AN ACTIVELY CONTROLLED DOUBLE-GLAZED WINDOW WITH SMALL PANE DISTANCE

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Jakob, André; Möser, Michael
Institute of Technical Acoustics, Technical University of Berlin
Einsteinufer 25
D-10587 Berlin
Germany
Tel: ++49 +30 314-22931 / 22932
Fax: ++49 +30 314-25135
E-mail: andre.jakob@tu-berlin.de

ABSTRACT

Recent investigations show that active noise control methods can improve sound transmission loss of double-glazed windows in the low frequency region [1,2,3,4,5]. Particularly around the mass-spring-mass resonance frequency of the double-panel system the sound insulation can be enhanced up to 10dB for white noise excitation and even more for tonal sound sources, at least when feedforward control is used. A previous experimental setup contained relatively large loudspeakers inside the cavity between the glass panes, thus implying a rather large pane distance of 200mm. In this paper experiments carried out with narrow loudspeakers, thus allowing a small pane distance, are reported. Even with “low-quality“ loudspeakers high improvements were obtained.

EXPERIMENTAL SETUP

A double-glazed window was built, which consists of two 4mm glass panes, as they are used for usual windows. Due to the use of very narrow loudspeakers the distance between the panes could be as small as 40mm (84mm in [4], 100mm in [5]). The Photograph in Fig. 1 shows the active double-glazed window installed in the window testing facility of the institute. The dimensions of the panes are 100cm wide and 125cm tall. A third-octave band measurement of the sound reduction index of the passive window, i.e. active control off, shows the lowest values around 125Hz due to the mass-spring-mass resonance frequency of the pane-cavity-pane system. Around this frequency active control is most efficiently. The passive sound reduction in the 125Hz third-octave band is as small as 11dB and the sound reduction index of the passive window according to DIN 4109 [6] is R'_w=33dB.

In Fig. 1 the (black) loudspeakers around the inner sides of the window frame can clearly be seen. Three loudspeakers were installed at each side. Out of these 12 loudspeakers only 9 were used in the experiments presented here. Out of these 9 loudspeakers 3 loudspeakers respectively, belonging to one side respectively, were driven in parallel by one controller output. Four error microphones were installed inside the windows cavity, too, out of which 2 were summed, forming together with the other 2 error microphones 3 error signals. Thus the control system was one with 3 inputs and 3 outputs (3i3o). No additional reference signal was used but a pure feedback scheme with adaptive filters and the well known multiple error LMS-algorithm as in [7,8]. The sampling frequency was set to 800Hz and a minimum number of filter coefficients for the secondary path filters of 100 was determined. Thus, due to the limitations of the controller hardware, a maximum number of 62 filter coefficients for the 9 adaptive filters could be used.

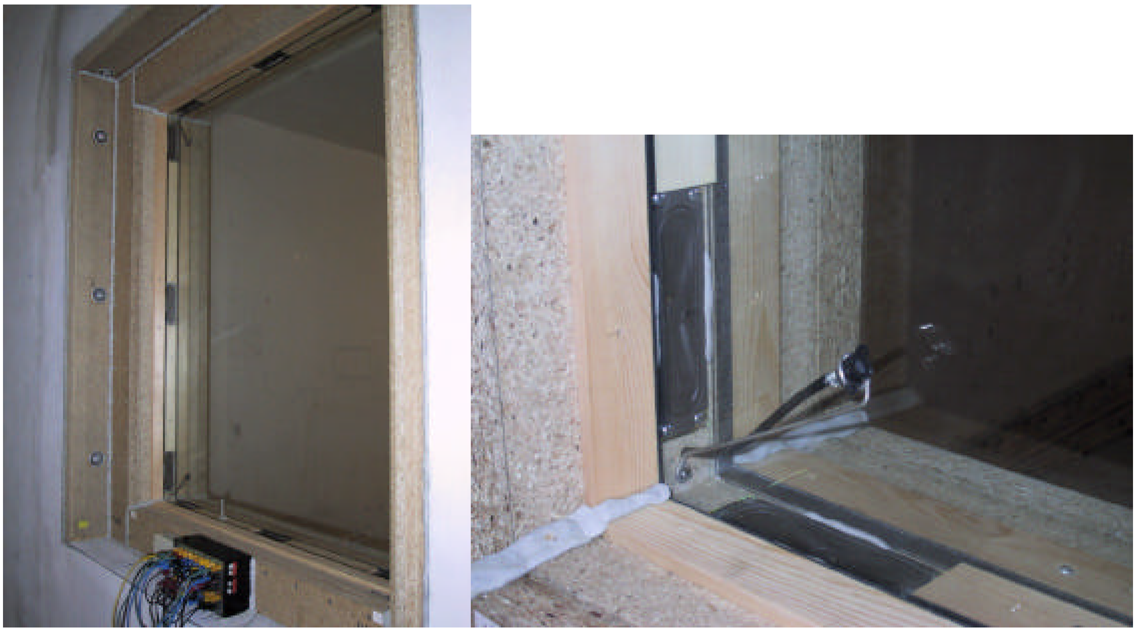

Fig. 1: Photographs of the active window

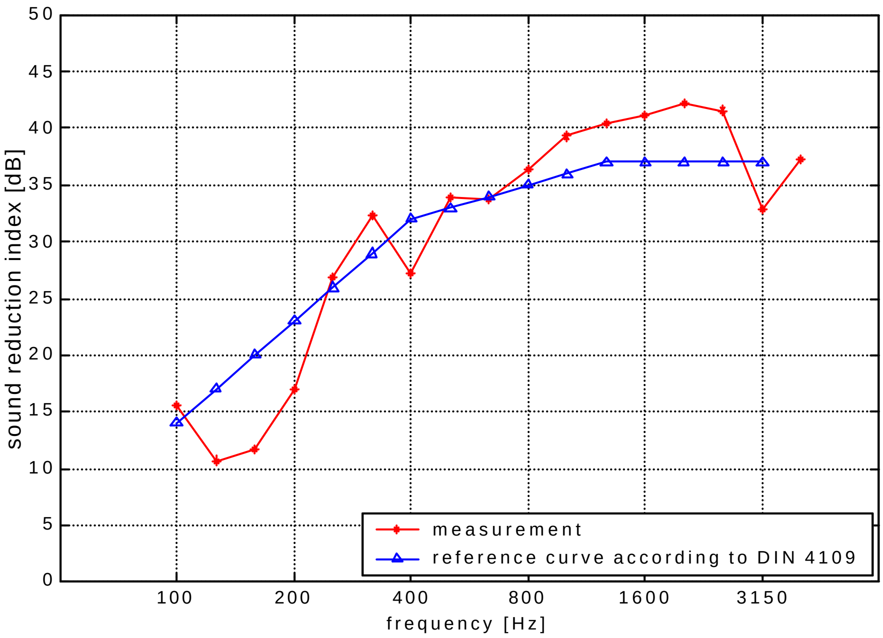

Fig. 2: Sound reduction index of the window without active control

LOUDSPEAKERS USED IN THE EXPERIMENTS

The loudspeakers were mainly chosen due to their dimensions. On the one hand the loudspeakers should be as narrow as possible allowing a small distance between the window panes, and on the other hand the loudspeakers should be as long as possibly to realize a sound radiating surface as large as possible. Thus we chose the loudspeakers shown in Fig. 3 with dimensions 130mm x 33mm x 33mm. The manufacturer of the loudspeakers specifies a power of 2W, a resistance of 16Ω and a frequency range of 180-17000Hz. The price of each loudspeaker was 1,- Euro.

Clearly the frequency range of the loudspeakers begins significantly above the frequency range considered here, i.e. around mass-spring-mass resonance frequency of approximately 125Hz. But it is, of course, a big difference if a loudspeaker radiates into open space or into a rather small volume (compare also the remarks made in [1]). Inside small rigid walled cavities rather high sound pressure levels can be achieved at low frequencies even with the low-cost loudspeakers used here. To illustrate this behaviour three measurements were made with a single loudspeaker. Fig. 4 compares power spectra of the sound pressure for three cases: Firstly, the loudspeaker was mounted at a wooden box, as it would be a loudspeaker box, and the sound pressure was measured at a distance of 1m from the loudspeaker in an anechoic chamber. Clearly the high-pass filter characteristic can be seen (blue curve). In the second experiment the loudspeaker was simply turned around to radiate into the cubic box, which had a volume equal to the volume of the windows cavity, and the sound pressure was measured inside the box. For that case it can be recognized that in the low frequency region the sound pressure is nearly constant down to approximately zero (red curve). The maximum at approximately 460Hz appears due to the first resonance of the cubic box with inner dimensions of 37cm. Between the two window panes, which are of course not rigid, the conditions are somewhat different. Thus the pressure level down to low frequencies again decreases but with a lower cut-on frequency (green curve). Additionally the values are higher over the whole frequency range, which is because the loudspeakers built into the window have only the small back-volume of the window frame.

Fig 3: Photograph of the loudspeakers

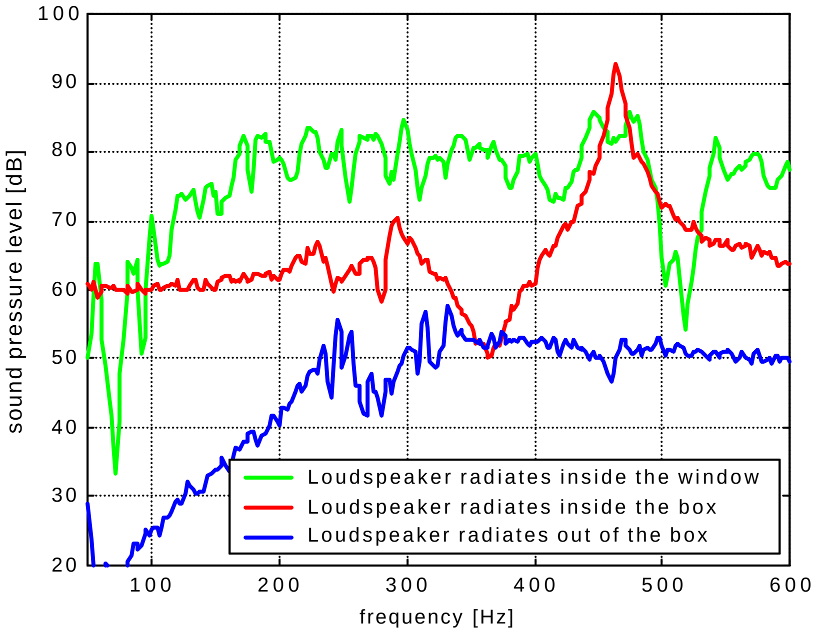

Fig. 4: Frequency responses of the loudspeaker radiating outside and inside a rigid box and radiating inside the double-glazed window

MEASUREMENTS

The following measurements with active control were all made with mean total sound pressure levels at the "outer" side of the window with more than 95dB. Fig. 5 shows the mean sound pressure levels taken directly in front of the window on the incident side by one microphone. With this signal levels no distortion due to the control loudspeakers could be observed. With higher levels these distortions could not totally be avoided. But in real applications it can be assumed that 95dB directly at the window is probably more than in the majority of all cases.

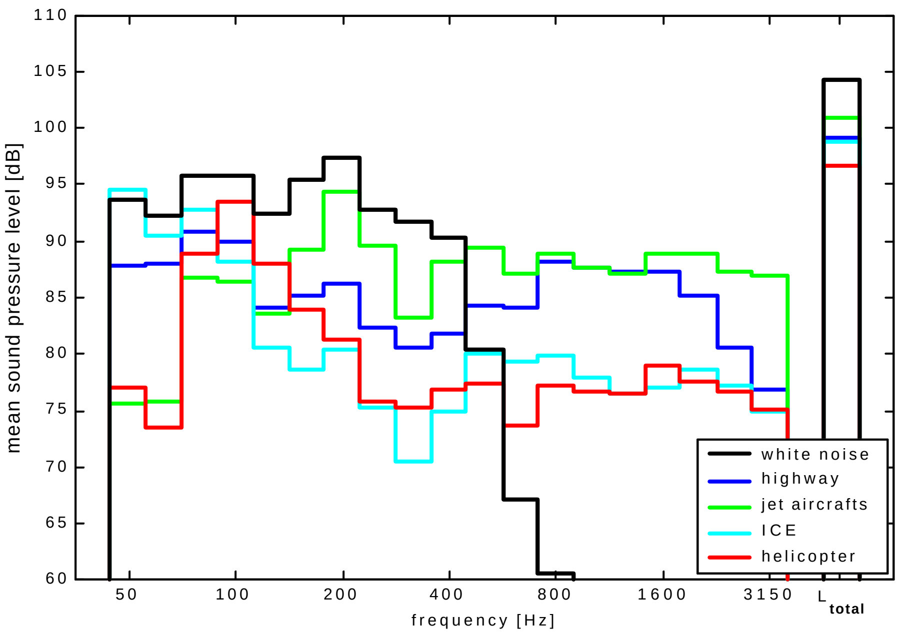

Fig. 5: Sound pressure levels of the noise excitation measured directly in front of the outer side of the active window

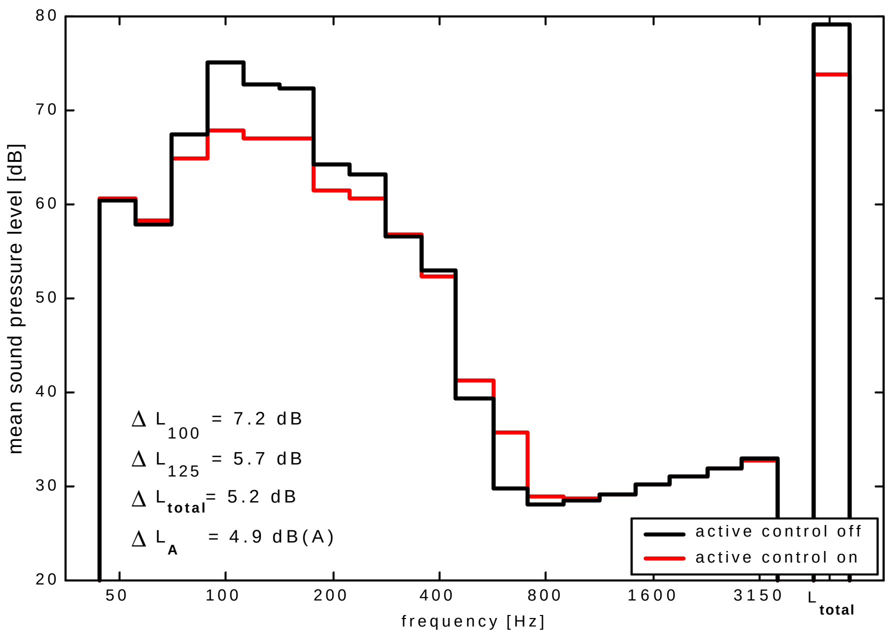

Fig. 6: Third-octave band mean sound pressure levels measured in the receiving room without and with active control for band-limited white noise excitation

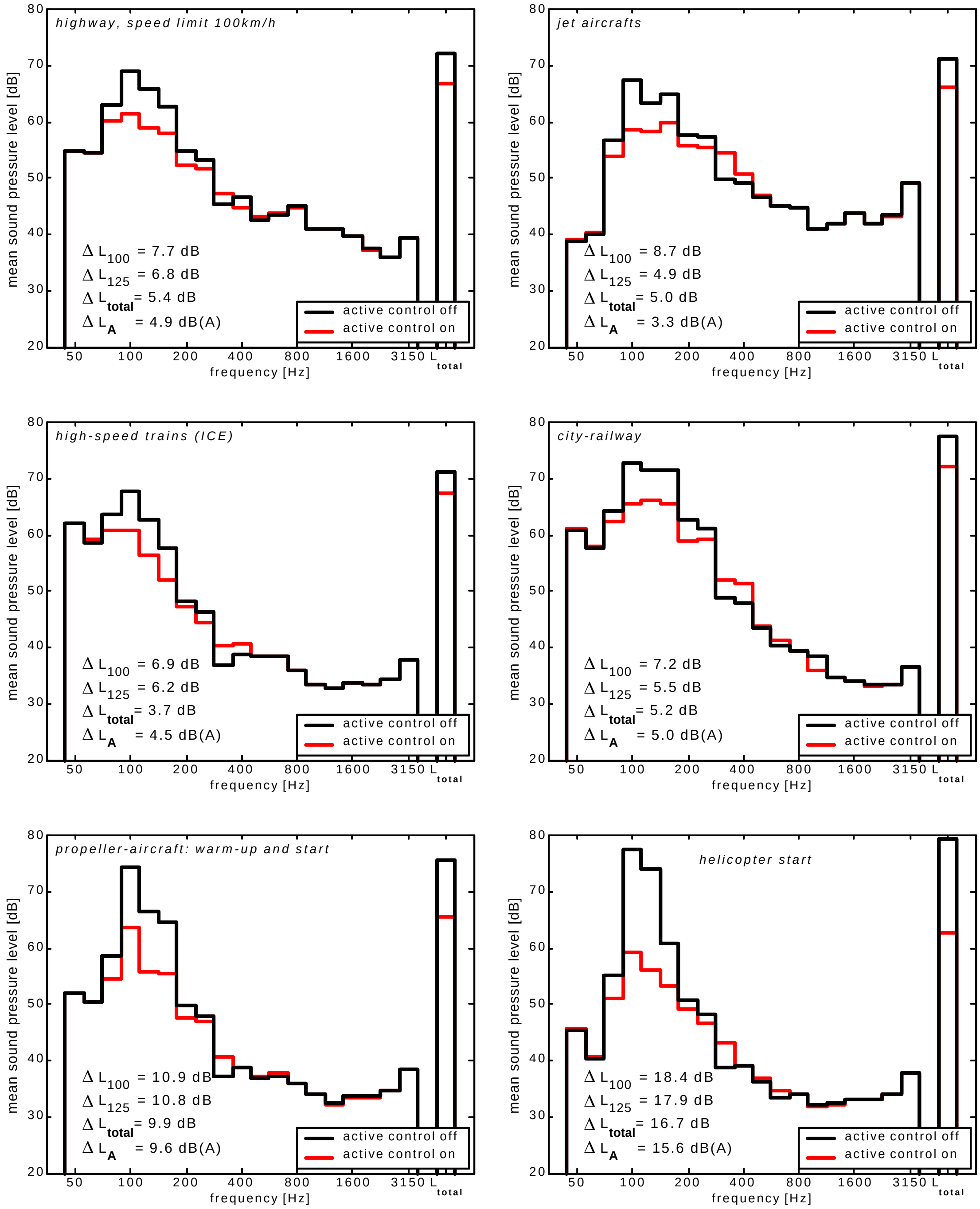

Fig. 7: Third-octave band mean sound pressure levels measured in the receiving room without and with active control for different traffic noise examples

In the following measurements not a sound reduction index is shown but level differences between the sound pressure level in the receiving room without and with active control as a mean over time and space. The sound reduction index, e.g. according to DIN 4109 [6], is defined for excitation with random noise. But particularly when adaptive filters are used in the controller, the achieved results depend strongly on the characteristics of the signal of excitation. In general the adaptive algorithm performs better with narrow-band signals with more or less constant signal statistics, but poorer with broad-band signals and possibly fast changing signal statistics. This behaviour can be seen clearly in the results given in Fig. 6 and 7. With white noise excitation (cf. Fig. 6) as well as with noise from a highway, from high-speed trains and from jet aircrafts (cf. Fig. 7) improvements of about 35dB(A) could be achieved. In the best third-octave bands around the mass-spring-mass resonance frequency level reductions of 7-

9dB were yielded. In these tests the mean sound pressure level was measured over a period of several minutes or over several different jet-aircraft over-flights respectively several different train passes. The last tests, also shown in Fig. 7, were performed with noise from propeller aircrafts and helicopters, both taken during warm-up and start phase. These noise examples contain highly tonal components changing rather slowly. Improvements of 10-16dB(A) were measured corresponding to 11-18dB in the "best" third-octave bands.

SUMMARY AND CONCLUDING REMARKS

It could be shown that remarkable improvements of the sound insulation of double windows can be realized, particularly in the region of the mass-spring-mass resonance frequency, even if the distance of the window panes is small and simple "low-cost" loudspeakers are used. The high improvements with narrow-band signals (compare also [1]) show the potential of the physical system "actively controlled double window", whereas the broad-band signals with possibly fast changing characteristics show the limitations of the signal processing, i.e. the adaptive controller. It follows from the principle of causality that particularly short delays of the digital signal processing unit, i.e. the controller, are required for the application discussed here. The controller used in the experiments showed a delay of 5ms with the chosen sampling frequency. As Elliott, et.al. [8] showed in simulations, a reduction of this delay can improve the performance of the active control system for non-stationary signals, particularly with the adaptive feedback controller used here.

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