Application Note

Improving Telephone Handset Performance

— On the Use of Ear Simulators ITU-T P.57 Type 1 and Type 3.2 for Telephonometric Measurements

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Brüel & Kjær have, during recent years, introduced new ear simulator types which provide realistic simulations of the conditions when a telephone handset is applied to a human ear. These ear simulators, also referred to as the Type 3.2 simplified pinna simulators (high- and low-leak version), conforms to the ITU-T P.57 recommendation. Standard acoustic receiving path measurements on telephone handsets have traditionally been performed using a more simplified model of the human ear; the IEC 318 coupler (ITU-T P.57 Type 1). When using the new Type 3.2 ear simulators, the measurement results obtained will in some cases be different (more realistic) than results obtained with the Type 1 ear simulator.

This application note explains the reason for these differences. It also suggests some basic rules for designing handsets which are less sensitive to differences in ear simulators and hence also less sensitive to the different conditions under which the handsets are used. Eventually, using the new ear simulator types may lead to an improved performance of the telephone handset, in terms of a better perceived sound quality.


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Introduction

Measurements on telephone handsets are traditionally done using the ITU-T P.57 Type 1 ear simulator. This ear simulator includes the IEC 318 coupler, which was introduced to the market more than two decades ago. The Type 1 ear simulator is a rather coarse simulation of the human ear, and the conditions under which it is designed to be used are not an accurate representation of the normal use of telephone handsets. Therefore, some new ear simulators have been specified by ITU (International Telecommunication Union) which better simulate the acoustical load of the human ear when using modern telephone handsets.

The introduction of these new ear simulator types in telephone standards during the recent years, has lead to some confusion among handset designers. First of all, using the new couplers leads to different measurement results than those obtained with the usual Type 1 ear simulator. Furthermore, it is questioned whether tolerances in telephone standards where the Type 1 ear simulator is specified are still applicable when using the new ear simulators types.

The scope of this application note is to describe how to use the different ear simulators for measurements on various telephone handsets, and in particular how to select the most appropriate simulator for a given handset. It is also explained how measurements made with different ear simulators lead to different results for some handsets.

Definitions

When discussing measurements on the human ear, several terms are used to describe the measurement conditions. An overview of these terms is presented in the following. Fig.1 shows a sketch of a human ear. When referring to the sound pressure level in the ear, three relevant measurement points are defined: the Ear Reference Point (ERP), the Drum Reference Point (DRP) and the Ear-canal Entrance Point (EEP). The exact location of these measuring points are shown in Fig.1.

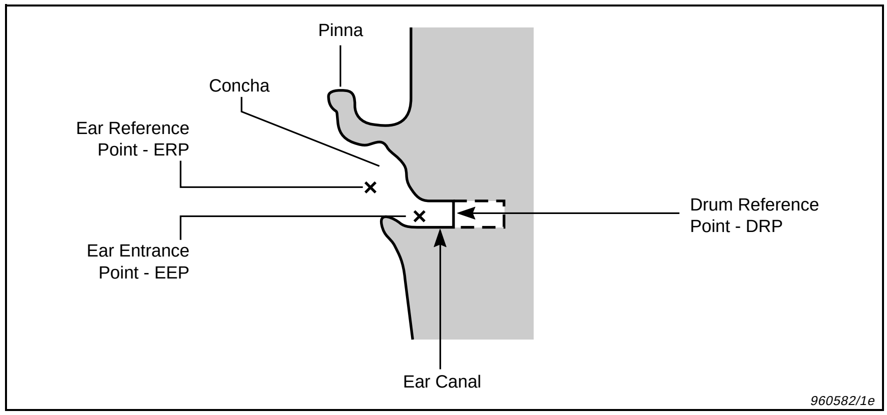


Fig.1 Ear anatomy and definitions

When measuring on earphones, the shape of the earphone can also influence the measurements. Therefore, some general earphone shapes have been defined, as shown in Fig.2a–d [1]. Most ear simulators are designed specifically for the use of one or more of these different earphone shapes. An overview is given in Table 1.

The physical properties of an earphone may affect measurements on ear simulators. If the ear is exposed to an enclosure (e.g., in a headphone), the sound field in the ear is much different than when in a free sound field. Two kind of earphones have been defined: open and closed. Acoustically open earphones intentionally provide an acoustic path between the external environment and the ear canal. Acoustically closed earphones are intended to prevent any acoustic coupling between the external environment and the ear canal. Normal

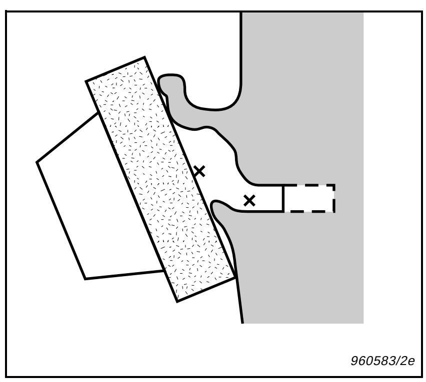


Fig.2a Supra-aural earphone (open type)

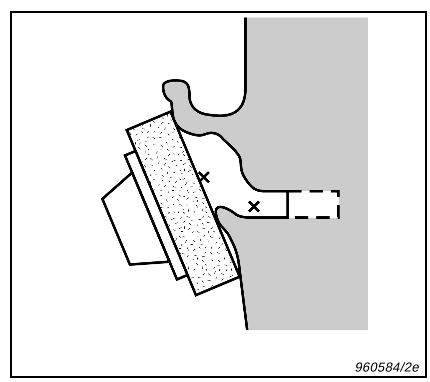


Fig.2b Supra-concha earphone (open type)

ITU-T P.57 Ear Type	Earphone Types	Measuring point	ERP-DRP correction function	Brüel & Kjær Type No.
1	Supra-aural, supra-concha	close to ERP	Individually calibrated	4185 / 4153
2	Insert earphones	DRP	ITU-T P.57 table 2a/b	4157
3.1	Intra-concha earphones	DRP	ITU-T P.57 table 2a/b	–
3.2	Supra-aural, supra-concha	DRP	Individually calibrated	4195
3.3	Supra-concha	DRP	ITU-T P.57 table 2a/b	4128 (with 4158 / 4159)
3.4	Supra-concha	DRP	ITU-T P.57 table 2a/b	–

Table1 Overview of ear simulator types

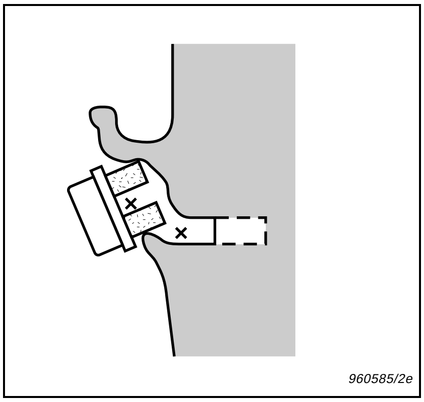


Fig.2c Intra-concha earphone (open type)

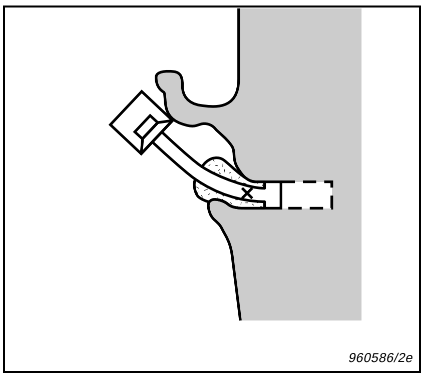


Fig.2d Insert earphone (open type)

telephone handsets are always of the open type.

Ear Simulator Types

An ear simulator is a device incorporating an acoustic coupler and a measurement microphone. The coupler simulates the physical properties of the ear, while the microphone, like the human eardrum, picks up the sound pressure. For a given frequency range, the artificial ear should simulate the physical acoustic impedance of the average human ear.

ITU-T P.57 recommendation [1] specifies several ear simulator types. In Table 1 an overview is given. In this application note we will concentrate on the Type 1 and Type 3.2 ear simulators and their use for measurements on telephone handsets, but a brief overview of the various types is given in the following.

Type 1

The coupler in the Type 1 ear simulator is further specified in IEC Publication 318 [2]. It is recommended that the Type 1 ear simulator should be used for measurements on supra-aural and supra-concha earphones, sealed, intended for normal telephone bandwidth (100 Hz to 4 kHz) applications. The acoustic input impedance and frequency sensitivity response of the Type 1 artificial ear are referred directly to the Ear Reference Point (ERP) using an individual calibration curve as described in the appendix. The Type 1 ear simulates the acoustic load of the human ear under no leakage conditions, and is therefore only applicable when the telephone handset is held completely sealed to the ear. This is not a very realistic situation for normal use of handsets. Therefore, a correction curve L_E is used for Loudness Rating calculations according to ITU-T P.79 [3] to simulate a leak condition. However, this correction factor has been derived for old telephone handsets where the leak was rather small. The leak obtained with modern handsets is often very different from the nominal L_E correction curve.

Type 2

The Type 2, also referred to as the IEC 711 [4] ear simulator, is used for measurements on insert earphones, both sealed and unsealed, such as hearing aids and headsets. The sound pressure measured by the Type 2 ear simulator is referred to the ear-drum reference point (DRP). Therefore a correction function (ITU-T P.57 table 2a/b) is used for converting data to the ear reference point (ERP) when it is required to calculate loudness ratings or check results against specifications based on measurements referred to ERP.

Type 3

All Type 3 artificial ears consists of the Type 2 IEC 711 occluded-ear simulator, to which an ear canal extension terminated with a pinna simulation device is added.

The Type 3.2 ear simulator uses a simplified pinna simulator. In this simulator, a well-defined leak (available in two grades) from the cavity to the exterior simulates the average real ear loss for telephone handsets which are held either comfortably (low-leak version) or loosely (high-leak version) against the human ear. Type 3.2 ear simulator is recommended for measurements on supra-aural and supra-concha earphones, sealed and unsealed, and of both high and low impedance (practically covering all kinds of earphone design). It can be used in the wide frequency range from 100 Hz to 8 kHz. The Type 3.2 ear simulator was made with the anatomically shaped Type 3.3 ear simulator as a reference. The acoustical behaviour of the Type 3.2 ear simulator is therefore very close to that of the Type 3.3. Measurements with Type 3.2 ear simulator are done at the ear drum position (DRP). By using the individually calibrated frequency response supplied with the ear simulator (described in the appendix) the measurements can be referred to ERP, when it is required to calculate loudness ratings or check results against specifications based on measurements referred to ERP.

The Type 3.3 ear simulator is a very close simulation of a real human ear realised by terminating the ear canal extension with an anatomically shaped pinna simulator as described in IEC 959 [5]. The pinna simulator is made of a high-quality elastomer with a well specified shore-A hardness. It is recommended that the Type 3.3 ear simulator be used for measurements on supra concha earphones, sealed and unsealed which due to their peculiar shape, do not fit the circular rims of Type 1 or Type 3.2 ear simulators, whichever is applicable. The sound pressure measured by the Type 3.3 ear simulator is referred to DRP. Therefore a correction curve (same as for Type 2) is used to convert data to the ERP when it is required to calculate loudness ratings or check results against specifications based on measurements referred to the ERP.

The pinna simulation is realised in Type 3.4 ear simulator by terminating the drum reference plane of the Type 2 ear simulator with an ear canal extension and a simplified pinna made of an elastomer with a well defined shore-A hardness. It is suggested that Type 3.4 can be used as a simplified alternative to Type 3.3 for measurements on supra-concha and supra-aural earphones, where the pressure dependent characterization of recieving performance is considered important. The sound pressure measured by the Type 3.4 ear simulator is also referred to DRP and therefore the DRP-ERP correction curve (the same as for Type 2 and Type 3.3) must be used when comparing data with measurements obtained in ERP.

Measurement Examples

To illustrate the differences when measuring on one handset with the different types of ear simulators, four different "receive transducers" have been tested:

1. Sennheiser HD 414 headphone (low acoustic impedance)
2. Bang & Olufsen, BeoCom telephone
3. Telekom Signo telephone
4. 1/2″ condenser microphone used as sound source (high acoustic impedance).

For each transducer the receive characteristic was measured with:

1. Type 1 artificial ear (IEC 318), Brüel & Kjær Type 4185.
2. Type 3.2 artificial ear (simplified pinna simulator, low leak version), Brüel & Kjær Type 4195 – low leak.
3. Type 3.2 artificial ear (simplified pinna simulator, high leak version), Brüel & Kjær Type 4195 – high leak.
4. Type 3.3 artificial ear (pinna simulator), Brüel & Kjær Type 4128. Force applied to the handset during measurement: 10 N.

The different test objects required different excitation conditions (different feeding conditions, different generator impedance and level). Hence, for each test object, generator conditions were selected to generate a sound pressure in the artificial ear which was typical for testing receive responses. This is acceptable as the focus is on the differences between measurements on the same test object with different artificial ears, and the generator conditions were held constant for each test object.

In order to be able to compare measurement results, they must refer to the same measurement point. Therefore, the receive frequency response measurements for the Type 1, Type 3.2 (low leak) and Type 3.2 (high leak) artificial ears must be corrected to refer to the equivalent sound pressure level at the ERP. This is done by dividing the measured responses open ear with the open ear frequency sensitivity responses of the ear simulators (found on the calibration chart or disk delivered with the product, as described in the appendix). For the Type 3.3 artificial ear, the measurements are corrected with the DRP to ERP transfer function, as given in ITU-T P.57, Table 2. From the measured responses the receive loudness rating (RLR) values are calculated according to the following formula [3]

$$RLR = -\frac{10}{m}\log_{10}\sum_{i=1}^{N} 10^{\frac{m}{10}(S_i - L_{E,i} - w_i)}$$

where

m = a constant (in order of 0.2)

W_i = weighting coefficient (different for the various Loudness Ratings).

S_i = the sensitivity at frequency F_i of the electroacoustic path under examination.

The summation is to be performed at frequencies F_i, spaced 1/3 octave apart.

For the responses measured with the Type 1 artificial ear, the L_E correction is included. For the other artificial ears no L_E correction is used ($L_E = 0$).

Sennheiser Headphone

Fig. 3 shows the receive responses and the RLR values of the Sennheiser HD 414 headphone. This headphone was used to show the behaviour of a transducer with a very low acoustic output impedance, that is, a constant sound pressure source. It is seen that this transducer is roughly independent of the type of artificial ear. Only in the frequency range around 3.5 kHz is some interaction with the load observed.

BeoCom Handset

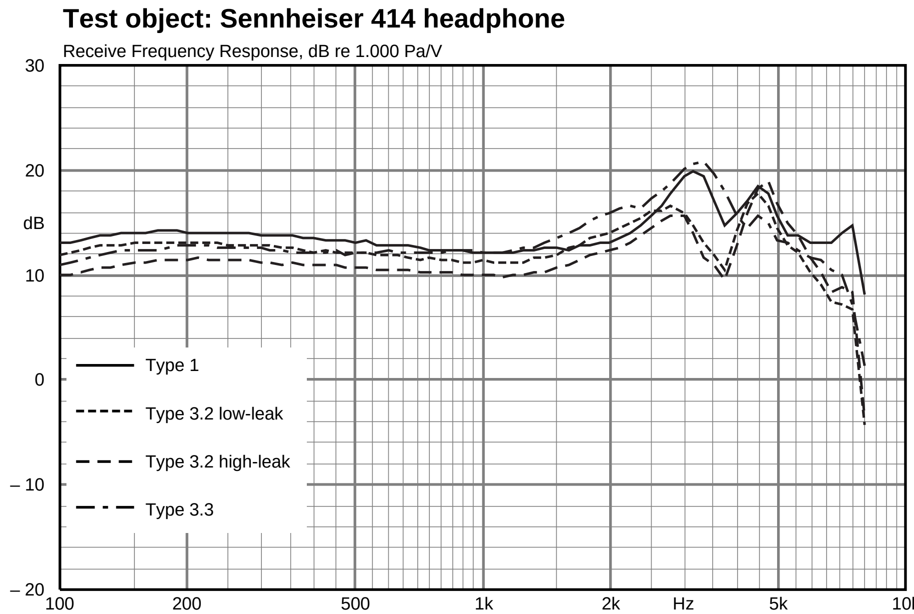
Fig. 4 shows the receive responses and the RLR values of the BeoCom handset. This telephone handset is usually regarded as an example of a low acoustic output impedance design. The response for the Type 3.2 (low leak) is slightly lower (except from a peak around 1.3 kHz) than for the Type 1 artificial ear at low frequencies. The RLR value is correspondingly 1.75 dB higher. The low-frequency roll off does not change (except from the slightly lower level). The responses for the Type 3.2 (high leak) and the Type 3.3 artificial ear are very similar, but below 1.5 kHz the responses are significantly lower (approximately 8 dB) than the two first responses. This results in an RLR value about 7 dB higher than for the Type 1 artificial ear indicating that the acoustical output impedance of the handset is relatively low when compared with the load of the Type 3.2 (low leak), but not when compared with the Type 3.2 (high leak) and Type 3.3 artificial ear. Note that below 1.5 kHz the shape of the responses remain the same with the different ear simulators, although shifted in level. This indicates that the acoustic output impedance is constructed not only to be relatively low, but also to match the impedance of a leakage.

Telekom Signo Handset

Fig. 5 shows the receive responses and the RLR values of the Telekom Signo. This telephone was chosen, with respect to acoustic impedance, as a representative of a standard telephone. The response for the Type 3.2 (low leak) shows a roll-off at both low and high frequencies compared to the response for the Type 1 artificial ear, and the RLR value is correspondingly 2.43 dB higher. The responses for the Type 3.2 (high leak) and the Type 3.3 artificial ear show a significant roll-off towards lower frequencies, starting at 1.5 kHz, resulting in RLR values about 8 – 13 dB higher than for the Type 1 artificial ear. This indicates that the acoustic output impedance of the handset must be regarded as being relatively high when compared with the load of the Type 3.2 (low leak), and high when compared with the Type 3.2 (high leak) and Type 3.3 artificial ear.

High Impedance Sound Source

Fig. 6 shows the receive responses and the RLR values for the 1/2″ condenser microphone used as a sound source. This transducer was included to show the behaviour of a transducer with a very high acoustic output impedance. As this transducer is not suitable for fitting to the Type 3.3 artificial ear mounted on the Head and Torso Simulator, it was not measured with the Type 3.3 artificial ear. A significant roll-off at lower frequencies is introduced when a leakage is applied by the Type 3.2 ears, compared to the Type 1 ear. The RLR values are 3 dB and 9 dB higher for the Type 3.2 ears, low leak and high leak respectively. The acoustic output impedance of this transducer is known to be very high (that is, a constant volume velocity source), and the effect when exposed to a leak is as expected.



Ear Simulator:	RLR:	
Type 1	- 2.66 dB	with Le correction
Type 3.2 low-leak	- 2.44 dB	no Le correction
Type 3.2 high-leak	- 1.07 dB	no Le correction
Type 3.3	- 3.25 dB	no Le correction

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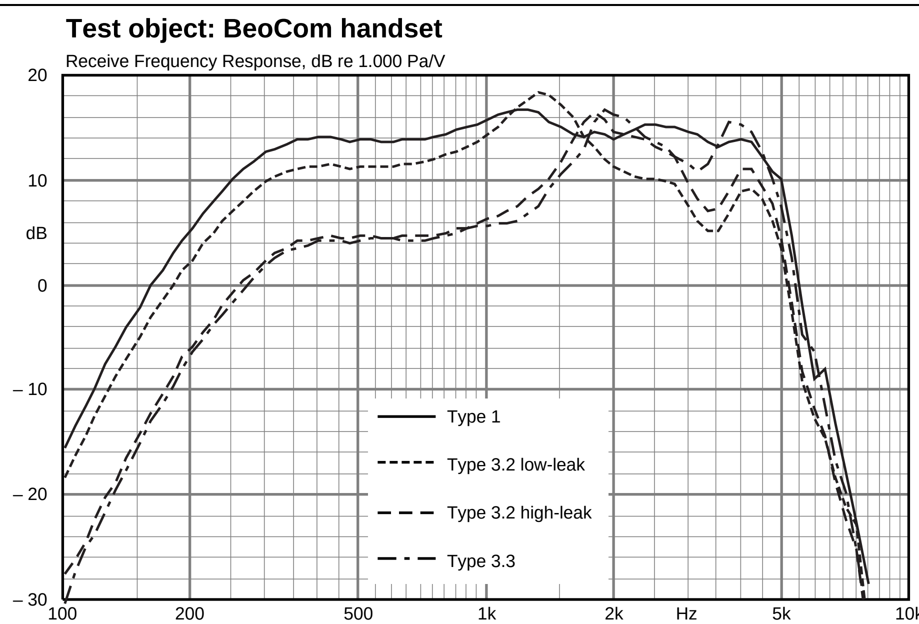
Fig.3 Frequency characteristics of the Sennheiser 414 headphone



Ear Simulator:	RLR:	
Type 1	- 3.33 dB	with Le correction
Type 3.2 low-leak	- 1.58 dB	no Le correction
Type 3.2 high-leak	3.40 dB	no Le correction
Type 3.3	3.66 dB	no Le correction

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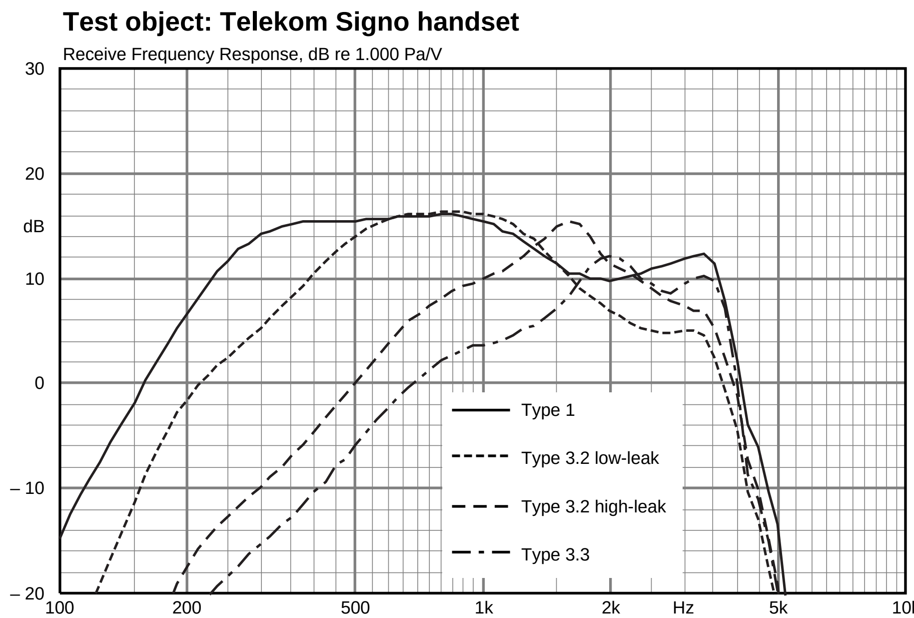
Fig.4 Frequency characteristics of the BeoCom handset



Ear Simulator:	RLR:	
Type 1	- 3.05 dB	with Le correction
Type 3.2 low-leak	- 0.62 dB	no Le correction
Type 3.2 high-leak	5.48 dB	no Le correction
Type 3.3	10.07 dB	no Le correction

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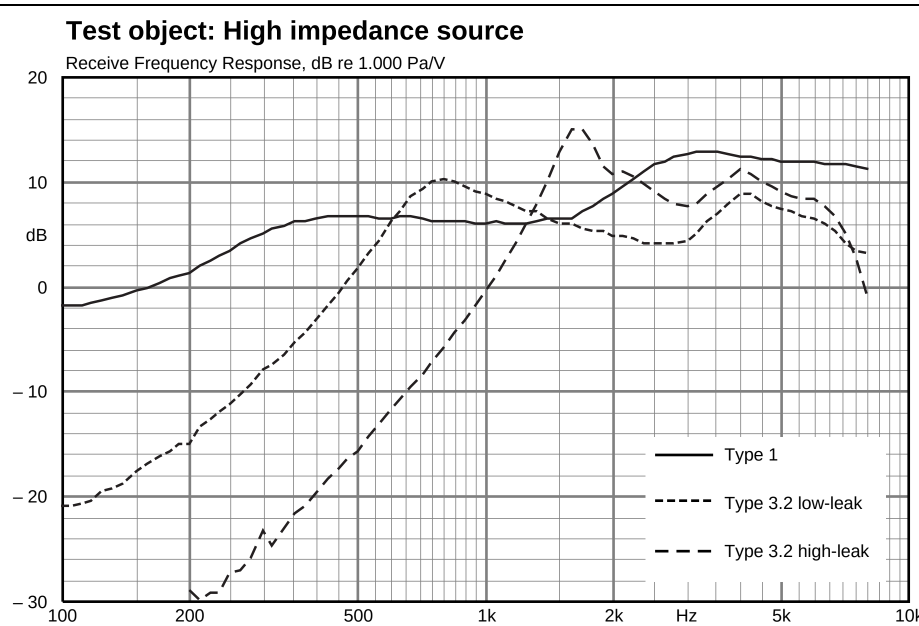
Fig.5 Frequency characteristics of the Telekom Signo handset



Ear Simulator:	RLR:	
Type 1	3.84 dB	with Le correction
Type 3.2 low-leak	6.91 dB	no Le correction
Type 3.2 high-leak	12.71 dB	no Le correction

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Fig.6 Frequency characteristics of the high impedance source

Selecting the Correct Ear Simulator for a Given Handset

The above examples show that for all the transducers designed for telephone handsets, the receive frequency response and the RLR value depend on the artificial ear used for the measurement. The effect of a leakage is usually a stronger low-frequency roll off. However, with a special handset design (BeoCom) the effect on the response can appear as a frequency independent decrease in level, which may be compensated for by a receive volume control (RVC) on the telephone.

The reason for obtaining different results on different ear simulators can be explained by looking at a simplified electrical equivalent circuit for the situation where the handset transducer is applied to an ear. The acoustic input impedance of the ear is $Z_{a,e}$, which is also the load impedance of the transducer when applied to the ear. The acoustic output impedance of the handset transducer (the sound source), is called $Z_{a,s}$. Using an impedance analogy for the electrical equivalent circuit, the sound pressure, p [Pa], will correspond to an electrical voltage, v [volts], and the volume velocity, q [m^3/s], will correspond to an electrical current i [A].

For a low impedance handset, $Z_{a,s}$ is much smaller than $Z_{a,e}$, and the transducer will act as a constant sound pressure source, equivalent to a constant voltage source (see Fig.7). This implies that the sound pressure, p in the ear will be independent of the acoustic input impedance, $Z_{a,e}$, of the ear. This illustrated in Fig. 3 with the measuring example of the Sennheiser headphone.

For a high-impedance handset, $Z_{a,s}$ will be much larger than $Z_{a,e}$, and the earphone transducer will act as a constant volume velocity source, equivalent to a constant current source (see Fig. 7). This implies that the sound pressure, p, in the ear will not be constant but dependent on the acoustic input impedance, $Z_{a,e}$, of the ear. This is illustrated in Fig. 6 with the measuring example of the high impedance sound source.

To summarise, the sound pressure generated by telephone handsets with low acoustic output impedance is generally not sensitive to the acoustic input impedance of the ear simulator (or a human ear), whereas the sound pressure generated by handsets with high acoustical output impedance is very sensitive to the acoustic input impedance of the ear simulator or to any changes in this impedance, for example as introduced by a leak.

When holding a telephone handset to the ear, it will normally not be held completely tight (sealed) to the ear.

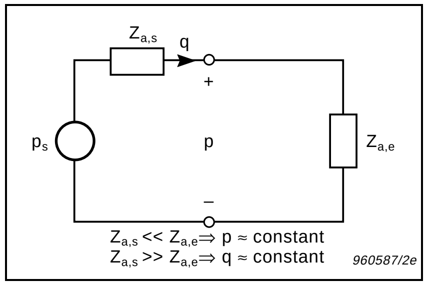


Fig.7 Simplified equivalent circuit of a low or high acoustical impedance handset applied to an ear simulator or a human ear

Often there will be a small path (leak) from the surroundings to the ear canal, as the handset is held more loosely. Furthermore, with the design of modern telephones it is often impossible to obtain a sealed situation. This is especially the case for mobile handsets. Therefore, the acoustical load impedance of an ear simulator should simulate either sealed, low-leakage or high-leakage conditions, depending on how the handset will be applied to a real ear when in use.

Conclusions

The Type 1 artificial ear is intended for measurements in the frequency range from 100 Hz to 4 kHz, where the measured sound pressure is almost identical to the equivalent sound pressure at the ERP. However, since the sound pressure is picked up at a position that does not correspond to DRP, the influence of the presence of a telephone handset is not correctly reflected in all cases. The size of the error depends on the type of transducer used in the handset.

The Type 1 artificial ear provides a sealed condition, and although leakage is known to be present in most real situations, the frequency response is not corrected. For RLR calculations, L_E is usually applied to include the effect of a leakage on the RLR value, which may only be a coarse approximation. This gives an inconsistency, since the frequency response is treated as if sealed conditions appear in real use, while the RLR calculation assumes a certain leakage with no dependency of the positioning and type of handset.

The Type 3.2 artificial ear is intended for measurements in the frequency range from 100 Hz to 8 kHz. The sound pressure is picked up at the DRP, which is in accordance with the definition of an ear simulator. Furthermore, correct calibration and a correction curve transfer the sound pressure measured with a Type 3.2 artificial ear directly to the equivalent sound pressure at the ERP under open ear conditions. This is convenient as most telephone standards refer to this measurement point.

The artificial ear physically provides a leakage, enabling the measured response to correspond to the actual leakage present in real use. Hence the calculation of RLR does not include any L_E correction. To provide realistic test results, the leakage of the artificial ear should be similar to that occurring with the handset in real use. Consequently, the Type 3.2 artificial ear is defined in both low-leakage and high-leakage versions in order to cover comfortably held and loosely held conditions respectively.

Only an earphone transducer with a very low acoustic output impedance (such as the Sennheiser HD 414 headphone) can be expected to meet the receive requirements of various telephone standards measured with more than one type of artificial ear, as it will to a high degree be insensitive to the acoustical load. Most telephone handset transducers in practice tend to approach the opposite condition (moderate to high output impedance). This emphasises the general importance of selecting the relevant artificial ear according to the actual acoustic load of the handset appearing in real use, both in the design phase as well as for the approval testing.

Most telephone standards are intended for measurements using the Type 1 ear simulator and do not reflect how the handset performs in real use when a leakage is introduced. Furthermore, as the requirements for frequency responses reflect a sealed situation and the requirements for loudness ratings reflects a situation with a leak, it gives no meaning to apply the same tolerances when using a Type 3.2 simulator, as it always incorporates a leak.

However, this paper has shown that it is anyway possible to design telephone handsets (like the BeoCom) which are quite insensitive to the applied leak, and therefore are able to pass the receive requirements of the telephone standards with the new and more realistic ear simulators. Thereby the way is shown for manufacturers to develop handsets which offer the user a better perceived sound quality.

References

[1]: ITU-T P.57, 1996
[2]: IEC 318, 1970
[3]: ITU-T P.79, 1993
[4]: IEC 711, 1981
[5]: IEC 959, 1990

International Standards, abbrev:

ITU-T: International Telecommunication Union – Telecommunication Standardization Sector

IEC: International Electrotechnical Commission

Appendix: Calibration of Ear Simulators

During manufacture at Brüel & Kjær, Denmark, the Type 4185 (ITU-T Type 1) and Type 4195 (ITU-T Type 3.2) ear simulators are calibrated according to ITU-T P.57 [1]. Both the acoustic input impedance and the frequency sensitivity response are individually measured. All calibration data are shown on the calibration chart and supplied as ASCII data on a floppy disk.

Acoustical Impedance

The acoustic impedance is defined as the acoustical input impedance seen from the ear reference point (ERP) of the ear simulator. It is measured using a specially designed impedance probe containing a built-in high acoustic impedance sound source and a calibrated probe microphone. When the impedance probe is mounted on the ear simulator, the tip of the probe microphone will be positioned exactly at the ERP. By measuring the sound pressure at the ERP from the high acoustic impedance sound source, the acoustic input impedance of the ear simulator can be calculated. The impedance is displayed in dB relative to 1 acoustical ohm. See Figs. 9 to 11.

Ear Simulator Type	$P_{4231,corrected}$ (open ear)	$P_{4231,corrected}$ (closed ear)
Type 1	93.8 dB	93.3 dB
Type 3.2 low-leak	98.2 dB	98.0 dB
Type 3.2 high-leak	84.7 dB	85.4 dB

Table 2 Calibration levels using Sound Level Calibrator Type 4231 for calibration of Ear Simulators Type 1 and Type 3.2 low and high leak

Frequency Sensitivity Response

The frequency sensitivity response (also referred to as the DRP to the ERP transfer function) is defined as the normalised ratio of output voltage of the ear simulator to input sound pressure at ERP. The normalisation is 0 dB at 1 kHz. The response is measured under "Open ear conditions" by mounting the artificial ear in a large plane baffle and exposing it to a plane incident wave perpendicular to the baffle. The sound pressure at the ERP is then measured with a calibrated probe microphone together with the output voltage of the ear simulator, both as a function of frequency. The frequency sensitivity response is calculated as the ratio of the measured output voltage of the ear simulator to the measured input sound pressure at the ERP.

Using the open ear frequency sensitivity response as a correction function, measurements made on any telephone handset can be referred to the equivalent sound pressure which would be present at the ERP (on a human being) if no handset were present. By this means a realistic situation is created comparable to the reference situation when two human beings are having a normal conversation (without telephones). The Ear Reference Point is used in most telephone standards as the reference point for telephone measurements.

For the Type 4185, the frequency sensitivity response under open ear conditions is practically independent of frequency up to 3 kHz and the correction is less than 1 dB up to 4 kHz. See Fig. 8. Hence, the frequency dependency is often ignored for the Type 4185 (the ear simulator is considered as measuring at the ERP requiring no further correction).

For Type 4195 the frequency sensitivity responses as shown in Fig. 9 and Fig. 10 show a stronger dependence on frequency. To refer measurements made with this ear simulator to ERP, the measured data must therefore be corrected by the frequency dependent sensitivity. The correction can be obtained using an equalising filter or as a post processing operation on the measurement data (by a simple division).

For practical reasons the closed ear frequency sensitivity response is also measured. This can be useful for instance when comparing measurements on high impedance handsets made with the Type 1 and Type 3.2 ear simulators.

Absolute Sensitivity

The absolute sensitivity at 1 kHz in [V/Pa] is defined as the absolute output voltage of the ear simulator to input sound pressure at ERP. The sensitivity is stated on the calibration chart for both open and closed ear conditions. The sensitivities can be verified using an acoustic calibrator, Brüel & Kjær Type 4231.

Normally the calibration level, P_{4231} produced by Sound Level Calibrator Type 4231 mounted on a 1/2″ microphone is 94 dB SPL. If an extra volume is added, caused for instance by the presence of a coupler unit or an adapter used for the calibration, the sound pressure produced by the calibrator will be affected.

In addition, the required measurement conditions will influence the calibration. When using the calibrator, the ear simulator is exposed to closed ear conditions. When calibrating, the sensitivity according to closed ear conditions is therefore found. As it is the open ear sensitivity which is of interest, the calibration data must be transformed to refer to this situation.

The required sensitivities therefore can be found if the calibration level of the sound level calibrator is corrected. The calibration level must be corrected by a factor $P_{\Delta V}$ caused by any added volume and, furthermore, to obtain the open ear sensitivity by a factor $P_{\Delta(open\text{-}closed)}$ to take into account the change in sensitivity when going from closed ear to open ear conditions.

The corrected calibration level to obtain the open ear sensitivity is then given by

$$P_{4231,\ \mathrm{corrected}}(\text{open ear}) = P_{4231} + P_{\Delta V} + P_{\Delta(\text{open-closed})}$$

and the corrected level to obtain the closed ear sensitivity by

$$P_{4231,\ \mathrm{corrected}}(\text{closed ear}) = P_{4231} + P_{\Delta V)}$$

The practical calibration procedures and the corresponding corrected calibration levels are described in the following.

Type 1 Ear Simulator

The absolute sensitivity at 1 kHz in [V/Pa] of Type 4185 as stated on the calibration chart is verified by applying the calibrator to the 1/2″ microphone of the coupler (after dismantling the microphone from the coupler). By using the corrected calibration levels as given in Table 2, the open or closed ear sensitivity of the (assembled) ear simulator is obtained.

Type 3.2 Ear Simulator

The absolute sensitivities at 1 kHz in [V/Pa] of Type 4195 as stated on the calibration charts are verified by means of adapter DP 0939 which is mounted in the calibrator and applied to the ear simulator. The calibration levels to obtain the open and closed ear sensitivities are given in Table 2.

Calibration Chart for
Ear Simulator Type 4185

Brüel & Kjær
DK-2850 Nærum
Denmark

Serial No.: 2007974 Calibrated with Preamplifier Type 2669: 2003374

Acoustical Impedance

The curve shows the modulus of the acoustical input impedance at the Ear Reference Point (ERP), in dB relative to 1 Pa·s/m³ (20·log [Z/(1Pa·s/m³)]).

Frequency Sensitivity Response

The curve shows the modulus of the ratio of output voltage of Type 4185 to input sound pressure at the ERP measured under two different load conditions. The full-drawn line shows the Open Ear Frequency Sensitivity Response and the dotted line the Closed Ear Frequency Sensitivity Response. The results are displayed in dB normalised to 0.0 dB at 1 kHz.

Absolute Sensitivity at 1 kHz:

Open Ear Sensitivity 1 kHz	***-38.4*** dB re 1 V/Pa
Equivalent to:	***12.1*** mV/Pa
Closed Ear Sensitivity 1 kHz	***-37.9*** dB re 1 V/Pa
Equivalent to:	***12.8*** mV/Pa
Uncertainty, 95 % confidence level:	***0.2*** dB

Traceable to: DPLA – Danish Primary Laboratories of Acoustics
NIST – National Institute of Standards and Technology, USA

Sound Pressure Level of built-in sound source:

SPL in closed coupler for 3.16 V 315 Hz at input terminals .... 96.0 dB SPL

Sensitivity Calibration using Sound Level Calibrator Type 4231:

Calibration output level from Calibrator Type 4231 to obtain
Open Ear Sensitivity at 1 kHz .... 93.8 dB

Calibration output level from Calibrator Type 4231 to obtain
Closed Ear Sensitivity at 1 kHz .... 93.3 dB

Measurements

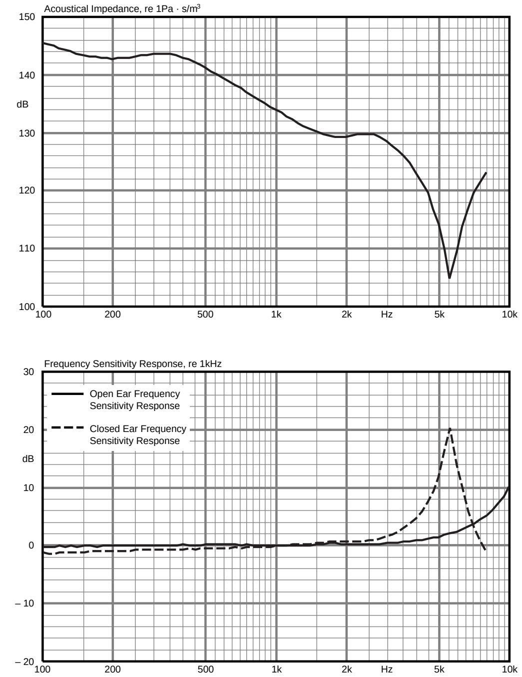
The Acoustical Impedance and Closed Ear Frequency Sensitivity Response measurements are performed using an impedance probe attached concentrically to the Soft Seal of the Ear Simulator Type 4185 – see fig. 1. A 1/2″ microphone acts as a high acoustical-impedance constant volume-velocity source and Probe Microphone Type 4182 measures the input sound pressure to the concha volume at the ERP. The Open Ear Frequency Sensitivity Response is measured mounting the Ear Simulator Type 4185 in a large plane baffle exposing the artificial ear to a plane incident wave perpendicular to the baffle – see fig. 2. A Probe Microphone Type 4182 is used to measure the input sound pressure to the concha volume at the ERP. Brüel & Kjær Mouth Simulator Type 4227 is used as sound source. All calibration data is also available on the disk BC 5003.

Environmental Calibration Conditions:

Static Pressure:	101.3 ± 3.0kPa
Temperature:	23 ± 3° C
Relative Humidity:	60 ± 20%

Procedure: 704665 **Ver:** 11
Date: 17. June 1997 **Signature:** ....

BC 0254–11



970333e

Ear Simulator Type 4185

Serial No.: 2007974

Fig.8 Calibration Chart of a Type 1 ear simulator

Calibration Chart for Wideband
Ear Simulator Type 4195 low-leak

Brüel & Kjær
DK-2850 Nærum
Denmark

Serial No.: 1833037 Calibrated with Preamplifier Type 2669: 1948864

Acoustical Impedance

The curve shows the modulus of the acoustical input impedance at the Ear Reference Point (ERP), in dB relative to 1 Pa·s/m³ (20·log [Z/(1Pa·s/m³)]).

Frequency Sensitivity Response

The curves show the modulus of the ratio of output voltage of Type 4195 low-leak to input sound pressure at the ERP measured under two different load conditions. The full-drawn line shows the Open Ear Frequency Sensitivity Response and the dotted line the Closed Ear Frequency Sensitivity Response. The results are displayed in dB normalised to 0.0 dB at 1 kHz.

Absolute Sensitivity at 1 kHz:

Open Ear Sensitivity 1 kHz	***-37.7*** dB re 1 V/Pa
Equivalent to:	***13.1*** mV/Pa
Closed Ear Sensitivity 1 kHz	***-37.5*** dB re 1 V/Pa
Equivalent to:	***13.3*** mV/Pa
Uncertainty, 95 % confidence level:	***0.2*** dB

Traceable to: DPLA – Danish Primary Laboratories of Acoustics
NIST – National Institute of Standards and Technology, USA

Sensitivity Calibration using Sound Level Calibrator Type 4231:

Calibration output level from Calibrator Type 4231 with Adapter DP 0939
to obtain Open Ear Sensitivity at 1 kHz .... 98.2 dB

Calibration output level from Calibrator Type 4231 with Adapter DP 0939
to obtain Closed Ear Sensitivity at 1 kHz .... 98.0 dB

Measurements

The Acoustical Impedance and Closed Ear Frequency Sensitivity Response measurements are performed using an impedance probe attached concentrically to the Soft Seal of the Wideband Ear Simulator Type 4195 – see fig. 1. A 1/2″ microphone acts as a high acoustical-impedance constant volume-velocity source and Probe Microphone Type 4182 measures the input sound pressure to the concha volume at the ERP. The Open Ear Frequency Sensitivity Response is measured by mounting the Wideband Ear Simulator Type 4195 in a large plane baffle exposing the artificial ear to a plane incident wave perpendicular to the baffle – see fig. 2. A Probe Microphone Type 4182 is used to measure the input sound pressure to the concha volume at the ERP. The Brüel & Kjær Mouth Simulator Type 4227 is used as sound source.

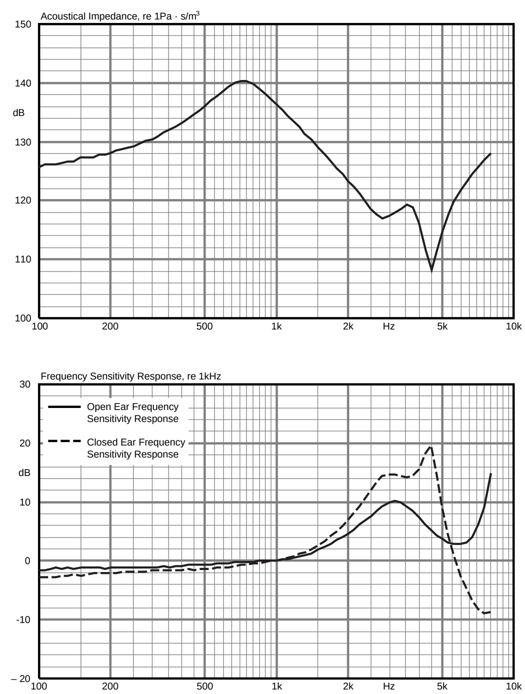
All calibration data is also available on the disk BC 5001.

Environmental Calibration Conditions

Static Pressure:	101.3 ± 3.0 kPa
Temperature:	23 ± 3° C
Relative Humidity:	60 ± 20%

Procedure: 704195 **Ver:** 13
Date: 17. June 1997 **Signature:** ....

BC 0238–11



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Wideband Ear Simulator Type 4195 low-leak

Serial No.: 1833037

Fig.9 Calibration Chart of a Type 3.2 (low-leak) ear simulator

Calibration Chart for Wideband Ear Simulator Type 4195 high-leak

Brüel & Kjær
DK-2850 Nærum
Denmark

Serial No.: 1833037 Calibrated with Preamplifier Type 2669: 1948864

Acoustical Impedance

The curve shows the modulus of the acoustical input impedance at the Ear Reference Point (ERP), in dB relative to 1 Pa·s/m³ (20·log [Z/(1Pa·s/m³)]).

Frequency Sensitivity Response

The curves show the modulus of the ratio of output voltage of Type 4195 high-leak to input sound pressure at the ERP measured under two different load conditions. The full-drawn line shows the Open Ear Frequency Sensitivity Response and the dotted line the Closed Ear Frequency Sensitivity Response. The results are displayed in dB normalised to 0.0 dB at 1 kHz.

Absolute Sensitivity at 1 kHz:

Open Ear Sensitivity 1 kHz	***-37.7*** dB re 1 V/Pa
Equivalent to:	***13.1*** mV/Pa
Closed Ear Sensitivity 1 kHz	***-36.6*** dB re 1 V/Pa
Equivalent to:	***11.2*** mV/Pa
Uncertainty, 95 % confidence level:	***0.2*** dB

Traceable to: DPLA – Danish Primary Laboratories of Acoustics
NIST – National Institute of Standards and Technology, USA

Sensitivity Calibration using Sound Level Calibrator Type 4231:

Calibration output level from Calibrator Type 4231 with Adapter DP 0939 to obtain Open Ear Sensitivity at 1 kHz .... 84.7 dB

Calibration output level from Calibrator Type 4231 with Adapter DP 0939 to obtain Closed Ear Sensitivity at 1 kHz .... 85.4 dB

Measurements

The Acoustical Impedance and Closed Ear Frequency Sensitivity Response measurements are performed using an impedance probe attached concentrically to the Soft Seal of the Wideband Ear Simulator Type 4195 – see fig. 1. A 1/2″ microphone acts as a high acoustical-impedance constant volume-velocity source and Probe Microphone Type 4182 measures the input sound pressure to the concha volume at the ERP. The Open Ear Frequency Sensitivity Response is measured by mounting the Wideband Ear Simulator Type 4195 in a large plane baffle exposing the artificial ear to a plane incident wave perpendicular to the baffle – see fig. 2. A Probe Microphone Type 4182 is used to measure the input sound pressure to the concha volume at the ERP. The Brüel & Kjær Mouth Simulator Type 4227 is used as sound source.

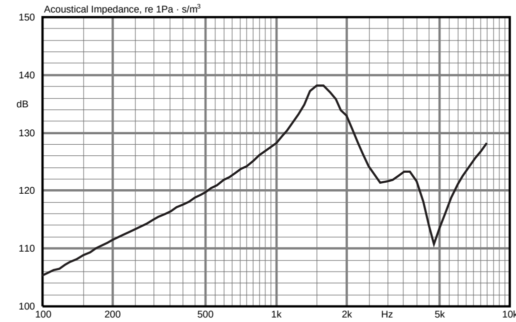
All calibration data is also available on the disk BC 5001.

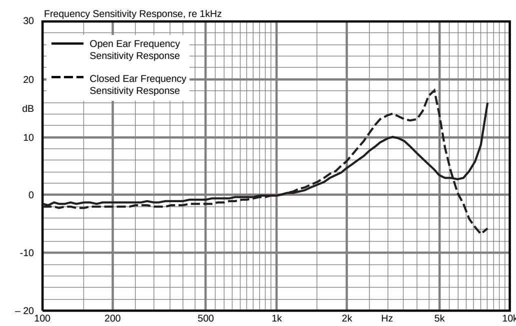
Environmental Calibration Conditions

Static Pressure:	101.3 ± 3.0 kPa
Temperature:	23 ± 3° C
Relative Humidity:	60 ± 20%

Procedure: 704195 **Ver:** 13
Date: 17. June 1997 **Signature:** ....

BC 0255–11





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Wideband Ear Simulator Type 4195 high-leak **Serial No.: 1833037**

Fig.10 Calibration Chart of a Type 3.2 (high-leak) ear simulator

Brüel & Kjær

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