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Adaptive Design of a Unidirectional Source in a Duct

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Outline

- Introduction
- Principal unidirectional two-element constructions
- Adaptive design of a unidirectional two-element source
- Simulation examples
- Conclusions and future work

Introduction

A unidirectional acoustic source in a narrow duct

- multiple actuators (see Refs. [1-7] of the paper)
- the input of each actuator must be processed (filtered)

Motivation

- to be used in *feedforward* broadband ANC systems
- anti-noise must to radiate downstream but not upstream

In this paper, we present structures and an adaptive design method for unidirectional two-element sources

Advantages of unidirectional sources

- the acoustic feedback is eliminated
- feedback neutralization filter is not needed
- SPL does not increase in the upstream direction due to the secondary source
- the sound pressure level may be attenuated in the upstream direction, since further reflections from duct terminations are eliminated

Disadvantages of unidirectional sources

- limited frequency band of about 2 to 4 octaves:

not unidirectional at low frequencies (close to 0 Hz) and above an upper frequency limit

- need for several actuators
- in practice, both disadvantages are tolerable
- also other ANC systems also suffer from these defects

Why adaptive design?

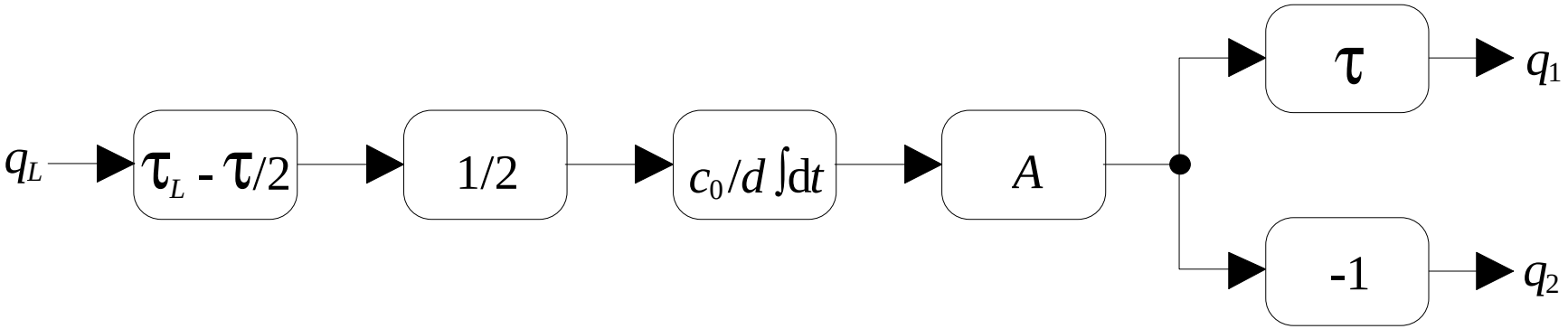
- deviations in the actuator responses degrade the obtainable attenuation of unidirectional ANC systems
  - mutual difference
- also, measurement error in the distance between the actuator elements causes degradation
- to automatically overcome both problems, we propose an adaptive design method that learns how to equalize the loudspeakers and account for the propagation delay between them
- related earlier work: Elliott, 1993

Principal unidirectional 2-element constructions

- 4 different unidirectional two-element structures have been proposed:
  - two-element Swinbanks source (Swinbanks, 1973)
  - three versions of the JMC-based two-element source (Uosukainen & Välimäki, 1998)
- these will be reviewed in the following

Two-element Swinbanks source

- ideal 2-element unidirectional source by Swinbanks:
  - delay the 1st actuator by delay between the sources, τ
  - feed the actuators in oppposite phases



- the amplification factor is $A = kd / \sin(kd)$

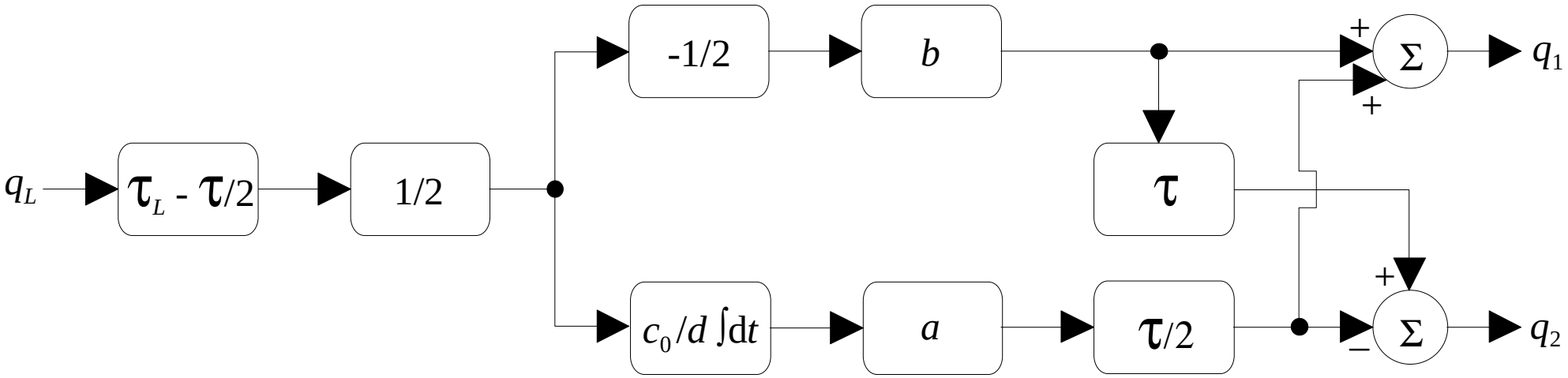
JMC-based solutions

- the JMC method (Jessel, Mangiante & Canévet) is suitable for formulating the ANC problem with the general system theory
- three types of secondary sources are needed: monopoles, dipoles, and quadripoles
- in the case of plane waves (such as in a narrow duct), quadripoles vanish
- ideal JMC actuators in a duct consist of monopole and dipole sources only

JMC-based two-element sources

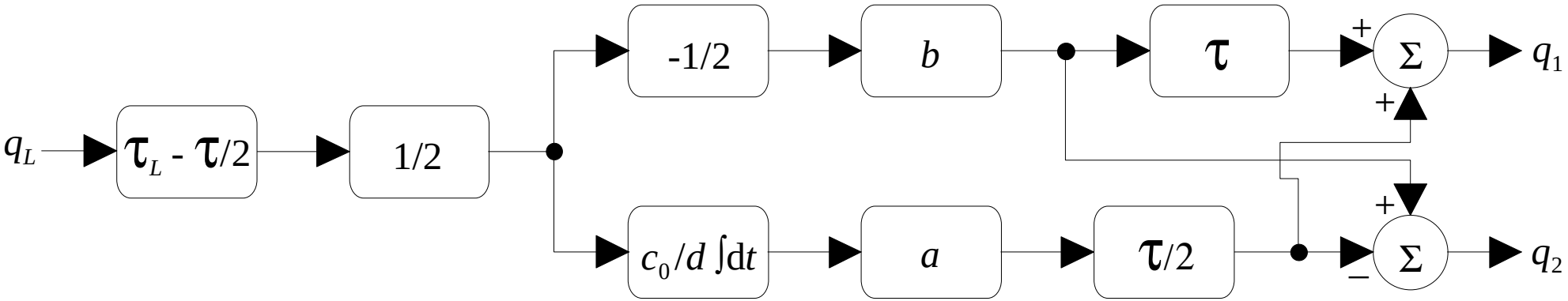
- inter-channel delay can be optimized in 3 different ways
  1. downstream
  2. upstream
  3. no delay at all
- the control structures for the 3 cases are illustrated next

Inter-channel delay optimized downstream

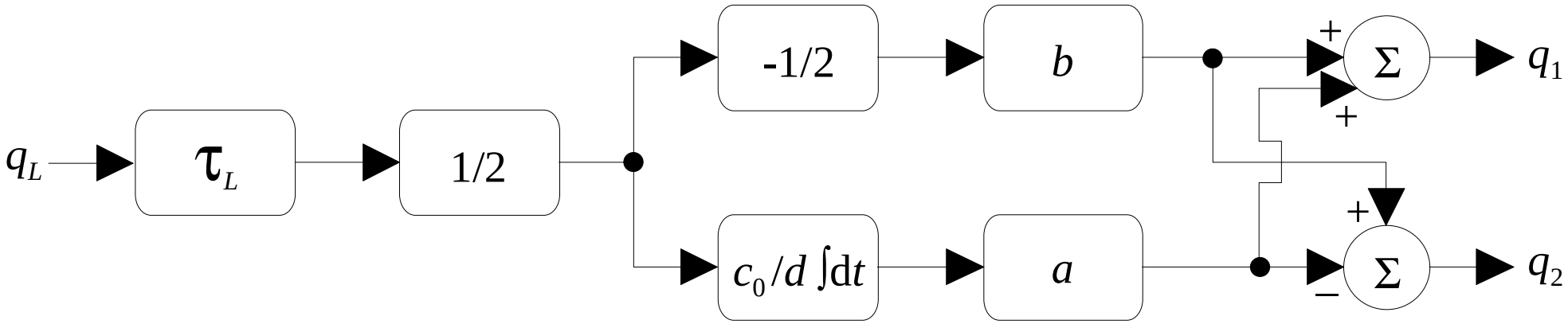


- filters *a* and *b* are given in Table 1

Inter-channel delay optimized upstream

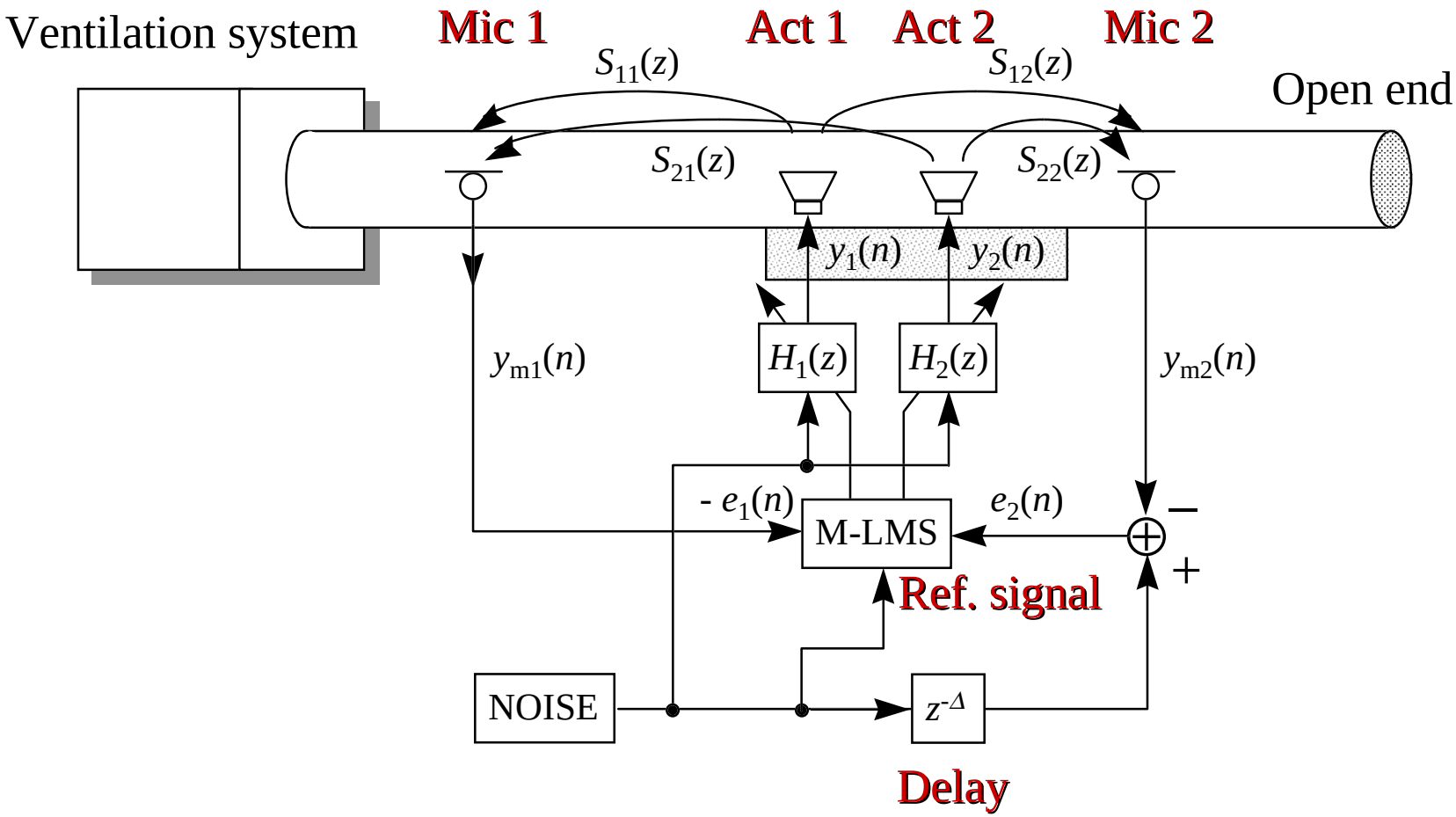


No Inter-channel delay



➤ in the non-adaptive case, the delayless version has been found to be easiest to design (Uosukainen & Välimäki, 1998)

Adaptive design of a unidirectional two-element source



Different phases of the adaptive design

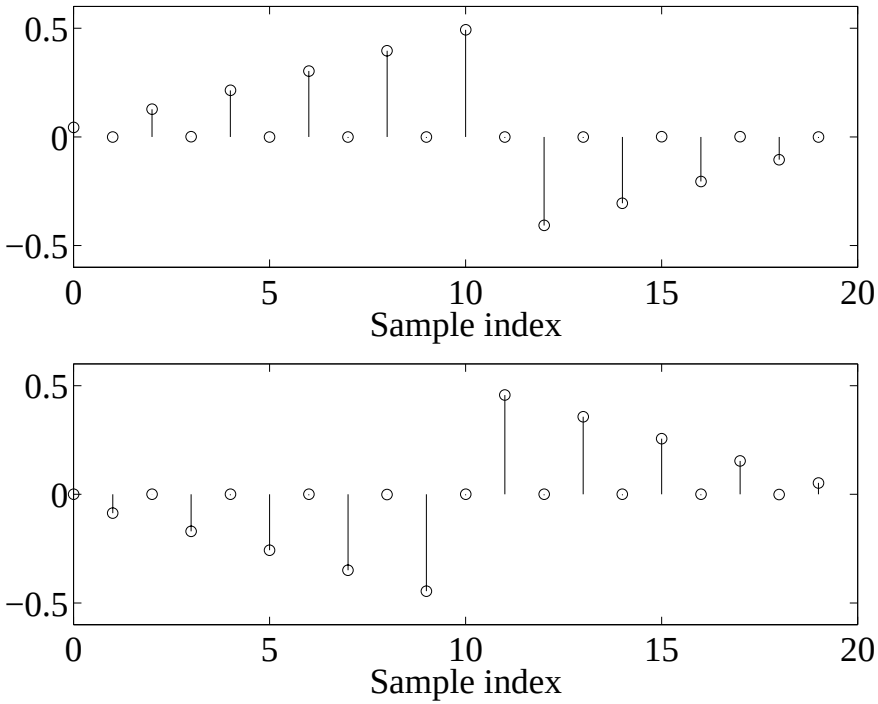
- adaptive design contains 3 phases
  1. calibrate transfer functions $S_{ij}(z)$ from both actuators to both microphones
  2. calibrate the unidirectionality (using the above system)
  3. calibrate the error path from the unidirectional source to the error detector
- after these phases, the ANC operation may start using a single-channel adaptive system (one more adaptive filter!)

Adaptive Swinbanks configuration

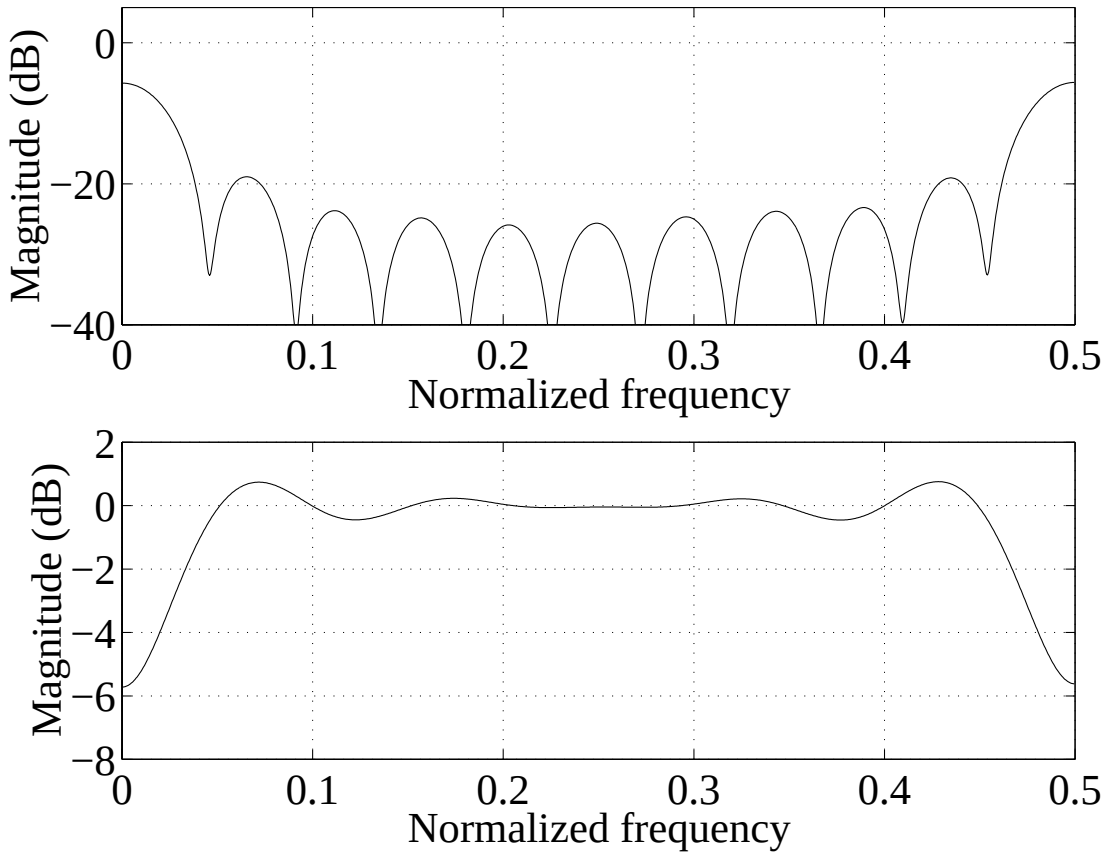
- the proposed adaptive structure can in principle design any of the four unidirectional two-element structures
- here we show examples of designing the Swinbanks source
- the adaptive structures for the JMC-based structures are shown in our paper

Example 1

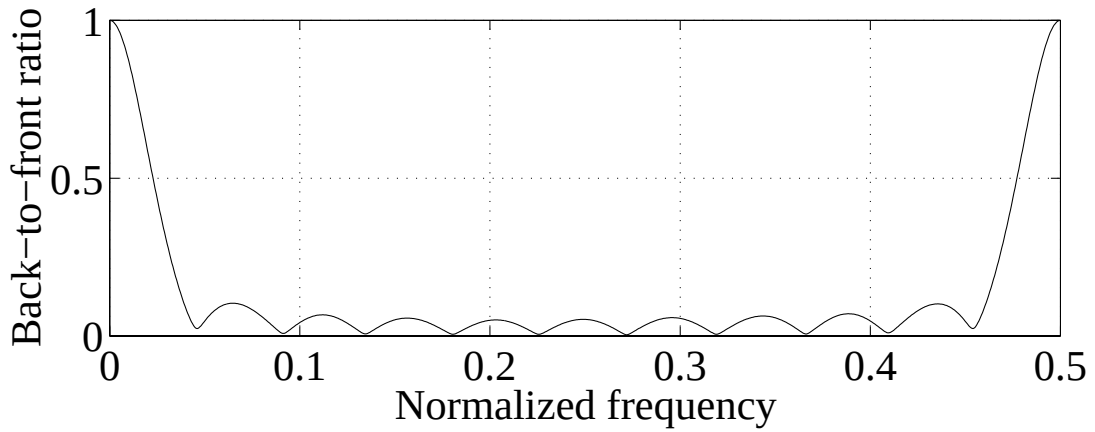
- the delay between the two actuators has been chosen to be $T = 1/f_s$, that is, one sampling interval
- the impulse responses of filters $H_1(z)$ and $H_2(z)$ are shown here (20 coefficients)



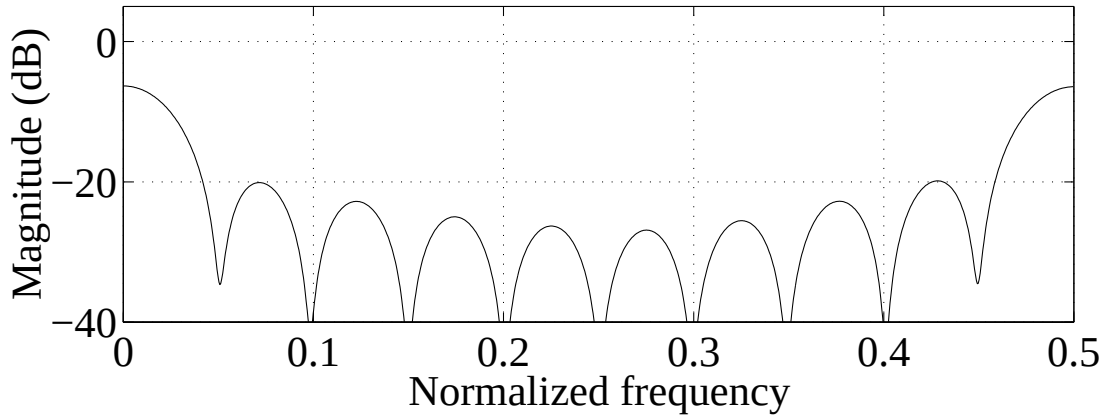
- magnitude responses upstream (upper) and downstream (lower) in Example 1



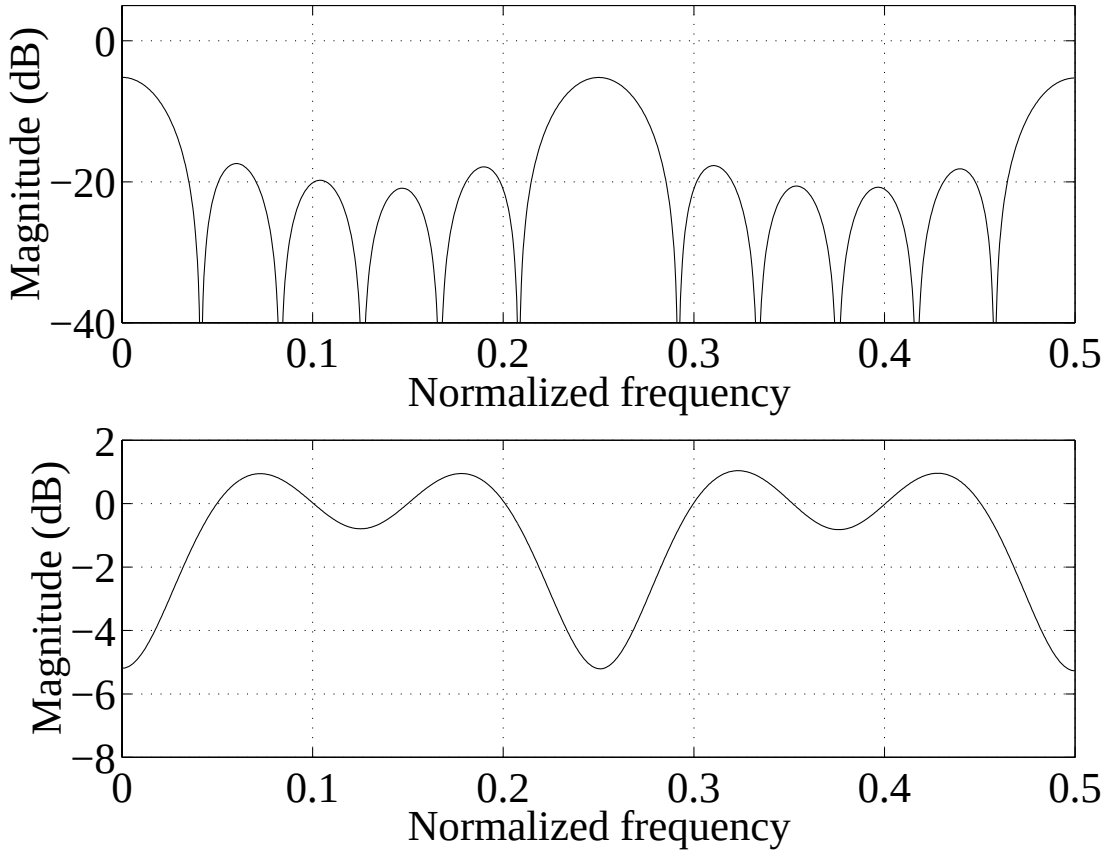
- back-to-front ratio (La Fontaine & Shepherd, 1985)



- obtainable sound radiation downstream (w/ideal anti-noise)



- magnitude responses upstream (upper) and downstream (lower) in Example 2 (delay between actuators = 2 samples)



Conclusions and future work

- automatic design of a unidirectional two-element system was described
- further work is needed to implement and evaluate the adaptive design of JMC-based unidirectional structures
- a more advanced adaptive system could be designed that adapts all transfer functions online: $H_1(z)$, $H_2(z)$, $S_{ij}(z)$, and the error path model
- finally, adaptive unidirectional systems should be tested in actual real-time situations