A Hybrid Active and Passive Noise Control (HAPNC) for open window was introduced last year at Internoise conference. In this paper, we outlined the HAPNC system configuration and performed experiment on bandlimited noise source propagating directly through window opening. We investigated multiple-input, multiple-output FxLMS algorithm and used passive approach of duct splitter to extend the frequency range for noise control for open windows. However, the noise reduction performance of HAPNC has not been studied for noise source propagating from different incidences. In this paper, we investigate different configurations of reference-secondary sources placement and study about different adaptation schemes to observe its noise reduction performance. These experimental studies provide us a guideline on how to adjust the control mechanism of the HAPNC and provide better noise control.

Keywords: active noise control, splitter silencer, feed forward control, fixed filters,

1. Introduction

Active noise control (ANC) is a technique used to reduce noise [1] and has been applied to air conditioning duct [2], ear protectors [3] and engine noise in car cabins [4]. These applications utilize the properties of ANC to achieve noise reduction together with passive noise control (PNC). Previously, there was a report in achieving noise reduction at an open window with active and passive noise control [5]. This approach uses loudspeakers with splitter silencer, which is often used as a device for noise reduction in the duct system [6]. Among the wide range of interest in improving the design of splitter silencer, splitter silencer with active noise control in the duct system is particularly attractive [7]. Therefore, the duct is able to obtain noise attenuation in high frequency region. Furthermore, the noise only propagate low frequency region. Thus, the ANC application was useful to control low frequency noise. However, an open window is not same as the duct regarding length. Nevertheless, the splitter silencer is useful device to attenuate noise of high frequency region when we choose an appropriate design. In previous study, we investigated on hybrid approach using both ANC and PNC for open window with a chamber [5]. The result showed that the splitter silencer with ANC system applied noise reduction. (Hereinafter, we refer the Hybrid Active and Passive Noise Control (HAPNC).
Control as “HAPNC”). Moreover, the HAPNC system worked together in normal incidence noise. In this study, we are interested in investigating another incidence noise in an open window. In particular, HAPNC use the same procedures that is based on an ANC window in previous work [8]. The arrangement of the ANC window used a fixed filter that updated by normal incidence. Thus, the system can remove the error microphones at final stage. Furthermore the system works when the primary noise is another incidence, in spite of using the fixed filter for normal incidence. Meanwhile, a limitation the fixed filter has been studied with simulation [8]. However, the HAPNC will be effect the noise reduction of ANC system when primary source is oblique incidence, because the splitter silenced blocked the propagating noise. Therefore, this research investigate a compression between using the fixed filter updated by normal incidence and another incidence. On the other hand, there are another limitation for noise reduction for high frequency region by the length between each loudspeaker. It was indicated by simulation and the result shows that the length is should chose within spatial Nyquist frequency [9]. Since splitter silenced has limitation in length and has a short duct, the noise reduction of splitter silenced is also restricted by its size. Thus, we choose the length of each speaker as Sec.2. The arrangement and algorithm of experiments are shown at Sec.2 also. Sec. 3 shows the experimental result that is comparison between noise reductions using fixed filter from normal incidence and using fixed filter from oblique incidence.

2. Basic concept

This section shows the fabrication of a splitter silenced for the hybrid approach. These units are based on previous works [5] and minor changes have been made to improve noise reduction in splitter silenced. For this work, plates were added in the front and back of splitter silenced.

2.1 Fabrication

Fig.1 shows a splitter silenced unit with loudspeakers. The distance between each speaker are 12 cm and the loudspeaker is 5.25 cm diameter. The arrangement applied for under 1433 Hz by spatial Nyquist frequency. Second, the splitter sizes are that thickness is 6 cm, width is 48 cm and length is 12 cm. These size chose for 50 % open space at opening that size are 48 cm width and 24 cm height. In particular, the length of splitter is most effective for noise reduction when the same open ratio. However, the window has limitation on thickness and we choose 12 cm as twice of the gap of splitter silenced.

![Figure 1: A unit of splitter silenced with loud speaker.](image)

2.2 Arrangements

The chambers are fabricated with wooden boards and absorbing materials. The size is 1.5 m length, 0.9 m width, and 1.2 m height and the opening is 0.48 m length and 0.24 m height for 2 ANC units. Fig. 2 shows the arrangement of an experiment. A primary source is placed at 0.6 m inside of the chamber from open space. 8 error microphones are placed in front of the 8 loudspeakers to update the
ANC system. These error microphones also measure error signals to determine the performance of ANC parts as a relative sound pressure level. Furthermore, there are 5 monitors to check global noise reduction that are each placed at 1 m in front of the open space pointing at 5 different directions, which are front, left, right, top and bottom with the 45-degree angle.

![Figure 2: 1 Arrangements of experiments.](image)

The primary source uses 2 type of sounds, band limited white noise from 100 Hz to 2 kHz and train noise. The position of primary source is shifted for another incidence. One of the positions is that the primary speaker is moved to left (-33 cm, y axis as pointed b) and it is rotated 28 degree to face the center of the opening (hereinafter, we called the arrangement "Horizontal incidence"). The other position is that the primary speaker is moved to bottom (-33 cm, z axis as pointed c) and it is rotated 28 degree to face the center of the opening (hereinafter, we called the arrangement "Vertical incidence"). There are 4 conditions for the measurements, which are opening fully, setting 2 splitter silencers, turn on ANC system with fixed filter that updated by normal incidence and turning on the ANC with the fixed filter that updated by oblique incidence by band limited white noise.

### 2.3 ANC algorithm

In this research, method based on multi-channel FxLMS with collocated ANC units from a previous research [8] of open window was applied. The method uses multi-channel FxLMS without cross-adaptive filters. First, primary source chooses the bandlimited white noise around spatial Nyquist frequency. However, in this study we choose 100 Hz to 2 kHz for the normal incidence as the same condition of previous study. Second, after update adaptive filters, those filters are fixed. Fig shows 8(1-1)-8 FxLMS and it has 8 reference microphones, 8 loudspeaker, and 8 error microphones. Equation 1 shows the update of the adaptive filter.

![Figure 3: Block diagram of 8(1-1)-8 FxLMS and the figure of the ANC unit with error microphone and without microphones.](image)
\[ w_n(n+1) = w_n(n) - \mu \sum_{k=1}^{8} \{ \hat{s}_k(n) \ast x_k(n) \} \cdot e_k(n) \quad (i = 1, 2, \cdots 8) \] (1)

3. Experiments

This section shows the result of experimentations as follows: the averaged power spectrum among 8 error microphones, averaged sound pressure level among 5 monitor point with sound pressure level meter. The former shows the maximum noise reduction as error signals. The latter shows global attenuation level at room. Each fixed filter is updated by bandlimited white noise 100 Hz to 2 k Hz.

3.1 Normal incidence

Fig.4, 5 and 6 show the result under normal incidence. The Fig.4 and 5 show the averaged relative sound pressure level among 8 error signals and the attenuation level. Fig. 4 shows that primary source is bandlimited white noise 100 Hz to 2 kHz. Fig. 5 is using train noise for primary noise. Blue lines show the condition under fully opening. Green lines show the condition under the setting splitters. Red lines show the condition under tuning on ANC system, it is mention total attenuation.

Fig.6 shows the attenuation level at monitor points with 1/3 octave band analysis. Each colour mention the same condition as Fig. 4 and 5. Finally, the system obtain noise attenuation from 200 Hz to 1.6 kHz by ANC system and noise attenuation above 2 kHz obtain by PNC.

![Figure 4](image1)

(a) Average of relative sound pleasure level

(b) Attenuation levels

Figure 4: Average of power spectrum among error signals (a) and attenuation level (b) under normal incidence with bandlimited white noise 100 Hz to 2 kHz

![Figure 5](image2)

(a) Average of relative sound pleasure level

(b) Attenuation levels

Figure 5: Average of power spectrum among error signals (a) and attenuation level (b) under normal incidence with train noise
Figure 6: Averaged sound pressure level and attenuation level among 5 monitor points at 1 m distance from the center of the window under normal incidence with train noise.

The reason why there is the difference between attenuation of splitter silencer in band limited white noise with train noise is that the calculation method of power spectrum and the train noise is fluctuated the gain. The power spectrum is averaged 18 times each 1 second of the data.

3.2 Horizontal Incidence

Fig. 7, 8 and 9 shows the result under Horizontal incidence. The Fig. 7 and 8 shows the averaged relative sound pressure level among 8 error signals and the attenuation level. Fig. 7 shows that primary source is bandlimited white noise 100 Hz to 2 kHz. Fig. 8 is using train noise and it is included above 2 kHz. Blue, green and red lines show the same condition as the Fig. 4 to 6, bright blue line shows the condition under using the fixed filter which updated by horizontal incidence.

Fig. 9 shows the attenuation level at monitor points with 1/3 octave band analysis, and the colour mention the same meaning as Fig. 7 and 8.

Figure 7: Average of power spectrum among error signals (a) and attenuation level (b) under horizontal incidence with band limited white noise 100 Hz to 2 kHz.

Fig. 7 to 9 shows that the fixed filter by normal incidence also obtain noise attenuation from 200 Hz to 20 k Hz by this system. However, there are degrading of the noise attenuation from 400 Hz to 900 Hz when use the fixed filter that is updated normal incidence. Moreover, the noise from 1.6 k Hz to 3.15 kHz is increasing at monitor points in both ANC conditions.
3.3 Vertical incidence

Fig. 10, 11 and 12 shows the result under Vertical incidence. The Fig. 10 and 11 shows the averaged relative sound pressure level among 8 error signals and the attenuation level. Fig. 10 shows that primary source is bandlimited white noise 100 Hz to 2 kHz. Fig. 11 is using train noise and it is included above 2 kHz. Blue, green and red lines show the same condition as the Fig. 4 to 6, bright blue line shows the condition under using the fixed filter which updated by normal incidence.

Fig. 12 shows the attenuation level at monitor points with 1/3 octave band analysis, and the colour mention the same meaning as Fig. 10 and 11.

Fig. 10 to 11 shows that the fixed filter by normal incidence also obtain noise attenuation from 200 Hz to 20 k Hz by this system. However, there are degrading of the noise attenuation from 600 Hz to 900 Hz when use the fixed filter that is updated normal incidence.

Regarding to global attenuation level, the noise in 1.6 kHz to 4 kHz is increasing at monitor points under every fixed filters.
Figure 10: Average of power spectrum among error signals (a) and attenuation level (b) under vertical incidence with band limited white noise 100 Hz to 2 kHz

Figure 11: Average of power spectrum among error signals (a) and attenuation level (b) under vertical incidence with train noise

Figure 12: Averaged sound pressure level and attenuation level among 5 monitor point at 1 m distance from the center of the window under vertical incidence with train noise.
4. Conclusions

In this paper, a hybrid noise control system consisted of the splitter type of silencer and an array ANC system. An effect for attenuation level of the system was investigated when the primary source is oblique incidence. The experimental results were as follows:

- The splitter silencer with 8 channel ANC system were fabricated for 50 % open ration at window.
- The ANC system was applied 8(1-1)-8 FxLMS to remove error microphones at final stage.
- The system use fixed filters that is updated by normal incidence in every conditions.
- In this time, we prepared the other fixed filters that is updated by oblique incidence.
- Each fixed filter were updated by bandlimited white noise from100 Hz to 2 kHz.
- In using the fixed filter by normal incidence, the hybrid system produce the noise reduction 200 Hz to 2 kHz by ANC and above 2 kHz by PNC in every incidence.
- However, there are degrading of the performance under the oblique incidence when the system using fixed filter by normal incidence.
- The degrading of noise attenuation level were at 400 Hz to 900 Hz by Horizontal oblique incidence, or 600 Hz to 900 Hz by vertical oblique incidence.

In this time, the reason of this degrading did not elucidate. In future work, the position of reference microphones move to nearby loudspeaker to return back the basic concept of previous open window to confirm the effect of another incidence.

REFERENCES