SPOT ON TECHNOLOGY

PASSIVE LIMITERS IN HEADPHONES

HEARING DAMAGE… SOME BACKGROUND INFORMATION…

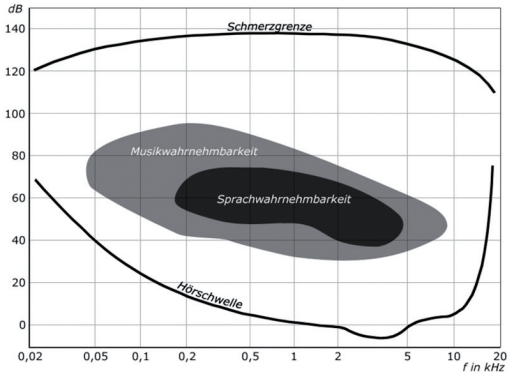
The title of this article already reveals that the subject is how to "limit" our headphones to protect the hearing.
Why is this necessary? How does hearing damage arise?
Two different kinds of hearing damage are distinguished.

1. BLAST AND EXPLOSION TRAUMA

The blast or explosion trauma is one way of how to suffer a permanent hearing damage. In that short moment the sound pressure which affects the ear is so extremely high that it can damage the internal ear. This can be caused by firing a pistol directly next to the ear or a knock on the ear or for instance by an extremely loud noise or whistling from loudspeakers or headphones due to operating errors. One known example is the microphone feedback when holding the microphone towards a loudspeaker. The damage caused by a blast trauma is often non-reversible and consequently leads to a permanent damage of the hearing. Often the blast trauma is referred to as an accident, but that does not change the dramatic effects on the health of the hearing.

2. PERMANENT THRESHOLD SHIFT

This may sound a little bit scientific, but it is the correct medical term. In science and medicine, healthy or damaged hearing is referred to as the level of threshold in quiet and this criterion is used as an evaluation. The measurement is defined as 0 dB (SPL), frequency-independent describing the sound pressure (more simple: the volume) at which the hearing just perceives sounds or noise.
Why is this term an indicator that it was too much for the hearing? Well, when listening to a high volume for a certain time, the consequence is a shift of the hearing threshold, i.e. the threshold for just perceiving sound is moved upwards. In general it is referred to as hardness of hearing; the technical term is threshold shift.



Picture 1 - Source: Wikipedia.de – Hearing Threshold

Fortunately the hearing is more robust than we think. When we listen to the music for thirty minutes with our iPod it does not immediately cause a permanent hardness of hearing. First of all it causes a temporary threshold shift, i.e. a temporary hardness of hearing. This period of reduced hearing happens after exposure to loud sounds, for example after a visit to a discotheque. This kind of hearing impairment is often temporary and after some time the trauma will stop. This, however, should not be taken as a free ticket for listening to loud music; it should only demonstrate that listening to loud music for a short time does not immediately cause hearing damage. In addition to the plain volume the period of listening is most of all a decisive factor.
It could be compared to a barrel of water. The barrel demonstrates the amount of noise we can cope with per day. Whether you turn on the water tap once a day and fill the barrel or add small amounts of water several times a day to fill the barrel remains the same. Important is that the barrel does not flow over.
This requires a certain discipline of the user (as with all matters of health), which especially refers to people who are exposed to "noise" all day for professional reasons such as sound engineers, simultaneous interpreters, musicians, DJs etc. In this case you cannot have a break to relax your ears as this would mean you would have to interrupt your work. Another source of danger is the period of time you are forced to listen to. This results in a quick tiring of the hearing and you tend to turn up the volume.
Especially for the people mentioned above it is important to work at a moderate volume level during the whole time of working to avoid deafness as occupational disease (permanent threshold shift). In many cases this would mean an occupational disability.

LEGAL CONDITIONS

1. LABOUR LAW

As the responsible handling with volumes is not known to each employee (or in the daily routine this fact is sometimes forgotten), it is the employer's duty to ensure a work environment which is not harmful to the health.

In Germany the legal conditions for noise exposure at work are determined in the regulations of the German employer's liability insurance association (BGV B3 - Noise). They differ between local and personal evaluation levels (i.e. the sound pressure level average over the whole time), which should not exceed a value of 85 dB(A) over a period of time of 8 hours and a maximum sound pressure level of 140 dB (SPL).

Similar legal limiting values for noise exposure at work are found in almost all European countries, such as the Statutory Instrument 2005 No. 1643 "The Control of Noise at Work Regulations 2005" in Great Britain determining a personal evaluation level of 87 dB(A)/8 hrs. or a maximum sound pressure level of 140 dB(C).

The basis of all legal regulations for noise exposure at work (including when working with headphones) is the so-called equivalent permanent sound pressure level LAeq. This means that the noise exposure is measured, summed up and averaged during the whole work duration (typically an 8-hour work day). This averaged value now corresponds to an even sound pressure level which affects the user during the whole work duration without variation in volume and without interruption (virtually as background noise) allowing a clear evaluation of the noise exposure at the workplace. The linear relation between sound pressure level and time of exposure is of special interest meaning that a sound pressure level higher by 3 dB results in halving the allowed time of listening.

The following values are just "healthy":
85dBA for 8 hours or…
88dBA for 4 hours or…
91dBA for 2 hours or…
94dBA for 1 hour or…
97dBA for 30 minutes or…
100dBA for 15 minutes
etc.

2. MOBILE PLAYERS

Another legal regulation for limiting the volume of listening with headphones is found in the European standard EN 50332-1 which deals with the sound pressure levels of headphones when used with mobile players.

Here it is determined that a mobile player must not produce a sound pressure of > 100 dB(A) on the headphone connected and should correspond to an equivalent permanent sound pressure level of 90dBLAeq.

Furthermore, in the past years more massive demands arose for a stricter regulation of volumes in the private environment. For example in 2008 the Scientific Committee of the EU warned against the dangers of high volumes with mobile players such as MP3 players by publishing their report "newly aroused and newly identified health risks" (SCENIHR) and recommended to tighten the current valid safety standards. They recommend reducing the currently valid volume restrictions for mobile players from 100 dB(A) to 89 dB(A).

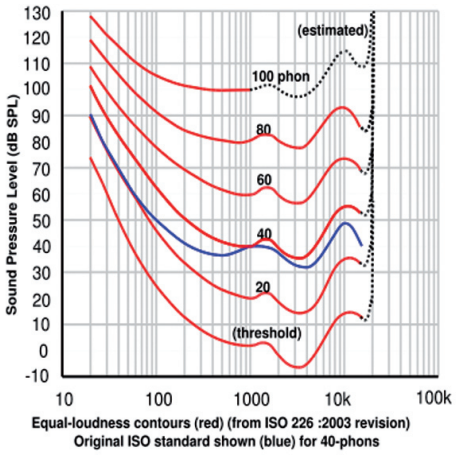
At the end of the day the efficiency and realisation of such measures always remains doubtful, because the user can avoid them by using for instance very powerful headphones or amplifiers.

WEIGHTING FILTER: A-WEIGHTED, C-WEIGHTED OR UNWEIGHTED… THAT'S THE QUESTION!

We all know the typical specifications for sound pressure measurements such as dB(A), dB(C) or dB(SPL) and have accepted them. Only few of us, however, know the background of these different weighting curves and know why they are used.

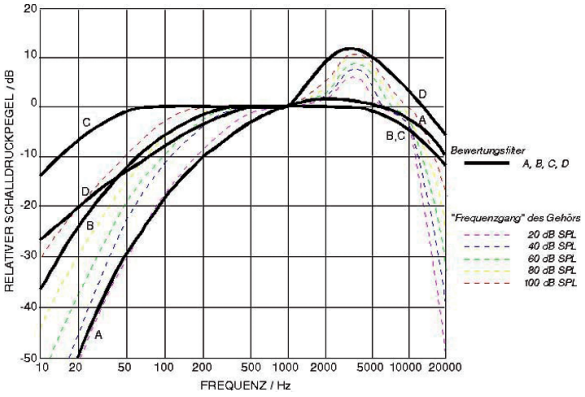
The reason for the big number of different weighting filters is simply the human auditory physiology. The properties of the human hearing are unfortunately far from linear regarding the frequency or volume. As shown in picture 1 the frequency curve of the human hearing is far from linear, but prefers individual frequency ranges. For example close to the level of threshold in quiet, deep frequencies below 100 Hz are perceived less stronger by more than 20 dB than frequencies in the range around 1 kHz.

From this the so-called A-weighting filter was developed, which reproduces the frequency selectivity of the human hearing relatively good at a volume level of approx. 40 phon. Unfortunately, this weighting filter is only valid for this volume range. If the hearing volume is increased, the frequency selectivity of the human hearing is changed. Deep frequencies are progressively perceived in the same proportion as medium and high frequencies.



Picture 2 - Source: Wikipedia.de – Frequency weighting

At a volume of 100 phon deep frequencies below 100 Hz are perceived almost in the same proportion as medium and high frequencies. This resulted in the introduction of further weighting curves such as B-weighting (db(B)), C-weighting (dB(C)) or an unweighted (dB)SPL)) measurement.



Picture 3 – Source: Wikipedia.de – Frequency weighting

Now the problem is that there are many different weighting filters for the same problem (perceived sound pressure level with the human hearing across different frequencies). Basically you should apply a different measurement method depending on the volume level. But this is hard to practice. Two measurement methods have been established:
A-weighted (dB(A)) and unweighted (dB(SPL)). Here, the dB(A) measurement is far more common for sound pressure measurements that refer to the human hearing. For the pure auditory sensation the application of the A-weighting is a good compromise. If it comes to hearing protection, however, it is technically not the best approach. As already mentioned, the A-weighting refers to the properties of the human hearing close to the level of threshold in quiet.

When we talk about hearing protection, we have to assume sound pressure levels that are far beyond the level of threshold in quiet. Depending on the volume range the B- or C-weighting might be the better one. In practice it is not possible to change between the different weighting filters all the time. Regarding hearing protection there are two measurement methods that make sense:
1. Measurements with A-weighting. They correspond to most common standards and measurement procedures and can be compared with each other. But you must note that high sound pressure levels are weighted significantly less harmful than they are in practice.
2. Unweighted measurements. They represent the highest safety factor, because in principle they correspond to the auditory sensation at very high volumes and weight all frequencies equally. In principle the measurement method represents the "worst case". You must accept, however, that with low sound pressure levels it is measured stricter as the impact on the human hearing actually is.

THE USE OF PASSIVE LIMITERS IN HEADPHONES…

Definition: What is a passive limiter?

Unlike active limiters, which only work when operated with a supply voltage, passive limiters are circuits which are built with electronic components such as diodes, transistors etc., but are designed to work without a power supply. They are used for headphones, because a headphone (as well as a speaker) usually does not have a power supply.

WHAT THEY CAN PROVIDE… AND WHAT THEY CANNOT PROVIDE…

Let us start with what they cannot provide. As described before, the degree of damage to the human hearing due to noise is not only caused by the sound pressure level, but especially by the time of exposure to noise. A limiter in a headphone cannot meet this requirement, because a limiter only limits the maximum sound pressure level without taking the time of noise into account.

The patented beyerdynamic EarPatron™ technology, which meets the requirements of the guidelines for labour protection is a hearing protection that also refers to the time of exposure to noise and is used for the SIS Simultaneous Interpretation System or the Headzone Pro XT surround headphone system.

Does this mean that the passive limiter regarding hearing protection is only a bad compromise? No, although a headphone limiter cannot take the time of exposure into account, it is an excellent tool to avoid too high volume levels and protect the user against damages to the hearing when used correctly. Furthermore, the use of passive limiters in headphones provides some important safety aspects.

1.The first big advantage of limiters in headphones is that the noise limiting is done locally because they are inseparably connected with the sound source, the headphone. As described before, the volume limitation of players such as headphone amplifiers, MP3 players etc. can be easily avoided by using another headphone or an amplifier. When a headphone itself is limited (as last item in the chain), such measures cannot be taken any more, which is also an important factor regarding the guidelines for labour protection when the compliance of noise levels of headphone workplaces must be guaranteed.

2.The second advantage of limiters in headphones is the fact that they are adapted and gauged to the acoustical properties of the headphone. In this way the limitation to a defined sound pressure can already be guaranteed by the manufacturer. An electronic limiter connected ahead is only able to limit the audio signal to a defined voltage value. The calibration to the sound pressure of the headphone in use has to be carried out by the user himself with an extensive measurement, which is often hardly possible due to missing measurement equipment.

THE BEYERDYNAMIC LIMITER CONCEPT

We all know the soft sound of a high-quality, electronic limiter as it is used in studios and for recording purposes. The sound of such an often VCA-based circuit corresponds to a remote-controlled volume increasing and decreasing and not a circuit which clips signals.
Of course it is possible to integrate such an extensive electronic circuit directly into a headphone, but this makes the headphone useless for daily use, as the headphone always has to be equipped with a supply voltage for the operation of the limiter electronics. But this is not available with standard headphone outputs of players.
In order to avoid this and to leave the headphone as passive listening tool, limiter circuits with passive components such as diodes are used. These circuits are known as diode limiter or brick wall limiter and can clip audio signals very fast and secure when the threshold is exceeded. In principle this is the same function as with an equalizer.
At beyerdynamic we have invested a lot of work to achieve a similar sound with a pure passive circuit as with an extensive electronic limiter circuit. This includes a two-stage concept to reduce gently the audio signal by 6 dB when the limiter threshold is achieved (similar to a compressor with a quick attack and slow release time). Then there is a second hard limiter downstream, which limits the audio signal with a brick wall limiter when the input volume is further increased.
The big advantage of this concept compared to others is the soft, compressor-similar range between the unlimited audio signal and the hard second limiter stage. This range still sounds very good and signals the user the achieved limiter threshold without producing immediately hard distortions.
As mentioned before, the question arises which weighting filter should be used for the limiter circuit. An A-weighted limiter function is close to standards and measuring specifications, but does not quite reflect the properties of the human hearing at high volumes. At beyerdynamic we decided to use a limiter concept WITHOUT weighting filter. Why?

What do we want to do with our limiter? We want to protect people against damaging their hearing. Due to the fact that the one and only weighting filter does not exist which reflects the properties of the hearing with all volume levels, we decided to assume the worst case, what means measuring the sound pressures unweightedly in dB (SPL). The procedure automatically meets all weighting filters which are provided for low sound pressures (A-, B-, C-weighting). Although passive limiters which operate with an A-weighting with normal, deep music material allow a higher sound pressure level before they respond, but the question arises if this really makes sense talking about limiters for high sound pressure levels. In our opinion a limiter should operate to protect the human hearing against damages and operate more conservatively than optimistically. This means the use of a limiter without a weighting filter. People who are looking for high sound pressure levels should prefer a headphone without limiter.

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