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Calibration Handbook

Interacoustics

Audiometry Tympanometry ABR OAE Hearing Aid Fitting Balance

1 - Preface

The intention of this document is to provide an explanation of the calibration procedure, which is a part of periodical service procedures of audiological equipment. This document is intended for new technicians and any other who may be interested.

Audiological equipment and related accessories should be handled with great care. This is to get accurate, consistent and comparable test results. Despite of proper care, the mechanical and electrical properties of the equipment are slightly altered with regular use.

It is therefore necessary to periodically service audiological equipment, where the electrical and mechanical properties are checked by a skilled technician, who also makes judgments concerning possible exchange of vital parts, such as cords and headsets, in order to avoid defects in the period up to the next service visit.

The recommended periodical service interval is one year or less for equipment in daily use. However, this is subject to local regulations as the standards only dictate how accurate the audiological equipment must be.

The description of the calibration procedure in audiometers is based on pure tone calibration. After this, calibration of speech, noise and free field are described. Tympanometer calibration and short duration signal (ABR/OAE) calibration are described in separate chapters.

Finally, there is a chapter with inspiration and guidelines on how to perform a scheduled calibration visit, in terms of which service should or could be performed.

The document describes the flow in a calibration situation. Both when it comes to the order of the calibration visit's tasks and in the difficulty of the calibration. Consequently, it can be read from beginning to end to provide a good overview. Hereafter, it can work as reference.

Table of contents:

2 - General description of an audiometer

The basic audiometer produces sine tones of fixed frequencies, which are presented to the patient using authorized transducers (headset). The output of the transducers can be controlled by a calibrated attenuator in the audiometer, and the tone can be interrupted or presented without introducing any switch noise. More advanced audiometers can also generate speech stimuli and noise stimuli in various standards. Any stimuli used in audiometers should be calibrated.

The international standards IEC 645-1, IEC 645-2, IEC 645-3 and IEC 645-4 specify the minimum demands for different kinds of audiometers.

3 - Sound, sound pressure level, and hearing level

In physics, sound is defined as a wave of local pressure changes. It is characterized by a frequency and an amplitude. When it comes to hearing, we talk about what is received by the ear and hearing organ (reception), and what is perceived by the brain (perception).

The aim with audiometry is to measure the sound perception; often in terms of hearing level or hearing loss (HL), by presenting sounds of known intensity.

3.1 - Sound pressure level

When we measure sound with a sound level meter, we get the sound pressure level (SPL) in decibel (dB). Decibel is a logarithmic unit, which means that 0 dB is not "no sound", but a defined reference level from which all other levels can be calculated based on actual sound pressure by using this formula:

$$SPL = 20 * \log \frac{actual\ pressure\ in\ Pa}{20 * 10^{-6}\ Pa}$$

where $20 * 10^{-6}$ Pa or expressed as 20 µPa is the reference level. The reference level is defined as the hearing threshold at 1000 Hz for a "normal hearing person". This means that it is expected that a "normal hearing person" can hear a sound of 0 dB at 1000 Hz. As a curiosity, it can be mentioned that 1 Pa pressure equals 94 dB, which is known from the acoustical calibrator.

3.2 - Hearing level

When we do hearing tests, we want a result that is easy to interpret. But humans do not perceive all frequencies equally well, so SPL is not a good choice to measure the hearing level. Figure 1 describes reference thresholds for hearing of pure tones in free field. This is also referred to as the 'hearing curve' and shows the sound pressure levels that is required for a "normal hearing person" to hear the tone, as a function of frequency.

As it can be seen in Figure 1, the higher and lower frequencies are not as well perceived as the mid frequencies (500-4000 Hz).

Instead of this curve, we want a curve that indicates a flat 0 dB hearing loss (HL) at all frequencies for a "normal hearing person". This can be seen in Figure 2, which also illustrates the HL level for the different severities of hearing loss.

To change the hearing curve into the flat audiogram, we use the 'HL to SPL corrections', and behind every HL level there is a certain SPL level. The difference between HL and SPL depends on the presented stimulus type and frequency, the headset that we use, and the coupler in which we measure the sound. The way we handle these corrections is described in detail in section 6.1.2 on page 14.

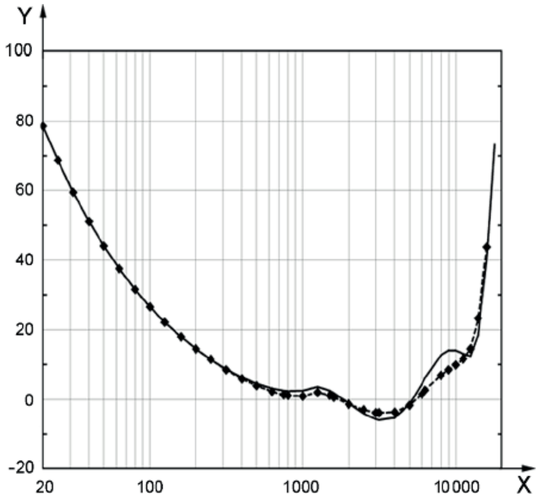

Figure 1 Reference thresholds for hearing of pure tones in free-field listening conditions (X: Frequency; Y: sound pressure level, dB; full line: free field; dotted line: diffuse field [1]).

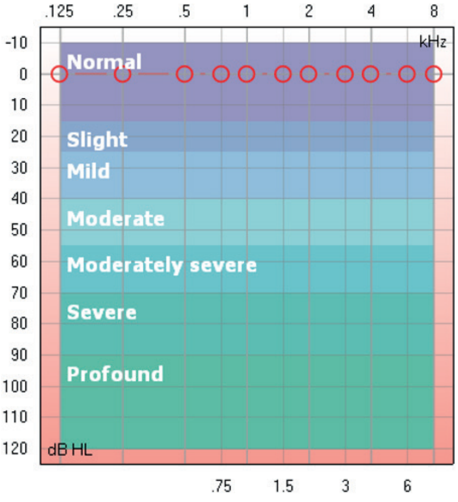

Figure 2 Audiogram for the "normal hearing person".

4 - Audiological stimuli

When it comes to calibration of an audiometer, it is important to know that we are adjusting the audiometer to give the correct output with its designated transducers. Both the sensitivity (voltage required over a transducer in order to give a certain acoustical output in dB) and the frequency response (variation in sensitivity across frequencies) vary between transducers. Because of this variation, we must adjust the audiometer to present the correct sound level with the transducers that are used. If a transducer is replaced, the calibration must be performed again.

It is important to ensure that all stimuli and frequencies are calibrated for all transducers (left/right) before performing tests on patients. Available stimulus types depend on the audiometer. The most common are listed here:

- Pure tone stimuli (all frequencies are calibrated individually)
- Narrow band stimuli (all frequencies are calibrated individually)
- Speech and speech noise
- Miscellaneous broadband noise signals (white noise, pink noise)
- Miscellaneous special stimuli

As mentioned above, some of the stimulus types are presented with different frequencies (e.g. pure tone audiometry presents 11 standard frequencies from 125-8000 Hz) and should be calibrated individually for each frequency.

5 - Calibration equipment setup

The main parts of a calibration setup are shown below:

- **Audiometer and transducer chosen to calibrate**

- **Acoustic coupler or artificial ear/ear simulator** (with the known 'HL to SPL correction' values for the calibrated transducer/headset)

- **Microphone** (with known frequency response that fits the above-mentioned coupler)

- **Sound level meter**

A typical calibration setup can be seen in Figure 3, and the individual parts will be described in section 5.2.

5.1 -Acoustical coupler and artificial ear/ear simulator

There are two types of couplers available which can be used for calibration:

- **Acoustical couplers** are constructions that in size and shape act as simulators of the human ear. They are shaped to fit the transducer they are used for, and are of a size such that the cavity the sound is presented to is similar to the cavity between the ear and transducer when the transducer is used on persons (e.g. 2cc and 6cc coupler).

- **Artificial ear/ear simulators** are two terms for the same thing. In addition to the characteristics of the couplers, artificial ear/ear simulators are produced in a way that their acoustical response (frequency response) is close to that of a human ear. This is usually achieved by making a coupler with several chambers that are connected via small channels (e.g. artificial ear for HF calibration and 711 coupler).

In the remaining part of this document, 'coupler' will be used and refers to either one of both above-mentioned, unless when it is a specific artificial ear/ear simulator that is referred to.

5.2 - Couplers and transducers

The coupler should match with the transducer that is intended for calibration. There are four types of transducers which are commonly used: supra-aural headphones, circum-aural headphones, insert headsets and bone conductors. More details on couplers and transducers are shown in Table 1 (presents the standard version numbers for the couplers and the 'HL to SPL corrections' for the different combinations of coupler and transducer). Sections 5.2.1 to 5.2.4 describe how the different types of transducers are calibrated, and section 6.1.2 describes how the 'HL to SPL corrections' are used in order to calculate the correct target level.

Figure 3 Typical setup for calibration equipment (transducer from audiometer is placed over coupler with microphone connected to sound level meter).

	6cc coupler IEC 60318-3	**Ear simulator** IEC 60318-1	**Flatplate** IEC 60318-1	**2cc** IEC 60318-1	**711 coupler**	**Artificial mastoid** IEC 60318-6
TDH39	ISO 389-1 ANSI S3.6	ISO 389-1 ANSI S3.6				
DD45	WDH corrections [2]	WDH corrections [2]				
HDA200/DD450			ISO 389-5 ANSI S3.6			
HDA300			Sennheiser Document [3]			
Inserts AUD				ISO 389-2		
Inserts ABR					IA std.	
B71/B81						ISO 389-3 ANSI S3.6

Table 1 Overview of suitable couplers for various transducers.

5.2.1 Couplers for supra-aural transducers

Supra-aural headsets include TDH39 and DD45. Further to this, TDH39 and DD45 can be placed in Amplivox Audiocups or Peltor noise excluders. These transducers must be calibrated on a coupler that fits the rubber cushion. This will either be the 6cc coupler seen in Figure 4 or the artificial ear seen in Figure 5.

The 6cc coupler is generally preferred for calibration of supra-aural headsets. For many SPL calibrated audiometers (see section 6.2), it is also the only one that is integrated in the software or firmware. If the artificial ear is used, the correct standard must be applied when the target levels are calculated.

If the TDH39 or DD45 transducer is placed in a noise excluder (Amplivox Audiocups or Peltor), it must be taken out of this and be calibrated directly on the coupler with its rubber cushion, and then re-fitted after calibration.

A variation of the supra-aural transducer in Peltor noise excluders is called DD65. Physically, DD65 is the same as a DD45 in Peltor noise excluders, and is still calibrated without the Peltors as seen on Figure 3, but it is calibrated with another set of 'HL to SPL corrections'. This is to adjust for the lower perception that is a result of the distance from the patient's ear to the transducer in the noise excluder. As such, audiograms made with a DD65 calibrated headset are closer to DD45/TDH39 audiograms without noise excluders than audiograms with normally calibrated DD45/TDH39 transducers placed in a noise excluder.

Figure 4 6cc couplers from G.R.A.S and B&K.

Figure 5 Artificial ear from G.R.A.S.

5.2.2 Couplers for circum-aural transducers

Circum-aural headsets include Sennheiser HDA200/HDA300, RadioEar DD450 and Koss R80. The term circum-aural covers that these headsets have cushions that surround the ear and rest on the head. Common to these headsets are also that they can be used for High Frequency audiometry (HF). Koss R80 can only be used for HF, whereas all the other above-mentioned headsets can be used for the complete frequency range.

The coupler that should be used for calibration of circum-aural headsets is the artificial ear in Figure 5 with a flat plate adapter as shown in Figure 6. The flat plate adapter helps to simulate conditions where the headset is placed over and around a patient's ear. HDA300 is very sensitive in regards to positioning on the flat plate adapter. Therefore, the centering adapter (Figure 7) is required.

Below, in Figures 8 and 9, the calibration setups for circum-aural transducers are shown. Note that the force is adjusted by the headband as the distance between the two cushions must be 14.5 cm; which is the diameter of a "standard head".

It should be noted that DD65 and DD45/TDH39 in Peltor noise excluders–even though they look like HDA200–cannot be calibrated on the flat plate adapter, but must be calibrated on the 6cc coupler or directly on the artificial ear as described in section 5.2.1.

DD65 version 2 can be calibrated on the artificial ear and flat plate adapter if the correct (version 2) 'HL to SPL corrections' are used.

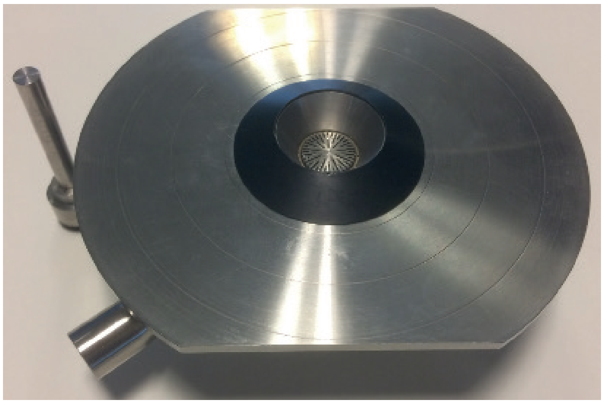

Figure 6 Artificial ear with flat plate adapter.

Figure 7 Centering adapter for HDA300

Figure 8 Calibration setup for Sennheiser HDA200 and Radioear DD450.

Figure 9 Calibration setup for Sennheiser HDA300 including mandatory centering adapter.

5.2.3 Couplers for insert headsets and tympanometer- and OAE probes

Insert headsets include IP30 and EARtone 3a/5a (both in 10Ω version for audiometry and 50Ω version for ABR), and CIR33/55, and these shall be calibrated in couplers that simulate an ear canal. This can either be 2cc couplers (as shown in Figure 10, or in the ear simulator as shown in Figure 11; which is most often referred to as the 711-coupler despite that it actually is an ear simulator).

Most insert headsets for audiometers and ABR are used with a foam ear tip that is attached either directly to the transducer or to a tube. For these headsets, a tube adapter must be used.

For tympanometers and many OAE probes, we use a single-use soft plastic ear tip for the clinical examination. When these transducers are calibrated, an ear tip adapter must be used. The ear tip adapter for the 711-coupler is mounted on the coupler, as in Figure 11, and must always be used with a small ear tip that can be fully inserted into the adapter. As such, it is ensured that we measure in the coupler and not in the adapter.

For tympanometers, the ear tip is mounted as an integrated part of the coupler lid as shown in Figure 12 for B&K and G.R.A.S. 2cc couplers, respectively.

Figure 10 2cc couplers. Ear mold substitute with tube adapter mounted on the coupler to the left.

Figure 11 Ear simulator – often referred to as 711-coupler. Ear tip adapter is mounted; separate part is ear mold substitute with tube adapter.

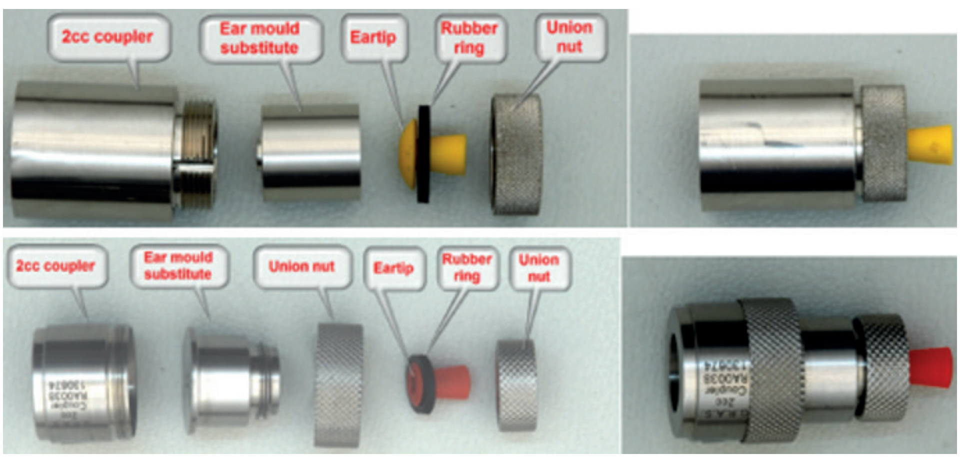

Figure 12 Placement of ear tip in B&K and G.R.A.S. 2cc couplers, respectively.

Below, the calibration setups for insert headsets and probes are shown.

Figure 13 Calibration setup for insert headset on 2cc coupler with tube adapter.

Figure 14 Calibration setup for CIR 22/33 on 2cc coupler with ear tip. Same setup is used for tympanometer probes.

5.2.4 Couplers for bone conductors

The most used bone conductors are B71(W) and B81. There are different ways these can be calibrated, but this section will only describe the gold standard, which is with the artificial mastoid Brüel & Kjær -4930-. Figure 15 shows an artificial mastoid with a correctly placed bone conductor.

As for couplers, the artificial mastoid simulates the user scenario by having a weight that is the same as a "standard head". The force on the bone conductor must be 550 grams (5.4 N), which is the same force with which the headband presses the bone conductor against the patient's head.

The correction standard for the artificial mastoid is based on a sound level meter set up to use a standard 1" microphone, meaning that the sensitivity is set to 50 mV/Pa (see Figure 20).

Figure 15 Brüel & Kjær -4930- artificial mastoid.

5.3 Microphone

There is a microphone in the coupler. All couplers described in this document are designed to be used with either a ½" or a 1" microphone. There are adapters that enable the use of other microphone sizes. For example, there is an adapter that makes it possible to use a 6cc coupler with a ½" microphone instead of the initially intended 1" microphone. However, it is recommended to use the intended microphones rather than adapters to avoid loose connections, and to attain a simple and stable setup. The microphone's influence on target level calculation is described in section 6.1.3.

5.3.1 Sound level meter

The sound level meter is connected to the microphone or artificial mastoid via a pre-amplifier. It measures the voltage from the microphone and converts it to a dB-level. An essential step is to set up the sensitivity in the sound level meter to match the microphone. The standard sensitivity level for a ½" microphone is 12.5 mV/Pa. The standard sensitivity level for a 1" microphone and the artificial mastoid (B&K -4930-) is 50 mV/Pa. For microphones, the 94 dB calibrator is used for the final adjustment, which brings an accuracy level of ±0.1 dB.

There is no final adjustment made for the artificial mastoid, because there does not exist a tool for it. Therefore, the calibration chart is made with a sensitivity similar to the standard 1" microphone as a prerequisite, i.e. the corrections are correct if the microphone sensitivity is set to 50 mV/Pa. The accuracy of the artificial mastoid can be tested with a new out-of-the-box factory-calibrated audiometer if this is available. It can be assumed that at new device is correctly calibrated, and hence the accuracy of the artificial mastoid is verified if no, or only small, adjustments are necessary.

The sensitivity of the microphone can be set up in different ways depending on which sound level meter is used. In some sound level meters (e.g. Norsonic Nor140 and Larson Davis System 824), the sensitivity is adjusted in a calibration mode where the sound level is adjusted to 94 dB with the calibrator applied to the microphone. This must be done every time the microphone is changed. In other sound level meters (e.g. Brüel & Kjær 2250), each microphone has its own profile, and when the profiles that match the used microphone have been selected, the measured sound level will be very close to 94 dB when using the calibrator. Final fine tuning can be done in the sound level meter's calibration menu. Figure 16 to Figure 20 show the necessary microphone setups for Brüel & Kjær 2250.

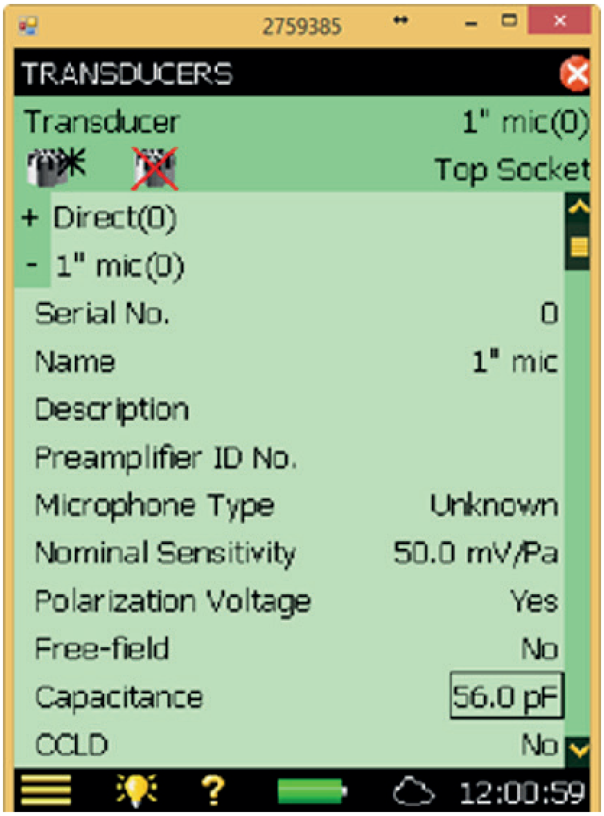

Figure 16 B&K 2250 setup for 1" microphone.

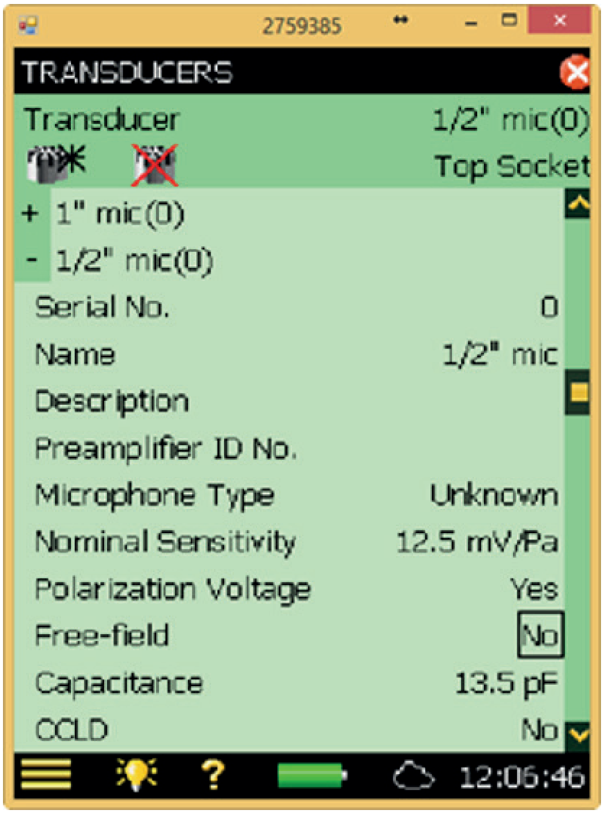

Figure 17 B&K 2250 setup for ½" microphone.

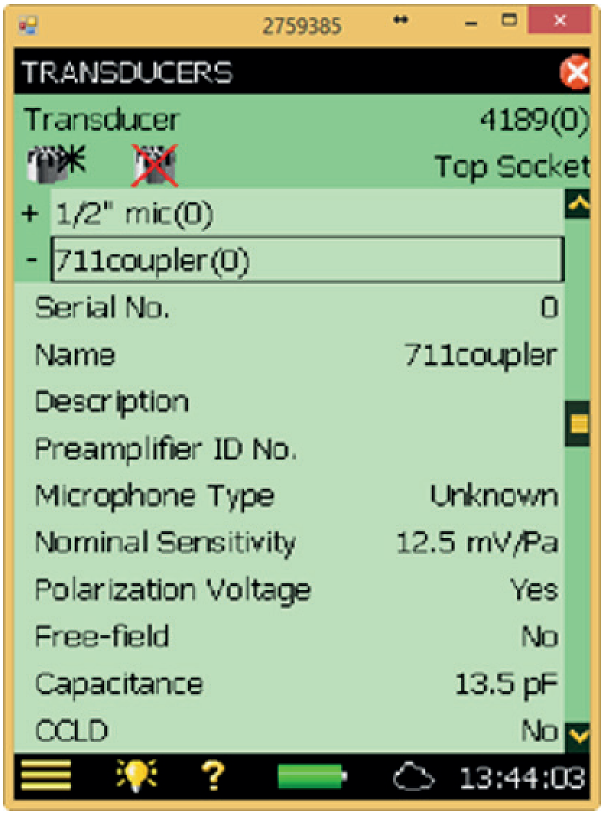

Figure 18 B&K 2250 setup for 711 coupler.

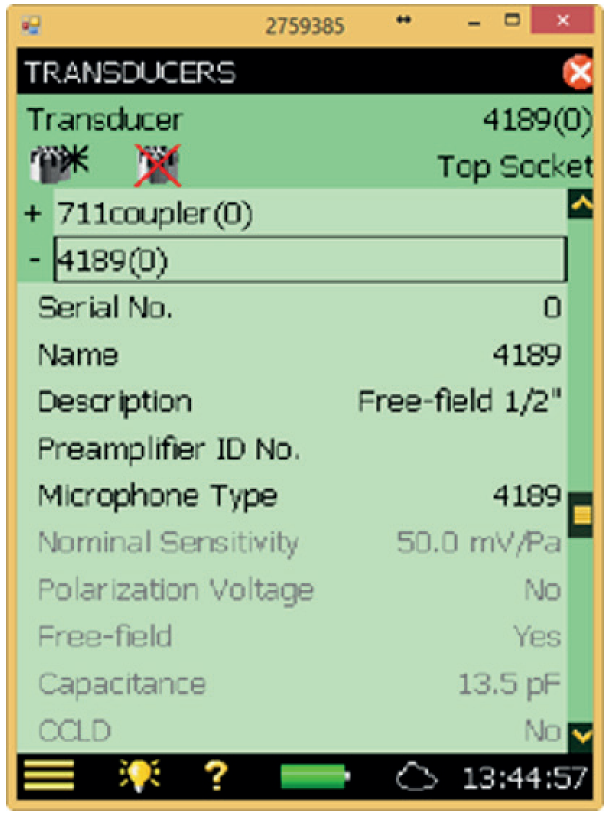

Figure 19 B&K 2250 setup for free field microphone.

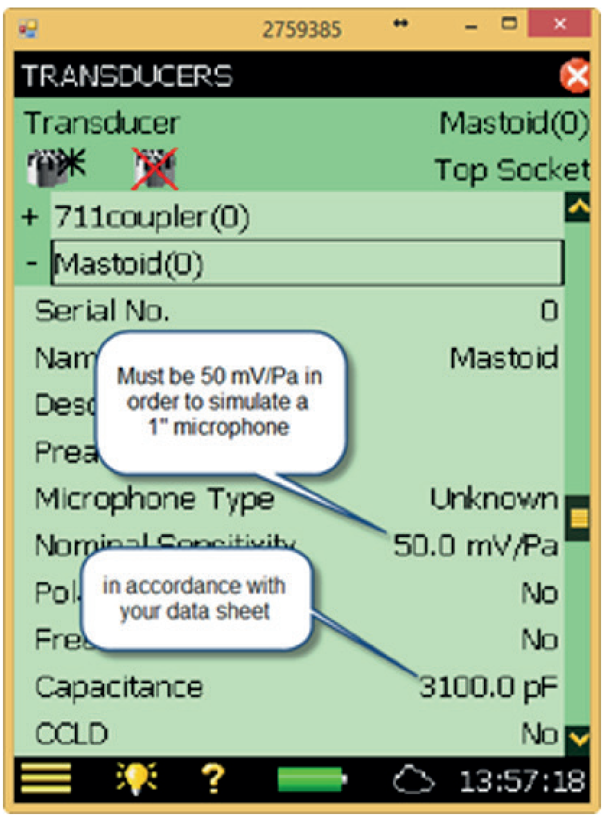

Figure 20 B&K 2250 setup for artificial mastoid.

Regardless of the sound level meter's setup, it is crucial to measure the sound level with the calibrator and verify that the equipment is assembled correctly, and that the sound level meter reads the value from the calibrator.

5.3.2 Weighting and filters

When the sound signal is measured, it may be subject to weighting and use of filters before the dB level is calculated. Weighting is a procedure where the intensity of different frequencies is weighted differently according to a specified protocol. Typical weightings are A, B, C and Z. The difference between these are not relevant here, as Z-weighting is always used for calibration of audiological equipment. In Z-weighting no weighting is done, so all frequencies count with full weight.

In principle, all calibration measurements can be performed in broadband mode, but in case of noise, which typically is low frequency noise from the surroundings, it may be necessary to apply a filter. In most sound level meters, 1/3 octave and 1/1 octave filters are available. The important thing is that the filter is broader than the signal we are measuring. More details about signals and filters are not necessary here, as this can be reduced to the following rules:

- Pure tones can be calibrated in broadband or with 1/3 octave and 1/1 octave filters

- Narrowband can be calibrated with broadband or 1/1 octave filter

- Noise signals must be calibrated in broadband

6 - Target level calculation

When all the calibration equipment has been set up, it is important to test the system with a calibrator (typically a 94 dB calibrator). When it is confirmed that the sound level meter gives the same value as the calibrator, we know that the equipment is assembled correctly, and that the sound level meter is set up correctly. If this is not the case, the connections and the sound level meter setup must be checked, and the check with the calibrator must be performed again.

An audiometer can be calibrated in different ways. Some are calibrated in stand-alone mode and some with a PC; and in both ways, there are many different procedures. As described in section 5.3.1, there are also several different sound level meters on the market with different setups. But regardless of this, calibration is always a question of:

1. Determining the target level; i.e. what shall the sound level meter display (described in section 6.1).

2. Adjusting the audiometer so that the target level is shown on the sound level meter.

As mentioned earlier, this procedure must be performed for each stimulus.

6.1 Calibration equation

When calibrating a stimulus, the sound pressure level (SPL) that the sound level meter (SLM) shall display (target level) must be calculated. For this, the following equation can be used:

$$SLM_{reading} = Attenuator + Standard\ Correction + Microphone\ Correction$$

or abbreviated:

$$SLM = ATT + STD + MIC$$

As written in the equation, the sound level meter shall always display the sum of the attenuator, the standard correction, and the microphone correction. These are individually described in the following.

6.1.1 Attenuator

The attenuator level is set by the audiometer and will in most devices be shown in the display panel of the audiometer (stand-alone calibrated devices) or in the PC-software (PC calibrated devices). However, for some older and simple devices, it may be necessary to consult the service manual in order to know the attenuator levels and calculate the target level.

The purpose of the attenuator is to increase the loudness of the presented stimulus to a sound pressure level sufficiently louder than the ambient noise so that it can be measured with the sound level meter. For instance, the "normal hearing person" can hear 2.4 dB SPL at 1000 Hz [1]; and with an ambient noise of typically 35-60 dB, that cannot be measured. The attenuator is usually set to a level so that the target level according to the calibration equation sums up to 80-100 dB SPL.

The attenuator can be considered as an HL level.

6.1.2 Standard correction

The next step in calculating the target level for a specific stimulus is to find the standard correction value, also referred to as 'HL to SPL correction'. This is found in the calibration standards for the used headset/coupler combination. Selected values are presented in Table 2. These tables can also be found in the audiometers' service manuals, and it should be emphasized that it is the transducer and coupler that give a standard; hence it is not relevant which audiometer is used.

The numbers given in the standards express the sound pressure level that is measured on the sound level meter for the specific transducer/coupler combination when the "normal hearing person" can just hear the stimulus. In other words, it is the difference between the measured sound level and 0 dB hearing level; hence it is referred to as the 'HL to SPL correction'.

Standard	ISO 389-1	ANSI S3.6	ISO 389-4 (NB - masking)	ISO 389-3	ANSI S3.6	ISO 389-2	ISO 389-7
Transducer	**TDH39**	**TDH39**		**B71**	**B71**	**Inserts**	**Free Field**
Coupler	**6cc - IEC 60318-3**	**6cc - IEC 60318-3**	**2cc - IEC 60318-5**	**IEC 60318-6**	**IEC 60318-6**	**2cc - IEC 60318-5**	**IEC 60318-6**
[Hz]	[dB re. 20 µPa]	[dB re. 20 µPa]	[dB re. 20 µPa]	[dB re. 1µN]	[dB re. 1µN]	[dB re. 20 µPa]	[dB re. 20 µPa]
125	45	45	4			26	22.0
250	25.5	25.5	4	67	67	14	11.0
500	11.5	11.5	4	58	58	5.5	4.0
750	7.5	8	5	48.5	48.5	2	2.0
1000	7	7	6	42.5	42.5	0	2.0
1500	6.5	6.5	6	36.5	36.5	2	0.5
2000	9	9	6	31	31	3	-1.5
3000	10	10	6	30	30	3.5	-6.0
4000	9.5	9.5	5	35.5	35.5	5.5	-6.5
6000	15.5	15.5	5	40		2	2.5
8000	13	13	5	40		0	11.5

Table 2 Standard corrections for pure tone audiometer calibration.

6.1.3 Microphone correction

The last term in the calibration equation is microphone correction. When the microphone profile is set up in the sound level meter, the calibration level is verified to be 94 dB at 1000 Hz. However, the sensitivity (mV output per Pa pressure on the microphone) varies with frequency as shown in Figure 21, and we must correct for this.

If the microphone's output is higher than the 1000 Hz reference level, the sound level meter will measure more than the actual sound pressure level on the microphone. Therefore, the target level must be higher and vice versa. In short, the values read from Figure 21 must be added in the calibration equation with operational signs.

6.1.4 Artificial mastoid correction

This section about artificial mastoid correction is reduced to deal with Brüel & Kjær -4930-. This artificial mastoid is described in section 5.2.4 on page 11.

When we calibrate bone conductors, the acoustical coupler and microphone are replaced with an artificial mastoid. It is mentioned in section 6.1.2 that standard corrections always concern the transducer and the coupler, and as the artificial mastoid replaces both the coupler and the microphone, it has to be considered in both the standard correction term and the microphone term of the calibration equation.

Regarding the standard correction term, the values are taken from the relevant table. The standard corrections for the B71 bone conductor on the Brüel & Kjær -4930- artificial mastoid are presented in Table 2. This table look-up is not different from what we do when we calibrate a headset; however, the values may appear higher when considered as a sound level. This should not cause confusion as it is a consequence of the conversion from the mechanical vibration force to electrical signals. As such, it should not be considered as real hearing levels.

Regarding the microphone correction term, we replace MIC in the calibration equation with mastoid correction (MAS).

The mastoid correction consists of two parts including a device-related correction (that converts a mechanical force level into an electrical signal), and frequency-dependent correction. The key to the device-related (force to voltage) correction ($Corr_{FS}$) is the 'Force Sensitivity' and is given on the calibration chart for the specific artificial mastoid. An example is shown in Figure 22.

The force sensitivity is given in mV/N and can be converted to dB (ref. 1V/1N) using this formula:

$$Corr_{FS} = 20 * \log(\text{force sensitivity [V]})$$

For the artificial mastoid in Figure 22,
$Corr_{FS}$ is calculated as:

$$Corr_{FS} = 20 * \log(0.130\ V) = -17.7\ dB$$

Note that the force sensitivity is entered in V, and that the result will be negative. When the force sensitivity correction has been calculated and the frequency-dependent correction has been found from the frequency response curve, the MAS that substitutes MIC can be calculated for each individual frequency:

$$MAS = Corr_{FS} + Corr_{freq}$$

Example: The graph indicates that $Corr_{freq}$ at 4000 Hz is -6 dB. Hence, the total mastoid correction will be
MAS = -17.7 dB + (-6 dB) = -23.3 dB.

It is recommended to make a table for each individual artificial mastoid with the total corrections for all frequencies.

MAS will always be negative, and the target levels will be smaller than what we are used to seeing in headset calibration. However, this is not a problem because the artificial mastoid is a closed mechanical system, and hence not as sensitive to ambient noise as the acoustical couplers are.

6.2 SPL- and HL-calibration – PC calibration and stand-alone calibration

The target level calculation and the amount of information built into the system varies from device to device. SPL-calibrated audiometers can both be PC-calibrated and stand-alone devices. In practice, HL-calibrated audiometers are the older devices that are calibrated in stand-alone mode; this is illustrated in Table 3.

It is important to remember that the sound level meter only "understands" SPL. Hence, if we have been given an SPL-level by the audiometer, the only thing we need to add is the microphone correction. Contrary, it is obvious that when given an HL-level, we need to add the 'HL to SPL correction' (and microphone correction) in order to have an SPL level that can be used as a target level.

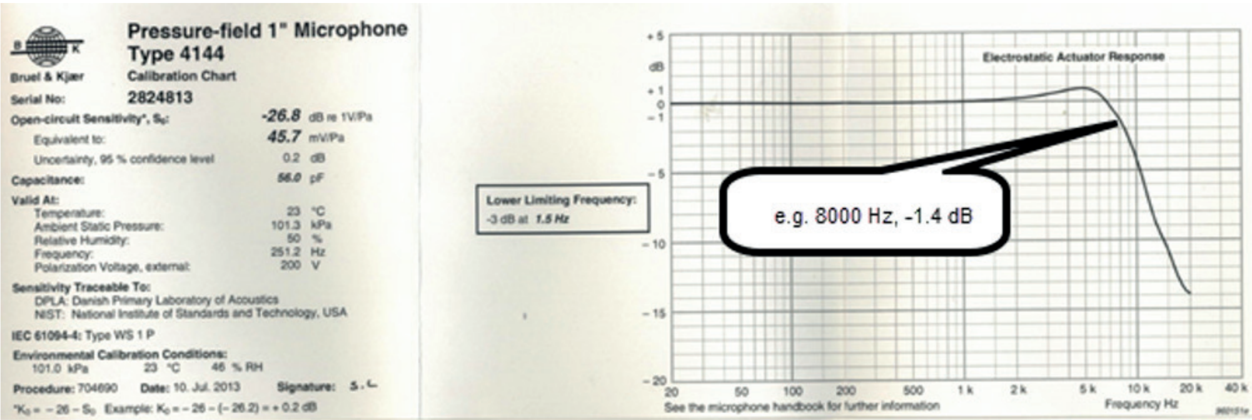

Figure 21 Calibration chart for a 1" microphone.

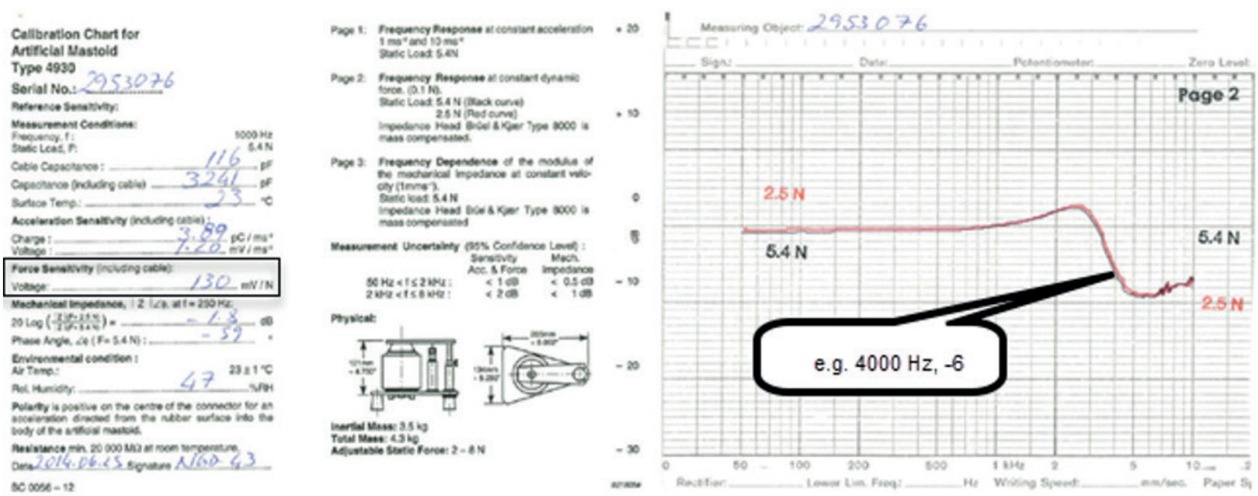

Figure 22 Calibration chart for artificial mastoid.

	HL-calibration	SPL-calibration
Stand-alone devices	Target level presented as HL level or without suffix. 'HL to SPL correction' must be applied manually. E.g. blueline AD229, AC33, AC40	Target level normally presented as SPL level. 'HL to SPL correction' is already included in target level based on selection of headset/coupler, which must be selected prior to calibration. E.g. AS608
PC-calibrated devices	No devices. HL-mode can be selected in some PC-calibrated devices. However, it is still the SPL target level that must be used.	Target level often presented as both HL-level (ATT setting) and SPL-level, which is used. The difference between the two is the 'HL to SPL correction'. 'HL to SPL correction' is already included in target level based on selection of headset/coupler, which must be selected prior to calibration. E.g. blackline AD226, AD629, AC40, Affinity, Callisto

Table 3 Types of calibration-modes and methods.

7 Calibration procedures

Previously, it has been described how to set up the calibration equipment and how to use the calibration equation to calculate the target level for pure tones. Calibration of other stimulus types will be explained in this chapter. In addition to this description, the technician can always refer to the service manual for procedures and device-specific details.

7.1 Calibration of pure tones

The pure tone stimulus is widely used for calibration by most technicians. As for all calibration, it is important to make sure that the target level is in SPL. This means that if the device presents an HL level, it must be transferred into an SPL-level by adding the 'HL to SPL correction' based on the transducer/coupler combination.

If the audiometer is equipped with a high frequency headset; whether this is the primary headset or an additional headset, the frequencies from 8 to 20 kHz must also be calibrated. Here it is also important to select the correct coupler, normally the artificial ear with the flat plate adapter, and to use the correct standard.

Some audiometers can present multiple frequencies, which are pure tones with frequencies in-between the 11 standard frequencies that are used in the "normal" audiogram. It will vary from audiometer to audiometer whether these frequencies must be calibrated individually or if the calibration levels can be interpolated from the standard frequencies. Information about this can be found in the device's service manual.

Pure tones can be calibrated in broadband mode or with a 1⁄3 octave or 1/1 octave filter.

7.1.1 Noise signals

There are two general types of noise signals: narrowband and broadband. A narrowband stimulus is technically the result of a broadband noise signal that has been filtered through a 1⁄2- or 1⁄3 octave filter. It has the same center frequency as the standard frequencies for pure tones, and on a spectrum view, it looks like a pure tone with "broader shoulders".

When narrowband stimuli are presented and measured with the sound level meter, the "shoulders" will contain energy. Thus, the presented peak-top-peak value for the signal will be lower than it is for a sine wave with the same measured sound pressure level. As we want narrowband noise signals that in HL-level have the same peak-to-peak levels as the pure tone, we need to have more energy on the sound level meter, and hence a higher value. This is corrected for in ISO 389-4 (check Table 2) and these numbers must be added as part of the standard (STD) in the calibration equation.

> *Example: The attenuator at 2000 Hz in a random audiometer is 80 dB, and we shall calibrate the narrowband for a TDH39 headset on the 6cc coupler. As seen in Table 2, the frequency-related 'HL to SPL correction' is 9 dB. In addition to this, 6 dB for narrowband shall be added. Hence the target level is:*

STD = ATT + STD + MIC = 80 dB + 9 dB + 6 dB + MIC = ***95 dB + MIC***

Because the signal has a width of 1⁄2- or 1⁄3 octave, narrowband should never be calibrated with a 1⁄3 octave filter, but always in broadband mode, or alternatively with a 1/1-octave filter.

The other type of noise signal is broadband noise. This can, among other, be white noise or pink noise. Common for them all are that they include all frequencies, but they can vary in how the frequencies are weighted. In most cases there is no 'HL to SPL correction' for the broadband noise signals, and these are calibrated to an SPL level. This will be described in the service manual.

For calibration of broadband signals, broadband mode must always be used on the sound level meter.

7.2 Calibration of speech and speech noise

Speech audiometry is an alternative to pure tone audiometry, where the stimulus is numbers, words or small sentences. The source for speech stimuli can be a CD player, iPod, WAV files installed on a PC/device, or live speech from the examiner via a microphone. A speech stimulus requires calibration as it must be presented with known intensities.

With exception of live speech, the stimuli are part of a 'speech material', which contains the words and a calibration track. Whether the 'speech material' is tracks on a CD or iPod or WAV files on the PC or audiometer, all the stimuli (numbers, words, and sentences) are aligned in intensity with the calibration track for the given 'speech material'. Therefore, it is the calibration track that is used in the calibration process.

If the 'speech material' is installed as WAV files, either on the audiometer or on a PC, the audiometer will usually be PC-calibrated, and the speech calibration tone will be generated by the audiometer. This is usually a 1 kHz tone, and it is calibrated in the same way as a normal 1 kHz tone. The target level will often be given as an SPL level, but this is still a sum of an attenuator level and an 'HL to SPL correction' based on the transducer and speech standard that is used–so the calibration equation is still valid.

7.2.1 Calibration with VU-meter

Many older audiometers use an external source for presenting the speech stimuli, typically via a tape/CD input with RCA-connectors. In this case, the VU-meter on the audiometer must be used for calibration as described below.

1. Connect an external device that presents a 1000 Hz pure tone. This can be the calibration track on the speech material, or from a tone generator (e.g. free tone generators can be installed on smart phones).

2. Adjust the input level on the audiometer and the output on the external source so that the VU meter is at 0 dB (all green and no red LEDs light up). It is recommended to position the input level on the audiometer between 50 and 75 percent as this might be adjusted in user mode.

3. Use the calibration equation to calculate the target level. Most often an HL-level is given on the audiometer and an 'HL to SPL correction' must be found based on which speech standard and transducer are used.

4. Adjust the calibration level on the audiometer until the calculated target level is reached on the sound level meter.

During clinical assessments, the audiologist must ensure that the level of a pure tone matches the correct target level when the VU-meter is 0 dB. Therefore, it is essential that the audiologist enters the system via user mode and adjusts the VU-meter with the calibration track from the speech material. By doing this, it can be assured that the speech stimulus is aligned with the calibration track and can be presented at the correct level.

Speech noise is also calibrated by using the 1 kHz pure tone as mentioned in the list above.

If target levels for speech noise are calculated manually, it is necessary to make sure that the narrowband corrections from ISO 389-4 (see Table 2 on page 15) are included in the 'HL to SPL correction'.

7.3 Calibration of free field speakers

Free field speakers are basically calibrated as any other transducer. The speaker is the transducer, the room acts as the coupler, and the standard 'HL to SPL correction' are from the free field standard (ISO 389-7).

After the correct setup (speaker positioning) has been selected, each speaker is calibrated individually with a free field microphone aimed directly at the speaker from the position of the patient's head.

Because of variations in the size and shape of sound booths and in the performance of amplifiers and speakers, it is not possible to predict a system's maximum level as it is for a normal headset. If a system setup cannot deliver the predicted maximum output level in user mode, the calibration functionality should be designed so that the calibration level cannot be reached. In newer PC calibrated audiometers, the maximum outputs can be re-defined in order to match the performance of the system. This is done by using "custom max", and the procedure is described in the service manual.

Custom max can also be used to limit the maximum output in cases where the stimuli is distorted at the louder levels in user mode. However, it is always recommended to use custom max, as this ensures that the calibration can be completed and that no distorted stimuli will be allowed in user mode.

7.4 Calibration of short duration signals

In ABR and OAE we stimulate with repetitive signals of short duration, whereas most signals from an audiometer are continuous. Between these repetitions there will be a short pause with no stimulation, and therefore the measured sound level will be lower than it is for a sine wave with the same amplitude as the highest peak-to-peak level for the short duration signal.

There are various short duration stimuli; some commonly used are bursts, clicks, and CE-chirps. In Figure 23 there is an example of a burst that is compared to a sine wave with the same maximum amplitude, or peak-to-peak value. It is clearly seen that there is more energy (area under the graph) in the sine wave than there is in the burst because of lower average oscillation and pauses.

Regarding calibration, this is a problem, because the sound level meter measures the energy, but we are really interested in the peak-to-peak value, and want to calibrate the short duration signal to a level that corresponds to a sine wave with the same peak-to-peak value. In other words, what we will call a 100 dB burst has the same peak-to-peak value as a 100 dB sine wave, but significantly less energy.

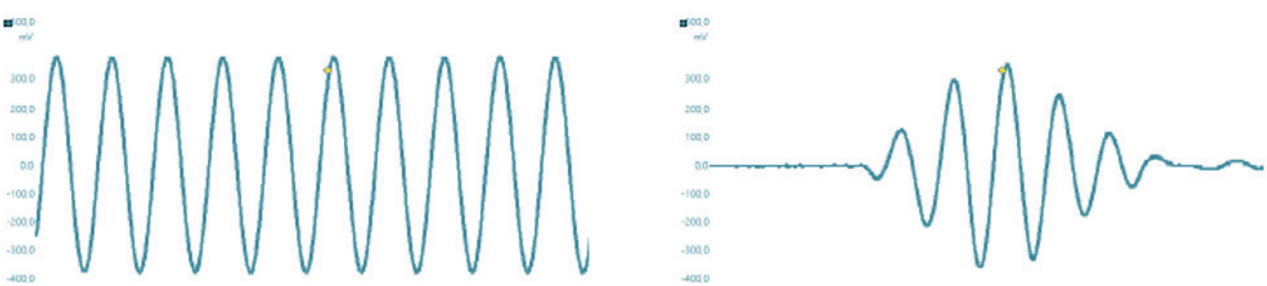

Figure 23 Left: A sine wave. Right: A burst with the same maximum amplitude as the sine wave to the left.

This calibration is performed with an oscilloscope and use of a reference tone. The reference tone is a sine wave tone of the same frequency as the stimulus we want to calibrate. If the stimulus is not a sine wave (e.g. broadband noise, click or broadband CE-chirp), 1000 Hz is used as the reference tone. The procedure is to adjust the relevant reference tone to the desired level; e.g. 80 dB SPL or 100 dB SPL, and then note the peak-to-peak value for that on the oscilloscope. As this peak-to-peak level is exactly what we want our short duration stimulus to have, we calibrate by adjusting our stimulus to this peak-to-peak value.

The detailed information about the stimulus and its calibration is described in the service manual or calibration software. However, a few important points are discussed below.

1. Select the relevant reference tone and adjust the intensity to the target level on the sound level meter

2. Note the peak-to-peak value (V1)

3. Select the stimulus and adjust the peak-to-peak value to V1 on the oscilloscope

The choice of coupler is also described in the service manual or calibration software. It is important to select the advised coupler, as the retSPL to nHL correction done in the software afterwards is based on the fact that the correct coupler is used.

Note that occasionally it is not peak-to-peak values that are used, but instead baseline-to-peak, or simply called peak value. In this case, the stimulus must be adjusted such that the stimulus' baseline-to peak value is the same as half of the peak-to-peak value of the reference tone. It may be necessary to use markers on the oscilloscope.

7.4.1 Notes on use of oscilloscope

The technician that performs the calibration is assumed to be able to operate the oscilloscope. However, it is relevant to give a few hints here.

Both stand-alone and PC oscilloscopes can be used. In general, PC oscilloscopes are considered easy to use and have a good resolution on the screen. Whichever is used, it is important to ensure that all the signal is presented on screen so that we are sure that there is triggered on the actual peak of the signal. This is most easily done by having a few repetitions on the screen and here the good resolution on the PC oscilloscope is an advantage.

It is also important to keep the amplitude gain on the oscilloscope constant throughout the calibration. For example, it is not allowed to change the vertical resolution on the screen between registering the peak-to-peak level of the reference tone and adjusting the stimulus to the same peak-to-peak level.

8 - Calibration of tympanometer

A tympanometer works by presenting a constant probe tone at a frequency of typically 226 Hz into the ear canal. For small infants, 1000 Hz is normally used. When a perfect seal is reached, the measurement can start. Depending on the protocol settings, a positive pressure will be built up and will gradually decrease until a certain negative pressure is reached. Meanwhile, the compliance is measured with a microphone, and a presentation of compliance as function of pressure (the tympanogram) is given.

The tympanometer can also do acoustic reflex measurements, where the change in compliance is measured after a short stimulus of relatively high intensity pure tones is presented.

This functionality gives us the following transducers that must be calibrated in a tympanometer:

1. **Probe tone(s)**: All the available probe tone frequencies must be calibrated to the given level, which most often is given in SPL. A 2cc coupler with ear tip, as shown in Figure 12 on page 10, must be used. After the probe tone has been calibrated, the compliance must be calibrated too.

2. **Compliance (volume)** calibration is done in hard-walled cavities. Some cavities fit the probe tip directly, and for some, it is necessary to use an ear tip. It is described in the service manual which cavity must be used. It is essential that the probe tone is calibrated prior to compliance calibration.

3. **Pressure sensor(s)** are calibrated with a manometer that is connected to the tympanometer and a syringe. The required pressure can then be applied to the probe with the syringe. The pressures at which the individual tympanometer is calibrated are mentioned in the service manual or the calibration software.

4. **Reflex tones** must be calibrated as normal audiometer pure tones. This means that the coupler is chosen based on the transducer, and the corresponding standard's 'HL to SPL correction' is used. Ipsilateral tones are calibrated as inserts in a 2cc coupler and contra tones are calibrated in a 2cc or 6cc coupler depending on the transducer. Everything in the setup and target level calculation is exactly as for audiometer calibration. Please note that the calibration level is often given in HL, and that 'HL to SPL correction' must be applied according to the calibration equation.

9 - Calibration anchors (calibration check list)

This chapter summarizes the calibration procedure and gives some tips that helps the technician to perform a correct calibration.

The first step in the calibration procedure is to know which transducer (headset) is calibrated, and hereafter to set up a coupler for which there exists 'HL to SPL correction' (standard) for the given headset/coupler combination.

When the equipment has been connected, the correct microphone profile must be selected in the sound level meter, and it must be tested with the calibrator on the microphone that the sound level meter provides the correct level.

Hereafter it is time to calculate the target levels and calibrate all the stimuli on both sides of the headset. When the target levels are calibrated, it is important to get an SPL level before the audiometer is adjusted to give this level on the sound level meter. If the audiometer presents an HL-level, the 'HL to SPL correction' must be added. Do not forget to adjust for the microphone or mastoid.

Always use Z-weighting. In principle, everything can be calibrated in broadband mode on the sound level meter, i.e. without use of 1/3 octave or 1/1 octave filters. However, low frequency noise can make it difficult to measure the stimulus, and we may benefit from filtering the signal. A 1/3 octave filter can be used for pure tones and a 1/1 octave filter can be used for pure tones and narrowband noise signals. All other noise signals must be calibrated in broadband mode. Spectrum view on the sound level meter shows the characteristics of the signal.

9.1 Stop and think (the 3 dB rule)

Most of the calibrations in the real world are performed on equipment in use, i.e. equipment recently used to assess hearing loss in patients. Therefore, it is expected that the measured values are relatively close to the target levels.

If a value differs more than expected, two things can be wrong. Either the calibration equipment is set up wrongly, or the device is presenting a wrong intensity. The latter is unfortunate, as this means patients have been assessed with a poorly functioning device.

Therefore, it is very important to **stop** whenever the present level (i.e. before adjustment) differs more than 3 dB from the calculated target level and **think** before adjusting the device. It is always recommended to check the calibration setup and measure 94 dB on the sound level meter with the calibrator placed over the microphone. The next thing to check is that the target level is calculated correctly. If this is in order, then examine the headset cable and the headset itself. In most cases, the reason for the incorrect measurement is revealed. If everything is checked, proceed with the calibration.

10 - Service visit

Service visits can both be ordered as an individual visit in order to calibrate specific devices, and as part of a Service Agreement. Regardless, it is always important to have an eye for the bigger picture and not focus on the calibration alone. After the visit, the devices must be ready for excessive use until the next visit. Therefore, it is important to make sure that the device, transducers, cables etc. are in good condition. Based on experience, you may choose to do a prophylactic change of fragile parts.

Finally, the service visit is also an opportunity to evaluate if your customers has the needed equipment and consumables, or if they need further device training.

11 - References

[1] ISO 389-7 2nd edition 2005: Reference zero for the calibration of audiometric equipment–Part 7: Reference thresholds of hearing under free-field and diffuse-field listining conditions, Brussels: European Committee for Standardization, 2005.

[2] C. Elberling, "WDH calibration values for DD45," WDH, 2011.

[3] Sennheiser, "HDA 300," [Online]. Available: http://en-de.sennheiser.com/downloads/download/file/4789/HDA300_RETSPL.pdf. [Accessed 14 09 2020]

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