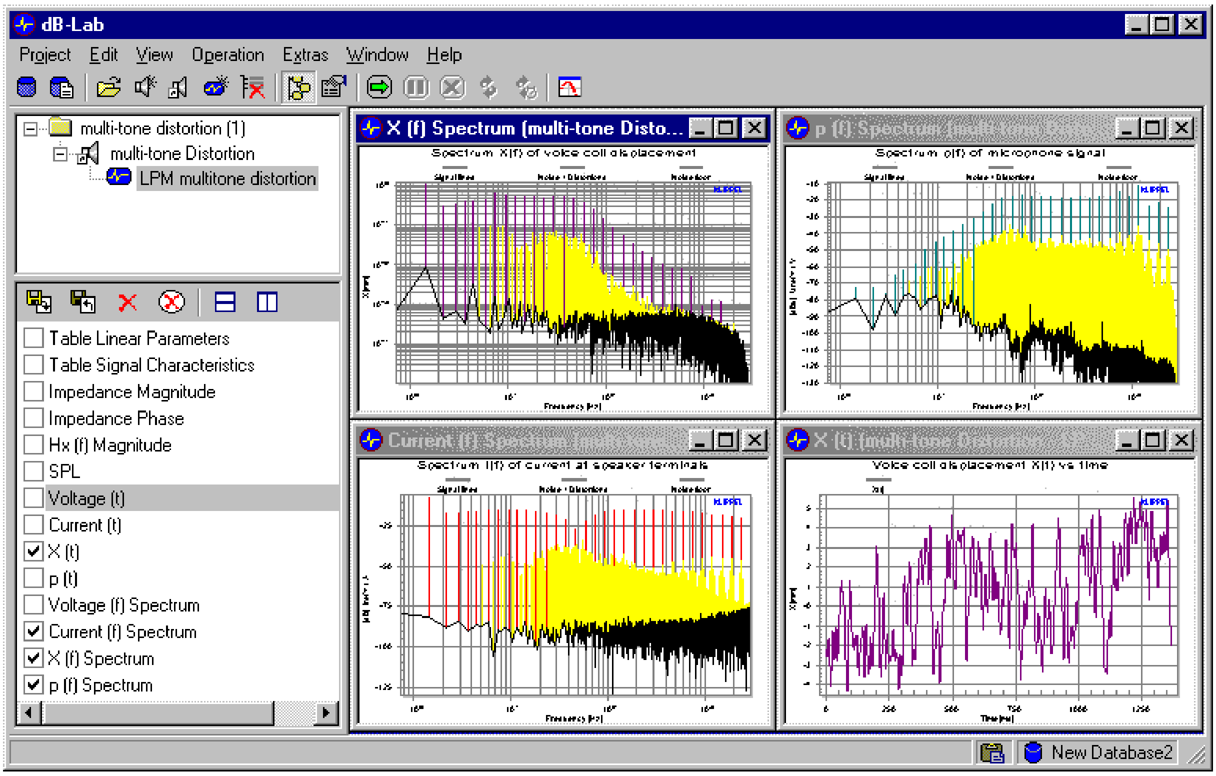
Multitone Distortion Measurement

AN 16

Application Note to the KLIPPEL R&D SYSTEM

Multi-tone excitation signals are optimal for the measurement of speakers similar to normal working conditions. Like a regular audio signal it generates harmonic and all kinds of intermodulation distortion. Using the module Linear Parameter Measurement (LPM) 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 discussed. They may be interpreted as fingerprints of the dominant nonlinearities in transducers.



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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 – 9 tones per octave to have enough free bins for the 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 generation of the intermodulation components. It is important that all tones are present at each time instant to have nonlinear interactions between the tones. This can be accomplished by using a random phase between the excitation tones.
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.
Spectral analysis	The measured signals are subject to a FFT analysis. Since the multi-tone excitation signal has a sparse spectrum the nonlinear distortion may be measured in the free bins of the FFT spectrum. It is useful to perform an additional measurement without excitation to determine the magnitude of noise floor caused by external or internal sources.
Working range	The maximal peak to peak displacement of the coil is the most important measurement condition. It is also recommended to measure the rms value of the voltage and current at the terminals.
Interpretation	The amplitude of the reproduced multi-tone signal represents the fundamental response. The nonlinear distortion are generated by complicated interactions between the fundamental components. It is very complicated to identify them as 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.

Distortion of a woofer system

	CURRENT SPECTRUM			**SOUND PRESSURE SPECTRUM**		
Nonlinearity	$f = f_s$	$f_s < f < 10f_s$	$f > 10f_s$	$f = f_s$	$f_s < f < 10f_s$	$f > 10f_s$
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

Using the Linear Parameter Measurement (LPM)

Transducer	Any transducer (drivers, systems, woofer, tweeter, horn loudspeaker) may be measured.
Loudspeaker Setup	The laser sensor is adjusted to the diaphragm. A dot of white ink may be used to increase the signal to noise ratio of the measured displacement signal. If the driver is mounted in the driver stand the microphone should be in the near field.

Requirements	The following hardware and software is required • Distortion Analyzer + PC • Software module Linear Parameter Measurement (LPM) + dB-Lab • Laser sensor head and laser controller • Microphone
Setup	Connect the microphone to the input **IN1** at the rear side of the Distortion Analyzer. Set the speaker in the approved environment and connect the terminals with **SPEAKER 1**. Switch the power amplifier between **OUT1** and connector **AMPLIFIER**.
Preparation	• Open the database within dB-Lab • Create a new object *DRIVER* and assign a new LPM operation based on the operation template "**LPM multitone dist. SP1 AN16**"
Measurement	1. Check the excitation level, drive the speaker in the nonlinear domain. 2. Start the measurement "**LPM multitone distortion SP1**", ignore any warning regardnbing too high distortion. 3. Open the result window **X(t)**. Read the maximal peak to peak value. 4. Open the result window **voltage(f) spectrum** and evaluate the distortion of the amplifier. 5. Open the result window **Current (f) spectrum** and evaluate the distortion from voice coil inductance $L_e(x)$ produced at high frequencies. 6. Open the result window **p(f) spectrum** and asses the distortion in the radiated sound pressure signal. 7. Compare the distortion in sound pressure and current at different frequencies to identify clues for the sources of distortion.

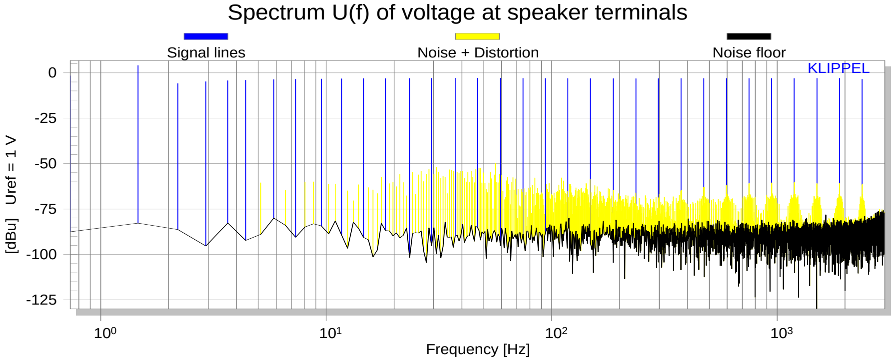
Setup Parameters for the LPM Module

Template	Create a new Object, using the operation template **LPM multitone distortion SP1 AN16** in dB-Lab. If this database is not available you may generate **LPM multitone distortion SP1AN16** based on the general LPM module. You may also modify the setup parameters according to your needs.
Default Setting	1. Open the property page **STIMULUS**. Set the maximal frequency to up to 10 kHz. Set the relative resolution to 1/10 lines per octave beginning at 21 Hz. Set the voltage at **Speaker Terminals** to 4 V rms. Increase voltage, if the loudspeaker is not in the nonlinear domain (strong distortion visible),and set the number of averaging to 1. 2. Open the property page **Input**. Set the routing to **Speaker 1**. Enable the laser and microphone as external sensors and the noise floor measurement. 3. Open the property page **Method**. Enable the laser measurement method and select the driver in free air.

Example

Amplifier

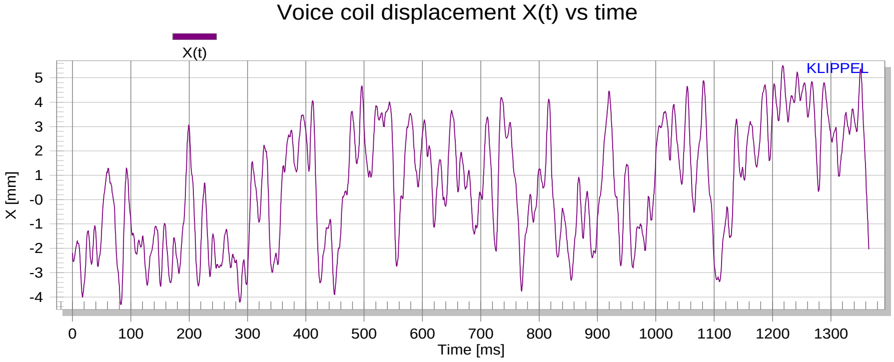
Open the result window **Voltage (f) Spectrum** to asses the distortion produced by the power amplifier.



In this example the amplifier has distortion about 0,5%. They are quite good separated from the noise floor which is 20 dB lower. Whereas the distortion components fill all bins at low and medium frequencies there are clearly separated intermodulation centered around the fundamentals at higher frequencies. This kind of distortion is typical for a digital amplifier (Class D) having a poor power supply rejection.

Peak to Peak Displacement

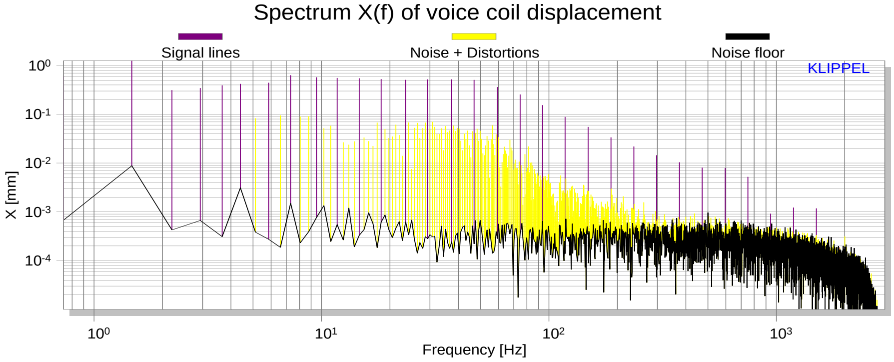
Open the result window **X (t)** to asses the peak to peak displacement of the loudspeaker.



In this example the driver produced a peak to peak displacement of X_{pp} = 9.82 mm. This value is also displayed on the result window **Table signal characteristics**. The time signal also reveals a good mixture of high frequency and low frequency components.

Displacement

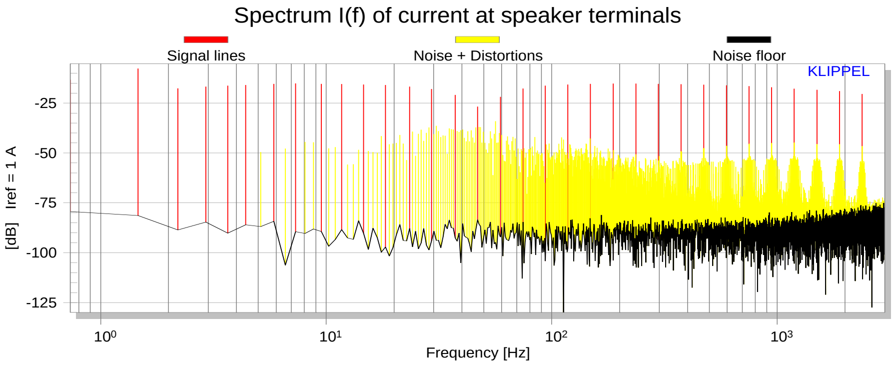
Open the result window **X (f) Spectrum** to asses the spectrum of the voice coil displacement.



Above the resonance frequency f_s at 70 Hz the amplitude of the displacement decreases by 12 dB per octave.

Current (f)

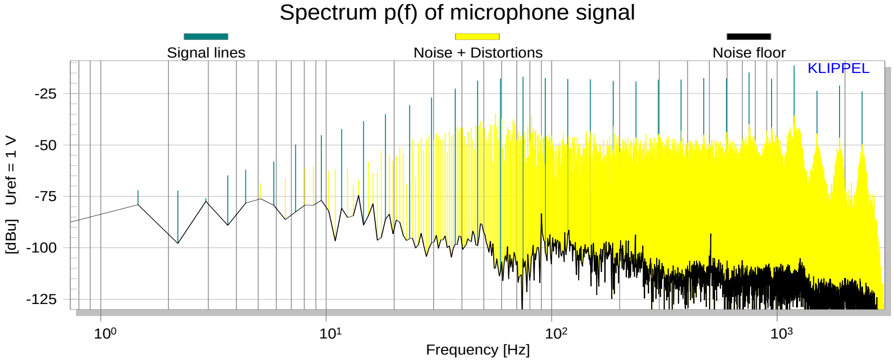
Open the result window **Current (f) Spectrum** to asses the spectrum of the input current.



The distortion close to the resonance frequency is mainly caused by the Bl(x) and Cms(x) nonlinearities. They are harmonic and intermodulation distortion filling all the bins in the FFT spectrum. At higher frequencies $f > f_s$ we see intermodulation distortion centered 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 $i(t)$. The magnitude of this distortion rises form –40 dB at 200 Hz to -25 dB at 2 kHz (relative to the fundamental). All distortion already generated and visible in input current will also show up in the sound pressure output signal.

Sound Pressure Level f)

Open the result window **p (f) Spectrum** to asses the spectrum in the radiated sound pressure signal.



The distortion floor is almost constant up to 1 kHz. At higher frequencies the distortion are centered around the fundamental component mainly caused by intermodulation between the displacement which is a low-pass filtered signal and the current. Comparing the distortion in current and sound pressure reveals dominant force factor distortion up to 1 kHz and dominant inductance distortion at higher frequencies.

More Information

Related Application Notes	"3D Intermodulation Distortion Measurement", Application Note 8 "3D Harmonic Distortion Measurement", Application Note 9
Related Specification	“LPM”, S2 “DIS”, S4
Software	User Manual and online help system of the Klippel R&D System.

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