DESIGN OF ACTIVE MULTIPLE-DEGREES-OF-FREEDOM ELECTROACOUSTIC RESONATORS FOR USE AS BROADBAND SOUND ABSORBERS

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ABSTRACT

We present a novel control method achieving stable multiple-degrees-of-freedom electroacoustic resonators. Such broadband absorbers, composed of a feedback-controlled electrodynamic loudspeaker, have many practical applications to real-world acoustic engineering problems, such as low-frequency industrial noise reduction in the range of [20 - 200 Hz]. The proposed control architecture combines a conventional microphone-based feedback control loop and a current-driven direct acoustic impedance control scheme, proven to perform optimally in recently reported acoustic impedance synthesis methods. This paper presents a methodology for designing the transfer function to be implemented in the controller, after specifying a target multiple-degree-of-freedom acoustic resonator impedance. Numerical simulations presents the expected acoustic performances, confirmed by experimental assessments in an impedance tube.

1   INTRODUCTION

Low-frequency noise is present everywhere in the environment, emanating either from transportation facilities or industrial equipments. However, soundproofing is hardly achievable below 200 Hz with conventional passive acoustic materials such as porous layers or Helmholtz resonators [1]. Therefore, active control techniques have been investigated in the last decades to identify novel soundproofing concepts capable of targeting this unaffordable frequency range. The concept of "electroacoustic absorber" [2] encompasses loudspeaker system, namely a loudspeaker in a dedicated cabinet, the electrical terminals of which can be loaded either by passive components (RLC resonators [3]), or active ones (feedback control based on pressure and/or velocity sensing). It has especially given rise to the more general concept of "electroacoustic resonator" [4], that may present multiple-degrees-of-freedom (MDOF) characteristics. In the following, we consider the situation where the loudspeaker is fed back with a current driven by a given filtered version of the sound pressure on its diaphragm [5].

2   ACHIEVING MDOF ELECTROACOUSTIC RESONATORS

2.1   Model of the electroacoustic resonator

The transducer used in the following is an electrodynamic loudspeaker, that can be assimilated to a single-degree-of-freedom oscillator (suspended diaphragm) mechanically driven by a voice coil within a permanent and almost constant magnetic field. Figure 1 (left) highlights the mechanical part assimilated to a simple mass - spring - losses resonator, with mass M_{ms}, spring compliance C_{mc} , and mechanical resistance R_{ms}. It is assumed that all forces acting on the transducer, especially those resulting from the total pressure p_t, are small enough so that the displacements remain proportional to applied forces.
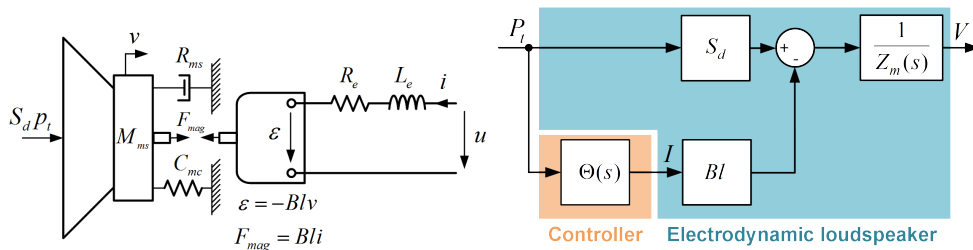

Figure 1:   Left:Schematic representation of the closed-box electrodynamic loudspeaker; right:Block diagram of the electroacoustic resonator.

If we denote S_d the effective piston area and Bl the force factor of the moving-coil transducer, the equation of motion of the loudspeaker membrane (Newton's second law) and the mesh law can be written in the Laplace domain ($s = j2\pi f$, where f is the frequency):

$$S_d P_t(s) = Z_m(s)V(s) + Bl\, I(s) \tag{1}$$

where $V(s)$ represents the membrane velocity, $P_t(s)$ represents the total sound pressure at the membrane surface, combination of the incident and reflected waves, and $I(s)$ is the current flowing through the voice coil. Here $Z_m(s) = sM_{ms} + R_{ms} + 1/(sC_{ms})$ is the mechanical impedance of the closed-box loudspeaker. We can also define the acoustic impedance $Z_s(s)$ presented by the diaphragm of the loudspeaker, considered as an electroacoustic resonator, as:

$$Z_s(s) = \frac{P_t(s)}{V(s)}. \tag{2}$$

2.2 Acoustic impedance control scheme

In the present concept, the loudspeaker is electrically fed with a current-driven amplifier, through a controller providing a filtered version of pressure P_t at the diaphragm through transfer function $\Theta(s)$, as illustrated on Figure 1 (right). Then, to assign a prescribed acoustic impedance Z_{st} at the electroacoustic resonator, the transfer function can be easily derived from Equation 1:

$$\Theta(s) = \frac{I(s)}{P_t(s)} = \frac{S_d Z_{st}(s) - Z_m(s)}{Bl\, Z_{st}(s)}. \tag{3}$$

With this setup, the closed-form expression of the achieved acoustic impedance at the electroacoustic resonator is given by:

$$Z_s(s) = \frac{P_t(s)}{V(s)} = \frac{Z_m(s)}{S_d - Bl\Theta(s)}. \tag{4}$$

2.3 Assigning a prescribed MDOF impedance

The MDOF resonator acoustic impedance considered here consists in the parallel arrangement of n one-degree-of-freedom acoustic resonators as:

$$Z_{st}(s) = \frac{1}{\sum_{k=1}^{n} j\omega \frac{M_{ms}}{\nu_{2k-1}S_d} + R_{st,k} + \frac{1}{j\omega}\frac{1}{S_d \nu_{2k} C_{mc}}} \tag{5}$$

where $R_{st,k}$ represents target acoustic resistances, and ν_i are real coefficients.

3 SIMULATION AND EXPERIMENTAL ASSESSMENT

The electrodynamic loudspeaker is a Peerless SDS-P830657, in a closed cabinet of volume $V_b = 10$ dm^3 (see Table 1). The various control parameters (C0, C2 and C3) are given in Table 2. The theoretical acoustic impedance achieved with each control configuration is processed according to Equations 3-5, and compared to experimental results measured in an impedance tube, as illustrated on Figure 2. The experimental results are in a good agreement with the analytical model, and show the significant extension of the resonator bandwidth when coupled with the proposed MDOF control architecture.

Parameter	Notation	Value	Unit
Effective piston area	S_d	151	cm^2
Moving mass	M_{ms}	12.9	g
Mechanical resistance	R_{ms}	1.23	N.s.m^1
Mechanical compliance	C_{mc}	260.79	μm.N^1
Force factor	Bl	5.98	N.A^1

Table 1. Peerless SDS-P830657 Thiele-Small parameters.

4 CONCLUDING REMARKS

The present concept aims at achieving MDOF resonators out of a conventional loudspeaker and a simple control law. The control architecture allows broadening the resonator bandwidth compared to the passive resonator (configuration $C0$). It is also possible to assign different values of acoustic resistance $R_{st,k}$ at prescribed frequencies $f_k = \frac{\nu_{2k-1}}{\nu_{2k}} \frac{1}{2\pi\sqrt{M_{ms}C_{mc}}}$, which is

Table 2. Control parameter values of one (C0), two (C2), and three (C3) DOF resonators.

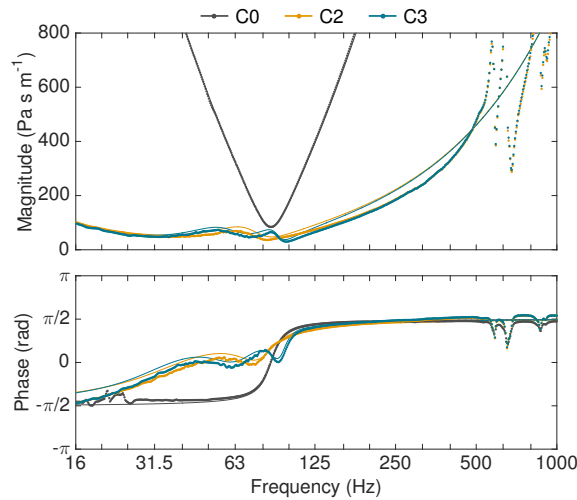| | ν_1 | R_{st_1} | ν_2 | ν_3 | R_{st_3} | ν_4 | ν_5 | R_{st_5} | ν_6 |
	(-)	(Pa·s·m^{-1})	(-)	(-)	(Pa·s·m^{-1})	(-)	(-)	(Pa·s·m^{-1})	(-)
C0	1.00	R_{ms}/S_d	1.00	-	-	-	-	-	-
C2	2.16	67.01	2.36	4.09	55.24	22.64	-	-	-
C3	1.86	85.99	2.86	1.32	54.81	1.11	3.07	57.32	21.03

Figure 2: Bode plot of the specific acoustic impedance of the electroacoustic absorber computed (solid lines) and measured (dotted lines) in cases C0, C2, and C3.

useful in the context of room modes damping [6]. This concept is readily applicable to low-frequency noise reduction

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