# THE INFLUENCE OF A LARGE REFLECTOR OVER THE ORCHESTRA PIT IN AN OPERA HOUSE


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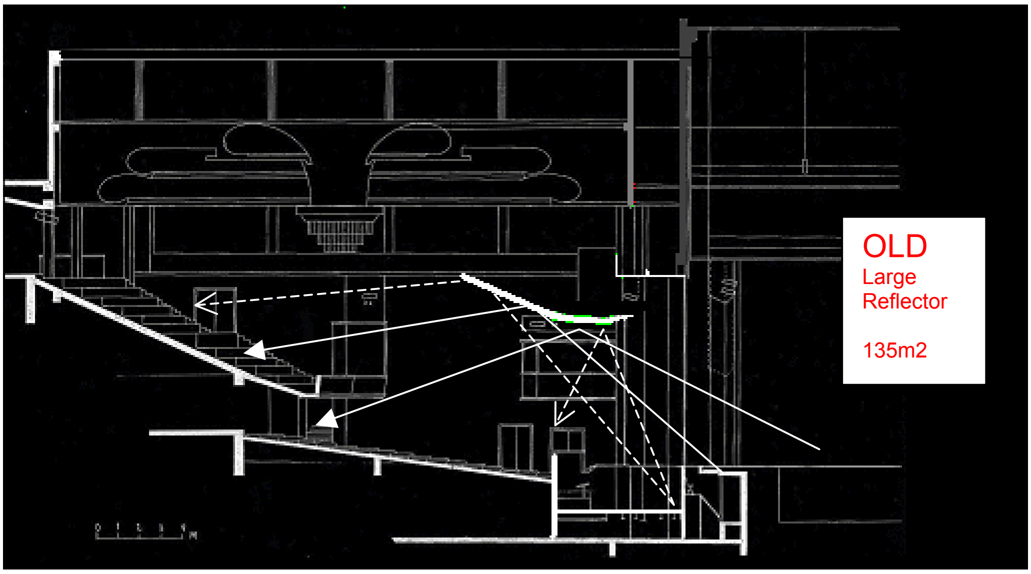
## 1. INTRODUCTION

Since the opening in 1958, the Norwegian National Opera has been located in “Folketeateret”, a former lyric theatre build in 1935. In the 1970´s a large reflector was introduced in front of the proscenium, over the orchestra pit, with the intention to enhance the singers. This large reflector was not installed as indicated by the acoustic consultant at that time, and the effect of this reflector has been questioned. Measurements in 1996 [1] indicated that one would want a reduction of clarity, an increase in reverberation, and better stage/pit balance. The large reflector was removed in 2001 and replaced by a much smaller horizontal underside of a lighting bridge. The comments from both audience and musicians after the removal has been very positive, and the acoustics of the hall was actually mentioned as ” *….A floating, tight interpretation which, thanks to the good acoustics, stayed fundamentally transparent”…* in a review of the 2002 performance of Lohengrin in the Das Opernglas (3/2002): Measurements [2] show that the intentions for the removal of the large reflector are fulfilled.

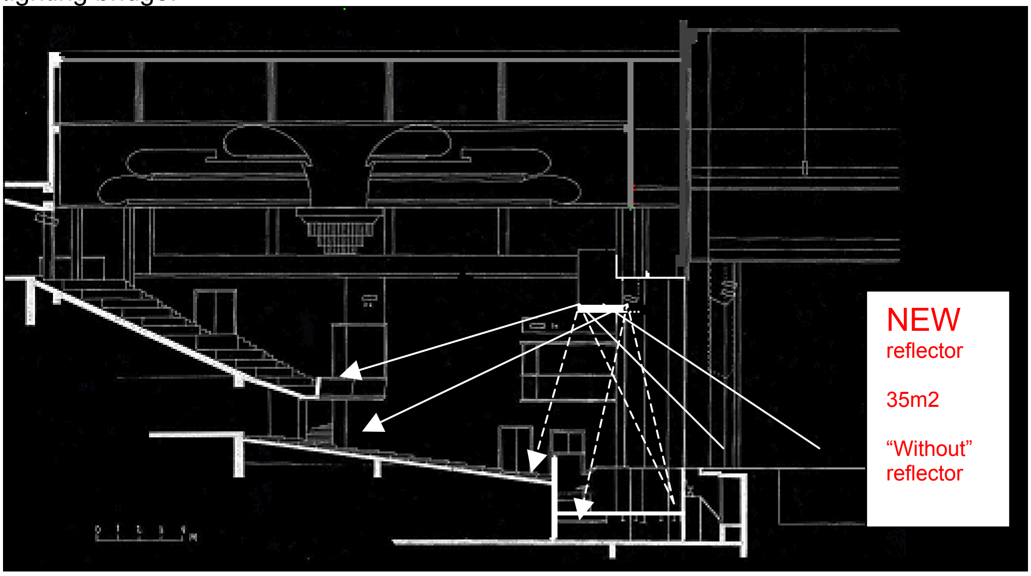
The investigations were done as a part of the planning for the new opera house in Oslo [3].

## 2. THE REFLECTOR

The following section of the auditorium shows the “OLD”, large curved reflector of canvas, stretched over a metal framework, with eight layers of paint on the underside:



This section shows the “NEW”, much smaller, flat, slightly diffusing wooden reflector underneath a lighting bridge:




The following pictures show that the OLD, large reflector shaded a large part of the ceiling.


*(Ceiling made in rabbitz, visually nice/acoustically strange)*

## 3. MEASUREMENTS

A plan of the auditorium, with source and receiver's positions, is given in App1. All measurements were taken with omni-directional loudspeakers and microphones. Software for the 1996 measurements was MLSSA. For the 2000 + 2002 measurements and the comparative analysis, WinMLS was used. The differences in equipment between the measurements should influence only on the calibration of strength (G) and possibly some uncertainty for the lower frequencies due to the different loudspeakers etc. The measurements in 2002 were made fully in accordance with ISO 3382 with a calibrated measurement chain for G-measurements.

# 4. BEFORE THE REMOVAL OF THE LARGE REFLECTOR

The measurements with the old reflector (1996) [1] gave:

- *A mid frequency Reverberation time of 1.31 sec, EDT 1.27 sec, (which might be considered to low for a modern opera house).*

- *Too high a clarity: C 80=3.3 dB, C 50=0.95 dB, Ts =70 msec. (mean values, mid-frequencies)*

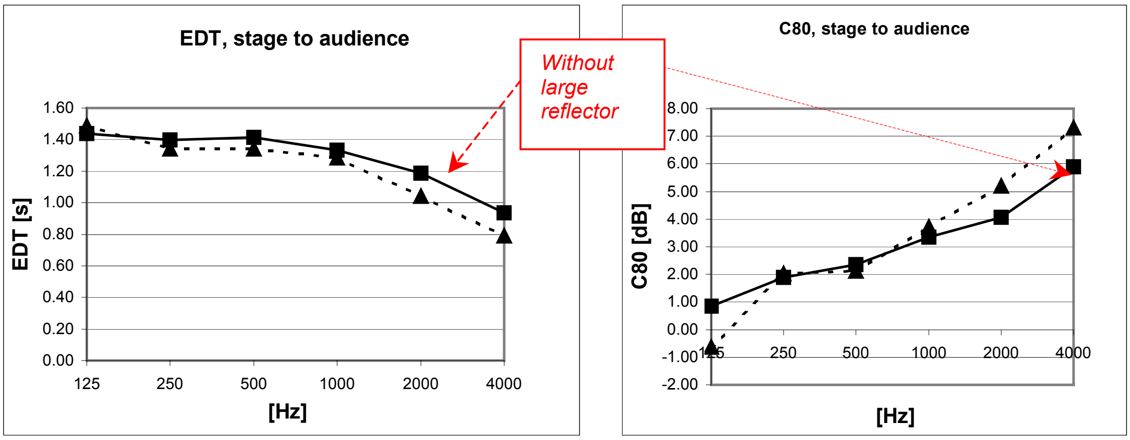
- *The impulse responses showed that the reflector gave stronger reflections from pit sources than from the stage for many receivers, most clearly on the balcony.*

In addition, it was observed that, due to the large reflector, the orchestra did not seem/hear to be located in the pit, but higher, almost at stage level. This horizontal image shift of the total orchestra was observed most clearly in the stalls. False localisation/Phantom source/Image shift is often reported in opera houses, but not well covered in acoustical literature. The interesting observation in this auditorium was that with the large reflector over the pit, the audience did not receive false localisation of just individual (treble) instruments, as often perceived in more traditional horseshoe shaped theatres [4], but a more general "rise" of the whole orchestra. This effect could be nice for orchestral overtures, but might give problems, as the orchestra appears to be located the same place as the singers. (This effect of a "raised" orchestra could indicate the need of yet another acoustical parameter: *"Apparent source height"*?)

# 5. REMOVAL OF THE REFLECTOR, COMPARISONS

## 5.1 REVERBERATION AND CLARITY FROM THE STAGE

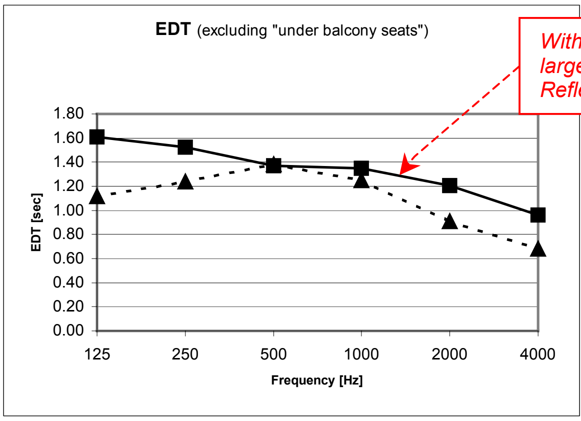
The figures below show that by removing the large reflector, EDT from the stage was increased some 0.1 s for frequencies above 1kHz, and C80 was slightly reduced (Average for all receiver positions).

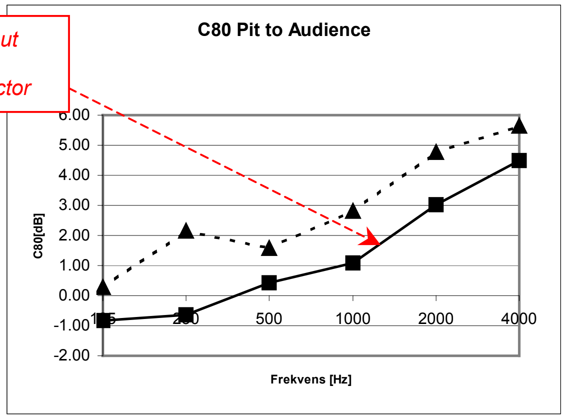



These changes were as wanted, not big, but larger than the Just Noticeable Difference. A part of the improvement might be due to the introduction of a humidity control system. A study of Relative Humidity over the years, and its influence on reverberation is given in App4 [5].

## 5.2 REVERBERATION AND CLARITY FROM THE PIT

Greater changes were expected/wanted for the sources in the pit. The left hand side of the figure below shows that EDT from the pit has increased after the removal of the large reflector.



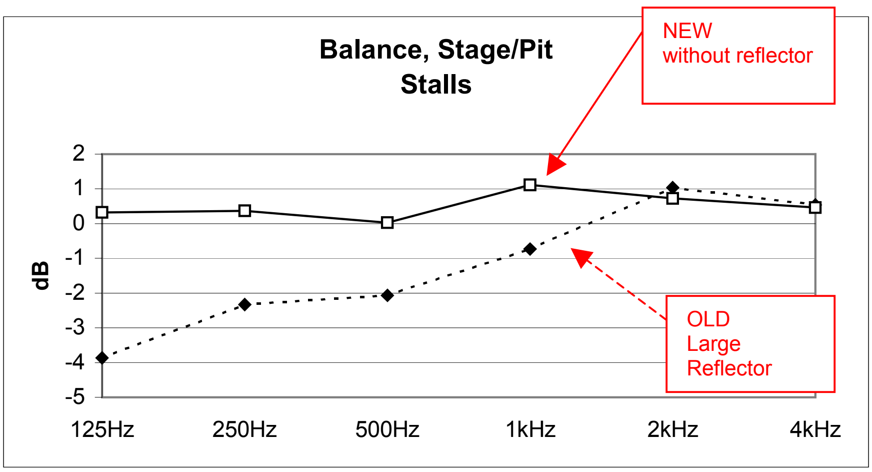




*(EDT-results below 500 Hz might be somewhat insecure due to the measurement chain for the first measurements).*

Measurements of RT are not shown here, but the changes in RT are less than for EDT, hence the ratio EDT/RT has increased for pit sources after removing the large reflector. This is in good agreement with Barron [6], who states that EDT will be reduced if early reflections are directed primarily towards audience areas.
The right hand side figure above shows that C80 from the pit has been reduced to values more favourable for opera houses. Some of our measurements are taken from a detailed investigation of pit-rail diffraction in this auditorium [7].

## 5.3 BALANCE STAGE/PIT

The figure below shows the Balance (stage/pit) before/after the removal of the large reflector. (Mean values for receivers in the stalls).




This figure shows that the stage/pit balance is improved, but still somewhat lower than what one would want for opera houses. The change is increasing with decreasing frequency. This might be due to that the large/old painted canvas reflector probably acted as an absorber for lower frequencies. More results on the G-parameter are given in App. 3.

### 5.4 SUBJECTIVE OBSERVATIONS

All comments from audience, staff, singers and musicians indicate that the removal of the large reflector has been beneficial acoustically. Before the refurbishment, the orchestra was considered *"Shrill", "Dead and too loud", "Too real, sources not blending"* in the stalls and (front) balcony. After the removal of the large reflector the observers indicate: *"Vocal sound appears to be broader, more beautiful", "The orchestra sounds more reverberant".*

The change in Balance stage/pit was (surprisingly?) not much commented by the observers. It is reason to believe that when judging balance stage/pit there might be too many varying factors: stage sets, singers, conductors and scores. Some comments "from old ladies" indicates that the spoken words in operettas are somewhat problematic to understand.

Comments from the musicians in the pit after the removal of the large reflector: *"Cleaner quality of sound", "Broader, more open towards lower register.", "Easier to maintain ensemble", "Like having a new hall. Why wasn't this done before!"*

Additional acoustician's observation: *"Orchestral image-shift, is now more lateral, not as disturbing".*

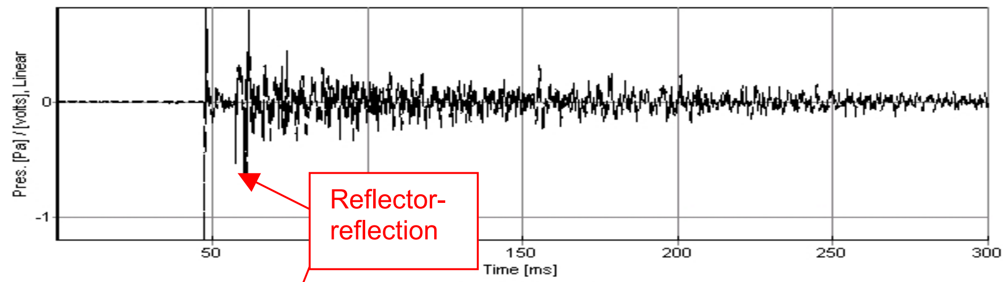
App.5 gives an overview of the observed changes of the acoustics due to the removal of the large reflector.

## 6. CLOSER EXAMINATION OF IMPULSE RESPONSES

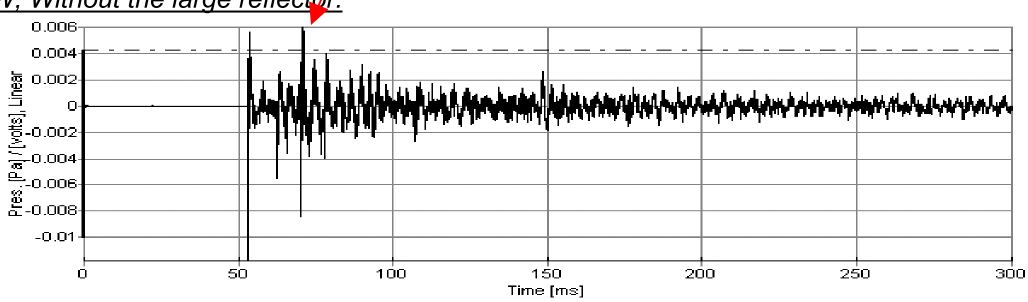
### 6.1 STAGE TO STALLS

The following figures show the impulse responses for a source on stage and receiver at (almost) the same position in the stalls, taken with/without the large reflector:

*OLD, With the large reflector:*

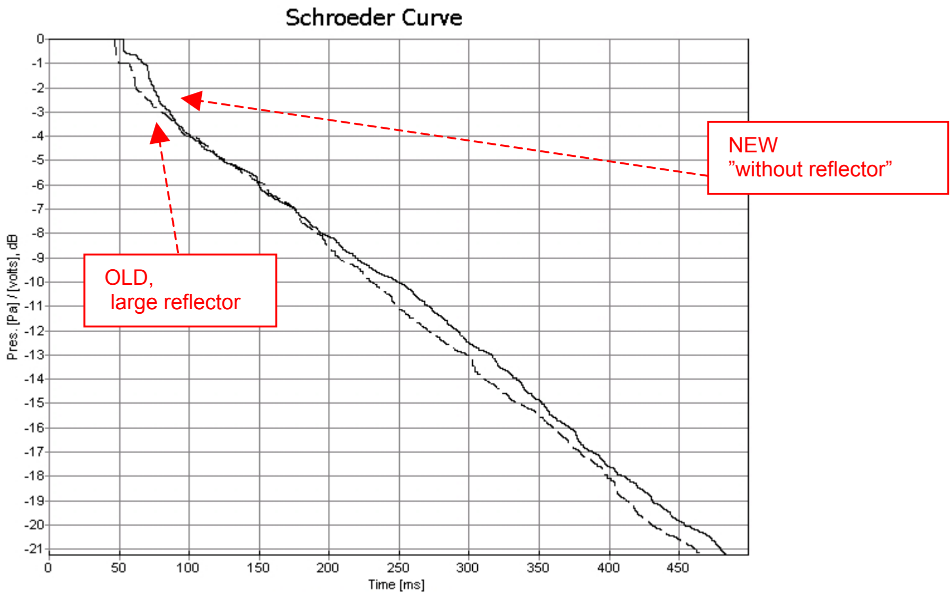



*NEW, Without the large reflector:*




We see that the reflections appear somewhat later for the situation after the removal of the large reflector, because the new, small reflector is placed somewhat higher. We see that both the new and the old reflector give nice reflections from the stage to the stalls.

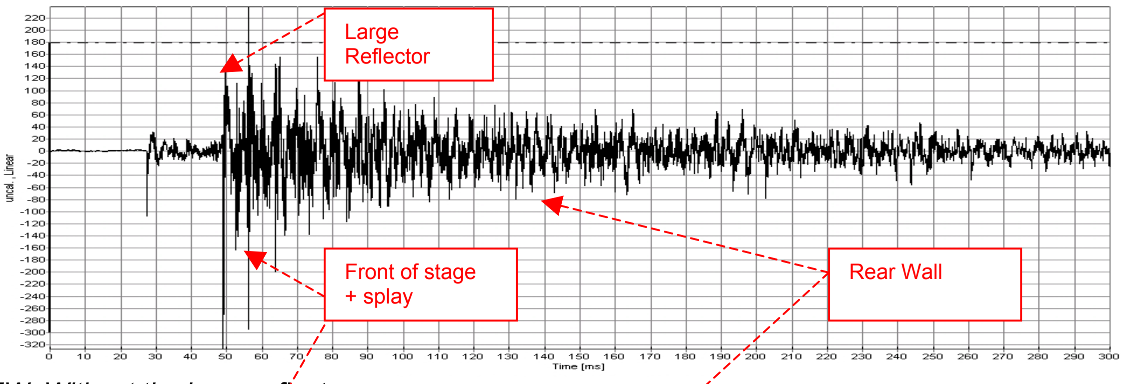
In the Schroeder curves, we see that the changes are not very large for stage/stalls:



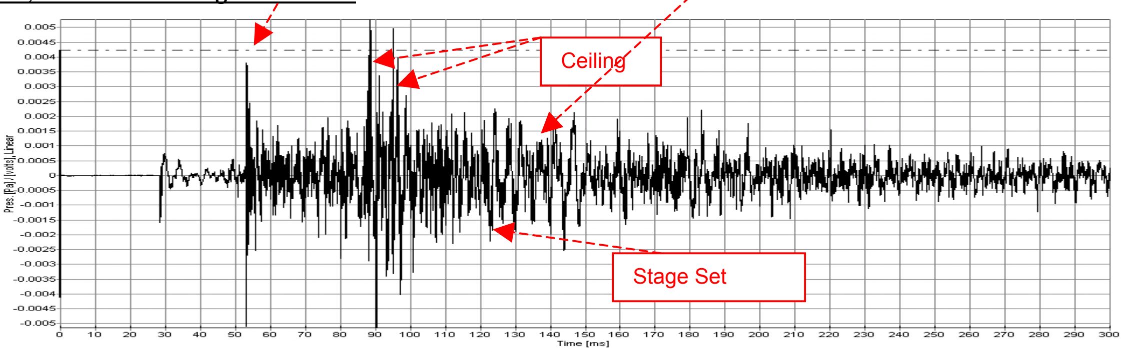

## 6.2 PIT TO STALLS

The following figures show the measurements for (approximately) the same source position in the pit and receiver in the stalls:

*OLD, With the large reflector:*



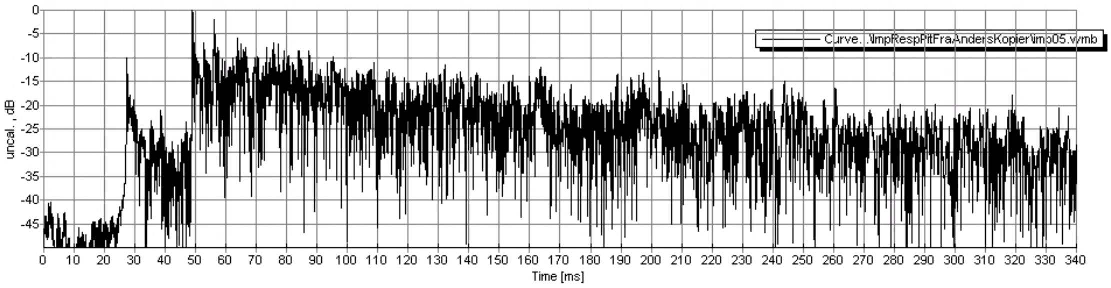

*NEW, Without the large reflector:*



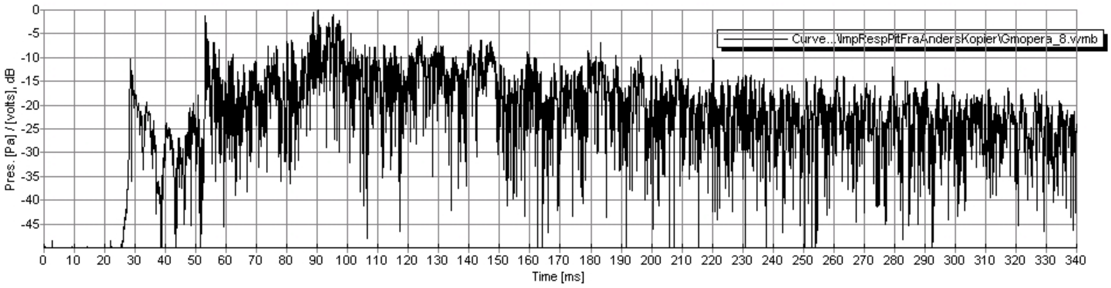

We see that the new, small reflector does not give a clear reflection from the pit to the stalls, but opens up for the later reflections from the ceiling etc.

Energy-Time-curves (integrated) for the same measurements are given in the two following figures:

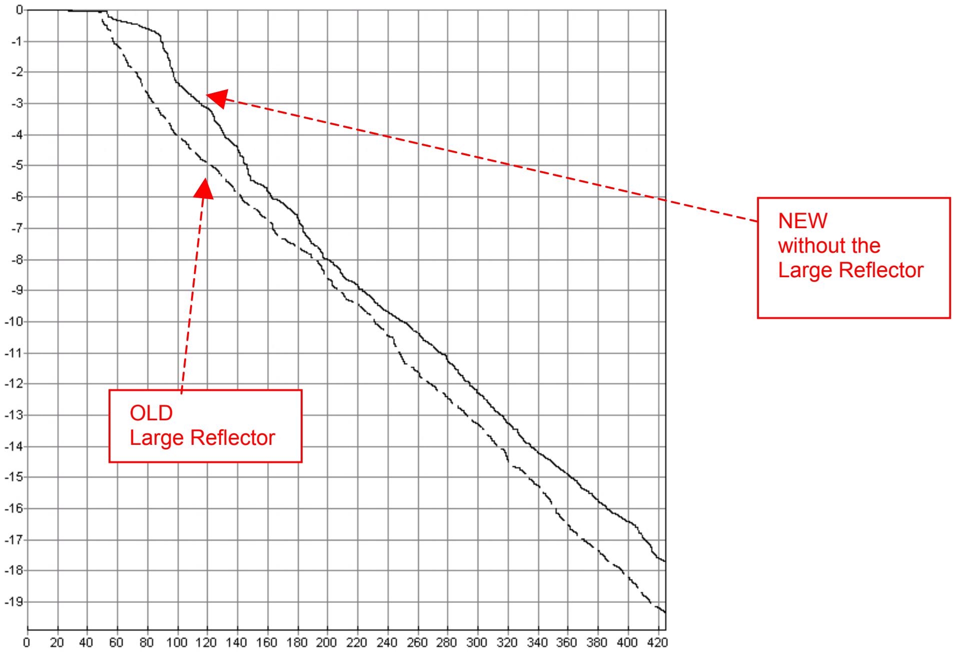
*OLD, With the large reflector:*




*NEW, Without the large reflector:*




A comparison of the Schroeder curves with/without the large reflector:




This might give what is referred to as a "singing tone" [8].
Room-acoustic parameters for these two measurements are given in App.6.

# 7. ADDITIONAL INVESTIGATIONS

## 7.1 OTHER ACOUSTICAL PARAMETERS

Our measurements/analysis included investigations of several others acoustical parameters. The overall conclusions on parameters like **Ts** and **Deutlichkeit** are covered in the analysis of RT, EDT, C80 and C50. **Support (ST)** for pit sources will not be discussed further, as the measurements were taken without an orchestra in the pit, and thus include reflections that might be unrealistic for a performance, see [9]. This also goes for our TOR (Through Orchestra Response measurements). **Speech Transmisson Index (STI)** from the stage was typically reduced from 0,63-0,58, (mean value for all measurements) when the large reflector was removed. This was as expected.

## 7.2 "AN ECHO IS NOT AN ECHO?"

A clear echo is observed when clapping/shouting, both on the stage and in the pit. However, there have been no complaints about this from the singers. This echo did not change by removing the old reflector. It is difficult to detect the echo from the measurements without actually listening to the impulse response and afterwards make closer analysis. The question of detecting/analysing echo in an opera house is discussed further in App.2.

# 8. CONCLUSION

The acoustics of the auditorium in the Norwegian Opera has been investigated with/without a large, curved reflector over the orchestra pit. It is shown that the removal of the large reflector gave the following positive influences on the acoustics:

- ***Balance stage/pit was improved.***
- ***Clarity was reduced to more favourable values.***
- ***EDT was increased (Most clearly for pit sources).***
- ***Image shift was reduced.***

In addition, a more flat frequency spectrum was achieved.

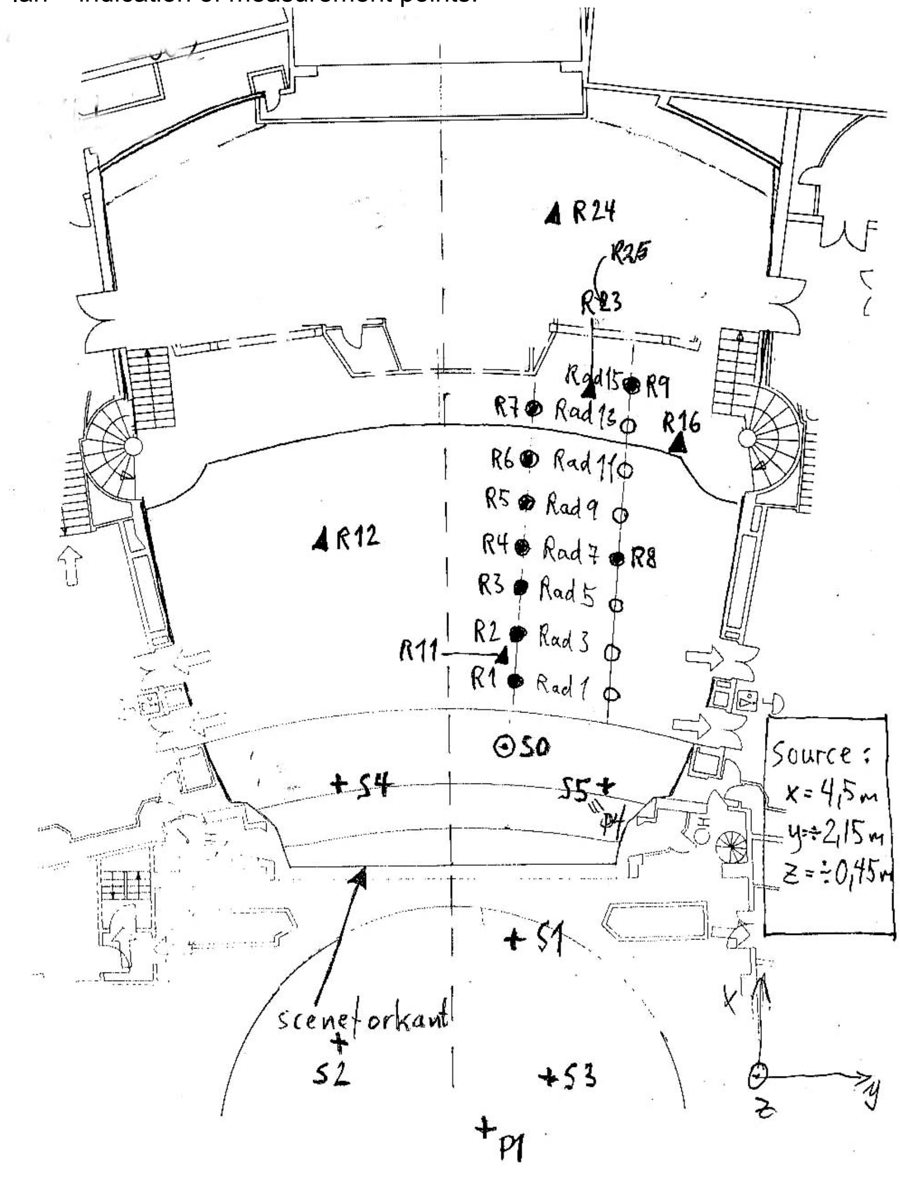
# 9. REFERENCES

[1] T. Halmrast: Statsbygg Akustikk Rapport nr 250/1997: *"Den Norske Opera, Folketeateret, Acoustical Measurements" (in Norwegian)*
[2] A. Buen: *"Acoustical Measurements in "Folketeateret"/Norw.Opera"* (Brekke and Strand Acoustics 2002)
[3] T. Halmrast *"A new Opera House in Oslo",* ICA, Rome 2001
[4] T. Halmrast: *"The delayed Phantom of the Opera",* ICA, Rome, 2001
[5] G.Ihlen +A. Buen: *"DNO Report on Humidity/Reverberation Time"* Measurements in "Folketeateret. *(in Norwegian)*
[6] M.Barron: *"Interpretation of Early Decay Times in Concert Auditoria".* Acustica, Vol 81 (1995)
[7] J.J. Dammerud *"Diffracted sound from orchestra pits".* Master of Science Thesis, NTNU, 2000 *(In Norwegian)*
[8] Jan Inge Gustaffson *"private conversation".* (+ ICA Trondheim 95)
[9] T. Halmrast: *"Orchestral Timbre: Comb-Filter Coloration from Reflections"* Journal of Sound and Vibration (2000) 232(1), 53-69 (+ICA/ASA98 + DFX99 )

## *APPENDIX 1*
## *PLAN OF THE AUDITORIUM*

The existing Opera house in Oslo is a refurbished theatre housing about 1050 persons. About 40 % is seated at one large balcony with 12 rows, and the stalls have 17 rows, 4 of which are under the balcony. The volume is about 6500 $m^3$ thus giving 6.2 $m^3$/seat.

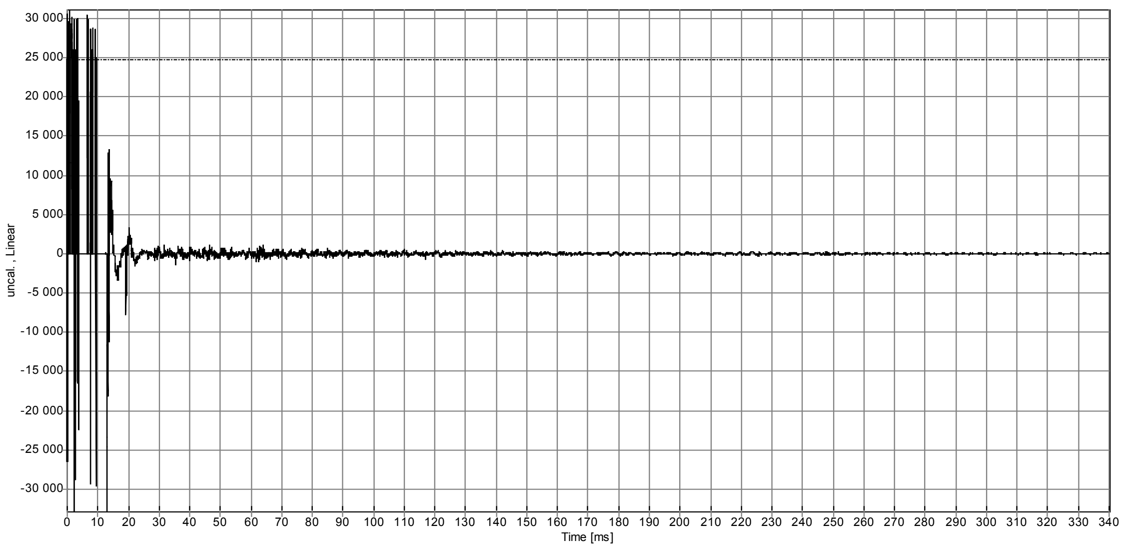
Plan + indication of measurement points:



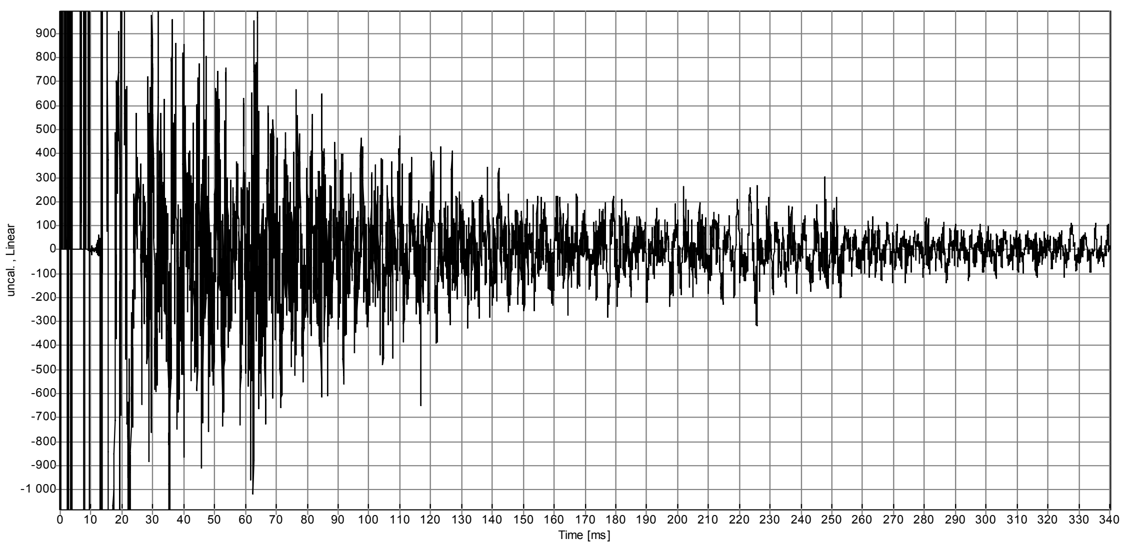
## *APPENDIX 2*
## *"AN ECHO IS NOT AN ECHO?"*

When clapping hands on the stage (and in the pit) one observes an echo. However, there have been almost no complaints from the singers. The echo is reported as almost "not perceived" when singing, (perhaps even giving a needed support for the singers?) but clearly perceived for spoken words in operettas. Even if the echo is clearly heard when clapping your hands, it is not very clearly shown in the measurements. Listening to the measured Impulse Response gives a better clue, and indicated further studies.
(The removal of the large reflector did not influence much on the perception of this echo.)

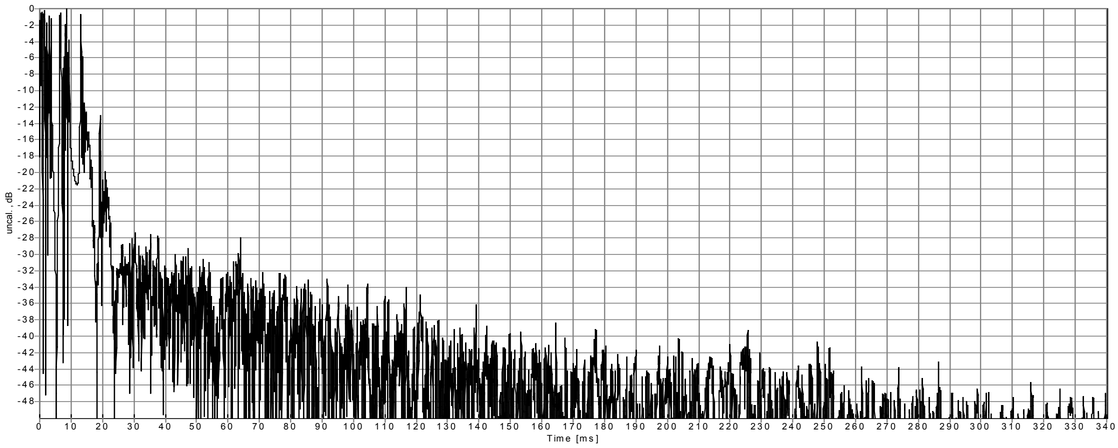
This Impulse Response measured from the stage, with the receiver placed 1m away, gives a clear echo in listening tests:



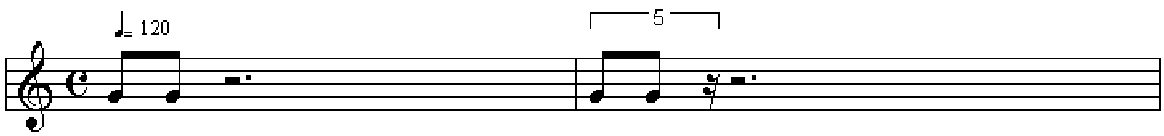

The same Impulse Response, zoomed in for the y-axis:



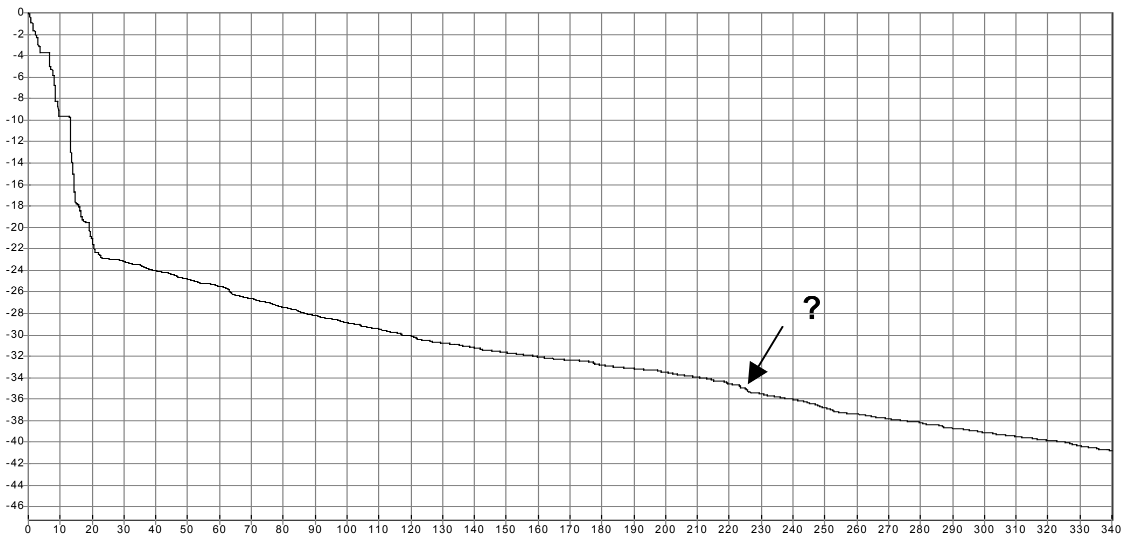
The same Impulse Response, squared (ETC-energy-time-curve):



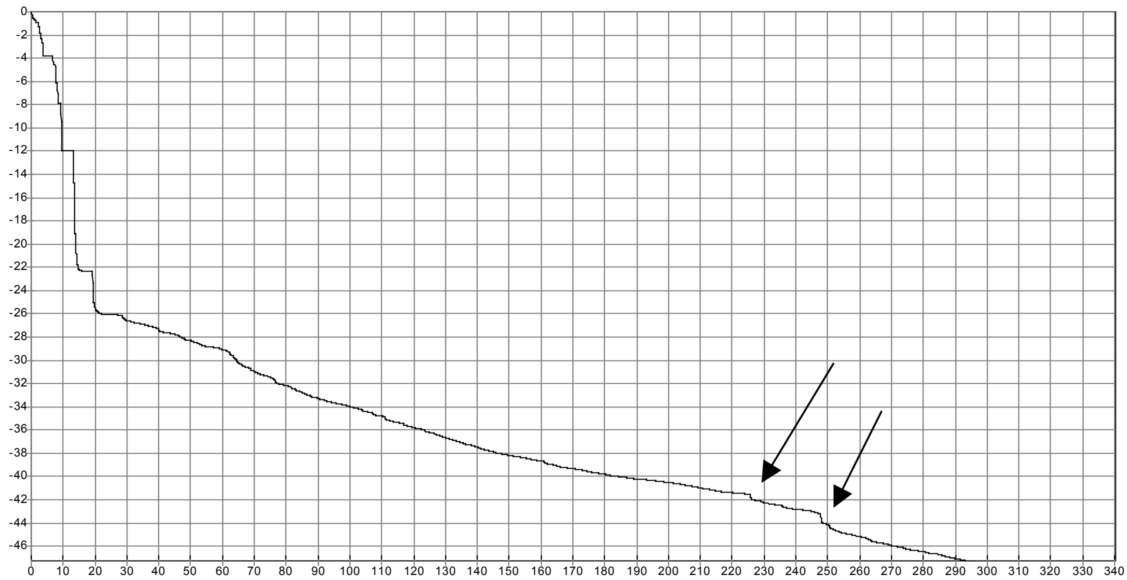

Looping the Imp Response for rhythmic detection in the listening tests indicated that the arrival of the echo was “quantisized” by ear” to be somewhere between these two notations:




corresponding to an arrival time somewhere between 225 to 250msec.
An overall Schroeder curve does not indicate any big “echo-problem”:




The lower frequencies are not that interesting regarding echoes. If we gradually high-pass filter the Schroeder response, we see the echoes somewhat more clearly. For the following figure, all frequencies below some 1kHz are filtered out:

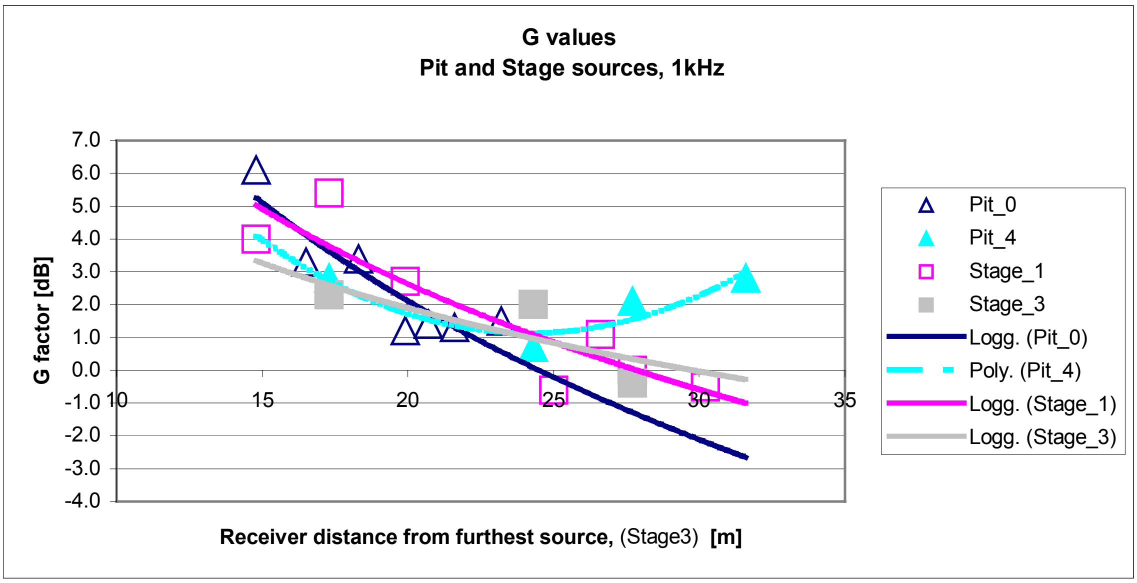


The reflections giving the echo are a combination of the reflection from the slightly curved rear wall directly (225msec) and from the rear corners (250msec). Some reflections from the “chandelier+ceiling”, arriving a bit earlier “disturbs” the Impulse Response somewhat, but the echo is still clearly perceived, both in the house and in the listening tests of the impulse response.

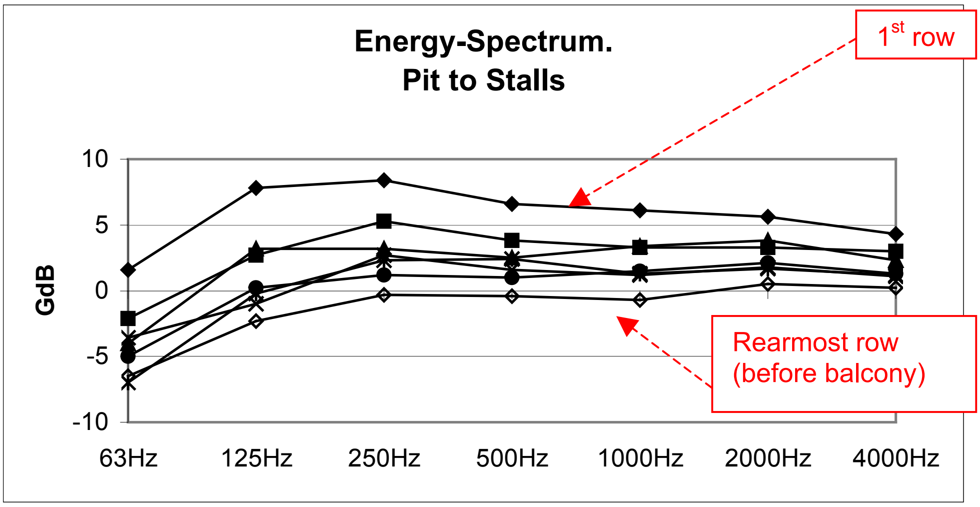
Our investigation shows that such an echo is not easily detected in common measurements. Cremer and Müller reported a somewhat similar echo in the Prinzregent Theatre in Munich.

## *APPENDIX 3*
## *FURTHER INVESTIGATIONS ON THE G-PARAMETER*

For the situation after the removal of the large reflector, we see the following distribution of G-values for different distances from the source (1kHz octave).



The following figure shows energy spectra in the stalls for a pit-source (after the removal of the large reflector), taken from seven positions positioned as an array parallel to the room's length-axis.




We see that objective loudness for orchestra is excessive (>5db, conf. Beranek) only for 1st row. (At all positions inadequate loudness is shown for lower bass (63Hz)).

## *APPENDIX 4*
## *HUMIDITY*

Measurements performed for the same Relative Humidity, with/without the large reflector, show that the removal of the large reflector gives clear changes in reverberation.

In addition, the Norwegian Opera has monitored relative humidity both outside and inside the auditorium carefully, and compared this with measurements and calculations of the reverberation time for different degrees of humidity. [5]. One conclusion is that a change of Relative Humidity (5-35 %) might influence the Reverberation Time for higher frequencies in an amount as large as what is shown by changing the reflector. A humidity control system has been installed. This adds to the positive results of the removal of the large reflector.

## *APPENDIX 5*
## *COMPARISON OLD/NEW REFLECTOR*

As reported from the Opera house

| | | LOW FREQUENCY | HIGH FREQUENCY |
|---|---|---|---|
| STAGE / STALLS | Old reflector | 1. Reflector absorbing energy.<br><br>2. Shading between sources and ceiling/upper sidewalls | 1. Reflector providing (gracing incidence) reflections to balcony.<br>2. Shading between sources and ceiling/upper sidewalls |
| | New reflector | Reflector projecting energy to middle and rear stalls. | Reflector projecting energy to middle and rear stalls |
| PIT/STALLS | Old reflector | 1. Reflector absorbing energy.<br><br>2. Shading between sources and ceiling/upper sidewalls | 1. Reflector projecting energy to front, middle and rear stalls.<br>2. Shading between sources and ceiling/upper sidewalls |
| | New reflector | 2. Sidewalls and ceiling spreading reflections over larger areas.<br>3. Sound perceived as more “singing”. | 2. Sidewalls and ceiling spreading reflections over larger areas.<br>3. Sound perceived as more “singing”. |
| PIT / PIT | Old reflector | Lack of support | Harsh impression of reflected sound. |
| | New reflector | 1. Energy returned to pit.<br>2. Good support. Possible to hear middle strings across the pit. Lower register of sound appearing more “open”.<br>3. Feeling of contact with room reverberance. | 1. Energy returned to pit.<br>2. Clean impression of reflected sound.<br><br>3. Feeling of contact with room reverberance |

## *APPENDIX 6*

Room Acoustic parameters for (almost) the same source/receivers (pit to stalls)
(for the measurements discussed in 6.2):

***WITH the large reflector:***

| *F(Hz)* | | *125* | *250* | *500* | *1000* | *2000* | *4000* | *8000* |
|---|---|---|---|---|---|---|---|---|
| EDT(s) | | 1.26 | 1.25 | 1.20 | 1.34 | 1.22 | 0.92 | 0.47 |
| T30(s) | | 1.54 | 1.47 | 1.40 | 1.30 | 1.18 | 1.01 | 0.75 |
| Tc(ms) | | 85.9 | 110.0 | 97.7 | 99.0 | 91.8 | 76.1 | 50.6 |
| C(dB) | | 1.4 | -3.8 | -2.1 | -1.5 | -0.9 | -0.3 | 3.5 |
| D(%) | | 63.7 | 27.7 | 38.5 | 40.9 | 44.7 | 48.5 | 69.4 |
| STI | 0.62 | | | | | | | |
| r(m) | 9.4 | | | | | | | |

***WITHOUT the large reflector:***

| *F(Hz)* | | *125* | *250* | *500* | *1000* | *2000* | *4000* | *8000* |
|---|---|---|---|---|---|---|---|---|
| EDT(s) | | 1.42 | 1.09 | 1.19 | 1.32 | 1.27 | 0.90 | 0.58 |
| T30(s) | | 1.56 | 1.45 | 1.47 | 1.33 | 1.21 | 1.03 | 0.65 |
| Tc(ms) | | 151.9 | 125.4 | 119.5 | 122.8 | 112.5 | 91.8 | 63.0 |
| C(dB) | | -13.6 | -12.9 | -9.6 | -8.0 | -6.8 | -7.3 | -2.0 |
| D(%) | | 4.1 | 4.9 | 9.8 | 13.8 | 17.4 | 15.6 | 38.5 |
| STI | 0.59 | | | | | | | |
| r(m) | 9.7 | | | | | | | |