Evaluating Microphone Noise

Signal-to-noise ratio (SNR) is one of the most important microphone metrics. Microphone noise is important because it is an indication of the quietest sound that the microphone can detect. When used in an array, microphone noise becomes even more important because the signal out of an array could be proportional to the difference between microphone signals, which can start to become similar in magnitude to the microphone noise. Although microphone noise is very important, it is often described with a single number, SNR, which does not necessarily represent the microphone's input noise across the frequency spectrum of interest. Further, the SNR can be increased or decreased by filtering the microphone output; so it is not really a characteristic of the microphone itself, but of the microphone system. The hearing aid industry often uses 1/3 octave band equivalent input noise (EIN) to evaluate microphone noise. This does not have many of the shortcomings of the SNR measurement listed above, but it can be more difficult to use because it is not a single number. Here, we introduce the equalized SNR as a microphone noise metric. The best metric to use depends on the system into which the microphone is being designed but equalized SNR is a more useful metric for many modern applications with signal processing capability.

The only two pieces of information necessary to calculate SNR, 1/3 octave band EIN, or equalized SNR are the microphone frequency response and output noise spectral density. The microphone frequency response should be measured from 20 Hz to 20 kHz and is typically reported in V/Pa. The output noise spectral density should also be measured from 20 Hz to 20 kHz and is typically reported in V/$\sqrt{Hz}$. Output noise may also be reported as power spectral density in V^2/Hz. An example of a frequency response measurement and output noise measurement can be seen in Figure 1.

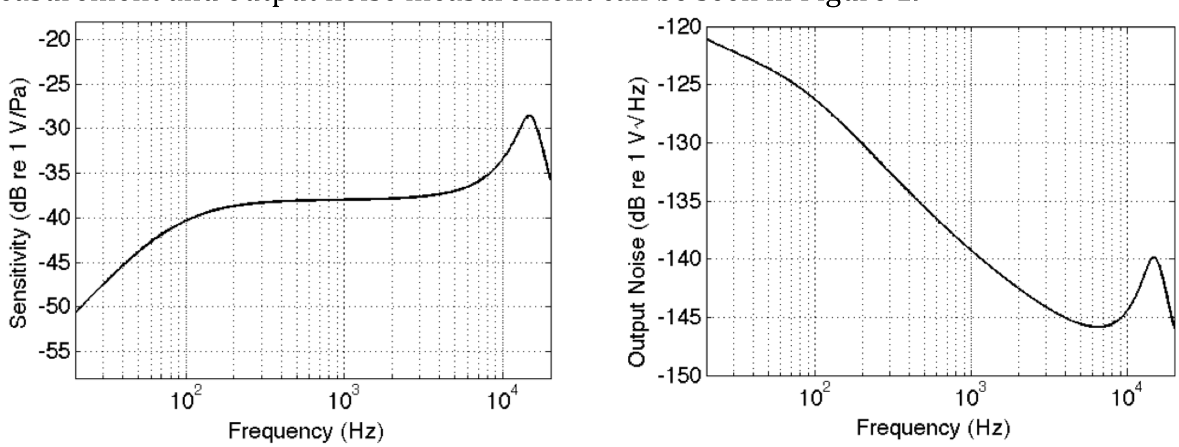

Figure 1. Frequency response and output noise of an example microphone. These two measurements can be used to calculate SNR, 1/3 octave band input noise, or equalized SNR.

The SNR calculation requires only the sensitivity at 1 kHz and the output noise spectral density. This is shown graphically in Figure 2. Because the signal is only considered at 1 kHz, the frequency response of the microphone below and above 1 kHz has no impact on the "signal" in the SNR calculation. Attenuation of the microphone output at frequencies other than 1 kHz, for example, the low-frequency roll-off, would reduce the noise but would have no impact on the signal, thereby improving SNR. Similarly, increased sensitivity such as that at the resonance frequency will cause an increased output noise and decreased SNR.

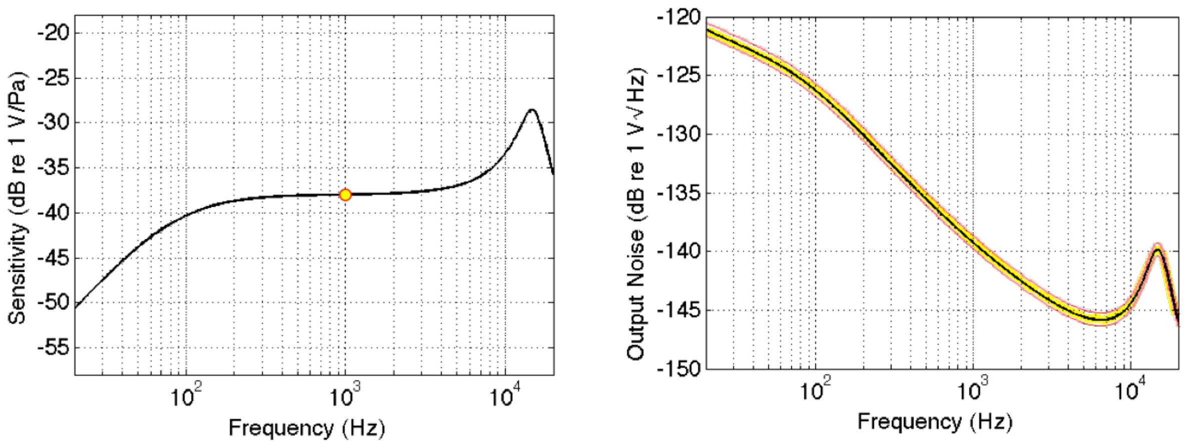

Figure 2. SNR is calculated by using the sensitivity at 1 kHz and the integrated noise over the entire frequency range from 20 Hz – 20 kHz.

An example SNR calculation can be carried out using the microphone outputs in Figure 1. In this example, the SNR will be converted to the decibel scale at the end of the calculation. The calculation can similarly be performed by converting to the decibel scale at other points in the process. The signal is the sensitivity at 1 kHz, which is 12.6 mV/Pa (-38 dB re 1 V/Pa). The noise is the integrated, A-weighted noise from 20 Hz to 20 kHz. The output noise in Figure 1b is A-weighted by multiplying it by the A-weighting curve, which is defined by IEC 61672 as

$$A(f) = 20\log_{10}\left[\frac{f_4^2 f^4}{\left(f^2+f_1^2\right)\left(f^2+f_2^2\right)^{1/2}\left(f^2+f_3^2\right)^{1/2}\left(f^2+f_4^2\right)}\right] - A_{1000} \qquad (1)$$

where f_1 = 20.60 Hz, f_2 = 107.7 Hz, f_3 = 737.9 Hz, f_4 = 12,194 Hz, and A1000 = -2.000 dB on the decibel scale. A plot of the A-weighting curve and the output noise multiplied by the A-weighting curve can be seen in Figure 3a and 3b. This output noise spectrum is then squared, to give units of V^2/Hz and integrated from 20 Hz to 20 kHz to give the square of the A-weighted, integrated output noise. The A-weighted output noise, integrated from 20 Hz to 20 kHz for this microphone is 7.97 uV (-102 dB). The SNR is, therefore,

$$SNR = \frac{12.6\cdot 10^{-3}}{7.97\cdot 10^{-6}} = 1{,}581 = 64dB\ . \qquad (2)$$

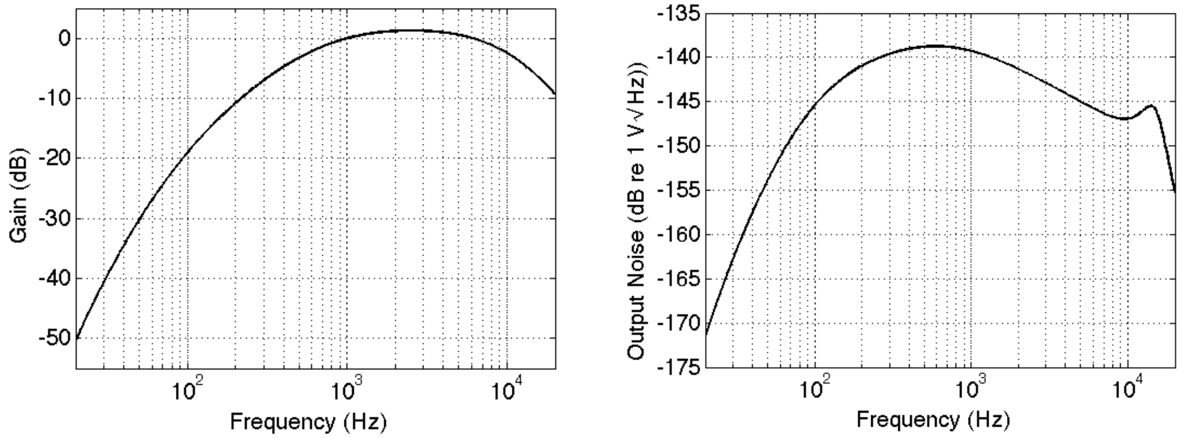

Figure 3. The A-weighting curve is shown on the left and the A-weighted output noise is shown on the right. This A-weighted output noise is used for the SNR calculation.

If the frequency response of the microphone is not flat, the SNR number alone can be misleading and can be a poor indicator of a microphones true performance. For example, many hearing aid microphones have a resonance well below 20 kHz. Most hearing aids, however, have enough signal processing ability to adjust amplification at various frequency bands. For example, if the microphone has higher output noise near resonance but the sensitivity has increased by more than the noise, then the input referred noise near resonance has actually decreased, giving lower equivalent input noise and better overall performance. Therefore, in the hearing aid industry, it is common to input-refer the noise at several 1/3 octave frequency bands instead of input-referring at a single frequency. This is shown graphically in Figure 4.

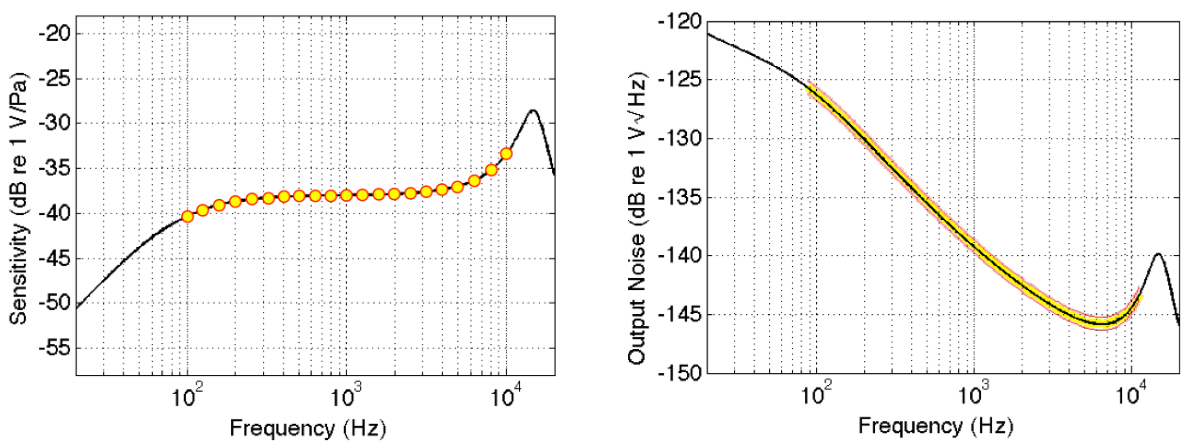

Figure 4. 1/3 Octave EIN is calculated by using the sensitivity at the center of each 1/3 octave frequency bin and the integrated noise over that frequency range.

An example of calculating 1/3 octave band EIN can be carried out using the same frequency response and output noise curves in Figure 1. For this calculation, the 1/3 octave bands are commonly divided with center frequencies of approximately 100 Hz, 125

Hz, 160 Hz, 200 Hz, etc. The full set of N center frequencies, starting at approximately 100 Hz can be calculated using the equation

$$f_{center} = 2^{6.621+n/3}, n = 0 \ldots N-1. \quad (3)$$

The boundary frequencies of the 1/3 octave bins can be calculated by adding or subtracting 1/6 from the exponent in Equation 3. The EIN for each band is calculated in a similar way as the SNR calculation above, except A-weighting is not used. The sensitivity at the center frequency is used to input refer the noise across a band. The first band has a center frequency of 98 Hz, and the band spans 88 Hz to 110 Hz. The, integrated noise from 88 Hz to 110 Hz is 2.3 uV. The sensitivity at 98 Hz is 9.5 mV/Pa. The EIN is calculated by input-referring the integrated noise using the center frequency sensitivity (dividing the integrated noise by sensitivity), giving 242 uPa or 21.7 dB SPL. This same method is used to calculate EIN at all frequency bands from 100 Hz to 10 kHz and the 1/3 octave band EIN is plotted in Figure 5.

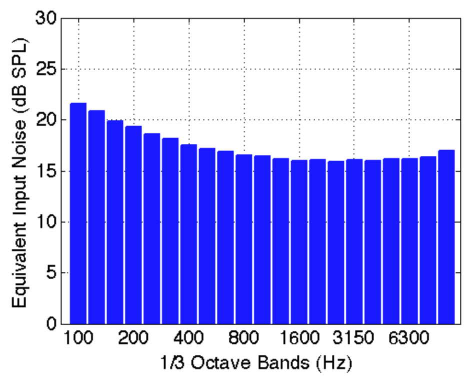

Figure 5. 1/3 octave equivalent input noise plot. This plot provides detail about the noise in specific parts of the frequency spectrum, giving a system designer a better idea of the microphone's input noise across the frequency spectrum relative to the SNR number.

This 1/3 octave band EIN is helpful to system designers because it provides input noise information across the frequency spectrum. If a system has the ability to adjust gain across the frequency range, this gives a better indication of the microphone performance. A single number, however, is often more useful than a plot like this when comparing performance of many microphones. Equalized SNR, therefore, provides a single number but also uses the sensitivity across the frequency spectrum to input-refer the noise. The equalized SNR is shown, graphically, in Figure 6.

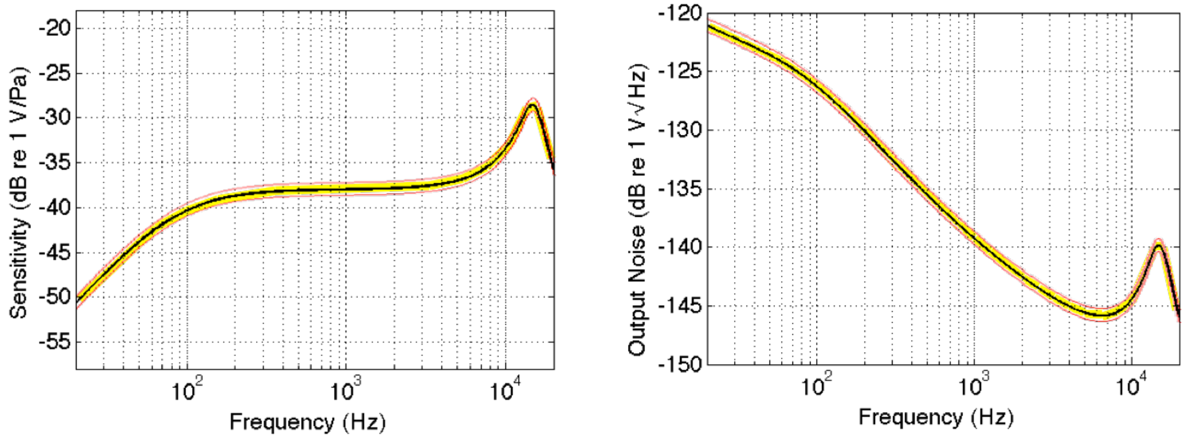

Figure 6. Equalized SNR is calculated by using the sensitivity and output noise over the entire spectrum from 20 Hz to 20 kHz.

An example of an equalized SNR calculation can, again, be carried out using the frequency response and output noise plots in Figure 1. To calculate equalized SNR, the output noise spectrum, in V/ $\sqrt{Hz}$, is converted to an input noise spectrum, in Pa/ $\sqrt{Hz}$, using the frequency response plot from 20 Hz to 20 kHz. A plot of the input-referred noise spectrum and A-weighted input referred noise spectrum can be seen in Figures 7a and 7b. This input-referred noise is now A-weighted and integrated as was previously done with the output-referred noise. The A-weighted, integrated noise is 523 uPa, or 28.4 dB SPL. The equalized SNR is, therefore, 94 dB – 28.4 dB = 65.6 dB. For this particular microphone, this means that by filtering the frequency response to give a flat response across the frequency range, the SNR would improve from 64.0 dB to 65.6 dB. These three methods of evaluating microphone noise are compared in Table 1.

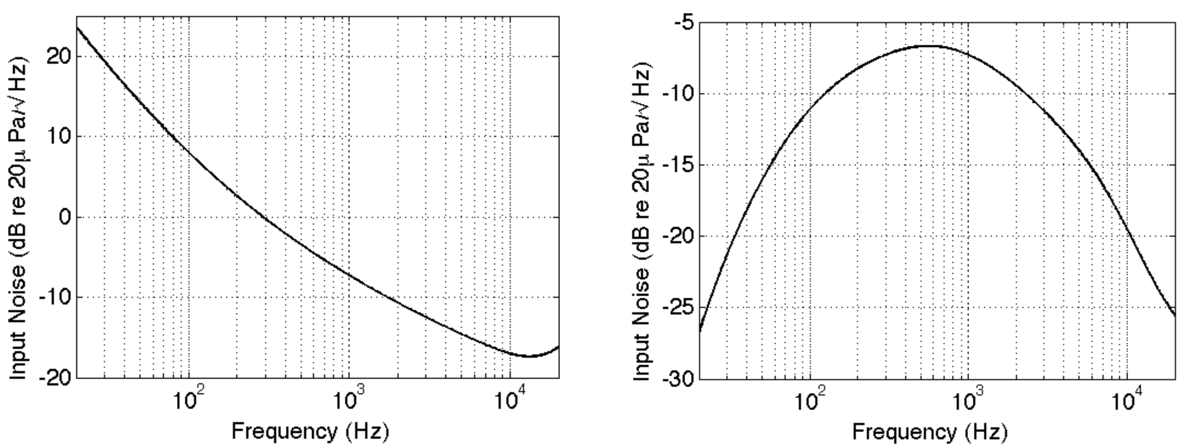

Figure 7. Input-referred noise spectral density and A-weighted input-referred noise spectral density. Unlike the output noise the input-referred noise does not show a peak at resonance or a roll-off at low frequency due to the response of the microphone.

Table 1. Comparison of SNR, 1/3 Octave Band EIN, and Equalized SNR.

	SNR	1/3 Octave Band EIN	Equalized SNR
Unchanged by adding filters or equalization		X	X
Appropriate for systems with DSP		X	X
Requires only a single sensitivity measurement	X		
Requires sensitivity measurements across frequency spectrum		X	X
Single Number	X		X
A-weighted	X		X