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Power-based thermal limits for micro-speaker protection algorithms

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ABSTRACT

The increasing demand for high-definition audio in mobile platforms is creating the necessity of adequate operation limits for smart amplifiers to safely maximize the power delivered to micro-speakers. The maximum voice-coil temperature (T_{max}) is an important parameter for protection algorithms that prevent damage. Standard tests used by micro-speaker suppliers to specify T_{max} provide a conservative estimate that depends on the voice-coil materials. Other tests consider the rated noise power, a specification obtained by rigorous lifetime tests. This paper investigates the thermal limits when micro-speakers operate at their specified rated power. These power-based thermal limits are contrasted with values of T_{max} specified in datasheets. The evidence found is used to recommend procedures to measure power-based thermal limits that avoid over-protection.

1 Introduction

The maximum voice-coil temperature for safe operation (T_{max}) is an important tuning parameter in smart amplifiers' protection algorithms that prevent thermal or mechanical overload in speakers. The increasing demand of mobile audio applications is creating the necessity of defining new protection limits for micro-speakers to ensure safe operation and deliver more output power.

Vignon and Scarlett [1] originally proposed rating methods to specify limits for another important protection parameter which is the maximum voice-coil excursion (X_{max}). Their contribution constitutes the first attempt to establish new limits for micro-speakers and simplify the communication between transducer manufacturers, software providers, and system integrators. Subsequently, Klippel [2] formulated rigorous definitions of X_{max} and comprehensively classified the protection algorithms reported until then in patents.

Regarding the specification of thermal limits, to the best of our knowledge, two definitions co-exist:

- *Material-based* T_{max}: A conservative estimate referred to voice-coil materials like enameled wire and glue; it is provided by micro-speaker suppliers in datasheets.
- *Power-based* T_{max}: Considers the rated noise power, a specification obtained by rigorous and adequate lifetime tests recommended by IEC [3] and AES [4].

Because power-based measurements are more reliable than material-based estimates, current protection algorithms that strictly use the material-based T_{max} might be causing over-protection.

This paper focuses on power-based thermal limits. We discuss the results of two experiments that monitored the voice-coil temperatures of 8 micro-speakers when they operated at their specified rated power (1.13 W). The monitored temperatures were contrasted with the material-based T_{max} (100 °C).

Section 2 describes the temperature rise time test. Sections 3 details the lifetime test that monitored temperature. Section 4 discusses the variation of spectral curves before and after the lifetime test. Section 5 summarizes the method to measure power-based thermal limits. Section 6 concludes this paper.

2 Temperature rise time

This experiment monitored the rise of voice-coil temperature for different audio sources as recommended by IEC [3] and AES [4]: pure tones, sweep signals, white noise, and pink noise. Every signal was reproduced at the specified rated power.

Figure 1 exemplifies measurements on a single micro-speaker. For all signals, temperatures exceeded the material-based T_{max} within a short period of time ranging from 20 to 70 seconds. A similar behavior was observed on every micro-speaker. Moreover, performances below the material-based T_{max} always operated at a relatively small power when compared with the rated power.

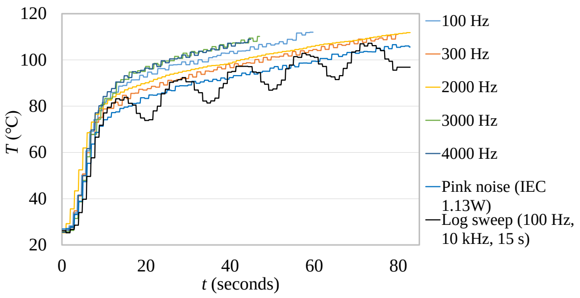

Figure 1. Rise of voice-coil temperature.

3 Lifetime test

This experiment monitored the voice-coil temperature throughout a lifetime test that lasted 72 hours. The audio source was composed of a 3 kHz pure tone of 15 seconds followed by a pink noise of 5 seconds; it was continuously reproduced by every micro-speaker during the whole lifetime test.

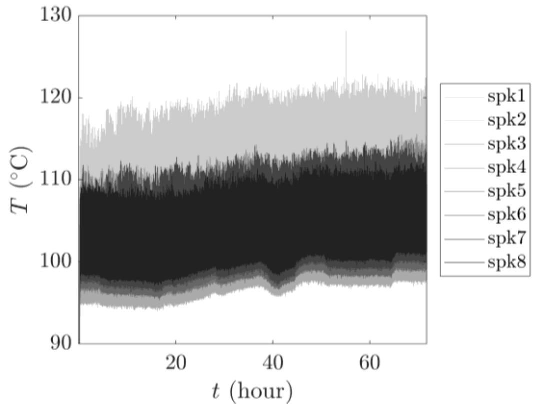

Figure 2. Voice-coil temperature during lifetime test.

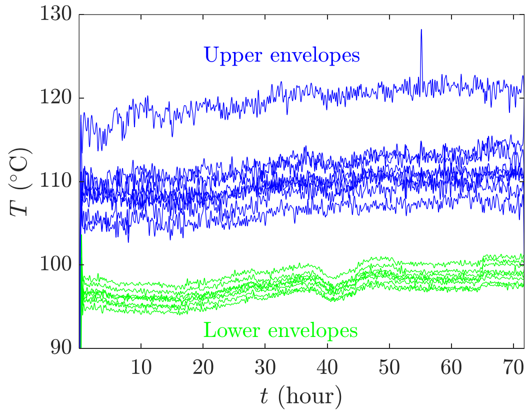

Figure 3. Envelopes of temperatures in Fig. 2.

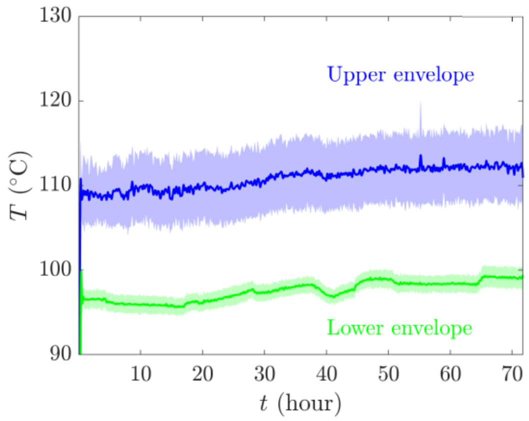

Figure 4. Statistics of envelopes in Fig. 3.

Figure 2 shows voice-coil temperatures (T) monitored on every micro-speaker throughout the lifetime test. Figure 3 shows the upper and lower peak envelopes of T for every micro-speaker. The envelopes were determined using spline interpolation over local maxima separated by at least 8.3 minutes.

Figure 4 summarizes the statistics of envelopes for all the micro-speakers. Here, mean values are shown with solid lines whereas standards deviations, with shaded areas. The blue solid line shows that, throughout the lifetime test, all micro-speakers continued to work at a power-based T_{max} that always exceeded the material-based T_{max} (100 °C).

4 Spectral variation due to lifetime test

The spectral curves that characterize the performance of micro-speakers were also measured before and after the lifetime test to detect whether they were damaged or not. The used equipment ensures reliable results in the interval [0.5, 10] kHz.

Figure 5 shows statistics for spectral curves (black) and their corresponding variations (blue). In the reliable frequency range, mean variations in transfer functions (TF) remained below 1 dB; this value can be considered in the order of the minimal perceptible change in amplitude [5]. In the full frequency range, mean variations in total harmonic distortions (THD) were below 10 % whereas mean variations in impedances (Z) remained below 2 %.

Throughout the lifetime test, all variations remained within the operability range and no significant differences among spectral curves were found. Moreover, the monitored power (mean and maximum values 0.7 W and 1.08 W, respectively) remained below the specified rated power (1.13 W). It can therefore be said that none of the micro-speakers suffered damage after the lifetime test.

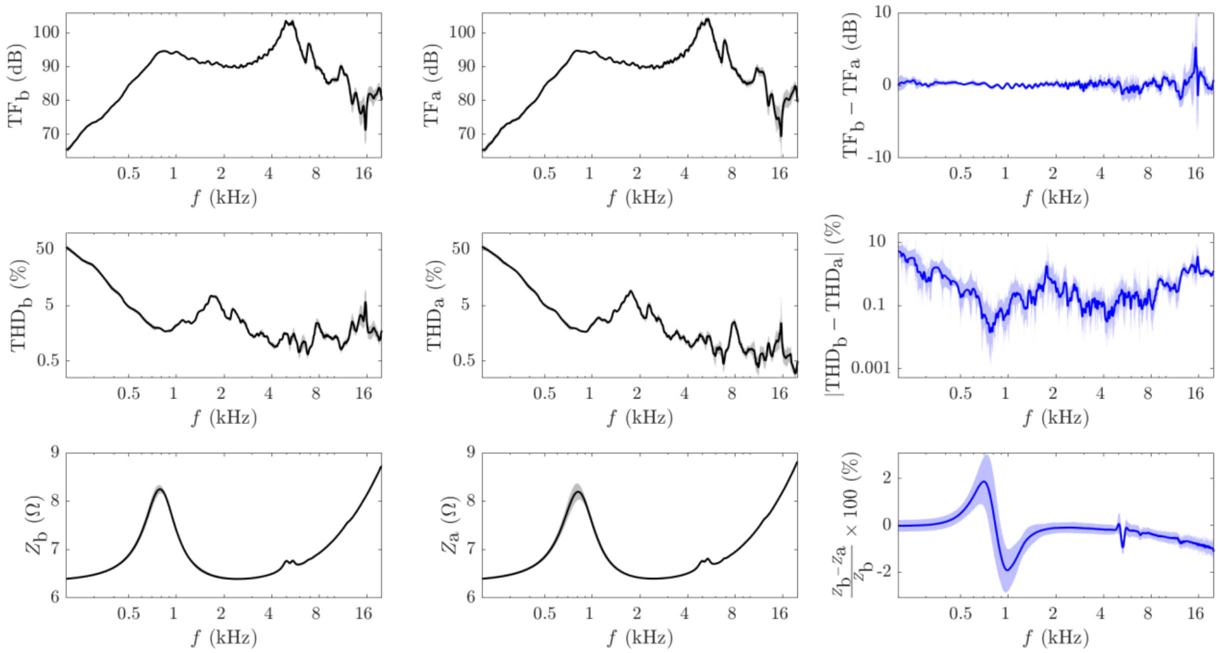

Figure 5. Statistics of spectral curves before (first column) and after (second column) life-time tests. The third column shows the variations. Spectral curves correspond to micro-speaker transfer functions (TF: first row), total harmonic distortions (THD: second row), and electrical impedances (Z: third row).

5 Methods and procedures

This section describes the methods and procedures used to measure the thermal limits discussed in previous sections.

Table 1 details the specifications of the 8 micro-speakers used in all experiments.

Name	**Value**
Rated power	1.13 W
short-term maximum power	1.7 W
Material-based $T_{\max}$	100 °C
$X_{\max}$	0.4 mm
Electrical impedance (Z)	7Ω±15% @2 kHz and 2.83 Vrms
Resonant frequency	700±100 Hz @ 2.83 Vrms
Maximum frequency	20 kHz
Sensitivities	93+3/-2 dB @ 2.83 Vrms/10 cm/baffle @ 2 kHz >84 dB @ 2.83 Vrms/10 cm/baffle @ 500 Hz

Table 1. Specifications of the 8 micro-speakers.

A linear model was used to estimate the voice-coil temperatures along time from normalized voice-coil resistances at ambient temperatures. To ensure a relative error below 2%, the constant of linearity was calibrated for ambient temperatures ranging from 25 °C to 95 °C at a spacing of 10 °C. An optimal calibration was obtained through error minimization of the linear model in a least-squares sense.

The equipment used in both experiments comprised a lifetime test circuit board, an APx500 audio analyser, and a heating box. The lifetime test circuit board was used to monitor in real-time the voltage and current delivered to the micro-speakers placed on the heating box. Voltage and current were used to estimate voice-coil resistance, voice-coil temperature, diaphragm displacement, and power. The audio analyser was subsequently used to obtain spectral curves of performance such as impedance, transfer function, and total harmonic distortion.

6 Conclusions

Evidence found in the temperature rise test and in the lifetime test, respectively detailed in sections 2 and 3, supports the suitability of specifying power-based thermal limits for protection algorithms used in smart amplifiers. In both tests, power-based thermal limits always exceeded the material-based $T_{\max}$. The use of such limits in fine-tuning of protection algorithms can help to avoid overprotection while maximizing the power delivered to micro-speakers. Therefore, we recommend the methods and procedures described in section 5 to specify a power-based $T_{\max}$.

Ongoing research is being conducted for obtaining instantaneous and overall thermal limits, which are being tested in the protection algorithms used in the smart audio amplifiers of the SIA810X family [6] to safely maximize their output power.

References

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