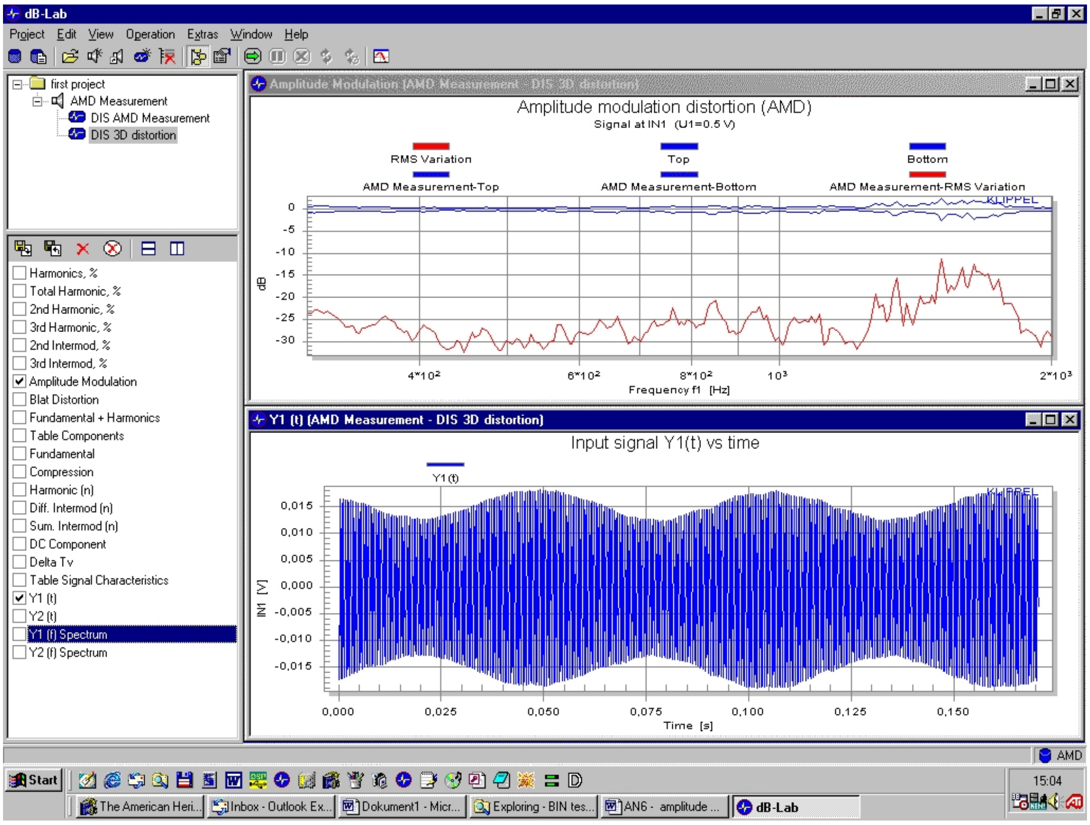
Measurement of Amplitude Modulation **AN 6**

Application Note to the KLIPPEL R&D SYSTEM

The amplitude modulation of a high frequency tone f_1 (voice tone) and a low frequency tone f_2 (bass tone) is measured by using the 3D Distortion Measurement module (DIS-Pro) of the KLIPPEL R&D SYSTEM. The maximal variation of the envelope of the voice tone f_1 during one period of the bass tone is represented by the top and bottom value referred to the fundamental response measured without bass tone. Both values reveal only the effects of amplitude modulation caused by *Bl(x)*, *Le(x)* and radiation nonlinearity but are immune against frequency modulation caused by the Doppler Effect. The difference between the amplitude response of the fundamental component f_1 with and without bass tone reveals nonlinear amplitude compression. This measurement is preferred in automotive applications for showing the impact of AM on the generation of intermodulation distortion.



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Method of Measurement

Loudspeaker Setup	The loudspeaker shall be operated under free-field or half-space free-field condition. The measurement is to be taken at 1 meter from the speaker (on axis).
1st Measurement (Reference)	Measure the frequency response $L_1(f_1) = 20\log(\lvert H_1(f_1)\rvert)$ of a 0.5 V rms sine wave, swept from f_{start}= 200 Hz (or 4 times resonance frequency f_s) to 10 kHz at a minimum resolution of 40 points per decade.
2nd Measurement (Intermodulation)	The loudspeaker is excited by a two-tone signal. Apply a 2.0 V rms sine wave signal (bass tone) to a frequency f_2 of 1/4th of resonance f_s. Apply a 0.5 V rms sine wave (voice tone) at frequency f_1, swept from f_{start}= 200 Hz (or 4 times resonance frequency $4f_s$) to 10 kHz, applied simultaneously with the bass tone at a minimum resolution of 40 points per decade. Measure the frequency response $L_2(f_1) = 20\log(\lvert H_2(f_1)\rvert)$ and the envelope E[t] of the voice tone f_1.
Mean Modulation	Calculate the mean modulation distortion as the difference between the amplitude responses of the voice tone measured with and without the bass tone f_2 $M_{mean}(f_1) = L_2(f_1) - L_1(f_1)$ in decibels.
Envelope of f_1	The amplitude modulation can be assessed by measuring the variation of the envelope of the high-frequency tone f_1 (voice tone) versus one period of the low-frequency tone f_2. The envelope E[t] of the voice tone f_1 is derived from the sound pressure signal p[t] by considering the fundamental of f_1 and the summed-tone and difference-tone intermodulation $f_1+(n-1)f_2$ and $f_1-(n-1)f_2$, respectively, with 2< n < N. If the envelope E[t] is constant over the period T= $1/f_2$ then the high frequency tone is not amplitude modulated. Frequency modulation caused by the Doppler effect will cause no variation of the envelope E[t] versus t.
Top Envelope	The maximal value of the envelope E[t] over one period T is called top modulation $E_{top} = 20\log\left(\max_{t}^{t+T}(E[t])\right)$
Bottom Envelope	The minimal value of the envelope E[t] over one period T is called bottom modulation $E_{bottom} = 20\log\left(\min_{t}^{t+T}(E[t])\right)$
Top Modulation	The Top modulation is determined by comparing the maximum of the envelope E_{top} with the amplitude response $L_1(f_1)$ of the reference measurement (without bass tone) $M_{top}(f_1) = E_{top}(f_1) - L_1(f_1)$
Bottom Modulation	The Bottom modulation is determined by comparing the minimum of the envelope E_{bottom} with the amplitude response $L_1(f_1)$ of the reference measurement (without bass tone) $M_{bottom}(f_1) = E_{bottom}(f_1) - L_1(f_1)$
Interpretation	The mean modulation M_{mean} shows the change of sensitivity of the fundamental of the voice tone due to the presence of the bass tone. The force factor Bl(x) and most other nonlinearities will reduce the mean output of the voice tone. Find more information about nonlinear amplitude compression in the reference enclosed.

INTERPRETATION

The causes for modulation distortion	Exciting with a two-tone signal the loudspeaker produces modulation distortion caused by amplitude and phase (frequency) modulation. Both types of modulation will produce difference intermodulation components at frequencies f_1 – (n-1)f_2 and summed-tone intermodulation distortion f_1+(n-1)f_2 of nth-order centered around the voice tone f_1. The phase of the intermodulation component depends on the type of modulation. To separate the effect of amplitude modulation from phase modulation the envelope of the high-frequency tone f_1 (voice tone) may be investigated. Amplitude modulation only varies the instantaneous amplitude (envelope) of voice tone while not distorting the phase of the voice tone. Contrary, the phase modulation does not change the envelope of the voice tone but varies only the instantaneous phase or frequency. Most of the nonlinearities in drivers such as variation of force factor Bl(x), inductance L_e(x) versus displacement x cause amplitude modulation. Variation of the radiation conditions causes both amplitude and frequency modulation distortion. The Doppler effect causes phase modulation because the time delay varies with the changed distance between moving diaphragm and fixed listening point.
$M_{top} \approx 0$ **$M_{bottom} \approx 0$**	If both $M_{top} \approx M_{bottom} \approx 0$ the envelope of f_1 is constant and the voice tone is not amplitude modulated by the bass signal f_2. No intermodulation distortion at summed- and difference-frequencies will be generated. This is typical for a linear system but also for nonlinearities (stiffness of the suspension) which do not produce significant intermodulation distortion at higher frequencies.
$M_{top} \approx 0$ **$M_{bottom} < 0$**	The case $M_{top} \approx 0$ and $M_{bottom} < 0$ is typical for a symmetrical Bl(x) nonlinearity because the sensitivity of the speaker decreases for any movement of the coil away from the rest position. In this case we usually find high values of third-order modulation distortion d_3 as defined in IEC 60268.
$M_{top} > 0$ **$M_{bottom} < 0$**	The case $M_{top} > 0$ and $M_{bottom} < 0$ is typical for an asymmetrical characteristic of Bl(x) or L_e(x) and for radiation distortion. In this case we measure usually high values of second-order modulation distortion d2 as defined in IEC 60268.
$M_{top} < 0$ **$M_{bottom} < 0$**	The case where both values M_{top} and M_{bottom} are negative is typical for loudspeaker having significant asymmetries in the parameters Bl(x), K_{ms}(x) or Le(x) which produce a dc component in the displacement. The may be interpreted as a dynamic offset of the coil position caused by a rectification of the ac excitation signal. Usually the bass tone f2 contributes most to the dc signal. The dynamic dc offset produce complicated interactions between the nonlinearities. For example a perfectly centered coil at the rest position coupled with a very asymmetric suspension may also produce broad band amplitude modulation because the asymmetry in the suspension produces a dc which pushes the coil to the softer side of the K_{ms}(x) characteristic and destroys the optimal coil position. In this case both M_{top} and M_{bottom} may become negative because the coil uses lower values of the B field. The generation of the dc displacement may be monitored on window *DC* **component** by using a laser displacement meter and switching to **Displacement** on the displayed signal on PP **Display**.

Using the 3D Distortion Measurement (DIS)

Requirements

- Distortion Analyzer + PC
- Software module 3D Distortion Measurement (DIS PRO) + dB-Lab
- Microphone
- laser displacement sensor (optional to measure X_{max})

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Setup

Connect the microphone to the input IN1 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

Create a new database within dB-Lab.
Create a new DRIVER object based on the template object **IM AM Dist. Automotive AN 6.**

Measurement

1. Select the created DRIVER and display the operations in the project window. Start the first measurement with the name "**DIS AM 1st measurement**"

2. Open the window **Fundamental** of the **DIS AM 1st measurement**. Select the displayed curve and copy the curve to the clipboard (mark the curve by clicking on the curve label, press the right mouse button and select **Copy Curve**).

3. Select the **DIS AM 2nd measurement** and open the property page **Input**. Import the calibration curve from clipboard (press button **for IN1**) and enable the calibration for Channel 1 (select adjoined checkbox). Check the result window **Calibration Curves** for the correct import of the curve.

4. Start the operation "**DIS AM 2nd measurement**".

5. Open the result window **Fundamental + Harmonics** in "**DIS AM 2nd measurement**"

6. Print the results or create a report based on the template **IM AM Dist. Automotive AN 6.**

Customizing Setup Parameters for the DIS Module

Template

Create a new Object, using the object template **IM AM Dist. Automotive AN 6** in dB-Lab. If this database is not available you may customize a general DIS module according to the following instructions:

DIS AM 1st measurement

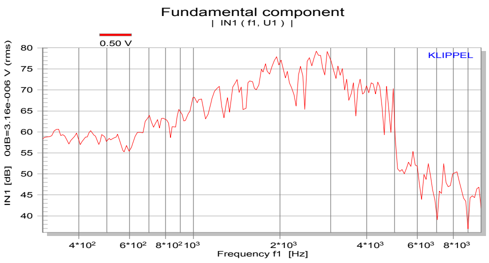
1. Create an object called Driver without any operations assigned (empty object). Assign a measurement **DIS AM 1st measurement** based on the generic **DIS 3D distortion module**.
2. Select the **DIS AM 1st measurement** and open the PP **Stimulus**. Select mode **Intermodulations (f1)**. Switch off Voltage Sweep. Set $\mathbf{U_{end}}$ to 0.5 V rms. Set $\mathbf{U_2/U_1}$ **= -** 100 dB. Set **Maximal order of distortion analysis** to 10. Switch on the Frequency Sweep with 100 points spaced logarithmically between 200 Hz and 10 kHz. Set frequency of the bass tone to $f_2=f_s/4$. Set **Additional excitation before measurement** to 0,1 s.
3. Open PP **Protection**. Disable **Monitoring** and any protection.
4. Open PP **Input**. Select (**Mic) IN1** in group **(Channel 1) Y1** and **Off** in group **(Channel 2) Y2**.
5. Open PP **Display**. Select **Signal at IN1** as **State signal**.

DIS AM 2nd measurement

1. Assign a measurement **DIS AM 2nd measurement** based on the generic **DIS 3D distortion** module.
2. Select the **DIS AM 2nd measurement** and open the PP **Stimulus**. Select mode **Intermodulations (f1)**. Switch off Voltage Sweep. Set $\mathbf{U_{end}}$ to 0.5 V rms. Set $\mathbf{U_2/U_1}$ = 12 dB. Set **Maximal order of distortion analysis** to 10. Switch on the Frequency Sweep with 100 points spaced logarithmically between 200 Hz and 10 kHz. Set the frequency of the bass tone to $f_2=f_s/4$. Set **Additional excitation before measurement** to 0,1 s.
3. Open PP **Protection**. Disable **Monitoring** and any protection.
4. Open PP **Input**. Select (**Mic) IN 1** in group **(Channel 1) Y1** and **Off** in group **(Channel 2) Y2**. To measure the displacement generated dynamically select **X (Displacement) Y2**
5. Open PP **Display**. Select **Signal at IN1** as **State signal**.

Example

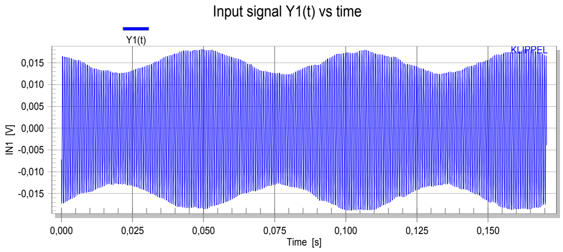
Amplitude Response



After performing the reference measurement with the voice tone f_1, the window **Fundamental** shows the amplitude response of the high frequency voice tone f_1 versus frequency.

Two-tone Signal

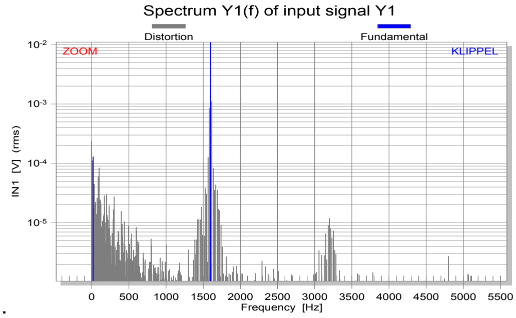
Open the window **Waveform Y1** to see the sound pressure versus measurement time.



This variation of the envelope shows a pure amplitude modulation of the voice tone f_1 according to frequency f_2 = 20 Hz.

Spectrum

Open the window **Spectrum Y1** to see the spectrum of the reproduced two-tone signal:



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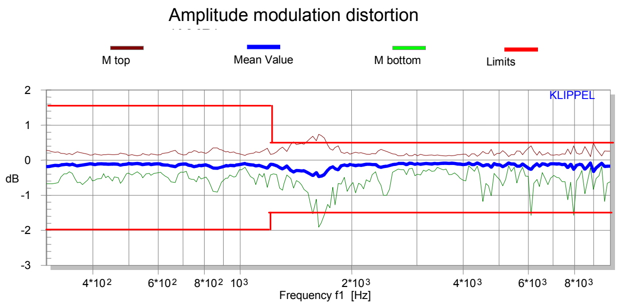
The bass tone at f_2=20 Hz causes harmonic distortion at lower frequencies and intermodulation centered around the voice tone at f_1 = 1600 Hz. The distortion above 3 kHz are harmonics of the voice tone f_1,

Amplitude Modulation

The figure below shows the result window **Fundamental + Harmonics** after performing the second measurement.



The top and bottom modulation M_{top} and M_{bottom} describe the minimal and maximal variation of the envelope. The mean modulation shows the variation of the amplitude response of the high frequency tone with and without bass tone.

Please note that you may modify or add additional limit curves to the result window by selecting any curve, copying the curve to the clipboard and editing the curve in the clipboard editor provided in dB-Lab and pasting the curve into the diagram. To select curves of interest, right-click the chart, select “Customize..”. In the Customization dialog, select the “Subsets” tab, and select the curves to display.

More Information

Related Application Notes	"3D Harmonic Distortion Measurement", Application Note AN 9 "AM and FM Distortion in Speakers", Application Note AN 10 "Multi-tone Distortion Measurement", Application Note AN 16
Related Specification	“DIS”, S4
Software	User Manual for KLIPPEL R&D SYSTEM.
References	M. Ziemba, Position Dependent Amplitude Response in Automotive Loudspeakers, SEA 2000 World Congress Detroit, Michigan, March 6-9, 2000 W. Klippel, "Assessment of Voice Coil Peak Displacement Xmax, paper presented at the 112th Convention of the Audio Engineering Society, 2002 May 10 – 13, Munich, Germany. Updated version on http://www.klippel.de/know-how/literature/papers.html

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