What makes a great headphone amp?

THE MARKET HAS A SEEN A PROFUSION OF HEADPHONE AMPS, BOTH WITH AND WITHOUT DIGITAL CONVERSION, AND FOR DESKTOP AND PORTABLE USE. BUT WHAT MAKES THE IDEAL 'HEAD-FI' COMPANION?

With the certainty of night following day, the renaissance of headphone listening – brought about first by the iPod, then the smartphone, and its subsequent transference to home listening – has brought in its wake a flowering of the separates headphone amplifier as the must-have 'head-fi' accessory. So, for one's audiophile headphones, what makes a dedicated amplifier worthy of them?

Time was when all but the most enthusiastic users of headphones would trustingly plug them into the jack socket on the fascia of their amplifier. Headphone amps existed, but were quirky, peripheral: their elevation to the mainstream is confirmation headphone provision is no longer an afterthought. But there seems to have been little analysis of exactly what's required of a headphone amplifier: What output voltage capability? What output current capability? What output impedance?

To answer these questions it helps to have a database of headphone measurements covering a wide range of manufacturers, models and types. I have exactly that, so I've plundered it to answer each of the above questions as definitively as I can. My assumption is that our putative ideal headphone amplifier is to be truly universal: to extract the best from any and all headphones. Accommodating the outliers – the particularly challenging headphones – is, of course, a design choice not everyone will adopt, not least because it may hike the amplifier's price tag.

Peak SPL

To answer the questions about voltage and current capability, it's necessary to specify the peak sound pressure level (SPL) you want the headphone to generate. Whenever I consider this issue – as I have previously for speakers – there's misunderstanding among some readers of what I mean by peak, and why I suggest what can appear extreme peak SPLs.

Wide dynamic range music recordings can have crest factors – the ratio of peak level to mean (RMS) level – in excess of 30dB. The highest I've ever measured is about 35dB. If you were to listen to the latter at a mean level of 80dB SPL, the short-term peaks would reach 115dB. Excessive and hearing-damaging as this level would be if maintained rather than transient, there is ample evidence that peak levels of this order are routinely encountered in live music.

Canadian audiologist Marshall Chasin has taken a particular interest in the protection of musicians' hearing, and in "How Loud Is That Musical Instrument?", a paper published in *Hearing Review* in 2006, set about measuring what peak levels musical instruments generate. Table 1 reproduces some of his results, the SPL in all cases being measured at a distance of 3m from the instrument or ensemble. The first column shows the range of values observed with A-weighting applied to the measurement, which reduces bass and treble contributions. Comparing these to the true peak levels listed in the last column shows how easily naive SPL measurement can give misleading results. Under-reading of peak levels can be much worse than this if the meter characteristics are intended to give an indication of average loudness, as with a VU meter. A genuine VU meter has a risetime – to 99 per cent

instrument(s)	dBA	peak SPL @ 3m (dB)
loud piano	70-105	110
keyboards (electric)	60-110	118
violin/viola	80-90	104
cello	80-104	112
clarinet	68-82	112
oboe	74-102	116
saxophone	75-110	113
flute	92-105	109
piccolo	96-112	120
French horn	92-104	107
trombone	90-106	109
trumpet	88-108	113
symphonic music	86-102	120-137
amplified rock music	102-108	140+

Table 1. Peak sound pressure levels at 3m from various musical instruments and ensembles (reproduced from M Chasin, 'How Loud Is That Musical Instrument?', Hearing Review, 13(3))

of the final value – of 300ms ±30ms, so it is utterly useless as a detector of signal peaks which may last for one or two milliseconds or less.

Chasin's results should be chastening to any designer or user of hi-fi equipment. It's not unreasonable, surely, to want a top quality audio system to be capable of reproducing the sound of a solo piccolo at 3m. But to do this requires generating a peak SPL of 120dB at the listener's ears – a feat well beyond the capability of most amplifier/loudspeaker combinations. This may go a long way to explaining why high-power amplifiers evince an ease about their music-making, and high-sensitivity loudspeakers likewise.

Achieving peak levels of 120dB SPL with headphones is much easier, and so is the target I've adopted here. Provided the peaks are of sufficiently short duration and sufficiently infrequent that they sum to a short cumulative duration, hearing damage need not result. Still, it's sensible not to expose yourself to such levels for protracted periods, and to ensure your ears have plenty of quiet time thereafter in which to recover. Long-term exposure to high SPLs – as experienced by some orchestral musicians when, for instance, seated in front of the trumpet section – can result in permanent hearing loss.

If you're adamant that 120dB peak capability is too high, then dividing the voltage and current values I'm about to calculate by a factor of three will give equivalent figures for 110.5dB peak SPL.

Output Voltage

Modern medium-impedance moving coil headphones (impedance around 40 ohms) typically have a voltage sensitivity at 1kHz of about 115dB SPL for 1 volt input. So to achieve 120dB at 1kHz requires around 1.8V – which should be easily within the capability any mains-powered headphone amp worth its salt. High impedance headphones (impedance around 300 ohms) more typically have a voltage sensitivity of about 105dB SPL for 1V at 1kHz, so the requirement for 120dB peak rises to 5.6V.

But there are much lower-sensitivity 'phones, the most challenging I've ever measured in this regard being the HIFIMAN Susvara – a planar magnetic type – which recorded a 1kHz sensitivity of 91.5dB for 1V, despite a modest 60 ohms nominal impedance. To drive it to 120dB peak output would require 26.6V, well beyond most headphone amplifiers. Even a loudspeaker amp rated at less than 44W per channel continuous into 8 ohms wouldn't be sufficient.

Historically there was the Wharfedale Isodynamic, the original planar magnetic headphone, launched in 1972. Its specified sensitivity of 95dB SPL for 30mW and impedance of 120 ohms suggest that it would require a whopping 33.7V to drive it to a peak SPL of 120dB.

If these exceptionally 'difficult' headphones are excluded from consideration, we should at least include those high impedance models which don't manage the aforementioned 105dB SPL for 1V. I recorded voltage sensitivity of 95.6dB for 1V for the Beyerdynamic DT 990 in 2012, and this headphone (measured impedance range 564 to 711 ohms, 20Hz - 20kHz) surely can't be considered a freak. It would require 16.6V for 120dB SPL.

Output Current

It's standard practice to specify headphone sensitivity for either 1 volt (1V) or 1 milliwatt (1mW) input. But at least as interesting as either of those is current sensitivity, hardly ever measured or specified – although I do in Headphone Test Lab (https://headphonetestlab.co.uk). Its significance lies in it being a true test of the efficacy of the drive unit's motor system, whose task is to convert voice coil current into force on the drive unit diaphragm.

Headphones combining low sensitivity with low impedance are clearly the most challenging when it comes to current requirement. The Susvara has the former but not the latter, but nevertheless its current sensitivity of 87.0dB SPL for 10 milliamps (mA) – the lowest I've ever measured – means it will require 447mA to deliver 120dB SPL. Not as tough but still challenging is the HEDD Audio HEDDphone, with its air motion transformer driver. Its 92.0dB for 10mA means it requires 251mA to achieve 120dB SPL.

To illustrate how far these two are from the most effective motors, the headphone with the best current sensitivity I've measured is the Beyerdynamic T1 gen2. Its 116.6dB for 10mA sensitivity means that it requires just 14.8mA for 120dB SPL.

Output Impedance

There is a school of thought that headphones should be driven from a signal source with high output impedance: in IEC standard 61938:1996 – since revised in 2013 and 2018 – 120 ohms was recommended. The reasoning for this was laudable but misguided: it was hoped high source impedance would lessen the loudness difference between high impedance, low voltage sensitivity headphones and low impedance, high sensitivity models, and thereby make exposure to damaging SPLs less likely. Headphone impedance and sensitivity are loosely related because low impedance means higher signal current for a given signal voltage, and it's current through the voice coil (assuming a non-electrostatic headphone, of course) which determines the force acting on the drive unit diaphragm.

That old version of IEC 61938 stated, 'For most types of headphones, the source impedance has very little effect on the performance' – a ridiculous claim which would prompt me to comment in a 2008