Understanding Microphone Sensitivity

By Jerad Lewis

Sensitivity, the ratio of the analog output voltage or digital output value to the input pressure, is a key specification of any microphone. Mapping units in the acoustic domain to units in the electrical domain, it determines the magnitude of the microphone output signal given a known input.

This article will discuss the distinction in sensitivity specifications between analog and digital microphones, how to choose a microphone with the best sensitivity for the application, and why adding a bit (or more) of digital gain can enhance the microphone signal.

Analog vs. Digital

Microphone sensitivity is typically measured with a 1 kHz sine wave at a 94 dB sound pressure level (SPL), or 1 pascal (Pa) pressure. The magnitude of the analog or digital output signal from the microphone with that input stimulus is a measure of its sensitivity. This reference point is but one characteristic of the microphone, by no means the whole story of its performance.

The sensitivity of an analog microphone is straightforward and easy to understand. Typically specified in logarithmic units of dBV (decibels with respect to 1 V), it tells how many volts the output signal will be for a given SPL. For an analog microphone, sensitivity, in linear units of mV/Pa, can be expressed logarithmically in decibels:

$$Sensitivity_{dBV} = 20 \times \log_{10}\left(\frac{Sensitivity_{mV/Pa}}{Output_{REF}}\right)$$

where $Output_{REF}$ is the 1000 mV/Pa (1 V/Pa) reference output ratio.

Given this information, with the appropriate preamplifier gain, the microphone signal level can be easily matched to the desired input level of the rest of the circuit or system. Figure 1 shows how the microphone's peak output voltage (Vmax) can be set to match an ADC's full-scale input voltage (Vin) with a gain of Vin/Vmax. For example, an ADMP504's maximum output voltage of 0.25 V could be matched to an ADC with a 1.0 V full-scale peak input voltage with a gain of 4, or 12 dB.
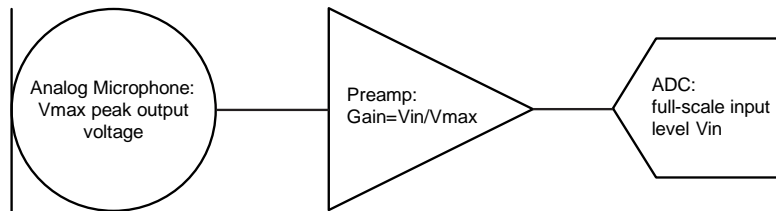

Figure 1. Analog Microphone Input Signal Chain with Preamp to Match Microphone Output Level to ADC Input Level

The sensitivity of digital microphones, with units dBFS (decibels with respect to digital full scale), is not so straightforward. The difference in units points to a subtle contrast in the definition of sensitivity of digital microphones compared to that of analog microphones. For an analog microphone with a voltage output, the only limit to the size of the output signal is the practical limit of the system's voltage supplies. Although it may not be practical for most designs, there is no physical reason why an analog microphone couldn't have 20 dBV sensitivity, with a 10 V output signal for a reference-level input signal. This sensitivity could be accomplished as long as the amplifiers, converters, and other circuits could support the required signal levels.

Sensitivity of a digital microphone is less flexible; it depends on a single design parameter, *maximum acoustic input*. As long as the full-scale digital word is mapped to the microphone's maximum acoustic input (the only sensible mapping, really), the sensitivity *must* be simply the difference between this maximum acoustic signal and the 94 dB SPL reference. So, if a digital microphone's maximum SPL is 120 dB, then its sensitivity will be –26 dBFS (94 dB – 120 dB). There is no way to tweak a design to make the digital output signal higher for a given acoustic input, unless the maximum acoustic input is lowered by the same amount.

For digital microphones, sensitivity is measured as a percentage of the full-scale output that is generated by a 94 dB SPL input. For a digital microphone, the conversion equation is

$$Sensitivity_{dBFS} = 20 \times \log_{10}\left(\frac{Sensitivity_{\%FS}}{Output_{REF}}\right)$$

where *Output_{REF}* is the full-scale digital output level.

One last *very* confusing piece of this comparison is the inconsistent usage of peak and rms levels between digital and analog microphones. The microphone's acoustic input levels in dB SPL are always *rms* measurements, regardless of the type of microphone. The output of analog microphones is referenced to 1 V$_{rms}$, as rms measurements are more commonly used for comparing analog audio signal levels. However, the sensitivity and output level of digital microphones are given as peak levels because they are referred to the full-scale digital word, which is a peak value. In general, this convention of using peak levels to specify the output of digital microphones must be kept in mind when configuring downstream signal processing that may rely on precise signal levels. For example, dynamic range processors (compressors, limiters, and noise gates) typically set thresholds based on rms signal levels, so a digital microphone's output must be scaled from peak to rms by lowering the dBFS value. For a sinusoidal input, the rms level is 3 dB (the logarithmic measure of (FS/√2) below the peak level; this difference between rms and peak may be different for more complex signals. For example, the ADMP421, a MEMS microphone with *pulse-density-modulated* (PDM) digital output, has a sensitivity of –26 dBFS. A 94 dB SPL sinusoidal input signal will give a –26 dBFS *peak* output level, or a –29 dBFS *rms* level.

As the outputs of digital and analog microphones have different units, comparing one type to another can be confusing; however, they share a common unit of measure in the acoustic domain, *SPL*. One may have an analog voltage output, another a modulated PDM output, and a third an I^{2}S output, but their maximum acoustic input and signal-to-noise ratio (SNR, the difference between the 94 dB SPL reference and the noise level) can be directly compared. By referring to the acoustic domain, not the output format, these two specifications provide a convenient way to compare different microphones. Figure 1 shows the relationship between an acoustic input signal and the output levels of analog and digital microphones for a given sensitivity. Figure 2 (a) shows the ADMP504 analog microphone, which specifies –38 dBV sensitivity and 65 dB SNR. Changing its sensitivity relative to the 94 dB SPL reference point on the left would result in sliding the dBV output bar up to decrease sensitivity or down to increase sensitivity.
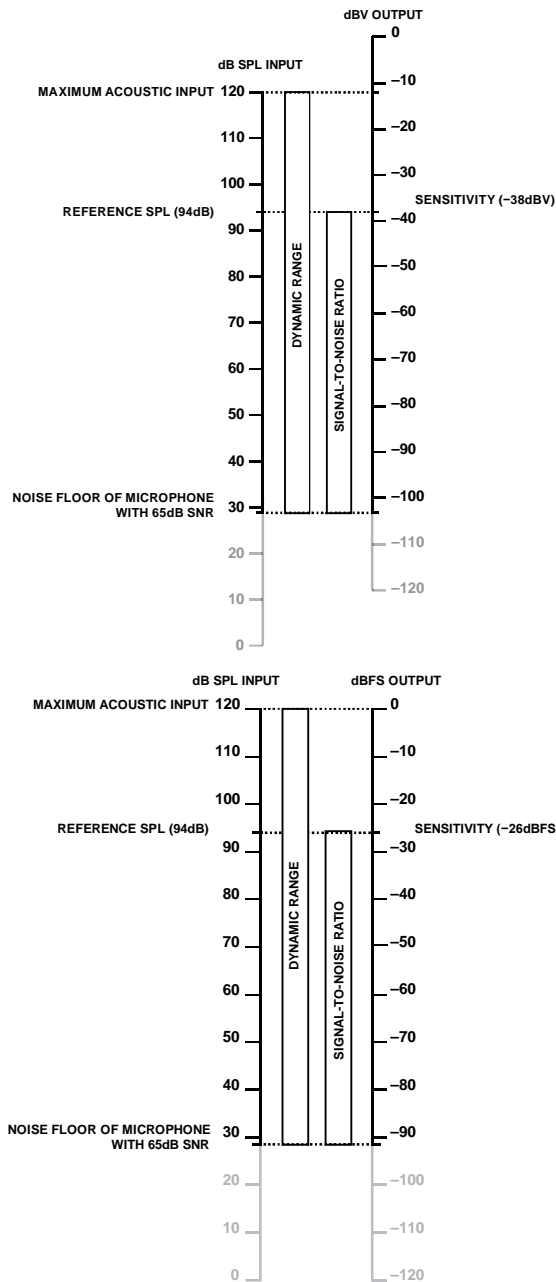
dBV OUTPUT
0

dB SPL INPUT

MAXIMUM ACOUSTIC INPUT 120 · · · · · · · · · · −10

110 −20

100 −30

SENSITIVITY (−38dBV)
REFERENCE SPL (94dB) −40

90

DYNAMIC RANGE   SIGNAL-TO-NOISE RATIO

80 −50

70 −60

60 −70

50 −80

40 −90

NOISE FLOOR OF MICROPHONE
WITH 65dB SNR 30 −100

20 −110

10 −120

0

dB SPL INPUT   dBFS OUTPUT

MAXIMUM ACOUSTIC INPUT 120 · · · · · · · · · · 0

110 −10

100 −20

REFERENCE SPL (94dB) SENSITIVITY (−26dBFS)

90 −30

DYNAMIC RANGE   SIGNAL-TO-NOISE RATIO

80 −40

70 −50

60 −60

50 −70

40 −80

NOISE FLOOR OF MICROPHONE
WITH 65dB SNR 30 −90

20 −100

10 −110

0 −120

Figure 2. Mapping Acoustic Input Level to (a) Voltage Output Level for an Analog Microphone; (b) Digital Output Level for a Digital Microphone

Figure 2 (b) shows the ADMP521 digital microphone, which specifies −26 dBV sensitivity and 65 dB SNR. This illustration of the input-to-output level mapping for a digital microphone shows that the sensitivity of this microphone cannot be adjusted without breaking the mapping between the maximum acoustic input and the full-scale digital word. Specifications such as SNR, dynamic range, power supply rejection, and THD are better indicators of microphone quality than sensitivity.

Choosing Sensitivity and Setting Gain

A high-sensitivity microphone isn't always *better* than a low-sensitivity microphone. Sensitivity tells something about the *characteristics* of the microphone, but not necessarily about its *quality*. A balance between the microphone's noise level, clipping point, distortion, and sensitivity determines whether a microphone is a good fit for a particular application. A microphone with a

high sensitivity may need less preamp gain before the analog-to-digital conversion, but it may have less headroom before clipping than a microphone with lower sensitivity.

In near-field applications, such as cell phones, where the microphone is close to the sound source, a microphone with higher sensitivity is more likely to reach the maximum acoustic input, clip, and cause distortion. On the other hand, a higher sensitivity may be desirable in far-field applications, such as conference phones and security cameras, where the sound is attenuated as the distance from the source to the microphone increases. Figure 3 shows how the distance of the microphone from the sound source can affect the SPL. The level of an acoustic signal decreases by 6 dB (one-half) each time the distance from the source is doubled.
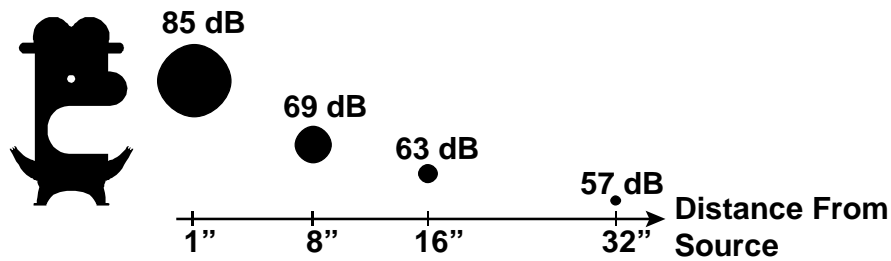

Figure 3. Sound Pressure Level at the Microphone is Reduced as the Distance from the Source Increases

For reference, Figure 4[i] shows the typical SPL of various sound sources, from quiet recording studios (below 10 dB SPL) up to the threshold of pain (above 130 dB SPL), the point at which the sound causes pain for the average person. Microphones can rarely cover all—or even most—of this range, so choosing the right microphone for the required SPL range is an important design decision. The sensitivity specification should be used to match the microphone's output signal level across the dynamic range of interest to the common signal level of the audio signal chain.
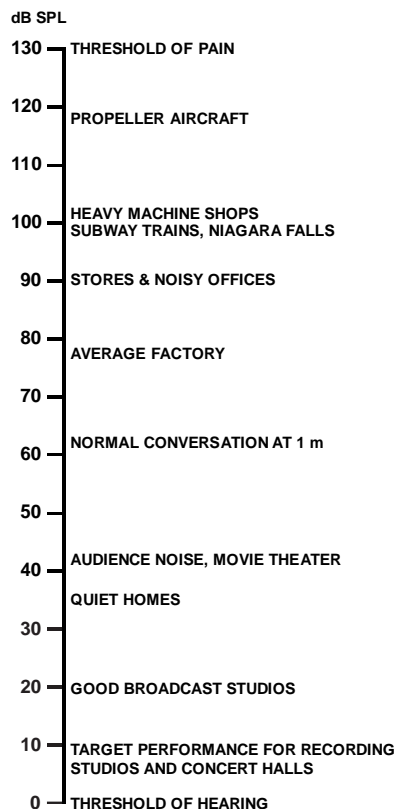

Figure 4. Sound Pressure Level of Various Sources

Analog microphones have a wide range of sensitivities. Some dynamic microphones might have sensitivity as low as –70 dBV. Some condenser microphone modules have integrated preamps so they have extra-high sensitivity of –18 dBV. Most analog electret and MEMS microphones have sensitivity between –46 dBV and –35 dBV (5.0 mV/Pa to 17.8 mV/Pa). This level is a good compromise between the noise floor— which can be as low as 29 dB SPL for ADMP504 and ADMP521 MEMS microphones—and the maximum acoustic input—which is typically about 120 dB SPL. An analog microphone's sensitivity can be tuned in the preamp circuit that is often integrated in the package with the transducer element.

Despite the perceived inflexibility of a digital microphone's sensitivity, the level of the microphone signal can be easily adjusted with gain in the digital processor. With digital gain, there is no danger of degrading the noise level of the signal as long as the processor has a sufficient number of bits to fully represent the dynamic range of the original microphone signal. In an analog design, every gain stage will introduce some noise into the signal; it is up to the system designer to ensure that each gain stage is quiet enough to keep its injected noise from degrading the audio signal. As an example, we can look at the ADMP441, a digital (I^2S) output microphone with a maximum SPL of 120 dB (–26 dBFS sensitivity) and an equivalent input noise of 33 dB SPL (61 dB SNR). The microphone's dynamic range is the difference between the largest (max SPL) and smallest (noise floor) signals it can faithfully reproduce (120 dB – 33 dB = 87 dB for the ADMP441). This dynamic range can be reproduced with a 15-bit data word. A 1-bit shift of the data in a digital word results in a 6 dB shift in the signal level, so even a 16-bit audio processor with a 98 dB dynamic range could use 11 dB of gain or attenuation before the original dynamic range is compromised. Note that in many processors, the digital microphone's maximum acoustic input is mapped to the DSP's internal full-scale level. In this case, adding any amount of gain reduces the dynamic range by an equal amount and lowers the system's clipping point. Using the ADMP441 as an example, adding 4 dB of gain in a processor with no headroom above full-scale would cause the system to clip with a 116 dB SPL signal.

Figure 5 shows a digital microphone, with either I^2S or PDM output, connected directly to a DSP. In this signal chain, no intermediate gain stage is necessary because the microphone's peak output level already matches the DSP's full-scale input word.
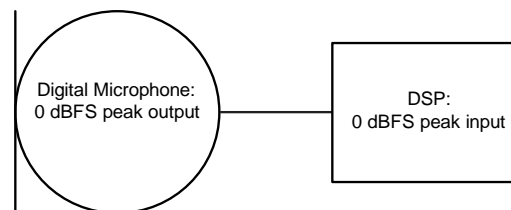

Figure 5. Digital Microphone Input Signal Chain Connected Directly to a DSP

Conclusion

This article explained how to understand a microphone's sensitivity specification, how to apply it to a system's gain staging, and why although sensitivity is related to SNR, it is not an indication of the microphone's quality as is SNR. Whether designing with an analog or digital MEMS microphone, this should help a designer choose the best microphone for an application and to get the fullest performance from that device.

Additional Material:

"Microphone Specifications Explained." Application Note AN-1112. InvenSense. 2013.

Author

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[1] Eargle, John, *The Microphone Book*, Elsevier/Focal Press, 2004.