COMSOL CONFERENCE
2015 BOSTON

PA Loudspeaker System Design Using Multiphysics Simulation

An approach to reduce prototype and measurement times to a minimum

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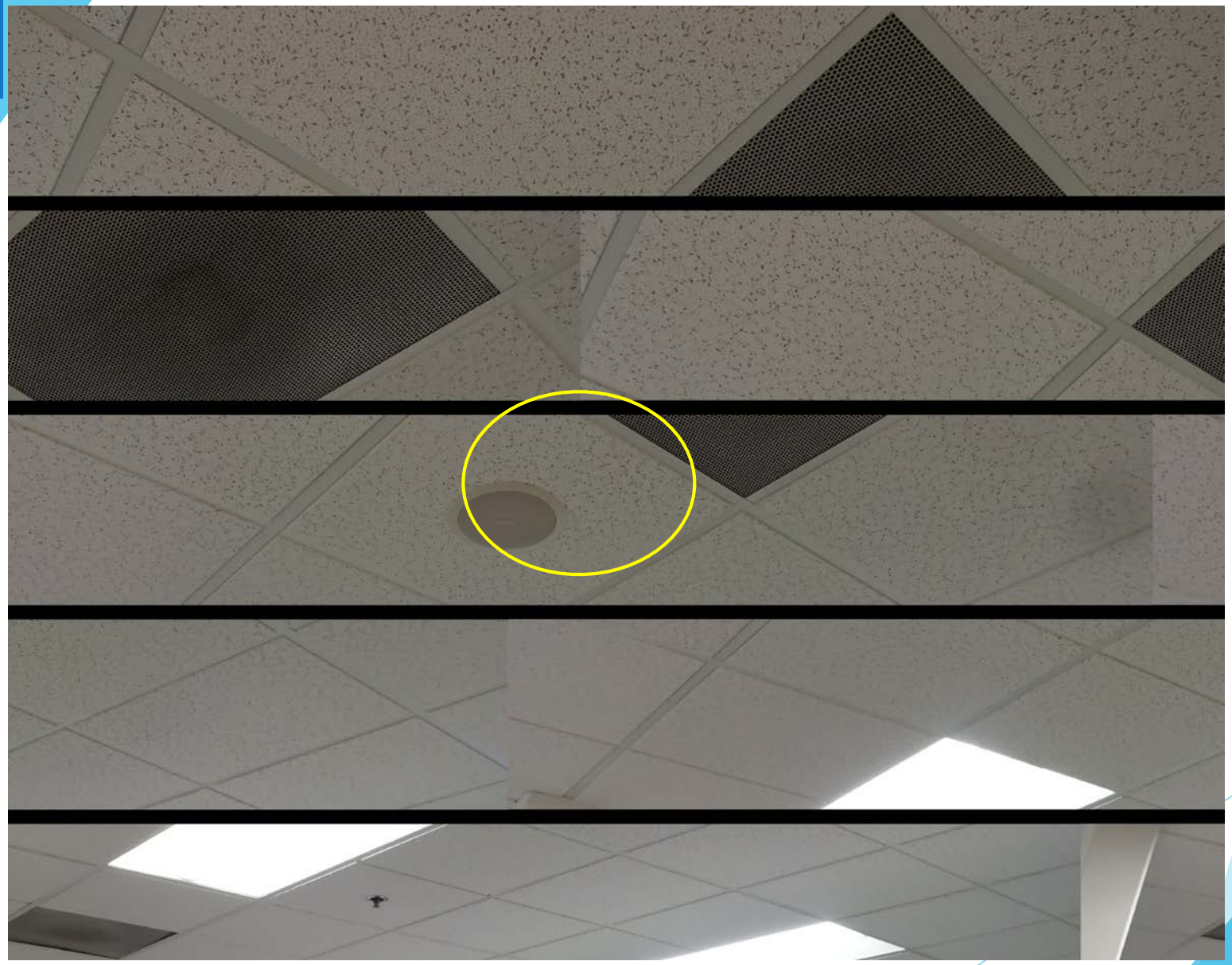
COMSOL

Ceiling PA Speaker



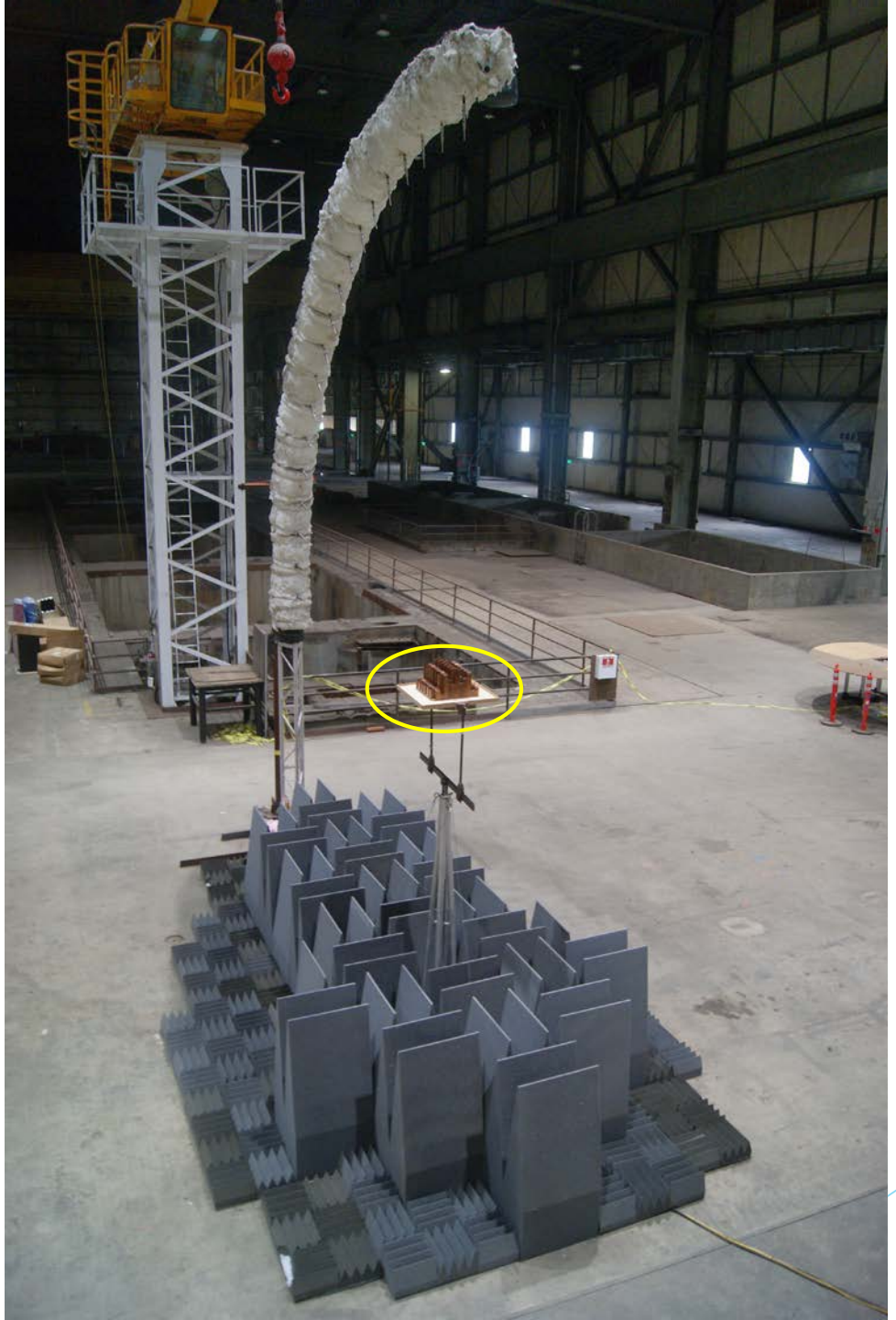
Ceiling PA Speaker System

Ceiling PA Speaker

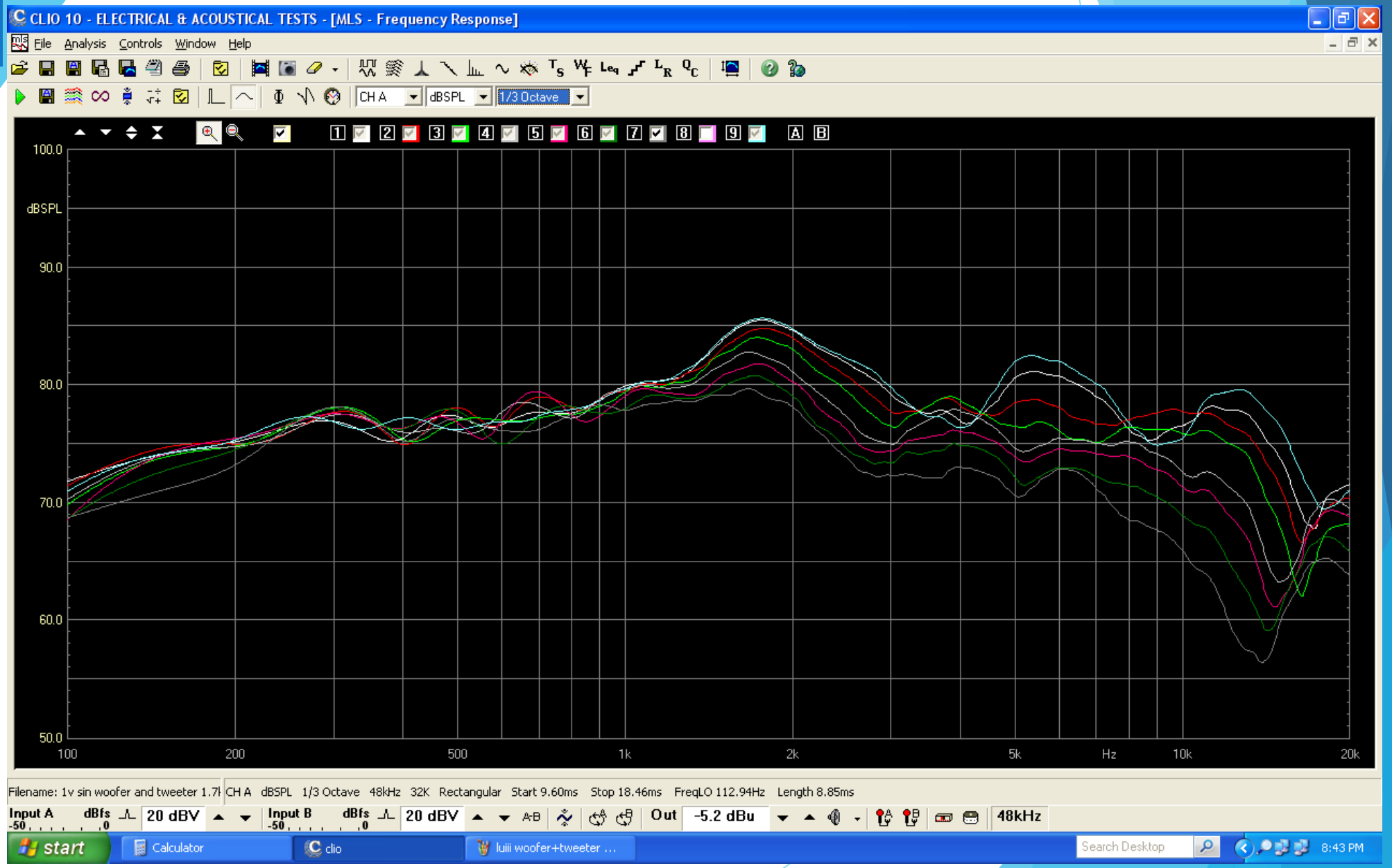
Without grille

Tweeter, Woofer, and Vent visible

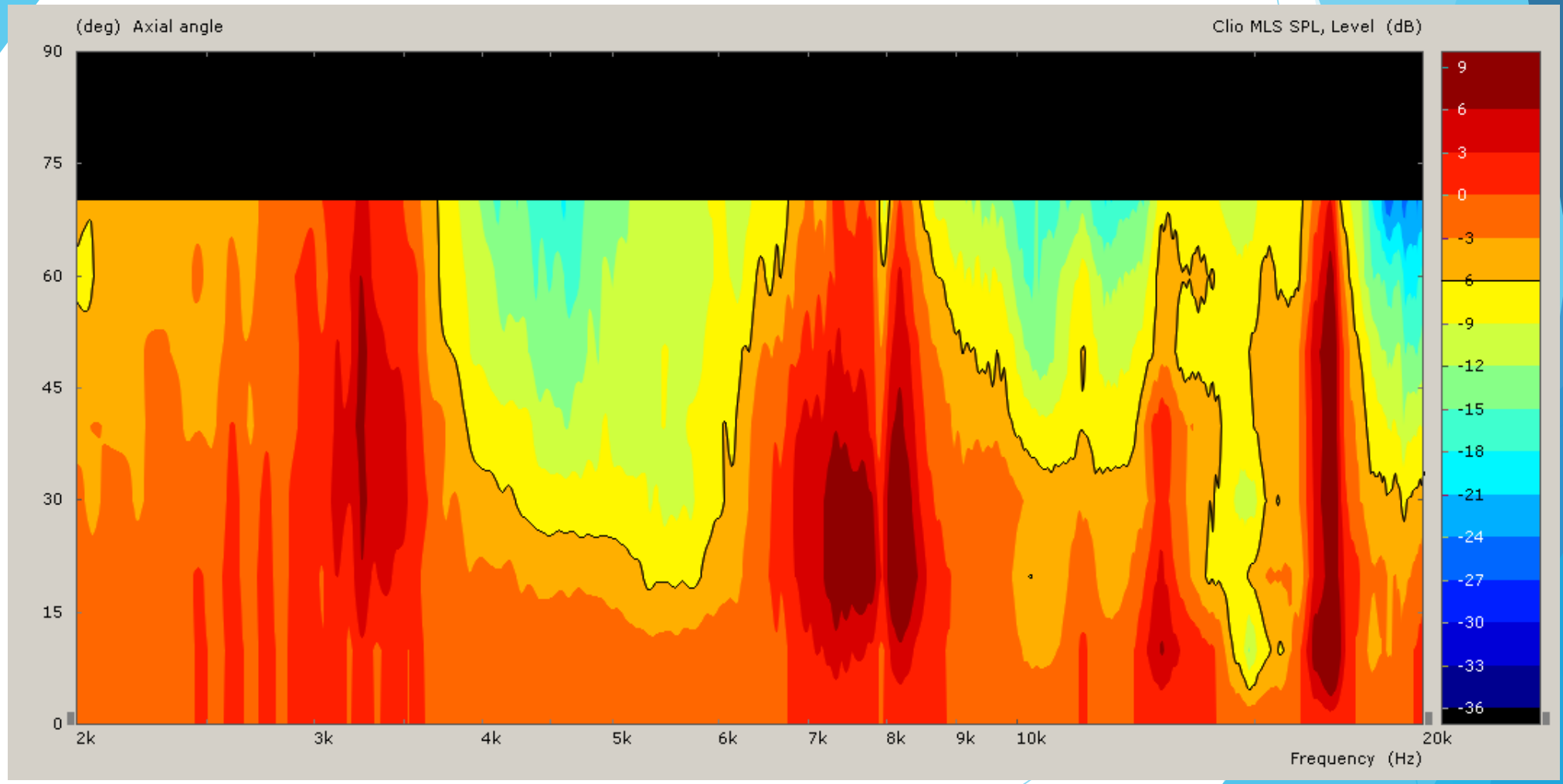
Microphone array courtesy of Ron Sauro NWAA Labs



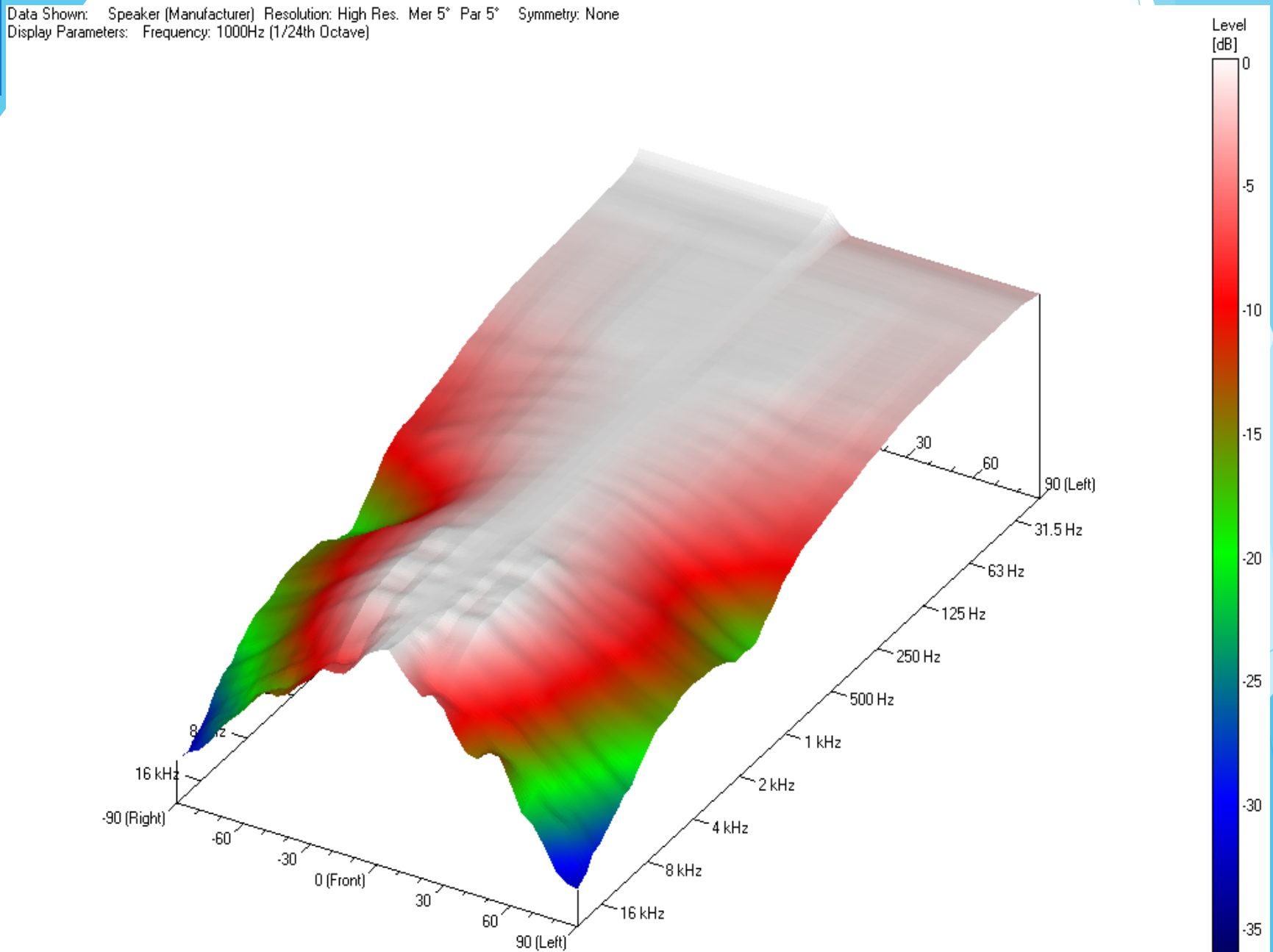
Frequency responses at different angles compared to on axis (usually the 0 degrees)



Frequency response versus angle, Sound Pressure Level displayed as gradient of colors (red=higher value, blue=lower).

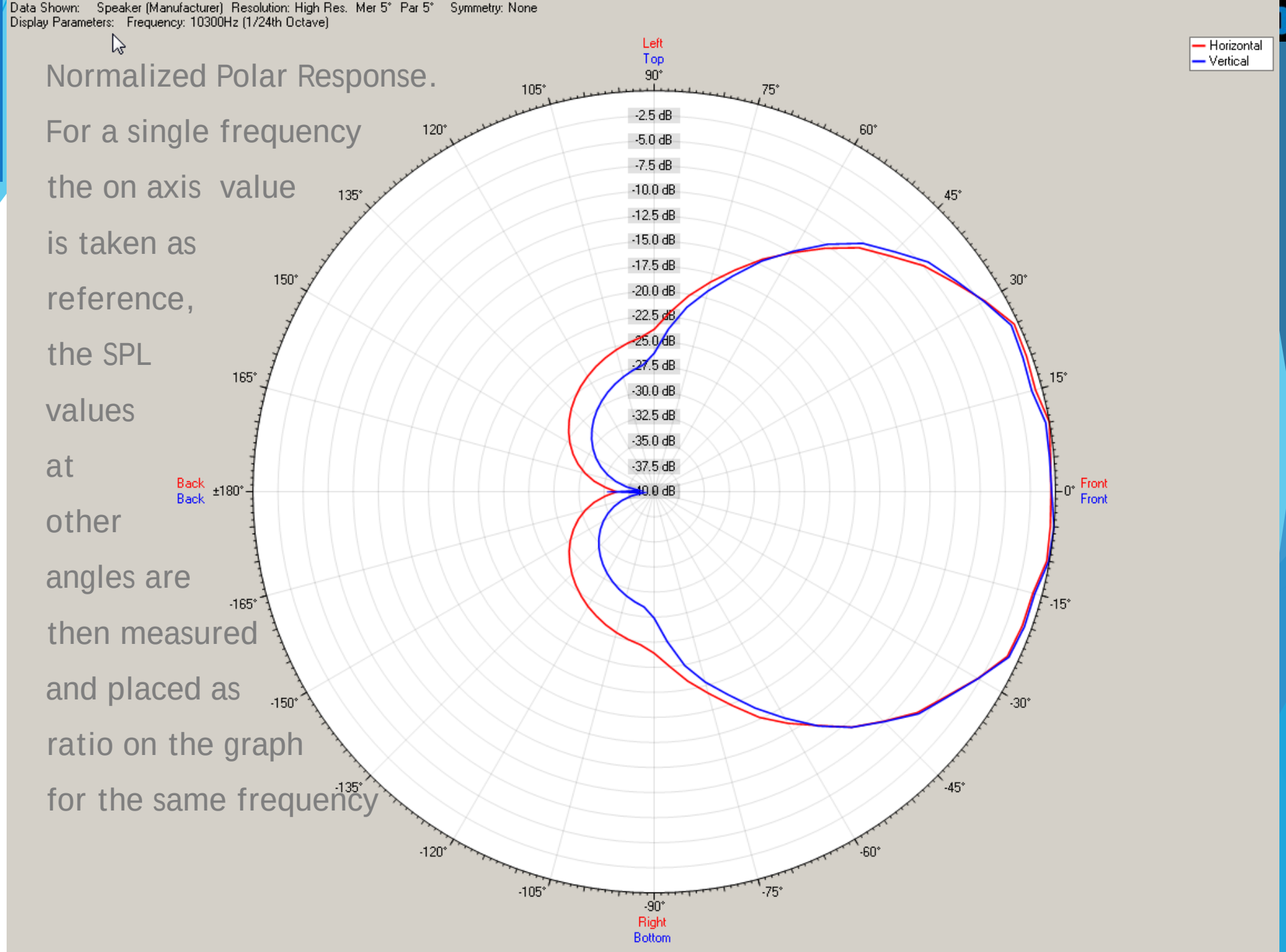


3d version of frequency response versus angle

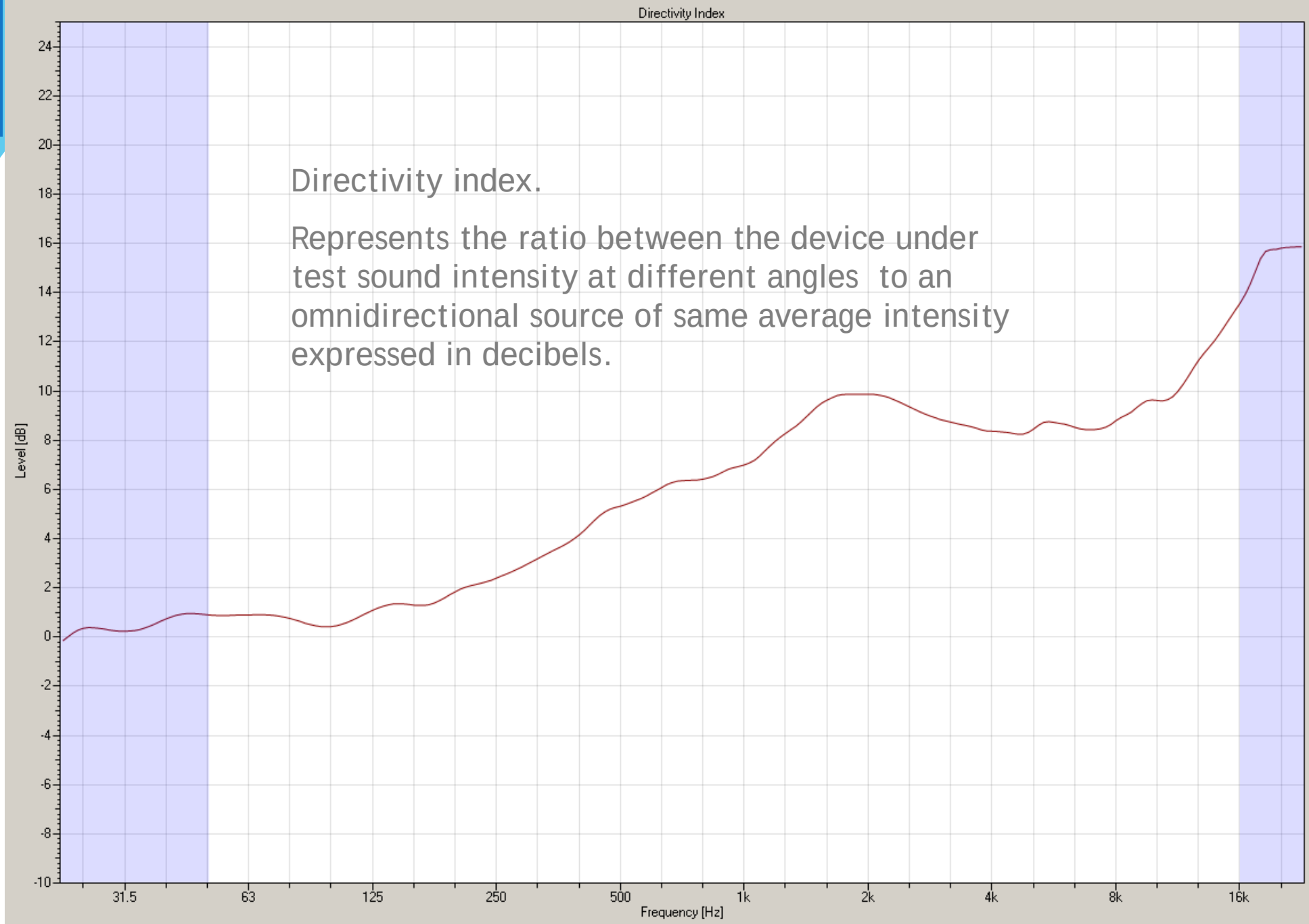


Normalized Polar Response.

For a single frequency the on axis value is taken as reference, the SPL values at other angles are then measured and placed as ratio on the graph for the same frequency



Data Shown: Speaker (Manufacturer) Resolution: High Res. Mer 5° Par 5° Symmetry: None
Display Parameters: Frequency: 10300Hz (1/24th Octave) Mer: 0° Par: 0°



Directivity index.

Represents the ratio between the device under test sound intensity at different angles to an omnidirectional source of same average intensity expressed in decibels.

Approach with COMSOL

Useful existing models:

Baffled Membrane

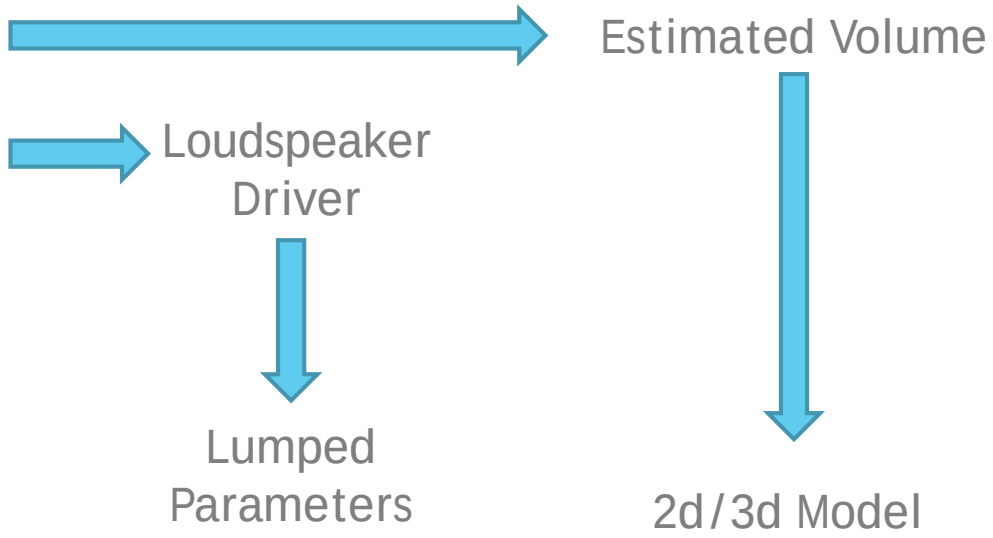
Loudspeaker Driver

Lumped loudspeaker Driver

Loudspeaker Driver in a Vented Enclosure

Design Guidelines for Product Development

- Baffle Diameters
- Enclosure Height
- Performance (SPL and frequency response)



Lumped Parameters

Woofer Thiele/Small Parameters

MLSSA SPO 4WI #980707-3553-3566 for GESTION TAYCAN

Line	Parameter	QSC 6.5 Value	Units	QC Limits
1	RMSE-free	1.27	Ohms	
2	Fs	78.61	Hz	
3	Re	13.34	Ohms[dc]	
4	Res	155.08	Ohms	
5	Qms	6.95		
6	Qes	0.60		
7	Qts	0.55		
8	L1	0.74	mH	
9	L2	1.40	mH	
10	R2	6.79	Ohms	
11	RMSE-load	0.67	Ohms	
12	Vas(Sd)	9.84	liters	
13	Mms	11.63	grams	
14	Cms	352	µM/Newton	
15	Bl	11.32	Tesla-M	
16	SPLref(Sd)	90.9	dB[Re]	
17	Rub-index	0.00		

Method: Mass-loaded (15.000 grams) Area (Sd): 141.03 sq cm
DCR mode: Measure (-0.51 ohms) QC file: CLOSED

Analysis successful. Shift in Fs = -35.2% (-20% to -50% is recommended).

Tweeter

Parameters are attained in a slight different way as they have their own enclosure

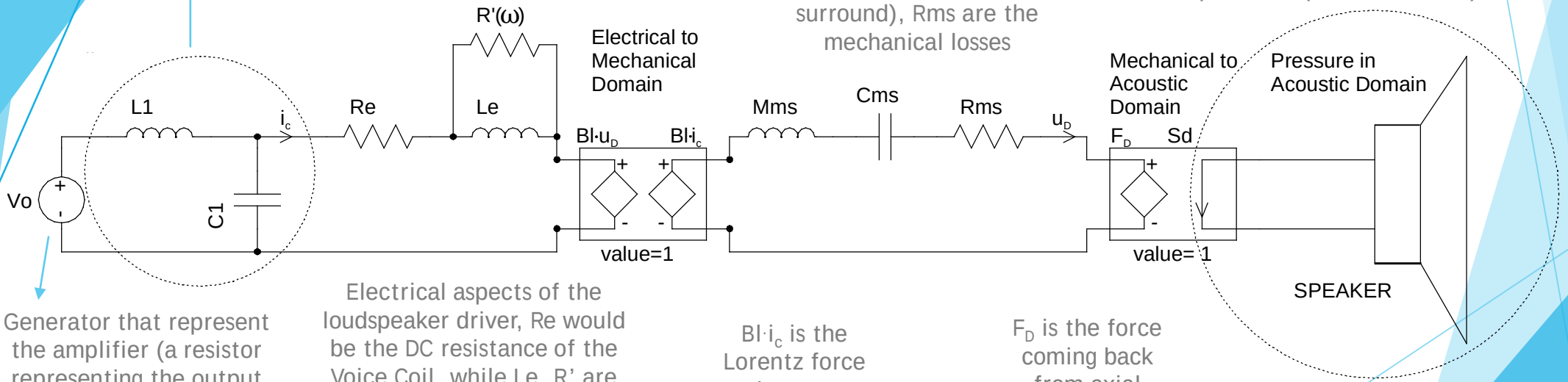
Lumped Parameters for the woofer side

Low pass filter, in this case 2nd order, but several configurations can be tried

$Bl \cdot u_D$ is the back EMF induced voltage where u_D is the velocity of the voice coil in the gap

Mechanical aspects of the loudspeaker driver, Mms would be the moving mass, (voice coil, cone, dust cap, portion of the spider etc.), Cms the compliance of the moving system (spider with surround), Rms are the mechanical losses

the axial acceleration of the diaphragm necessary in the FEA model is coming from the velocity per pulsation (inverse of time)



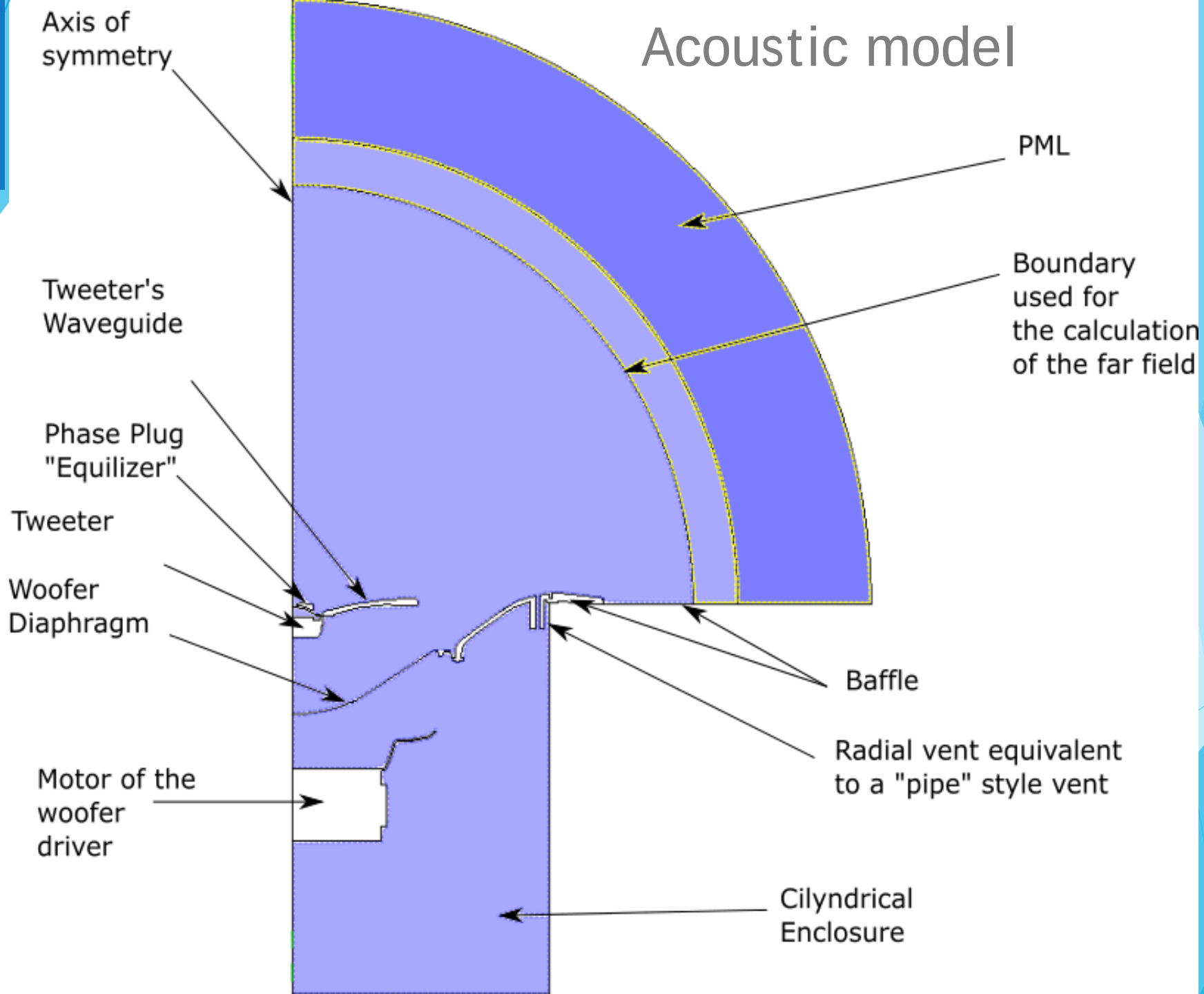
Generator that represent the amplifier (a resistor representing the output impedance could also be included…)

Electrical aspects of the loudspeaker driver, Re would be the DC resistance of the Voice Coil, while Le, R' are frequency dependent parameters, a more complex model that includes other function dependent parameters can be used

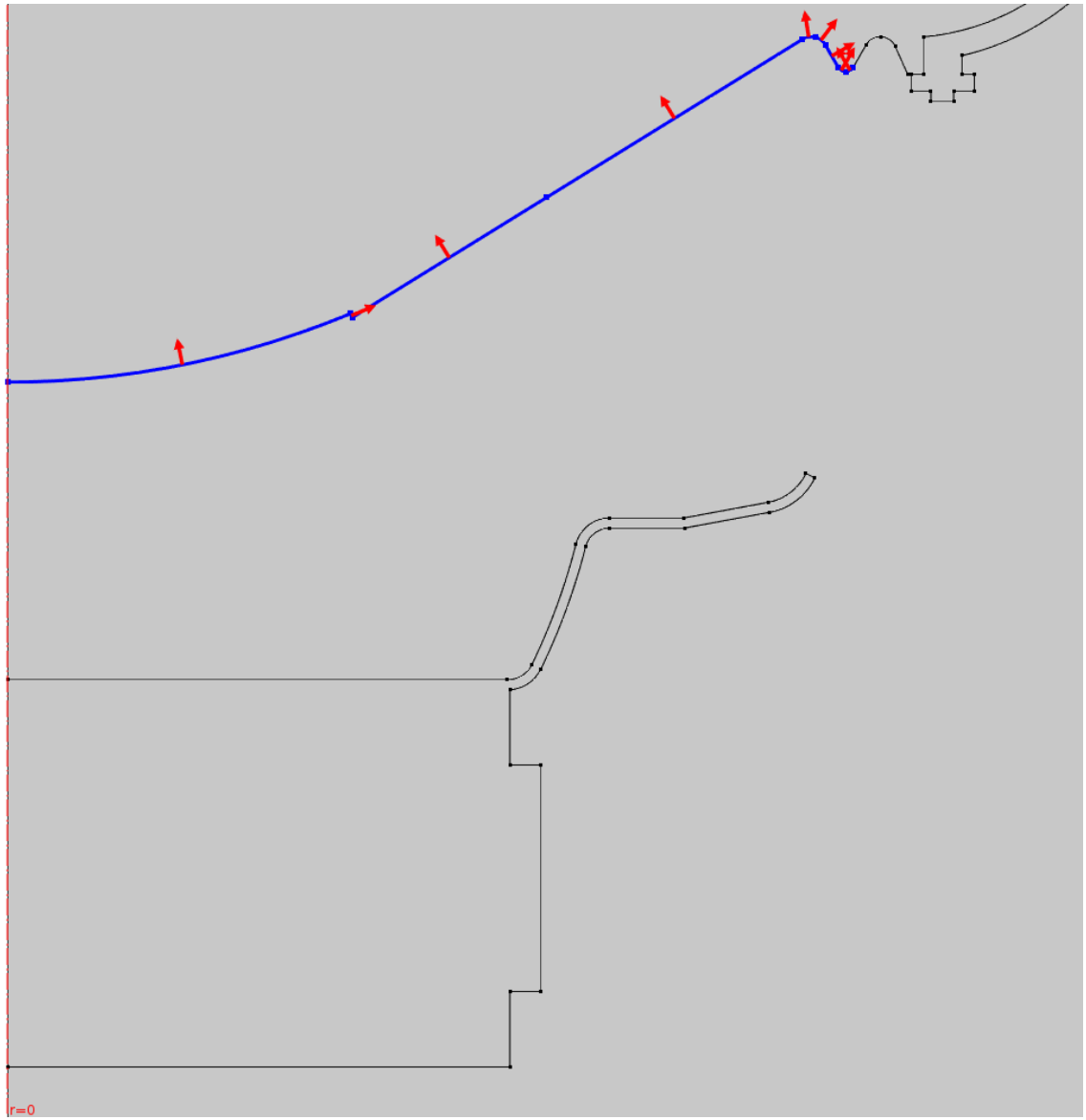
$Bl \cdot i_c$ is the Lorentz force that gets applied to the moving parts

F_D is the force coming back from axial pressure on the diaphragm coming back from the FEA model

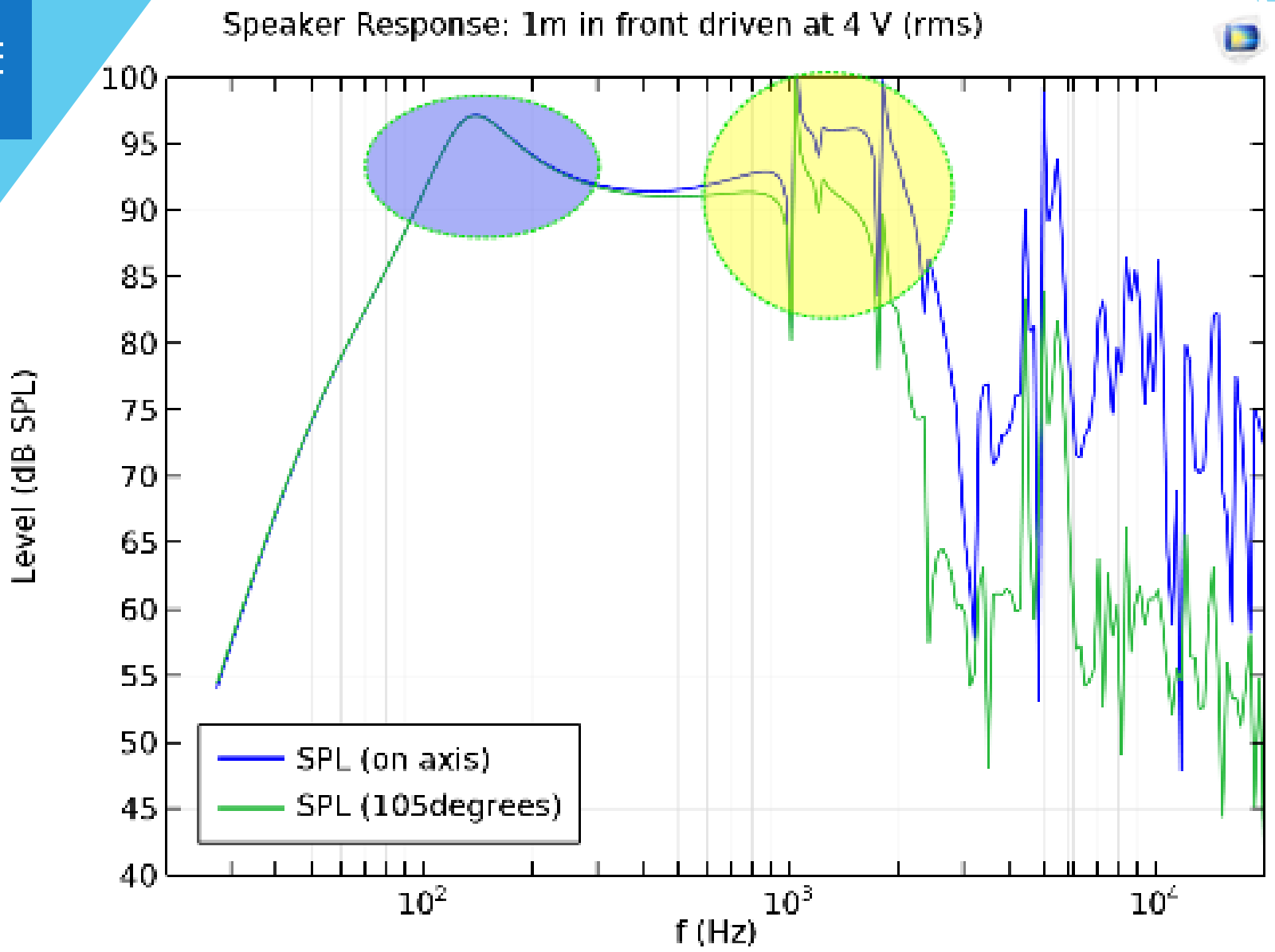
Acoustic model



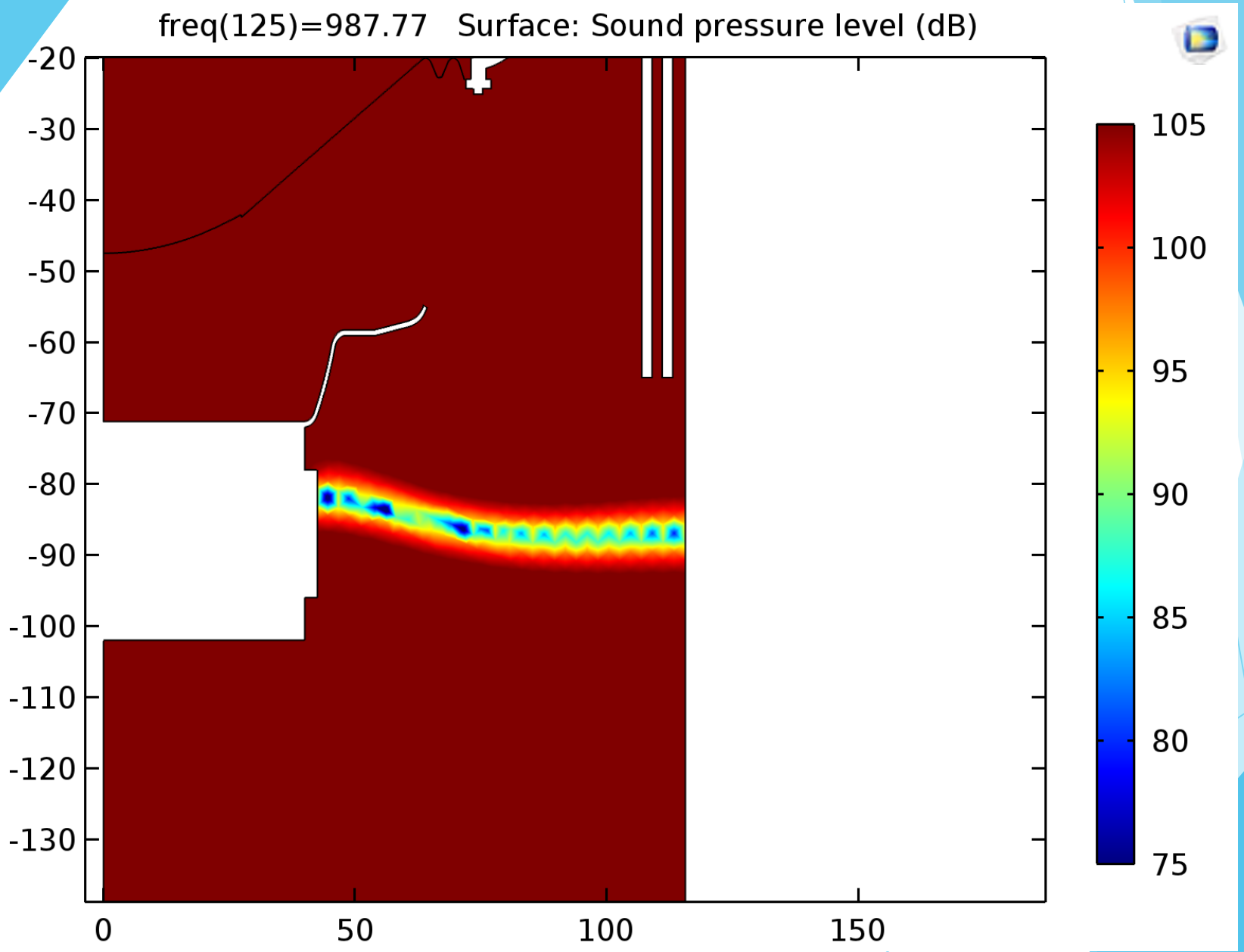
Acoustic model



Results


Speaker Response: 1m in front driven at 4 V (rms)
Level (dB SPL)
100
95
90
85
80
75
70
65
60
55
50
45
40
10^2
10^3
10^4
f (Hz)
SPL (on axis)
SPL (105degrees)

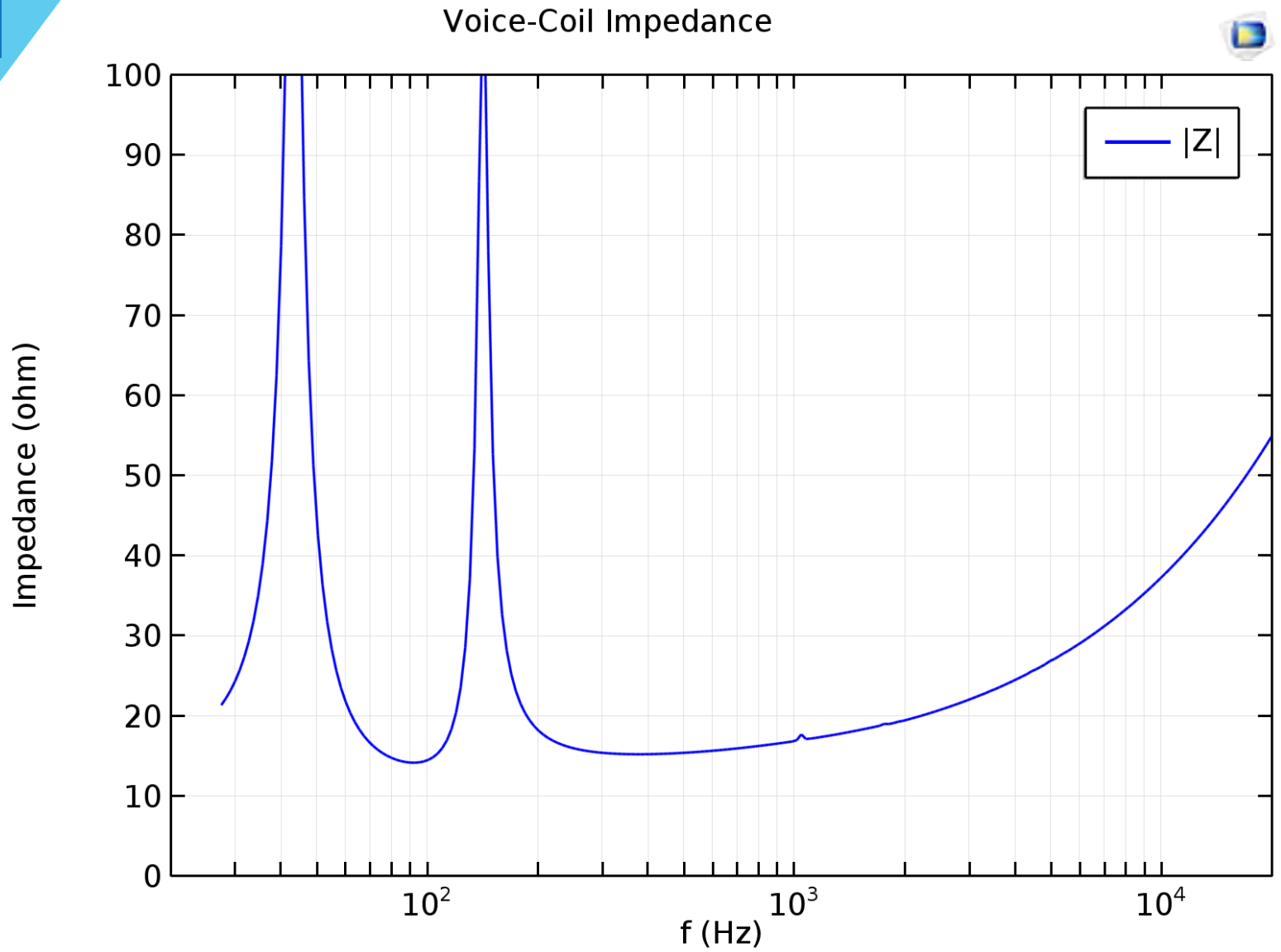
Results



Inside the Box

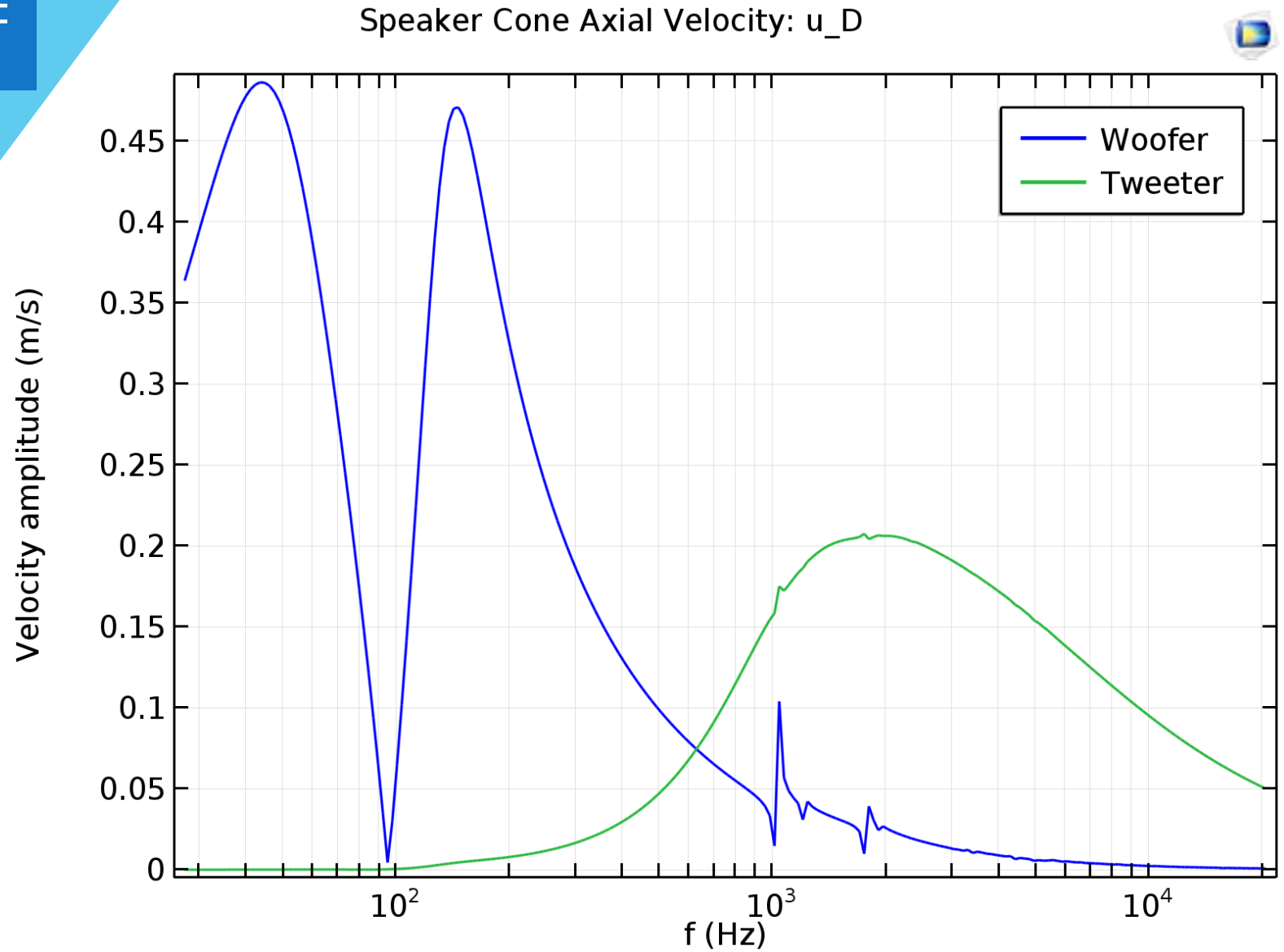
Results

Vented box

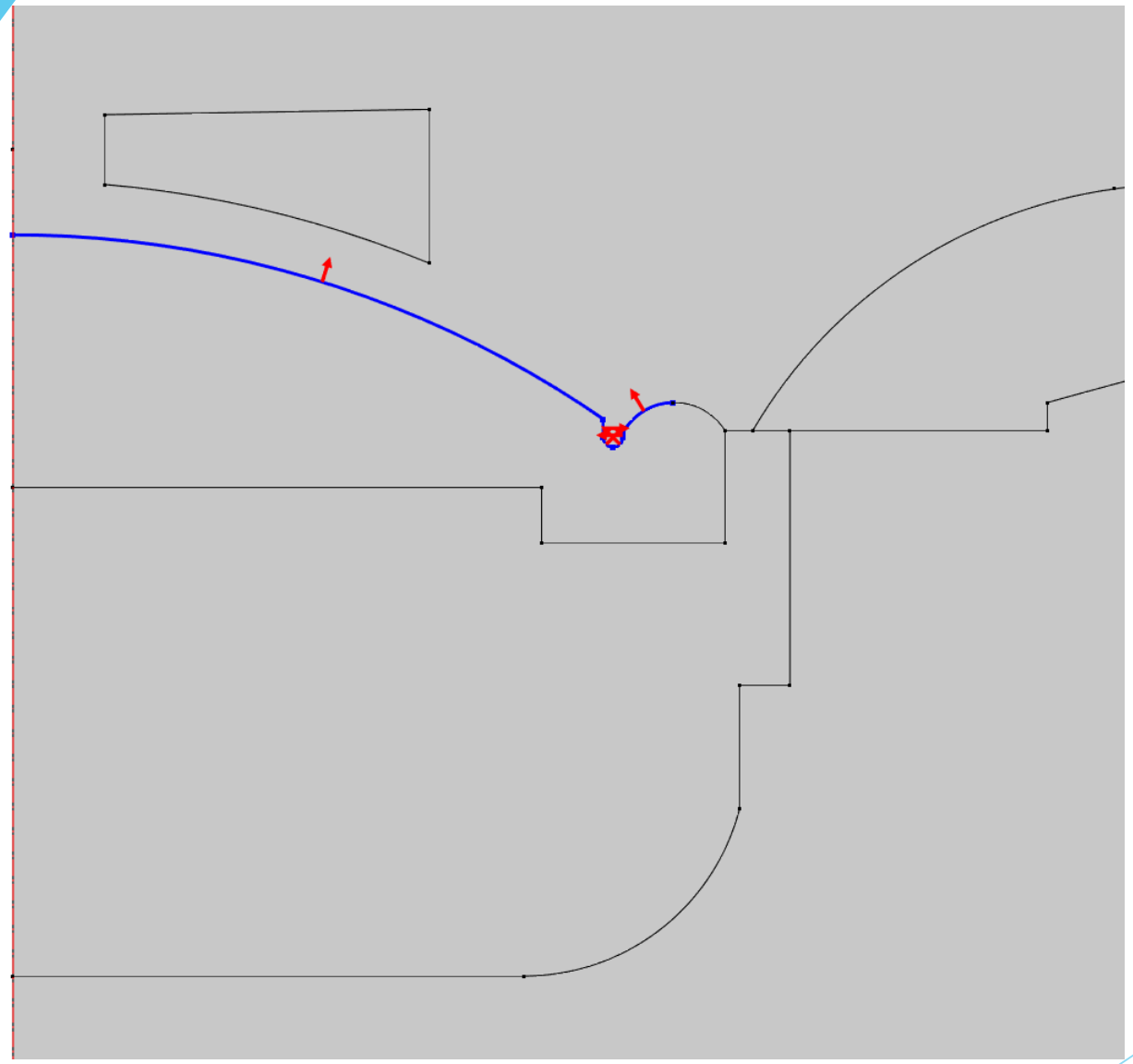


Results

Vented box

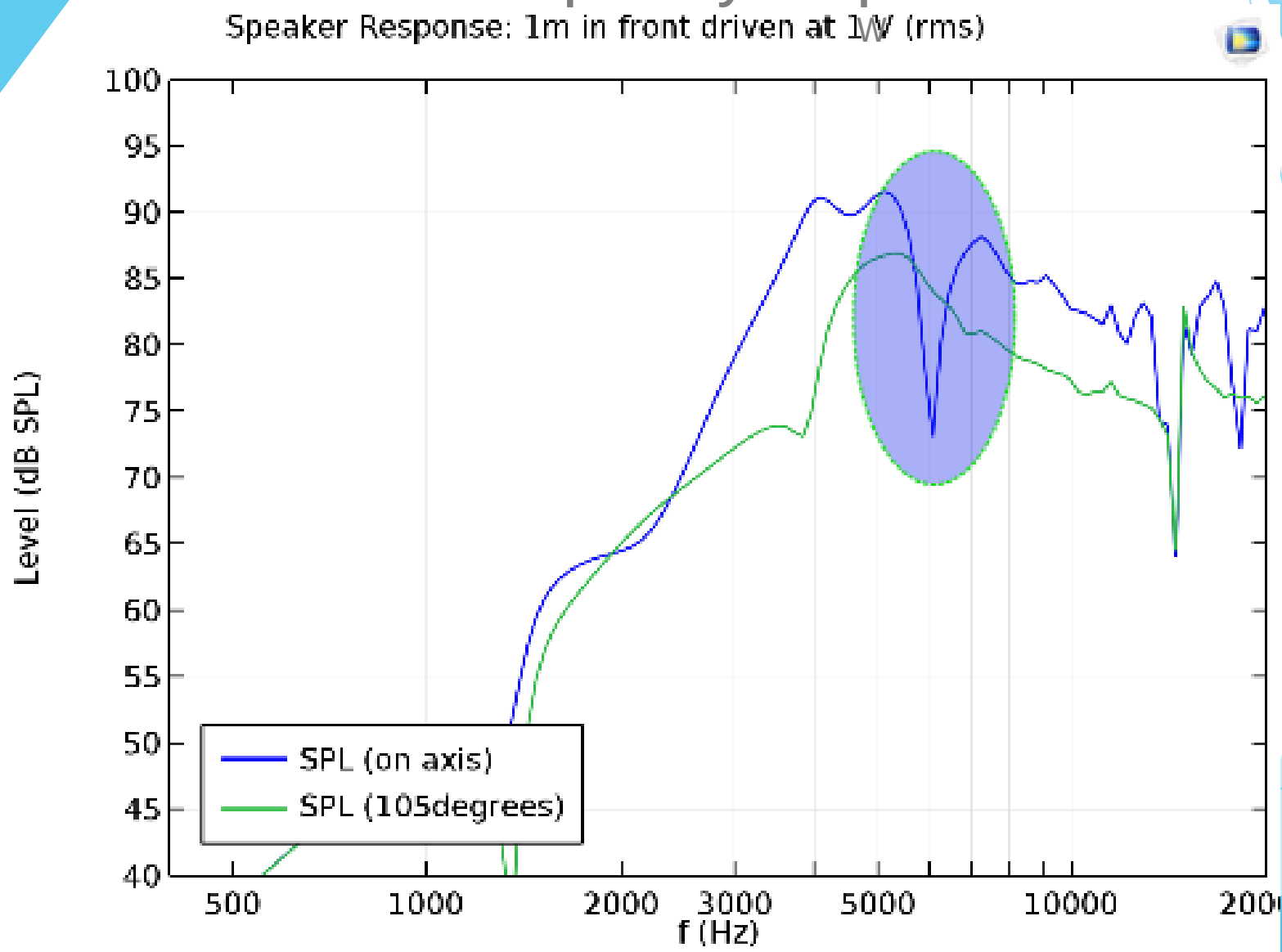


Acoustic model



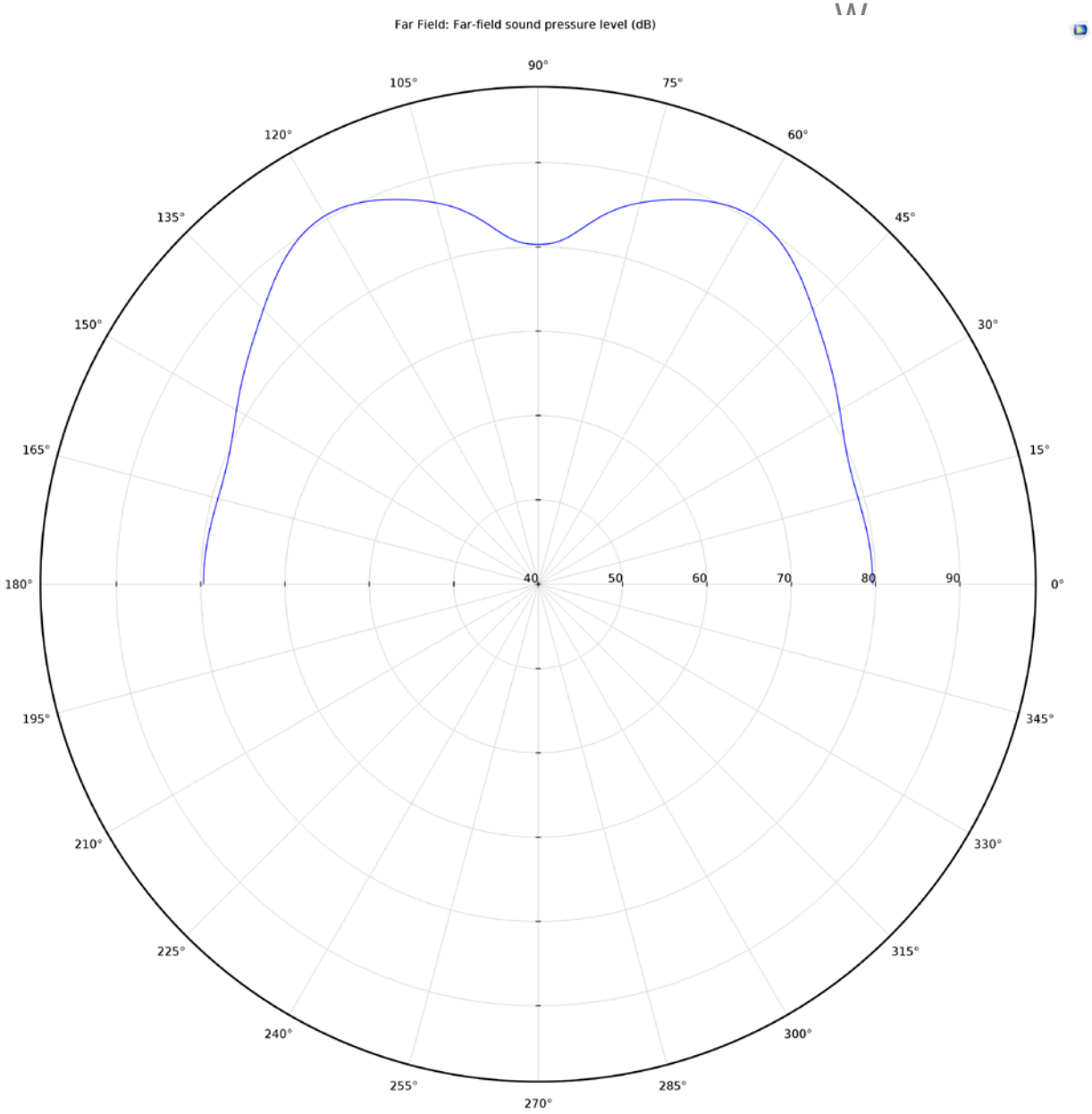
Results

Tweeter frequency response



A look at the problem

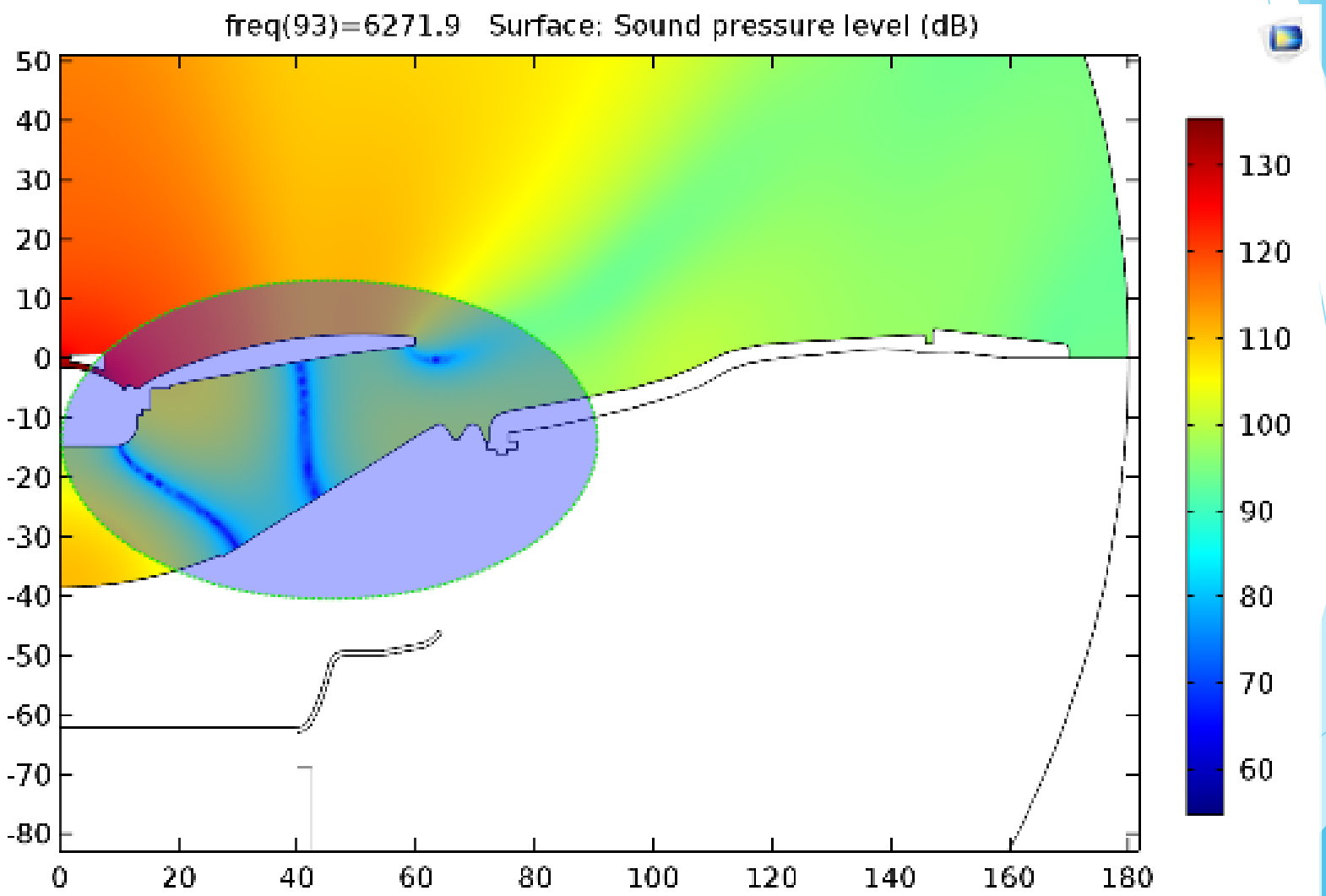
Results



A look at the problem

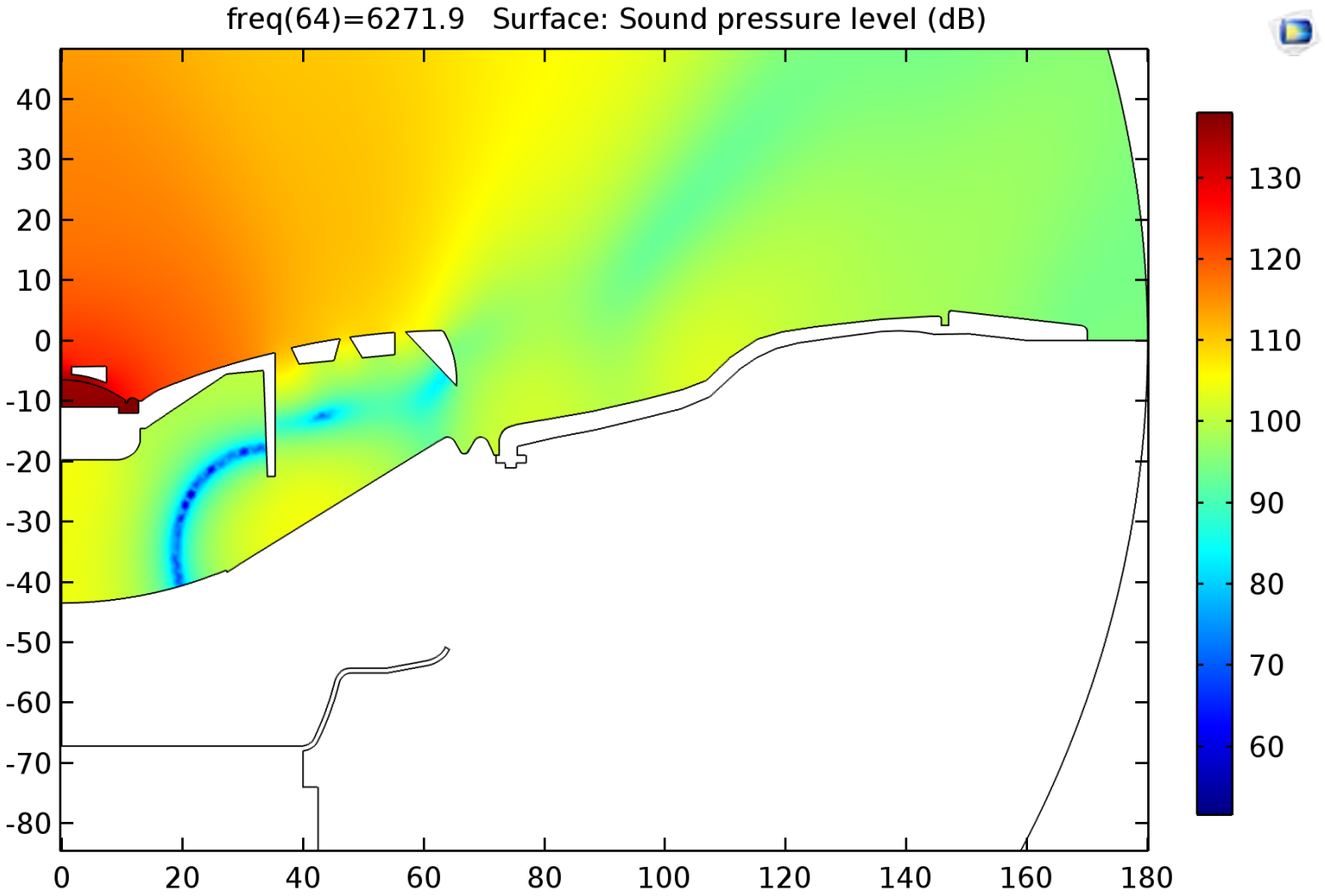
Results

w



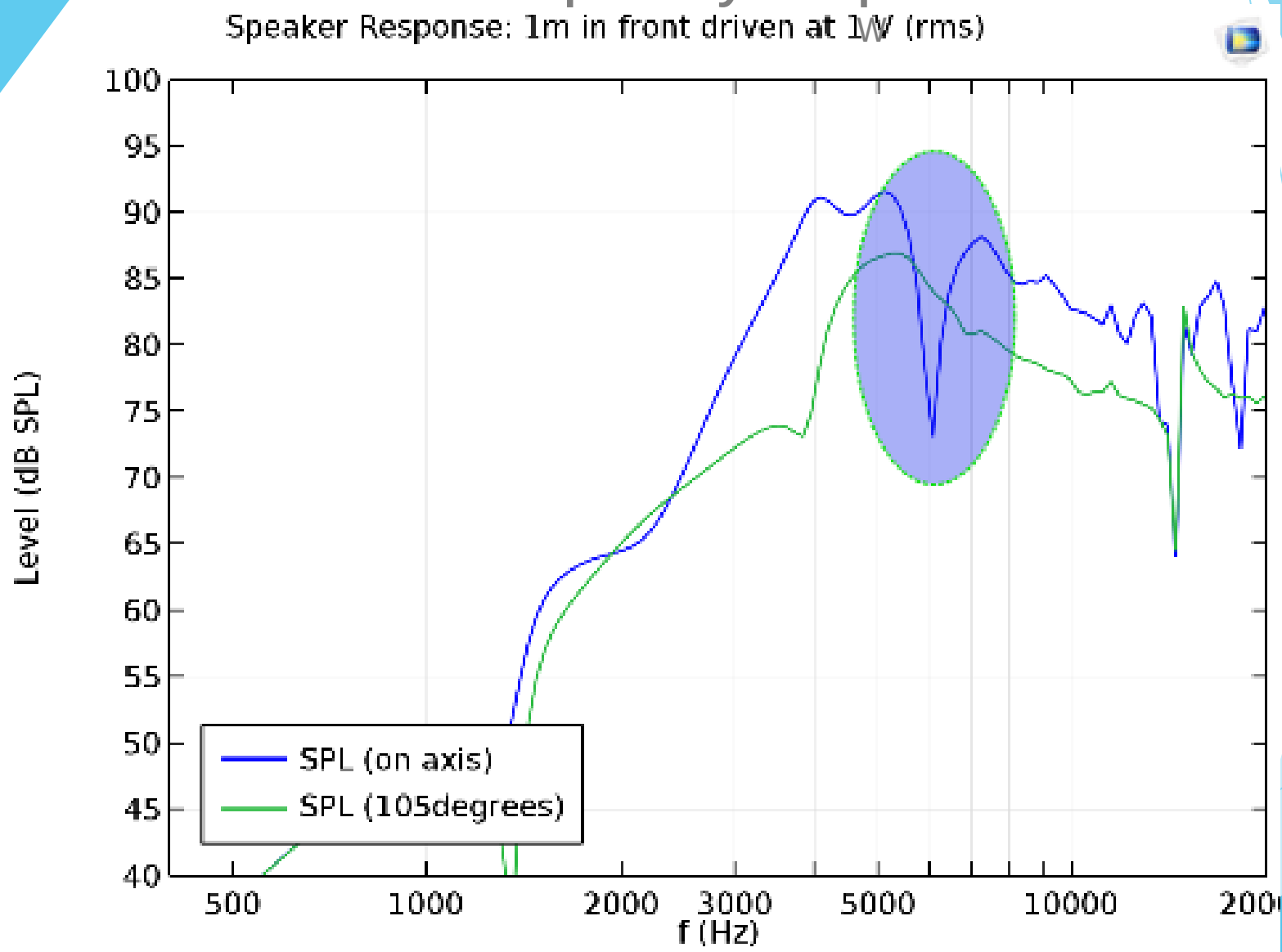
A solution to the problem

W



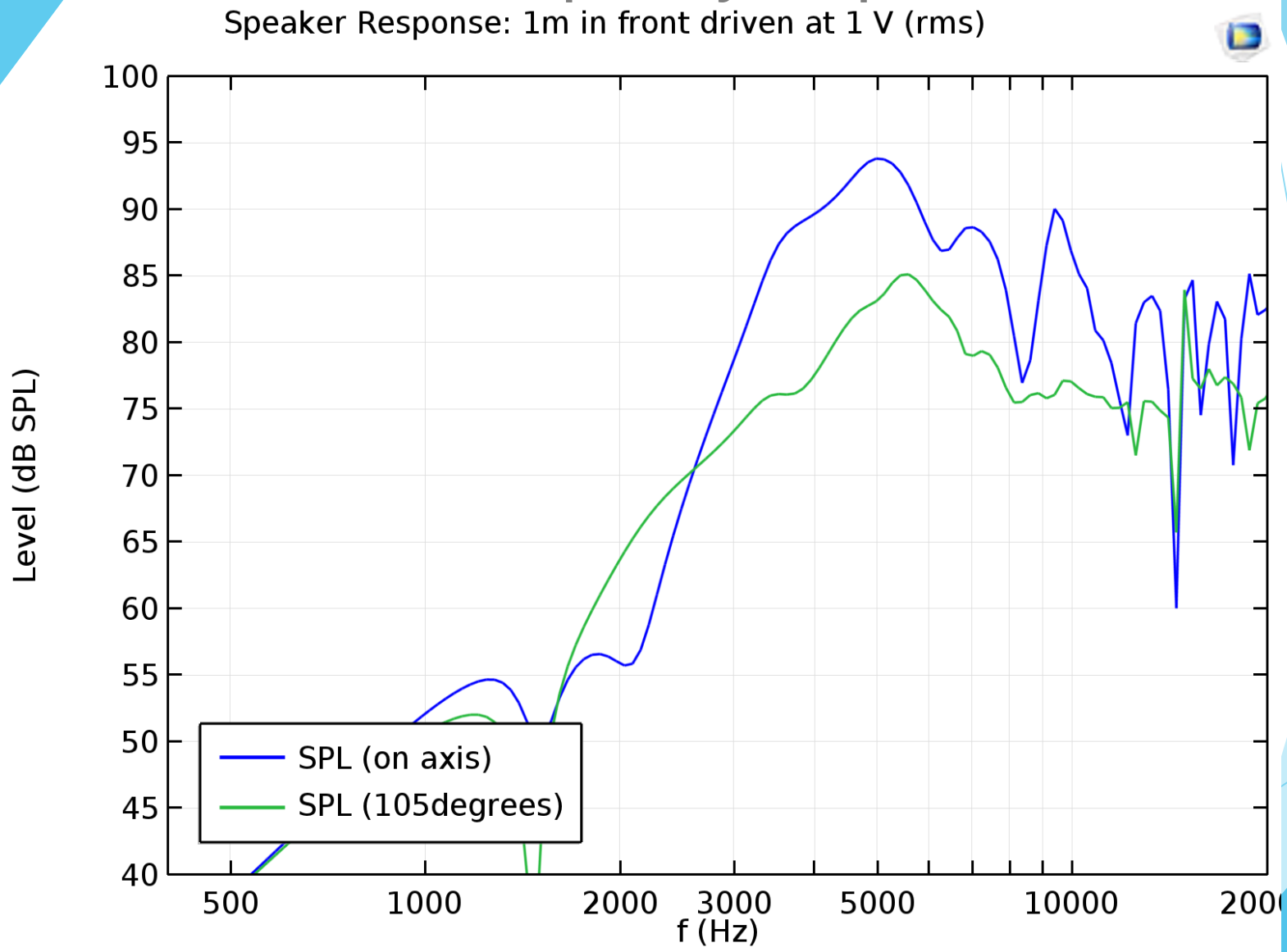
Results

Tweeter frequency response



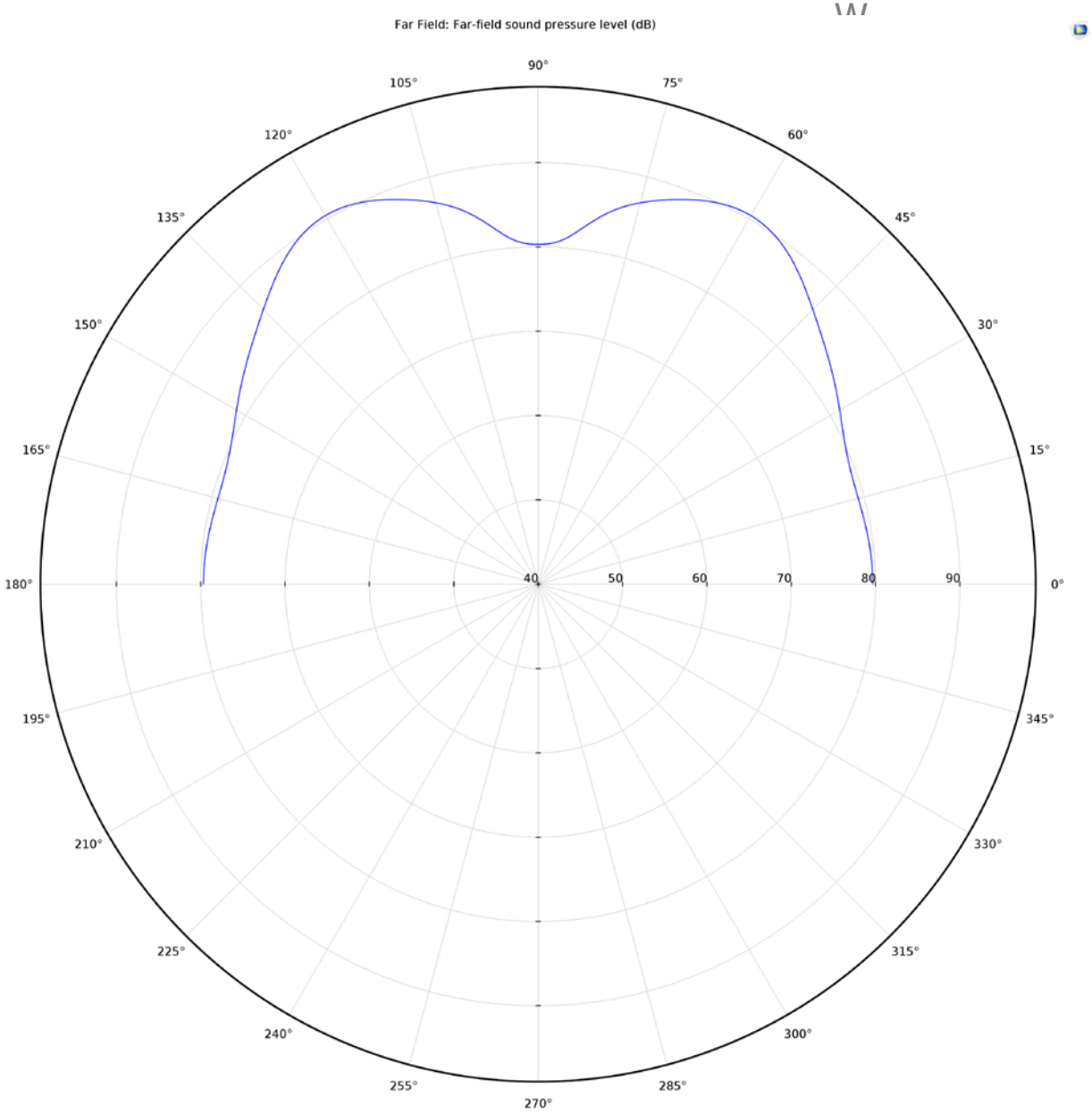
Results

Tweeter frequency response



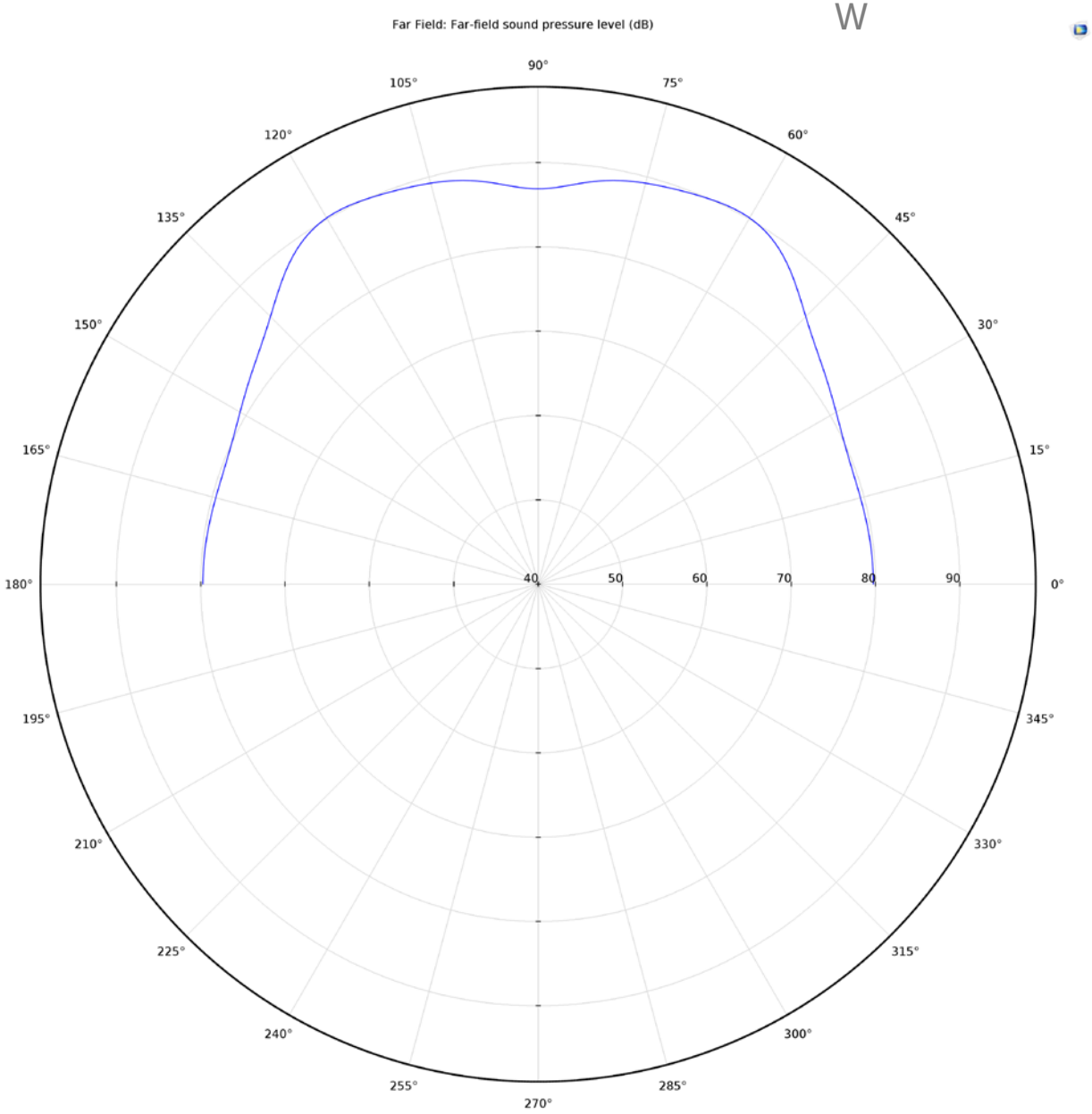
A look at the problem

Results



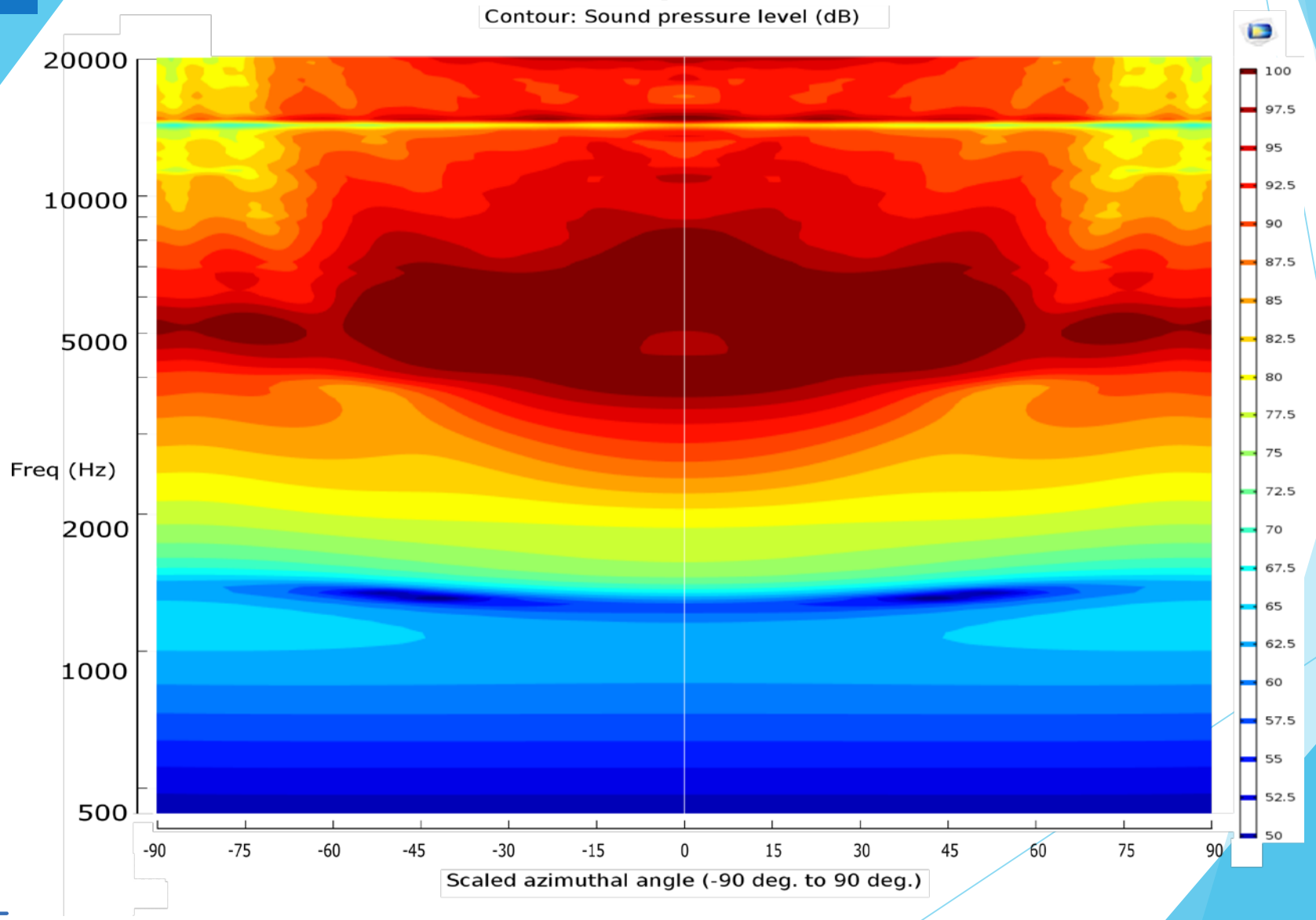
A look at the problem

Results



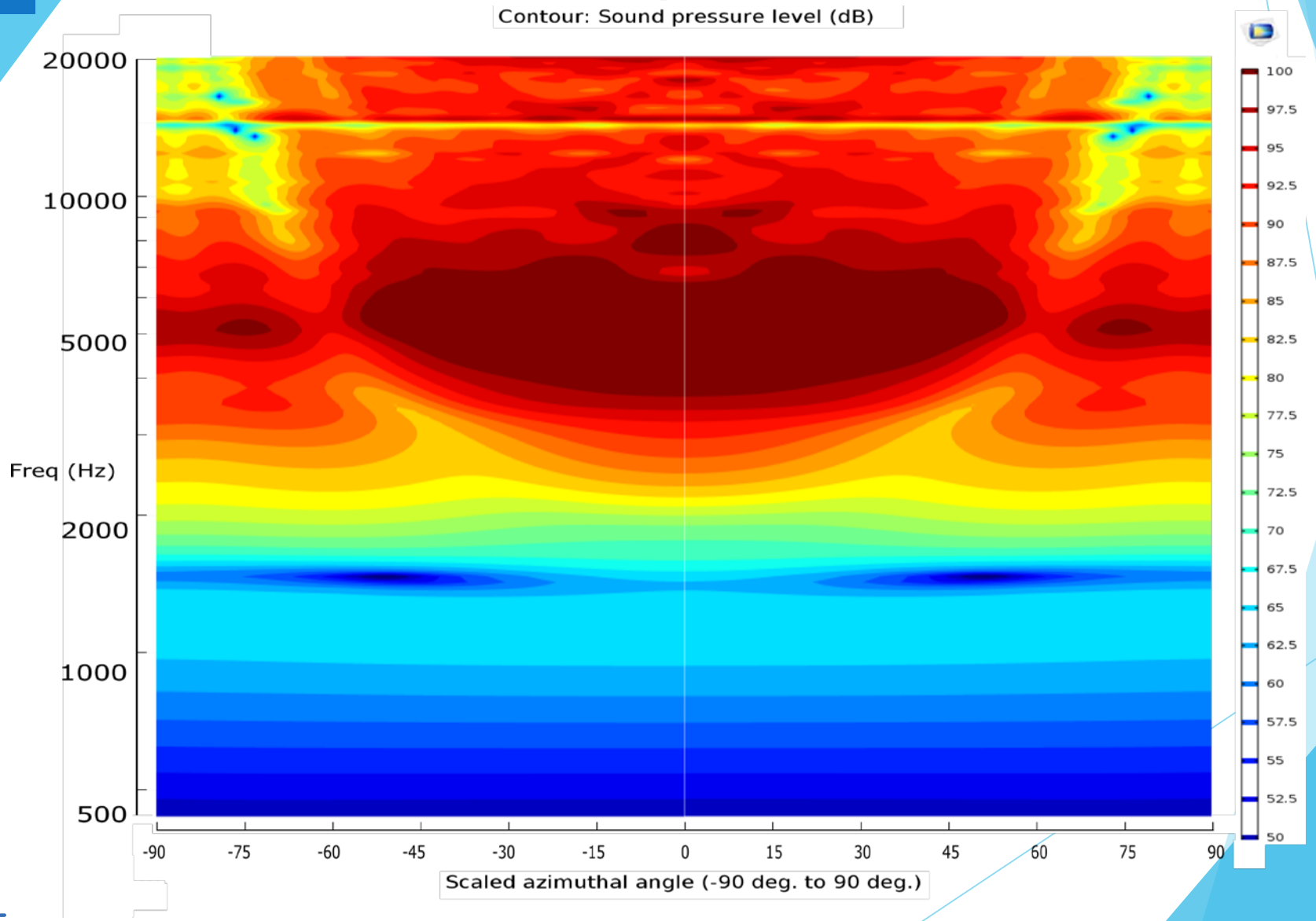
Results

Map


Contour: Sound pressure level (dB)
20000
10000
5000
2000
1000
500
Freq (Hz)
-90
-75
-60
-45
-30
-15
0
15
30
45
60
75
90
Scaled azimuthal angle (-90 deg. to 90 deg.)
100
97.5
95
92.5
90
87.5
85
82.5
80
77.5
75
72.5
70
67.5
65
62.5
60
57.5
55
52.5
50

Results

Map


Contour: Sound pressure level (dB)
20000
10000
5000
2000
1000
500
Freq (Hz)
-90
-75
-60
-45
-30
-15
0
15
30
45
60
75
90
Scaled azimuthal angle (-90 deg. to 90 deg.)
100
97.5
95
92.5
90
87.5
85
82.5
80
77.5
75
72.5
70
67.5
65
62.5
60
57.5
55
52.5
50

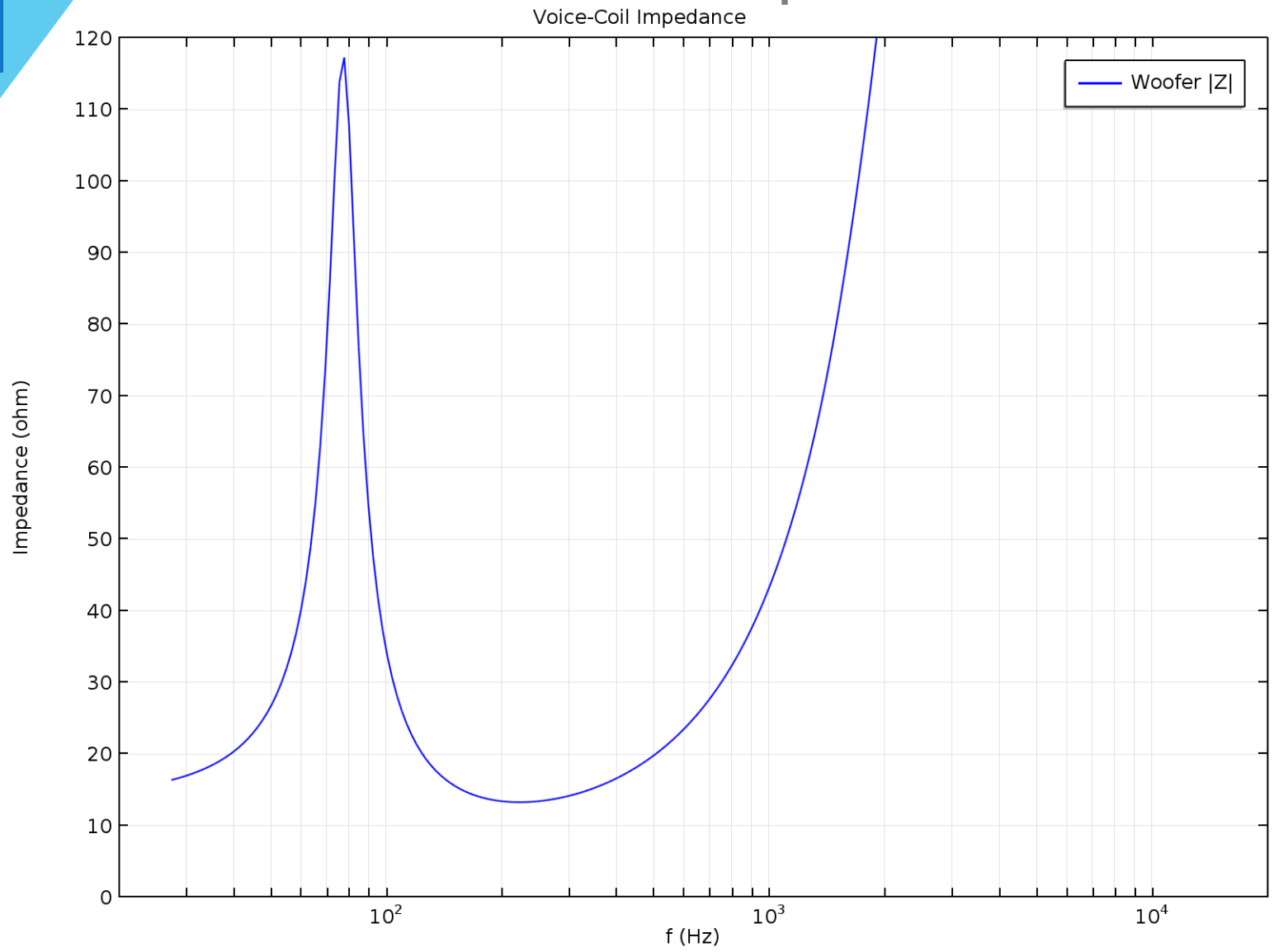
Results

Other example this

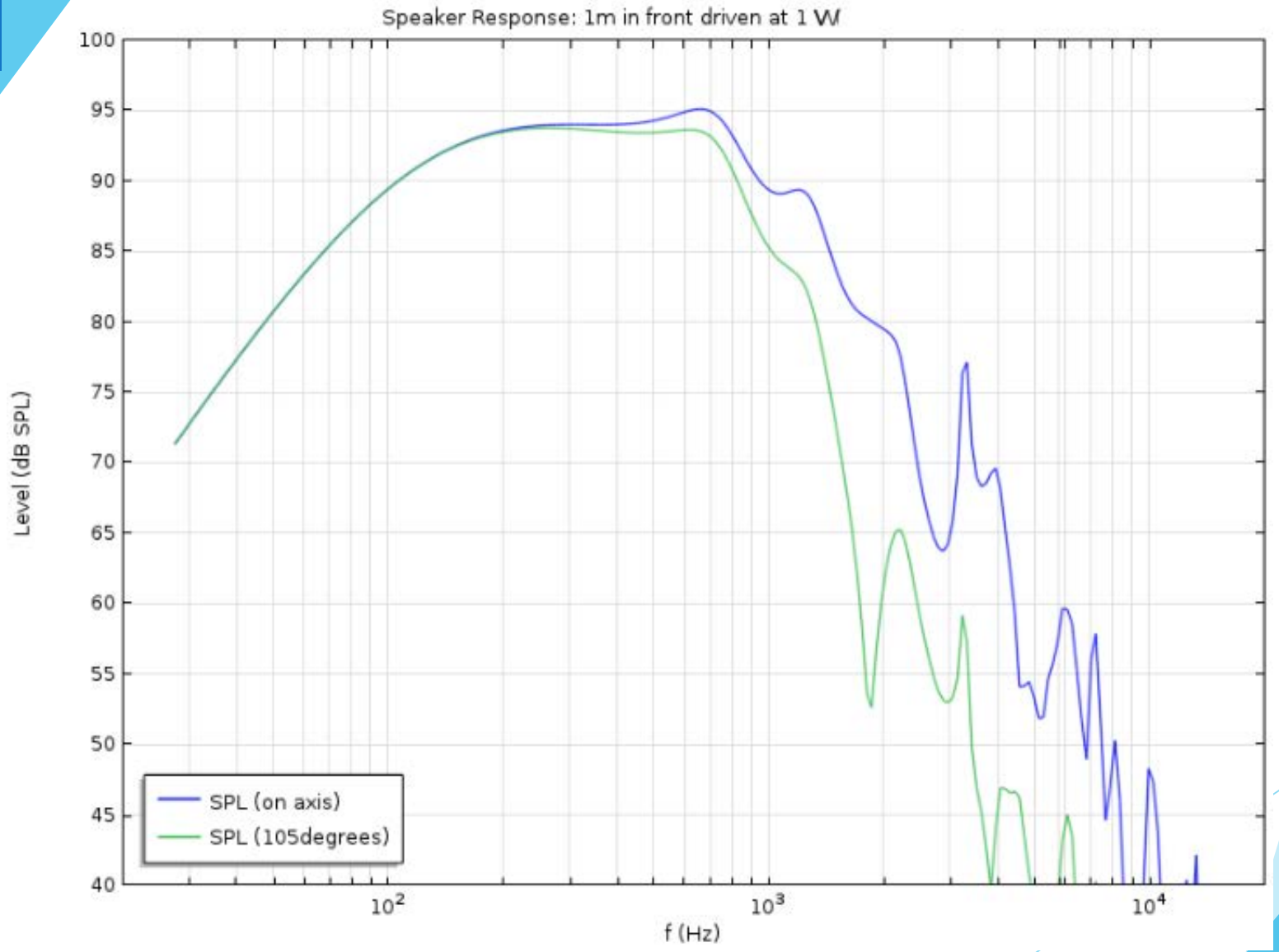
time with a closed box and a low pass filter

Results

Closed box with low pass filter

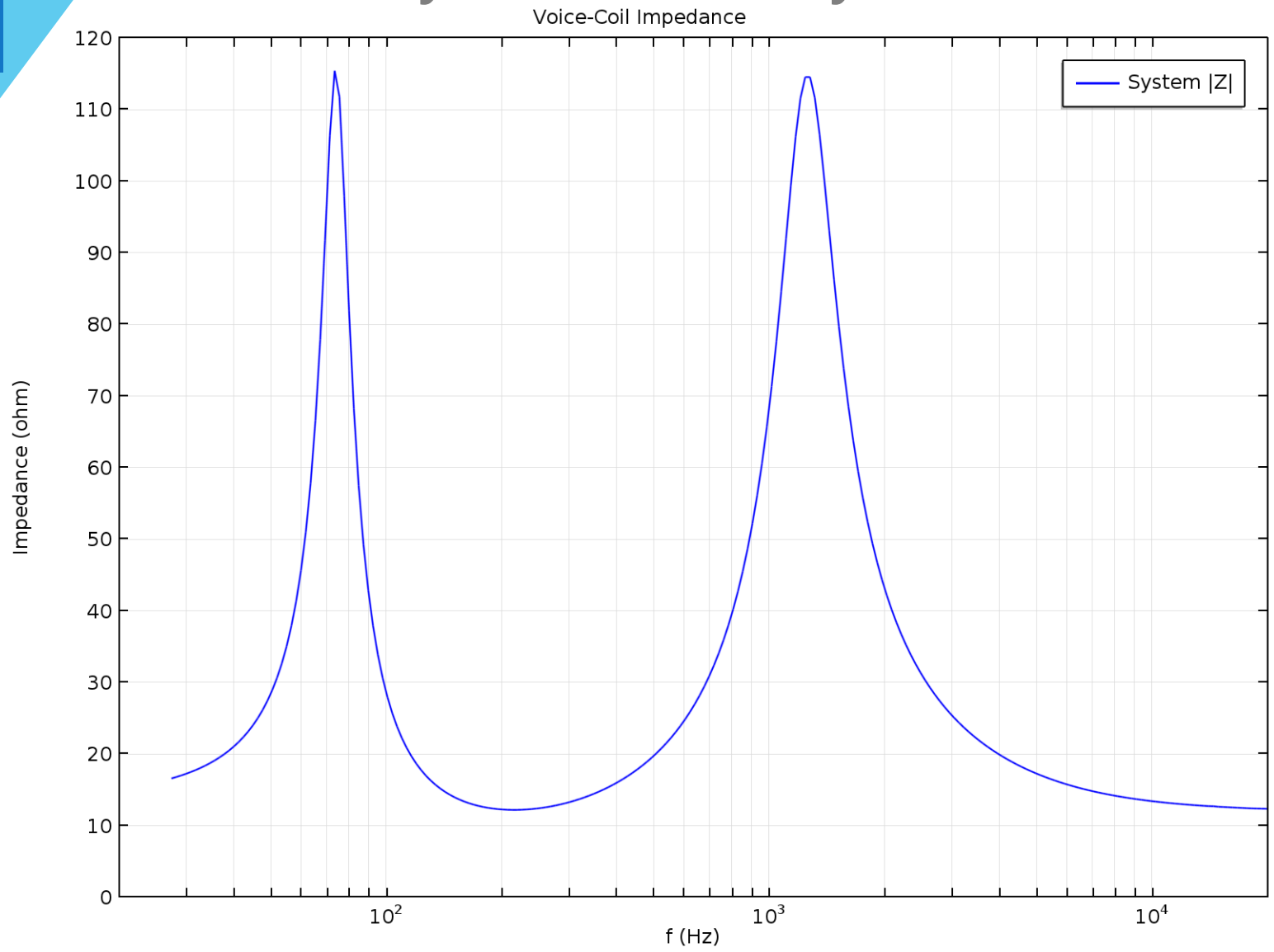


Results
Frequency response with filter

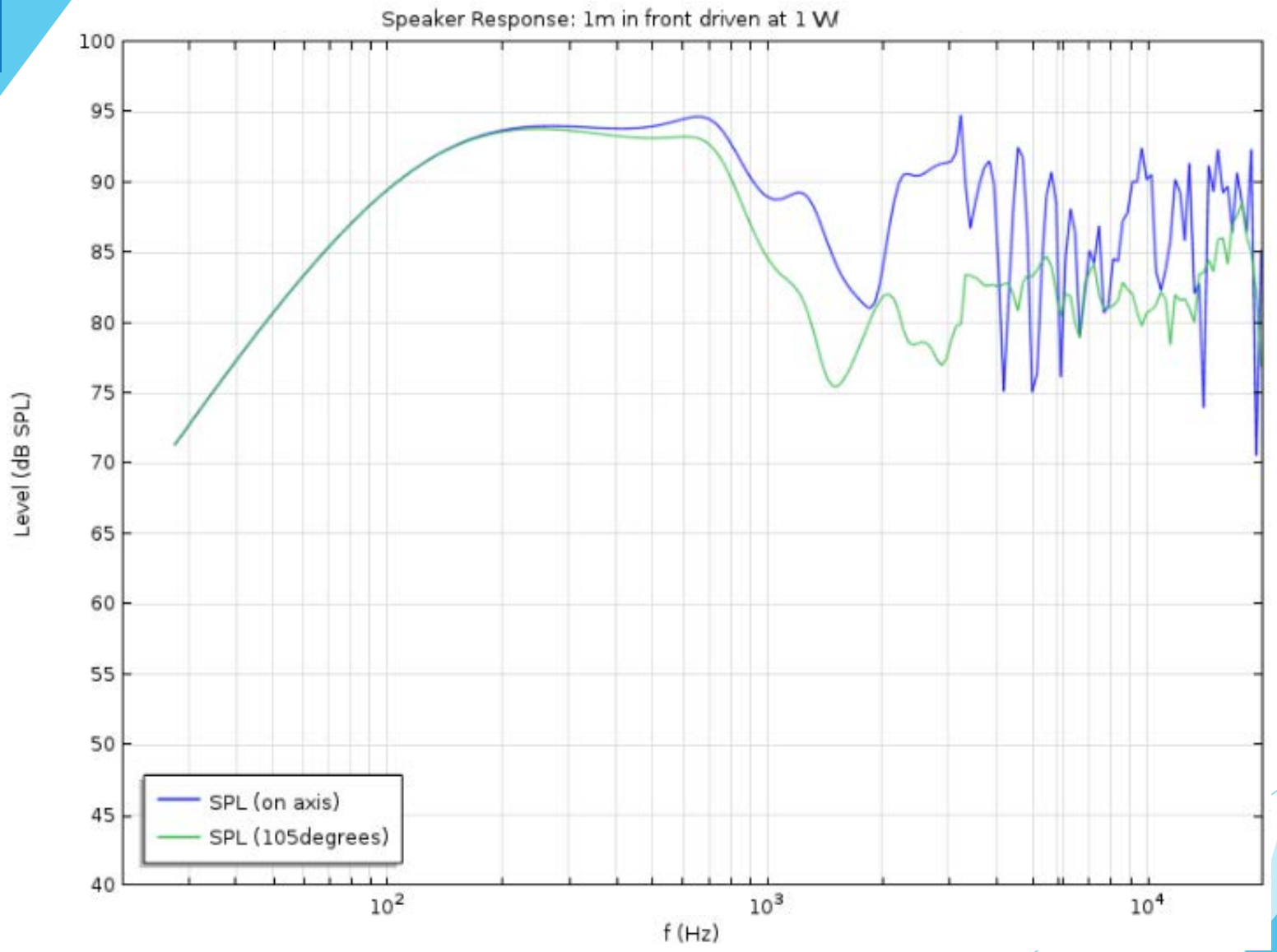


Results

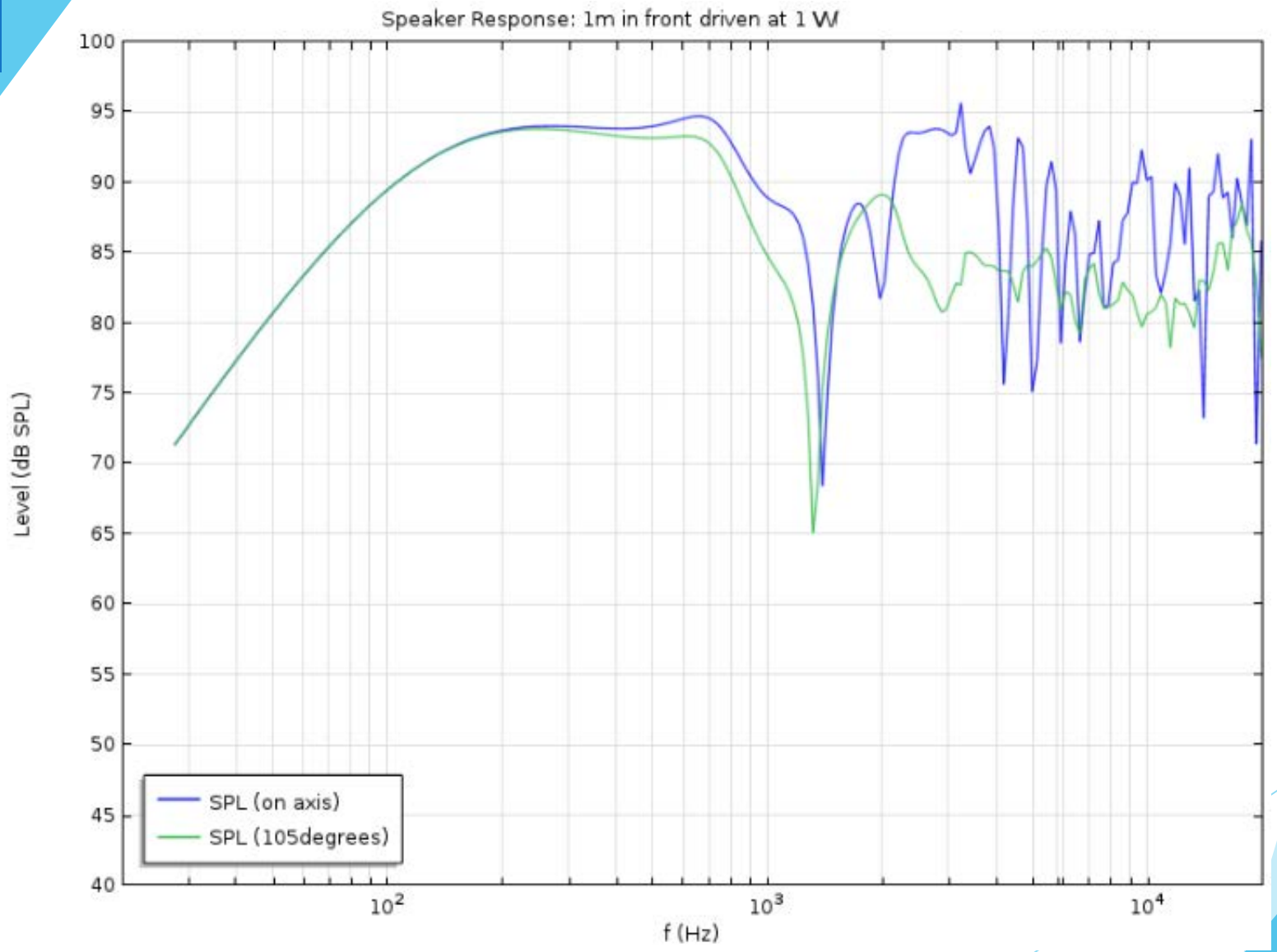
Two way closed box system



Results


Speaker Response: 1m in front driven at 1 W
Level (dB SPL)
f (Hz)
SPL (on axis)
SPL (105degrees)
100
95
90
85
80
75
70
65
60
55
50
45
40
10^2
10^3
10^4

Results
tweeter polarity inverted

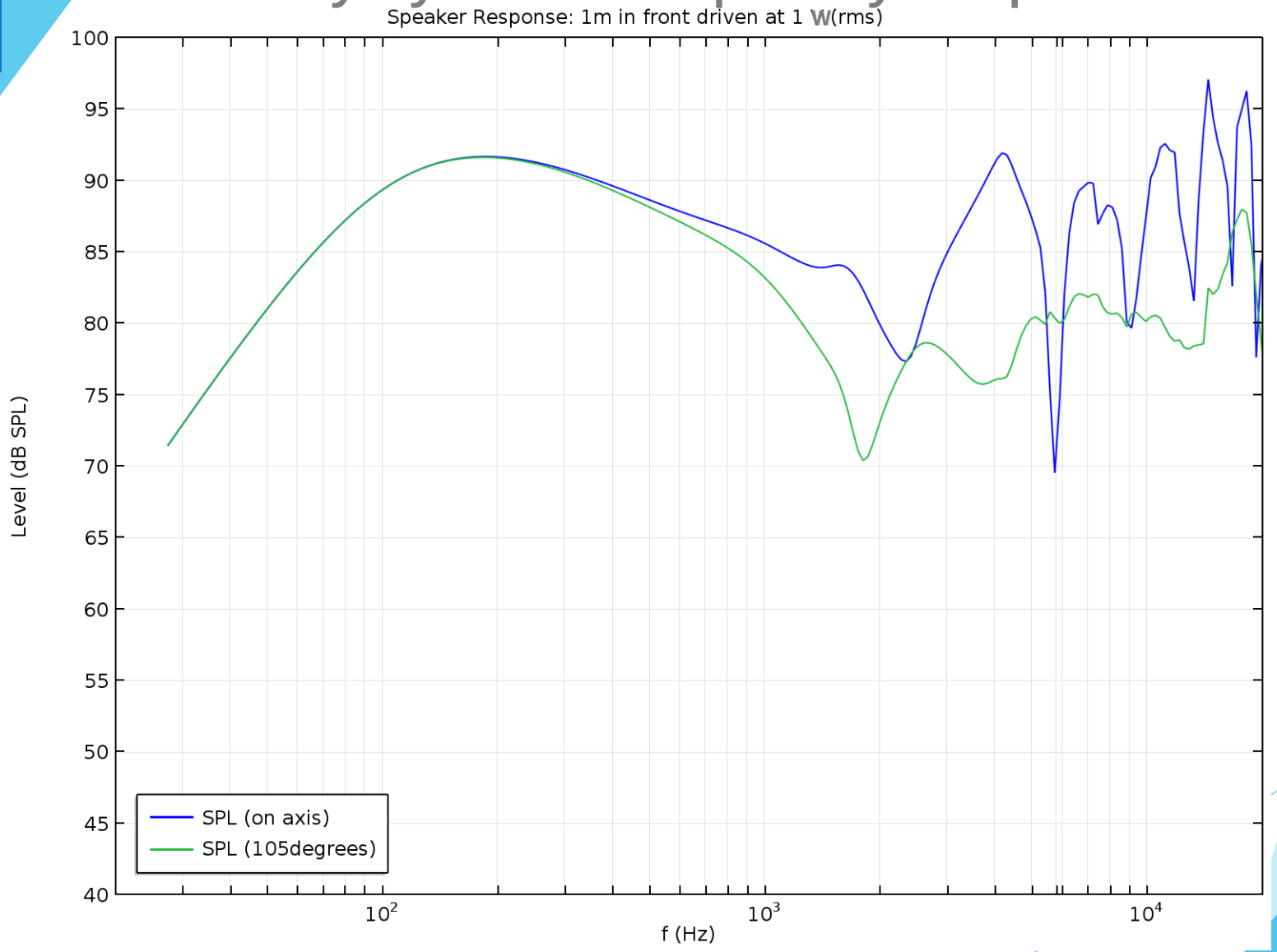


Results

Using parameters for another woofer…
different tweeter and waveguide geometry
and crossover for both

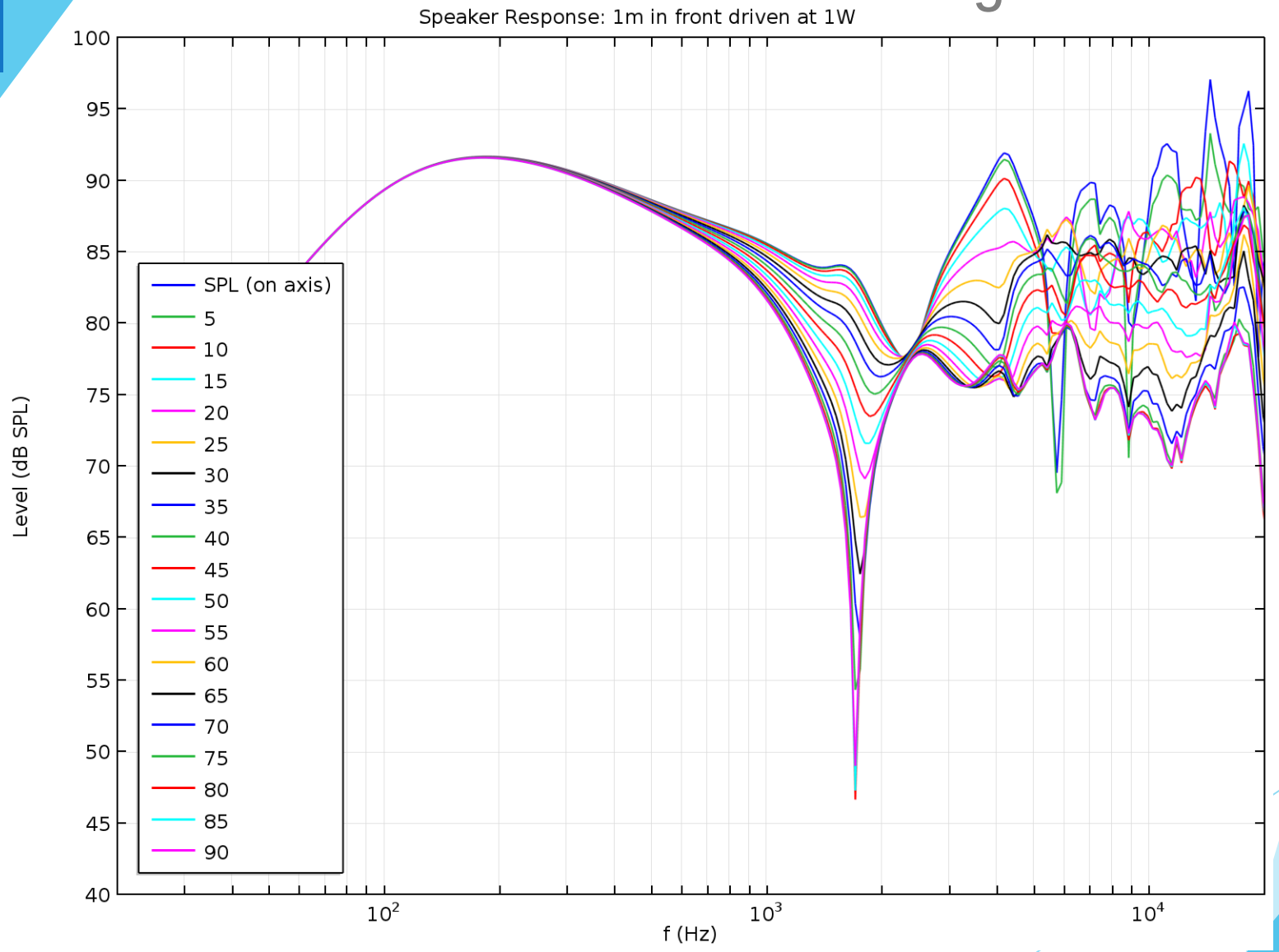
Results

Two way system frequency response

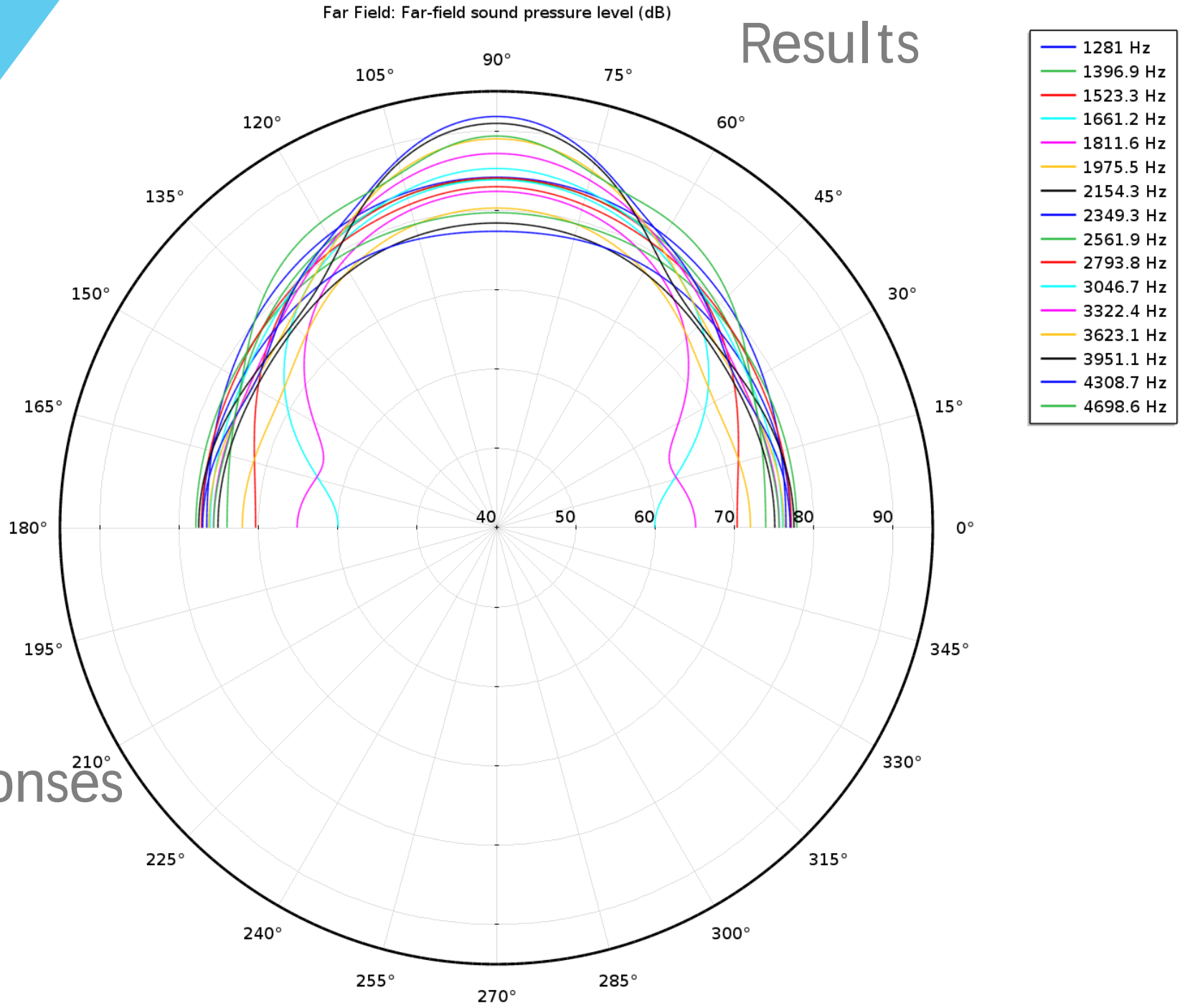


Results

Same seen at different angles



Results

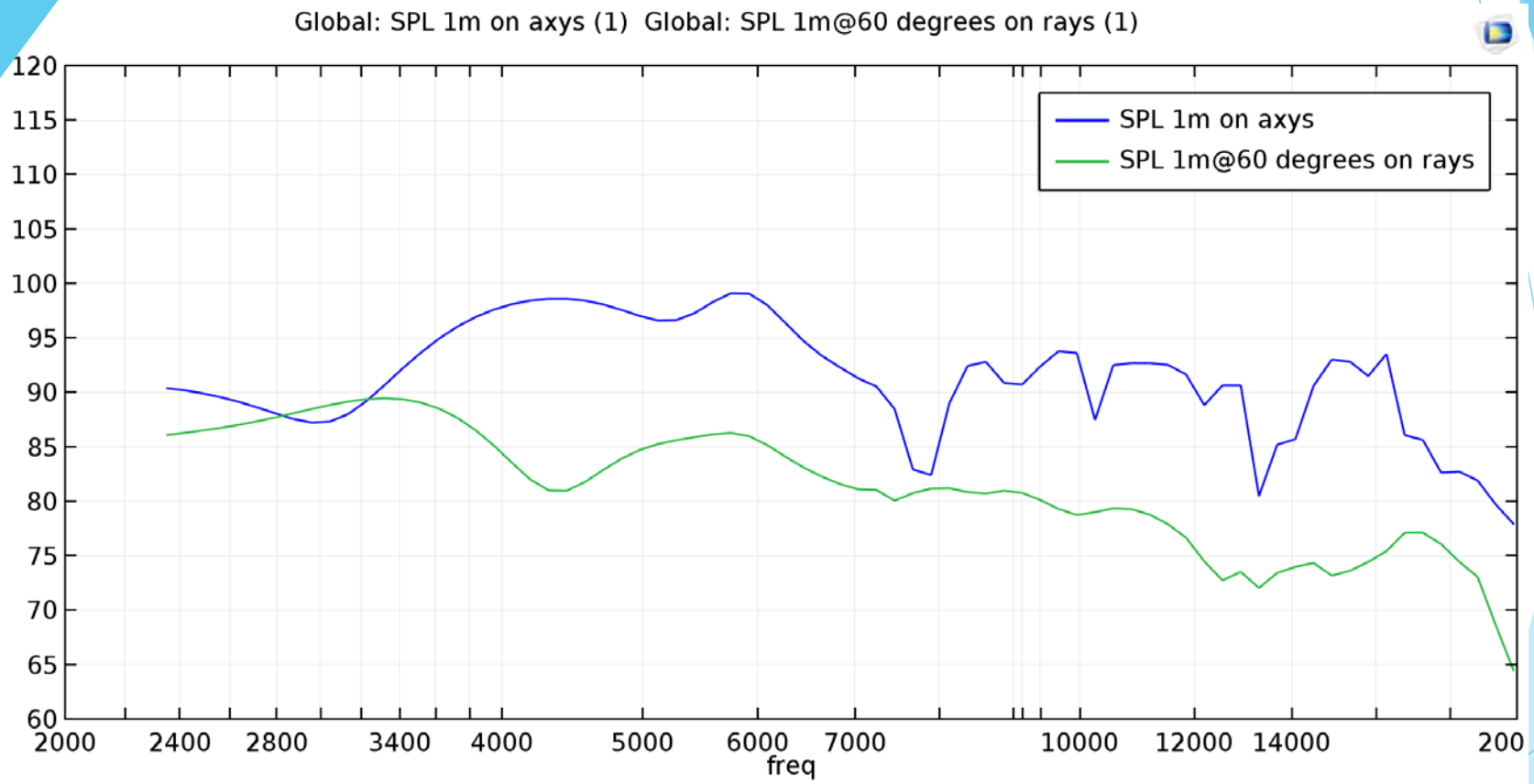


Polar responses

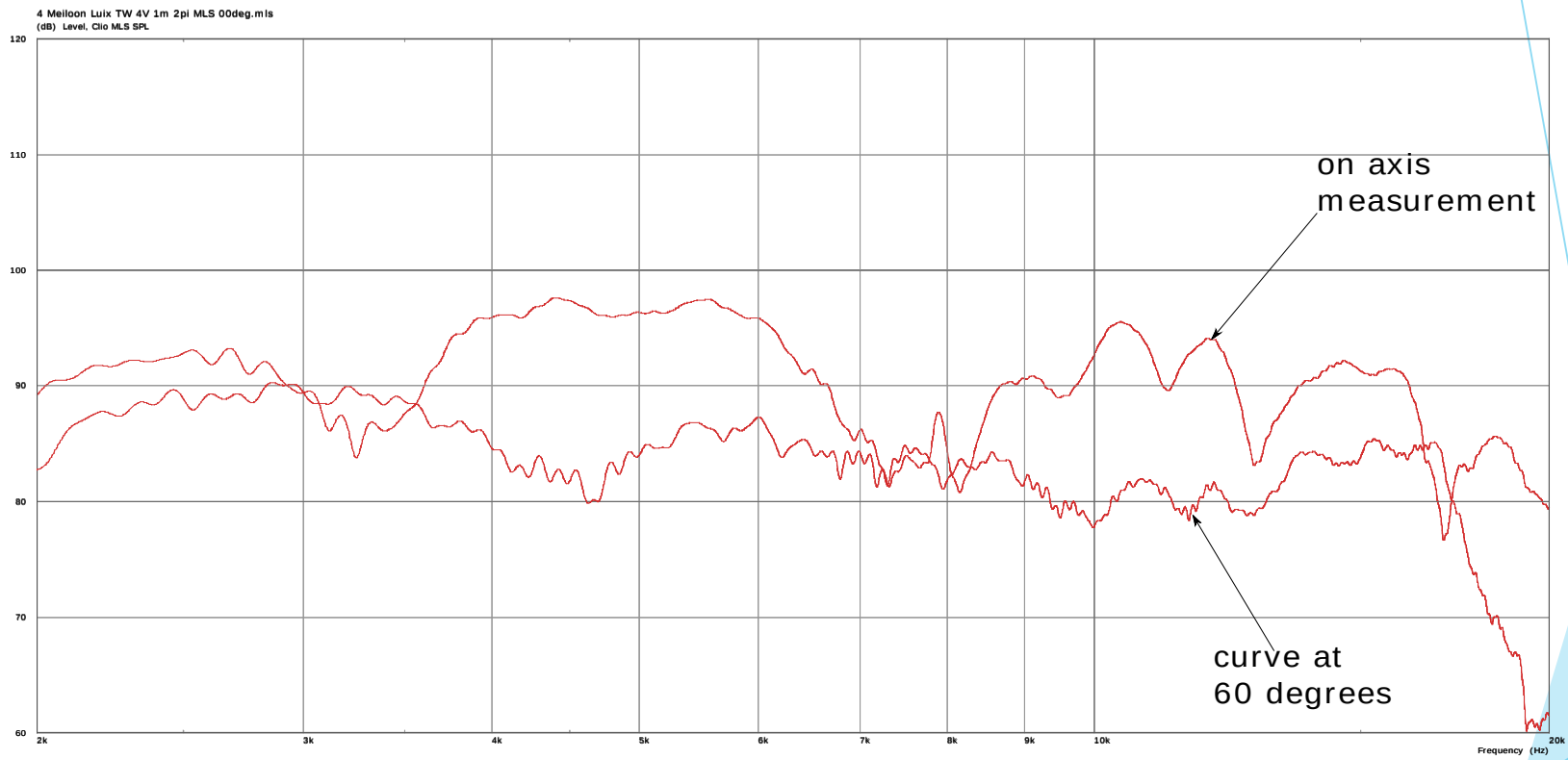
Results

How close simulations are to reality?

Results


Global: SPL 1m on axys (1) Global: SPL 1m@60 degrees on rays (1)
SPL 1m on axys
SPL 1m@60 degrees on rays
120
115
110
105
100
95
90
85
80
75
70
65
60
2000
2400
2800
3400
4000
5000
6000
7000
10000
12000
14000
200
freq

Results


4 Meiloon Luix TW 4V 1m 2pi MLS 00deg.mls
(dB) Level, Clio MLS SPL
120
110
100
90
80
70
60
2k
3k
4k
5k
6k
7k
8k
9k
10k
20k
Frequency (Hz)
on axis measurement
curve at 60 degrees

Results

Thank you