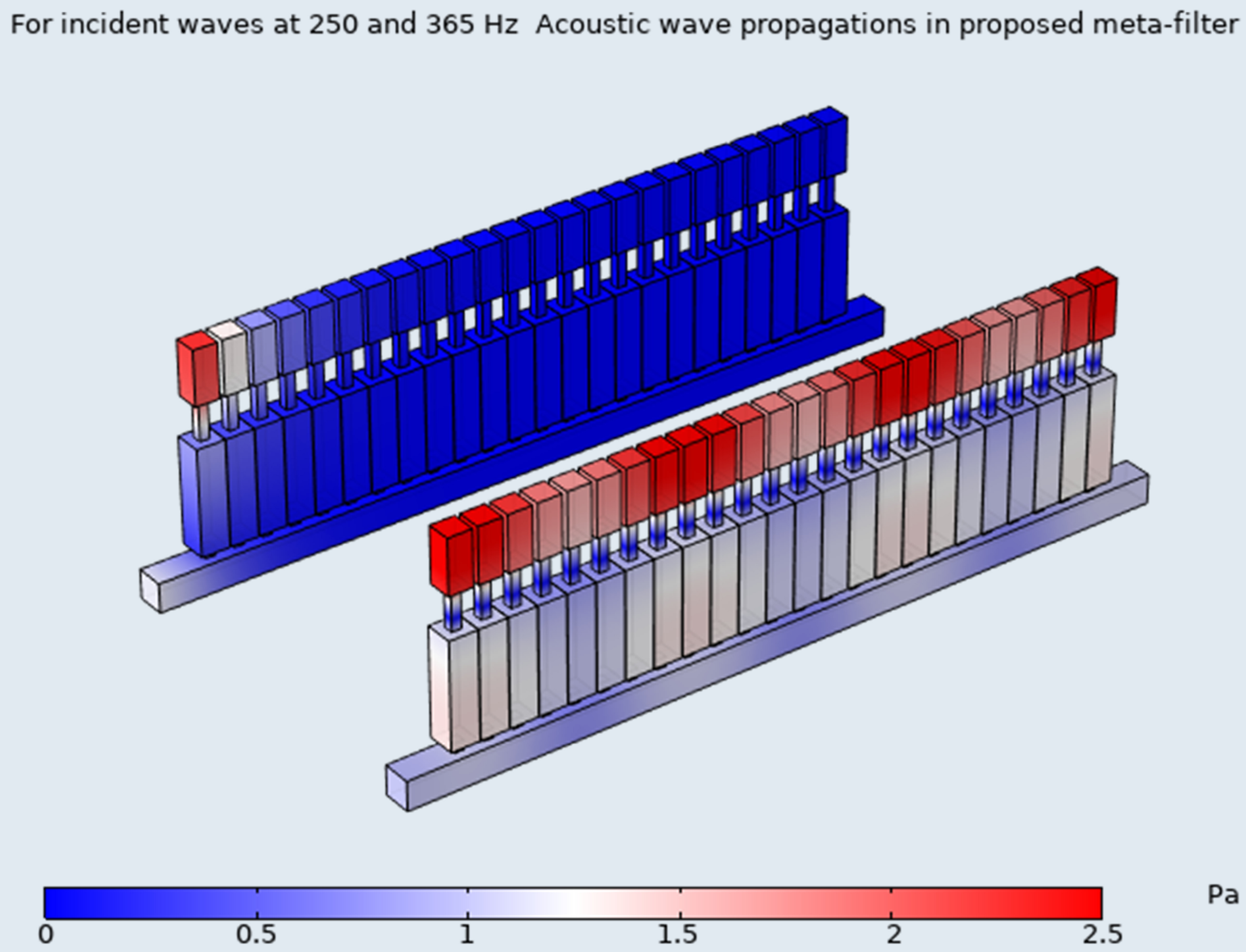

Design of One-Dimensional Acoustic Meta-Filter with Multiple Resonator

New design structure of acoustic metamaterial for achieving selective noise reduction and sound transmission is presented. Also, analytical results that can serve as an appropriate design guideline is derived from the mathematical expression for the negative modulus.

M. Kim[1], J. Lee[1]

1. CAE Solution Team, ALTSOFT Inc., Seoul, Republic of Korea

Abstract

New design structure for generating and tuning the multi-bands of negative modulus is presented by introducing metamaterial concept. To effectively achieve selective noise reduction and sound transmission, acoustic metamaterial consisted of arrayed multiple resonators with extended necks is proposed. Also, mathematical expression for the effective bulk modulus is developed by using a mechanical-acoustic analogy. The bandwidths and starting frequencies of multi-bands are tuned by changing only the mass ratio of the extended necks, which are converted to equivalent mass elements. Numerical investigation by using FEM simulation (Acoustics Module of COMSOL Multiphysics®) is carried out to support the mathematical expression and tunability performance of multi-bands in the acoustic metamaterial. In view of the date of many passive acoustic filters and ultrasonic devices, it is expected that the proposed design structure can overcome the limitations of sound blocking in a low frequency range and precise signal transmission.

Methodology

From the mechanical-acoustic analogy and mathematical modeling of equivalent system of single unit cell, the effective bulk modulus is derived – if a original lattice is modeled as an equivalent system of single unit cell, the effective bulk modulus of the equivalent lattice would become negative for frequencies above the resonant frequency. Fig. 1 compares the effective bulk modulus curve, which is plotted on a log scale, and the transmission coefficient curve, which is plotted on a linear scale, of an acoustic metamaterial with a double resonator. The resonant frequencies of the double resonator are 212 and 420 Hz. In the frequency range of negative modulus ($B_{\mathrm{eff}} < 0$) which is represented by light orange colored rectangles, the transmission coefficient (|t|) is extremely low.

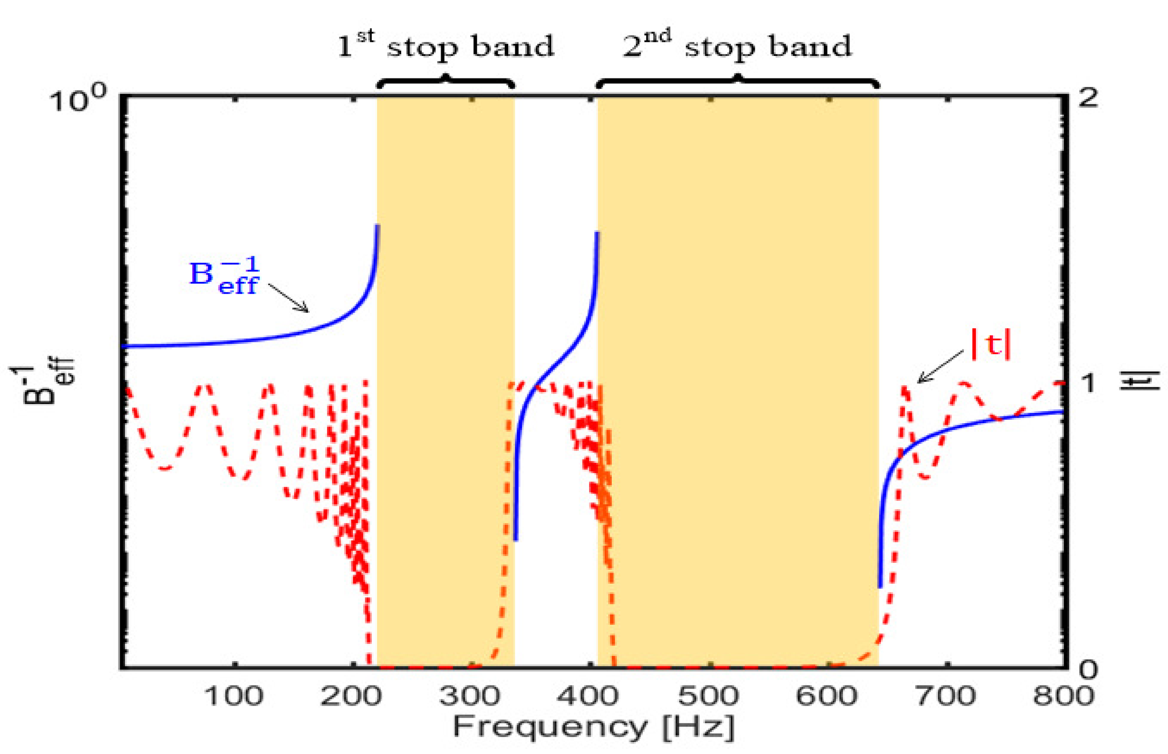

Figure 1. Effective bulk modulus and numerically calculated transmission coefficient.

Results

Fig. 2 (a) compares the transmission coefficient curves of four cases of different mass ratios – for the resonator with extended neck, the equivalent mass of the resonator could be much increased without an increase in its outer dimensions. As the mass ratio increases, the 1st stop band becomes narrower but the 2nd stop band becomes wider. This phenomenon results from the change of the resonant frequencies (f_2^* and f_1^*) of each double resonator, which approximately coincides with the starting frequencies of stop bands. Also, this change makes the pass band between two stop bands decrease or increase. As shown in Fig. 2 (b), the resonant frequencies (lower limit frequencies, $f_{l_1}^*$ and $f_{l_2}^*$) of the two stop bands increase with the f_2/f_1. The difference between resonant frequencies decreases with the mass ratio and becomes a minimum value for $f_2/f_1 = 1$.

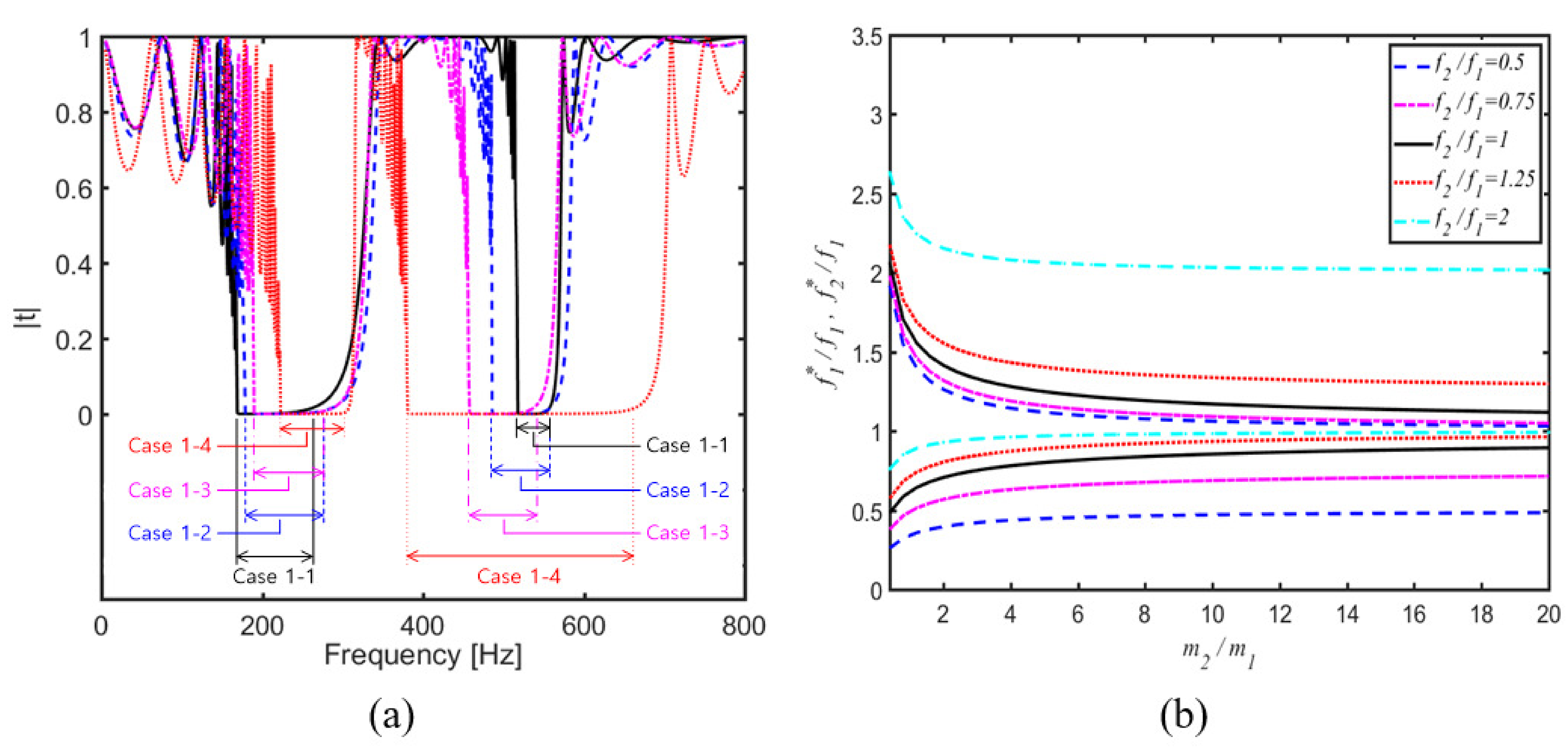

Figure 2. (a) Numerically calculated transmission coefficient and (b) normalized resonant frequencies of the double resonator as a function of the mass ratio for various resonant frequency ratios (f_2/f_1).

REFERENCES

[1] N. Fang, et al., "Ultrasonic metamaterials with negative modulus", Nature materials, 5(6): 452-456, 2006.

[2] U. Ingard, "On the theory and design of acoustic resonators", The Journal of the acoustical society of America, 25(6): 1037-1061, 1953.

*Key references

ALTSOFT