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EUROMET PROJECT 363 - HARMONISATION OF AUDIOMETRY MEASUREMENTS WITHIN EUROPE FINAL REPORT

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ABSTRACT

NPL, along with partners from Denmark, France, Germany, Norway, Sweden and Switzerland undertook a calibration intercomparison for audiometric earphones, the purpose of which was to ensure the harmonisation of measurement standards for air-conduction audiometry within Europe. The project was organised radially, with NPL acting as the central co-ordinator and each of the participating laboratories using their own IEC 318 artificial ear systems. This report explains the background to the project, describes the measurements made by each of the partners and presents the results. Overall the results were encouraging, with differences generally no greater in magnitude than ± 0.5 dB between the partners, at the common audiometric frequencies.

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Approved on behalf of Managing Director, NPL,
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CONTENTS

Page

1 INTRODUCTION

2 BACKGROUND 2

3 SELECTION AND DISTRIBUTION OF INTERCOMPARISON DEVICES 4

4 CALIBRATION OF SOUND CALIBRATORS 5

5 INITIAL MEASUREMENTS MADE BY NPL, UNITED KINGDOM 6
5.1 The NPL artificial ear system and its calibration .. 6
5.1.1 Artificial ear system .. 6
5.1.2 Calibration of artificial ear system .. 7
5.2 Calculations .. 8
5.3 Earphone calibration procedure .. 9
5.4 Uncertainties .. 9
5.4.1 Uncertainty budget for the calibration of an air-conduction system .. 10
5.4.2 Uncertainty budget for earphone calibrations .. 10
5.5 Results of initial earphone calibrations at NPL .. 10

6 INTERCOMPARISON MEASUREMENTS MADE BY DTU, DENMARK 14
6.1 Introduction .. 14
6.2 Measurement procedure .. 14
6.3 Test results .. 17
6.4 Conclusion .. 19

7 INTERCOMPARISON MEASUREMENTS MADE BY LNE, FRANCE 20
7.1 Introduction .. 20
7.2 Measurement system .. 20
7.2.1 Equipment .. 20
7.2.2 Basic measurement system .. 20
7.3 Measurement procedure .. 20
7.4 Uncertainties .. 22
7.4.1 Type A uncertainties .. 22
7.4.2 Type B uncertainties .. 22
7.4.3 Overall uncertainties .. 23
7.5 Results .. 23
7.5.1 Holmco No 95-01 Blue A .. 23
7.5.2 Holmco No 95-01 Red F .. 23
7.5.3 TDH-49P B06903 .. 24
7.6 Conclusions .. 24

8 INTERCOMPARISON MEASUREMENTS MADE BY PTB, GERMANY 25
8.1 Introduction .. 25
8.2 Measuring conditions .. 25
8.3 Results .. 26

8.3.1 Ear simulator sensitivity levels of earphones 26
8.3.2 Static pressure coefficients 27
8.3.3 Temperature coefficients 28
8.3.4 Humidity coefficients 29
Measurement uncertainty 30
8.4.1 Calculation of type A uncertainties 30
8.4.2 Calculation of type B uncertainties 30
8.4.3 Overall uncertainty 30
8.5 Conclusions 30

9 INTERCOMPARISON MEASUREMENTS MADE BY SINTEF, NORWAY 32
9.1 Introduction 32
9.2 Equipment 32
9.3 Calibration of the measuring system 32
9.4 Results 32
9.4.1 Telephonics TDH-49P Serial No. B06915 33
9.4.2 Holmco No. 95-01 Red B 36
9.4.3 Holmco No. 95-01 Blue E 39

10 INTERCOMPARISON MEASUREMENTS MADE BY SP, SWEDEN 42
10.1 Introduction 42
10.2 Equipment 42
10.3 Environment 42
10.4 Method 42
10.5 Results 43
10.6 Comments 43
10.7 Uncertainty 43

11 INTERCOMPARISON MEASUREMENTS MADE BY OFMET, SWITZERLAND 44
11.1 Measurement procedure 44
11.2 Uncertainties 45
11.2.1 Type A Uncertainties 45
11.2.2 Type B Uncertainties . 45
Results 46

12 RESULTS 47

13 DISCUSSION AND CONCLUSIONS 54

14 ACKNOWLEDGEMENTS 56

15 REFERENCES 57

APPENDIX 1 LIST OF PARTNERS 58

1 INTRODUCTION

The principle objective of this project was to inter-compare measurement standards for air-conduction audiometry at national standards laboratories in Denmark, France, Germany, Norway, Sweden, Switzerland and the United Kingdom. The test pieces for the intercomparison were two types of supra-aural earphones (Telephonics TDH-49 and Holmco 95-01) commonly used for audiometry in Europe. Calibrations were carried out on a group of these earphones at the eleven common audiometric test frequencies between 125 Hz and 8000 Hz.

The project was organised radially with NPL acting as the central coordinator and each of the participating laboratories calibrating and using their own IEC 318 artificial ear systems and sound calibrators. All of the earphones were initially calibrated by NPL and then distributed in sets to the other participants. The sound calibrators were also calibrated by NPL, to ensure a common basis for setting up the overall sensitivities of the artificial ear systems used. Each of the participants then calibrated the earphones and returned them to NPL, where check measurements were carried out to ensure that their sensitivities had not changed. The overall aim was to test the consistency of standards for air-conduction audiometry within Europe and identify the cause of any anomalies, and to identify ways of improving the design or method of use of the standard instruments employed.

2 BACKGROUND

Pure-tone air-conduction audiometry is the measurement of the hearing threshold level of a person (using pure-tone test signals delivered through earphones) relative to the defined threshold of hearing for people with normal hearing. The audiometer is calibrated using an IEC-standard artificial ear (specified in IEC 318:1970[1]) or reference coupler (specified in IEC 303:1970[2]), in conjunction with the standardised data on the normal threshold of hearing. Reference Equivalent Threshold Sound Pressure level (RETSPL) values for the IEC 303 acoustic reference coupler and the IEC 318 artificial ear were published in ISO 389:1985[3] and its two Addenda[4&5]. ISO 389:1986 Add. 2 specifically stated that the RETSPLs in the standard applied only to a TDH-39 earphone with MX 41/AR cushion or a Beyer DT48 earphone with flat cushion calibrated on an IEC 303 acoustic reference coupler. This implied that if a TDH-39 earphone was fitted with the new style Model 51 cushion it should be calibrated using an IEC 318 artificial ear together with the RETSPLs for that device.

ISO decided to revise the standard and clarify any ambiguity by defining the cushions as equivalent in ISO 389:1991[6]. This now states that the IEC 303 acoustic reference coupler should only be used with Beyer DT48 earphones with flat cushions and with Telephonics TDH-39 earphones fitted either with MX 41/AR cushions or with the newer style one-piece Model 51 (P/N 510C017-1) cushions, when the RETSPLs given in ISO 389 Table 1 should be used. The IEC 318 artificial ear and RETSPLs given in ISO 389 Table 2 should be used for any other combination within specified limits.

The artificial ear or reference coupler is generally used in a complete measurement system consisting of the device itself, a sound level meter and a filter set. A sound calibrator is often included as well, as a means of setting up the overall sensitivity of the measuring system. Calibration of the artificial ear/reference coupler involves calibrating the microphone-sound level meter-filter set system at each of the common audiometric test frequencies in the range 125 Hz to 8000 Hz so that the relationship between the sound pressure level at the microphone, and the sound level meter reading, is established. It is also necessary to verify that the critical dimensions and acoustic impedance of the artificial ear/reference coupler are within the specification of IEC 318/IEC 303. For the purpose of calibration, various forms of microphone coupler are used to apply a known sound pressure level to the microphone. Whatever the type of microphone coupler, some knowledge is required of the front cavity and equivalent volumes of the microphone. In the case of the artificial ear, which contains a "half-inch" microphone, the microphone may need to be fitted with an adaptor to make it fit the coupler.

The artificial ear or reference coupler presents to the earphone an acoustical load similar to that of the average human ear. It also contains a microphone (connected to the sound level meter and filter) which measures the sound pressure level developed in it by the earphone. Thus a measure of the level of the test signal in the average human ear is obtained.

An unsatisfactory aspect of present standards for audiometry is the existence of two different standardised devices - the artificial ear and the reference coupler - for audiometer calibration. The need for every calibration centre to hold two different transfer standards adds both cost and complication to the calibration of audiometers. Preferably, only one transfer standard should be needed, for use with all types of audiometric earphone. The artificial ear is recognised as being a better approximation to the human ear than is the reference coupler, and is the device used for the calibration of all modern earphone types (Telephonics TDH-49, Telephonics TDH-50, Holmco 95-01 etc). At the same time, doubt has been cast by Canning[7] and Sherwood, McNeill and Torr[8] on whether the plastic-cased Telephonics TDH-39P earphones now in use are truly equivalent to the old metal-cased TDH-39 earphones for which the reference coupler is specified as the appropriate calibration device. In the belief that the reference coupler is now obsolescent, its use was excluded from this study.

Methods of calibrating the microphone of the artificial ear are not defined in present standards and are likely to differ from one laboratory to another. The extent of these differences is not known as there have been no international comparisons of calibrations of artificial ears or reference couplers, or of earphones or audiometers. The current international standard on the normal threshold of hearing is founded on subjective measurements carried out in various countries in the 1970s and earlier. This work involved the

use of calibrated artificial ear and reference coupler systems, but was carried out at a time when calibration techniques were considerably less accurate than is possible now.

This project therefore involved a comparison of measurements of the sensitivity of two different types of supra-aural earphone, using the IEC-standard artificial ear. The sensitivity is defined in terms of the sound pressure level produced in the artificial ear when the earphone is driven by a specified voltage applied at its terminals. This mimics the practical situation when the earphone is connected to an audiometer. The effect of atmospheric pressure and temperature on the performance of the earphones was also investigated. In principle, the sensitivities determined by the participating laboratories should agree within their quoted uncertainties of measurement.

To complete the background, Table 2.1 summarises the current International Electrotechnical Commission (IEC) and International Organization for Standardization (ISO) standards which are relevant to the calibration of audiometric earphones.

Table 2.1 Current Standards relating to calibration of audiometric earphones

IEC Publications	ISO Standards	Description
	ISO 389:1991	Reference zero for the calibration of pure tone audiometers
IEC 303:1970		Acoustic coupler for the calibration of audiometric earphones
IEC 318:1970		Artificial ear for the calibration of audiometric earphones

3 SELECTION AND DISTRIBUTION OF INTERCOMPARISON DEVICES

Ten Telephonics TDH-49P and twenty Holmco 95-01 earphones all with a nominally 10 Ω impedance were purchased. All of the earphones and cushions were inspected to ensure that there were no signs of damage. The manufacturers' specifications for the two earphone types are given below:

Telephonics TDH-49P

Receiver type:	dynamic with metal diaphragm
Impedance:	10 ohms
Frequency response:	100 Hz to 8000 Hz
Continuous Power Rating	300 milliwatts at any single frequency in the 100 Hz to 8000 Hz range
Linearity:	Linear for power inputs from 0 to 400 milliwatts
Sensitivity:	106 dB ± 2 dB (Reference 0 dB = 20 μPa) output with 1 milliwatt input at 1000 Hz
Distortion	less than 1 %

Holmco 95-01

Receiver type:	dynamic with metal diaphragm
Impedance:	10 ohms
Frequency response:	50 Hz to 12000 Hz
Power handling capability	500 milliwatts according to DIN 45582
Linearity:	Linear for power inputs from 0 to 400 milliwatts
Sensitivity:	106 dB ± 2 dB (Reference 0 dB = 20 μPa) output with 1 milliwatt input at 1000 Hz
Distortion	less than 1 % @ 130 dB SPL f = 1000 Hz

One Telephonics TDH-49P and two Holmco 95-01 earphones were distributed to each of the six partners as follows:

DTU, Denmark	Telephonics TDH-49P Serial No. B06904 Holmco No 95-01 Serial Nos. Red A & Blue F
SINTEF, Norway	Telephonics TDH-49P Serial No. B06915 Holmco No 95-01 Serial Nos. Red B & Blue E
Swiss Federal Office of Metrology	Telephonics TDH-49P Serial No. B06894 Holmco No 95-01 Serial Nos. Red C & Blue D
PTB, Germany	Telephonics TDH-49P Serial No. B06893 Holmco No 95-01 Serial Nos. Red D & Blue C
SP, Sweden	Telephonics TDH-49P Serial No. B06896 Holmco No 95-01 Serial Nos. Red E & Blue B
LNE, France	Telephonics TDH-49P Serial No. B06903 Holmco No 95-01 Serial Nos. Red F & Blue A

4 CALIBRATION OF SOUND CALIBRATORS

Sound calibrators belonging to each of the participating laboratories were calibrated at NPL, issued with a calibration certificate for use with a Brüel and Kjær type 4134 half inch pressure microphone and returned so as to ensure a common basis for setting up the overall sensitivities of the artificial ears used. The typical overall uncertainty on these calibrations is 0.07 dB. In practice, all of the sound calibrators submitted were of the pistonphone type. Listed below are the devices calibrated by NPL:

DTU, Denmark	Brüel and Kjær Pistonphone type 4220 Serial No. 894267
SINTEF, Norway	Brüel and Kjær Pistonphone type 4220 Serial No. 1164890
Swiss Federal Office of Metrology	Brüel and Kjær Pistonphone type 4228 Serial No.1504104
PTB, Germany	Brüel and Kjær Pistonphone type 4220 Serial No.1297294
SP, Sweden	Brüel and Kjær Pistonphone type 4228 Serial No.1818796
LNE, France	Brüel and Kjær Pistonphone type 4228 Serial No.1587920

5 INITIAL MEASUREMENTS MADE BY NPL, UNITED KINGDOM

5.1 The NPL artificial ear system and its calibration

5.1.1 Artificial ear system

An artificial ear system as shown in Figure 5.1 was used by NPL for the initial measurements of the sensitivities of the earphones. The system consisted of:

Brüel and Kjær Half inch pressure microphone type 4134 Serial No. 1611993

Brüel and Kjær IEC 318 artificial ear type 4153 Serial No. 1552229

Brüel and Kjær connecting lead type AO 0027

Brüel and Kjær adaptor type ZC 0020

Brüel and Kjær IEC type 1 sound level meter type 2235 Serial No. 1382863

Brüel and Kjær Third octave filter set type 1625 Serial No. 1406919

Brüel and Kjær Pistonphone type 4220 Serial No. 1164468

Brüel and Kjær Sound calibrator type 4231 Serial No. 1761931

For all measurements, the sound level meter was switched to Pol. Voltage "200 V", Sound Incidence "Frontal", Frequency Weighting "Lin.", Time Weighting "Fast", Range "40-110", Ext. Filter "In", Display "Inst"; the filter set was switched to Step Size "1/3 oct." and Bandwidth "1/3 oct.".

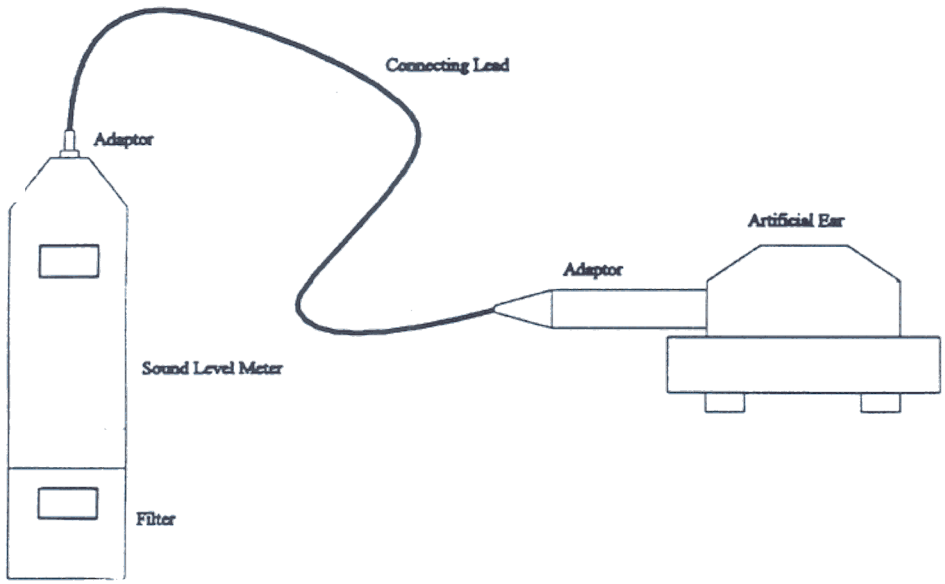


Figure 5. Artificial ear system

5.1.2 Calibration of artificial ear system

The artificial ear was sent to Brüel and Kjær for servicing to ensure that all the vents were free from any form of blockage and that the device was functioning correctly. Upon return, the artificial ear system was calibrated by the substitution method, using a standard calibrated one-inch microphone as reference. The principle of the calibration was as follows. With the cylindrical body of the artificial ear removed, the half-inch microphone of the artificial ear system was coupled to a one-inch transmitter microphone using a standard air filled microphone plane wave coupler (Brüel and Kjær type DB 1392). For this purpose, the grid of the half-inch microphone was removed and replaced by an adaptor ring (Brüel and Kjær type WA 0220/WA 0221) to make it the same geometric shape as a one-inch microphone.

A level of 74 dB as indicated by the artificial ear system was then set up in the microphone coupler using the transmitter. The artificial ear system was then replaced by a standard microphone and the true sound pressure level in the coupler was measured using the insert voltage technique. Figure 5.2 shows the system used to drive the transmitter microphone and determine the sound pressure level in the coupler using the standard microphone.

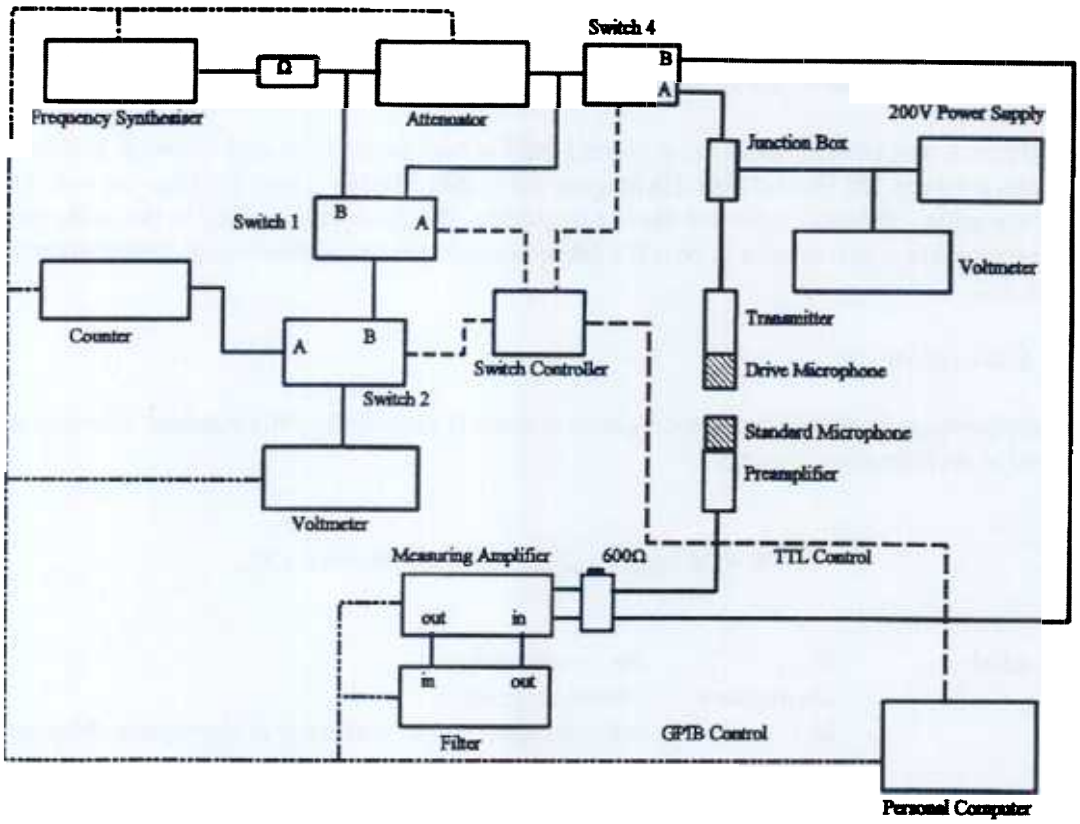


Figure 5.2 Facility for calibration of artificial ear system. (The transmitter microphone drives a microphone coupler fitted either to the artificial ear or to the standard microphone)

The performance of the calibration system shown in Figure 5.2 was itself checked using two NPL calibrated sound calibrators (Brüel and Kjær pistonphone type 4220 and sound calibrator type 4231). These were applied to the standard microphone and for the calibration system to be functioning correctly the measured sound source SPL was required to agree with the known output to within 0.05 dB.

A calibrated sound calibrator (Brüel and Kjær type 4220) was used to make the initial sensitivity adjustment of the artificial ear system and to verify that the system remained stable during the course of the calibration of the earphones. All measurement systems were located in a temperature-controlled room, and the calibration of the artificial ear system and the subsequent calibration of the earphones were carried

out under the following ambient conditions, as agreed by the participating laboratories:

Pressure	99.0 kPa to 103.5 kPa
Temperature	21.5°C to 24.5°C

As part of the calculation process, account was taken of the change in sound pressure in the coupler associated with the difference in volume between the artificial ear microphone and the standard microphone. This required the total effective volume of each microphone to be known. The total effective volume is the sum of the front cavity volume and the equivalent volume of the diaphragm impedance. It was measured for each microphone by comparing the sound pressure generated in a small cavity formed partly by the microphone, with that when the microphone was replaced with other known volumes.

Using these results, a correction was calculated based on the change in acoustical transfer impedance of the coupled microphone arrangement that occurs when the standard microphone is substituted by the microphone from the artificial ear system. At low frequencies this is simply given by the ratio of the total volumes in each configuration. However as the frequency increases, account must also be taken of the difference in acoustic impedance of the artificial ear and standard microphones. Nominal values for the acoustic impedance of the artificial ear microphone were used in the calculation. These are based on previous measurements on a large sample of the given type of microphone. The acoustic impedance of the standard microphone had also been measurement previously. Applying the correction to the measured data then enabled the response of the system to be calculated.

The calibration was carried out at the preferred third octave frequencies and common audiometric test frequencies between 125 Hz and 8000 Hz as specified in ISO 389:1991, with the filter set switched to the third octave centre frequency closest to the test frequency. The overall uncertainty in the calibration of the artificial ear system was estimated to be ± 0.2 dB for a confidence probability of approximately 95% (see section 6.1).

5.2 Calculations

The sound pressure level inside the microphone coupler is measured by the standard microphone and is calculated at each frequency using:

$$SPL = 20\ log_{10}\ V_{insert} + 93.98 - attenuation - M_f$$

where:		
	V_{insert}	the insert voltage
	$attenuation$	attenuator reading
	M_f	standard microphone sensitivity at appropriate frequency

The mean SPL from six measurements at each frequency $\bar{x}$ was then calculated along with the associated standard deviation $s(x_k)$. The estimated standard deviation of the uncorrected mean of the measurand $s(\bar{x})$ for n measurements is given by the formula:

$$s(\bar{x}) = \frac{s(x_k)}{\sqrt{n}}$$

A correction for the difference in volume between the standard microphone and the adapted microphone of the artificial ear was then applied at each frequency to obtain the corrected mean SPL values. The "response" of the artificial ear system (indicated SPL - true SPL) was then given by:

$$Response = 74 - SPL_{corrected\ mean}$$

5.3 Earphone calibration procedure

The NPL earphone drive system and artificial ear system are illustrated in Figure 5.3. The performance of the artificial ear system was verified using the calibrated NPL pistonphone. Then, each earphone in turn was connected to the signal source using a double lead to measure the drive voltage at the earphone terminals and was coupled to the artificial ear with a static force of 4.5 N (excluding the weight of the earphone). This force was supplied by a brass cylindrical mass mounted on top of the earphone.

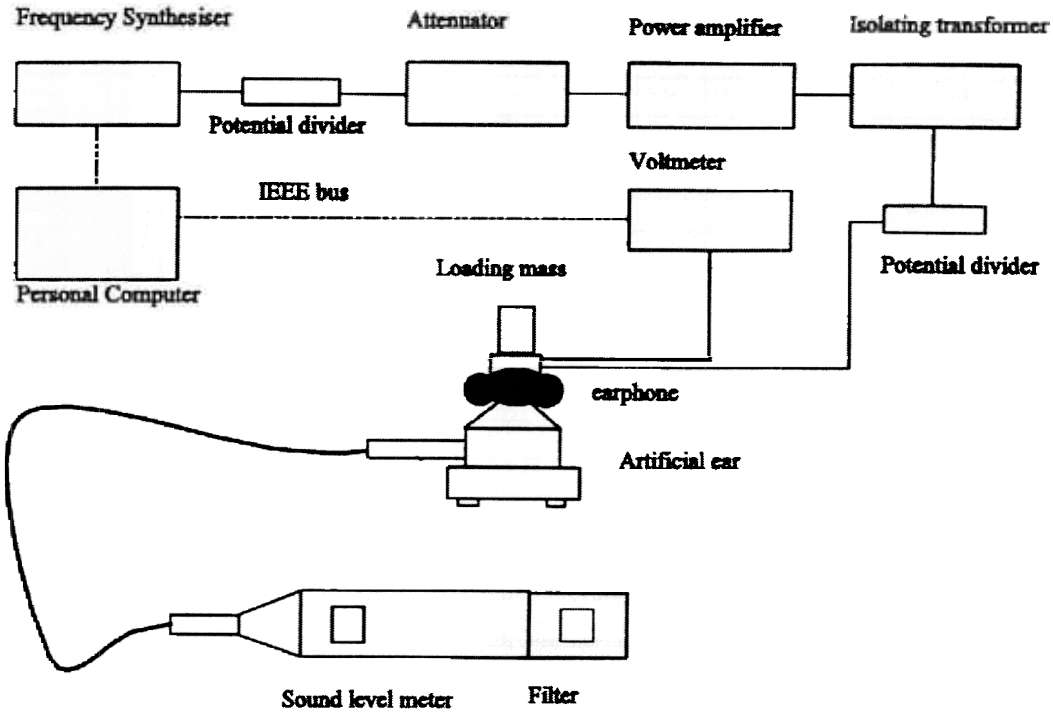


Figure 5.3 Earphone drive system and artificial ear system

The earphone was driven by a r.m.s. voltage of 100.0 ± 0.1 mV applied across the earphone terminals at each of the preferred third octave frequencies and common audiometric test frequencies between 125 Hz and 8000 Hz. Using the third octave filter closest to the excitation frequency, the sound level meter reading was recorded. Measurements were made in sets of six, the earphone being rotated by 120° for each measurement. These measurements were repeated on at least five separate days when the ambient pressure was within the allowed limits stated in section 5.1.2. The overall uncertainty in these measurements was estimated to be ± 0.3 dB for a confidence probability of approximately 95% (see section 5.4.2).

5.4 Uncertainties

The two types of uncertainty components listed here are combined in accordance with the recommendations of NAMAS publication NIS 3003 Edition 8 1995[9] to give the overall uncertainty based on a standard uncertainty multiplied by a coverage factor k = 2, providing a confidence probability of approximately 95 %. All values quoted are calculated using the worst value over the measurement frequency range unless otherwise stated. The random uncertainties quoted are typical values, but in practice the total uncertainty was calculated individually for each test system.

5.4.1 Uncertainty budget for the calibration of an air-conduction system

Symbol	Source of uncertainty	Value	Probability	Divisor	c_i	u_i	v_i or v_{eff}
S_{SLM}	Setting to fixed mark on sound level meter or MA scale	0.1	rectangular	√3	1	0.058	∞
L_{DG}	Resetting level of drive signal to transmitter microphone	0.02	rectangular	√3	1	0.012	∞
V_I	Measurement of insert voltage to standard microphone	0.02	rectangular	√3	1	0.012	∞
U_A	Accuracy of standard attenuator	0.03	normal	2	1	0.015	∞
V_P	Polarizing voltage to standard microphone	0.025	rectangular	√3	1	0.014	∞
P_{SM}	Pressure coefficient of standard microphone	0.01	rectangular	√3	1	0.006	∞
D_{PV}	Difference between front volumes of test and standard microphone	0.03	rectangular	√3	1	0.017	∞
R	Rounding of final result	0.05	rectangular	√3	1	0.029	∞
U_{MS1}	Sensitivity of standard microphone up to 2 kHz	0.03	normal	2	1	0.015	∞
U_{MS2}	Sensitivity of standard microphone at 3 kHz and 4 kHz	0.04	normal	2	1	0.02	∞
U_{MS3}	Sensitivity of standard microphone at 6 kHz and 8 kHz	0.05	normal	2	1	0.025	∞
$L_{s\,125}$	Typical repeatability at 125 Hz	0.08	normal	2	1	0.04	5
$L_{s\,250\text{-}8000}$	Typical repeatability above 250 Hz	0.05	normal	2	1	0.025	5
$U_c(L_s)_{125}$	Combined Uncertainty 125 Hz		normal			0.084	∞
$U_c(L_s)_{250\text{-}2000}$	Combined Uncertainty up to 2 kHz		normal			0.079	∞
$U_c(L_s)_{3000\text{-}4000}$	Combined Uncertainty at 3 kHz and 4 kHz		normal			0.079	∞
$U_c(L_s)_{6000\text{-}8000}$	Combined Uncertainty at 6 kHz and 8 kHz		normal			0.080	∞
U_{AC250}	Expanded uncertainty 250 Hz		normal (k=2)			0.17	∞
$U_{AC250\text{-}2000}$	Expanded uncertainty up to 2 kHz		normal (k=2)			0.16	∞
$U_{AC3000\text{-}4000}$	Expanded uncertainty at 3 kHz and 4 kHz		normal (k=2)			0.16	∞
$U_{AC6000\text{-}8000}$	Expanded uncertainty at 6 kHz and 8 kHz		normal (k=2)			0.16	∞
U_{TAC}	Expanded uncertainty (worst case)		normal (k=2)			0.17	∞

5.4.2 Uncertainty budget for earphone calibrations

Symbol	Source of uncertainty	Value ± dB	Probability distribution	Divisor	c_i	u_i (dB) ± dB	v_i or v_{eff}
U_{TAC}	Calibration of air-conduction system	0.17	normal	2	1	0.085	∞
S_{SLM}	Setting up sound level meter	0.05	rectangular	√3	1	0.029	∞
P_E	Positioning of earphone on artificial ear by trained operator	0.1	normal	2	1	0.05	∞
R	Rounding of final result	0.05	rectangular	√3	1	0.029	∞
L	Typical repeatability (6 measurements)	0.1	normal	2	1	0.05	5
$U_c(L_s)$	Combined Uncertainty		normal			0.118	∞
U_{EC}	Expanded uncertainty (worst case)		normal (k=2)			0.24	∞

5.5 Results of initial earphone calibrations at NPL

As described in section 5.3, sound level meter readings in response to each earphone were recorded in sets of six, the earphone being rotated by 120° between each recording. From the six readings recorded at each frequency, a mean reading was calculated. This mean was then corrected to account for the known response of the artificial ear system (see section 5.2) to give the true mean sound pressure level in the artificial ear.

Finally, these measurements were repeated on at least five separate days from which a grand mean sound pressure level and associated standard deviation were calculated. These results are presented in tables 5.1, 5. 2 and 5.3.

Frequency (Hz)	Earphone type Telephonics TDH-49P					
	B06893		B06894		B06896	
	mean	sd	mean	sd	mean	sd
125	103.21	0.05	103.72	0.06	103.71	0.05
250	106.10	0.05	106.65	0.09	106.50	0.04
500	106.94	0.06	107.52	0.09	107.39	0.04
750	107.00	0.04	107.68	0.11	107.55	0.04
1000	107.13	0.10	107.95	0.10	107.81	0.05
1500	107.04	0.05	107.64	0.07	107.50	0.03
2000	107.52	0.03	108.10	0.06	107.66	0.04
3000	109.52	0.05	109.63	0.06	109.77	0.02
4000	107.16	0.06	107.69	0.04	107.50	0.04
6000	104.22	0.06	104.54	0.13	104.22	0.05
8000	98.65	0.05	98.84	0.03	98.86	0.02
	B06903		B06904		B06915	
	mean	sd	mean	sd	mean	sd
125	103.71	0.04	103.71	0.04	103.63	0.04
250	106.51	0.07	106.54	0.08	106.38	0.05
500	107.33	0.05	107.44	0.08	107.29	0.04
750	107.43	0.08	107.66	0.03	107.48	0.08
1000	107.51	0.06	107.97	0.08	107.79	0.05
1500	107.07	0.04	107.66	0.04	107.66	0.04
2000	107.32	0.03	107.80	0.03	107.87	0.08
3000	109.40	0.08	109.10	0.01	108.62	0.07
4000	107.49	0.08	107.44	0.09	106.99	0.09
6000	103.78	0.01	104.24	0.05	104.20	0.07
8000	98.10	0.06	98.68	0.01	98.12	0.08

Table 5. Grand mean sound pressure level (dB) and associated standard deviation (sd) generated in the artificial ear by driving each of the Telephonics TDH-49P earphones with a 100 mV sinusoidal signal.

Frequency (Hz)	Earphone type Holmco No. 95-01					
	Red A		Red B		Red C	
	mean	sd	mean	sd	mean	sd
125	119.24	0.01	118.04	0.01	118.42	0.09
250	119.81	0.01	119.43	0.01	119.81	0.01
500	121.2	0.01	120.44	0.01	120.98	0.04
750	121.88	0.01	121.02	0.02	121.54	0.05
1000	122.17	0.01	121.16	0.01	121.81	0.03
1500	120.35	0.01	119.47	0.01	120.11	0.08
2000	118.2	0.02	117.6	0.04	118.24	0.01
3000	114.23	0.01	114.48	0.01	115.38	0.07
4000	110.98	0.01	111.76	0.02	112.54	0.01
6000	105.87	0.01	104.65	0.03	107.16	0.05
8000	110.42	0.02	108.35	0.02	107.68	0.09
	Red D		Red E		Red F	
	mean	sd	mean	sd	mean	sd
125	118.75	0.01	118.02	0.02	118.87	0.05
250	119.84	0.01	118.09	0.03	118.50	0.15
500	121.08	0.04	117.70	0.02	120.54	0.07
750	121.63	0.04	118.91	0.01	121.70	0.02
1000	121.85	0.01	119.26	0.02	122.24	0.04
1500	120.02	0.02	117.94	0.03	119.07	0.01
2000	118.06	0.01	116.81	0.03	116.63	0.06
3000	115.11	0.01	115.09	0.01	112.48	0.14
4000	111.75	0.02	112.15	0.02	106.95	0.05
6000	106.76	0.07	106.21	0.01	108.23	0.01
8000	109.26	0.03	110.53	0.04	108.12	0.01

Table 5.2 Grand mean sound pressure level (dB) and associated standard deviation (sd) generated in the artificial ear by driving each of the Holmco No. 95-01 (red) earphones with a 100 mV sinusoidal signal.

Frequency (Hz)	Earphone type Holmco No. 95-01					
	Blue A		Blue B		Blue C	
	mean	sd	mean	sd	mean	sd
125	118.68	0.01	118.87	0.03	117.95	0.01
250	119.94	0.01	119.74	0.01	119.40	0.01
500	121.14	0.01	120.92	0.01	120.54	0.01
750	121.79	0.01	121.49	0.01	120.78	0.03
1000	122.15	0.01	121.66	0.01	120.85	0.01
1500	120.31	0.01	120.00	0.01	119.10	0.01
2000	118.24	0.01	118.35	0.01	117.56	0.01
3000	114.87	0.01	115.48	0.01	116.40	0.01
4000	111.71	0.01	111.93	0.01	112.23	0.01
6000	104.63	0.01	106.07	0.01	105.05	0.01
8000	109.58	0.01	107.50	0.01	107.67	0.01
	Blue D		Blue E		Blue F	
	mean	sd	mean	sd	mean	sd
125	118.86	0.01	118.84	0.03	118.60	0.01
250	120.07	0.02	120.05	0.02	120.03	0.01
500	121.23	0.01	121.34	0.01	120.92	0.01
750	121.59	0.01	121.88	0.03	121.59	0.01
1000	121.66	0.01	121.85	0.01	121.67	0.01
1500	119.86	0.01	119.99	0.01	119.80	0.01
2000	118.25	0.01	118.09	0.01	118.16	0.01
3000	115.56	0.01	115.05	0.01	116.17	0.01
4000	111.52	0.01	111.48	0.01	111.33	0.01
6000	105.88	0.01	105.02	0.01	104.49	0.01
8000	110.11	0.01	110.53	0.01	110.69	0.01

Table 5.3 Grand mean sound pressure level (dB) and associated standard deviation (sd) generated in the artificial ear by driving each of the Holmco No. 95-01 (blue) earphones with a 100 mV sinusoidal signal.

6 INTERCOMPARISON MEASUREMENTS MADE BY DTU, DENMARK

6.1 Introduction

This section of the report describes the measurement method used at the Department of Acoustic Technology at DTU for determining the transfer function of three audiometric earphones received from NPL, UK. The measurements have been performed as a part of EUROMET Project 363 initiated by NPL. The earphones measured were:

Holmco No 95-01 Red cap marked A
Holmco No 95-01 Blue cap marked F
Telephonics TDH-49P Serial No. B06904

All transfer functions were determined using a Brüel and Kjær artificial ear type 4153 Serial no. 207335, which fulfils IEC 318:1970[1]. The Artificial Ear was recalibrated at the manufacturer about a month before the measurement presented here.

The transfer functions are determined in the frequency range 20 Hz - 20 kHz using pure tones in steps of 1/40-decade (approx. 1/12-octave), ie in total 120 frequencies. The transfer function is expressed in dB re 1 Pa/V. The actual driving voltage used is 100 mV.

6.2 Measurement procedure

The basic measurement system used is shown in figure 6.1

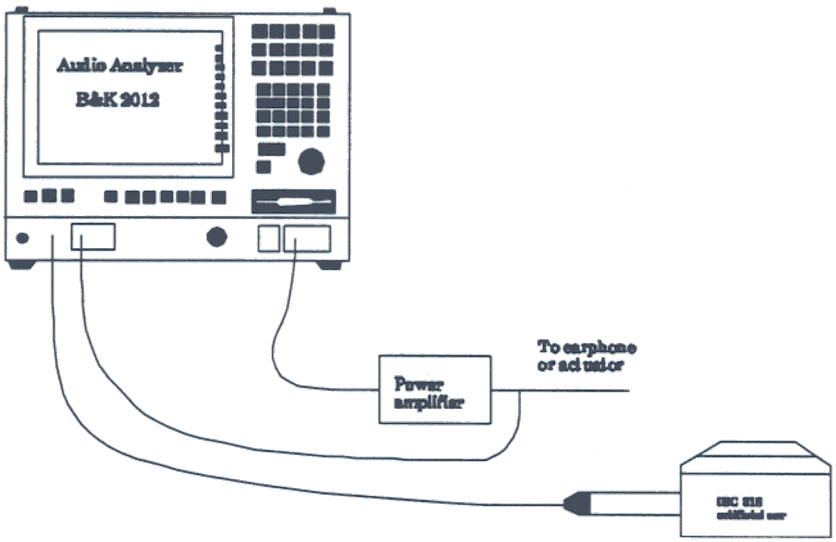


Figure 6.1 Basic measurement system

The analyser Brüel and Kjær type 2012 provides the driving voltage from the internal signal generator having a fixed, calibrated output impedance of 50 Ohm. The signal passed through a power amplifier in order to ensure a low-impedance source (< 0.1 Ohm) to drive the earphones. The output voltage of the power amplifier was measured (monitored) by the analyser using balanced wiring on the direct input terminals. The microphone used in the artificial ear, Brüel and Kjær type 4134S Serial no. 982320 with standard grid, was connected to the microphone input connector of the analyser.

The determination of the transfer function of the earphones was accomplished in 6 steps:

1) Determination of the relative frequency response of the microphone by an electrostatic actuator Brüel and Kjær UA 0033.

2) Determination of the absolute sensitivity of the microphone at 250 Hz using a pistonphone.

3) Measurement of the absolute driving voltage applied to the earphone as function of frequency.

4) Measurement of the absolute output voltage of the microphone as function of frequency, using the earphone driving voltage determined above (step 3).

5) Calculation of the transfer function in dB re 1 Pa/V using the results from step 1-4.

6) Repetition of step 4 and 5 in total five times.

Step

The measurement setup is shown in figure 6.2.

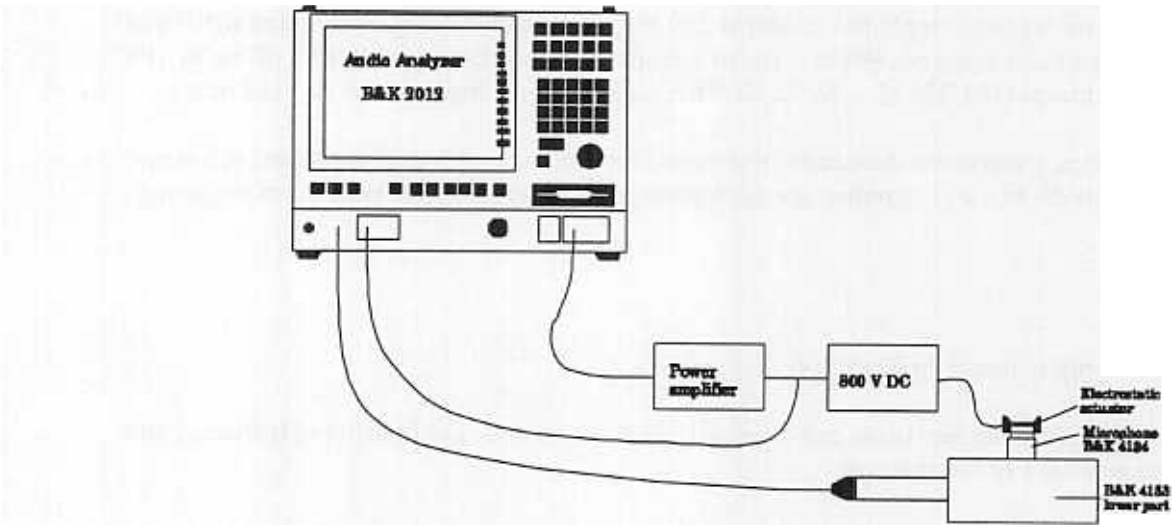


Figure 6.2 Setup for measuring the actuator response

First the driving voltage (output voltage of the power amplifier) was measured as a function of frequency and temporarily stored in the analyser. Next the output voltage of the microphone was measured and stored. The output voltage of the microphone was then divided by the driving voltage and the result was normalized by the value at 250 Hz. The result, which is stored in the memory bank of the analyser, represents the relative pressure sensitivity of the microphone using 250 Hz as reference.

Step 2

The measurement setup is shown in figure 6.3.

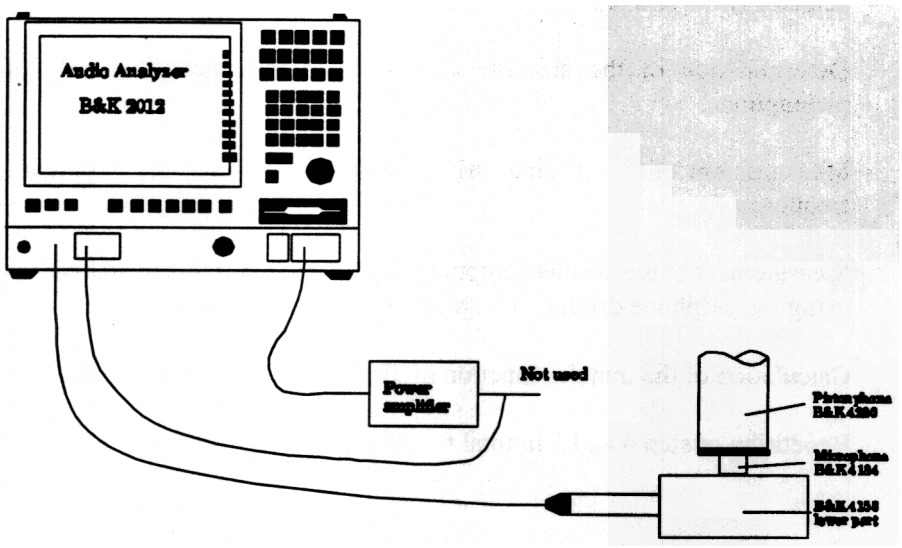


Figure 6.3 Setup for microphone calibration

The absolute sensitivity of the microphone channel at 250 Hz is determined using a calibrated Brüel and Kjær pistonphone type 4220 Serial no. 894267. The SPL from the pistonphone was 124.03 dB re 20 µPa under reference conditions (101.325 kPa, 23 C, 50 %RH and a nominal load volume of 1333 mm^3).

The analyser automatically converted the measured voltages from the microphone input channel to a sound pressure in pascals (or dB re 1 Pa) assuming the microphone sensitivity to be independent of frequency.

Step 3

The measurement setup is shown in figure 6.4.

The absolute driving voltage applied to the earphone under test was measured as function of frequency and stored in the memory bank of the analyser.

Step 4

The measurement setup is the same as used in step 3 see figure 6.4.

The sound pressure (absolute output voltage of the microphone converted into pascals, see step 2) in the coupler was measured using the driving voltage determined under step 3. The result was temporarily stored in the analyser.

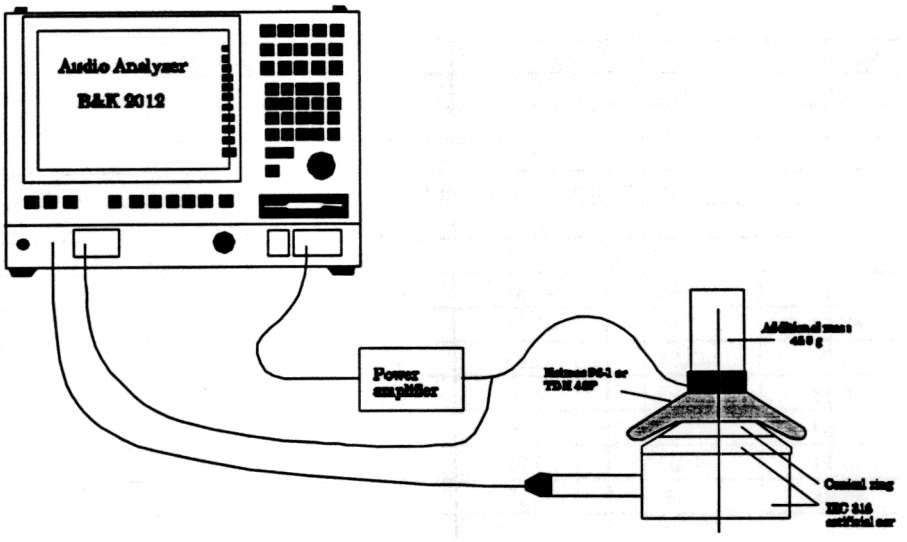


Figure 6.4 Setup for earphone measurement

Step 5

The sound pressure determined under step 4 was corrected for the frequency response of the microphone determined in step 1 thus giving the true sound pressure in the coupler as function of frequency. This result was then divided by the absolute driving voltage determined under step 3. The final result represents the transfer function of the earphone in Pa/V and was stored in the memory bank of the analyser.

Step 6

Steps 4 and 5 were repeated four times, ie. in total the transfer function was measured five times. Between each repetition the earphone is removed and repositioned on the artificial ear. All five transfer functions were stored in the memory bank of the analyser. When the measurements were finished the content of the memory banks of the analyser was transferred as ASCII files to an ordinary PC. The files were then imported into a spreadsheet where average values, standard deviation and confidence interval were determined and plotted.

When more earphones were measured, steps 1 and 2 were only performed once or twice during a measurement session. The whole measurement procedure for one earphone was carried out in 15 minutes.

6.3 Test results

During all measurements the necessary force acting on the earphone was obtained by placing a cylindrical mass of 450 g on top of the earphones as indicated in figure 6.4. For each earphone under test, the above described measurement procedure was repeated over 5 days. Thus for each earphone a total of 25 measurements were performed. The final results over the five days for each earphone are given in tables 6.1-6.3. Only the values referring to the standard audiometric frequencies are listed although the measurements were performed at 120 frequencies. Further the resulting uncertainty (2 level) corresponding to a coverage factor two are derived from all 25 measurements. Graphical representations of the results at all frequencies are shown in figure 6.5 which also show the corresponding 95% confidence interval of the measurements.

Date	96-06-14	96-06-17	96-06-18	96-06-19	96-06-20		
p_s kPa	101.9	101.3	99.9	99.5	99.3		
t °C	23.3	22.8	22.8	23	23.2		
% RH	45	45	45	45	45		
Freq	Transfer function in dB re 1 Pa/V					mean	sd
125	45.03	44.98	44.9	44.96	44.98	44.97	0.07
250	45.52	45.49	45.36	45.4	45.42	45.35	0.07
500	46.94	46.93	46.82	46.83	46.86	46.88	0.06
750	47.67	47.62	47.51	47.56	47.56	47.58	0.07
1000	48.06	47.98	47.89	47.93	47.89	47.95	0.08
1500	46.18	46.18	46.1	46.13	46.15	46.15	0.05
2000	43.87	43.87	43.96	44	44	43.94	0.07
3000	40.11	40.02	39.78	39.81	39.79	39.9	0.15
4000	36.88	36.6	36.38	36.32	36.38	36.51	0.21
6000	31.86	31.89	31.47	31.57	31.46	31.65	0.20
8000	36.09	36.03	35.87	35.85	35.83	35.93	0.12

Table 6.1 Measured transfer functions. Holmco No 95-01 Serial No. Red A

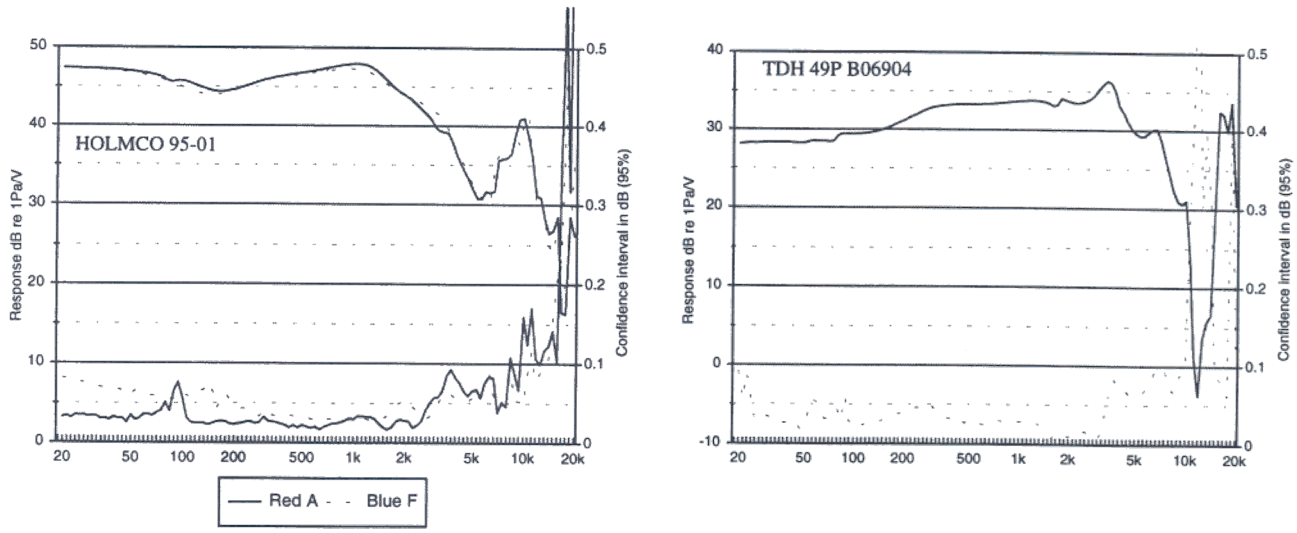
Date	96-06-14	96-06-17	96-06-18	96-06-19	96-06-20		
p_s kPa	101.9	101.3	99.9	99.5	99.3		
t °C	23.3	22.8	22.8	23	23.2		
% RH	45	45	45	45	45		
Freq	Transfer function in dB re 1 Pa/V					mean	sd
125	44.16	44.09	44.21	44.11	44.32	44.18	0.16
250	45.53	45.49	45.56	45.37	45.58	45.51	0.10
500	46.6	46.61	46.66	46.47	46.66	46.6	0.08
750	47.23	47.23	47.27	47.12	47.26	47.22	0.08
1000	47.35	47.31	47.35	47.21	47.35	47.31	0.09
1500	45.56	45.57	45.63	45.51	45.66	45.59	0.08
2000	43.83	43.85	44.02	43.89	44.04	43.93	0.13
3000	41.84	41.83	41.76	41.63	41.76	41.77	0.11
4000	36.93	36.97	36.84	36.65	36.77	36.83	0.15
6000	30.21	30.24	30.07	29.88	30.06	30.09	0.19
8000	36.2	36.19	36.15	35.94	36.08	36.11	0.13

Table 6.2 Measured transfer functions. Holmco No 95-01 Serial No. Blue F

Date	96-06-14	96-06-17	96-06-18	96-06-19	96-06-20		
p_s kPa	101.9	101.3	99.9	99.5	99.3		
t °C	23.3	22.8	22.8	23	23.2		
% RH	45	45	45	45	45		
Freq	Transfer function in dB re 1 Pa/V					mean	sd
125	29.78	29.78	29.66	29.65	29.62	29.7	0.07
250	32.34	32.32	32.13	32.09	32.07	32.19	0.12
500	33.33	33.34	33.21	33.17	33.16	33.24	0.08
750	33.52	33.49	33.37	33.36	33.33	33.42	0.08
1000	33.79	33.76	33.65	33.63	33.61	33.69	0.08
1500	33.42	33.43	33.36	33.35	33.35	33.38	0.04
2000	33.62	33.62	33.67	33.66	33.67	33.65	0.03
3000	35.21	35.25	33.22	35-22	35.21	35.22	0.02
4000	33.33	33.21	32.93	32.9	32.89	33.05	0.19
6000	29.99	29.86	29.61	29.55	29.52	29.71	0.19
8000	24.51	24.39	24.06	24.04	24.1	24.22	0.20

Table 6.3 Measured transfer functions. Telephonics TDH-49P No. B 06904

Figure 6.5 Transfer response and confidence intervals for Holmco 95-01 earphones and Telephonics TDH-49P earphones



6.4 Conclusion

When the present project was planned, it was decided to carry out 5x5 measurements, ie 5 repetitions over at least 5 days. The uncertainty observed during the measurements indicates that it is not necessary to repeat the measurements over 5 days provided of course that the standard deviation on the 5 measurements carried out over one work-day is sufficiently low. It should be noted that no corrections have been introduced to the measurement results because of changes in the static pressure and temperature over the measurement period. The static pressure coefficient of the transfer impedance of the artificial ear depends on the frequency but varies in the range -0.01 to -0.11 dB/kPa up to 16 kHz. Thus the expected variations are of the same order as the repeatability of the measurements.

For some unknown reasons the Holmco Blue cap F earphone had to be very carefully aligned on the artificial ear in order to avoid a leakage. A leakage lowering the level at 50 Hz by 6 - 10 dB was quite common if the earphone was not properly aligned. The Holmco Red cap A did not exhibit the same behaviour. The very hard cushion supplied with this type of earphone of course will make it more difficult to achieve a good seal for this coupler/earphone combination.

7 INTERCOMPARISON MEASUREMENTS MADE BY LNE, FRANCE

7.1 Introduction

This inter-comparison of earphone calibrations for air conduction audiometry is managed by EUROMET and driven by the pilot laboratory (NPL United Kingdom) and supported by the Bureau National de Métrologie.

First, the pistonphone used for the calibration was calibrated at NPL (Certificate of calibration S 3673, 25 January 1996).

The tests started at L.N.E in September 1996 after receiving the 3 earphones listed below :

Holmco 95-01 Red F
Holmco 95-01 Blue A
Telephonics TSH-49P B06903

This report describes the methods used for the measurements and presents the results obtained.

7.2 Measurement system

7.2.1 Equipment

Frequency analyser HP 36650 sn 2608A00474 driven by a PC
Reference pistonphone B&K type 4228 sn 1587920
Artificial ear B&K type 4153 sn 1826493
Microphone B&K type 4134 sn 950785 with protecting grid
Microphone preamplifier B&K type 2669 sn 1834650
Measuring amplifier B&K type 2607
Isolation transformer AOIP TE1B
Reciprocity calibration apparatus B&K type 4133 sn 1235504
Electrostatic actuator B&K type UA 0033
Cylindrical shaped mass of 448 g

7.2.2 Basic measurement system

The internal generator of the HP 36650 analyser provides the earphone driving voltage through an isolation transformer. The electrical input of the earphone is connected to the reference input of the analyser (channel B).

The artificial ear microphone output is connected to the second input of the analyser (channel A) through a B&K type 2669 preamplifier and a B&K type 2607 measuring amplifier.

The measurement system used for the test of the earphones is shown in figure 7.1.

7.3 Measurement procedure

Each test of the set of 3 earphones took about 1⅓ hours and started with a calibration procedure. The absolute sensitivity of the microphone was determined using the calibrated B&K 4228 pistonphone, the voltage output being corrected to take into account the static pressure.

The test of the set of 3 earphones was repeated 5 times, each time on a separate day. Each test day, the air

static pressure and the air temperature were in the allowed limits fixed by the pilot laboratory :

Static pressure	99.0 kPa to 103.5 kPa
Air temperature	21,5 °C to 24,5 °C

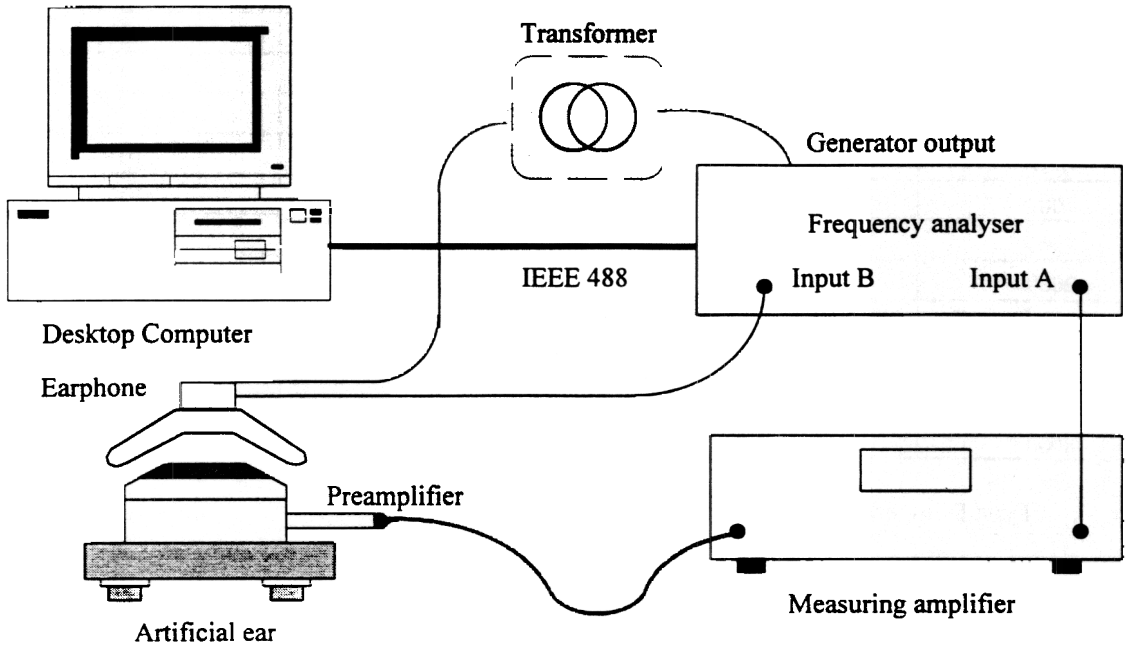


Fig. 7.1 The measurement system

Each day, for each earphone under test, measurements were repeated 5 times, the earphone being rotated by about 120 degrees before each measurement. Before starting any measurements, atmospheric parameters were automatically measured and recorded.

For each frequency, the driving voltage applied to the earphone was adjusted to the nearest available value of 100 mV (in the worst case the difference was 0,15 dB). Then, the two channel transfer function of the analyser was averaged for 8 seconds, and corrected by the microphone calibration value at 250 Hz and the true driving voltage.

When a test was completed, information and results (expressed in dB referred to the 250 Hz sensitivity) were transferred onto a spreadsheet, then frequency microphone corrections were made and statistical calculations performed.

The microphone frequency sensitivity corrections were determined by using an electrostatic actuator B&K UA 0033.

7.4 Uncertainties

Type A uncertainties

Type A uncertainties are based on 5 successive measurements and include leakage problems and alignment repeatability. Results are presented in the following table with an estimated confidence level of approximately 95 % (k=2)

Type A expanded uncertainties (dB) using k = 2			
Freq (Hz)	Holmco 95-01 Blue A	Holmco 95-01 Red F	TDH-49P B06903
125	0.12	0.10	0.01
250	0.01	0.12	0.01
500	0.01	0.06	0.01
750	0.01	0.04	0.01
1000	0.01	0.07	0.01
1500	0.01	0.05	0.01
2000	0.01	0.03	0.01
3000	0.01	0.05	0.01
4000	0.03	0.02	0.01
6000	0.04	0.07	0.03
8000	0.05	0.08	0.02

Type B uncertainties

Measurement	Expanded uncertainty	Unit	k factor
Measured static pressure	0.2	kPa	2
Measured air temperature	0.2	°C	2

Influence quantity	Expanded uncertainty	Unit	k factor
Pistonphone level	0.07	dB	2
Microphone frequency response	0.1	dB	2
Electrical transfer function measurement	0.01	dB	2
BK 4153 pressure deviation	1.7 x s(f)	dB	$2\sqrt{3}$
BK 4153 pressure offset	1.3 x s(f)	dB	1
BK 4153 temperature deviation	0.05	dB	2
Earphone pressure and temperature deviation	0.15	dB	2

s(f) is the computed artificial ear static pressure sensitivity. S(f), as a function of frequency, is calculated using the pressure sensitivity of the reactive parameters of the equivalent circuit given in IEC 318. The corresponding values, expressed in dB/kPa, are listed in the following table.

Computed artificial ear static pressure sensitivity s(f)					
Frequency (Hz)	Influence (dB/kPa)	Frequency (Hz)	Influence (dB/kPa)	Frequency (Hz)	Influence (dB/kPa)
125	0.045	1000	0.070	4000	0.098
250	0.055	1600	0.046	6000	0.090
500	0.107	2000	0.058	8000	0.087
630	0.092	3150	0.110		

7.4.3 Overall uncertainties

The overall expanded uncertainty with a coverage factor $k = 2$, is less than 0.3 dB at low frequencies and reaches 0.35 dB at mid- to high frequencies. The spread of the static pressure is 1.7 kPa and its distribution is assumed to be rectangular. The mean static pressure is 1.3 kPa above the reference static pressure.

7.5 Results

7.5.1 Holmco No 95-01 Blue A

Holmco No 95-01 Blue A							
Pressure (kPa) :	101.10	100.06	99.43	99.66	100.14	Mean	sd
Temperature (°C) :	22.7	22.7	23	22.7	23.4	(dB)	(dB)
125	118.20	118.32	118.29	118.40	118.20	118.28	0.09
250	119.79	119.81	119.79	119.77	119.75	119.78	0.02
500	121.09	121.09	121.07	121.06	121.05	121.07	0.02
750	121.80	121.80	121.79	121.78	121.76	121.79	0.02
1000	122.17	122.16	122.13	122.13	122.12	122.14	0.02
1500	120.33	120.32	120.29	120.27	120.26	120.29	0.03
2000	118.01	118.03	118.00	117.95	117.94	117.99	0.04
3000	115.19	115.18	115.10	115.08	115.08	115.13	0.06
4000	112.05	111.99	111.79	111.81	111.77	111.88	0.13
6000	104.66	104.42	104.56	104.64	104.77	104.61	0.13
8000	109.41	109.37	109.32	109.36	109.39	109.37	0.03

7.5.2 Holmco No 95-01 Red F

Holmco No 95-01 Red F							
Pressure (kPa) :	101.10	100.04	99.43	99.65	100.13	Mean	sd
Temperature (°C) :	22.8	22.8	23.2	22.7	23.8	(dB)	(dB)
125	118.79	118.84	118.96	119.02	118.99	118.92	0.10
250	118.39	118.47	118.58	118.63	118.57	118.53	0.10
500	120.53	120.58	120.62	120.64	120.60	120.59	0.04
750	121.68	121.71	121.75	121.76	121.73	121.73	0.03
1000	122.16	122.21	122.21	122.24	122.11	122.19	0.05
1500	119.04	119.03	119.09	119.11	119.11	119.08	0.04
2000	116.32	116.38	116.33	116.27	116.22	116.30	0.06
3000	112.41	112.48	112.21	112.11	112.00	112.24	0.20
4000	107.22	107.10	107.12	107.22	107.33	107.20	0.09
6000	108.24	108.05	108.00	108.07	108.17	108.10	0.10
8000	107.93	107.91	107.85	107.86	107.86	107.88	0.04

7.5.3 TDH-49P B06903

TDH-49P B06903							
Pressure (kPa) :	101.10	100.02	99.44	99.65	100.11	Mean	sd
Temperature (°C) :	22.8	22.9	23.2	22.8	24.1	(dB)	(dB)
125	103.77	103.76	103.73	103.73	103.72	103.74	0.02
250	106.49	106.47	106.42	106.43	106.41	106.44	0.03
500	107.53	107.50	107.45	107.46	107.44	107.48	0.03
750	107.55	107.52	107.48	107.48	107.46	107.50	0.04
1000	107.64	107.61	107.56	107.56	107.54	107.58	0.04
1500	107.13	107.13	107.09	107.08	107.05	107.10	0.04
2000	107.40	107.44	107.42	107.40	107.36	107.41	0.03
3000	109.67	109.73	109.72	109.68	109.65	109.69	0.03
4000	107.54	107.42	107.31	107.35	107.36	107.40	0.09
6000	103.55	103.45	103.32	103.35	103.32	103.40	0.10
8000	98.33	98.22	98.15	98.18	98.22	98.22	0.07

7.6 Conclusions

The results show that the Telephonics TDH-49P earphone presents the best measurement repeatability. The hard cushion supplied with the Holmco earphones could explain the standard deviation increase at low frequency where leakages are more critical.

Without any measured data on the atmospheric influences on both artificial ear and earphones, the overall estimated uncertainties include only theoretical estimation and might be slightly underestimated.

8 INTERCOMPARISON MEASUREMENTS MADE BY PTB, GERMANY

8.1 Introduction

An intercomparison of measurements on earphones involving 7 laboratories (DTU, EAM, LNE, NPL, PTB, SINTEF and SP) is being carried out as EUROMET Project 363, with NPL acting as pilot laboratory. The task of the participating laboratories is to determine the ear simulator sensitivity levels of 3 audiometric earphones and - in addition and on a voluntary basis - to determine their dependency on atmospheric pressure, temperature and humidity. On the basis of these measurements the accuracy of earphone (and audiometer) calibrations within the European Community will be evaluated.

8.2 Measuring conditions

1) Test earphones:
   a) Telephonics TDH-49P serial no. B 06893
   b) Holmco 95-01 red cup marked D
   c) Holmco 95-01 blue cup marked C

   The earphone's cable was regarded as an integral part of the earphone and the constant driving voltage therefore was applied across the open end of that cable. A common TDH 49 cable (2x0,17Ω) was used with the Telephonics earphone, as that earphone was delivered without cable. On one of the earphones (Holmco 95-01 red cup marked D) slight signs of damage were detected on the black central metal grid.

2) Frequencies: 125, 250, 500, 750, 1000, 1500, 2000, 3000, 4000, 6000 and 8000 Hz

3) Drive voltage: 100 mV; output resistance of amplifier: < 60 mΩ

4) IEC 318 ear simulator: Brüel and Kjær type 4153 (# 1251 448). The type 4134 microphone was used with its grid in place. The ear simulator has passed PTB's routine test for customer's IEC 318 ear simulators.

5) Microphone calibration: Both microphones Brüel and Kjær type 4134 (# 1534 506 and # 1857 375) used with the ear simulator have been calibrated in PTB by means of the reciprocity method.

6) Static force of application: Cylindrical shaped mass of 450 g

7) Measuring equipment: see Figure 8.1

8) Calibration: Overall calibration of the measurement set-up by means of a Brüel and Kjær pistonphone type 4220 (# 1297 294), calibrated at NPL.

9) Climatic conditions: During calibrations the ear-simulator/earphone combination was placed in a pressure-regulated pot. The static pressure within this pot was set to 101.325 kPa. The temperature in the test room varied only between 21.3 °C and 22.5 °C, the relative humidity varied between 40% and 50%.

10) Test procedure: The ear simulator sensitivity levels M of all 3 earphones were measured at all frequencies on 5 different days. On each day the sensitivity levels were determined twice, using two different microphones of type 4134 and taking the mean of both results. At each frequency the driving voltage was adjusted to 100 mV and then the sound pressure level L_{ES} in the ear simulator was measured by means of a sound level meter type Brüel and Kjær 2610 taking into account the corrections for the microphone sensitivity levels. M was calculated as follows: $M = (L_{ES} - 74)$ dB re 1 Pa/V.

11) Variation of static pressure: At a constant temperature and humidity the ear simulator

sensitivity levels of all 3 earphones were determined as a function of static pressure by changing this pressure from 91.3 kPa to 111.3 kPa in steps of 10 kPa. A stabilising time of 5 min was allowed at each measuring point.

12) Variation of temperature: At a constant static pressure and humidity the ear simulator sensitivity levels of all 3 earphones were determined as a function of temperature by changing the temperature within a range of 10 °C to 30 °C in steps of 10 °C. A stabilising time of 2 hours was allowed at each measuring point.

13) Variation of rel. humidity: At a constant static pressure and temperature the ear simulator sensitivity levels of all 3 earphones were determined as a function of relative humidity by changing the humidity within a range of 30 % to 80 % in steps of 25 %. A stabilising time of 2 hours was allowed at each measuring point.

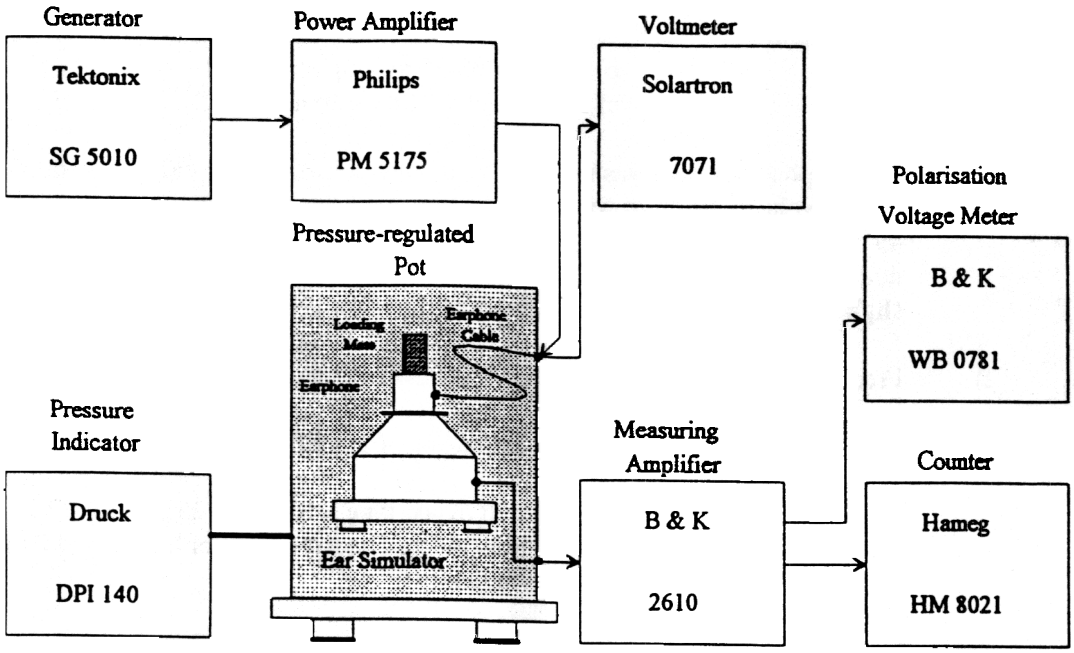


Figure 8.1 Test equipment used to measure the audiometric earphones

8.3 Results

8.3. Ear simulator sensitivity levels of earphones

Individual ear simulator sensitivity levels, the means averaged over all days and the standard deviations are given in Tables 8.1 to 8.3.

Telephonics TDH-49P Serial No. B 06893							
Date:17-24. 9.1996	Temperature: 21.3 - 22.3 °C				Pressure : 101.3 ± 0.05 kPa		
Ear simulator sensitivity level (re 1 Pa/V) in dB							
Freq	1	2	3	4	5	mean	sd (dB)
125	29.25	29.25	29.30	29.30	29.30	29.30	0.027
250	31.80	31.85	31.80	31.85	31.85	31.85	0.027
500	32.60	32.60	32.60	32.65	32.60	32.60	0.022
750	32.65	32.65	32.65	32.70	32.70	32.65	0.027
1000	32.90	32.90	32.90	32.95	32.90	32.90	0.022
1500	32.60	32.65	32.65	32.70	32.70	32.65	0.042
2000	33.20	33.25	33.25	33.25	33.25	33.25	0.022
3000	35.50	35.55	35.50	35.50	35.50	35.50	0.022
4000	32.85	32.85	32.90	32.90	32.90	32.90	0.027
6000	29.65	29.80	29.80	29.85	29.80	29.80	0.076
8000	24.20	24.30	24.35	24.35	24.35	24.30	0.065

Table 8. Ear simulator sensitivity levels of Telephonics TDH-49P (rounded to nearest 0.05 dB)

Holmco 95-01 Serial No. Red D							
Date:17-24. 9.1996		Temperature: 21.5 - 22.5 °C			Pressure : 101.3 ± 0.05 kPa		
Ear simulator sensitivity level (re 1 Pa/V) in dB							
Freq	1	2	3	4	5	mean	sd (dB)
125	44.10	44.10	44.10	44.10	44.10	44.10	0
250	45.30	45.35	45.35	45.40	45.35	45.35	0.035
500	46.50	46.50	46.50	46.50	46.50	46.50	0
750	47.15	47.20	47.20	47.25	47.20	47.20	0.035
1000	47.60	47.60	47.60	47.65	47.60	47.60	0.022
1500	45.70	45.75	45.70	45.75	45.75	45.75	0.027
2000	43.45	43.50	43.50	43.55	43.55	43.50	0.042
3000	40.20	40.30	40.30	40.30	40.35	40.30	0.055
4000	36.75	36.85	36.80	36.85	36.85	36.80	0.045
6000	33.80	33.75	33.80	33.75	33.75	33.75	0.027
8000	34.25	34.25	34.30	34.30	34.35	34.30	0.042

Table 8.2 Ear simulator sensitivity levels of Holmco 95-01, red D (rounded to nearest 0.05 dB)

Holmco 95-01 Serial No. Blue C							
Date:17-24. 9.1996		Temperature: 21.5 - 22.5 °C			Pressure : 101.3 ± 0.05 kPa		
Ear simulator sensitivity level (re 1 Pa/V) in dB							
Freq	1	2	3	4	5	mean	sd (dB)
125	43.60	43.55	43.55	43.60	43.60	43.60	0.027
250	44.85	44.80	44.80	44.85	44.85	44.85	0.027
500	45.90	45.80	45.85	45.90	45.90	45.85	0.045
750	46.20	46.15	46.15	46.20	46.20	46.20	0.027
1000	46.20	46.15	46.15	46.25	46.25	46.20	0.050
1500	44.50	44.45	44.50	44.55	44.55	44.50	0.042
2000	42.85	42.85	42.85	42.85	42.85	42.85	0
3000	42.20	42.20	42.25	42.25	42.25	42.25	0.027
4000	38.70	38.70	38.70	38.75	38.75	38.70	0.027
6000	31.15	31.30	31.20	31.25	31.20	31.20	0.057
8000	34.80	34.85	34.85	34.80	34.85	34.85	0.027

Table 8.3 Ear simulator sensitivity levels of Holmco 95-01, blue C (rounded to nearest 0.05 dB)

8.3.2 Static pressure coefficients

The deviations of ear simulator sensitivity levels of the 3 earphones at 91.3 kPa and 111.3 kPa from the values at reference ambient pressure are given in Tables 8.4 to 8.6. Linear regression was used to calculate the corresponding static pressure coefficients.

	Deviation of ear simulator sensitivity level in dB			Pressure coefficient
Frequency	91.3 kPa	101.3 kPa	111.3 kPa	dB/kPa
[illegible]	-0.22	0	0.18	0.020
[illegible]	-0.41	0	0.34	0.038
	-0.45	0	0.36	0.041
	-0.46	0	0.39	0.043
[illegible]	-0.45	0	0.41	0.043
[illegible]	-0.26	0	0.23	0.025
[illegible]	0.09	0	-0.08	-0.009
	0.10	0	-0.30	-0.020
	-1.33	0	1.22	0.128
[illegible]	-1.35	0	1.10	0.123
8000	-1.31	0	1.14	0.123

Table 8.4 Deviation of ear simulator sensitivity level of earphone TDH-49P (# B 06893) from the value at reference ambient pressure (101.3 kPa) and corresponding pressure coefficients as a function of frequency

	Deviation of ear simulator sensitivity level in dB			Pressure coefficient
Frequency	91.3 kPa	101.3 kPa	111.3 kPa	dB/kPa
[illegible]	0.0 3	0	-0.02	-0.003
[illegible]	0	0	0	0
[illegible]	-0.08	0	0.07	0.008
	-0.13	0	0.11	0.012
	-0.25	0	0.21	0.023
	-0.26	0	0.26	0.026
[illegible]	-0.18	0	0.13	0.016
[illegible]	-0.61	0	0.48	0.055
4000	-1.01	0	0.86	0.094
6000	-1.10	0	0.97	0.104
8000	-0.86	0	0.61	0.074

Table 8.5 Deviation of ear simulator sensitivity level of earphone 95-01 (# red cup marked D) from the value at reference ambient pressure (101.3 kPa) and corresponding pressure coefficients as a function of frequency

	Deviation of ear simulator sensitivity level in dB			Pressure coefficient
Frequency	91.3 kPa	101.3 kPa	111.3 kPa	dB/kPa
125	0.0 8	0	-0.08	-0.008
250	0.01	0	-0.02	-0.002
500	-0.08	0	0.05	0.007
750	-0.15	0	0.10	0.013
1000	-0.26	0	0.21	0.024
1500	-0.20	0	0.20	0.020
2000	-0.03	0	0.02	0.003
3000	-0.52	0	0.41	0.047
4000	-0.91	0	0.70	0.081
6000	-1.09	0	0.99	0.104
8000	-0.61	0	0. 57	0.059

Table 8.6 Deviation of ear simulator sensitivity level of earphone 95-01 (# blue cup marked C) from the value at reference ambient pressure (101.3 kPa) and corresponding pressure coefficients as a function of frequency

8.3.3 Temperature coefficients

The deviations of ear simulator sensitivity levels of the 3 earphones at 10°C and 30°C from the values at 20 °C are given in Tables 8.7 and 8.8. Linear regression was used to calculate the corresponding temperature coefficients.

At 8 kHz the temperature coefficient of the TDH-49 shows a non-linear behaviour. This is well known from earlier experiments in PTB. It was not possible to get stable results for the earphone Holmco 95-01 red cup marked D (see section 8.2.1).

	Deviation of ear simulator sensitivity level in dB			Temperature Coefficient
Frequency	10 °C	20 °C	30 °C	dB/°C
125	0.27	0	-0.28	-0.028
250	0.42	0	-0.43	-0.043
500	0.38	0	-0.40	-0.039
750	0.40	0	-0.42	-0.041
1000	0.45	0	-0.43	-0.044
1500	0.44	0	-0.44	-0.044
2000	0.45	0	-0.45	-0.045
3000	0.47	0	-0.44	-0.046
4000	0.65	0	-0.47	-0.056
6000	1.17	0	-1.06	-0.112
8000	2.21	0	-0.22	-------

Table 8.7 Deviation of ear simulator sensitivity level of earphone TDH-49P (# B 06893) from the value at 20 °C and corresponding temperature coefficients as a function of frequency

	Deviation of ear simulator sensitivity level in dB			Temperature coefficient
Frequency	10 °C	20 °C	30 °C	dB/°C
125	0.0 9	0	-0.14	-0.012
250	0.19	0	-0.22	-0.021
500	0.25	0	-0.27	-0.026
750	0.25	0	-0.26	-0.026
1000	0.25	0	-0.28	-0.027
[illegible]	0.16	0	-0.15	-0.016
[illegible]	0.14	0	-0.11	-0.013
3000	0.11	0	-0.06	-0.009
4000	-0.45	0	0.20	0.033
6000	1.02	0	-0.88	-0.095
8000	0.09	0	-0.27	-------

Table 8.8 Deviation of ear simulator sensitivity level of earphone 95-01 (# blue cup marked C) from the value at 20 °C and corresponding temperature coefficients as a function of frequency

8.3.4 Humidity coefficients

Measurements of the humidity coefficients could only be performed after the original earphones under test had been sent back to NPL. Other earphones of types 95-01 and TDH-49P (2 samples per type) were used. The mean deviations of the ear simulator sensitivity levels of both samples of each type of earphone at 30 % and at 80 % from the values at 55% relative humidity are given in tables 8.9 and 8.10. Linear regression was used to calculate the corresponding humidity coefficients. At high audiometric frequencies, the humidity coefficient of both types of earphone showed non-linear behaviour.

	Deviation of ear simulator sensitivity level (dB)			Humidity coefficient (dB / % r.H.)	
Freq (Hz)	80 % r.H.	55 % r.H.	30 % r.H.	r.H. ≥ 55 %	r.H. < 55 %
125	-0.03	0	-0.02	0	0
250	-0.04	0	-0.04	0	0
500	-0.03	0	-0.05	0	0
750	-0.02	0	-0.07	0	0.003
1000	0	0	-0.13	0	0.005
1500	0	0	-0.20	0	0.008
2000	0.02	0	-0.21	0.001	0.008
3000	0.04	0	-0.21	0.002	0.008
4000	0.01	0	-0.0	0	0.003
6000	0.04	0	-0.49	0.002	0.020
8000	0.19	0	-0.25	0.008	0.01

Table 8.9 Mean deviations of ear simulator sensitivity level of two earphones of type TDH-49P from the value at 55% relative humidity and corresponding humidity coefficients as a function of frequency

	Deviation of ear simulator sensitivity level (dB)			Humidity coefficient (dB / % r.H.)	
Freq (Hz)	80 % r.H.	55 % r.H.	30 % r.H.	r.H. ≥ 55 %	r.H. < 55 %
125	0.01	0	0	0	0
250	-0.05	0	-0.02	0	0
500	-0.03	0	-0.03	0	0
750	-0.02	0	-0.05	0	0
1000	-0.01	0	-0.06	0	0
1500	-0.04	0	-0.07	0	0
2000	-0.05	0	0.03	0	0
3000	-0.28	0	0.09	-0.011	-0.004
4000	-0.71	0	0.34	-0.028	-0.014
6000	-0.29	0	0.05 -0.64	-0.012	-----
8000	-0.21	0	0.28	-0.008	-0.011

Table 8.10 Mean deviations of ear simulator sensitivity level of two earphones of type Holmco 95-01 from the value at 55% relative humidity and corresponding humidity coefficients as a function of frequency

8.4 Measurement uncertainty

The measurement uncertainties of the ear simulator sensitivity levels of earphones (one measurement under reference ambient conditions) are calculated as follows:

Ambient pressure	controlled at	101.325 kPa (± 0.05 kPa)
Temperature :	measured	22°C (± 0.7 °C)
Humidity :	measured	45 % (± 5 %)
Driving voltage :	measured	100 mV (± 0.02 mV)

8.4.1 Calculation of type A uncertainties

Typical standard deviation of earphone calibration on 5 different days: 0.04 dB. Typical type A uncertainties at an estimated confidence probability of approximately 95 % ($k = 2$) :

=0.08 dB

8.4.2 Calculation of type B uncertainties

Influence quality		semi range in dB	
Impedance behaviour of ear simulator		±	0.2 (see Fig.8 2)
Microphone sensitivity (outside 250 Hz)		±	0.03
Level of pistonphone		±	0.035
Reading of B&K 2610		< ±	0.05
Driving voltage		±	0.001
Polarisation voltage		< ±	0.025
Ambient pressure measurements		±	0.002
Deviation of temperature from 23°C		< ±	0.05
Deviation of humidity from 50%		< ±	0.05
Earphone position		< ±	0.02
Rounding of final results±		±	0.01
	SUMSQ		0.051 dB
	SQRT of SUMSQ		0.225 dB

Typical type B uncertainty based on a standard uncertainty multiplied by a coverage factor k=2, providing a confidence probability of approximately 95 % :

=0.45 dB

8.4.3 Overall uncertainty

Typical overall uncertainty based on a standard uncertainty multiplied by a coverage factor k=2, providing a confidence probability of approximately 95 %, rounded to nearest 0.1 dB

=0.5 dB

8.5 Conclusions

In a previous study, PTB measured the sensitivity of one earphone many times, using the same microphone but different IEC 318 artificial ears. Figure 8.2 shows variations in earphone sensitivity of almost ± 0.3 dB. Although part of this variation will be due to earphone placement, it must also be attributable to variations in the impedance of the artificial ears used for this investigation.

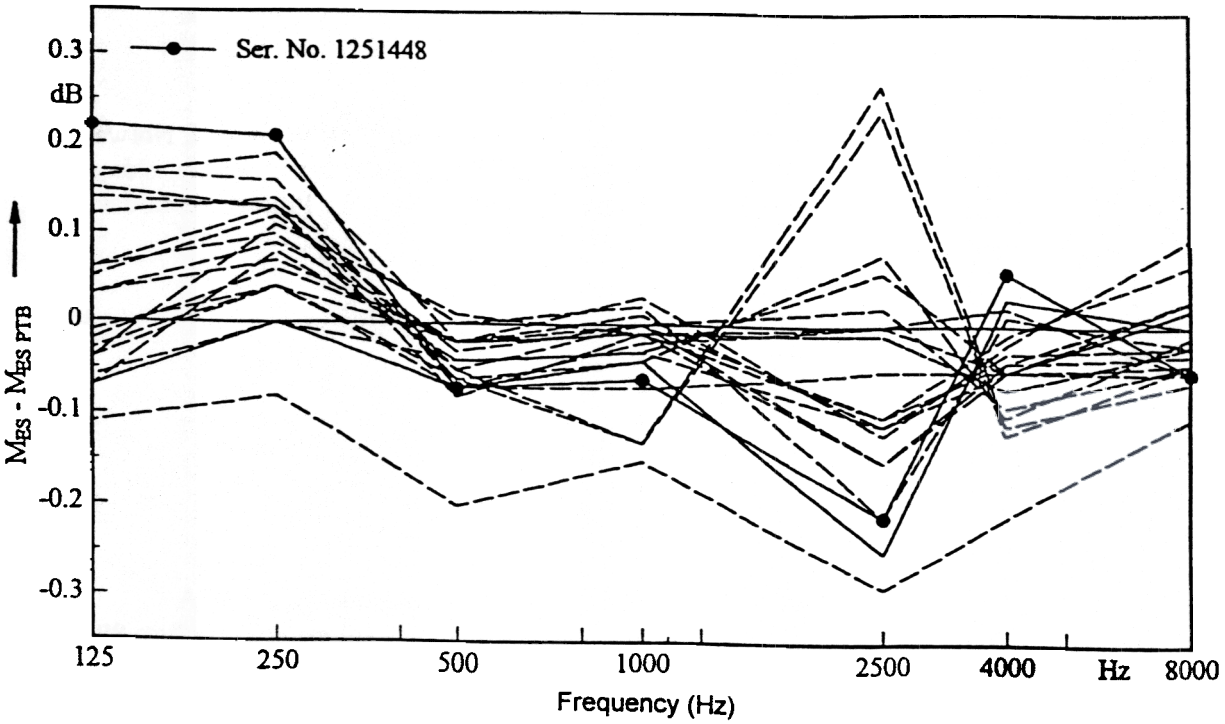


Figure 8.2 Ear simulator sensitivity levels M_{ES} of one earphone (DT 48) measured on 20 different type 4153 IEC 318 artificial ears (fitted with the same microphone) and referenced to the corresponding sensitivity level M_{ESPTB} measured by means of a PTB 4153 ear simulator

The repeatability ($2\sqrt{2}sd$)[‡] of the ear simulator sensitivity levels of all 3 earphones under practically constant ambient conditions was on average better than 0.1 dB, and no more than 0.2 dB in the worst case, for repeated measurements on different days. The sensitivity levels increase, however, with increasing static pressure P_S and decreasing temperature T. Therefore the calibration results of one and the same earphone (or audiometer) can differ under different ambient conditions (for instance P_{S1}: 103 kPa, T_1: 19°C and P_{S2}: 93 kPa, T_2: 30°C) by about 1 dB at low frequencies and by about 2.5 dB at high frequencies.

[‡]According to ISO 5725 "Accuracy (Trueness and Precision) of Measurement Methods and Results" the repeatability r of a result equals 2 times square root of 2 times the standard deviation for repeated trials, where any two results of repeated trials can differ by r.

9 INTERCOMPARISON MEASUREMENTS MADE BY SINTEF, NORWAY

9.1 Introduction

This section of the report describes the measurement method used at SINTEF Metrology, Norway for determining the sound pressure output for a known drive voltage, of three audiometric earphones received from NPL, UK. The measurements have been performed as a part of EUROMET Project 363 initiated by NPL. The earphones measured were:

Holmco No. 95-01 Red cap marked B
Holmco No. 95-01 Blue cap marked E
Telephonics TDH-49P Serial No. B06915

9.2 Equipment

The following equipment was used for the investigation:

IEC 318 Artificial ear Brüel and Kjær type 4152
Microphone Brüel and Kjær type 4134
Preamplifier Brüel and Kjær type 2639
Measuring amplifier Brüel and Kjær type 2610
Band pass filter Brüel and Kjær type 1617
Pistonphone Brüel and Kjær type 4220

Counter Fluke type 1941A
True rms voltmeter Fluke type 8920A
Power amplifier Adyton type P3000
Oscillator Tektronix type 56505
Multimeter Fluke type 8840A

9.3 Calibration of the measuring system

Step 1: Fluke 8840A and Fluke 8920A are calibrated with a Fluke 5100 calibrator over the frequency range for the headphone measurements. Uncertainty: 0.00 dB

Step 2: Calibration of the pre.amp. B&K 2639, measuring amp.B&K 2610 and filter B&K 1617:The microphone was removed from the artificial ear B&K 4153 and replaced by a capacitor equal to the B&K 4134 capacitance, and the signal was inserted through this. For each frequency of the test, 125Hz to 8000Hz, the deviation from flat response was recorded. Corrections for the response were added to the measurements. Uncertainty: 0.00 dB

Step 3: Control of the microphone response. The mic.4134 was mounted on the ear, and with the B&K 4290 the pressure response was recorded with electrostatic actuator. Uncertainty: 0.20 dB

Step 4: Control of artificial ear. The mic. cap. and the coupler was mounted on the ear. With the red cap. following the artificial ear and a ref B&K 4134 mic. as transmitter, the response of the ear was recorded. The ref. mic. is calibrated at B&K Denmark on a regular basis.
Uncertainty: 0.40 dB including deviation from the curve recorded by B&K at delivery.

Step 5: Sensitivity Calibration. With pistonphone 4220 calibrated by NPL and calibrated barometer. A 1000 Hz calibrator was also used for control (B&K 4220). Uncertainty: 0.10 dB.

9.4 Results

Sound level readings in response to each earphone were recorded in sets of three, the earphone being rotated by 120° between each recording. From the three readings recorded at each frequency, a mean reading was calculated (tables 9.1 - 9.5 for the Telephonics TDH-49P earphone, serial no. B06915, 9.7 - 9.11 for the Holmco 95-01 Red B earphone and 9.13 - 9.17 for the Holmco 95-01 Blue E earphone).

These measurements were repeated on five separate days from which a grand mean sound pressure level and associated standard deviation were calculated. These results are presented in tables 9.6, 9.12 and 9.18.

9.4.1 Telephonics TDH-49P Serial No. B06915

Date:10:07:96		Temperature: 24.5° C		Pressure: 100.4 kPa	
Earphone type Telephonics TDH-49P Serial No. B06915					
Frequency (Hz)	Earphone output (dB)				
	1	2	3	mean	sd
125	103.66	103.63	103.64	103.64	0.02
250	106.12	106.08	106.08	106.09	0.02
500	107.15	107.13	107.13	107.14	0.01
750	107.37	107.37	107.34	107.36	0.02
1000	107.73	107.71	107.70	107.71	0.02
1500	107.83	107.80	107.78	107.80	0.03
2000	108.22	108.22	108.20	108.21	0.01
3000	108.81	108.80	108.80	108.80	0.01
4000	106.70	106.72	106.70	106.71	0.01
6000	103.79	103.79	103.70	103.76	0.05
8000	98.06	98.06	98.10	98.07	0.02

Table 9.1 Sound pressure level (dB) and associated mean and standard deviation generated in the artificial ear by driving Telephonics TDH-49P earphone Serial No. B06915 with a 100 mV sinusoidal signal (set 1).

Date: 11:07:96		Temperature: 24.2° C		Pressure: 100.4 kPa	
Earphone type Telephonics TDH-49P Serial No. B06915					
Frequency (Hz)	Earphone output (dB)				
	1	2	3	mean	sd
125	103.62	103.59	103.62	103.61	0.02
250	106.07	106.04	106.06	106.06	0.02
500	107.11	107.09	107.11	107.10	0.01
750	107.31	107.28	107.29	107.29	0.02
1000	107.67	107.67	107.68	107.67	0.01
1500	107.77	107.75	107.76	107.76	0.01
2000	108.18	108.17	108.18	108.18	0.01
3000	108.77	108.74	108.77	108.76	0.02
4000	106.68	106.67	106.70	106.68	0.02
6000	103.70	103.68	103.79	103.72	0.06
8000	98.12	98.12	98.02	98.09	0.06

Table 9.2 Sound pressure level (dB) and associated mean and standard deviation generated in the artificial ear by driving Telephonics TDH-49P earphone Serial No. B06915 with a 100 mV sinusoidal signal (set 2).

Date: 12:07:96		Temperature: 24.0° C		Pressure: 101.0 kPa	
Earphone type Telephonics TDH-49P Serial No. B06915					
Frequency (Hz)	Earphone output (dB)				
	1	2	3	mean	sd
125	103.69	103.65	103.63	103.66	0.03
250	106.14	106.09	106.08	106.10	0.03
500	107.18	107.15	107.13	107.15	0.03
750	107.36	107.33	107.32	107.34	0.02
1000	107.74	107.70	107.69	107.71	0.03
1500	107.82	107.77	107.76	107.78	0.03
2000	108.22	108.18	108.16	108.19	0.03
3000	108.78	108.76	108.74	108.76	0.02
4000	106.78	106.75	106.74	106.76	0.02
6000	103.87	103.80	103.76	103.81	0.06
8000	98.19	98.18	98.18	98.18	0.06

Table 9.3 Sound pressure level (dB) and associated mean and standard deviation generated in the artificial ear by driving Telephonics TDH-49P earphone Serial No. B06915 with a 100 mV sinusoidal signal (set 3).

Date: 14:07:96		Temperature: 24.8° C		Pressure: 100.2 kPa	
Earphone type Telephonics TDH-49P Serial No. B06915					
Frequency (Hz)	Earphone output (dB)				
	1	2	3	mean	sd
125	103.64	103.63	103.62	103.63	0.01
250	106.06	106.05	106.03	106.05	0.02
500	107.12	107.11	107.09	107.11	0.02
750	107.32	107.32	107.30	107.31	0.01
1000	107.69	107.68	107.67	107.68	0.01
1500	107.77	107.74	107.71	107.74	0.03
2000	108.19	108.16	108.15	108.17	0.02
3000	108.76	108.73	108.73	108.74	0.02
4000	106.63	106.62	106.64	106.63	0.01
6000	103.61	103.56	103.56	103.58	0.03
8000	98.06	98.08	98.04	98.06	0.02

Table 9.4 Sound pressure level (dB) and associated mean and standard deviation generated in the artificial ear by driving Telephonics TDH-49P earphone Serial No. B06915 with a 100 mV sinusoidal signal (set 4).

Date:15:07:96		Temperature: 24.1° C		Pressure: 101.0 kPa	
Earphone type Telephonics TDH-49P Serial No. B06915					
Frequency (Hz)	Earphone output (dB)				
	1	2	3	mean	sd
125	103.68	103.68	103.66	103.67	0.01
250	106.11	106.10	106.09	106.10	0.01
500	107.18	107.16	107.15	107.16	0.02
750	107.38	107.36	107.36	107.37	0.01
1000	107.76	107.75	107.73	107.75	0.02
1500	107.83	107.82	107.79	107.81	0.02
2000	108.22	108.21	108.18	108.20	0.02
3000	108.77	108.78	108.74	108.76	0.02
4000	106.77	106.78	106.77	106.77	0.01
6000	103.78	103.89	103.89	103.85	0.06
8000	98.15	98.14	98.16	98.15	0.01

Table 9.5 Sound pressure level (dB) and associated mean and standard deviation generated in the artificial ear by driving Telephonics TDH-49P earphone Serial No. B06915 with a 100 mV sinusoidal signal (set 5).

Earphone type Telephonics TDH-49P Serial No. B06915							
Frequency (Hz)	Mean earphone output (dB)						
	1	2	3	4	5	mean	sd
125	103.64	103.61	103.66	103.63	103.67	103.64	0.02
250	106.09	106.06	106.10	106.05	106.10	106.08	0.03
500	107.14	107.10	107.15	107.11	107.16	107.13	0.03
750	107.36	107.29	107.34	107.31	107.37	107.33	0.03
1000	107.71	107.67	107.71	107.68	107.75	107.70	0.03
1500	107.80	107.76	107.78	107.74	107.81	107.78	0.03
2000	108.21	108.18	108.19	108.17	108.20	108.19	0.02
3000	108.80	108.76	108.76	108.74	108.76	108.77	0.02
4000	106.71	106.68	106.76	106.63	106.77	106.71	0.06
6000	103.76	103.72	103.81	103.58	103.85	103.74	0.11
8000	98.07	98.09	98.18	98.06	98.15	98.11	0.05

Table 9.6 Grand mean sound pressure level (dB) and associated standard deviation generated in the artificial ear by driving Telephonics TDH-49P earphone Serial No. B06915 with a 100 mV sinusoidal signal.

9.4.2 Holmco No. 95-01 Red B

Date: 10:07:96	Temperature: 24.5° C		Pressure: 100.4 kPa	
Earphone type Holmco No. 95-01 Red B				
Frequency (Hz)	Earphone output (dB)			
	1	2	3	mean	sd
125	118.32	118.30	118.29	118.30	0.02
250	119.13	119.12	119.13	119.13	0.01
500	120.25	120.24	120.26	120.25	0.01
750	120.73	120.72	120.68	120.71	0.03
1000	121.05	120.99	120.94	120.99	0.06
1500	119.99	119.89	119.89	119.92	0.06
2000	118.48	118.40	118.40	118.43	0.05
3000	114.35	114.32	114.30	114.32	0.03
4000	111.23	111.26	111.21	111.23	0.03
6000	104.48	104.53	104.57	104.53	0.05
8000	108.46	108.49	108.45	108.47	0.02

Table 9.7 Sound pressure level (dB) and associated mean and standard deviation generated in the artificial ear by driving Holmco No 95-01 earphone Red B with a 100 mV sinusoidal signal (set 1).

Date: 11:07:96	Temperature: 24.2° C		Pressure: 100.4 kPa	
Earphone type Holmco No. 95-01 Red B				
Frequency (Hz)	Earphone output (dB)			
	1	2	3	mean	sd
125	118.25	118.26	118.26	118.26	0.01
250	119.16	119.11	119.09	119.12	0.04
500	120.27	120.22	120.21	120.23	0.03
750	120.73	120.69	120.69	120.70	0.02
1000	121.00	120.92	120.91	120.94	0.05
1500	119.86	119.82	119.82	119.83	0.02
2000	118.36	118.32	118.33	118.34	0.02
3000	114.32	114.29	114.34	114.32	0.03
4000	111.33	111.24	111.26	111.28	0.05
6000	104.41	104.49	104.54	104.48	0.07
8000	108.54	108.50	108.50	108.51	0.02

Table 9.8 Sound pressure level (dB) and associated mean and standard deviation generated in the artificial ear by driving Holmco No 95-01 earphone Red B with a 100 mV sinusoidal signal (set 2).

Date: 12:07:96	Temperature: 24.0° C		Pressure: 101.0 kPa	
Earphone type Holmco No. 95-01 Red B				
Frequency (Hz)	Earphone output (dB)			
	1	2	3	mean	sd
125	118.27	118.24	118.23	118.25	0.02
250	119.14	119.12	119.09	119.12	0.03
500	120.28	120.27	120.23	120.26	0.03
750	120.78	120.76	120.74	120.76	0.02
1000	120.99	120.99	120.94	120.97	0.03
1500	119.90	119.84	119.83	119.86	0.04
2000	118.37	118.36	118.34	118.36	0.02
3000	114.36	114.37	114.35	114.36	0.01
4000	111.39	111.31	111.32	111.34	0.04
6000	104.54	104.65	104.61	104.60	0.06
8000	108.41	108.45	108.47	108.44	0.03

Table 9.9 Sound pressure level (dB) and associated mean and standard deviation generated in the artificial ear by driving Holmco No 95-01 earphone Red B with a 100 mV sinusoidal signal (set 3).

Date: 14:07:96	Temperature: 24.8° C		Pressure: 100.2 kPa	
Earphone type Holmco No. 95-01 Red B				
Frequency (Hz)	Earphone output (dB)			
	1	2	3	mean	sd
125	118.29	118.25	118.23	118.26	0.03
250	119.09	119.06	119.05	119.07	0.02
500	120.22	120.19	120.17	120.19	0.03
750	120.71	120.68	120.66	120.68	0.03
1000	120.92	120.87	120.85	120.88	0.04
1500	119.84	119.82	119.79	119.82	0.03
2000	118.35	118.33	118.32	118.33	0.02
3000	114.30	114.31	114.30	114.30	0.01
4000	111.25	111.18	111.17	111.20	0.04
6000	104.46	104.58	104.61	104.55	0.08
8000	108.47	108.44	108.47	108.46	0.02

Table 9.10 Sound pressure level (dB) and associated mean and standard deviation generated in the artificial ear by driving Holmco No 95-01 earphone Red B with a 100 mV sinusoidal signal (set 4).

Date: 15:07:96	Temperature: 24.1° C		Pressure: 101.0 kPa	
Earphone type Holmco No. 95-01 Red B				
Frequency (Hz)	Earphone output (dB)			
	1	2	3	mean	sd
125	118.26	118.23	118.22	118.24	0.02
250	119.09	119.08	119.06	119.08	0.02
500	120.24	120.22	120.21	120.22	0.02
750	120.75	120.72	120.71	120.73	0.02
1000	120.99	120.97	120.89	120.95	0.05
1500	119.87	119.85	119.83	119.85	0.02
2000	118.37	118.37	118.36	118.37	0.01
3000	114.35	114.37	114.35	114.36	0.01
4000	111.39	111.33	111.30	111.34	0.05
6000	104.49	104.55	104.68	104.57	0.10
8000	108.48	108.49	108.51	108.49	0.02

Table 9.11 Sound pressure level (dB) and associated mean and standard deviation generated in the artificial ear by driving Holmco No 95-01 earphone Red B with a 100 mV sinusoidal signal (set 5).

Earphone type Holmco No. 95-01 Red B							
Frequency (Hz)	Mean earphone output (dB)						
	1	2	3	4	5	mean	sd
125	118.30	118.26	118.25	118.26	118.24	118.26	0.03
250	119.13	119.12	119.12	119.07	119.08	119.10	0.03
500	120.25	120.23	120.26	120.19	120.22	120.23	0.03
750	120.71	120.70	120.76	120.68	120.73	120.72	0.03
1000	120.99	120.94	120.97	120.88	120.95	120.95	0.04
1500	119.92	119.83	119.86	119.82	119.85	119.86	0.04
2000	118.43	118.34	118.36	118.33	118.36	118.36	0.04
3000	114.32	114.32	114.36	114.30	114.36	114.33	0.03
4000	111.23	111.27	111.34	111.20	111.34	111.28	0.06
6000	104.53	104.48	104.6	104.55	104.57	104.55	0.05
8000	108.46	108.51	108.44	108.46	108.49	108.48	0.03

Table 9.12 Grand mean sound pressure level (dB) and associated standard deviation generated in the artificial ear by driving Holmco No 95-01 earphone Red B with a 100 mV sinusoidal signal.

9.4.3 Holmco No. 95-01 Blue E

Date: 10:07:96	Temperature: 24.5° C		Pressure: 100.4 kPa	
Earphone type Holmco No. 95-01 Blue E				
Frequency (Hz)	Earphone output (dB)			
	1	2	3	mean	sd
125	119.0	119.97	118.86	119.28	0.06
250	119.71	119.68	119.63	119.67	0.04
500	121.01	120.97	120.93	120.97	0.04
750	121.48	121.44	121.38	121.43	0.05
1000	121.54	121.57	121.45	121.52	0.06
1500	120.37	120.33	120.29	120.33	0.04
2000	118.78	118.77	118.73	118.76	0.03
3000	114.95	114.94	114.94	114.94	0.01
4000	110.91	110.84	110.77	110.84	0.07
6000	105.00	105.00	105.00	105.00	0.00
8000	110.67	110.65	110.63	110.65	0.02

Table 9.13 Sound pressure level (dB) and associated mean and standard deviation generated in the artificial ear by driving Holmco No 95-01 earphone Blue E with a 100 mV sinusoidal signal (set 1).

Date: 11:07:96	Temperature: 24.2° C		Pressure: 100.4 kPa	
Earphone type Holmco No. 95-01 Blue E				
Frequency (Hz)	Earphone output (dB)			
	1	2	3	mean	sd
125	118.94	118.93	118.91	118.93	0.02
250	119.68	119.66	119.66	119.67	0.01
500	120.97	120.95	120.94	120.95	0.02
750	121.39	121.39	121.39	121.39	0.00
1000	121.55	121.52	121.50	121.52	0.03
1500	120.29	120.27	120.27	120.28	0.01
2000	118.71	118.70	118.69	118.70	0.01
3000	114.95	114.94	114.95	114.95	0.01
4000	110.83	110.80	110.82	110.82	0.02
6000	105.00	105.00	105.00	105.00	0.00
8000	110.67	110.68	110.65	110.67	0.02

Table 9.14 Sound pressure level (dB) and associated mean and standard deviation generated in the artificial ear by driving Holmco No 95-01 earphone Blue E with a 100 mV sinusoidal signal (set 2).

Date: 12:07:96	Temperature: 24.0° C		Pressure: 101.0 kPa	
Earphone type Holmco No. 95-01 Blue E				
Frequency (Hz)	Earphone output (dB)			
	1	2	3	mean	sd
125	119.00	118.97	118.95	118.97	0.03
250	119.78	119.75	119.71	119.75	0.04
500	121.08	121.06	121.01	121.05	0.04
750	121.55	121.65	121.48	121.56	0.09
1000	121.67	121.65	121.58	121.63	0.05
1500	120.39	120.37	120.33	120.36	0.03
2000	118.78	118.76	118.75	118.76	0.02
3000	114.94	114.94	114.94	114.94	0.00
4000	110.94	110.87	110.83	110.88	0.06
6000	105.15	105.17	105.15	105.16	0.01
8000	110.38	110.33	110.34	110.35	0.03

Table 9.15 Sound pressure level (dB) and associated mean and standard deviation generated in the artificial ear by driving Holmco No 95-01 earphone Blue E with a 100 mV sinusoidal signal (set 3).

Date: 14:07:96	Temperature: 24.8° C		Pressure: 100.2 kPa	
Earphone type Holmco No. 95-01 Blue E				
Frequency (Hz)	Earphone output (dB)			
	1	2	3	mean	sd
125	119.00	118.93	118.93	118.95	0.04
250	119.73	119.68	119.66	119.69	0.04
500	121.01	120.96	120.94	120.97	0.04
750	121.47	121.43	121.39	121.43	0.04
1000	121.52	121.48	121.51	121.50	0.02
1500	120.33	120.30	120.28	120.30	0.03
2000	118.76	118.73	118.72	118.74	0.02
3000	114.93	114.93	114.91	114.92	0.01
4000	110.87	110.76	110.73	110.79	0.07
6000	105.00	104.97	104.95	104.97	0.03
8000	110.61	110.58	110.56	110.58	0.03

Table 9.16 Sound pressure level (dB) and associated mean and standard deviation generated in the artificial ear by driving Holmco No 95-01 earphone Blue E with a 100 mV sinusoidal signal (set 4).

Date: 15:07:96		Temperature: 24.1° C		Pressure: 101.0 kPa	
Earphone type Holmco No. 95-01 Blue E					
Frequency (Hz)	Earphone output (dB)				
	1	2	3	mean	sd
125	119.00	118.99	118.97	118.99	0.02
250	119.77	119.73	119.72	119.74	0.03
500	121.03	121.05	121.03	121.04	0.01
750	121.56	121.53	121.49	121.53	0.04
1000	121.67	121.61	121.62	121.63	0.03
1500	120.44	120.40	120.37	120.40	0.04
2000	118.83	118.81	118.79	118.81	0.02
3000	114.95	114.95	114.96	114.95	0.01
4000	111.01	110.92	110.90	110.94	0.06
6000	105.11	105.11	105.11	105.11	0.00
8000	110.36	110.37	110.45	110.39	0.05

Table 9.17 Sound pressure level (dB) and associated mean and standard deviation generated in the artificial ear by driving Holmco No 95-01 earphone Blue E with a 100 mV sinusoidal signal (set 5).

Earphone type Holmco No. 95-01 Blue E							
Frequency (Hz)	Mean earphone output (dB)						
	1	2	3	4	5	mean	sd
125	119.28	118.93	118.97	118.95	118.99	119.02	0.14
250	119.67	119.67	119.75	119.69	119.74	119.70	0.04
500	120.97	120.95	121.05	120.97	121.04	121.00	0.04
750	121.43	121.39	121.56	121.43	121.53	121.47	0.07
1000	121.52	121.52	121.63	121.50	121.63	121.56	0.06
1500	120.33	120.28	120.36	120.30	120.40	120.34	0.05
2000	118.76	118.70	118.76	118.74	118.81	118.75	0.04
3000	114.94	114.95	114.94	114.92	114.95	114.94	0.01
4000	110.84	110.82	110.88	110.79	110.94	110.85	0.06
6000	105.00	105.00	105.16	104.97	105.11	105.05	0.08
8000	110.65	110.67	110.35	110.58	110.39	110.53	0.15

Table 9.18 Grand mean sound pressure level (dB) and associated standard deviation generated in the artificial ear by driving Holmco No 95-01 earphone Blue E with a 100 mV sinusoidal signal.

10 INTERCOMPARISON MEASUREMENTS MADE BY SP, SWEDEN

10.1 Introduction

This section of the report describes the measurement method used at the SP - Swedish National Testing and Research Institute, National Laboratory for Sound Pressure, for determining the sound pressure level output for a known drive voltage, of three audiometric earphones received from NPL, UK. The measurements were performed as a part of EUROMET Project 363 initiated by NPL. The earphones measured were:

Earphone Telephonics TDH-49P Ser.No. B06896
Earphone Holmco No 95-01 Blue B
Earphone Holmco No 95-01 Red E

Unfortunately one of the earphones, Holmco No 95-01 Red E was found to be damaged on arrival at SP and was excluded for the investigation.

10.2 Equipment

The following equipment was used for this investigation.

Standard Microphone Brüel & Kjær 4180	Artificial Ear Brüel & Kjær 4185
Microphone Preamplifier Brüel & Kjær 2645	Sound Calibrator Brüel & Kjær 4226
Microphone Brüel & Kjær 4134	Sound Calibrator Brüel & Kjær 4228
Microphone Preamplifier Brüel & Kjær 2619	Voltmeter Hewlett Packard 34401A
Power Supply Brüel & Kjær 2801	Voltmeter Datron 1271

10.3 Environment

The calibration of the artificial ear system and the subsequent calibration of the earphones were carried out under the following ambient conditions:

Air pressure	99.0 kPa - 100.8 kPa
Temperature	21,0 °C - 24,0 °C

10.4 Method

The setup in the figure below has been used for measurements on the earphones. The earphone was driven by a low impedance amplifier with a r.m.s. voltage of 100 mV. The driving voltage was measured at the earphone terminals. The earphone was coupled to the special telephonometry artificial ear, Brüel & Kjær type 4185, and loaded by a mass giving a static force of 4,5 N. The output voltage of the artificial ear was measured by a r.m.s. voltmeter.

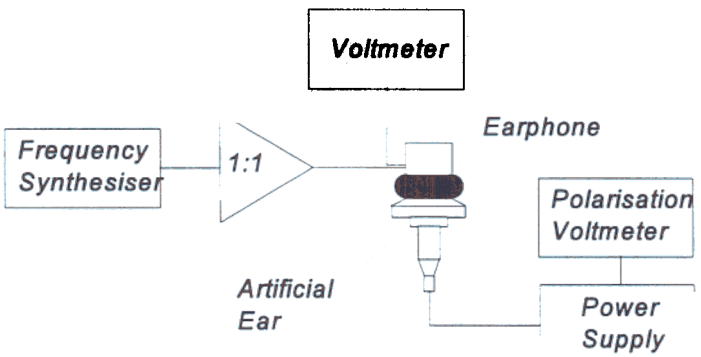


Figure 10.1 Setup of earphone measurement system

Three measurements has been made each day with the earphone rotated by 120° for each measurement. The measurements have been repeated on five different days. The overall sensitivity of the artificial ear system was calibrated by a pistonphone, using the NPL figures. The frequency response was also calibrated each day by a comparison method. The artificial ear was compared to a standard microphone Brüel & Kjær type 4180, using a multi frequency calibrator Brüel & Kjær type 4226 as a transfer standard.

During the comparison the grid on the microphone used in the artificial ear was replaced by an adaptor ring type UA 0825. The frequency of the calibrator was controlled by an external sine generator with 1 V output voltage. The level of the calibrator was 104 dB. The standard microphone was calibrated by the reciprocity technique.

10.5 Results

The sound pressure level in the artificial ear with an earphone driving voltage of 100 mV is given in table 10.1.

	TDH-49P Ser.No. B06896		Holmco No 95-01 Blue B	
Frequency (Hz)	Mean (dB)	sd (dB)	Mean (dB)	sd (dB)
125	103.61	0.06	118.86	0.06
250	106.56	0.01	119.65	0.04
500	107.59	0.02	121.01	0.04
750	107.73	0.02	121.55	0.04
1000	107.96	0.02	121.69	0.05
1500	107.56	0.02	119.71	0.05
2000	107.74	0.09	117.68	0.13
3000	110.22	0.03	115.57	0.15
4000	107.63	0.03	112.21	0.12
6000	104.24	0.05	106.14	0.09
8000	99.05	0.04	107.71	0.05

Table 10.1 Grand mean sound pressure level (dB) and associated standard deviation generated in the artificial ear by driving the Telephonics TDH-49 P and the Holmco No. 95-01 (blue) earphones with a 100 mV sinusoidal signal

10.6 Comments

The multi frequency calibrator Brüel & Kjær type 4226 seems not to be stable, at frequencies 2-4 kHz, during the sequential comparison calibration. This may be improved by using only the coupler itself.

Most of the measurements were made at or near the lower limit of the allowed ambient pressure range. Differences in the microphone sensitivity between grid and adaptor configuration have not been corrected for, but included in the uncertainty.

10.7 Uncertainty

The overall uncertainty is less then 0.3 dB. The uncertainty is given as the standard deviation multiplied by two, i.e. the confidence level is approximately 95 %. In the standard deviations are uncertainties from equipment, method and random errors summed up according to WECC Doc. 19-1990.

11 INTERCOMPARISON MEASUREMENTS MADE BY OFMET, SWITZERLAND

11.1 Measurement procedure

The measurements have been performed with the setup shown in the schematic drawing (Figure 11.1)

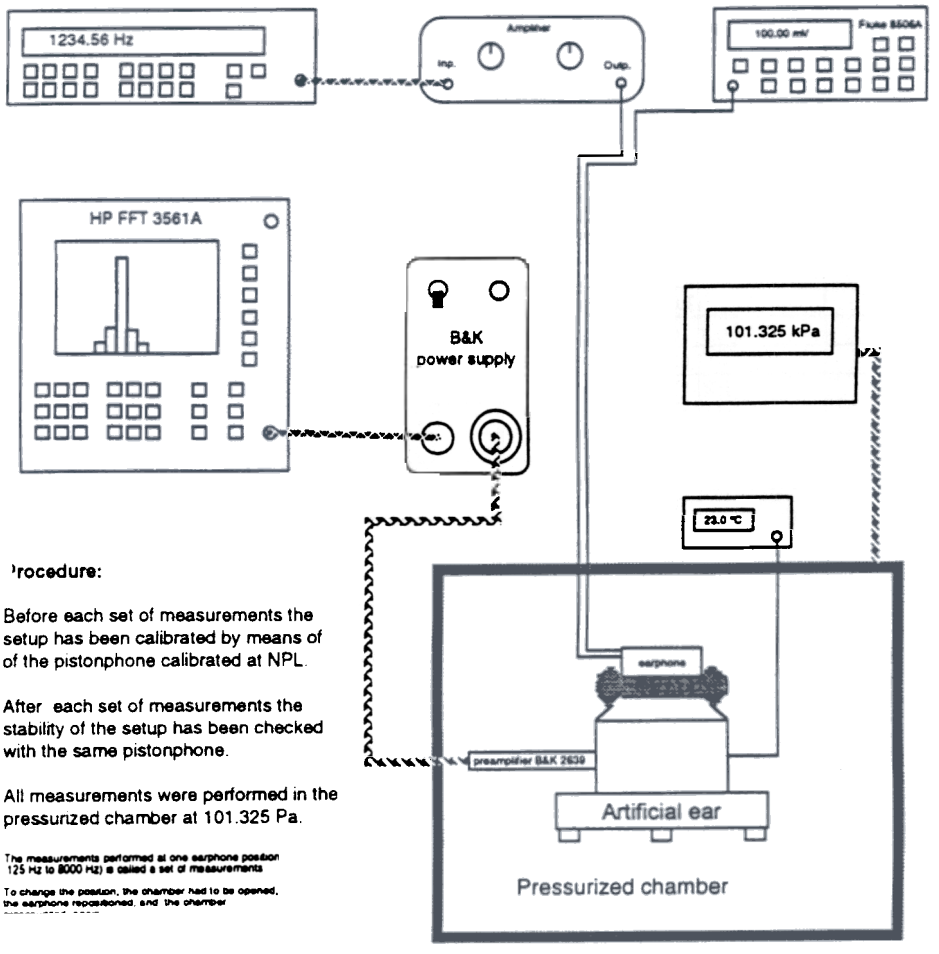


Figure 11. Equipment setup

The setup has been regularly calibrated/checked before and after each set of measurements by means of the Brüel and Kjær pistonphone type 4228 Serial No. 1504104 (Ref. value 124.00 dB issued by NPL)

The measurements of all SPL's in the artificial ear (125 Hz to 8 kHz) in three different positions (0°, 120° and 240°) is called a set of measurements. We performed 8 sets of measurements with the TDH 49P earphones and 7 sets with the two Holmco earphones.

The positions have been marked on the earphones to be able to measure the same positions during all the tests. The influence of the position was found to be of minor influence on the final uncertainty.

The mean atmospheric pressure in our laboratory is around 95 kPa (OFMET is 552 m above sea level). We therefore performed all measurements in a pressurized chamber. The chamber had to be opened (depressurized first) to change the earphone's position on the artificial ear, and of course pressurized again to continue with the measurements.

The frequency response of the Brüel and Kjær type 4134 microphone used has been determined by means of the so called electrostatic actuator. The measurements have been performed with the microphone mounted on the artificial ear, at a pressure of 101.325 kPa and with the preamplifier used for the measurements.

The SPL's have been measured with the HP FFT analyser type 3561A in third octave mode. The linearity of this instrument (in the level range used) was found to be in the order of 0.01 dB. The flatness of the third octave filters is approximately of the same order.

The stability of the setup (checked by means of the above mentioned pistonphone) was found to be in the order of 0.01 to 0.02 of a dB.

11.2 Uncertainties

11.2.1 Type A Uncertainties

Measured type A uncertainties (repeatability of 8 measurements) at an estimated confidence probability of approximately 95%:

	Telephonics TDH-49P Serial No. B06894		Holmco No. 95-01 Red C		Holmco No. 95-01 Blue D	
Frequency (Hz)	measured sd (dB)	type A Uncertainty (dB)	measured sd (dB)	type A Uncertainty (dB)	measured sd (dB)	type A Uncertainty (dB)
125	0.043	0.015	0.060	0.023	0.095	0.036
250	0.049	0.017	0.158	0.060	0.155	0.059
500	0.039	0.014	0.027	0.010	0.033	0.012
750	0.041	0.014	0.035	0.013	0.037	0.014
1000	0.040	0.014	0.029	0.011	0.037	0.014
1500	0.042	0.015	0.022	0.008	0.034	0.013
2000	0.040	0.014	0.021	0.008	0.035	0.013
3000	0.041	0.015	0.027	0.010	0.032	0.012
4000	0.044	0.015	0.061	0.023	0.094	0.035
6000	0.076	0.027	0.133	0.050	0.140	0.053
8000	0.036	0.013	0.025	0.009	0.036	0.014

1.2.2 Type B Uncertainties

Influence quantity		dB	conf. level		conf. level 1
Pistonphone level uncertainty	±	0.07	2	NPL value	0.035
Determination of microphone frequency response	±	0.12	2	estimated	0.06
Uncertainty reading HP 3561A analyser	±	0.02	half range	checked	0.012
Stability (measurement set up)	±	0.02	half range	checked	0.012
Uncertainty pressure measurements 0.03 kPa	<±	0	half range	estimated	0.001
Uncertainty temperature measurements 0.2 °C	<±	0	half range	estimated	0.001
Influence pressure deviations	<±	0.01	half range	estimated	0.003
Influence temperature deviations	<±	0.02	half range	estimated	0.012
Determination of driving voltage	<±	0	half range	estimated	0.001
Influence of earphone position Telephonics TDH-49P	±	0.02	half range	checked	0.012
Influence of earphone position (Holmco No. .95-01)	±	0.04	half range	checked	0.023

SUMSQR (Telephonics TDH-49P)	0.005
SUMSQR (Holmco No. 95-01)	0.006
Type B Uncertainty Telephonics TDH-49P (SQRT of SUMSQR)	0.073
Type B Uncertainty Holmco No. 95-01 (SQRT of SUMSQR)	0.076

11.3 Results

	Telephonics TDH-49P Serial No. B06894		Holmco No. 95-01 Red C		Holmco N0. 95-01 Blue D	
Frequency (Hz)	Corrected SPL (dB)	Total Uncertainty (dB)	Corrected SPL (dB)	Total Uncertainty (dB)	Corrected SPL (dB)	Total Uncertainty (dB)
125	103.94	0.15	118.24	0.16	118.67	0.17
250	106.80	0.15	119.51	0.19	119.79	0.19
500	107.75	0.15	121.06	0.15	121.30	0.15
750	107.90	0.15	121.60	0.15	121.67	0.15
1000	108.20	0.15	121.86	0.15	121.72	0.15
1500	107.92	0.15	120.37	0.15	120.13	0.15
2000	108.50	0.15	118.67	0.15	118.62	0.15
3000	109.95	0.15	115.49	0.15	115.72	0.15
4000	107.80	0.15	112.55	0.16	111.76	0.17
6000	104.41	0.16	107.36	0.18	105.89	0.19
8000	98.91	0.15	107.58	0.15	110.00	0.15

12 RESULTS

The grand mean sensitivity level (dB re 1 Pa/V) and associated standard deviation were calculated for each earphone measured by each laboratory and these results are presented in tables 12.1, 12.2 and 12.3.

Figures 12.1, 12.2 and 12.3 show results for the six laboratories (including NPL) which measured each of the earphone types. Results for Holmco No 95-01 Red E measured by SP Sweden are not given as the earphone was damaged in transit, the PTB sample Holmco 95-01 Red was also found to be damaged but the results are included.

The format of these figures requires some explanation. As the participants measured the sensitivity levels of different earphones, the figures show the difference between the sensitivity level reported by each participant and that for the same earphone determined by NPL. In order not to use NPL results as a baseline, the mean difference between the participants and NPL has been calculated at each frequency for each set of earphones (Telephonics TDH-49P, Holmco No 95-01 Red and Holmco No 95-01 Blue), and these mean differences have been used as the baseline. Consequently, it is possible to plot curves for NPL itself in the form of minus these mean differences, while at the same time representing faithfully the individual differences between participants and NPL.

In addition to the sensitivity level measurements PTB determined the dependency on atmospheric pressure, temperature and humidity and these coefficients are shown in Figures 12.4, 12.5, and 12.6.

At a constant temperature and humidity the ear simulator sensitivity levels of all 3 earphones were determined as a function of static pressure by changing the pressure from 91.3 kPa to 111.3 kPa in steps of 10 kPa. A stabilising time of 5 min was allowed at each measuring point. Linear regression was used to calculate the corresponding static pressure coefficients and this is shown in figure 12.4.

At a constant static pressure and humidity the ear simulator sensitivity levels of all 3 earphones were determined as a function of temperature by changing the temperature within a range of 10 °C to 30 °C in steps of 10 °C. A stabilising time of 2 hours was allowed at each measuring point. Linear regression was used to calculate the corresponding temperature coefficients and this is shown in figure 12.5. At 8 kHz the temperature coefficient of the TDH-49P shows a non-linear behaviour. This is well known from earlier experiments in PTB. It was not possible to get stable results for the earphone Holmco 95-01 red cup marked D.

Measurements of the humidity coefficients could only be performed after the original earphones under test had been sent back to NPL so other Holmco 95-01 and Telephonics TDH-49P earphones were used. At a constant static pressure and temperature the ear simulator sensitivity levels were determined as a function of relative humidity by changing the humidity within a range of 30 % to 80 % in steps of 25 %, 55% relative humidity being taken as the reference point. A stabilising time of 2 hours was allowed at each measuring point. Linear regression was then used to calculate the corresponding humidity coefficients and this is shown in Figure 12.6.

The following abbreviations are used in the tables and figures:

Technical University of Denmark, Denmark	DTU
Laboratoire National D'Essais, France	LNE
Physikalisch-Technische Bundesanstalt, Germany	PTB
SINTEF Metrology, Norway	SINTEF
SP - Swedish National Testing and Research Institute, Sweden	SP
Swiss Federal Office of Metrology, Switzerland	OFMET
National Physical Laboratory, United Kingdom	NPL

	Earphone type Telephonics TDH-49P											
	B06893				B06894				B06896			
Freq (Hz)	NPL		PTB		NPL		OFMET		NPL		SP	
	$\bar{x}$	σ	$\bar{x}$	σ	$\bar{x}$	σ	$\bar{x}$	σ	$\bar{x}$	σ	$\bar{x}$	σ
125	29.21	0.05	29.30	0.027	29.72	0.06	29.94	0.043	29.71	0.05	29.61	0.06
250	32.10	0.05	31.85	0.027	32.65	0.09	32.80	0.049	32.50	0.04	32.56	0.01
500	32.94	0.06	32.60	0.027	33.52	0.09	33.75	0.039	33.39	0.04	33.59	0.02
750	33.0	0.04	32.65	0.027	33.68	0.11	33.90	0.041	33.55	0.04	33.73	0.02
1000	33.13	0.10	32.90	0.022	33.95	0.10	34.20	0.040	33.81	0.05	33.96	0.02
1500	33.04	0.05	32.65	0.042	33.64	0.07	33.92	0.042	33.50	0.03	33.56	0.02
2000	33.52	0.03	33.25	0.022	34.10	0.06	34.50	0.040	33.66	0.04	33.74	0.09
3000	35.52	0.05	35.50	0.022	35.63	0.06	35.95	0.041	35.77	0.02	36.22	0.03
4000	33.16	0.06	32.90	0.027	33.69	0.04	33.80	0.044	33.50	0.04	33.63	0.03
6000	30.22	0.06	29.80	0.076	30.54	0.13	30.41	0.076	30.22	0.05	30.24	0.05
8000	24.65	0.05	24.30	0.065	24.84	0.03	24.91	0.036	24.86	0.02	25.05	0.04
	B06903				B06904				B06915			
Freq (Hz)	NPL		LNE		NPL		DTU		NPL		SINTEF	
	$\bar{x}$	σ	$\bar{x}$	σ	$\bar{x}$	σ	$\bar{x}$	σ	$\bar{x}$	σ	$\bar{x}$	σ
125	29.71	0.04	29.74	0.02	29.71	0.04	29.70	0.07	29.63	0.04	29.64	0.02
250	32.51	0.07	32.44	0.03	32.54	0.08	32.19	0.12	32.38	0.05	32.08	0.03
500	33.33	0.05	33.48	0.03	33.44	0.08	33.24	0.08	33.29	0.04	33.13	0.03
750	33.43	0.08	33.50	0.04	33.66	0.03	33.42	0.08	33.48	0.08	33.33	0.03
1000	33.51	0.06	33.58	0.04	33.97	0.08	33.69	0.08	33.79	0.05	33.70	0.03
1500	33.07	0.04	33.10	0.04	33.66	0.04	33.38	0.04	33.66	0.04	33.78	0.03
2000	33.32	0.03	33.41	0.03	33.80	0.03	33.65	0.03	33.87	0.08	34.19	0.02
3000	35.40	0.08	35.69	0.03	35.10	0.01	35.22	0.02	34.62	0.07	34.77	0.02
4000	33.49	0.08	33.40	0.09	33.44	0.09	33.05	0.19	32.99	0.09	32.17	0.06
6000	29.78	0.01	29.74	0.10	30.24	0.05	29.71	0.19	30.20	0.07	29.74	0.11
8000	24.10	0.06	24.22	0.07	24.68	0.01	24.22	0.20	24.12	0.08	24.11	0.05

Table 12.1 Comparison of grand mean sensitivity levels (dB re 1 Pa/V) and associated standard deviations for the Telephonics TDH-49P earphones driven by a 100 mV sinusoidal signal.

	Earphone type Holmco 95-01											
	Red A				Red B				Red C			
Freq (Hz)	NPL		DTU		NPL		SINTEF		NPL		OFMET	
	$\bar{x}$	σ	$\bar{x}$	σ	$\bar{x}$	σ	$\bar{x}$	σ	$\bar{x}$	σ	$\bar{x}$	σ
125	45.24	0.01	44.97	0.07	44.04	0.01	44.26	0.03	44.42	0.09	44.24	0.023
250	45.81	0.01	45.35	0.07	45.43	0.01	45.10	0.03	45.81	0.01	45.51	0.060
500	47.20	0.01	46.88	0.06	46.44	0.01	46.23	0.03	46.98	0.04	47.06	0.010
750	47.88	0.01	47.58	0.07	47.02	0.02	46.72	0.03	47.54	0.05	47.60	0.013
1000	48.17	0.01	47.95	0.08	47.16	0.01	46.95	0.04	47.81	0.03	47.86	0.011
1500	46.35	0.01	46.15	0.05	45.47	0.01	45.86	0.04	46.11	0.08	46.37	0.008
2000	44.20	0.012	43.94	0.07	43.60	0.04	44.36	0.04	44.24	0.01	44.67	0.008
3000	40.23	0.01	39.90	0.15	40.48	0.01	40.33	0.03	41.38	0.07	41.49	0.010
4000	36.98	0.01	36.51	0.21	37.76	0.02	37.28	0.06	38.54	0.01	38.55	0.023
6000	31.87	0.01	31.65	0.20	30.65	0.03	30.55	0.05	33.16	0.05	33.36	0.050
8000	36.42	0.012	35.93	0.12	34.65	0.02	34.48	0.03	33.68	0.09	33.58	0.009
	Red D				Red E				Red F			
Freq (Hz)	NPL		PTB		NPL		SP		NPL		LNE	
	$\bar{x}$	σ	$\bar{x}$	σ	$\bar{x}$	σ	$\bar{x}$	σ	$\bar{x}$	σ	$\bar{x}$	σ
125	44.75	0.01	44.10	0	44.02	0.02			44.87	0.05	44.92	0.10
250	45.84	0.01	45.35	0.035	44.09	0.03			44.50	0.15	44.53	0.10
500	47.08	0.04	46.50	0	43.70	0.02			46.54	0.07	46.59	0.04
750	47.63	0.04	47.20	0.035	44.91	0.01			47.70	0.02	47.73	0.03
1000	47.85	0.01	47.60	0.022	45.26	0.02			48.24	0.04	48.19	0.05
1500	46.02	0.02	45.75	0.027	43.94	0.03			45.07	0.01	45.08	0.04
2000	44.06	0.01	43.50	0.042	42.18	0.03			42.63	0.06	42.30	0.06
3000	41.11	0.01	40.30	0.055	41.09	0.01			38.48	0.14	38.24	0.20
4000	37.75	0.02	36.80	0.045	38.15	0.02			32.95	0.05	33.20	0.09
6000	32.76	0.07	33.75	0.027	32.12	0.01			34.23	0.01	34.10	0.10
8000	35.26	0.03	34.30	0.042	36.53	0.04			34.12	0.01	33.88	0.04

Table 12.2 Comparison of grand mean sensitivity levels (dB re 1 Pa/V) and associated standard deviations for the Holmco No. 95-01 (red) earphones driven by a 100 mV sinusoidal signal.

	Earphone type Holmco 95-01											
	Blue A				Blue B				Blue C			
Freq (Hz)	NPL		LNE		NPL		SP		NPL		PTB	
	$\bar{x}$	σ	$\bar{x}$	σ	$\bar{x}$	σ	$\bar{x}$	σ	$\bar{x}$	σ	$\bar{x}$	σ
125	44.68	0.01	44.28	0.09	44.87	0.03	44.86	0.06	43.95	0.01	43.60	0.027
250	45.94	0.01	45.78	0.02	45.74	0.01	45.65	0.04	45.40	0.01	44.85	0.027
500	47.14	0.01	47.05	0.02	46.92	0.01	47.01	0.04	46.54	0.01	45.85	0.045
750	47.79	0.01	47.76	0.02	47.49	0.01	47.55	0.04	46.78	0.03	46.20	0.027
1000	48.15	0.01	48.12	0.02	47.66	0.01	47.69	0.05	46.85	0.01	46.20	0.050
1500	46.31	0.01	46.26	0.03	46.00	0.01	45.71	0.05	45.10	0.01	44.50	0.042
2000	44.24	0.01	43.94	0.04	44.35	0.01	43.68	0.13	43.56	0.01	42.85	0
3000	40.87	0.01	41.08	0.06	41.48	0.01	41.57	0.15	42.40	0.01	42.25	0.027
4000	37.71	0.01	37.77	0.13	37.93	0.01	38.21	0.12	38.23	0.01	38.70	0.027
6000	30.63	0.01	30.61	0.13	32.07	0.01	32.14	0.09	31.05	0.01	31.20	0.057
8000	35.94	0.01	35.37	0.03	33.50	0.01	33.71	0.05	33.67	0.01	34.85	0.027
	Blue D				Blue E				Blue F			
Freq (Hz)	NPL		OFMET		NPL		SINTEF		NPL		DTU	
	$\bar{x}$	σ	$\bar{x}$	σ	$\bar{x}$	σ	$\bar{x}$	σ	$\bar{x}$	σ	$\bar{x}$	σ
125	44.86	0.01	44.67	0.095	44.84	0.03	45.02	0.14	44.60	0.01	44.18	0.16
250	46.07	0.02	45.79	0.155	46.05	0.02	45.70	0.04	46.03	0.01	45.51	0.10
500	47.23	0.01	47.30	0.033	47.34	0.01	47.00	0.04	46.92	0.01	46.60	0.08
750	47.59	0.01	47.67	0.037	47.88	0.03	47.47	0.07	47.59	0.01	47.22	0.08
1000	47.66	0.01	47.72	0.037	47.85	0.01	47.56	0.06	47.67	0.01	47.31	0.09
1500	45.86	0.01	46.13	0.034	45.99	0.01	46.34	0.05	45.80	0.01	45.59	0.08
2000	44.25	0.01	44.62	0.035	44.09	0.01	44.75	0.04	44.16	0.01	43.93	0.13
3000	41.36	0.01	41.72	0.032	41.05	0.01	40.94	0.01	42.17	0.01	41.77	0.11
4000	37.52	0.01	37.76	0.094	37.48	0.01	36.85	0.06	37.33	0.01	36.83	0.15
6000	31.88	0.01	31.89	0.140	31.02	0.01	31.05	0.08	30.49	0.01	30.09	0.19
8000	36.11	0.01	36.00	0.036	36.53	0.01	36.53	0.15	36.69	0.01	36.11	0.13

Table 12.3 Comparison of grand mean sensitivity levels (dB re 1 Pa/V) and associated standard deviations generated for the Holmco No. 95-01 (blue) earphones driven by a 100 mV sinusoidal signal.

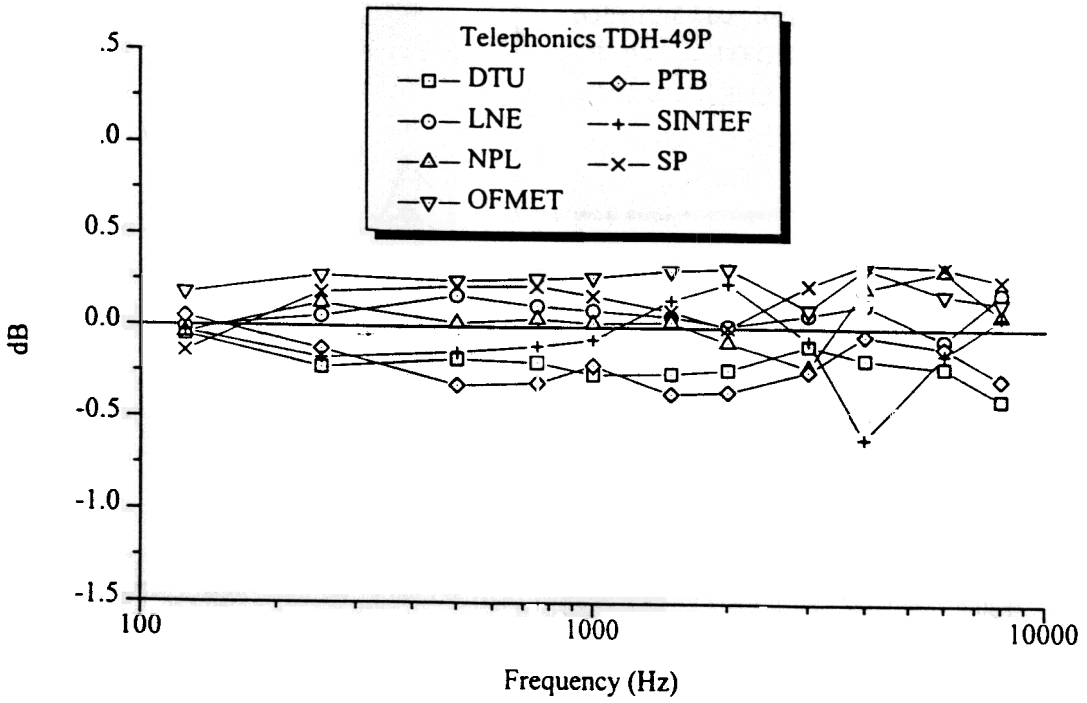


Figure 12.1 Difference between the sensitivity levels of Telephonics TDH-49P earphones reported by participating laboratories and the sensitivity levels determined by NPL plotted, at each frequency, relative to the mean difference

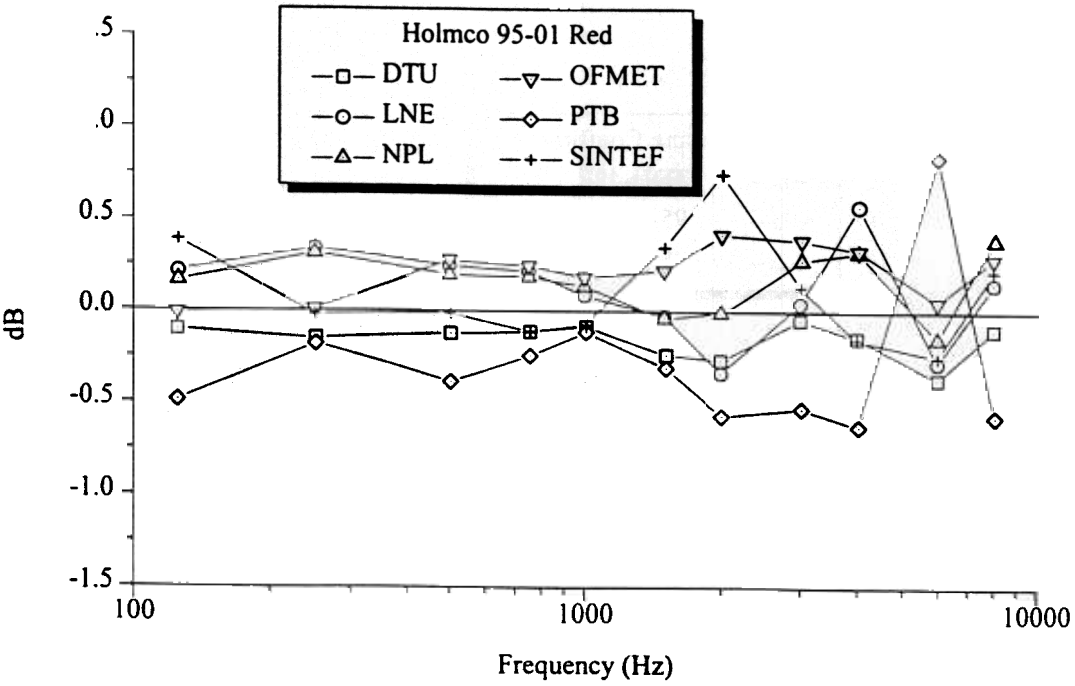


Figure 12.2 Difference between the sensitivity levels of Holmco No. 95-01 Red earphones reported by participating laboratories and the sensitivity levels determined by NPL plotted, at each frequency, relative to the mean difference

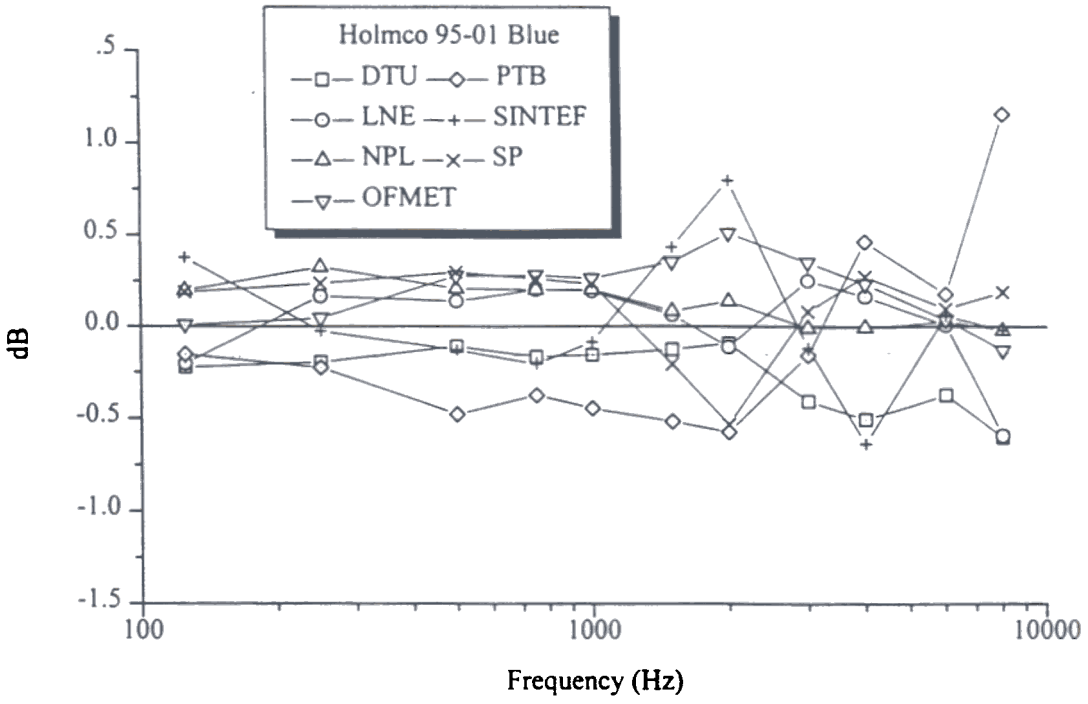


Figure 12.3 Difference between the sensitivity levels of Holmco No. 95-01 Blue earphones reported by participating laboratories and the sensitivity levels determined by NPL plotted, at each frequency, relative to the mean difference

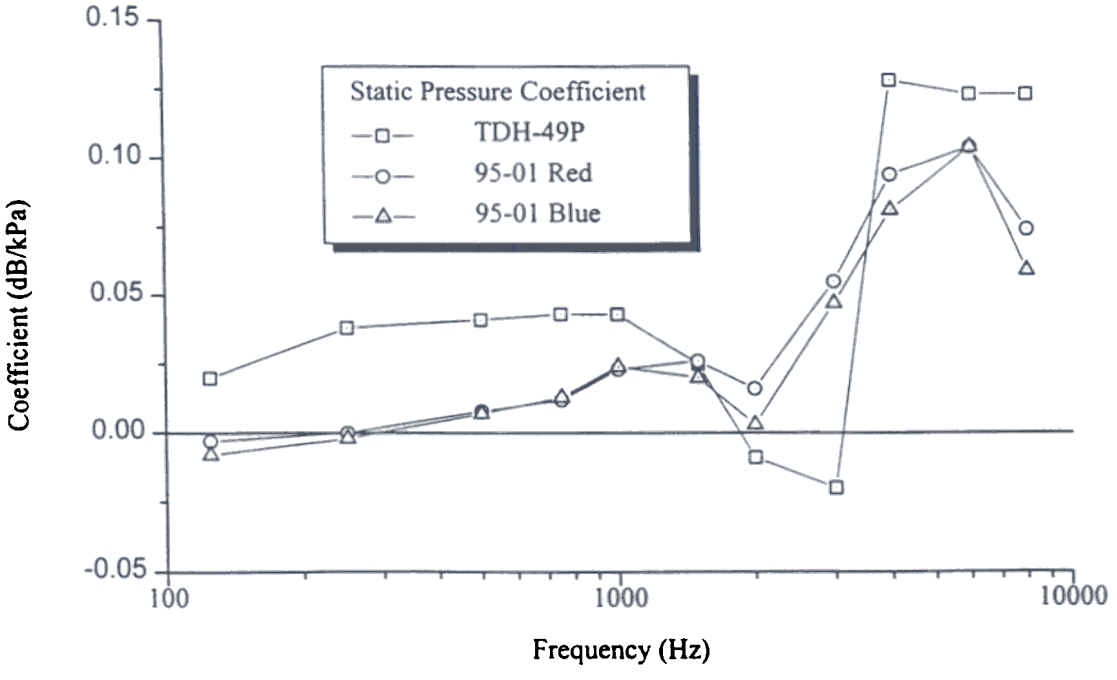


Figure 12.4 Static pressure coefficients as calculated by PTB for Telephonics TDH-49 earphones and Holmco 91-01 earphones

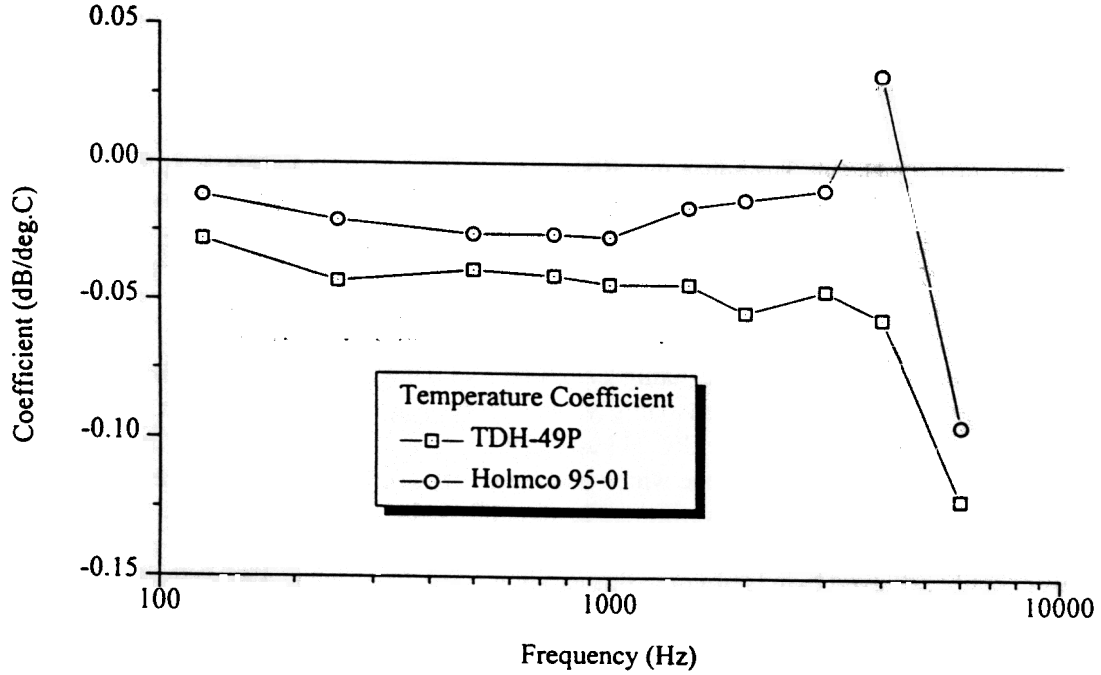


Figure 12.5 Temperature coefficients as calculated by PTB for Telephonics TDH-49 earphones and Holmco 91-01 earphones

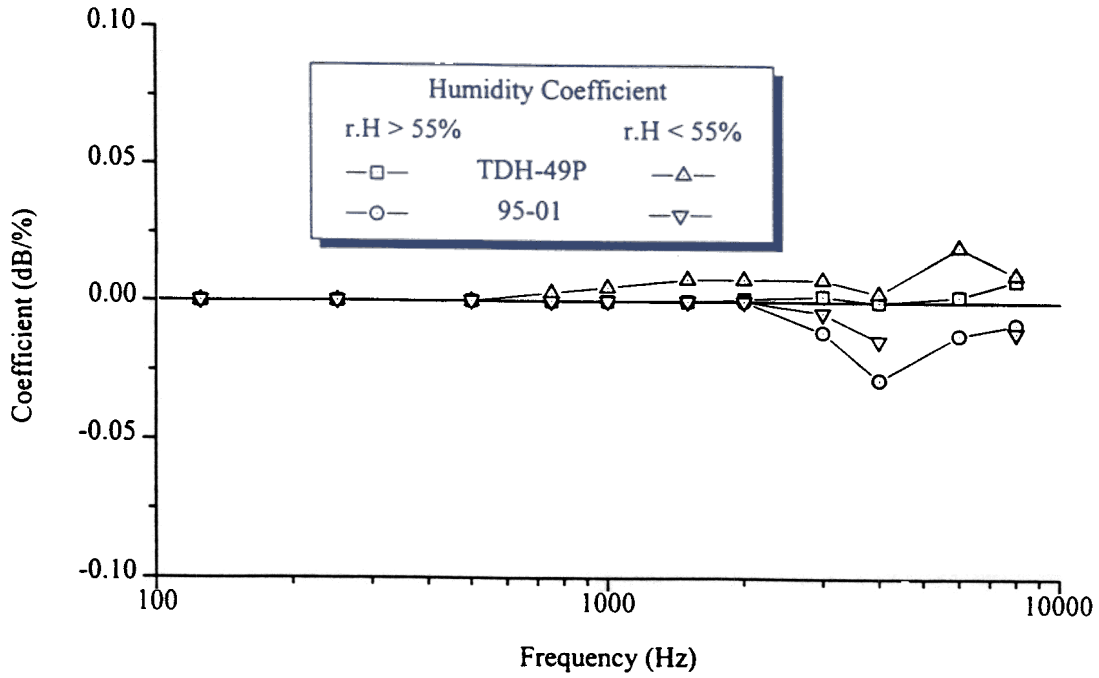


Figure 12.6 Humidity coefficients as calculated by PTB for Telephonics TDH-49 earphones and Holmco 91-01 earphones

13 DISCUSSION AND CONCLUSIONS

Figures 12.1, 12.2 and 12.3 show the difference between the sensitivity levels of each earphone type reported by participating laboratories and the sensitivity levels determined by NPL plotted at each frequency relative to the mean difference. It can be seen that in general good agreement is shown between the results.

For the Telephonics TDH-49P earphones the differences agree within ± 0.5 dB at all frequencies. In general for any one earphone the measured difference is less than 0.4 dB, though a difference of 0.8 dB is seen in one instance at 4000 Hz. For the Holmco 95-01 earphone the differences agree within ± 0.5 dB at lower frequencies (250 Hz - 1500 Hz) and ± 0.8 dB at higher frequencies (2000 Hz - 8000 Hz) except for one result at 8000 Hz which exhibited a difference of 1.2 dB.

Problems were noticed by all of the participating laboratories with the Holmco 95-01 earphones and it was concluded that the very hard cushion fitted to this type of earphone sometimes made it difficult to achieve a good seal between the earphone and the IEC 318 artificial ear. On particular example of this problem was seen with the Holmco Blue cap F earphone which had to be very carefully aligned on the artificial ear in order to avoid a leakage. A leakage lowering the level at 50 Hz by 6 - 10 dB was quite common if the earphone was not properly aligned. In general differences of 1 dB over the frequency range 125 Hz to 8000 Hz were easily achieved by mis-aligning this earphone type. The problem of achieving a good seal between the earphone and the IEC 318 artificial ear does not seem to exist when using the Telephonics TDH-49P earphone fitted with the newer style one-piece Model 51 (P/N 510C017-1) most probably because this cushion type is much less rigid. Two samples of the Holmco earphone were also found to be damaged.

Additionally, the results are also affected by the position at which the earphone drive voltage was measured. In some instances the drive voltage was measured at the earphone terminals and others measured at the end of the leads. Any voltage drop along the length of the lead would have resulted in a lower measured earphone sensitivity.

When this project was planned, it was decided to carry out five sets of five measurements, ie five repetitions over at least five days. The five repeated determinations of the response of any one earphone on any one coupler produced standard deviations of typically 0.05 dB though in some cases at high frequencies this increased to as much as 0.2 dB. The good repeatability observed during the measurements indicates that it is not necessary to repeat the measurements over five days provided of course that the standard deviations on the five measurements carried out during one work-day are sufficiently low.

In addition to the sensitivity level measurements, PTB determined the dependancy on atmospheric pressure, temperature and humidity and calculated the corresponding coefficient. It should be noted that although measured, no corrections have been made to the measurement results due to any changes in the atmospheric pressure, temperature and relative humidity over the measurement period. The repeatability of the IEC 318 artificial ear sensitivity levels of all three earphones types under practically constant climatic conditions was on average better than 0.1 dB, and no more than 0.2 dB in the worst case, for repeated measurements on different days.

From Figure 12.4 it can be seen that the sensitivity level of the IEC 318 artificial ear/earphone combination increases with an increase in static pressure and from Figure 12.5, the sensitivity level also increases with a decrease in temperature.

The sensitivity levels for the IEC 318 artificial ear/earphone combination increase with increasing static pressure (PS) see Figure 12.4, and decreasing temperature (T), see figure 12.5. Therefore the calibration results of one and the same earphone (or audiometer) can differ under different climatic conditions (for instance PS_1: 103 kPa, T_1: 19 °C and PS_2: 93 kPa, T_2: 30 °C) by about 1 dB at low frequencies and by about 2.5 dB at high frequencies. Attention needs to be paid to this, especially with the advent of high frequency audiometry.

At 8000 Hz the temperature coefficient of the artificial ear/TDH-49P earphone combination shows a non-linear behaviour. This is well known from earlier experiments carried out at PTB.

Measurements of the humidity coefficients could only be performed after the original earphones under test had been sent back to NPL so earphones of types 95-01 and TDH-49P (2 samples per type) were used. Initially it appears from Figure 12.6 that the effect of humidity for both earphone types measured on the artificial ear is negligible. Less than ± 0.01 dB/% r.H. can be attributable at low to mid frequencies with a maximum value of - 0.025 dB/% r.H. reported at 4000 Hz for the Holmco 95-01 and 0.02 dB/% r.H. reported at 6000 Hz for the Telephonics TDH-49P. Relative humidity though can easily vary by 50% and this could give rise to a difference as large as 1.25 dB! It should be noted that at high audiometric frequencies the humidity coefficient of both types of earphone measured on the artificial ear shows non-linear behaviour.

From a previous study, PTB reported measurements made of the sensitivity of one earphone repeated many times using the same microphone but different IEC 318 artificial ears. Results from this indicated that variations in the impedance of artificial ears could result in a difference of ± 0.2 dB in the measurement of earphone sensitivity.

The aim of this project was that the results from participating laboratories should agree within their quoted uncertainties of measurement. Typical overall uncertainties varied from 0.15 dB to 0.5 dB. Although some harmonisation in the overall measure of uncertainty is required, a good agreement was achieved by European laboratories for measurements made using these two earphone types measured on the IEC 318 artificial ear. This implies a good level of agreement in the calibration of the IEC artificial ear and therefore a uniformity in audiometer calibration using this device within Europe.

14 ACKNOWLEDGEMENTS

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