Multi-Tone Distortion Measurement AN16

Application Note for the KLIPPEL R&D and QC SYSTEM

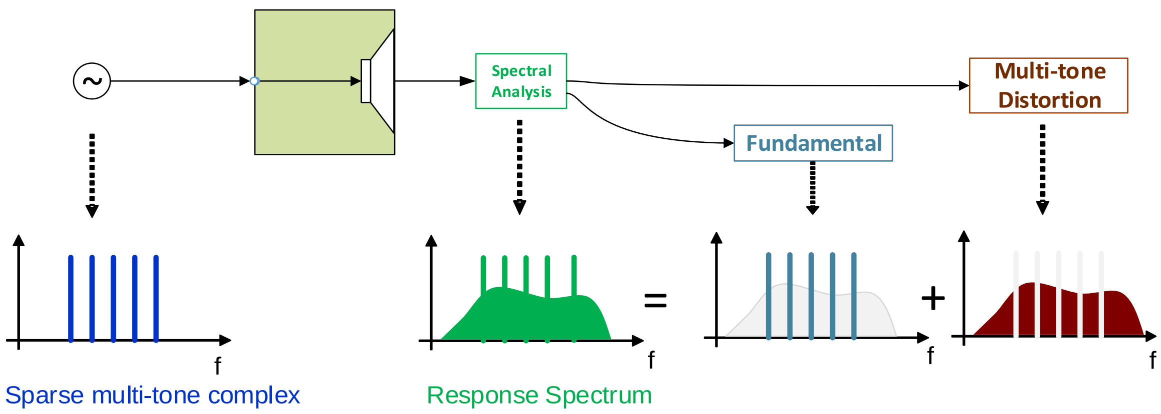
(Document Revision 2.0)

DESCRIPTION

Multi-tone excitation signals are optimal for the measurement of speakers similar to normal working conditions. Like a typical audio signal such as speech or music, it generates harmonic and all kinds of intermodulation distortion.

Using the module Multi-Tone Measurement (MTON) of the Klippel R&D System a multi-tone excitation signal is generated and the voltage, current, voice coil displacement and radiated sound pressure may be measured and analyzed simultaneously. Typical distortion pattern produced by factor *Bl(x)*, compliance $C_{ms}(x)$, inductance $L_e(x)$, Doppler and nonlinear radiation are assessed. They may be interpreted as *fingerprints* of the dominant nonlinearities in transducers and audio systems. MTON provides flexible methods to ramp up test levels, determine maximum SPL level for given distortion threshold and copes with clock jitter inherent in wireless / Bluetooth® applications. It is compliant to IEC 60268-21 [3].

In addition, the multi-tone distortion is a comprehensive metric to evaluate the overall behaviour of any kind of audio products at the end of the production line. The Multi-Tone Distortion Task (MTD) in the Klippel QC system allows multi-tone based testing and is checking the fundamental and distortion components against limits in extremely short time in both RnD and End-of-Line (EoL) environments.



CONTENT

1 Overview

1.1 Measurement Principle

Signal	A multi-tone signal is a steady-state signal comprising a multitude of tones generated at known frequencies. A logarithmic spacing of the tones is used typically. The number is usually limited to 3 – 12 tones per octave to have enough free bins for a distortion analysis. The amplitude of the tones can be adjusted to represent a normal audio signal. However, the phase relationship of the tones will determine the actual time signal and hence the generated intermodulation components in audio products.
Measured signals	It is very useful to measure not only the sound pressure output but also the voltage and current at the transducer terminals and the voice coil displacement. The inspection of the voltage signal shows the distortion of the power amplifier used. The dominant nonlinearities such as $Bl(x)$, $C_{ms}(x)$ and $L_e(x)$, Doppler Effect are directly related with the voice coil displacement. The comparison between the current and sound pressure spectrum allows identifying the cause of distortion [1].
Spectral analysis	The measured signals are subject to a FFT analysis. Since the multi-tone excitation signal has a sparse spectrum the nonlinear distortion can be accessed at non-excited frequencies of the FFT spectrum.
Noise Floor	It is useful to perform an additional measurement without excitation to determine the magnitude of noise floor caused by external or internal sources. This helps to separate distortion and noise symptoms.
Working range	The maximal peak to peak displacement of the voice coil indicates the mechanical working range as the most important measurement condition. It is recommended to measure the rms value of the voltage and current at the terminals.
Interpretation	The amplitude of the reproduced signal at excited frequencies represents the fundamental response. The nonlinear distortion is generated by complicated interactions between the fundamental components. It is hardly possible to separate harmonic and intermodulation distortion. However, they are more a nonlinear fingerprint of the speaker showing the amplitude of the distortion in an audio-like signal. The table below gives a summary on typical distortion responses in sound pressure and electrical input current for a common woofer system

1.2 Distortion of a woofer system

	CURRENT SPECTRUM			**SOUND PRESSURE SPECTRUM**		
Nonlinearity	**$f = f_s$**	**$f_s < f < 10\ f_s$**	**$f > 10\ f_s$**	**$f = f_s$**	**$f_s < f < 10\ f_s$**	**$f > 10\ f_s$**
Force factor	High	Falling with f	Small	High	High	High
Compliance	High	Small	Negligible	High	Small	Negligible
Inductance	Small	High	High	Small	High	High
Doppler	No	No	No	Negligible	Small	High
Radiation	No	No	No	Negligible	Small	High

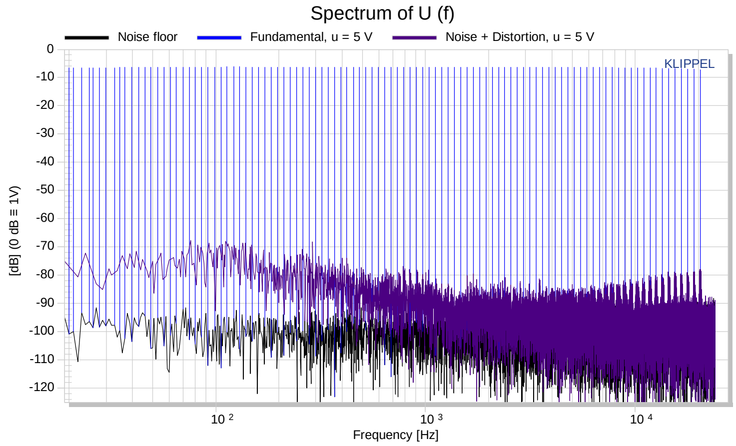
2 Using the Multi-Tone Measurement (MTON)

Test Object	Any transducer (drivers, systems, woofer, tweeter, horn loudspeaker) or audio system (active, passive systems, Bluetooth® systems) may be measured
Setup	An optional laser sensor is adjusted to the vibrating diaphragm. A dot of white ink may be used to increase the signal to noise ratio of the measured displacement signal. The microphone should be in the near field to obtain high signal to noise ratio. Set the test object in an approved environment and connect the terminals with SP1. Switch the power amplifier between OUT1 and connector AMP. If KA3 device is used, configure the signal settings.
Requirements	• Klippel Analyzer (KA3) or Distortion Analyzer (DA2) • Software module Multi-Tone Measurements (MTON) • Power amplifier or self-powered speaker • Microphone • Optional: Laser sensor • Optional: Pro Driver Stand or Micro speaker Clamping
Preparation	• Open any database with dB-Lab or create a new one • Create a new MTON operation with default settings.
Measurement	1. Check the input configuration in parameter page *Input / Processing* 2. Introduce the microphone calibration. 3. Adjust the excitation level in the parameter page *Stimulus*, make sure the test object is operated in the nonlinear domain generating noticeable distortion. 4. Start the measurement, take care to protect your ears. 5. Check acoustic distortion in result window *In (f) Spectrum*. Significant distortion should be at least 10dB above measured noise floor. 6. When using laser sensor, read the working range (maximal displacement value in the result window *Table Results + Settings*). 7. Evaluate the distortion of the amplifier in the result window *U (f) Voltage Spectrum*. For typical results see example below. 8. Evaluate the distortion from voice coil inductance *Le(x)* produced at high frequencies in the result window *I (f) Current Spectrum*. For details, check reference [1]. 9. Compare the distortion in sound pressure and current at different frequencies to identify clues for the sources of distortion.

3 Examples using the Multi-Tone Measurement (MTON)

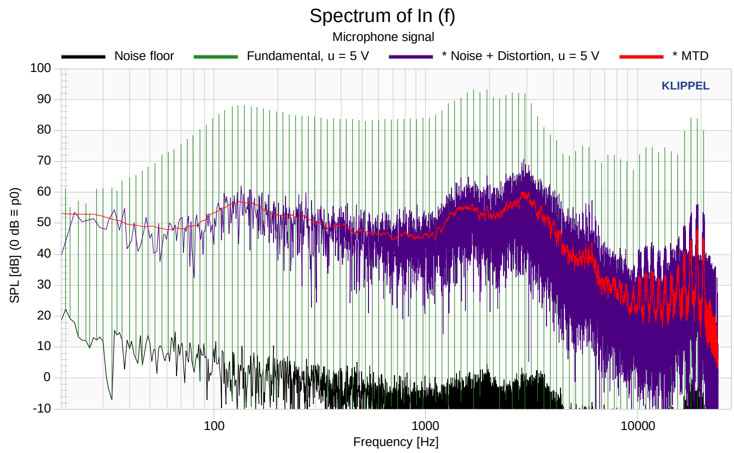
<table>
<tr><th colspan="2">3.1 Single Measurement of a Woofer</th></tr>
<tr><td>Measurement Conditions</td><td>This example was measured in free air using the Pro Stand to obtain the multi-tone distortion produced in voltage, current, pressure and displacement measurements.</td></tr>
<tr><td>Setup</td><td>Multi-tone stimulus is defined as follows:

Minimal Frequency: 20 Hz
Maximal Frequency: 20 kHz
Relative resolution: 10 lines per octave
Signal duration: 1 second
5 V rms at speaker terminals
</td></tr>
<tr><td>Results: Voltage (f)</td><td>Open the result window Voltage (f) Spectrum to assess the distortion produced by the power amplifier.

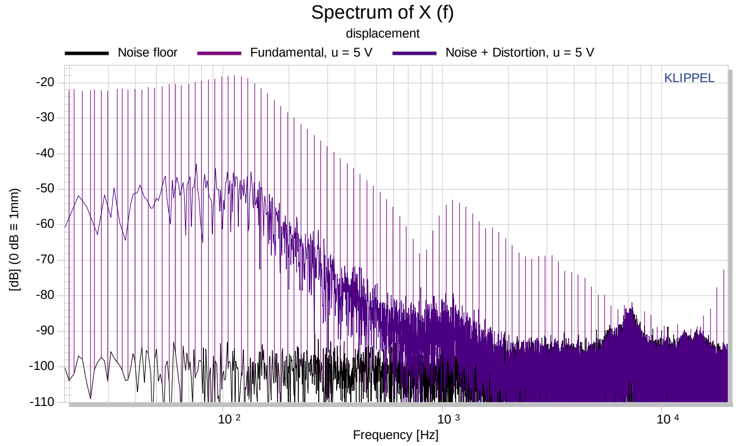


In this example the amplifier shows distortion at -60dB below fundamental which corresponds to about 0.1%. This indicates a reliable, clean excitation signal.

The distortion is separated well from the noise floor which is even 20 dB lower over the full frequency band.</td></tr>
<tr><td>Results: Sound Pressure Level (f)</td><td>Open the result window p (f) Spectrum to assess the spectrum in the radiated sound pressure signal.

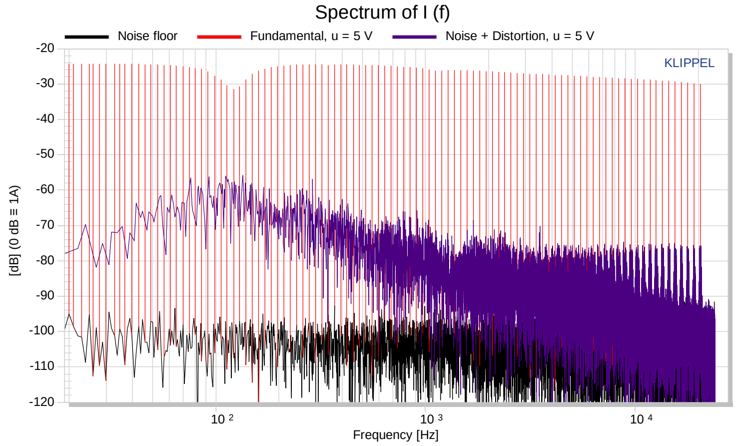


The distance between fundamental component and distortion is almost constant. The distortion is around 20dB below the fundamental (10%), indicating strong nonlinear operation. The distortion are also well above noise floor, indicating reliable distortion measurement. For detailed interpretation and analysis of causes see reference [1].</td></tr>
</table>

Results: Displacement (f)	Open the result window *X (f) Spectrum* to assess the spectrum of the voice coil displacement.  Above the resonance frequency f_s at 120 Hz the amplitude of the fundamental component decreases by 12 dB per octave typical for any electrodynamic loudspeaker. The resonance at 1kHz may be a parasitic vibration such as a rocking mode. Compared to Sound Pressure Level (f) the fundamental to distortion ratio is similar. This indicates nonlinear mechanisms occurring already in the mechanical domain, typically *Bl(x)*, $C_{ms}(x)$.

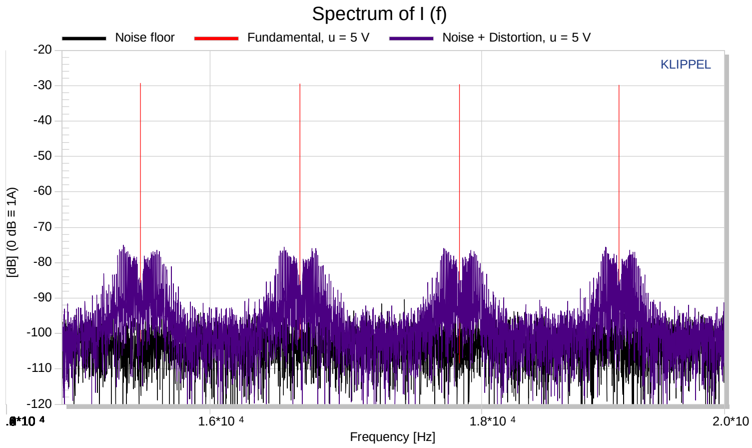
Results: Current (f)

Open the result window *Current (f) Spectrum* to assess the spectrum of the input current.



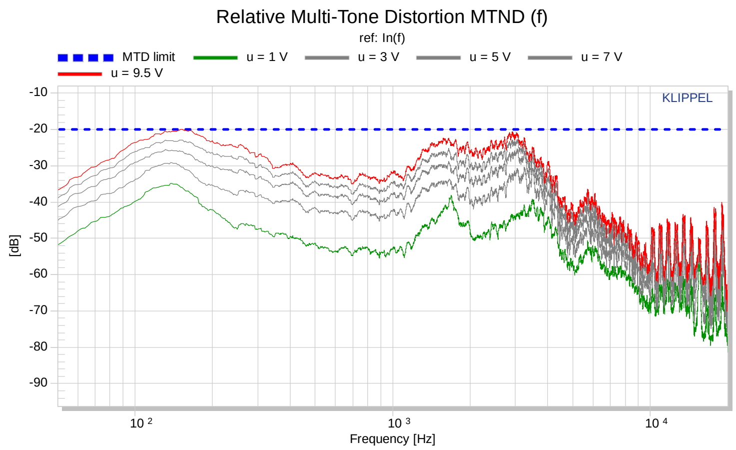
The distortion close to the resonance frequency is mainly caused by the *Bl(x) and* $C_{ms}(x)$ nonlinearities. Outside the resonance the fundamental to distortion ration is about 40dB. This indicates a minor contribution by the electrically relevant non-linearities such as $L_e(x)$ in this example.

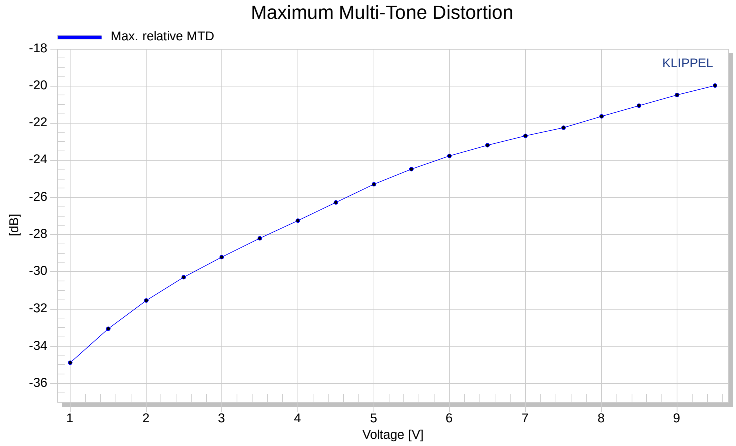
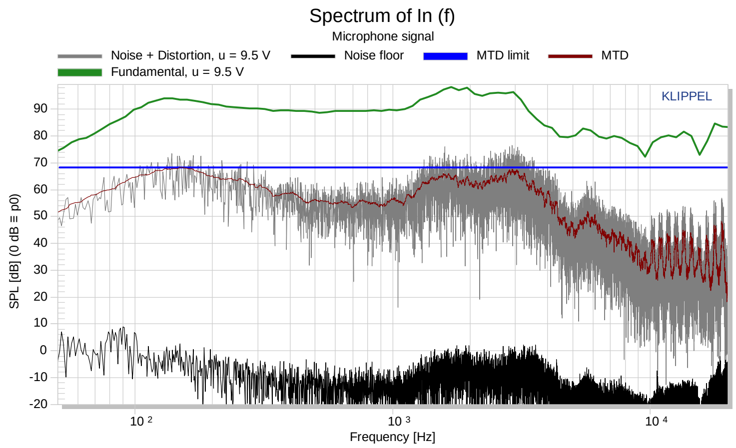
Detailed analysis at high frequencies:



At high frequencies *f* > 10kHz we see intermodulation distortion centred around the fundamental components. These are typical distortion from nonlinear inductance $L_e(x)$ caused by the interaction of the low-frequency components of the displacement signal *x(t)* and the high-frequency components in the current signal *i(t)*. All distortion already generated and visible in input current will also show up in the sound pressure output signal.

3.2 Multiple measurement Example: Increase Voltage protected by multi-tone distortion limit

Measurement Conditions	A woofer is measured multiple times increasing the measurement voltage to obtain the maximum SPL generating a certain, user defined multi-tone distortion. This measurement is useful to find the operation limits of a device under test and protecting it during the measurement sequence. In this example the limit is defined as relative multi-tone distortion of sound pressure according to standard IEC 60268-21 [3] (where multi-tone distortion is labelled *MDS(f)*).
Setup	Multi-tone stimulus is defined as follows: • Minimal Frequency: 20 Hz • Maximal Frequency: 20 kHz • Relative resolution: 10 lines per octave • Signal duration: 1 second Measurement sequence: • Minimum (start) Voltage: 1 V • Maximum Voltage: 20 V • Voltage step size: 0.5 V • Pause between measurements: 10 s (for cooling) Multi-tone Distortion Limit: • Applied at microphone signal • Multi-tone Distortion Limit: -20 dB relative to fundamental mean level
Results: Multi-Tone Distortion (relative)	Open the result window *MTND (f) Multi-Tone Distortion (rel)*, where the multi-tone distortion curves relative to the mean spectrum of the microphone measurements are displayed.  The sequence is stopped at 9.5 V, since the multi-tone distortion limit is reached at 150 Hz (red curve).

Results: Maximum Multi-Tone Distortion	Open the result window *Maximum MTND* to track the multi-tone distortion develop.  The peak distortion reached at each measurement is displayed versus the stimulus voltage. This curve provides a simple tracking of the relative multi-tone distortion across the measurement sequence.
Results: Sound pressure level	Open the result window *p (f) Spectrum* to assess the spectrum in the radiated sound pressure signal of the last (highest level) measurement of the sequence.  In addition to the noise floor, fundamental and distortion curves, the MTD and MTD limit are displayed. The MTD curve (brown curve) is the multi-tone distortion processed according to IEC 60268-21 [3] (special smoothing proposed by Voishvillo [2]), while the blue curve is the multi-tone distortion limit (defined as -20 dB relative to fundamental mean). The smoothing process is applied to simplify the interpretation of the multi-tone distortion. In addition, the smoothing makes the limitation more robust compared to the peaky full resolution multi-tone distortion result (see grey curve).

3.3 Wireless Measurement

Measurement Conditions

Bluetooth® devices require a special measurement configuration, since the particularities of wireless audio transmission such as long delays and clock drift causes several problems in the measurement. A complete description of the measurements with Bluetooth® devices is available in the application note AN72 “Testing Wireless Audio Devices”.

A Bluetooth® device is measured with and without clock drift tolerance to show up the differences between both processing modes.

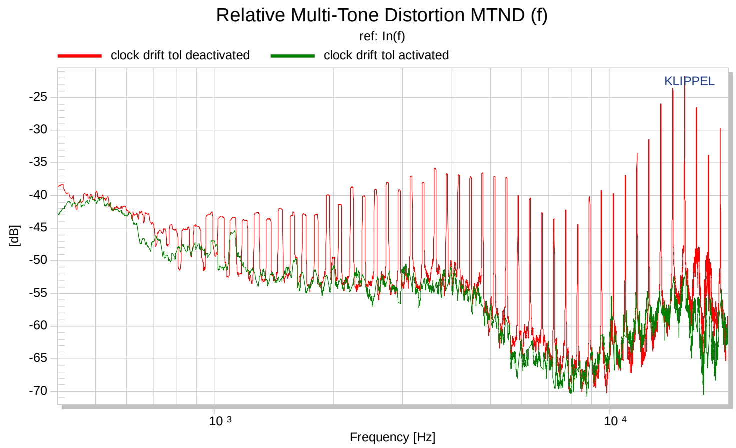
Setup

Multi-tone stimulus is defined as follows:

- Minimal Frequency: 20 Hz
- Maximal Frequency: 20 kHz
- Relative resolution: 10 lines per octave
- Signal duration: 1 second
- 0.1 V rms at Bluetooth® speaker input

Results: Multi-Tone Distortion

The relative multi-tone distortion of both measurements with (green) and without (red) clock drift tolerance are shown.



The clock drift caused by Bluetooth® connection smears the excited signal frequencies into the adjacent (non-excited) frequencies. If not compensated correctly. This smearing effect is interpreted as distortion, leading to massively wrong assessment of multi-tone distortion (up to 40dB in this example!). This effect is automatically compensated by MTON using the *clock drift tolerance* option.

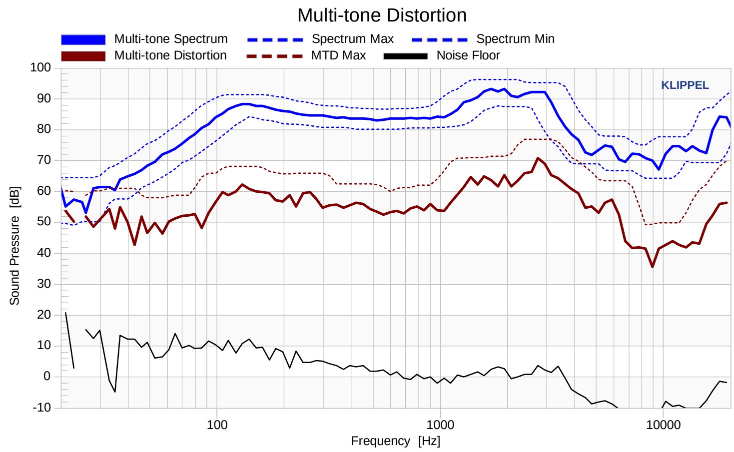
4 Using the QC Multi-Tone Distortion Task (MTD)

Target	Any test object (drivers, systems, woofer, tweeter, horn loudspeaker, systems) may be measured.
Requirements	• Klippel Analyzer (KA3) or Production Analyzer (PA) • Software module Multi-Tone Distortion (MTD) • Power amplifier • Microphone
Preparation	• EoL Measurement: ○ Open Klippel QC Start – Engineer. ○ Create a new empty test. ○ Open the new test by clicking on *Measure*. QC Operation in dB-Lab is automatically logged. ○ Add Multi-Tone Distortion Task (*Add…* button, open *mtd.task*). • RnD Measurement: ○ Create a new QC operation based on the template *QC Multi-tone Distortion (MTD)*.
Measurement	1. Start the QC Operation (Login). 2. Check the excitation level, frequency range, resolution and duration of stimulus. 3. Check the routing configuration. 4. Run the test (*Start* button), take care to protect your ears. 5. Check the multi-tone spectrum and the multi-tone distortion in the result window *Multi-Tone Distortion*. 6. Check the signal characteristics in the result window *Summary*.

5 Examples using the QC Multi-Tone Distortion Task (MTD)

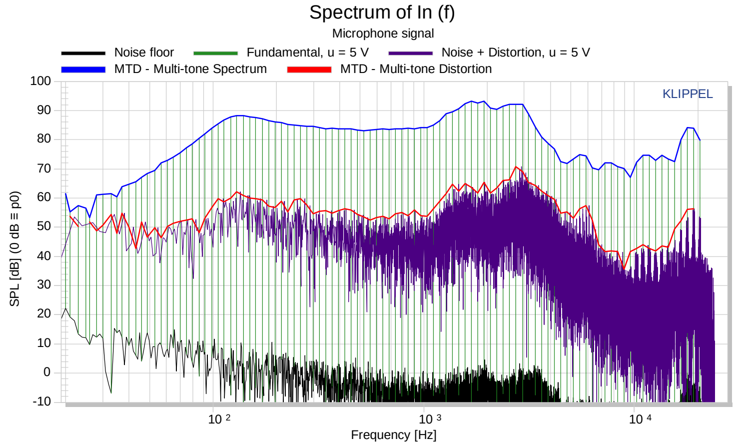
<table>
<tr><th colspan="2">5.1 Single Measurement</th></tr>
<tr><td>Measurement Conditions</td><td>A woofer is measured at the end of the assembly line to test if its multi-tone spectrum and distortion are within the limits defined previously by measuring a reference unit.

This example is using identical conditions and test object as the first MTON example above.</td></tr>
<tr><td>Setup</td><td>Multi-tone stimulus is defined according the single measurement example described in chapter 3.1:
• Minimal Frequency: 20 Hz
• Maximal Frequency: 20 kHz
• Relative resolution: 10 lines per octave
• Signal duration: 1 second
• 5 V rms at speaker terminals</td></tr>
<tr><td>Results: Multi-tone Distortion</td><td>The spectrum and distortion of the radiated sound pressure signal are displayed in the result window Multi-tone Distortion.



The multi-tone spectrum (blue) and distortion (brown) measurements are displayed together with the defined limits (dotted lines). Since both metrics are within the boundaries of the valid range, the DUT has passed the test.

Since the end-of-line testing requires ultra-fast measurements, the MTD Task reduces the full resolution of the multi-tone distortion curve to save processing time. Two modes of data reduction are available: rms and peak mode, please see manual and spec sheet for details.</td></tr>
</table>

Comparison MTON vs. MTD	The results of the MTON measurement described in chapter 3.1 are displayed together with the MTD measurement to be compared.  Since both measurements are configured using the same setup, the multi-tone spectrums (blue curve: MTD, green lines: MTON) are identical. Regarding the multi-tone distortion, the MTON module shows the full resolution curve (violet curve), while the MTD (red curve) reduces the resolution according to the peak distortion value (peak mode). Despite the data reduction, both multi-tone distortion measurements are almost identical, they match at the maximum values.

6 References

6.1 Related Modules	Multi-Tone Measurement (MTON) Multi-Tone Distortion Task (MTD)
6.2 Application notes	AN72: Testing wireless audio devices with Klippel R&D System
6.3 Specifications	A5: Professional Driver Stand A10: Micro Speaker Clamping S64: MTON Multi-Tone Measurement S68: QC – Multi-Tone Distortion Task
6.4 Publications	[1] W. Klippel: Physical and Perceptual Evaluation of Electric Guitar Loudspeakers [2] Voishvillo, et. al.: Graphing, Interpretation, and Comparison of Results of Loudspeaker Nonlinear Distortion Measurements
6.5 Standards	[3] IEC 60268-21 – Sound System Equipment – Acoustical (output-based) measurements
6.6 Web-Seminars	Series 1, #7: Amplitude Compression – Less Output at Higher Amplitudes Series 1, #11: Pitfalls in Testing Wireless Audio Devices

Find explanations for symbols at:

http://www.klippel.de/know-how/literature.html

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