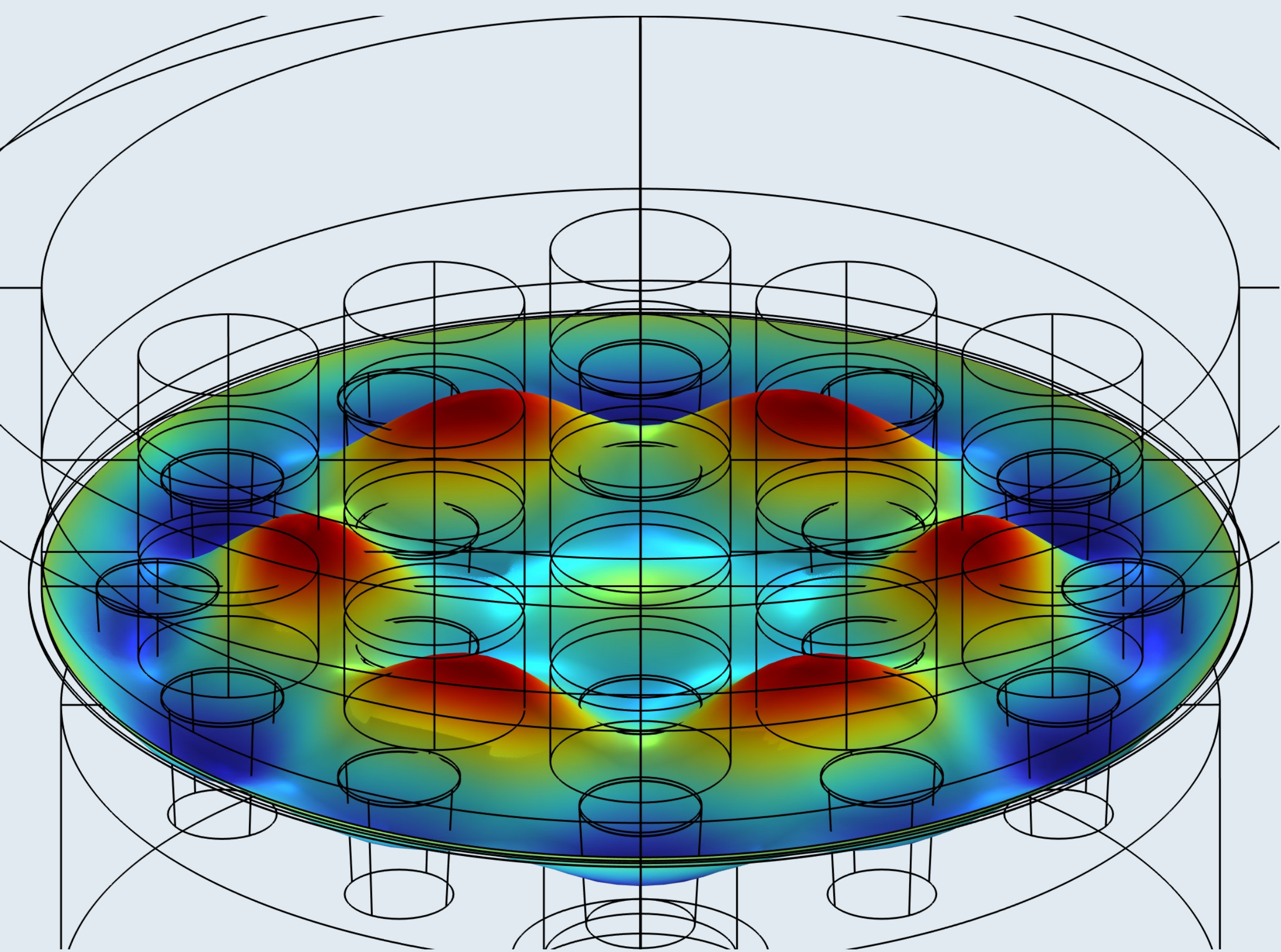




Workflow for Pressure-Gradient Microphone Capsule Design Optimization

This project presents a COMSOL workflow for the simulation and optimization of a pressure-gradient microphone capsule. It enables systematic analysis of coupled acoustic, structural, and electrostatic effects relevant to capsule performance.

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Introduction & Goals

This work focuses on a pressure-gradient condenser capsule, where performance is set by the interaction of front and rear acoustic inputs rather than a single incident pressure field. The model combines a coupled front/rear acoustic network, directionality-defining resistive and phase-shifting path elements, thermoviscous losses in narrow passages, and a prestressed membrane under electrostatic bias. This captures the key physics behind directional capsule behavior, where small geometric or material changes can significantly shift sensitivity, low-frequency response, and polar-pattern stability.

The main goal is to establish a workflow for robust engineering decisions, not only to match one operating point. It is designed to reveal which parameters dominate directional response, bass behavior, and tolerance sensitivity, while keeping tradeoffs transparent early in development. A further goal is manufacturing-aware optimization by linking acoustic targets to realizable geometry and operating constraints, enabling faster iteration and more reliable capsule tuning.

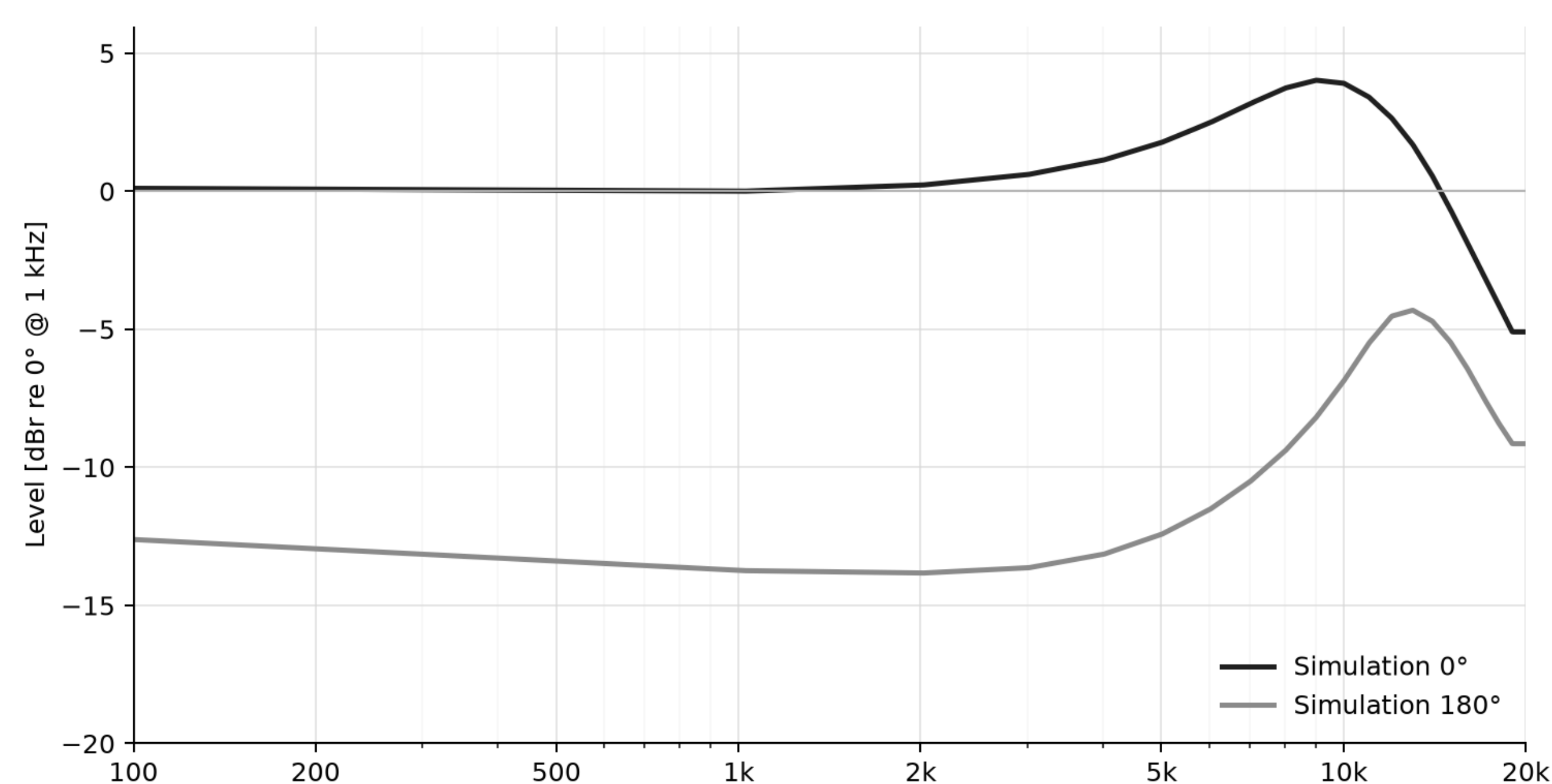


Figure 1: Simulated directional pressure sensitivity (0° and 180°), expressed as the pressure-to-voltage transfer sensitivity $M_{\theta(f)} = \frac{U_{out,\theta(f)}}{p_{in}(f)}$ [V/Pa] with level representation $L_{\theta} = 20 \log_{10} \left(\frac{|M_{\theta(f)}|}{|M_{0^\circ(1 \text{ kHz})}|} \right)$

Results

The simulation-to-measurement agreement is good in the low- and mid-frequency bands, indicating that the model captures the relevant pressure-gradient capsule behavior in these frequency ranges well.

For on-axis, the mean signed deviation is +0.59 dB in 100-500 Hz and -0.34 dB in 1-5 kHz; in 10-20 kHz, the mean deviation is -0.31 dB with a wider spread of approximately +2.4 to -3.0 dB. For 180°, the mean deviation is +0.16 dB in 100-500 Hz, +0.41 dB in 1-5 kHz, and +3.5 dB in 10-20 kHz.

Across the full 100 Hz-20 kHz range, the overall mean deviation is +0.26 dB for on-axis and +0.27 dB for 180°; The remaining high-frequency discrepancy may be influenced by measurement setup factors such as angular alignment, fixture/source scattering, and positioning tolerances.

Methodology

The methodology uses a coupled multiphysics finite-element model of the capsule that links acoustics, membrane mechanics, and electrostatics in a single simulation workflow. Front and rear acoustic domains are solved in the frequency domain, with thermoviscous modeling applied to narrow, loss-critical passages and resistive path elements governing directional phase and amplitude balance.

A prestressed membrane operating point under polarization bias is included before linearized small-signal analysis. Parameter sweeps are then used to quantify sensitivity of low-frequency response, directivity, and robustness to realistic geometry and material tolerances.

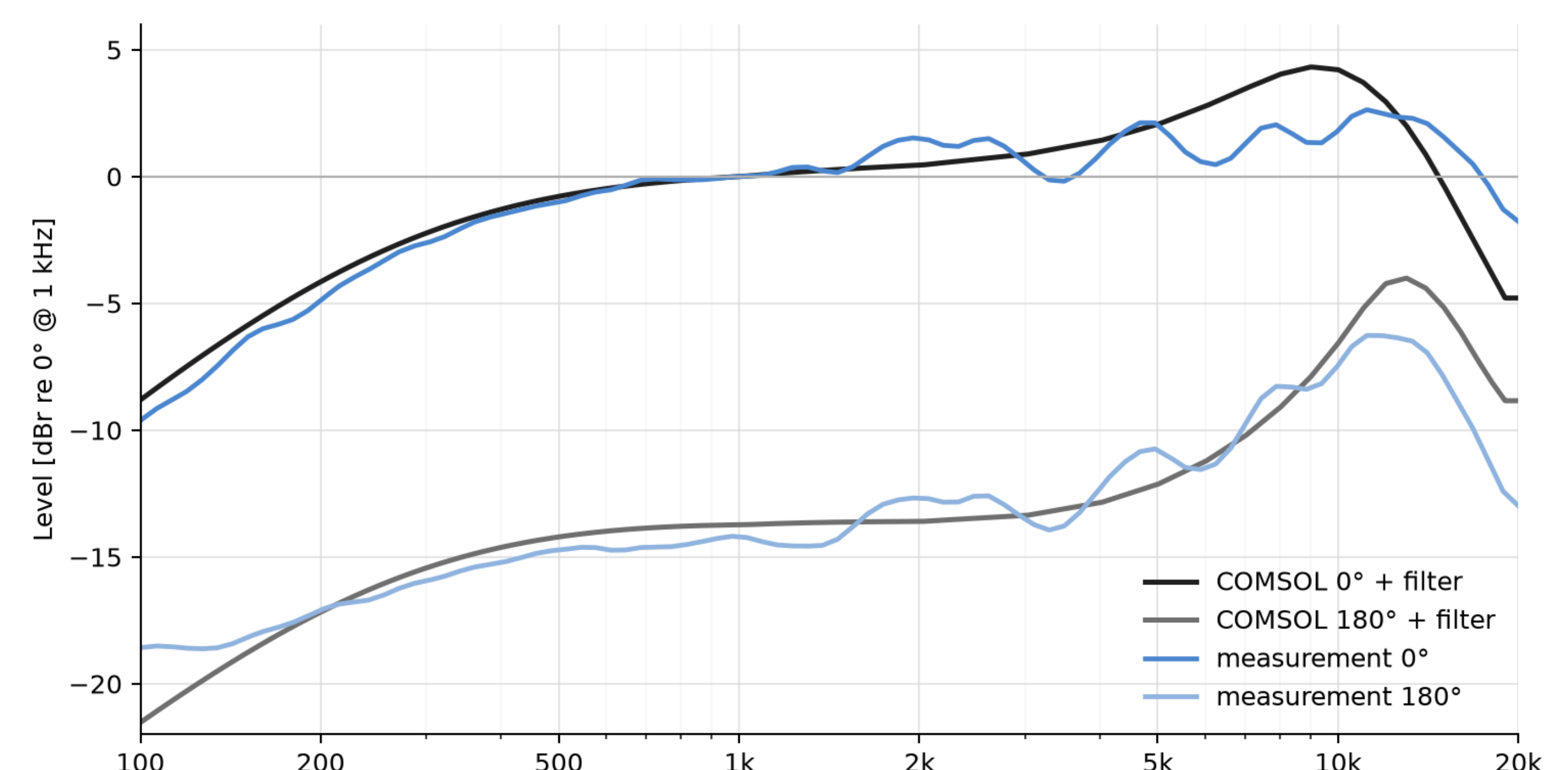


Figure 2: Comparison of simulated and measured directional responses using the same normalized sensitivity metric, where simulated transfer sensitivity $M_{\theta(f)}$ is post-processed with a first-order low-cut electronics model

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