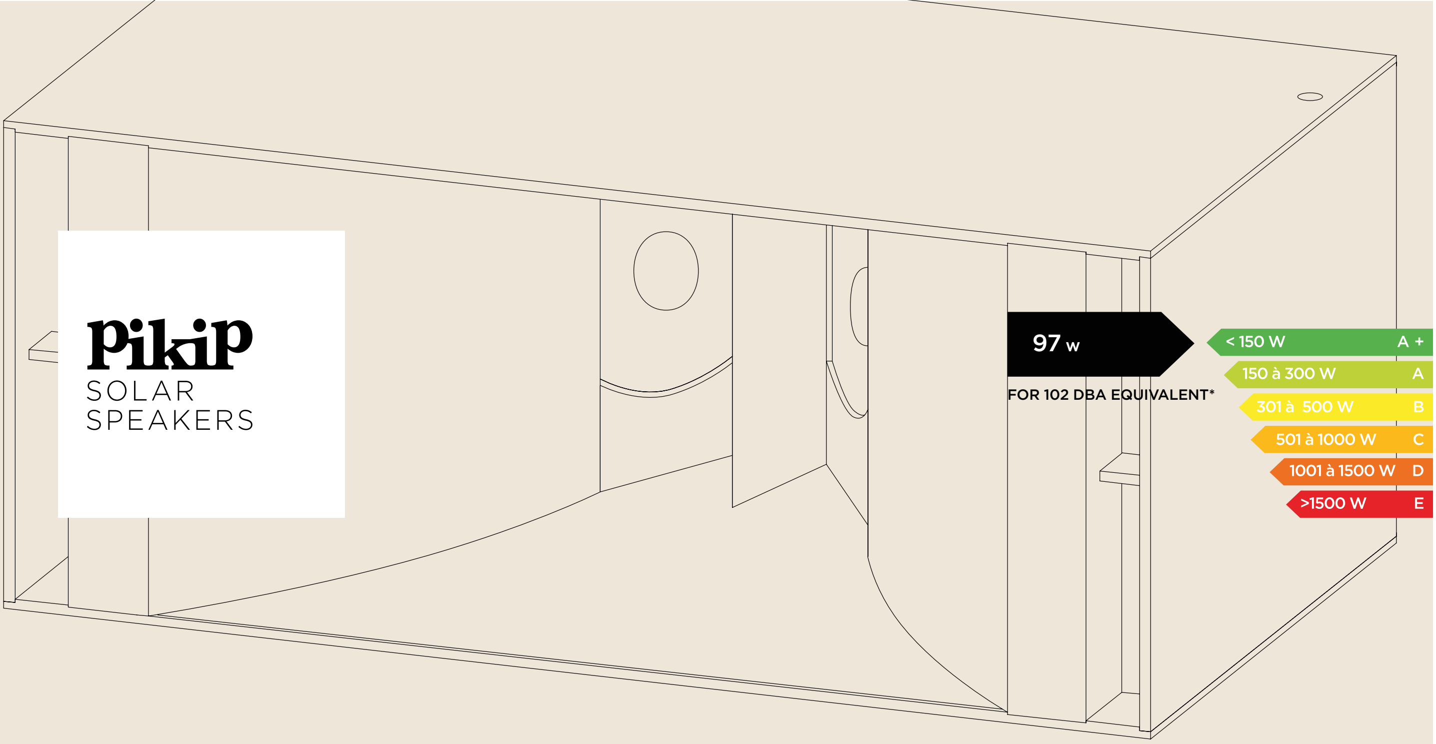


WHITE PAPER : ACOUSTIC EFFICIENCY LABEL

Characterization of Passive Speakers' Power Consumption

Energy sobriety is the reduction of power consumption, through lifestyle and social changes. It implies, among other things, to increase the efficiency of our day-to-day electrical devices and systems.
Sound is reproduced using electricity: sound signal is nothing else than an electrical signal, amplified in order to make loudspeakers' cones vibrate and create the sound we hear.

Loudspeaker drivers have always been the weak link of the audio chain. Speaker cabinets allow to increase efficiency, through the use of acoustic circuits that "load" the driver, that is adapt the acoustic impedance of the driver to the impedance of the surrounding air. Those circuits are numerous: horns, ports, resonators… Their main con is size. They can be large and cumbersome, but when finely tuned, they allow the speaker to have a high efficiency, which means that the ratio of acoustic power over electrical power gets close to 1.

With the increase of available amplifier power, in particular with the introduction of transistors, and then of class D amplification, the audio industry slowly turned away from the pursuit of high efficiency. Size reduction was considered more important than efficiency, and the use of horns decreased. The more amplifiers efficiency increased, the lower speakers efficiency became. Nowadays, festival sound systems can dissipate more than several hundreds kiloWatts.

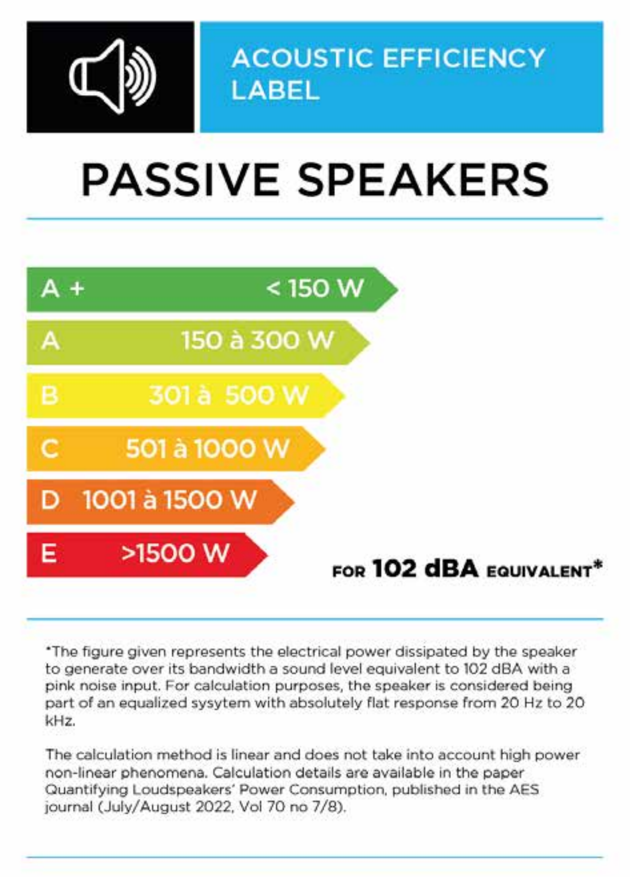
High efficiency is necessary not only for ecological reasons, but also for autonomy and practicality: a very power hungry speaker requires more battery and more solar panels. On the contrary, a very efficient speaker allows to reduce the battery size and the number of solar panels (for similar autonomy and sound level), which implies a reduction of size, weight, and cost for transport and storage.

OBJECTIVE

Having noted that currently existing metrics and standards are not suited for loudspeakers power consumption quantification, Pikip Solar Speakers developed new metrics. The results of the work - which covers a detailed analysis of the existing metrics and the introduction of new models of power prediction - have been published in the Audio Engineering Society Journal - the reference scientific journal for audio, under the title "Quantifying Loudspeakers Power Consumption".

The acoustic efficiency label is derived from one of the models introduced in the paper. It is a simple way of specifying the efficiency class of a loudspeaker. It classifies loudspeakers in six different categories from A+ to E), depending on the required power to generate a target sound level. Both class and power consumption are specified on the efficiency label.

The quantification is done in Watt for a sound level equivalent to 102 dBA. All details required for calculation and the reasons for the chosen conditions are given in the following.



ACOUSTIC EFFICIENCY LABEL

PASSIVE SPEAKERS

A +	< 150 W
A	150 à 300 W
B	301 à 500 W
C	501 à 1000 W
D	1001 à 1500 W
E	>1500 W

FOR **102 dBA** EQUIVALENT*

*The figure given represents the electrical power dissipated by the speaker to generate over its bandwidth a sound level equivalent to 102 dBA with a pink noise input. For calculation purposes, the speaker is considered being part of an equalized sysytem with absolutely flat response from 20 Hz to 20 kHz.

The calculation method is linear and does not take into account high power non-linear phenomena. Calculation details are available in the paper Quantifying Loudspeakers' Power Consumption, published in the AES journal (July/August 2022, Vol 70 no 7/8).

STATE OF THE ART

Currently, no metrics widely used by manufacturers or users allow for simple electrical power consumption quantification, such as for white goods or for cars.

Some of them, such as sensitivity, seems to give a relevant piece of information in that regard, but are actually misleading, and often wrongly used. For instance, high efficiency is often associated with high sensitivity, but they are two very different things, and a high sensitivity speaker can have a very low efficiency.

Electro-acoustic efficiency is well defined in a standard (IEC 60268-22:2020), but is too general to have a practical use, and isn't designed for music diffusion.

Over the years, authors have introduced some very useful and relevant metrics, but they are unfortunately little known and little used. Among those, the Constant Input Power (CIP) frequency response is worth citing. It is similar to the usual Constant Input Voltage frequency response, but is actually relevant for power consumption.

In summary, numerous metrics exist, each having pros and cons. However, none allows to directly quantify loudspeakers' power consumption.

PRINCIPLE AND PROTOCOL

On the one hand, the efficiency label needs to be simple to understand and to reproduce (the calculation must be based only on data easy to measure by manufacturers). On the other hand, it must give useful information on real life conditions power consumption. Obviously, conditions change drastically from one use case to the other, depending on the type of music, the sound operator, the venue… therefore, the chosen conditions are idealized, and try to reproduce a typical, universal use case.

1 - MEASURING CONDITIONS

- Input signal is pink noise (i.e a signal made of all frequencies, with a spectral power density decreasing in 1/f, that is 3 dB per octave) from 20 Hz to 20 kHz.

It is the best trade off between a very complex signal similar to actual music and an easy to generate and widely used signal.

- Speaker's frequency response is equalized so to be absolutely flat

It doesn't correspond to real use cases, but it limits the positive (but fictional) impact of characteristic that some badly designed speaker sometimes have (strong resonances, irregularities…). It is an easy equalization to apply for the calculation, and as there is as many equalization profiles as sound operators, it is simpler to target a flat and neutral response.

- The target level is 102 dBA, 5 meters away from the speaker.

102 dbA is the max level for French standards. 5 m is a reasonable trade off distance for the audience first rows. Again, it is more about comparisons than absolute values.

- The speaker is considered being part of a system reproducing perfectly a signal in the 20 Hz to 20 kHz bandwidth. The consumption calculation is done over the speaker's bandwidth specified in the data sheet.

The speaker is only fed with the part of the signal being in its data sheet bandwidth. It means that the speaker doesn't generate the entire target level, but only a portion of it that depends on its bandwidth, that is what is called 102 dBA equivalent level. Example: because of pink noise spectral distribution, the 1000-2000 Hz octave band and the 100-200 Hz octave band contribute equally to the overall level, although the latter is 100 Hz wide and the former 1000 Hz wide. However, due to the use of A-weighting, the equivalent level of the 1000-2000Hz octave band is 95 dBA, whereas 100-200 Hz octave band's equivalent level is 79 dBA. 20-20000 Hz octave band's equivalent level is obviously 102 dBA, as it is the reference. Bandwidth 20 Hz-20 kHz obviously has an equivalent of 102 dBA, as it is used as a reference.

- Data used for calculation (frequency response and impedance) must be measured in the linear range of the speaker, that is using small signals.

Small signals measurement is the standard for drivers characterization. Of course, speakers behave differently from one to another in their non-linear range, but having a common ground is necessary to allow comparison.

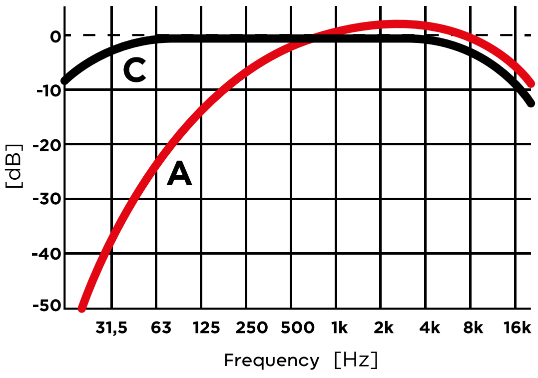
- Six efficiency categories exist (A+, A, B, C, D, E), ranging from a consumption inferior to 150 Watts for class A+ to a consumption superior to 1500 Watts for class E.

Class A+ and E have a 10 ratio that allows to cover the span of speakers usually found on the pro audio market.

WHY 102 DBA?

The level of 102 dBA chosen for the label corresponds to the French law regarding noise hazard prevention.

The limit is 102 dBA or 118 dBC over 15 minutes. The dBC limit helps take into account the low frequencies level which impact is greatly reduced by the A weighting.



Décret n° 2017-1244 du 7 août 2017 relatif à la prévention des risques liés aux bruits et aux sons amplifiés https://www.legifrance.gouv.fr/jorf/id/JORFTEXT000035388481

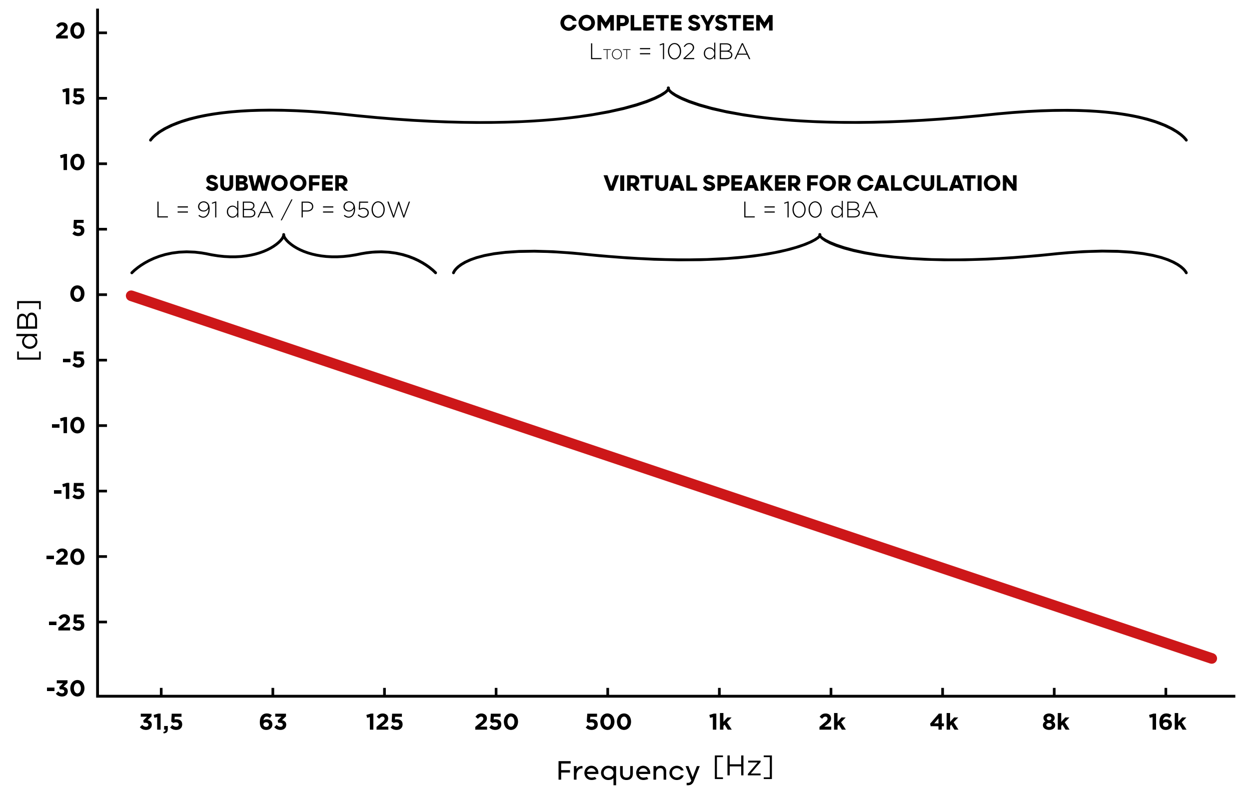


Illustration of the calculation for a subwoofer consumption. The 102 dBA equivalent level at 5 meters over the bandwidth 20-200 Hz is 91 dBA, for a power consumption of 950 Watt. The frequencies above 200 Hz are generated by a virtual speaker (102 dBA equivalent level = 100 dBA). The equalized and normalized frequency response of the speaker to a white noise is displayed in thirds of octave.

2 - CONSEQUENCES

Those conditions have the following consequences:

The first is that, if several speakers are used to reproduced the full 20-20000 Hz bandwidth (for instance a three-way system: 20-100 Hz subwoofer, 100-2000 Hz medium and 2-20 kHz tweeter), getting the total consumption for an absolute level of 102 dBA is just a matter of summing each speaker's consumption at their 102 dBA equivalent level.

Furthermore, it is difficult to compare speakers that have different bandwidths. A compression driver reproducing 2-15 kHz bandwidth needs less power for its equivalent level than a wide-band driver (50-1000 Hz), because the portion of signal (energy wise) is a lot lower, and because A weighting reduces drastically the contribution of low frequencies to the global level. Therefore, tweeters are more often in the higher classes than subwoofers.

Third, using the data-sheet bandwidth for calculation refrains the temptation to artificially extend the low cut-off limit. Indeed, lowering the data-sheet low-end limit to make a sub look more attractive is tempting, but it implies a rise of the consumption figure, since speakers often have a poor efficiency in the low frequencies.

Finally, the calculation is linear, and based on small signal data, therefore it does not take into account any power compression phenomena (thermal compression, air non-linearities, motor non-linearities, etc.)

CALCULATION DETAILS

Power calculation is based on the amplitude of the frequency response and on the complex impedance of the loudspeaker, measured in the linear range. Considering those are known, four steps lead to the final result:

First, it is necessary to work out L_c, the 102 dBA equivalent target level over the relevant bandwidth for a pink noise normalized at 20 Hz, with an overall level of 102 dBA, that is the portion of the sound level corresponding to that bandwidth.

Next, we work out L_{Uin}, the sound level in dBA generated by the perfectly equalized speaker over the aforementioned bandwidth, when fed with a pink noise input normalized at 20 Hz (to which is equalized is added), with a small RMS voltage U_{in} (linear range). From it, we deduce $U_{in}(f_k)$, the RMS input voltage for each frequency bin.
Third, we determine the gain difference Delta L between the target level L_c and the level generated by the speaker L_{Uin}, and we apply this gain to voltage $U_{in}(f_k)$ in order to get Ureq(102dbA$_{eq}$, f_k) ***Equation 1***

Four, we compute the total power P_{elec},tot(102dBA$_{eq}$), by sum the power per frequency bin, using the impedance and the input voltage U_{req}(102dBA$_{eq}$, f_k). ***Equation 2***

$$U_{req}(102dBA_{eq}, f_k) = U_{in}(f_k) \cdot 10^{\Delta L/20} \tag{1}$$

$$P_{elec,tot}(102dBA_{eq}) = \sum_{k=f_{min}}^{f_{max}} \Re(Z(f_k)) \cdot \frac{U_{req}^2(102dBA_{eq}, f_k)}{|Z(f_k)|^2} \tag{2}$$

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