. 1.5 s with variable absorbents and appr. 2.1 s without. The voice system is not finally measured.

4 PAGING AND VOICE ALARM SYSTEM

A general Public Address system is installed. The system is a very important tool to stage managers. Tasks handled by the system are:

- Voice alarm
- Paging to staff
- Paging to audience
- Talk-back to stages
- Live audio monitoring from stages to common back of house ares
- Local sound reinforcement in certain areas

Throughout the House this system comprises more than 1.750 loudspeakers on a number of more than 200 loudspeaker circuits, with a total amplifier power of 26 kilowatts. Additional systems are installed to spread audio and video live monitoring from stages both on a traditional cable TV system as well as on the house IP Network to any PC in the house.

4.1 Loudspeaker system in Foyer

The Foyer is a very large room first of all characterized by its sloping ceiling; increasing from less than 2 m height in the western end, holding the audience wardrobes, up to more than 20 m in the north-east corner close to the small hall.

In addition to the regular paging purpose, the PA system is designed to handle local sound reinforcement for speech and simple performances. Wireless microphones and control facilities are installed as well as an option to connect a separate mixer. Sound pressure level, frequency response, coverage and STI within a specified percentage of the area of coverage was specified.

To cover the Foyer several different loudspeaker types as well as installation principals have been used: The basic of the Foyer coverage is a row of two-way, horn loaded cabinet loudspeakers built into the waved wooden rib wall next to the performance halls. They are mutually spaced approximately 5 to 6 meters. In the galleries themselves, 8 inch dual cone coaxial speakers are installed behind oak rib ceilings. The ceilings are sound transparent as the rib walls are.

The main part of the ceiling of the Foyer is covered by a Barrisol micro perforated plastic foil that is stretched and applied approximately one meter below the concrete roof. Above the Barrisol membrane thick mineral wool absorbents are mounted. All loudspeakers in this area are installed above this plastic foil, and are totally invisible.

The "Barrisol Microsober 036" inserts noticeable attenuation of high frequencies. Absorption data from the manufacturer indicated that the foil acoustically acts as tight, and it is not possible to breath through it. From the foil mass of approximately 50g/m^2 the transmission loss was calculated to be:

Frequency:	2 kHz	4 kHz	8 kHz	16 kHz
Transmission loss [dB]:	2,0 dB	5,5 dB	7,5 dB	16 dB

This was confirmed later by measurements, with the below result. The graph on top is level without foil, the next shows level measured through the foil, and the bottom curve is the difference.

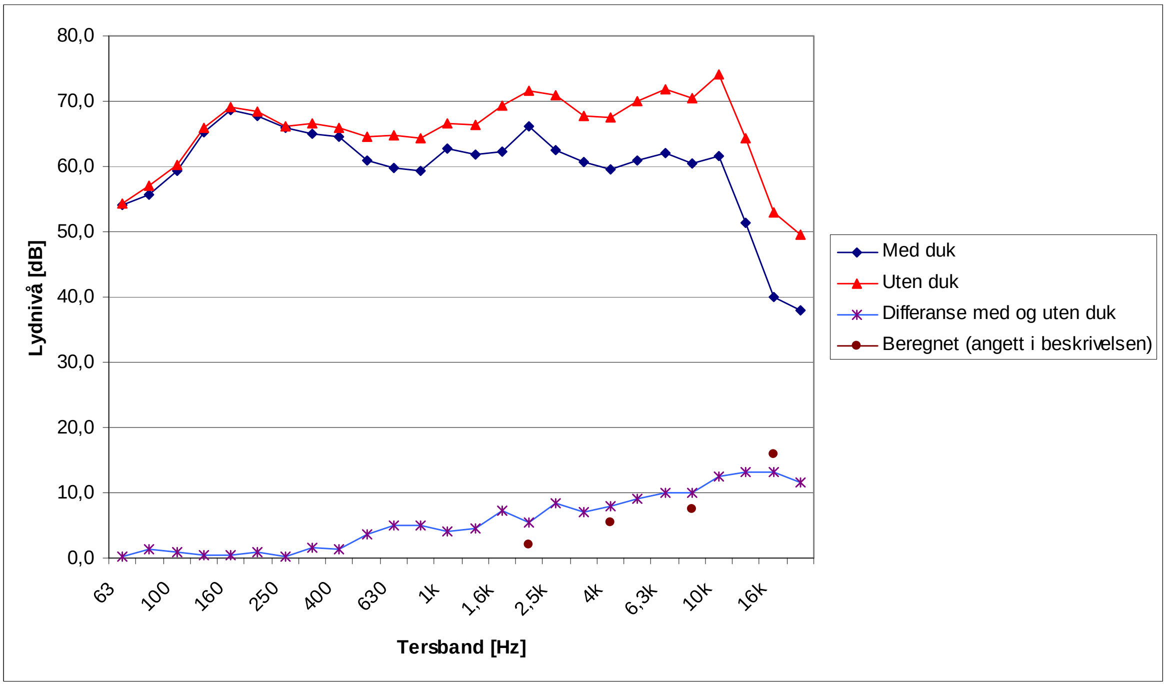

Figure 5. *Measured transmission loss trough the Barrisol foil ceiling.*

Due to this attenuation all loudspeakers of same type above foil ceiling are connected to the same amplifier circuit equalized reversely.

Inmost – where the ceilings are very low and consist of regular gypsum boards – the audience wardrobes and toilet areas are located. Here square, steel grilled, 4 inch single cone speakers are installed quite densely.

5 REFERENCES

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