Active noise control as a solution to low frequency noise problems

Steve Wise[1] and Geoff Leventhall[2]
[1]Wise Associates, Madison, Wisconsin USA
stevewise@att.net
[2]Consultant, Ashtead, Surrey UK
geoff@activenoise.co.uk

The control of low frequency noise presents special problems which do not occur at higher frequencies. These problems relate mainly to the long wavelength at low frequencies, which leads to little absorption by conventional means, unless large quantities of absorbing material or large volumes of space are used. There are many examples of low frequency noise problems which can be solved by active attenuation, without the use of thick absorbing material. Some of these are given in this paper.

1. INTRODUCTION

Active attenuation operates by producing an opposite noise to the one which it is wished to control and mixing the two together. Although this seems to be a very simple concept, its implementation has a number of problems due to the difficulty of reproducing the unwanted noise as an exactly opposite time function at the volumes in space where cancellation is required. However, some differences between unwanted noise and cancelling noise are permitted when the required attenuation is relatively modest, say about 10dB, which can be a very effective reduction at low frequencies.

In order to reproduce the noise it is necessary to detect it through an input microphone, process it in a controller and apply it back to the system to achieve cancellation of the unwanted noise. Early systems were analog but most, with the exception of active headsets, are now digital, using fast signal processors. Some processing time is required, which leads to the cancelling signal being applied at a small distance downstream from the input microphone. This means that the processing must also compensate for the acoustical path between input microphone and cancelling loudspeaker, in addition to any effects of the microphones and loudspeakers on the signal. In practice, it takes a short time to develop the model of the acoustical and electro-acoustical paths and the operation is continuously monitored by an error microphone, which feeds information back to the processor in order to optimize the attenuation. This continuous monitoring also takes care of changes in the system. Typical locations for a double, duct-mounted active noise control system are in Fig 1, which shows the input microphones, loudspeakers and error microphones in a double system. A single system is often adequate.

Active attenuation in ducts is successful when

- there is good coherence between the outputs of the signal and error microphones
- the modes in the system e.g. duct modes, can be separately detected and individually cancelled.

Introductions to active control are

given in Snyder (2000) and Hansen (2001). More advanced books are Nelson and Elliott (1992); Fuller, Elliott et al. (1996); Kuo and Morgan (1996); Hansen and Snyder 1997)

2. COHERENCE

The coherence requirement arises because each microphone assumes that the signal which it detects has also been received by the other microphone. That is, all the noise is assumed to travel through the system. Maximum attenuation is related to coherence by

$$\text{Attenuation} = 10\log(1-\gamma^2)\ \text{dB}$$

where γ^2 is the coherence between the two microphone signals. A value of $\gamma^2 = 0.9$ or greater is required to give attenuation in excess of 10dB. One factor which corrupts the coherence is additional localised noise generated within the system, perhaps from turbulence, which affect the two microphones in different ways.

3. HIGHER MODES

Considering a duct as an example, the plane wave mode (0,0) is uniform across the duct and can be detected and cancelled at any point across the system. The next mode (1,0), is non uniform across the duct and has to be detected and replicated by a more complex system. However, in systems which are not too large, frequencies up to the first mode are often the only ones requiring attenuation.

4. EXAMPLES OF APPLICATIONS

4.1 ANC FOR SCHOOLS

In the USA in 2004, a guideline was developed by ANSI recommending 35 dBA as a maximum for HVAC background noise in classrooms. The rationale is that higher levels reduce the signal-to-noise ratio of the teacher's voice, inhibiting the intelligibiilty for hearing-impaired students which represent, by some estimates, 25% of US children. Further, droning low-frequency noise tends to have a fatiguing effect on occupants, who spend long days in the classroom.

At the same time, ongoing concerns about indoor air quality, particularly the possibility of mould growth in air ducts, has led many jurisdictions to limit the use of porous sound absorbing materials in ductwork. This puts a restriction on noise control options.

ANC can help, in that at least the low-frequency noise is attenuated without any porous materials. Also, without pressure loss, there is significant energy saving. Two configurations of HVAC systems are common in school construction. One

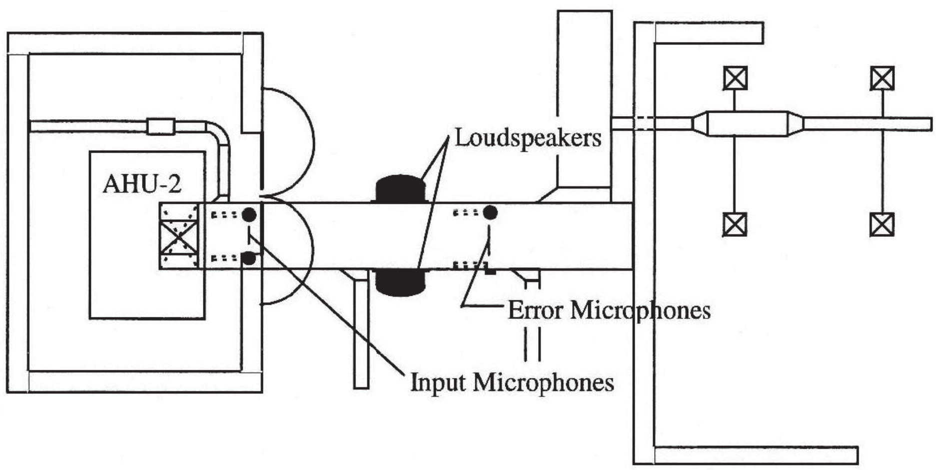


Figure 1. Air handling unit and duct system

utilizes central mechanical rooms, while the other uses rooftop mounted equipment. Locations of ANC implementation and performance results follow.

In the layout shown in Fig1, a 1m x 0.5 m trunk duct runs from a central mechanical equipment room toward the first classroom. An active duct silencer is installed above a hallway between the two. The airfoil centrifugal fan has a noticeable blade-pass tone frequency as well as low-frequency broadband noise. This is easily attenuated by the ANC system as shown in the performance plot in Fig 2.

In order to save building floor area, some schools eliminate central mechanical equipment rooms (MERs) and place the air handling unit (AHU) on the rooftop.

Pictured in Fig 3 are duct penetrations from such a rooftop AHU, above a ceiling in a classroom. Low-frequency noise breaks out of the thin-gauge rectangular duct into the space below.

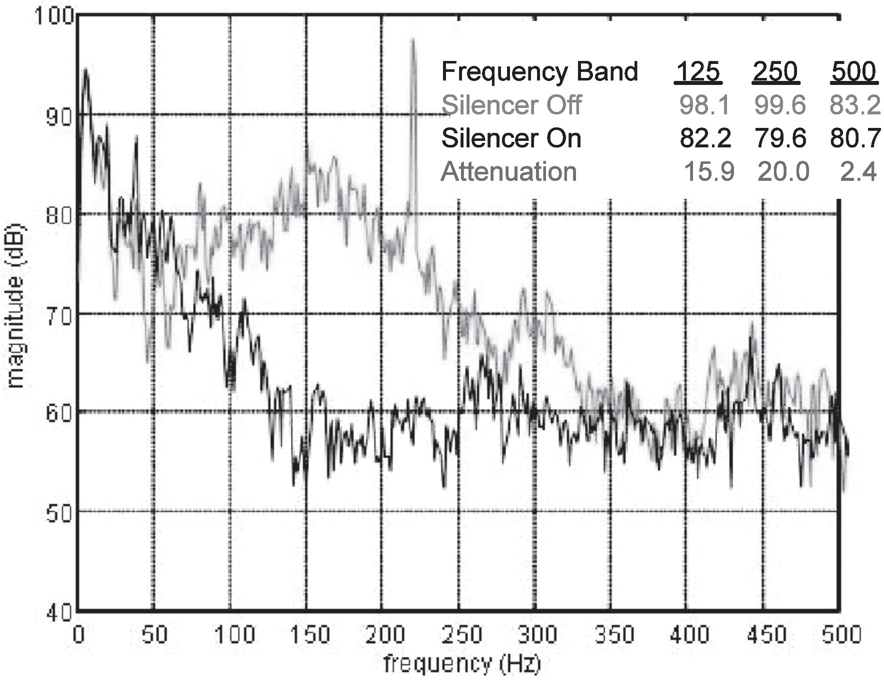


Figure 2. Performance of active control system on tone and noise

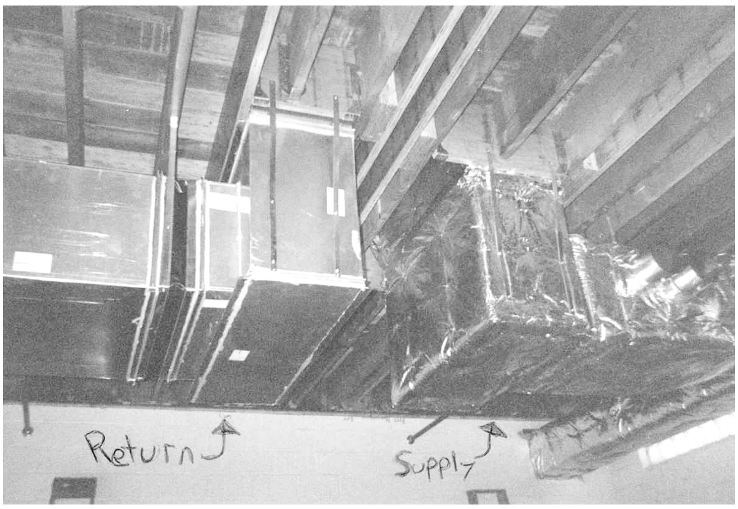


Figure 3. Duct penetrations

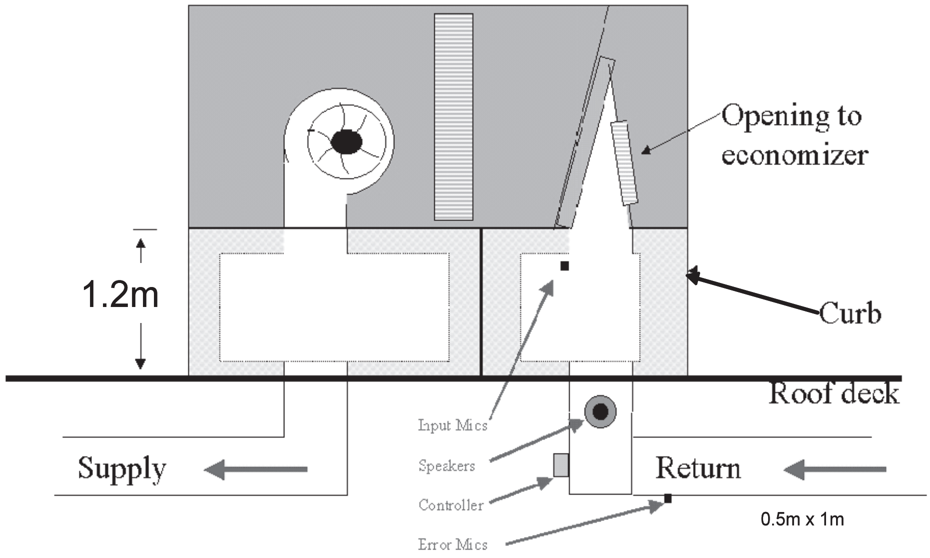


Figure 4. Sectional diagram of Fig 3

Space limitations and pressure loss concerns prohibit the use of conventional passive silencers.

As seen in the cross-section diagram, Fig 4, the AHU is actually placed on top of a special curb that serves as a vibration isolator as well as a passive silencer. The problem in this case is that a second fan for the economizer has a rather direct noise propagation path into the return duct. The size of the plenum does not adequately reduce low-frequency noise. ANC components were added to the existing plenum and duct.

Fig 5 is a narrowband low-frequency plot of in-duct performance. The effect in the room varies according to exact location due to standing waves, and ranges from 5 dB to 9 dB at 63 Hz.

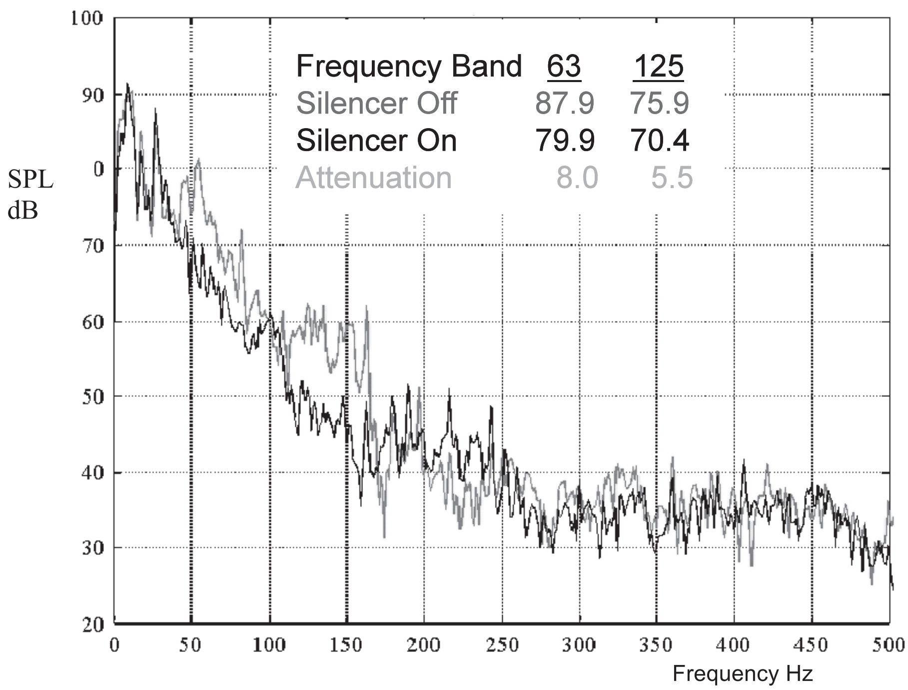
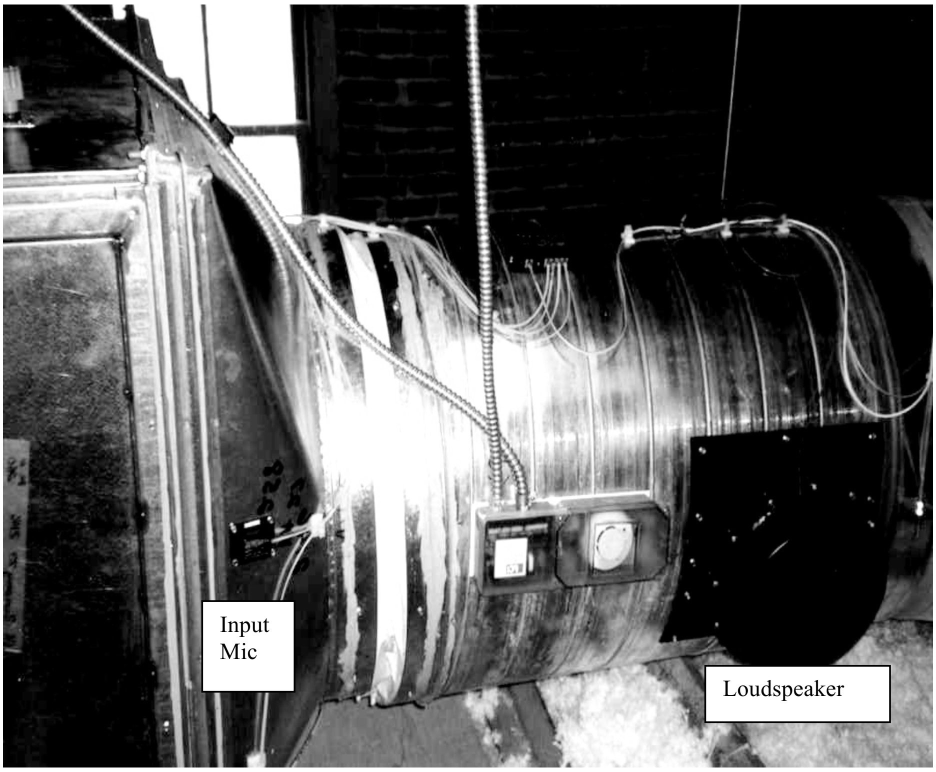


Figure 5. Performance of active controller for roof top unit



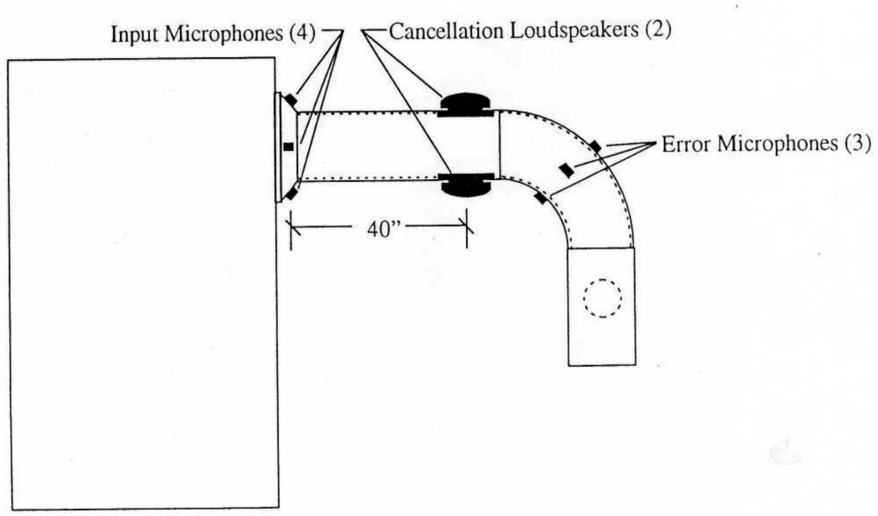


Figure 6. Active system on air handling unit

4.2 ANC FOR HOSPITALS

A veterans' hospital requires fairly high ventilation rates of very clean air in the burns unit. The noise from air supply fans can be a major source of discomfort for these patients who may spend many months in their rooms.

The photo and diagram of Fig 6 show how ANC components were applied to the 600mm round duct from a small AHU. The air moving device is a plug fan, airfoil wheel, that has a distinctive blade pass tone frequency and band-limited random noise.

The performance of the ANC system is shown in Fig7. A common characteristic of the ANC systems depicted throughout this paper is the ability to adapt to changing conditions such as fan speed. Any modulation of amplitude or frequency is compensated for in real time and the controller always provides peak attenuation at the loudest part of the noise spectrum.

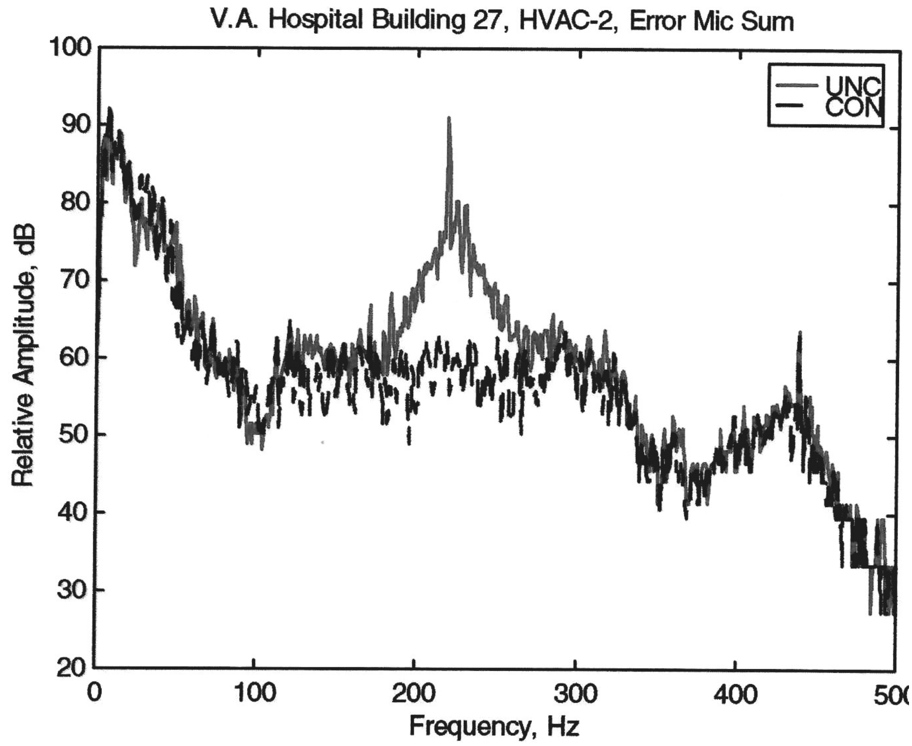


Figure 7. System performance. More than 30dB reduction of tone plus band attenuation

Reliability has been outstanding. The microphones and speakers live well in the cool clean environment of HVAC system ductwork, with no failures reported in nearly 20 years of operation. The controllers also exhibit long lifetimes but, as with any electronic components, it is necessary that they are protected in a dry, clean, and relatively cool environment. Built-in power surge protection and automatic re-powering ensure that the systems function in locations with unreliable power supply. They are also designed to be immune to RFI contamination, and are certified to be compliant with RF emission standards.

4.3 ANC FOR GAS PLATFORM

Being out to sea on a 3-week 12-hour on/12-hour off work schedule on a noisy rig presents a problem for workers requiring a little “quiet time”. In order to enhance productivity, platform

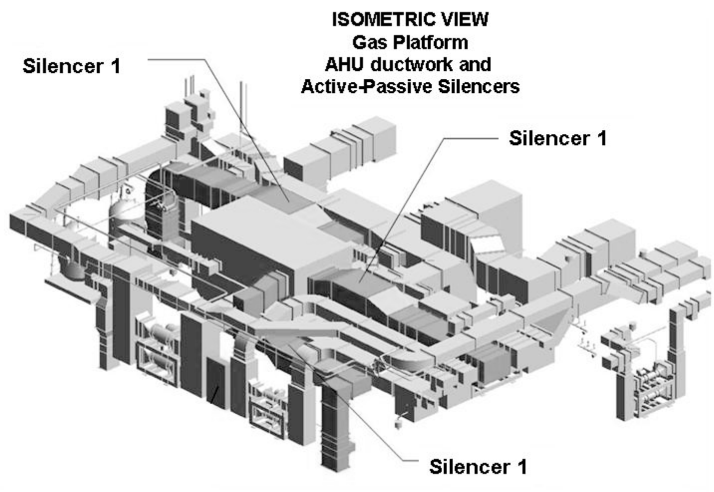


Figure 8. Duct and AHU arrangement on gas platform

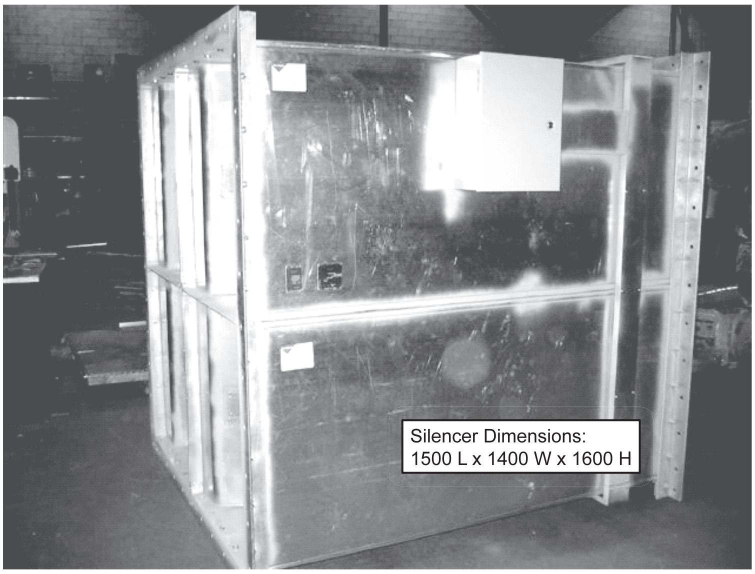


Figure 9. Combined active passive silencer for full range attenuation

owners strive to improve the ambiance of the crew quarters. Although there are many sources and transmission paths of noise, heavy-duty chambers offer some chance of isolation. Still, the environment requires an HVAC system and this can be another annoying source of noise.

In a recent application, a large central AHU served crew quarters. The air supply consists of a large plenum and three take-off ducts. Low-frequency noise, particularly at 125 Hz, was a concern. As shown in Fig 8, there is little space for low frequency passive silencers.

The silencer developed was an active – passive system with overall dimensions

1500mm long - 1400mm wide - 1600mm long

containing four modules, as in Fig 9. The blockage ratio of the absorbing lining was about 50%, which would give little low frequency absorptive attenuation. As seen in Fig 10, performance of the ANC system alone provides significant attenuation. Combined with the absorption of passive silencer baffles, as seen in Fig. 9, the total

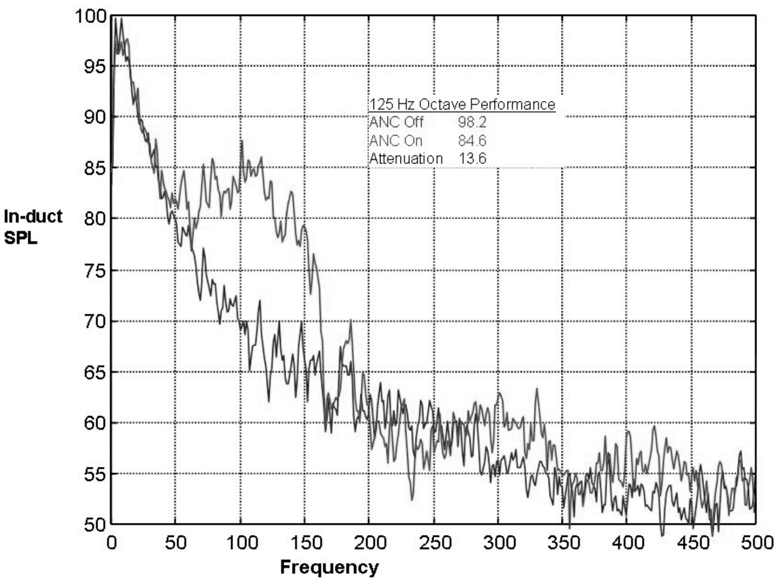


Figure 10. Attenuator performance

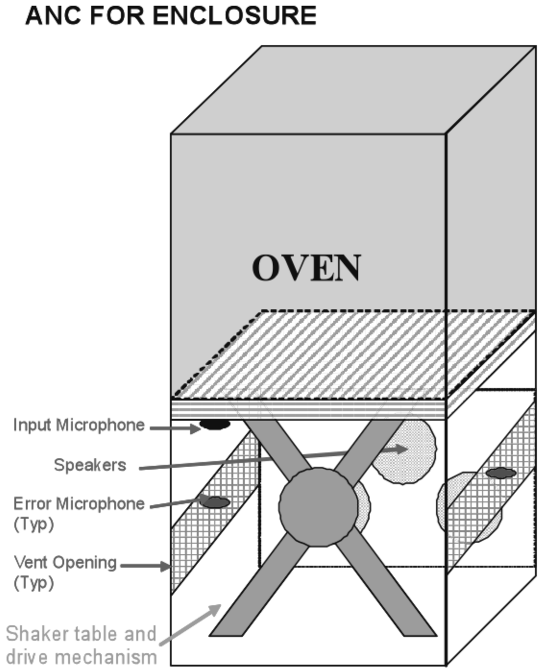


Figure 11. Active noise control for openings in enclosure

attenuation at 125 Hz is nearly 20 dB, in a package that is only 1.5m long.

4.4 NOISE FROM AN ENCLOSURE

A manufacturer of military sensors has a requirement for 100% parts testing for humidity and temperature in an environmental oven. The parts must also be tested for vibration resistance, which is accomplished in the same fixture by means of a shaker table that serves as the bottom of the oven.

The shaker drive mechanism is contained in an enclosure below the oven. Since the high-power motor requires ventilation air supply, there are

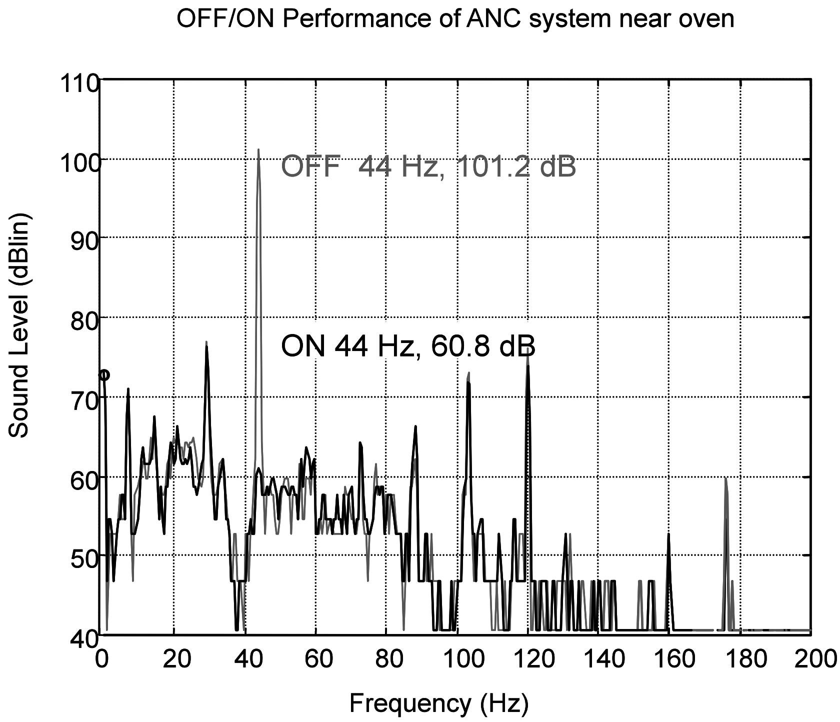


Figure 12. Active noise control from openings in an enclosure

openings in the sides of the enclosure. The shaker table acts effectively as a large piston, pumping sound energy that radiates out of the openings in the enclosure, causing a noise problem for factory workers in the surroundings.

ANC was implemented by placing loudspeakers in the enclosure to cancel the noise from the table as it exited the ventilation openings. Control (error) microphones were placed near the openings, while another microphone close to the vibrating table provided the input to the controller.

As shown in Fig 12, the annoying low-frequency tone(44Hz) was reduced by over 40 dB.

This application shows that there are circumstances when it is not necessary to use a passive duct silencer to reduce sound emission from an opening

5. CONCLUSIONS

It has been shown that active noise control can be applied to a range of problems of low frequency noise, including both ducted and localized sources. Space and cost restrictions would have made it difficult to solve these noise problems by conventional passive means.

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ALSTOM LAUNCHES QUIET 3 MW ECO 110 WIND TURBINE

Alstom, has announced the introduction of its 3 MW ECO 110 wind turbine, designed to ensure the highest energy production on low to medium wind speed sites throughout Europe and worldwide. The ECO 110 features a 110m-rotor diameter, one of the largest rotors available today for onshore applications — to capture even greater amounts of wind on a given site, maximizing the energy yield of the turbine. Its 53 meter-long blades are designed to capture more power more effectively. This means fewer turbines and less land space are required to generate the same amount of renewable power. Alstom's wind turbines are based upon the unique Alstom Pure Torque rotor support concept, which protects the gearbox and other drive train components from deflection loads. The concept fully separates the gearbox from the supporting structure ensuring that only torque is transmitted through the shaft to the gearbox, and all deflection loads are transmitted directly to the tower. The ECO 110 has been designed to minimize noise emission. By keeping the rotor speed below 13.7 rotations per minute, Alstom Wind's innovation team has designed one of the most silent wind turbines available on the market. With its low noise emission, the ECO 110 is ready to contribute to the continuous and harmonious development of onshore wind power.