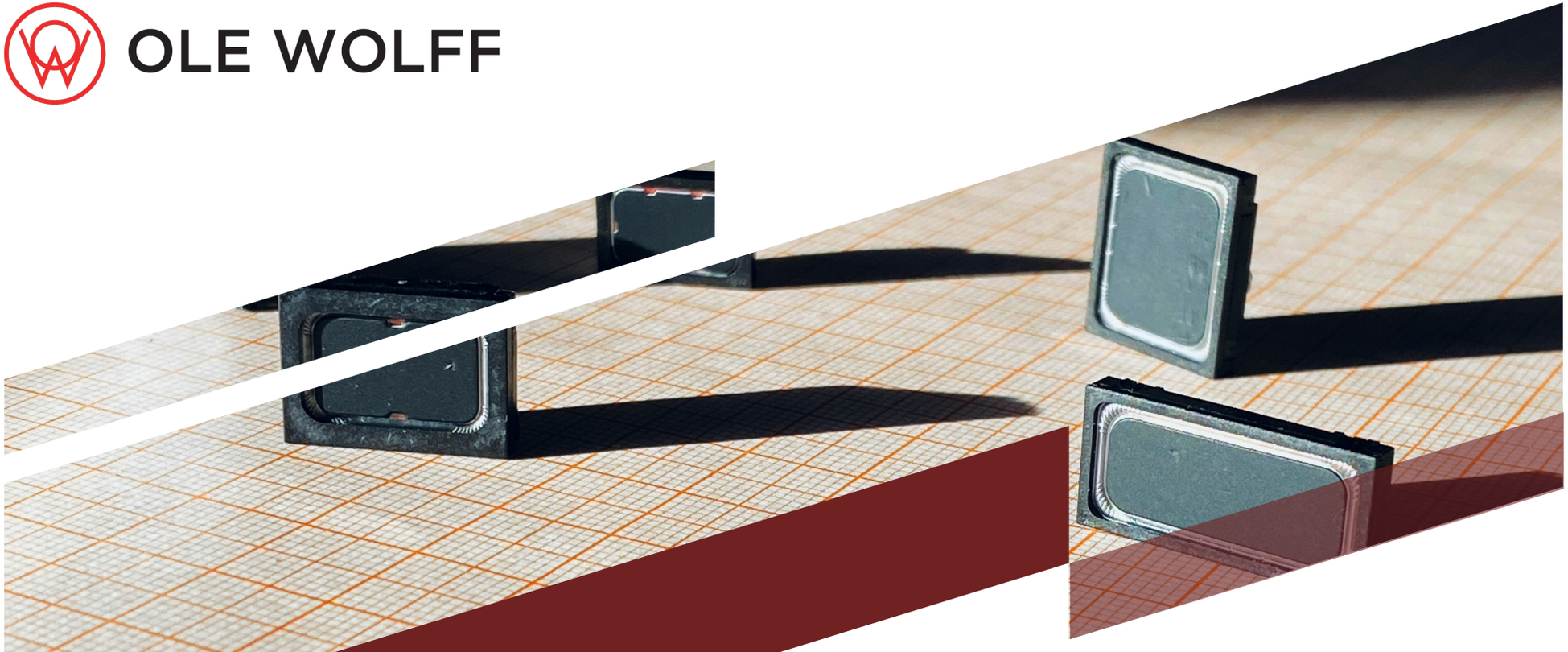
OLE WOLFF



Smart Amp

- The Intelligent Loudness Solution

WP11

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Scope

Hifi (high fidelity) stereo systems for households have been a “part of furniture” for many years with huge amplifiers and loudspeakers powered directly from the electrical grid giving them virtually unlimited energy at their disposal.

These analog sound devices are optimized for delivering the most lifelike sound reproduction mirroring the original recordings from concert halls, sound studios, festivals etc. to perfection giving the listener access to very high sound pressure levels (SPL) and loudness.

When it comes to today’s portable audio devices like mobile phones, portable loudspeakers/sound boxes, audio wearables, and basically all battery powered devices capable of delivering audio, the situation is different though. These equipment’s all have limited access to power, limited space available for loudspeaker sizes and overall squeezed to pocket sizes leading to a genuine challenge in getting enough loudness and SPL out of these small high-tech boxes.

This White Paper deals with the different tools available for solving this issue.

Loudness function (analog amplifiers)

A commonly used feature in Stereo systems for households is the amplifier having a loudness function (button activated).
When activating this, the bass frequencies are emphasized/gained for making the sound impression more “full bodied” and seem louder. This function is also often integrated in the volume control to automatically be active at low volume and then degrade as volume is turned up.

The reason for this feature is related to the knowledge of the behavior of the human ear, which at low frequencies has a low sensitivity to low sound pressure levels and then rises in sensitivity at higher sound pressure levels. This has long been documented and is known as the **Fletcher-Monson curves.** *See Fig. 1:*

Fig. 1

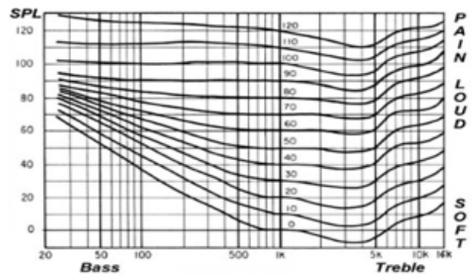


Fig. 1: Fletcher-Munson Equal Loudness Curves.

Fig. 2

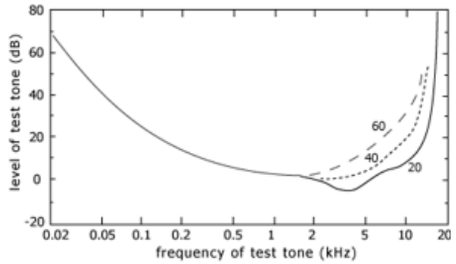


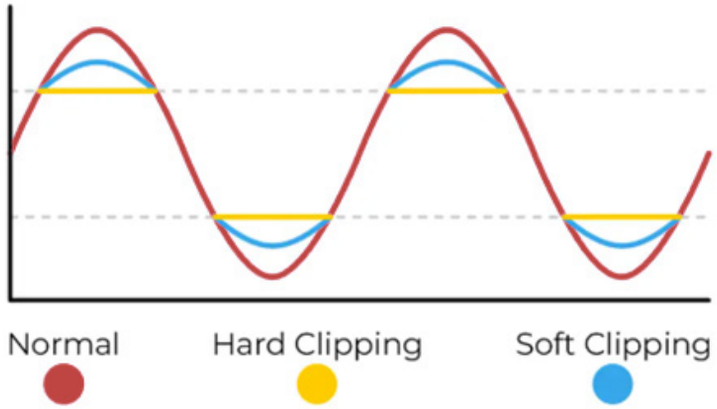
Fig. 2: Loudness function Compensation Curves.

The loudness function in amplifiers also boosts high frequencies at low SPL to compensate for reduced sensitivity to these tones, especially with age. *Fig. 2* shows loudness curves for typical hearing at ages 20, 40, and 60.

Soft clipping

Another commonly used principle for increasing the perceived loudness is by the introduction of soft clipping in the amplifier. *See Fig. 3:*

Fig. 3



Soft clipping is rounding off the peaks of transients, allowing for squeezing a little extra volume out and thereby helping increase the perceived loudness.

Obviously soft clipping introduces a small amount of distortion, but it prevents the signal from hard clipping and acts as a form of dynamic range compression.

Signal compression

Signal compression is probably the most common way of improving loudness nowadays. – Basically, all soundtracks are compressed for this reason.

First, what is compression? – Compression is a way to make sounds appear louder without simply turning them up. So, if you want a sound to be louder, why not just turn it up? The simple answer is, there is a hard limit to how loud you can turn up before "hitting the roof" of the dynamic range of the amplifier.
The dynamic range of an amplifier is the ratio between the largest signal it can handle without distortion and the smallest signal just above the amplifiers noise floor.

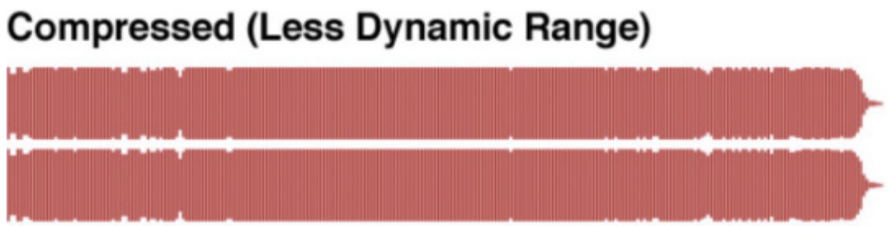
The dynamic range has a lot to do with the "perceived" volume or intensity of sound. Humans "perceive" loudness based on the average loudness (RMS) of a signal. Therefore, those sounds having a higher average loudness (RMS) will be perceived as being louder than a sound signal having a higher PEAK intensity.

Fig. 4 illustrates an uncompressed signal:

Fig. 4

On the other hand, *Fig. 5* shows the comparison to the same compressed signal (exaggerated for clarity):

Fig. 5



Signal compression is not the same as **file compression** used for reducing the overall size of an audio file. However, signal/dynamic range compression can indirectly impact file size, but the primary goal is to improve perceived loudness of audio, not to reduce file size.

Loudness function, soft clipping & signal compression techniques dealt with in the above sections of this paper all result in a rise in the **RMS power level** of the supplied signal to the loudspeaker. This, compared to the initially non processed signal will stress the loudspeaker both on thermal handling in voice coil as well as on increased diaphragm displacement (mechanical stress in diaphragm and voice coil wires).
This challenge is of course most severe for micro speakers being very small and compact but still capable of handling power level beyond 1W (size example: **8x15x2.5mm**).

For being able to handle this very genuine loudspeaker reliability issue, we fortunately today have access to **Smart Amps**.

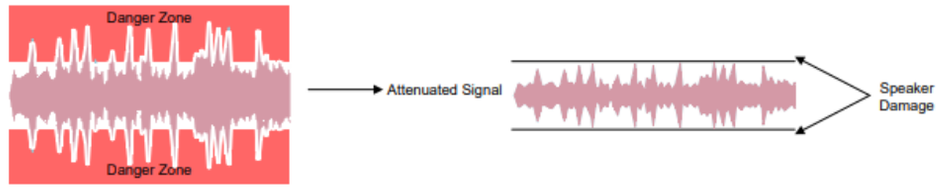
Smart Amps

Smart Amps has the capability to real-time monitor the temperature of the voice coil and excursion of the diaphragm in the speaker it drives.

Though, this is only possible, if the amplifier “knows” which loudspeaker it is supposed to drive.
Having this “knowledge” of the speaker, the real- time temperature of the voice coil and excursion of the diaphragm is controlled by an algorithm running in the DSP (Digital Signal Processor) inside the device and instantly updating the speaker model in real-time.

This is visualized in *Fig. 6:*

Fig. 6



The knowledge of the specific speaker must be delivered by the manufacturer of the speaker and a list of the needed parameters are shown in *Table 1*:

Table 1

Key Parameters	Obtained From Speaker Vendor Data Sheet
Xmax (mm)	Yes
Tmax (°C)	Yes
Temperature Coefficient (K^{-1})	Yes
Sd (cm^2)	Yes
Bl	Yes
Re (Ω)	Yes
f0 (Hz)	Yes
Tolerances of Re	Yes
Impedance transfer function	Yes
Excursion transfer function	Yes

As a case study, we describe the Ole Wolff OWS-111525TA-8C micro speaker (11×15×2.5 mm) in a sealed box. *See Fig. 7:*

Table 2 contains the maximum allowed parameters for excursion of the membrane and maximum voice coil temperature (supplied by Ole Wolff):

Fig. 7

Micro speaker OWS-111525TA-8C mounted into a sealed box.
(Blurred to protect customer confidentiality).

Table 2

X-max	Maximum linear excursion based on BL82%	+/- 0.20 mm peak
	Maximum peak excursion before damaging	+/- 0.25 mm peak
T-max	Voice coil max temperature	120°C
VC temp coef	Copper wire	0.0038
Power	1.0W rater / 1.3W maximum	

The linear parameters (Thiele- Small) for the micro speaker mounted in the sealed box are measured by manufacturer (Ole Wolff) as can be seen in *table 3*:

Table 3

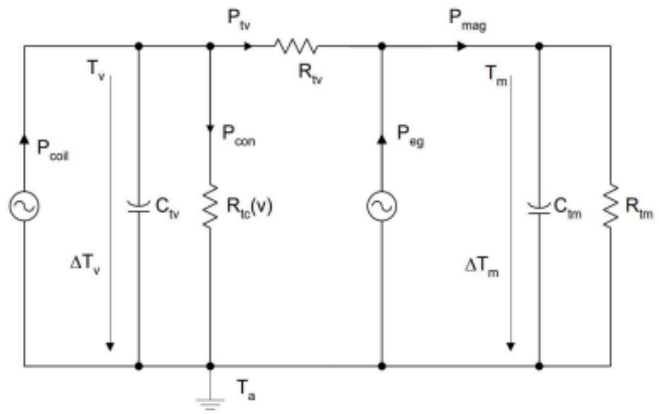
Electrical Parameters			
Re	7.02	Ohm	electrical voice coil resistance at DC
Le	0.032	mH	frequency independent part of voice coil inductance
L2	0.002	mH	para-inductance of voice coil
R2	0.26	Ohm	electrical resistance due to eddy current losses
Cmes	181.35	µF	electrical capacitance representing moving mass
Lces	0.12	mH	electrical inductance representing driver compliance
Res	2.22	Ohm	resistance due to mechanical losses
fs	1091.9	Hz	driver resonance frequency
Mechanical Parameters (using laser)			
Mms	0.054	g	mechanical mass of driver diaphragm assembly including air load and voice coil
Mmd (Sd)	0.053	g	mechanical mass of voice coil and diaphragm without air load
Rms	0.135	kg/s	mechanical resistance of total-driver losses
Cms	0.391	mm/N	mechanical compliance of driver suspension
Kms	2.56	N/mm	mechanical stiffness of driver suspension
Bl	0.547	N/A	force factor (Bl product)
Lambda s	0.202		suspension creep factor
Loss factors			
Qtp	2.099		total Q-factor considering all losses
Qms	2.764		mechanical Q-factor of driver in free air considering Rms only
Qes	8.728		electrical Q-factor of driver in free air considering Re only
Qts	2.099		total Q-factor considering Re and Rms only
Other Parameters			
Vas	0.0006	l	equivalent air volume of suspension
n0	0.009	%	reference efficiency (2 pi-radiation using Re)
Lm	71.78	dB	characteristic sound pressure level (at 1 m for 1 W @ Re)
Lnom	72.35	dB	nominal sensitivity (SPL at 1 m for 1 W @ Zn)
rmse Z	0.84	%	root-mean-square fitting error of driver impedance Z(f)
rmse Hx	3.63	%	root-mean-square fitting error of transfer function Hx(f)
Series resista	0.00	Ohm	resistance of series resistor
Sd	1.07	cm^2	diaphragm area

Finally, a thermal network for the micro speaker inside the box is derived based on Klippel AN19 document. *See Fig. 8:*

Fig. 8

Thermal Model, based on Klippel AN19 document

RTV	62,0	K/W
RTM	108	K/W
RTC(v)	160	K/W
CTV	0,0564	Ws/K
CTM	0,849	Ws/K



By feeding all these data into the data storage of the Smart Amp, the Smart Amp can “handshake” with the micro speaker in real-time assuring that the electrical signal supplied will go to the limit of the micro speaker’s handling capacity but never exceeding these limits.

The result is, as mentioned, that the speaker box can deliver the optimal loudness possible and thereby the best ratio of SPL/space occupied in the specific audio device.

Conclusion

Referring to the scope in this paper mentioning the audio performance target for the “old fashioned” hifi systems in households, namely the most life-like sound reproduction mirroring the original orchestra recordings to the utmost, and following the timeline to today’s portable audio devices, the audio performance target has moved significantly.

Due to loudness enhancement, audio compression etc. the sound signal does not represent the original recorded soundtrack to a very high degree anymore but has all the focus on loudness.

This seems to be a fair trade off. Otherwise, all these portable devices capable of delivering sound “on the run” would fall short of the audio performance expected by consumers of pocket-sized sound units.

Ole Wolff being a major supplier of micro loudspeakers for all portable sound devices, offers all the specific loudspeaker parameters on all their micro-speaker models needed for the smart Amp to “handshake” with the specific micro loudspeaker chosen for a given project.

This assuring the highest level of loudness possible in any portable sound device without sacrificing short as well as long time reliability of the audio performance.