Virtual Acoustic Prototyping for Loudspeaker Horn Development

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Outline

1. 2D (Axisymmetric) Horn Simulations
   - Figure of merit
   - Method
   - Example

2. 3D Horn Simulations
   - Pitfalls and solutions
   - Case Study
Beamwidth Calculation

One way to evaluate horn dispersion is to plot the polar pattern at multiple frequencies.

Ideally the polars should be similar over a wide frequency range.
An alternate way to evaluate this data is to find the 6dB down angles – called the beamwidth.

Plotting the beamwidth angle vs frequency as an XY graph is the most common way to show this data.
Beamwidth Calculation

Example of a non-constant beamwidth
Beamwidth versus frequency is the primary measure of horn performance.
Simulating axi-symmetric 2D horns
Deep 70 Degree Waveguide
Deep 70 Degree Waveguide

Diaphragm
Deep 70 Degree Waveguide
Deep 70 Degree Waveguide
Deep 70 Degree Waveguide
Deep 70 Degree Waveguide

PML (Perfectly Matched Layer)
Meshing

To resolve the pressure wave and get accurate results, we use about 6 elements per wavelength.

- 500Hz mesh
- 10kHz mesh
- 20kHz mesh
Solution Output (20 kHz)
Frequency Response from 0-90 degrees in 10 steps

Frequency Response Normalized

Beamwidth in degrees versus frequency
Simulated vs. Measured Beamwidth

Measured vs Simulated Beamwidth
Using Comsol

Freq, Hz

Beamwidth, deg

Simulated BW
Measured BW

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Simulating 3D horns with Comsol
3D Horns

3D Geometry takes much longer to run!

• To speed up solution time, the mesh is recalculated at each frequency to keep the number of elements down.

• Since the run time grows with the cube of the number of elements, the solution slows down greatly at the higher frequencies.

• Expanded matlab script performs many functions:
  
  Remeshing
  Batch processing multiple CAD files
  Calculation and graphing (frequency response, beamwidth, acoustic impedance, etc)
  Saving results (Excel, PDF, Comsol files)
Procedure for 3D horn Simulation

1. Generate CAD file of the horn airspace, add absorbing air layer
2. Load CAD into Comsol, set up piston source and symmetry planes and save the file
3. Open this file in Matlab and cut/paste it into the horn program
4. Run the horn program
From Geometry to Simulation

Original Geometry Ready for Simulation

12”x12” Mouth 90X50 coverage

Qtr Section

Half Space Added

Perfectly Matched Layer

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Program Runs and Prints Graphs
Detailed postprocessing in Comsol Interface
Horn Program Automatically generates output
Case Study – Application Engineered “AE” Project

- 2\textsuperscript{nd} generation product required improvements to several different existing horns:
  - 100 x 100
  - 120 x 60
  - 60 x 40
  - 90 x 50
  - 60 x 60
90 x 50 Horn
Original 90 x 50 Performance (Measured vs Simulated)

AM95 Beamwidth
Existing Horn Measured vs. Comsol

Green and Orange = Simulated
Red and Blue = Measured
After Optimization in Comsol …

Orange = Simulated
Red = Measured
60 x 40 Horn

©2010 Harman. All rights reserved.
Original Horn 60 x 40
(Measured vs Simulated)

AM64 Beamwidth
Existing Horn Measured Free-Air vs. Comsol 4pi

- Green and Orange = Simulated
- Red and Blue = Measured
After Optimization in Comsol

AM64 Beamwidth
n33 Comsol vs. Measured

Frequency (Hz)

Beamwidth (Degrees)

Green and Orange = Simulated
Red and Blue = Measured

Horizontal
Vertical
Horn Simulations in Comsol - Summary

– Comsol shows good predictive power for the virtual prototyping of acoustics of arbitrary horns.

– A high resolution frequency response for 2D Axisymmetric horns can be solved for in a short time, generally a matter of minutes. 3D horns can be solved in hours, depending on physical size and highest frequency of interest.

– The ability to interface with Matlab is a key requirement for both pre and post-processing, and allows a high degree of flexibility to customize the program operation and workflow.