Significant Size-Reduction and Wideband Response of Acoustic Metamaterials with Non-Foster Technologies

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According to general transmission line (TL) theory, the telegraph equation on line voltages is given by

$$\frac{\partial^2 V}{\partial x} = L'C'\frac{\partial^2 V}{\partial t^2}, \qquad (1)$$

where L' and C' designate a series inductance and a shunt capacitance of a unit-length TL. While, the telegraph equation for acoustic waves propagating in x direction is expressed as

$$\frac{\partial^2 P}{\partial x} = \frac{\rho}{\kappa}\frac{\partial^2 P}{\partial t^2}, \qquad (2)$$

where P, ρ and κ designate pressure, mass density and bulk modulus, respectively. When the phase constant is defined as $\beta \equiv \sqrt{L'C'}\omega = \sqrt{\rho/\kappa}\,\omega$, the solutions of both equations are given by $F(x) = Ae^{-j\beta x} + Be^{j\beta x}$, where F is V for TLs and F is P for acoustic waves. This means that the acoustic wave propagation can be treated like the TL circuit theory. That is, by assuming $L'=\rho$ and $C'=1/\kappa$, then, characteristic impedance, phase velocity and group velocity are expresed as Z_0=sqrt($\rho\kappa$), $v_p=v_g$=1/sqrt(ρ/κ), respectively. For example, when the acoustic parameters of "*air*", ρ=1.2 kg/m^3 and κ=1.4x10^5 Pa, are utilized, the corresponding equivalent TL parameters becomes L'=1.2 H, C'=7.14 μF, Z_0=410 Ω, and $v_p=v_g$=342 m/s.

Generally, a unit cell of acoustic metamaterials is composed of a thin membrane and a Helmholz resonator, each of which generates a left-handed series capacitor and a left-handed shunt inductor. However, the size of the acoustic metamaterials tends to be large due to presence of Helmholz resonators. In this presentation, we propose to replace the resonators by non-Foster elements, that is, negative capacitors. Fig. 1 presents a unit cell of an acoustic metamaterial. Simulated scattering characteristics based on TL approach are shown in Fig. 2. Noted that the acoustic metamaterial with 8 unit cells generates a wide left-handed response below 200Hz.

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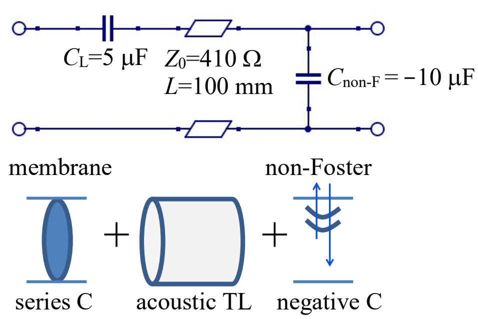

Fig. 1 A unit cell of acoustic metamaterials.

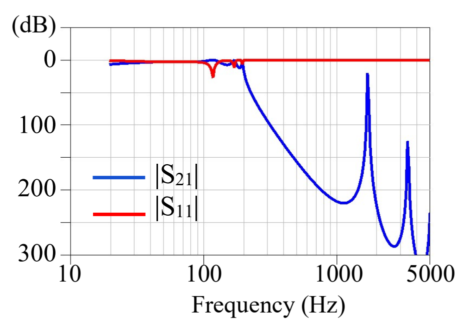

Fig. 2 Scattering characteristic of an acoustic metamaterial with 8 unit cells.