MICROPHONE SPECIFICATIONS EXPLAINED

INTRODUCTION

A MEMS microphone IC is unique among InvenSense, Inc., products in that its input is an acoustic pressure wave. For this reason, some specifications included in the data sheets for these parts may not be familiar, or familiar specifications may be applied in unfamiliar ways. This application note explains the specifications and terms found in MEMS microphone data sheets so that the microphone can be appropriately designed into a system.

SENSITIVITY

The sensitivity of a microphone is the electrical response at its output to a given standard acoustic input. This is expressed as the ratio of the input pressure to the electrical output (voltage or digital word). The standard reference input signal for micro-phone sensitivity measurements is a 1 kHz sine wave at 94 dB sound pressure level (SPL), or 1 pascal (Pa, a measurement of pressure). A microphone with a higher sensitivity value has a higher level output for a fixed acoustic input than a microphone with a lower sensitivity value. Microphone sensitivity in decibels (dB) is typically a negative number; therefore, a higher sensitivity is a smaller absolute value.

It is important to note the units presented with the sensitivity specifications of the microphone. It is incorrect to directly compare the sensitivity of two microphones if the sensitivity is not specified with the same unit. For analog microphones, the sensitivity is typically specified in units of dBV, that is, decibels with reference to 1.0 V rms. For digital microphones, the sensitivity is typically specified in dBFS, that is, decibels with reference to a full-scale digital output (0 dBFS). For digital microphones, a full-scale signal is defined as the highest signal level that can be output from the microphone; for InvenSense MEMS microphones, this level is 120 to 140 dB SPL. See the Acoustic Overload Point section for a fuller description of this signal level.

A microphone's sensitivity tolerance indicates the range of sensitivity for any given individual microphone. In the data sheet, this is shown as the minimum and maximum sensitivity specification, but is commonly discussed in terms of plus/minus some dB value. The sensitivity tolerance of InvenSense' microphone ranges from ±1 dB to ±3 dB.

Analog microphones' sensitivity can be measured with units mV/Pa. This measurement is converted to a decibel value with the following equation:

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

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

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 (1.0).

The sensitivity of a PDM output microphone is specified in units of dBFS (decibels relative to a full-scale digital output). A 0 dBFS sine wave is defined as a signal whose peak just touches the full-scale code of the digital word (see Figure 1). This measurement convention means that signals with a different crest factor may have an rms level higher than 0 dBFS. For example, a full-scale square wave has an rms level of 3 dBFS.

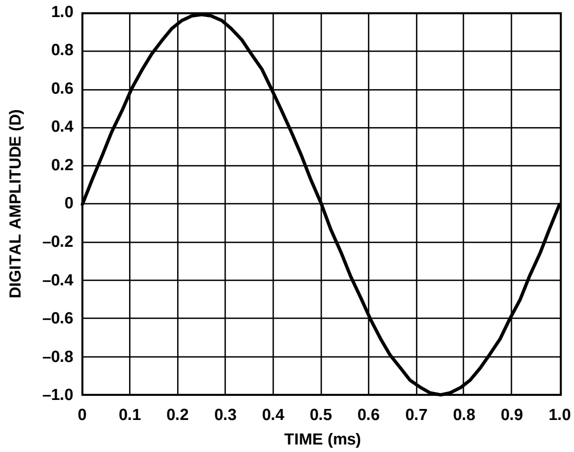

Figure 1. 1 kHz, 0 dBFS Sine Wave

The definition of a 0 dBFS signal must be understood when measuring the sensitivity of a digital microphone. An acoustic input signal of a 1 kHz sine wave at 94 dB SPL applied to a digital microphone like the ADMP521 results in an output signal with a −26 dBFS level. This means that the output digital word peaks at −26 dB below the digital full-scale level. A common misunderstanding is that the output has an rms level of −29 dBFS; however, this is not the case because of the definition of a 0 dBFS sine wave.

There is no commonly accepted unit of measurement to express the instantaneous level of a digital signal output from the microphone, as opposed to the rms level of the signal. Some measurement systems express the instantaneous level of an individual sample in units of D, where 1.0 D is digital full scale (see Figure 1). In this case, a −26 dBFS sine wave has peaks at 0.05 D.

Higher sensitivity does not always indicate a better microphone. A microphone with higher sensitivity typically has less headroom between the output level under typical conditions, such as conversational speech, and the maximum output level. In near-field (close-talking) applications, a microphone with higher sensitivity is more likely to cause distortion. This distortion often reduces the overall dynamic range of the microphone.

DIRECTIONALITY

Directionality describes the pattern in which the microphone's sensitivity changes when the sound source changes position in space. All InvenSense MEMS microphones are omnidirectional (or omni), which means that they are equally sensitive to sound coming from all directions, regardless of the orientation of the microphone. Figure 2 shows a 2-axis polar plot of the microphone's response. This plot looks the same regardless of whether the microphone's port is oriented in the x-y, x-z, or y-z plane.

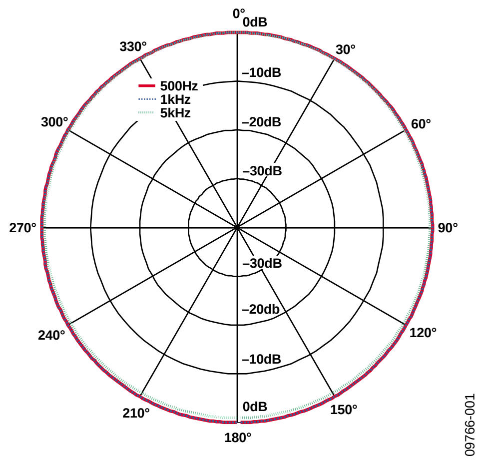

Figure 2. Omnidirectional Microphone Response Plot

The directional response of a system may not be omnidirectional when an omni microphone is designed into a larger enclosure, such as a cell phone. For the system designer, an omnidirectional microphone provides greater flexibility in the design of the system response to an acoustic input than if the microphone itself has a directional response.

Multiple omnidirectional microphones can be arranged in arrays to create various directivity patterns and for beamforming applications.

SIGNAL-TO-NOISE RATIO (SNR)

The signal-to-noise ratio (SNR) specifies the ratio of a reference signal to the noise level of the microphone output. This measurement includes noise contributed by both the microphone element and the ASIC incorporated into the MEMS microphone package. The SNR is the difference in decibels between the noise level and a standard 1 kHz, 94 dB SPL reference signal.

SNR is calculated by measuring the noise output of the microphone in a quiet, anechoic environment. This specification is typically presented over a 20 kHz bandwidth as an A-weighted value (dBA), which means that it includes a correction factor that corresponds to the human ear's sensitivity to sound at different frequencies. When comparing SNR measurements of different microphones, it is important to make sure that the specifications are presented using the same weighting and bandwidth; a reduced bandwidth measurement makes the SNR specification better than it is with a full 20 kHz bandwidth measurement.

EQUIVALENT INPUT NOISE (EIN)

Equivalent input noise (EIN) is the output noise level of the microphone, expressed in dB SPL, as a theoretical external noise source placed at the microphone's input. Input SPLs below the EIN level are under the noise floor of the microphone and outside the dynamic range of signals for which the microphone produces an output. EIN can be derived from either the dynamic range or SNR specification as follows:

EIN = acoustic overload point − dynamic range

EIN = 94 dB − *SNR*

The EIN of a microphone with 62 dB SNR and 120 dB acoustic overload point is 32 dB SPL—approximately the SPL that would be generated by a soft whisper in a quiet library at a distance of 5 meters. Figure 3 and Figure 4 show the EIN of the microphones.

DYNAMIC RANGE

The dynamic range of a microphone is a measure of the difference between the loudest and quietest SPLs to which the microphone responds linearly. The dynamic range of a microphone is not the same as its SNR (in contrast with audio ADCs or DACs, where the dynamic range and SNR are typically equivalent).

The SNR of the microphone measures the difference between the noise floor and a 94 dB SPL reference, but the microphone still has a great deal of useful signal response above this reference level. The microphone responds linearly to acoustic signals from 94 dB SPL up to its acoustic overload point (AOP). Therefore, the dynamic range of a MEMS microphone is the difference between its AOP and EIN. For example, the ADMP504 with an acoustic overload point of 120 dB SPL and EIN of 29 dB SPL has a dynamic range of 91 dB. Figure 3 shows the relationship between an acoustic input measured in dB SPL and a microphone's voltage output in dBV. The dynamic range and SNR measurements are shown between these two scales for reference. Figure 3 uses an ADMP504 with a −38 dBV sensitivity and 65 dB SNR to show these relationships.

A similar relationship between dB SPL input and dBFS output for digital microphones is shown in Figure 4. Note that in this figure, the full-scale digital input level of 120 dB SPL is mapped directly to a 0 dBFS output signal. As long as the full-scale acoustic input corresponds to 0 dBFS and is set at 120 dB SPL, a digital microphone always has a sensitivity of −26 dB. This is a function of the definition of sensitivity being measured at 94 dB SPL and is not a design parameter that is adjustable by changing the gain of the microphone ASIC.

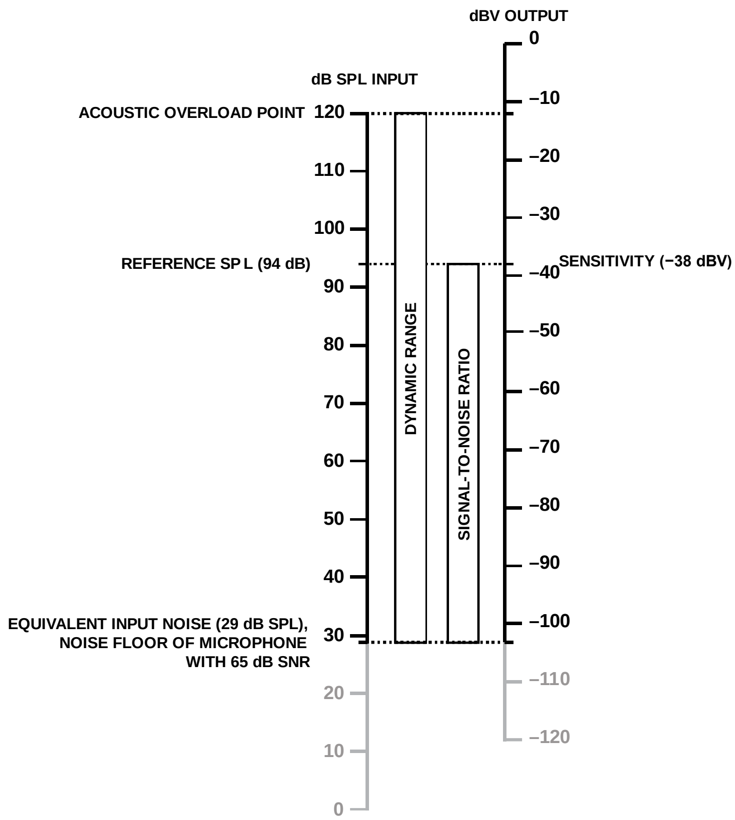

Figure 3. Relationship Between dB SPL Input and dBV Output for Analog Microphones

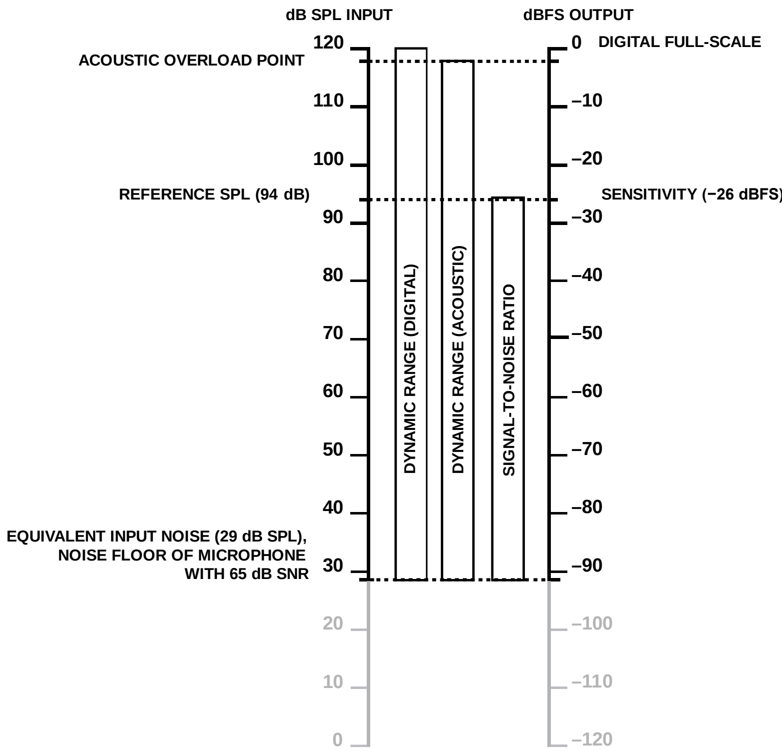

Figure 4. Relationship Between dB SPL Input and dBFS Output for Digital Microphones

Some digital microphone data sheets specify both an acoustic dynamic range and a digital dynamic range. The acoustic dynamic range is described in this section above Figure 3 – the difference between the EIN and the acoustic overload point. The digital dynamic range is the difference between the microphone's EIN and the SPL that is mapped to the full-scale digital word (0 dBFS). A digital microphone's acoustic dynamic range can be the same as the digital dynamic range, but no larger.

FREQUENCY RESPONSE

The frequency response of a microphone describes its output level across the frequency spectrum. The high and low frequency limits are described as the points at which the microphone response is 3 dB below the reference output level at 1 kHz. The reference level at 1 kHz is customarily normalized to 0 dB.

The frequency response specification also includes the deviation limits from a flat response within the pass band. These values, expressed as units of ±x dB, show the maximum deviation of the output signal from a typical level between the −3 dB points.

For InvenSense MEMS microphones, the low frequency roll-off below the lower −3 dB point is first order (6 dB/octave, or 20 dB/decade). The high frequency roll-off above the upper −3 dB point is second order (−12 dB/octave, or −40 dB/decade).

The data sheets for MEMS microphones show this frequency response in two figures: one figure shows the frequency response mask, and the other figure shows the typical measured frequency response. The frequency response mask figure shows the upper and lower limits of the microphone output across frequency; the microphone output is guaranteed to be within this mask. The typical frequency response figure shows an actual microphone's response across the frequency band. Figure 5 and Figure 6 show examples of these two plots taken from the ADMP510 data sheet.

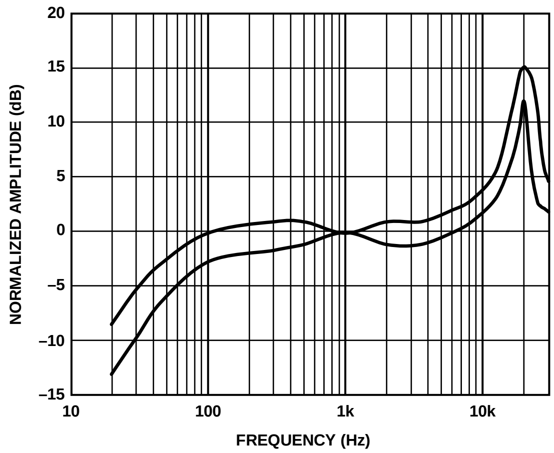

Figure 5. Frequency Response Mask

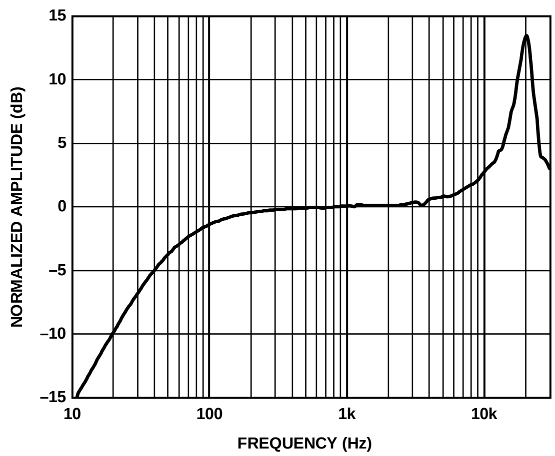

Figure 6. Typical Frequency Response (Measured)

TOTAL HARMONIC DISTORTION (THD)

Total harmonic distortion (THD) is a measurement of the level of distortion on the output signal for a given pure tone input signal. This measurement is presented as a percentage. This percentage is the ratio of the sum of the powers of all harmonic frequencies above the fundamental frequency to the power of the tone at the fundamental frequency.

$$THD = \frac{\sum_{x=1}^{5} Power\,(f_{harmonic\_x})}{Power(f_{fundamental})}$$

A higher THD measurement indicates a higher level of harmonics present at the output of the microphone. The THD of the MEMS microphones is calculated from the first five harmonics of the fundamental.

The input signal for this test is typically at 105 dB SPL, which is 11 dB above the reference SPL of 94 dB. THD is measured at a higher SPL than other specifications because, as the level of the acoustic input signal increases, the THD measurement typically increases as well. A rule of thumb is that the THD triples with every 10 dB increase in input level. Therefore, THD less than 3% at 105 dB SPL means that the THD will be less than 1% at 95 dB SPL.

Most InvenSense microphone data sheets show plots of the input acoustic level vs. total harmonic distortion plus noise (THD + N). THD + N measures not only the level of the harmonics but also all other contributions to noise on the outputs. THD + N, rather than just THD, is shown because at lower acoustic amplitudes it is almost impossible to separate the distortion measurement from the microphone's noise floor. This noise contribution appears in the THD + N plot as an increasing value as the input SPL decreases.

A plot of the microphone's linearity shows the electrical output amplitude vs the acoustic input amplitude. Examples of this and the THD + N plots, taken from the ADMP411 data sheet, are shown in Figure 7 and Figure 8.

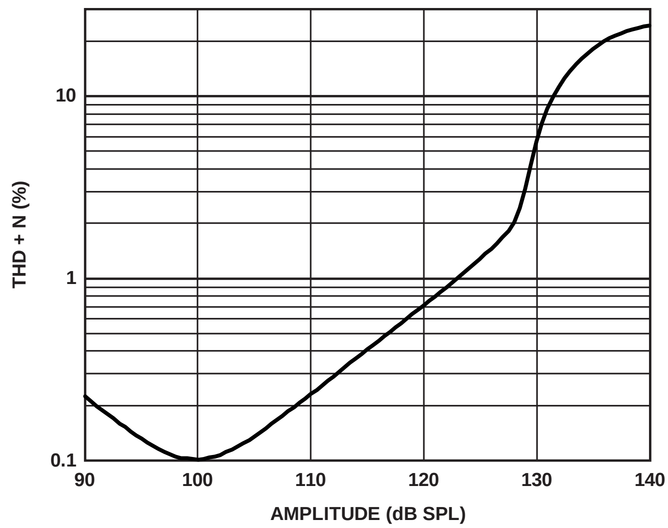

Figure 7. THD + N vs. Input Level

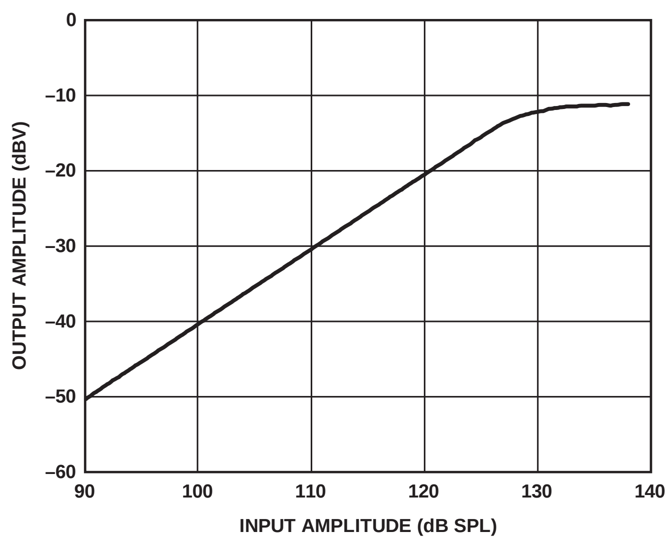

Figure 8. Linearity

POWER SUPPLY REJECTION (PSR) AND POWER SUPPLY REJECTION RATIO (PSRR)

Power supply rejection and power supply rejection ratio are two similar measurements that indicate a microphone's ability to reject noise present on the power supply pins from the signal output. These show a measurement of how much noise on the power supply will feed through to the output signal.

PSR is measured by superimposing a 100 mV peak-to-peak square wave at 217 Hz on the V_{DD} pin of the microphone. The PSR spec is an A-weighted, integrated value of the microphone's total output signal across a 20 kHz bandwidth with this power supply disturbance and no acoustic input. PSR is given as a negative number with units dBV for analog microphones and dBFS for digital microphones. If a microphone would have complete power supply rejection, the value for this specification would simply equal the microphone's A-weighted noise floor.

The disturbance on the power supply is given at 217 Hz because, in GSM phone applications, the 217 Hz switching frequency is typically a dominant source of noise on the power supply.

PSRR is measured with a 100 mV peak-to-peak sine wave, rather than the square wave that is used for PSR measurements. PSRR also measures the microphone's ability to reject power supply noise across a range of frequencies. An analog microphone's PSRR at a single frequency (1 kHz) is shown in the data sheet's specification table. PSRR measurements are not A-weighted.

A plot of the PSRR with the power supply disturbance swept from 100 Hz to 10 kHz is shown in the microphone data sheets. For analog microphones, the plot shows the ratio of the 100 mV peak-to-peak (−20 dBV) input signal on the V_{DD} pin to the output signal measured at the same frequency. The absolute level in dBV of the output signal at each frequency for this measurement will be 20 dB lower than what's shown in the plot. An example of this plot for the ADMP510 is shown in Figure 9.

A similar plot is shown in digital microphone data sheets, but the output level is the absolute level of the output signal with units dBFS. This plot cannot be shown as a ratio because the units of the input signal (dBV) do not match the units of the output (dBFS). For this reason, the plot is titled PSR, although this is a slightly different use than described in the second paragraph of this section.

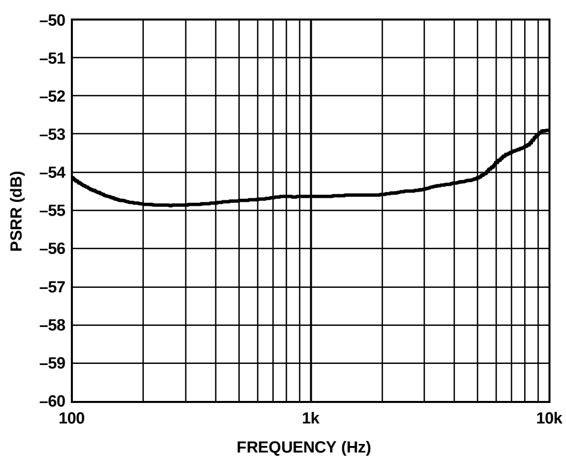

Figure 9. Typical Power Supply Rejection Ratio vs. Frequency

A summary of the differences between PSR and PSRR measurements is shown in Table 1.

TABLE 1. DIFFERENCES BETWEEN PSR AND PSRR

Test Condition	PSR	PSRR
Input Level	100 mV p-p square wave	100 mV p-p sine wave
Input Frequency	217 Hz	100 Hz to 10 kHz sweep
Spectral Weighting	A-weighted	None
Units	dBV (analog) dBFS (digital)	dB (analog) dBFS (digital)
Measurement Result	Integrated over a 20 kHz bandwidth	Output at a single frequency

ACOUSTIC OVERLOAD POINT

The acoustic overload point is the sound pressure level (SPL) at which the THD of the microphone's output equals 10%. This is also commonly referred to as the microphone's clipping point. SPLs higher than this specification cause severe nonlinear distortion of the output signal. The AOP can be determined by looking at the THD plot for the 10% measurement (see Figure 7).

The AOP and THD measurements are not perfect indicators of how the output of the microphone will sound as distortion increases. The type of clipping that leads to the distortion, whether it is hard clipping or soft clipping, will give some additional information that is indicative of the sound quality. To try to show the characteristics of the microphone's output as the input SPL increases, some data sheets show the microphone's clipping characteristics as a time domain plot. As seen in Figure 10, for the ADMP411, this shows a representative output waveform with a 1 kHz sine wave input at different SPLs.

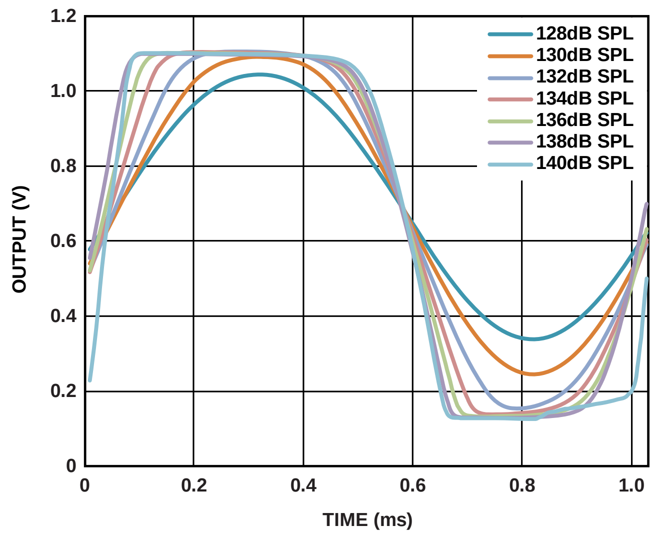

Figure 10. Clipping Characteristics

The acoustic overload point of InvenSense microphones can be as high as 133 dB SPL, which corresponds to a sound pressure level in air of 89 Pa.

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