The Sound of Silence:
The Relationship Between Expansion and EIN

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Introduction

Noise plays a critical role in hearing aid acceptance and perceived sound quality,[1] but "noise" is not a singular phenomenon. In most environments, ambient noise is the predominant noise source, masking any internal noise produced by the hearing aid.[2] On the other hand, the internal noise may become audible in particularly quiet environments.

The total audible noise level depends on the hearing aid's gain, amplifying the small, constant internal noise produced by the microphone and hearing aid circuit, along with external sound. Historically, standard input noise tests developed for linear amplifiers have allowed comparison and acceptable limits to be set in amplification systems like hearing aids. In linear operation, the equivalent input noise (EIN) of a hearing aid is a practical metric to quantify the constant internal noise independently of the fitting parameters. This had led hearing care professionals to expect the EIN specification to reflect the level of audible internal noise. However, factors such as acoustic coupling, expansion, and noise reduction algorithms complicate this notion. Focusing on expansion in particular (although it reduces the level of noise heard in quiet), the use of expansion in EIN measurements undermines the utility of EIN in characterizing hearing aid hardware.

This whitepaper revisits the definitions around EIN; how it is measured and interpreted; and ambiguities around this number when comparing across manufacturers.

The Case for EIN

The noise level depends on gain

Low-level noise is an inherent characteristic of electronic components, including microphones and other circuitry[3] and is present even in the absence of external acoustic input. We refer to the total self-generated noise as "internal noise" throughout this paper.

This internal noise can be broken down into input- and output-stage noise, as depicted in Figure 1. Here, the input-stage noise includes both the microphone and circuit noise, with the microphone noise typically the dominant of the two.

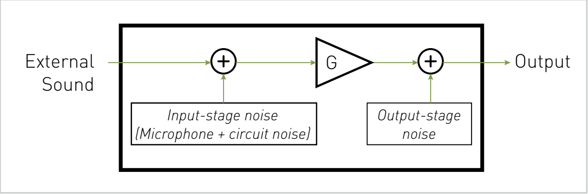


Figure 1: A simple hearing aid model showing sources of noise.[3]

The total hearing aid noise is dominated by input-stage noise since it has gain (G) applied to it. This contrasts with the output-stage noise, which may become audible only when the microphone gain is significantly reduced. The small contribution of the output-stage noise to the total noise floor is negligible when the microphone signal is present at the output.

If we assume linear operation, the overall noise level is a function of the configured gain setting. For example, Figure 2 shows that if a noise level of A_0 is measured in a very quiet environment with 0 dB of gain, then the noise level of A_{30} will be measured when the gain is increased to 30 dB.

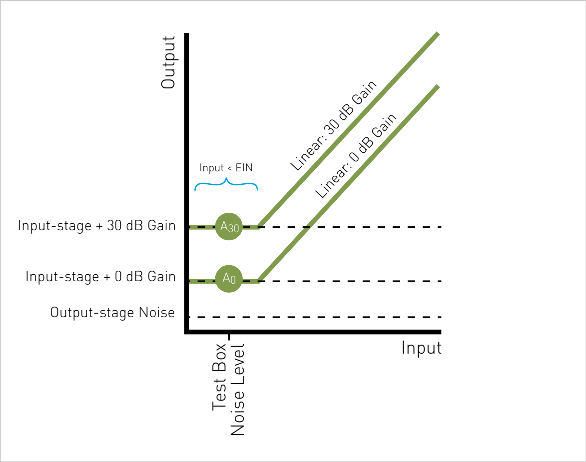


Figure 2: With linear processing, the hearing aid's noise output is a function of gain. The flat segment of the Input/Output curves (labeled in blue) represents the area where the input signal is significantly lower than the hearing aid's input-stage noise.

EIN does not depend on gain

The gain-dependence of internal noise at the output makes it tedious to compare the system noise of different hearing aids with different parameters. The EIN metric solves this by referring the measured noise level to the input, based on the reference test gain (RTG). In other words, we can characterize the noise produced by a real hearing aid in a silent environment as an equivalent acoustic input-noise level being amplified by a noiseless hearing aid. Although the gain appears explicitly in the EIN formula, it is intended to cancel out the gain amplifying the internal noise *(seen in Figure 1)*, thus the true EIN does not depend on gain.

EIN Measurement

The EIN measurement consists of two separate measurements made in a 2cc coupler: 1) a gain measurement with a 50 dB SPL stimulus, which is averaged across the high frequency average (HFA) frequencies: 1, 1.6, and 2.5 kHz, and 2) a broadband noise measurement with no stimulus. For these tests, the device must be configured in test-mode at reference test setting (RTS) and with adaptive features disabled.

EIN is defined as follows:

$$\textbf{EIN = 2cc output noise – 2cc HFA Gain}\big|_{\textbf{RTS}}$$

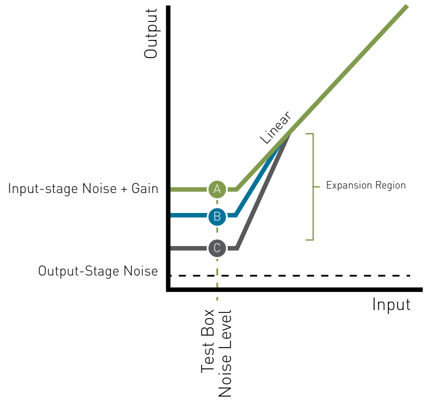
where the bandwidth of the output noise measurement is defined as 200 Hz – 5 kHz or 200 Hz – 8 kHz according to the American National Standards Institute and International Electrotechnical Commissio (ANSI) S3.22[4] and International Electrotechnical Commission (IEC) 60118-0[5] hearing aid standards, respectively.

Both standards prohibit the use of adaptive features during these tests; however, the language regarding the use of expansion is less restrictive. For example, the IEC states, "If low-level expansion is active in the hearing aid during the measurement, this condition shall be stated by the manufacturer."[4] Consequently, expansion is used by some manufacturers during EIN measurement, but is inconsistently reported and specific expansion settings are never given. This makes it difficult to compare EIN values across manufacturers.

The measured EIN can be decreased by expansion

The EIN metric inherently assumes that the RTS gain is the same gain that will be applied to the input-stage noise during the EIN measurement. That is precisely how we can refer the measured output noise back to the input. When expansion is applied however, the effective gain amplifying the noise is actually lower, which reduces the measured EIN.

Therefore, the use of expansion theoretically allows for the "measurement" of arbitrarily low EINs, limited only by the output-stage noise floor, as shown in Figure 3. For example, with the mild expansion shown by line B, the level of the noise floor reflects the reduced gain on input-stage noise. The output noise measurements (A, B, C) are converted into EIN estimates by subtracting the HFA gain, as shown in the lower panel of Figure 3.



Expansion	Measured Output [dB SPL]	HFA RTG [dB]	Calculated EIN [dB SPL]
Off	A 61	37	24
Mild	B 54	37	17
Aggressive	C 41	37	4

Figure 3: Theoretical display of varying expansion ratios resulting in different measured output levels and therefore different calculated EIN values.

What do these EIN values mean?

The preceding example raises the question of how this array of possible EIN values can be interpreted. Only in the linear case does the EIN represent the total input-stage noise as an acoustic pressure, as assumed in the basic model. One interpretation of this simple linear EIN is that it defines the lower bound for an acoustic input signal that can be detected. Regardless of the hearing aid gain, an acoustic signal that is quieter than the linear EIN will be masked by the input-stage noise. The use of expansion decreases the value of EIN in the test but does not reduce the true input-stage noise or the lowest detectable signal level.

In contrast, the expanded EIN is challenging to interpret. It represents the equivalent sound pressure level of the sound producing the expanded noise level, but as if expansion were turned *off*. On the surface, this technique produces more attractive EIN values and reflects expansion that the patient experiences, but it can no longer effectively characterize the hearing aid hardware or its input noise.

Does EIN predict real-world noise performance?

The relationship between EIN and the audibility of internal noise is not straightforward. Some factors complicating their relationship include acoustic coupling, environmental noise—which is often higher in level than the EIN of modern hearing aids—and nonlinear processing, which reduces the perceived noise floor without changing the true EIN.

For example, consider that low frequencies contribute substantially to the EIN, yet the majority of fittings involve venting, which significantly reduces the low frequency output delivered to the eardrum. Consequently, the low-frequency contribution to the EIN is likely inaudible,[6] meaning that the EIN measure may overestimate the audibility of noise in unoccluded fittings.

Other practical factors such as the patient's own hearing loss affect the perception of noise from the hearing aid while in quiet environments. Patients with near normal hearing in certain frequency regions may perceive noise more clearly than those with more severe hearing loss. While linear EIN remains a useful hardware specification, other factors limit the utility of ANSI/IEC EIN in predicting real-world noise performance, in most cases.

Finally, a practical clinical use of EIN measurements is to check that the hearing aid is working properly—higher than normal EIN measures are commonly indicative of an issue with the microphone.

Clinical evaluation of real-world application

EIN measurements are an important piece in the evaluation of hearing aid microphone performance, but it is the hearing aid user's perception of hearing aid noise in quiet that ultimately dictates acceptability of the hearing aid.

In a clinical evaluation, 53 hearing aid users (mean age, 72 years [SD, 8.0]; 32% female) were recruited to investigate the perception of hearing aid noise in a quiet environment, across receiver-in-the-canal and in-the-ear custom hearing aid styles. The average hearing loss for the group was mild-sloping-to-severe sensorineural hearing loss. Figure 4 shows the range of audiograms of the participants evaluated.

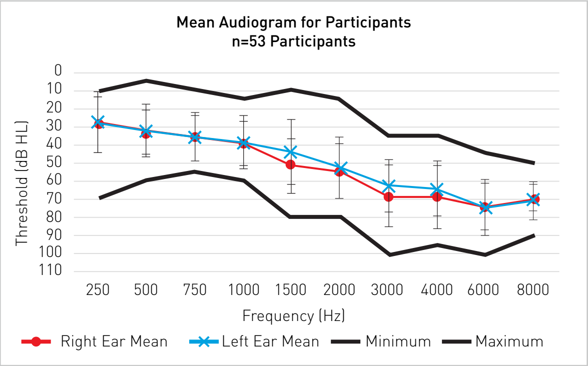


Figure 4: Average audiogram of the participants evaluated. Red and blue lines and symbols show the average hearing thresholds for the right and left ears, respectively. The standard deviation is plotted by frequency for right and left ears. The black lines show the minimum and maximum hearing thresholds

Participants were fit with hearing aids that were programmed for their hearing loss and asked to answer "yes" or "no" on whether they heard circuit noise from their hearing aids, based on their experience evaluating the hearing aids in the field for approximately six weeks. Ninety-six percent (51 out of 53) of participants reported not hearing any circuit noise from the Edge AI hearing aids. For the two that did, one reported it as "5-Not Bothersome at all" and one reported it was "3-Moderately Bothersome" on a 5-point Likert scale, with "1" being "Extremely Bothersome" and "5" being "Not at all Bothersome."

For mild-sloping-to-severe hearing loss, the results indicated overall negligible perception of hearing aid circuit noise with the Edge AI hearing aid devices.

Conclusion

EIN is intended to characterize the internal noise of hearing aid hardware, but is often mischaracterized as the noise level that a hearing care professional and patient might hear while the aid is in use. In linear operation, the EIN metric reflects the noise generated by the hearing aid hardware. However, the unstandardized use of expansion in test mode leaves this value open to interpretation and more difficult to compare between products. We encourage hearing care professionals to consider whether expansion and noise reduction is being used when looking at data sheets; expansion should always be *off* in test mode to make fair assessments of EIN. More importantly, hearing care professionals and their patients should focus on how internal noise is (or isn't) perceived in quiet. This level of perception depends on a myriad of factors such as noise reduction algorithms, acoustic coupling, and the patient's own hearing loss.

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Author Biographies

Daniel Smieja is a Senior Acoustic Engineer at Starkey. He joined Starkey in 2019 with a BEng from McMaster University and an MHSc in Clinical Engineering from the University of Toronto. He is passionate about improving the next generation of hearing aids through novel transducer applications and acoustic modeling.

Kris Peck is a Principal Electrical Engineer at Starkey with 25 years of experience in the hearing industry, contributing to designs of many new hearing aid products. Since joining Starkey in 2004 he has been immersed in many aspects of electrical and electroacoustic design, continuously working to improve acoustic performance and sound quality. He also serves on the IEC and ANSI committees for the development of hearing aid standards.

Maddie M. Olson, Au.D., joined Starkey as a Research Audiologist in 2021, and earned her Au.D. at the University of Wisconsin-Madison. She organizes product validation efforts to evaluate hearing technologies prior to market release, ensuring patients' needs are being met. Additionally, Dr. Olson evaluates device efficacy over the lifetime of hearing aids, allowing for longitudinal assessment of patient benefit through post-market studies. She is particularly interested in areas of research that help to investigate long-term, positive patient outcomes for hearing aid users.

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