SIM-AUR Simulation-Auralization S24

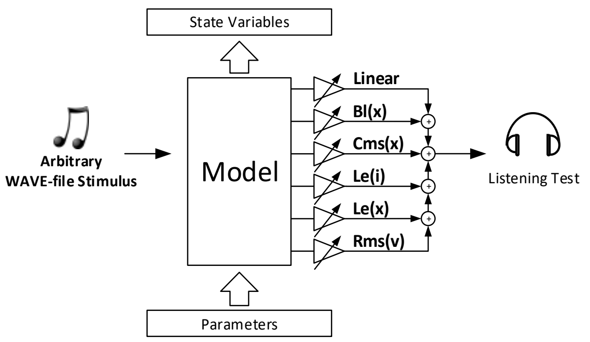
Specification to the KLIPPEL ANALYZER SYSTEM (Document Revision 1.1)

FEATURES

- Simulate transducer behaviour using arbitrary stimuli
- Simulate long time thermal behaviour
- Auralization and analysis of arbitrary nonlinear effects
- Calculates history of electrical, mechanical, acoustical and thermal state variables over time

BENEFITS

- Assess long time performance of the transducer in target applications
- Exploit the main source of nonlinear distortion in the output signal
- Evaluate the audible performance of the speaker at the target application
- Save time and costs in prototyping



DESCRIPTION

The SIM-AUR module performs a numerical simulation of electro-dynamical drivers mounted in common enclosure systems. Unlike other modules, the applied stimulus can be any kind of signal (e.g. test signals, music, …) and arbitrary in length.

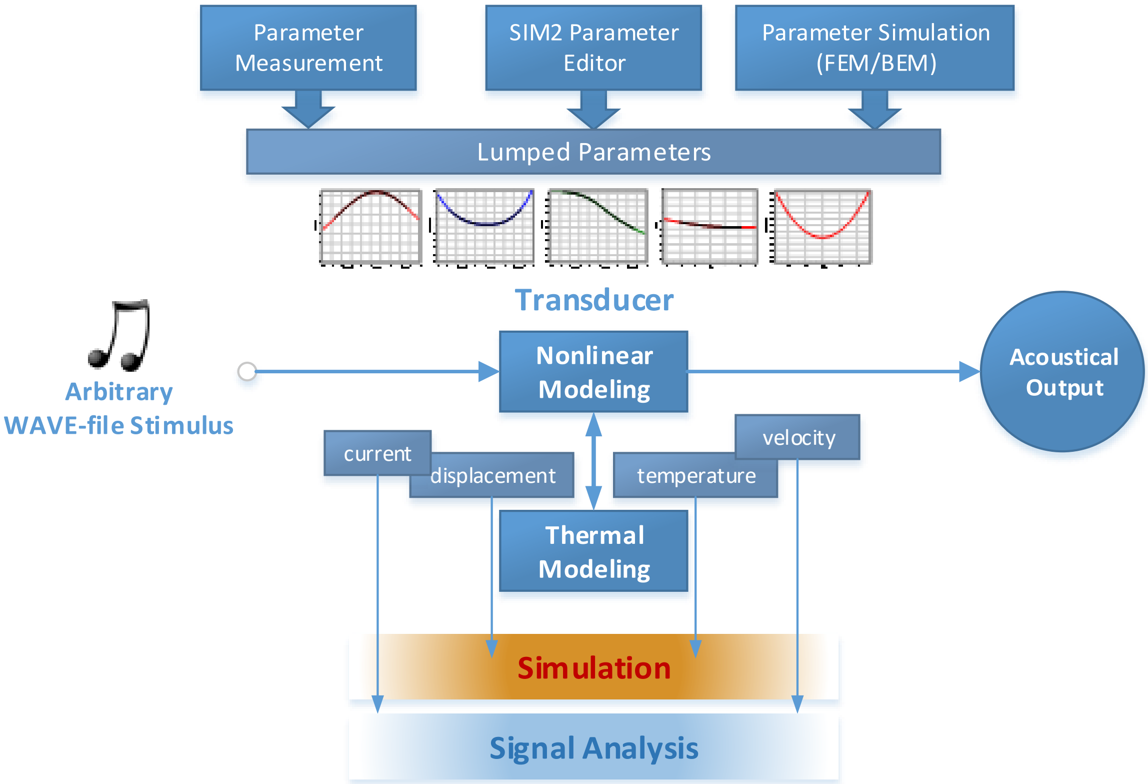
The SIM-AUR module uses an extended lumped-parameter model to describe the transfer behaviour in the full working range. The electrical, mechanical, acoustical and thermal state variables are calculated and available for extended analysis. Both real or fictitious driver and system data may be used as basis for the simulation.

In addition, distinct nonlinear effects can be separated without affecting the simulated transducer system. This separation of the distortion in the acoustical output signal from the linear component is the basis for a new auralization technique where double blind A/B comparisons may be performed and the threshold of audibility is determined systematically. In addition, the separated signals are available for further analysis.

Article number	1000-601

CONTENT

1 Principle



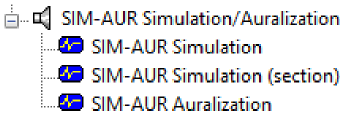
The SIM-AUR module performs the simulation and auralization of electro-dynamic transducers based on large signal modelling. The simulated model may represent a real or fictitious driver and enclosure system, either exported using the Linear Parameter Measurement (LPM), the Large Signal Identification (LSI) or the Simulation 2.0 (SIM2) module. Using the common wave-file format as stimulus, any kind of signal may be applied. The simulation considers the dominant nonlinearities of the driver (motor and suspension), dynamic thermal effects (compression due heating of the voice-coil), the enclosure (air compression, port losses, passive radiator suspension) and radiation (Doppler effect).

By using a time-lapse technique, the long term temperature of voice-coil, pole tips and magnet can be approximately determined. Using this data, interesting sections of the input stimulus can be identified and later on simulated in detail.

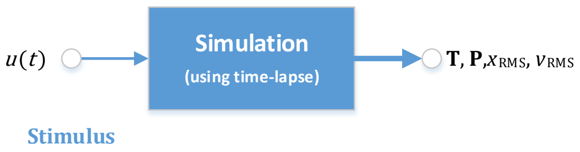
Using an auralization technique, nonlinear effects can be separated from the simulated transducer without affecting the internal states. The effect can be separated for every state variable of the electro-mechanical system. Besides analysis of the separated signals, root-cause analysis and auralization of the distortion signal can be performed. The auralization can be used as basis for A/B tests even in prototyping, to determine the impact of design choices to the listener.

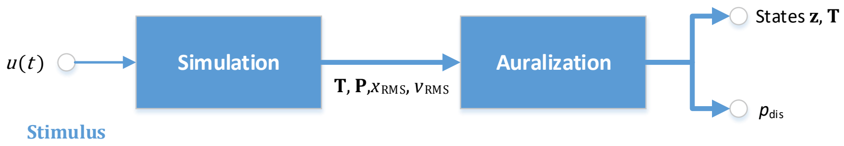
2 Operation Principle

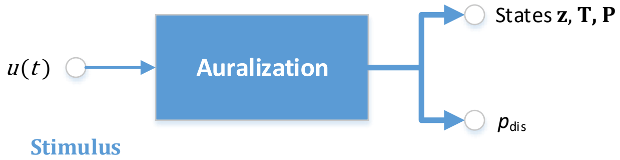
2.1 SIM-AUR Operations

General Scheme	 The SIM-AUR module basically consists of 2 modes. Every mode is used for a distinct part of the SIM-AUR module. A default workflow is shown in the picture above. The two available operations are • **Simulation:** The “Simulation”-mode is used to determine the long term performance of the transducer. In respect to the states of the electro-mechanical system, thermal states are changing relative slow (time constant of the magnet might be about ~1.5 h). To speed up the prediction of the thermal states, a time-lapse technique can be used. The predicted temperatures can reveal section of great interest (e.g. sudden changes in the signal energy). • **Auralization:** The “Auralization”-mode is used to auralize the simulated transducer. After performing the auralization, you can listen to the predicted sound pressure and virtually in- or decrease the distortions of the transducer via a very simple mixing console. If you want to change the possible gain factors of the distortion part S_{dis}, no new auralization has to be performed.
Simulation	This mode performs a long-term thermal simulation of the loudspeaker / -system. Input parameters are the setup parameters describing the speaker-model as well as the stimulus. These values are provided automatically to depending operations. The simulation can either be precise (solving the speaker-model over the full stimulus length using the sampling rate f_{sample}) or using the time-lapse technique (solving the speaker model over short times and predict the power and effective displacement / velocity, see section 4). Please note that a simulation using time-lapse technique will only produce precise solutions on special points. Thus, if you are interested in the full long-time behaviour, you may avoid the time-lapse technique. After finishing the operation, you can specify a section of interest and automatically generate an “*Auralization*”-operation, which can be used for further investigations.
Auralization	The “*Auralization*”-operation is used to calculate the precise speaker-model in a user defined target section. The operation gives insight in the state of the transducer (e.g. current at terminals, dissipated powers, bypass factor) as well as the “Total Distortion Ratio” to determine the impact of the nonlinearities. Depending on the solving method of the “*Simulation*”-operation (either time-lapse or precise), the results of the target section may vary from the “*Simulation*”-operation. In addition, you can also auralize the predicted transducer sound pressure signal. Using a simple mixing console, you can virtually diminish or enhance the nonlinear distortion part p_{dis} in the auralized signal.

2.2 Applications

<table>
<tr><td>Long-term response only (using time-lapse)</td><td>


For an assessment of the long-term performance of the transducer it may be sufficient to run a thermal simulation only. The simulation data helps to identify critical regions of excitation and estimate the thermal response of the transducer in the target application. For a fast estimation it is convenient to use the time-lapse technique.</td></tr>
<tr><td>Assess and auralize signal distortion in distinct sections</td><td>


The user may want to assess the nonlinear distortion of the transducer in distinct sections of a long-term performance. In order to get meaningful values such as the Total Distortion Ratio (TDR) an initial identification of the long-term behaviour must be performed. For a fast estimation, the time-lapse technique decreases the simulation time significant. Afterward, a precise simulation on a specified section may be performed giving access to the precise solutions of the section such as a detailed insight in the transducer states.
In addition, the user can listen to the predicted sound pressure signal p_{dis} of the transducer. The data is available for either analysis or export as wave-file.</td></tr>
<tr><td>Auralize signal distortion</td><td>


In some cases, it might be of interest to directly auralize the nonlinear signal distortion. For that cases, the SIM-AUR offers the possibility to directly auralize the signal without running a simulation in prior.
In that case, the user may choose the mode "Auralization (independent)".</td></tr>
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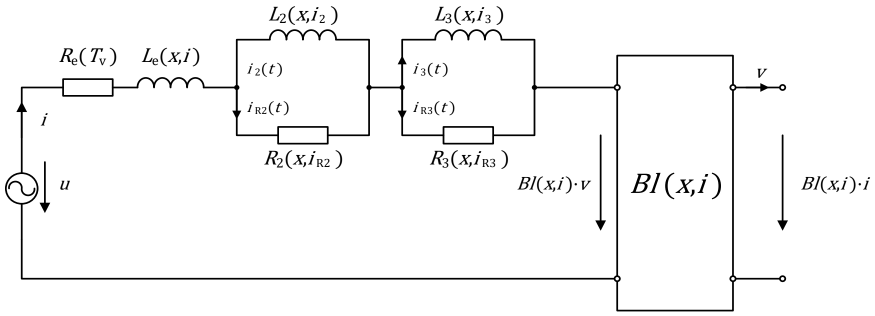
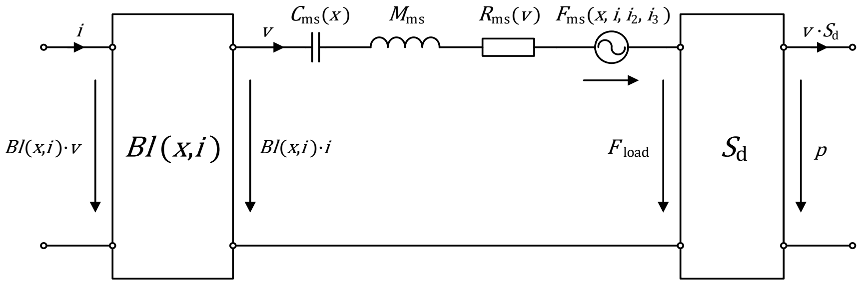
3 Large signal modeling

<table>
<tr>
<td>Equivalent Circuit</td>
<td>


Equivalent electrical circuit


Equivalent mechanical circuit

A lumped parameter model is used to describe the large signal behaviour of electro-dynamical transducers mounted in common acoustical systems. The model consists of three subsystems, describing the electrical, mechanical and acoustical domain. In contrast to the well-known linear model the components of the large signal model are not constant but rather depend on one or more speaker states (e.g. displacement x, voice-coil temperature T_v, sound pressure p_{box}, volume velocity in the port q_p).
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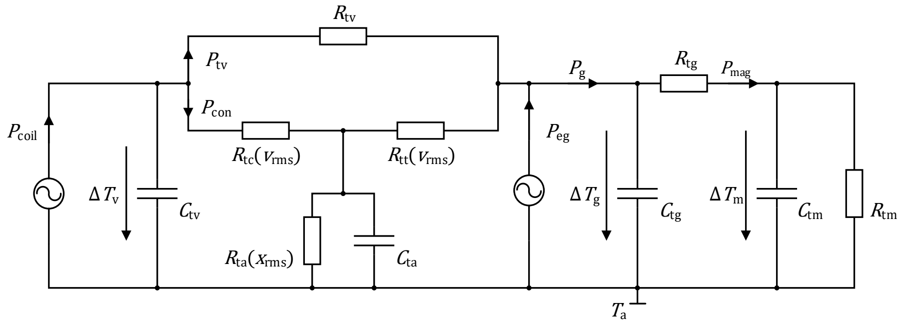
<tr>
<td>Thermal Modelling</td>
<td>


Nonlinear thermal model

The heating of the voice-coil is modelled using a nonlinear thermal equivalent circuit. The model describes the heat transfer from the voice-coil to the pole tips and the magnet. It considers convection cooling (dependent on cone displacement and velocity) and direct heating of voice-coil and magnet due to eddy currents.
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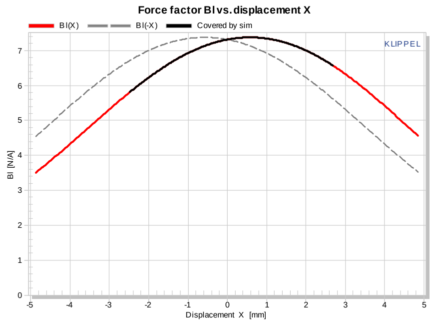
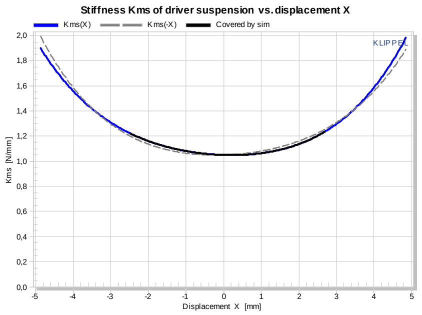
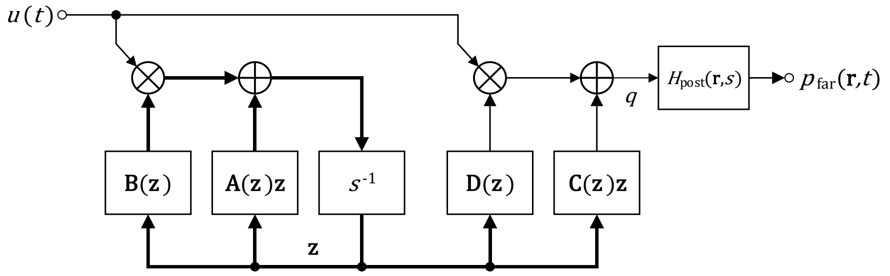
Parameters





The linear, nonlinear and thermal parameters of the driver can be identified using the *Large Signal Identification* module (LSI), which is part of the KLIPPEL ANALYZER SYSTEM. Additionally, the user is able to import parameters modified or identified using the *Simulation 2.0* module (SIM2). The driver parameters can be copied to the clipboard and imported to the SIM-AUR. No import parameters are required to consider the nonlinear compliance of the air in the enclosure and nonlinear radiation due to the Doppler effect.
To edit the parameters (both linear/nonlinear) of the transducer model, the preferences of the SIM2 module should be used and can be imported to the SIM-AUR.

State Space Model

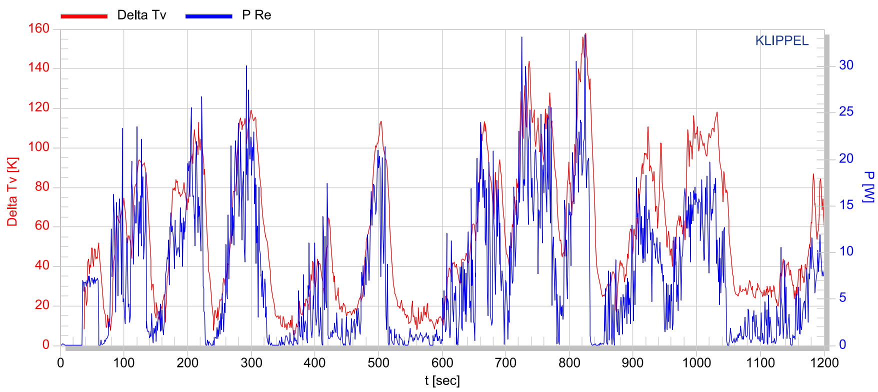
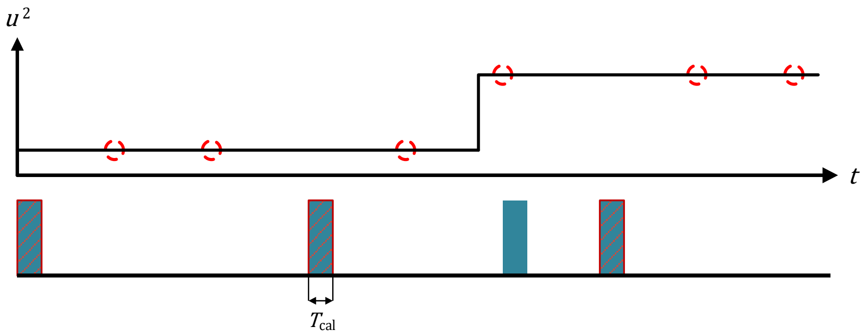


$$\dot{\mathbf{z}}(t)=\mathbf{A}(\mathbf{z})\mathbf{z}(t)+\mathbf{B}(\mathbf{z})\cdot u(t)$$
$$q(t)=\mathbf{C}(\mathbf{z})\mathbf{z}(t)+\mathbf{D}(\mathbf{z})\cdot u(t)$$
$$p_{\text{far}}(t)=h_{\text{post}}(t)*q(t)$$

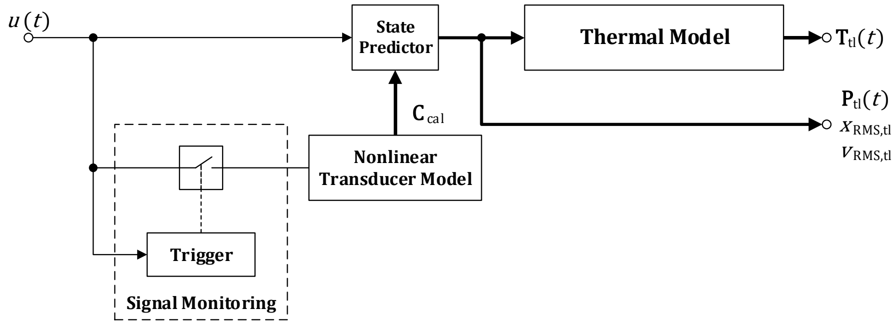
using

- $u(t)$ is the stimulus (input signal),
- $\mathbf{z}$ comprises the state variables of the nonlinear lumped equivalent circuit represented by the nonlinear parameters **A**(**z**), **B**(**z**), **C**(**z**) and **D**(**z**) with $\mathbf{z}^T=[x,v,i,i_2,i_3,p_{\text{box}},q_p,p_{\text{rear}},x_p]$,
- $q(t)$ is the acoustical source signal,
- $h_{\text{post}}(t)$ is the impulse response of the linear post filter representing cone vibration and radial propagation,
- $p_{\text{far}}(t)$ is the sound pressure at the listening point

4 Time-lapse Technique

Objectives	Increase of voice coil temperature Delta Tv (t) and electrical input power P (t)  To assess the long time performance of the transducer, time consuming measurements or simulations must be performed. The longest time constants occur in the thermal system, which are a result of the slow heating of the magnet structure. As shown in the picture above, the voice-coil temperature of the transducer is directly depending on the dissipated power. Since the thermal variation is relatively slow compared to the electro-mechanical transducer, a significant increase in simulation speed can be achieved by predicting the dissipated power and effective state variables. The most important objectives are: • Fast thermal estimation of the long-term transducer performance. • Exploit critical working conditions due strong thermal heating. • Find regions of interest for further investigation of the thermal power flows, to improve the thermal behaviour of the transducer.
Basic Principle	 For a fast prediction of the long term temperature response of the speaker, a simplified transducer model is used. To cope with the nonlinear performance of the speaker, the elements of the simplified model can be determined by solving the nonlinear model over a specific section T_{cal}. Therefore, this process is therefore called „calibration“ and represented by the blue blocks in the upper figure. Under the assumption of relative slow variations in the spectral properties of the input signal, it can be assumed that the temperatures can be predicted. In case the signal properties have changed, the prediction may become invalid. To increase the prediction accuracy, multiple calibrations can be performed. Using monitoring of the input signal, a new estimation of the calibration parameters can be automatically triggered. In the upper graph, the red circles represents timestamps, when the signal is checked. If a change in the spectral properties is identified, an additional calibration is performed automatically to ensure a higher accuracy in the temperature prediction.

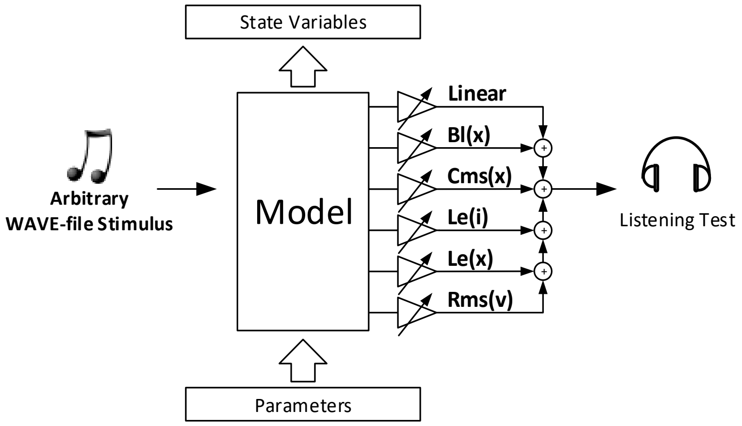
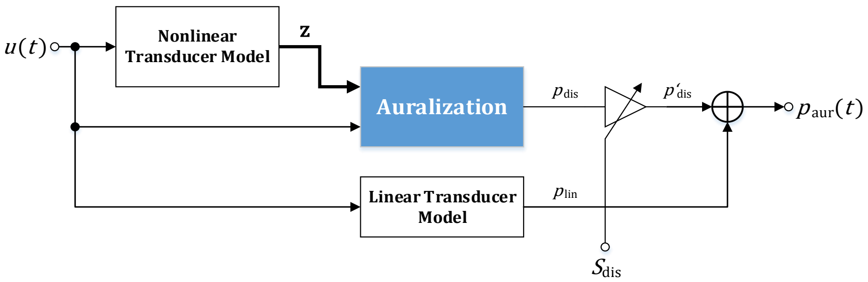
Flowchart



To predict the dissipated power of the transducer, the nonlinear transducer model in the large signal domain is solved over a distinct time (*calibration time* T_{cal}). Using the precise solution, calibration parameters are calculated. Afterward, the state variables can be predicted approximately using the input stimulus and the calibration parameters. The temperatures are predicted using the nonlinear thermal model as described in 0.

$u(t)$	is the stimulus (input signal),
$\mathbf{C}_{cal}$	are the calibration parameters $\mathbf{C}_{cal}^T=[Y_{coil,cal}, Y_{eg,cal}, X_{cal}, V_{cal}]$ used to predict the input variables of the thermal model,
$\mathbf{P}_{tl}(t)$	are the predicted dissipated powers of the transducer $\mathbf{P}_{tl}=[P_{coil,tl},P_{eg,tl}]$,
$x_{RMS,tl}$	is the predicted effective displacement,
$v_{RMS,tl}$	is the predicted effective velocity,
$\mathbf{T}_{tl}(t)$	are the predicted temperatures of transducer $\mathbf{T}_{tl}^T=[T_{v,tl},T_{g,tl},T_{m,tl}]$

5 Auralization

Overview	 The new auralization technique is used to separate distinct nonlinear effects, such as effects due to nonlinear *Bl*, L_e or R_{ms} or other, without affecting the model state. These separation does not affect the speaker model itself. The separated effects can be used to determine the root cause of the nonlinear distortion. Also, the separated signal can be stored as a wave-file, gaining the possibility to easy design auditory experiments to evaluate the impact on audible quality. The most important objectives are: • Separation of nonlinear effects without affecting the modelled speaker. • Exploit the main source of nonlinear distortion in the output signal. • Design auditory experiments to evaluate the audible impact of the nonlinear distortion. • Evaluate the audible performance of the speaker at the target application. • Find optimal performance-cost ratio. • Assess distortion ratio in audio signals.
Basic Principle	 The auralization is based on the precise nonlinear simulation of the transducer. Since all states **z**, which are used to describe the speaker at a distinct sample k, are known, nonlinear effects in each state variable can easily be separated using separation matrices. This technique gains the benefit of separating the nonlinear effects but not affecting the simulated speaker itself. The separated distortion signal p_{dis} can easily scaled using a linear gain S_{dis}. $u(t)$ is the stimulus (input signal), $p_{dis}(t)$ is the sound pressure of the nonlinear distortion, $p_{lin}(t)$ is the sound pressure of the linear signal, $S_{dis}(t)$ is the linear gain factor for amplifying p_{dis}, $p_{aur}(t)$ is the auralized signal (output signal).

6 Simulation and Auralization Technique

6.1 Input Signal

Format	Any external wave-file may be used as stimulus. The processing may be applied to the selected left and right channel or to the mono signal. Also, the user can chose folders containing wave-files. The folders are recursive processed and all containing wave-files are used for simulation, gaining the benefit of creating simple simulation playlists.

6.2 Solving the differential equations

Numerical Integration	The large signal model with the specified driver and enclosure parameters is excited by the input wave-file. The electrical, mechanical and acoustic state variables of the model are calculated using numerical integration algorithms. Their waveform may be viewed versus time
Deactivation of Nonlinearities	To find the dominant source of distortion and to investigate design choices, the following nonlinearities might be enabled or disabled during simulation: • force factor nonlinearity Bl(x) vs. displacement x • force factor nonlinearity Bl(i) vs. current i • inductance nonlinearity due to Le(x) vs. displacement x • inductance nonlinearity Le(i) vs. current i • nonlinearity of para-inductances L2(x,iR2), L3(x,iR3) • nonlinearity of resistances R2(x,iR2), R3(x,iR3) due to eddy current losses • mechanical suspension nonlinearity due to Kms(x) • mechanical resistance Kms(v) • reluctance force Fm (electromagnetic drive) • adiabatic compression in enclosure Cab(pbox) • adiabatic compression of rear enclosure Cr(prear) • nonlinearity due to leakage losses Ral(pbox) • nonlinearity of port losses Rap(vp) • nonlinearity of passive radiator suspension losses Rmp(vp) • passive radiator stiffness nonlinearity Kmp(xp) If a nonlinearity is disabled, the small signal parameter value is used. ***Note*:** The deactivation of nonlinearities affects the internal state variables of the system, thus simulated values may differ from separation in the "*AUR*"-operation.
Separation of nonlinear effects	The basis of the auralization and psychoacoustical evaluation of sound quality is the decomposition of the total sound pressure signal $$p_{aur}(t) = p_{lin}(t) + \sum_{n=1}^{N} p_{dis,n}(t)$$ into a • linear signal component $p_{lin}(t)$ using the small signal parameters in **A**(**z**=**0**), **B**(**z**=**0**), **C**(**z**=**0**), **D**(**z**=**0**) and nonlinear distortion components such as • $p_{dis,1}(t)$ due to force factor nonlinearity $Bl(x)$ vs. displacement x • $p_{dis,2}(t)$ due to force factor nonlinearity $Bl(i)$ vs. current i • $p_{dis,3}(t)$ due to inductance nonlinearity $L_e(x)$ vs. displacement x • $p_{dis,4}(t)$ due to inductance nonlinearity $L_e(i)$ vs. current i • $p_{dis,5}(t)$ due lossy inductance $Z_L(f,x)$ vs. x • $p_{dis,6}(t)$ due to lossy inductance $Z_L(f,i)$ vs. i • $p_{dis,7}(t)$ due to mechanical suspension nonlinearity $K_{ms}(x)$ • $p_{dis,8}(t)$ due to nonlinear mechanical resistance $R_{ms}(v)$ • $p_{dis,9}(t)$ due to adiabatic compression in enclosure $C_{ab}(p_{box})$ • $p_{dis,10}(t)$ due to adiabatic compression of rear enclosure $C_r(p_{rear})$

	• $p_{dis,11}(t)$ due to leakage losses $R_{al}(p_{box})$ • $p_{dis,12}(t)$ due to nonlinearity of port losses $R_{ap}(v_p)$ • $p_{dis,13}(t)$ due to nonlinearity of passive radiator suspension losses $R_{mp}(v_p)$ • $p_{dis,14}(t)$ due to passive radiator stiffness nonlinearity $K_{mp}(v_p)$ ***Note:*** In the present version, the distinct separation is deactivated and will be enabled in future versions. The auralized signal contains the linear part of the sound pressure output as well as a scalable nonlinear part, separated by the technique presented in section 5.
Initial Conditions	The displacement of the voice coil at the beginning of the numerical integration may be specified by the user to investigate the stability of the driver. Performing two simulations with varied initial displacement ($x(t=0)=x_{min}$ and $x(t=0)=x_{max}$) reveal critical frequencies where the driver bifurcates into different solutions.
Cone, Radiation, Room	Actually, the sound pressure in the far field is calculated using a simple model. A piston like cone and “ideal” 2π- or 4π-radiation without any deterioration of the room are assumed.
Heating of voice coil, pole tips and magnet	Simultaneously with the solution of the electrical, mechanical and acoustical system the temperature of the voice coil, the pole tips and the magnet will be predicted using the nonlinear thermal model and the thermal parameters. The thermal dynamics of the loudspeaker according to the thermal time constants of the coil, gap and magnet are simulated.
Different Solvers	Different algorithms for the numerical integration are provided. For certain combinations of model parameter values the system behaves stiff due to large voice-coil displacements. In this case a special solver is used that can cope with the problem. ***Note:*** Any numerical simulation algorithm may fail to converge. This is especially the case for very stiff models. Normally a divergence can easily be detected as meaningless results are produced.

7 Components of the SIM-AUR

For performing a SIM-AUR operation, either the Distortion Analyzer, Klippel Analyzer 3 hardware unit or a UKey USB Dongle is required.
No additional hardware is required.

8 Inputs

8.1 SIM-AUR Simulation

The following parameters can be imported via clipboard on the "*Im/Export*" property page of the module. LPM, LSI, SIM2 or SIM-AUR data import is supported. It is recommended to change power-series related parameters using the property pages "*Transducer*" and "*System*" of the SIM2 (*Simulation 2.0*) module. All parameters are presented in a separate window to check the values and validate the nonlinear curves.

	Symbol	Min	Typical	Max	Unit
Measurement Setup					
Mode		SIM-AUR Mode: Simulation or Auralization			
Cut and Auralize		Create a new Auralization in between the section defined by the cursors, using the simulated initial values.			
Solver		Solver type used for the operation: Fast or Precise			
Stimulus					
Stimulus source path		Path to the input signal			
Used channel		Channel of the stimulus file used for the simulation.			
Input gain (voltage at loudspeaker terminals)	G_{input}	-100		120	dB
Time-lapse factor	r_{tl}	1	5		
Initial conditions					
Initial displacement of the voice-coil	$x(t=0)$		0		mm
Lumped driver parameters (advanced)					
DC resistance of the cold voice-coil at ambient temperature	R_e	0.01			Ω
Force factor (*Bl* product; linear)	Bl	0.1			$^{N}/_{A}$
Voice-coil inductance (linear)	L_e	0.01			mH
Electrical resistance due to eddy current losses	R_2, R_3	0.01			Ω
Voice-coil para-inductance	L_2, L_3	0.01			mH
Moving mass including air load	M_{ms}	0.001		5000	g
Mechanical resistance of suspension losses (linear)	R_{ms}	> 0		10000	$^{Ns}/_{m}$
Stiffness of suspension	K_{ms}	> 0		100	$^{N}/_{mm}$
Coefficients of power series $Bl(x)$		$Bl(x) > 0$ for $x_{min} < x < x_{max}$ x_{min} minimal simulated displacement x_{max} maximal simulated displacement			
Coefficients of power series $Bl(i)$		$Bl(i) > 0$ for $i_{min} < i < i_{max}$ i_{min} minimal simulated current i_{max} maximal simulated current			
Coefficients of power series $L_e(x)$		$L_e(x) > 0$ for $x_{min} < x < x_{max}$			

	Symbol	Min	Typical	Max	Unit
Coefficients of power series $L_e(i)$		$L_e(i) > 0$ for $i_{min} < i < i_{max}$			
Coefficients of power series $R_2(x)$, $R_3(x)$		$R_2(x)$, $R_3(x) > 0$ for $x_{min} < x < x_{max}$			
Coefficients of power series $L_2(x)$, $L_3(x)$		$L_2(x)$, $L_3(x) > 0$ for $x_{min} < x < x_{max}$			
Coefficients of power series $K_{ms}(x)$		$K_{ms}(x) > 0$ for $x_{min} < x < x_{max}$			
Coefficients of power series $R_{ms}(v)$		$R_{ms}(v) > 0$ for $v_{min} < v < v_{max}$ v_{min} minimal simulated velocity v_{max} maximal simulated velocity			
Area of diaphragm	S_d	0.1			cm²
Lumped acoustical parameters (*advanced*) ***Note:*** Several lumped parameters are only shown depending on the chosen enclosure configuration.					
Enclosure type	Driver in baffle, closed box, vented box, passive radiator, bandpass.				
Volume of air in enclosure	V_b	0.01			dm³ (liter)
Volume of the rear enclosure	V_r	0.01			dm³ (liter)
Area of the port	S_p	> 0			cm²
Acoustic stiffness of air in enclosure	K_{ab}	Checkbox activating nonlinear behaviour			
Acoustic mass of air moved in vent	M_{ap}	> 0			N/m^5
Acoustic resistance of enclosure losses (linear)	R_{al}	> 0			$\mathrm{kNs}/\mathrm{m}^5$
Acoustic resistance of vent losses (linear)	R_{ap}	> 0			$\mathrm{kNs}/\mathrm{m}^5$
Mechanical resistance of passive radiator suspension losses (linear)	R_{mp}	> 0			$\mathrm{kNs}/\mathrm{m}^5$
Stiffness of passive radiator suspension (linear)	K_{mp}	> 0			N/mm
Acoustic stiffness of air in rear enclosure	K_r	Checkbox activating nonlinear behaviour			
Coefficients of power series $R_{al}(p_{box})$		$R_{al}(p_{box})$ for $p_{box,min} < p_{box} < p_{box,max}$ $p_{box,min}$ minimal simulated sound pressure inside the enclosure $p_{box,max}$ maximal simulated sound pressure inside the enclosure			
Coefficients of power series $R_{ap}(v_p)$		$R_{ap}(v_p)$ for $v_{p,min} < v_p < v_{p,max}$ $v_{p,min}$ minimal simulated velocity of air in port $v_{p,max}$ maximal simulated velocity of air in port			
Coefficients of power series $R_{mp}(v_p)$		$R_{mp}(v_p)$ for $v_{p,min} < v_p < v_{p,max}$			
Coefficients of power series $K_{mp}(x_p)$		$K_{mp}(x_p)$ for $x_{p,min} < x_p < x_{p,max}$ $x_{p,min}$ minimal simulated passive radiator displacement $x_{p,max}$ maximal simulated passive radiator displacement			
Model for cone, radiation, room		• Piston / 2π / anechoic • Piston / 4π / anechoic			

	Symbol	Min	Typical	Max	Unit
Distance between diaphragm and listening position	r	0.001			m
Thermal model (*advanced*)					
Material of voice-coil wire	copper, aluminium or user defined, affects the resistance value of the voice-coil due heating of the voice-coil				
Temperature coefficient	δ	> 0			-
Thermal resistance of path from coil to pole tips and magnet surface	R_{tv}	0.001			K/W
Thermal resistance of path from pole tips to magnet and frame	R_{tg}	0.001			K/W
Thermal resistance of path from magnet to ambient air	R_{tm}	0.001			K/W
Thermal capacity of the voice-coil	C_{tv}	0			Ws/K
Thermal capacity of the gap	C_{tg}	0			Ws/K
Thermal capacity of the magnet	C_{tm}	0			Ws/K
Convection cooling parameter considering the effect of cone displacement	r_x	> 0			Ws/Km
Convection cooling parameter describing the dependence of R_{tc} from cone velocity	r_v	> 0			Ws/Km
Convection cooling parameter describing the dependence of R_{tt} from cone velocity	r_b	> 0			Ws/Km
Factor describing the distribution of heat caused by eddy currents on voice-coil and magnet	α	> 0			

8.2 SIM-AUR Auralization

	Symbol	Min	Typical	Max	Unit
Interval describing the linear gain applied to the distortion components	S_{dis}	-100		100	dB
Step width of the gain factors	S_{step}	-100	6	100	dB
State variable		Dropdown list containing the available state variables for export and / or displayed result.			

9 Results

Available Result Windows of the Operations		
Result Window	*"Simulation"*	*"Auralization"*
Voltage / Current	✓	✓
Displacement	✓	✓
Velocity	✓	✓
Temperature	✓	✓
Input Power	✓	✓
Thermal Power Flow	✓	✓
Bypass Factor		✓
Re(t)		✓
Total Distortion Ratio		✓
SPL		✓
State Variable		✓
State Distortion Ratio		✓
Crest Factor		✓
Model Parameters	✓	✓
Auralization		✓
Bl(x)	✓	✓
Le(x)	✓	✓
Le(i)	✓	✓
L2(x)/L3(x)	✓	✓
R2(x)/R3(x)	✓	✓
Kms(x)	✓	✓
Rms(v)	✓	✓
Ral(pbox)	✓	✓
Rap(vp)/Rmp(vp)	✓	✓
Kmp(xp)	✓	✓
Sd(x)	✓	✓

9.1 Result Parameters

9.1.1 Model Parameters

Nonlinear Parameters	Shows the activated/deactivated nonlinearities of the speaker model.
Thiele/Small Parameters	Thiele/Small parameters of the transducer model.
Thermal System Parameters	Parameters of the thermal transducer model.
Enclosure Parameters	Linear enclosure parameters of the model.
Cone, Radiation, Room	Simulated radiation condition and the distance from the source point.

9.1.2 Auralization

The "*Auralization*"-window can be used to play a mixed auralized the far-field sound pressure p_{aur} with

$$p_{aur} = p_{lin} + S_{dis} \cdot p_{nl}$$

by pressing the buttons. The mixing depends on the chosen values S_{dis} and S_{step}. Changing these parameters will update the result page, no additional auralization must be performed. This window displays the TDR of the auralized signal.

This output page can be exported using the "*Export*"-button and inspected in every web-browser.

9.2 Result Curves

Note: The number of displayed points is fixed. Therefore, decreasing the size of a detailed section will lead to an increasing of the temporal resolution. The minimum achievable time-step is T_{data} = 100 ms. Peak, bottom, DC and RMS values are determined using the temporal resolution. Therefore, max(RMS) equals the maximum effective value under respect of the current time-step.

Result windows of the "*Simulation*"-operation may include curves determined by the time-lapse technique. Results calculated using the time-lapse technique are approximated values and may not be match with measurements or a precise simulation.

Grey curves are hidden by default.

Voltage/Current

Shows the maximum of the absolute as well as the RMS value of the voltage at terminals *u* and input current *i* versus measurement time *t*.

Symbol	Description	Unit
$u_{abs,max}$	Maximum value of the absolute terminal voltage *u*	V
u_{RMS}	Effective value of the terminal voltage *u*	V
$i_{abs,max}$	Maximum value of the absolute input current *i*	A
i_{DC}	Maximum value of the short time DC in input current *i*	A
i_{RMS}	Effective value of the input current *i*	A

Displacement

The output window shows the maximum absolute and RMS values of displacement *x* in respect to the time *t*. In the mode "*Auralization*", also the distortion part of the maximum absolute displacement can be inspected.

Symbol	Description	Unit
$x_{abs,max}$	Maximum value of the absolute voice-coil displacement	mm
x_{RMS}	Effective voice-coil displacement	mm
$x_{dis,abs,max}$	Maximum value of the absolute voice-coil displacement	mm

Velocity

The output window shows the maximum absolute as well as the RMS values of velocity *v* in respect to the time *t*.

Symbol	Description	Unit
$v_{abs,max}$	Maximum value of the absolute voice-coil velocity	m/s
v_{RMS}	Effective voice-coil velocity	m/s

Window	Symbol	Description	Unit
Temperature		This window shows the mean and peak difference temperatures of the voice-coil, gap and magnet versus measurement time *t*.	
	Symbol	**Description**	**Unit**
	$dT_{v,peak}$	Peak difference temperature of the voice-coil	K
	$dT_{g,peak}$	Peak difference temperature of the pole tips	K
	$dT_{m,peak}$	Peak difference temperature of the magnet	K
	$dT_{v,mean}$	Mean difference temperature of the voice-coil	K
	$dT_{g,mean}$	Mean difference temperature of the pole tips	K
	$dT_{m,mean}$	Mean difference temperature of the magnet	K
Input Power		Shows the input powers of the thermal model versus measurement time *t*.	
	Symbol	**Description**	**Unit**
	$P_{Re,\ mean}$	Peak power dissipated over the DC-Part of the voice-coil impedance.	W
	$P_{Re,\ peak}$	Mean power dissipated over the DC-Part of the voice-coil impedance.	W
Thermal Power Flow		This window shows the effective dissipated powers versus measurement time *t* of the thermal model.	
	Symbol	**Description**	**Unit**
	$P_{coil,mean}$	Mean power dissipated in voice-coil and former	W
	$P_{coil,peak}$	Peak power dissipated in voice-coil and former	W
	$P_{Re,mean}$	Mean power dissipated in R_e	W
	$P_{Re,peak}$	Peak power dissipated in R_e	W
	$P_{con,mean}$	Mean power transferred to air in gap due convection cooling	W
	$P_{con,\ peak}$	Peak power transferred to air in gap due convection cooling	W
	$P_{tv,mean}$	Mean power transferred to the pole tips from coil	W
	$P_{tv,peak}$	Peak power transferred to the pole tips from coil	W
	$P_{g,mean}$	Mean power transferred to the pole tips	W
	$P_{g,peak}$	Peak power transferred to the pole tips	W
Bypass factor		This window shows the bypass factor γ versus measurement time *t*.	
	Symbol	**Description**	**Unit**
	γ	$\gamma(t)=\frac{P_{con}(t)+P_{eg}(t)}{P_{con}(t)+P_{eg}(t)+P_{tv}(t)}$	-
R_e (t)		This window shows the DC resistance of the voice-coil versus measurement time *t*.	
	Symbol	**Description**	**Unit**
	$R_e(t)$	DC resistance of the voice-coil	Ω

<table>
<tr><td rowspan="3">Total Distortion Ratio</td><td colspan="3">This window shows the total distortion ratio TDR of the acoustical output signal p_{far} versus measurement time t.</td></tr>
<tr><td>Symbol</td><td>Description</td><td>Unit</td></tr>
<tr><td>TDR</td><td>$$TDR(t)=\frac{\max_{T_{data}}\left|p_{far,dis}(t)\right|}{\max_{T_{data}}\left|p_{far,lin}(t)+p_{far,dis}(t)\right|}\cdot 100\%$$</td><td>%</td></tr>
<tr><td rowspan="4">SPL</td><td colspan="3">This window shows sound pressure level of both total radiated signal p_{far} as well as the nonlinear distortion part $p_{far,dis}$ versus measurement time t.</td></tr>
<tr><td>Symbol</td><td>Description</td><td>Unit</td></tr>
<tr><td>Total SPL</td><td>SPL of the total radiated signal p_{far}</td><td>dB</td></tr>
<tr><td>Distortion SPL</td><td>SPL of the nonlinear distortion part $p_{far,dis}$</td><td>dB</td></tr>
<tr><td rowspan="8">State variable</td><td colspan="3">This window shows the peak, bottom, maximum DC, DC as well as the RMS value of one state variable of the state vector z of the electro-mechanic-acoustical system versus measurement time t.
Note: The displayed state variable is depending on the input selection. The available state variables are depending on the simulated transducer and system.</td></tr>
<tr><td colspan="3">The displayed curves follow the scheme:</td></tr>
<tr><td>Symbol</td><td colspan="2">Description</td></tr>
<tr><td>$\mathbf{z}_{peak}$</td><td colspan="2">Peak value of the chosen state variable</td></tr>
<tr><td>$\mathbf{z}_{bottom}$</td><td colspan="2">Bottom value of the chosen state variable</td></tr>
<tr><td>$\mathbf{z}_{max(DC)}$</td><td colspan="2">Maximum DC value in the time interval of the chosen state variable</td></tr>
<tr><td>$\mathbf{z}_{DC}$</td><td colspan="2">DC value of the chosen state variable</td></tr>
<tr><td>$\mathbf{z}_{RMS}$</td><td colspan="2">RMS value of the chosen state variable</td></tr>
<tr><td rowspan="3">State Distortion Ratio</td><td colspan="3">The window shows the ratio of one nonlinear distortion state variable $\mathbf{z}_{dis}$ and the state variable z versus measurement time t. The shown state variable is depending on the input selection.</td></tr>
<tr><td>Symbol</td><td>Description</td><td>Unit</td></tr>
<tr><td>Distortion ratio of z</td><td>$$DR_{\mathbf{z}}(t)=\frac{\max_{T_{data}}\left|\mathbf{z}_{dis}(t)\right|}{\max_{T_{data}}\left|\mathbf{z}_{lin}(t)+\mathbf{z}_{dis}(t)\right|}\cdot 100\%$$</td><td>%</td></tr>
<tr><td rowspan="3">Crest Factor</td><td colspan="3">This window shows the crest factor of one state-variable of the electro-mechanic-acoustical system versus measurement time t.
Note: The displayed state variable is depending on the input selection. The available state variables are depending on the simulated transducer and system.</td></tr>
<tr><td>Symbol</td><td>Description</td><td>Unit</td></tr>
<tr><td>Crest Factor of z</td><td>$$d_{crest}(t)=\frac{\max_{T_{data}}\left|\mathbf{z}(t)\right|}{\mathbf{z}_{RMS}\big|_{T_{data}}}$$</td><td>-</td></tr>
</table>

10 Patents

USA	8,964,996

Find explanations for symbols at:
http://www.klippel.de/know-how/literature.html
Last updated: January 23, 2020