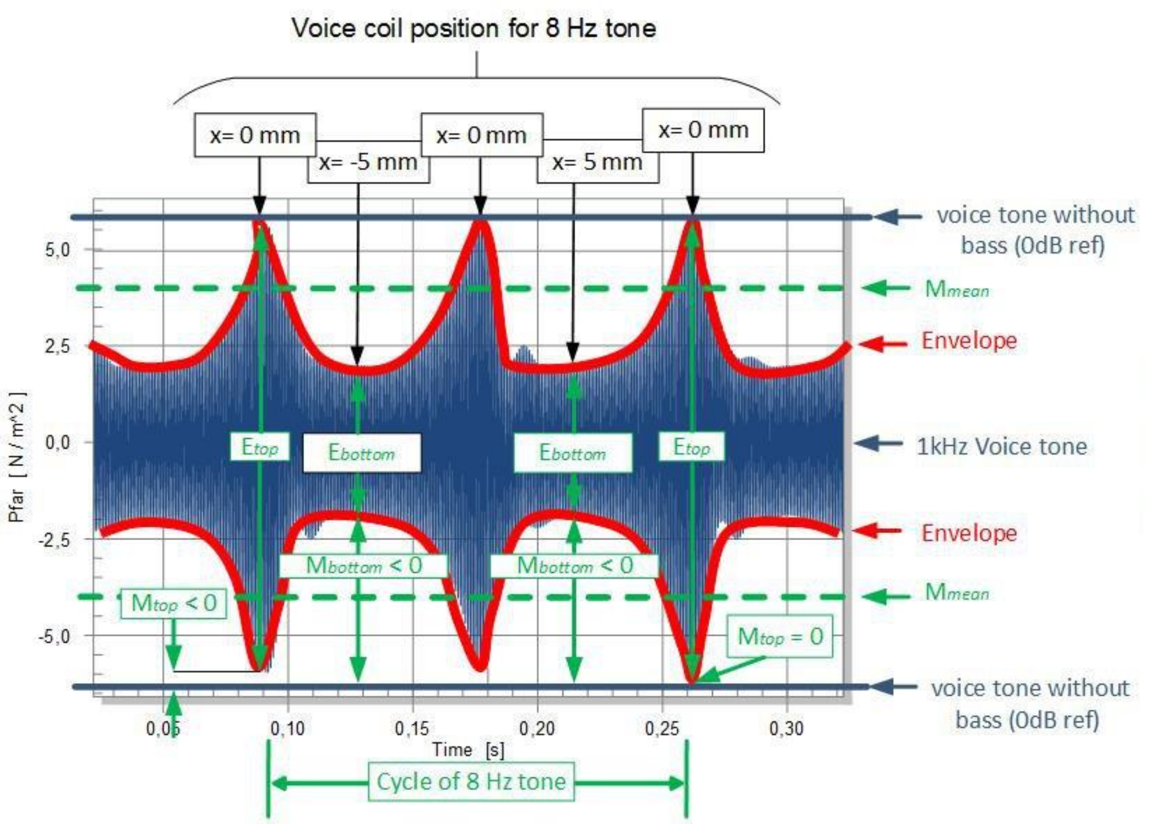
Measurement of Amplitude Modulation AN 6

Application Note to the KLIPPEL R&D System (Document Revision 1.1)

DESCRIPTION

In a loudspeaker transducer, the difference between the amplitude response of the fundamental high frequency tone f_1 measured with and without bass tone f_2 reveals nonlinear amplitude compression and amplitude modulation (AM) distortion. The 3D-distortion measurement module (DIS-Pro) of the KLIPPEL R&D SYSTEM is setup to sweep a voice tone while a bass tone produces a constant displacement and, as a result, a conventional spectral analysis of the IMD is plotted. Sophisticated processing links the IMD measurement to temporal variations in the envelope of the fundamental response. These temporal variations in the voice tone envelope are compared to the reference fundamental response measured without bass tone modulation. The calculated values M_{mean}, M_{top}, and M_{bottom} show the symmetry and asymmetry in the variations which reveal the effects of nonlinear *Bl(x)*, *Le(x)* and cone vibrations on the amplitude modulation. The amplitude variations are immune to frequency modulation (FM) caused by the Doppler Effect and the FM distortion is the difference between the AM distortion and the total IMD. For these reasons, this measurement is preferred in automotive applications where the impact of AM distortion can be determined from the generated intermodulation distortion.



CONTENT

1 Method of Measurement

Loudspeaker Setup	The transducer shall be operated under free-field or half-space free-field conditions. The measurement is to be taken in the far field, which depends on the size of the transducer but usually the distance is 1 meter (on axis).
1st Measurement (Reference)	Measure the frequency response of the fundamental component $$L_1(f_1) = 20\log(\lvert H_1(f_1)\rvert)$$ using a 0.5 V rms sine wave swept from f_{start}= 200 Hz (or 4 times the resonance frequency f_s) to 10 kHz at a minimum resolution of 40 points per decade.
2nd Measurement (Intermodulation)	Measure the frequency response of the fundamental component $$L_2(f_1) = 20\log(\lvert H_2(f_1)\rvert)$$ using a two-tone signal. Simultaneously, apply a 2.0 V rms sine wave (bass tone f_2) at one quarter the resonance (f_s/4) with a 0.5 V rms sine wave (voice tone f_1) swept from f_{start}= 200 Hz (4 times the resonance frequency 4f_s) to 10 kHz at a minimum resolution of 40 points per decade.
Mean Modulation	Calculate the mean modulation distortion M_{mean} as the difference between the amplitude responses of the voice tone f_1 measured with and without the bass tone f_2 $$M_{mean}(f_1) = L_2(f_1) - L_1(f_1)$$ in dB.
Envelope of f_1	The amplitude modulation can be assessed by determining the variation in the envelope *E[t]* of the high-frequency tone f_1 (voice tone) within one period of the low-frequency tone f_2 (bass tone). The envelope *E[t]* is derived from the sound pressure measurement *p[t]* by considering the spectral components of the voice tone: the fundamental f_1 and the summed and difference tones $f_1+(n-1)f_2$ and $f_1-(n-1)f_2$ 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 not affect the variations in the envelope *E[t]*.
Top Envelope	The maximal value of the envelope *E[t]* over one period T is $$E_{top} = 20\log\left(\max_{t}^{t+T}(E[t])\right)$$
Bottom Envelope	The minimal value of the envelope *E[t]* over one period T is $$E_{bottom} = 20\log\left(\min_{t}^{t+T}(E[t])\right)$$

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 in sensitivity of the voice tone fundamental due to the presence of the bass tone. The nonlinear force factor *Bl(x)* and most other nonlinearities will affect the symmetry and asymmetry of the top M_{top} and bottom M_{bottom} modulations with respect to the mean modulation M_{mean}. For more information, see the "reference" section in this application note.

2 Performing the Measurement

Requirements	To measure intermodulation distortion and determine the amplitude modulation using a two tone stimulus the following hardware and software are required: • Distortion Analyzer + PC • Software module 3D Distortion Measurement (DIS pro) + dB-Lab • Microphone • Amplifier and Cables • A driver stand or similar clamping (recommended) • Laser displacement sensor (optional to measure X_{max})
Template	Create a new object *DRIVER* using the object template ***IM AM Dist. Automotive AN 6*** in dB-Lab. If this template is not available, use the object template ***(empty)*** and follow the customized setup procedure shown below:
Customized Setup Procedure	First Measurement (reference voice tone without bass tone): 1) Create a new DIS operation based on the Default template. Name the operation *DIS AM 1st measurement*. 2) Open the property page (PP) ***Stimulus*** and set the parameters as follows: ***Mode*** = ***Intermodulations (f1)***, U_{end} = *0.5 V rms,* U_2/U_1 = (*-100 dB),* ***Maximal order of distortion analysis*** = *10,* ***Points*** = *100,* ***Spaced*** = *log,* f_{start} = 200 Hz, f_{end} = 10 kHz and $f_2 = f_s/4$. 3) Open PP ***Protection***. Disable ***Monitoring*** by switching off ***Voice coil temperature and amplifier gain***. 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 the ***State signal***
	Second Measurement (voice tone with bass tone): 1) Create a new DIS operation based on the Default template. Name the operation *DIS* 2) Open the PP ***Stimulus*** and set the parameters as follows: ***Mode*** = **Intermodulations (f1)**, U_{end} = 0.5 V rms, U_2/U_1 = *12 dB*, ***Maximal order of distortion analysis*** = *10*, ***Points*** = 100, ***Spaced*** = *log*, f_{start} = 200 Hz, f_{end} = 10 kHz and f_2 to $f_s/4$.

	3) Open PP Protection. Disable Monitoring by switching off Voice coil temperature and amplifier gain 4) Open PP **Input**. Select ***(Mic) IN 1*** in group ***(Channel 1) Y1*** and ***Off*** in group ***(Channel 2) Y2***. To measure the displacement using an optional laser, select ***X (Displacement)*** in group ***(Channel 2) Y2.*** 5) Open PP ***Display***. Select ***Signal at IN1*** as the ***State signal***.
Measurement  	1) Connect the microphone to the input IN1 of the Distortion Analyzer. 2) Connect the Power Amplifier in between the OUT1 and AMPLIFIER connections located on the back of the DA. 3) Connect the SPEAKER 1 output of the Distortion Analyzer to the input terminals of the DUT 4) Operate the DUT in free air. 5) Select the created object DRIVER and start the first measurement with the name DIS AM 1st measurement. 6) Open the result window Fundamental of the DIS AM 1st measurement. Right click on the displayed curve and select copy curve. 7) Select the DIS AM 2nd measurement and open the property page Input. Select the checkbox located beside the label for IN1. Select from Clipboard in the DIS Calibration curve vs. frequency pop-up window. Select OK 8) Start the operation DIS AM 2nd measurement. 9) Open the result window Fundamental + Harmonics in DIS AM 2nd measurement.

3 Post Processing and Interpretations

The causes for modulation distortion	Excited with a two-tone signal the transducer produces intermodulation distortion caused by amplitude and phase (frequency) modulation. Both types of modulation will produce summed and difference intermodulation components at frequencies $f_1 - (n-1)f_2$ and $f_1+(n-1)f_2$ of n^{th}-*order* centered around the voice tone f_1. 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 the phase modulation only varies the instantaneous phase or frequency of the voice tone. Most of the nonlinearities in transducers such as force factor $Bl(x)$ and inductance $L_e(x)$ cause amplitude modulation. Variation of the radiation conditions, such as cone vibrations, create both amplitude and frequency modulation distortion. The Doppler Effect causes phase modulation because the time delay varies between the fixed listening point and the changing distance along the radius of the moving diaphragm.
$M_{top} \approx 0$ **$M_{bottom} \approx 0$**	If both M_{top} and $M_{bottom} \approx 0$, the envelope of f_1 is constant and the voice tone is not amplitude modulated by the bass signal f_2. Therefore, no harmonics at the summed and difference frequencies are generated. This is typical for a linear system and for nonlinearities that do not produce significant intermodulation distortion at higher frequencies such as the stiffness of the suspension $K_{ms}(x)$.

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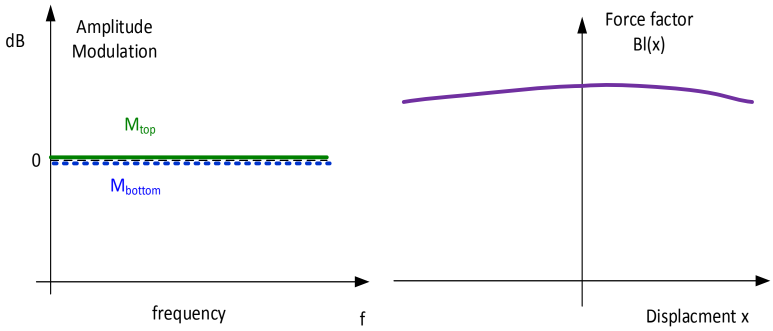
<td>
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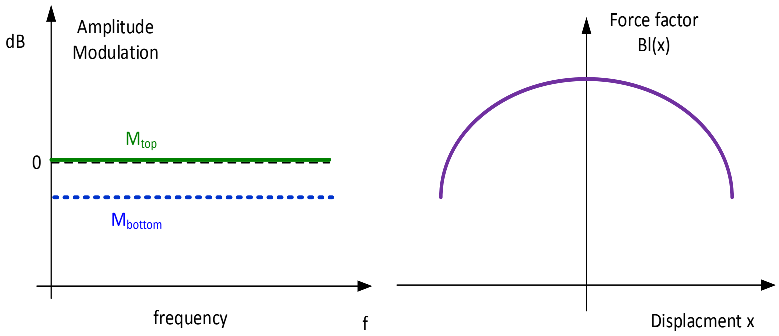
<tr>
<td>M$M_{top} \approx 0$
$M_{bottom} < 0$</td>
<td>The case $M_{top} \approx 0$ and $M_{bottom} < 0$ is typical for a symmetrical Bl(x) nonlinearity because the sensitivity of the speaker decreases for any movement of the coil away from the rest position. A symmetrical Bl(x) usually indicates high values of third-order modulation distortion d_3 as defined in IEC 60268.

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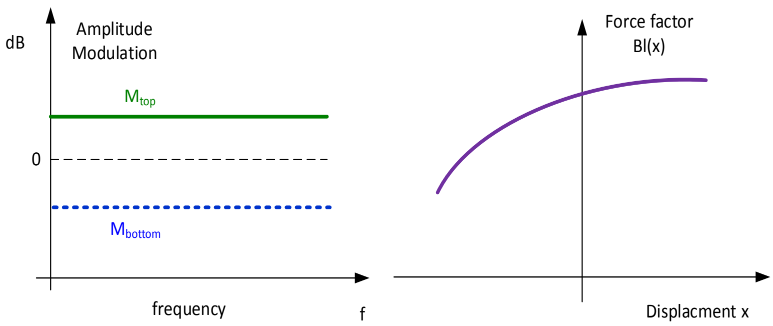
<tr>
<td>$M_{top} > 0$
$M_{bottom} < 0$</td>
<td>The case $M_{top} > 0$ and $M_{bottom} < 0$ is typical for an asymmetrical Bl(x), $L_e(x)$ or a radiation nonlinearity. An asymmetrical Bl(x), Le(x) or a radiation nonlinearity usually indicates high values of second-order modulation distortion d2 as defined in IEC 60268.

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<td>$M_{top} < 0$
$M_{bottom} < 0$</td>
<td>The case where both M_{top} and M_{bottom} are negative is typical for transducers having significant asymmetries in the nonlinearities Bl(x), $K_{ms}(x)$ or Le(x) producing a dc component X_{DC} in the displacement. The DC component may be interpreted as a dynamic offset of the coil position caused by a rectification of the AC excitation signal. Due to the high displacements, the bass tone f_2 is usually the main contributor towards the DC component. The dynamic DC offset produces complicated interactions between the nonlinearities.</td>
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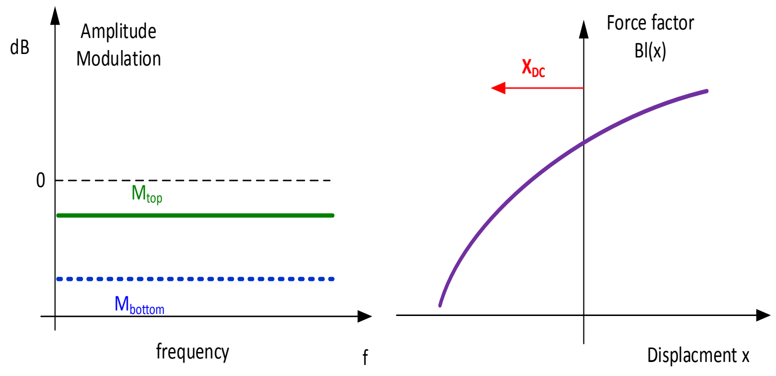
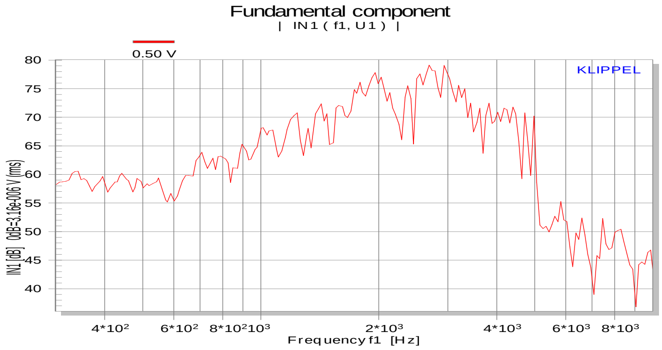
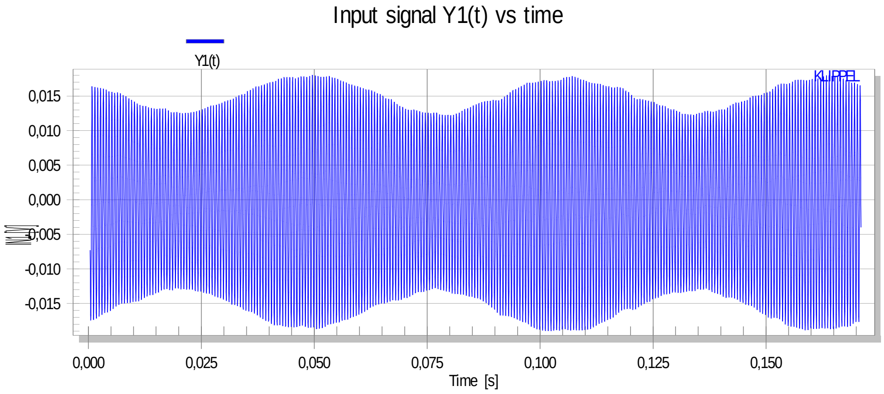
For example, a perfectly centered coil at the rest position coupled with a very asymmetric suspension may produce a DC offset that pushes the coil to the softer side of the suspension characteristic $K_{ms}(x)$, thereby, destroying the optimal rest position. In this case, both M_{top} and M_{bottom} may become negative because the coil is displaced dynamically and operates at lower values in the B field. The generation of the dc displacement may be monitored in the result window ***DC component*** by using a laser displacement meter and changing the ***state signal*** to ***Displacement X*** under the PP ***Display***.



4 Examples

Amplitude Response	After performing the first measurement *DIS AM 1st measurement,* the result window ***Fundamental*** shows the amplitude frequency response of the reference voice tone  f_1.
Two-tone Signal	After performing the second measurement *DIS AM* ***2nd*** *measurement*, open the result window ***Waveform Y1*** to see the sound pressure measurement versus time.  The variation in the envelope shows a pure amplitude modulation of the voice tone f_1 by the bass tone $f_2 = f_s/4 = 20$ Hz.

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<td>Spectrum</td>
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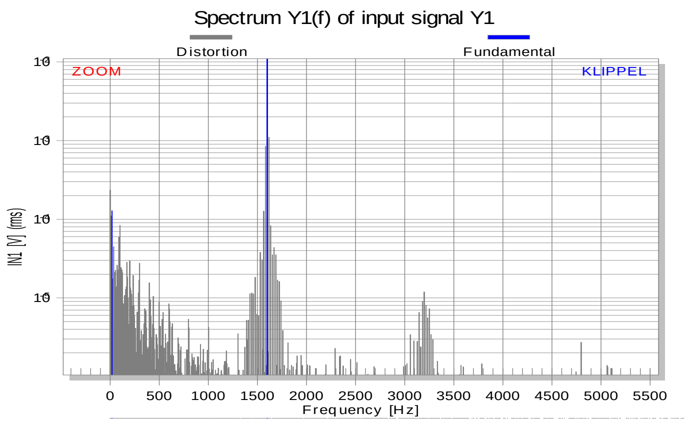
In the operation DIS AM 2nd measurement, open the window Spectrum Y1 to see the spectrum of the reproduced two-tone signal.



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.
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<td>Amplitude Modulation</td>
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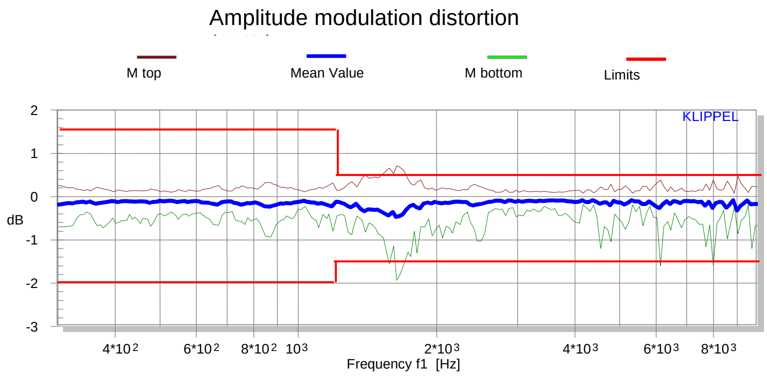
Open the result window Fundamental + Harmonics from the second measurement DIS AM 2nd measurement.



The top and bottom modulation M_{top} and M_{bottom} describe the minimal and maximal variations of the envelope of the voice tone f1. The mean modulation shows the variation in the amplitude response between the high frequency voice tone with and without the bass tone f2.

Please note that you may modify or add additional limit curves to the result window by performing the following procedure:

1) Right click on the header label of the desired limit curve. The curve will change color indicating that it has been selected correctly.
2) Select copy curve.
3) Open the clipboard editor by selecting View/Clipboard from the top menu or alternatively, double click on the clipboard icon in the tool bar.
4) Edit the curve in the clipboard editor and select OK when finished.
5) Right click in the desired chart location and select paste curve. The curve will be displayed and permanently stored in the database.
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	6) To select saved curves of interest, right click in the chart, select ***Customize...*** and select the desired curve to be displayed under the ***Subsets*** tab.

5 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 X_{max}, 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

Find explanations for symbols at:

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

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