Bio-Inspired Flow Velocity Microphone: Acoustic Simulation of Encapsulating Packages

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1 Introduction

With the emergence of voice assisted devices like smart speakers and wireless earbuds, there is a need to design voice capture systems that are more robust to background noise and reverberation. Current directional far field audio capture systems are based on omnidirectional microphone arrays or pressure gradient microphones that provide bidirectional polar pickup patterns. The array microphones suffer from lower sensitivities and directionality limited to few bands. The fundamental sensing mechanism of such systems is based on 'acoustic pressure' sensing which is scalar in nature, with no directional information. On the contrary, the use of thin bio-inspired nano hair follicles as sensors (for eg : mimicking the moving spider auditory sensing) enable "acoustic particle velocity" sensing that is vectorial quantity carrying spatial information. This inherent directional nature of acoustic particle velocity enables the development of novel directional microphones.

The current research focuses on the optimal acoustic design of sound ports and signal paths to integrate this kind of velocity microphone into various consumer use cases by retaining or improving the acoustic performance of the bare (a.k.a. un-encapsulated flow sensing element. For comparison of simulation models, two case studies (closed pipe & open pipe) were presented. A multiphysics FEM software was used to model these cases in pressure & thermoviscous acoustic modules. The key acoustic performance targets for these cases, such as resonant frequencies, sensitivity and directivity were presented with theoretical validation.

2 Bio-inspired velocity microphone

The innovative technology behind the velocity microphone was invented by Professor Ronald N. Miles [1] at Binghamton University. Soundskrit and Professor Miles colloborated [2] to advance the design of nano sensors for consumer industry applications. Soundskrit has leveraged this novel bio-inspired flow velocity microphone to overcome the directional audio capture challenge, while maintaining high fidelity audio at a broad range of frequencies in it's latest generation microphone. Fundamentally the sensing technology is based on how insects perceive sounds even at longer distances in the presence of background noise as shown in Figure 1. Acoustic sensitivity of these latest generation microphones have been tested at Soundskrit's labs as shown in Figure 1 with PCB, two pressure microphones and a speaker source. In an "out-of-plane", acoustic flow in the plane of sensor fiber is ignored and out of plane signal is only captured. A schematic representation of a basic "out-of-plane" MEMS package, in a Figure 2, show the sensor fibers and the resulting acoustic flow.

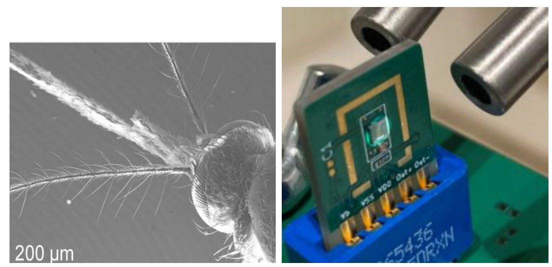

Figure 1 – Closeup view of insect hair (Left) [2], Soundskrit Mic (Right)

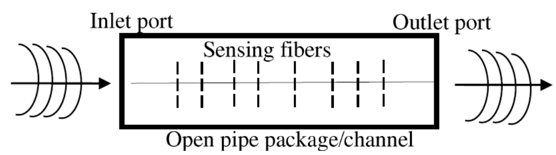

Figure 2 – Basic schematic of Soundskrit sensing mechanism

2.1 Acoustic modeling and simulation setup

Two simulation cases were modelled in COMSOL Multiphysics v5.6 (COMSOL AB, Stockholm, Sweden) to predict and compare the key acoustic performance parameters. The first case is a closed pipe (single port), which is a representative of sound path for a pressure microphone with diaphragm. The second case is an open pipe (dual port), which is a representative of sound path for a flow velocity microphone package. The open-pipe case falls under "out of plane" sensing mode as described in Section 2. A computationally efficient 3D hybrid model comprising of pressure model for inlet & outlet acoustic domains and thermoviscous acoustic model for pipe cavity were developed in COMSOL, as illustrated in Figure 3. In an open pipe model, both inlet and outlet acoustic domains were modelled to excite the pipe with unit pressure background field on both ports. In case of a closed pipe model, only inlet acoustic domain is used to excite the inlet port with hard wall termination at other end. For a fair comparison between two cases, the dimensions of the closed pipe & the open pipe cases were similar with a length of 10 mm and diameter of 2 mm. The size of acoustic domains is equal to six times the diameter of pipe. Acoustic flow velocity of sensor fiber and air velocity are almost similar with very tiny sensory fiber in

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the order of nanometers as per [3]. The acoustic simulations predicted the air velocity spectrum at the center of the open pipe, as well as the pressure at the closed end of the pipe near diaphragm for the closed pipe.

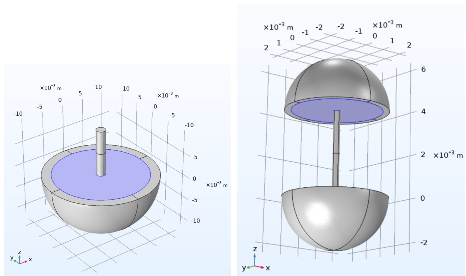

FIGURE 3 – 3D COMSOL model of closed pipe(left) & open pipe(right)

3 Results and Discussion

3.1 Sensitivity response

Resonant frequency for a closed pipe pressure response can be observed around 7.5 kHz which is close to theoretical value of 8.5 kHz from organ pipe theory as in Figure 4. Similarly for a open pipe resonant peak can be seen around 17 kHz close to it's theoretical value of 17.1 kHz and therefore validating the mode developed. For similar pipe dimensions, open pipe case has a higher value of resonant frequencies. In fact the velocity sensitivity of the open pipe case has higher gain and much flat response over a wide range of frequencies compared to the pressure response from closed pipe case.

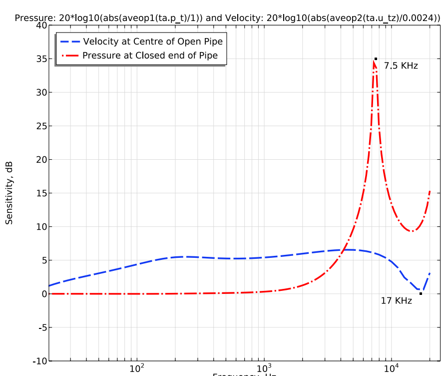

FIGURE 4 – Senstivity for Closed pipe and Open pipe

3.2 Directivity pattern

The omni-directional nature of pressure microphone near and above 8 kHz is lost due to the presence of resonant peak as shown in Figure 5. Above that resonance, it becomes subcardiod and even supercardiod at much higher frequencies. Unlike pressure microphone, directivity of open pipe case for a velocity microphone in Figure 6, maintains the so-called "figure 8" directivity pattern even at a higher frequency of 16 kHz with 20 dB off-axis rejection which is beneficial for far-field audio capture.

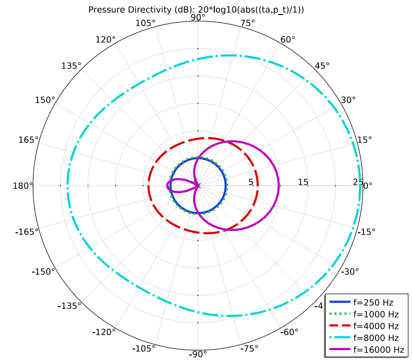

FIGURE 5 – Pressure Directivity at the closed end of pipe

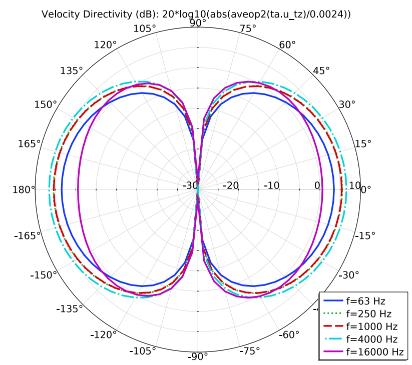

FIGURE 6 – Velocity Directivity at the center of open pipe

4 Conclusions

The directivity of closed pipe for a pressure microphone has an omni-directional nature as expected with a resonant peak well ahead in comparison with open pipe for same dimensions. Resonant frequencies compare well with theory, validating the simulation. Directivity of an open pipe case for a velocity microphone shows a perfect "figure 8" pattern even at higher frequencies as well as moderate boost in sensitivity depending on dimensions of open pipe. Finally this simulation methodology can be extended to more complicated sound paths configurations that can utilize in-plane sensing and aesthetic placement of sound ports for various use-cases.

Acknowledgments

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