2010

Active noise barrier minimizing pressure gradient

Carl Hart
University of Nebraska-Lincoln

Siu-Kit Lau
University of Nebraska-Lincoln

Proceedings of Meetings on Acoustics

Volume 11, 2010 http://asa.aip.org

160th Meeting
Acoustical Society of America
Cancun, Mexico
15 - 19 November 2010
Session 1pNS: Noise

1pNS12. Active noise barrier minimizing pressure gradient

Carl Hart* and Siu-Kit Lau

***Corresponding author's address: Durham School of Architectural Eng. and Construction, University of Nebraska - Lincoln, 1110 S. 67th St., Omaha, Nebraska 68182, carl.hart@huskers.unl.edu**

Minimization of the sound pressure field within the shadow zone of a noise barrier is achieved by reducing the pressure gradient along a line, at the top of a barrier, via active noise control. The noise control effectiveness of a barrier is increased by this strategy, especially for specific system configurations. The proposed method was evaluated by numerical simulation. Results indicate that system orientation has little effect on minimizing the pressure gradient at the top of the barrier when the error sensors are invisible to the primary noise disturbance. Highly effective control within the shadow zone and close to the barrier is possible when the system is oriented at an angle where two or more error sensors are in line with the first diffracting edge and the primary noise disturbance. Increasing the spatial extent of the quiet zone is possible by increasing the number of control sources, where the error sensors have a line of sight with the primary noise disturbance. [Work supported by a fellowship (CRH) and grant (SKL) from the University of Nebraska - Lincoln.]

Published by the Acoustical Society of America through the American Institute of Physics

Received 7 Jan 2011; published 25 Feb 2011

1. Introduction

Noise barriers are a common noise control device for noise sources, such as public transportation, in close proximity to residences. The coupling of active noise control (ANC) with passive noise barriers is a particular noise control strategy to limit sound transmission, beyond a noise barrier. The combination is known as an active noise barrier. The first study on active noise barriers was done by Ise, Yano and Tachibana (1991). The ANC system utilized single channel control in order to minimize the pressure at the error sensor. The error sensor was placed in the shadow zone and the control source adjacent to the barrier top, in the shadow zone. The study was a proof of concept: gains in noise control could be realized by combining ANC with passive noise barriers. Later, Omoto and Fujiwara (1993) employed a modified ANC method by minimizing the sum of squared pressures in order to create a 'soft' edge. Error sensors were placed at the barrier top in order to create a zone of quiet in the vicinity of the top of the barrier. The most effective configuration was shown to have the error sensors placed less than half a wavelength apart and placing the control sources nearest to the noise source. Later, Duhamel (1995) confirmed Omoto and Fujiwara's results. Guo and Pan (1998) then discovered that the optimal error sensor placement of Omoto and Fujiwara's study is not exactly less than half of a wavelength but depends upon a relationship between wavelength, control source to error sensor distance and noise source to control source distance. Afterwards, another active noise barrier study was conducted examining the combination of near-field and far-field error sensing (Berkhoff 2005).

In dense urban areas the use of an ANC configuration distributed over a large area, as in the cited studies above, poses a significant issue. Thus, the motivation of this current study is to determine an effective ANC configuration that is compact, residing near the barrier top. The motivation is based on a previous study by Lau and Tang (2009). Their hypothesis was based on creating a dipole configuration, with the barrier top and ANC system, in order to achieve a significant additional insertion loss. In their study the use of pressure gradient control was utilized and is utilized in this study as well. This study builds upon the previous study by examining which parameters of the previous ANC configurations most affect the additional insertion loss in the shadow zone of the barrier.

2. Methodology

The additional insertion losses of various ANC configurations were estimated by numerical simulation. The inhomogeneous wave equation, with a volumetric source, was numerically solved.

The computational domain consists of an inner and outer domain (see Fig. 1). The interior domain is a homogeneous domain that consists of a rigid barrier and rigid ground ($-10 < x < 10$ and $y = 0$). The extents of the interior domain are 10 m by 20 m. The exterior domain is formulated as a perfectly matched layer (Chen and Liu 2005). Additionally the ground ($-30 < x \leq -10$ or $10 < x < 30$, and $y = 0$) is formulated as an impedance matched boundary (Tang and Lau 2002). The extents of the exterior domain are 30 m by 60 m. The interior domain has a barrier that is 3 m tall and 0.2 m thick, with the left face of the barrier at $y = -2.4$ m (see Fig. 2). The noise source is 2.9 m in front of the barrier. A measurement plane lies 1.7 m above the ground in order to quantify the additional insertion loss. The ANC system is placed at the top of the barrier.

The ANC system resides at the barrier top (see Fig. 3). Several parameters of the ANC system are varied. The system is rotated from 90 degrees to 180 degrees in 9 degree increments. The center of rotation lies at the midpoint of the barrier top. The number of secondary control sources is varied from one to two. The spacing of the error sensors and control sources is varied from 0.05 m to 0.15 m in 0.05 m increments. The orientation of control sources to error sensors are maintained constant relative to each other. The control sources lie along a line that is mutually perpendicular to the line the error sensors lie along. The line the error sensors lie along intersects the midpoint between the first control source and point of rotation.

The minimization of the sum of squared acoustic pressures for two closely spaced error sensors leads to the minimization of the local pressure gradient (Elliott and Garcia-Bonito 1995). Based on this fact it is desired to minimize the pressure gradient along a line parallel to the barrier top in order maintain a dipole configuration between control sources and diffracting barrier top.

The metric used to quantify the extra sound attenuation due to ANC is the additional insertion loss. The additional insertion loss is defined as,

$$AIL = -10\log\left(\frac{p_{anc}^2}{p_{barrier}^2}\right),$$

where p_{anc}^2 is the squared pressure with the ANC system on and $p_{barrier}^2$ is the squared pressure without ANC. In order to quantify the additional insertion loss in the shadow zone a spatial average of the squared pressure, with and without ANC, is taken along the measurement plane:

$$AIL_{MP} = -10\log\left(\frac{<p^2>_{x,anc}}{<p^2>_{x,barrier}}\right).$$

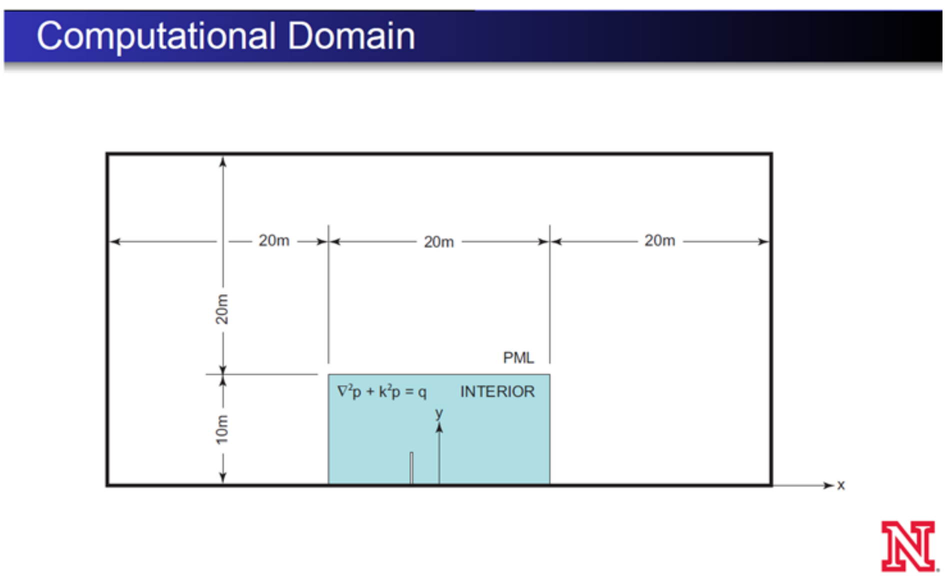

Figure 1: The computational domain of the study.

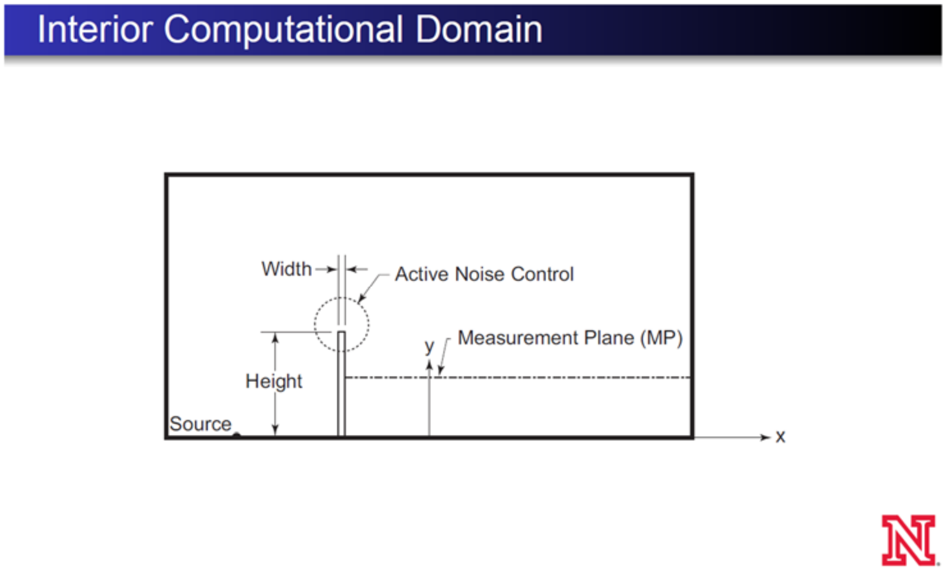

Figure 2: Interior computational domain.

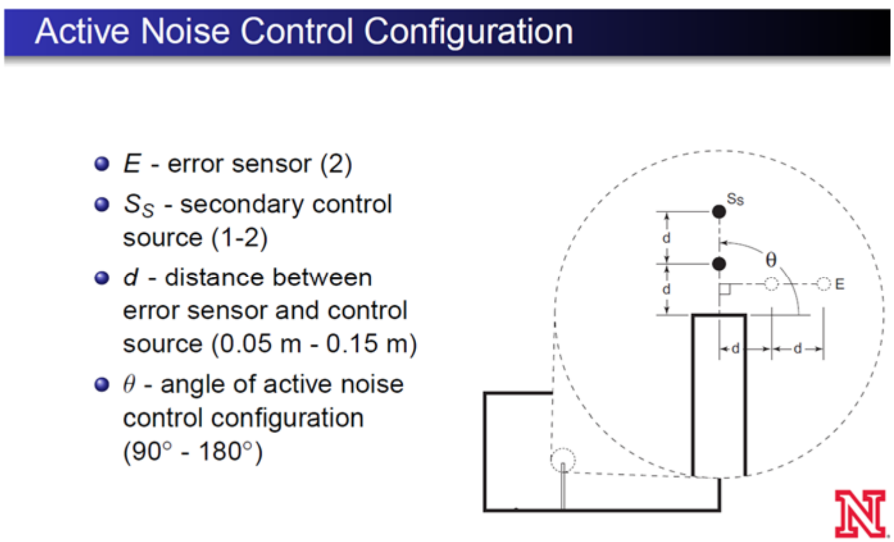

Figure 3: ANC system and configuration parameters.

3. Results

The additional insertion loss based on the various parameters varied and for frequencies of 171.5 Hz, 343 Hz, and 514.5 Hz are shown in Figures 4, 5 and 6, respectively. For the case of one control source there is little dependence upon the angle of orientation. However, for two control sources the angle of orientation plays a greater role in the calculated additional insertion loss. Generally, as the spacing for the error sensors and control sources increases the additional insertion loss increases at frequencies of 171.5 Hz and 343 Hz. For all the frequencies the additional insertion loss increases beyond 135 degrees (i.e. 0.75 π), for two control sources. The angle of orientation is a critical factor in affecting the additional insertion loss for two control sources because of the line of sight between the furthest error sensor and noise source (refer to

Figure 7). For angles greater than 145 degrees (i.e. 0.81 π) and a separation distance of 0.10 m or greater the error sensors have clear visibility of the noise source. When the angle of orientation is within the vicinity of a clear line of sight, for a separation distance of 0.15 m and two control sources, a peak in additional insertion loss is observed.

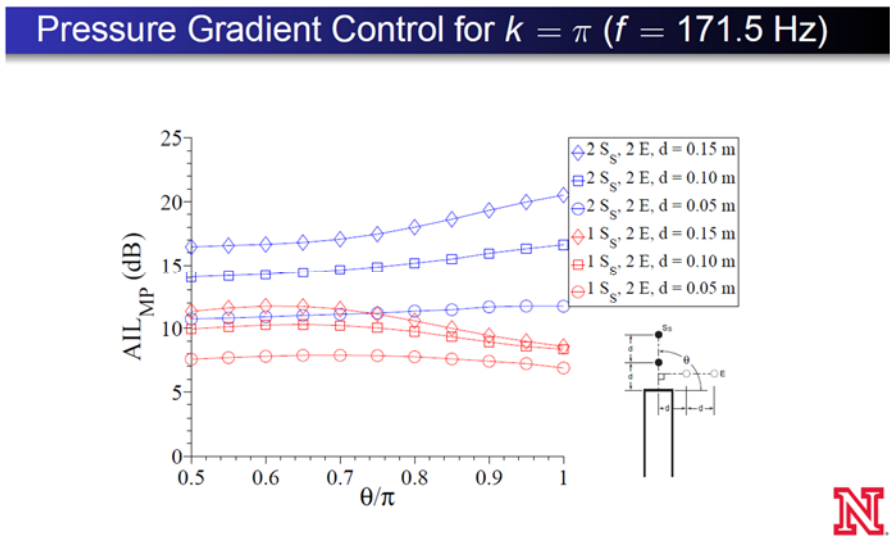

Figure 4: Additional insertion loss along the measurement plane for a frequency of 171.5 Hz. S_s and E are the numbers of control sources and error sensors, respectively.

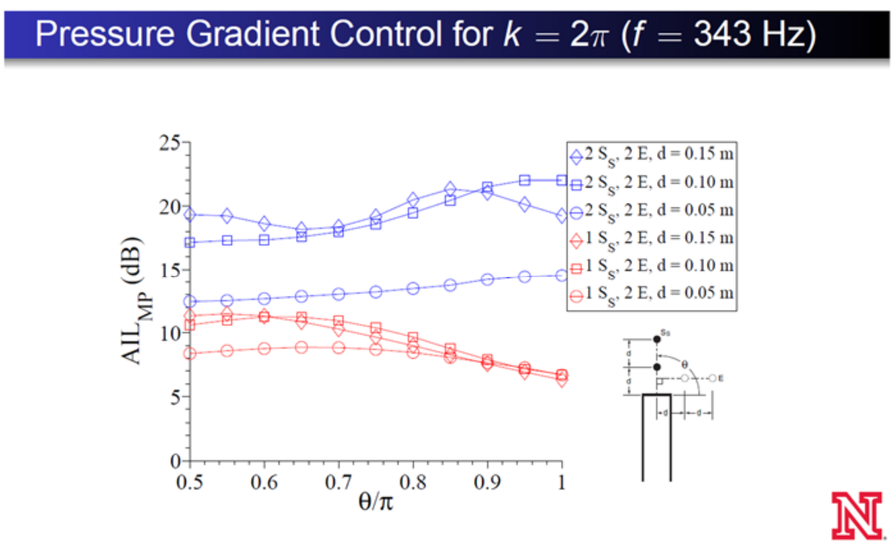

Figure 5: Additional insertion loss along the measurement plane for a frequency of 343 Hz. S_s and E are the numbers of control sources and error sensors, respectively.

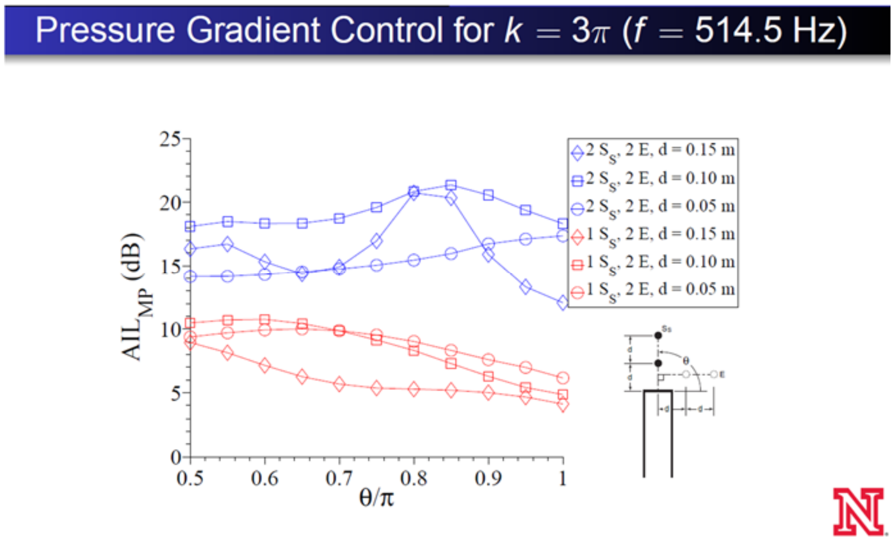

Figure 6: Additional insertion loss along the measurement plane for a frequency of 514.5 Hz. S_s and E are the numbers of control sources and error sensors, respectively.

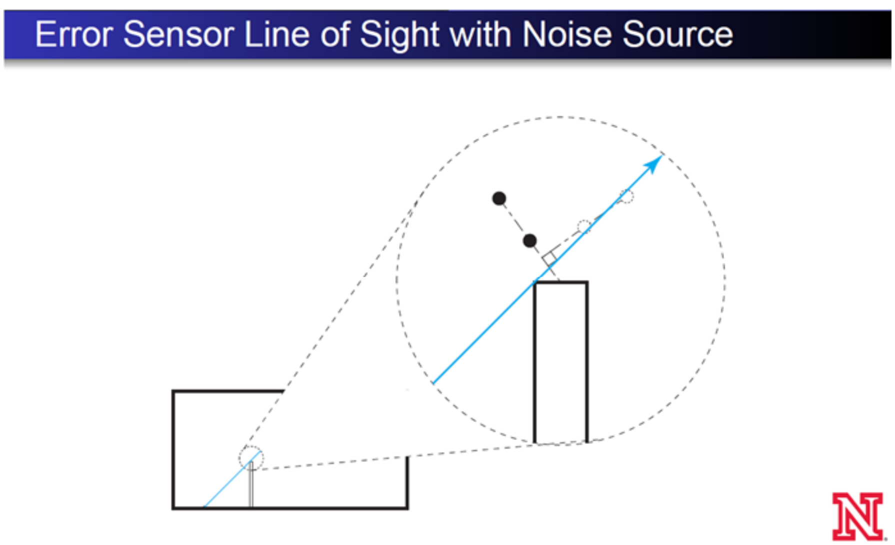

Figure 7: Line of sight between error sensors and noise source.

The additional insertion loss fields for a frequency of 343 Hz, two error sensors, two control sources, a separation distance of 0.15 m and angles of 90 degrees (i.e. 0.5 π) and 153 degrees (i.e. 0.85 π) are shown to have considerable differences (see Figs. 8 and 9). Figure 5 exhibits a peak in additional insertion loss near the angle where a clear line of sight is established for one of the error sensors. The spatial extent of extra sound attenuation afforded by ANC is shown to be highly dependent upon angle for two control sources. For these two particular cases the spatial extent of extra sound attenuation is greater for an angle of configuration of 153 degrees rather than 90 degrees.

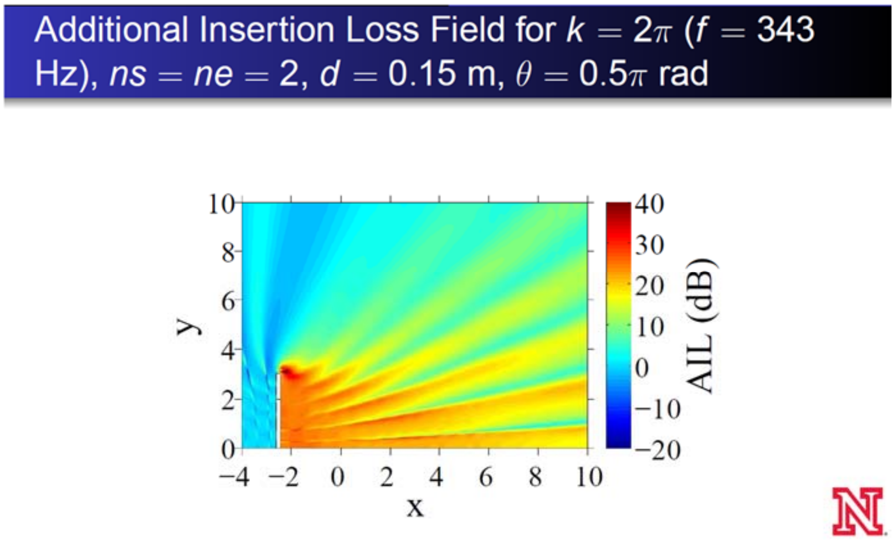

Figure 8: Additional insertion loss field for an angle of 90 degrees (i.e. 0.5 π) with two control sources and two error sensors at 343 Hz. d = 0.15m.

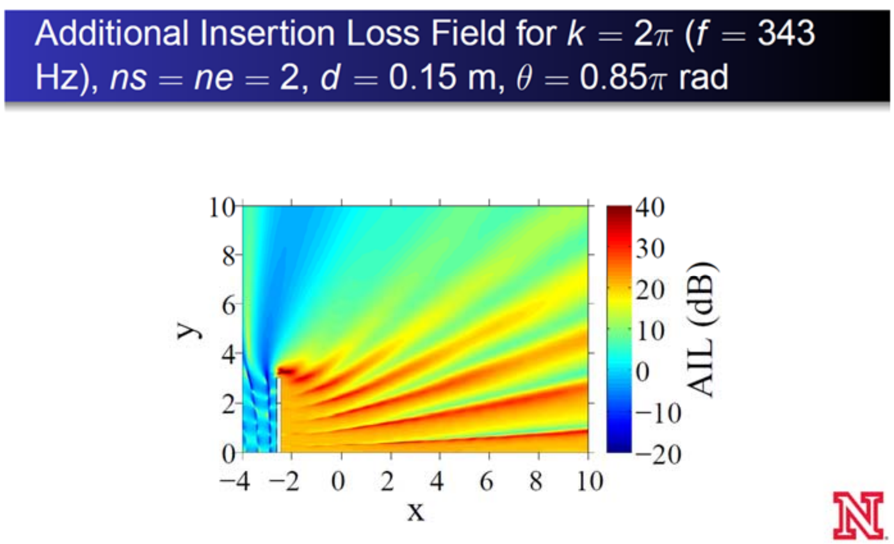

Figure 9: Additional insertion loss field for an angle of 153 degrees (i.e. 0.5 π) with two control sources and two error sensors at 343 Hz. d = 0.15m.

4. Summary

The additional insertion loss due to pressure gradient control, for one control source, is fairly uniform across several tilt angles. Tilting the error sensors beyond a line of sight of the first diffracting edge and primary noise source causes a significant rise in additional insertion loss, for two control sources.

References

Berkhoff, Arthur P. 2005. Control strategies for active noise barriers using near-field error sensing. *The Journal of the Acoustical Society of America* 118 (3) (September 2005): 1469-79.

Chen, Zhiming, and Xuezhe Liu. 2005. An adaptive perfectly matched layer technique for time-harmonic scattering problems. *SIAM Journal on Numerical Analysis* 43 (2) (2005): 645-71.

Duhamel, D. 1995. Improvement of noise barrier efficiency by active control. *Acta Acustica* 3 (1): 25-35.

Elliott, S. J., and J. Garcia-Bonito. 1995. Active cancellation of pressure and pressure gradient in a diffuse sound field. *Journal of Sound and Vibration* 186 (4): 696-704.

Guo, Jingnan, and Jie Pan. 1998. Increasing the insertion loss of noise barriers using an active-control system. *The Journal of the Acoustical Society of America* 104 (6): 3408-16.

Ise, S., H. Yano, and H. Tachibana. 1991. Basic study on active noise barrier. *Journal of the Acoustical Society of Japan* 12 (6): 299-306.

Lau, Siu-Kit, and Shiu-Keung Tang. 2009. Investigation of system configuration and pressure gradient control for active noise barrier. Paper presented at Inter-Noise 2009: 38th International Congress and Exposition on Noise Control Engineering, Ottawa, Canada.

Omoto, A., and K. Fujiwara. 1993. A study of an actively controlled noise barrier. *The Journal of the Acoustical Society of America* 94 (4): 2173-80.

Tang, S. K., and C. K. Lau. 2002. Sound transmission across a smooth nonuniform section in an infinitely long duct. *The Journal of the Acoustical Society of America* 112 (6): 2602-11.