CHALMERS

A study of room acoustical conditions in multi function "Project Studios"

Master's Thesis in the Master's programme in Sound and Vibration

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Division of Applied Acoustics
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CHALMERS UNIVERSITY OF TECHNOLOGY
Göteborg, Sweden 2007

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Cover:
Microphone and speaker setup for measurement of $h_{PP}(t)$, the speech studio aspect, read more at *3. Measured quantities, Figure 0.1*.

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ABSTRACT

The desired room acoustical properties in studios for speech reproduction and their control rooms have been well investigated during the last fifty years. In contemporary radio broadcast though, the trend is to build multi function studios. These studios can be used both as studios with adjacent control rooms, and as combined studios and control rooms where the programme presenter herself/himself functions as the sound engineer. The latter usage of the multi function studios presents special problems, which have not yet been thoroughly examined. The purpose of this thesis has been to examine the acoustical properties in multi function studios used as combined studios and control rooms, that provides good acoustical conditions both for critical listening in loudspeakers and for speech pick up in microphones. For this purpose listening tests have been derived from acoustical measurements of selected multi function studios. An expert jury of sound technicians was used to rate the sound quality of the multifunctional studios as control rooms. A non-expert jury was used to rate speech studio qualities. The result of the listening tests show that the subjects did not like studios with reverberation time that is significantly shorter in one frequency region than the average reverberation time. It also shows that the subjects did not like studios that have discrete early reflections that are stronger than the surrounding reflections. The conclusion is that equal reverberation time in the third octave bands is important for uncolored sound, and that strong discrete early reflections should be avoided in order to preserve stereo separation.

Key words: Control room, studio, speech and listening tests.

Acknowledgements

Contents

Preface

While still working part-time as sound engineer at Sveriges Radio, I started to wonder whether any research had been done in combined speech and control rooms for radio broadcast. After some search on the internet and the AES journal, I found no research at all in this field, this encouraged me to make this problem my master´s thesis. The work started in april 2006 at Akustikon AB with Jan-Inge Gustavsson as supervisor. The work with the thesis lead to a job at Akustikon AB, where I am employed as an acoustic consultant since June 2006.

Göteborg December 2007

Anders Westbrandt

Notation

Roman upper case letters

T_{30}	Reverberation time, T-5,-35
T_m	Mean reverberation time in of the third octave bands between 200 Hz and 3150 Hz
MRIR	The omnidirectional Room Impulse Response
BRIR	The Binaural Room Impulse Response
ETC	Energy-Time Curve

Roman lower case letters

$h_{XY}(t)$	Various room impulse responses depending on sub index

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1 Introduction

1.1 Background

The desired room acoustical properties for studios and control rooms have been well investigated during the second half of the past century. Desired acoustical properties such as reverberation time, modal density etc. for studio rooms have been formulated [1]. Desired acoustical properties of control rooms on the other hand have been more focused on quantities like the time gap between the direct sound and the first early reflections arriving at the listener's position, and the direction where these reflections come from [2]. In modern studio and control room design for broadcast purpose there is a tendency to build control rooms that have microphones for speech installed. This means that the programme presenter can handle the broadcast alone, without a sound engineer, see *Figure 1.1 a*, using the headphones as monitors. Next to the mentioned control room a studio room for speech is often located. This adjacent studio is used for speech when shows are more complicated such as broadcasts from sports events, debates etc. In that case a sound engineer is broadcasting the show from the control room using the loudspeakers for monitoring purpose, while the programme presenter speaks in the studio room using headphones, see *Figure 1.1 b.* The demands on these combined control rooms are good acoustic performance, not only as control rooms, but also as studios for speech.
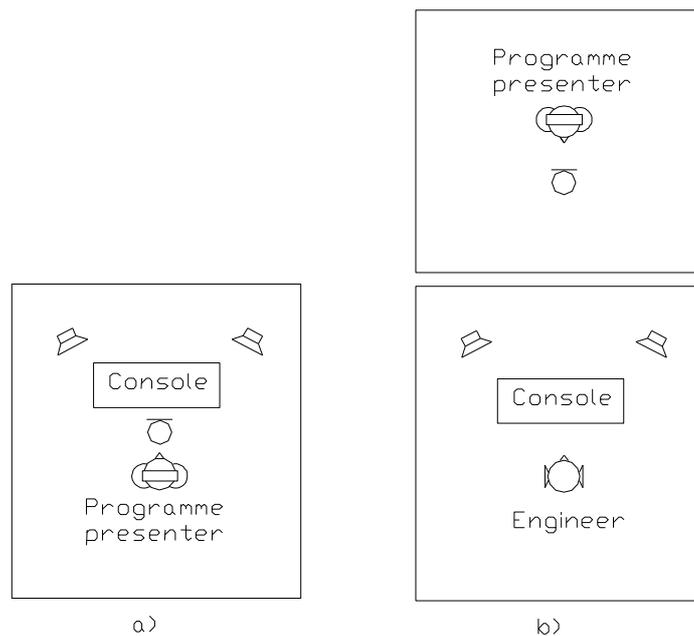
Figure 1.1.   *a) Programme presenter engineering the broadcast in the control room, using headphones for audio monitoring.*

b) Shows traditional studio control room configuration, with the programme presenter in studio and the engineer in the control room broadcasting the programme using loudspeakers for audio monitoring.

1.2 Purpose and method

The purpose of this master's thesis is to find room acoustic properties that give good sound quality in combined speech studios/control room. The method has been performing and evaluating psychoacoustic listening tests. Hopefully the knowledge gained will be useful when designing and building new combined control room and speech studios. These combined studios and control rooms will further on be referred to as Talks Broadcast Room, using the acronym TBR.

2 Known desired properties

2.1 Speech studio acoustic properties

In a speech studio the desired average reverberation time is short, typically 0.2-0.5s. It is important that there are only small deviations, preferably less than ±20% between the different 1/3 octave bands. One can allow the reverberation time to increase some below 200 Hz, since the speech has little energy below 100 Hz, as suggested by Walker [3]. Above 3150 Hz it is also acceptable for the reverberation time to get slightly shorter as the frequency increases, typically 0.2-0.12s at 10 kHz. The arithmetic mean value of the reverberation times in 1/3 octave bands, between 200 Hz and 3150 Hz, are denoted T_m. The formulas for calculating desired reverberation times using T_m can be seen in *Table 2.1.*

Table 2.1. The formulas that are used to calculate desired reverberation times in different third octave bands according to Walker.

	50 Hz	200 Hz	3150 Hz	10 kHz
Upper limit	$2,5* T_m$	$1.2* T_m$	$1.2* T_m$	$1.0* T_m$
T_m	T_m	T_m	T_m	T_m
Lower limit	$0.8* T_m$	$0.8* T_m$	$0.8* T_m$	$0.6*T_m$

Using Walkers formula and a reverberation time T_m of 0.3s, one arrives with recommended reverberation times that can be seen in *Figure 2.2.*
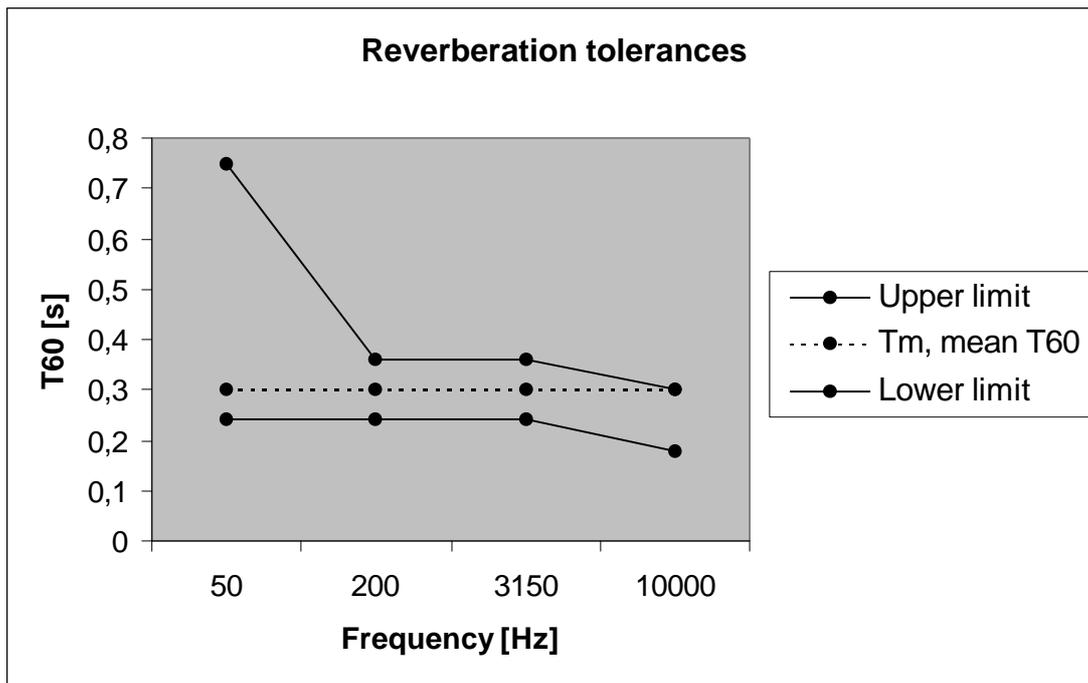
Figure 2.2. The tolerances of the desired reverberation times for a speech studio with a volume of approximately 65m³ according to Walker.

2.2 Absorbers in speech studios

The approximate amount of absorbers needed in speech studios can be calculated using Sabine's formula, and the reverberation times shown in *Figure 2.2*. The absorbers should be spread out over the surfaces in the room. By spreading out the absorbing material, a more diffuse sound field can be created than if all the absorbing material was gathered on one surface. To avoid flutter echoes one should not leave two reflective parallel walls (or floor/ceiling) without absorbers.

2.3 Control room acoustic properties

In control rooms for speech the same reverberation times as above are desired, although with some small modifications. Since radio broadcast often involves music, the reverberation time in low frequencies should not increase as much as can be allowed in the speech studio, or else it will be difficult to obtain a proper balance between speech and music.

It is important that the control room has equal or shorter reverberation time than the adjacent studio. Otherwise the control room will act as a masker, and it becomes more difficult to detect unwanted reverberation picked up by the microphones in the studio. In control rooms acousticians often try to create an anechoic part around and behind the loudspeakers, see *Figure 2.3.*

Diffusers, that give diffuse reflections with a controlled time gap between the direct sound and first reflections, are placed behind the engineer. This time gap usually is around 20ms, when within the reflection free zone (see *Figure 2.4*). The time gap between the direct sound and the early reflections should be greater in the control room than in the studio. If the time gap between the direct sound and the early reflections in the control room is smaller, the early reflections of the studio will be masked and impossible to hear, when listening in the control room loudspeakers.
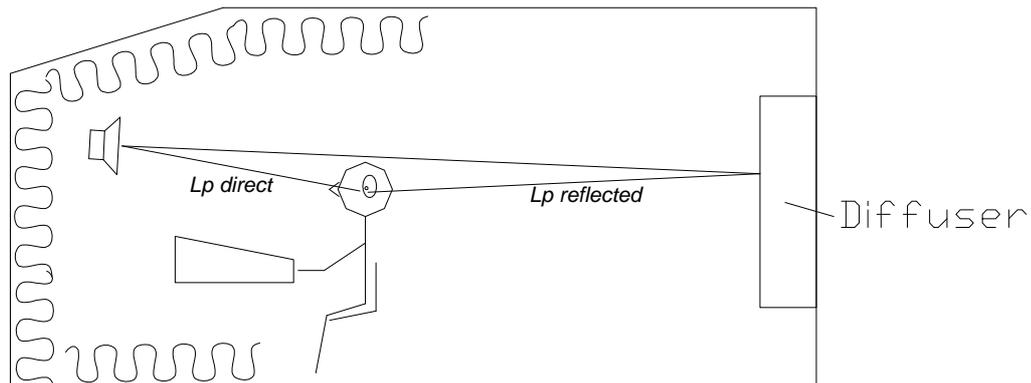
Figure 2.3.   Side view of control room with the absorptive front and diffuse back.

The Energy-Time curve of a studio that has been designed in the above-mentioned fashion can be seen in *Figure 2.5.* The idea of making the front part absorptive and the rear part reflective is called Live End Dead End, LEDE™.
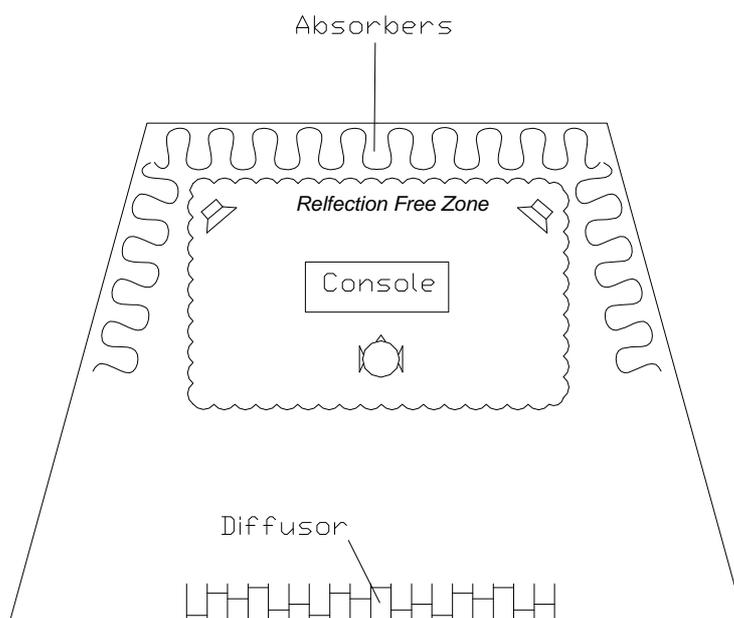
Figure 2.4.   *Plan view of the "Live End Dead End" LEDE™ control room. Behind the engineers head a primitive root diffuser is placed to provide the listening position with lateral reflections that are spread out in time.*
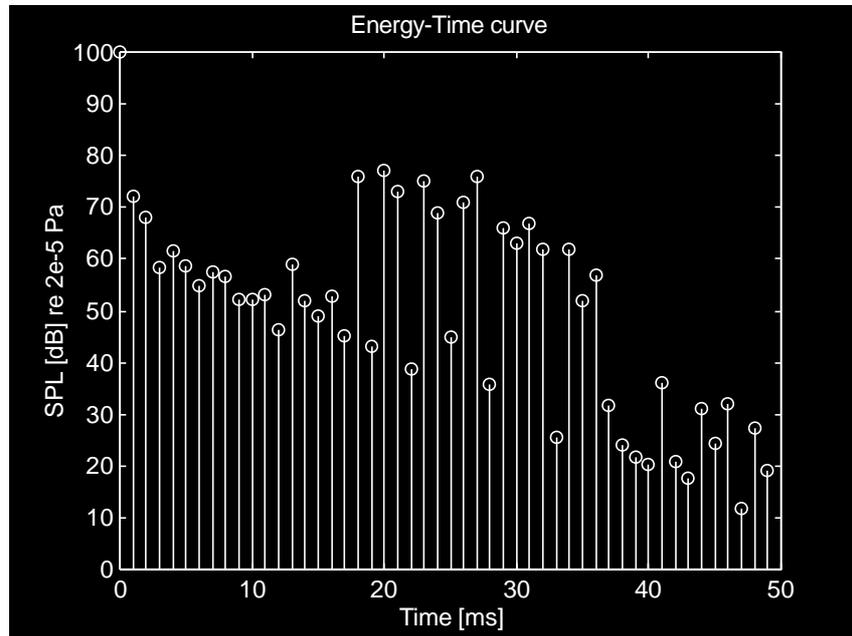
Figure 2.5.   *The Energy-Time curve of a typical LEDE control room. The direct sound arrives at listening position at t=0 and the time gap between the direct sound and the first early reflection is 18ms.*

3   Measured quantities

The acoustic quantities of the studios that were measured in this thesis can be divided into two major groups, one that is related to the TBR as a control room, and the other as a studio for speech.

3.1 The TBR as a speech studio

When the TBR is used as a studio for speech, the sound of speaking people is picked up by one or more microphones in the room. Microphones that have cardioid directivity are most frequently used in commercial applications. To capture the sound as it is normally picked up, a microphone with cardioid directivity has been used in the measurements. To mimic the directivity of a person speaking a small sound source was used. The used sound source has a driver cone diameter of approximately 35mm, and the spherical speaker enclosure a diameter of 110mm.

In the TBR guests that are interviewed by the programme presenter are common. Two microphone positions and two source positions were used in the measurements. These source positions and receiver positions were chosen to give four different measurements for each TBR. The first measurement corresponds to the programme presenter speaking into the programme presenter microphone, see *Figure 3.1 a,* denoted $h_{PP}(t)$. The second measurement corresponds to the guest speaking into the guest microphone, see *Figure 3.1 b* denoted $h_{GG}(t)$. The third measurement is the unwanted sound of the programme presenter leaking into the guest microphone, see *Figure 3.1 c,* denoted $h_{PG}(t)$. The fourth and final measurement is the unwanted sound of the guest leaking into the programme presenter microphone, see *Figure 3.1 d)* denoted $h_{GP}(t)$.
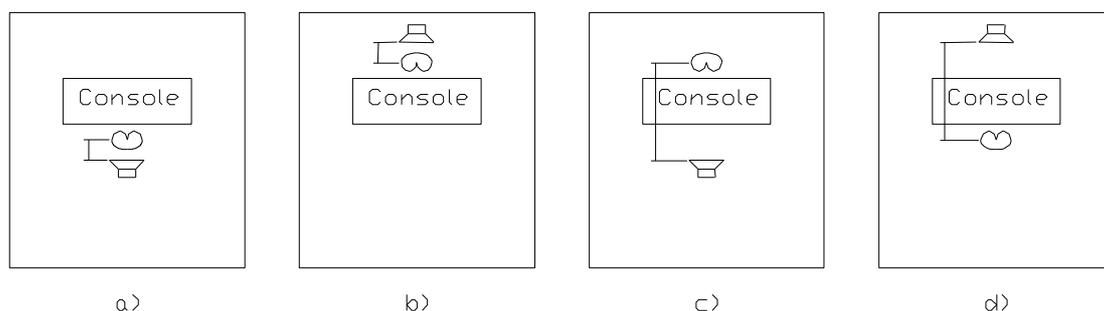
Figure 3.1. The MRIR measurements. In a) presenter to presenter microphone position $h_{PP}(t)$. In b) guest to guest microphone position $h_{GG}(t)$. In c) presenter to guest microphone position $h_{PG}(t)$. In d) guest to presenter microphone position $h_{GP}(t)$.

All MRIR (Monoaural Room Impulse Response) measurements were performed with a Neumann TLM103 microphone, which is a large membrane cardioid condenser microphone. The TLM103 was chosen since it, according to the author´s experience, has a detailed low end, and does not exclude the sound of room modes. As sound source an Apple M8756G/A Pro Speaker was used. Due to its small dimensions (sphere diameter 11 cm and loudspeaker diaphragm diameter 3 cm) the loudspeaker was assumed to have directional properties similar to that of a human talker. A picture of the loudspeaker can be seen in *Figure 3.2.*

Figure 3.2.   *The speaker that was used in the MRIR measurement. The speaker has a diameter of approximately 11cm.*

3.2 The TBR as a control room

When the TBR is used as a control room the purpose of the room is to present the sound engineer with as neutral a sound as possible. The normal listening position is right behind the mixing console, and the Binaural Room Impulse Response (BRIR) was measured in this position, see *Figure 3.4.* Since the employed sound card VX pocket was a two channel sound card, it was necessary to make four different measurements to get a complete BRIR that could be convoluted with a stereo signal. The performed measurements were set up as follows:

Dummy Head in normal listening position, see *Figure 3.3 b),* with left loudspeaker active, denoted $h_{L-L}(t)$ and $h_{L-R}(t)$

Dummy Head in normal listening position, see *Figure 3.3 c),* with right loudspeaker active, denoted $h_{R-L}(t)$ and $h_{R-R}(t)$

<p align="center"><i>a</i>   <i>b</i></p>
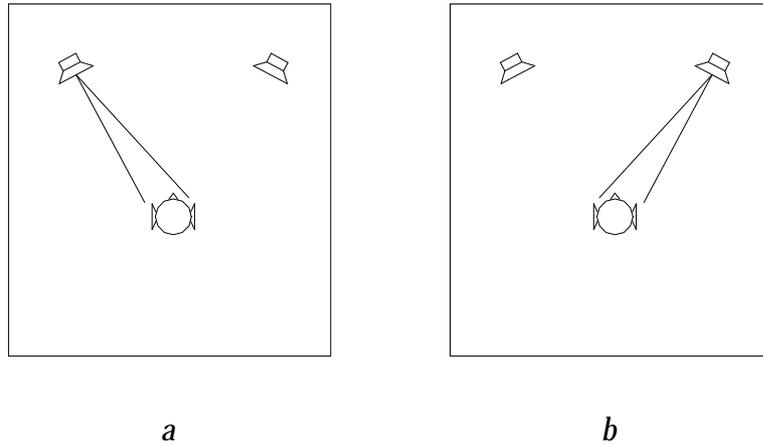
Figure 3.3. The measurement setup for the Binaural Room Impulse Responses. In a) the BRIR from left speaker to dummy head. In b) the BRIR from right speaker to dummy head.

A stereo signal was achieved by first convoluting the left input signal with the left BRIR, which is $h_{L-L}(t)$ and $h_{L-R}(t)$, and then convoluting the right input signal with the right BRIR, $h_{R-L}(t)$ and $h_{R-R}(t)$. After this procedure the output signals were summed up. This can be written as:

$$y_{Bin,S}(t) = x_L(t){}^*[h_{L-L}(t) + h_{L-R}(t)] + x_R(t){}^*[h_{R-L}(t) + h_{R-R}(t)] \qquad (1.1)$$

Calculation of reverberation time in the control room case has been performed at normal listening position at a height of 1.6m in denoted T_{30}. The reverberation time is an ensemble average of $h_{L-L}(t)$, $h_{L-R}(t)$, $h_{R-L}(t)$ and $h_{R-R}(t)$.

The BRIR's were measured with a commercial manikin, KEMAR (Knowles Electronics Manikin for Auditory Research). As sound source the TBR's own speakers where used. No equalisation was made to compensate for the frequency response of the loudspeakers.

Figure 3.4.   Binaural manikin" KEMAR" in position for measurement of the BRIR.

4 Experimental set up

4.1 Set up for room measurements

BRIR and MRIR measurements have been performed in six studios at Sveriges Radio Uppland, Bredgränd, Uppsala, and at Sveriges Radio Göteborg, Pumpgatan, Göteborg, between 2006-11-25 and 2007-07-25. Reference loudspeaker measurements were performed in the anechoic lab at the department of applied acoustics, Chalmers University of Technology, in 2006-04-28.

List of used equipment for the measurements:

- Computer equipped with WinMLS

- Digigram VX pocket 2, sound Card

- Binaural Dummy head, KEMAR

- Neumann TLM103, condenser microphone

- Marenius smf-222, microphone preamplifier

- Apple M8756G/A Pro Speaker

- Dodekaeder power amplifier , Akusikon AB

4.2 Set up for listening tests

Listening tests were performed at Sveriges Radio, Göteborg and Sveriges Radio Uppland, Uppsala.

List of used equipment for the listening tests:

- CD with test material

- Yamaha CDX393 MK II

- NAD amplifier

- Headphones Sennheiser HD414

5   Listening tests

5.1 Testing material

In the first of the two listening tests the subjects were given the task to rate how they liked the sound of a person speaking in the studio. First the person was speaking at programme presenter position. After a short break the same person was speaking at the guest position. The test material was produced by convolution of an anechoic recording with measured MRIR's, see *Table 5.1.* The subjects in the first group were "non sound engineers" working at Sveriges Radio Göteborg and Sveriges Radio Uppland, mainly reporters, journalists and producers. In the second listening test the subjects were to rate 1) stereo separation, 2) the ability to hear details of a voice speaking in the right speaker with music playing simultaneously in the left speaker and 3) an overall judgement of how well the room performed as a control room for radio production. The second group of subjects were sound engineers working at Sveriges Radio Göteborg and Sveriges Radio Uppland. In both listening tests headphones were used for playback. No compensating equalisation was applied to compensate for the headphones frequency response.

Table 5.1 The structure of the test material that was used in the first listening test.

First part =(Anechoic speech)*($h_{PP}(t) + h_{PG}(t)$)
Pause
Second part =(Anechoic speech)*($h_{GG}(t) + h_{GP}(t)$)

5.2 Method for evaluation of listening tests

In order to be able to draw conclusions from the performed listening tests, the mean value and standard deviation was calculated for each studio. Based on the mean values the studios were sorted in increasing order (see *Figure 5.2*). The studios were given names based on the order given in *Figure 5.2* which have been used throughout the entire thesis.

5.3 Results and conclusions from the listening test

Studio 2 was given the lowest rating as speech studio, see *Figure 5.2* and *Figure 5.3.* Studio 4 was the lowest rated control room. Both studio 2 and studio 4 are referred to as non-preferred rooms in each category. Studio 6 was given the best ratings in both categories and referred to as the most preferred

room. Studio 6 was also given the best rating as control room and the second best rating as speech studio, see *Figure 5.4 - Figure 5.6*.
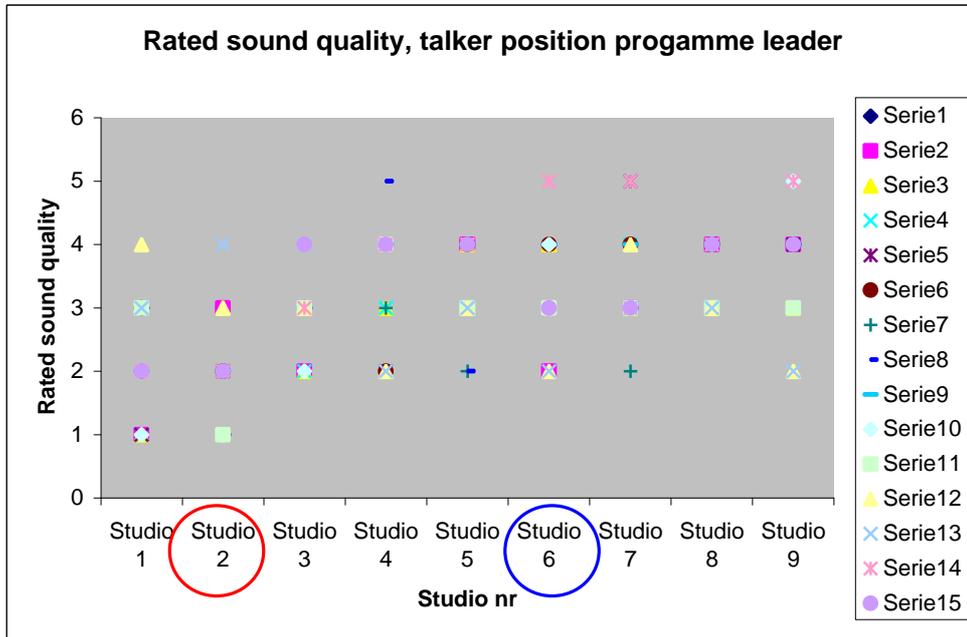
Figure 5.2 The left (red) circle marks the lowest common rated speech studio in this plot and Figure 5.3. The right (blue) circle marks the highest common rated studio also as control room.
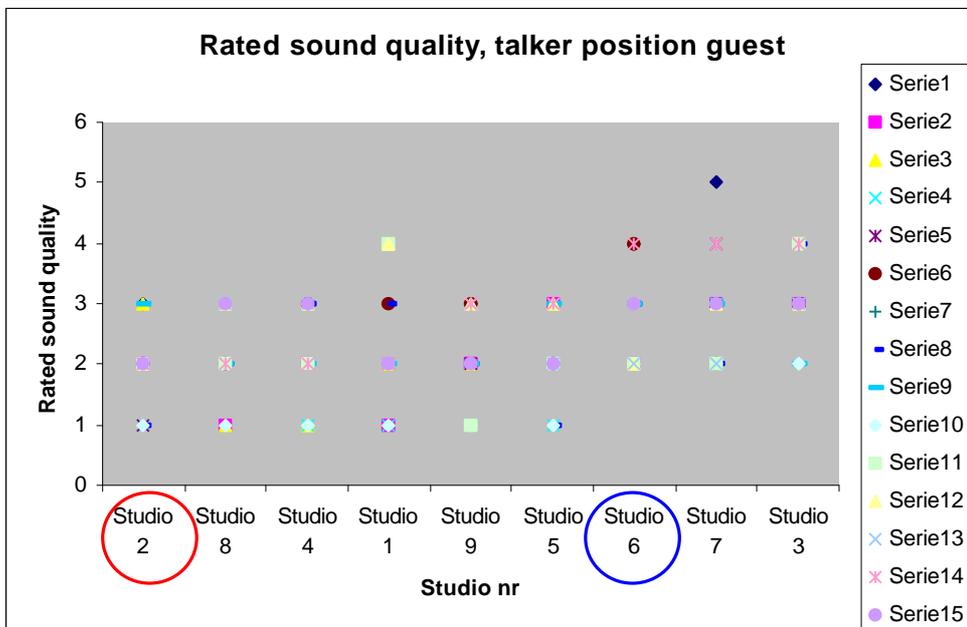
Figure 5.3. The left (red) circle marks the lowest rated speech studio in this plot and Figure 5.2. The right (blue) circle marks the highest common rated studio also as control room.
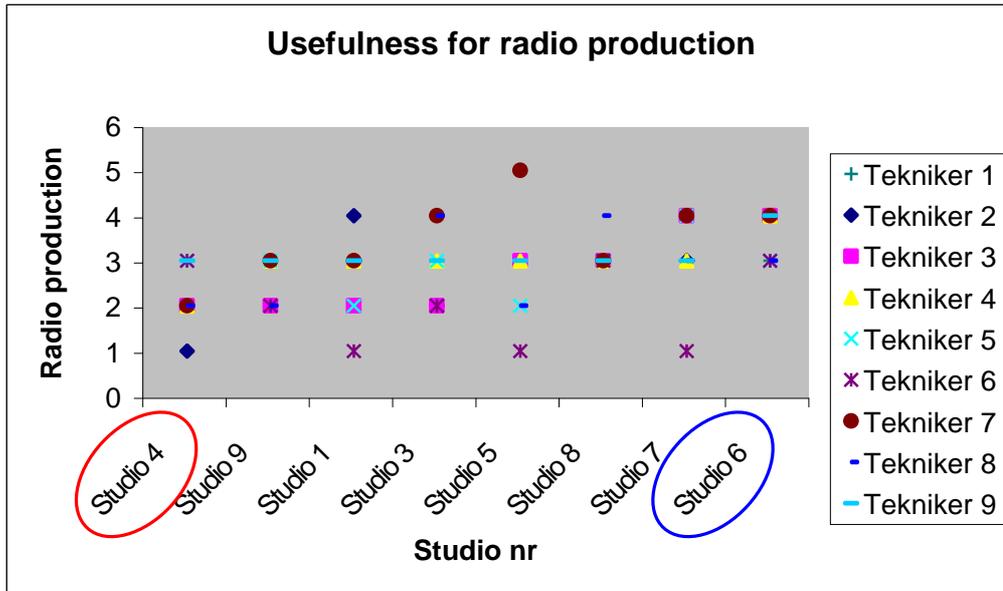
Figure 5.4. *Usefulness for radio production. Left (red) circle marks the lowest rated control room studio in this plot and Figure 5.5 and Figure 5.6*
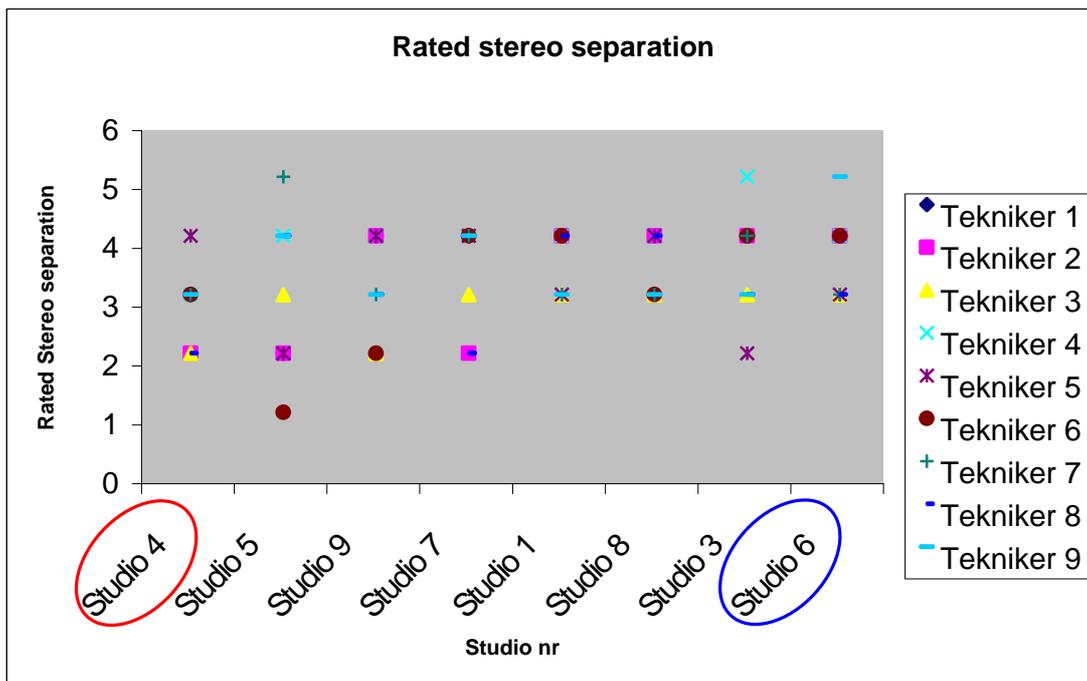
Figure 5.5. *Usefulness for radio production. Left (red) circle marks the lowest rated control room studio in this plot and Figure 5.4 and Figure 5.6.*

CHALMERS, *Civil and Environmental Engineering*, Master's Thesis 2007:145
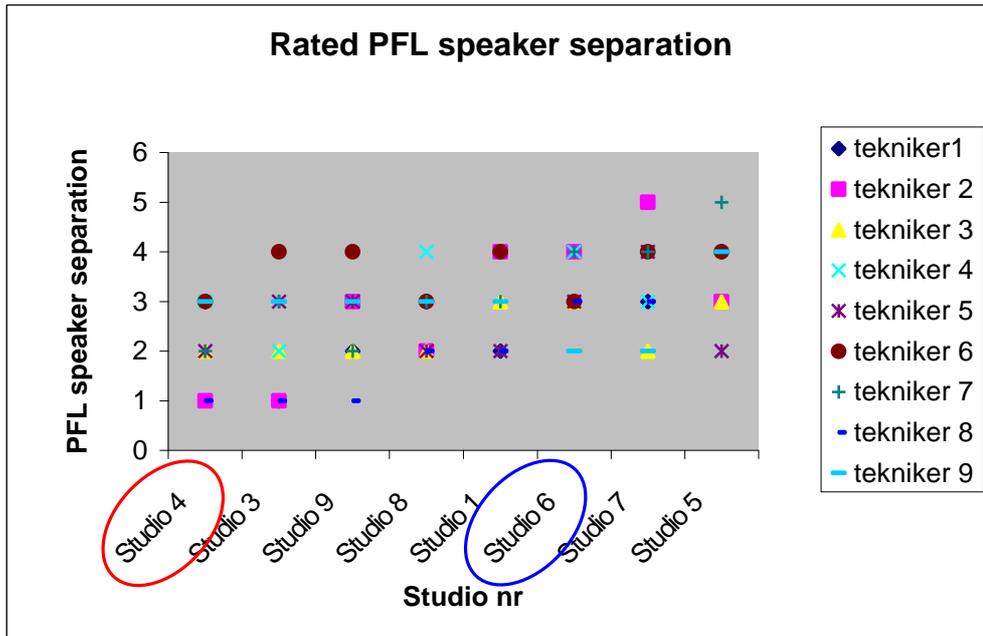
Figure 5.6.   Usefulness for radio production. Left (red) circle marks the lowest rated control room studio in this plot Figure 5.4 and Figure 5.6

6   Physical- and acoustical properties of the examined studios

6.1 The TBR as a speech studio, physical properties for the non-preferred room, studio 2.

The non-preferred room has four non-parallel walls, and all large windows are angled upwards, except the control room window (see *Figure 6.1.*), which is angled downwards. The two small windows that face the corridor are vertical.

Figure 6.1.   *The non-preferred room as speech studio, view towards an identical control room. A (dark grey) diffuser can be seen in the middle of the picture. The glass window in the left of the picture is angled downwards. The other two windows in the picture are vertical.*

A diffuser (AD40, Svanà miljöteknik), which provides lateral diffusion in the room, is located between the two small windows in *Figure 6.1.* The same type of diffuser is located behind the engineer/programme presenter. To the left there is an area of untreated gypsum board. Below the ceiling (upper part of *Figure 6.1.*) a Helmholtz absorber is located. The Helmholtz absorber has a

height of 600mm and surrounds all walls except the wall that faces the adjacent control room. All other wall areas are covered with Ecophon Wall panel 40mm, mounted on top of 45mm layer of mineral wool.

Figure 6.2.   *The non-preferred room as speech studio. View towards the diffuser behind engineer/programme presenter. The white area to the left of the diffuser consists of painted gypsum board.*

The ceiling is horizontal and consists mainly of Ecophon Master alpha 40mm, mixed with 20% Ecophon Master gamma. Close to the wall (*Figure 6.6.* Ecophon Master alpha +Extra Bass is mounted. The ceiling height is 2.7m. The entire floor is covered with a soft carpet. A drawing that shows the plane view of the non-preferred room could be seen in *Figure 6.6.*
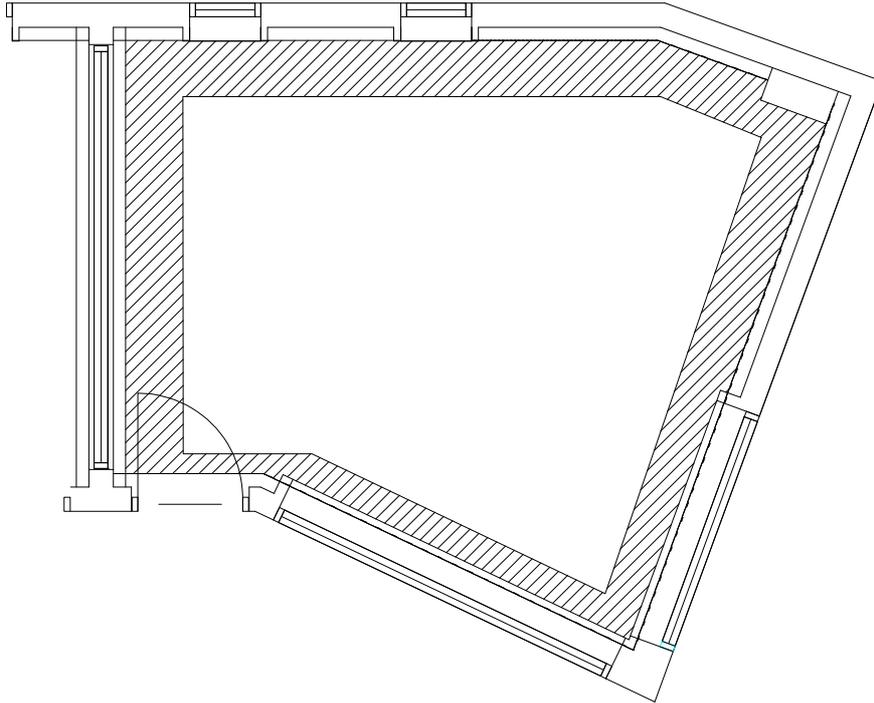
Figure 6.3. *The non-preferred room, speech studio aspect, plan view. Hatched area showing where Ecophon Master alpha+ Extra Bass is mounted. Original drawing by Arkitekterna Krook & Tjäder AB Göteborg.*

In *Table 6.1* one can see the physical and geometrical properties of the non-preferred room. *V* represents the total room volume and A_F the floor area. A_W represents the wall area and A_{tot} the total enclosing area in the room. I_{glass} is an index that is computed by dividing the total wall area that is made of glass, with the wall area, A_W.

Table 6.1. The physical properties of the non-preferred room, speech studio aspect.

V	A_F	A_W	A_{tot}	I_{glass}	I_{v125}	h
64m³	23.7m²	55.6m²	103m²	34.7%.	0.83	2.7m

To compare different room volumes a room volume index, I_{v125} has been created. I_{v125} is calculated by dividing the room volume with a reference volume, $V_{125,}$ that is 76.8m³. V_{125} is the volume that a room with a reverberation time of 0.3s needs to get a Schröder frequency of 125Hz, see *Equation 10.1*

$$V_{125} = T*(2000/f_s)^2 = 76.8m^3 \qquad (10.1)$$

6.2 The TBR as a speech studio, physical properties for the most preferred room, studio 6*.

The most preferred room has two parallel walls, three non-parallel walls and all windows are vertical. Walls marked with "W" in *Figure 6.5* are treated with Ecophon Wall panel 40mm, that is mounted on top of 45mm mineral wool. Below the ceiling walls marked with "H" in *Figure 6.5*, Helmholtz absorbers are located. The Helmholtz absorber has a height of 600mm and is mounted towards the ceiling.
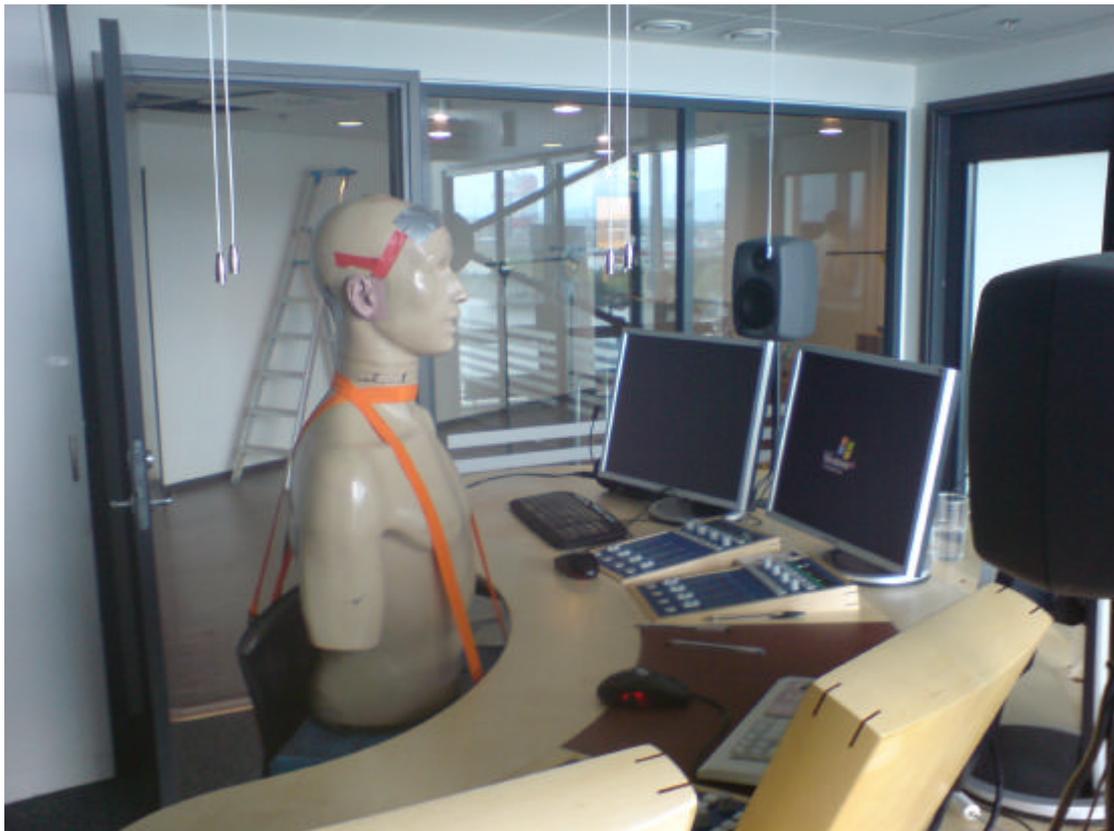
Figure 6.4.   The most preferred room as speech studio, view towards the corridor.

* This is the same room as described in 6.5.
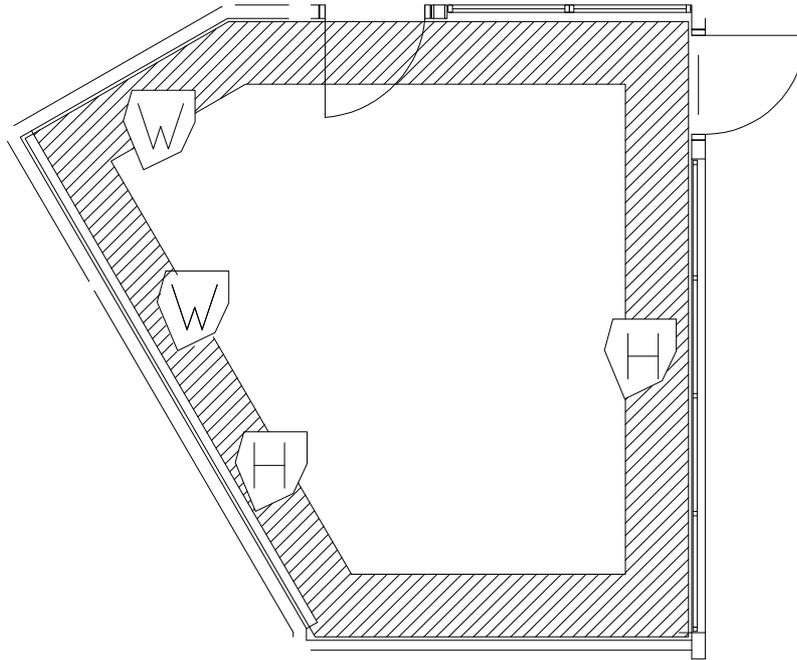
Figure 6.5.   *The most preferred room, speech studio aspect, plan view. Hatched area showing where Ecophon Master alpha+ Extra Bass is mounted. Walls marked with "W" are treated with Ecophon Wall panel 40mm, mounted on top of 45mm mineral wool. Walls marked with "H" have a Helmholtz absorber below the ceiling. Original drawing by Arkitekterna Krook & Tjäder AB Göteborg.*

As with the non-preferred room, the ceiling is horizontal and consists mainly of Ecophon Master alpha 40mm, mixed with 20% Ecophon Master gamma. Close to the wall (see *Figure 6.5.*) Ecophon Master alpha +Extra Bass is mounted. The ceiling height is 2.7m. The entire floor is covered with a soft carpet. A drawing that shows the plane view of the non-preferred room can be seen in *Figure 6.5.*

Table 6.2. The physical properties of the most preferred room, speech studio aspect.

V	A_F	A_W	A_{tot}	I_{glass}	I_{v125}	h
60.7m³	22.5m²	54.9m²	100m²	40%	0.79	2.7m

Table 6.2 shows the physical and geometrical properties of the non-preferred room.

6.3 The TBR as a speech studio, room acoustical properties

The reverberation time T_{30}, that is plotted in *Figure 6.6* was calculated as the arithmetic mean value of h_{PP}, h_{GG}, h_{PG} and h_{GP}.

a)
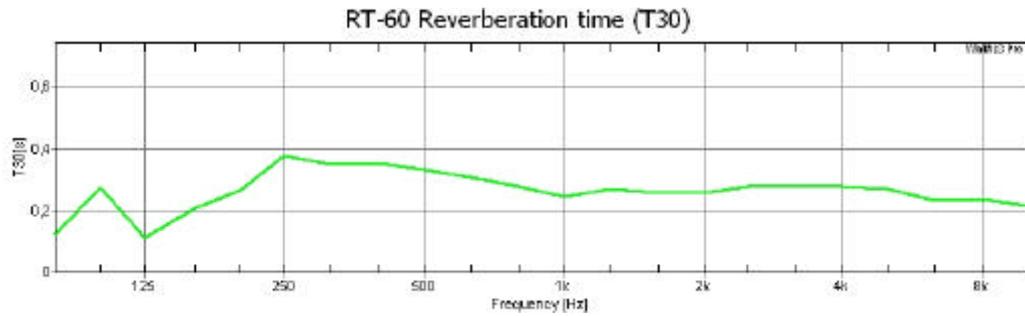
b)
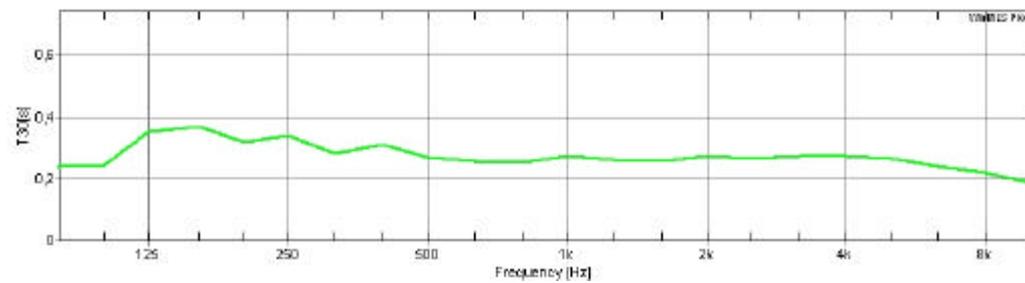
Figure 6.6.   a) Mean reverberation time of the non-preferred room. b) Mean reverberation time of the most preferred room, speech studio aspect.

Reverberation times that are as short as in *Figure 6.6* are perceived more as a coloration than an audible tail of decaying sound.

The frequency response plots from the speech studio measurements are shown in *Figure 6.7.* The level increase below 150Hz in the black (blue) and grey (red) curve is caused by the proximity effect. The proximity effect causes an increased low frequency response, when a cardioid microphone is close to a sound source.

a)
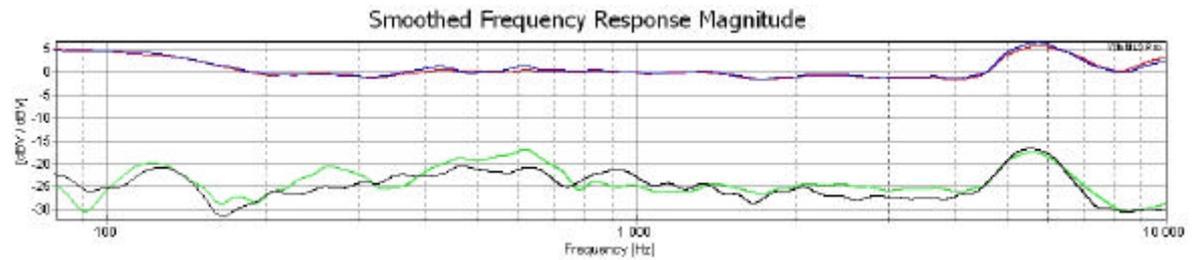
b)
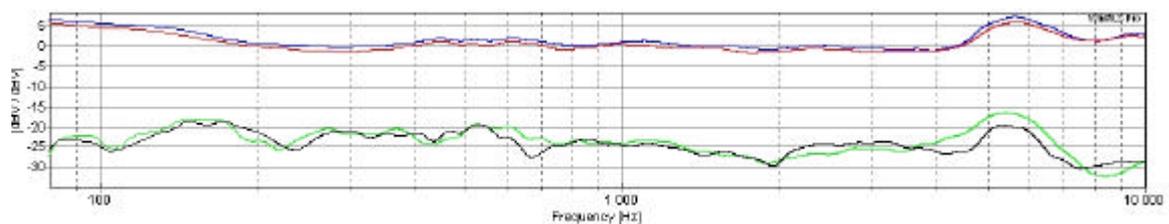
Figure 6.7.   *a) Frequency response of the four different microphone responses in the non-preferred room, and b) in the most preferred room. The level increases in the black (blue) (h_{PP}) and grey (red) (h_{GG}) curve below 150Hz is due to the proximity effect and the increase in all curves at 5kHz is caused by the microphone frequency response. The curves of lower level (at -20dB) are: grey (green) curve h_{PG} and black curve h_{GP}.*

The level increase between 5 and 6kHz in all plots of *Figure 6.7.* is caused by the microphone frequency response. Anechoic measurement of the measurement loudspeaker (Apple M8756G/A), has been used to compensate for the loudspeaker's frequency response in *Figure 6.7.*

The Energy-time curves, h_{PG}, of the most preferred room, black (blue) curve and the h_{GP} of the non-preferred room grey (red) curve are plotted in *Figure 6.8.* Between 15 and 20 ms there are strong reflections in the 2kHz, 4kHz and 8kHz octave bands. In 1kHz band the reflections between 15 and 20 ms are not as strong as in the other plots of *Figure 6.8.*

a) 1kHz
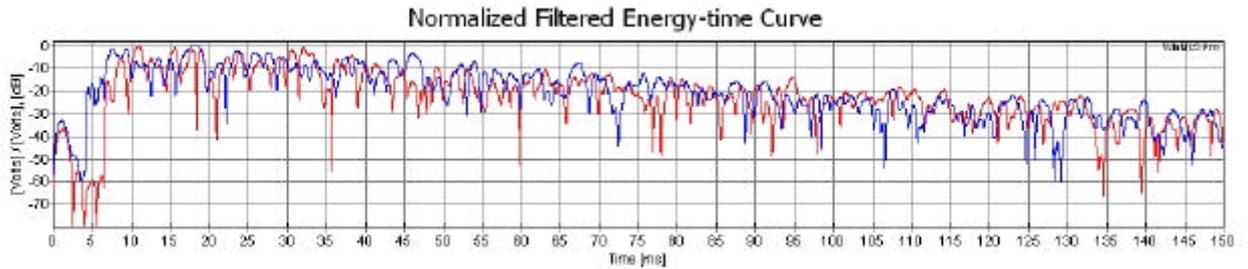
b) 2kHz
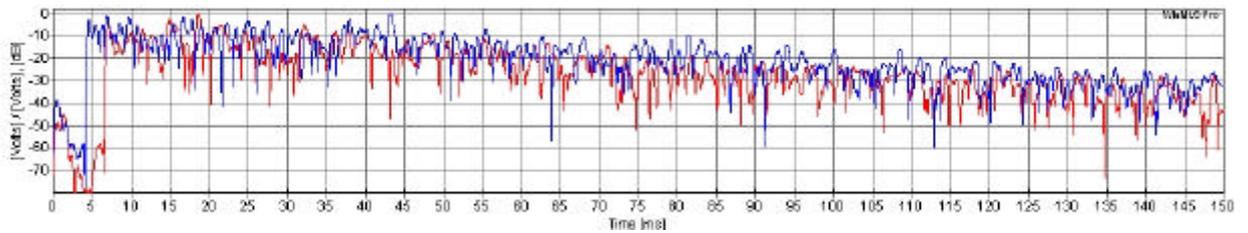
c) 4kHz
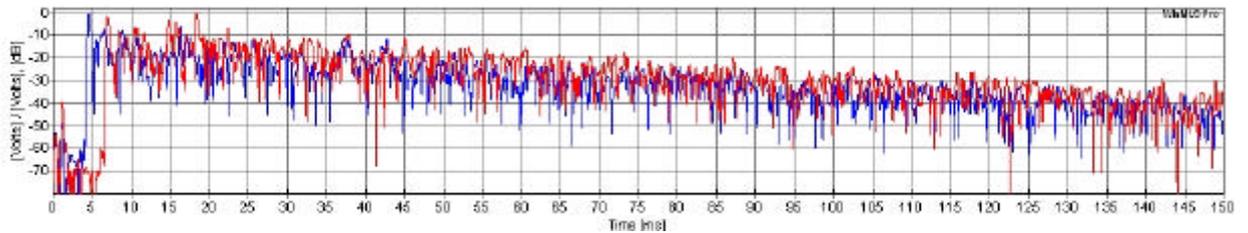
c) 8kHz
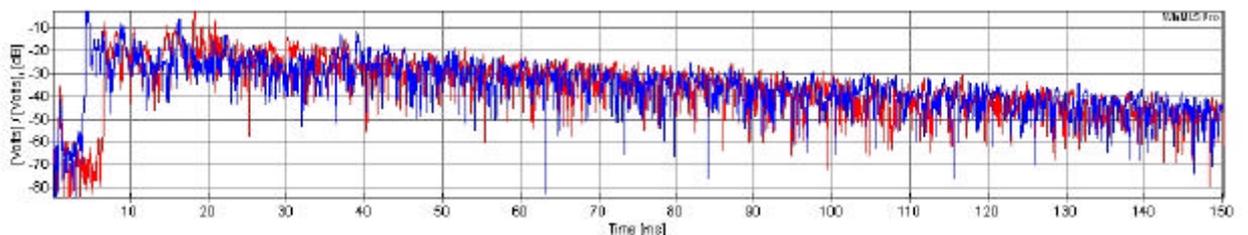
Figure 6.8.   *ETC of different octave bands. In a) 1kHz, b) 2kHz, c) 4kHz and d) 8kHz band of the non-prefered room grey (red) curve (h_{PG}) and most preferred room black(blue) curve (h_{PG}). h_{PG} corresponds to the MRIR of Figure 3.1 c).*

6.4 The TBR as a control room, physical properties for the non-preferred room, studio 4

The room has four parallel walls. All windows are hung vertical but are splayed horizontally (see *Figure 6.10.* and *Figure* 6.11*)*. The ceiling is horizontal and half of the ceiling area is covered with Ecophon Wall panel 40mm, while the other half consists of diffusing panel, AD10 Svaná miljöteknik.

Figure 6.9.   *The non-preferred room, control room aspect, side view showing Ecophon Wall panel to the left. In the middle and to the right of the picture, Svaná miljöteknik AD10 diffuser panel is mounted. Note that AD10 panel is also mounted in the ceiling.*

The ceiling height is 3.2m. The entire floor in the studio is covered with a linoleum carpet. To obtain higher bass absorption, the AD10 panel has been spaced apart to form a Helmholtz absorber.

Figure 6.10.   The non-preferred room, control room aspect, view towards the "dead end" Ecophon Wall panel is mounted on the wall. Windows in the centre of the picture are splayed horizontally.

Figure 6.11.   The non-preferred room, control room aspect, side view showing Svanå miljöteknik AD10 diffuser panel to the left and Ecophon Wall panel to the right. The windows are splayed horizontally.

AD10 DIFFUSER
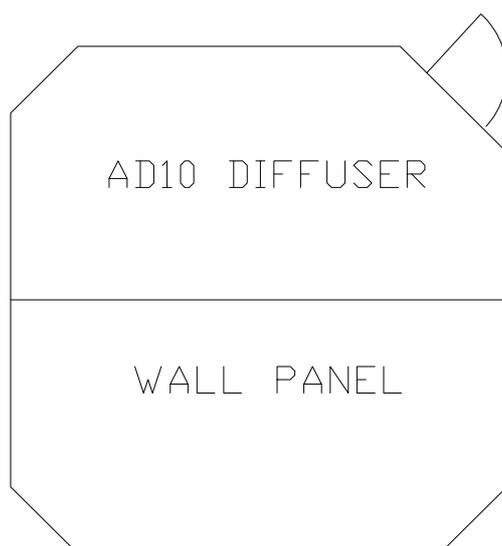
WALL PANEL

Figure 6.12.   The non-preferred room, control room aspect, plane view. Both walls and ceiling consists of Ecophon Wall panel. In the upper part of the figure, walls and ceiling consists of Svanå miljöteknik AD10. The floor is covered with a reflective linoleum carpet. Original drawing by Werket Arkitekter AB Uppsala.

In table 6.3 the physical properties of the non-preferred control room are listed. The table shows that area, A_W, and volume, V, are of the same order as in all of the previously described rooms. The table also shows that the I_{glass} is 9.5%. The I_{glass} in the previously described rooms is much higher 34.7% in studio 2, and 40% in studio 6.

Table 6.3. The physical properties of the non-preferred room, control room aspect.

V	A_F	A_W	A_{tot}	I_{glass}	I_{v125}	h
72.3m³	24.1m²	61.8m²	110m²	9.5%	0.94	3.2m

During the measurements of the BRIR the studio was equipped with two Genelec 1029A speakers.

6.5 The TBR as a control room, physical properties for the most preferred room, studio 6*.

The physical properties of studio 6 is shown in chapter 6.2.

During the measurements of the BRIR, studio 6 was equipped with two Genelec 8040A speakers.

* This is the same room as described in 6.2.

6.6 The TBR as a control room, acoustical properties

The reverberation time, T_{30}, of the control rooms is plotted in *Figure 6.13.* The reverberation time was calculated as an arithmetic mean value of the four measured BRIR´s, h_{L-L}, h_{L-R}, h_{R-L} and h_{R-R}.

a)
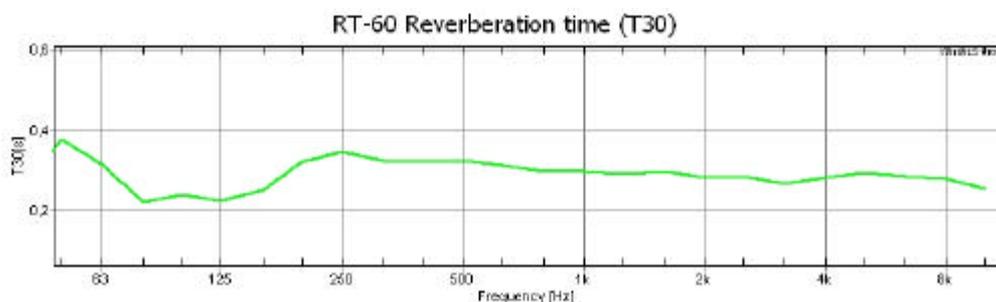
b)
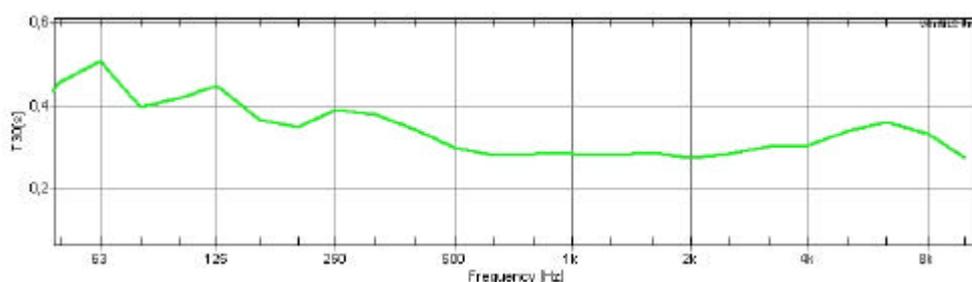
Figure 6.13.   *a) Mean reverberation time of the non-preferred room. b) Mean reverberation time of the most preferred room, control room aspect, reverberation time calculated from the four BRIR measurements.*

The non-preferred control room has shorter reverberation time in the 125Hz, 100Hz and 80Hz band, than in the 250Hz band (see *Figure 6.13.a*). The most preferred control room has slow increase in reverberation time below 500Hz (*Figure 6.13.b*).

The Energy-time curve of the non-preferred control room grey (red) curve and the most preferred control room black (blue) curve are plotted in *Figure 6.14.* Both plots show the Energy-time curves from the left speaker to the right ear, h_{L-R}.
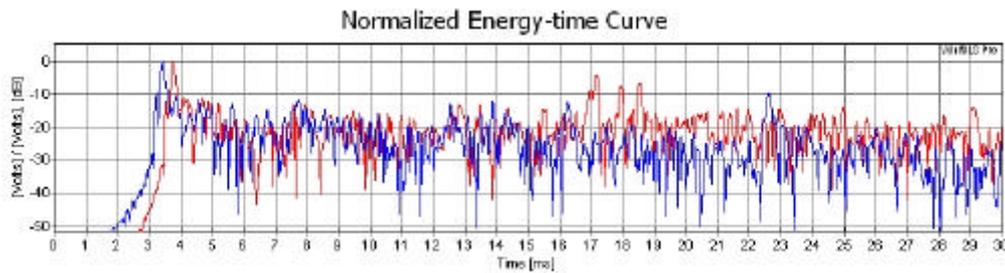
Figure 6.14.   *ETC of the non-prefered room, grey (red) curve,* (left speaker to right ear*) and most preferred room, black (blue) curve,* (left speaker to right ear*), control room aspect.*

The grey (red) curve (non-preferred room) has three strong reflections around 18ms that are not presents in the black (blue) curve (most preferred room).

7 Conclusions

7.1 The TBR as a speech studio

There is a rather small difference in the average reverberation time between the non-preferred and the most preferred room. But the shorter reverberation time in the non-preferred room in 1/3 octave bands between 125-200Hz, is probably the reason why the non-preferred room sounds thinner. This can also be seen as a dip in the frequency response of the black and green curve at 180Hz, *Figure 6.7 a*. It seems as the magnitude of the early reflections and how they are distributed in time plays a role in how the sound is perceived. In *Figure 6.8* the ETC is plotted in four octave bands. With rising frequency some early reflections become louder in the non-preferred room. In *Figure 6.8 d,* at 18 ms red curve (h_{PG}) has one reflection that is 5dB louder than the direct sound and the surrounding reflections are about 5dB weaker. The sparseness that increase with frequency is probably due to reflections becoming more specular and less diffuse i.e. reflective surfaces become "larger" with rising frequency, but also the frequency depending directivity of the microphone. Cardioid microphones have been used which can result in early reflections that are louder than the direct sound in ETC-plots. This is important to keep in mind when looking at echograms in computer simulations where the receivers often are modelled omni directional. The distance between the microphone and the surface of the first and second order reflections that falls in on the front of the microphone should either be highly absorbent or at a distance where they are damped due to the path length. The differences between the examined studios, using h_{PP} and h_{GG} are very small and has not been investigated further. Using only h_{PP} and h_{GG} corresponds to having only one microphone open at the time.

7.2 The TBR as a control room

The non-preferred room has shorter reverberation time in the 80-125Hz band than the most preferred room, see *Figure 6.13 b,* where the reverberation time slowly increases below 250Hz. This disturbs the tonal balance of the non-preferred room. Between 17 and 19ms in the red curve *Figure 6.14,* three strong reflections 5-8 dB weaker than the direct sound occur, while the blue curve in *Figure 6.14* has only one strong reflection around 23ms that is 10dB weaker than the direct sound. It is likely that these strong reflections cause the low rated stereo separation and PFL speaker separation in the non-preferred room.

8   Future Research

Due to time limitations the conclusions drawn from the listening tests have not been verified by independent experiments. Future research in this field could be to verify the results by listening tests from auralization of computer models.

9   Data from listening tests

Table 9.1. The results of the listening test of the speech studio aspect. Programme presenter speaking.

Participant nr.	Studio 1	Studio 2	Studio 3	Studio 4	Studio 5	Studio 6	Studio 7	Studio 8	Studio 9
1	2	3	2	4	4	4	4	4	4
2	1	3	2	4	4	2	3	4	4
3	1	3	2	3	4	4	3	3	3
4	1	1	2	3	3	3	4	4	4
5	1	2	3	2	3	3	5	4	4
6	3	2	3	2	4	4	4	4	4
7	1	1	2	3	2	3	2	3	3
8	3	1	3	5	2	4	3	4	4
9	2	2	3	4	4	4	4	4	4
10	1	1	2	4	3	4	3	4	5
11	3	1	3	4	3	3	3	3	3
12	4	3	3	2	3	2	4	3	2
13	3	4	4	2	3	2	3	3	2
14	2	2	3	4	4	5	5	4	5
15	2	2	4	4	4	3	3	4	4
Mean value	2	2,07	2,73	3,33	3,33	3,33	3,53	3,67	3,67
Standard deviation	0,9045	0,8739	0,522	0,93	0,786	0,69	0,82	0,47	0,603

Table 9.2. The results of the listening test of the speech studio aspect. Guest speaking.

Participant nr.	Studio 2	Studio 8	Studio 4	Studio 1	Studio 9	Studio 5	Studio 6	Studio 7	Studio 3
1	3	2	3	2	3	3	4	5	4
2	2	1	2	1	2	3	2	3	3
3	3	1	1	2	2	3	2	3	3
4	1	2	1	1	2	1	2	3	3
5	1	2	2	2	2	2	2	4	4
6	2	2	3	3	3	2	4	2	3
7	1	1	1	1	1	2	2	2	2
8	1	2	3	3	2	1	3	2	4
9	3	2	2	2	2	3	3	3	2
10	1	1	1	1	1	1	2	2	2
11	2	2	2	4	1	2	2	2	4
12	2	3	3	4	3	3	2	3	3
13	2	3	3	2	3	2	2	2	3
14	2	2	2	2	3	3	4	4	4
15	2	3	3	2	2	2	3	3	3
Mean value	1,87	1,93	2,13	2,13	2,13	2,2	2,6	2,87	3,13
Standard deviation	0,8739	0,505	0,83	1	0,7	0,831	0,82	0,982	0,83

Table 9.3. The results of the listening test of the control room aspect. Usefulness for radio production.

	Studio 4	Studio 9	Studio 1	Studio 3	Studio 5	Studio 8	Studio 7	Studio 6	Studio 2
Participant nr									*
1	3	2	3	2	3	3	3	3	*
2	1	2	4	2	3	3	3	4	*
3	2	2	2	2	3	3	4	4	*
4	2	3	3	3	3	3	3	4	*
5	3	3	2	3	2	3	4	3	*
6	3	2	1	2	1	3	1	3	*
7	2	3	3	4	5	3	4	4	*
8	2	2	3	4	2	4	3	3	*
9	3	3	3	3	3	3	3	4	*
									*
Mean value	2,33	2,44	2,67	2,78	2,78	3,11	3,11	3,56	*
Standard deviation	0,7071	0,5270	0,8660	0,8333	1,0929	0,3333	0,9280	0,5270	*

* No result was received for studio 2, due to playback difficulties during the listening test

Table 9.4. The results of the listening test of the control room aspect. Rated stereo separation.

	Studio 4	Studio 5	Studio 9	Studio 7	Studio 1	Studio 8	Studio 3	Studio 6	Studio 2
Participant nr									*
1	3	2	4	4	4	4	4	4	*
2	2	2	4	2	4	4	4	4	*
3	2	3	2	3	3	3	3	3	*
4	3	4	4	4	4	4	5	4	*
5	4	2	4	4	3	4	2	3	*
6	3	1	2	4	4	3	4	4	*
7	3	5	3	4	3	3	4	3	*
8	2	4	3	2	4	4	3	3	*
9	3	4	3	4	3	3	3	5	*
									*
Mean value	2,78	3	3,22	3,44	3,56	3,55	3,56	3,67	*
Standard deviation	0,6667	1,3229	0,8333	0,8819	0,5270	0,5270	0,8819	0,7071	*

* No result was received for studio 2, due to playback difficulties during the listening test

Table 9.5. The results of the listening test of the control room aspect. Rated PFL speaker separation.

Participant nr	Studio 4	Studio 3	Studio 9	Studio 8	Studio 1	Studio 6	Studio 7	Studio 5	Studio 2 *
1	3	1	2	3	2	3	3	4	*
2	1	1	3	2	4	4	5	3	*
3	2	2	2	2	3	3	2	3	*
4	3	2	3	4	2	4	3	2	*
5	2	3	3	2	2	3	4	2	*
6	3	4	4	3	4	3	4	4	*
7	2	3	2	3	3	4	4	5	*
8	1	1	1	2	2	3	3	4	*
9	3	3	3	3	3	2	2	4	*
									*
Mean value	2,22	2,22	2,56	2,67	2,78	3,22	3,33	3,44	*
Standard deviation	0,8333	1,0929	0,8819	0,7071	0,8333	0,6667	1	1,0134	*

* No result was received for studio 2, due to playback difficulties during the listening test

References

[1] Gilford, C.L.S. (1979): The Acoustic Design of Talks Studios and Listening Rooms. Journal of Audio Engineering Society, Vol. 27, No. 1/2 {January/February} pp. 17-31.

[2] Davis, D., Davis, C. (1980): The LEDE- Concept for the Control of Acoustic and Psychoacoustic Parameters in Recording Control Rooms. Journal of Audio Engineering Society, Vol. 28, No. 9, {September} pp. 585-595.

[3] R. Walker (2002): Acoustic criteria and specification. BBC Research and Development White Paper No. WHP 021, {January} pp. 12-14.

Appendix A

Measurement report

Loudspeaker frequency response measurement

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3 Measurement setup

The measurement was performed in the anechoic laboratory at the department of applied acoustics at Chalmers University of Technology, between 6 - 8.45 pm, 2006-04-28.

List of used equipment:

- B&K 4130-6-001 ½" condenser microphone. Serial number 2477 289
- G.R.A.S. 12 AA, Dual microphone power supply, power module
- Amplifier YAMAHA M35
- Dell Inspiron computer, Equipped with Win MLS
- M-Audio sound card

The measured loudspeaker type were M87566/A Pro Speakers, serial number:::::::
The loudspeakers were placed inside the anechoic lab, facing the front side of the measurement microphone see Figure 1. A swept sinusoidal of 40 s duration was used as a measurement signal and a sampling rate of 44.1 kHz.
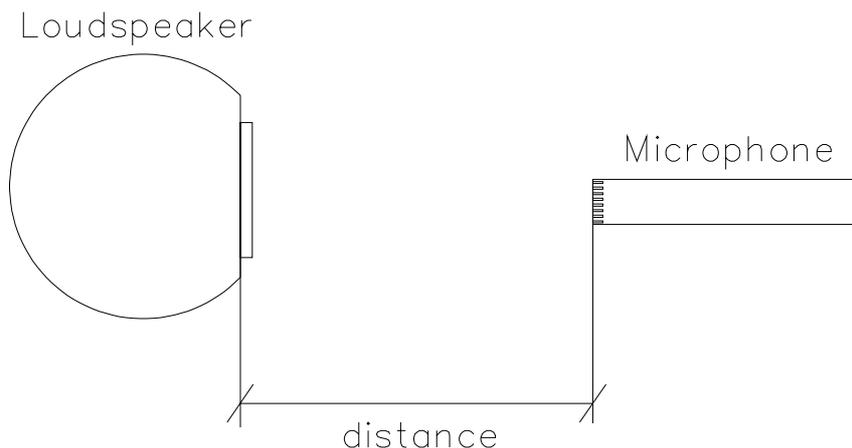
Figure 1. The loudspeaker and microphone arrangement.

One impulse response was measured at the following distances:
10cm – 20 cm in steps of 1 cm and at 30, 40, 50, 100, 150 cm. The definition of distances can be seen in Figure 1.

The impulse responses can be found on the CD that is attached to this report and filenames are arranged in the following order:

Measurement at 10 cm with "Guest microphone" corresponds to filename: *guest_dist_10.wav*
Measurement at 50 cm with "Presenter microphone" corresponds to filename: *presenter_dist_50.wav*

Appendix B

Namn: **Nr….**

Telefonnummer:

Datum/tid: **Ordning:**

Plats:

Frågeformulär lyssningsförsök talstudio

Du kommer att i detta lyssningsförsök att få lyssna på talljud inspelade i 9 st olika studios. Varje studio motsvarar ett exempel och varje exempel består av följande delar:

Programledare pratar 10s
Paus 2s
Programledare pratar från gästplats i studion10s

Din uppgift är att bedöma dessa studios akustiska kvalitet och kommer därför att få svara på följande frågor två gånger för varje studio som ska bedömas. Ringa in ditt svar för hur du tycker att första delen " Programledare pratar" låter: Kryssa ditt svar för hur du tycker att " Programledare pratar från gästplats" låter!
Se följande exempel:

Hur tycker du att ljudkvaliteten är på talet i exemplet:

Dåligt   1   ⊗2   3   ④   5   Bra

Nedan skall du bedöma flera olika kvaliteter på talet i exemplet genom att ringa in det som stämmer överens bäst med hur du tycker att det låter.

Hårt	1	2	⊗3	4	⑤	Mjukt
Ljust	1	②	3	⊗4	5	Mörkt
Tunt	1	2	⊗③	4	5	Fylligt
Otydligt	1	②	3	4	⊗5	Tydligt
Burkigt	①	⊗2	3	4	5	Öppet
Distans	1	2	⊗3	④	5	Närhet
Rått	1	2	③	⊗4	5	Behagligt

Vänd blad för att börja!

Exempel 1

Hur tycker du att ljudkvaliteten är på talet i exemplet:

Dåligt   1   2   3   4   5   Bra

Nedan skall du bedöma flera olika kvaliteter på talet i exemplet genom att ringa in det som stämmer överens bäst med hur du tycker att det låter.

Hårt	1	2	3	4	5	Mjukt
Ljust	1	2	3	4	5	Mörkt
Tunt	1	2	3	4	5	Fylligt
Otydligt	1	2	3	4	5	Tydligt
Burkigt	1	2	3	4	5	Öppet
Distans	1	2	3	4	5	Närhet
Rått	1	2	3	4	5	Behagligt

Osv……

Appendix C

Namn: **Nr….**

Telefonnummer:

Datum/tid: **Ordning:**

Plats:

Frågeformulär lyssningsförsök kontrollrum

Du kommer att i detta lyssningsförsök att få lyssna på ljudkvaliteten hos inspelningar gjorda i 9 st olika kontrollrum. Varje kontrollrum motsvarar ett exempel och varje exempel består av följande delar:

Prata ca 37s
Musik ca 37s
Musik i vänster högtalare samt förlyssning av studioprata i höger högtalare 40s
Musik ca 7s

Din uppgift är att bedöma dessa kontrollrums akustiska kvaliteter och kommer därför att få svara på följande frågor en gång för varje kontrollrum som ska bedömas. Ringa in ditt svar. *Se följande exempel:*

Tycker du att detta kontrollrum har god stereoseparation:

Mono   1   2   3   (4)   5   ”Hörlursseparation”

Tycker du att det är lätt eller svårt att urskilja detaljer i ljudet som kommer ifrån förlyssningshögtalaren (Höger högtalare i detta försök):

Lätt   1   2   (3)   4   5   Svårt

Hur upplever du att ljudnivån är på ”pratan” är i början av exemplet i förhållande till musiken.

För svag   -3   -2   (-1)   0   1   2   3   För stark

Ge ett helhetsomdöme om hur bra respektive dåligt du tror att detta kontrollrum är att för dig jobba i vid radioproduktion.

Dåligt   1   2   3   (4)   5   Bra

Vänd blad för att börja!

Kontrollrum 1

Tycker du att detta kontrollrum har god stereoseparation:

Mono 1 2 3 4 5 "Hörlursseparation"

Tycker du att det är lätt eller svårt att urskilja detaljer i ljudet som kommer ifrån förlyssningshögtalaren (Höger högtalare i detta försök):

Lätt 1 2 3 4 5 Svårt

Hur upplever du att ljudnivån är på "pratan" är i början av exemplet i förhållande till musiken.

För svag -3 -2 -1 0 1 2 3 För stark

Ge ett helhetsomdöme om hur bra respektive dåligt du tror att detta kontrollrum är att för dig jobba i vid radioproduktion.

Dåligt 1 2 3 4 5 Bra

Övriga kommentarer:

OSV…..