# Active Control of the Acoustic Quality in Open-plan Offices Using a Noise Barrier System with Sound Masking

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（音声マスキング効果を有する能動的遮音壁によるオープンプランオフィス音環境の能動的制御）

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## 論　文　内　容　の　要　旨
## Thesis Summary

This work is concerned with the active control of the acoustic quality in open-plan offices, which is an important aspect affecting the job satisfaction of the employees. Two of the primary complaints about the working environment in open-plan offices are high background noise level and lack of speech privacy. Both of these acoustic problems can be dealt with by active methods: active noise control (ANC) for reducing background noise, and sound masking for improving speech privacy. Based on this concept, an active noise barrier (ANB) applying the ANC and sound masking techniques is proposed. The ANC part of the proposed system uses a novel hybrid (HB) ANC system that combines the feedback (FB) and feedforward (FF) controller to reduce the speech sound, and the sound masking part covers the residual sound after control to realize the quietness and the speech privacy simultaneously in open-plan offices. This thesis describes the development process of the proposed ANB system. The contents of the thesis is organized as follows:

Chapter 1 introduces the background and objectives of this work.

Chapter 2 focuses on the design process of the FB controller which will be applied in the acoustic boundary control part of the HB control strategy. A practical FB controller should be with robust stability, limited noise amplification outside the control bandwidth, and adaptability to the time-variant noise. According to this philosophy, two methods for designing a robust adaptive FB controller are proposed in this chapter. The first one is a frequency domain method based on the direct formulation of the FB controller. By considering the easiness of real-time realization, the second method finds a constraint of the control filter coefficients by converting the frequency domain robust stability condition and noise amplification constraint into the time domain. The effectiveness of the proposed methods is verified by simulations and experiments.

Chapter 3 investigates the noise attenuation performance of the proposed ANB system using the HB-ANC system. Based on the HB control structure, a technique for canceling the noise amplification of the FB control propagating into the control area behind the ANB is also proposed in this chapter. First, the proposed control strategies are described, and an

efficient system implementation of the control strategies is presented. Then, the noise attenuation performance of the ANB under different sound field conditions is investigated by simulations and experiments. Finally, an experiment is conducted to verify the effectiveness of the proposed ANB in a real office room.

In Chapter 4, selection of the maskers for the sound masking part of the proposed system is considered. Two listening experiments are conducted to investigate the masking efficiency and annoyance of several representative energetic and informational maskers. According to the experimental results, the features of the energetic and informational maskers are discussed, and a criterion of selecting an appropriate masker for the sound masking system in offices is concluded.

In Chapter 5, the whole proposed system combining the ANB system with sound masking is implemented based on the investigations in the preceding chapters. The noise attenuation and the sound masking performance of the proposed system are validated by simulations.

Chapter 6 presents an approach to achieving overall noise attenuation in a certain area based on the concept of wavefront synthesis, which can be applied to the sound pressure control part of the HB control strategy. The basic idea of this approach is to divide a global ANC system into two sub-systems according to the different control objectives. One sub-system is to reproduce the wavefront of the incident noise into the target area, and the other one is to tune the amplitude and phase of the reproduced control sound wavefront. By using this approach, the control algorithm and the hardware configuration of a global ANC system can be significantly simplified. The effectiveness of the approach is verified by numerical simulations.

Chapter 7 presents a summary of the work in this thesis.