Lehmannaudio®

Techletter

Headphone Amplifiers

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Why headphones?

The use of headphones enables an outstanding music reproduction at a fraction of the costs you would have to pay for a comparable high-class hi-fi system based on loudspeakers. Concerning resolution and dynamics high-quality headphones are not only on par with the best speakers, but in most cases even superior. Moreover, they offer the possibility to enjoy music even at night or in suboptimal, not totally quiet surroundings. The first helps to keep the peace e.g. within the family or with your neighbours, the latter blocks out environmental noise and makes you totally independent of the room acoustics.

What does a headphone do differently?

There is a number of parallels between (dynamic) headphones and loudspeakers. Both are – technically speaking – so-called 'complex loads' for the connected amplifiers and should therefore be run on rather stable outputs. There are high-impedance headphones which, for technical reasons, require a higher operating voltage, and low-impedance models, which demand more current to deliver optimum results and the appropriate sound level.

Whoever simply plugs any headphone into a correspondingly labelled output socket without heeding the data of the respective headphone, may be badly disappointed by the result. This is due to the fact that with headphones the product diversity regarding impedance and sensitivity is actually even more confusing than with loudspeakers. Common headphones have impedance values ranging from 16 ohms to 600 ohms. If we transferred this to loudspeakers, we would obtain a range between, say, 4 ohms and 150 ohms.

Does a headphone have to sound neutral? Why?

Basically, work results can be evaluated faster in the professional sector with a really neutral headphone. This is especially true of situations where you, as the monitoring listener, are confronted with a new headphone. But it also applies: those who can judge the deficiencies of their systems correctly, may of course also use headphones that reveal a certain colouration in the frequency response or other imperfections. Things get more complicated, however, with effects based on a high transient accuracy. For instance, how do you want to determine over the headphone the necessary amount of spot microphone for a recording, if you cannot depend on the result at this point because of the characteristics of the headphone you're using?

Certainly there are even fewer mandatory recommendations for private music listeners with regard to colourations than for the pros. Here anything goes. Unlike loudspeakers, the number of headphones rather depends on your personal budget than on the consent or even the goodwill of potential flatmates. Yet concerning possible colourations, we ought to convince ourselves that a specific tonal colouration could be compared to the steady use of a single spice on all the dishes we enjoy. Do we really want to have curry with all meals, or vanilla, or garlic …? On the other hand, different headphones with different characteristics for different music styles or moods can be a real enrichment to the respective music lovers.

Transient response

Due to our evolutionary development, the human hearing is super sensitive to transients. To put it crudely, those who didn't hear a snapping twig in time, would soon fall prey to the sabre-tooth tiger. Sure, listening over headphones isn't a matter of life and death, but headphone amplifiers and headphones with an inadequately precise transient reproduction will always become noticeable negatively in multiple respect.

One example would be a musician in the studio: the musician doesn't hear the playback signal correctly, because he's missing the transient portions, so he turns up the volume. But this won't improve the transient reproduction. So the volume is further increased. The possible, immediately audible result: there's more crosstalk from the headphone to active microphones, and the sound engineer is facing problems with the track separation. Moreover, the musician is unfocused and feels uncomfortable instead of inspired and relaxed, so he's going to make more mistakes. The performance is poor, thus more takes and more studio time (= higher costs) will probably be needed, and most likely the final product will be somewhat less than perfect (= fewer proceeds). At the end of the studio day the persons, who have been ill-treated in such a way, will go home with a headache. Moreover, health implications of the hearing are inevitable in the long run.

One problem here is primarily the lack of problem awareness. In most cases the performers do not realise at all what's happening. The musician simply gets a headphone on the ears, and often the studio planner or studio owner is happy if he can save at least a few euros here, while he's otherwise looking after his premium-grade console or the latest digital audio workstation. Bottom line: wherever headphones are used for monitoring, headphone amplifiers of the highest possible quality are of enormous importance to the overall result, whether during mixdown or mastering or for undisturbed music enjoyment at home.

Power and sensitivity

Irrespective of their impedance, headphones – just like loudspeakers – have very different sensitivities, thus they transform the signal voltage, which is present at the headphone output, more or less efficiently into acoustical energy. With loudspeakers we normally use the achievable sound pressure level for 1 W of input power (dB/1 W) as the measure of efficiency. Something similar also exists with headphones, the most common characteristic variable, however, being dB/mW this time, hence the achievable sound pressure level for 1 mW of input power (not per milliwatt!), which equals 1/1000 watt.

With each doubling of the power, the sound pressure level is increased by 3 dBs. By implication, a headphone whose sensitivity is greater by 3 dBs will require only half of this power to achieve the same sound level. The rule with 3 dBs more SPL for each power doubling equally applies to headphones and loudspeakers. From the sensitivity information one can therefore easily calculate the required power for a desired sound level.

The required power for the same SPL can vary with the different headphone models by a factor of approximately up to 500 (!) at the max.

When using or choosing headphones and headphone amps, the first point that matters is, of course, if the desired volume level can be achieved without distortions. But it's also important to know above which levels the respective headphone or – far worse – your own hearing may suffer from damages. The maximum power handling capacity is usually specified in the specs sheet as maximum power. Based on these data, one can in turn calculate the maximum voltage which may be applied to the headphone. When the headphone is overloaded, i.e. when the applied signal voltage is too high, the voice coil will melt.

Reference level for headphones, referencing

When monitoring over loudspeakers, monitor controls with a listening level indicator used to be common practice e.g. in the ARD studios. The so-called monitoring cassettes in the control room equipment had volume controls calibrated in dB. Here an extra calibration was carried out by the acousticians to create identical monitoring conditions in all studios regarding the volume levels. However, even in the professional sector this subject is most often neglected in headphone monitoring. The user simply turns up the volume until it fits. Yet for a really precise sonic evaluation, especially in long-term headphone monitoring, a corresponding referencing to standard monitoring levels would not only be desirable here, but utterly helpful as well. For this purpose, however, one would have to agree within the respective house on using a reference headphone and possibly other models of identical sensitivity, since otherwise the calibration would become void due to the potential sensitivity differences among the available headphone models.

A note on sound

Some headphones can be bought with alternative impedances. Here the high-Z versions should be given preference over the low-Z ones.

Stress for your ears

When listening over a headphone, the volume levels can get very loud pretty fast. Here is a first chart with different sound pressure levels for comparison:

Table 1: Comparison of different sound pressure levels

dBA	Sound pressure level
150	Firecracker
140	Jet engine
130	Starting jet
120	Rock concert/live band
110	Disco/Walkman/jackhammer
100	Rehearsal room/car stereo
90	Factory/heavy-duty traffic
80	Road traffic
70	Restaurant
60	Conversation

Despite all the joy we can treat ourselves to with music listening, we should take good care of our hearing health, especially when listening over headphones. For the permissible acoustic impact on our hearing, depending on the time of exposure, Germany has the so-called workplace ordinance, a federal law which has been in force since 1975 in its current wording. It stipulates that – grossly simplified – the noise exposure at the workplace with so-called 'other activities' must not exceed **85 dBA** (weighted continuous noise level). Comparable limit values apply in other European countries.

A full workday is assumed, i.e. eight hours. For this we have once again a 3 dB formula: for each 3 dBs more sound level the so-called permissible exposure time is reduced by half. There is no dedicated ordinance for leisure time. The following chart shows that with increasing loudness very short permissible times are achieved very quickly.

Table 2: Permissible exposure times depending on SPL (dBA)

Sound pressure level (dBA)	Permissible duration (hours)	Permissible duration (minutes)	Permissible duration (seconds)
85	8	–	–
88	4	–	–
91	2	–	–
94	1	–	–
97	–	30	–
100	–	15	–
103	–	7,5	–
106	–	–	225
109	–	–	112
112	–	–	56
115	–	–	28
118	–	–	14
121	–	–	7

Calculations based on the German Lärm- und Vibrations-Arbeitsschutzverordnung (LärmVibrationsArbSchV) [Noise and Vibrations Occupational Safety and Health Directive]

These times should be taken seriously, because if they are exceeded, health damages cannot be excluded, as has been proven (recourse claims against the perpetrator/employer). For logical reasons, you should therefore put on the

headphone only after the volume level has been set accordingly before to avoid unpredictable acoustic strains.

Remarkably the USA have significantly different limit values: for an eight-hour workday 90 dBs are allowed over here, and the permissible exposure time is halved with every five dBs[1] more. 115 dBs are still allowed in the USA for 15 minutes per day, whereas in Germany for only 28 seconds.

Automatic limiters, which limit the level as a function of an applied input voltage, make sense only if they are calibrated to the respective headphone model in use and its sensitivity. Otherwise the resulting control processes have nothing to do with reality, suggesting a deceptive occupational safety.

Table 3: Power consumption by headphones at different voltage levels

Level (U_{eff})	Headphone impedances				
	16 ohms (e.g. DT 100)	**60 ohms** (e.g. HD-25 SP)	**120 ohms** (e.g. K1000)	**300 ohms** (e.g. HD 650)	**600 ohms** (e.g. K240 DF)
0,1V	0,63 mW	0,16 mW	0,08 mW	0,033 mW	0,016 mW
0,5V	15,63 mW	4,2 mW	2,1 mW	0,83 mW	0,42 mW
1V	62,5 mW	16,7 mW	8,3 mW	3,3 mW	1,7 mW
2V	250 mW	66,7 mW	33,3 mW	13,3 mW	6,7 mW
3V	563 mW	150 mW	75 mW	30 mW	15 mW
6V	2.250 mW	600 mW	300 mW	120 mW	60 mW
9V	5.063 mW	1.350 mW	680 mW	270 mW	135 mW

1 | https://www.osha.gov/pls/oshaweb/owadisp.show_document?p_table=STANDARDS&p_id=9735

Table 4: Required voltage level for 1 mW of power

Level	Headphone impedances				
	16 ohms	**60 ohms**	**120 ohms**	**300 ohms**	**600 ohms**
Voltage	127 mV	245 mV	347 mV	550 mV	775 mV
dBu	-15,7	-10	-7	-3	0
dBV	-17,9	-12,2	-9,2	-5,5	-2,2

Among other things, the above chart clarifies that in connection with headphones of different impedance values the same voltage level can produce deviations in power of up to 37.5 as the factor e.g. for the gap between 16 ohms and 600 ohms. But how loud the respective headphone will actually play, depends on its sensitivity.

Table 5: Common headphones

	Impedance in ohms	Sound pressure level in dBs for 1 mW power	Voltage for 100 dBs sound pressure level in mV	Power for 100 dBs sound pressure level in mW
AKG				
K-141 MKII	55	101	209	0,8
K701	62	93	558	5
K812	63	96	300	2,6
Audeze				
EL-8	30	102	138	0,6
LCD-2	70	93	592	5
LCD-X	102	93	742	5
Audio Technica				
ATH-M20X	47	96	344	2,5
ATH-M40X	35	96	297	2,5
ATH-SR9	47	97	306	2
ATH-AD2000X	40	103	142	0,5
ATH-R70X	470	99	770	1,6
Beyerdynamic				
DT 100	16	94	253	4
DT 1770 PRO	250	102	398	0,6
DT 880/990	250	96	800	2,6
T1	600	102	620	0,6

	Impedance in ohms	Sound pressure level in dBs for 1 mW power	Voltage for 100 dBs sound pressure level in mV	Power for 100 dBs sound pressure level in mW
Grado				
SR80	32	98	225	1,6
SR125	32	98	225	1,6
SR225	32	98	225	1,6
Koss				
Porta Pro	60	101	218	0,8
Sennheiser				
HD-25 SP	60	90	800	10
HD-280 PRO	64	90	800	10
MOMENTUM	18	93	314	5,5
HD-650/800	300	97	775	2
HD-700	150	97	550	2
Sony				
MDR-7506	63	106	126	0,3
MDR-7509	24	107	69	0,2
Ultrasone				
HFI 580	32	101	160	0,8
Edition 10	32	99	201	1,3
Signature PRO	32	98	225	1,6

The headphones listed below are all relatively large headband models. In-ear phones, which are designed for battery-powered devices, mostly have an even far greater sensitivity.

One can easily recognise that headphones can reveal big differences as to their impedance and/or sensitivity, even within the product range of one manufacturer, whereby the headphone impedance plays a hitherto overrated role, at least if the headphone amplifier is capable of delivering enough current. Consequently the sensitivity is meanwhile specified as dBs/1 V for many headphone models; for in-ear phones the unit dB/100 mV is normally used in this case because of their greater sensitivity. Manufacturer information regarding the sensitivity without specifying the reference unit (V or mW) are pointless – but can be observed time and again even with well-reputed manufacturers.

Related to the sheer voltage level, up to about 30 dBs of gain remain with the models in the above chart to achieve the same sound level on the headphone. For this reason it is important to either choose headphone and headphone amp as a combined matched package or to pick a headphone amp with an adjustable gain, which goes together well with most headphones on the market.

Notes

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HEADPHONE GALLERY

by Lehmannaudio

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