Super-Absorption of Acoustic Waves with Bubble Meta-Screens: Supplemental Material

Valentin Leroy,[1] Anatoliy Strybulevych,[2] Maxime Lanoy,[3, 1] Fabrice Lemoult,[2, 3] Arnaud Tourin,[3] and John H Page[2]

[1]*Laboratoire Matière et Systèmes Complexes, Université Paris-Diderot, CNRS (UMR 7057), Paris, France*
[2]*Department of Physics and Astronomy, University of Manitoba, Winnipeg, Canada*
[3]*ESPCI Paris Tech, PSL Research University, CNRS, Institut Langevin, F-75005 Paris*
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We show that having a fully analytic expression, and a better physical insight into the problem, allows us to design meta-screens with better performance than has been predicted previously. The first step is to tune the resonance to the desired frequency.
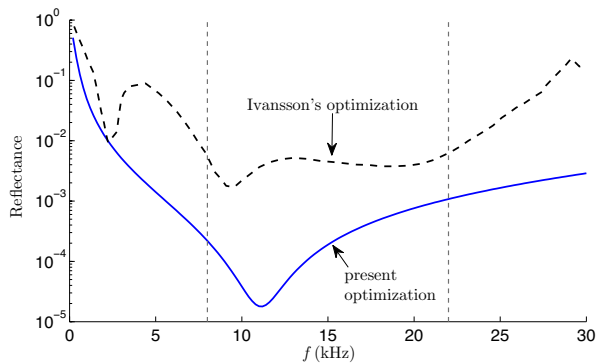

FIG. S1: Reflectance as a function of frequency for the optimal configuration predicted by Ivansson (dashed line, extracted from Ref. [S3] for his case b, which is shown by the solid line in his Fig. 8), and for our optimization (solid line), guided by the analytic model. In the first case (Ivansson's optimization), the reflectance reduction is 22 dB over the 8-22 kHz range with a 12 mm structure. In the second case (our optimization), a 35 dB reduction is achieved with a 4 mm meta-screen.

Two main parameters affect the resonance frequency: the size of the bubbles and the shear modulus of the solid. As we want the bubbles to be as small as possible (to reduce the thickness of the meta-screen), a low value of the shear modulus is preferable. Let us take for instance $\mu = 0.2$ MPa, which makes a very soft material, but still hard enough for centimeter-thick slabs not to lose their shape under their own weight. With such a

value of the shear modulus, bubbles of 1 mm radius resonate at 6 kHz. This is below our range of interest for sonar applications, but we know that coupling between bubbles tends to increase the resonance frequency. To be sure there is enough material around each bubble to efficiently dissipate the energy, let us make the thickness of the solid twice the diameter of the bubbles: $e = 4$ mm. The next step is to chose the viscosity of the solid. Obviously, the higher the better, because high damping makes the super-absorption broader in frequency. We pick a value of $\eta = 100$ Pa.s, which is very high (10 times the viscosity of honey) but easily reached by silicone oils [S1]. We then choose $d = 7$ mm, following the super-absorption prescription $\eta = 2\eta^\star$. Note that we assume that the solid is impedance matched with water, to avoid reflection on the front face of the meta-screen [S2]. Figure S1 shows that our optimization beats the best performance prediction in the literature by Ivansson [S3]. It appears that, in his simulations, Ivansson did not explore high enough values of viscosity to reach $\eta^\star$. Note, however, that the performance of the meta-screen is found to be quite sensitive to the exact bubble spacing: the reflectance reduction drops to 32 dB for $d = 7.2$ mm.

[S1] P. Y. Longin, C. Verdier, M. Piau *J. Non-Newtonian Fluid Mech.* **76**, 213 (1998)
[S2] Note that it should be possible in practice to achieve perfect impedance matching for longitudinal waves by adding appropriate submicron filler particles to the soft solid, so as to tailor its acoustic effective medium properties.
[S3] S. M. Ivansson, *J. Acoust. Soc. Am.* **124**, 1974 (2008)