

Acoustic Horn

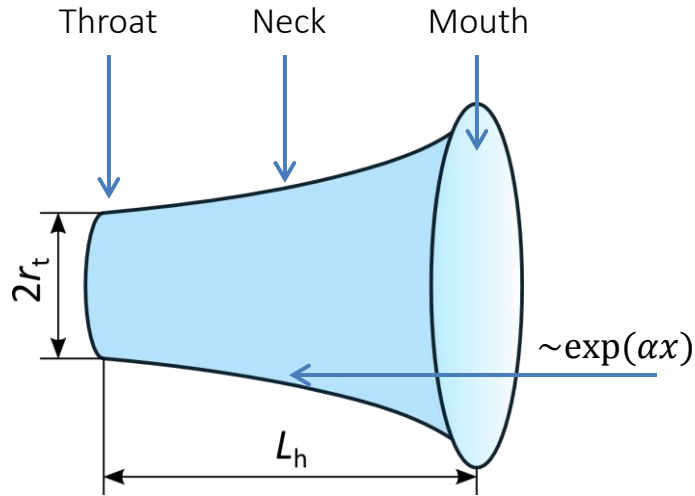
Nonlinear Sound Propagation using the Westervelt Model

DB# 54021

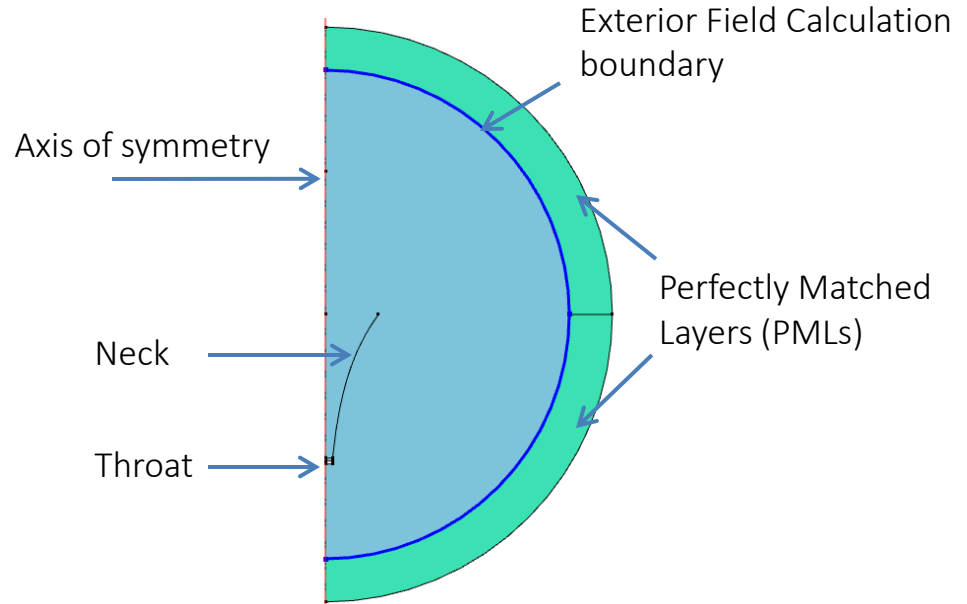
Background and Motivation

- This tutorial shows how to model the propagation of nonlinear acoustic waves generated by an exponential horn.
- The nonlinear behavior is due to a high amplitude input signal which results in high sound pressure levels in the horn throat.
- A harmonic input driven at the frequency $f_0 = 130$ Hz generates an acoustic wave with the frequency spectrum that contains the harmonics $2f_0$, $3f_0$, etc.
- This makes the frequency domain analysis irrelevant and requires a full nonlinear transient analysis of the system.

Model Geometry



Exponential horn sketch



2D axisymmetric model setup

Model Setup: Physics Interfaces

- The *Pressure Acoustics, Transient* interface is used for transient computation of the acoustic pressure
- The dissipative—Thermally conducting and viscous—material model and the *Nonlinear Acoustics (Westervelt)* features describe the nonlinear propagation of acoustics in the physical domain
- PMLs are used together with the lossless Transient Pressure Acoustics Model to model the nonreflecting condition towards infinity
- The *Exterior Field Calculation* feature provides the radiation pattern of the acoustic field

Equation

Show equation assuming:

Study 1 - Frequency Domain, Frequency Domain

$$\frac{1}{\rho c^2} \frac{\partial^2 p_t}{\partial t^2} + \nabla \cdot \left(-\frac{1}{\rho} (\nabla p_t - \mathbf{q}_d) \right) = Q_m + \frac{\beta}{\rho^2 c^4} \frac{\partial^2 p_t^2}{\partial t^2}$$

$\beta = 1 + \frac{B}{2A}$

Model Input

Coefficient of Nonlinearity

From parameter of nonlinearity

Parameter of nonlinearity:

B/A From material

← Westervelt equation

Material Contents

Property	Variable	Value	Unit	Property group
<input checked="" type="checkbox"/> Bulk viscosity	muB	muB(T)	Pa·s	Basic
<input checked="" type="checkbox"/> Dynamic viscosity	mu	eta(T)	Pa·s	Basic
<input checked="" type="checkbox"/> Ratio of specific heats	gamma	1.4	1	Basic
<input checked="" type="checkbox"/> Heat capacity at constant pressure	Cp	Cp(T)	J/(kg·K)	Basic
<input checked="" type="checkbox"/> Density	rho	rho(pA,T)	kg/m³	Basic
<input checked="" type="checkbox"/> Thermal conductivity	k_iso;...	k(T)	W/(m·K)	Basic
<input checked="" type="checkbox"/> Speed of sound	c	cs(T)	m/s	Basic
<input checked="" type="checkbox"/> Parameter of nonlinearity	BA	(def.gamma+1)/2	1	Nonlinear model
Coefficient of thermal expansion	alpha_i...	alpha_p(pA,T)	1/K	Basic
Mean molar mass	Mn	0.02897	kg/mol	Basic
Relative permeability	mur_is...	1	1	Basic

Model Setup: Study and Solver Settings

- This model resolves the frequency components up to $4f_0$
- The nonlinear transient study contains two steps: *Time Dependent* and *Time to Frequency FFT*
- The *Nonlinear Acoustics (Westervelt)* feature automatically tunes the Time Dependent Solver, which makes it effective for the underlying nonlinear problem
- The *Time to Frequency FFT* step is applied on the time interval where the solution has reached steady state. The result is only stored on the exterior field boundary that is used for the exterior field calculation.

▼ Transient Solver Settings

Changes made to these settings only take effect when the default solver is generated.

Maximum frequency to resolve:
 $f_{\max, \text{sol}}$ Hz

Time stepping:
Fixed (preferred)

▼ Study Settings

Prescribed by:

Input study:

Time unit:

Start time: s

End time: s

▼ Values of Dependent Variables

— Values of variables not solved for

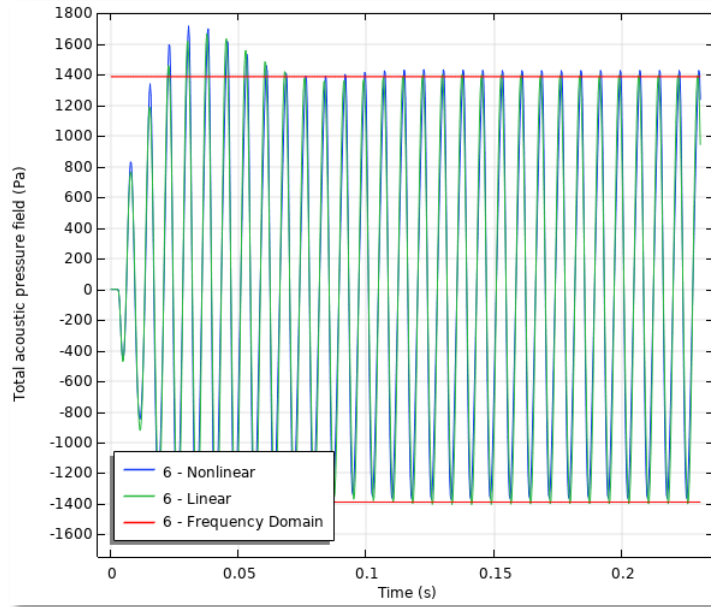
Settings:

— Store fields in output

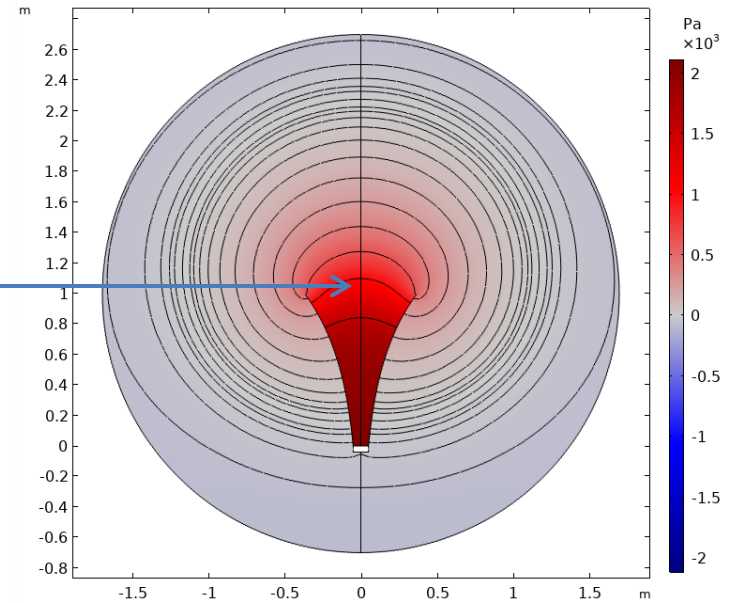
Settings:

Selections:

Results: Acoustic Pressure

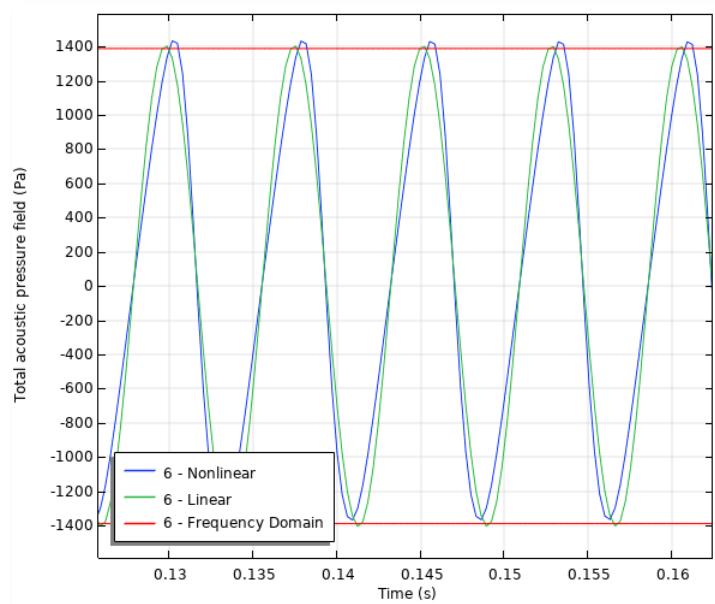


Acoustic pressure at point: linear vs nonlinear approach

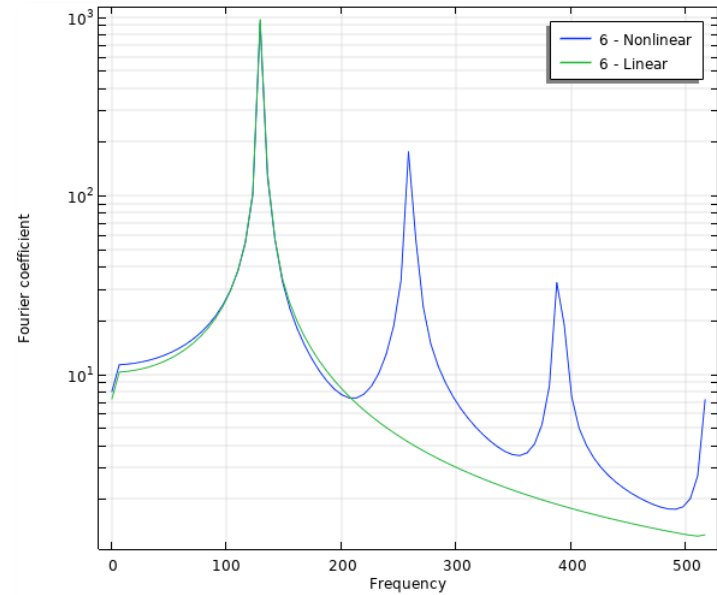


Total nonlinear acoustic pressure profile
with contours

Results: Exterior Pressure

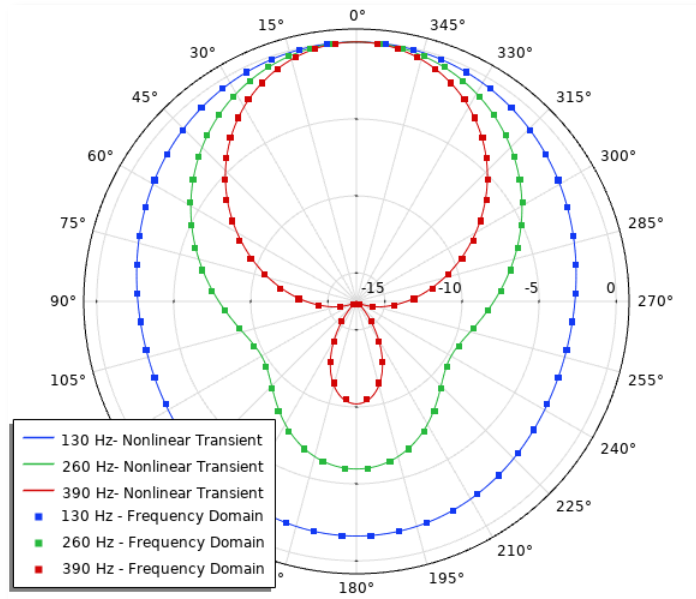


Acoustic pressure at point: Transient

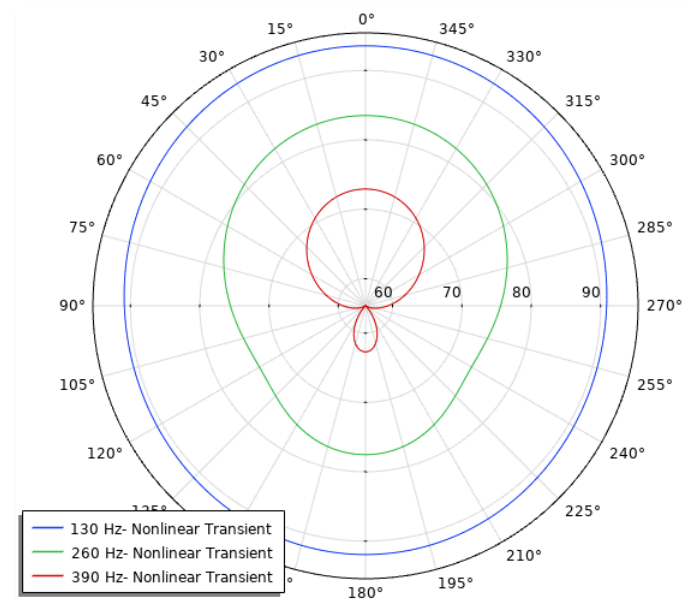


Acoustic pressure at point: Frequency spectrum

Results: Exterior Field SPL



Normalized exterior field SPL at 10 m:
nonlinear analysis vs single frequency domain



Exterior field SPL at 10 m:
Nonlinear transient analysis, first three harmonics