Sound Quality Improvements in Compression Driver Systems

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Background

- Compression drivers on horns have a poor reception among high-end audiophiles because of poor sound quality issues.
  - While many “audiophile” issues are hard to impossible to verify, it is quite apparent that horns on compression drivers have notable sound quality problems.
    - It ***is not*** widely agreed upon as to what these problems are due to.

Background

- Research and new developments in the last ten to fifteen years have led to a better understanding of horns and compression drivers that has shed new light on these problems.
- This knowledge has led to new designs that offer up compression driver subsystems with a sound quality that is equal to or better than the very best direct radiator drivers, but with vastly better radiation control, output level and power handling.

History

- In 1991, this writer did several papers on "Waveguides".
- The term "Waveguide" was coined to distinguish devices that were designed from the new theory and those which derived from the here-to-for standard approach offered up in the early 1900's by Webster – known as Webster's Horn Equation.

Waveguides

- In my work, I showed how a new approach to a flaring conduits based on the full mathematical machinery that of the wave equation could be used to solve the problem.
- This approach is far more mathematically laborious than the Horn Eq, but offers up several new insights into the state-of-the-art.

Waveguides

- It was found that a full Wave Equation solution to the waveguide problem defined a new set of contours
  - but these contours also had several new restrictions.
- It was also found that this new approach predicted “higher order mode” (HOM) wave propagation, which are not and cannot be predicted by Webster's approach
  - This stems from the limiting assumptions of the Horn Eq.

Waveguides

- Webster assumed planar waves in his analysis and the true planar waves are seldom, if ever, possible.
  - There are instances where the Horn Eq is exactly correct, but only for the lowest mode propagation - it is never correct when higher order modes exist, which will virtually always be the case.
- The presence of HOM in waveguides turns out to be a highly significant factor.

HOM in Waveguides

- HOM modes do not travel straight down the body of the waveguide, but instead reflect off of the walls as they propagate.
- They travel a longer path length than the main axi-symmetric mode and thus exhibit dispersion – frequency dependent velocity.
- They also exhibit a "cut-off" phenomena where-by these modes do not propagate below some given frequency.

HOM cutoff

- The mode cutoff phenomena is dependent on the physical size and coverage of the device and acts virtually identical to modal cutoff in a planar tube, albeit at different frequencies.
- At low frequencies in waveguides, only the “planar” mode can exist and it is only in this region that the Horn Eq has any validity.
  - even there its validity is in doubt.

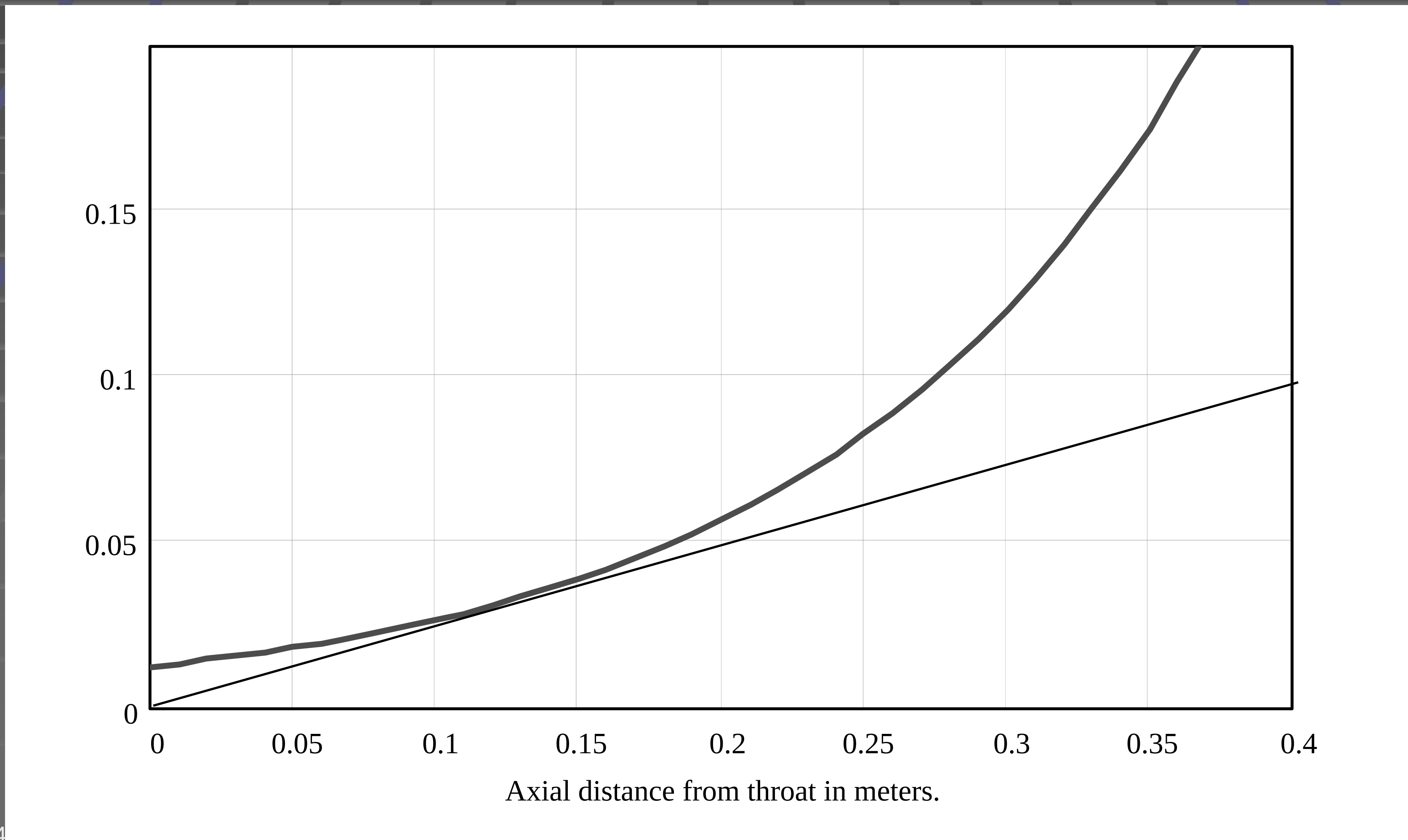
HOMs

- It is interesting to examine Webster's assumptions in more detail.
- From Morse we know that Webster's equation is valid as long as

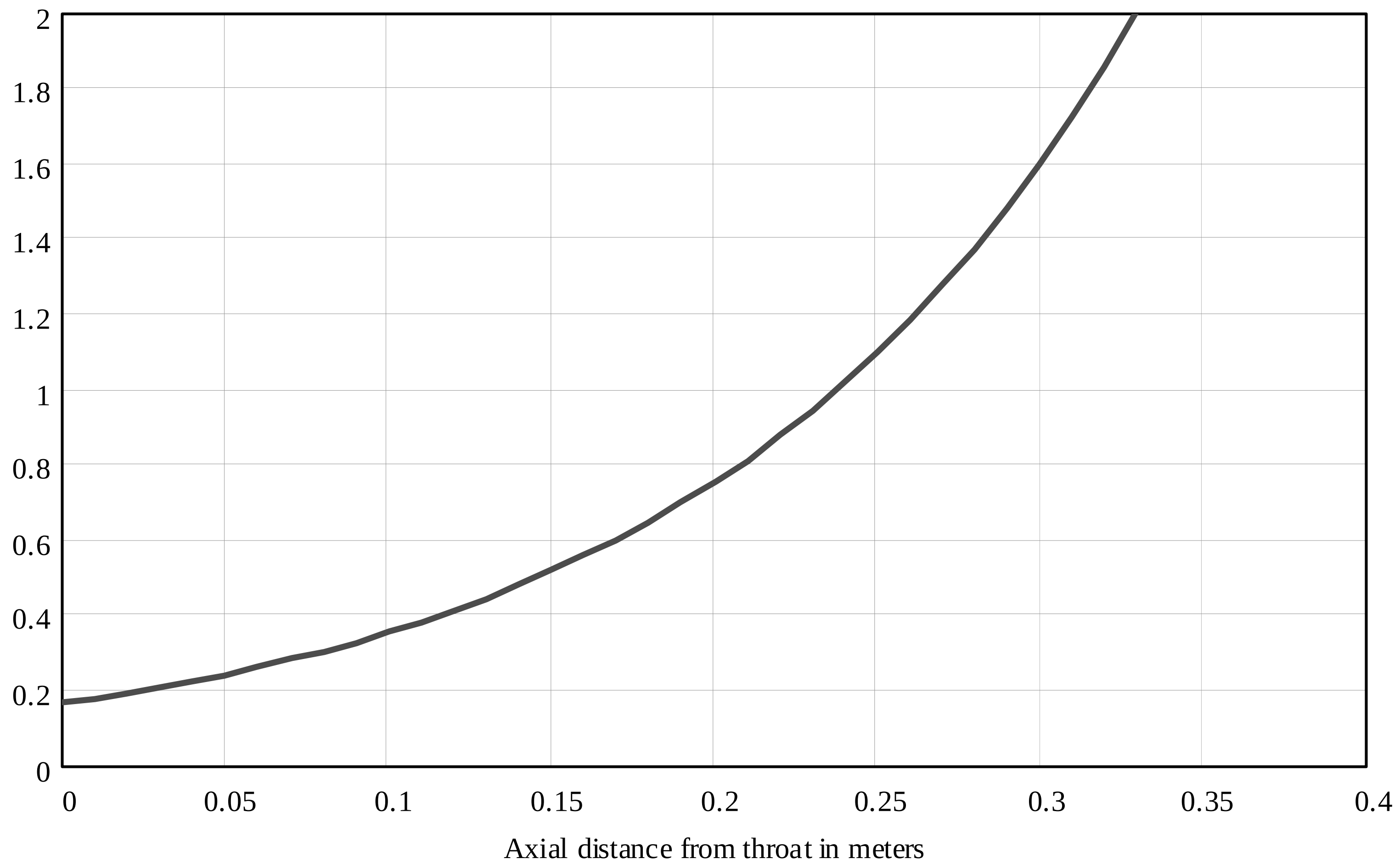
$$\left| \frac{d}{dx} \sqrt{S_0 \cdot e^{m \cdot x}} \right| << 1.0$$

(in an exponential horn)

An exponential Horn Contour



The Assumption equation



HOM

- Beyond the axial point where the waves must diffract, there will be HOMs.
- The Horn Eq cannot deal with this situation and hence it is not useful.
- Only in very short horns at very low frequencies can we expect the Horn Eq. to yield an approximation which is close to reality.

HOM

- Further, the Horn Eq does not yield any information about how to predict, minimize or control the HOM.
- Only the waveguide approach allows for such an analysis.
- This was exactly the analysis that was done by this writer in the late 90’s.

Waveguides

- Although all waveguides must generate some level of HOMs (except in a few extreme situations that are not feasible in practice), it can be proven that the separable coordinates waveguides (Oblate Spheroidal, Prolate Spheroidal, etc.) will generate a minimum of HOMs.
  - All separable coordinate surfaces are catenoid surfaces.

Waveguides

- It can also be shown how the phase plug in the compression driver has a significant effect on the generation of HOMs even before the waves enter the waveguide because of a mismatch of wavefronts at these surfaces.
- Current phase plug designs are sub-optimal in this regard.
  - See Patent Application Geddes, 20060034475 filed Aug. 2003

Horns

- Traditional designs of horns that use diffraction as a mechanism for directional pattern control generate enormous amounts of HOMs.
- These devices are know to have limited sound quality acceptance and are used only where pattern control – and not sound quality - is the principle requirement.
- Waveguides achieve better control with a minimum of HOM generation.

Subjective aspects

- How does all this relate to the subjective perception of sound quality in these devices?
- To answer this question, we need to look at the results of several recent studies of Sound Quality.

Distortion Perception

- In 2001, Geddes and Lee and Lee and Geddes showed how current measures of nonlinear distortion were completely inaccurate in regards to the subjective impression or perception of this distortion.
- A new metric was proposed – the GedLee Metric – which was shown to be significantly more accurate at predicting the subjective perception of nonlinear effects.

Distortion Perception

- Concerning our interest here, the pertinent result of this work was how it showed that the nature of our hearing mechanism does not allow us to readily perceive nonlinear system characteristics that are of low order.
- This has significant implications to loudspeakers since, in general, the high levels of distortion noted in them are dominated by the lower orders.

Distortion Perception

- These results appear to suggest that nonlinear problems in loudspeakers might be of relatively small importance except in those cases where the drivers are used at the limits of their capabilities.
- *This is a most discomforting idea given the large amount of resources spent on reducing these distortions.*

New Results on Perception

- In 2003, Geddes, Lee and Magalotti reported on a subjective test that they had performed with compression drivers.
- In this test three drivers were tested for the perception of linear and nonlinear distortions. 26 listeners participated in this double blind test.
- It was found that none of these listeners could reliably perceive the nonlinear distortions even when these distortions were upwards of 20% THD.

New Results on Perception

- While this result was quite surprising to all, it is none-the-less completely consistent with the results and conclusions from the previous set of tests on nonlinear distortion.
- Nonlinear distortion in a compression driver is simply not a subjective factor.
- But what about the Horn/Waveguide?

Distortion in Horns

- It can also be surmised that the nonlinear distortions created by a Horn or Waveguide would be of negligible importance regarding sound quality.
- The reason for this is that the nonlinearity of air is of very low order. Only in a very long horn of slow expansion would the nonlinearity of a horn generate any appreciable level of higher order nonlinearity.

The Newest Results on Perception

- This situation leads to some very interesting questions. The following (unproven) points are noteworthy:
  1. Compression drivers on horns/waveguides do exhibit an increasingly poor sound quality with increasing sound level
  2. This effect is not likely to be a result of a nonlinear process within the system as these processes are not audible

Hypothesis

- Perhaps there are linear processes within this system which are actually perceived in a nonlinear fashion.
- There is substantial evidence to say that this is in fact the case.
  - Moore, et. al. showed how the perception of Group Delay was highly level dependent
  - Toole, et. al. showed a similar result

Perception of Group Delay

- In 2006, Lee and Geddes showed also how the perception of group delay - as implemented by a signal characteristic of a HOM - was strongly dependent on the absolute level.
- These results confirmed the hypothesis that the ears perception is nonlinear and imply that a perceived nonlinearity in an audio system need not be due to a nonlinearity in the audio system itself.

Back to the HOMs

- Since the HOMs in a waveguide travel at a slower speed along the axis of the waveguide (they are dispersive) they will have a substantially greater group delay that the main mode.
- These group delayed modes become more audible with greater HOM level, greater delays (higher order) and at higher SPL levels.

Sound Quality in Waveguides

- It appears then that a major sound quality issue in compression driver/waveguide combinations could be a result of the presence of HOMs.
- To test this hypothesis a driver/waveguide system was design with the intent to reduce HOM to an absolute minimum.

The Summa Waveguide

- In order to minimize the HOMs a waveguide was designed using the Oblate Spheroidal contour.
- This contour guarantees that there will be a minimum of HOM generated from a circular throat compression driver.
  - Of course, the compression driver itself may still be a substantial source of HOMs.

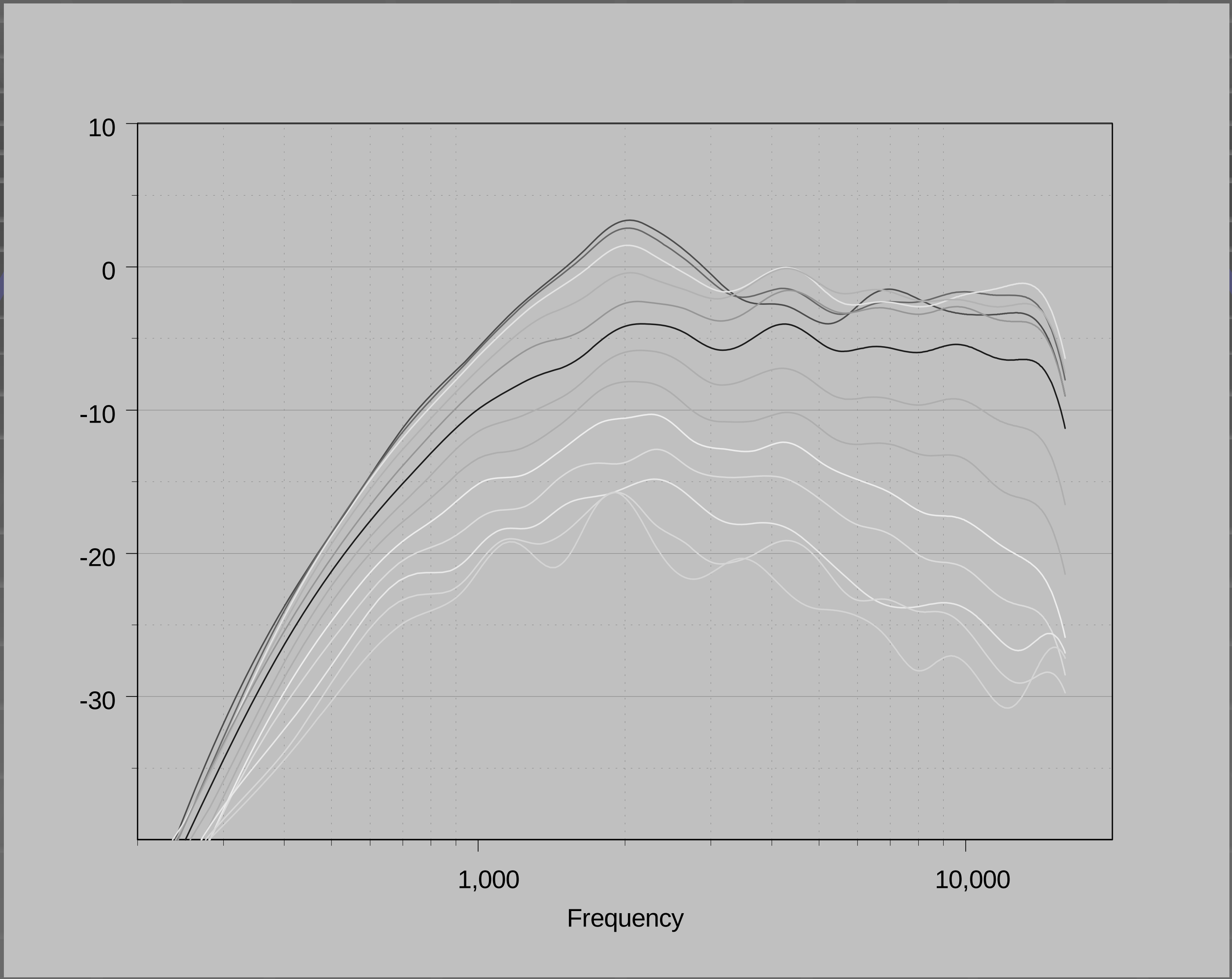
The Refractive Foam Insert

- In order to further reduce the HOM a piece of open cell polyurethane foam of density 30 PPI was cut to exactly fit, and fill, the interior of the waveguide.
- The concept here is that the foam will attenuate the HOM more than the fundamental mode because the HOM travel a longer distance.

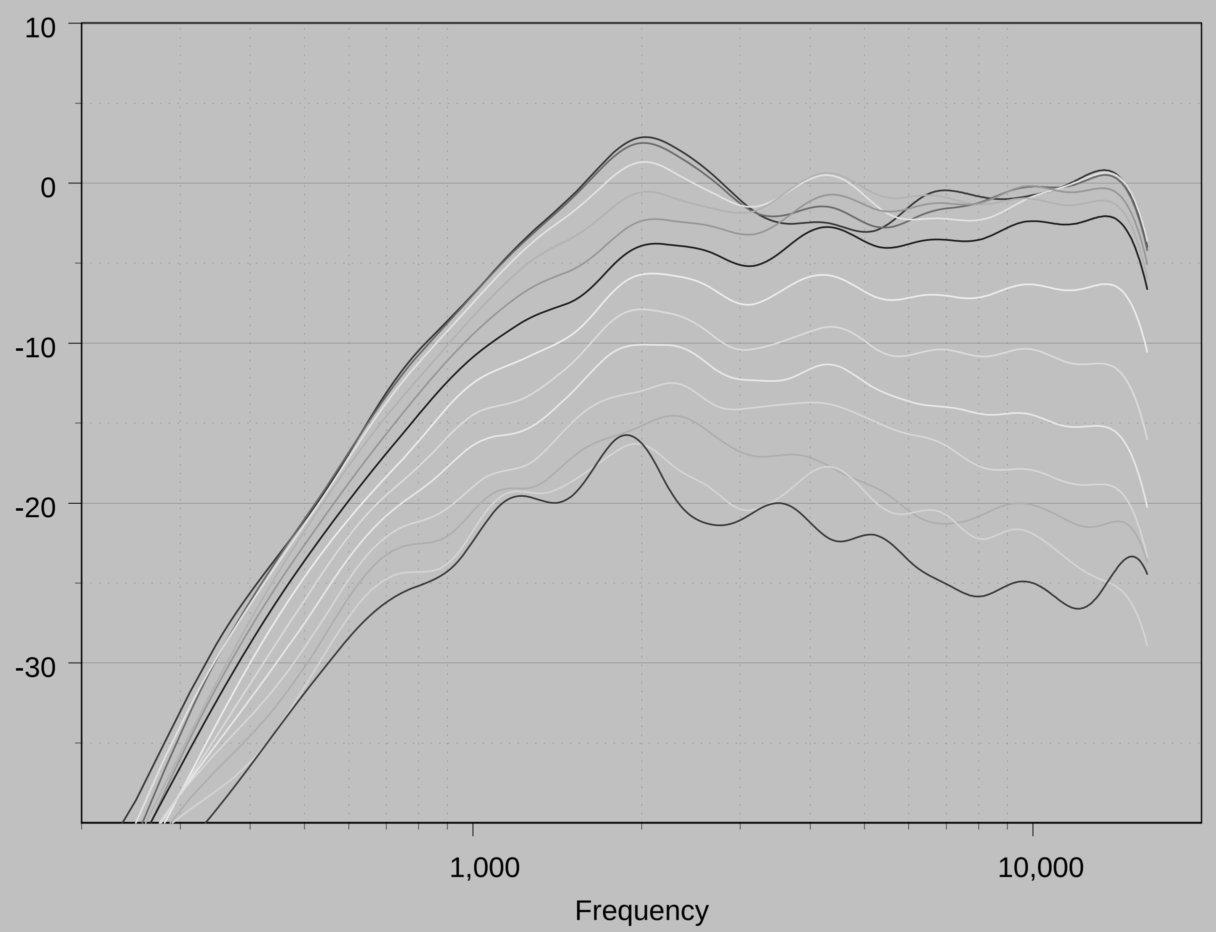
The Refractive Foam Insert

- The foam plug will also attenuate the mouth reflections thus reducing a major cause of linear distortion.
- The polar response for this waveguide/ driver combination is shown in the following slide.
- This system is un-equalized, except for a +6 dB/Oct power to pressure response correction.

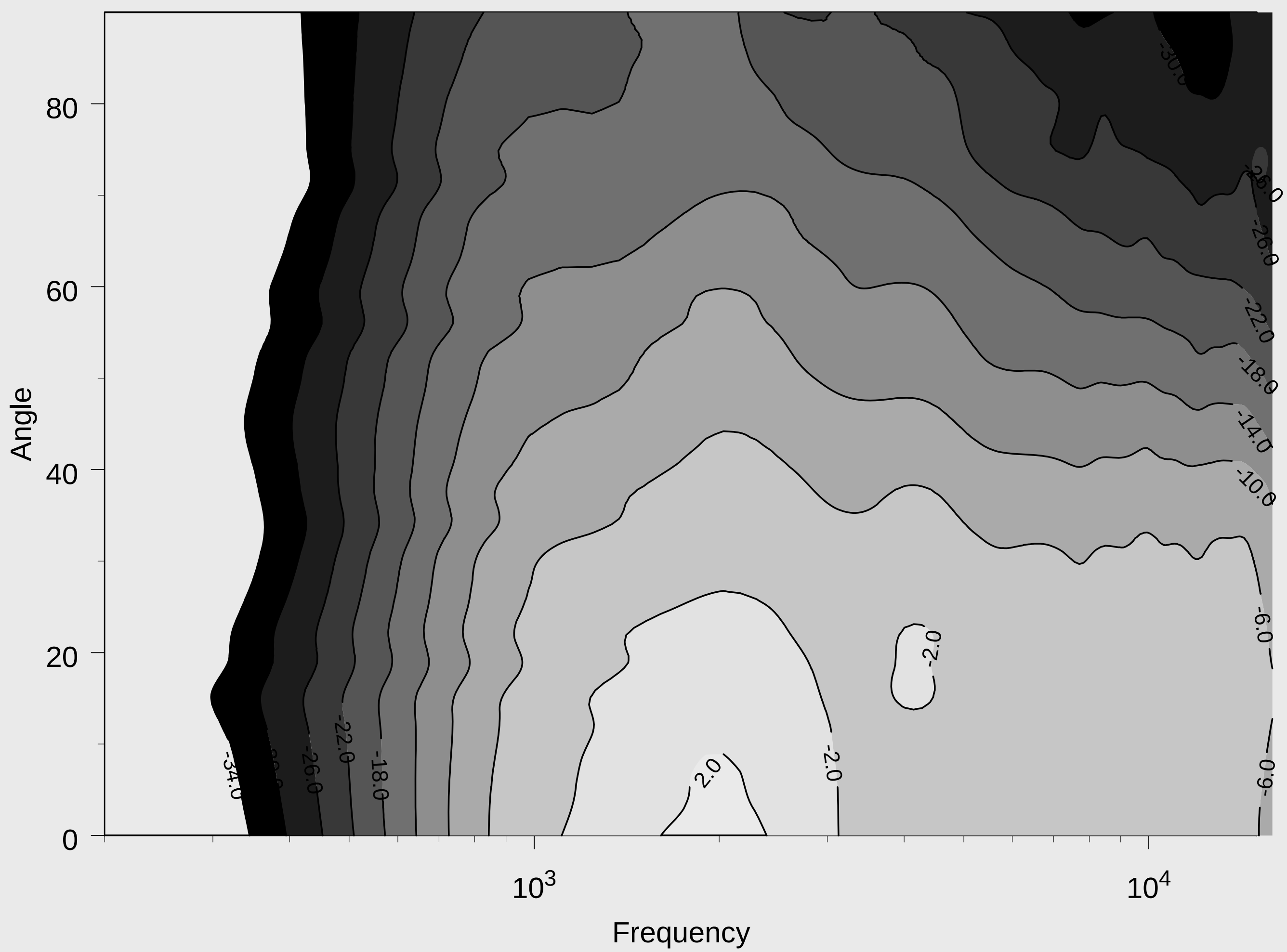
With foam



Without foam

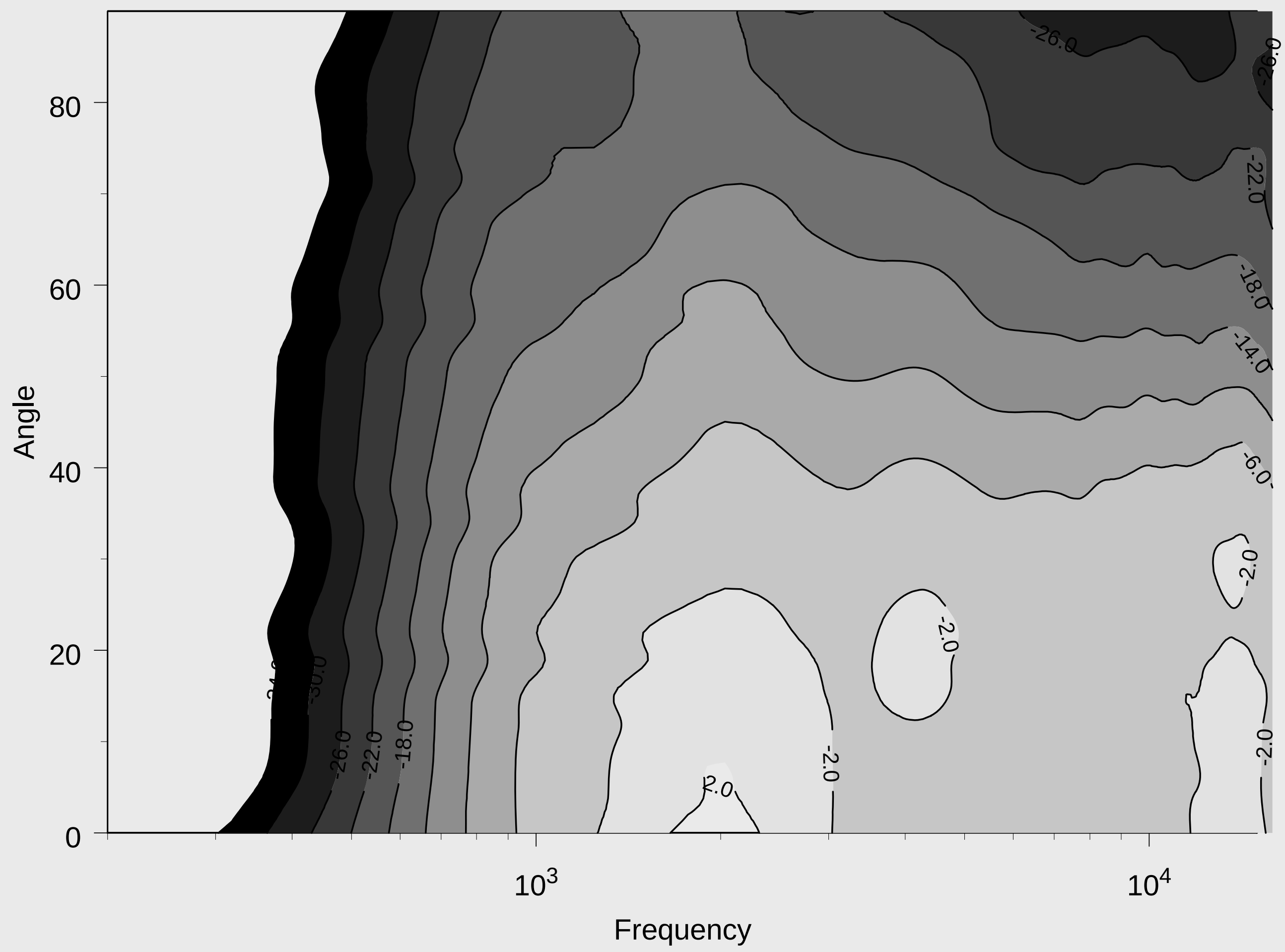


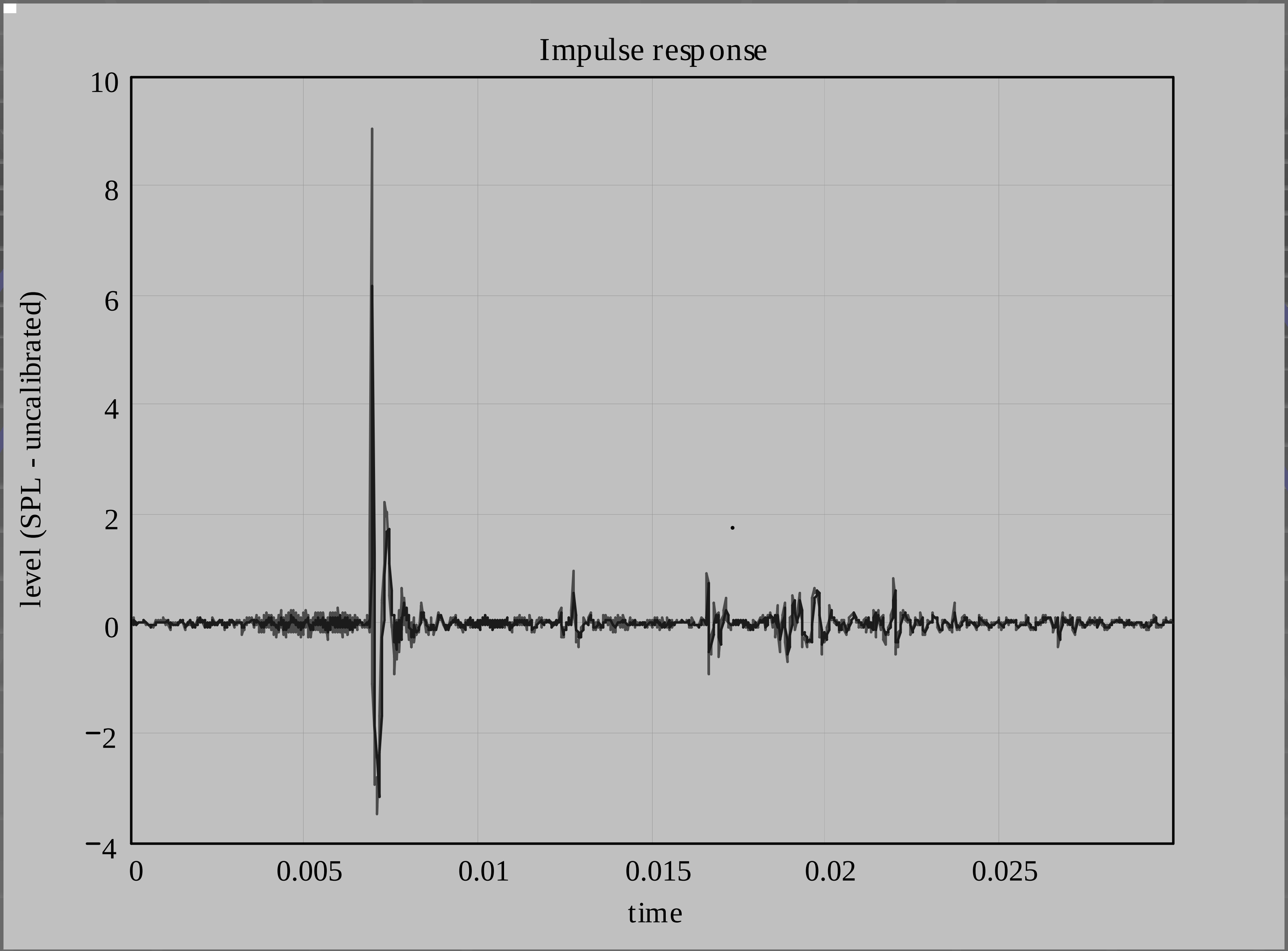
With foam

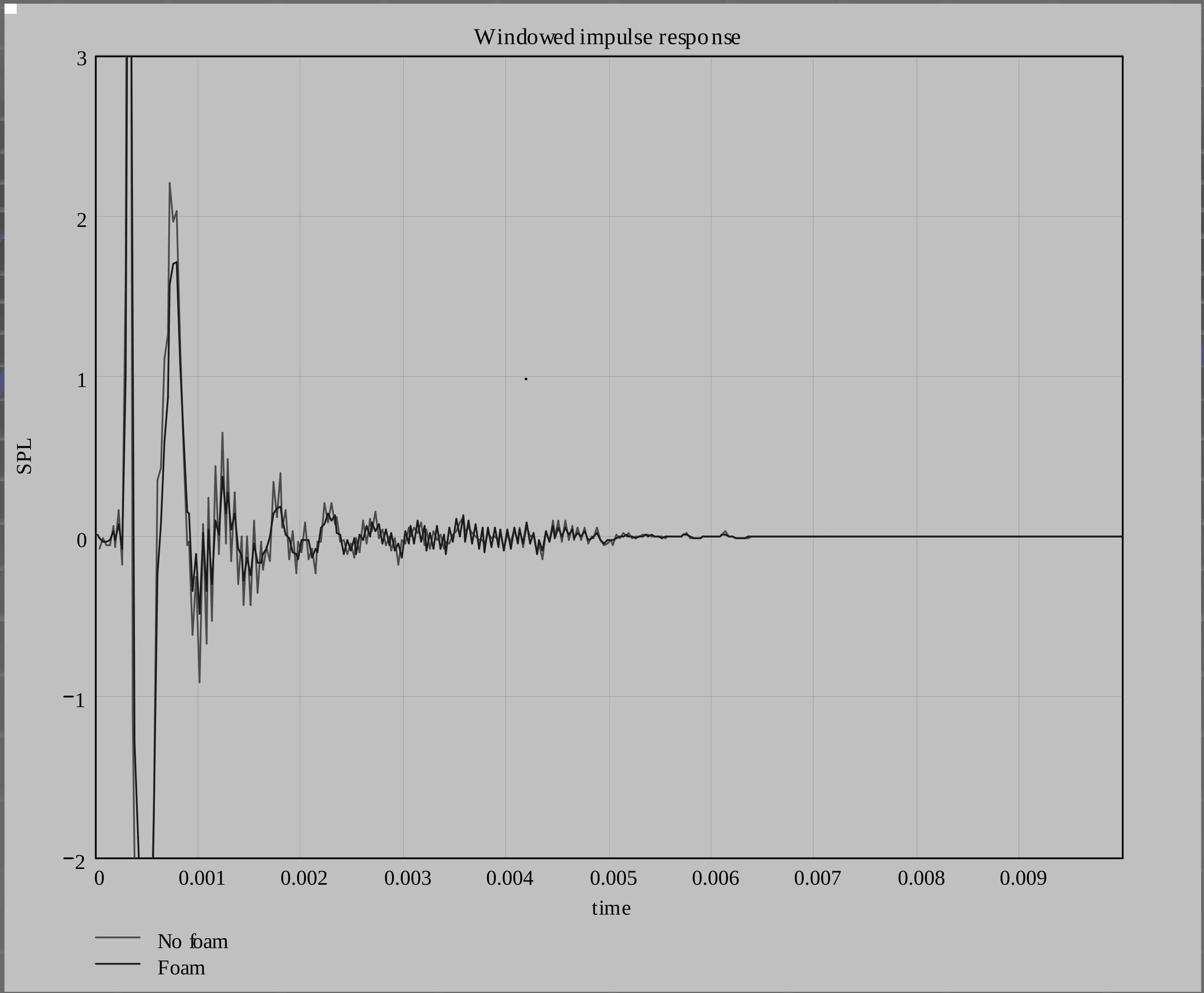


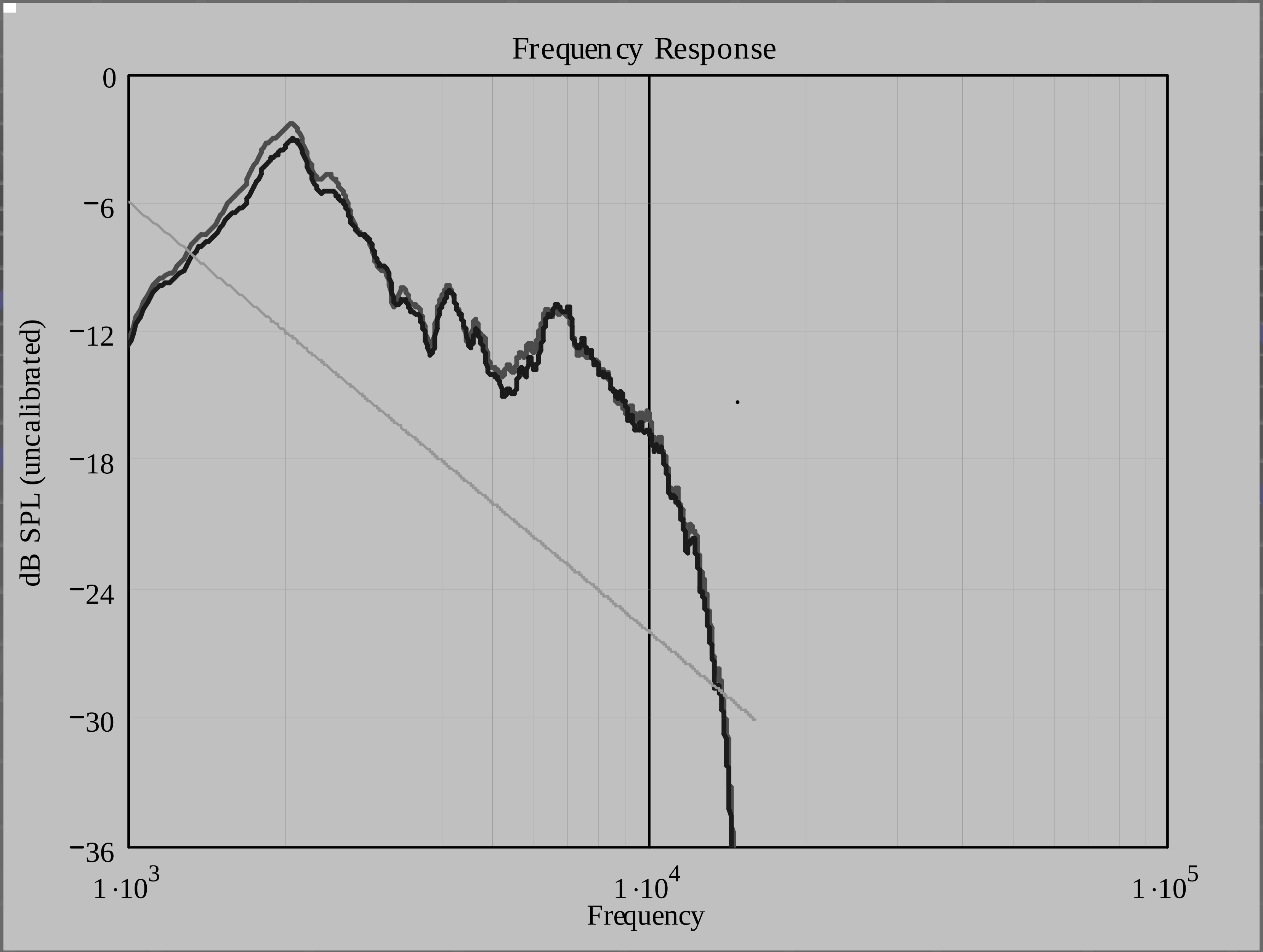
Angle
0
20
40
60
80
Frequency
10^3
10^4
-34.0
-26.0
-22.0
-18.0
-2.0
2.0
-2.0
-6.0
-6.0
-10.0
-14.0
-18.0
-22.0
-26.0
-30.0

Without foam




Impulse response
level (SPL - uncalibrated)
10
8
6
4
2
0
−2
−4
0
0.005
0.01
0.015
0.02
0.025
time


Windowed impulse response
SPL
time
3
2
1
0
−1
−2
0
0.001
0.002
0.003
0.004
0.005
0.006
0.007
0.008
0.009
No foam
Foam


Frequency Response
dB SPL (uncalibrated)
0
−6
−12
−18
−24
−30
−36
$1 \cdot 10^3$
$1 \cdot 10^4$
$1 \cdot 10^5$
Frequency

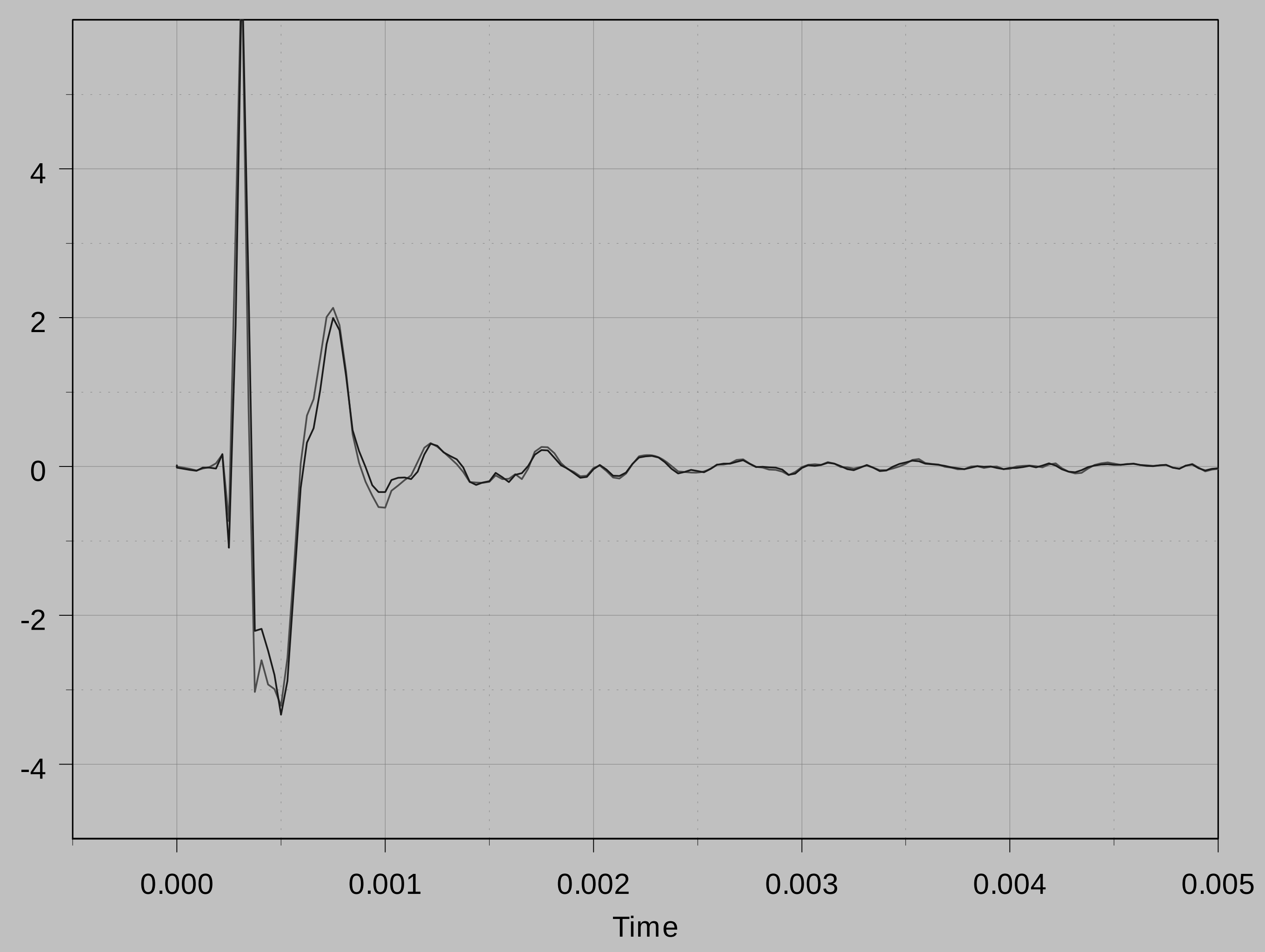
Power vs. Pressure

- In any device which radiates a constant coverage pattern at high frequencies, the pressure response must fall at -6 dB / Oct.
- This is because the radiation resistance is constant while the source velocity is falling at -6 dB / Oct.
- The power response (constant coverage) must be the same as the pressure response.

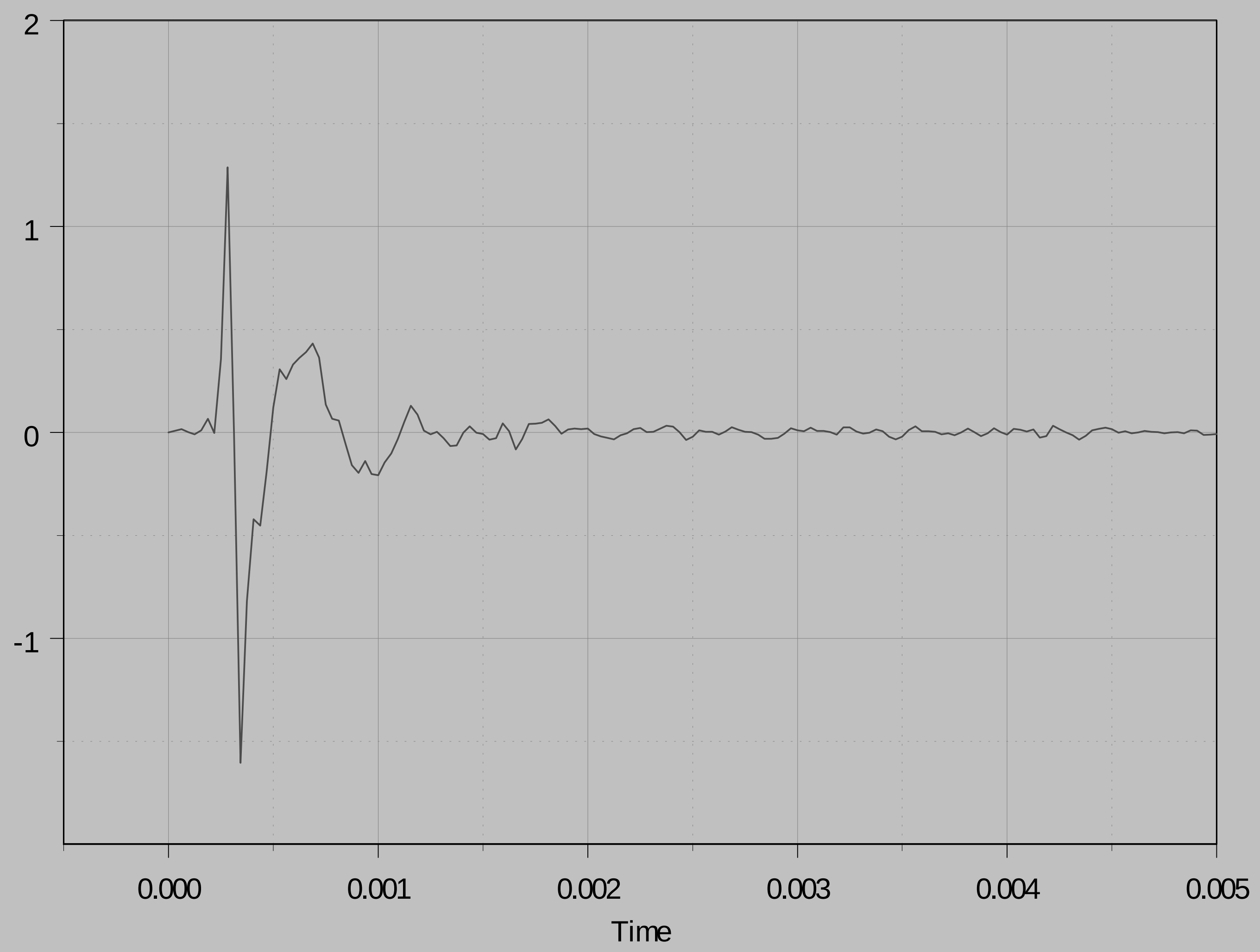
Power vs. Pressure

- Direct radiators do not exhibit this effect, and cannot be made to exhibit this characteristic.
- The author feels that this is the single most important characteristics of waveguides which favors them over direct radiators.
  - There are others of course.

Impulse responses



Difference in impulse responses



Results

- The difference impulse response clearly shows that the foam has reduced the already small group delayed distortions.
- The remaining group delay distortions are most likely due to the phase plug design within the driver.
  - Work is progressing on a new driver/phase plug that will further reduce the group delay distortions.

Subjective impressions

- In a blind test of some 15 subjects no one detected the difference between the Summa waveguide and a "Hi-End" direct radiating soft dome device.
- The Summa waveguide had 10 dB more efficiency and about 20-30 dB more headroom that the soft dome device.
- The Summa waveguide is CD, the dome is not.

Subjective aspects

- While opinions of any loudspeaker vary widely, it is universally acknowledged that the Summa Waveguide has absolutely none of the poor sound quality normally associated with “horns”.
- To my taste the Summa waveguide is the best high frequency source that I have ever heard.

Patent Coverage

- The Oblate Spheroidal waveguide contour is public domain, however much proprietary trade secrets in making these device work well resides within GedLee.
- The Foam plug is a pending patent within the US PTO
- The phase plug design for minimum HOM resides within two patents – one issued and the other pending.