Nonlinear Modeling of a Guitar Loudspeaker Cabinet

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Digital Audio Effects That Emulate Analog Equipment Are Popular

- “Modeling” amplifiers – Line 6, Yamaha, Roland, Korg, Digidesign, etc.
- CAPS open source LADSPA suite
  - http://quitte.de/dsp/caps.html
- Emulate guitar amplifier in software
- For portability and flexibility

Loudspeaker Modeling Work

- Linear response is primary contributor
  - Convolutional impulse response libraries
    e.g., http://noisevault.com/nv/
  - CAPS Audio Suite, http://quitte.de/dsp/caps.html
  - Virtual Air Guitar (Karjalainen et al. JAES 2006)
- Nonlinear studies and simulations
  - Fränken et al. (IEEE 2001): nonlinear WDF
  - Klippel (AES 2001, etc): nonlinear state space
  - Quaegebeur and Chaigne (JAES 2008): nonlinear state space

Guitar Loudspeakers and Cabinets

- Electro-dynamic driver, closed- or open-back box
  - Classical driver models with relatively soft cone and stiff suspension have complicated behavior

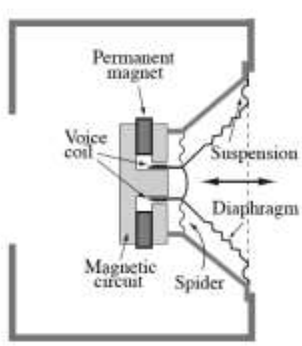


Figure 1: Open-back cabinet and electrodynamic drive

- Linearity only at low power levels
- High directivity at high frequencies
- Limited bandwidth, e.g. 100 – 6000Hz

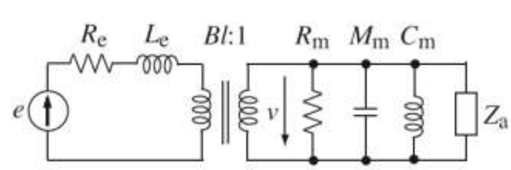
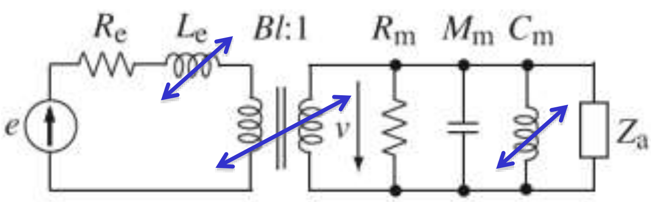


Figure 2: Equivalent circuit of a loudspeaker driver.

Nonlinearities in Loudspeakers

- Many types of nonlinearities (↙↗), especially:
  - Nonlinear compliance (C_m), stiffer for large excursion
  - Inhomogeneous magnetic field (Bl)
  - Variation of voice coil inductance (L_e)
  - Nonlinearity of cone stiffness in guitar loudspeakers



Linear example

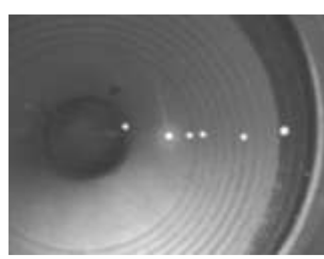
Nonlinear

Nonlinearities in lumped element speaker model

Measurement Setups (1)

- Sound pressure response (anechoic chamber)
  - Near field, far field in azimuth and elevation angles
- Cone vibration (laser vibrometer)
- Voltage/current relationship

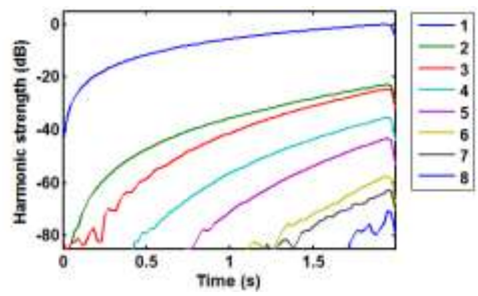
Engl 12 inch cabinet with
Celestion G12 Vintage 30 driver



Measurement Setups (2)

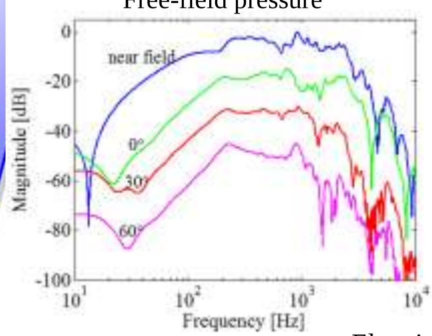
- Linear response measured by logarithmic sweep
  - FuzzMeasure (Macintosh)
- Nonlinearity measured at single frequencies by linearly growing sine-wave ramps
  - Harmonic distortion analyzed from sine responses

Example of fundamental (1) and harmonics level (dB) growth for sine-wave ramp

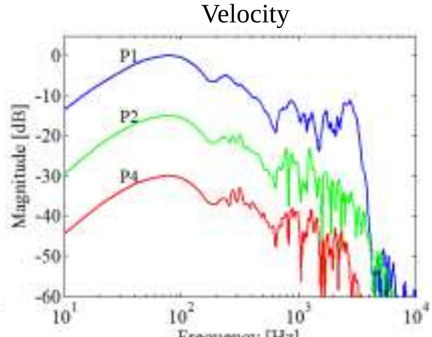


Linear Response

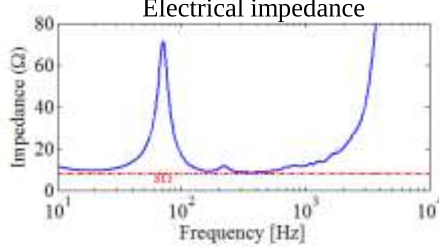
Free-field pressure



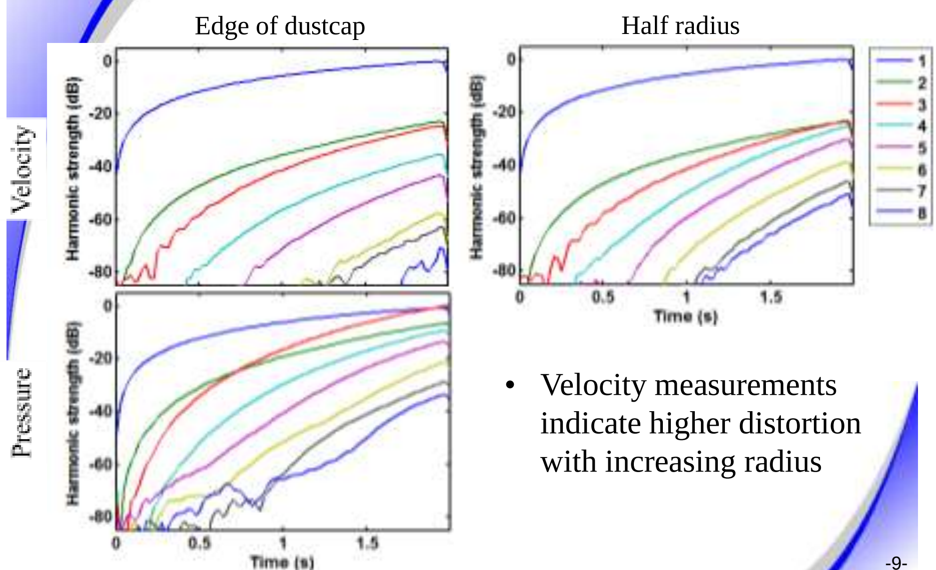
Velocity



Electrical impedance

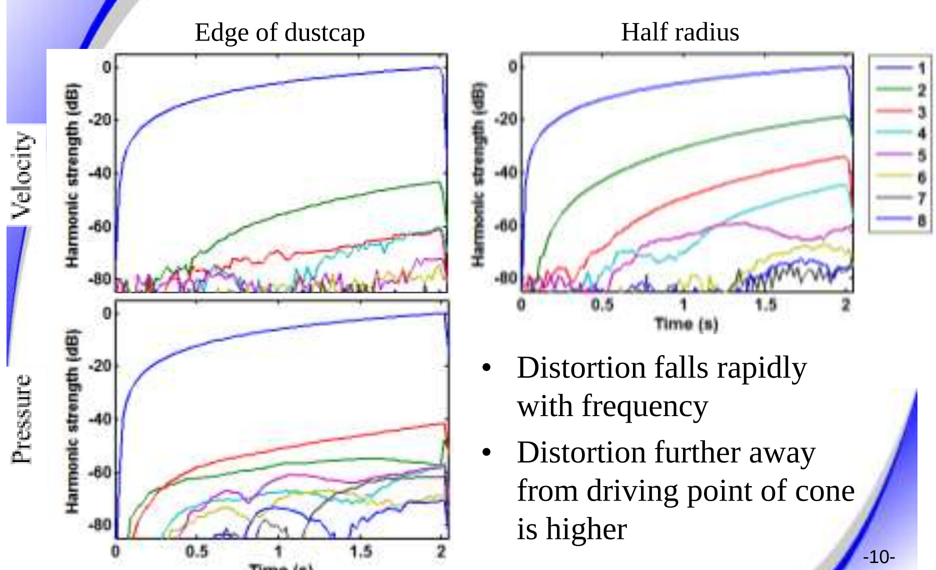


Nonlinear Measurements, 70 Hz



- Velocity measurements indicate higher distortion with increasing radius

Nonlinear Measurements, 200 Hz

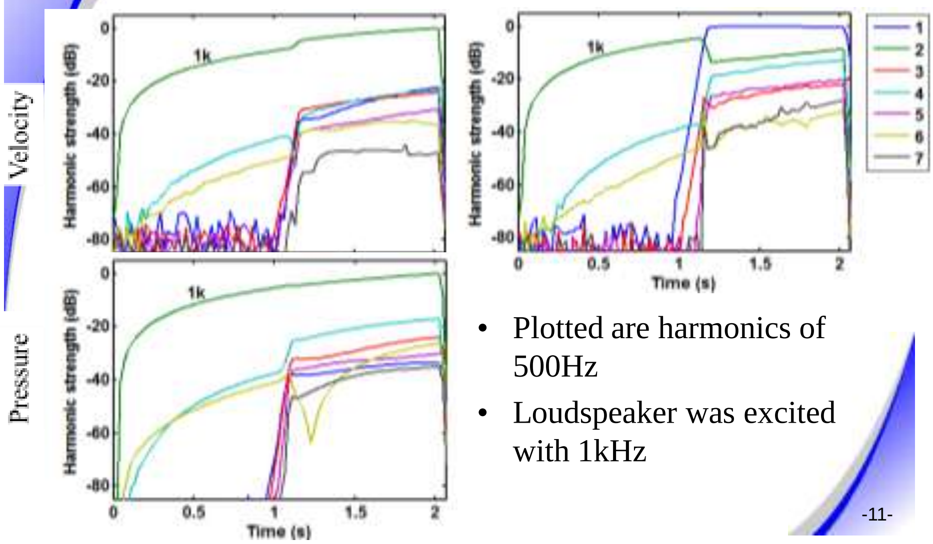


- Distortion falls rapidly with frequency
- Distortion further away from driving point of cone is higher

Complicated Nonlinear Behavior at 1kHz

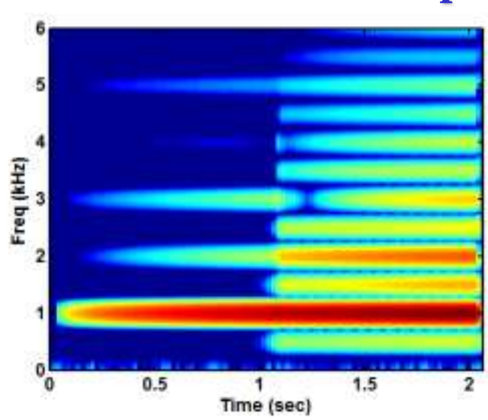
Edge of dustcap

Half radius



- Plotted are harmonics of 500Hz
- Loudspeaker was excited with 1kHz

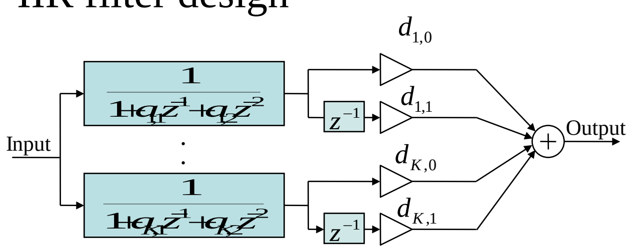
Complicated Nonlinear Behavior at 1kHz - Spectrogram



- Pressure signal shown.
- Pitch halving effect at 1 s.

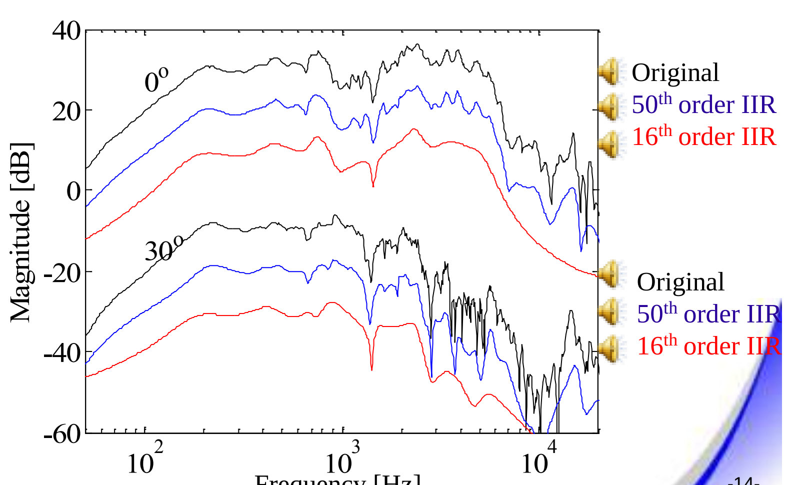
Linear modeling (1)

- Common pole modeling with parallel second-order filters
- Logarithmic frequency resolution as a result of estimating the poles by warped IIR filter design



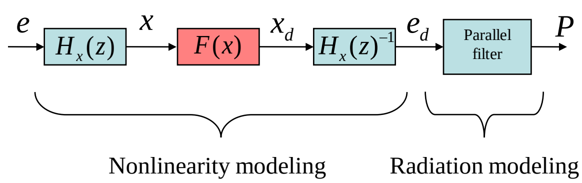
Linear modeling (2)

- Common pole modeling results:

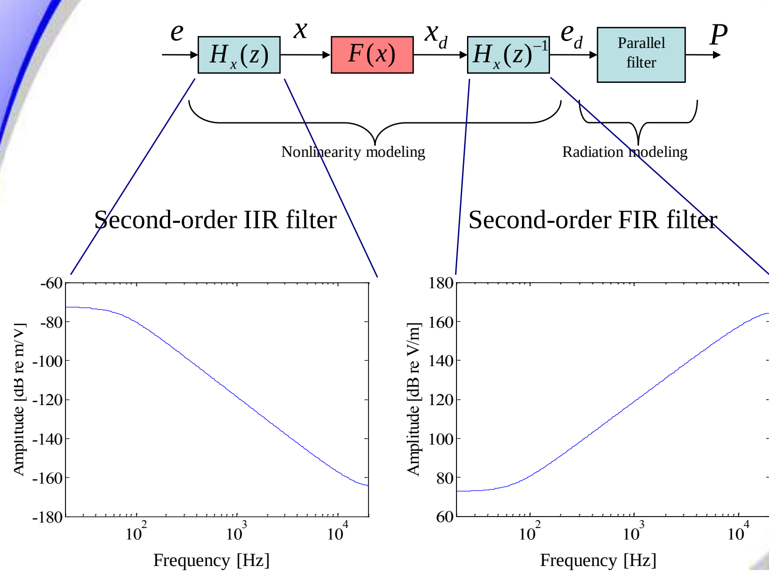


Nonlinear modeling

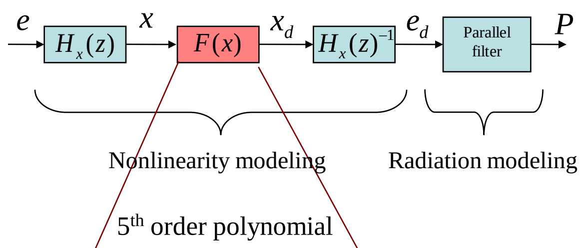
- Distortion modeling only at low frequencies where it is most significant
- Distortion at low frequencies depends on cone displacement

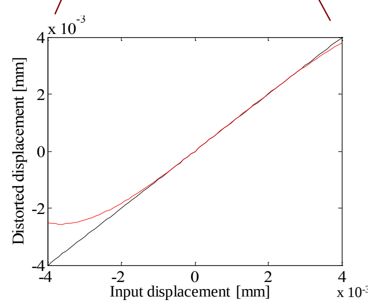


Nonlinear modeling (1)



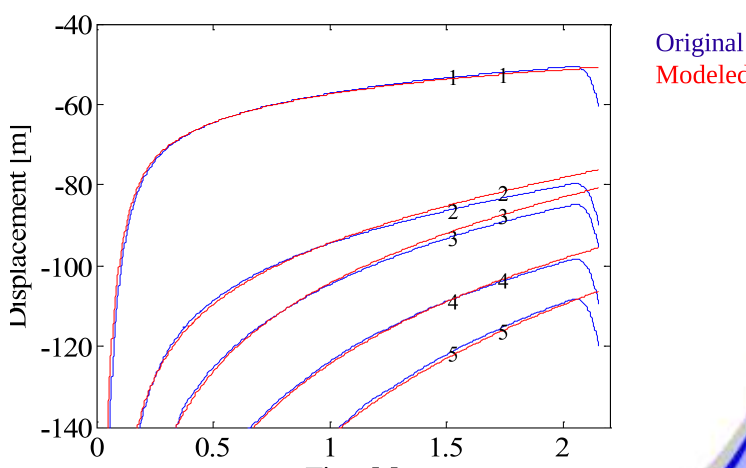
Nonlinear modeling (2)





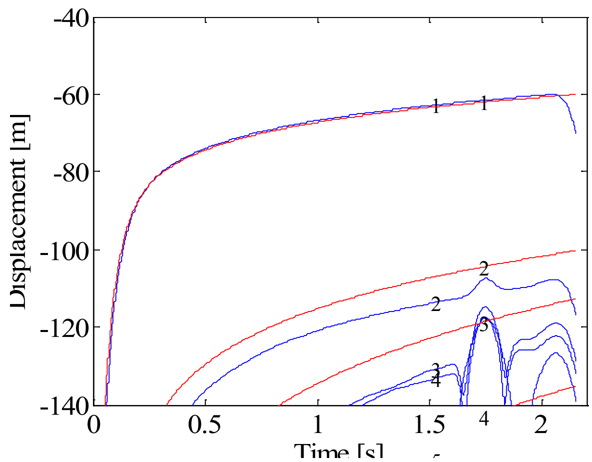
Nonlinear modeling (3)

- Perfect fit only at a single frequency: Polynomial coefficient fit for 70Hz

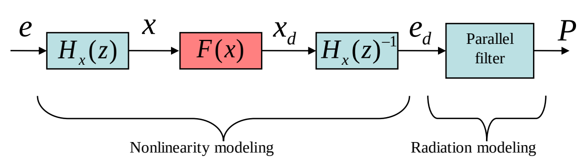


Nonlinear modeling (4)

- Qualitatively correct behavior at higher frequencies (140 Hz displayed)



Nonlinear modeling sound examples



	Linear response	Nonlinear model
Sine wave (82 Hz)		
Power chord (E)		

Summary

- Measured linear and nonlinear behavior of a Celestion G12 guitar loudspeaker.
- Proposed linear model based upon parallel filter bank design.
- Proposed simple/efficient model with static nonlinearity.
- Most salient effects are linear.
  Nonlinear effects are subtle.
- Nonlinear behavior is complicated and requires further investigation.

Thank you for your attention!

Acknowledgements: Jyri Pakarinen, Miikka Tikander