An Axiometrix Solutions Brand

Application Note: Loudspeaker Rub and Buzz Measurements

Introduction

"Rub and buzz" is a loosely defined term that is widely used to refer to a class of annoying distortions in loudspeakers, typically caused by manufacturing defects. It can result from flaws in the speaker drivers themselves, or defects introduced as the relatively fragile drivers assembled into finished products (speaker cabinets, smart speakers, televisions, phones, etc.). Although most often associated with defects in loudspeaker drivers and finished products containing them, rub and buzz can also be critically important for products with microphones, such as modern smart devices or automobile handsfree systems. For example, rattling or buzzing of a microphone's protective grille can seriously impair speech quality and even speech intelligibility, which can significantly degrade the performance of smart devices when processing spoken commands.

Rub and buzz is squarely the domain of quality assurance professionals. Ideally, they want to detect annoying rub and buzz distortion in products at the end of production lines, to prevent such faulty products from being shipped to end customers. This applies to loudspeaker drivers when they are manufactured and again when they are assembled into finished products.

Loudspeaker Rub and Buzz Defects

Loudspeakers are complex electro-mechanical assemblies, which by their nature are susceptible to a multitude of potential defects that could result in rub and buzz distortion. For example, consider the cutaway view of the loudspeaker driver shown in Figure 1. This is a classic low-frequency driver, but similar components – and potential sources of rub and buzz defects – exist in all types of drivers. The voice coil, moving in the cylindrical magnetic field created by the magnet and the pole piece constitutes a linear motor. It is held in place by the suspension at the back of the cone which provides a restoring force and helps guide it to move smoothly in the gap between the magnet and pole piece. The surround at the front of the cone must hold the cone in place while allowing relatively large displacements at low frequencies. Many of the components are glued together with adhesive. Potential defects that could result in rub and buzz include:

- Misalignment between the axis of the voice coil and the magnet, causing the voice coil to rub as it moves within the air gap.
- Particles such as chipped magnet material, strings of excess glue, etc. trapped in the gap between the voice coil and magnet (or pole piece).
- Poorly adhered sections in glue joints between components (e.g., cone, surround, housing, voice coil former, dust cap) causing parts to buzz against each other as the speaker is driven at high levels.
- Voice coil suspended too close to rear plate causing impacts at high excursion levels.
- Improper dressing of lead wires between tag panel and cone, causing wires to slap against the cone at high levels.

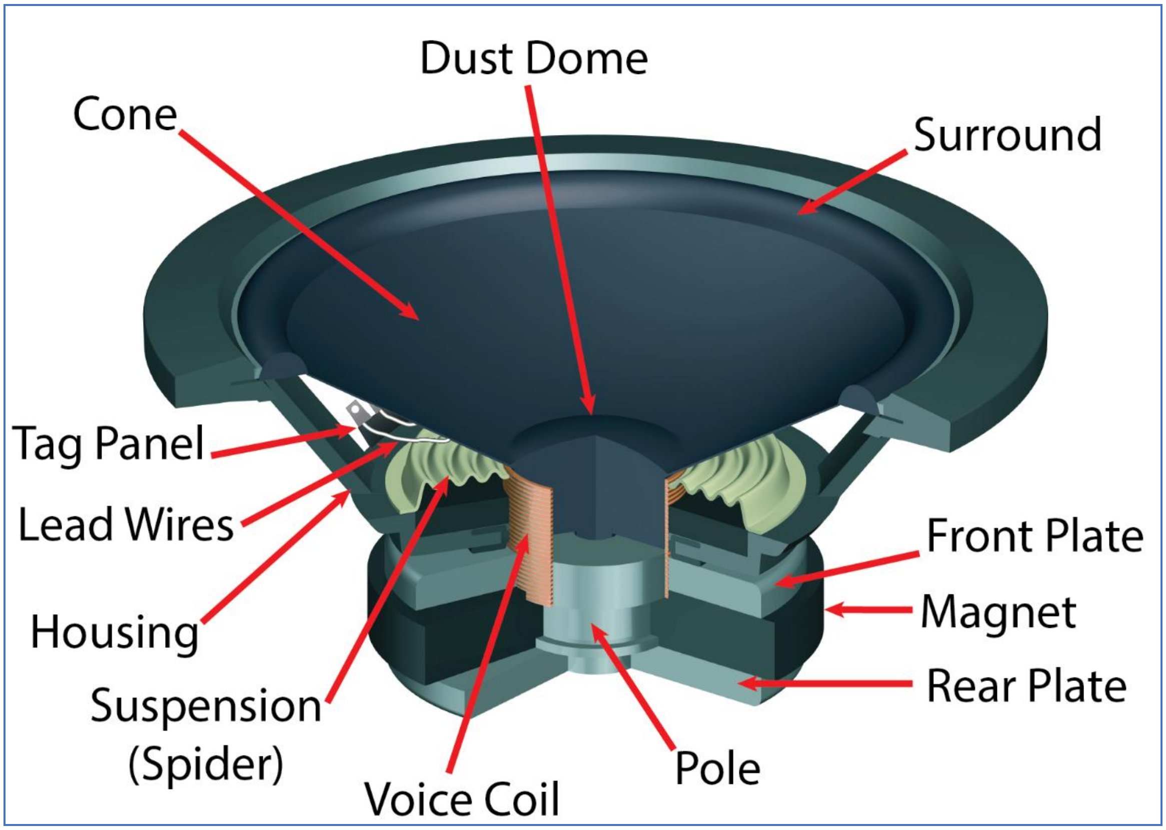


Figure 1. Cutaway view of a low-frequency driver (woofer) with components labeled.

Finished Products

Given the potential for rub and buzz defects in loudspeaker drivers, it's important to screen the drivers themselves for rub and buzz on their manufacturing lines. But defects resulting in distortion that would be classified as rub and buzz can also occur when drivers (or microphones) are assembled into finished products. Tools can easily puncture some of the soft materials of driver components and parts can be improperly fastened or misaligned, leading to vibration and ultimately noise as the product is used in service. Furthermore, external components such as speaker grilles, microphone screens or a car door panel in which an automotive speaker is mounted can buzz and rattle if not properly assembled.

Rub and Buzz Detection

The defects described above in loudspeakers or finished acoustic products tend to cause distortions that are usually – but not always – harmonically related to the main signal. For example, if the device is driven with a pure tone (a sine signal) at a single frequency that stimulates rub and buzz, the rub and buzz distortion artifacts will likely appear in a measured spectrum at integer multiples of the sine frequency.

Although rub and buzz may be clearly audible to the average person, measuring it reliably with measurement algorithms is a difficult problem for several reasons, including:

1. <u>Traditional audio quality metrics don't work</u>: Although useful for quantifying many aspects of audio quality, traditional metrics like frequency response and total harmonic distortion (THD) are all but useless for detecting rub and buzz. Figure 2 shows the virtually identical measured frequency response and THD response curves of three small drivers, one good unit and two units with audible rub and buzz. Rub and buzz defects would have to be extremely severe to cause a measurable change in frequency response or THD.

Calculation Mode: IEC ☐ Normalized

Figure 2. Graphs of frequency response (upper) and THD response (lower) of three samples of a small driver – one with no audible defects and two with audible rub and buzz distortion.

2. <u>Rub and buzz artifacts are low-level and high-frequency</u>: Rub and buzz signals tend to be very low in level. For example, rub and buzz artifacts might be 50 dB or more below the fundamental signal (i.e., about 300 times lower in measured sound pressure level). But human hearing is incredibly adept at recognizing the presence of these small signals even though in measurement results they might seem to be "swamped" by the fundamental signal. Rub and buzz artifacts also

tend to occur at relatively high frequencies where ambient noise in most environments is lower and where harmonics are high in order. As such, ambient noise doesn't mask them, nor does the fundamental (and the first couple of harmonics, which tend to be high for loudspeakers).

3. Rub and buzz is a subjective problem: Most measurements provide objective results but rub and buzz is a subjective problem. Rub and buzz noise may be perceived with varying levels of annoyance by different people, and there is no universal criterion for what is and is not acceptable.

4. The production test environment is difficult: Speakers and finished acoustic products need to be tested at the end of manufacturing lines where levels of ambient noise are typically high, including transient noises from manufacturing activities. Acoustic test chambers help with noise isolation but can only do so much. Detecting low-level rub and buzz signals in the presence of such noise can be very difficult.

One approach that has been used for rub and buzz detection is to have a trained person listen to the product as it is stimulated through its working frequency range. As good as human hearing is at detecting rub and buzz, this approach is problematic, because listening to speakers driven with sine waves at high level quickly leads to listener fatigue. Over the past 10 to 20 years, various techniques have become available which, in a sense, attempt to mimic the ability of a human's "two ears and a brain" to detect these subtle, low-level signals in the presence of a strong fundamental signal and ambient noise. Several new techniques were added to the APx500 software in 2021. Measurement result for rub and buzz detection now available in APx500 include:

- Rub and Buzz
- High Order Harmonic Distortion (HOHD)
- SoneTrac Rub and Buzz (and SoneTrac Residual)
- Rub and Buzz Loudness

These measurement results are discussed in detail below.

Rub and Buzz Result

The Farina log-swept sine (or chirp) measurement was a hallmark of the APx500 platform, first introduced in 2006, with the Continuous Sweep measurement geared toward electronic audio test. In addition to being a very fast technique to measure frequency response, it offers the advantage of being able to simultaneously measure not only THD versus frequency, but the contribution of each harmonic (up to about the 20th) to the THD. Acoustic Response, a version of this measurement which includes the ability to window out reflections in the impulse response for quasi-anechoic testing of loudspeakers and microphones was added to APx in 2009. Measurement results specifically for rub and buzz detection in loudspeakers were added to the Acoustic Response measurement in 2013.

The original rub and buzz algorithm in Acoustic Response works as shown in Figure 3. The chirp signal is generated and passed through a power amplifier to the speaker (DUT). A measurement microphone captures the acoustic output of the speaker and sends it for regular chirp processing (to determine frequency response and THD, etc.). To help detect rub and buzz, the microphone signal is also passed through a tracking high-pass filter. This filter's corner high-pass frequency is a multiple of the fundamental frequency ("high-pass factor" = 5 or more), meaning it filters out the fundamental sine frequency and the first four harmonics (or more, depending on the specified high-pass factor). The output of this filter is called the “Residual”. Two detectors are applied to the Residual signal on a cycle-by-cycle basis – one measures the Residual peak and the other measures the Residual rms. A third detector is applied to the main microphone signal to determine the rms level of this signal on a cycle-by-cycle basis. From these three detectors, two result curves are derived: the Residual Crest Factor (ratio of Residual Peak to Residual RMS) and the Peak Ratio (ratio of Residual Peak to Main rms). The impetus for using these results is that rub and buzz defects often cause noise signals that are “spiky” in nature, as components impact or rub against each other and buzzes are generated. If both the Residual Crest Factor and the Peak Ratio are high in certain frequency ranges, this is often an indication that a defect is present.

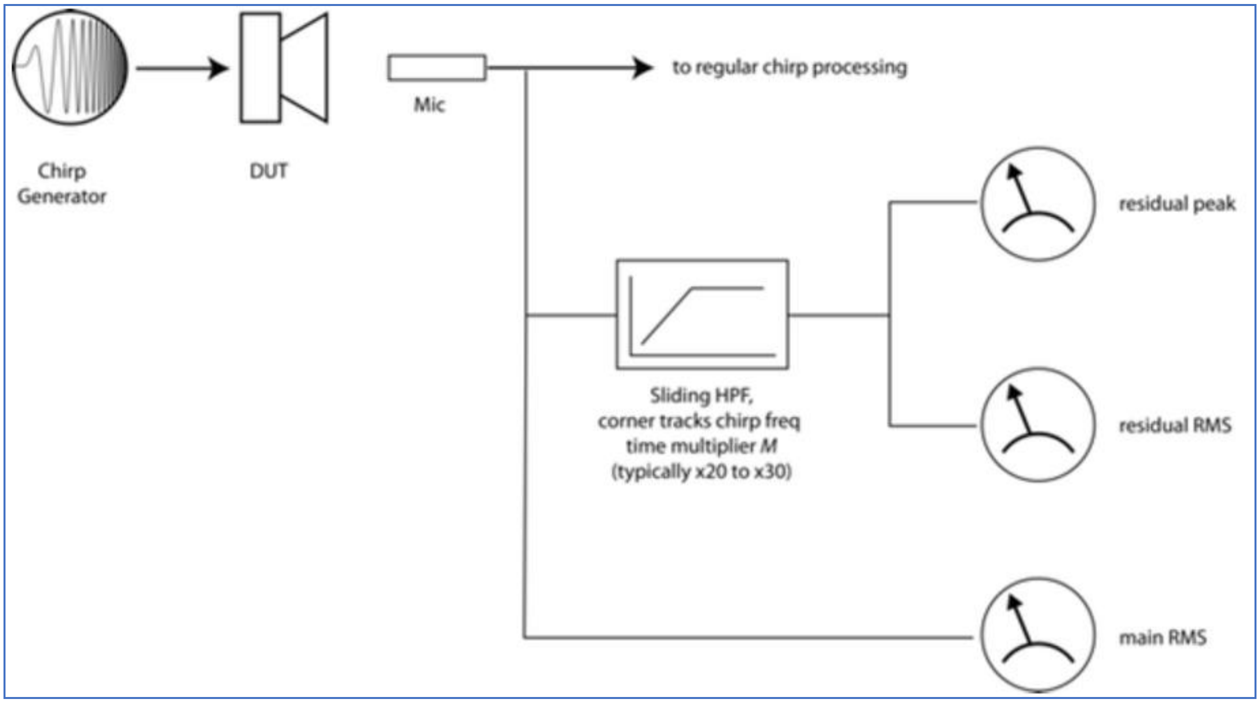


Figure 3. Schematic diagram illustrating rub and buzz detection in the Acoustic Response measurement.

Figure 4 shows the measured Rub and Buzz Crest Factor and Peak Ratio for two samples of a 4-½ inch (115 mm) driver – one good sample and one with a severe rub and buzz defect. Note how both the Crest Factor and the Peak Ratio are elevated in the 50 to 70 Hz and 80 to 180 Hz ranges for the sample with the defect.

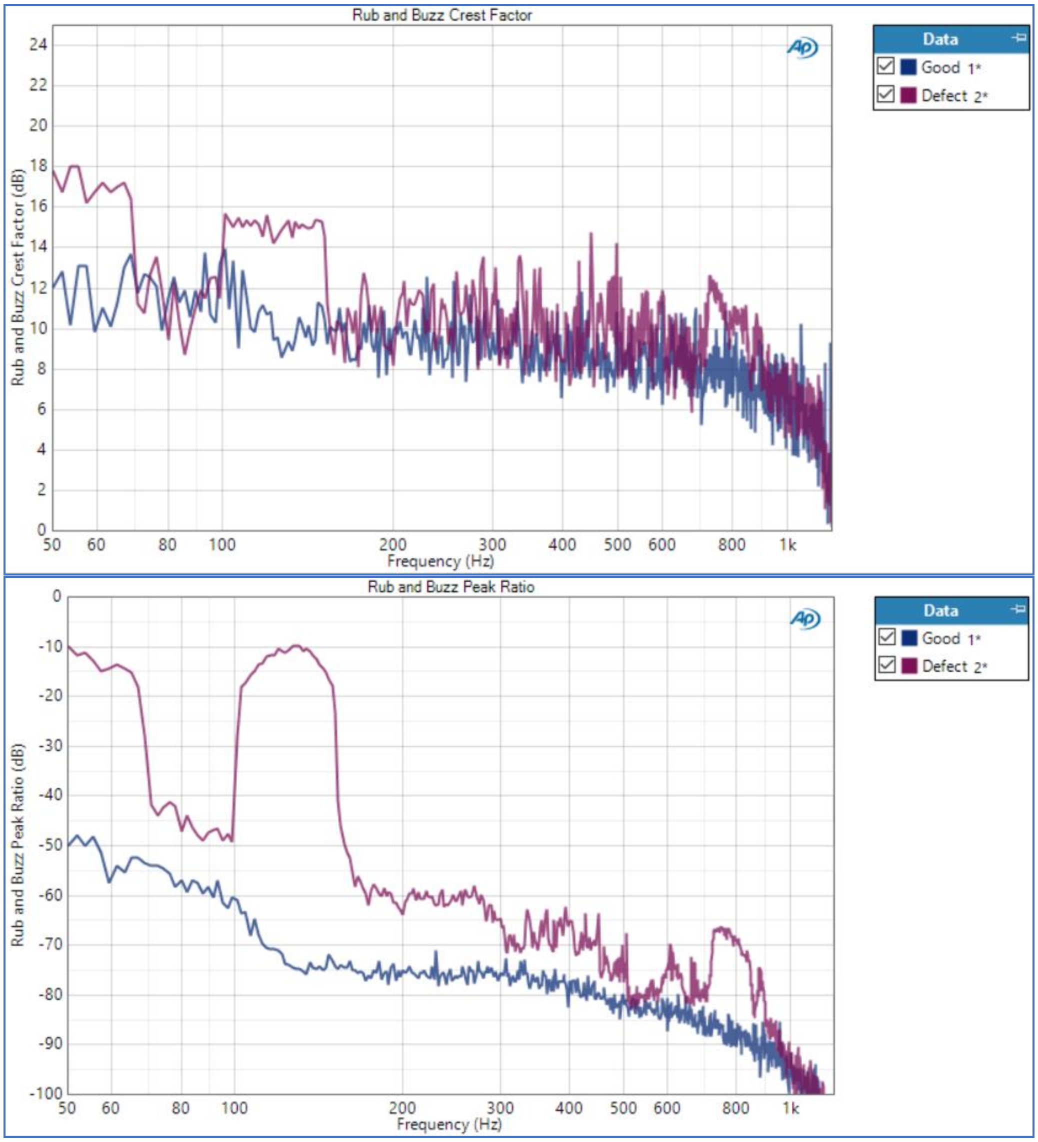


Figure 4. Rub and Buzz Crest Factor (upper) and Peak Ratio (lower) measured on a good sample and a sample with severe defects of a 115 mm driver.

High Order Harmonic Distortion (HOHD) Result

HOHD is a classic method for detecting rub and buzz which has been is use for many years. It is a crude way of mimicking the frequency masking effect in human perception. It simply measures harmonic distortion, but excludes the lower order harmonics (e.g., H2 through H4 or H2 through H10, etc.). Most rub and buzz mechanisms produce a spectrum rich harmonic content. For example, Figure 5 shows the FFT spectrum of two driver samples stimulated with a 150 Hz sine signal – one good driver (Control) and one with a very severe defect (voice coil impinging on the back plate). In this graph, the frequency axis is plotted on a linear rather than logarithmic scale to make the harmonics more discernible. For the Control sample (green trace), harmonics of the fundamental disappear in the noise after about the tenth harmonic, whereas for the defective sample (red trace), harmonics are more than 20 dB above the background noise all the way to 20 kHz (H133) and beyond.

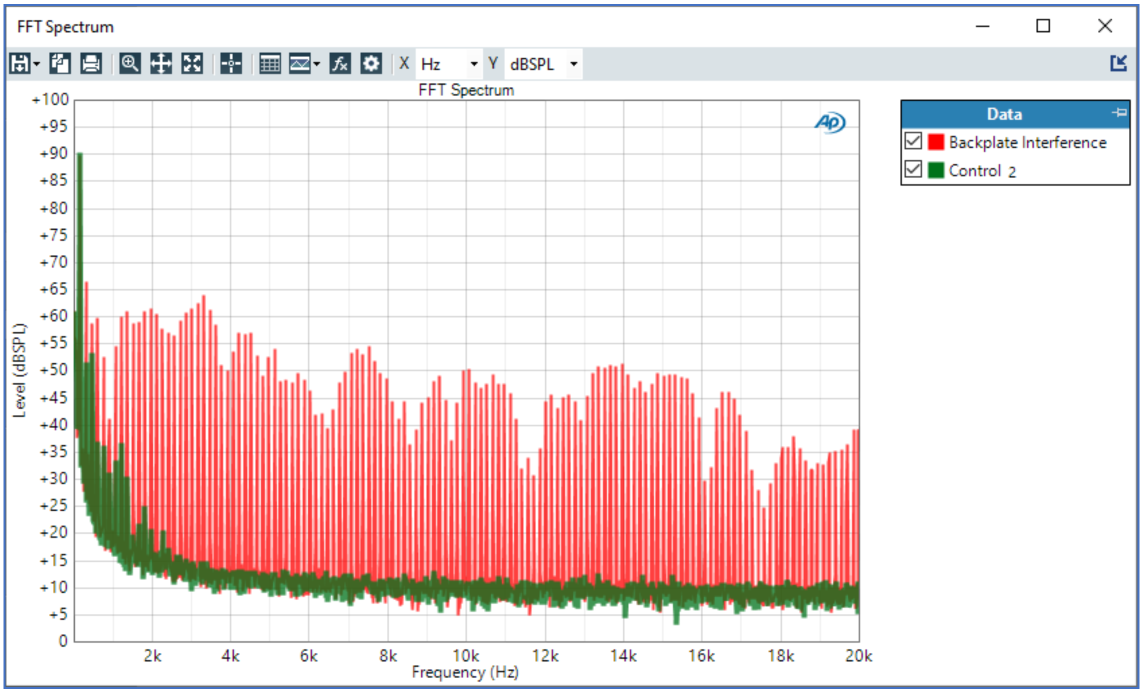
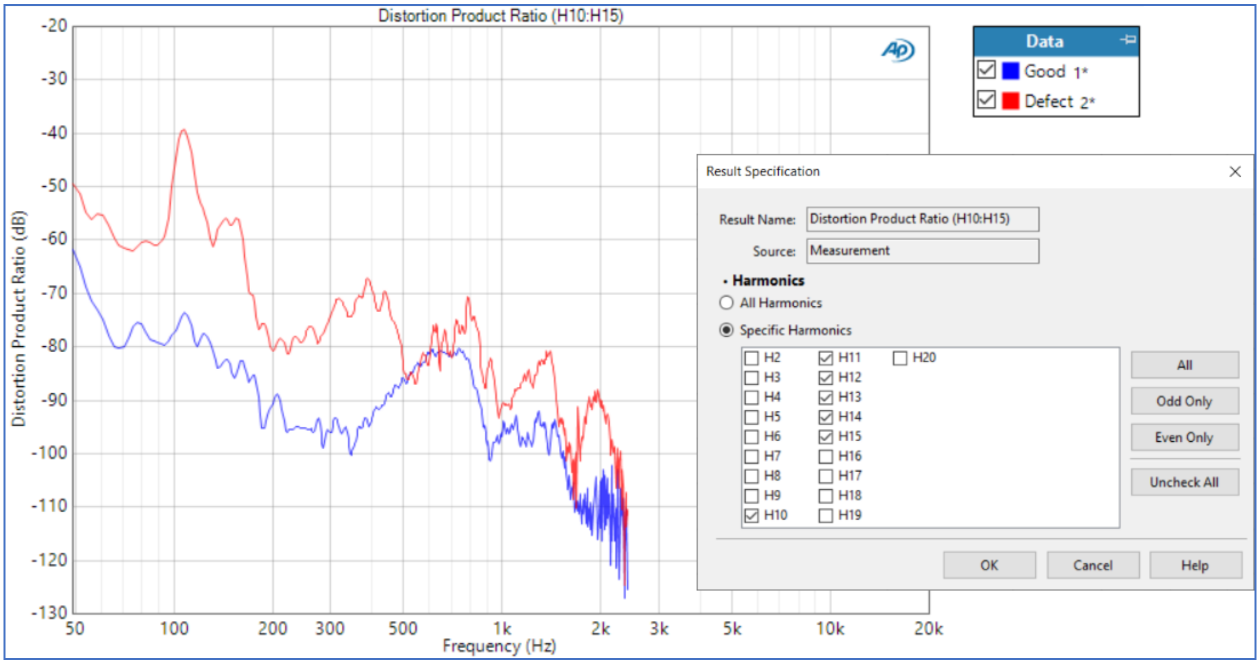


Figure 5. FFT spectrum of two driver samples stimulated with a 150 Hz sine - a good sample (Control) and one with a severe defect (back plate interference).

HOHD in Chirp Measurements

A limited form of HOHD has been available in the APx500 software since it was introduced in 2006, by way of the Distortion Product Ratio result, which allows you to specify a sum of harmonics – for example H10 through H15 (Figure 6).



Result Specification

Result Name: Distortion Product Ratio (H10:H15)

Source: Measurement

Harmonics

○ All Harmonics

● Specific Harmonics

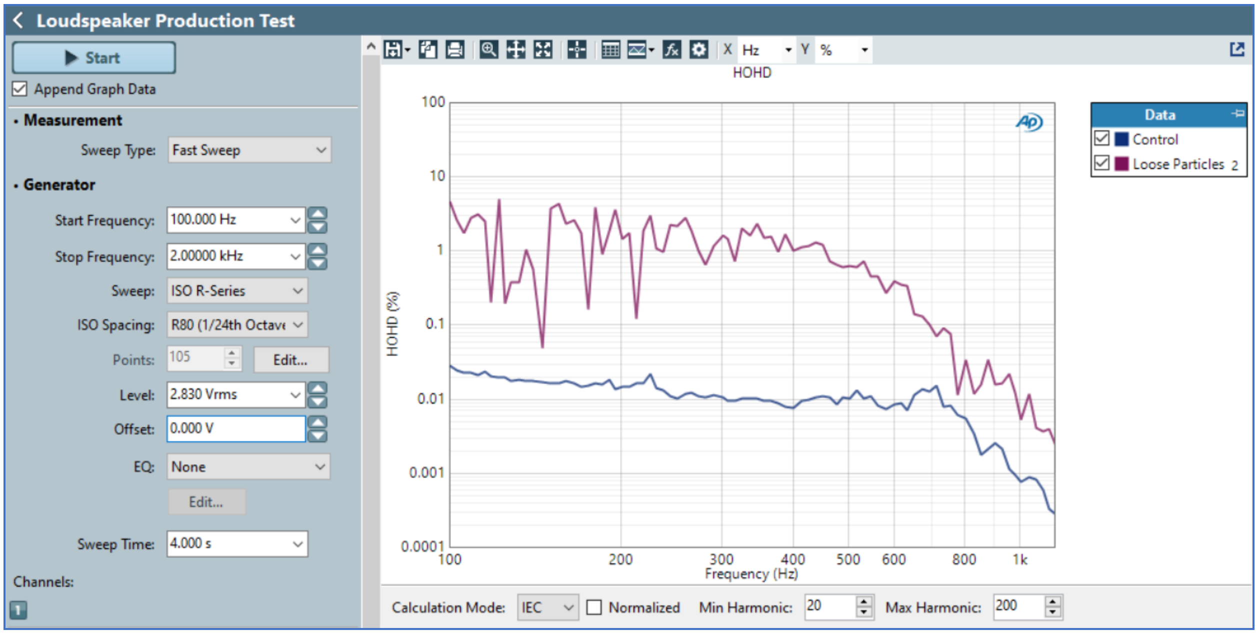
☐ H2
☐ H3
☐ H4
☐ H5
☐ H6
☐ H7
☐ H8
☐ H9
☑ H10
☑ H11
☑ H12
☑ H13
☑ H14
☑ H15
☐ H16
☐ H17
☐ H18
☐ H19
☐ H20

Figure 6. Distortion Product Ratio (H10:H15) of the same driver samples as featured in Figure 4.

One shortfall of using the Distortion Product Ratio result in chirp measurements for HOHD is that it only allows specifying up to about the twentieth harmonic (H20). This is an inherent limitation of the Farina log-swept sine technique, wherein harmonics show up as small impulses before the main impulse in the impulse response result. There simply isn't enough resolution to derive more than about the twentieth harmonic.

HOHD with Fast Sweep Stimulus

The above limitation in the APx500 software was overcome in 2021 with the addition of a Fast Sweep stimulus to the Loudspeaker Production Test measurement. This uses a special type of stepped frequency sweep which is optimized for speed — transitions between steps are implemented smoothly to minimize transient effects that would require settling, and analog input and output ranges are fixed throughout the sweep, to further avoid transients. As a result, the total sweep time can be comparable to that of a log-swept sine chirp. With the Fast Sweep stimulus, because harmonics are simply derived via FFT analysis, very high order harmonics (up to H200) can be included. For example, Figure 7 shows the HOHD result for a Fast Sweep of a driver from 100 Hz to 2.0 kHz with and without a loose particle defect. Note that harmonics from H20 to H200 are included, as specified by the controls below the graph.



Sweep Type: Fast Sweep

Start Frequency: 100.000 Hz

Stop Frequency: 2.00000 kHz

Sweep: ISO R-Series

ISO Spacing: R80 (1/24th Octave

Points: 105

Level: 2.830 Vrms

Offset: 0.000 V

EQ: None

Sweep Time: 4.000 s

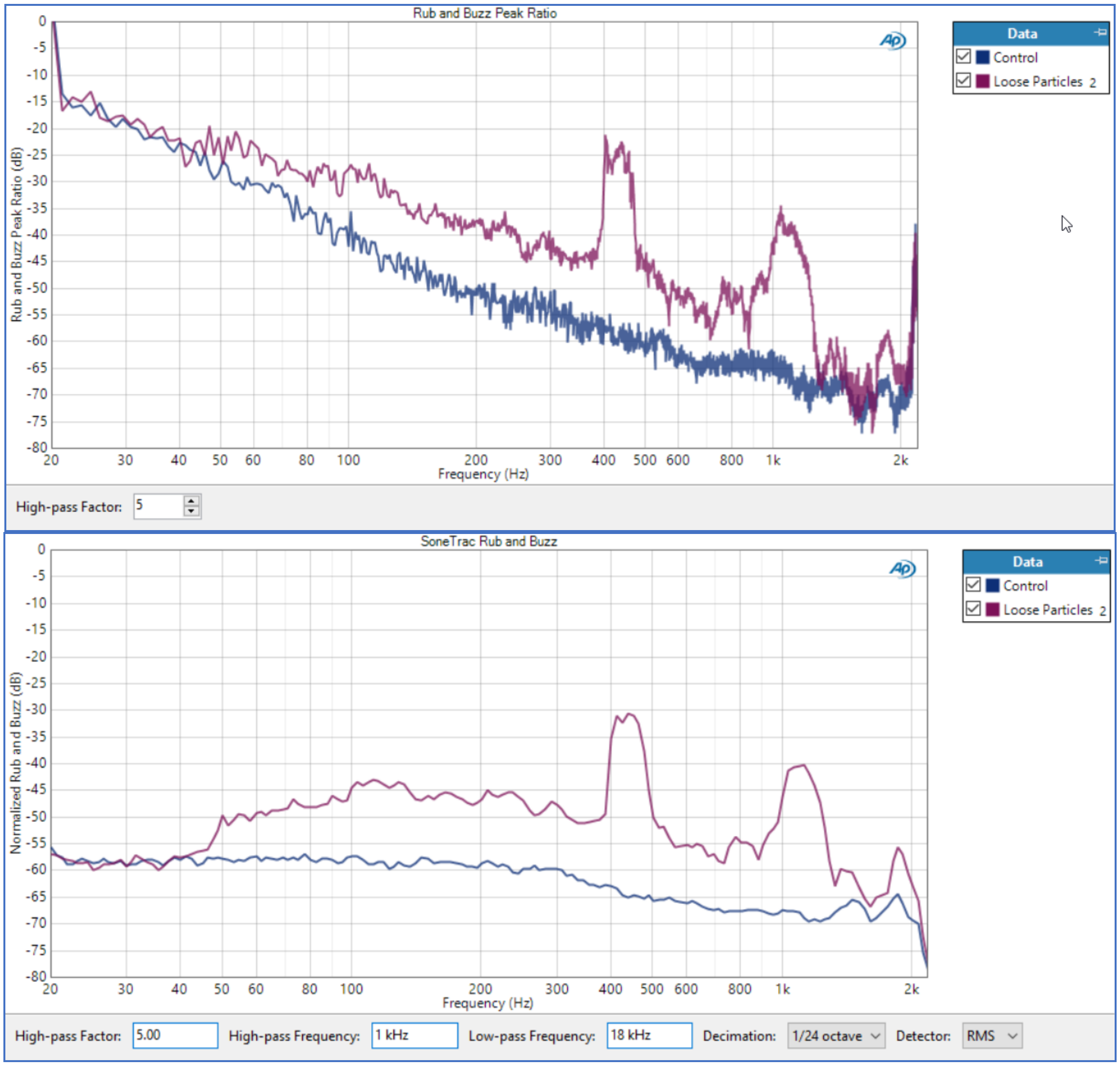
Calculation Mode: IEC ☐ Normalized Min Harmonic: 20 Max Harmonic: 200

Figure 7. The HOHD result in the Loudspeaker Production Test measurement can include high-order harmonics (up to H200).

SoneTrac Rub and Buzz Result

The SoneTrac Rub and Buzz algorithm was developed by Gerry Mariona of Bose Corporation. Although developed independently from Audio Precision, this algorithm has much in common with the one used to derive the Peak Ratio in the original APx rub and buzz result. Both techniques use a log-swept sine chirp stimulus, a high-pass tracking filter and analysis of the energy contained in the Residual (the signal left when the fundamental and low-order harmonics are removed). But SoneTrac offers several refinements that make rub and buzz detection even easier than with the original APx technique. Figure 8 compares the APx Rub and Buzz Peak Ratio and SoneTrac Rub and Buzz results for tests of a small full-range driver with and without loose particle defects, measured during the same sweep from 20 Hz to 2.0

kHz with a 4-second sweep time. While both techniques clearly identify differences between the two samples that likely indicate rub and buzz, several aspects of the SoneTrac algorithm provide enhancements, including:



High-pass Factor: 5

High-pass Factor: 5.00 High-pass Frequency: 1 kHz Low-pass Frequency: 18 kHz Decimation: 1/24 octave Detector: RMS

Figure 8. APx original Rub and Buzz Peak Ratio result (upper) and SoneTrac Rub and Buzz result (lower) for a driver with and without loose particle defects.

1. The SoneTrac Rub and Buzz results indicates the level of energy in the residual at each frequency normalized to the overall rms level of the entire acquired chirp waveform. The APx Peak Ratio result is similar, but it normalizes the energy in the residual at each frequency to the rms level of the acquired waveform at that frequency. As a result, the Peak Ratio has high values at low frequencies, where the driver is not very efficient. The SoneTrac result makes it easier to identify differences between the two driver measurements.

2. SoneTrac allows the High-Pass Factor to be specified as a decimal fraction with values as low as 1.0, whereas the APx High-pass Factor is an integer value of 5 or greater.

3. SoneTrac has additional High-pass and Low-Pass filter controls to specify filtering applied to the residual. These additional filters can eliminate noise and help to clarify rub and buzz artifact detection.
4. SoneTrac has built-in optional decimation of the rub and buzz curve to fractional octave frequencies. As shown in Figure 8, this provides smoother, less noisy traces. It also eliminates a lot of unnecessary data points.

Another enhancement of the SoneTrac rub and buzz algorithm is that it provides a Residual Waveform result – shown in Figure 9 for the measurements in Figure 8. The residual waveform is the acquired waveform with the fundamental and the first few harmonics filtered out. The APx software enables saving waveforms. Some users like to save the residual waveform and/or the acquired waveform so that they can listen to them with headphones, to help decide whether rub and buzz defects are likely to be audible.

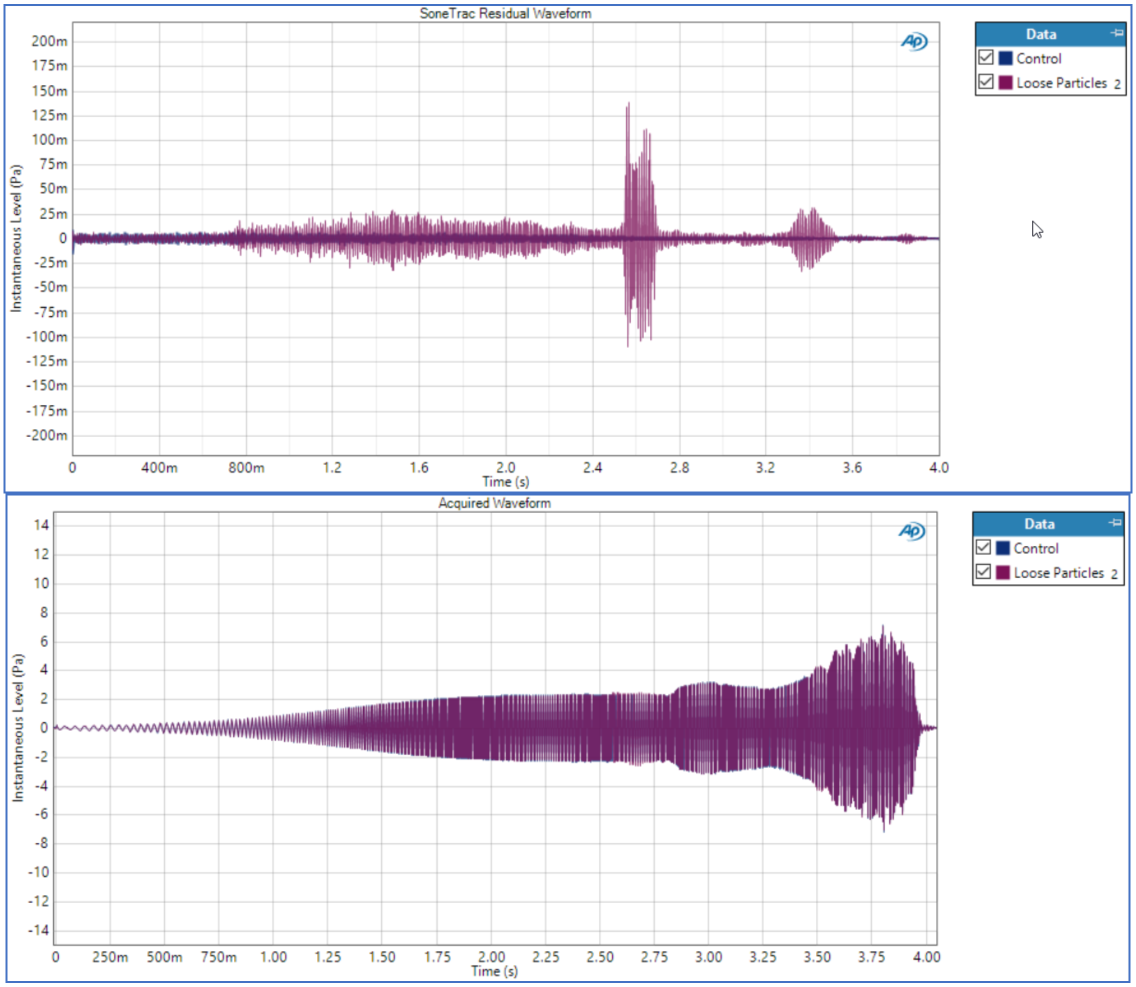


Figure 9. The SoneTrac Residual result (upper) and the unfiltered Acquired Waveform result (lower) for the measurements shown in Figure 8.

Rub and Buzz Loudness Result

A problem with all the rub and buzz detection techniques discussed above is that while they are good at finding differences between samples that are indicative of defects, they provide no indication of how audible these rub and buzz artifacts are. For example, consider Figure 10, which shows the Rub and Buzz Crest Factor and Peak Ratio of two samples of a 4-½ inch (114 mm) driver. Sample LS4-28 has a significantly higher Crest Factor and Peak Ratio than sample LS4-30 in the frequency range from about 80 to 180 Hz, indicating a potential rub and buzz defect. Yet neither sample had any audible rub and buzz. Should we reject this sample and absorb the cost of scrapping or reworking it, or should we pass it and risk the potential of a dissatisfied customer returning it as defective? This is never an easy choice to make.

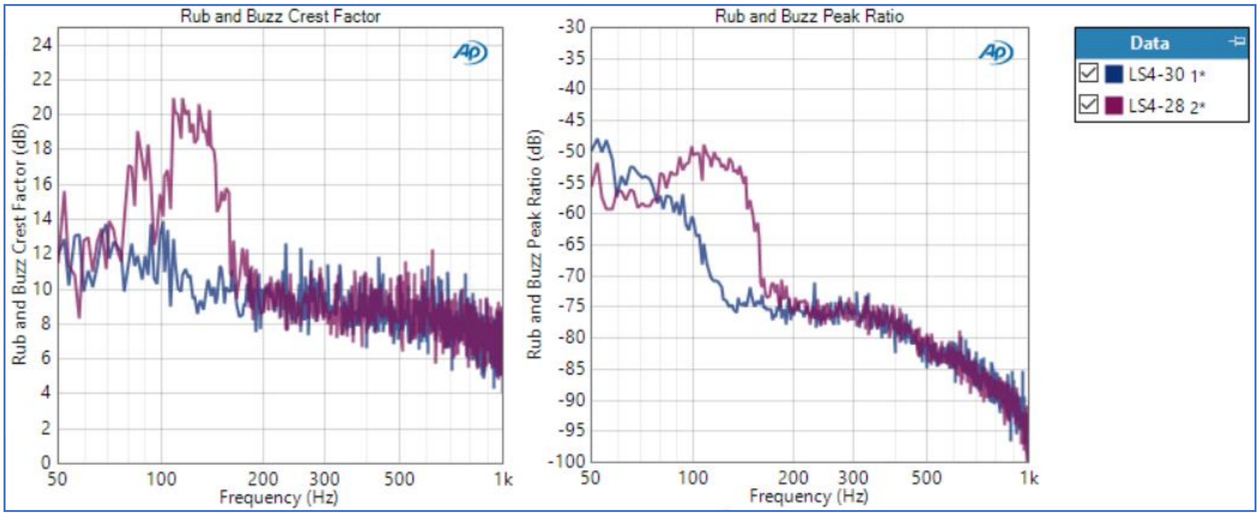


Figure 10. Rub and Buzz Crest Factor (left) and Peak Ratio (right) measured for two samples of a 4-½ inch driver, neither of which had audible rub and buzz.

Rub and Buzz Loudness is a new measurement result added to the APx500 software in 2021. Its intent is to provide a rub and buzz metric that indicates the perceived loudness of the rub and buzz noise emitted by a device to the typical human listener.

Loudness and the Phon Loudness Level Scale

Loudness is a psychoacoustic metric that indicates the *subjective* impression of the intensity or magnitude of a sound. It depends on several factors, including the frequency, sound pressure level, waveform type (pure tone, noise, music, etc.) and duration of a sound. As an audio and acoustic test and measurement company, we strive to manufacture analyzers and microphones that are highly linear and have a flat frequency response over the audible frequency range. But human perception of loudness is quite different – it varies significantly with frequency and with sound pressure level (SPL).

Figure 11 is a graph of equal-loudness contours for pure tones adapted from ISO standard 226. These curves of SPL versus frequency have been established over many years by having human subjects listen to a pure tone presented first at a reference frequency (1 kHz) and then at different frequencies in the range from 20 Hz to 20 kHz. In loudness listening tests, the listener is instructed to adjust the level of the tone at each frequency until it sounds as loud as the tone at 1 kHz. As shown, perceived loudness varies significantly with both frequency and level. Each curve is assigned a loudness level in units of phons (usually pronounced “fawns”), which corresponds to the measured SPL at the reference frequency of 1 kHz. For example, the 40 phon curve has SPL values of 40 dBSPL at 1 kHz, 100 dBSPL at 20 Hz and 55 dBSPL at 10 kHz. This indicates that a 20 Hz pure tone with a sound pressure level of 100 dBSPL has the same perceived loudness as a 1 kHz tone at 40 dBSPL or a 10 kHz tone at 55 dBSPL. It has also been established experimentally that an increase or decrease of 10 phons is perceived as a doubling or halving of loudness, respectively. The zero phon curve represents the threshold of human hearing.

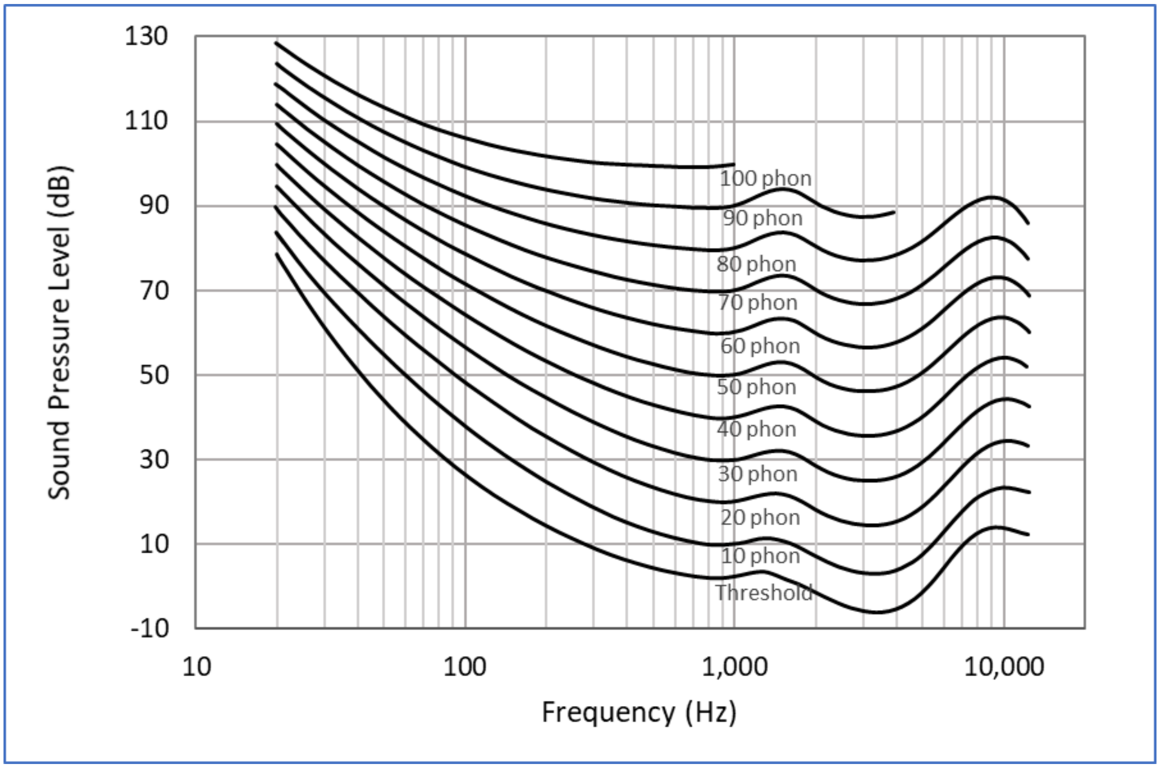


Figure 11. Equal loudness contours for pure tones (adapted from ISO 226:2003).

The key attribute of the phon loudness scale is that it can be used to quantify the loudness of sounds at any frequency; For example, a sound with a loudness 50 phons is twice as loud as a sound of loudness 40 phons – i.e., twice as loud as a 1 kHz pure tone with a level of 40 dBSPL.

The APx Rub and Buzz Loudness algorithm applies a modern loudness model to the problem of rub and buzz detection. The loudness model observes the difference between the response from the device under test and the stimulus applied to it and accounts for various factors, including:

- Frequency weighting of the ear
- Auditory filter bands which simulate the frequency resolution of hearing
- Sound masking due to internal noise of the inner ear caused by blood flow
- Frequency masking in human hearing
- Harmonic distortion in the response from the DUT.

The algorithm uses a *stationary* loudness model, which is meant for sounds that are relatively constant in amplitude and frequency content. As such, the Rub and Buzz Loudness result is only available when the Fast Sweep stimulus is used, because for a portion of the time spent at each frequency step, the response can be considered as stationary.

Figure 12 shows the Rub and Buzz Loudness result from measurements of four samples of a small full-range speaker - one sample with no defects (Control) and three samples with the following defects in increasing order of severity:

- A sample with Loose Particles in the gap.
- A sample in which the voice coil could strike the backplate causing a severe buzz (Backplate Interference).
- A sample in which the surround had partially separated from the housing (Loose Surround)

The four samples were tested with the APx Fast Sweep stimulus from 20 Hz to 20 kHz with a sweep time of 15 seconds and an input level of 2.83 Vrms (1 watt into 8 ohms). The frequency steps used were the ISO R80 series (1/24-octave). For all tests the microphone was located on-axis with close proximity to the dust cap, to maximize the signal to noise ratio of the measurement. The rms level versus frequency of the four speakers is shown in Figure 13.

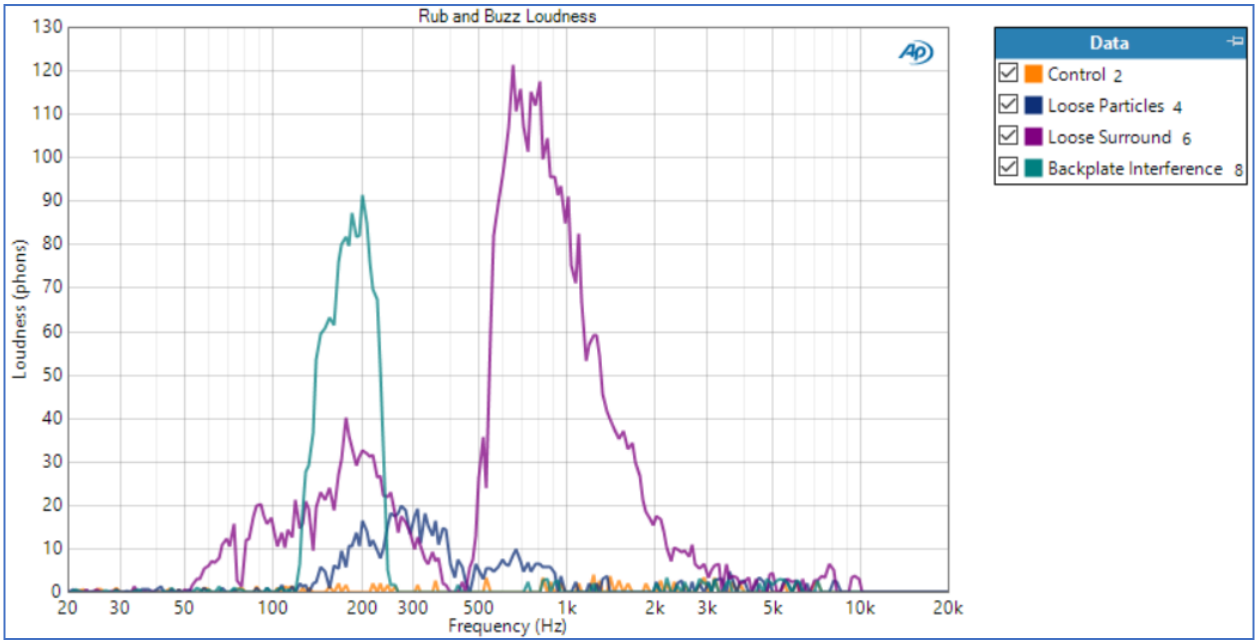


Figure 12. Rub and Buzz Loudness as measured on 4 samples of a small full-range speaker.

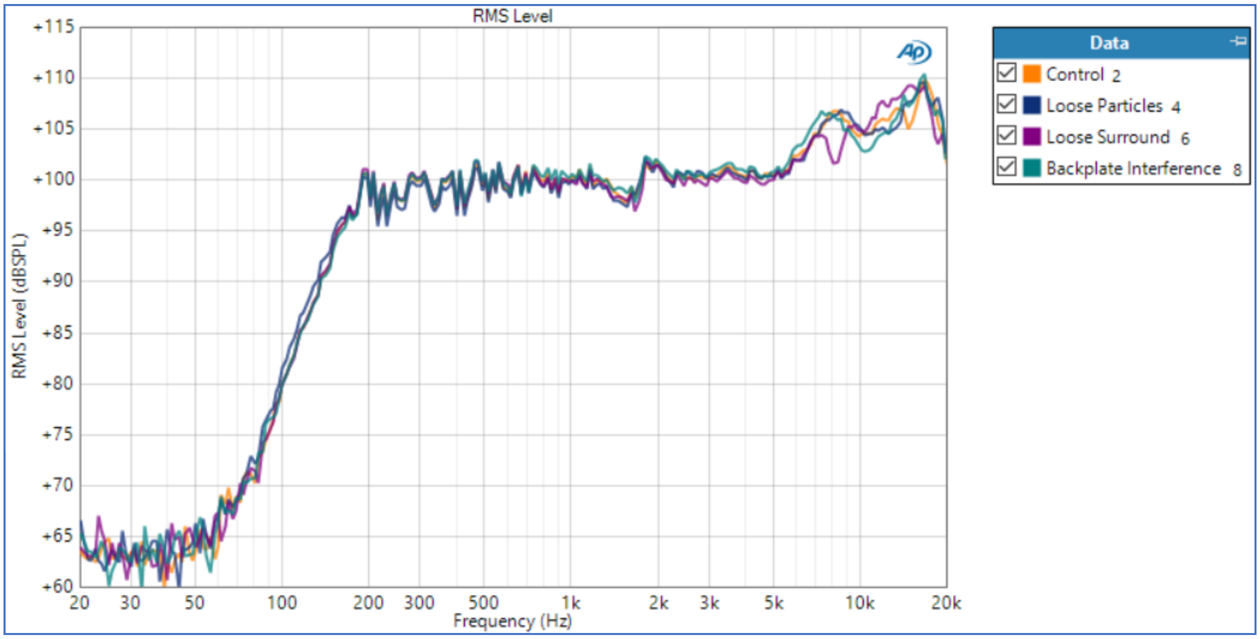


Figure 13. Level response of the 4 speaker samples featured in Figure 12.

Two aspects of the Rub and Buzz Loudness plot of these samples (Figure 12) are worth noting:

1. The Control sample had a Rub and Buzz Loudness curve with values of zero or close to zero phons at all frequencies (maximum value about 4 phons). Also, no audible rub and buzz artifacts could be heard emanating from this sample as it was tested.
2. For the remaining samples, the Rub and Buzz Loudness results seem to be in agreement with the perception of listeners in the room: A slight buzz could be heard from the Loose Particle sample as the sweep frequency passed through the 200 to 500 Hz region; a much louder buzz could be heard from the Backplate Interference Sample as the sweep frequency passed through the 150 to 250 Hz range; and a very loud buzz could be heard from the Loose Surround sample, especially as the sweep frequency transitioned the 500 Hz to 1.5 kHz range.

The approximate maximum Rub and Buzz Loudness values measured for these four samples in the frequency range from 20 Hz to 20 kHz are listed in Table 1.

Table 1. Maximum Measured Rub and Buzz Loudness from 20 Hz to 20 kHz by Sample

Sample ID	Rub and Buzz Loudness (phons)
Control	4
Loose Particles	20
Backplate Impingement	91
Loose Surround	121

In terms of absolute level, a rub and buzz loudness of 121 phons might seem questionable. According to the definition of the phon scale this indicates that the rub and buzz noise would sound as loud as a 1 kHz pure tone at 121 dBSPL – close to the threshold of pain! Granted, the microphone was very close to the speaker (just a few mm away), but this is even higher than the measured fundamental signal (100 to 110 dBSPL). Could a buzz sound louder than the main swept sine signal driving the speaker? Possibly, when human perception is involved. In any case, what’s important here is that because a loudness model was used, we can quantify the relative loudness among the measured rub and buzz results. For example, based on the rule that each 10 phon increase corresponds to a doubling of loudness, compared to the Backplate Impingement sample (91 phons), the buzz from the Loose Surround sample (121 phons) would sound about eight times as loud ($2^{\left(\frac{131-91}{10}\right)} = 2^3 = 8$).

Because it’s based on a loudness model, the Rub and Buzz Loudness result has several advantages over other rub and buzz metrics, including:

1. Once the measurement is configured correctly, if a sample has Rub and Buzz Loudness levels of a few phons or less at all frequencies, you can be reasonably confident that it does not have audible rub and buzz defects.
2. It provides a measure that can be used to determine the perceived relative loudness of rub and buzz defects – Sample A is X times as loud as sample B, etc.
3. Setting pass/fail limits is much easier. A typical limit curve on the Rub and Buzz Loudness graph is a flat line at a fixed Loudness in phons (for example, a limit of 30 phons for the results above would allow the Loose Particles sample to pass but would fail any samples with rub and buzz noise twice as loud or louder. In contrast, other rub and buzz metrics require measuring and analyzing a large number of samples, deciding what level of the rub and buzz metric is significant and creating complex limit curves that are offset from the measured curve within certain frequency ranges.

Conclusion

Detecting rub and buzz defects in loudspeakers and finished acoustic products is a difficult problem and depending on the device under test, some techniques may work better than others. The APx500 software now offers four different rub and buzz detection results and users are encouraged to try them all. This is relatively simple, because all four results can be found in the same measurement context. For example, in the Loudspeaker Production Test measurement, the legacy Rub and Buzz and SoneTrac Rub and Buzz results are available when the log chirp stimulus is selected. By simply changing the stimulus to Fast Sweep, with the same frequency range and generator level settings, you can measure HOHD and Rub and Buzz Loudness and compare the four rub and buzz results to decide which one works best for your application.