

Audio Product Development at Samsung Audio Lab

Better and Faster With Simulations

Andri Bezzola, PhD

COMSOL Conference | 2018-10-23 | Lausanne, Switzerland | 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



$\frac{1}{5}$

OF ENTIRE
WORKFORCE

40.7 M DAILY
INVESTMENT (USD)

14.9 B TOTAL
INVESTMENT (USD)

73

Countries

15

Regional Offices

39

Production Sites

35

R&D Centers

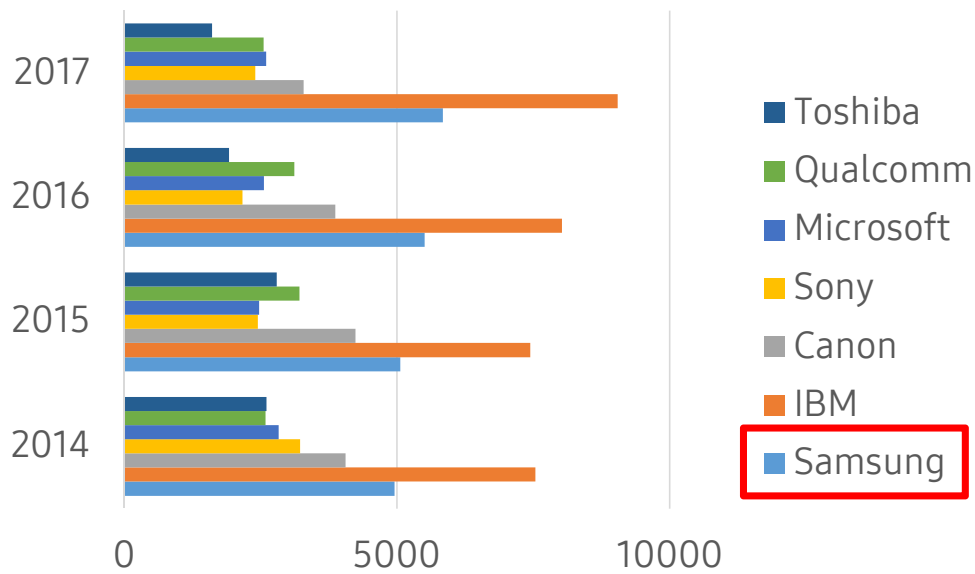
7

Design Offices

Issued Patents

US

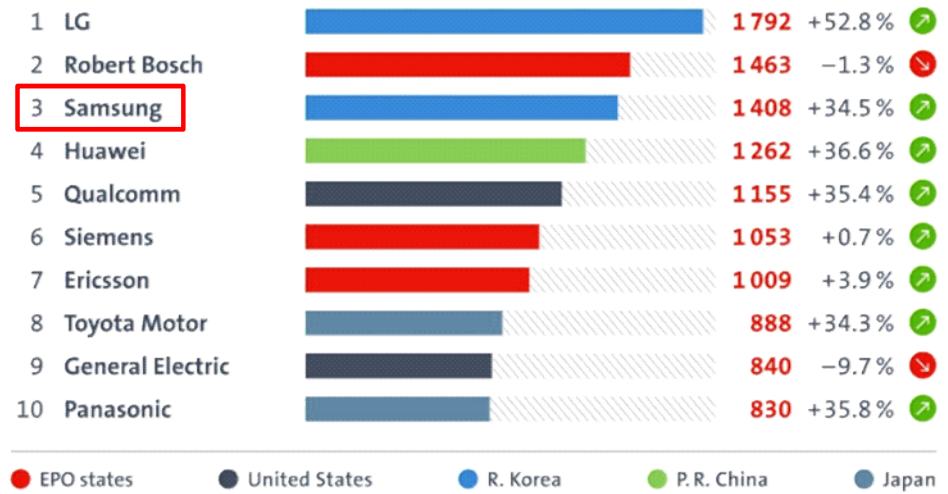
Issued US Utility Patents By Year



Europe

Top 10 Patentees in 2017

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



Samsung Audio Lab

Valencia, CA

2013 First Hire

1700 Lab Area in m²

2 Anechoic Chambers

3 Listening Rooms

2 Transducer Test Rooms



AUDYSSEY



SONOS



Roland



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



R7



R6 Portable



R5



R3



R1

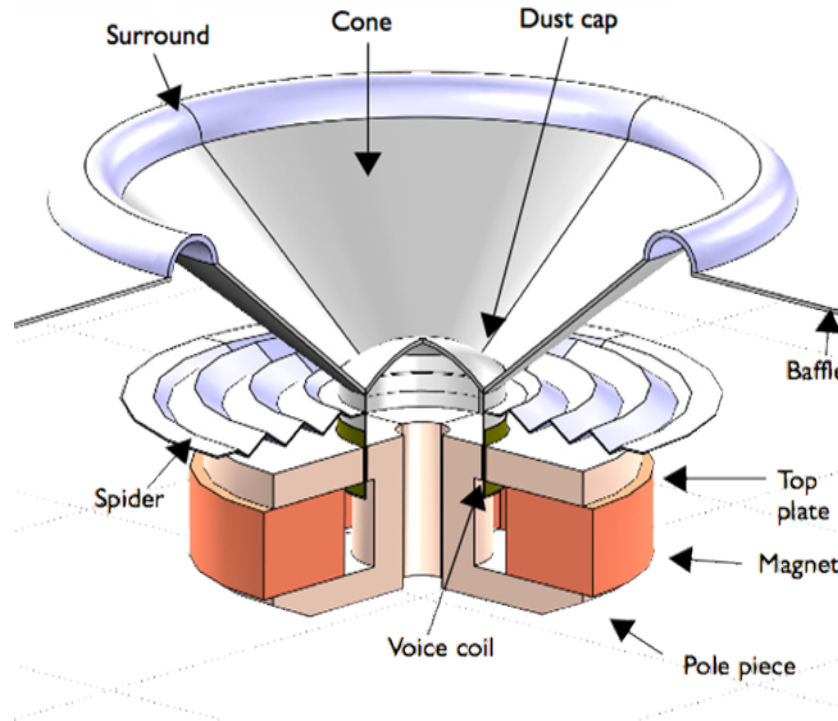
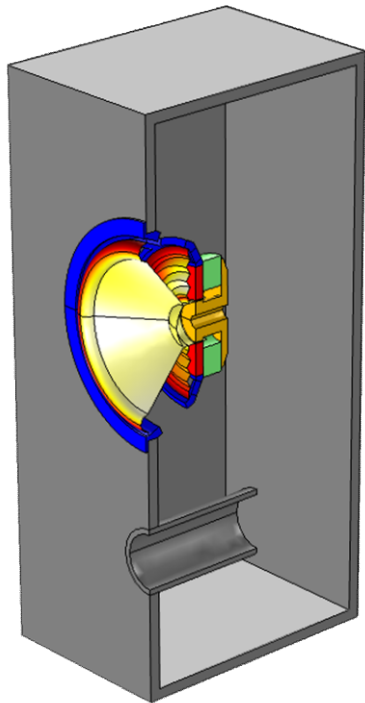
Samsung Audio Lab Products

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

- $f = 20 \text{ Hz to } 20 \text{ kHz}$
- $\lambda = 17 \text{ m to } 17 \text{ mm}$
- Infinite domains and far-field measurements
- Losses in narrow regions

Heat Transfer

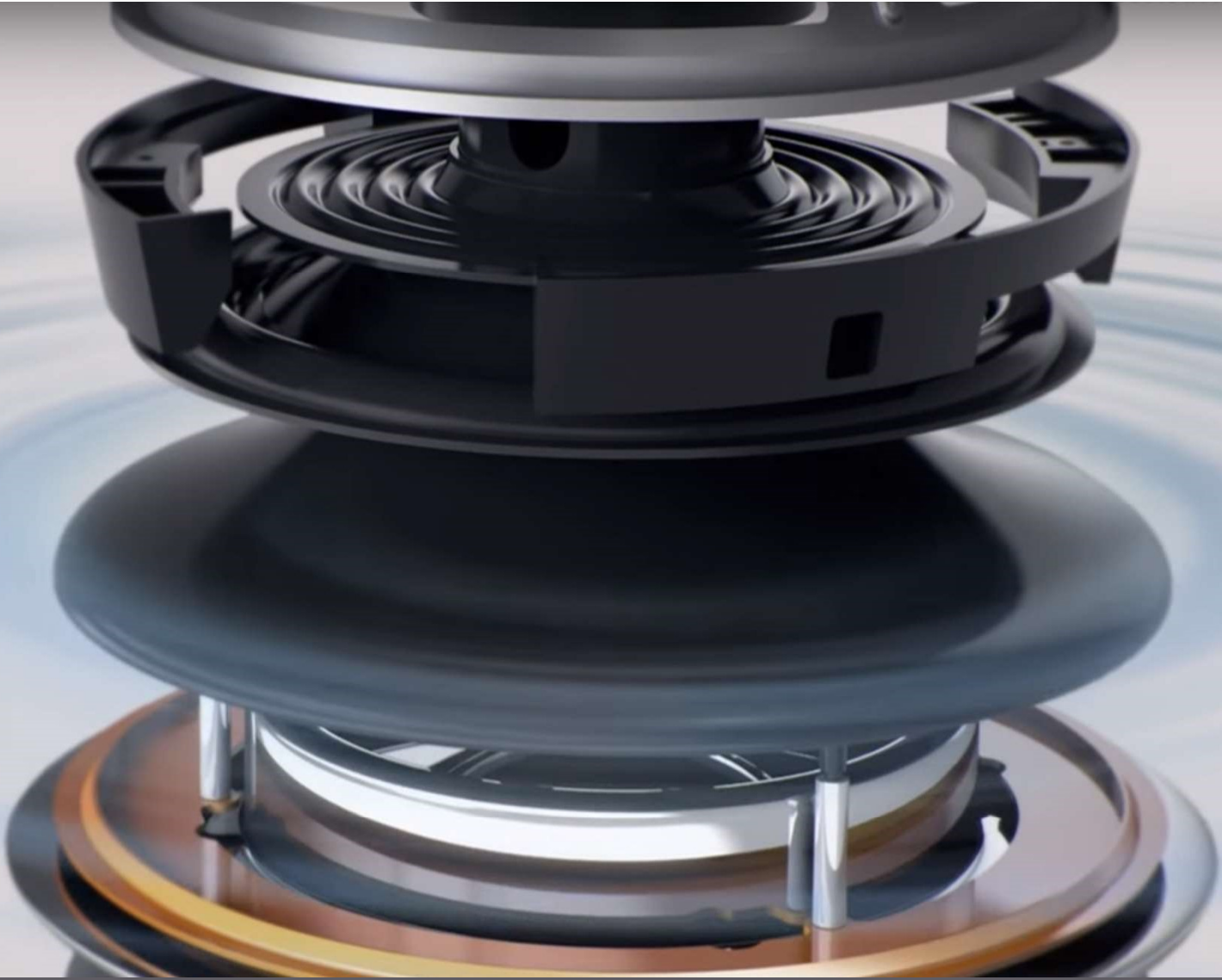
- Temperature from -20°C to 200°C

Fluid Dynamics

- Turbulent bidirectional air flow through ports and vents

Nonlinear Distortion

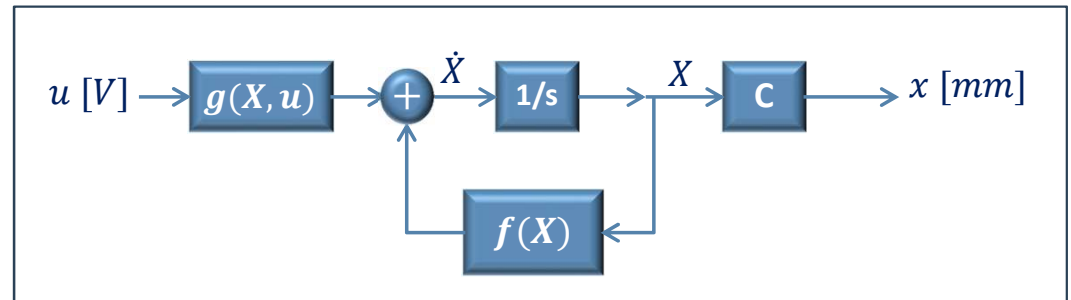
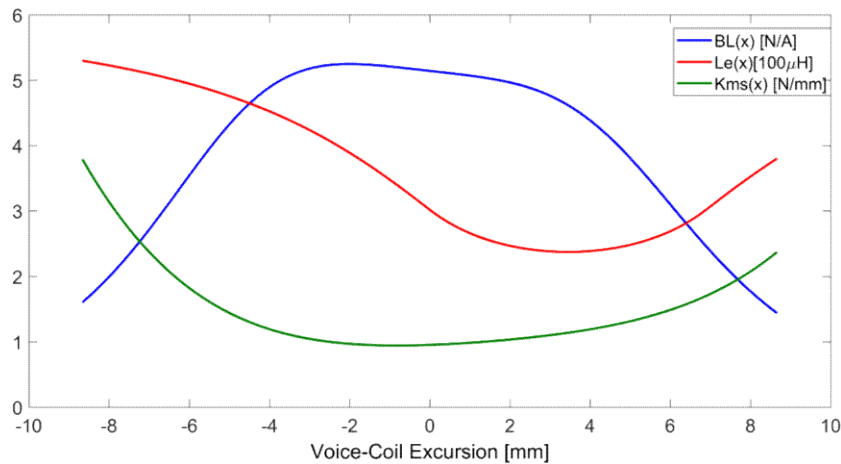
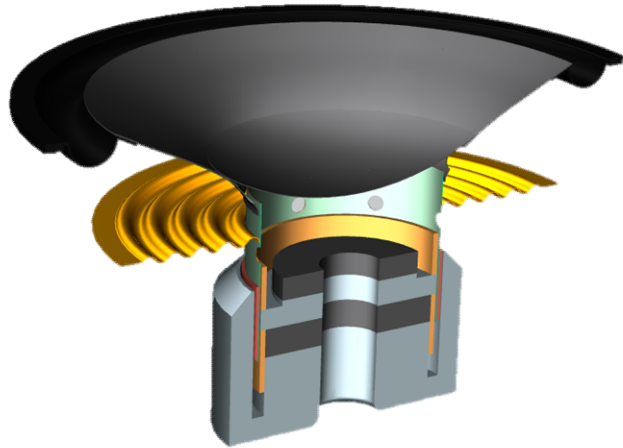
Sounds Bad



	Linear Woofer	Non-Linear Woofer
Track 1		
Track 2		

Nonlinear Distortion

Anti-Distortion



$$X = [x, \dot{x}, i]^T$$

$$\dot{X} = g(X, u) + f(X)$$

$$x = C X$$

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

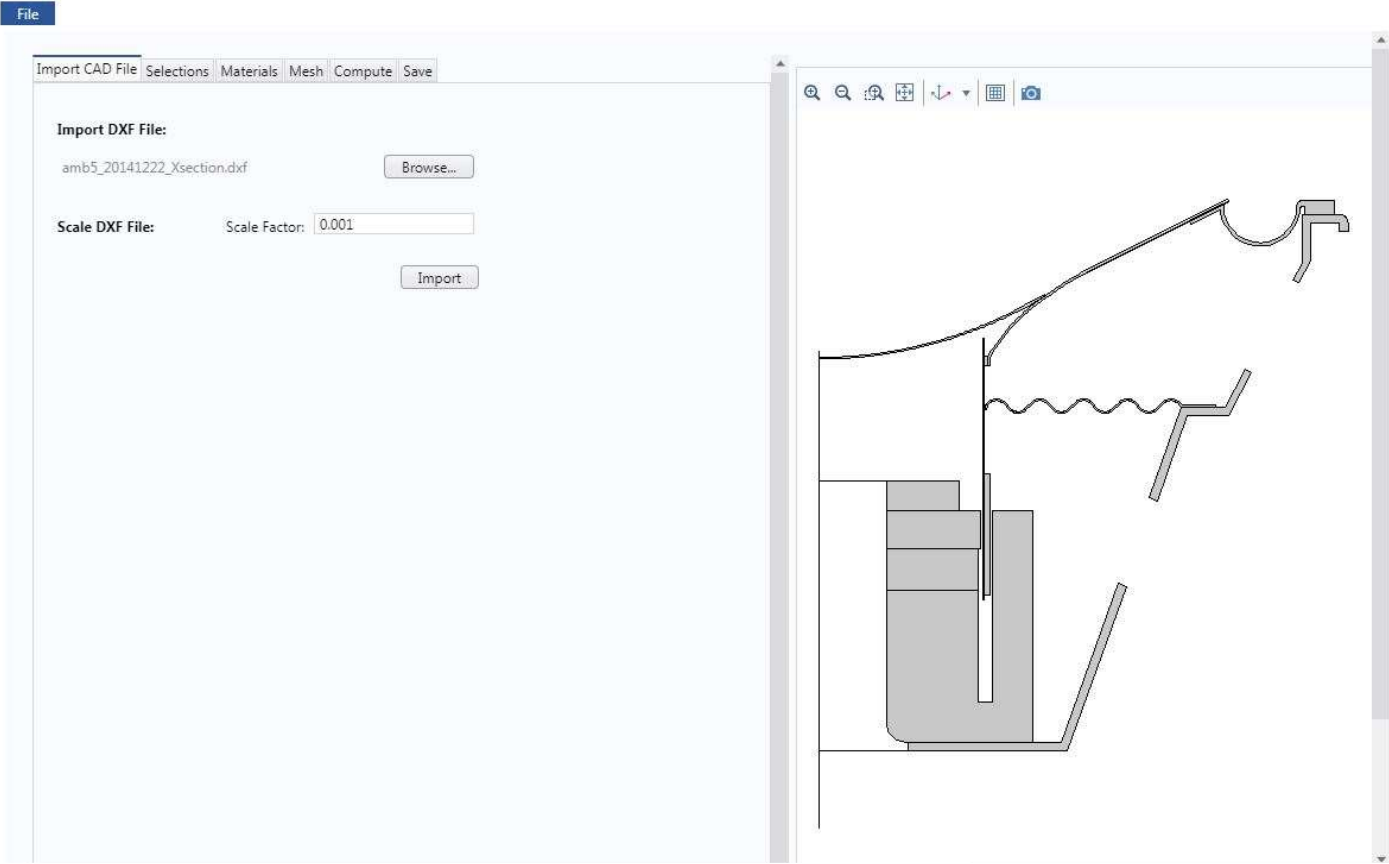
$$C = [1, 0, 0]$$

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

	Linear Woofers	Non-Linear Woofers	Corrected
Track 1			
Track 2			

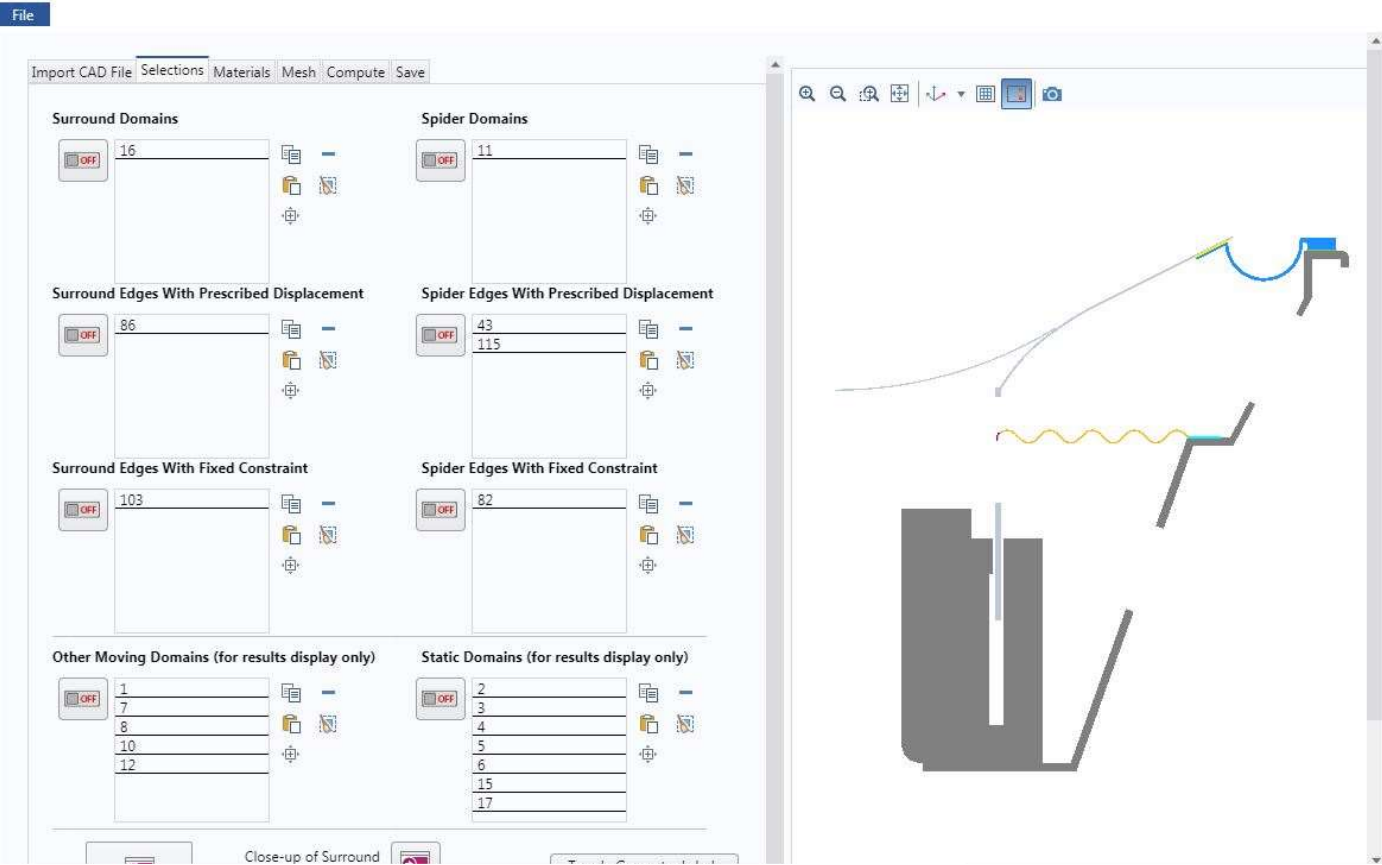
COMSOL Apps for Calculation of $K_{ms}(x)$

Geometry Import



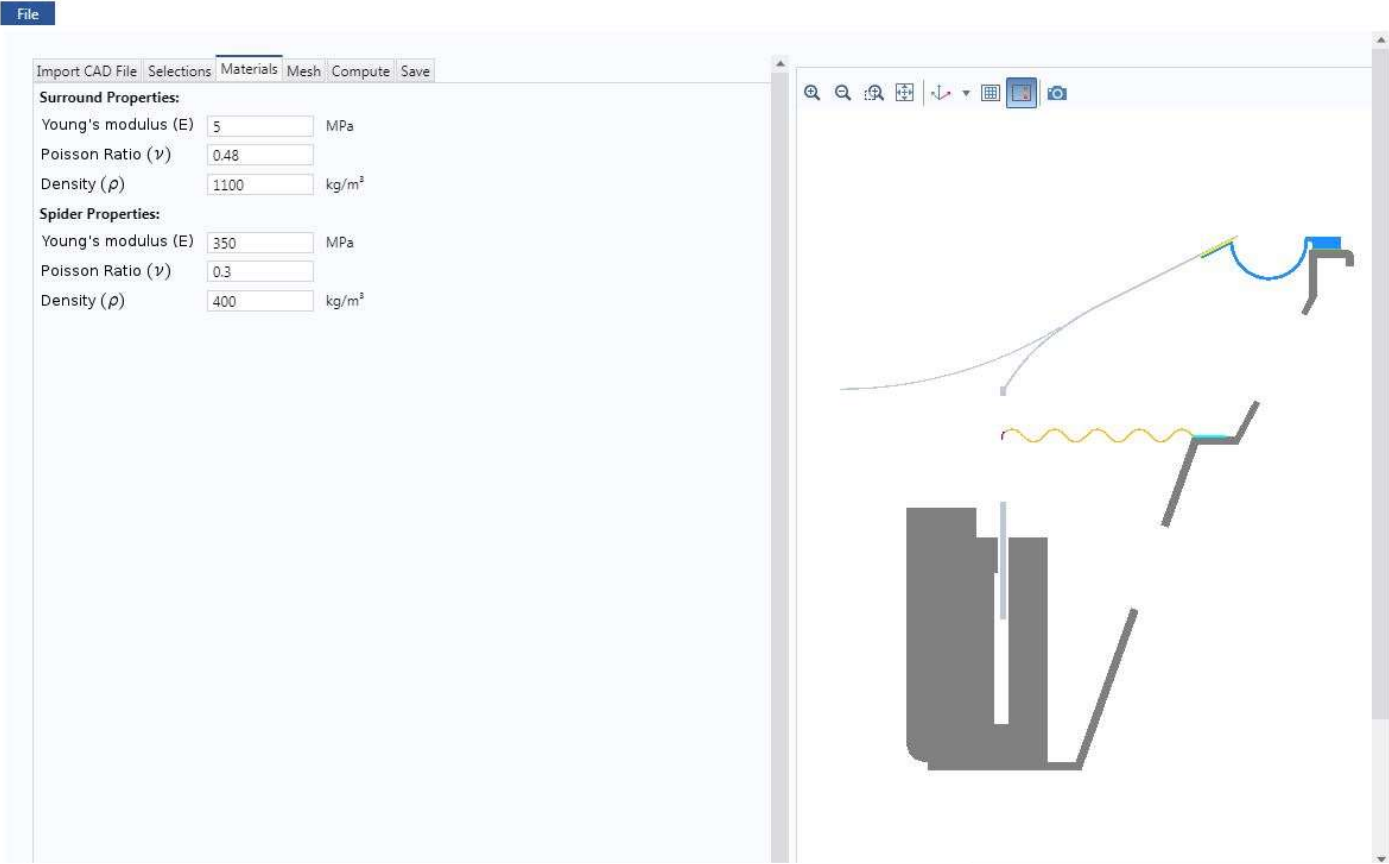
COMSOL Apps for Calculation of $K_{ms}(x)$

Selection Definition



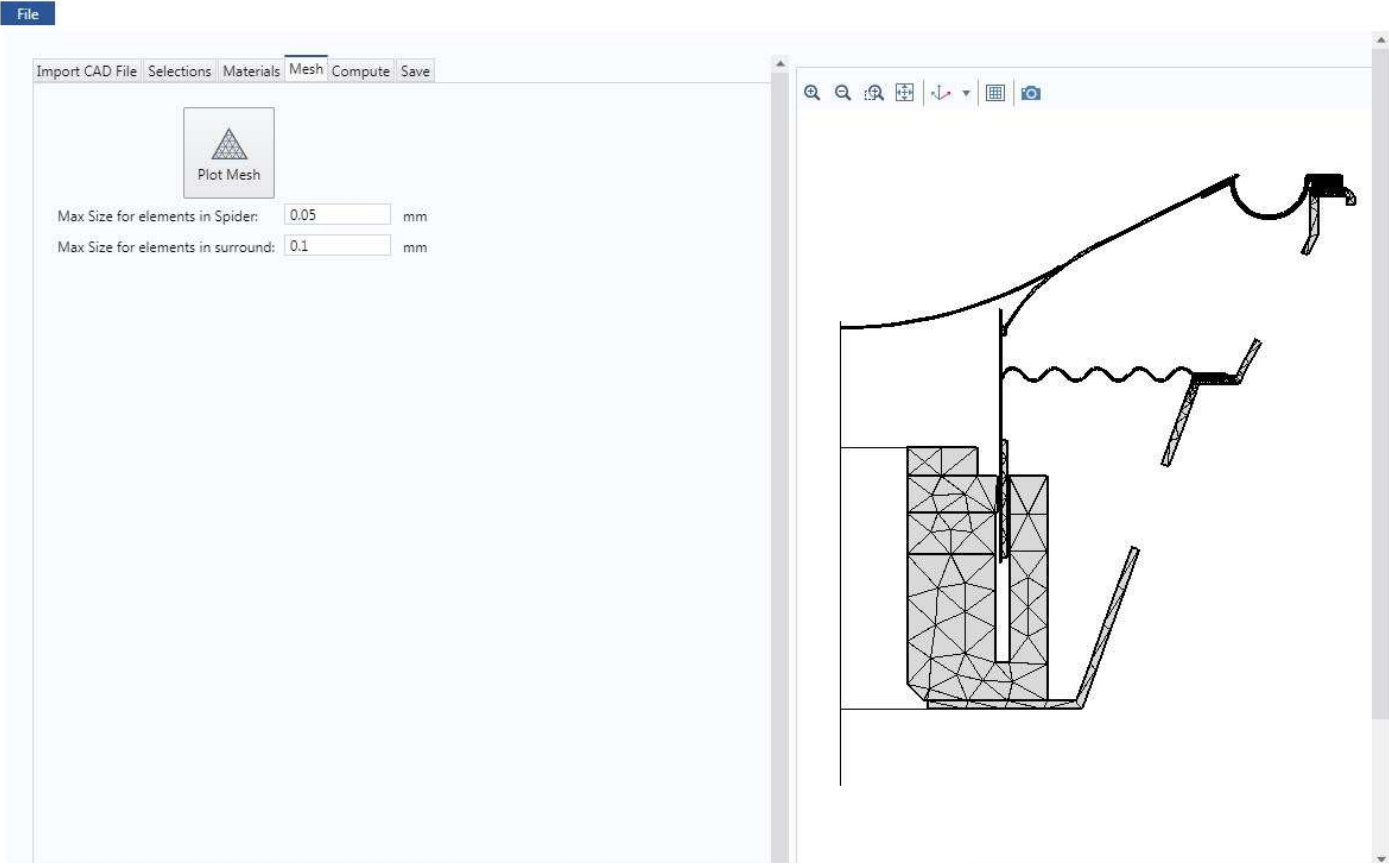
COMSOL Apps for Calculation of $K_{ms}(x)$

Material Definition



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

Mesh Setup



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

Solve

The screenshot displays the COMSOL software interface. On the left, the 'Compute' tab is active, showing the following parameters:

- Final Excursion: 8 mm
- Excursion Step: 0.5 mm
- Max Iterations: 25

Two 'Compute' buttons are visible: 'Compute Outstroke' and 'Compute Instroke'. Below these are 'Plot Outstroke' and 'Plot Instroke' buttons, each with a 'Plot at displacement' dropdown menu. The 'Plot Outstroke' dropdown is set to 0.001 mm, and the 'Plot Instroke' dropdown is set to -8 mm. At the bottom of the left panel are 'Plot $K_{ms}(x)$ ' and 'Plot Force-Deflection' buttons.

In the center, a log window displays the following data:

Continuation parameter DispZ = 0.007.

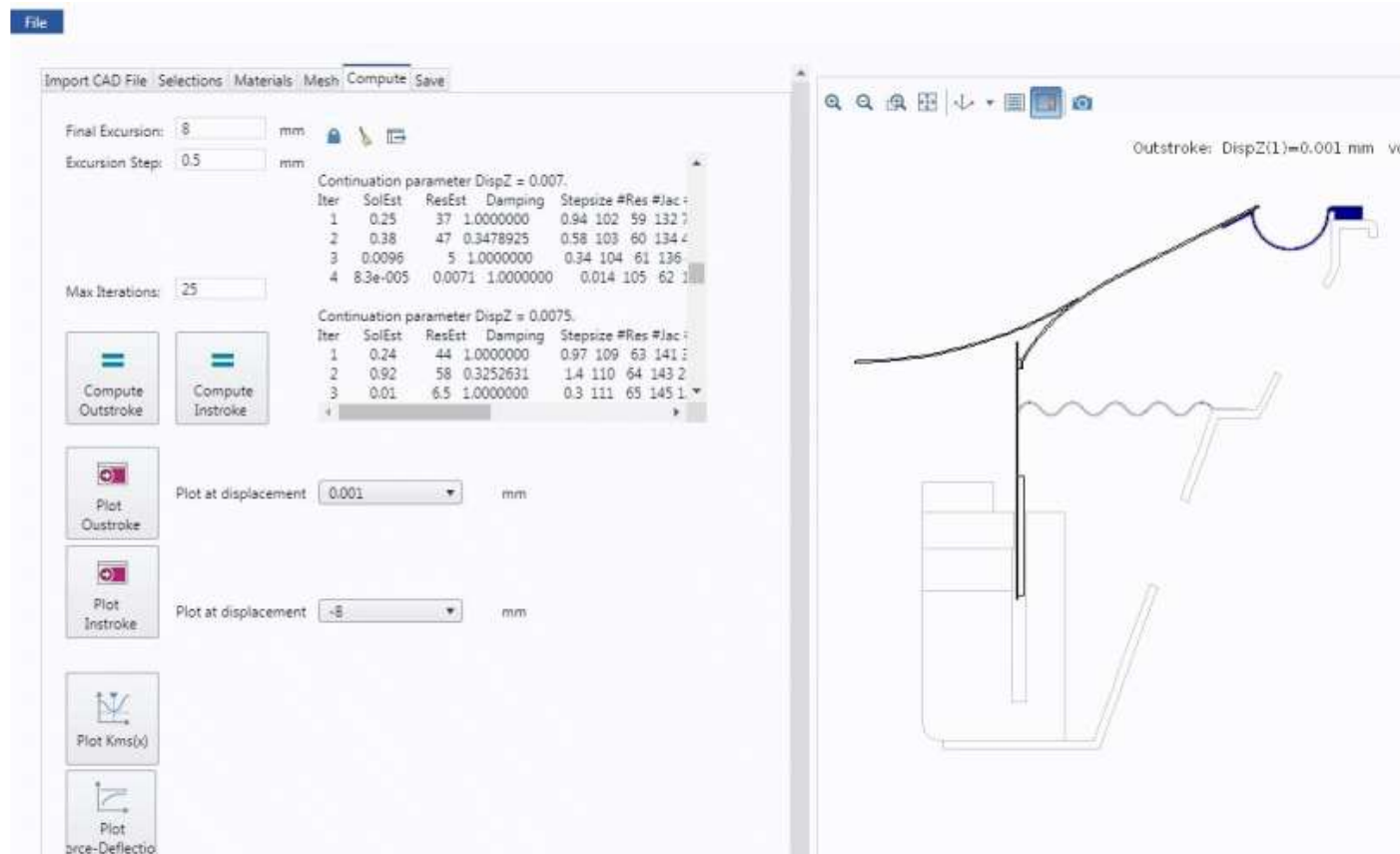
Iter	SolEst	ResEst	Damping	Stepsize	#Res	#Jac
1	0.25	37	1.0000000	0.94	102	59
2	0.38	47	0.3478925	0.58	103	60
3	0.0096	5	1.0000000	0.34	104	61
4	8.3e-005	0.0071	1.0000000	0.014	105	62

Continuation parameter DispZ = 0.0075.

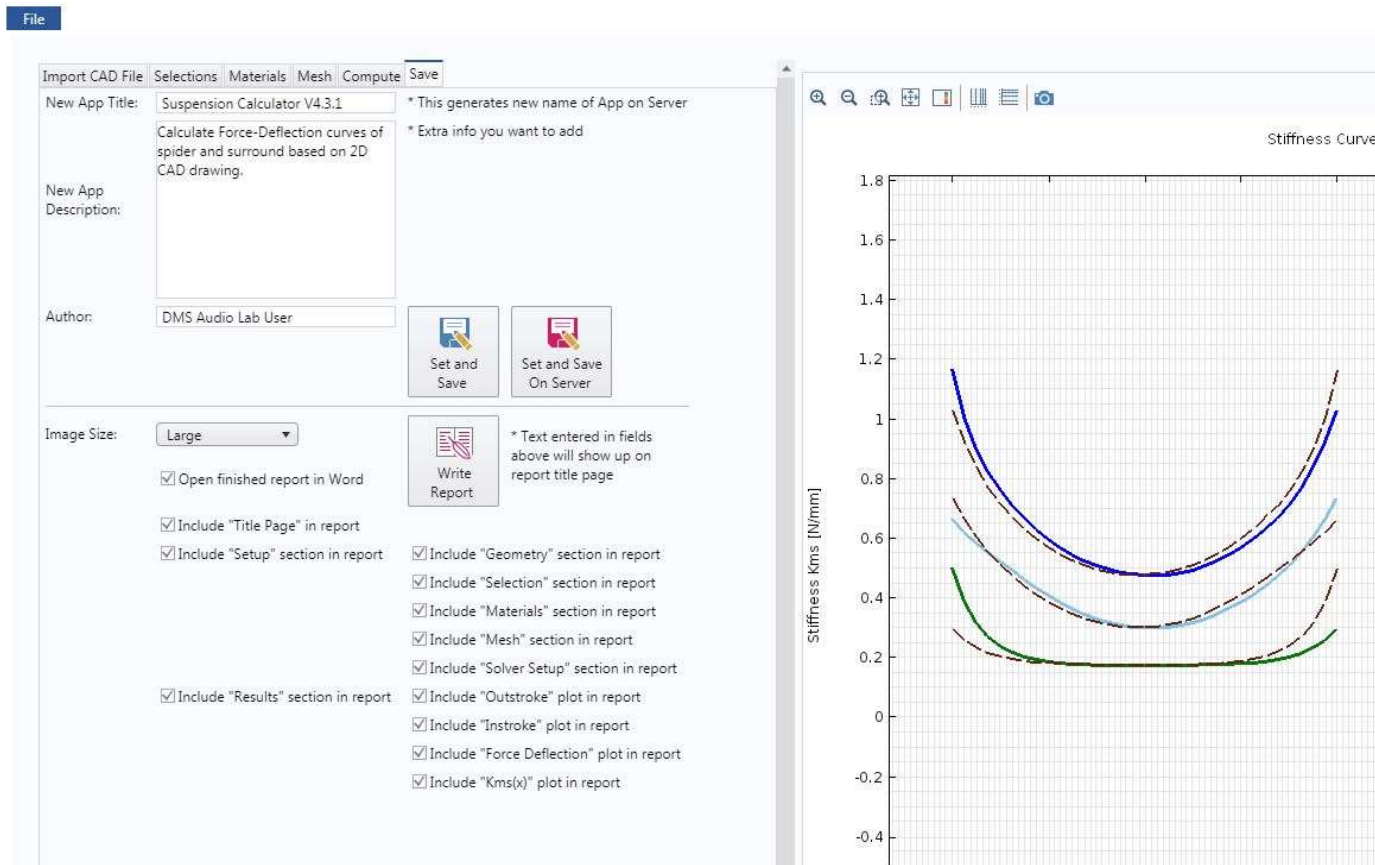
Iter	SolEst	ResEst	Damping	Stepsize	#Res	#Jac
1	0.24	44	1.0000000	0.97	109	63
2	0.92	58	0.3252631	1.4	110	64
3	0.01	6.5	1.0000000	0.3	111	65

On the right, a 3D model of a mechanical part is shown. The top surface is highlighted in blue. The text 'Outstroke: DispZ(1)=0.001 mm' is visible in the top right corner of the model window.

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



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

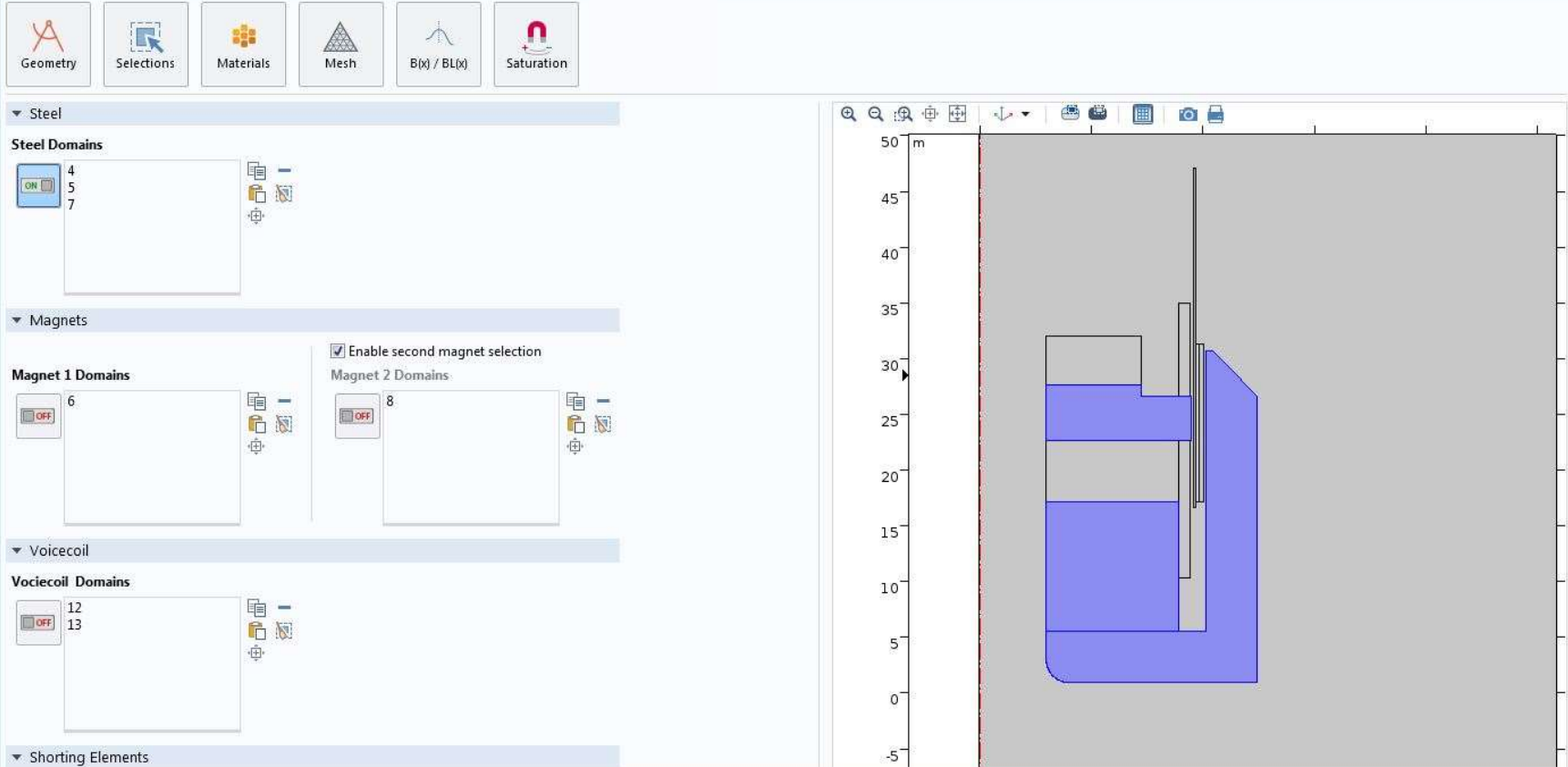


COMSOL Apps for Calculation of BL(x) Geometry Import

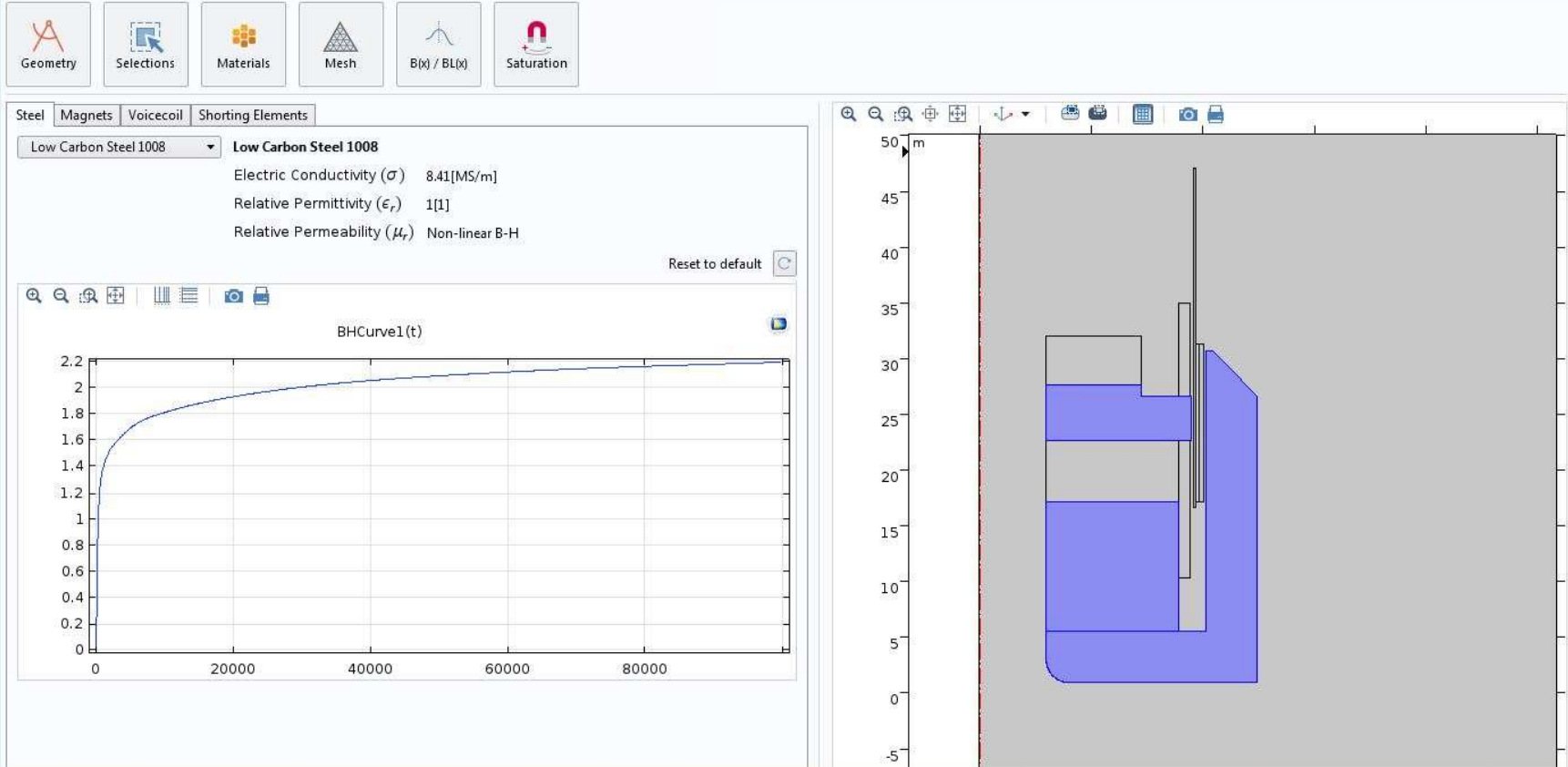
The screenshot displays the COMSOL software interface. At the top, there is a toolbar with icons for Geometry, Selections, Materials, Mesh, B(x) / BL(x), and Saturation. Below this is the 'Import DXF File' dialog box. It includes a 'Browse...' button, a 'Units of DXF File' dropdown set to 'm', and a 'Scale Factor DXF File' set to '1'. The 'Select Voicecoil' section shows a list with items 12 and 13, and a 'Max Excursion' input field set to '5 mm'. A note states: 'Note: At least one domain must be selected for the voicecoil before geometry can be finalized.' Below the note are 'Finalize Import' and 'Update Air Geometry' buttons. At the bottom of the dialog, there are fields for 'Radius of Air' (78.73349684219544 m), 'Max R-coordinate' (24.95 m), 'Max Z-coordinate' (47.18 m), and 'Min Z-coordinate' (1 m). To the right of the dialog is a 2D plot showing a complex, multi-layered geometry on a gray background. The vertical axis is labeled 'm' and ranges from -5 to 50.

COMSOL Apps for Calculation of BL(x)

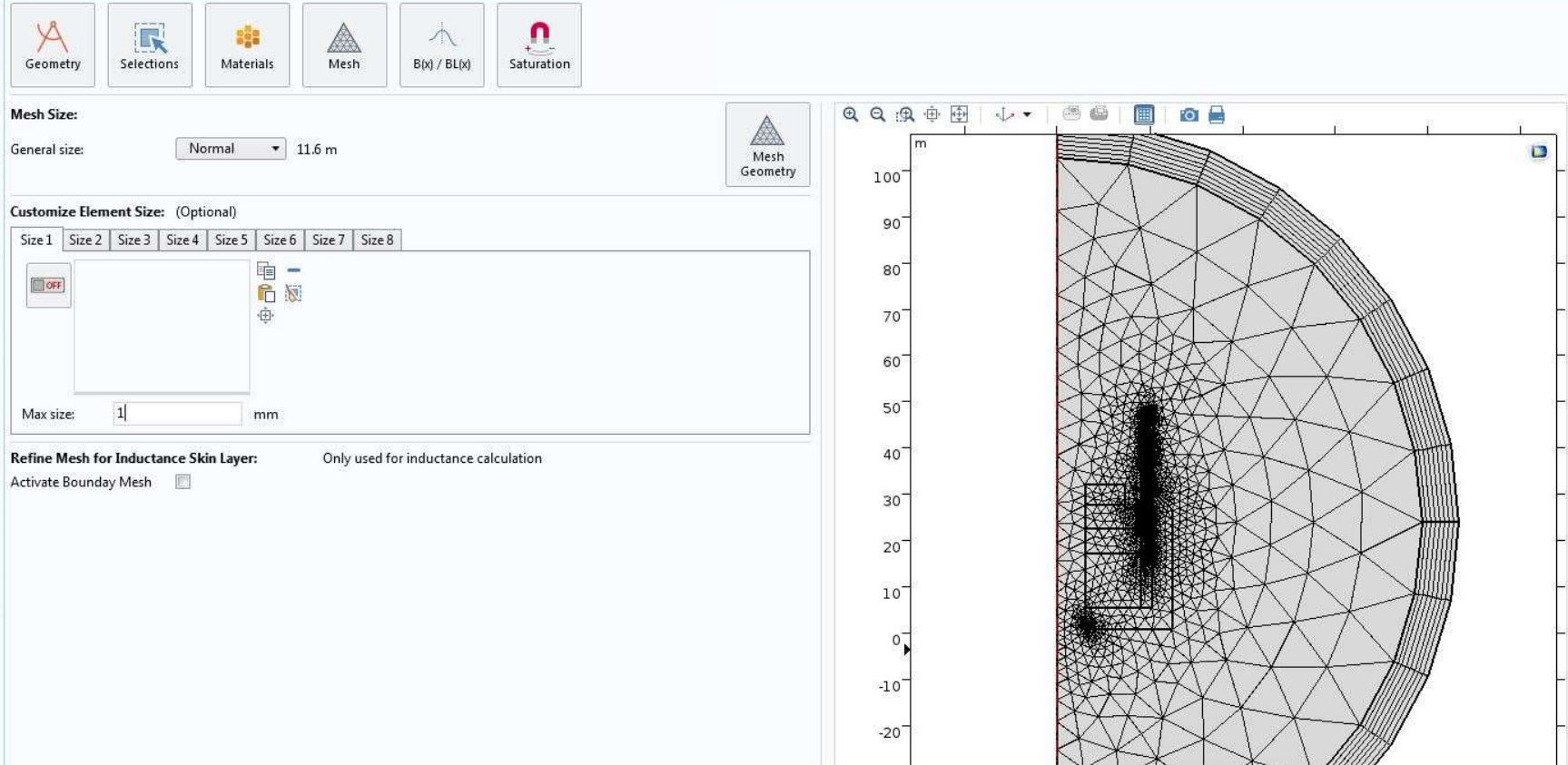
Selection Definition



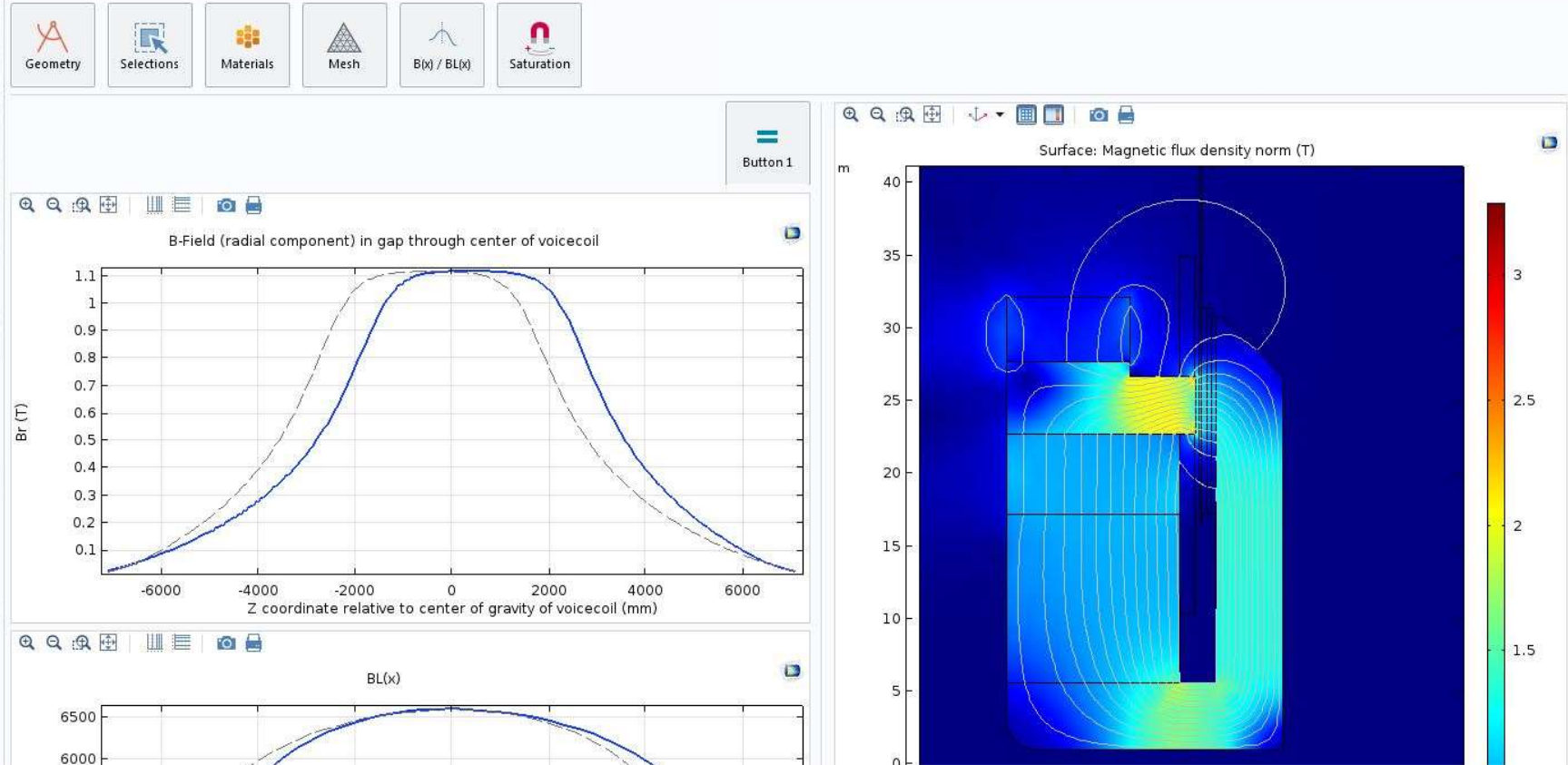
COMSOL Apps for Calculation of BL(x) Material Choice



COMSOL Apps for Calculation of BL(x) Mesh

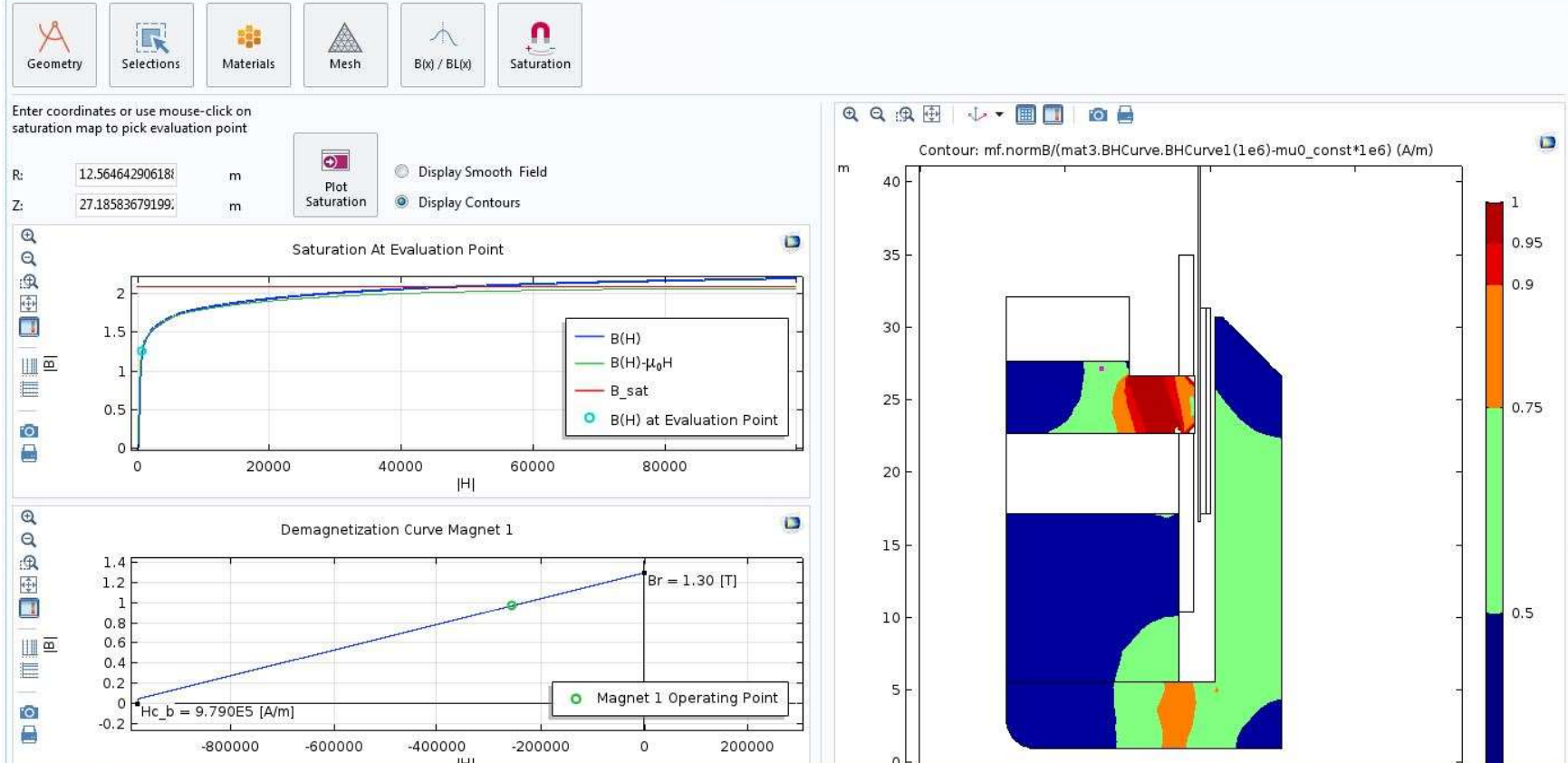


COMSOL Apps for Calculation of BL(x) B-Field and BL Curve



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

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

- Magnetic Flux

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

- Ampère's Law

$$\nabla \times \mathbf{B} = \mu_0 \mathbf{J}$$

- 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

\mathbf{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

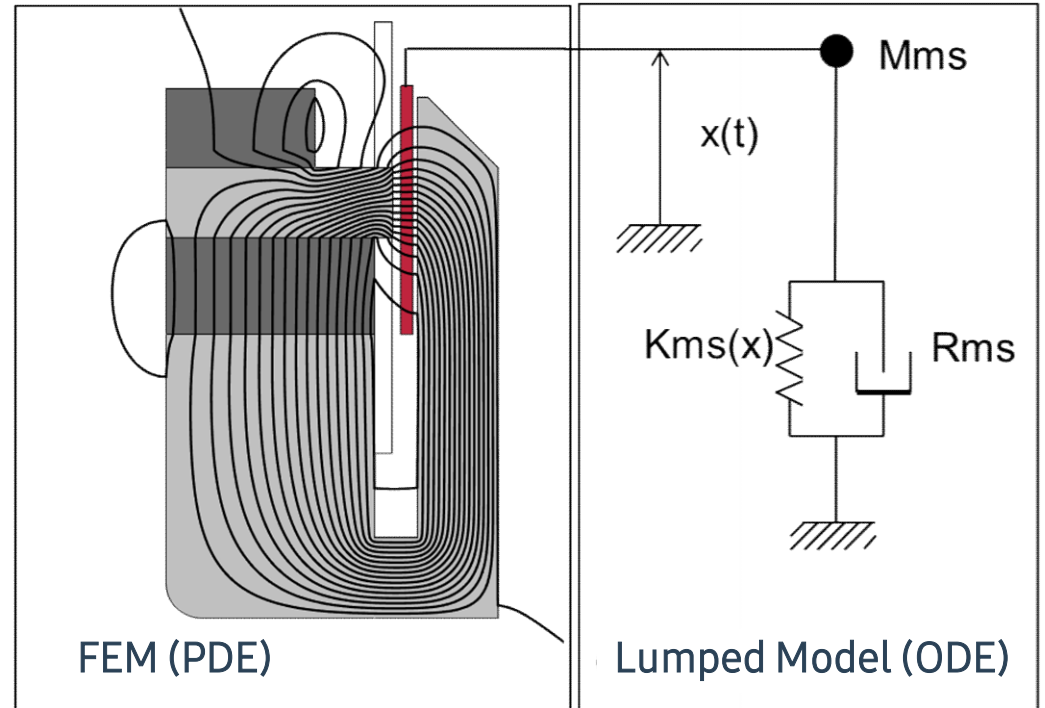
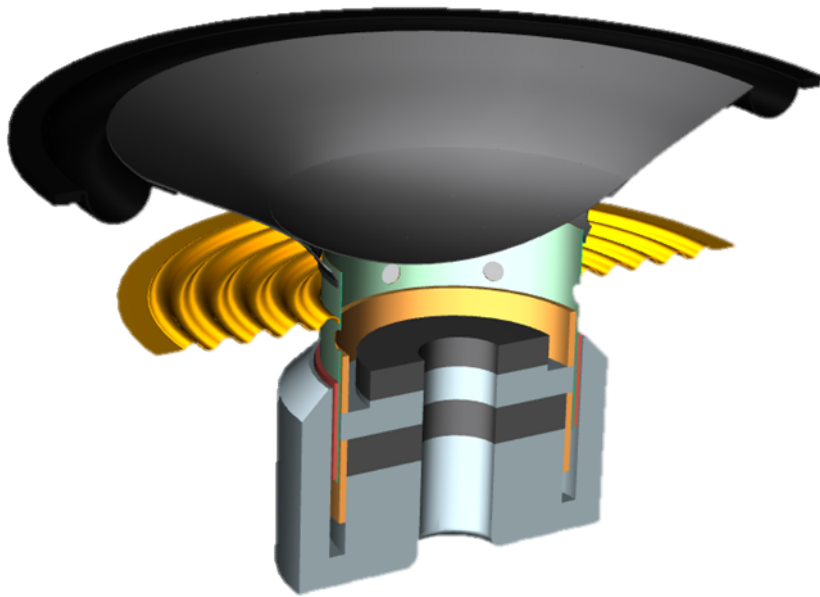
V_0 : Applied voltage from amplifier

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

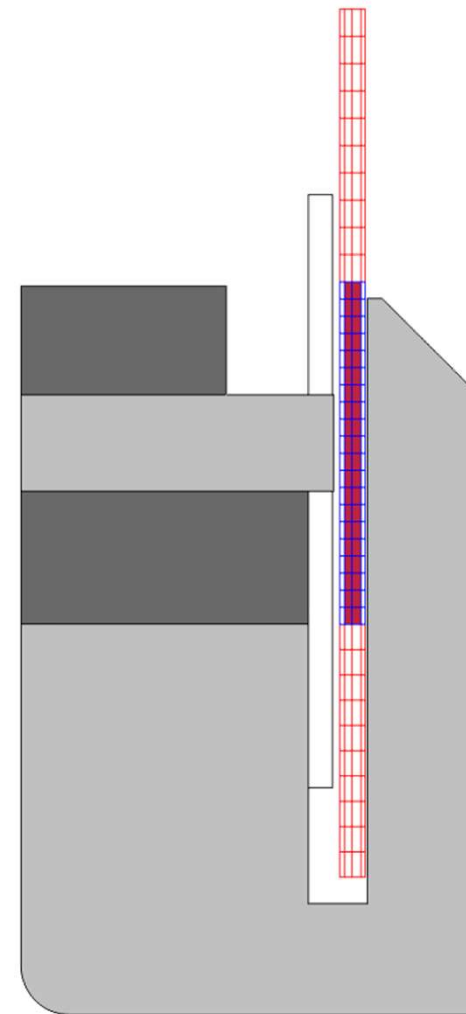
Laplace smoothing ensures even distribution

Static Mesh

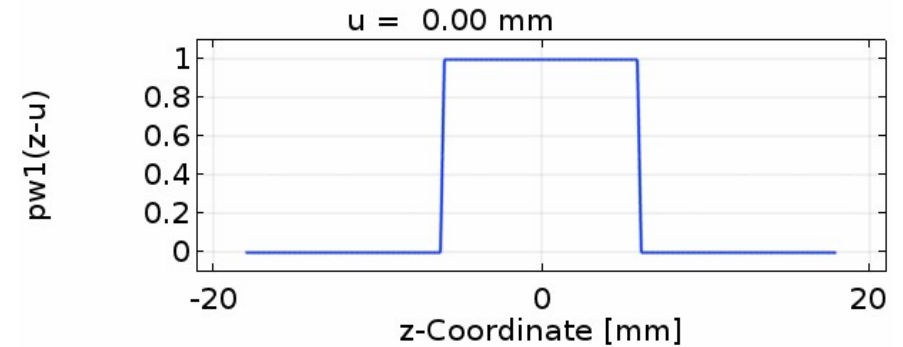
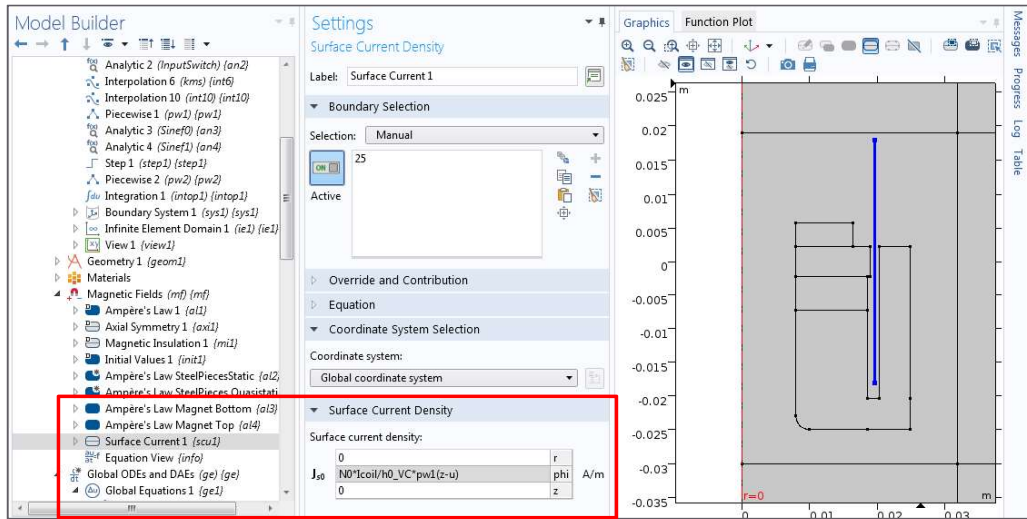
Everywhere else

Continuity Condition

Between moving mesh and static mesh

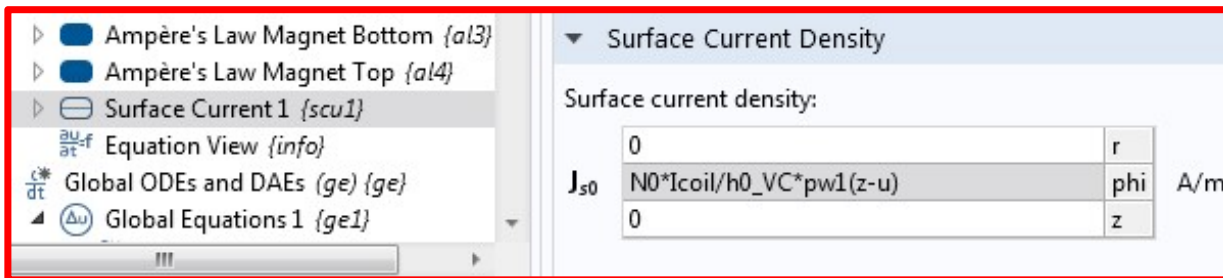


A Better Approach in COMSOL®: Moving Physics



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

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



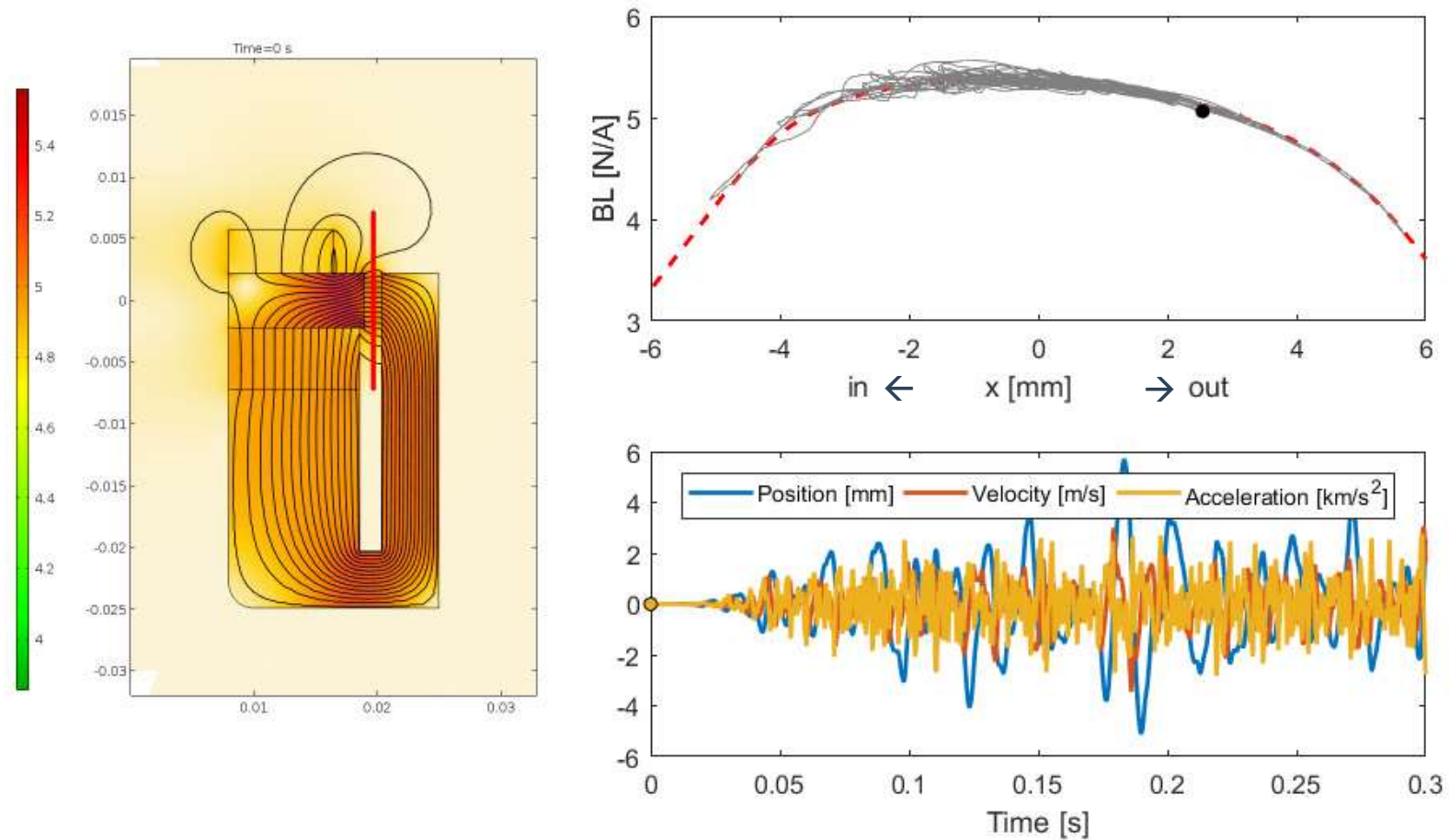
u : Voice coil position from ODE

N_0 : Number of turns

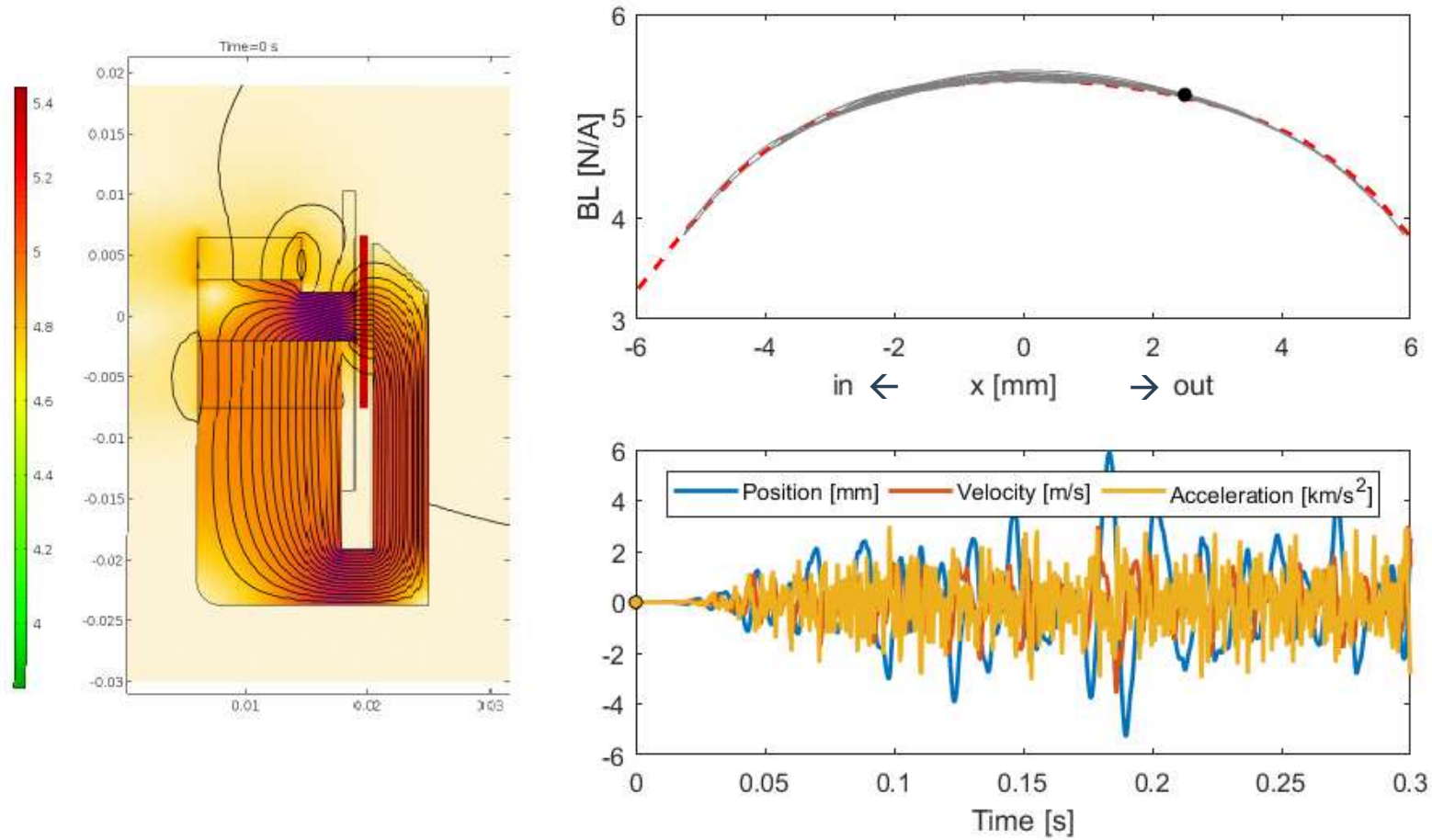
h_{0_VC} : Height of voice coil

I_{coil} : Current in voice coil

Dynamic Simulation Transducer A

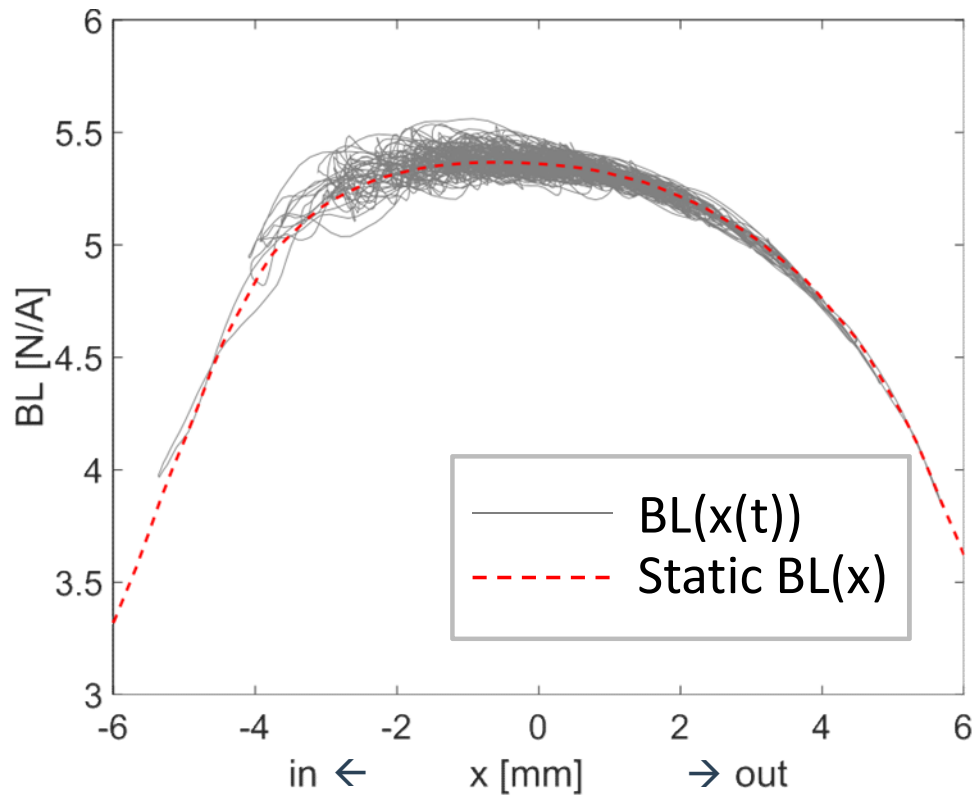


Dynamic Simulation Transducer B

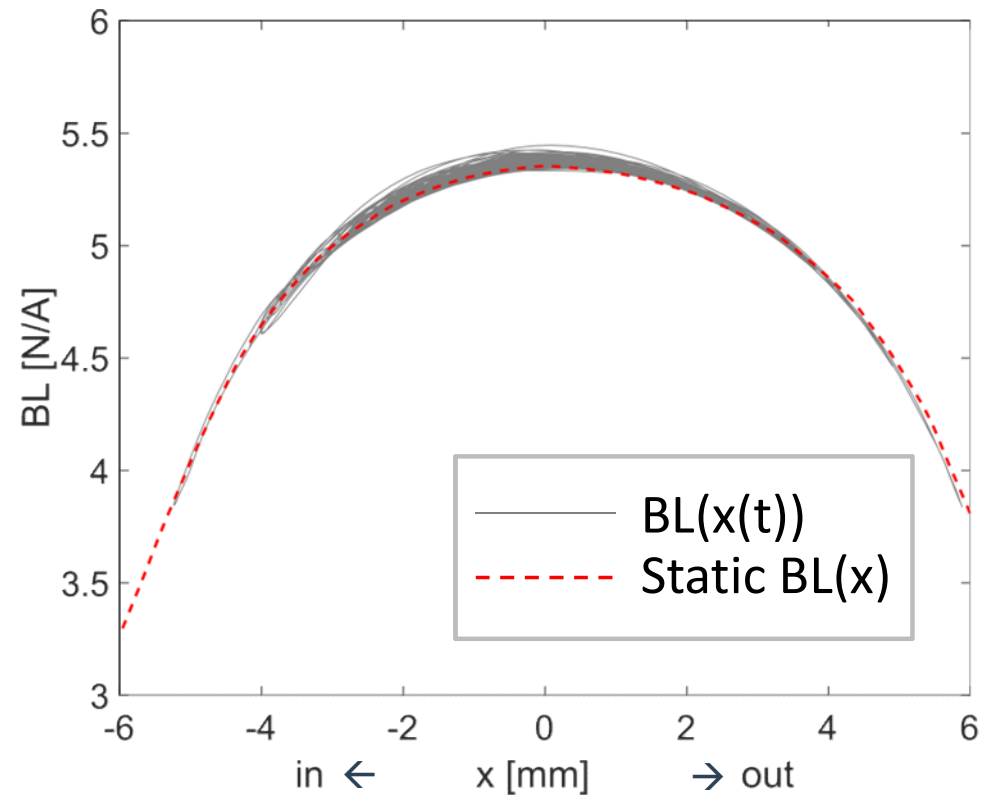


Quantifiably Better Drivers Through Simulation

Driver A



Driver B



Optimizing a Waveguide

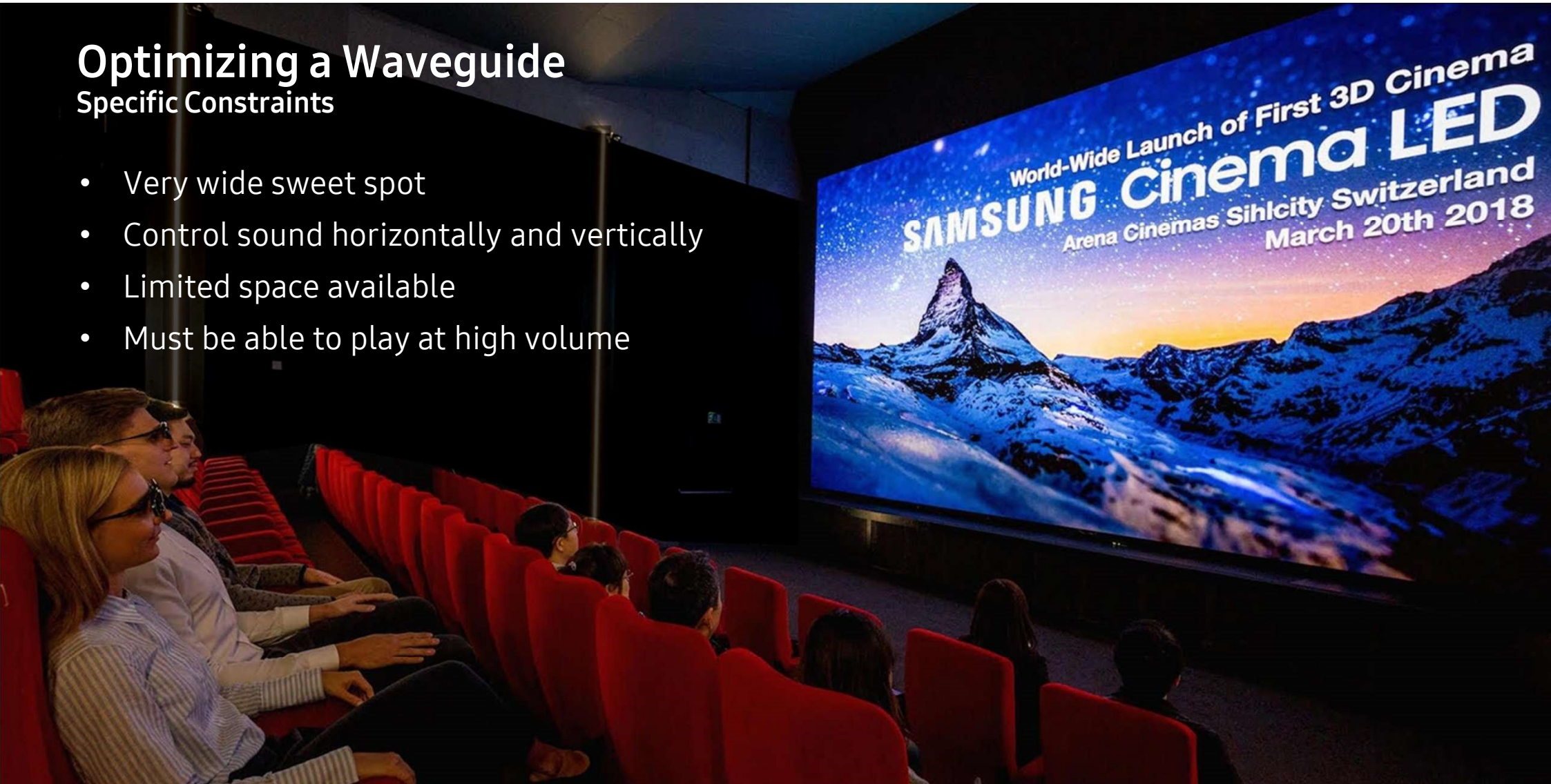
SAMSUNG LED WALL



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

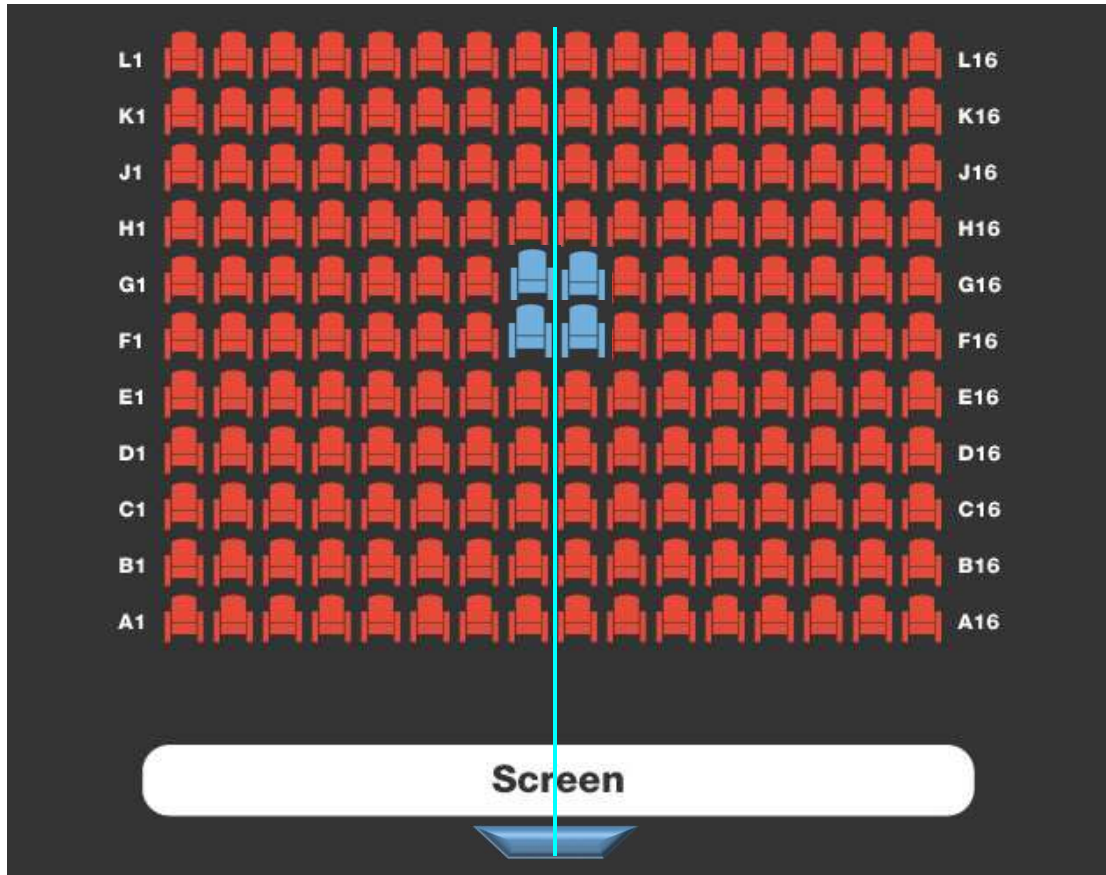


Traditional Cinema Loudspeaker Systems

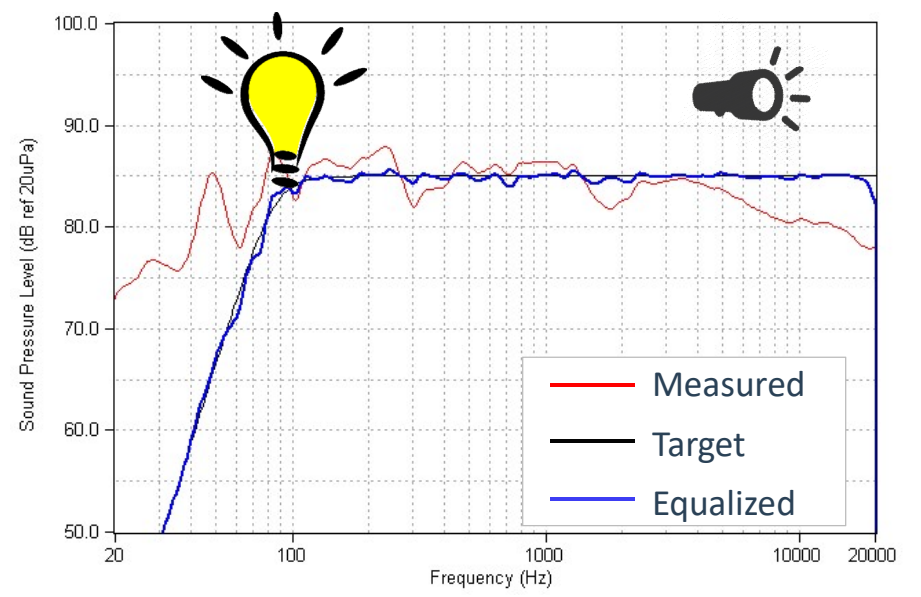
Waveguides and Compression Drivers



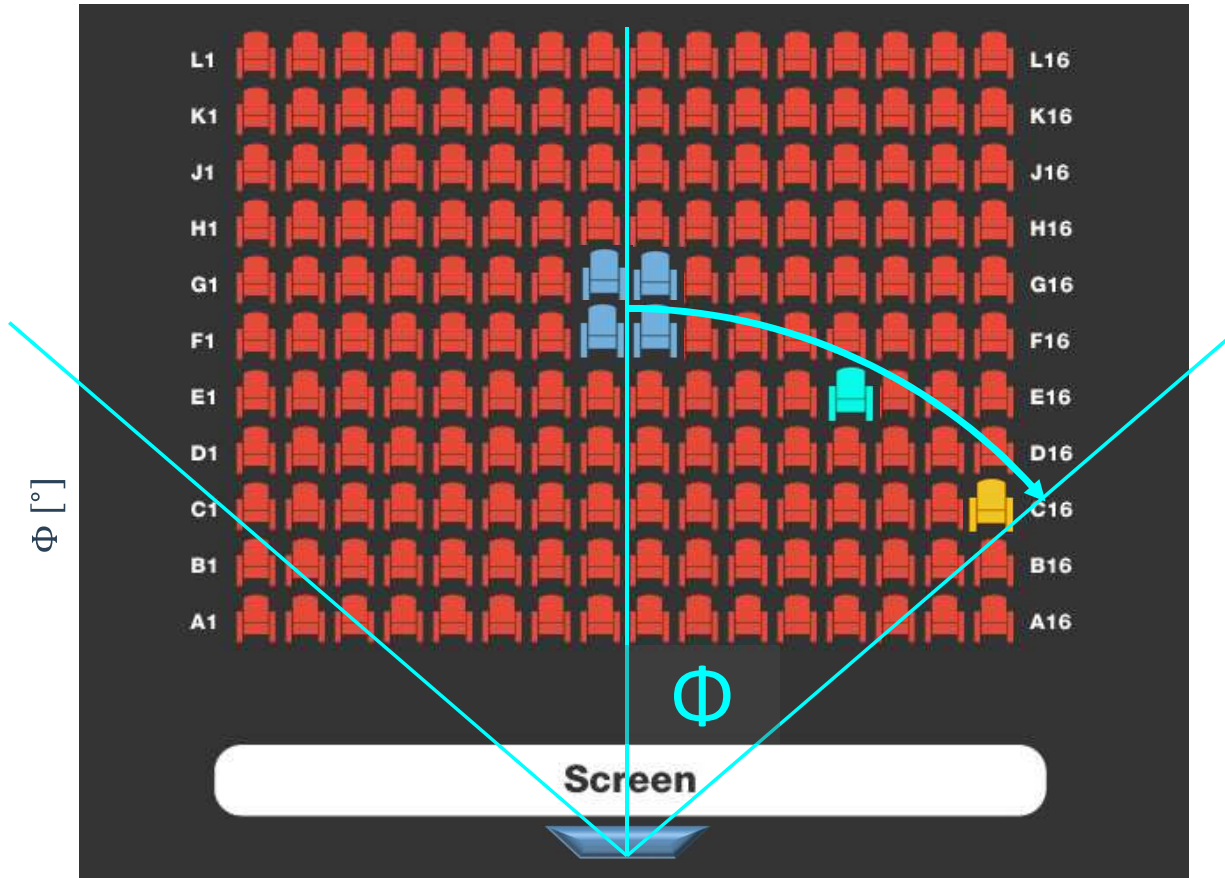
Best Frequency Response at Sweet Spot



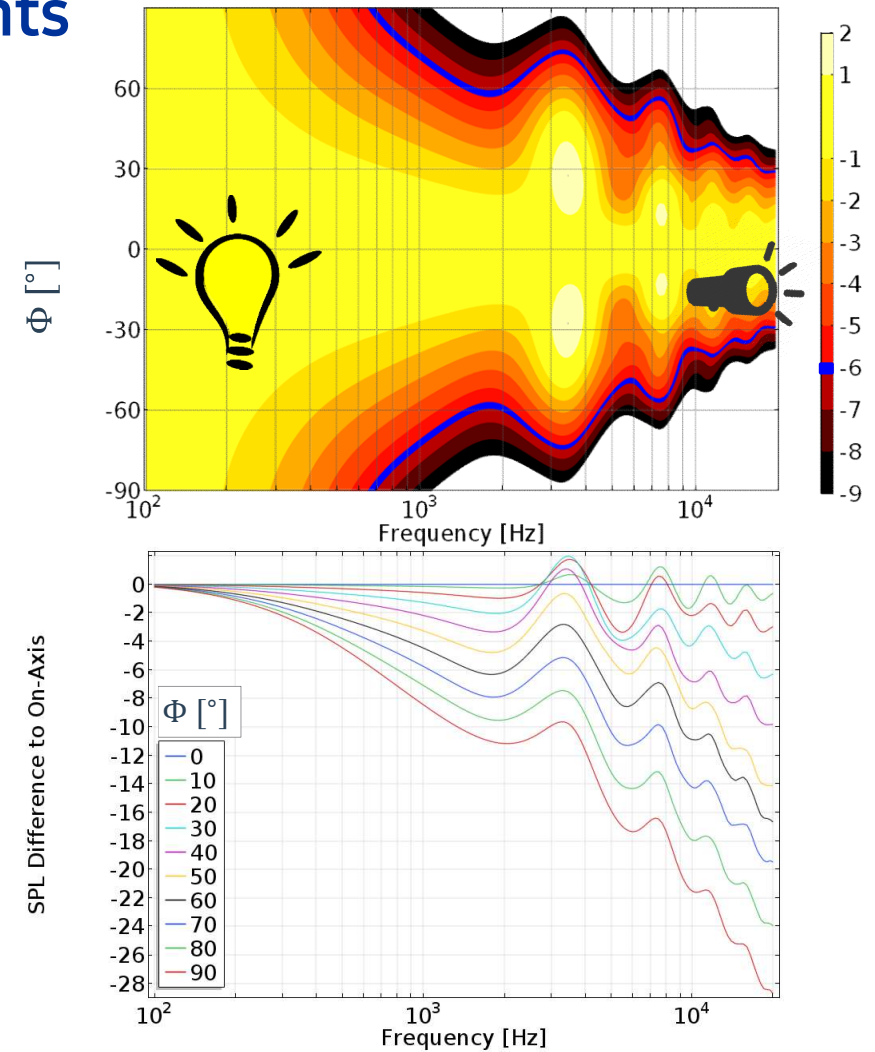
Equalization (EQ)



Optimal Frequency Response at Many Points



Normalized to Sweet Spot

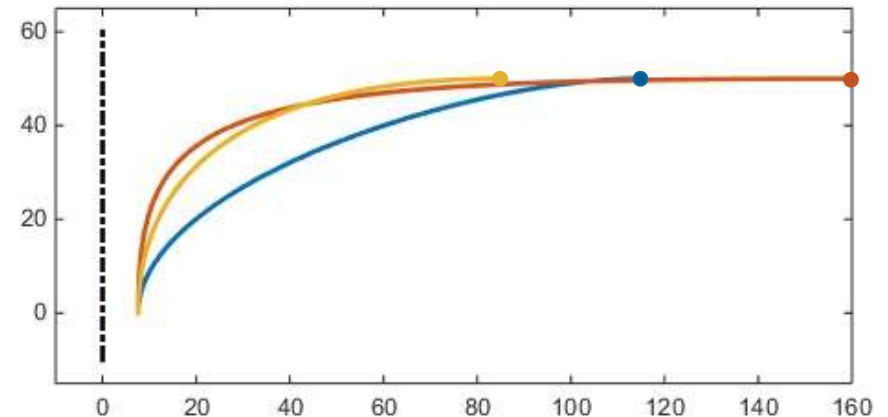
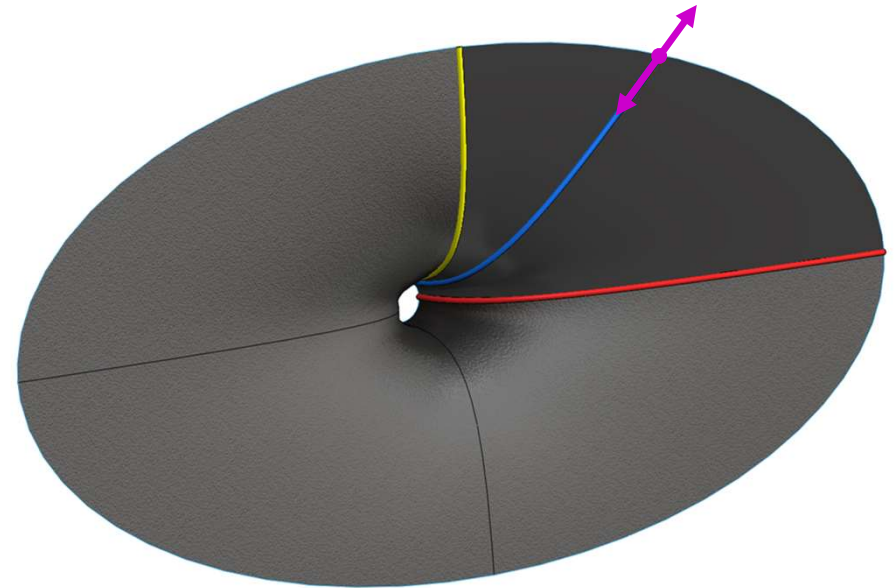
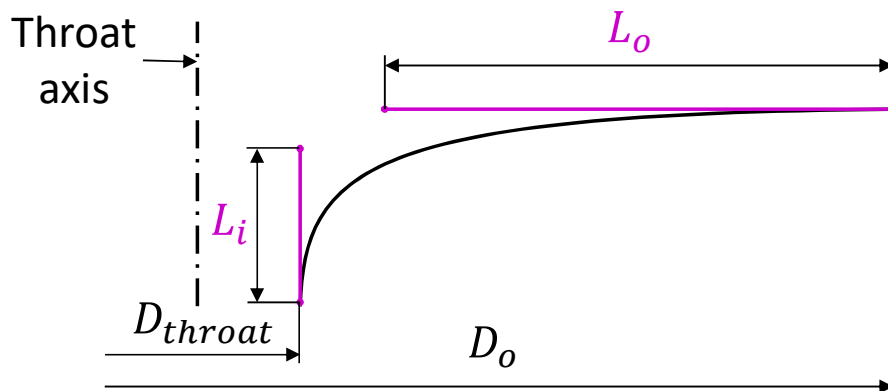


Optimizing a Waveguide

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

$1 + (3 \times 2)$
 $=$
7 Control Variables

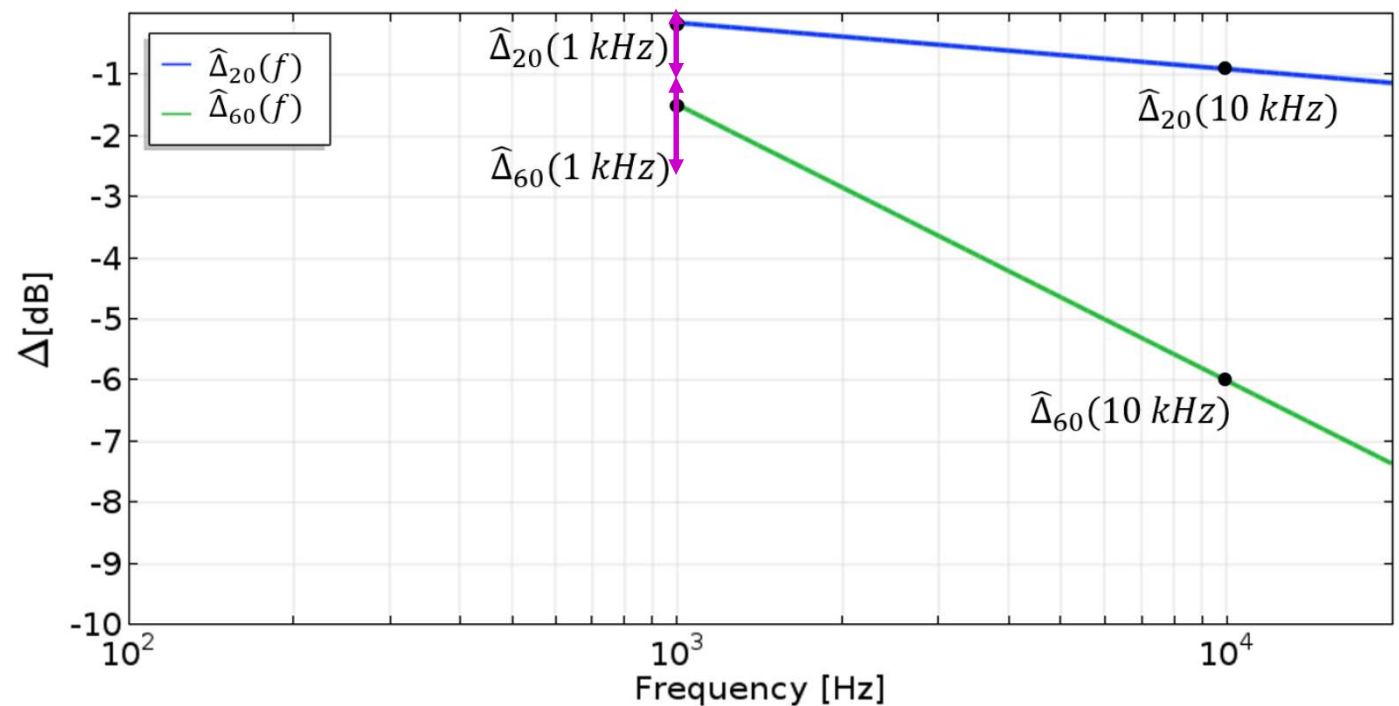


Optimizing a Waveguide

Target

Straight Lines in Off-Axis Plot

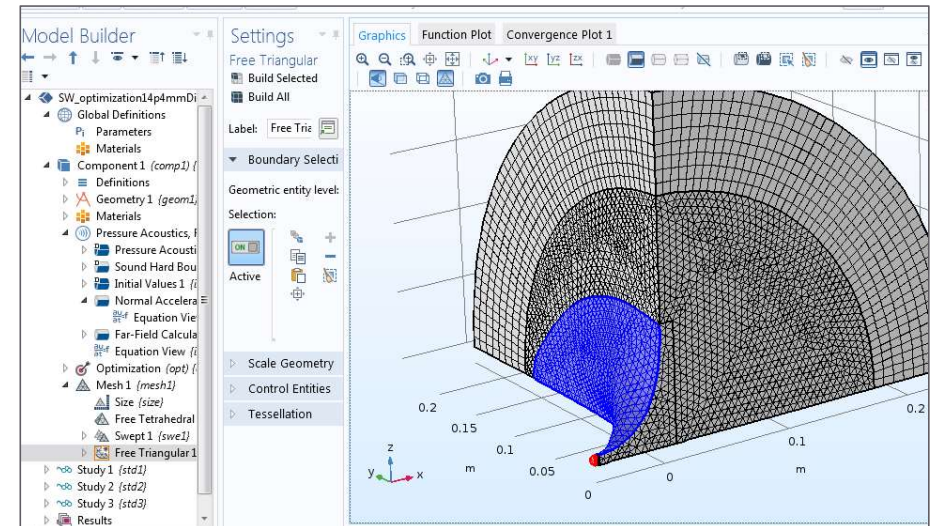
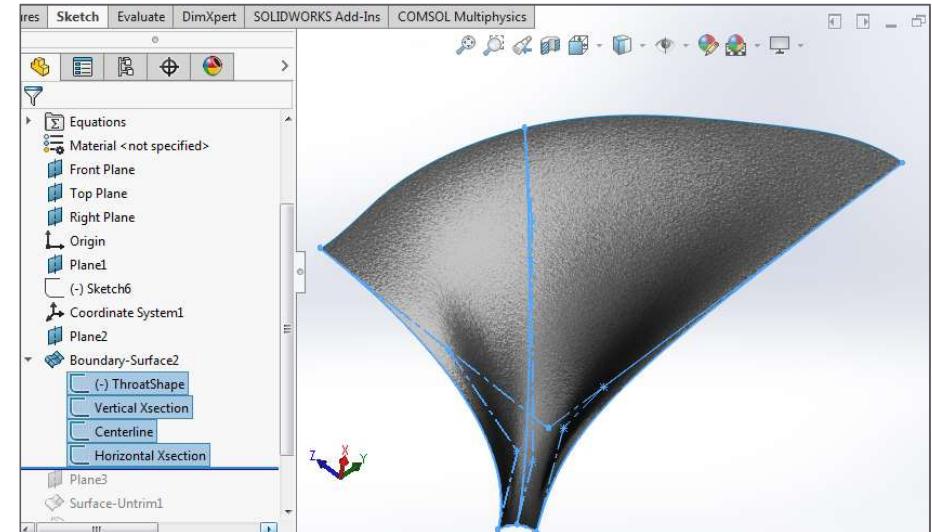
- Fixed 1 dB down at 20° and 10 kHz
- Fixed 6 dB down at 60° and 10 kHz
- Straight lines with variable values at 1 kHz
- 2 additional control variables



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



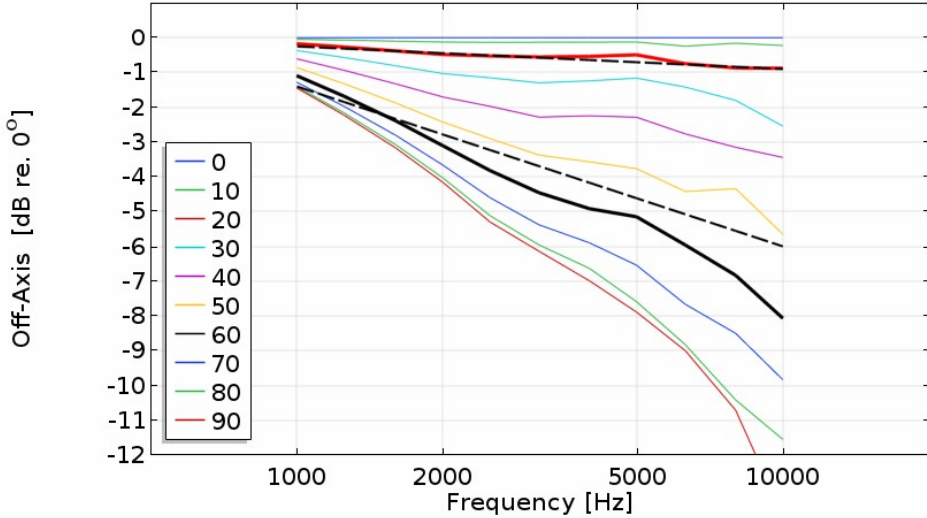
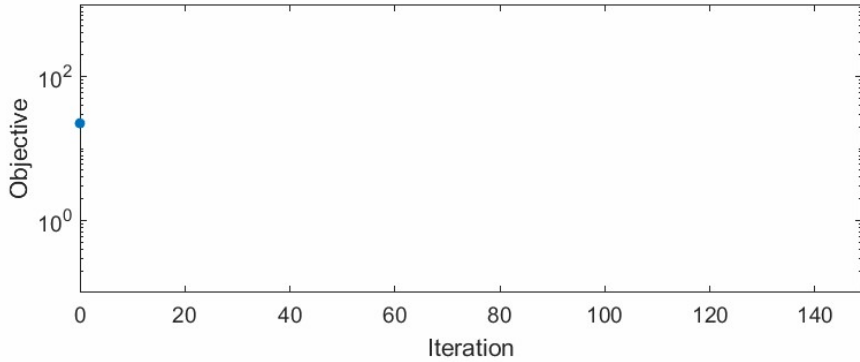
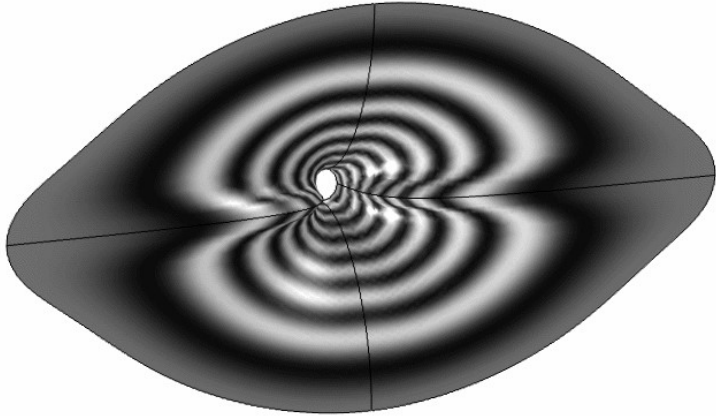
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SAMSUNG

Optimizing a Waveguide

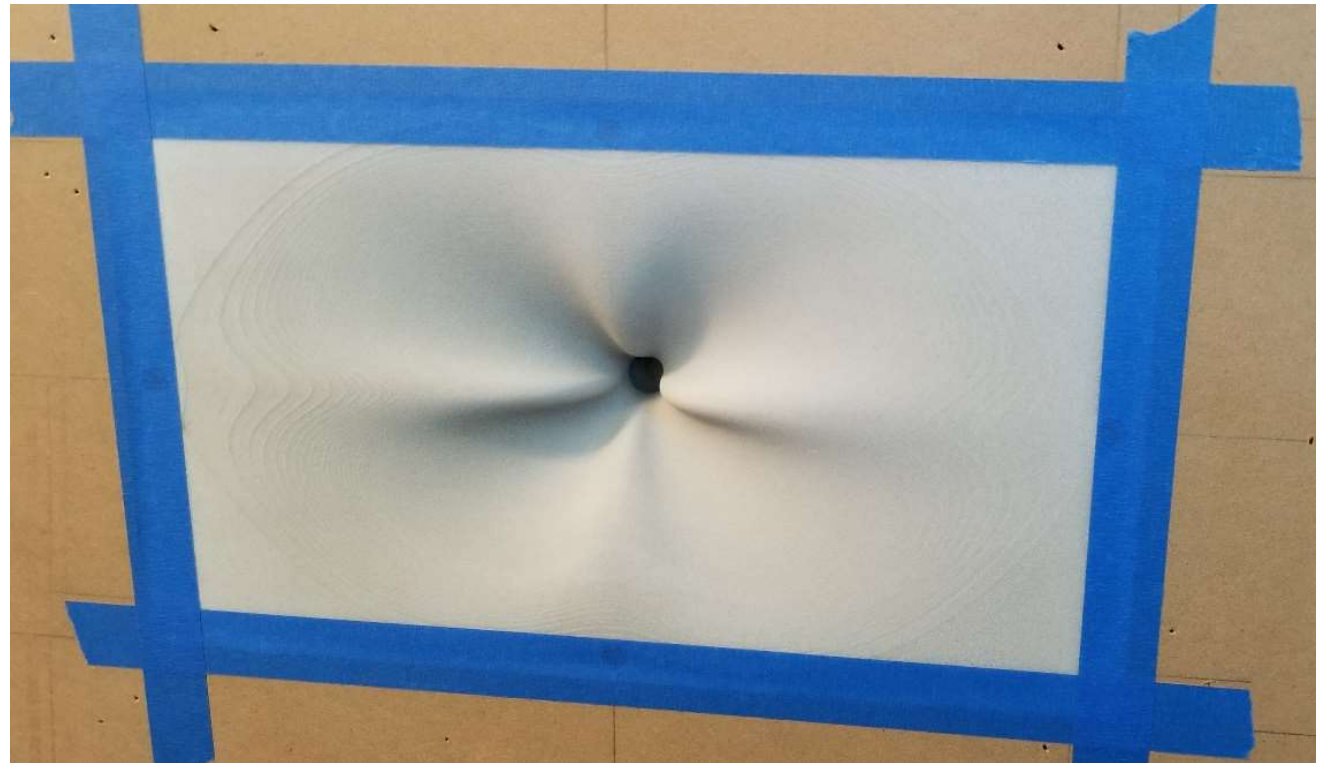
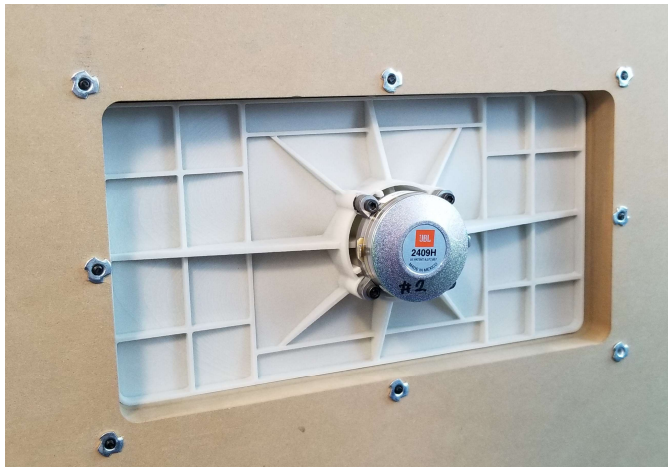
Optimization



Optimizing a Waveguide

3D Printed Prototype

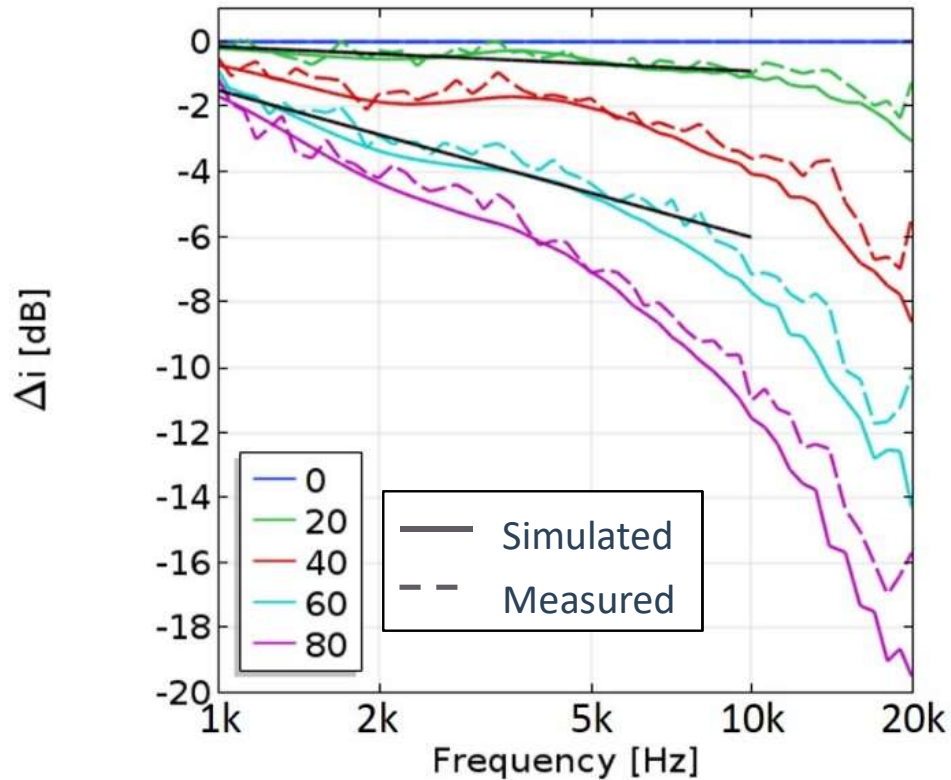
- Measured in 2π -configuration
- Mounted flush to wall of 2π anechoic chamber



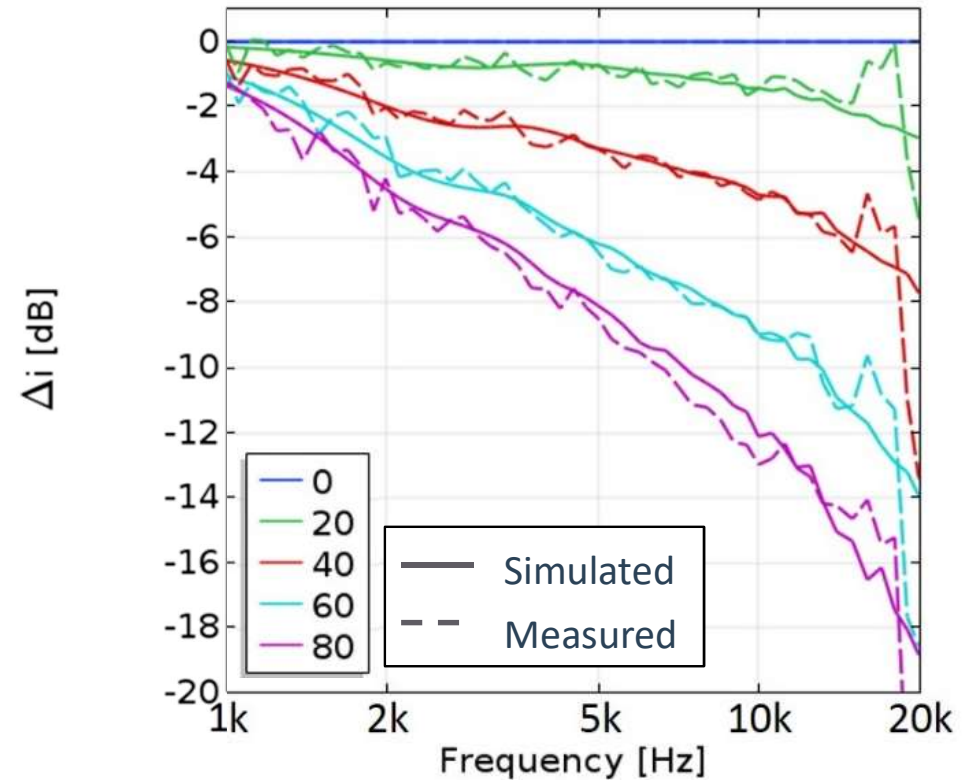
Optimizing a Waveguide

Off-Axis Results

Horizontal Off-Axis Response



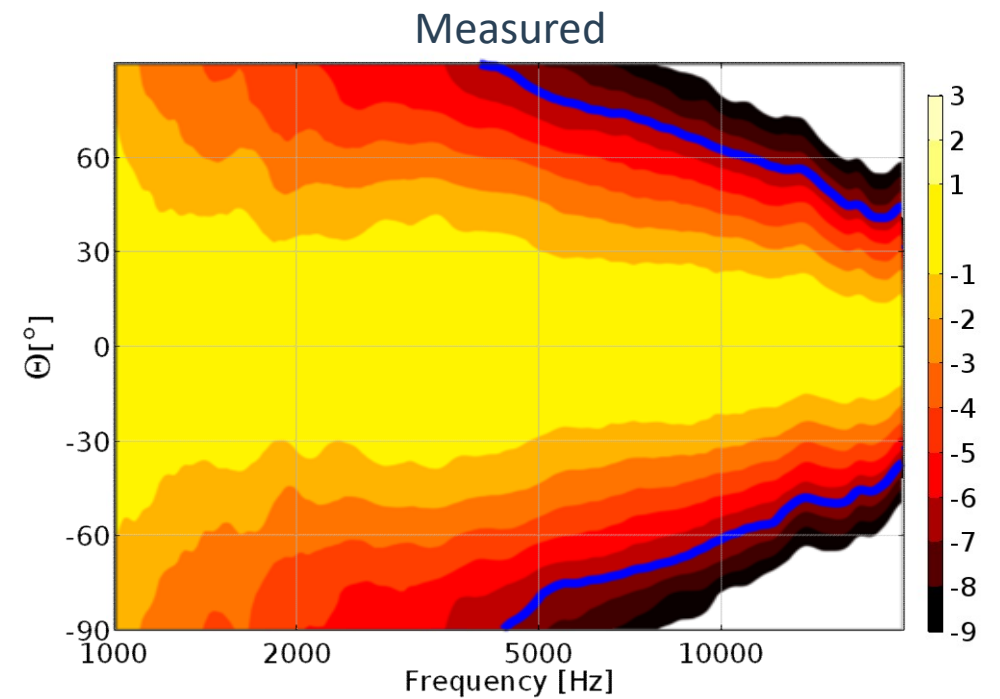
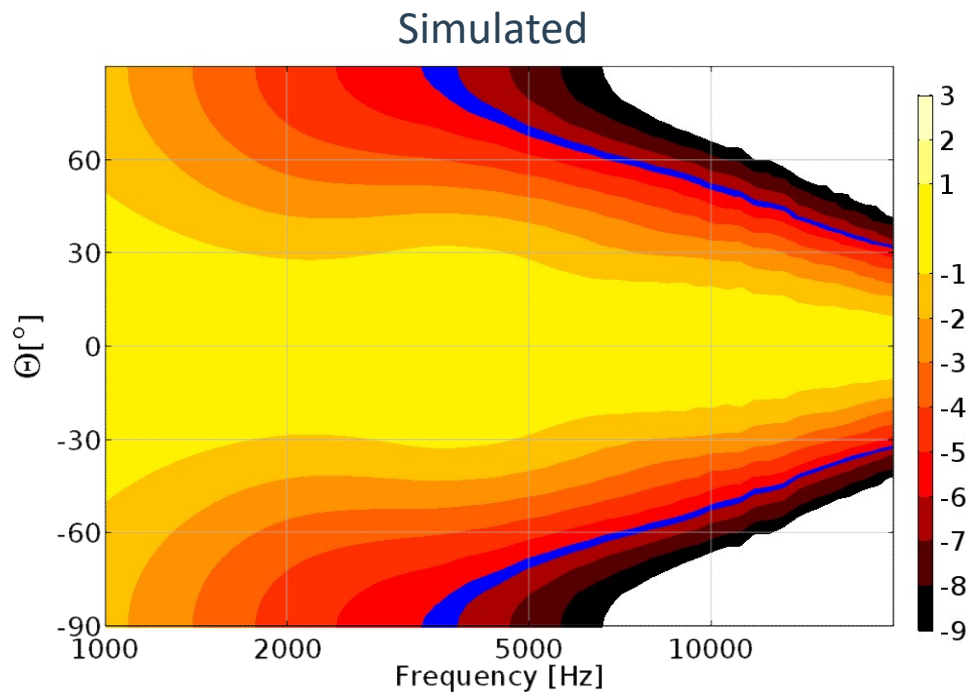
Vertical Off-Axis Response



Optimizing a Waveguide

Results

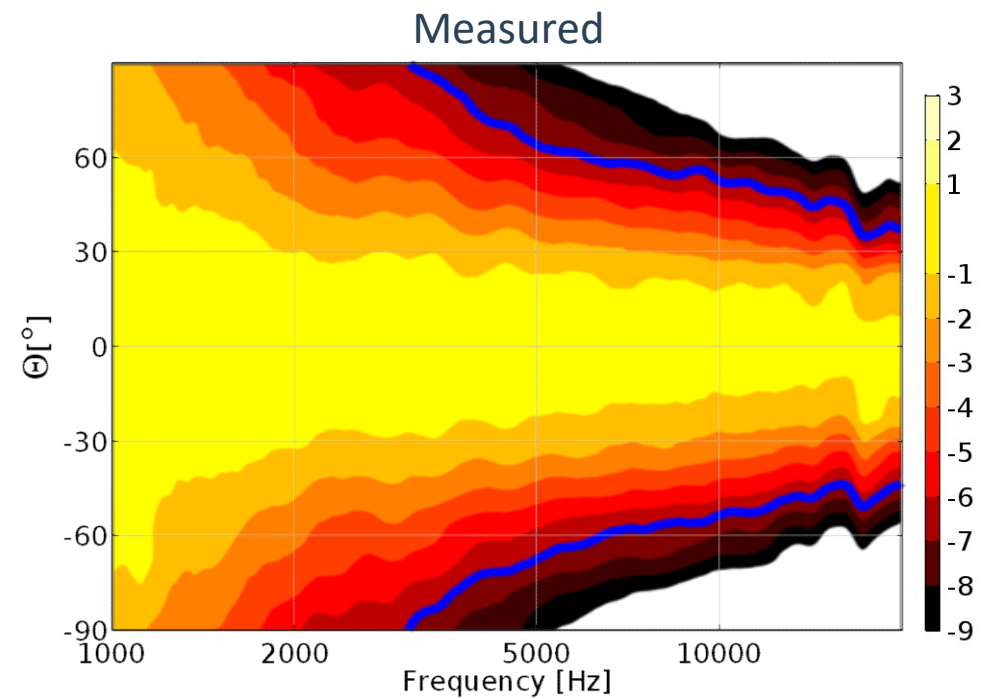
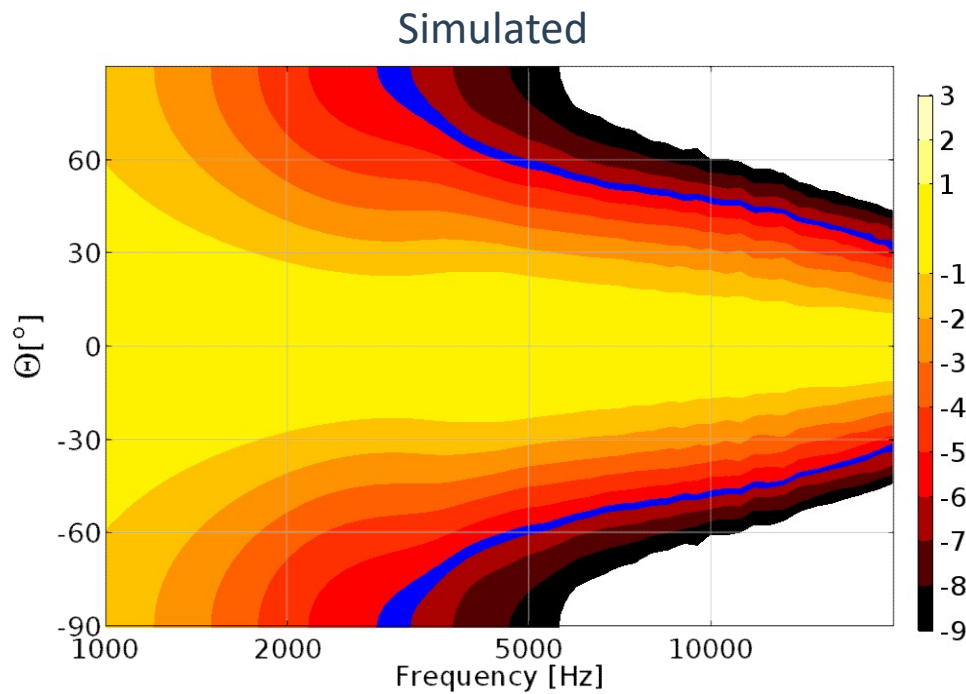
Directivity Plots: Horizontal Plane



Optimizing a Waveguide

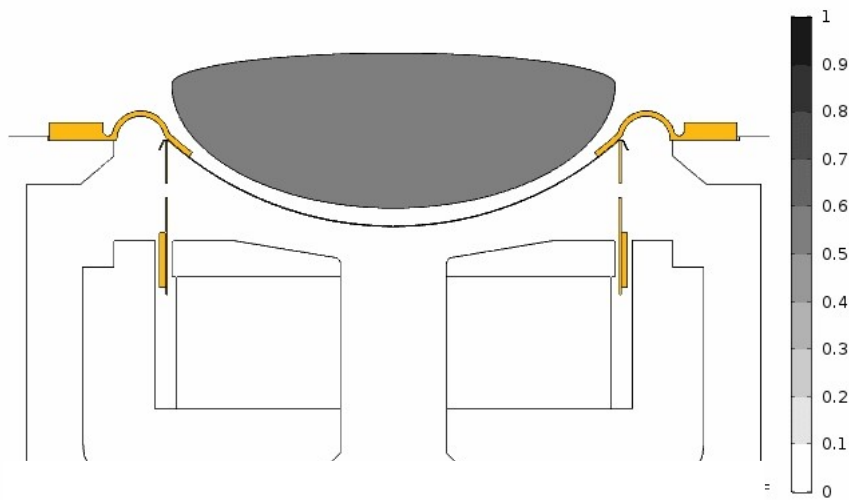
Results

Directivity Plots: Vertical Plane



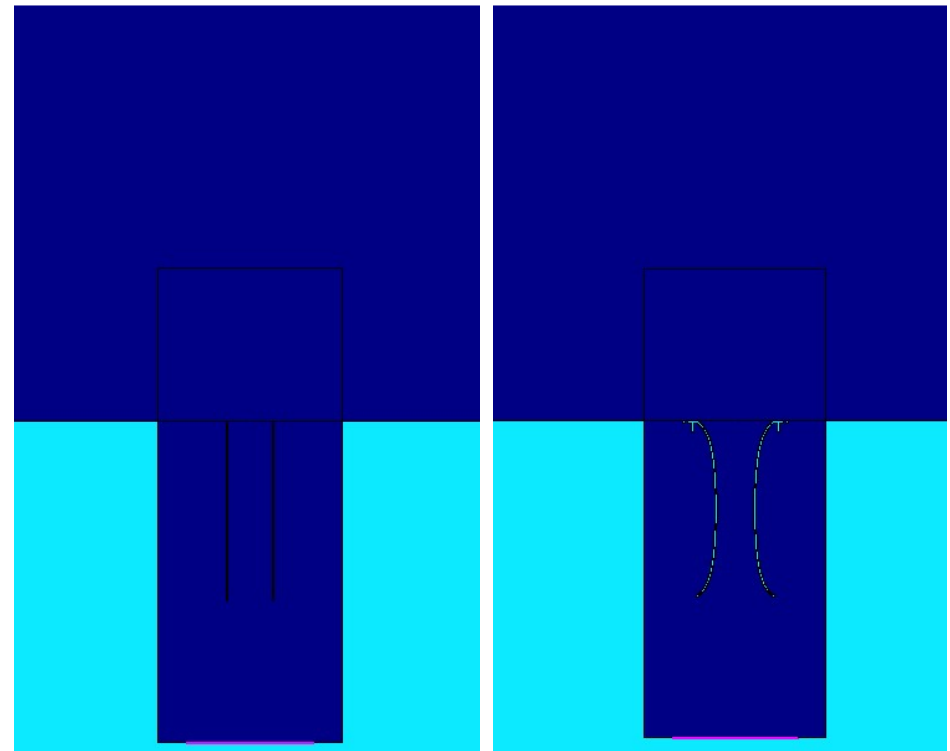
Other Fun Simulations

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

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SAMSUNG



Thank you!

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Special thanks to:

- Alyona Friedel and Zoran Vidakovic
- COMSOL Support Team
- COMSOL Team in Los Angeles
- Samsung Research America
- Samsung Audio Lab Team

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