Audio Product Development at Samsung Audio Lab

Better and Faster With Simulations

Andri Bezzola, PhD

SAMSUNG

Overview

- Introduction
- Nonlinear Distortion in a Woofer
- Optimization of SAMSUNG LED WALL HF Waveguide
- Conclusion & Outlook

Samsung Electronics
Fast Facts

1969
Year Founded

Vision 2020
Inspire the World, Create the Future

320,671
# of Employees (Dec 2017)

Global R&D Network

73	15	39	35	7
Countries	Regional Offices	Production Sites	R&D Centers	Design Offices

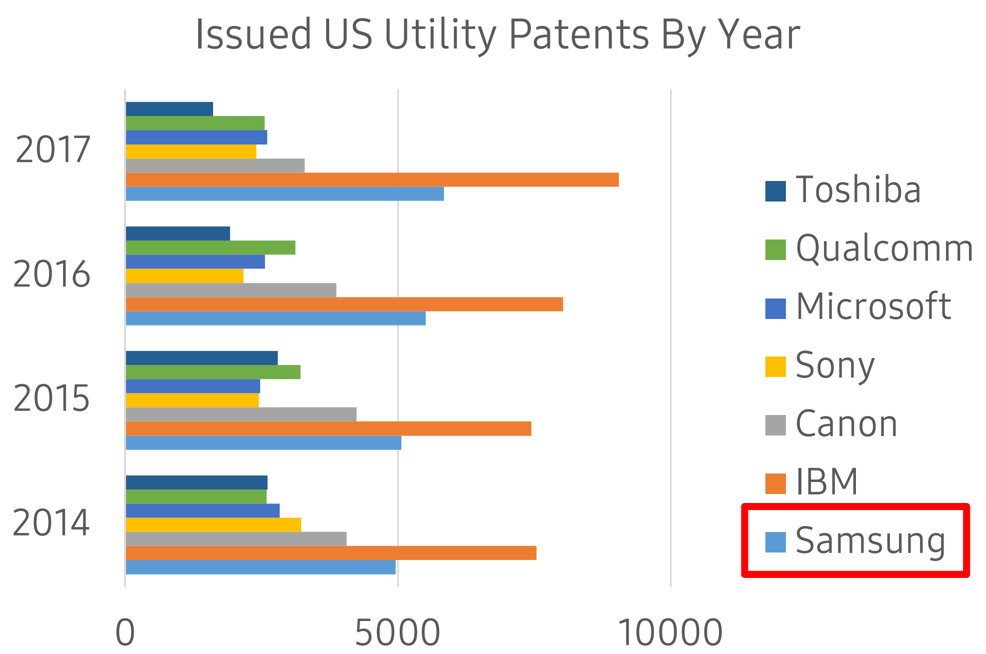
1⁄5 OF ENTIRE WORKFORCE

40.7 M DAILY INVESTMENT (USD)

14.9 B TOTAL INVESTMENT (USD)

Issued Patents

US



Europe

Top 10 Patentees in 2017

2016: 3rd
2015: 2nd
2014: 1st

1	LG	R. Korea	1 792	+52.8 %
2	Robert Bosch	EPO states	1 463	−1.3 %
3	Samsung	R. Korea	1 408	+34.5 %
4	Huawei	P. R. China	1 262	+36.6 %
5	Qualcomm	United States	1 155	+35.4 %
6	Siemens	EPO states	1 053	+0.7 %
7	Ericsson	EPO states	1 009	+3.9 %
8	Toyota Motor	Japan	888	+34.3 %
9	General Electric	United States	840	−9.7 %
10	Panasonic	Japan	830	+35.8 %

EPO states · United States · R. Korea · P. R. China · Japan

Samsung Audio Lab
Valencia, CA

2013 First Hire

1700 Lab Area in m^2

2 Anechoic Chambers

3 Listening Rooms

2 Transducer Test Rooms




21 FTEs | 300+ Years of Audio Engineering and Research Experience
4 PhD | 6 MSc | 8 Active Musicians

Samsung Audio Lab Products

2015 R-Series Wireless Speaker

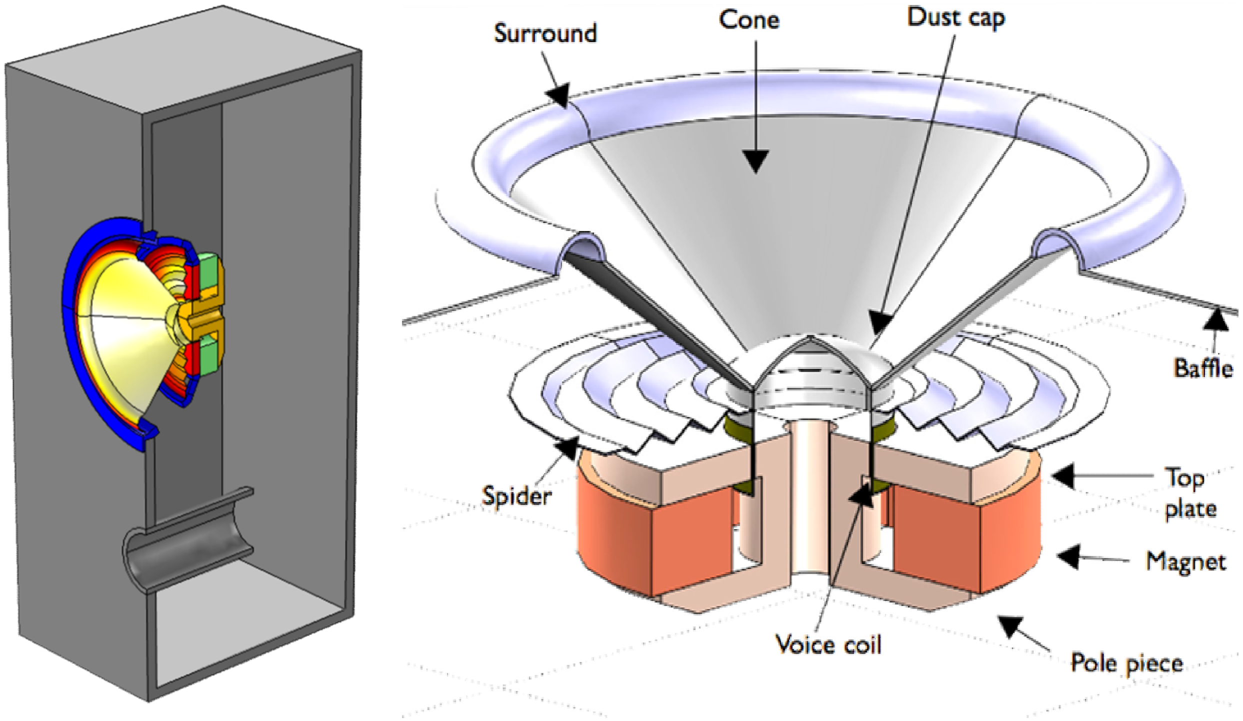
- Acoustic simulations for tweeter phase plug
- Acoustic simulations for woofer lens
- Static Electromagnetic simulations for woofer driver

Samsung Audio Lab Products

2016 First Dolby ATMOS Soundbar K950

- Acoustic simulations for height channel
- Project launch to CES prototype: 6 weeks
- Project launch to mass production: 5 months
- First Samsung soundbar to ever achieve 5 star rating from Home Cinema Choice

Loudspeakers are Multiphysics, Multiscale, and Nonlinear



AC/DC
- Nonlinear magnets
- Saturation in steel

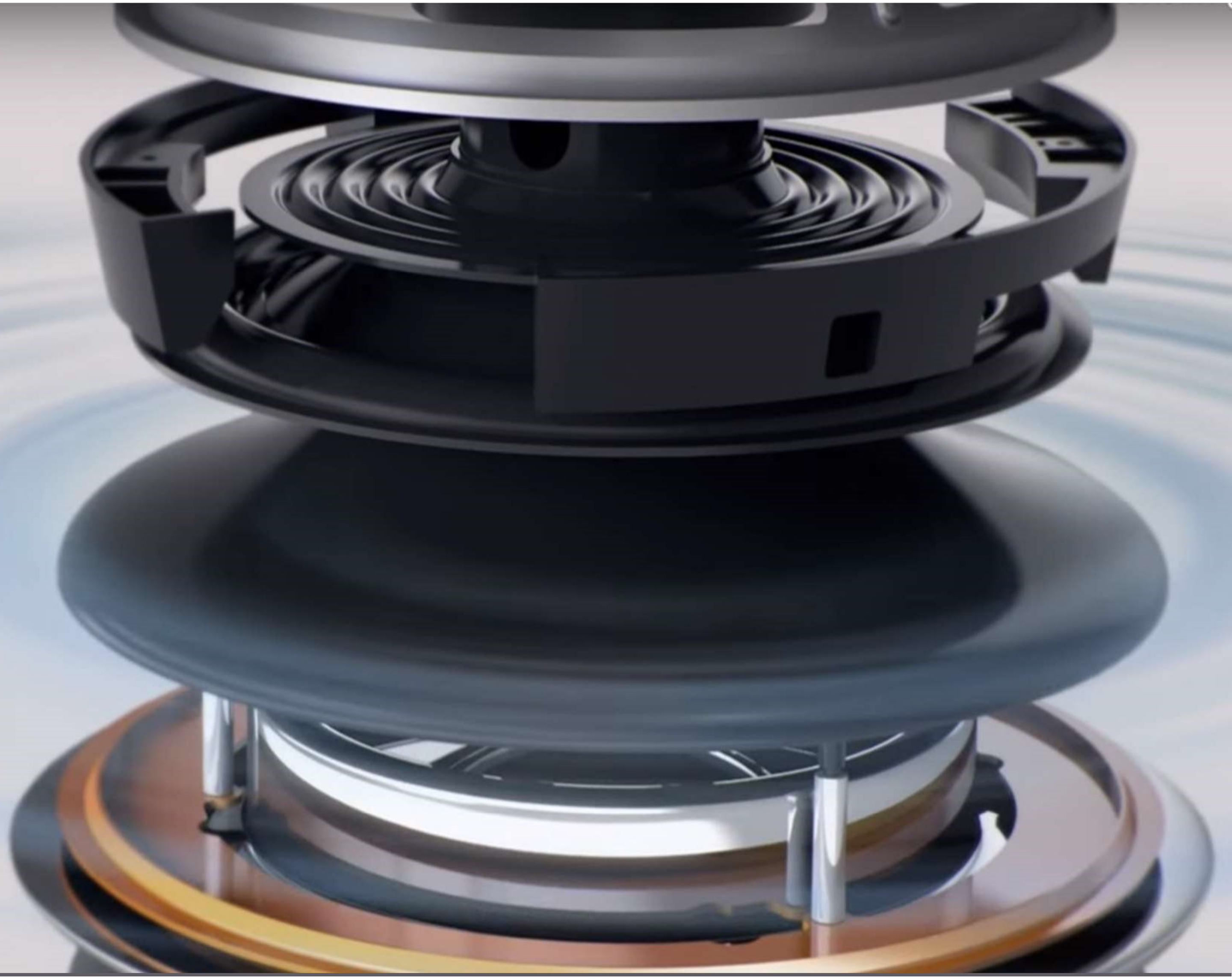
Structural Mechanics
- Anisotropic materials
- Large deformations
- Frequency dependent damping

Acoustics
- f = 20 Hz to 20 kHz
- λ = 17 m to 17 mm
- Infinite domains and far-field measurements
- Losses in narrow regions

Heat Transfer
- Temperature from -20°C to 200°C

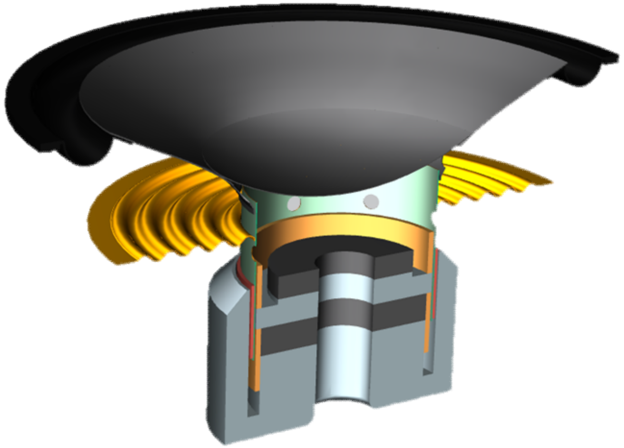
Fluid Dynamics
- Turbulent bidirectional air flow through ports and vents

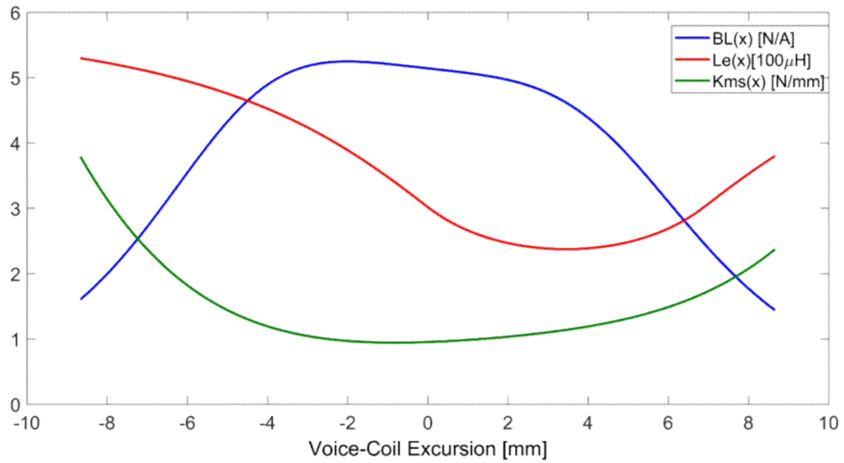
Nonlinear Distortion
Sounds Bad

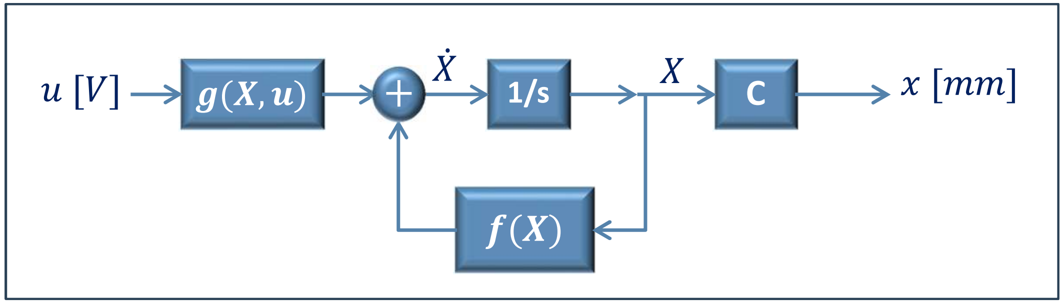


	Linear Woofer	Non-Linear Woofer
Track 1		
Track 2		

Nonlinear Distortion
Anti-Distortion







$$X = [x, \dot{x}, i]$$
$$\dot{X} = g(X,u) + f(X)$$
$$x = C\,X$$

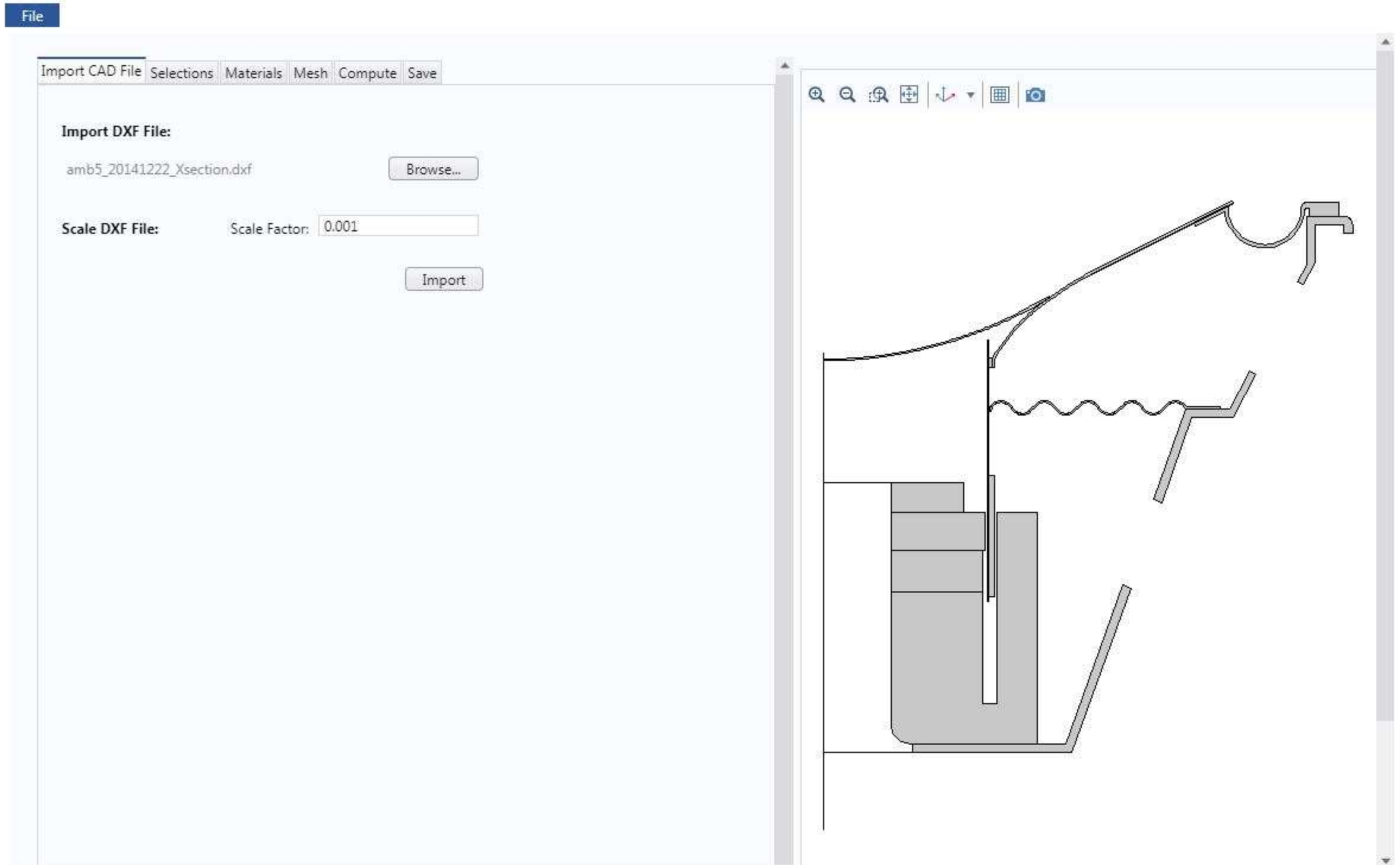
$$g(X,u) = [0, 0, u/L_e(x)]^T$$
$$C = [1, 0, 0]$$

$$f(X) = \begin{bmatrix} \dot{x} \\ \frac{1}{M}\left(-K_{ms}(x)x - R_{ms}\dot{x} + BL(x)i + \frac{i^2}{2}\frac{dL_e(x)}{dx}\right) \\ \frac{1}{L_e(x)}\left(-BL(x)\dot{x} - R_e i - \frac{dL_e(x)}{dx}\dot{x}\,i\right) \end{bmatrix}$$

	Linear Woofer	Non-Linear Woofer	Corrected
Track 1	🔊	🔊	🔊
Track 2	🔊	🔊	🔊

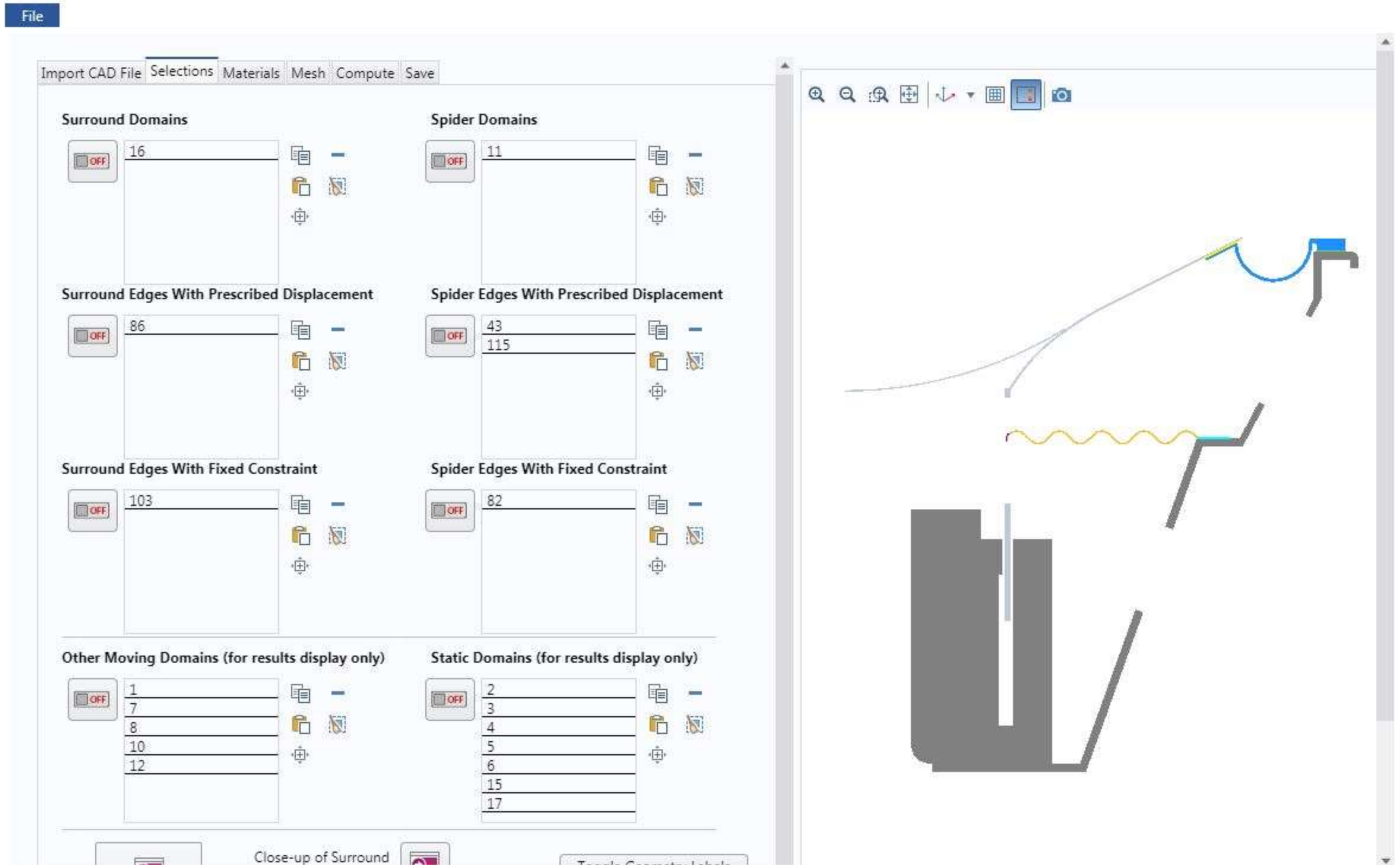
COMSOL Apps for Calculation of $K_{ms}(x)$

Geometry Import

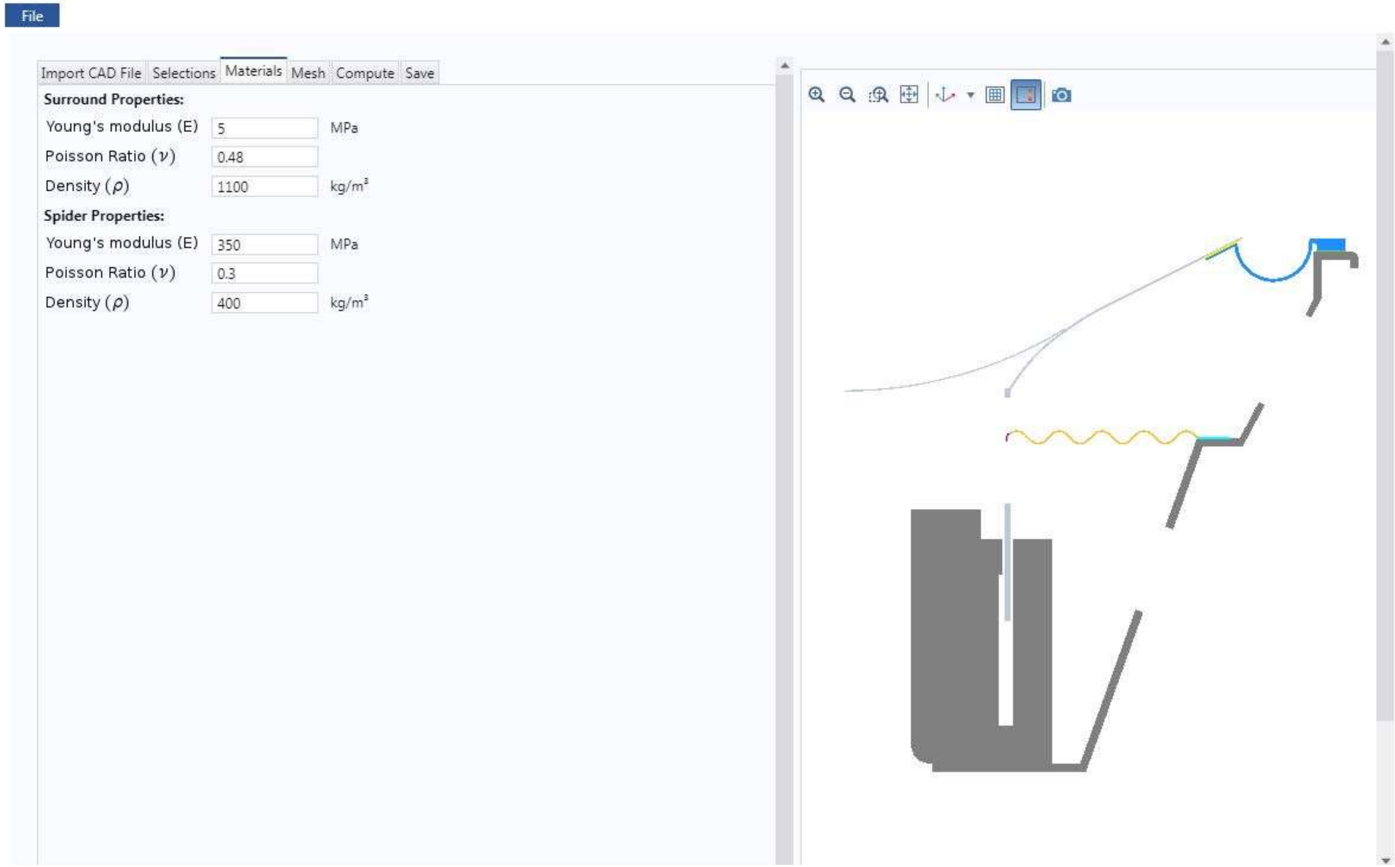


COMSOL Apps for Calculation of $K_{ms}(x)$

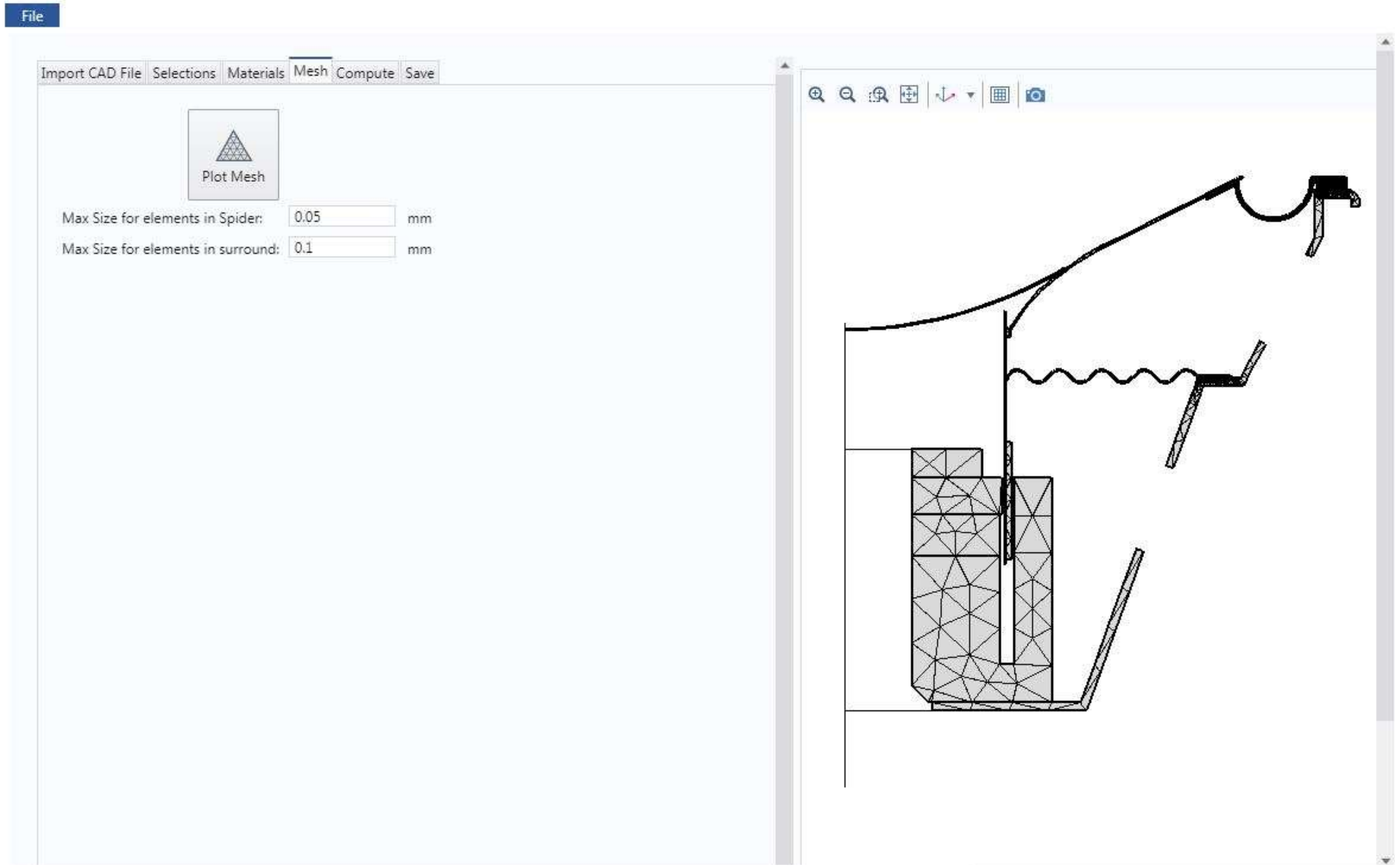
Selection Definition



COMSOL Apps for Calculation of $K_{ms}(x)$
Material Definition

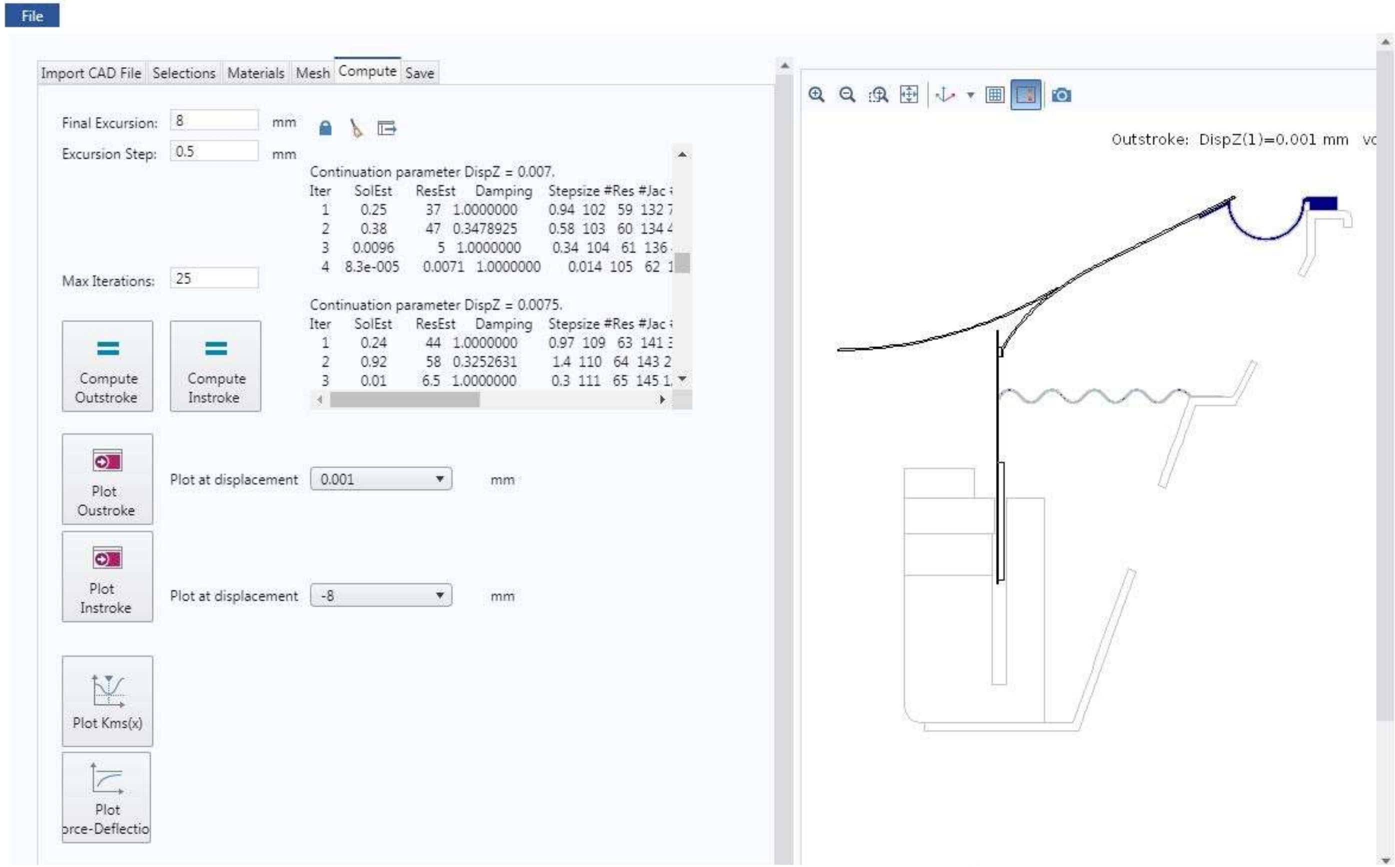


COMSOL Apps for Calculation of $K_{ms}(x)$
Mesh Setup



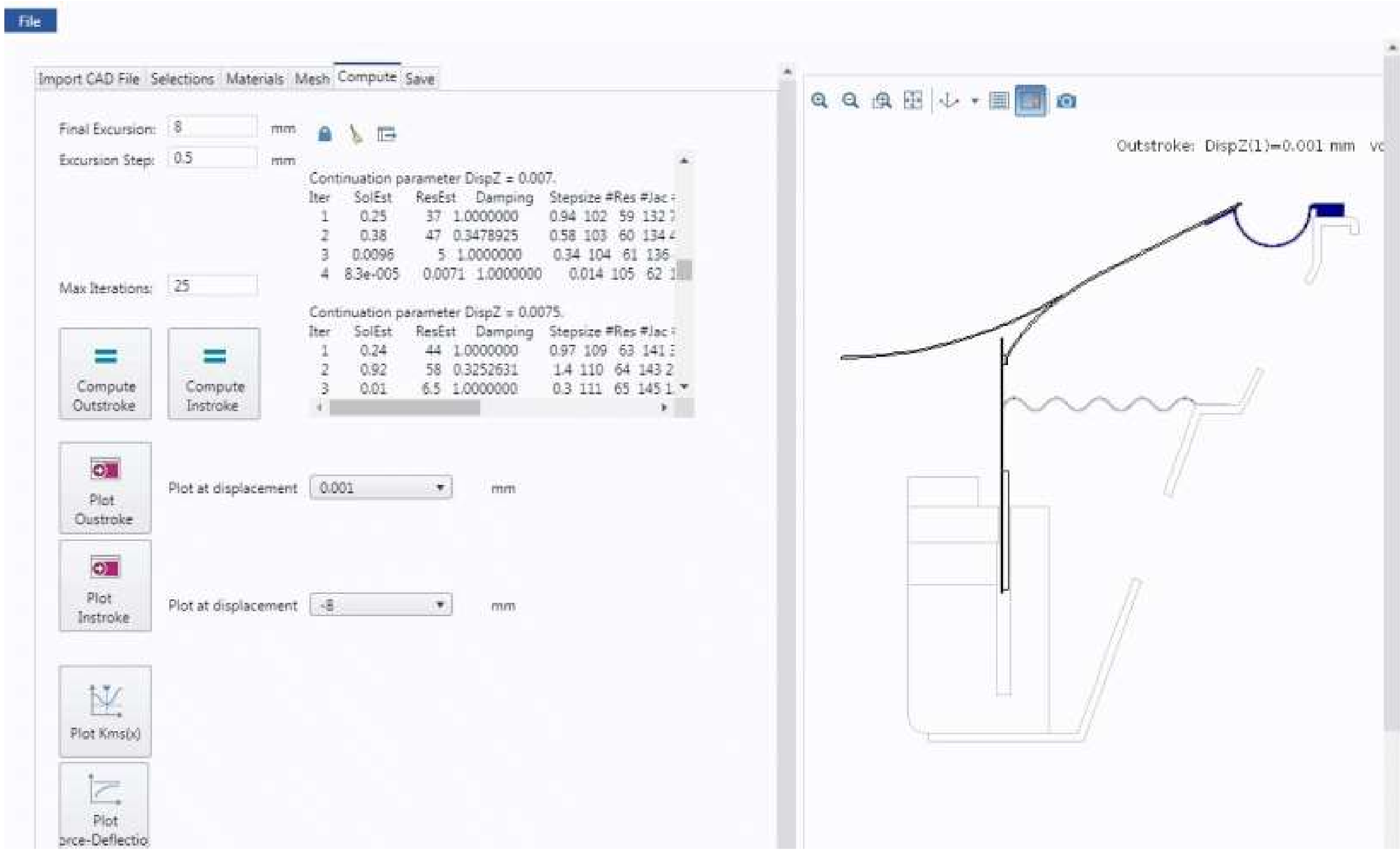
COMSOL Apps for Calculation of $K_{ms}(x)$

Solve



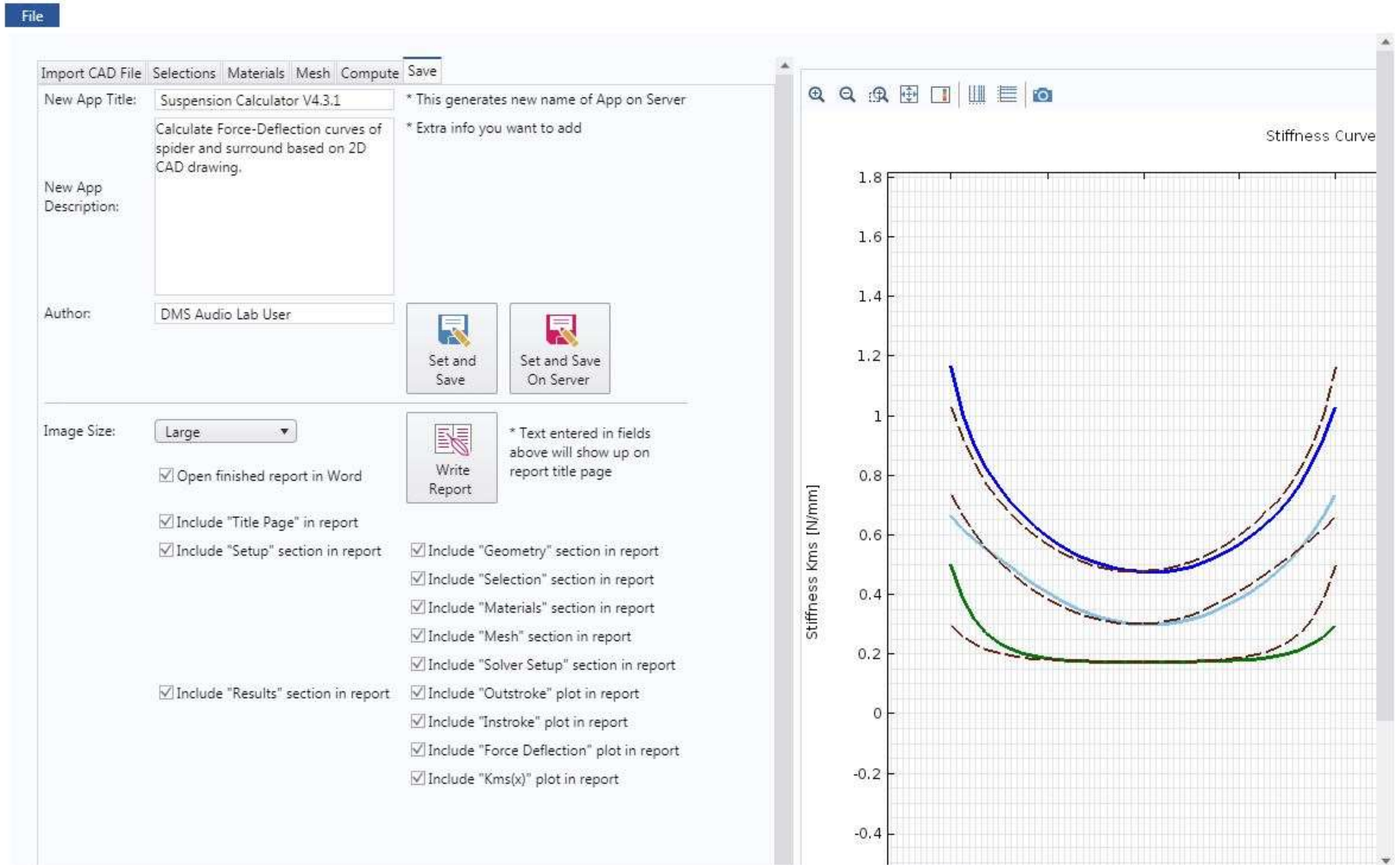
COMSOL Apps for Calculation of $K_{ms}(x)$

Outstroke and Instroke

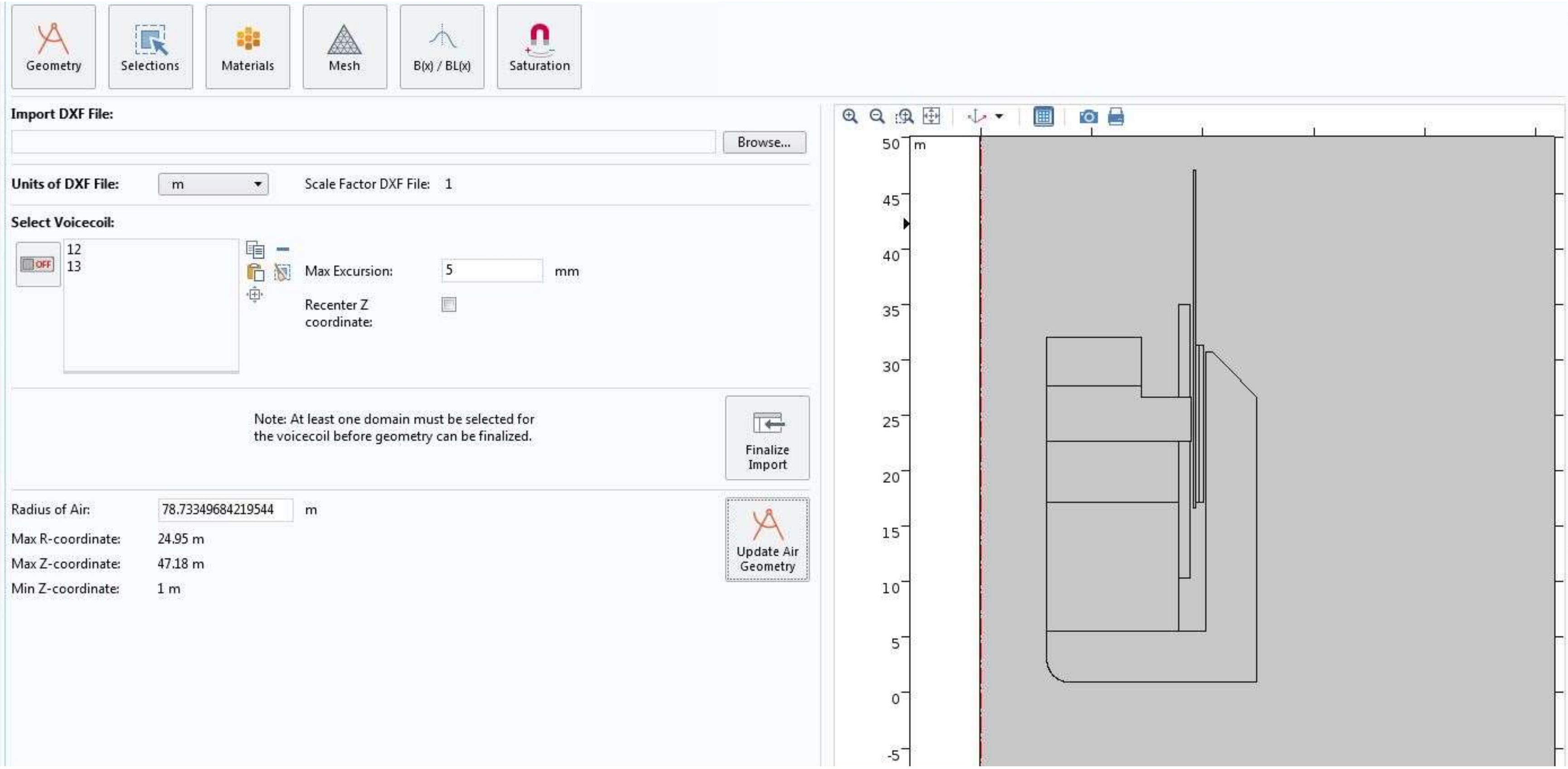


COMSOL Apps for Calculation of $K_{ms}(x)$

Results

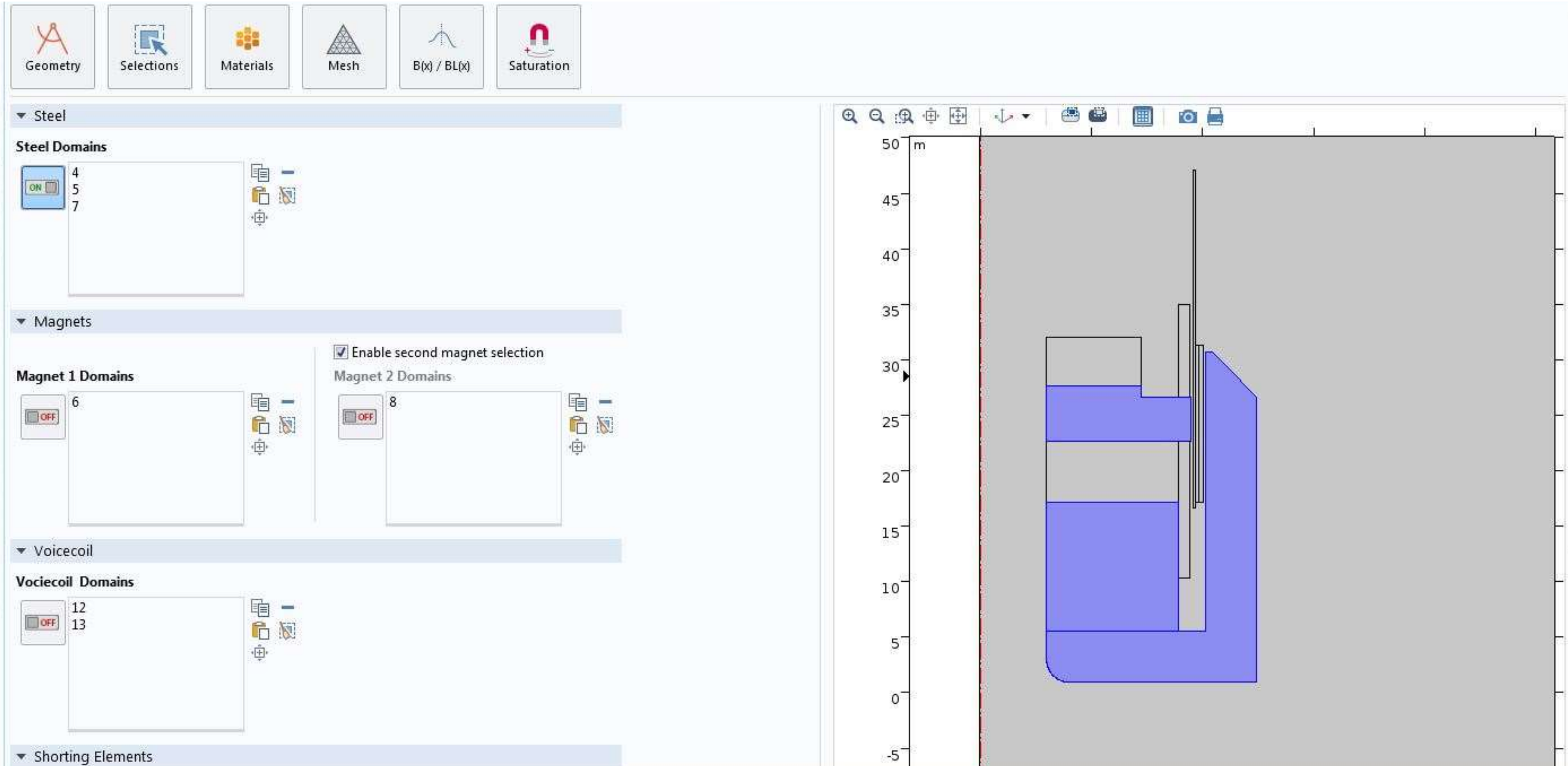


COMSOL Apps for Calculation of BL(x)
Geometry Import



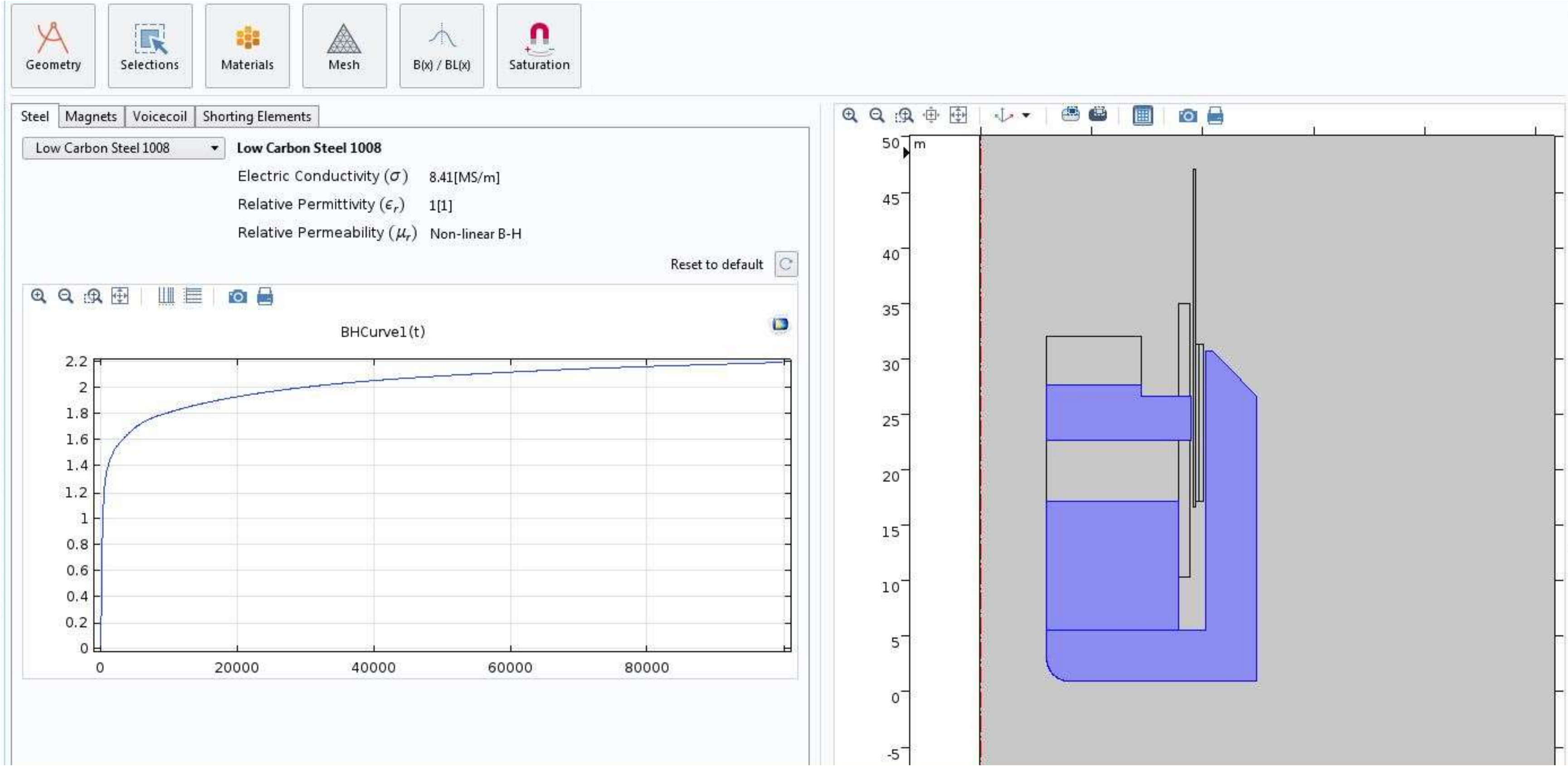
COMSOL Apps for Calculation of BL(x)

Selection Definition



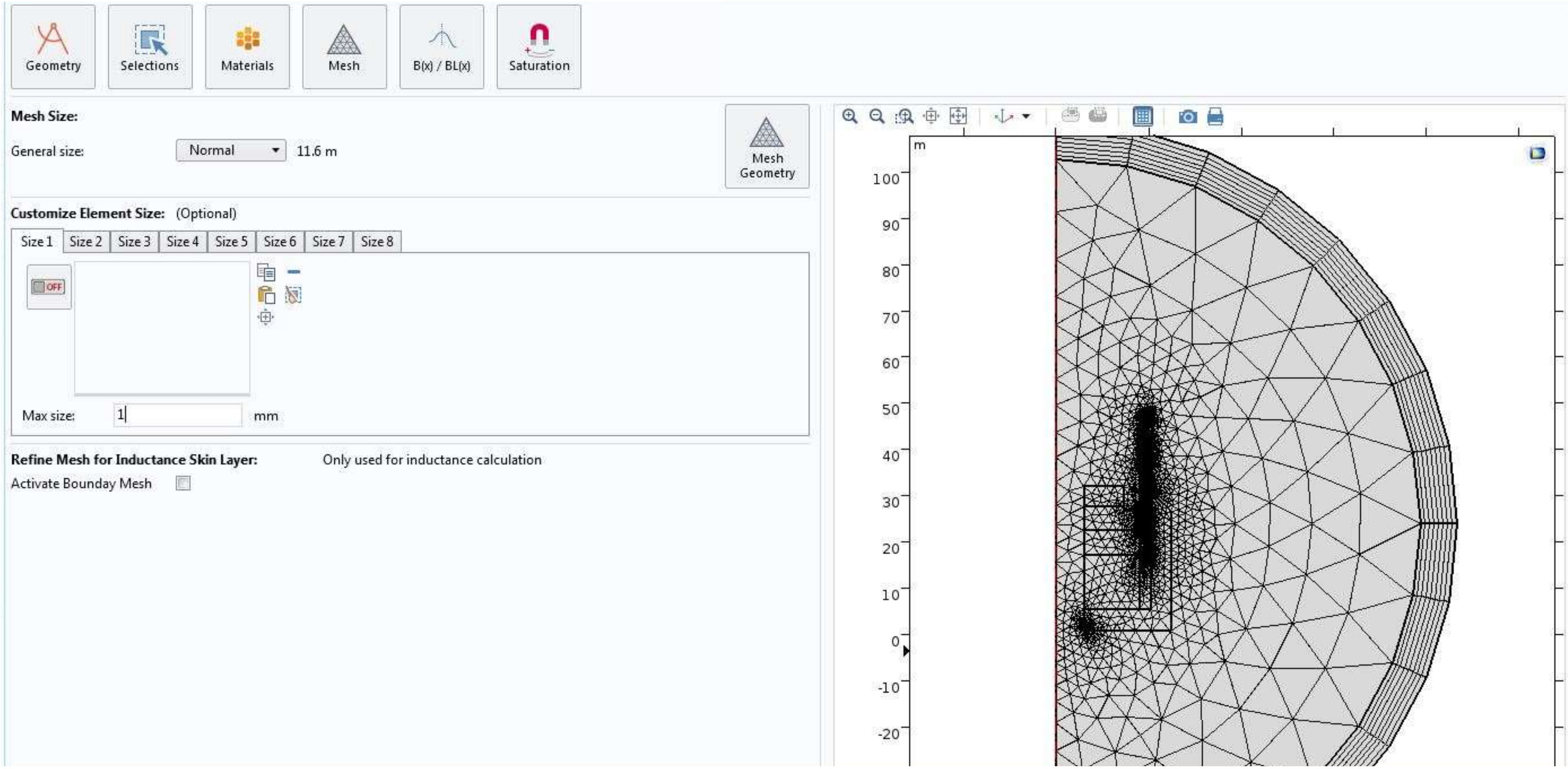
COMSOL Apps for Calculation of BL(x)

Material Choice



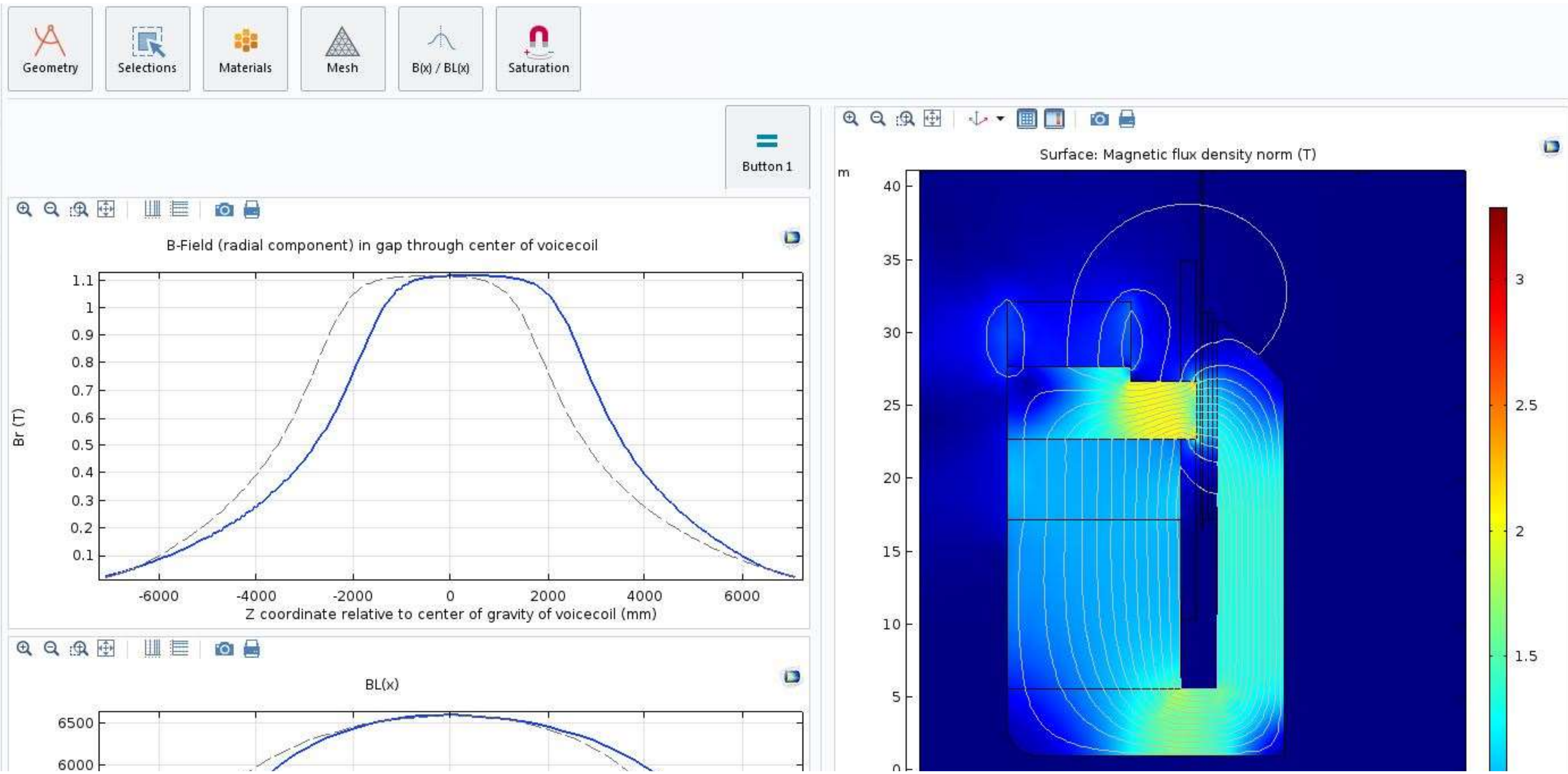
COMSOL Apps for Calculation of BL(x)

Mesh



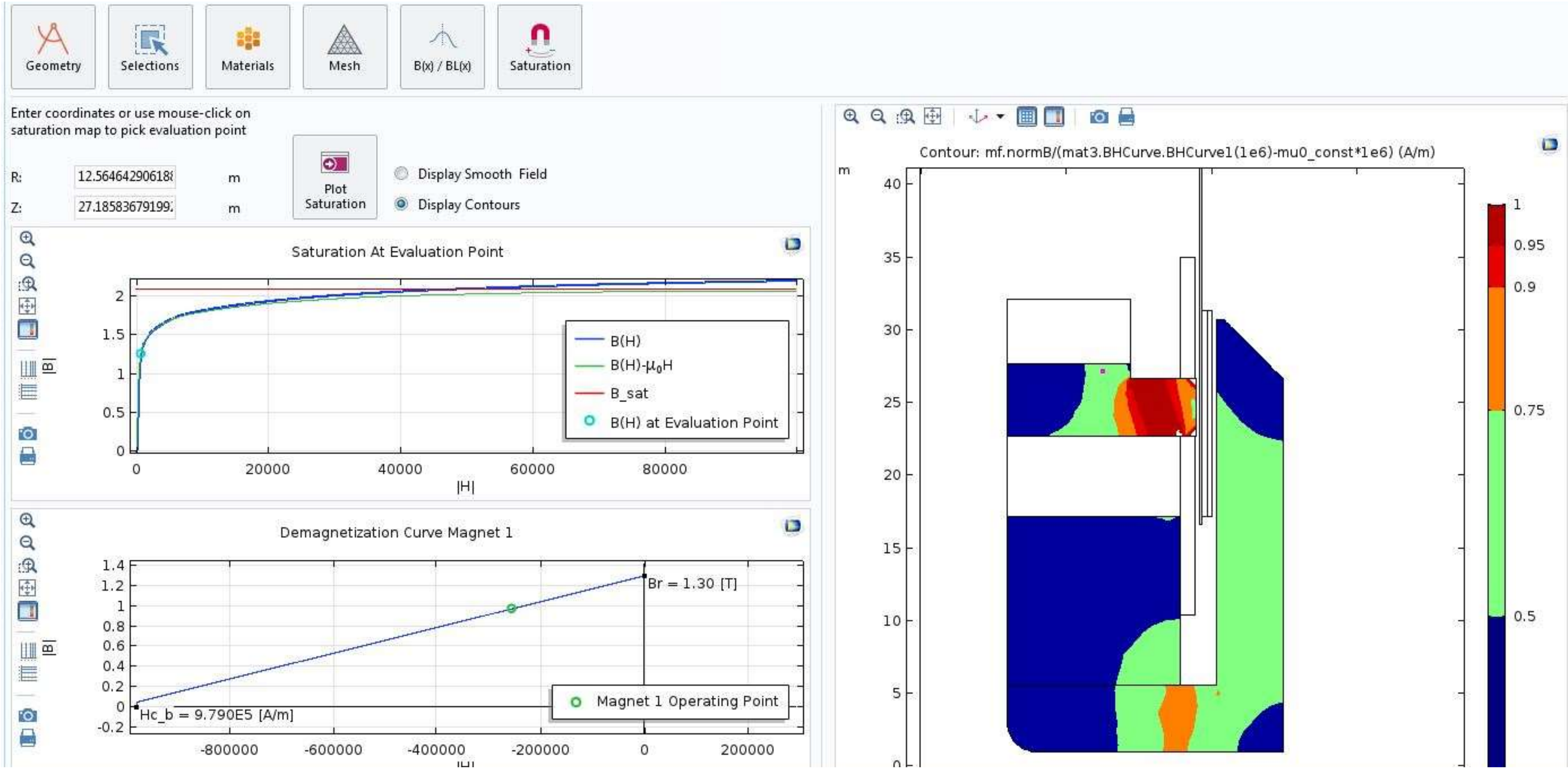
COMSOL Apps for Calculation of BL(x)

B-Field and BL Curve



COMSOL Apps for Calculation of BL(x)

B-Field and BL Curve



Inductance

Coupling of B-Field, Current, and Velocity

- Self Inductance of a Wire Loop

$$V_{ind}(t) = L_e \frac{di(t)}{\mathrm{dt}} = -\frac{d\Phi}{dt}$$

- Magnetic Flux

$$\Phi = \int_S B \, da = \int \mu_0 \mu_r \, H \, da$$

- Ampère's Law

$$\nabla \times B = \mu_0 J$$

- Current in Voice Coil

$$i = \frac{V_0 - BL\,v\, - \frac{d\Phi}{dt}}{R_e}$$

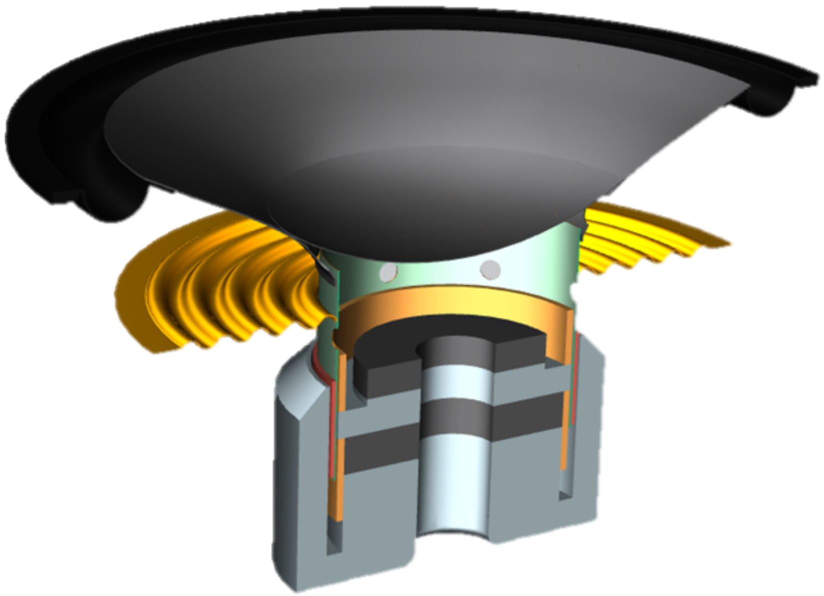
- Magnetic Force on Voice Coil

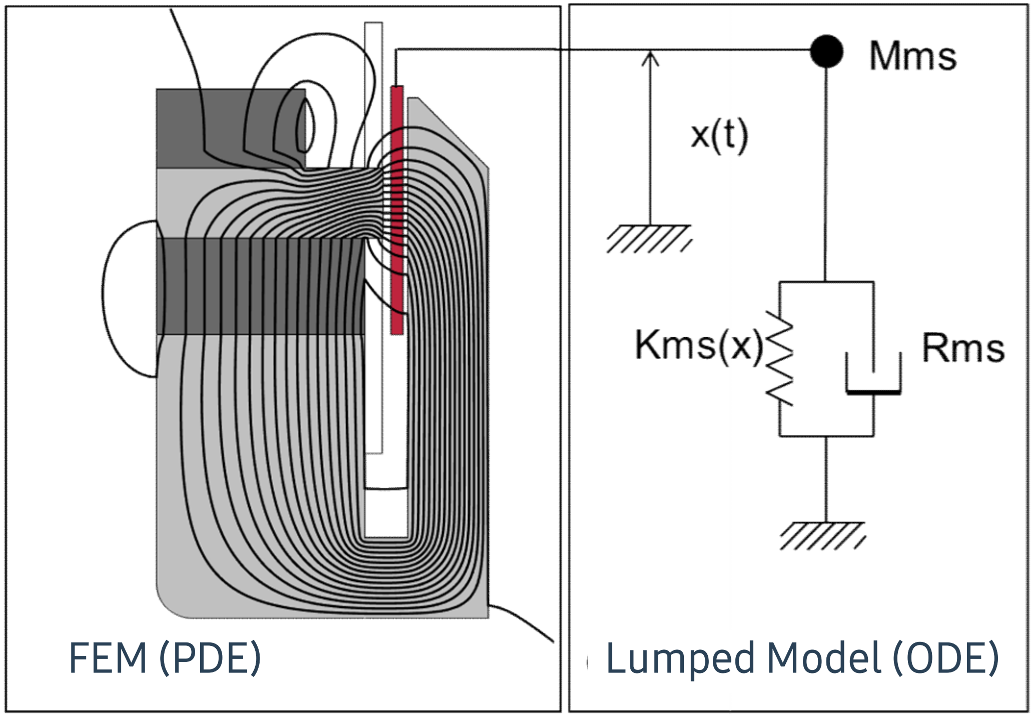
$$F = BL\, i$$

L_e:	Inductance
i:	Current in the voice coil wire
Φ:	Magnetic flux through voice coil
B:	Magnetic flux density vector field
μ_0:	Magnetic permeability in vacuum
μ_r:	Relative permeability (saturation dependent)
H:	Magnetic strength
BL:	Radial component of magnetic B-field integrated over the length of the voice coil wire
J:	Total current density per square meter
V_0:	Applied voltage from amplifier
v:	Voice coil velocity
R_e:	Resistance of voice coil wire

Non-Linear Distortion in a Woofer

Coupling PDE and ODE





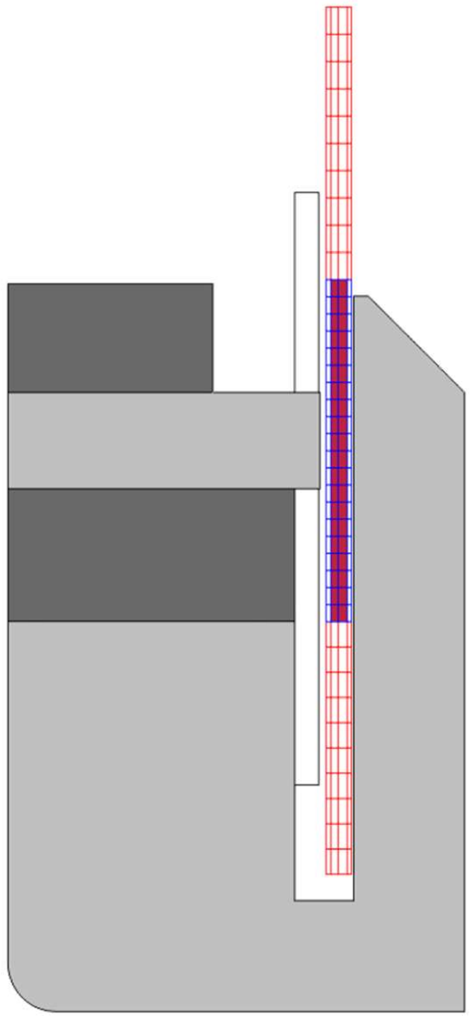
Moving Mesh for Large Deformations

Prescribed Deformation
x(t) from ODE

Free Deformation
Laplace smoothing ensures even distribution

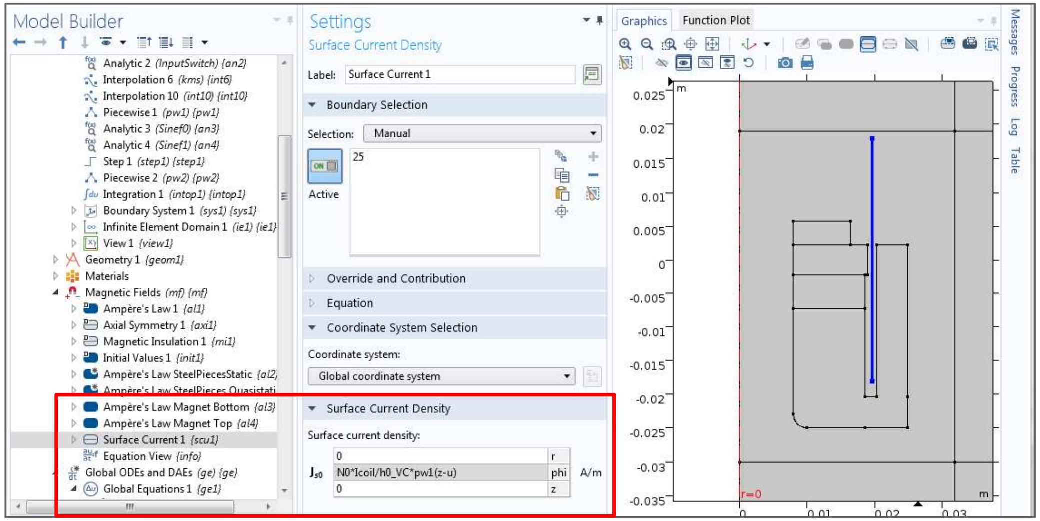
Static Mesh
Everywhere else

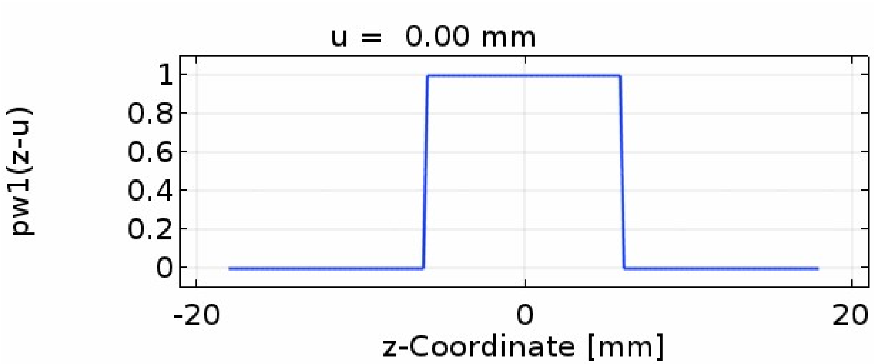
Continuity Condition
Between moving mesh and static mesh



A Better Approach in COMSOL®:

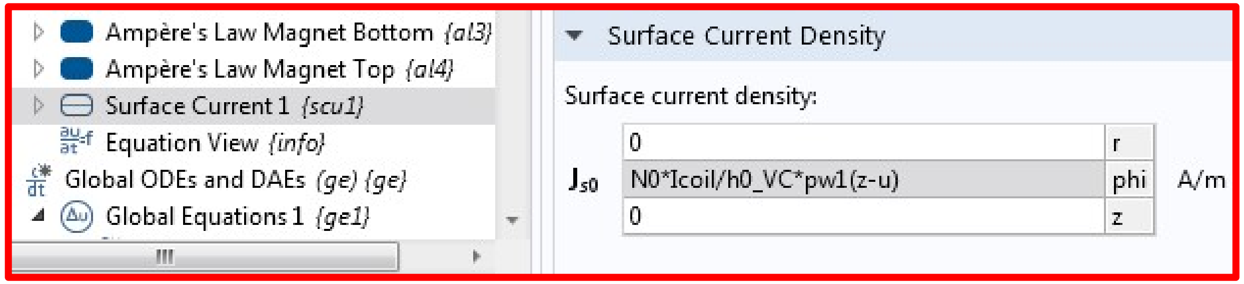
Moving Physics





$$i_{coil} = \frac{V_0 - BL\,v - V_{ind}}{R_e}$$

$$V_{ind} = -\frac{d\phi}{dt} = \frac{2\,\pi R_{vc} N_0}{h_{vc}} \int \frac{dA_\varphi}{dt}\, pw1(z-u)dz$$



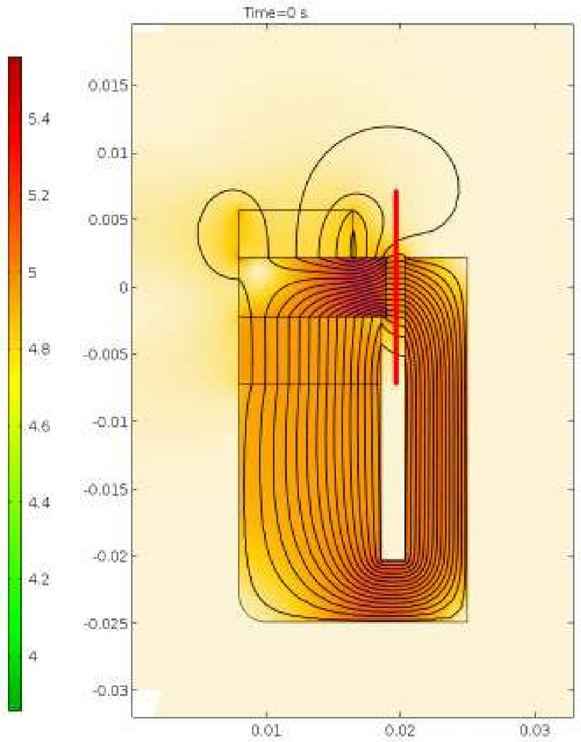
u: Voice coil position from ODE

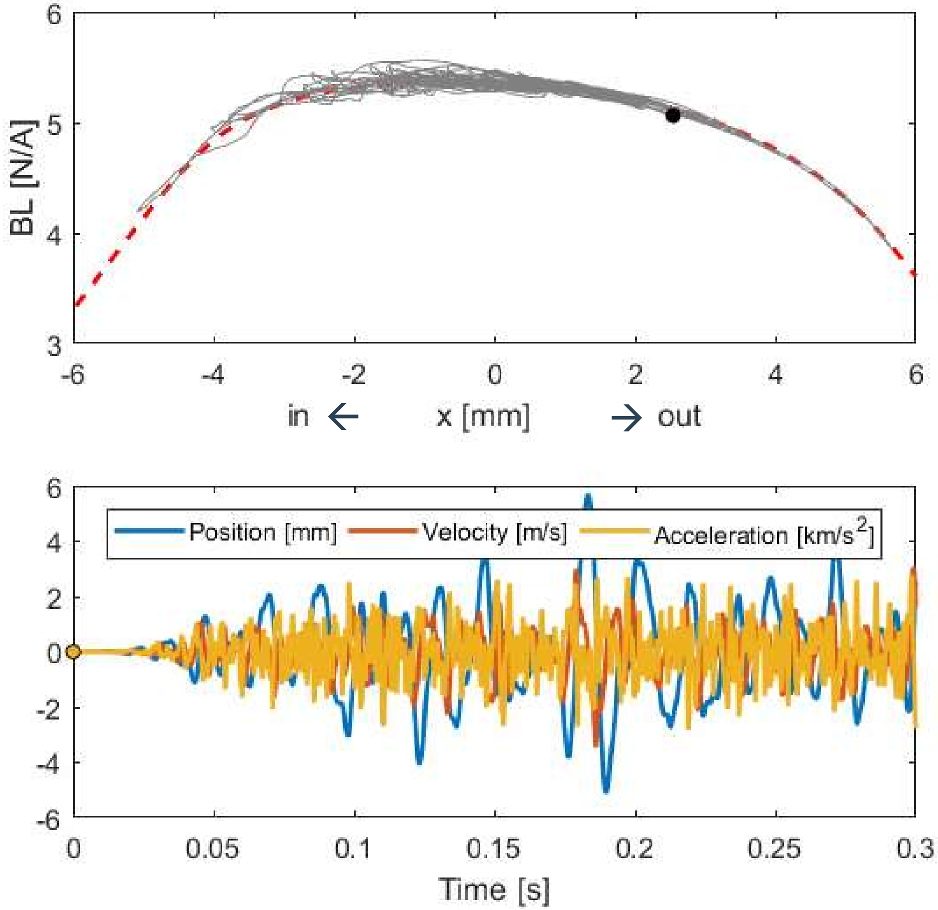
N0: Number of turns

h0_VC : Height of voice coil

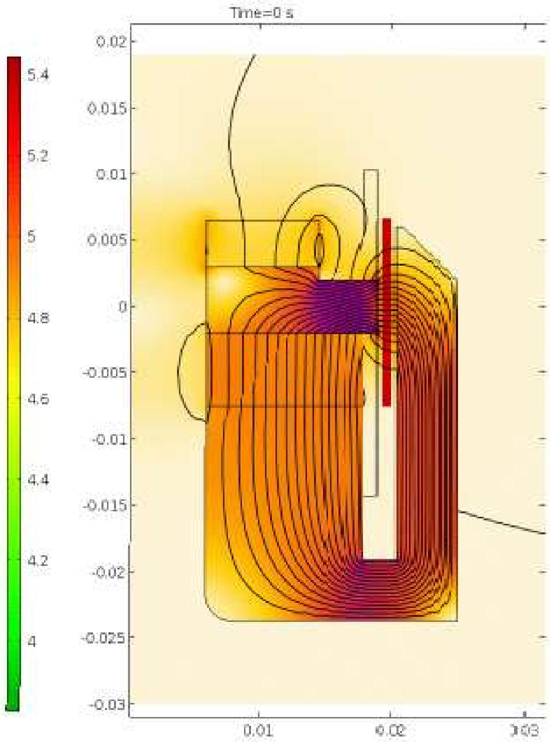
Icoil: Current in voice coil

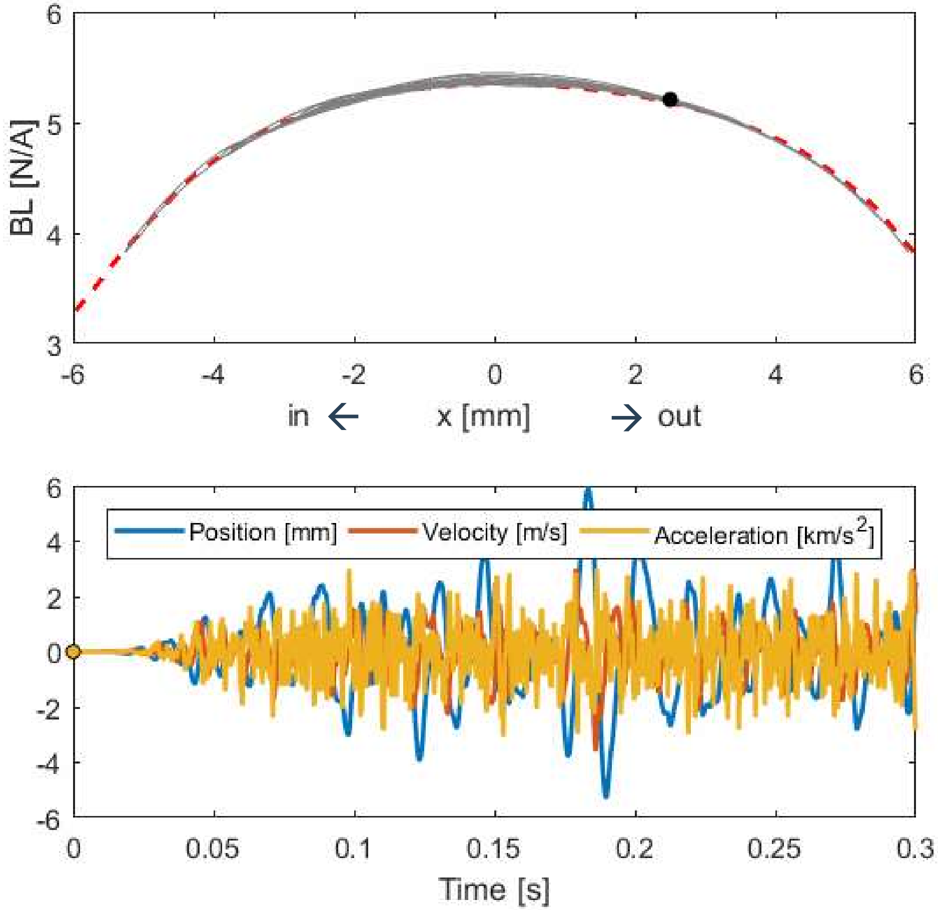
Dynamic Simulation Transducer A





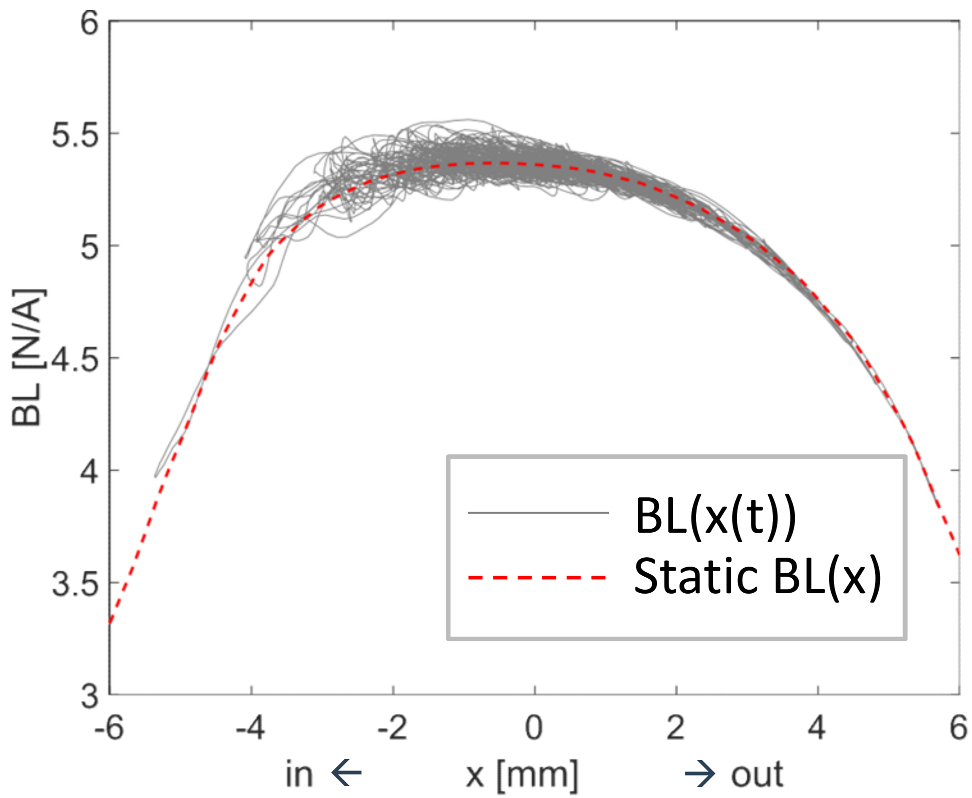
Dynamic Simulation Transducer B



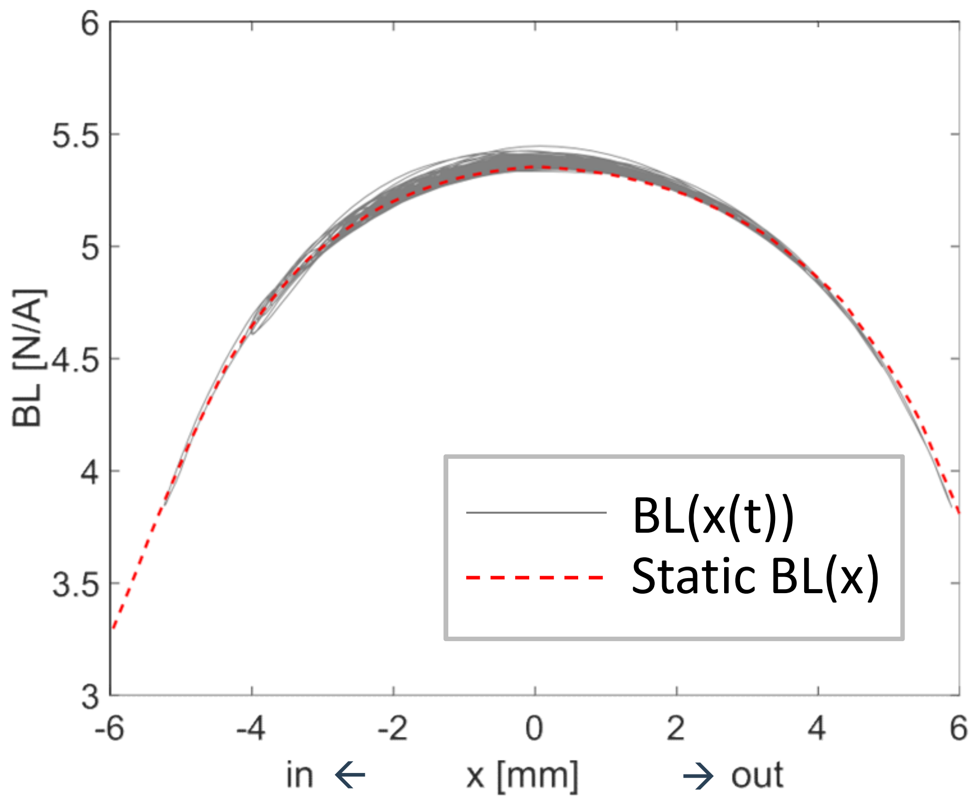


Quantifiably Better Drivers Through Simulation

Driver A



Driver B



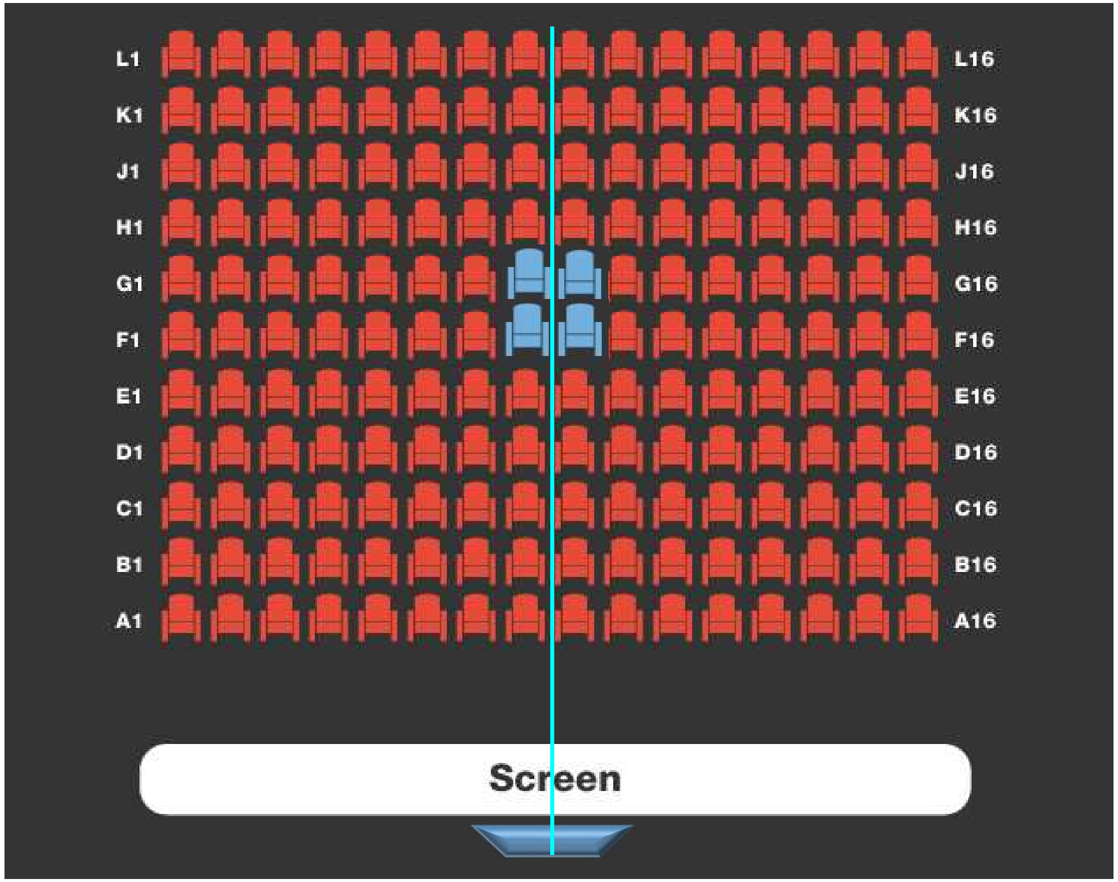
Optimizing a Waveguide
SAMSUNG LED WALL

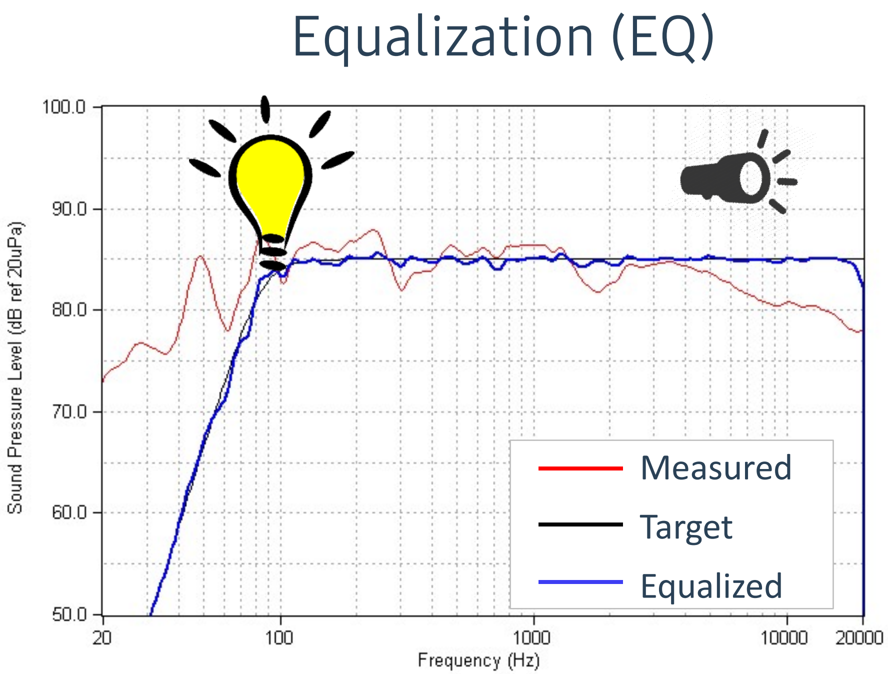
Optimizing a Waveguide
Specific Constraints

- Very wide sweet spot
- Control sound horizontally and vertically
- Limited space available
- Must be able to play at high volume

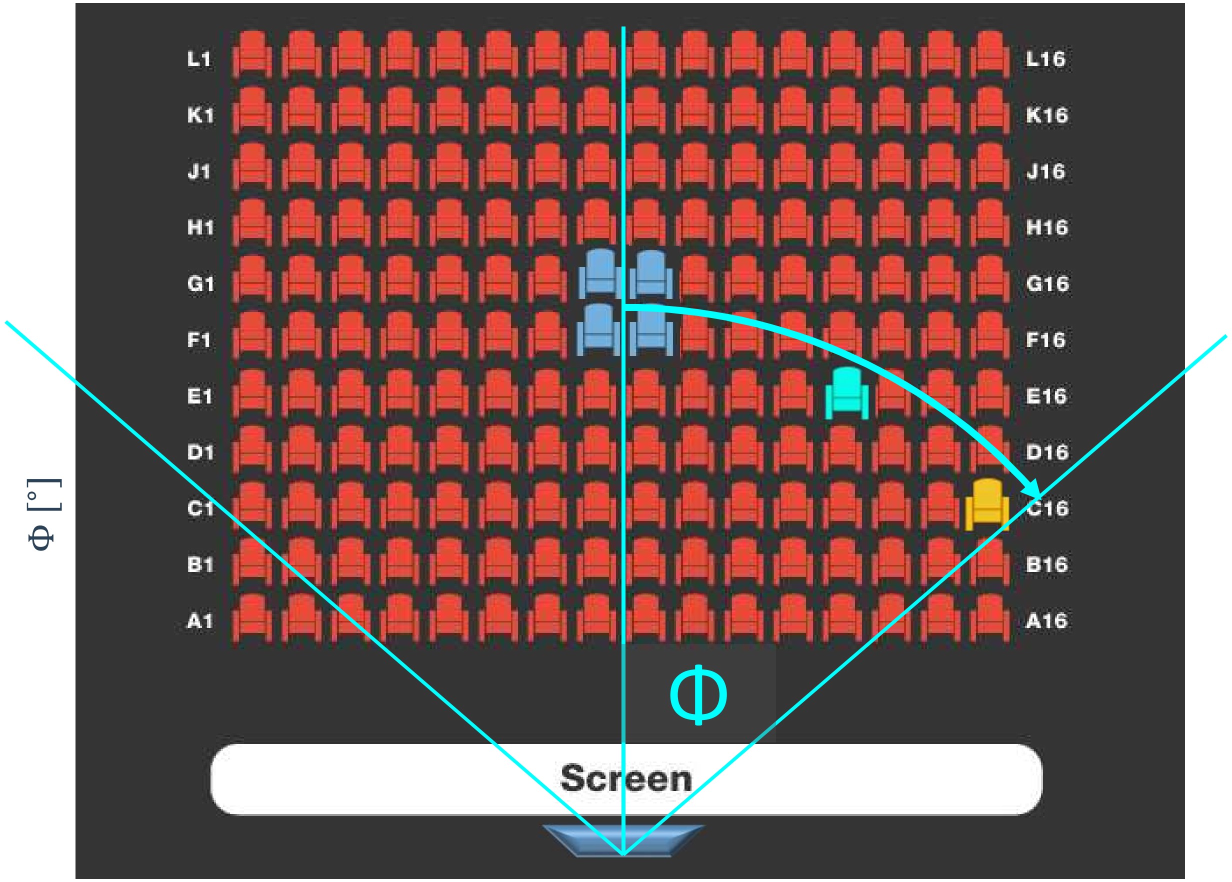
Traditional Cinema Loudspeaker Systems
Waveguides and Compression Drivers

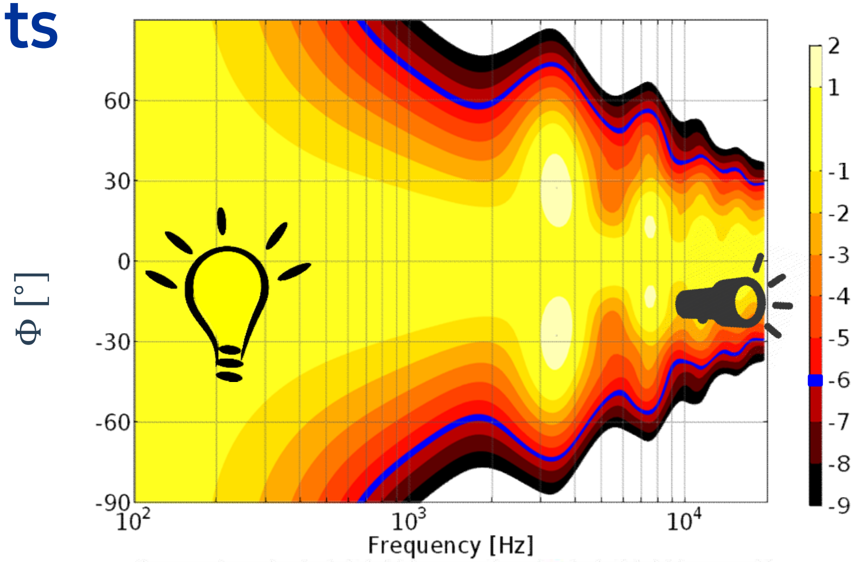
Best Frequency Response at Sweet Spot

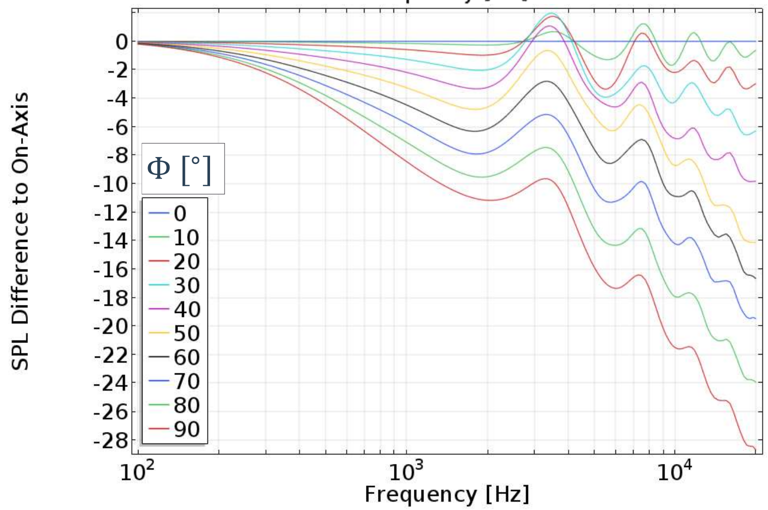




Optimal Frequency Response at Many Points



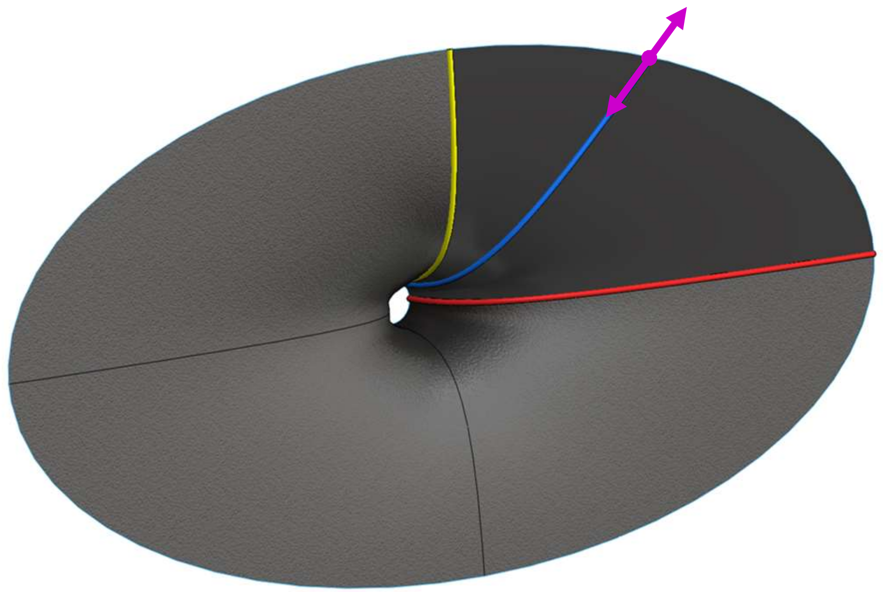


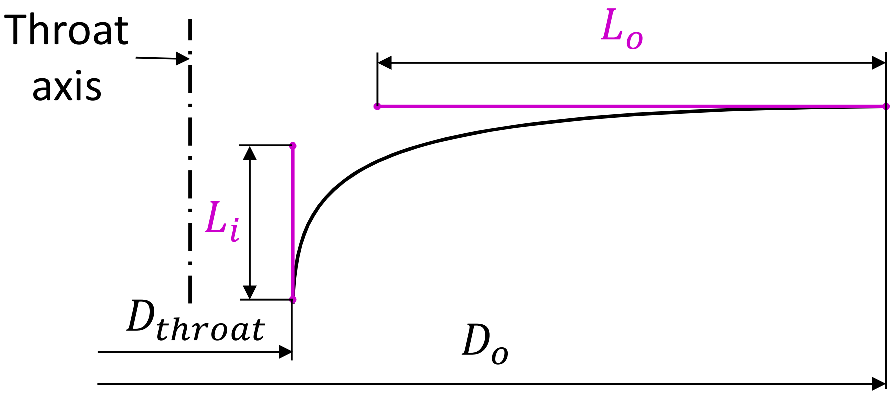


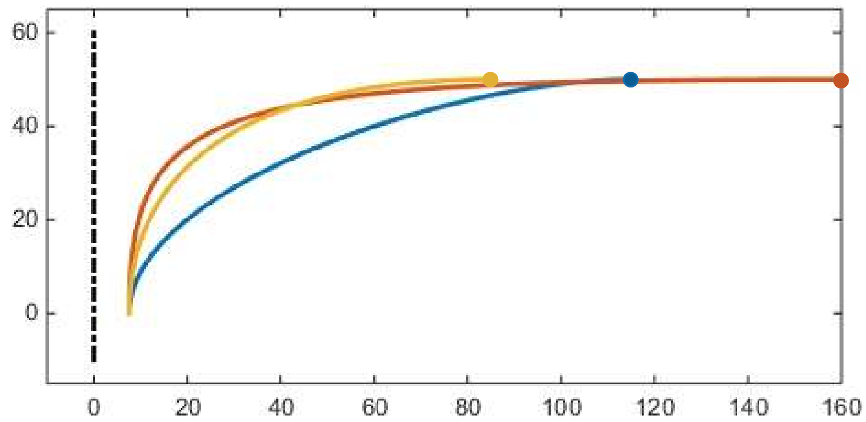
Optimizing a Waveguide
Parametrization

- 3 Bezier Cross Sections
- Waveguide depth (fixed)
- Inner Diameter (fixed)
- Outer Diameter (fixed, except 45°)
- Tangency to driver exit and baffle
- Strength of tangency given by L_i, L_o

1+(3x2)
=
7 Control Variables



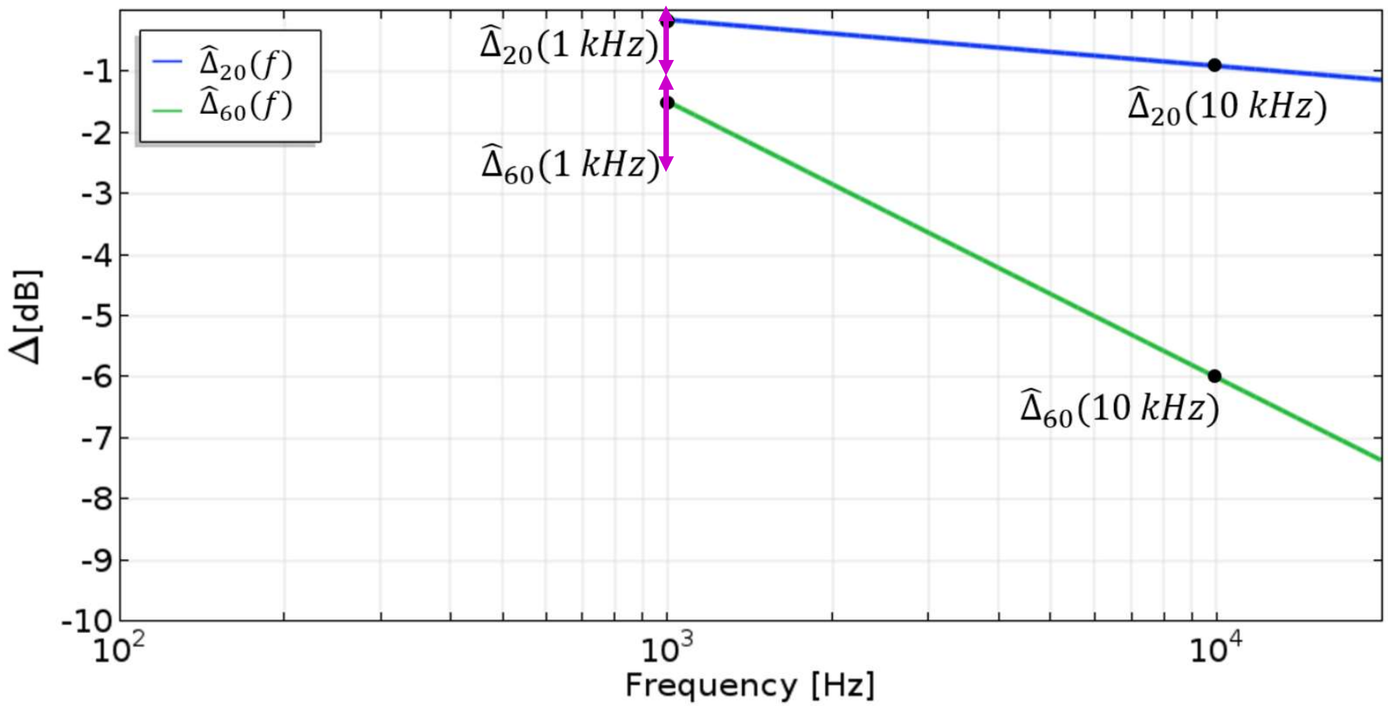




Optimizing a Waveguide
Target

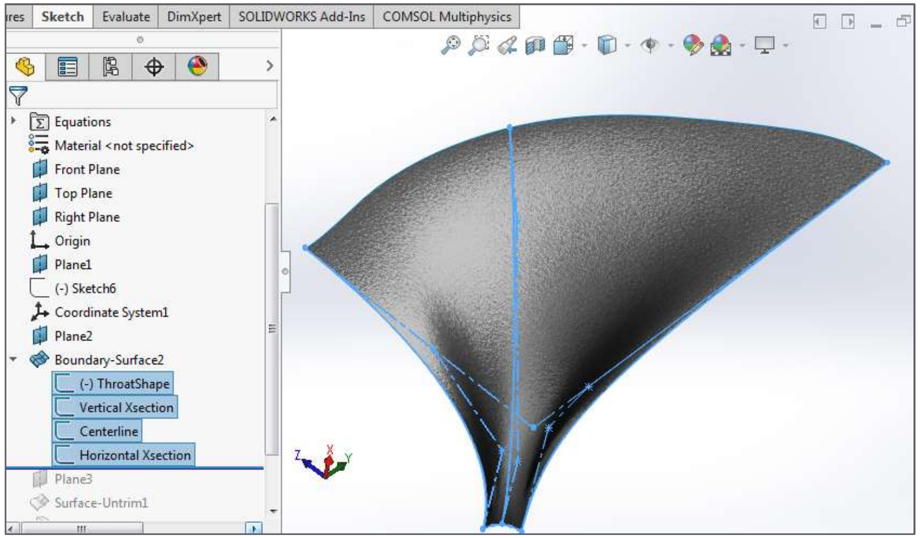
Straight Lines in Off-Axis Plot

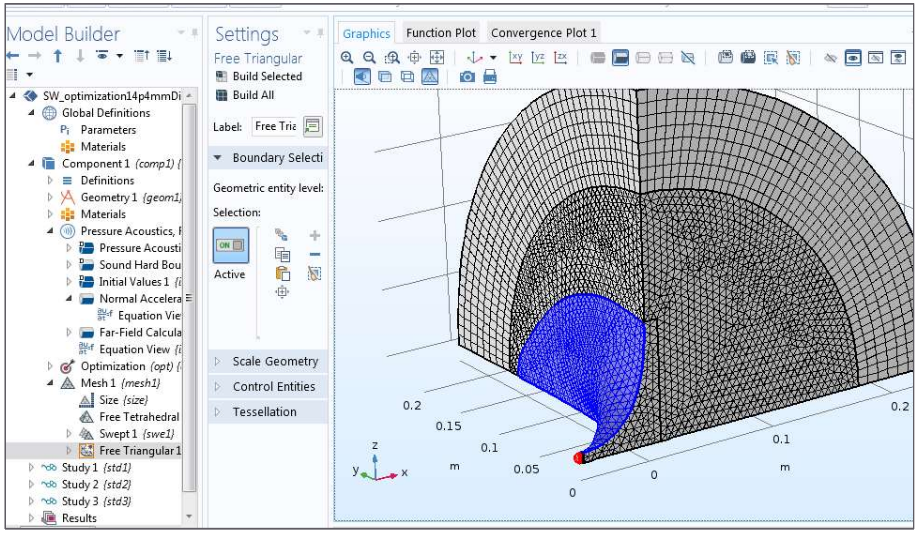
- Fixed 1 dB down at 20° and 10 kHz
- Fixed 6 dB down at 60° and 10 kHz
- Straight lines with variable values at 1 kHz
- 2 additional control variables



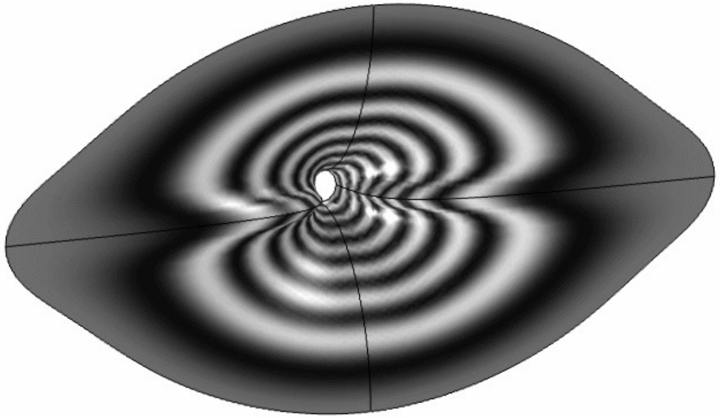
Optimizing a Waveguide
COMSOL® Implementation

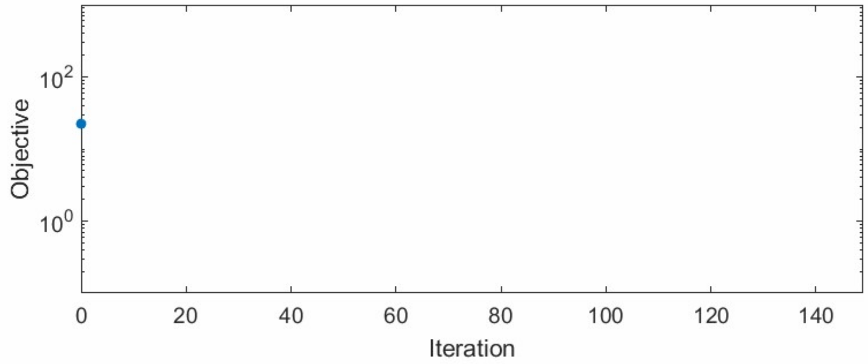
- LiveLink™ *for* SOLIDWORKS®
- Pressure Acoustics, Frequency Domain (acpr)
  - Semi-infinite domain (PML)
  - Speaker mounted to infinite wall (3 x symmetry)
  - Constant acceleration at throat
- Optimization
  - Parameter Optimization
  - Nelder-Mead
- Mesh
  - Free tetrahedral and swept mesh (in PML)
- Study
  - Frequency Domain, 3rd octave frequencies

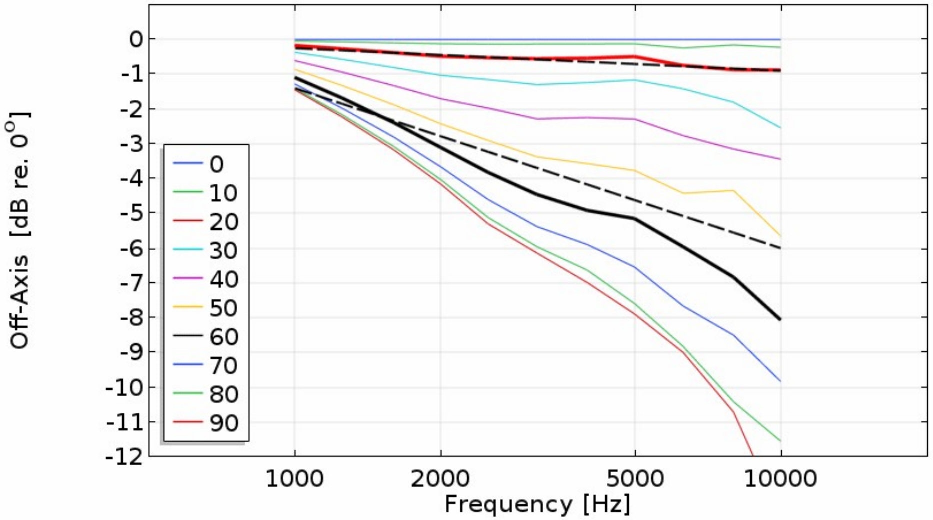




Optimizing a Waveguide
Optimization

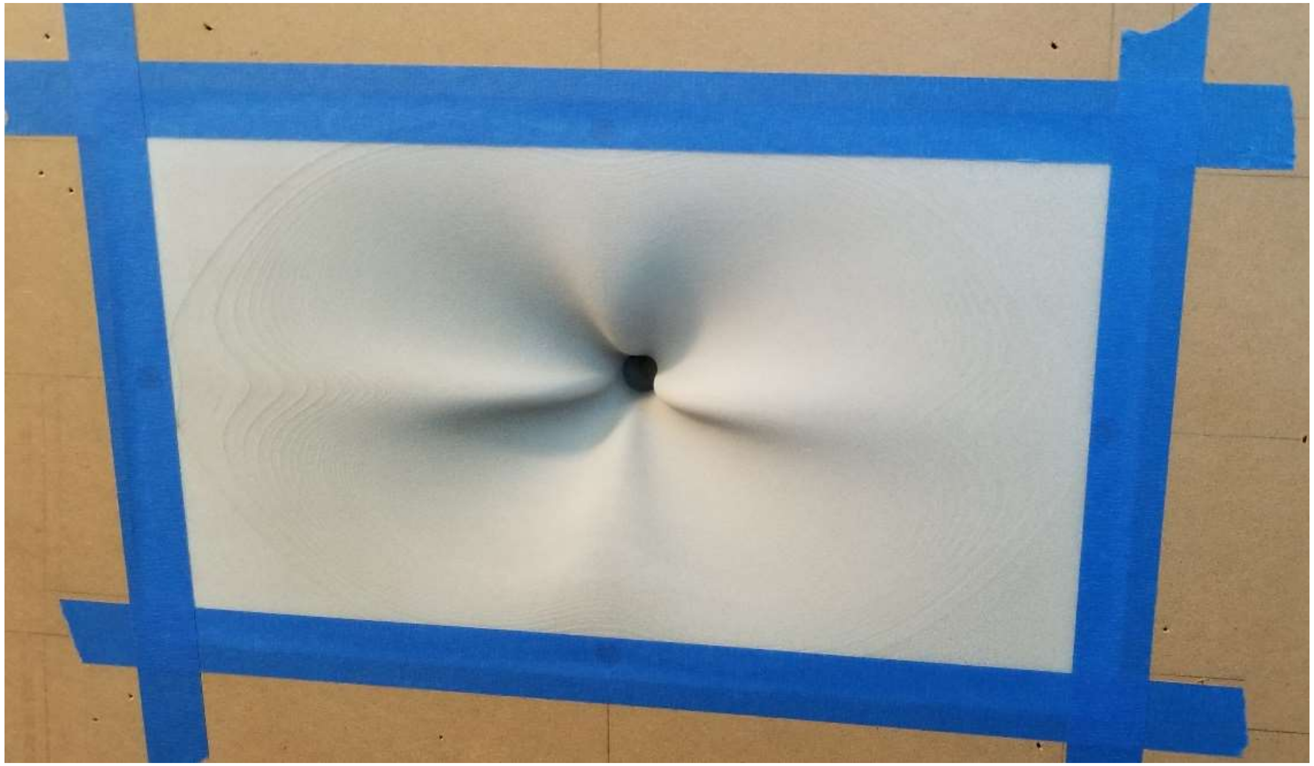






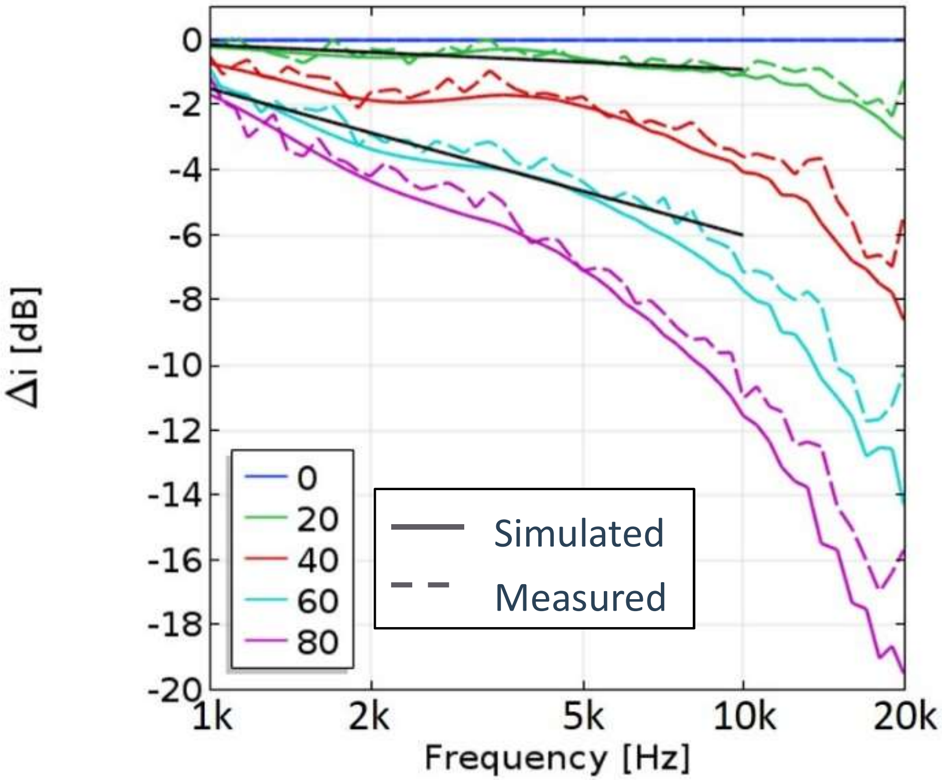
Optimizing a Waveguide
3D Printed Prototype

- Measured in 2π-configuration
- Mounted flush to wall of 2π anechoic chamber

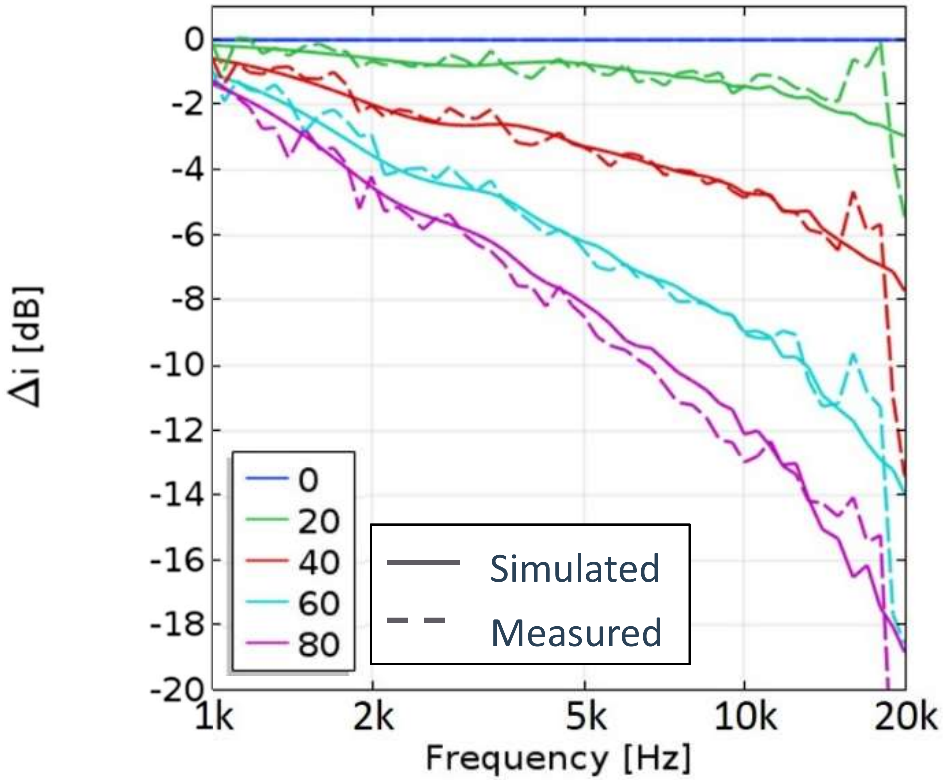


Optimizing a Waveguide
Off-Axis Results

Horizontal Off-Axis Response

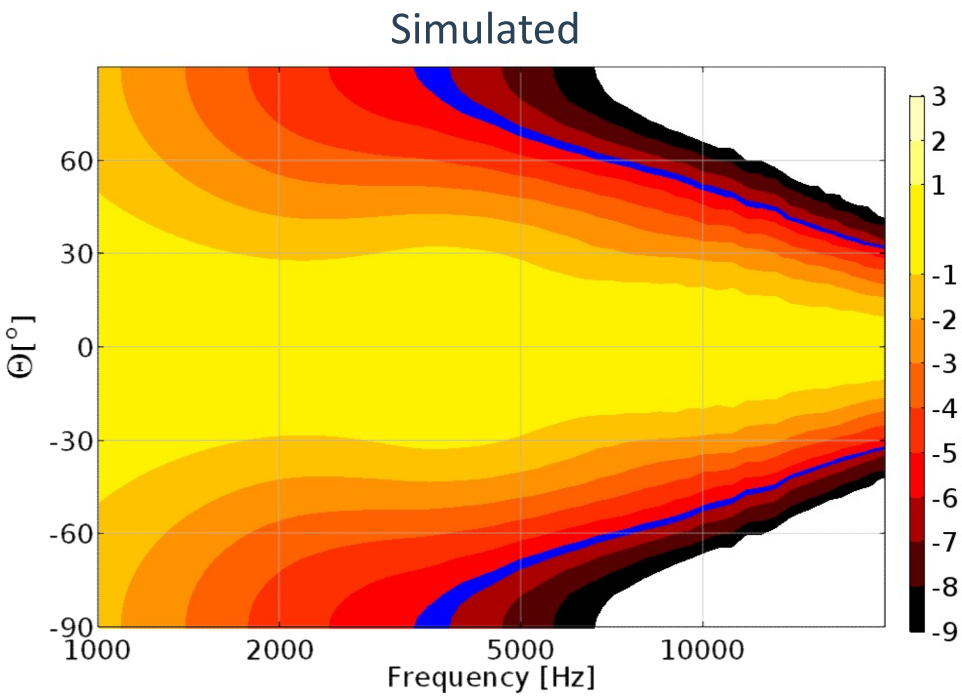


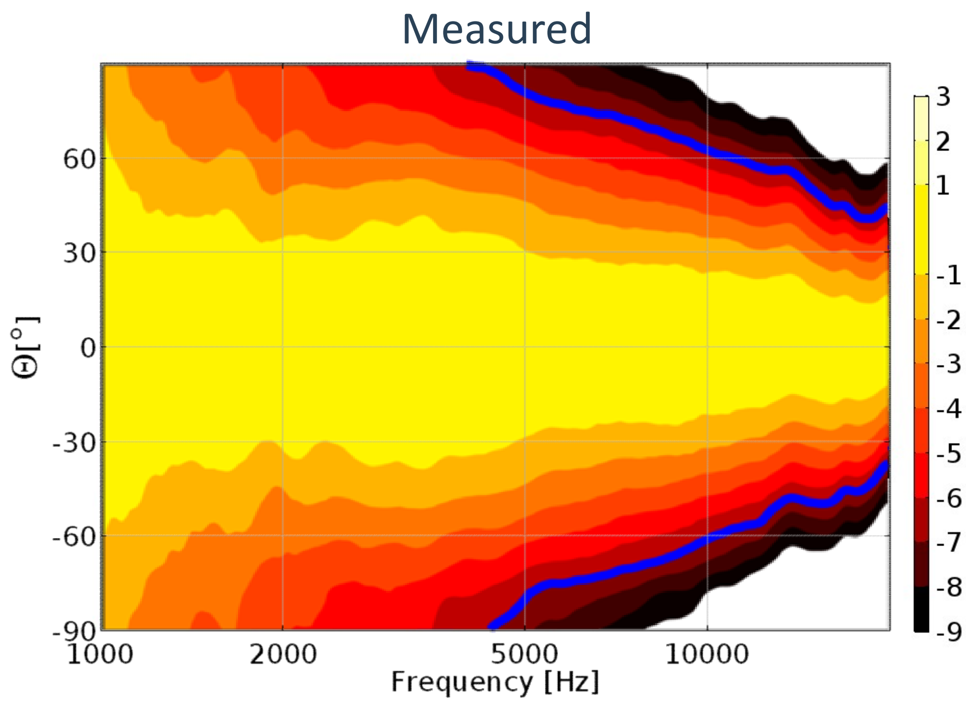
Vertical Off-Axis Response



Optimizing a Waveguide
Results

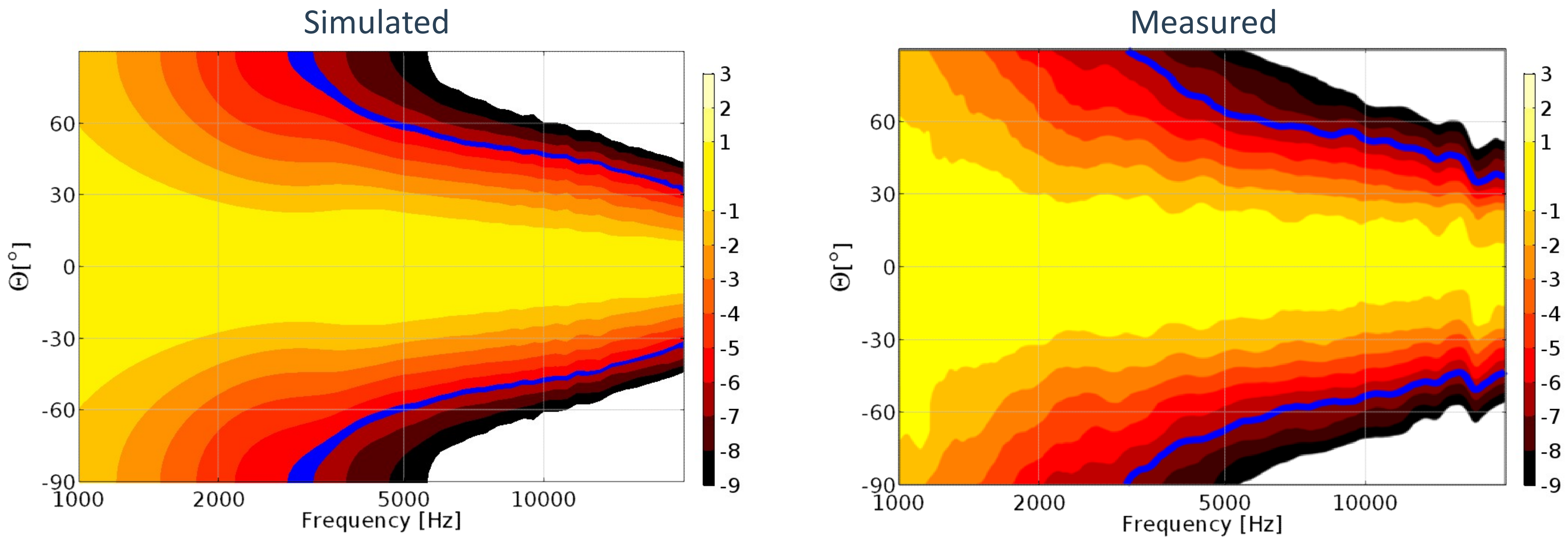
Directivity Plots: Horizontal Plane





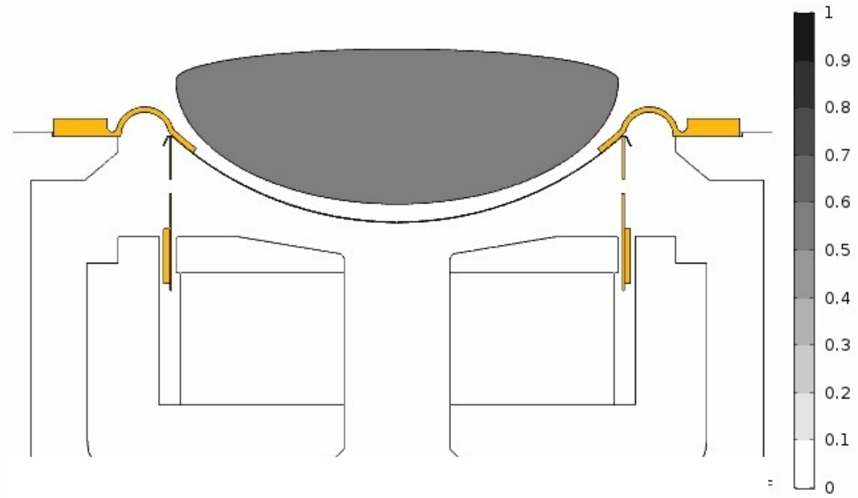
Optimizing a Waveguide
Results

Directivity Plots: Vertical Plane



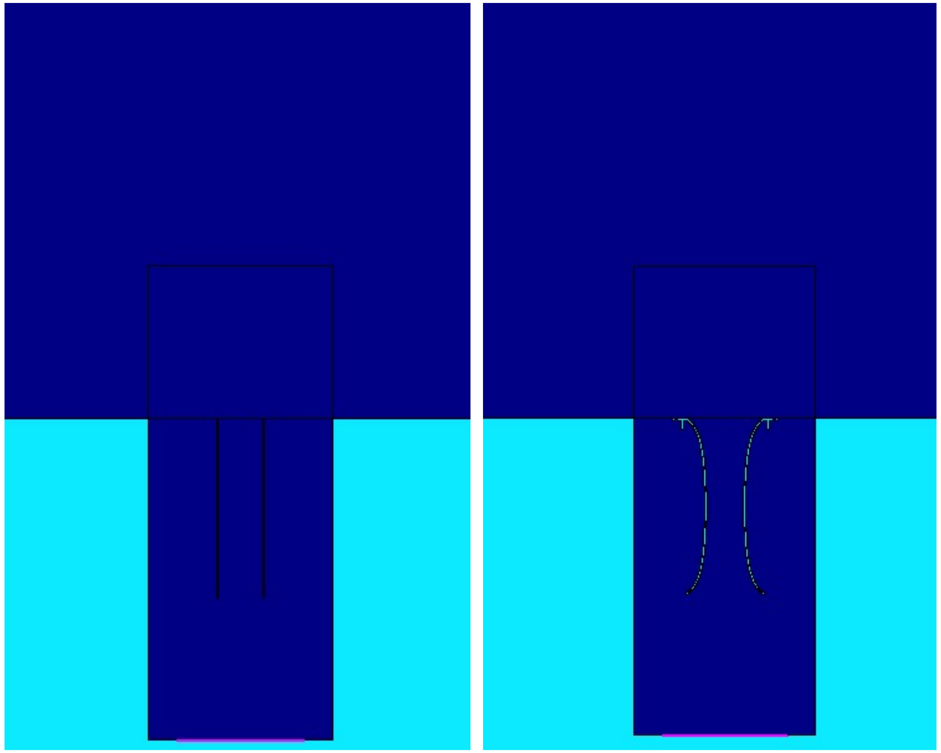
Other Fun Simulations

Topology Optimization for Acoustics



Bezzola, A., "Numerical Optimization Strategies for Acoustic Elements in Loudspeaker Design," in *145th Audio Eng. Soc. Int. Conv. 2018*, p.10046, New York City, 2018

Fluid-Structure & Fluid-Acoustic Interaction



Straight Port Flared Port

Conclusion & Outlook

- Loudspeakers are inherently multiphysics
- Simulations with COMSOL® are integral to product development at Samsung Audio Lab
- Simulation Apps accelerate product development
- Optimization reduces development time
- Simulations need empirical backup, simulation engineers need a team!
- Do not hesitate to consult COMSOL support

SAMSUNG

Thank you!

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www.linkedin.com/in/andribezzola

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