



Non-linear loudspeaker simulation

Guitar loudspeaker

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problems

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IR measurement
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Communication Outline

ABAV

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Section 1

Guitar loudspeaker problems

Non-linear model



FIGURE: Loudspeaker emulation

Advantages :

- ▶ Wide selection of loudspeakers.
- ▶ Weight and overcrowding
- ▶ Playing with high amplification at low sound pressure level

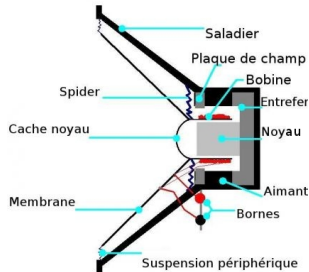


FIGURE: Electrodynamic loudspeaker

Non linearities :

- ▶ Force factor $BL(x)$
- ▶ K_M stiffness
- ▶ change in L_e with coil position
- ▶ ...

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Section 2

Non-linear modelling of loudspeakers

Impulse response I

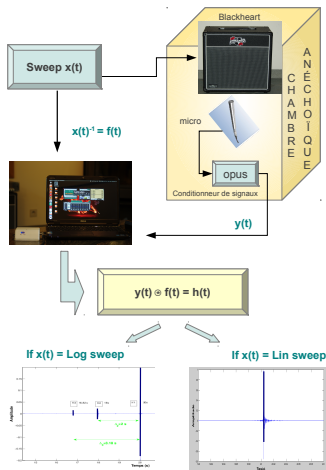


FIGURE: IR measurement

$$\text{Sweep } x(t) = A \sin(z(t))$$

- ▶ Lin sweep if frequency grows linearly
- ▶ Log sweep if frequency grows exponentially

- ▶ Search Δt that satisfies :

$$M \frac{dz(t)}{dt} = \frac{dz(t + \Delta t)}{dt}$$

- ▶ We obtain :

$$\Rightarrow \Delta t_M = T \frac{\ln(M)}{\ln\left(\frac{w_2}{w_1}\right)}$$

Impulse response II

Example : Log sweep $x(t)$ with params :

- ▶ Sweep duration : $T=20$ s
- ▶ Sweep frequency in range [20 20000] Hz

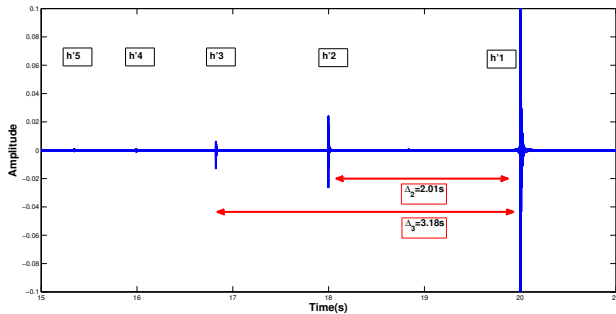


FIGURE: Loudspeaker impulse response with logsweep deconvolution

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Relation between input $x[n]$ and output $y[n]$ for non-linear system

$$\left\{ \begin{array}{l} y[n] = \sum_{i=1}^M \sum_{\tau_1=0}^N \dots \sum_{\tau_i=0}^N h_i[\tau_1, \dots, \tau_i] x[n - \tau_1] \dots x[n - \tau_i] \end{array} \right. \quad (1)$$

With non-linear model without memory, system (1) becomes :

$$\begin{aligned} y[n] = & \sum_{\tau_1=-\infty}^{\infty} h_1[\tau_1] x[n - \tau_1] \\ & + \sum_{\tau_2=-\infty}^{\infty} h_2[\tau_2] x^2[n - \tau_2] \\ & + \sum_{\tau_3=-\infty}^{\infty} h_3[\tau_3] x^3[n - \tau_3] \\ & + \dots \end{aligned} \quad (2)$$

where h_i is the i^{th} order Volterra's kernel

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Connection between Volterra kernels h_i and measured kernels h'_i

We have proved :

$$\mathcal{F}(h_i) \xleftrightarrow{\text{link}} \mathcal{F}(h'_i)$$

So that, we obtain :

$$\mathcal{F}(h_i) \iff \mathcal{F}(h'_i)$$

$$\left\{ \begin{array}{l} H_1(w) = H'_1(w) + 3e^{2jB} H'_3(w) + 5e^{4jB} H'_5(w) \\ H_2(w) = \frac{2}{A} je^{jB} [H'_2(w) + 4e^{2jB} H'_4(w)] \\ H_3(w) = \frac{-4}{A^2} e^{2jB} [H'_3(w) + 5e^{2jB} H'_5(w)] \\ H_4(w) = \frac{8}{A^3} (-je^{3jB}) H'_4(w) \\ H_5(w) = \frac{16}{A^4} H'_5(w) e^{4jB} \end{array} \right. \quad (3)$$

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Example 1 : reconstruction of the linear response

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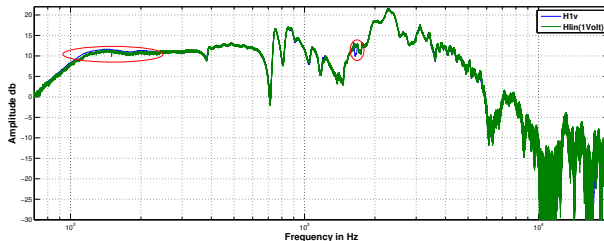


FIGURE: Comparison between reconstructed linear response (blue curve) and measured linear response (green curve).

Note :

The two curves are very close

Example 2 : Fourier transform of first three Volterra kernels

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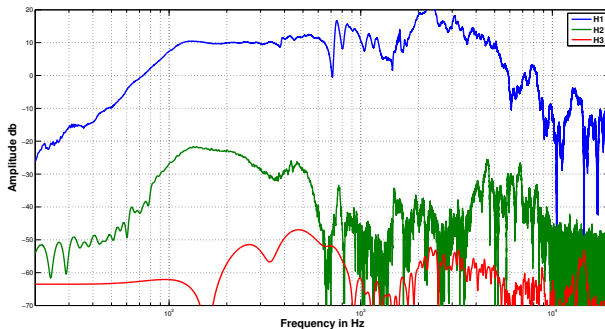


FIGURE: H_i : Fourier transform of Volterra kernels

Example 3 : reconstruction of the linear response with another loudspeaker

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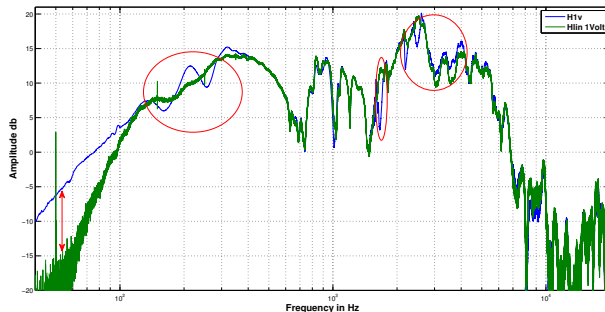


FIGURE: Comparison between reconstructed linear response (blue curve) and measured linear response (green curve).

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Section 3

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VST Plugin

VST (Virtual Studio Technology) :

- ▶ C++ language
- ▶ Works with several hosts :
 - ▶ Reaper
 - ▶ Cubase
 - ▶ Adobe Audition ...
- ▶ Multi-threads plugin

What does the Plugin ?

In real time :

$$\begin{aligned} y[n] = & h1[n] \otimes x[n] \\ & + h2[n] \otimes x^2[n] \\ & + h3[n] \otimes x^3[n] \end{aligned} \quad (4)$$

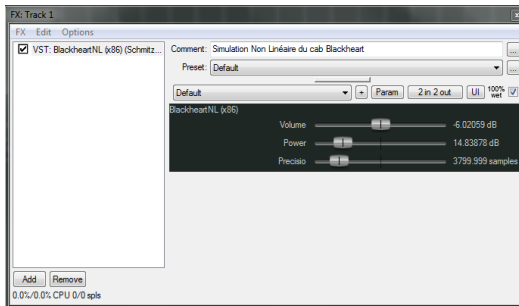
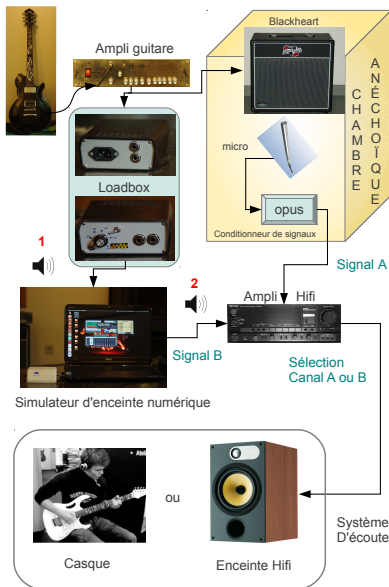


FIGURE: Non linear speaker simulation GUI plugin.

Play sample

Comparisons between the sound directly coming from the loudspeaker and the simulated sound



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Section 4

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Conclusion

- ▶ Loudspeaker simulation can make musician's life easier.
- ▶ Loudspeaker modelisation with Volterra series
- ▶ We created a Plugin to simulate loudspeaker's behaviors

Future works

- ▶ plugin with choices in :
 - ▶ loudspeaker model
 - ▶ microphone placed in front of the loudspeaker (model and placement)
- ▶ modelisation of systems with more non-linearities (like guitar's power amplifier)

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Thanx for your attention !



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