Hans G. Jonasson
Geir Andresen

Measurement of Emission Sound Pressure Levels Using Sound Intensity

Nordtest Project 1129-93

Swedish Work Environment Foundation 94-0711

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Abstract

To fulfil the requirements of the European machine directive, 89/392/EC, the noise emission of machines shall be declared. The prime descriptor, according to the directive, is the A-weighted emission sound pressure level. Today, measurements of the emission sound pressure levels at the work station or at other specified positions are carried out according to the ISO 11200-series which require either specially defined test rooms or, in case of field measurements, calculated corrections for the environment to be subtracted from the measured values. In this report a new, alternative method approximating the emission sound pressure level by the sound intensity level has been investigated. The new method aims at being a better alternative than ISO 11202 and 11204 for field measurements.

A proposal for Nordtest method is given. The method is applicable even if room reflections increase the sound pressure level more than 10 dB. It has been tested by 4 different Nordic laboratories. Simultaneously ISO 11202 and 11204 have been tested. ISO 11201 has been used as reference method. The result is that, for A-weighted values, the intensity method will, in average, give values within ± 1 dB of ISO 11201 with a standard deviation which is less than or equal to 1 dB. For individual frequency bands the corresponding values will be ± 2 dB and 2 dB respectively.

The intensity method is more accurate than ISO 11202, which tends to overestimate the emission sound pressure level. It is of about the same accuracy as ISO 11204, which, however, has an applicability, which is much more limited than that of the intensity method.

Key words: emission, sound pressure level, measurement method, intensity

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Postal address:
Box 857, S-501 15 BORÅS, Sweden
Telephone +46 33 16 50 00
Telex 36252 Testing S
Telefax +46 33 13 55 02

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Preface

This project has been supported by Nordtest, project no 1129-93, and the Swedish Work Environment Foundation(Now Swedish Council for Work Life Research), project no 94-0711.

The project has been carried through by a project group consisting of

Hans G. Jonasson, project leader
Geir Andresen, SP measurements and work up of measurement data
Swedish National Testing and Research Institute, S-501 15 Borås

Kaj Dam Madsen
Delta Acoustics & Vibration, DK-8000 Århus

Asbjörn Ustad
DELAB, N-3074 Trondheim

Lasse Lamula
VTT, FIN-331 01 Tampere

The project would not have been possible without the kind cooperation of the above individuals and institutes. Thank you!

Hans Jonasson & Geir Andresen

1 Introduction

To fulfil the requirements of the European machine directive, 89/392/EC, the noise emission of machines shall be declared. The prime descriptor, according to the directive, is the A-weighted emission sound pressure level. Today, measurements of emission sound pressure levels at the work station and other specified positions are carried out according to the ISO 11200-series which require either specially defined test rooms or, in case of field measurements, calculated corrections for the environment to be subtracted from the measured values. For field measurements primarily ISO 11202 and 11204 are to be used. However, as ISO 11202 is just a survey method and ISO 11204 has some severe limitations, it would be advantageous to have an alternative method with greater accuracy than that of ISO 11202.

For a plane progressing wave the sound intensity level equals the sound pressure level. Also at some finite distance from a source in a free field the sound intensity level will be nearly equal to the sound pressure level. In a diffuse sound field the sound will come from all directions and the vector sum will be close to zero, that is the sound intensity will be very small. If a sound source is placed in a room, the sound intensity at a specified position will be the sum of the intensity of the direct wave from the source and the intensity of the reflected waves. If the reflected waves make a diffuse sound field the intensity of that field will be negligible. The only intensity left will be that of the direct wave. Thus it would principally be possible to measure free field sound pressure levels in a diffuse field simply by approximating them with the sound intensity levels. An illustration is given in figure 1.1. A traditional microphone will record the direct + diffuse sound while an intensity probe will approximately record the direct sound only.

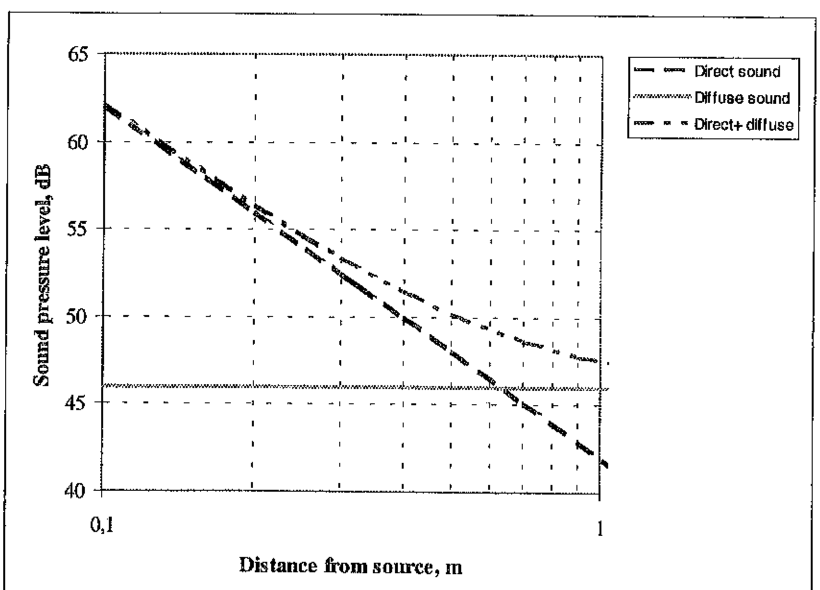

Figure 1.1 The different sound fields close to a point source on the floor

There are some problems though. A perfectly diffuse field does not occur in reality and the diffusivity varies from room to room. The intensity level outside of the direct field therefore never becomes zero and the determination of what is diffuse enough can become troublesome. Also the directivity of the sound source and the intensity probe plays an important role. If a lot of sound energy is emitted in other directions than in the direction of the microphone the reflections off ceiling, walls and floor will make it difficult to measure the true direct levels. Also here it is difficult to differentiate between different sound sources and varying environments.

2 Test sources and installations

This clause deals with the introductory measurements preceding the first proposal for Nordtest method. The internordic comparison measurements are described in clause 8.

2.1 Test sources and specified positions

Two sources were used. One was the B&K 4204 reference sound source in different positions above the floor and the other was the same source mounted in a box as described below.

An artificial, directional sound source was constructed. Due to a hole in one of the side walls no two sides were identical. A reference sound source(RSS), type B&K 4204, was placed in the middle of a chip board box. see figure 2.1. The distance from the edge of the front side of the box to the nearest part of the RSS is 100 mm. The front side is the open part of the box. The other sides are fully enclosed except the left side corner which has a hole with the dimension 60 x 25 mm for the electric connection. The chip board box was placed on a standard table according to ISO 7779. The microphone position of the bystander and a standing stationary operator are shown. The measures within the parenthesis is the operator's position according to ISO 7779.

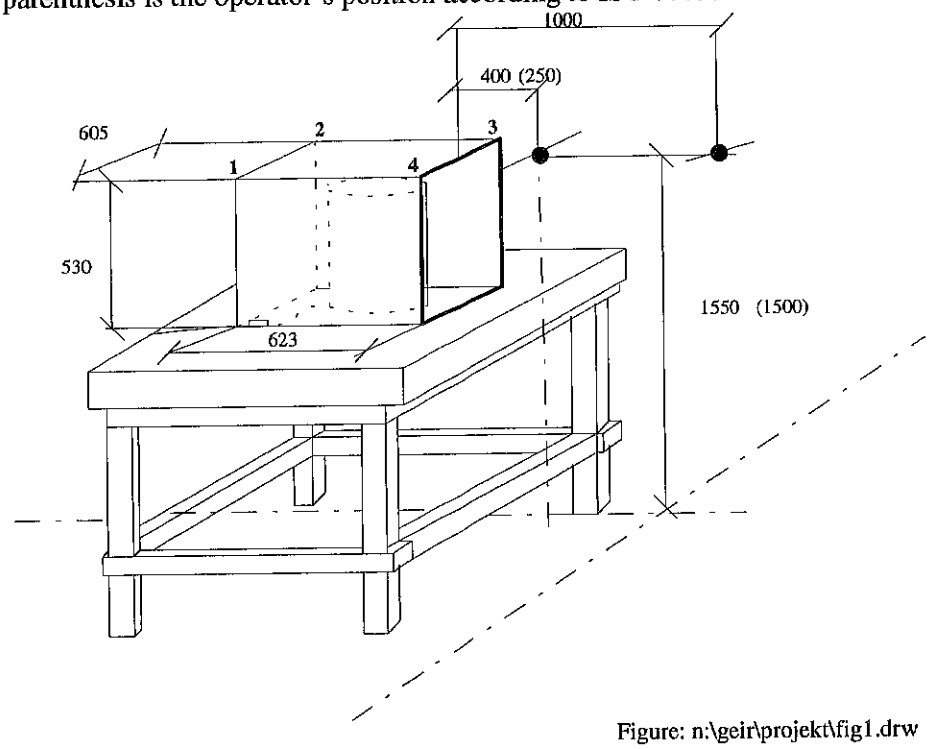

Figure 2.1 Arrangement with reference sound source in an open box.

2.2 Probe and microphone

An intensity probe type Brüel and Kjaer 3519 with microphones type Brüel and Kjaer 4181 have been used for the emission sound pressure level measurements and the intensity measurements. For frequencies above 3150 Hz the frequency response has been corrected, unless otherwise specified, in accordance with the manufacturer`s specifications. Without these corrections, we will have underestimated the sound intensity level by about 0,8 dB at 4000 Hz and about 4 dB at 8000 Hz. At the reference measurements in accordance with ISO 11201 in a hemanechoic room additional measurements were carried out using a free field microphone type Brüel and Kjaer 4165.

3 Measurements in a hemi-anechoic room.

3.1 Introduction

In order to get reference measurements according to ISO 11201 with the environmental indicator K_2= 0 the source was first tested in a hemi-anechoic room complying with the acoustic requirements of ISO 3745. The complete measurement results are given in annex A. Some results are given as reference when comparing different kinds of measurement methods.

Theoretically one would expect that $L_I = L_p$ in a hemi-anechoic room provided that the sound is coming from one direction only. However, if the source is large, or if it is small and located far above the floor, the sound may come from several directions. For the latter case the sound wave reflected in the floor will have a direction very different from that of the direct wave.

Notation used in this clause:
ISO 11201: Emission sound pressure levels measured with free field microphone type B&K 4165.
Ieq: Sound intensity levels.
Leq: Emission sound pressure levels measured with 2 microphone intensity probe
F_{pI}: The sound field pressure-intensity indicator ($F_{pI} = L_p - L_I$)

3.2 Comparison between the emission sound pressure levels and the sound intensity at specified positions

3.2.1 The sound field pressure-intensity indicator as a function of the direction of the incident sound

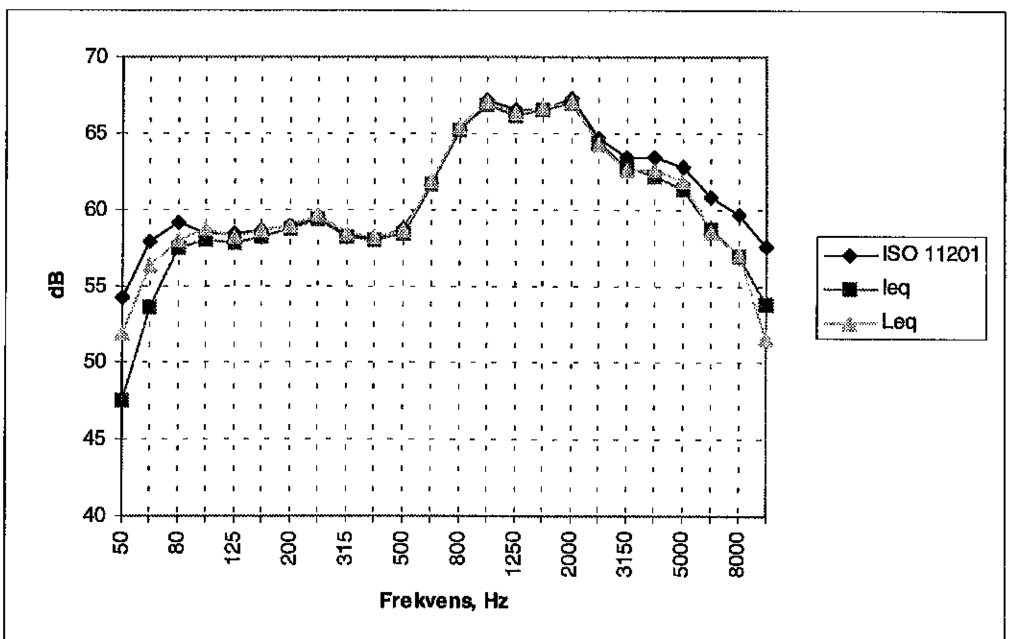

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Figure 3.1 Comparison between the emission sound pressure levels and the intensity levels 1 m from the RSS, located *on the floor*, and with the probe 1,55 m above the floor in a hemi-anechoic room. Intensity probe uncorrected at high frequencies.

Figure 3.1 illustrates an excellent agreement between intensity levels and sound pressure levels when the source is located on the floor and the microphone is 1 m above the floor.

There is a high frequency deviation between the freefield microphone of ISO 11201 and the probe microphone. However, this can be corrected for. Below 80 Hz the results have been influenced both by the test room, which is not qualified below 80 Hz, and the small microphone spacing, 12 mm, used for the intensity probe.

Table 3.1 The measured values of figure 3.1

Frequency	**ISO 11201**	Ieq	Leq	F_{pI}
50	**54,2**	47,5	51,9	4,5
63	**57,9**	53,6	56,3	2,6
80	**59,1**	57,5	58	0,5
100	**58,4**	58	58,7	0,7
125	**58,4**	57,8	58,2	0,4
160	**58,6**	58,2	58,6	0,3
200	**58,9**	58,7	58,9	0,2
250	**59,3**	59,3	59,6	0,3
315	**58,3**	58,2	58,4	0,2
400	**58,1**	58	58,2	0,2
500	**58,7**	58,4	58,6	0,2
630	**61,7**	61,6	61,8	0,2
800	**65,2**	65,2	65,4	0,2
1000	**67,2**	66,9	67,1	0,3
1250	**66,5**	66,1	66,3	0,2
1600	**66,6**	66,5	66,7	0,2
2000	**67,3**	67	67,1	0,2
2500	**64,7**	64,4	64,3	-0,1
3150	**63,4**	62,8	62,6	-0,2
4000	**63,4**	62,2	62,6	0,4
5000	**62,8**	61,3	61,8	0,5
6300	**60,8**	58,7	58,5	-0,2
8000	**59,6**	56,9	57	0,1
10000	**57,6**	53,8	51,6	-2,2
A-weight	**76**	**75,5**	**75,7**	**0,2**

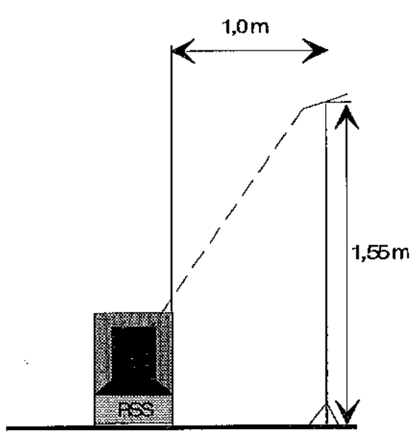

Figure 3.2 Test set up used in figure 3.1 and table 3.1.

In figure 3.3 the corresponding measurement with the reference source elevated 1,1 m above the floor is given. A new error is obviously introduced at low frequencies. This is obviously due to the fact that the direct and reflected waves are added differently for sound pressure and sound intensity. This kind of error will be difficult to avoid in the test method as the floor reflex is an integral part of the hemi-anechoic reference measurement. On the other hand the error does not seem to be very large, in this case the maximum is 1,8 dB at 80-100 Hz and these frequencies are rarely of interest as to A-weighted sound pressure levels at positions in the vicinity of a machine. The problem is probably worse at low frequencies because of the directivity of the sound source. It is more omnidirectional at low frequencies and cosequently the floor reflex becomes stronger.

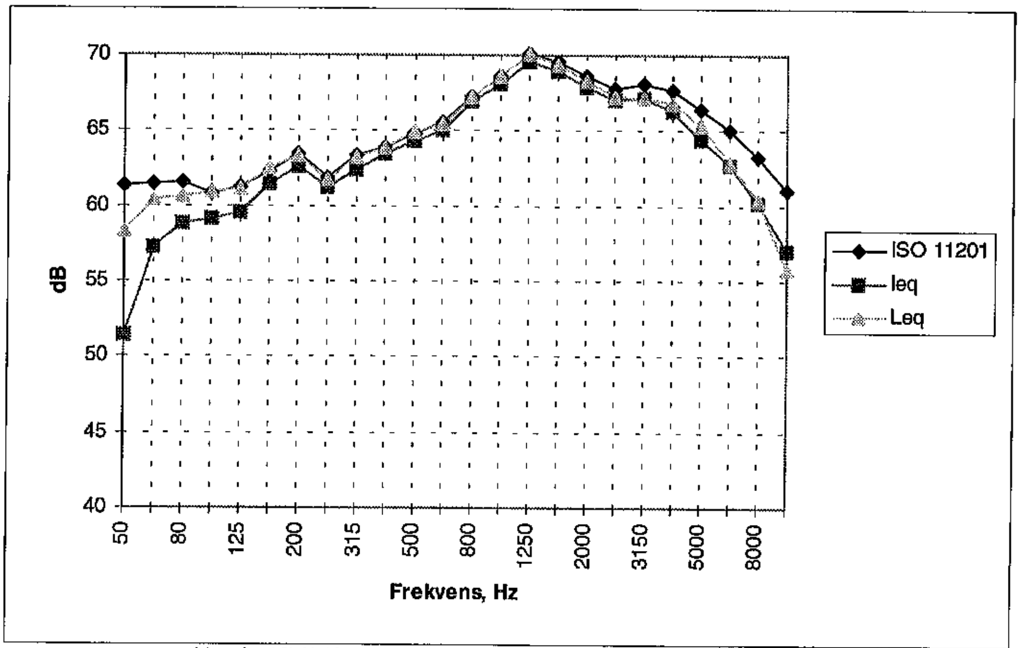

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Figure 3.3 Comparison between the emission sound pressure levels and the intensity levels 1 m from the RSS, located 1,1 m above the floor, and 1,55 m above the floor in a hemi-anechoic room. Intensity probe uncorrected at high frequencies.

Table 3.2 The measured values of figure 3.3

Frequency	**11201**	Ieq	Leq	F_{pI}
50	**61,3**	51,4	58,3	6,9
63	**61,4**	57,2	60,4	3,2
80	**61,5**	58,8	60,6	1,8
100	**60,8**	59,1	60,9	1,8
125	**61,2**	59,5	61,1	1,6
160	**62,3**	61,4	62,5	1,1
200	**63,4**	62,6	63,3	0,7
250	**61,9**	61,2	61,8	0,6
315	**63,3**	62,4	63,2	0,7
400	**63,9**	63,4	63,9	0,5
500	**64,8**	64,3	64,9	0,6
630	**65,6**	65	65,5	0,6
800	**67,3**	66,9	67,3	0,4
1000	**68,6**	68,1	68,6	0,6
1250	**70,1**	69,6	70,1	0,5
1600	**69,6**	68,9	69,4	0,5
2000	**68,6**	67,9	68,3	0,5
2500	**67,8**	67	67,3	0,3
3150	**68,1**	67,1	67,2	0
4000	**67,7**	66,3	66,8	0,5
5000	**66,4**	64,4	65,4	0,9
6300	**65**	62,7	62,8	0,2
8000	**63,2**	60,2	60,4	0,2
10000	**61**	57	55,7	-1,4
A-weigh	**79,1**	**78,2**	**78,6**	**0,5**

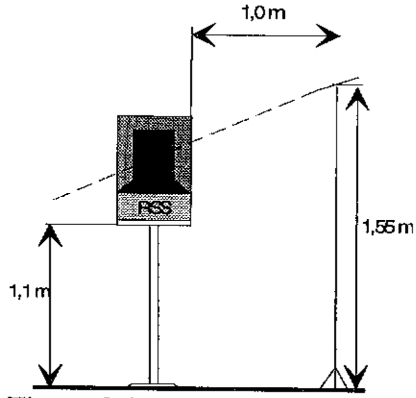

Figure 3.4 Test set up used in figure 3.3 and table 3.2

3.2.2 The sound field pressure-intensity indicator as a function of the direction of the probe

Because of the directivity of the probe and the sound field, the orientation of the probe relative to the incident sound will also influence the result. An example is given in figure 3.6 and table 3.3 which show the sound intensity levels with different orientations of the intensity probe, see figure 3.5. Depending on probe orientation the A-weighted sound pressure level will vary between 82,3 dB and 84,2 dB. As a comparison the same sound pressure level measured with a free field microphone, see table 3.3, was 84,5 dB. It is obviously important to orientate the probe to register the maximum intensity level. The error between L_{Imax} and L_{p11201} is largest below 200 Hz.

Table 3.3 The measured values of figure 3.6
* Negative intensity at the frequency bands 50 and 63 Hz.
** Measured on May 23, 1995

Freq	Ieq1	Ieq2	Ieq3	Ieq4**	Ieq 4	Ieq5	Ieq6	**11201**
50	61,1	62,4	63,1	66	60,6	*61,9	60,4	**71,9**
63	57	58,8	64,1	64,1	61,3	*46,1	64,8	**70,6**
80	65,5	70,3	69,3	72,3	67,2	70,9	68,8	**75,7**
100	63,6	62,3	65,5	67,7	64,2	65,5	64,4	**70,3**
125	62,8	61,7	64,5	66,7	65,4	65,1	65,3	**69,2**
160	64,8	65,5	66,2	66,9	66,5	67	66,6	**68,7**
200	65,8	66,2	66,8	67,8	67,4	67,9	67,3	**68,5**
250	65,5	66	66,5	67,5	67,2	67,3	67	**68,1**
315	66,3	67	67,5	68,2	67,9	68,1	67,7	**68,6**
400	67,2	67,9	68,4	69,1	68,9	69,1	68,7	**69,3**
500	68,3	68,9	69,4	70	70	69,9	69,7	**70**
630	69,2	69,7	70,4	71	71	70,9	70,5	**71**
800	70,9	71,6	72,2	72,6	72,5	72,6	72,1	**72,7**
1000	71,8	72,2	72,8	73,5	73,4	73,4	73	**73,5**
1250	73,3	73,8	74,6	75,1	75,1	75,1	74,6	**75,2**
1600	73,1	73,7	74,4	75,1	75	74,9	74,6	**75,1**
2000	72,2	72,6	73,4	74	73,8	73,8	73,4	**74,1**
2500	71,6	72	72,7	73,4	73,2	73,2	72,7	**73,5**
3150	71,7	72,2	72,9	73,6	73,4	73,4	72,9	**73,8**
4000	70,4	71	71,7	72,5	72,4	72,4	71,9	**73,4**
5000	68,4	69,2	70,1	70,9	70,8	70,8	70,2	**72,2**
6300	66,3	67	67,9	68,8	68,7	68,8	68	**70,6**
8000	63,8	64,6	65,6	66,5	66,5	66,5	65,4	**68,9**
10000	60,9	61,5	62,4	63,1	63	62,9	61,8	**66,7**
A-	**82,3**	**82,8**	**83,5**	**84,2**	**84,1**	**84,1**	**83,6**	**84,5**

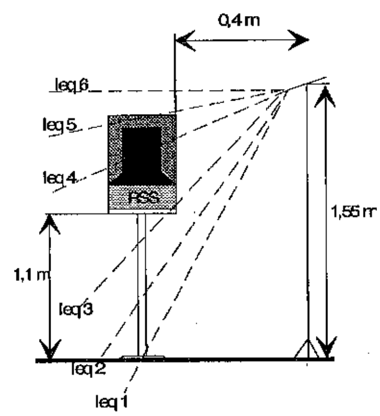

Figure 3.5 Test set up used in figure 3.6 and table 3.3

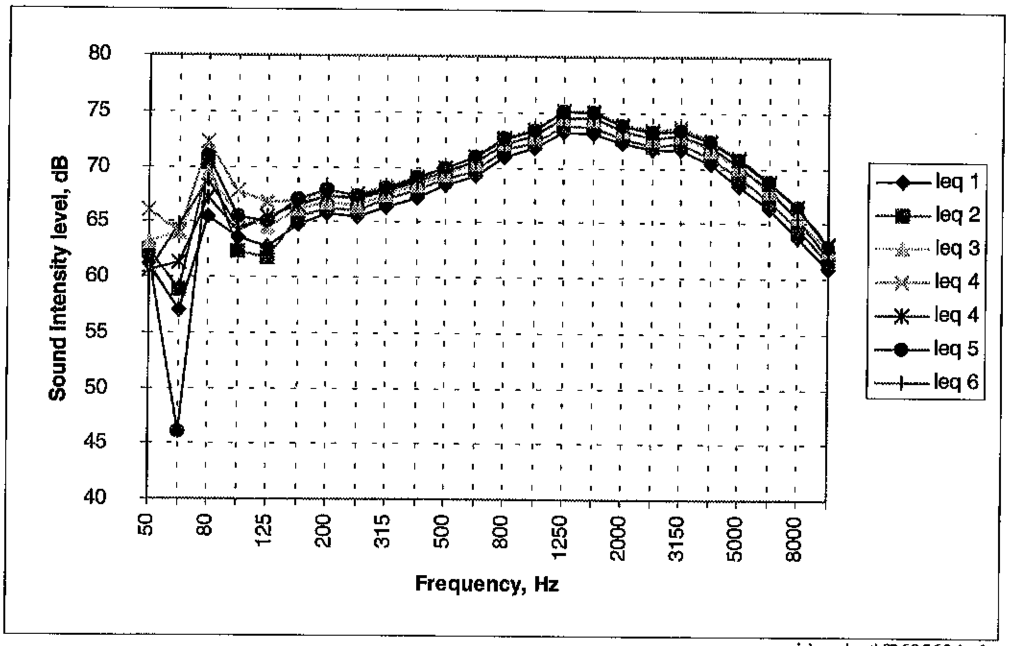

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Figure 3.6 The sound intensity level as a function of probe direction 0,4 m from the RSS, located 1,1 m above the floor, and 1,55 m above the floor in a hemi-anechoic room. Intensity probe uncorrected at high frequencies.

3.2.3 The sound field pressure-intensity indicator as a function of the measurement distance in a hemi-anechoic room

The sound field pressure-intensity indicator($F_{PI}= L_p-L_I$) of the A-weighted sound pressure levels is given in figure 3.7. L_p has been measured with the intensity probe and the source was the one shown in figure 2.1.

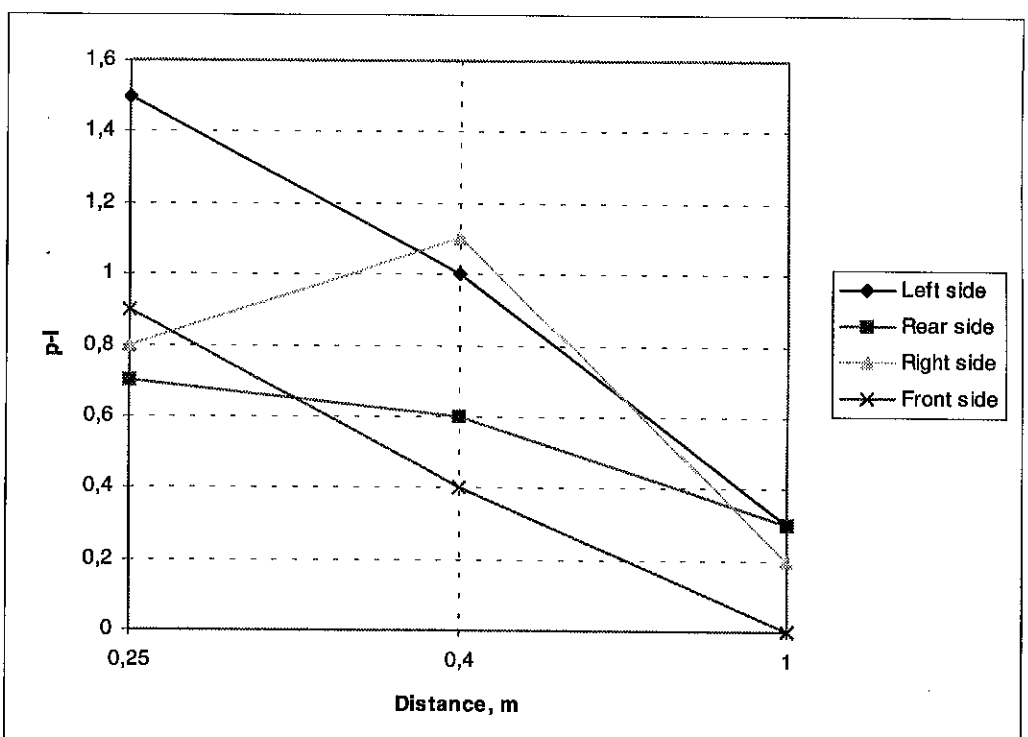

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Figure 3.7 The sound field pressure-intensity indicator as a function of the distance. A-weighted values only.

Figure 3.7 indicates that the pI-indicator is rather large close to the source and that it does not approach 0 dB until at 1 m from the source. The explanation is probably the directivity of the probe in combination with the table reflection.

3.2.2 Some additional examples

The complete measurement results of the two most extreme cases in figure 3.7 are shown in figure 3.8 and 3.9.

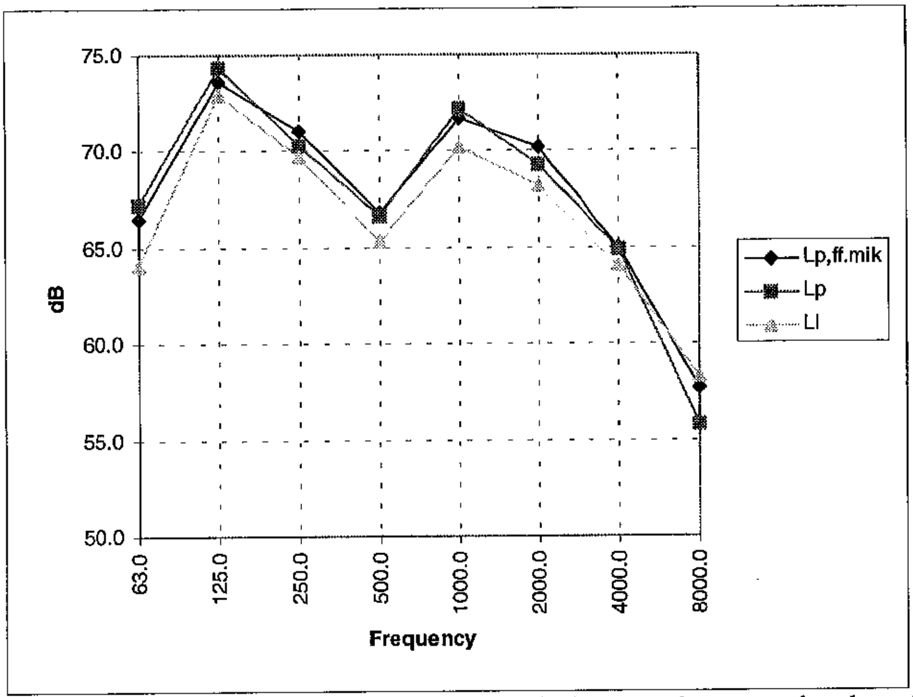

Figure 3.8 Comparison between the the emission sound pressure levels and intensity level at the left side of the test object in a hemi-anechoic room. 0,25 m from the reference box 1,55 m above the floor.(Lp,ff.mic=- emission sound pressure level measured with free field microfone type B&K 4165, Lp= the same with intensity probe and LI=- sound intensity level). n:\geir\project\pi05r2

Table 3.4 The measured values of figure 3.8.

Left side			
Frequency	Lp,ff.mik	**Lp**	LI
63.0	66.5	**67.2**	64.1
125.0	73.6	**74.3**	72.9
250.0	71.0	**70.3**	69.7
500.0	66.8	**66.6**	65.3
1000.0	71.7	**72.2**	70.2
2000.0	70.2	**69.3**	68.2
4000.0	65.0	**64.9**	64.1
8000.0	57.7	**55.8**	58.3
A-weighted	75.8	**75.6**	74.2

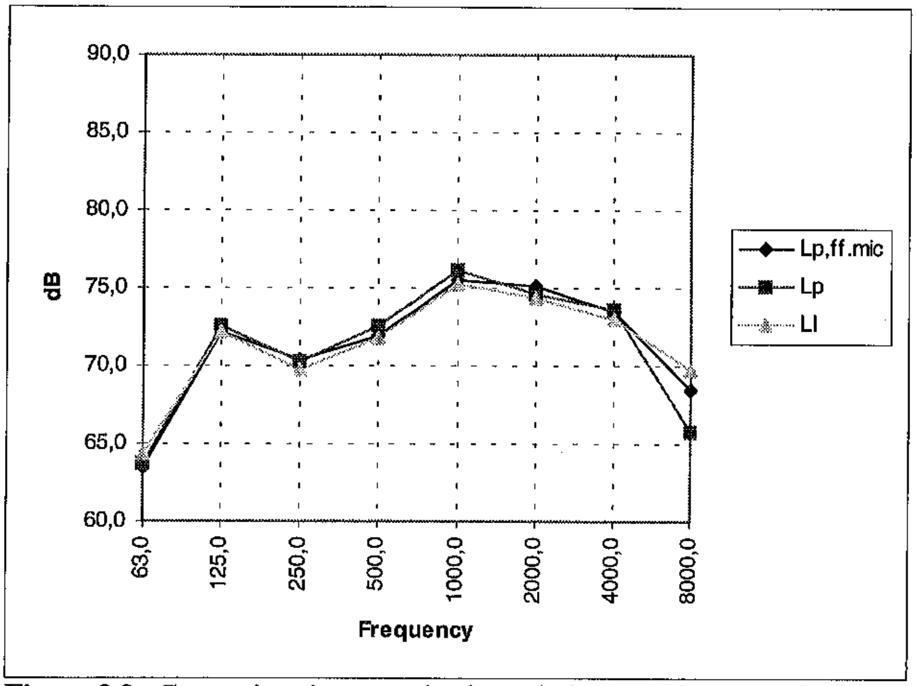

Figure 3.9 Comparison between the the emission sound pressure levels and the intensity level at the front side of the test object in a hemi-anechoic room. 1,0 m from the reference box 1,55 m above the floor. .(Lp,ff.mic=- emission sound pressure level measured with free field microfone type B&K 4165, Lp= the same with intensity probe and LI=- sound intensity level). n:\geir\project\pi02r2

Front side			
Frequency	Lp,ff.mic	Lp	LI
63.0	63.5	63.7	64.3
125.0	72.2	72.6	72.2
250.0	70.4	70.2	69.8
500.0	71.9	72.6	71.8
1000.0	75.5	76.2	75.2
2000.0	75.1	74.6	74.4
4000.0	73.5	73.6	73.0
8000.0	68.5	65.8	69.7
A-weighted	80.9	80.9	80.4

Table 3.5 The measured values of figure 3.9.

4 Measurements in a reverberation room

These measurements have been carried out in a 200 m^3 reverberation room. The reverberation time is about 2 s at 5000 Hz and about 5 s at low and medium high frequencies.

In figure 4.1 - 4.12 a number of measurements on the source described in figure 2.1 are reported. The results are summarized in figure 4.1. The figure contains the error L_{IA}-$L_{pA11201}$ and L_{pA}-$L_{pA11201}$ and 3 indicators L_{IA}-L_{IAm}, L_{pA}-L_{IA} and L_{pA}-L_{pAm}. L_{pA} is the actual sound pressure level measured in the reverberation room and *m* indicates energy mean value. The first indicator is the difference between the sound intensity level measured at a certain position and the energy mean intensity level of the four positions at the same distance from the machine. Thus it is a measure of the directivity of the source under test. The measurement conditions get worse the smaller this indicator becomes. The second indicator is the wellknown field indicator and the third indicator is a measure of the diffusivity of the sound field around the machine.

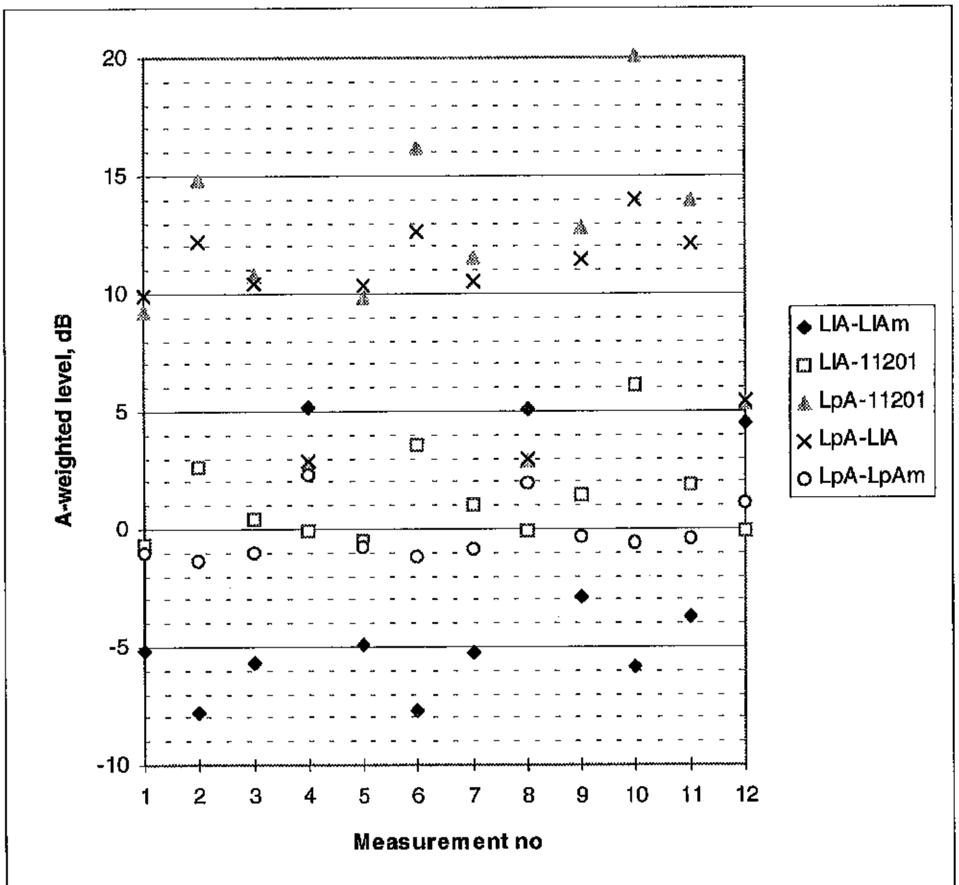

Figure 4.1 A summary of the results of the reverberation room measurements. Positions 1-4 are at 0,25 m, 5-8 at 0,4 m and 9-12 at 1 m.

The three worst cases, measurements no 2, 6 and 10 on the rear side of the box, where the error exceeds 2 dB have both a very low L_{IA}-L_{IAm} indicator, - 6 dB or lower, and a very high field indicator, 12 dB or higher. As expected the result is at its best when the L_{IA}-L_{IAm} indicator is large, that is when the main directivity is towards the measurement probe.

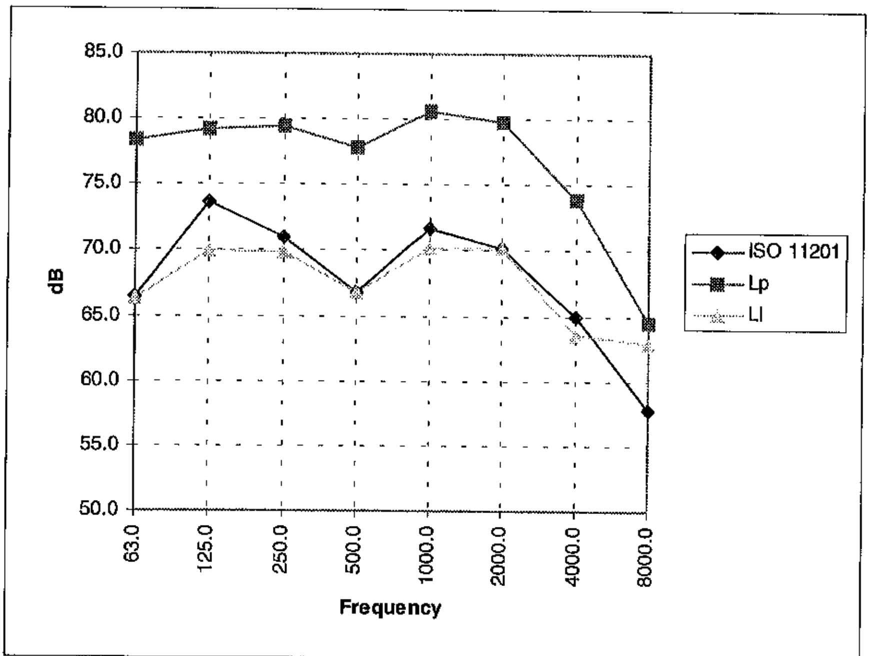

Figure 4.2 Left side. 0,25 m from the reference box. Reverberation roomn:\geir\project\pi05r3

Table 4.1. The values of figure 4.2

Left side	**ISO 11201**		
Frequency	**Lp,ff.mik**	Lp	LI
63.0	**66.5**	78.4	66.3
125.0	**73.6**	79.2	70.0
250.0	**71.0**	79.4	69.9
500.0	**66.8**	77.8	66.8
1000.0	**71.7**	80.6	70.2
2000.0	**70.2**	79.8	70.1
4000.0	**65.0**	73.9	63.6
8000.0	**57.7**	64.5	62.8
A-weighted	**75.8**	85.0	75.1

Table 4.2. The values of figure 4.3

Rear side	**ISO 11201**		
Frequency	**Lp,ff.mic**	Lp	LI
63.0	**62.1**	76.5	60.3
125.0	**66.3**	79.7	68.2
250.0	**62.4**	77.9	64.9
500.0	**62.3**	77.1	58.3
1000.0	**66.0**	80.6	69.0
2000.0	**64.7**	79.5	66.4
4000.0	**57.2**	73.4	61.6
8000.0	**47.6**	63.9	62.5
A-weighted	**69.9**	84.7	72.5

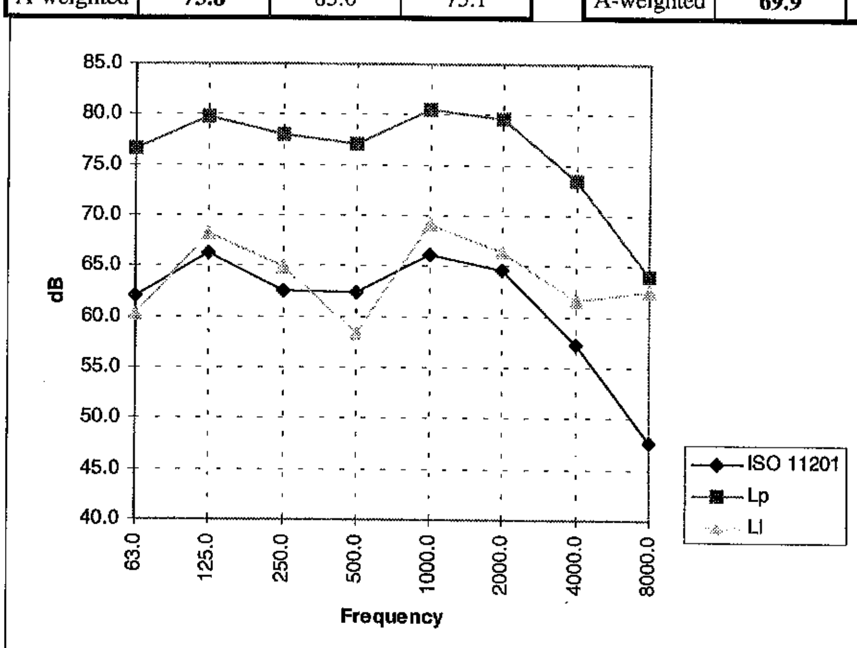

Figure 4.3 Rear side. 0,25 m from the reference boxn:\geir\project\pi05r3

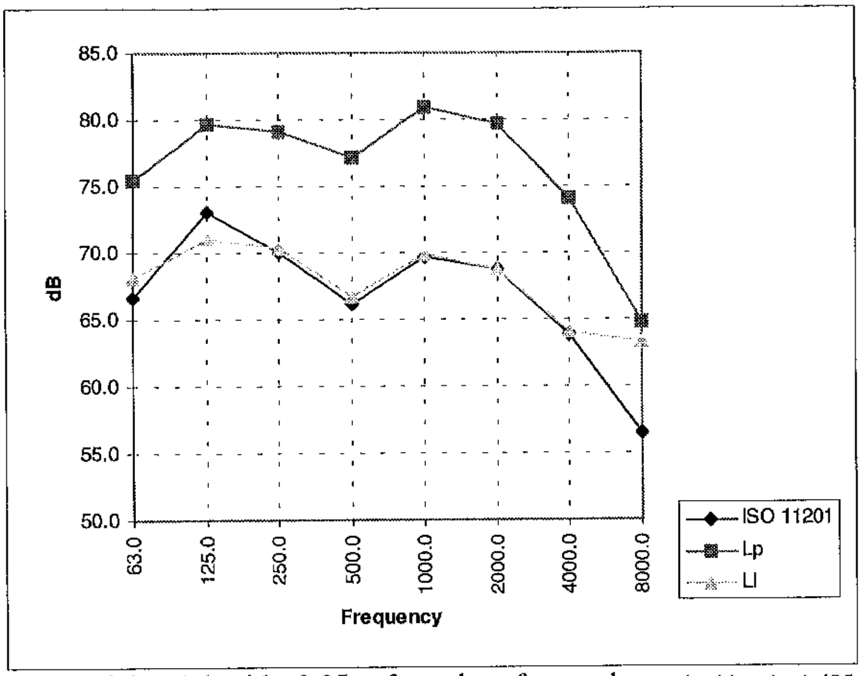

Figure 4.4 Right side. 0,25 m from the reference box. n:\geir\project\pi05r3

Table 4.3 The values of figure 4.4

Right side	**ISO 11201**		
Frequency	**Lp,ff.mic**	Lp	LI
63.0	**66.6**	75.5	68.1
125.0	**73.1**	79.7	71.0
250.0	**70.0**	79.1	70.3
500.0	**66.1**	77.2	66.7
1000.0	**69.7**	80.9	69.9
2000.0	**68.8**	79.7	68.7
4000.0	**63.8**	74.0	64.1
8000.0	**56.5**	64.8	63.3
A-weighted	**74.2**	85.0	74.6

Table 4.4. The values of figure 4.5

Front side	**ISO 11201**		
Frequency	**Lp,ff.mic**	Lp	LI
63.0	**69.9**	77.9	71.5
125.0	**80.2**	83.2	78.0
250.0	**74.0**	80.2	74.2
500.0	**75.0**	79.5	75.0
1000.0	**80.0**	83.5	79.5
2000.0	**80.3**	83.2	80.3
4000.0	**77.9**	79.2	77.5
8000.0	**73.1**	72.2	75.4
A-weighted	**85.5**	88.3	85.4

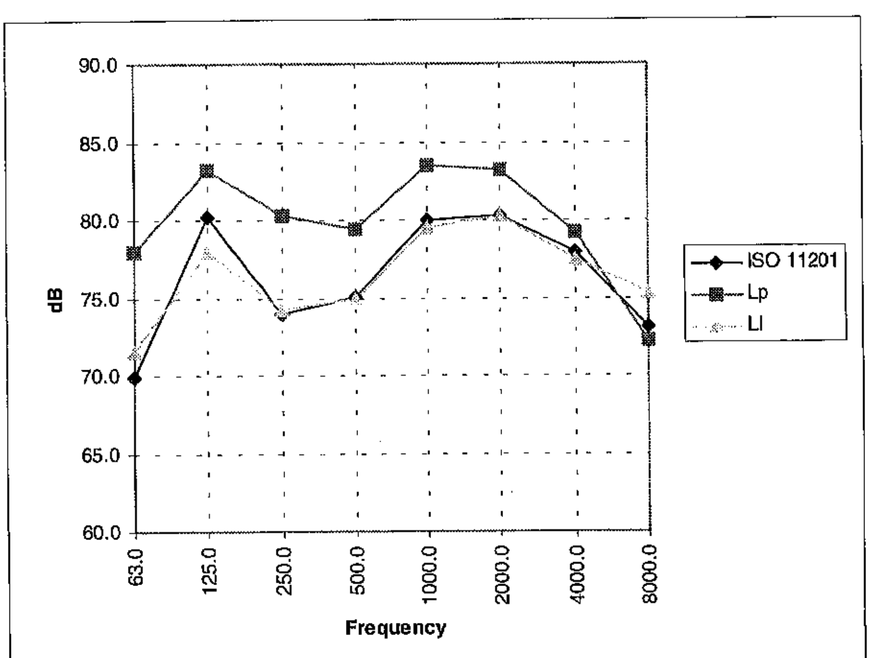

Figure 4.5 Front side. 0,25 m from the reference box in the reverberation room. n:\geir\project\pi05r3

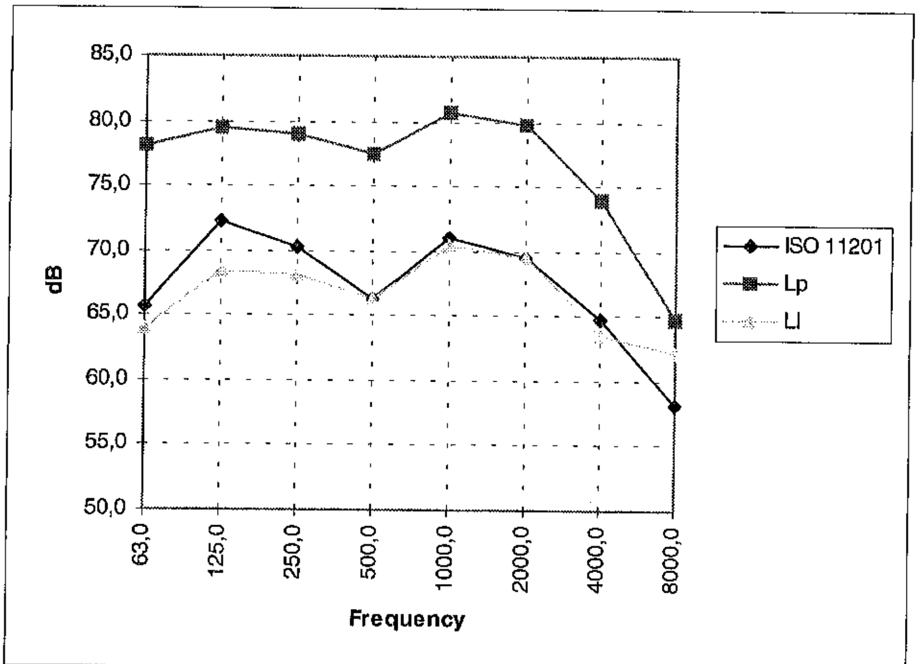

Figure 4.6 Left side. 0,4 m from the reference box. n:\geir\project\pi01r3

Table 4.5 The values of figure 4.6

Left side	ISO 11201		
Frequency	Lp,ff.mik	Lp	LI
63.0	**65,6**	78.1	64.0
125.0	**72,3**	79.5	68.4
250.0	**70,3**	79.0	68.1
500.0	**66,3**	77.5	66.2
1000.0	**71**	80.7	70.4
2000.0	**69,6**	79.7	69.4
4000.0	**64,7**	73.9	63.5
8000.0	**58,1**	64.7	62.2
A-weighted	**75,2**	85.0	74.7

Table 4.6. The values of figure 4.7

Rear side	ISO 11201		
Frequency	Lp,ff.mic	Lp	LI
63.0	**61,2**	73.2	58.1
125.0	**64,6**	80.3	69.3
250.0	**61,9**	77.6	64.6
500.0	**61,1**	76.8	65.4
1000.0	**64,6**	80.2	67.7
2000.0	**62,7**	79.3	64.9
4000.0	**56,3**	73.7	62.0
8000.0	**47**	64.8	62.6
A-weighted	**68,3**	84.5	71.9

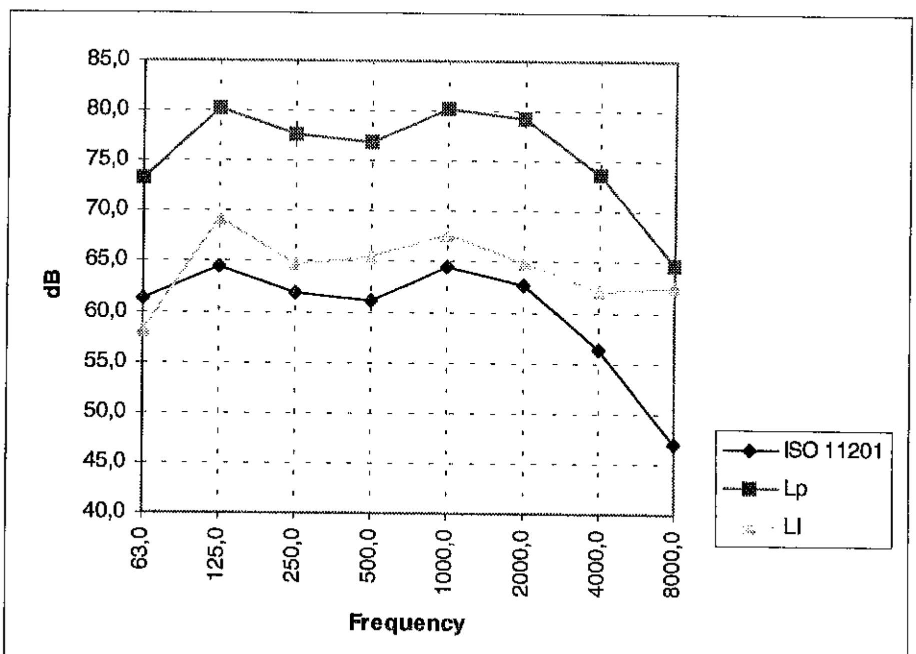

Figure 4.7 Rear side. 0,4 m from the reference box. Reverberation room.n:\geir\project\pi01r3

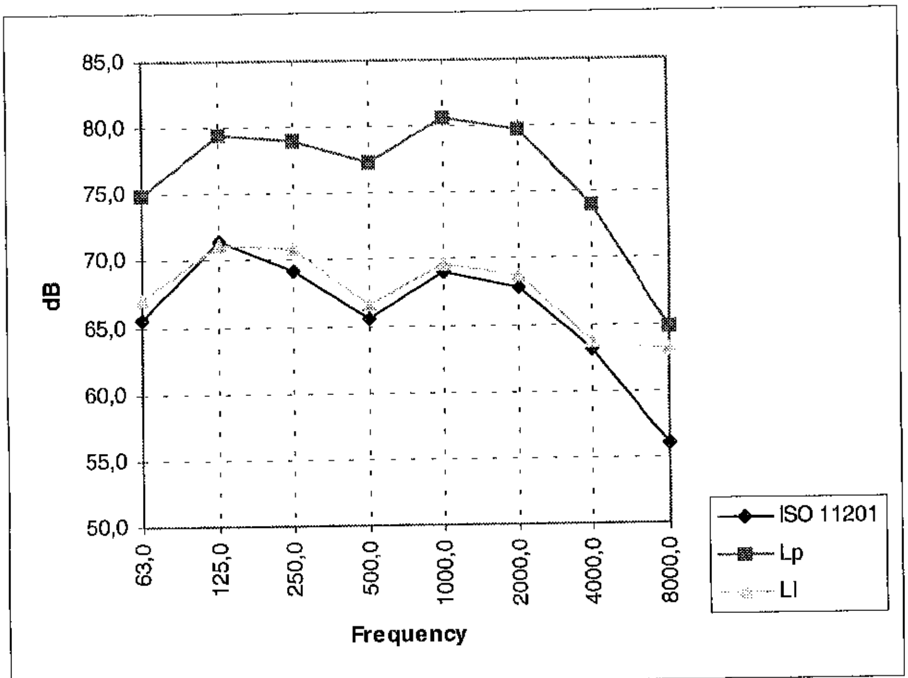

Figure 4.8 Right side. 0,4 m from the reference box.n:\geir\project\pi01r3

Table 4.7 The values of figure 4.8

Right side	ISO 11201		
Frequency	**Lp,ff.mic**	Lp	LI
63.0	**65,6**	74.9	67.0
125.0	**71,3**	79.5	71.1
250.0	**69,2**	78.9	70.8
500.0	**65,5**	77.3	66.7
1000.0	**69**	80.7	69.6
2000.0	**67,8**	79.7	68.6
4000.0	**63,1**	73.9	63.7
8000.0	**56,0**	64.8	63.1
A-weighted	**73,4**	84.9	74.4

Table 4.8 The values of figure 4.9

Front side	ISO 11201		
Frequency	**Lp,ff.mic**	Lp	LI
63.0	**67,1**	77.7	69.4
125.0	**78,1**	82.5	76.3
250.0	**72,9**	79.6	73.9
500.0	**74,7**	79.4	74.4
1000.0	**79,5**	83.0	79.1
2000.0	**79,2**	82.4	79.2
4000.0	**77,4**	78.7	77.0
8000.0	**72,8**	71.6	74.8
A-weighted	**84,8**	87.7	84.7

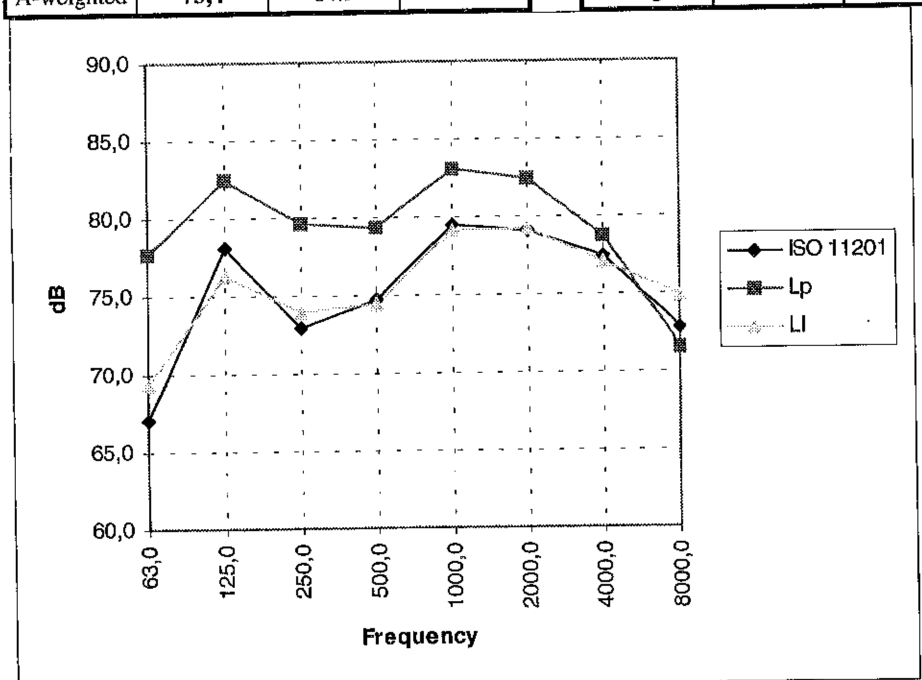

Figure 4.9 Front side. 0,4 m.Reverberation room.n:\geir\project\pi01r3

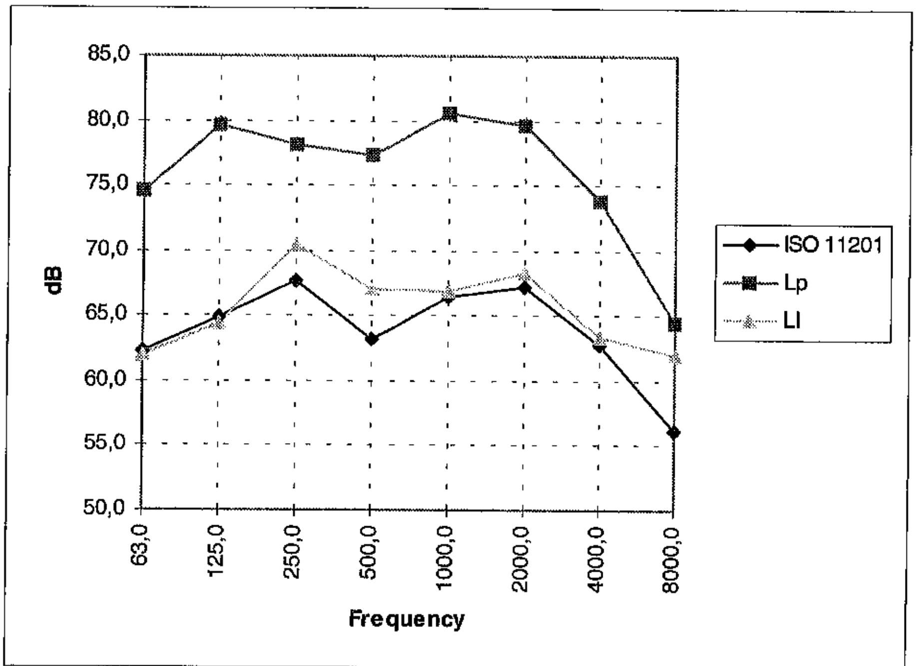

Figure 4.10 Left side. 1,0 m. Reverberation room.n:\geir\project\pi02r3

Table 4.9 The values of figure 4.10

Left side	**ISO 11201**		
Frequency	**Lp,ff.mik**	Lp	LI
63.0	**62,2**	74.5	61.9
125.0	**64,9**	79.6	64.4
250.0	**67,7**	78.0	70.4
500.0	**63,1**	77.3	67.0
1000.0	**66,5**	80.6	66.8
2000.0	**67,2**	79.6	68.3
4000.0	**62,8**	73.7	63.3
8000.0	**56,2**	64.4	62.0
A-weighted	**72,0**	84.8	73.4

Table 4.10 The values of figure 4.11

Rear side	**ISO 11201**		
Frequency	**Lp,ff.mic**	Lp	LI
63.0	**57,4**	71.6	56.8
125.0	**60,8**	79.2	68.5
250.0	**58,9**	78.0	65.5
500.0	**58,1**	76.9	62.3
1000.0	**59,3**	80.1	65.4
2000.0	**59,5**	79.3	63.8
4000.0	**53,2**	73.6	61.7
8000.0	**46,8**	64.4	62.2
A-weighted	**64,4**	84.5	70.5

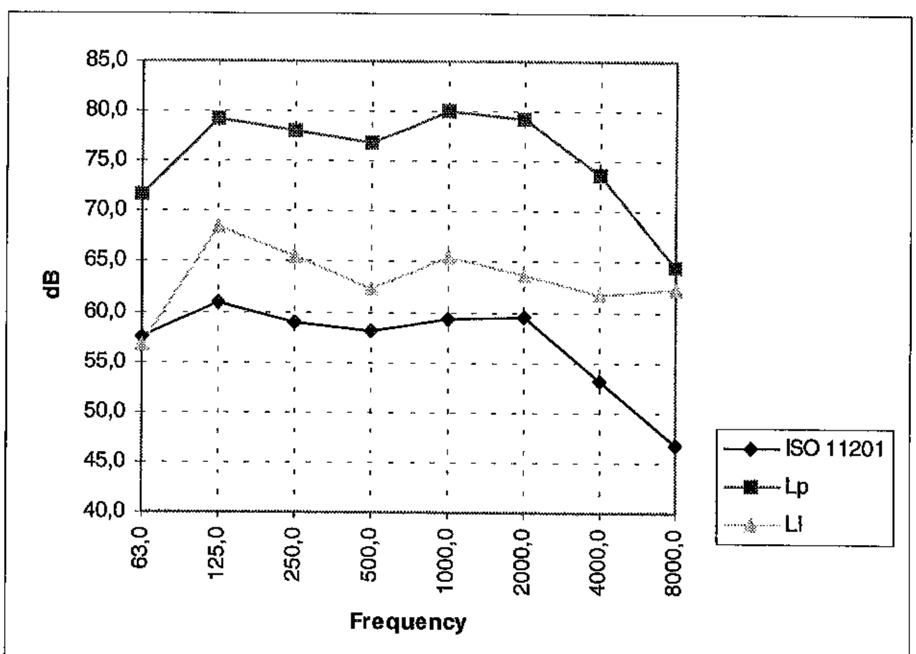

Figure 4.11 Rear side. 1,0 m. Reverberation room.n:\geir\project\pi02r3

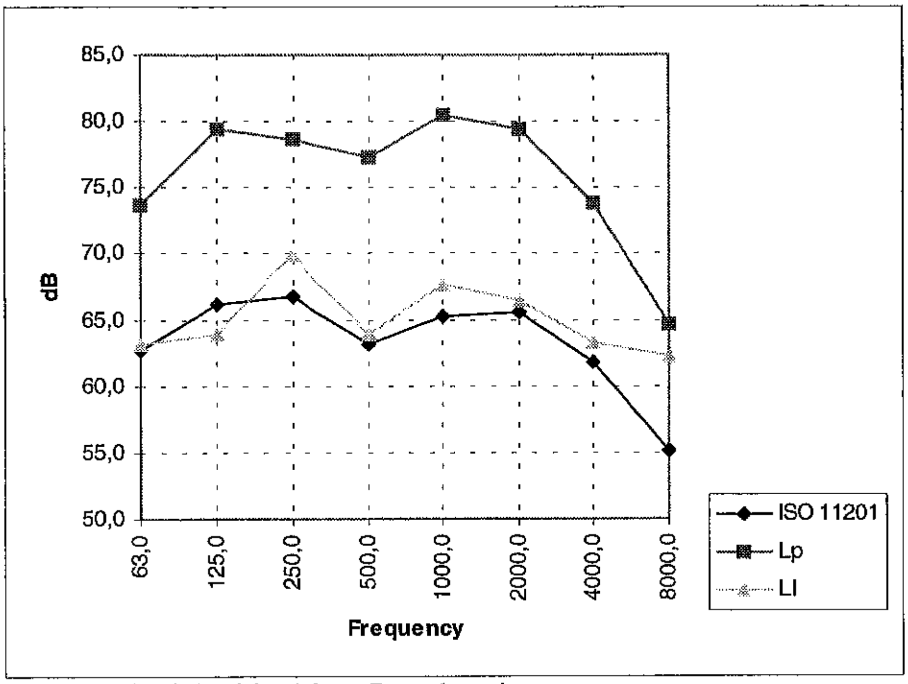

Figure 4.12 Right side. 1,0 m. Reverberation room.n:\geir\project\pi02r3

Table 4.11 The values of figure 4.12

Right side	ISO 11201		
Frequency	Lp,ff.mic	Lp	LI
63.0	**62,7**	73.6	63.2
125.0	**66,2**	79.5	63.8
250.0	**66,7**	78.7	69.9
500.0	**63,1**	77.4	63.8
1000.0	**65,2**	80.5	67.6
2000.0	**65,5**	79.4	66.5
4000.0	**61,7**	73.8	63.2
8000.0	**55,1**	64.6	62.2
A-weighted	**70,7**	84.7	72.6

Table 4.12. The values of figure 4.13

Front side			
Frequency	ISO 11201	Lp	LI
63.0	**63.5**	75.6	63.2
125.0	**72.2**	80.0	64.5
250.0	**70.4**	78.8	70.8
500.0	**71.9**	78.4	72.2
1000.0	**75.5**	81.7	75.2
2000.0	**75.1**	80.9	75.2
4000.0	**73.5**	76.6	73.2
8000.0	**68.5**	68.8	70.8
A-weighted	**80.9**	86.2	80.8

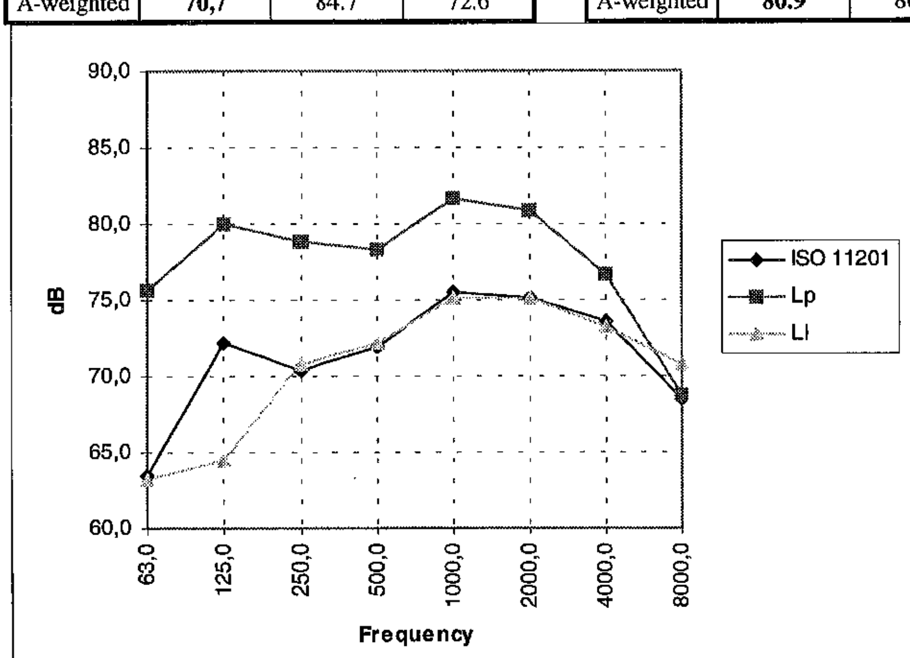

Figure 4.13 Front side. 1,0 m. Reverberation room.n:\geir\project\pi02r3

5 Measurements in an office

5.1 The office

Measurements were carried out in an ordinary office, room no 8:211 at SP Acoustics laboratory, with a suspended sound absorbing ceiling and office screens. The floor is made of concrete and the walls are made of gypsum boards. Book cases covered large parts of the two short walls. The dimensions are

L=	8,82 m
W=	6,21 m
H=	2,40 m
V=	131,5 m^3
S_w=	183,4 m^2
S_{floor}=	17,1 m^2

5.2 Repeatability and directionality

The repeatability was tested by repeating the measurements once. This test was carried out in the hemi-anechoic room and in the office. In addition the influence of the directional characteristics of the measurement probe was tested by comparing two different orientations of the intensity probe, see figure 5.1 and 5.2.

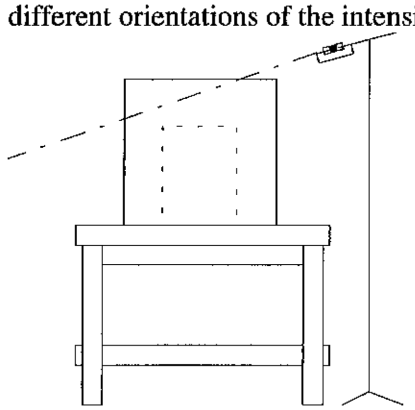

Figure 5.1 Microphone position 1. The microphone was tilted 30° downwards.
Figure:n\geir\projekt\fig2.drw

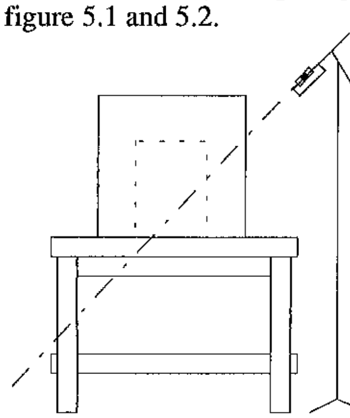

Figure 5.2 Microphone position 2. The microphone was oriented towards the center of the bottom of the object.
Figure:n\geir\projekt\fig2.drw

In table 5.1-5.3 some results are summarized. The first column indicates the different frequency bands, the next 4 columns give the results of the *repeatability* tests with the two different microphone orientations, the 6th column with bold figures gives the reference measurements using a free field microphone in a hemi anechoic room and the 9th and last column gives the result of a single repeatability test in a hemi anechoic room using a free field microphone. The 7th column indicates the directivity expressed as the difference between L_I in position 1 and measurement 1(mea 1) and the L_I mean level of the four positions on each side of the measurement box.

The 8th column indicates a kind of maximum error using the intensity technique expressed as the difference between the lowest intensity level of columns 2-5 and the reference measurement.

These results indicate that the repeatability in general is good but that it is worse at high frequencies for the left side. The reason is the small hole in one of the corners.

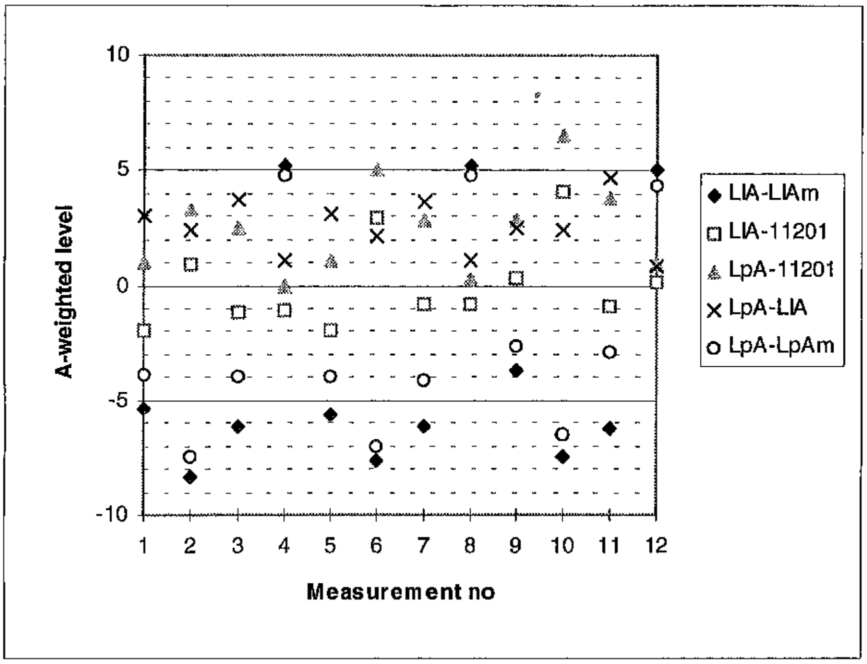

Figure 5.3 A summary of the measurements reported in table 5.1-5.4. Positions 1-4 are at 0,25 m, 5-8 at 0,4 m and 9-12 at 1 m.

In figure 5.3 the same indicators as those in clause 4 have been used.

The two worst cases, measurements no 6 and 10, where the error exceeds 2 dB have a low L_{IA}-L_{IAm} indicator, about -8 dB but the field indicator is rather low. As expected the result is at its best when the L_{IA}-L_{IAm} indicator is large, that is when the main directivity is towards the measurement probe. The result of measurement no 2 is surprisingly good considering the bad L_{IA}-L_{IAm} indicator. There does not seem to be any simple explanation to this. Obviously the different indicators are unable to explain everything.

Table 5.1a Front side. Repeatability and directionality 0,25 m from the reference box.

	Pos 1 Mea 1	Pos 1 Mea 2	Pos 2 Mea 1	Pos 2 Mea 2	Reference 11201	Directivity	Max "error"	Repeatability 11201
Freq.	$L_{I,1}$	L_I	L_I	L_I	$\mathbf{L_p}$	$L_{I,1}-L_{I,mean}$	$L_{I,min}-L_p$	$L_{p1}-L_{p2}$
63	67.1	73.6	66.7	73	**69.9**	2.0	-3.2	-5.4
125	77.9	78.2	77.9	79.2	**80.2**	4.4	-2.3	-0.5
250	73.6	73.8	73.5	74.8	**74**	3.2	-0.5	-0.5
500	74	74.1	73.8	75	**75**	4.7	-1.2	-0.3
1000	78.1	78.4	78.2	79.4	**80**	4.9	-1.9	0.1
2000	79.2	79.3	78.9	80.2	**80.3**	5.3	-1.4	-0.2
4000	76.8	76.9	76.5	78	**77.9**	5.6	-1.4	-0.2
8000	74.5	74.6	74.2	75.8	**73.1**	5.7	-1.1	-0.8
A	84.4	84.5	84.2	85.5	**85.5**	5.2	-1.3	-0.2

Data:n:geir\project\fig3-10.xls

Table 5.1b Left side. Repeatability and directionality 0,25 m from the reference box.

Freq.	L_I	L_I	L_I	L_I	L_p	$L_{I,1}-L_{I,mean}$	$L_{I,min}-L_p$	$L_{p1}-L_{p2}$
63	65.4	65.9	65.7	66.2	66.5	0.3	-1.1	-2.1
125	70.7	71.2	71.6	72.1	73.6	-2.8	-2.9	-0.2
250	70.1	70	70.4	70.6	71	-0.3	-1	0.5
500	65.7	65.5	66.1	66	66.8	-3.6	-1.3	0.0
1000	68.7	68.5	69.5	69.5	71.7	-4.5	-3.2	1.5
2000	68.5	68.7	68.8	69.5	70.2	-5.4	-1.7	0.2
4000	63.7	63.5	64.5	64.3	65	-7.5	-1.5	0.6
8000	59.3	59	60.4	60.4	57.7	-9.5	1.3	-0.3
A	73.8	73.7	74.3	74.6	75.8	-5.4	-2.1	0.7

Data:n:geir\project\fig3-11.xls

Table 5.1c Rear side. Repeatability and directionality 0,25 m from the reference box.

Freq.	L_I	L_I	L_I	L_I	L_p	$L_I-L_{I,mean}$	$L_{I,min}-L_p$	$L_{p1}-L_{p2}$
63	62.5	66.1	61.5	64.9	62.1	-2.6	-0.6	-1.5
125	64.2	63.1	64.2	62	66.3	-9.3	-4.3	0.2
250	63	63.1	62.6	62	62.4	-7.4	-0.4	-0.9
500	62.3	62.5	62.6	62.1	62.3	-7.0	-0.2	-0.6
1000	66.4	66.5	66.6	66	66	-6.8	0	0.4
2000	65.2	65.6	65	65.2	64.7	-8.7	0.3	0.2
4000	60.9	61	60	60.1	57.2	-10.3	2.8	0.4
8000	59.1	59.3	58.3	57.8	47.6	-9.7	10.2	0.5
A	70.8	71.1	70.7	70.5	69.9	-8.4	0.6	0.2

Data:n:geir\project\fig3-12.xls

Table 5.1d Right side. Microphone position 0,25 m from the reference box

Freq.	L_I	L_I	L_I	L_I	$\mathbf{L_p}$	$L_I-L_{I,mean}$	$L_{I,min}-L_p$	$L_{p1}-L_{p2}$
63	64.1	64.8	66.1	65.4	**66.6**	-1.0	-2.5	0.3
125	71.3	70.9	72.3	72.5	**73.1**	-2.2	-2.2	-1.1
250	69.6	69.2	70.2	70.1	**70**	-0.8	-0.8	-0.2
500	65.5	65.1	66.3	66.5	**66.1**	-3.8	-1	-0.5
1000	68.1	67.6	69.4	69.5	**69.7**	-5.1	-2.1	0.0
2000	67.5	67.6	68.3	68.5	**68.8**	-6.4	-1.3	-0.1
4000	62.6	62.4	63.9	64	**63.8**	-8.6	-1.4	-0.2
8000	58.3	58.2	59.5	59.8	**56.5**	-10.5	1.7	-0.6
A	73	72.8	74	74.2	**74.2**	-6.2	-1.4	-0.2

Data:n:geir\project\fig3-13.xls

Table 5.2a Front side. Repeatability and directionality 0,4 m from the reference box.

	Pos 1 Mea 1	Pos 1 Mea 2	Pos 2 Mea 1	Pos 2 Mea 2	Reference 11201	Directivity	Max "error"	Repeatability 11201
Freq.	$L_{I,1}$	L_I	L_I	L_I	L_p	$L_{I,1}-L_{I,mean}$	$L_{I,min}-L_p$	$L_{p1}-L_{p2}$
63	73.9	70.8	71	70.1	**67.1**	4.7	3	-5,4
125	76.4	76.4	77.3	77.4	**78.1**	4.1	-1.7	-0,2
250	72.8	73.2	73.8	73.5	**72.9**	3.2	-0.1	-0,6
500	73.8	74.2	74.7	74.4	**74.7**	4.8	-0.9	0,0
1000	78.5	78.3	79.1	78.8	**79.5**	5.1	-1	0,1
2000	78.3	78.2	79.1	78.8	**79.2**	5.2	-0.9	-0,2
4000	76.7	76.8	77.6	77.2	**77.4**	5.6	-0.7	0,0
8000	73.9	74	75.1	74.8	**72.8**	5.6	1.1	-0,3
A	84	84	84.8	84.5	**84.8**	5.2	-0.8	-0,1

Data:n:geir\project\fig3-2.xls

Table 5.2b Left side. Repeatability and directionality 0,4 m from the reference box.

Freq.	$L_{I,1}$	L_I	L_I	L_I	L_p	$L_I-L_{I,mean}$	$L_{I,min}-L_p$	$L_{p1}-L_{p2}$
63	67.5	64.5	65.2	67.2	**65.6**	-1.7	-1.1	-2.5
125	69.9	69.9	70.2	70.6	**72.3**	-2.4	-2.4	0.1
250	69	69.5	69.8	70.1	**70.3**	-0.6	-1.3	-0.2
500	64.5	65.7	65.8	65.8	**66.3**	-4.5	-1.8	-0.1
1000	68.5	68.5	68.9	69.1	**71**	-4.9	-2.5	1.1
2000	67.8	68.2	68.7	68.9	**69.6**	-5.3	-1.8	0.4
4000	63.1	63.3	63.9	64	**64.7**	-8.0	-1.6	0.9
8000	58.9	59.2	60.1	60.1	**58.1**	-9.4	0.8	0.8
A	73.2	73.5	74	74.1	**75.2**	-5.6	-2	0.7

Data:n:geir\project\fig3-3.xls

Table 5.2c Rear side. Repeatability and directionality 0,4 m from the reference box.

Freq.	$L_{I,1}$	L_I	L_I	L_I	L_p	$L_{I,1}-L_{I,mean}$	$L_{I,min}-L_p$	$L_{p1}-L_{p2}$
63	59.9	65	62.9	63.4	**61.2**	-9.3	-1.3	-0.2
125	65.8	63.9	61.5	62.2	**64.6**	-6.5	-3.1	0.1
250	62.5	61.7	61.3	62.4	**61.9**	-7.1	-0.6	-0.6
500	63	61.7	60.9	61.4	**61.1**	-6.0	-0.2	-0.1
1000	66.4	65.6	64.9	65.2	**64.6**	-7.0	0.3	0.2
2000	65.7	64.8	64.2	64.4	**62.7**	-7.4	1.5	0.2
4000	61.9	60.6	59.9	60.3	**56.3**	-9.2	3.6	0.3
8000	59.4	59	57.6	57.9	**47**	-8.9	10.6	0.1
A	71.2	70.3	69.6	69.9	**68.3**	-7.6	1.3	0.1

Data:n:geir\project\fig3-4.xls

Table 5.2d Right side. Repeatability and directionality 0,4 m from the reference box.

	$L_{I,1}$	L_I	L_I	L_I	L_p	$L_{I,1}-L_{I,mean}$	$L_{I,min}-L_p$	$L_{p1}-L_{p2}$
63	63.2	64.4	63.2	64.3	**65.6**	-6.0	-2.4	-0.1
125	70.3	70.6	70.9	71.4	**71.3**	-2.0	-1	0.1
250	68.7	69.7	70.1	70	**69.2**	-0.9	-0.5	-0.1
500	64.6	65.8	66.3	66.2	**65.5**	-4.4	-0.9	-0.2
1000	67.8	68.2	68.7	68.6	**69**	-5.6	-1.2	0.6
2000	67.2	67.5	68.2	68.1	**67.8**	-5.9	-0.6	-0.1
4000	62.3	62.4	63.4	63.3	**63.1**	-8.8	-0.8	0.4
8000	57.6	58.4	59.7	59.5	**56**	-10.7	1.6	-0.1
A	72.6	73	73.7	73.6	**73.4**	-6.2	-0.8	0.2

Data:n:geir\project\fig3-5.xls

Table 5.3a Front side. Repeatability and directionality 1 m from the reference box.

	Pos 1 Mea 1	Pos 1 Mea 2	Pos 2 Mea 1	Pos 2 Mea 2	**Reference 11201**	Directivity	Max "error"	Repeatability 11201
Freq.	$L_{I,1}$	L_I	L_I	L_I	$\mathbf{L_p}$	$L_{I,1}$-$L_{I,mean}$	$L_{I,min}$-L_p	L_{p1}-L_{p2}
63	68.2	64	67	66.9	**63.5**	3.1	0.5	-3.6
125	71.5	71.6	72	71.8	**72.2**	3.8	-0.7	-0.1
250	71.6	71.5	71.5	71.4	**70.4**	3.4	1	-0.4
500	71.9	71.9	71.9	71.7	**71.9**	4.7	-0.2	-0.2
1000	75.3	75	75.4	75.2	**75.5**	5.0	-0.5	0.1
2000	75.3	75.1	75.5	75.3	**75.1**	4.9	0	-0.3
4000	73.6	73.4	73.8	73.6	**73.5**	5.3	-0.1	-0.1
8000	70.7	70.3	70.5	70.5	**68.5**	5.3	1.8	-0.5
A	81	80.8	81.1	80.9	**80.8**	5.0	0	-0.1

Data:n:geir\project\fig3-6.xls

Table 5.3b Left side. Repeatability and directionality 1 m from the reference box.

Freq.	$L_{I,1}$	L_I	L_I	L_I	$\mathbf{L_p}$	$L_{I,1}$-$L_{I,mean}$	$L_{I,min}$-L_p	L_{p1}-L_{p2}
63	66.8	64	65.6	66.3	**62.2**	1.7	1.8	-4.2
125	66.1	63.2	64.4	65.2	**64.9**	-1.6	-1.7	-0.3
250	68	68.4	68.4	68.5	**67.7**	-0.2	0.3	-0.1
500	64	63.4	63.7	63.4	**63.1**	-3.2	0.3	-0.6
1000	66.6	66.5	66.9	66.9	**66.5**	-3.7	0	0.3
2000	67.2	67.4	67.6	67.4	**67.2**	-3.2	0	0.0
4000	62.9	62.7	63.3	63.5	**62.8**	-5.4	-0.1	0.6
8000	59.4	59.2	59.6	59.9	**56.2**	-6.0	3	0.7
A	72.3	72.2	72.6	72.5	**72**	-3.7	0.2	0.1

Data:n:geir\project\fig3-7.xls

Table 5.3c Rear side. Repeatability and directionality 1 m from the reference box.

Freq.	L_I	L_I	L_I	L_I	$\mathbf{L_p}$	L_I-$L_{I,mean}$	$L_{I,min}$-L_p	L_{p1}-L_{p2}
63	58	62	63.8	63.5	**57.4**	-7.1	0.6	-4.7
125	64.9	64.5	64.7	64.7	**60.8**	-2.8	3.7	-0.8
250	61.8	61.2	60.8	60.7	**58.9**	-6.4	1.8	-1.6
500	60.1	59.8	59.9	59.5	**58.1**	-7.1	1.4	0.2
1000	62.6	63.5	63.4	63.3	**59.3**	-7.7	3.3	-0.1
2000	63.3	62.5	62.6	62.4	**59.5**	-7.1	2.9	-0.2
4000	59.6	59.1	59.2	58.8	**53.2**	-8.7	5.6	1.2
8000	58.7	58	57.6	57.4	**46.8**	-6.7	10.6	2.4
A	68.5	68.3	68.3	68.1	**64.4**	-7.5	3.7	-0.1

Data:n:geir\project\fig3-8.xls

Table 5.3d Right side. Repeatability and directionality 1 m from the reference box.

Freq.	$L_{I,1}$	L_I	L_I	L_I	$\mathbf{L_p}$	L_I-$L_{I,mean}$	$L_{I,min}$-L_p	L_{p1}-L_{p2}
63	59.7	62.2	61.8	61.8	**62.7**	-5.4	-3	0.3
125	63.2	64.8	65.5	65.4	**66.2**	-4.5	-3	0.3
250	66.4	68.2	67.9	67.5	**66.7**	-1.8	-0.3	-0.6
500	63.4	62.5	63	62.6	**63.1**	-3.8	-0.6	-0.6
1000	63.7	64.8	65.6	65.7	**65.2**	-6.6	-1.5	0.0
2000	64.4	65.3	66	66	**65.5**	-6.0	-1.1	-0.1
4000	60.8	62.1	62.8	62.9	**61.7**	-7.5	-0.9	-0.1
8000	55.8	58.3	58.9	59.2	**55.1**	-9.6	0.7	-0.4
A	69.8	70.8	71.4	71.4	**70.7**	-6.2	-0.9	-0.2

Data:n:geir\project\fig3-9.xls

5.3 Comparisons between different methods

The test object of figure 2.1 was placed in the middle of the room on the standard test table. The microphone was oriented 30° below the horizontal plane. In addition the emission sound pressure level was determined according to ISO 11202 and, when possible, ISO 11204. The result is sumarized for A-weighted levels in figure 5.4. As before L_{IA} is the measured sound intensity level and L_{pA} is the actual sound pressure level in the measurement position. As before the different measurement positions are

1. 0,25 m left
2. 0,25 m rear
3. 0,25 m right
4. 0,25 m front
5. 0,4 m left
6. 0,4 m rear
7. 0,4 m right
8. 0,4 m front
9. 1 m left
10. 1 m rear
11. 1 m right
12. 1 m front

ISO 11204 was only applicable in one single case!

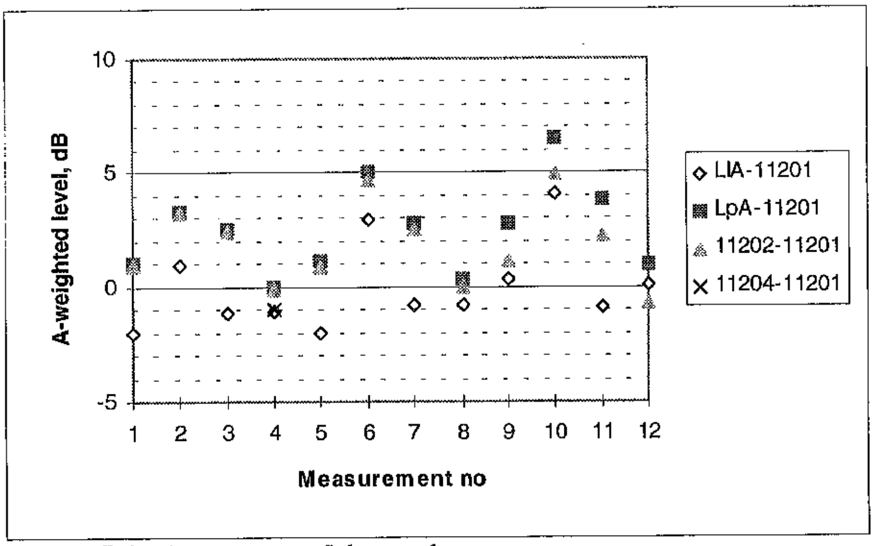

Figure 5.4 A summary of the results

The results indicate that ISO 11204 has severe limitations in its applicability and that the intensity method normally is better than ISO 11202. ISO 11202 is better in some cases where the intensity method underestimates the emission sound pressure level. In this test the underestimate was especially large because the probe was not alway orientated to yield the highest sound intensity level. It was constantly directed 30° below the horizontal plane. 11202 is very bad in positions 2, 6 and 10 on the rear side of the source where the main sound radiation of the source is in other directions.

The following notation has been used in the following tables:

$L`_p$- The uncorrected sound pressure level measured at the specified position with intensity probe.
L_I- The sound intensity level measured at the specified position.
$L_{p,1\text{-}6}$- the sound pressure level corrected according to ISO 11204. See explanation below.
$L_{p,7}$- the sound pressure level corrected according to ISO 11202
$L`_{p,4165}$- The uncorrected sound pressure level measured at the specified position with free field microphone
L_p- the sound pressure level according to ISO 11201, see clause 3.
L_I-$L_{I,\,mean}$- The difference between the sound intensity level and the mean sound intensity level around the object. (directivity indicator).
p-I- The field indicator (notation L_k, Norsonic 830, or F2, ISO 9614) is the difference between the two levels, $L_k = L_p$-L_I
$L_{p,1}$- The corrected emission sound pressure level. The local environmental correction, K_3, is calculated from A.2 according to ISO 11204. L` mean is determined from five sound pressure measurements around the the object under test. K_2 is determined from measurements of the sound absorption of the room.
$L_{p,2}$- The corrected emission sound pressure level. The local environmental correction, K_3, is calculated from A.2 according to ISO 11204. L` mean is determined from five sound pressure measurements around the the object under test. K_2 is determineded according to table 5 in ISO 3746
$L_{p,3}$- The corrected emission sound pressure level. The local environmental correction, K_3, is calculated from A.2 according to ISO 11204. L` mean is determined from sound power measurements. K_2 is determined from measurements of the sound absorption of the room.
$L_{p,4}$- The corrected emission sound pressure level. The local environmental correction, K_3, is calculated from A.2 according to ISO 11204. L` mean is determined from sound power measurements. K_2 is determined according to table 5 in ISO 3746.
$L_{p,5}$- The corrected emission sound pressure level. Calculated the local environmental, K_3, from A.3 according to ISO 11204. L` mean is determinated from five sound pressure measurements around the the test object under test. K_2 is determined with measurements of the absorptions coefficients in the room.
$L_{p,6}$- The corrected emission sound pressure level. The local environmental correction, K_3, is calculated from A.2 according to ISO 11204. L` mean is determined from five sound pressure measurements around the the object under test. K_2 is determined according to table 5 in ISO 3746.
$L_{p,7}$- The corrected emission sound pressure level. The local environmental correction, K_3, is calculated according to ISO 11202 .

Table 5.4a Front side. Microphone 0,4 m from the object. Standing operator.

Freq.	Measured L`p	L_I	11204 L_p1	11204 L_p2	11204 L_p3	L_p4	L_p5	L_p6
63	73.7	73.9	71.7	71.5	72.8	72.6	71.7	72.6
125	76.9	76.4	75.9	75.5	76.1	75.5	75.9	75.5
250	74.7	72.8	73.1	72.3	74.1	73.4	73.1	73.4
500	75.5	73.8	74.7	74.2	75.1	74.6	74.7	74.6
1000	80.3	78.5	79.7	79.4	79.9	79.6	79.7	79.6
2000	79.6	78.3	79.1	78.9	79.1	78.8	79.1	78.8
4000	77.2	76,7	76.5	76.4	76.6	76.2	76.5	76.2
8000	71.1	73,9	69.9	69.4	70.2	69.2	69.9	69.2
A	85.1	84,0	84.5	84.3	84.6	84.3	84.5	84.3

Figure and data: n:\geir\projekt\PI10fs.xls

Freq.	Measured L`p	L_I	11202 L_p7	$L`_{p,4165}$	L_p	L_I-$L_{I, mean}$	F_{pI}
63	73.7	73.9	73.4	73.6	**67,1**	7,8	-0.2
125	76.9	76.4	76.6	76.8	**78,1**	5,8	0.6
250	74.7	72.8	74.4	74.5	**72,9**	4,6	1.9
500	75.5	73.8	75.2	75.5	**74,7**	7,3	1.6
1000	80.3	78.5	80.0	80.2	**79,5**	8,2	1.8
2000	79.6	78.3	79.3	79.7	**79,2**	8,6	1.3
4000	77.2	76,7	76.9	77.9	**77,4**	10,7	0,5
8000	71.1	73,9	70.8	73.5	**72,8**	11,5	-2,8
A	85.1	84	84.8	85.4	**84,8**	8,7	1,1

Figure and data: n:\geir\projekt\PI10fs.xls

Table 5.4b Left side. Microphone 0,4 m from the object. Standing operator.

Freq.	L`p	L_I	11202 L_p7	L_p	L_I-$L_{I, mean}$	F_{pI}
63	68.4	67.5	68.0	**65,6**	1,4	0.9
125	70.5	69.9	70.2	**72,3**	-0,7	0.6
250	70.7	69.0	70.4	**70,3**	0,8	1.7
500	67.3	64.5	67.0	**66,3**	-2,0	2.7
1000	71.6	68.5	71.3	**71,0**	-1,8	3.1
2000	71.1	67.8	70.8	**69,6**	-2,0	3.3
4000	66.7	63,1	66.4	**64,7**	-2,9	3,6
8000	61.3	58,9	61.0	**58,1**	-3,9	2,4
A	76.3	73.2	76.0	**75,2**	-2,0	3,1

Figure and data: n:\geir\projekt\PI10vs.xls

Table 5.4c Rear side. Microphone 0,4 m from the object. Standing operator.

Freq.	L`p	L_I	L_p7	L_p	L_I-$L_{I, mean}$	F_{pI}
63	64.7	59.9	64.4	**61,2**	-6,2	4.8
125	65.8	65.8	65.5	**64,6**	-4,8	0.0
250	65.5	62.5	65.2	**61,9**	-5,8	2.9
500	65.8	63.0	65.5	**61,1**	-3,5	2.8
1000	68.7	66.4	68.4	**64,6**	-3,9	2.3
2000	67.8	65.7	67.5	**62,7**	-4,1	2.1
4000	63.9	61,9	63.6	**56,3**	-4,1	2,0
8000	58.2	59,4	57.9	**47,0**	-3,1	-1,2
A	73.3	71,2	73.0	**68,3**	-4,0	2,1

Figure and data: n:\geir\projekt\PI10bs.xls

Table 5.4d Right side. Microphone 0,4 m from the object. Standing operator.

Freq.	L`p	L_I	L_p7	L_p	L_I-$L_{I, mean}$	F_{pI}
63	67.0	63.2	66.7	65,3	-2,9	3.8
125	72.1	70.3	71.8	71,3	-0,3	1.8
250	72.0	68.7	71.7	69,2	0,5	3.4
500	67.6	64.6	67.3	65,5	-1,9	3.0
1000	71.6	67.8	71.3	69,0	-2,5	3.8
2000	70.6	67.2	70.3	67,8	-2,6	3.4
4000	66.5	62,3	66.2	63,1	-3,7	4,2
8000	60.5	57,6	60.2	56,0	-4,9	2,9
A	76.2	72.6	75.9	73,4	-2,6	3,6

Figure and data: n:\geir\projekt\PI10hs.xls

Table 5.5a Left side. Microphone 1 m from the object. Standing operator.

Freq.	L`p	L_I	11202 L_p7	L_p	L_I-$L_{I, mean}$	F_{pI}
63	70.2	66.8	68.5	62,2	3,7	3.3
125	65.5	66.1	63.8	64,9	-3,2	-0.6
250	69.6	68.0	67.9	67,7	0,2	1.6
500	66.0	64.0	64.4	63,1	-1,1	2.0
1000	69.8	66.6	68.2	66,5	-0,6	3.2
2000	69.6	67.2	68.0	67,2	-0,5	2.4
4000	65.3	62.9	63.7	62,8	-1,4	2,4
8000	59.4	59,4	57.8	56,2	-1,5	0
A	74.8	72.3	73.1	72,0	-0,7	2,5

Figure and data: n:\geir\projekt\PI11vs.xls

Table 5.5b Rear side. Microphone 1 m from the object. Standing operator.

Freq.	L`p	L_I	L_p7	L_p	L_I-$L_{I, mean}$	F_{pI}
63	64.6	58.0	62.9	57,4	-2,0	6.5
125	67.6	64.9	66.0	60,8	-1,1	2.7
250	66.5	61.8	64.8	58,9	-2,9	4.7
500	62.9	60.1	61.3	58,1	-4,2	2.8
1000	65.8	62.6	64.1	59,3	-4,6	3.2
2000	65.5	63.3	63.8	59,5	-4,6	2.2
4000	61.8	59,6	60.2	53,2	-4,9	2,2
8000	57.0	58,7	55.4	46,8	-3,9	-1,7
A	70.9	68.5	69.3	64,4	-4,6	2,4

Figure and data: n:\geir\projekt\PI11bs.xls

Table 5.5c Right side. Microphone 1 m from the object. Standing operator.

Freq.	L`p	L_I	L_p7	L_p	L_I-$L_{I, mean}$	F_{pI}
63	64.7	59.7	63.0	62,7	-1,8	5.0
125	70.8	63.2	69.2	66,2	2,1	7.7
250	68.5	66.4	66.8	66,7	-0,9	2.0
500	66.5	63.4	64.9	63,1	-0,6	3.1
1000	69.5	63.7	67.9	65,2	-0,9	5.8
2000	68.9	64.4	67.3	65,5	-1,2	4.5
4000	65.7	60.8	64.1	61,7	-1,0	4,9
8000	59.7	55.8	58.1	55,1	-1,2	3,9
A	74.5	69.8	72.9	70,7	-1,0	4,7

Figure and data: n:\geir\projekt\PI11hs.xls

Table 5.5d Front side. Microphone 1 m from the object. Standing operator.

Freq.	L`p	L_I	11202 L_p7	**L_P**	L_I-$L_{I, mean}$	F_{pI}
63	66.7	68.2	65.1	**63,5**	0,2	-1.5
125	70.9	71.5	69.2	**72,2**	2,2	-0.7
250	73.0	71.6	71.4	**70,4**	3,6	1.4
500	73.0	71.9	71.4	**71,9**	5,9	1.1
1000	76.5	75.3	74.9	**75,5**	6,1	1.2
2000	76.5	75.3	74.9	**75,1**	6,4	1.2
4000	73.9	73,6	72.2	**73,5**	7,2	0,3
8000	67.6	70,7	65.9	**68,5**	6,7	-3,1
A	81.8	81,0	80.2	**80,8**	6,3	0,8

Figure and data: n:\geir\projekt\PI11fs.xls

Table 5.6a Front side. Microphone 0,25 m from the object. Standing operator.

Freq.	L`p	L_I	L_p7	**L_p**	L_I-$L_{I, mean}$	pI
63	70.6	67.1	70.5	**69,9**	2,3	3.5
125	79.1	77.9	78.9	**80,2**	6,9	1.2
250	75.3	73.6	75.2	**74,0**	4,5	1.7
500	75.7	74.0	75.6	**75,0**	7,1	1.7
1000	79.7	78.1	79.6	**80,0**	7,8	1.6
2000	80.7	79.2	80.6	**80,3**	9,1	1.5
4000	77.6	76.8	77.5	**77,9**	10,8	0.7
8000	71.9	74.5	71.7	**73,1**	11,7	-2.6
A	85.5	84.4	85.4	**85,5**	8,9	1,1

Figure and data: n:\geir\projekt\PI14fs.xls

Table 5.6b Left side. Microphone 1 m from the object. Standing operator.

Freq.	L`p	L_I	L_p7	**L_p**	L_I-$L_{I, mean}$	F_{pI}
63	66.5	65.4	66.4	**66,5**	0,6	1.2
125	73.0	70.7	72.9	**73,6**	-0,3	2.3
250	72.2	70.1	72.1	**71,0**	1,0	2.1
500	68.6	65.7	68.4	**66,8**	-1,2	2.9
1000	72.1	68.7	72.0	**71,7**	-1,6	3.4
2000	71.6	68.5	71.5	**70,2**	-1,6	3.0
4000	66.7	63.7	66.6	**65,0**	-2,3	3.0
8000	60.9	59.3	60.8	**57,7**	-3,5	1.7
A	76.8	73.8	76.7	**75,8**	-1,7	3,0

Figure and data: n:\geir\projekt\PI14vs.xls

Table 5.6c Rear side. Microphone 1 m from the object. Standing operator.

Freq.	L`p	L_I	L_p7	**L_p**	L_I-$L_{I, mean}$	F_{pI}
63	66.0	62.5	65.9	**62,1**	-2,3	3.6
125	67.0	64.2	66.9	**66,3**	-6,8	2.8
250	67.0	63.0	66.9	**62,4**	-6,1	4.0
500	65.3	62.3	65.1	**62,3**	-4,6	3.0
1000	68.9	66.4	68.8	**66,0**	-3,9	2.5
2000	67.5	65.2	67.4	**64,7**	-4,9	2.3
4000	63.1	60.9	63.0	**57,2**	-5,1	2.2
8000	57.9	59.1	57.7	**47,6**	-3,7	-1.3
A	73.2	70.8	73.1	**69,9**	-4,7	2,4

Figure and data: n:\geir\projekt\PI14bs.xls

Table 5.6d Right side. Microphone 1 m from the object. Standing operator.

Freq.	L'_p	L_I	L_p7	L_p	L_I-$L_{I, mean}$	F_{pI}
63	69.7	64.1	69.6	66,6	-0,7	5.6
125	71.8	71.3	71.7	73,1	0,3	0.5
250	71.6	69.6	71.5	70,0	0,5	2.0
500	69.6	65.5	69.5	66,1	-1,4	4.1
1000	72.2	68.1	72.1	69,7	-2,2	4.2
2000	71.2	67.5	71.0	68,8	-2,6	3.6
4000	66.4	62.6	66.3	63,8	-3,4	3.8
8000	60.1	58.3	60.0	56,5	-4,5	1.8
A	76.7	73.0	76.6	74,2	-2,5	3,7

Figure and data: n:\geir\projekt\PI14hs.xls

6 Discussion of the preliminary measurements

The preliminary measurements have shown that the sound intensity method is very promising. However, there are still some problems:

1. Close to a sound source or when the sound source is elevated above the ground the sound intensity methods tends to underestimate the emission sound pressure level. It should, however, be possible to keep this underestimate within reasonable limits by directing the intensity probe in the direction of maximum sound intensity level and by limiting the method to cases where the environmental indicator, K_2, is larger than 1 or 2 dB.
2. It seems to be difficult to evaluate the reliability of the measurements. Three different indicators have been tested. The most promising one seems to be the directivity indicator, L_I-L_{Imean}. When it is positive the error seems to be small. The other indicators seem to give rather confusing information. The traditional field indicator L_p-L_I varies much between, for example, the reverberation room and the office. In the reverberation room it is possible to get accurate results with the indicator larger than 10 dB and in the office an indicator less than 5 dB will not guarantee good results. Anyhow it seems to be clear that the field indicator alone cannot be used to assess the measurement uncertainty.
3. There seems to be a trend, see the table below, to overestimate the sound pressure level when the field indicator, F_{pI}, is large and to underestimate it when it is small. The underestimate occurs when there are non-diffuse reflections.

F_{pI}	L_I - L_{Imean}	Error
Low	Large	Underestimate
Low	Small	Overestimate
High	Large	Accurate
High	Small	Overestimate

Despite the problems above it seems clear that the intensity method is superior to all alternatives. ISO 11204 has a surprisingly limited applicability and it cannot be regarded as a universal field method. ISO 11202, on the other hand, is always applicable but it has the disadvantage of occasionally making very large errors, in particular in reverberant test environments and when the main sound radiation is in directions other than that towards the measurement point.

The remaining problems are not strictly coupled to the measurement itself but rather to the assessment of the measurement uncertainty afterwards.

7 Preliminary proposal for Nordtest method

Before the comparison measurements started a first proposal for Nordtest method was elaborated and discussed by the participants. This first proposal did not say anything about the measurement uncertainty nor did it state how to assess the test results. As the comparison measurements did not have any consequence on the measurement procedure but only on the assessment of the quality of the measurements the preliminary proposal is not repeated here. In stead reference is made to the final proposal in clause 9.

In the final proposal the following supplements in relation to the preliminary proposal have been made:

- The field indicator has been restricted to 12 dB.
- The environmental indicator has been restricted to > 2 dB
- When the probe is located closer than 0,5 m to a reflecting surface this surface is to be covered with sound absorbing material
- The background level has to at least 10 dB below the source level and no corrections are allowed
- If the intensity flow is in the wrong direction the measurement is not valid
- If the machine is located in front of a wall it is not possible to simulate hemi free conditions.

8 Nordic comparison measurements

8.1 General

The test program and the instructions to the participants were as follows(The sound power determinations are not included in this report):

Test two different machines, preferably of different sizes. Apply the procedures of the relevant ISO standard and the Nordtest proposal dated 1995-01-24. To save time you may always measure L_p with the intensity probe(at least with a B&K 2-microphone probe. On each machine carry out the following measurements, in third octave bands, 50-10 000(intensity 5000, correct for frequency response) Hz:

1. Determine the sound power level with at least 4 different methods, preferably a) ISO 3741, b) 3743-1, c) 3744 och d) 9614-2. You are welcome to add ISO 3746 as an option!
2. Measure the repeatability 5 times using one of the sound power methods. Denote the measurement a), b), c) or d) depending on the sound power method used.
3. Measure the emission sound pressure level(L_{eq} and L_{pCpeak}) and the intensity level in an environment according to ISO 11201. Measure at at least 3 different distances: a) 0,25 m, b) 0,4 m and c) 1,0 m. Measure in 4 directions(We need 4 directions to evaluate indicators according to the proposed Nordtest method): denote the measurements 3d)-3l). Note. At our meeting we talked about scanning around the measurement point. Include such measurements in one direction, but only in the 11201 environment.
4. Move the machine to another environment, envirinment I, preferably a "normal" environment, and mount it away from the walls. Carry out the same measurements as in 3, denote 4a)-4l) but, in addition, evaluate the result according to ISO 11202, 4.1 a)-4.1 l) and 11204(use L_W according to ISO 3741 when evaluating K_3, 4.2 a)-4.2 l).
5. Move the machine to another environment, environment II, preferably a "normal" environment, and mount it away from the walls. Carry out the same measurements and evaluations as in 4.
6. Repeat 4 or 5 with the machine along one of the walls.
7. Evaluate the emission sound pressure level according to ISO 11204 for the three distances according to 3, denote 7a)-7c).

Report the results on disk, if possible in Excel for Windows format. Use the notation above(1a), 3b) etc). Report data primarily in third octaves but include octave band data and A-weighted for emission sound pressure level. For future use also report all third octave band values.

Your test report should also contain the following:

- A short description of the test rooms(including K_2 for non-laboratory rooms)
- A description of the machines tested
- The partial sound power levels of ISO 9614-2 of the 5 sides of the measurement surfaces
- The sign of the intensity level whenever it is <0.

The reference measurements of each laboratory according to ISO 11201 are to be found in annex B. The repeatability and stabilty of the sound sources are given in annex C.

8.2 Sources and test environments used by the participants

8.2.1 Swedish National Testing and Research Institute(SP)

SP used two test sources as shown in figure 8.1 and 8.2. Test source 1 was a radio base station. It had one opening with cooling fans as shown in figure 8.1. The other test source was a traditional household vaccuum cleaner placed on a table as shown in figure 8.2. Both sources had a rather high directivity, see annex B.

Figure 8.1 Test source 1 of SP, 0,705 m x 0,45 m x 1,292 m.

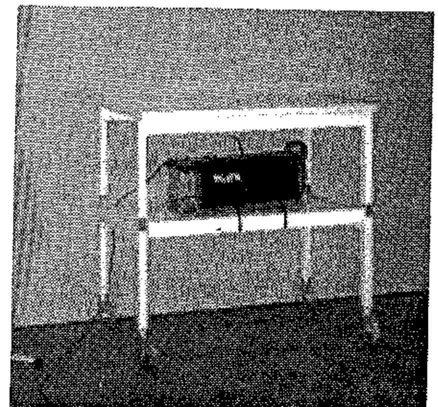

Figure 8.2 Test source 2 of SP. Vaccuum cleaner in wall position, 0,9 m x 0,6 m x 0,85 m.

The sources were tested in 3 different environments. One was a hemi-anechoic room complying with ISO 3745 which was used to get the ISO 11201 reference values for the 12 different measurement points around each machine. The others were a small office, 3,95 m x 2,9 m x 2,4 m = 27,5 m^3, and a carpenter's workshop, 8,31 m x 6,08 m, 2,44 m = 123 m^3. Both rooms were without sound absorptive treatment with floor and ceiling of concrete and walls of gypsum boards.

8.2.2 National Research Centre of Finland(VTT)

VTT used two test sources as shown in figure 8.3 and 8.4. Both sources, in particular the disc saw, had a bad repeatability and narrow band noise at 125 and 250 Hz.

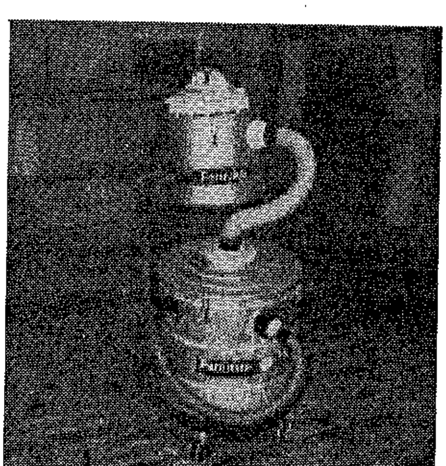

Figure 8.3 Test source 1 of VTT Vaccuum cleaner, 0,6 m x 0,5 m x 1,2 m

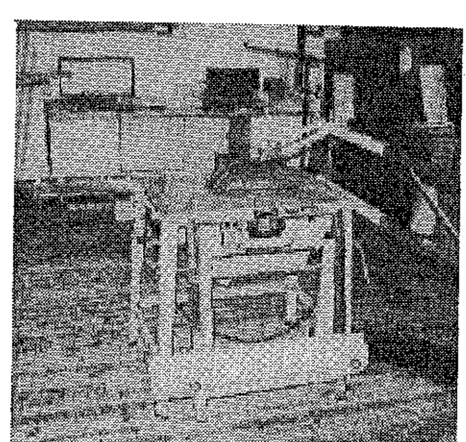

Figure 8.4 Test source 2 of VTT. Disc saw, 0,8 m x 0,6 m x 1 m

The sources were tested in 3 different environments. One was a hemi-anechoic room complying with ISO 3745 which was used to get the ISO 11201 reference values for the 12 different measurement points around each machine. The other two environments were a carpenter's workshop, 6 m x 7 m x 3,1 m with a 30 mm ceiling absorber, and a metal workshop, L-shaped 6,3 m x 5,8 m + 9,1 m x 3,9 m with the height 6,7 m, respectively.

8.2.3 DELAB, Norway

DELAB used two test sources. One was a B&K 4204 reference sound source as shown in figure 8.5 and the other was an ILG fan source mounted in a chipboard box, 0,34 m x 0,44 m x 0,35 m. The box had two holes, Φ 140 mm, in each short wall nearly aligned with the horizontal motor axis. The hole at the motor end was equipped with a mesh to reduce wind at the microphone position. The box was equipped with 40 mm high foam plastic base for vibration insulation. The total source reference box dimensions W x L x H = 0,34 x 0,44 x 0,39 m. Measurement direction no.1 was outside the hole at the fan end, no. 3 outside the hole at the motor end.The sources were placed on a table, see figure 8.6

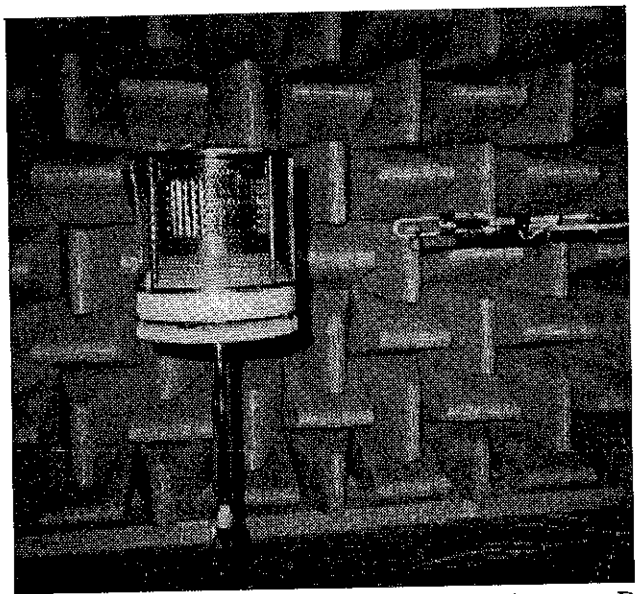

Figure 8.5 A B&K 4204 reference sound source. Diameter x Height = 300 x 320 mm.

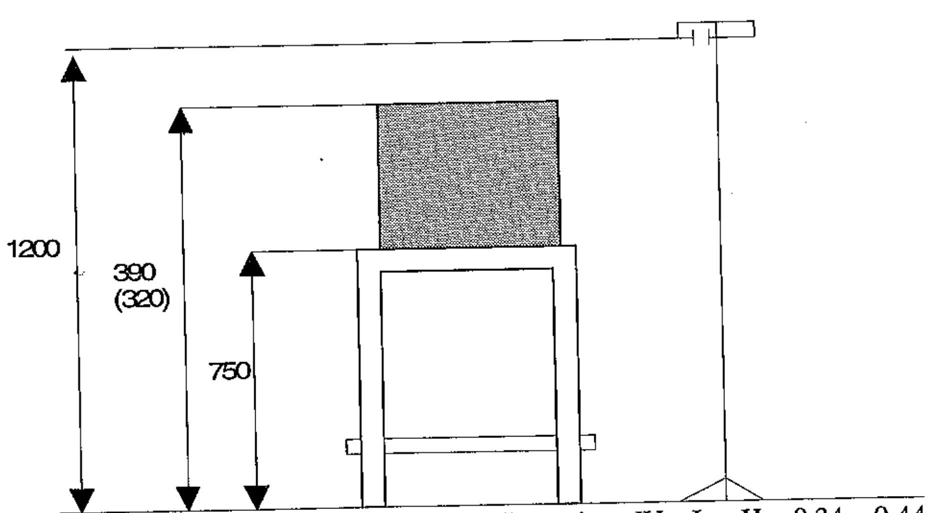

Figure 8.6. Test arrangement Delab. Table dimensions W x L x H = 0,34 x 0,44 x 0,75 m.

The sources were tested in 4 different environments. One was a hemi-anechoic room complying with ISO 3744 which was used to get the ISO 11201 reference values for the 12 different measurement points around each machine. The hemi-anechoic room does not comply with ISO 3745 below 400 Hz. Two of the other environments were in the middle of a large hall, 14 m x 9 m x 6 m with some sound absorbers in the ceiling and with miscellaneous objects, and close to one of the walls respectively. Finally one environment was a hard room, 4 m x 6 m x 4.6 m with concrete surfaces, some hard objects and some low frequency absorbers.

8.2.4 Delta, Denmark

Delta used two test sources as shown in figure 8.7 and 8.8. Test source 1 was a fan unit with the outlet directed towards the floor to give a directional source, see figure 8.7. The other test source was a vaccuum cleaner placed on a plastic box. The motor was partially shielded and the suction device was partially covered(giving high frequency noise) and directed in a different direction, see figure 8.8.

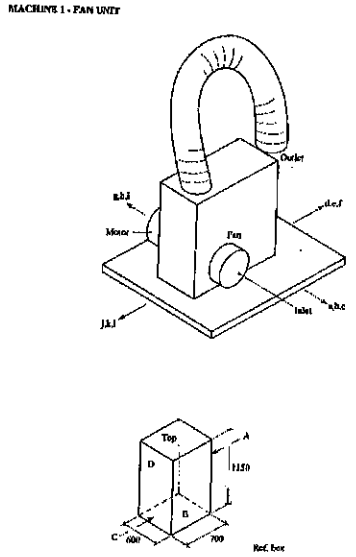

Figure 8.7 Test source 1 of Delta
0,6 m x 0,7 m x 1,15 m

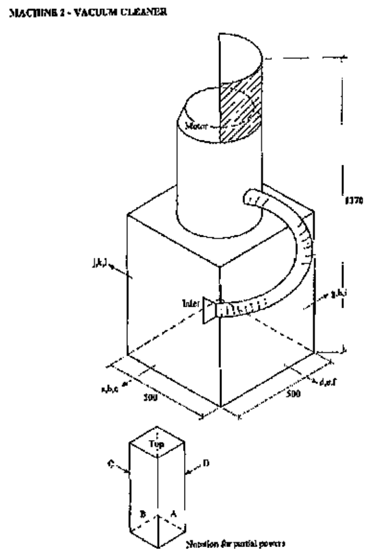

Figure 8.8 Test source 2 of Delta.
0,5 m x 0,5 m x 1,37 m

The room used for the reference measurements according to ISO 11201 was qualified according to ISO 3744 but unfortunately not for ISO 3745. This means that the reference for Delta is not the same as the one for SP and VTT. The dimensions of the room was (l x w x h): 7,75 m x 6,85 m x 3,25 m. The walls were covered by sound absorbing material and the ceiling was of "wooden concrete".

One of the other test environments was the same room as the one above but with only a small amount of sound absorbing material along the walls. The third environment had the dimensions (l x w x h): 6,15 m x 4,9 m x 3,9 m. The floor and ceiling were concrete and there were small amounts of sound absorbing material along the walls.

8.3 Results

8.3.1 SP

In figure 8.9 all results with the intensity method are summarized. By excluding measurements close to a wall(indicated ° in figure 8.9) the mean error drops from 0,2 dB to 0 dB and the standard deviation from 1,3 dB to 1 dB. The remaining points with an error exceeding 3 dB come from the measurements in a small office which also had some positions close to a wall. Obviously the method does not work well when the source is close to a wall. This is quite natural as that case in fact is quite different from the one we have in the hemi anechoic room. In order to get a fair comparison the source has to be mounted in front of a wall also in the "hemi-anechoic" case.

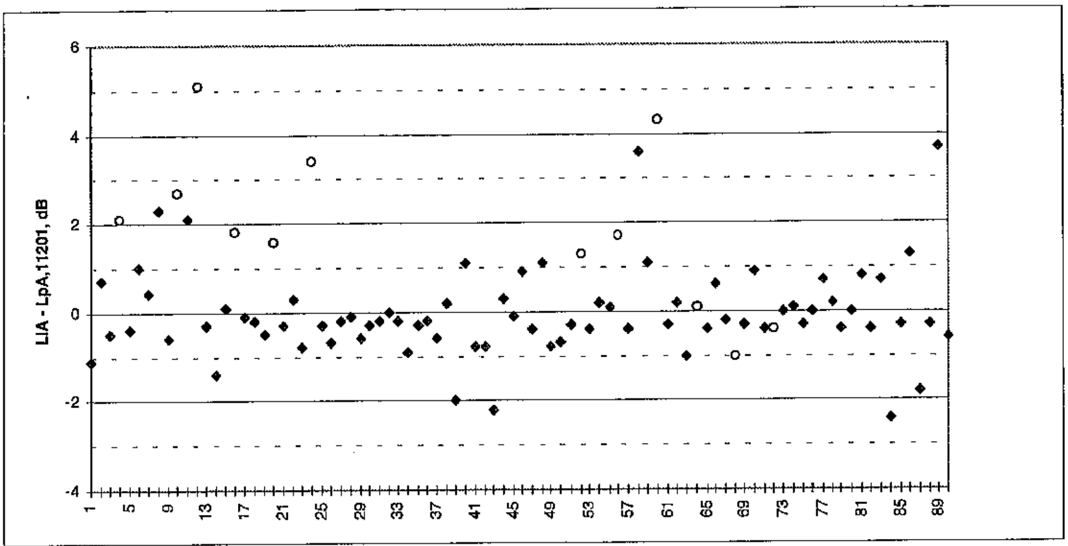

Figure 8.9 SP results for the intensity method. 2 machines in 4 different environments, 90 measurements. ° indicates measurements in side positions in front of a wall.

In table 8.1 and figure 8.10 all measurements apart from those in front of a wall have been included. We can see that the intensity method is superior to all alternatives but ISO 11204. However, ISO 11204 is applicable in less than 10% of all cases and these cases are the simplest ones. In general ISO 11202 overestimates the emission sound pressure level by several dB. Please note that the intensity values at 63 Hz and 8000 Hz are not very reliable and that ISO 11202 normally is used to determine A-weighted levels only.

Table 8.1 The numerical values of figure 8.10

Frequency	std .LI. 72 m.p.	mean LI, 72 m.p.	std.11202, 28 m.p.	mean 11202, 28 m.p.	std. 11204, 5 m.p.	mean 11204, 5.m.p.
63	3,6	-0,1	2,6	2,3	1,3	0,3
125	1,9	0,0	2,7	3,6		
250	1,4	-0,2	1,9	3,5	2,1	0,1
500	1,9	0,0	3,3	5,3	0,8	-0,4
1000	1,5	-0,6	3,1	5,1	1,3	-0,9
2000	1,3	0,5	3,8	6,1	0,7	-1,0
4000	2,5	1,0	4,8	7,8	1,9	-0,6
8000	3,4	2,3	4,1	7,3		
A-weighted	1,0	-0,1	2,8	4,9	1,1	-0,5

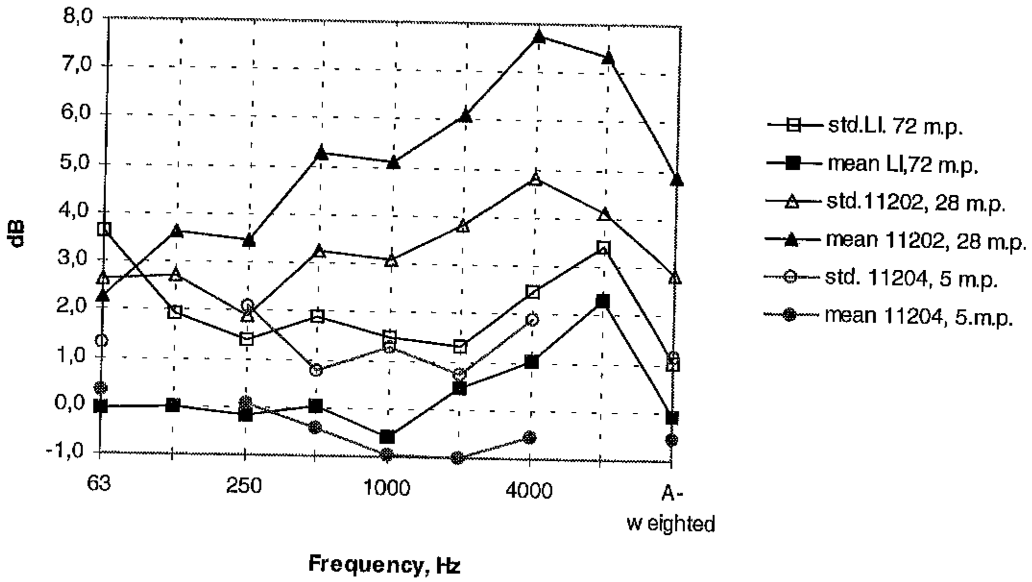

Figure 8.10 Mean values and standard deviations of the difference between the measured value and that of ISO 11201. Measurements on two sources at 3 distances in 3 test environments. Values with K2 > 7dB and < 2 dB have been excluded for ISO 11202. ISO 11204 did not work in most of the situations. All values with the test objects close to a wall have been excluded. (m.p = measurements points) res.concl/CU261

In figure 8.11 the intensity method is studied for the case L_I-$L_{I,mean}$> 0, that is we just look at the most favourable condition where we have the highest emission sound pressure level around the machine. The result is rather similar to that of figure 8.10 although there is a tendency of having significantly better results at high frequencies(4-8000 Hz).

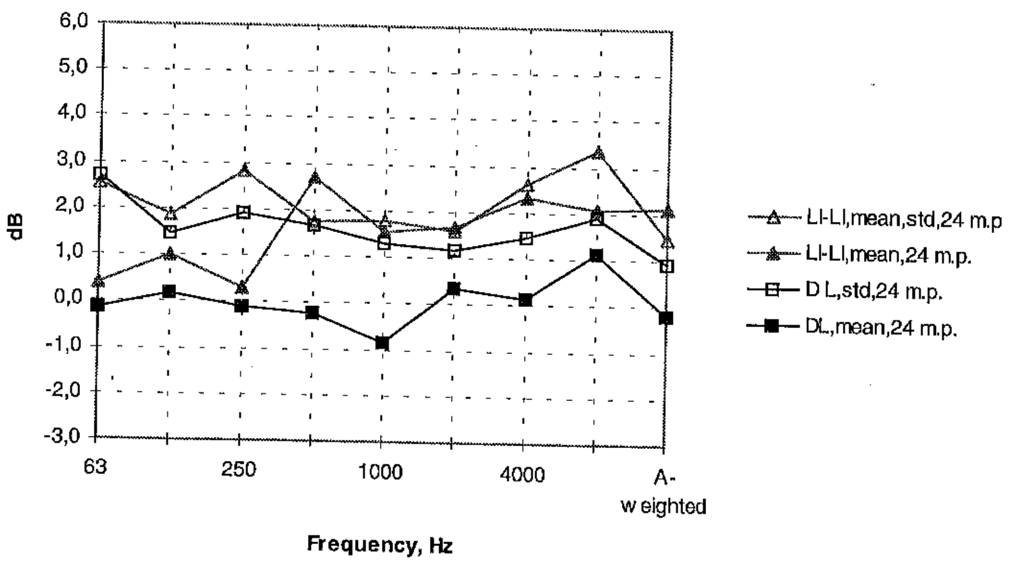

Figure 8.11 SP results. Mean values and standard deviations of L_I-$L_{I,mean}$ and ΔL when $L_{I\,A}$- $L_{IA,mean}$ is > 0 dB. From 24 measurements. ($\Delta L = L_I - L_p$,11201, the difference between the measured value and that of ISO 11201). indikator/GU198

In figure 8.12, on the other hand, the intensity method is studied for the case L_I-$L_{I,mean}$< 0, that is we just look at the most unfavourable condition where we have excluded the highest emission sound pressure level around the machine. The result is rather similar to that of figure 8.10 although there is a tendency of having significantly worse results at high frequencies(4000 Hz).

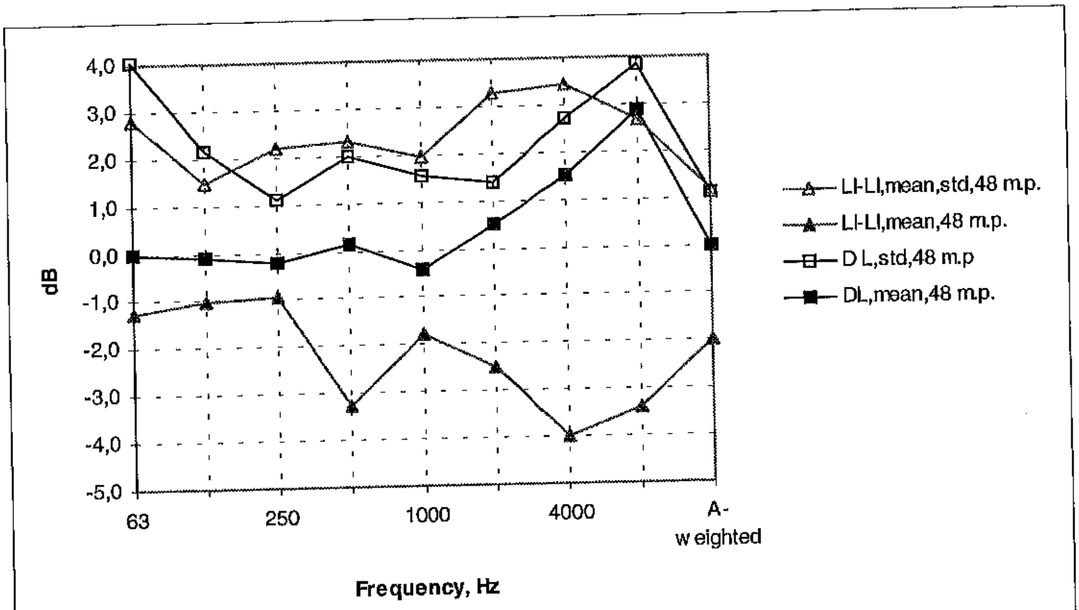

Figure 8.12 SP results. Mean values and standard deviations of L_I-$L_{I,mean}$, FpI and ΔL when $L_{I\,A}$- $L_{IA,mean}$ is < 0 dB. From 30 measurements. (ΔL =L_I-L_p,11201, the difference between the measured value and that of ISO 11201). indikator/GU236

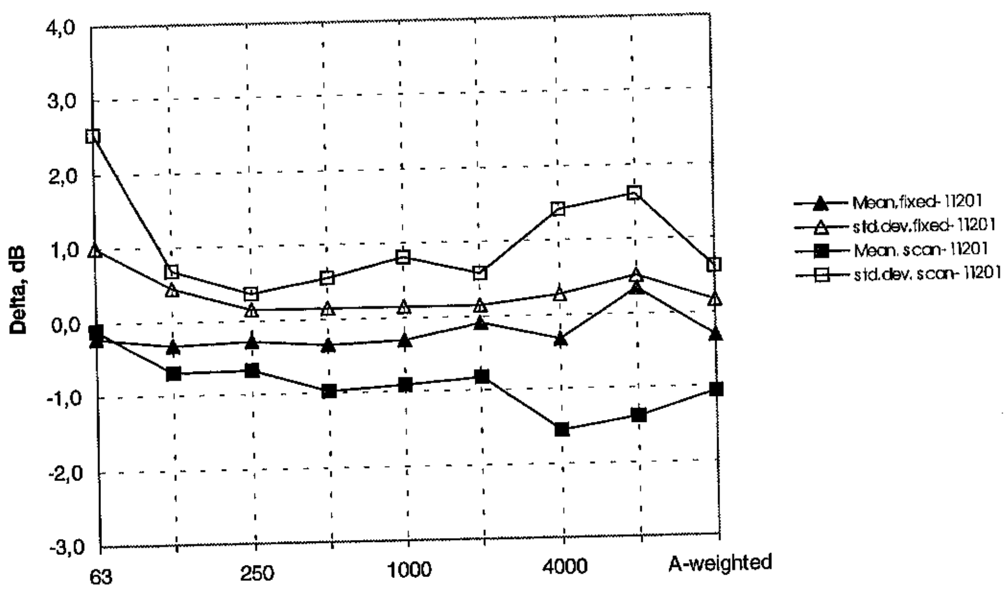

Figure 8.13 SP results. Mean values and standard deviations of the difference between the measured value and that of ISO 11201 when used fixed probe position and scanning around the measurement point for one direction. Measurements on two sources at 3 distances in hemi anechoic test environment

Finally in figure 8.13 the difference between one probe direction, the one giving the highest value, and a scan around the measurement point is shown. The result indicates that it is most accurate using a fixed position, at least as long as it is in the direction of maximum sound intensity level.

8.3.2 VTT

In figure 8.14 all results with the intensity method are summarized. As for SP, by excluding measurements close to a wall(indicated ° in figure 8.14), the result improves considerably.

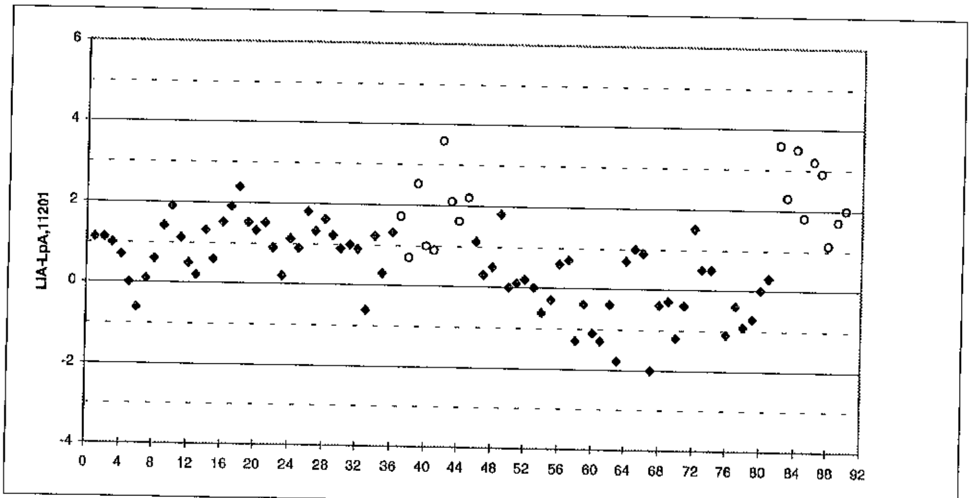

Figure 8.14 VTT results for the intensity method. 2 machines in 4 different environments. 90 measurements.° indicates measurements when the objects were placed near a wall. Sparad n:project\ntlpi\ finres.xls under blad:res.concl/BX157

In table 8.2 and figure 8.15 all VTT measurements apart from those in front of a wall have been included. Considering the large standard deviation of ISO 11204 the intensity method comes out with the best results. However the difference between the different methods is small. VTT did not report 63 Hz and 8000 Hz and they did only report A-weighted values for ISO 11202 and 11204.

Table 8.2 Numerical values of figure 8.15

Frequency	std,LI 72 m.p	mean,LI, 72 m.p.	std,11202, 48.m.p.	mean,11202, 48 m.p.	std,11204, 68 m.p.	mean,11204, 68 m.p
63						
125	2,0	0,6				
250	3,8	-2,0				
500	1,4	0,5				
1000	0,8	1,0				
2000	1,1	0,7				
4000	2,2	-1,3				
8000						
A-weighted	1,0	0,4	1,4	0,6	3,0	-1,3

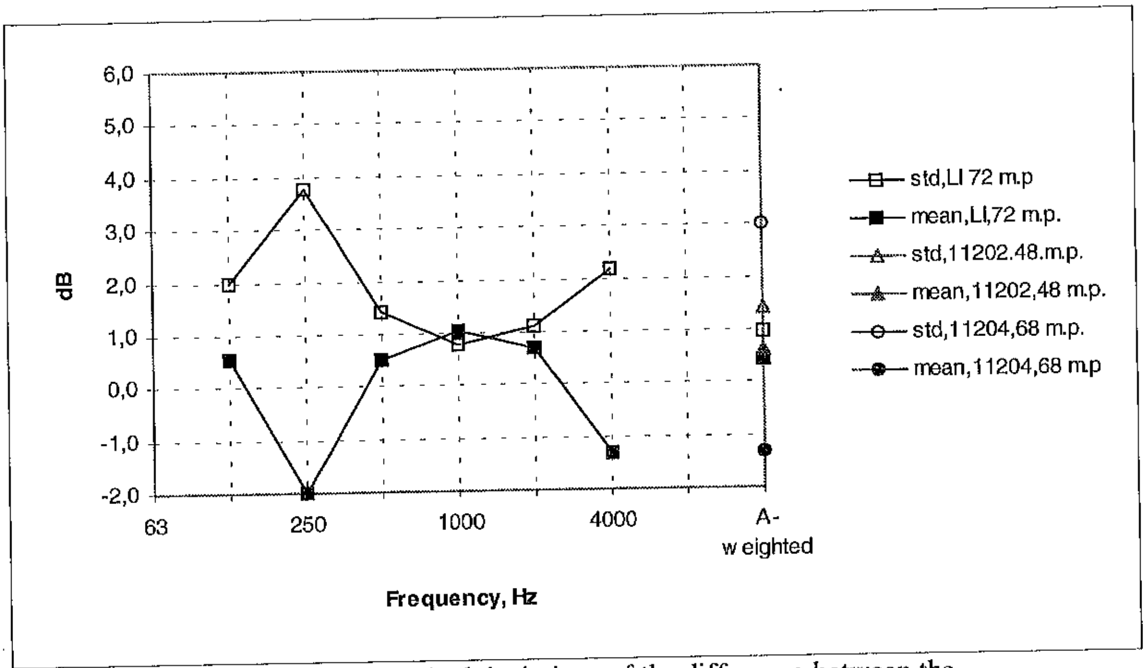

Figure 8.15 Mean values and standard deviations of the difference between the measured value and that of ISO 11201. Measurements on two sources at 3 distances in 3 test environments. Values with K2 < 2 dB have been excluded for ISO 11202. All values when the objects were placed near a wall have been excluded (m.p = measurements points).
n:project\ntlpi\ finres.xls under blad:res.concl/CS111

In figure 8.16 the intensity method is studied for the case L_I-$L_{I,mean}$> 0, that is we just look at the most favourable condition where we have the highest emission sound pressure level around the machine. The result is almost identical to that of figure 8.14.

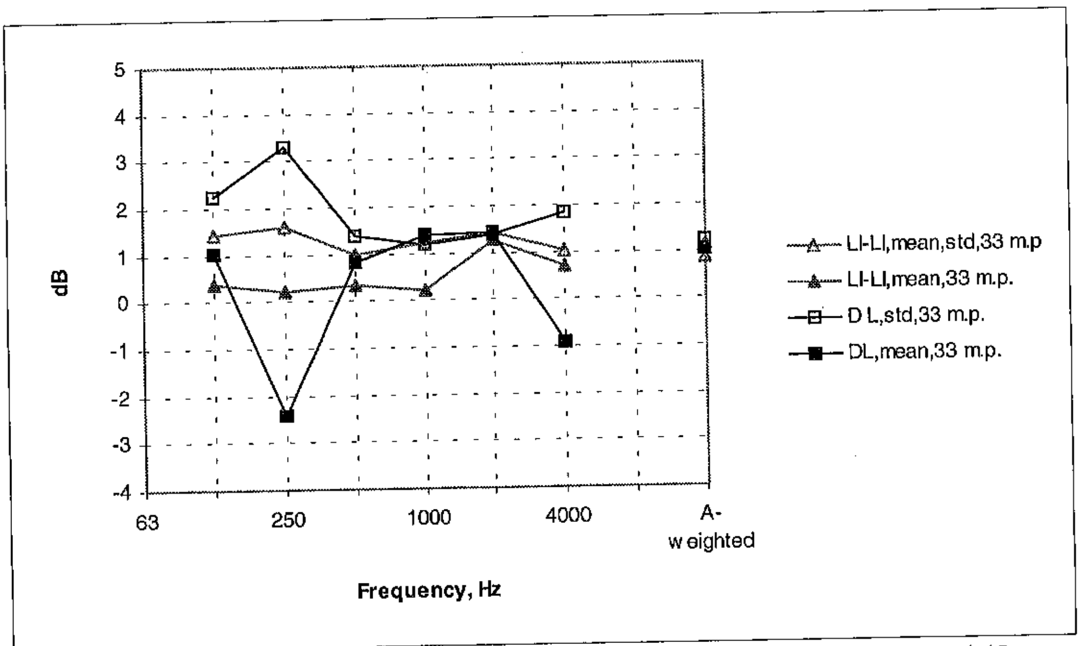

Figure 8.16 VTT results. Mean values and standard deviations of L_I-$L_{I,mean}$ and ΔL when $L_{I\ A}$- $L_{IA,mean}$ is > 0 dB. From 33 measurements. FpI was not recorded. (ΔL =L_I-L_p,11201, the difference between the measured value and that of ISO 11201). Sparad under blad:indicator/GK162

In figure 8.17, on the other hand, the intensity method is studied for the case L_I-$L_{I,mean}$< 0, that is we just look at the most unfavourable condition where we have excluded the highest emission sound pressure level around the machine. Also this result is almost identical to that of figure 8.15.

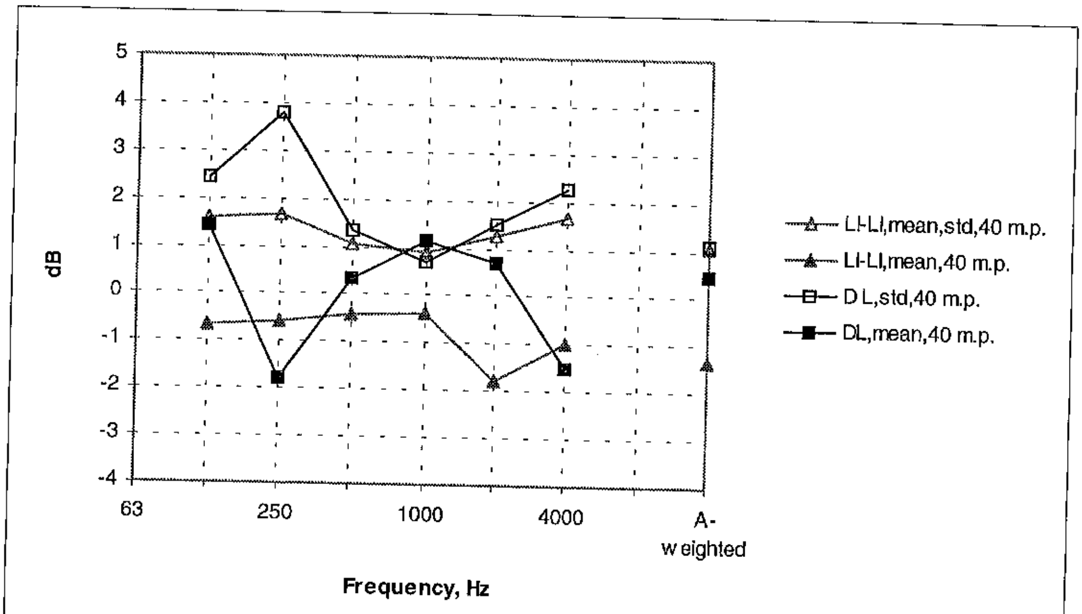

Figure 8.17 VTT results. Mean values and standard deviations of L_I-$L_{I,mean}$ and ΔL when $L_{I\ A}$- $L_{IA,mean}$ is < 0 dB. From 40 measurements. F_{pI} was not recorded. (ΔL =L_I-$L_{p,11201}$, the difference between the measured value and that of ISO 11201).
indicator/GK206

8.3.3 DELAB

In figure 8.18 all results with the intensity method are summarized. As for SP, by excluding measurements close to a wall(indicated ° in figure 8.18), the measured intensity levels drop considerably. We can see that the intensity method in the DELAB measurements tends to underestimate the emission sound pressure level. There are two known explanations for this. One is that DELAB did not adjust the direction of the probe for maximum reading. As can be seen in figure 8.21 scanning around the measurement point tends to give about 0,5 dB higher values on average. The direction of the maximum should increase this value further. Thus this measurement error should explain at least 0,5 dB of the nehgative mean error. Another explanation for the low values is that with this small and high mounted source the floor reflection contributes more to the sound pressure than to the sound intensity. The DELAB sources and mounting correspond closely to the example shown in figure 3.6.

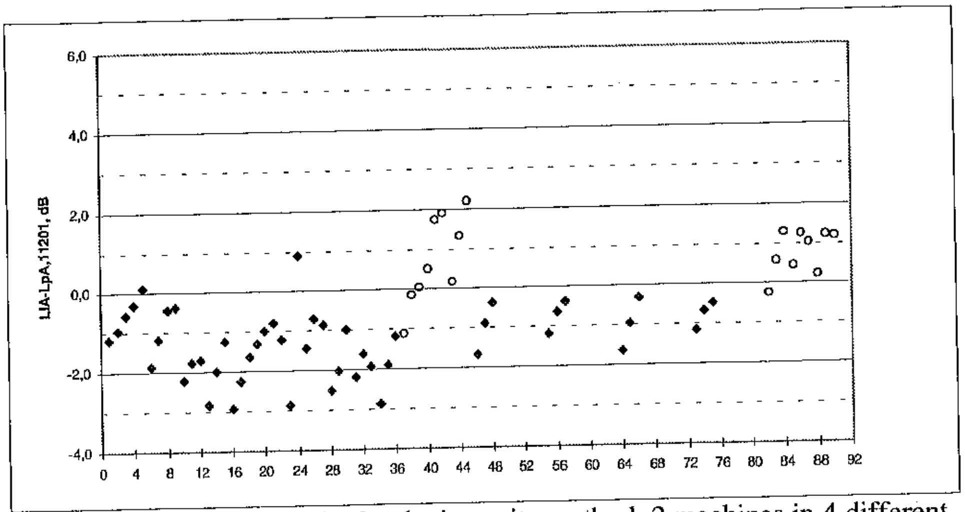

Figure 8.18 DELAB results for the intensity method. 2 machines in 4 different environments. 66 measurements. ° indicates measurements when the objects were placed near a wall. Sparad n:project\ntlpi\ nores.xls under blad:res.concl/cv202

In table 8.3 and figure 8.19 all DELAB measurements apart from those in front of a wall have been included.

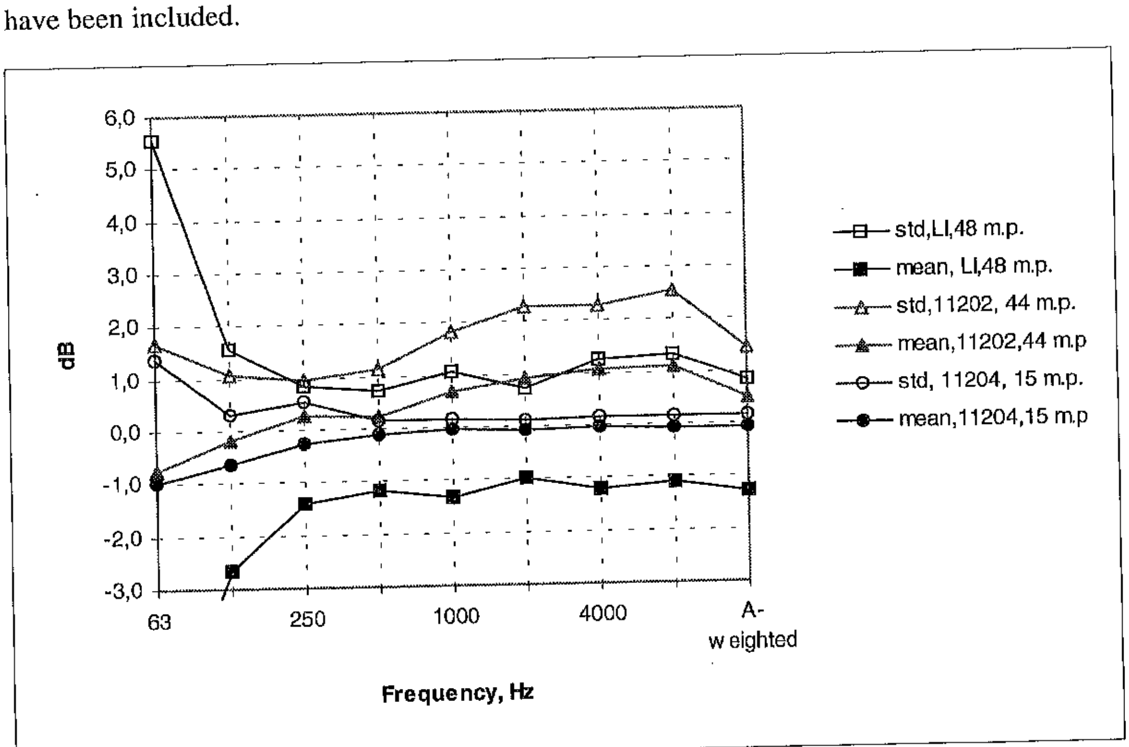

Figure 8.19 Mean values and standard deviations of the difference between the measured value and that of ISO 11201. Measurements on two sources at 3 distances in 3 test environments. All values when the objects were placed near a wall are excluded. Sparad under blad res.concl/CV161

Table 8.3 Numerical valus of figure 8.19

Frequency	std,LI, 48 m.p.	mean, LI, 48 m.p.	std,11202, 44 m.p.	mean,11202, 44 m.p	std, 11204, 15 m.p.	mean,11204, 15 m.p
63	5,5	-6,3	1,7	-0,8	1,4	-1,0
125	1,6	-2,6	1,1	-0,2	0,3	-0,6
250	0,8	-1,4	1,0	0,3	0,5	-0,3
500	0,7	-1,2	1,2	0,2	0,2	-0,1
1000	1,1	-1,3	1,8	0,7	0,1	0,0
2000	0,7	-1,0	2,3	0,9	0,1	-0,1
4000	1,3	-1,2	2,3	1,1	0,1	-0,1
8000	1,3	-1,1	2,5	1,1	0,1	-0,1
A-weighted	0,8	-1,3	1,4	0,5	0,2	-0,1

In figure 8.20 the intensity method is studied for the case L_I-$L_{I,mean}$> 0, that is we just look at the most favourable condition where we have the highest emission sound pressure level around the machine. The result is rather similar to that of figure 8.19 although the standard deviation is significantly lower.

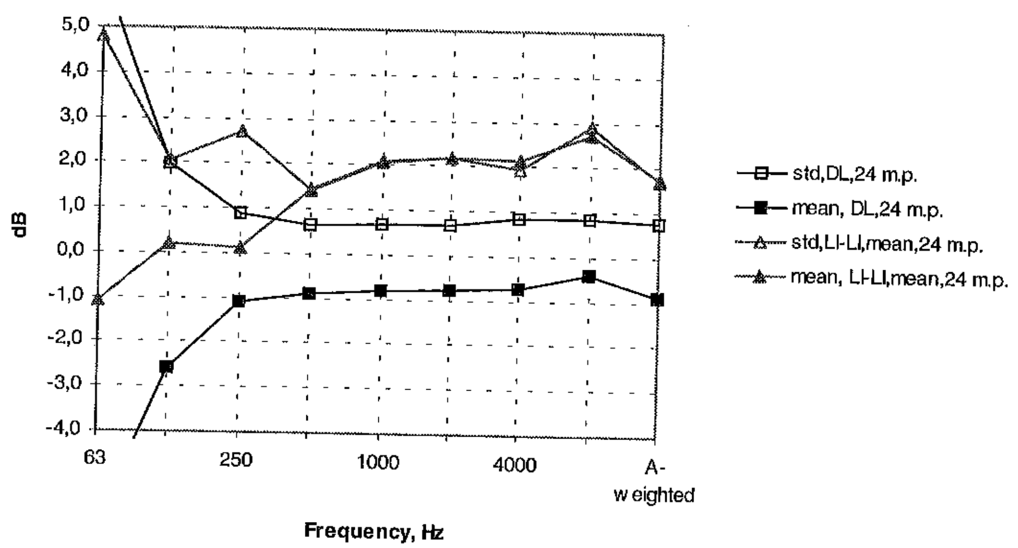

Figure 8.20 DELAB results. Mean values and standard deviations of L_I-$L_{I,mean}$ ΔL when $L_{I\ A}$- $L_{IA,mean}$ is > 0 dB. From 32 measurements. (ΔL =L_I-L_p,11201, the difference between the measured value and that of ISO 11201). res.concl/GY54

In figure 8.21, on the other hand, the intensity method is studied for the case L_I-$L_{I,mean}$< 0, that is we just look at the most unfavourable condition where we have excluded the highest emission sound pressure level around the machine. In general the results tend to be a little worse than those of figure 8.20.

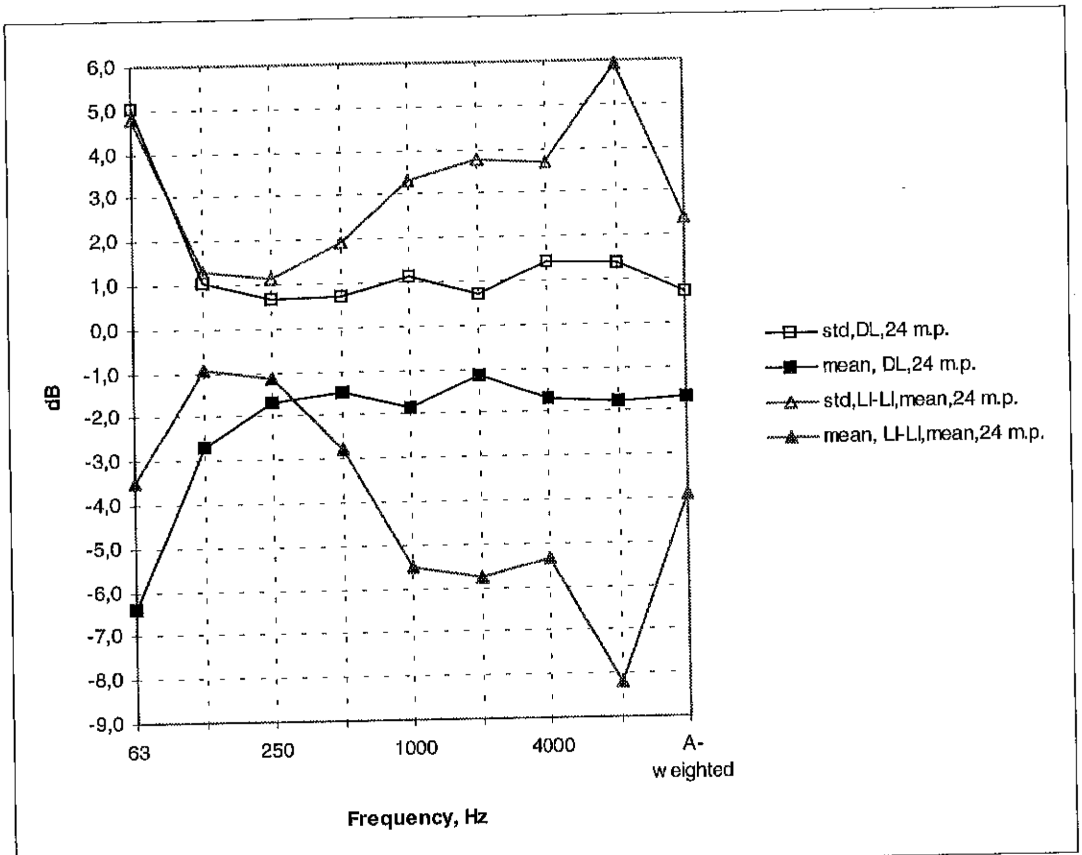

Figure 8.21 DELAB results. Mean values and standard deviations of L_I-$L_{I,mean}$, FpI and ΔL when $L_{I\,A}$- $L_{IA,mean}$ is < 0 dB. From 24 measurements. (ΔL =L_I-L_p,11201, the difference between the measured value and that of ISO 11201). res.concl/GY93

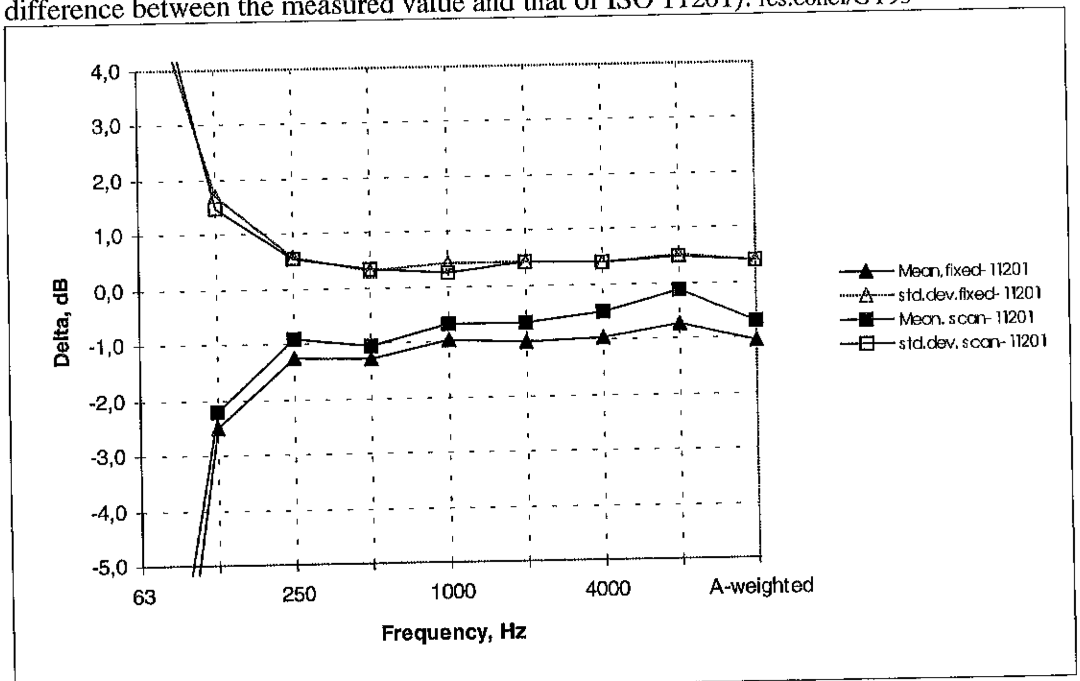

Figure 8.22 DELAB results. Mean values and standard deviations of the difference between the measured value and that of ISO 11201 when used fixed probe position and scanning around the measurement point for one direction. Measurements on two sources at 3 distances machine 1 and 2 distances machine 2 in hemi anechoic test environment. res.concl/GY116

Finally in figure 8.22 the difference between a fixed probe direction and a scan in different directions around the measurement point is shown. The result indicates that scanning gives better agreement with ISO 11201 than the fixed probe direction. However, it must be born in mind that the fixed position in this case may not have been the one giving the highest emission level.

8.3.4 Delta

In figure 8.23 all results with the intensity method are summarized. The result is rather confusing. The intensity method strongly underestimates the emission sound pressure level. One explanation to these results is that the reference 11201 measurement was not carried out in a room qualified for ISO 3745 but in a room qualified only for ISO 3744, that is the environmental indicator K_2 was not 0 but rather 2 or maybe even more.

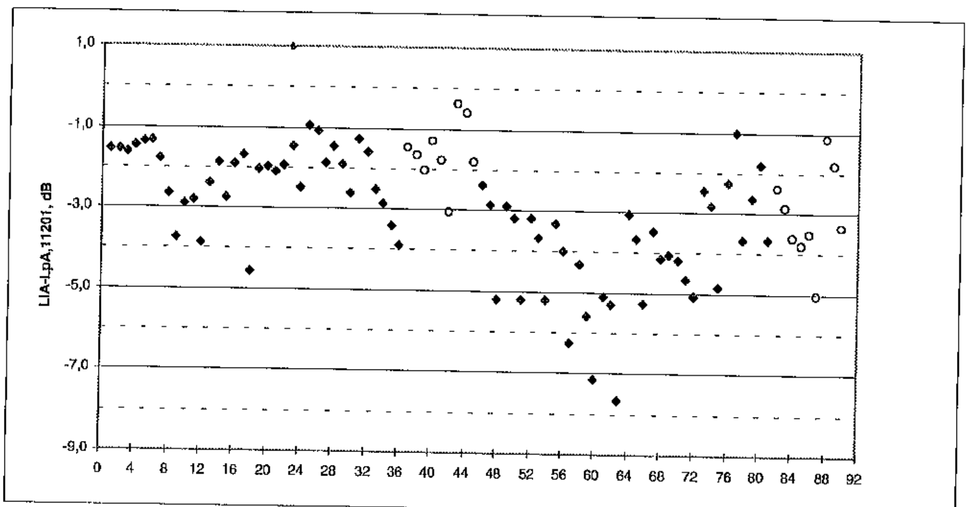

Figure 8.23 Delta results for the intensity method. 2 machines in 4 different environments. 90 measurements. ° indicates measurements when the objects were placed near a wall. Sparad n:project\ntlpi\ dkres.xls under blad:res.concl/cp180

In table 8.4 and figure 8.24 all the Delta measurements apart from those in front of a wall have been included.

Table 8.4 Numerical values of figure 8.24

Frequency	std,LI, 72 m.p	mean,LI, 72 m.p	std,11202, 48 m.p.	mean,11202, 48 m.p.	std,11204, 35 m.p.	mean,11204, 35 m.p.
63	10,9	-6,4	5,5	-0,4	2,8	-1,5
125	2,8	-3,3	6,5	1,9		
250	3,0	-2,0	4,3	-0,4	1,5	-1,0
500	1,1	-1,7	3,3	-0,5	0,8	-0,2
1000	0,9	-1,7	1,1	0,2	1,0	-0,7
2000	1,3	-2,0	1,2	-0,1	1,3	-1,4
4000	3,7	-3,5	1,9	-0,4		
8000			1,5	0,8	0,8	-0,8
A-weighted	1,5	-3,1	1,1	0,2	1,0	-0,9

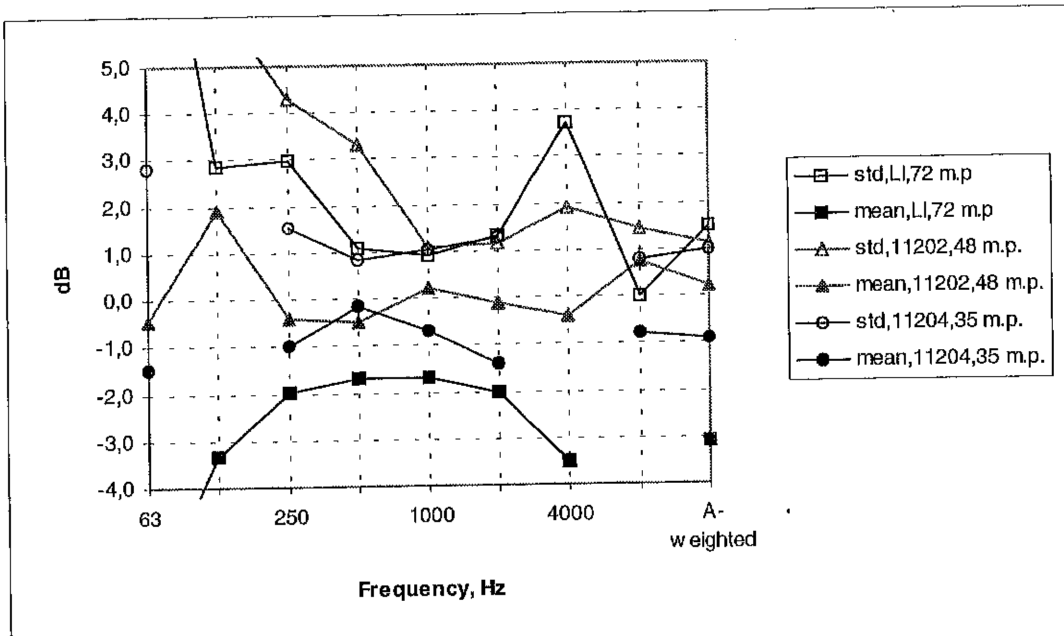

Figure 8.24 Mean values and standard deviations of the difference between the measured value and that of ISO 11201. Measurements on two sources at 3 distances in 3 test environments. All values when the objects were placed near a wall have been excluded. Values with $K_2 < 2$ dB hemi-anechoic room have been excluded for ISO 11202. (m.p = measurements points) Sparad under blad res.concl/CV186

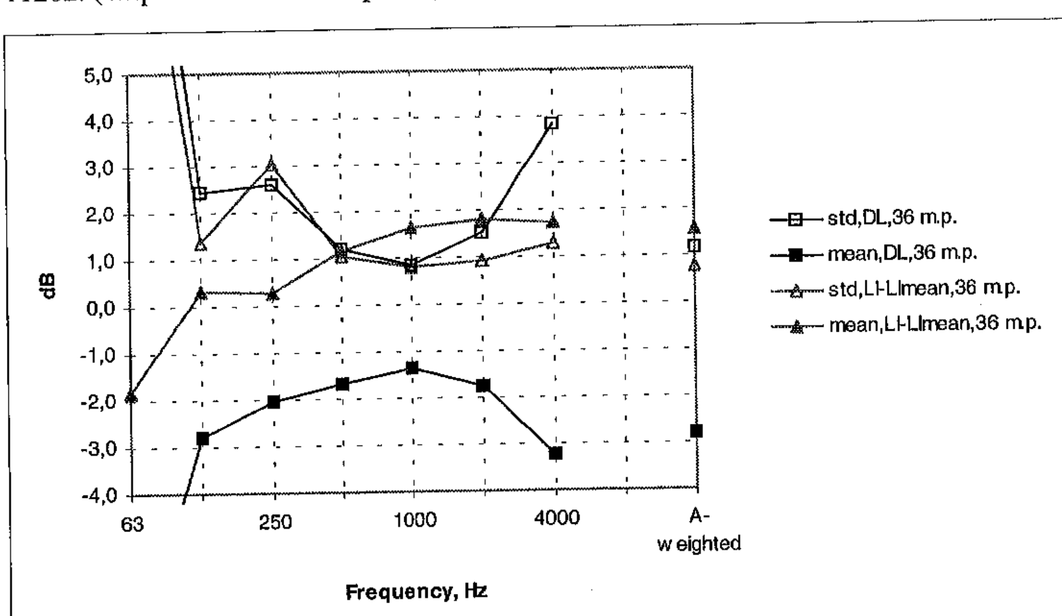

Figure 8.25 Delta results. Mean values and standard deviations of L_I-$L_{I,mean}$ and ΔL when $L_{I\,A}$- $L_{IA,mean}$ is > 0 dB. From 36 measurements. (ΔL =L_I-L_p,11201, the difference between the measured value and that of ISO 11201). res.concl/DD99

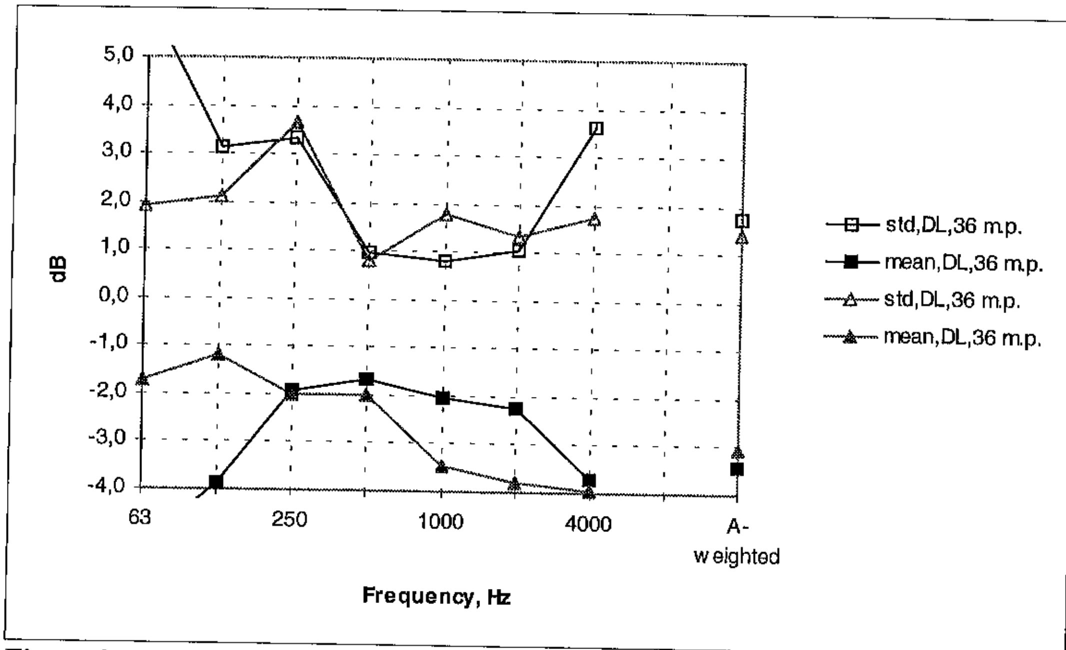

Figure 8.26 Delta results. Mean values and standard deviations of L_I-$L_{I,mean}$, FpI and ΔL when $L_{I\,A}$- $L_{IA,mean}$ is < 0 dB. From 36 measurements. (ΔL =L_I-L_p,11201, the difference between the measured value and that of ISO 11201). Sparad under blad:res.concl/DD125

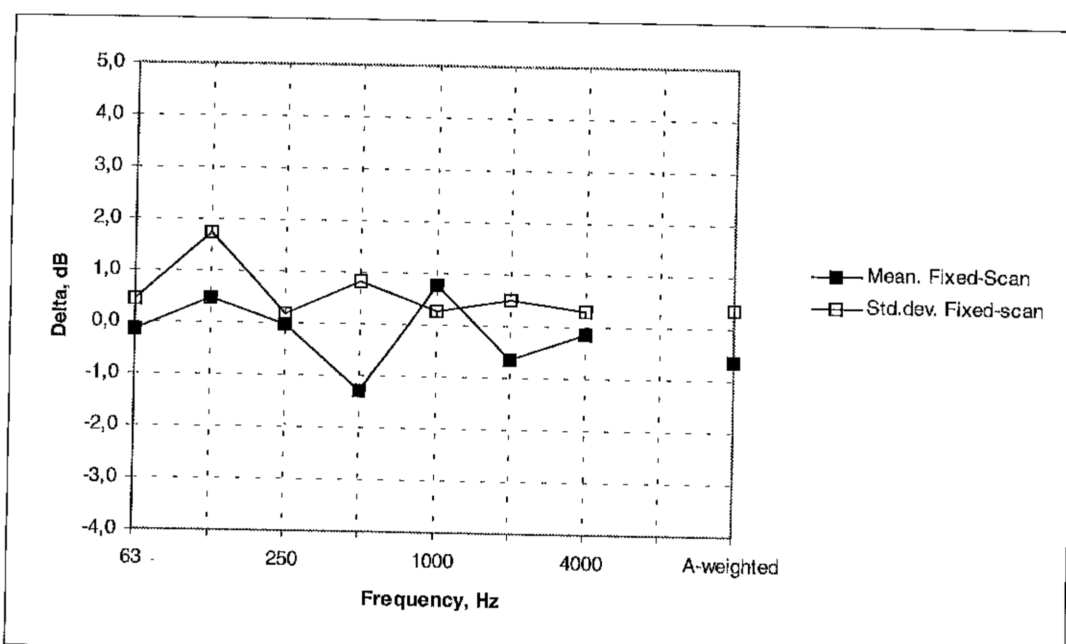

Figure 8.27 Delta results. The figure shows the difference of the mean value and the standard deviation between the sound intensity level with fixed probe position and scanning around the measurement point for one direction. Measurements on one source at three distances in hemi anechoic test environment. n:project\ntpi\emkils1.xls.N56

9 Discussion of comparison measurements

9.1 Results

Normally the measurement data of the four participants should have been combined and treated statistically. However this is not the best method in this case. Some important observations have to be considered:

1. Delta carried out the reference measurements according to ISO 11201 but unfortunately the laboratory was not qualified according to IS 3745(K_2=0) but only for ISO 3744(K_2<2). Unfortunately it is not possible to determine the environmental indicator K_2 accurately at discrete microphone positions. Delta volunteered to make new measurements but unfortunately the sound sources turned out not to be available any more. The consequence for this project is that we cannot use Delta's measurements fully.
2. DELAB did not adjust the direction of the intensity probe for maximum intensity level. This may partly explain why the intensity values were underestimated. A few scanning measurements were carried out and these measurements yielded about 0,5 dB higher values than the discrete probe positions. The true maximum values should be a little higher than the scan values. Another explanation is that with DELABs small and highmounted sources the floor reflection contributes more to the sound pressure than to the sound intensity.
3. DELAB:s room for 11201 measurements was not very good for low frequencies. The 125 Hz values are probably unreliable and the 63 Hz values cannot be used.
4. Normally 12 mm spacing was used for the intensity probes. Due to the great number of measurement points it was not possible to change the spacing to cover a larger frequency range. This means that the 63 Hz and the 8000 Hz values are rather unreliable.
5. When the comparison measurements were planned the intention was to test a number of field indicators and then to couple the values of these to the measurement uncertainty. However, it does not seem to be possible to do so, at least not within the frame of this project. There does not seem to be any simple relationship between the indicators and the measurement uncertainty. Further investigations will be required before this can be done.
6. VTT had sources with narrow band noise and bad repeatability at 125 and 250 Hz, see annex C.
7. Many of the sources used for the comparison measurements were extremely directional.
8. The in front of wall case is not relevant unless the reference value also has been determined with the machine located in front of a wall.

Despite all the negative comments above it seems to be quite clear that the intensity method normally is the best alternative in an adverse test environment. Removing the Delta measurements, the in front of wall measurements, the low frequency bad repeatability frequencies and adjusting DELABs measurements 0,5 dB upwards yield the results of table 9.1-9.4.

Table 9.1 Error of the sound intensity method. All measurements apart from those in front of a wall. Error and standard deviation. Range or max values. VTT 125 and 250 Hz have been excluded because of bad repeatability.

	ΔL_{mean}				Standard deviation			
	125	**250-2000**	**4000**	**A-weighted**	**125**	**250-2000**	**4000**	**A-weighted**
SP	0	(-0,6)-0,5	1	-0,1	1,9	1,9	2,5	1,0
VTT	----	0,5-1,0	-1,3	0,4	----	1,4	2,2	1,0
DELAB	----	(-0,9)-(-0,5)	-0,7	-0,8	----	1,1	1,3	0,8

Table 9.2 Measurements with L_I-L_{Imean} > 0 dB. Error and standard deviation. Range or max values.

	ΔL_{mean}				Standard deviation			
	125	**250-2000**	**4000**	**A-weighted**	**125**	**250-2000**	**4000**	**A-weighted**
SP	0,2	(-0,7)-0,3	0,1	-0,1	1,5	2,0	1,5	1,0
VTT	1,3	0,9-1,4	-0,9	1,0	----	1,4	1,8	1,2
DELAB	----	(-0,6)-(-0,3)	-0,2	-0,4	----	0,9	0,9	0,8

Table 9.3 Measurements with L_I-L_{Imean} < 0 dB. Error and standard deviation. Range or max values.

	ΔL_{mean}				Standard deviation			
	125	**250-2000**	**4000**	**A-weighted**	**125**	**250-2000**	**4000**	**A-weighted**
SP	-0,1	(-0,2)-0,6	1,6	0,0	2,1	2	2,7	1,1
VTT	----	0,3-1,2	-1,5	0,4	----	1,6	2,3	1,1
DELAB	----	(-0,5)-(-1,4)	-1,3	-1,2	----	1,4	1,3	0,8

In table 9.4 the different test methods are compared as to A-weighted values. The picture is a little confusing as the different test laboratories have had very different test environments. SP has used more reverberant rooms while the others have used rooms with a very small environmental indicator. The results indicate that the intensity method is very superior in reverberant environments but that the difference to 11202 is not very large in rooms with K_2 close to 2. ISO 11204 seems to work rather good when it works. The main problem with that standard is that its applicability is very limited. Delta's measurements indicate that the ISO 11202 measurements in average yield 1 dB higher A-weighted values.

Table 9.4 All mesurements apart from those close to a wall. Error and standard deviation of the different methods. A-weighted values.

	Intensity		**11202**		**11204**	
	Mean	s	Mean	s	Mean	s
SP	-0,1	1,0	4,9	2,8	0,3	1,3
VTT	0,4	1,0	0,6	1,4	-1,3	3,0
DELAB	-0,8	0,8	0,5	1,4	-0,1	0,2

9.2 Conclusions

For A-weighted values the intensity method will, in average, give values within ± 1 dB of ISO 11201 with a standard deviation which is about 1 dB. For individual frequency bands the corresponding values will be ± 2 dB and 3 dB respectively.

There is no simple indicator to use to assess the measurement uncertainty of the intensity method. The directivity indicator L_I-L_{Imean} seems to have some applicability at high(4000 Hz) frequencies.

The intensity method is more accurate than ISO 11202, which tends to overestimate the emission sound pressure level. It is of about the same accuracy as ISO 11204, which, however, has an applicability, which is much more limited than that of the intensity method. Under reverberant conditions the intensity method is very superior to all alternatives.

The best result is obtained by pointing the intensity probe in the direction of the highest sound intensity level. Scanning around the measurement point will yield lower and more erroneous values.

10 Final proposal for Nordtest method

Machines:
Determination of emission sound pressure levels using sound intensity

1 Scope and field of application

1.1 General

This NORDTEST method specifies how to determine the emission sound pressure level at the work station or at other specified positions of machines using sound intensity. The method applies to all kinds of test environments as long as the requirements on background noise and field indicator are fulfilled and as long as the environmental indicator, K_{2A}, as defined in ISO 11201 is larger than 2 dB.

Note 1 If the method is applied on a machine located in front of a reflecting wall or in a corner the result will be the emission sound pressure level corresponding to the one obtained in a hemianechoic room with the machine in front of one and two reflecting panels respectively.

The method is applicable to equipment operating under steady state conditions and emitting broad-band noise with or without discrete-frequency or narrow-band components. The method yields results comparable with those of ISO 11201 and 11204.

1.2 Measurement uncertainty

The uncertainty of this Nordtest method is not known(see note 1).

There is no strict correlation between the measurement uncertainty and the field indicator. However, when the field indicator F_{pI} exceeds 5 dB the emission sound pressure level will normally tend to be overestimated. When F_{pI} exceeds 12 dB the measurement uncertainty will tend to be outside the normal range of this method.

Note 2 Comparison measurements carried out between 3 Nordic laboratories indicate that this Nordtest method, on average, with a standard deviation of 1 dB, will yield values equivalent to those of ISO 11201(with $K_2 = 0$) within 1 dB in A-weighted emission sound pressure level. For individual frequency bands the uncertainty may be twice as large.

2 Normative references

The following standards contain provisions which, through reference in this text, constitute provisions of this Nordtest method. At the time of publication, the editions indicated were valid. All standards are subject to revision, and parties to agreements based on this Nordtest method are encouraged to investigate the possibility of applying the most recent edition of the standards indicated below. Members of IEC and ISO maintain registers of currently valid international standards.

ISO 9614-1:1993, Acoustics - Determination of sound power levels of noise sources using sound intensity - Measurement at discrete points.
ISO 9614-2:1994[1)], Acoustics - Determination of sound power levels of noise sources using sound intensity - Measurement by scanning
ISO 11200:1995[1)], Noise emitted by machinery and equipment - Guidelines for the use of basic standards for the determination of emission sound pressure levels at the work station and at other specified positions.
ISO 11201:1995[1)], Noise emitted by machinery and equipment - Engineering method for the measurement of emission sound pressure level at the work station and at other specified positions.
ISO 11202:1995[1)], Noise emitted by machinery and equipment - Survey method for the measurement of emission sound pressure levels at the work station and at other specified positions

ISO 11203:1995[1)], Noise emitted by machinery and equipment - Determination of emission sound pressure levels at the work station and at other specified positions from the sound power level
ISO 11204:1995[1)], Noise emitted by machinery and equipment - Determination of emission sound pressure levels at the work station and at other specified positions in situ
IEC 942:1988, Sound calibrators.
IEC 1043: 1993[1)], Instruments for the measurement of sound intensity.

1) At present at the stage of draft international standard.

3 Definitions

3.1 sound intensity, I:

Time averaged rate of flow of sound energy per unit of surface area oriented in the direction of the local particle velocity. This is a vectorial quantity which is equal to

$$\vec{I} = 1/T \int_0^T p(t) \vec{u}(t)\, dt \ \mathrm{W/m^2} \qquad (1)$$

where
$p(t)$ is the instantaneous sound pressure at a point, in pascals;
$u(t)$ is the instantaneous particle velocity at the same point, m/s;
T is the averaging time, in seconds;

3.2 normal sound intensity, I_n:

Sound intensity component, in W/m^2, in the direction normal to the measurement surface.

3.3 normal sound intensity level, L_{In}:

Ten times the common logarithm of the ratio of the unsigned value of the normal sound intensity to the reference intensity I_0 as given by:

$$L_{In} = 10 \lg(\vec{I}_n \mid / I_0) \quad \mathrm{dB} \qquad (2)$$

where

$I_0 = 10^{-12}$ W/m2

3.4 sound field pressure-intensity indicator or field indicator, F_{pI}:

The difference between time and surface averaged sound pressure level, L_p, and the normal sound intensity level, L_{In}, on the measurement surface given by:

$$F_{pI} = L_p - L_{In} \ \mathrm{dB} \qquad (3)$$

Note 3 In ISO 9614-1 the notation F_2 is used.

3.5 residual pressure-intensity index, δ_{pIo}:

The difference, in decibels, between indicated sound pressure level and sound intensity level when the probe is placed in a sound field in such an orientation that the particle velocity in the direction of the probe measurement axis is zero(e.g. in an acoustic coupler or transverse to the direction of propagation of a plane sound wave).

3.6 emission sound pressure level, L_p:

The sound pressure level, in decibels, at a specified position near a noise source, when the source is in operation under specified operating and mounting conditions on a reflecting plane surface, excluding the effects of background noise as well as the effect of reflections other than those from the plane or planes permitted for the purpose of the test.

3.7 specified position:

A position defined in relation to a machine, including, but not limited to, an operator's position. The position can be a single, fixed point, or a combination of points along a path or on a surface located at a specified distance from the machine, as described in the relevant test code, if any.

3.8 environmental indicator, K_2:

A term, in decibels, to describe the influence of reflected or absorbed sound on the surface sound pressure level; K_2 is frequency dependent, and, in the case of A-weighting, is denoted K_{2A}(see ISO 11201, 11202, 3744 or 3746).

4 Instrumentation

4.1 General

The intensity measuring instrumentation shall be able to measure intensity levels re 10^{-12} W/m^2 in decibels in one-third octave bands. The instrument, including the probe, shall comply with a class 1 instrument in accordance with IEC 1043. A probe wind screen shall always be employed.

The residual pressure-intensity index δ_{pIo} of microphone probe and analyzer shall be higher than F_{pI}+10 dB in each third octave band.

4.2 Calibration

The instrument and the probe shall be calibrated at least at one frequency in the range from 200 to 1000 Hz in accordance with the calibration procedure and at intervals specified by the manufacturer.

The following field checks to test the instrument shall be made before each series of measurements:

a) Carry out a field check according to the instrument manufacturer's specifications.

If no field check is specified by the instrument manufacturer check the instrumentation according to b) and c):

b) Sound pressure level: Check each pressure microphone of the intensity probe for sound pressure level using a class 1 calibrator or better in accordance with IEC 942.

c) Intensity: Calibrate using an intensity calibrator. If such a calibrator is not available or if the probe build up does not allow it make a check as follows:

Place the intensity probe at the specified position, oriented towards the most important source of sound emission, at a position where the noise from the source is characteristic for that source. The intensity probe should be mounted on a stand to retain the same position while carrying out the measurement check. Measure the intensity. Rotate the intensity probe through 180° about a normal to its measurement axis in the same position as the first measurement. Measure the intensity again. For the maximum sound intensity level measured in one-third octave or octave bands the unsigned difference between the two sound intensity levels shall be less than 1,5 dB for the measurement instrumentation to be acceptable.

Note 4 - This test may not be completely appropriate for pressure-velocity probes for which the manufacturer's instruction should apply.

5 Installation and operation of the source

See ISO 11201.

6 Test procedure

6.1 Principle

The basic principle of the test method is to eliminate diffuse sound reflections by approximating the emission sound pressure level by the sound intensity level. In a diffuse sound field the sound intensity is very small. A lack of diffusivity is one source of error in this test method. Sound first reflected from surfaces very close to the machine will not be part of the diffuse sound field at a specified position close to the machine unless the test environment is extremely reverberant. Thus the sound intensity level will normally be determined by a combination of sound arriving directly from the sound source and sound reflected from surfaces close to the machine. Adding sound from different directions will affect the sound pressure and the sound intensity differently. This difference is another source of error.

A lack of diffusivity will tend to yield an overestimate of the emission sound pressure level and strong reflections from several different directions will tend to an underestimate the emission sound pressure level.

6.2 The specified position

Mount the intensity probe at the specified position of the object under test. Direct it towards the most important source of sound emission. Try some different orientations and select the one giving the highest sound intensity level. No reflecting objects, other than the machine under test, are allowed within 0,5 m of the intensity probe. If there are such objects they shall be covered with sound absorbing material.

Note 5 In many cases reflections from the floor or from a table will contribute to the sound intensity level. These reflections will also affect the optimum probe direction. In such cases the most important source of sound emission will move towards the reflecting surface.

Note 6 If the machine under test is located in front of a wall the wall must be covered with sound absorbing material if it is the intention to simulate hemi-anechoic measurement results according to ISO 11201. However, if the normal location of the machine is in front of a wall and it is desirable to include the wall reflection, the method is applicable without any additional measures.

Measure the sound intensity level and the sound pressure level in the frequency bands in which the emission sound pressure level is to be determined. The averaging time shall be at least 30 s in each probe position. If possible, measure the time integrated sound pressure level L_p simultaneously. If this is not possible, measure the sound pressure level afterwards at the same point or along the same path as during the intensity measurements. Calculate the sound field pressure-intensity indicator, F_{pI}.

6.3 Criterion for the adequacy of the test environment

For this Nordtest method, the environmental indicator K_{2A}, see ISO 11201, for a measurement surface enveloping the measurement position(s) shall not be less than 2 dB.

The field indicator F_{pI} shall be less than 12 dB.

6.4 Criterion for background noise

At the probe position(s), the background sound pressure level and the background sound intensity level measured as a weighted level or in each of the frequency bands of interest shall be at least 10 dB below the level due to the machine under test. No corrections shall be made.

6.5 Frequency range of measurements

The sound pressure level and the sound intensity level shall be measured using octave band filters having the following mid band frequencies in hertz:

63 125 250 500 1000 2000 4000

Optionally the measurements can be made in third octave bands with mid band frequencies of at least from 50 to 5000 Hz.

Note 6 - Frequency bands without influence on the A-weighted emission sound pressure level may be excluded

6.6 Evaluation of the measurement result

The emission sound pressure level L_p is given by

$$L_p = L_I \qquad (4)$$

For each frequency band for which the sound intensity flow is towards the source the measurement is not valid.

7 Information to be reported

In addition to the relevant requirements of ISO 11201 the following shall be reported

a) The value of the emission sound pressure level together with the field indicator F_{pI} for each frequency band of interest.

b) Description of the measurement probe and its calibration.

11 Annexes

Annex A Measurements in a hemi-anechoic room
Annex B Reference measurements for the comparison measurements
Annex C Repeatability tests of the sound power levels of the sources according to ISO 3741.

Annex A Measurements in a hemi-anechoic room

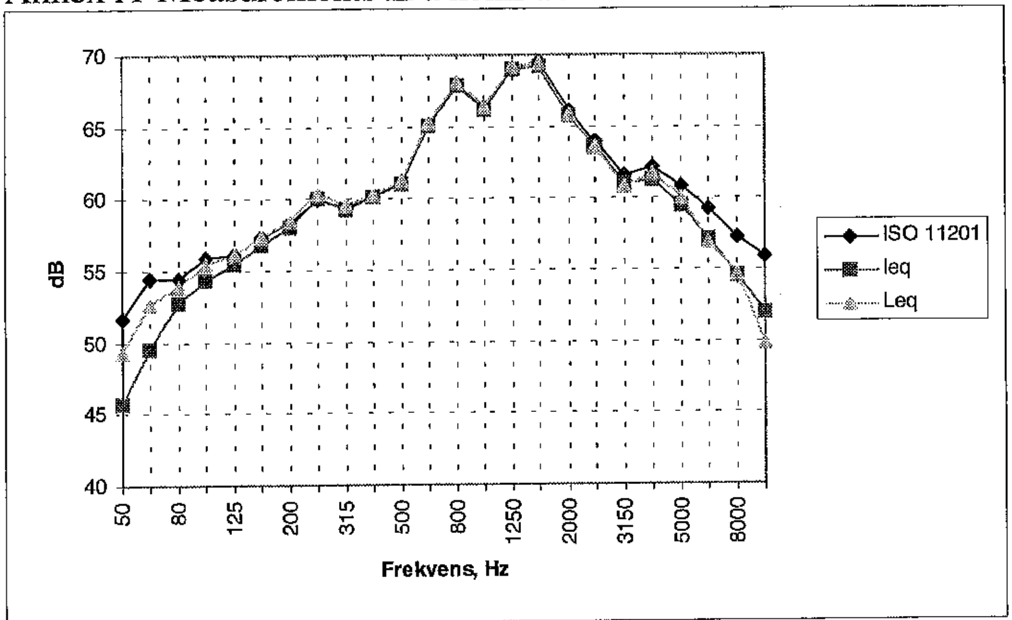

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Figure A1 RSS mounted on the floor. Microphone/probe position: 0,25 m from the RSS, 1,55 m above the floor.

ISO 11201: Emission sound pressure levels measured with free field microphone type B&K 4165.
Ieq: Sound intensity levels.
Leq: Emission sound pressure levels measured with intensity probe
F_{pI}: The sound field indicator pressure-intensity indicator ($F_{pI} = L_p - L_I$)

Table A1 The measured values of figure A.1

Frequency	11201	Ieq	Leq	F_{pI}
50	**51,6**	45,7	49,3	3,6
63	**54,4**	49,5	52,6	3,1
80	**54,4**	52,8	53,9	1,1
100	**55,9**	54,3	55,5	1,3
125	**56,1**	55,4	56,1	0,6
160	**57,4**	56,8	57,4	0,6
200	**58,4**	58	58,5	0,5
250	**59,9**	60	60,4	0,3
315	**59,4**	59,3	59,6	0,3
400	**60,1**	60,1	60,3	0,2
500	**61,2**	61,1	61,3	0,2
630	**65,2**	65,1	65,3	0,2
800	**68**	67,9	68,1	0,2
1000	**66,3**	66,2	66,4	0,2
1250	**69,1**	69	69,2	0,2
1600	**69,5**	69,2	69,4	0,1
2000	**66,1**	65,8	65,9	0,1
2500	**63,9**	63,6	63,5	-0,1
3150	**61,6**	61	60,8	-0,2
4000	**62,2**	61,3	61,7	0,5
5000	**60,8**	59,5	60	0,5
6300	**59,2**	57,1	56,9	-0,2
8000	**57,2**	54,6	54,7	0,2
10000	**55,9**	52	49,9	-2,1
A-weighted	**76,7**	**76,4**	**76,5**	**0,2**

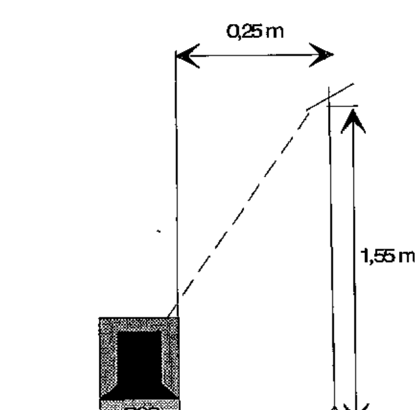

Figure A2 Test set up for figure A1 and table A1.

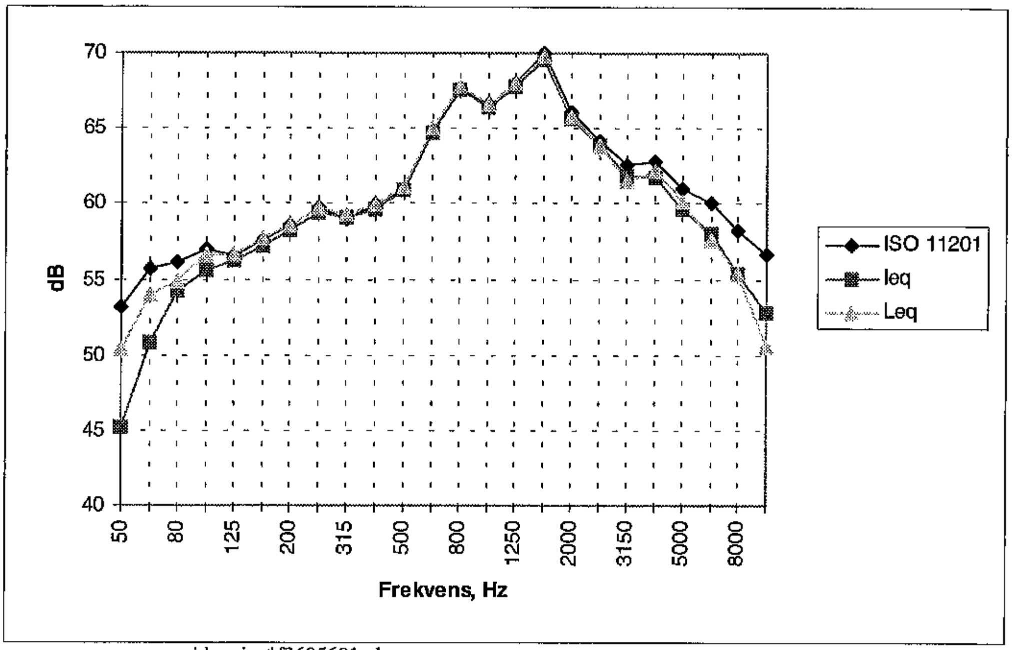

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Figure A3 RSS mounted on the floor. Microphone/probe position: 0,4 m from the RSS, 1,55 m above the floor.
ISO 11201: Emission sound pressure levels measured with free field microphone type B&K 4165.
Ieq: Sound intensity levels.
Leq: Emission sound pressure levels measured with intensity probe
F_{pI}: The sound field indicator pressure-intensity indicator ($F_{pI} = L_p - L_I$)

Table A2 The measured values of figure A3

Frequency	11201	Ieq	Leq	F_{pI}
50	**53,1**	45,2	50,4	5,2
63	**55,7**	50,8	54	3,2
80	**56,1**	54,2	54,8	0,6
100	**57**	55,6	56,6	1
125	**56,5**	56,2	56,6	0,4
160	**57,6**	57,2	57,7	0,4
200	**58,5**	58,2	58,6	0,4
250	**59,7**	59,4	59,7	0,3
315	**59**	59,1	59,3	0,3
400	**59,9**	59,6	59,9	0,2
500	**61**	60,9	61,1	0,2
630	**64,7**	64,7	65	0,2
800	**67,7**	67,6	67,8	0,2
1000	**66,6**	66,4	66,6	0,2
1250	**68**	67,8	68	0,2
1600	**70**	69,6	69,8	0,1
2000	**66,1**	65,7	65,8	0,1
2500	**64,2**	63,9	63,8	-0,1
3150	**62,6**	61,8	61,5	-0,3
4000	**62,8**	61,7	62,2	0,5
5000	**61**	59,6	60,1	0,5
6300	**60**	58	57,6	-0,3
8000	**58,2**	55,4	55,4	0
10000	**56,6**	52,8	50,6	-2,2
A-weight	**76,7**	**76,3**	**76,5**	**0,1**

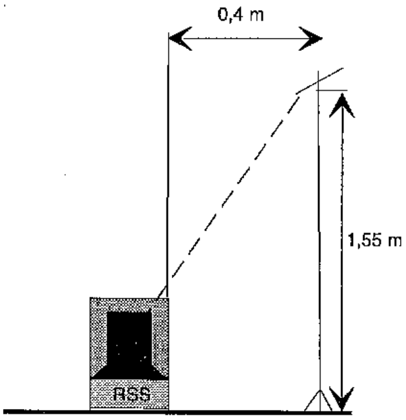

Figure A4 RSS mounted on the floor.

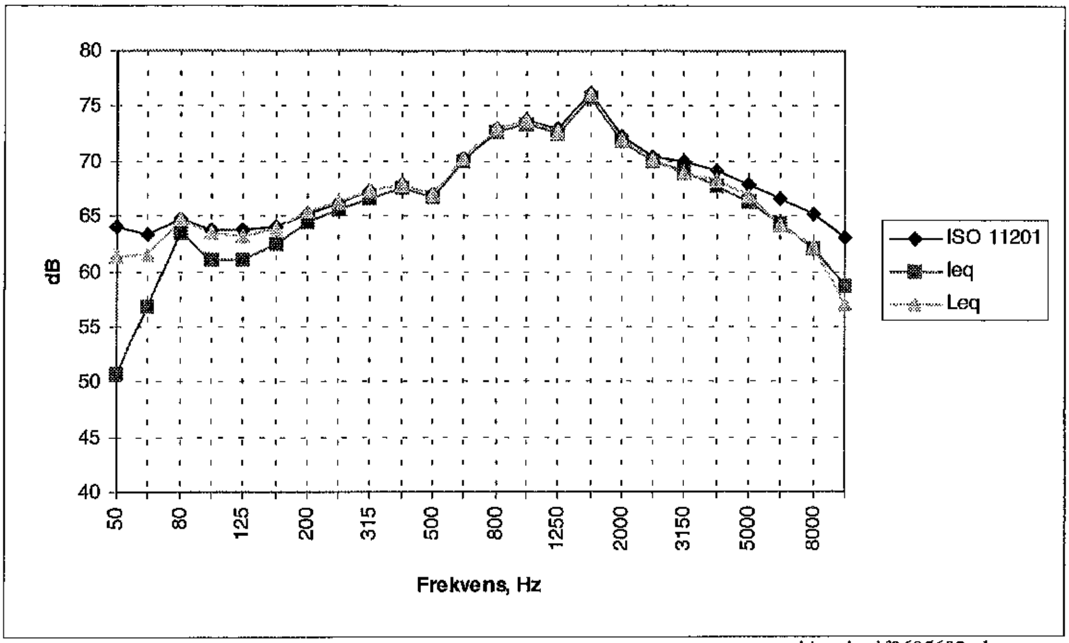

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Figure A5 RSS mounted on the standard test table.
Microphone/probe position: 0,25 m from the RSS, 1,55 m above the floor
ISO 11201: Emission sound pressure levels measured with free field microphone type B&K 4165.
Ieq: Sound intensity levels.
Leq: Emission sound pressure levels measured with intensity probe
F_{pI}: The sound field indicator pressure-intensity indicator ($F_{pI} = L_p - L_I$)

Table A3 The measured values of figure A5

Frequency	**11201**	Ieq	Leq	F_{pI}
50	**64**	50,7	61,3	10,6
63	**63,3**	56,8	61,5	4,7
80	**64,8**	63,4	64,8	1,4
100	**63,7**	61	63,4	2,3
125	**63,7**	61,1	63,2	2,1
160	**64**	62,5	63,9	1,4
200	**65,1**	64,4	65,4	1
250	**66,1**	65,6	66,3	0,7
315	**67,3**	66,6	67,3	0,6
400	**67,8**	67,5	67,9	0,4
500	**67**	66,7	67	0,3
630	**70,2**	69,9	70,2	0,4
800	**73**	72,6	73	0,4
1000	**73,6**	73,3	73,7	0,4
1250	**73**	72,5	72,7	0,3
1600	**76,2**	75,7	76	0,4
2000	**72,2**	71,8	72	0,2
2500	**70,4**	70	70,1	0,1
3150	**69,9**	69,1	68,9	-0,2
4000	**69,1**	67,7	68,3	0,6
5000	**67,8**	66,3	66,9	0,6
6300	**66,6**	64,3	64,2	-0,1
8000	**65,1**	62	62,2	0,2
10000	**63**	58,7	56,9	-1,8
A-weight	**82,9**	**82,3**	**82,6**	**0,3**

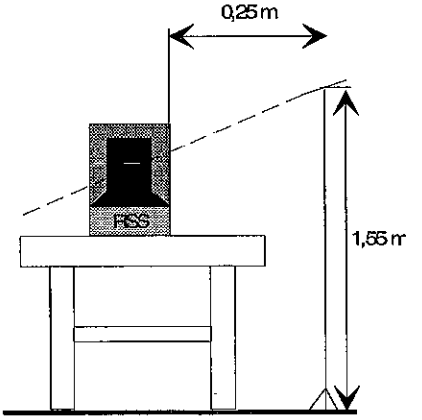

Figure A6 Test set uo of figure A5 and table A3.

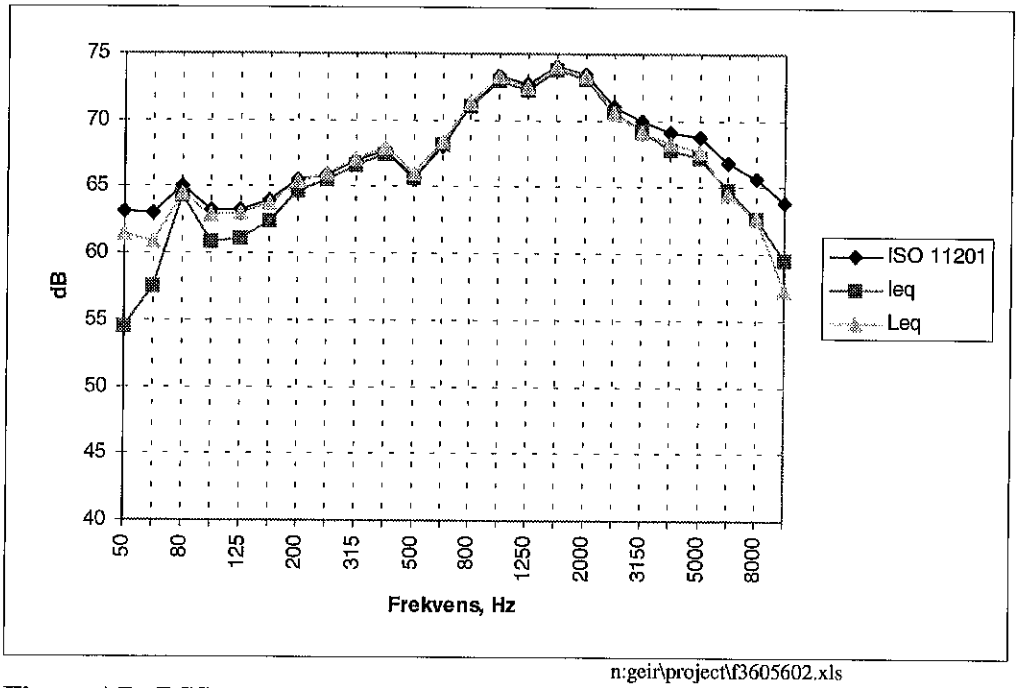

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Figure A7 RSS mounted on the standard test table.
Microphone/probe position: 0,4 m from the RSS, 1,55 m above the floor

ISO 11201: Emission sound pressure levels measured with free field microphone type B&K 4165.
Ieq: Sound intensity levels.
Leq: Emission sound pressure levels measured with intensity probe
F_{pI}: The sound field indicator pressure-intensity indicator ($F_{pI} = L_p - L_I$)

Table A4 The measured values of figure A7

Frequency	**11201**	Ieq	Leq	F_{pI}
50	**63,1**	54,5	61,5	10,6
63	**63**	57,5	60,8	4,7
80	**65,1**	64,3	64,4	1,4
100	**63,2**	60,8	62,9	2,3
125	**63,2**	61,1	63	2,1
160	**64**	62,4	63,7	1,4
200	**65,5**	64,7	65,4	1
250	**65,9**	65,5	66	0,7
315	**67**	66,6	67,1	0,6
400	**67,7**	67,5	67,9	0,4
500	**65,6**	65,7	66	0,3
630	**68**	68,2	68,4	0,4
800	**71,2**	71	71,3	0,4
1000	**73,3**	73	73,3	0,4
1250	**72,7**	72,2	72,5	0,3
1600	**74**	73,8	74	0,4
2000	**73,5**	73,1	73,3	0,2
2500	**71,1**	70,6	70,6	0,1
3150	**70**	69,3	69,1	-0,2
4000	**69,1**	67,8	68,3	0,6
5000	**68,8**	67,2	67,7	0,6
6300	**66,8**	64,8	64,5	-0,1
8000	**65,6**	62,6	62,7	0,2
10000	**63,8**	59,5	57,3	-1,8
A-weight	**82,4**	**81,9**	**82,1**	**0,3**

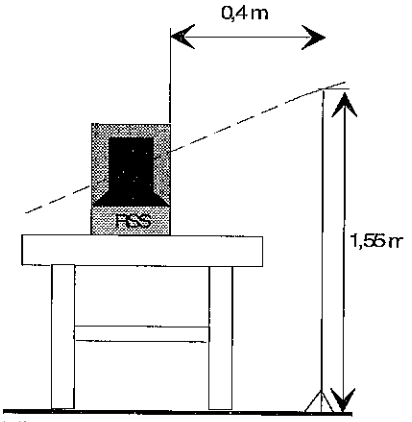

Figure A8 Test set up of figure A7 and table A4.

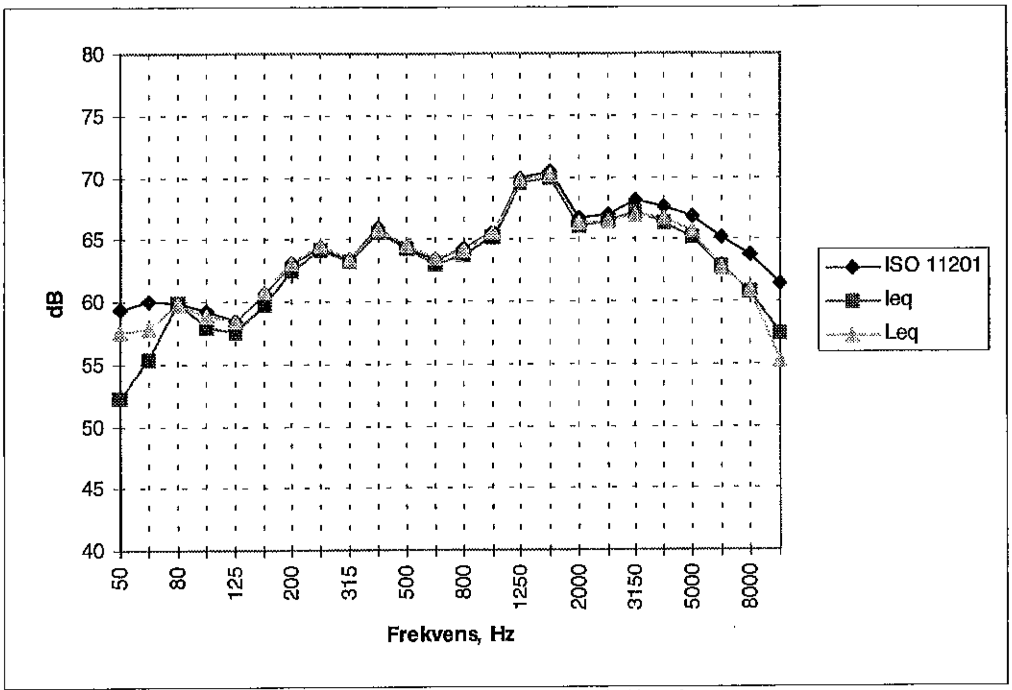

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Figure A9 RSS mounted on the standard test table.
Microphone/probe position: 1,0 m from the RSS, 1,55 m above the floor

ISO 11201: Emission sound pressure levels measured with free field microphone type B&K 4165.
Ieq: Sound intensity levels.
Leq: Emission sound pressure levels measured with intensity probe
F_{pI}: The sound field indicator pressure-intensity indicator ($F_{pI} = L_p - L_I$)

Table A6 The measured values of figure A9

Frequency	11201	Ieq	Leq	F_{pI}
50	59,3	52,3	57,5	7
63	60	55,3	57,8	3,3
80	59,9	59,9	59,7	0,1
100	59,2	58	58,9	2
125	58,4	57,6	58,5	1,9
160	60,7	59,8	60,8	1,3
200	63,1	62,5	63,1	0,8
250	64,3	64,1	64,5	0,5
315	63,3	63,2	63,4	0,5
400	66	65,5	65,8	0,4
500	64,3	64,2	64,5	0,2
630	63,4	63	63,5	0,3
800	64,3	63,8	64,1	0,3
1000	65,5	65,1	65,5	0,3
1250	70	69,5	69,8	0,2
1600	70,5	70	70,2	0,2
2000	66,7	66,1	66,3	0,1
2500	67	66,4	66,4	0
3150	68,1	67,2	67	-0,2
4000	67,6	66,3	66,7	0,5
5000	66,8	65,1	65,7	0,6
6300	65,1	62,9	62,7	-0,3
8000	63,8	60,8	60,9	0,1
10000	61,4	57,4	55,2	-2,1
A-weight	78,6	77,8	78	0,2

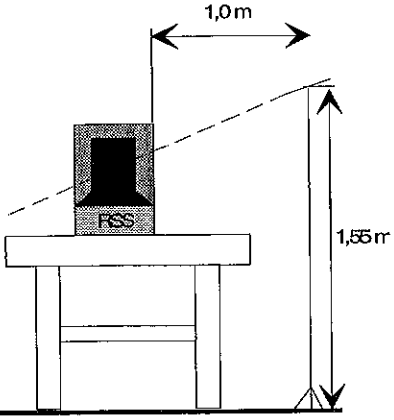

Figure A10 Test set up of figure A9 and table A6

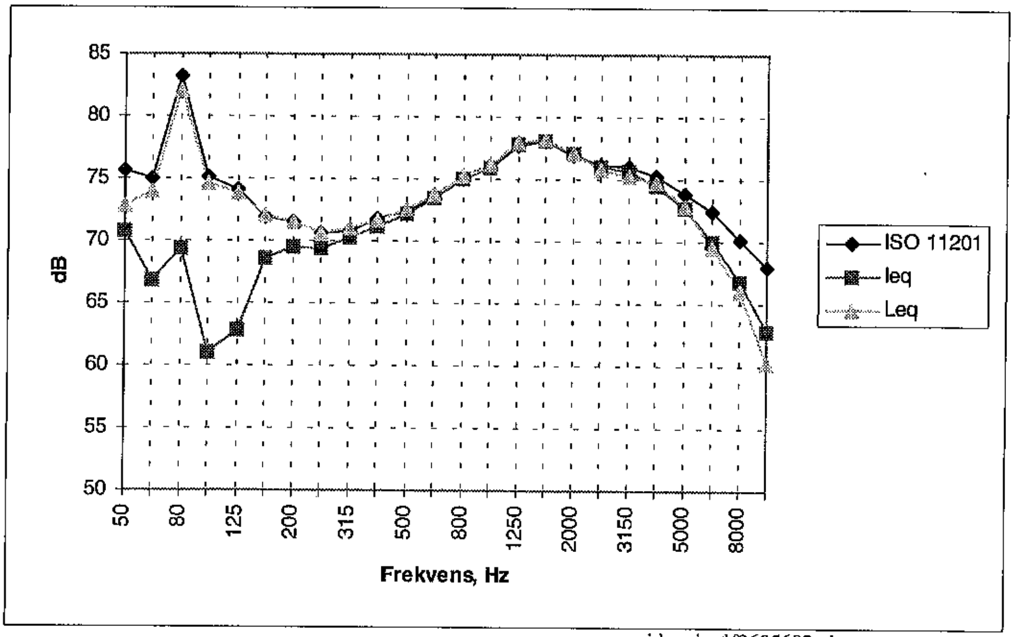

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Figure A11 RSS mounted on a support 1,1 m above the floor.
Microphone/probe position: 0,25 m from the RSS, 1,55 m above the floor
. ** Note. Negative intensity at the frequency bands 50-80 Hz due to fan wind.*
ISO 11201: Emission sound pressure levels measured with free field microphone type B&K 4165. Wind screen at the microphone
Ieq: Sound intensity levels. Wind screen at the probe
Leq: Emission sound pressure levels measured with intensity probe. Wind screen at the probe
F_{pI}: The sound field indicator pressure-intensity indicator ($F_{pI} = L_p - L_I$)

Table A7 The measured values of figure A11

Frequency	**11201**	Ieq	Leq	F_{pI}
50	**75,6**	*70,8	72,8	2
63	**75**	*66,8	74	7,2
80	**83,2**	*69,4	82	12,6
100	**75,1**	61	74,6	13,6
125	**74,1**	62,8	73,9	11,1
160	**71,9**	68,6	72	3,5
200	**71,6**	69,5	71,6	2,1
250	**70,7**	69,4	70,7	1,4
315	**70,8**	70,2	71	0,8
400	**71,8**	71,2	71,7	0,6
500	**72,4**	72,2	72,6	0,4
630	**73,5**	73,4	73,7	0,3
800	**75**	75	75,2	0,2
1000	**75,9**	75,9	76,1	0,2
1250	**77,7**	77,8	77,9	0,1
1600	**78,1**	78,1	78,2	0,1
2000	**76,9**	77	77	0
2500	**76,1**	76	75,8	-0,3
3150	**76**	75,7	75,3	-0,4
4000	**75,2**	74,5	74,8	0,3
5000	**73,8**	72,7	72,8	0,1
6300	**72,4**	70	69,5	-0,5
8000	**70,1**	66,8	66	-0,8
10000	**68**	62,8	60,2	-2,6
A-weight	**86,9**	**86,7**	**86,7**	**0,1**

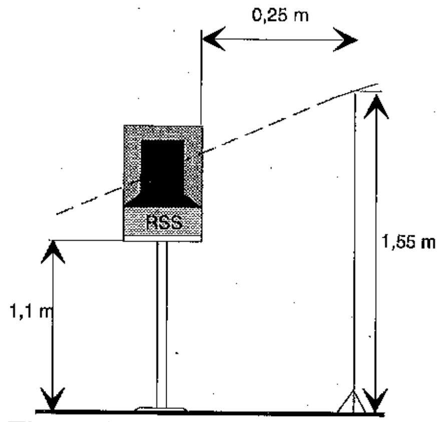

Figure A12 Test set up og figure A11 and table A7

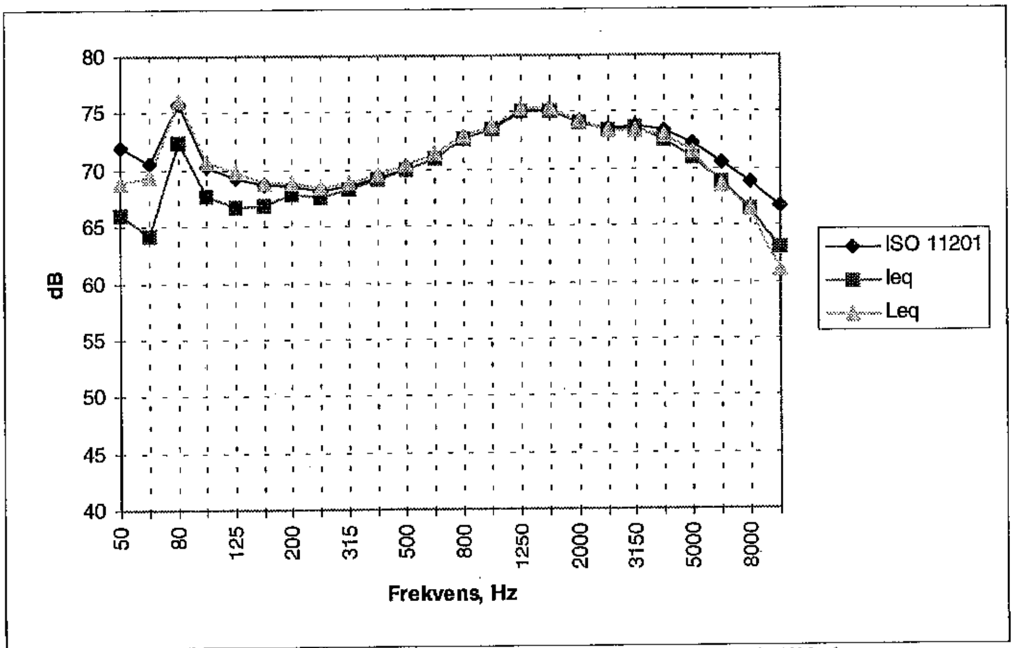

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Figure A13 RSS mounted on a support 1,1 m above the floor.
Microphone/probe position: 0,4 m from the RSS, 1,55 m above the floor
ISO 11201: Emission sound pressure levels measured with free field microphone type B&K 4165.
Ieq: Sound intensity levels.
Leq: Emission sound pressure levels measured with intensity probe
F_{pI}: The sound field indicator pressure-intensity indicator ($F_{pI} = L_p - L_I$)

Table A9 Measured values of figure A13.

Frequency	**11201**	Ieq	Leq	F_{pI}
50	**71,9**	66	68,8	2,8
63	**70,6**	64,1	69,4	5,3
80	**75,7**	72,3	76,1	3,8
100	**70,3**	67,7	70,7	3,1
125	**69,2**	66,7	69,8	3,1
160	**68,7**	66,9	68,9	2,1
200	**68,5**	67,8	68,9	1,1
250	**68,1**	67,5	68,4	1
315	**68,6**	68,2	68,8	0,7
400	**69,3**	69,1	69,5	0,5
500	**70**	70	70,4	0,4
630	**71**	71	71,4	0,4
800	**72,7**	72,6	72,9	0,3
1000	**73,5**	73,5	73,8	0,3
1250	**75,2**	75,1	75,3	0,2
1600	**75,1**	75,1	75,3	0,2
2000	**74,1**	74	74,2	0,2
2500	**73,5**	73,4	73,4	0,1
3150	**73,8**	73,6	73,3	-0,2
4000	**73,4**	72,5	72,9	0,4
5000	**72,2**	70,9	71,5	0,5
6300	**70,6**	68,8	68,6	-0,2
8000	**68,9**	66,5	66,4	-0,1
10000	**66,7**	63,1	61	-2,1
A-weight	**84,5**	**84,2**	**84,4**	**0,2**

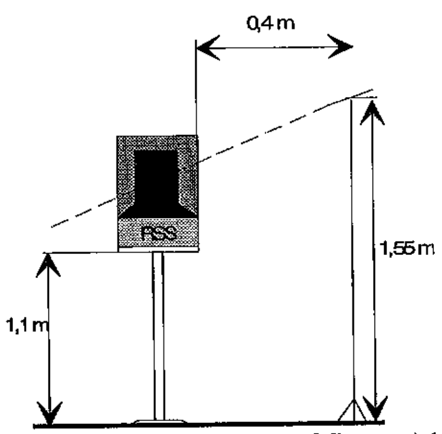

Figure A14 Test set up of figure A13 and table A9

Annex B Measurements results according to ISO 11201

SP

	Front side			Right side			Left side			Rear side		
Frequency	0,25m	0,4m	1m	0,25m	0,4m	1m	0,25m	0,4m	1m	0,25m	0,4m	1m
63	64,8	64,4	61,5	61,0	60,6	58,2	60,8	60,2	57,4	59,6	58,8	56,6
125	68,3	67,2	61,2	64,8	63,3	57,3	63,4	61,9	56,0	64,1	62,1	55,7
250	67,6	66,9	63,6	64,0	63,0	59,3	63,3	62,4	59,5	60,4	59,4	56,3
500	64,9	64,9	61,4	57,2	56,2	51,7	57,3	56,2	51,6	55,7	54,4	51,4
1000	54,5	54,6	51,4	47,8	47,1	44,1	47,9	47,2	44,0	52,7	51,2	46,2
2000	50,5	51,6	49,9	41,2	40,1	37,7	41,7	41,3	38,8	50,6	49,6	44,1
4000	51,3	49,0	46,8	35,7	33,9	32,2	35,1	34,1	32,1	42,8	41,8	37,4
8000	41,9	40,2	36,5	29,1	27,1	24,6	28,9	27,7	24,4	32,9	29,5	25,6
A-weighted	64,5	64,2	60,9	58,1	57,0	53,1	57,9	56,8	53,3	58,4	57,1	52,9

Table B1 SP. Radio base station

	Front side			Right side			Left side			Rear side		
Frequency	0,25m	0,4m	1m	0,25m	0,4m	1m	0,25m	0,4m	1m	0,25m	0,4m	1m
63	47,6	47,5	45,5	48,3	48,2	47,2	46,7	46,3	44,9	47,6	47,1	45,5
125	53,3	53,0	52,6	54,0	53,6	52,6	53,7	53,7	53,2	54,0	53,2	51,6
250	63,7	63,2	58,7	60,4	59,3	54,1	61,6	60,6	55,5	62,6	62,2	59,1
500	55,1	55,1	54,6	62,5	62,1	58,5	59,5	59,2	55,4	54,7	55,7	54,9
1000	53,6	53,9	55,2	54,6	55,4	57,1	56,9	56,7	57,6	53,4	53,6	55,1
2000	50,8	52,0	54,1	54,3	55,4	54,4	51,8	53,0	53,3	51,7	52,2	53,1
4000	46,6	48,6	50,2	51,7	56,6	52,6	48,7	49,4	47,7	46,1	50,5	50,3
8000	38,4	39,5	41,1	45,3	49,0	44,9	37,1	38,1	38,2	39,1	39,3	41,4
A-weighted	59,9	60,2	60,2	63,0	63,9	61,8	61,5	61,5	60,5	59,4	60,1	60,0

Table B2 SP. Vacuum cleaner placed inside a table

VTT

	Dir 1			Dir 2			Dir 3			Dir 4		
Frequency	0,25m	0,4m	1m	0,25m	0,4m	1m	0,25m	0,4m	1m	0,25m	0,4m	1m
63	44,9	44,0	42,1	45,6	44,6	42,3	46,2	45,3	42,1	45,5	44,5	42,1
125	56,9	55,6	49,6	57,4	56,1	50,4	58,3	57,0	51,1	57,8	56,1	51,0
250	68,8	67,1	60,4	71,5	70,5	66,0	72,2	71,3	64,8	69,4	68,1	62,2
500	72,4	71,0	66,2	73,0	71,3	66,9	75,7	74,0	68,4	74,4	72,6	68,3
1000	76,4	74,6	69,2	76,7	75,0	69,5	79,8	77,9	72,1	77,3	75,5	70,0
2000	76,2	74,2	69,1	76,7	76,0	72,3	78,4	75,5	67,7	72,6	71,2	68,5
4000	68,6	66,7	60,2	70,9	68,6	62,6	71,0	69,7	63,2	70,6	68,9	65,6
8000	62,8	61,1	56,7	64,8	63,6	57,4	62,8	62,9	56,5	65,6	64,3	59,8
A-weighted	80,6	78,8	73,5	81,4	80,1	75,7	83,4	81,3	74,7	80,3	78,6	74,4

Table B3 VTT. Vacuum cleaner

	Dir 1			Dir 2			Dir 3			Dir 4		
Frequency	0,25m	0,4m	1m	0,25m	0,4m	1m	0,25m	0,4m	1m	0,25m	0,4m	1m
63	55,5	53,2	46,3	57,3	54,5	42,9	60,6	58,7	51,9	61,1	59,4	53,5
125	56,0	53,4	50,3	54,5	53,8	48,9	55,2	52,3	48,8	54,5	54,6	49,5
250	62,3	61,3	57,7	63,1	62,1	59,2	63,2	62,5	58,2	64,8	64,1	61,7
500	62,6	61,6	59,0	62,8	61,9	60,0	61,1	60,5	59,0	62,4	62,2	60,5
1000	64,4	64,4	61,0	63,2	62,7	62,5	64,2	63,9	62,3	61,7	61,6	61,5
2000	70,5	71,5	69,8	74,6	74,4	73,8	70,6	70,4	67,5	72,0	72,3	70,7
4000	67,2	67,5	64,0	71,7	70,9	69,2	67,1	66,1	63,5	70,2	69,0	68,0
8000	55,0	55,0	53,9	60,6	59,6	57,9	56,2	55,4	53,1	58,7	58,6	55,8
A-weighted	74,1	74,7	72,5	77,8	77,4	76,6	74,1	73,7	71,0	75,8	75,5	74,2

Table B4 VTT. Disc saw

Measurements results according to ISO 11201

DELAB

Frequency	Pos 1 0,25m	Pos 1 0,4m	Pos 1 1m	Pos 2 0,25m	Pos 2 0,4m	Pos 2 1m	Pos 3 0,25m	Pos 3 0,4m	Pos 3 1m	Pos 4 0,25m	Pos 4 0,4m	Pos 4 1m
63	68,4	64,0	55,4	63,8	60,2	54,3	68,2	64,9	57,6	62,3	59,4	54,8
125	76,3	73,0	63,5	73,0	71,1	64,9	75,9	72,8	63,0	73,2	71,1	63,2
250	69,2	66,4	59,2	64,7	63,2	57,6	62,5	60,5	55,3	64,8	63,2	57,2
500	64,9	62,7	56,2	58,0	56,4	51,7	62,1	59,9	53,6	57,7	56,4	51,8
1000	65,2	63,0	57,5	54,3	52,8	49,1	61,8	59,4	53,5	54,6	52,9	49,1
2000	66,5	63,4	58,2	53,3	52,7	48,9	63,2	60,1	53,9	53,3	52,5	49,7
4000	60,1	57,2	51,3	48,7	46,7	43,8	57,7	54,6	48,2	48,7	47,6	45,5
8000	53,9	50,9	44,7	38,1	37,3	35,5	52,5	49,2	42,3	38,5	37,1	36,2
A-weighted	71,6	68,9	63,1	62,8	61,3	56,7	68,6	65,8	59,4	63,0	61,4	56,6

Table B5 DELAB. ILG fan in box

Frequency	Pos 1 0,25m	Pos 1 0,4m	Pos 1 1m	Pos 2 0,25m	Pos 2 0,4m	Pos 2 1m	Pos 3 0,25m	Pos 3 0,4m	Pos 3 1m	Pos 4 0,25m	Pos 4 0,4m	Pos 4 1m
63	83,1	77,1	65,1	83,9	78,6	66,6	83,6	78,0	65,9	82,4	77,5	64,5
125	77,6	73,8	66,5	77,0	73,8	66,3	77,8	74,2	66,2	77,3	73,9	66,6
250	76,3	74,5	69,6	76,2	74,4	69,8	76,7	74,9	69,6	76,1	74,2	69,8
500	77,3	75,9	71,2	77,6	76,0	71,3	77,6	76,3	71,1	77,4	75,9	71,4
1000	81,8	79,3	73,6	81,0	79,2	73,0	81,9	79,5	73,7	81,0	79,2	73,2
2000	81,7	79,5	73,8	80,8	79,0	74,2	81,8	79,7	73,7	80,9	78,8	74,1
4000	79,0	77,9	71,6	78,4	76,9	71,9	79,3	78,1	71,5	78,5	76,9	71,8
8000	73,3	72,4	66,1	72,5	71,1	66,3	73,6	72,5	66,0	72,7	71,2	66,1
A-weighted	87,0	85,1	79,3	86,3	84,5	79,3	87,1	85,3	79,2	86,3	84,5	79,3

Table B6 DELAB. Reference sound source B&K 4204

DELTA

Frequency	Side 1 0,25m	Side 1 0,4m	Side 1 1m	Side 2 0,25m	Side 2 0,4m	Side 2 1m	Side 3 0,25m	Side 3 0,4m	Side 3 1m	Side 4 0,25m	Side 4 0,4m	Side 4 1m
63	66,0	65,7	62,6	64,9	64,3	61,5	64,1	63,6	63,1	66,3	64,9	62,3
125	74,6	74,0	71,9	74,3	74,3	73,5	72,7	71,0	67,3	74,9	74,9	73,3
250	67,5	67,2	64,3	64,2	64,0	66,7	66,9	65,9	64,5	67,3	66,3	67,5
500	65,0	64,7	62,5	63,2	62,7	61,1	63,3	62,8	60,6	63,5	63,1	61,7
1000	59,5	58,6	59,0	57,5	57,0	56,5	57,6	57,3	55,9	59,0	58,6	57,9
2000	55,9	56,2	56,8	52,8	52,8	51,4	53,7	53,0	51,5	56,7	55,4	54,6
4000	51,8	52,8	53,0	48,8	48,3	47,1	49,5	48,6	47,7	52,1	51,8	50,2
8000	44,5	45,0	45,6	40,9	40,7	39,2	41,6	41,1	40,2	44,9	44,6	42,6
A-weighted	66,5	66,3	65,2	64,8	64,2	63,6	64,4	63,8	62,2	65,8	65,5	64,7

Table B7 Delta. A fan unit

Frequency	Side 1 0,25m	Side 1 0,4m	Side 1 1m	Side 2 0,25m	Side 2 0,4m	Side 2 1m	Side 3 0,25m	Side 3 0,4m	Side 3 1m	Side 4 0,25m	Side 4 0,4m	Side 4 1m
63	57,9	57,6	56,2	57,4	58,2	56,6	55,2	54,4	51,6	56,6	55,6	52,8
125	59,0	57,2	52,4	57,6	55,8	52,1	58,1	56,2	51,1	59,4	57,3	52,4
250	82,5	79,6	67,7	76,4	74,4	69,3	80,8	79,2	73,3	80,4	78,6	73,6
500	76,9	74,4	70,1	73,3	71,6	67,9	73,2	71,0	66,9	76,7	74,1	69,4
1000	83,4	81,4	75,9	76,5	74,5	71,6	75,8	73,9	69,3	81,6	79,5	75,1
2000	85,1	82,1	76,2	79,8	77,3	73,4	77,4	76,0	70,7	84,1	80,7	75,1
4000	84,3	82,8	79,6	79,3	78,1	76,0	76,6	75,8	71,8	82,8	80,1	76,5
8000	78,9	77,9	75,5	73,6	72,9	71,3	70,5	69,6	67,1	77,6	75,8	72,9
A-weighted	90,4	88,3	83,8	85,0	83,2	80,3	83,3	82,2	77,3	89,0	86,3	81,8

Table B8 Delta. A vacuum cleaner placed on a plastic box

Annex C - Repeatability tests of the sound power levels of the sources according to ISO 3741.

Swedish National Testing and Research Institute, SP

The figures show the standard deviation and the maximum deviaton of the repeatability and stability of the sources. The stability tests have been carried out without moving the machine between the measurements.

Test objects: Source 1. A radio base station
Source 2. A household vacuum cleaner

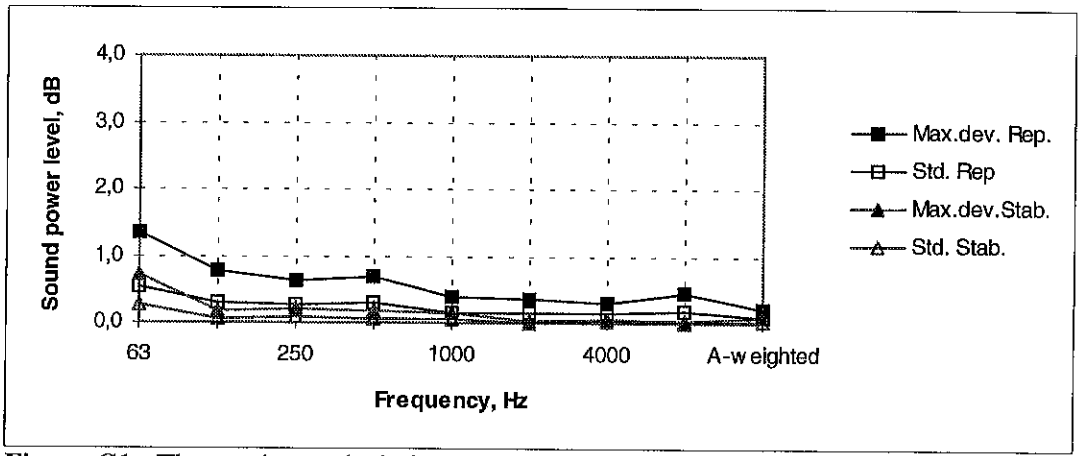

Figure C1. The maximum deviation and the standard deviation of 5 repeatability and stability tests of ISO 3741, source 1

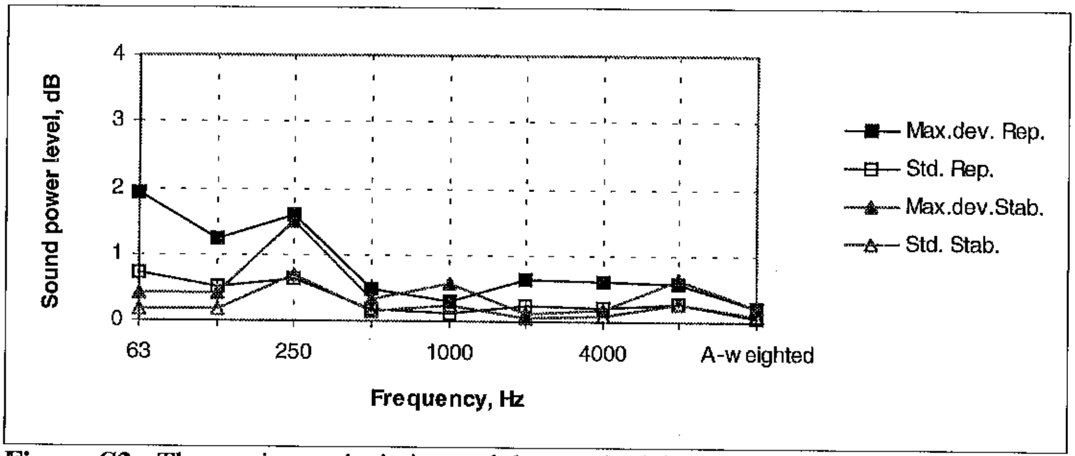

Figure C2 The maximum deviation and the standard deviation of 5 repeatability and 4 stability tests of ISO 3741, source 2

Annex C - Repeatability tests of the sound power levels of the sources according to ISO 3741.

National Research Centre of Finland, VTT

The figures show the standard deviation and the maximum deviaton of the repeatability of the sources.

Test objects: Source 1. A vacuum cleaner
Source 2. A disc saw

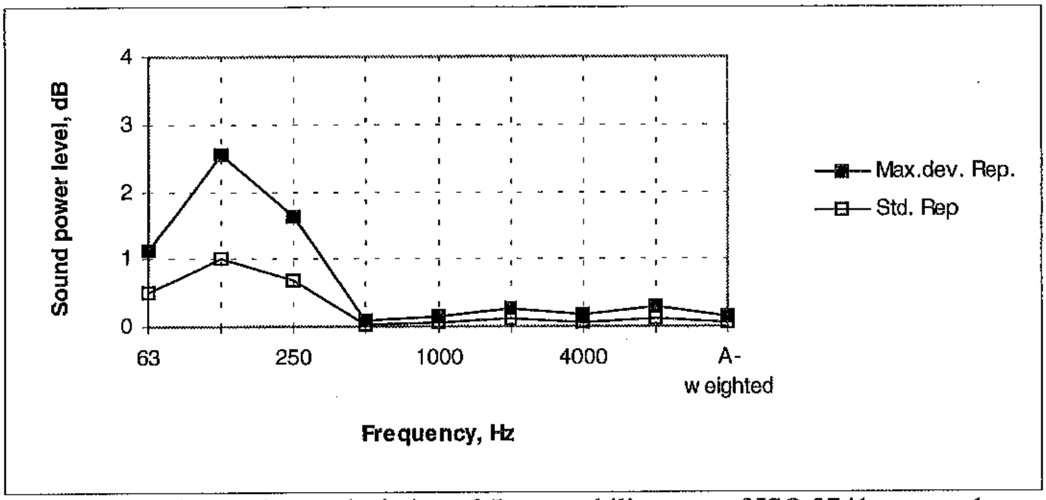

Figure C3 The maximum deviation of 5 repeatability tests of ISO 3741, source 1

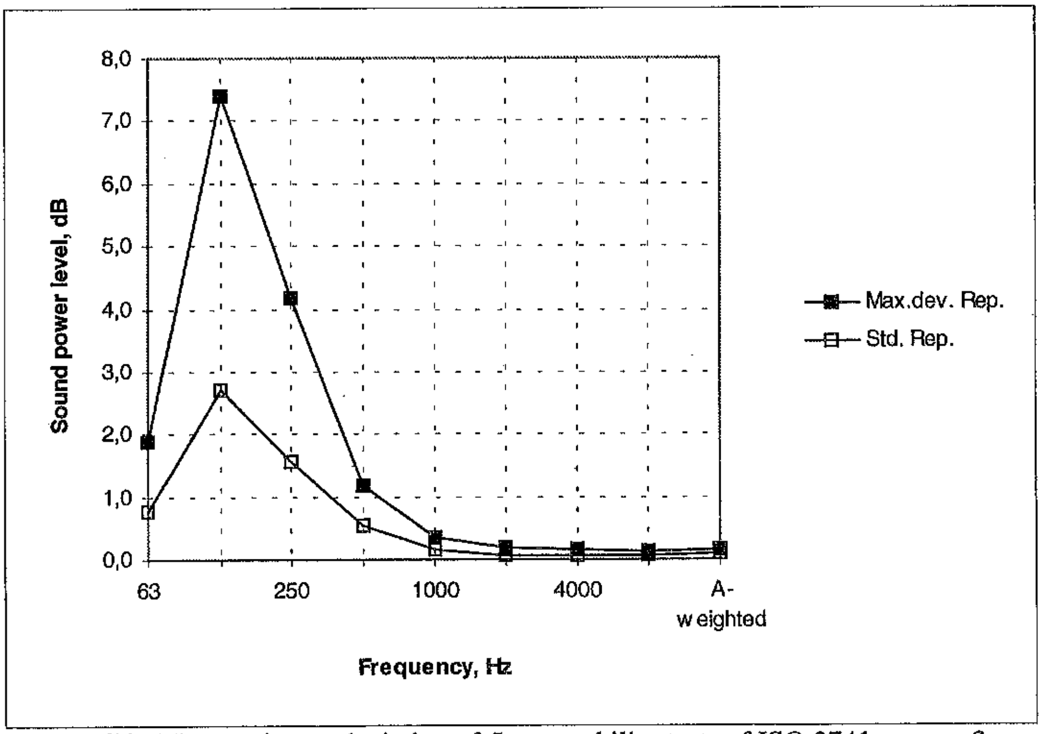

Figure C4 The maximum deviation of 5 repeatability tests of ISO 3741, source 2

Annex C - Repeatability tests of the sound power levels of the sources according to ISO 3741.

Delta, Denmark

The figures shows the standard deviation and the maximum deviaton of the repeatability of the sources.

Test objects: Source 1. A fan unit
Source 2. A vacuum cleaner placed on a plastic box.

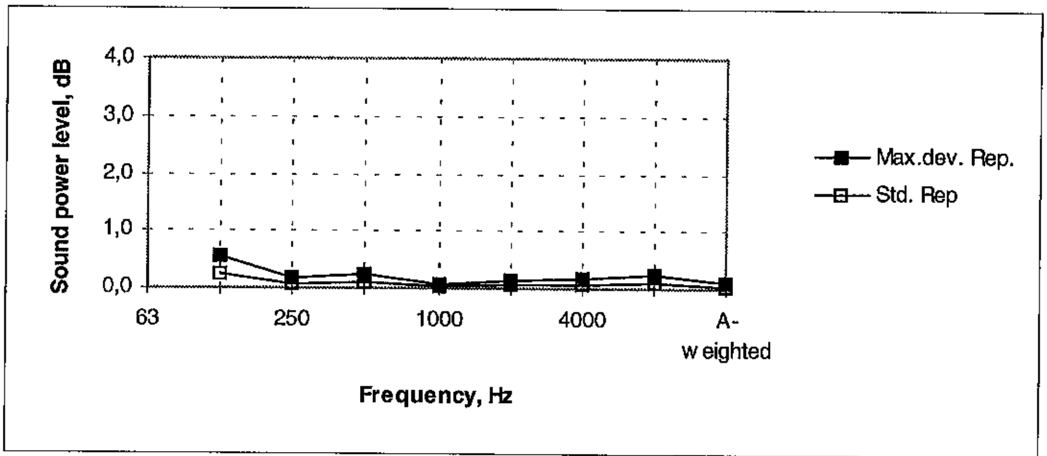

Figure C5 The maximum deviation of 5 repeatability tests of ISO 3741, source 1.

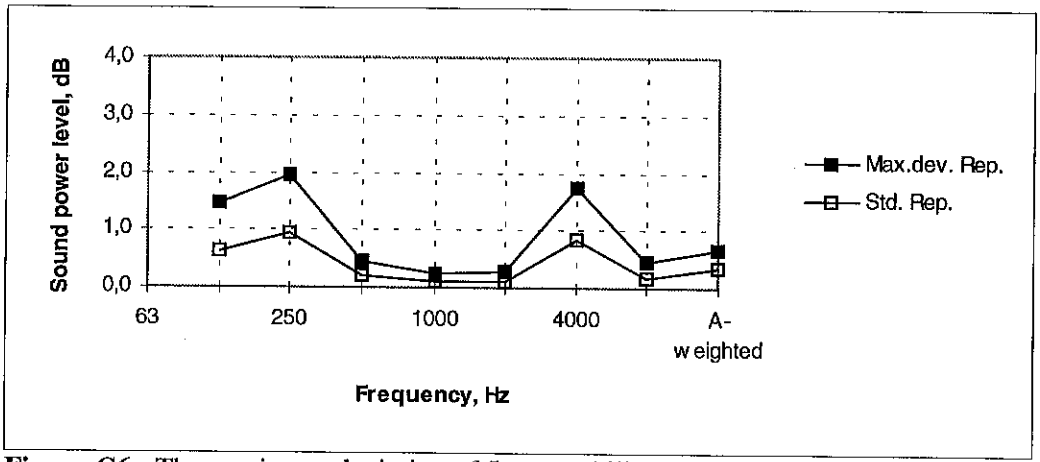

Figure C6 The maximum deviation of 5 repeatability tests of ISO 3741, source 2.

Annex C - Repeatability tests of the sound power levels of the sources according to ISO 3741.

DELAB, Norway

The figure shows the standard deviation and the maximum deviaton of the repeatability of the sources.

Test object: Source 1. ILG fan source mounted in a chipboard box.
Source 2 was a reference sound source B&K 4204

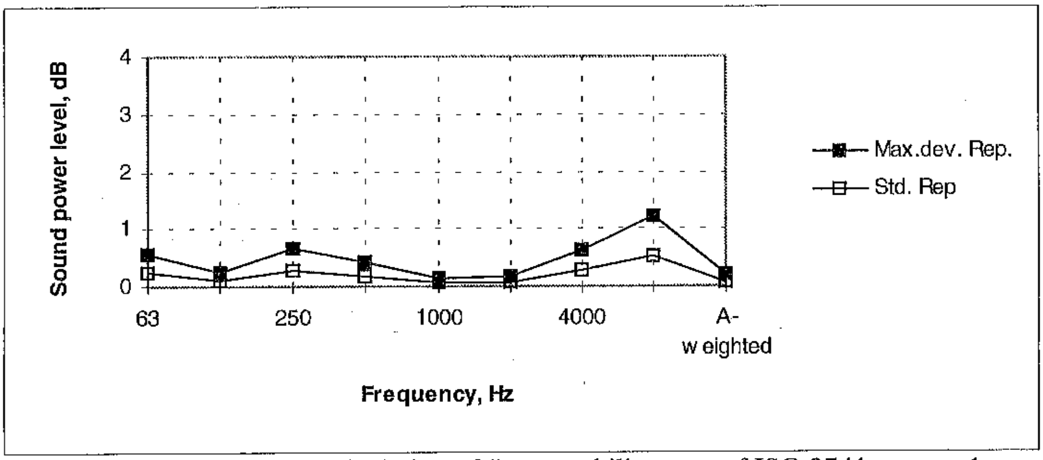

Figure C7 The maximum deviation of 5 repeatability tests of ISO 3741, source 1