

# Harmonic Distortion Measurements in the Presence of Noise Application Note

## Products:

- | R&S®UPV/UPV66
- | R&S®UPP200
- | R&S®UPP400
- | R&S®UPP800

It is the purpose of this application note to investigate and discuss the influence of wideband noise on harmonic distortion measurements.

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# 1 Harmonic Distortion Measurements

## 1.1 Introduction

Harmonic distortion measurements are usually performed on passive components like loudspeakers and with high test tone amplitude on active components like amplifiers. The validity of the distortion measurement result is based on the assumption that eventually present wideband noise has no influence on these results.

However, there are some digital or mixed signal audio devices with extremely low harmonic distortion like bitstream A/D and D/A converters and there are other devices with relatively low signal to noise ratio, like e.g. hearing aids at low input levels.

Instead of a pure harmonic distortion measurement, in most of these cases a combined measurement of noise and harmonic distortion is preferred, i.e. “total harmonic distortion plus noise” (THD+N) or “signal to noise and distortion” (SINAD), in which both distortion products and noise components are regarded together as “distortion plus noise”.

If nevertheless a pure harmonic distortion measurement is performed on such devices, the result may by definition and nature of the measurement depend not only on the harmonic distortion alone, but also on the level of existing wideband noise.

It is the purpose of this application note to investigate and discuss the influence of wideband noise on harmonic distortion measurements.

## 1.2 Theory

### 1.2.1 Nth Order Distortion Factor

Nth order distortion factor is defined e.g. in different parts of IEC 60268 as the ratio between the RMS voltage of the nth harmonic and the total RMS voltage of the signal:

$$d_n = \frac{V_{RMS,n}}{V_{RMS,total}} * 100\%$$

or in logarithmic unit

$$d_n = 20 * \log\left(\frac{V_{RMS,n}}{V_{RMS,total}}\right) dB$$

## 1.2.2 Total Harmonic Distortion

Accordingly, the total harmonic distortion (THD) is defined as the ratio between the RMS voltage of all distortion products and the total RMS voltage of the signal:

$$d_n = \frac{\sqrt{V_{RMS,2}^2 + V_{RMS,3}^2 + \dots + V_{RMS,n}^2}}{V_{RMS,total}} * 100\%$$

or in logarithmic unit

$$d_n = 20 * \log \left( \frac{\sqrt{V_{RMS,2}^2 + V_{RMS,3}^2 + \dots + V_{RMS,n}^2}}{V_{RMS,total}} \right) dB$$

This definition is taken as basis for the analyzer function “THD” in the UPV. It delivers distortion values  $\leq 100\%$  corresponding to negative dB values. It should be noted that an alternative definition exists, wherein the RMS value of the distortion products is related to the RMS value of the fundamental instead of the total RMS value. This definition allows distortion values beyond 100% and also positive dB values.

## 1.2.3 Measurement Method

The total RMS voltage of the distorted signal including fundamental is measured as  $V_{RMStotal}$ .

The RMS value  $V_{RMS,i}$  of the nth order harmonic is suggested to be measured each at the output of a suitable band-pass filter.

The measured RMS value  $V_{RMS,i}$  of any harmonic does not change with the analysis bandwidth as long as the frequency of the harmonic is within the passband of the filter, and the distortion factor does not change.

The measured RMS level  $V_{RMS,i\_noise}$  caused by wideband noise is determined by the effective bandwidth of the bandpass filter  $B_{eff}$ , and by the spectral noise density  $e_n$  in  $V/\sqrt{Hz}$  of the wideband noise at the input:

$$V_{RMS,i\_noise} = e_n * \sqrt{B_{eff}}$$

## 1.3 Measurement Method in Audio Analyzer R&S® UPV

### 1.3.1 General

Harmonic distortion measurement is implemented in the audio analyzer R&S® UPV in analyzer function “THD”. Function result is the total harmonic distortion factor calculated from the harmonics specified in the “Meas Mode” field. Alternatively to the harmonic distortion factor, the absolute level of the specified distortion products can be determined and displayed. Nth order distortion factors or levels can be displayed simultaneously in one of the bargraph displays.

### 1.3.2 Spectral Analysis

The bandpass functionality required to determine the RMS values of the harmonics is implemented in this analyzer function in the form of a Fast Fourier Transform (FFT). Several FFT bins are combined for each of the required bandpass filters. The size of the FFT and consequently its frequency resolution is automatically determined from the fundamental frequency which is either measured ("Fundamental = Auto") or set as parameter ("Fundamental = Value" or tracked to the generator frequency "Fundamental = Gen Track") in the analyzer function panel. The frequency resolution and the selected windowing function determine the effective bandwidth of the bandpass filters.

The FFT spectrum used for the THD calculation can be displayed in the R&S<sup>®</sup> audio analyzers UPV and UPP as "Post FFT".

### 1.3.3 Minimum FFT Size and Refinement

As can be seen from the above, using a large FFT size would be desirable for a good noise immunity of the measurement. However, a large FFT size means a long acquisition time, and therefore a compromise has to be found between noise immunity and measurement speed.

At medium and high frequencies the THD function of the audio analyzer R&S<sup>®</sup> UPV uses the specified minimum FFT size which can be seen when the "Post FFT" checkbox is activated. This minimum FFT size is optimized for both resolution and measurement speed. If the frequency resolution of the minimum FFT size is not sufficient to separate the harmonics for a given fundamental frequency, a larger FFT size is selected.

From firmware version 3.2.0 the UPV provides a parameter "Refinement" in the THD analyzer function. The FFT size determined automatically depending on the fundamental frequency is additionally enlarged by this refinement factor. If the enlarged FFT size is smaller than the specified minimum FFT size, the minimum FFT size is applied instead. The minimum FFT size is not affected by the refinement factor. It can be changed separately by activating the Post FFT and changing the parameter there.

## 1.4 Effect of Wideband Noise

Wideband noise creates a level reading in the FFT at the harmonic frequencies which depends on the noise density and the effective bandwidth of the bandpass filters used to measure the RMS value  $V_{RMS, i}$  of each harmonic. If this noise level is not significantly below the level of the real harmonic, the reading of the single harmonic and total harmonic distortion is deteriorated. If the noise level is significantly higher than the level of the real harmonic, the distortion result is totally depending on the noise density and effective bandwidth. In this case doubling the FFT size yields the same THD result as the measurement with original FFT size and 3 dB higher S/N ratio.

To illustrate the interrelationship set forth above, a synthetic signal with  $d2 = 0.4\%$ ,  $d3 = 0.3\%$  (i.e. THD = 0.5%), mixed with white noise is subject to a THD measurement with the fundamental set to 1 kHz. Figure 1 shows the FFT spectra of such test signals yielding 50 dB, 32 dB and 20 dB S/N ratio in a 22 kHz bandwidth.

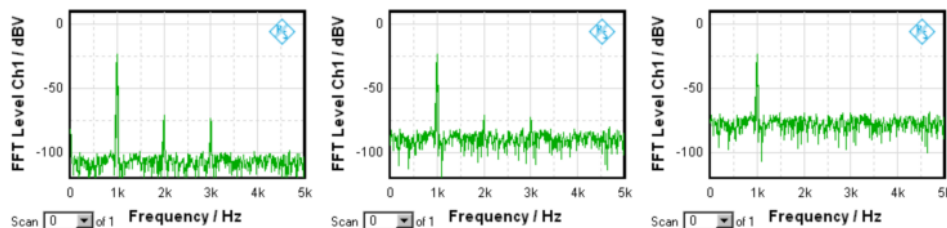


Figure 1: FFT spectrum of synthetic test signal with 0.5% THD and a S/N ratio of 50 dB, 32 dB and 20 dB. FFT size is 8k.

Figure 2 shows the THD reading for the synthetic test signal described above. The S/N ratio measured in a 22 kHz bandwidth is shown on the x-axis.

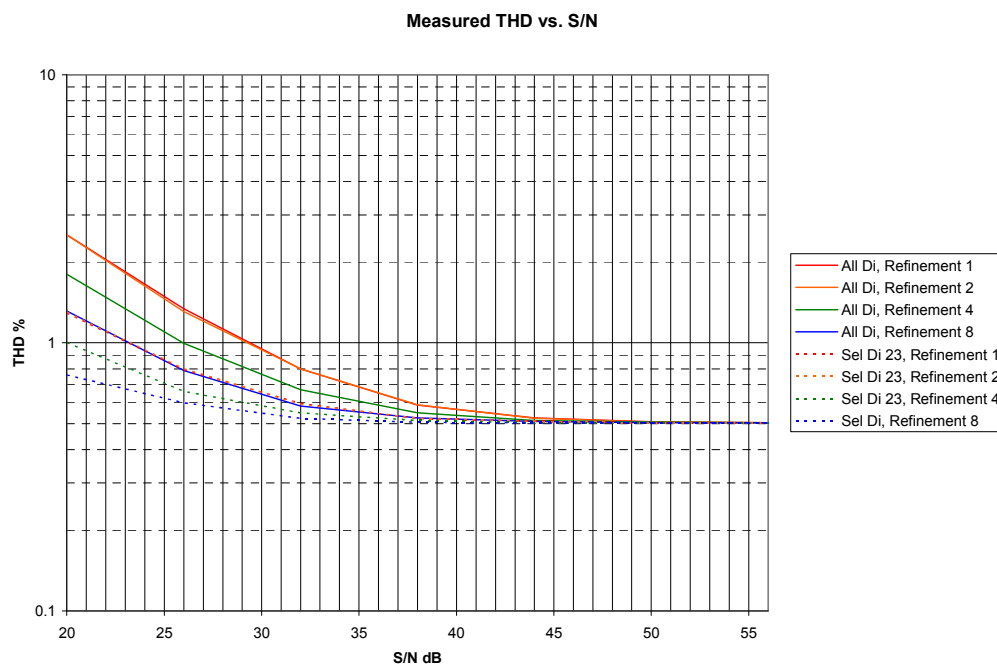
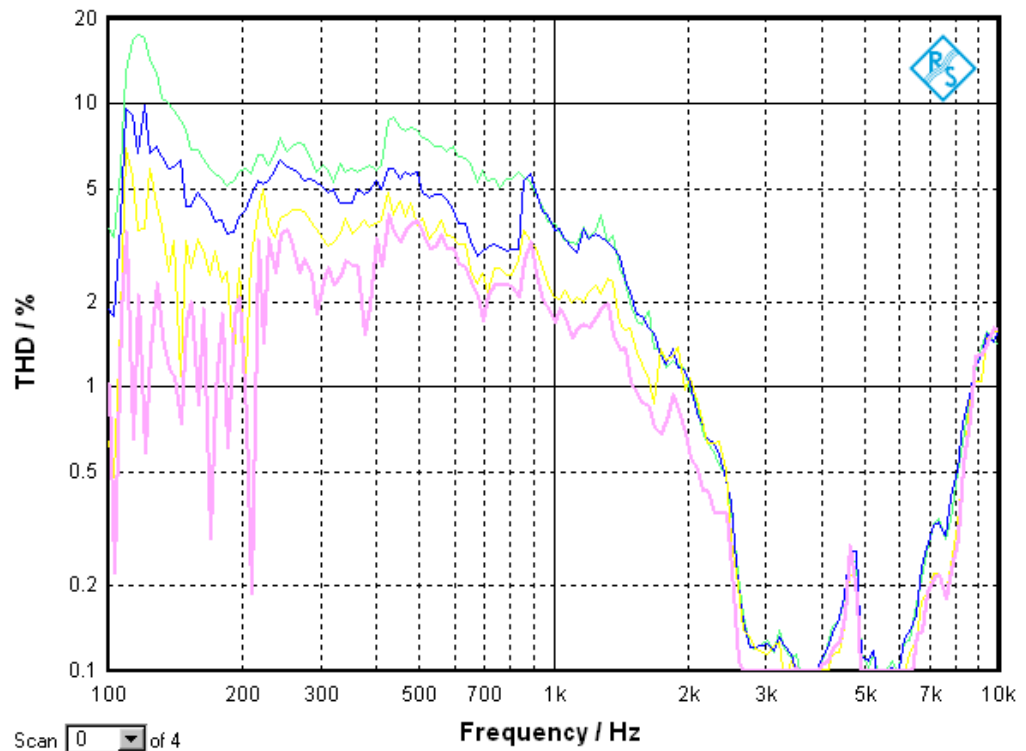


Figure 2: THD result for a 1kHz signal with THD = 0.5%, depending on the S/N ratio

Down to a S/N ratio of about 50 dB, the THD measurement shows the expected result. Below 50 dB, the THD result is rising with decreasing S/N ratio. Below about 25 dB S/N ratio, the THD result is totally noise dominated and therefore doubling for each 6 dB decrease of S/N ratio.

At 1 kHz signal frequency, refinement 2 uses the same 8k FFT size which is specified as minimum FFT size. Therefore there is no difference between refinement 1 and refinement 2. Refinements 4 and 8 each reduce the THD by the same amount as would be the effect of 3 dB increase of S/N ratio.

Figure 2 shows a real-world example of a THD measurement swept over frequency, performed on a hearing aid at medium input level. Below about 2 kHz the measurement result is more or less noise-dominated. An increase of the FFT size by a factor of 2 reduces the THD result by a factor of about 1.4, corresponding to 3 dB difference.



**Figure 3: THD sweep over frequency with refinement 1 (light blue), 2 (dark blue), 4 (yellow) and 8 (pink)**

The Post FFT in the R&S® audio analyzer UPV or UPP can be used to monitor the relation between harmonics and wideband noise like shown in figure 1. Activate Checkbox “Post FFT” in the analyzer function panel and click the “Show” button next to it. The configuration panel corresponding to the FFT graph can be opened by right-clicking into the FFT graph and choosing context menu item “Config”.

## 1.5 Effect of Narrowband Noise

Narrowband interference like mains hum can also have an influence on the harmonic distortion measurement result. Depending on the resolution of the FFT, the effect will stay constant as long as the frequency of the interferer falls within the same bin as (one of) the measured harmonics. It will disappear when the frequency of the interferer is outside the passband of the respective bandpass filter.

## 1.6 Conclusion

By definition and nature of harmonic distortion measurement, its result can be dominated by noise if the distortion factor and/or signal to noise ratio is low. Increasing the FFT size can help by reducing the spectral level of wideband noise and discriminating harmonics against narrowband noise.

The noise and harmonic distortion situation can be monitored by displaying the "Post FFT" spectrum.

## 2 Literature

- IEC 60268-3:2001 Sound system equipment - Part 3: Amplifiers
- IEC 60268-4:2010 Sound system equipment - Part 4: Microphones
- IEC 60268-5:2003 Sound system equipment - Part 5: Loudspeakers
- R&S UPV Operating Manual
- R&S UPP Operating Manual

## 3 Ordering Information

Audio Analyzer		
Type	Designation	Order No.
UPV	Audio analyzer, analog interfaces, DC to 250 kHz	1146.2003.02
UPV66	Audio analyzer, without display, keyboard and CD drive	1146.2003.66
UPP200	Audio Analyzer two channels	1411.1003.02
UPP400	Audio Analyzer four channels	1411.1003.04
UPP800	Audio Analyzer eight channels	1411.1003.08



### About Rohde & Schwarz

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- Continuous improvement in environmental sustainability
- ISO 14001-certified environmental management system



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