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THE FIRST 1000 ACTIVE DUCT SILENCERS INSTALLED IN HVAC SYSTEMS - A SUMMARY OF APPLICATIONS, SUCCESSES, AND LESSONS LEARNED

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ABSTRACT
The authors have been involved in the design and start-up of over 1000 active duct silencers installed in the USA and Europe to silence fans on a variety of Heating Ventilating and Air-conditioning (HVAC) applications. Applications include both retrofit and new construction. This paper answers these questions: What are some of the best examples of installation success? How does one best measure the performance of the active duct silencer? What are the most common flanking noise paths which can be detrimental to the final result? What types of fans are best silenced by active noise control? What is the realistic performance expectation for an active duct silencer?

1 - INTRODUCTION
An overview of the commercial (non-residential) applications served by air-handlers with active duct silencers is as shown in the table below:

Application	*Auditoria*	*Cleanrooms*	*Hospitals*	*Labs*	*Offices*	*Schools*	*Ships*
# of Units	56	322	59	10	447	183	11

Table 1.

General office space leads the way by virtue of the fact that it represents a grand proportion of regularly occupied, noise-sensitive spaces. **Cleanrooms** (for semi-conductor micro-electronic fabrication and also pharmaceutical manufacturing) are an attractive niche for active duct silencers because: 1) with very large quantities of air that must be moved throughout the space, the reduced pressure loss of active silencers greatly reduces the high cost of energy associated with conventional, passive means; and 2) new production machinery to produce high-power chips is extremely sensitive to vibration that can be induced by ductborne low-frequency noise from the huge airhandlers, which is effectively reduced by active silencers. **Schools** are a cost-sensitive, but growing niche. Notably in the USA, there is growing sentiment among the acoustical consultants, educators, audiologists and architects that the background noise level in schools is so high as to interfere with speech intelligibility, especially for the growing numbers of hearing-impaired youth [1]. Active duct silencers offer greater attenuation in a more compact package than passive attenuators. In **hospitals**, there is a desire for quiet, well-ventilated areas, but also a concern about the use of porous materials inside the duct, like those generally used in passive attenuation. Active duct silencers can greatly reduce the amount of such materials that must be used. In **auditoria** and **laboratories**, the inclusion of active duct silencers enables any required ventilation to be quieted to the threshold of hearing at even the lowest frequencies. With **ships**, not known for quiet spaces, active duct silencers can fit into the tight duct configurations.

2 - EVOLUTIONARY TRENDS

Over the last 12 years, the cost of active duct silencers has dropped by an order of magnitude, from approximately 10,000 US$ to less than 1,500 US$ per system. At the same time, with multi-channel control and new modular designs, the size of airhandlers that can be treated with active silencers has increased, from 10,000 m^3/h to 100,000 m ^{3}/h or more. The factory-assembled modularity also eliminates the expensive on-site customization common in the earlier designs.
Combining active duct silencers with passive, sound absorbent materials gives attenuation in all octave bands from 31.5 to 8000 Hz. One such embodiment is shown below in Figure 1 [2].

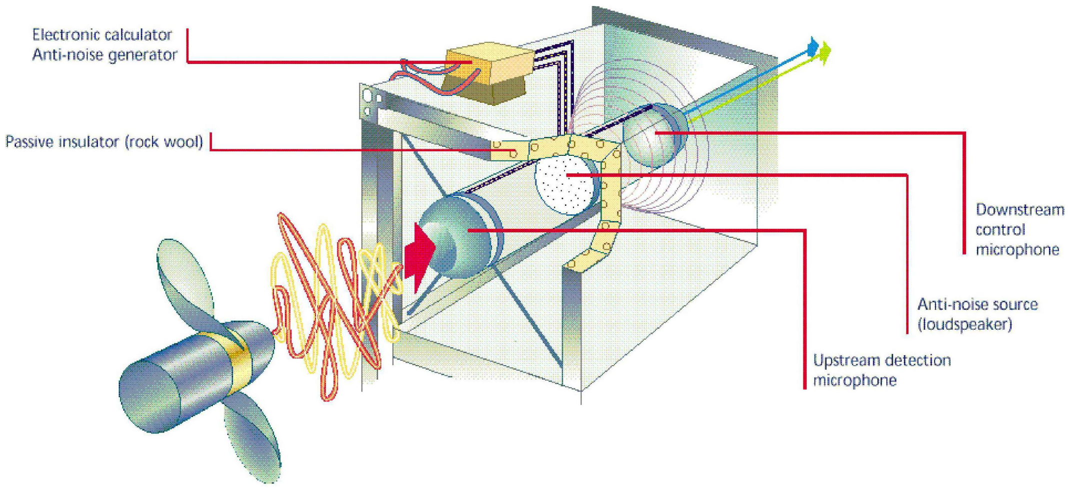

Figure 1: Modular active-passive duct silencer with internal electronic components.

3 - APPLICATION

Location #1 in the MER layout shown in Figure 2 identifies the best location for active duct silencers for the supply side, and #11 shows a typical location for the return (ducted or un-ducted). Also seen are 12 other paths for the transmission of noise, or of vibration that can induce noise. Noise attenuation in the duct from the active silencer can only be fully translated to the room if these other paths are controlled. Leaks due to improperly sealed MER openings are a common problem. At 31.5 and 63 Hz, noise transmitted through the MER wall is a limiting factor, especially if the wall construction is gypsum board rather than concrete block. The ability to turn the active system on and off in the field allows the ductborne noise path to be isolated, which in many installations has revealed startling facts about the flanking paths. The noise transmission loss (TL) of wall panels, for example, is normally specified based on standardized testing of specific section sizes. The custom sizes and non-uniform field erection technique have shown a wide range of actual TL. Worse, the standards typically only address the frequency range of 125 to 4000 Hz, so the TL at 31.5 and 63 Hz can indeed be very low, diminishing the benefits of the good performance of the active silencers at those frequencies.
Not shown in the graphic are the additional concerns of downstream secondary noise sources such as dampers and diffusers which can create additional noise after the active silencing. Particularly in the USA, fan boxes above suspended ceilings are an additional source in the 125 through 500 Hz octave bands

4 - PERFORMANCE

An example of performance is shown in Figure 3. The uncancelled noise spectrum is typical of forward-curved fans. The cancellation range extends to very low frequencies. The upper frequency limit is the cut-on frequency of the first mode in a 550 mm square (ID) active silencer module. Above that, passive attenuation from sound absorbent materials is sufficient.
The performance is measured with an array of in-duct microphone probes. Given the ability to simply turn the system on and off, performance of active silencers, unlike passive silencers, can be measured easily in the duct or in the room at any time. However, since the active system is typically packaged in a passive section, the overall contractual performance includes both effects. There is typically additional passive attenuation of 5-10 dB in the low-frequency range, and 25 to 40 dB from 500 to 8000 Hz.
The smooth, residual spectrum after cancellation is the "pseudo-noise" floor of the airflow turbulence on the sensing microphones. This pressure level is dependent on the mean flow velocity. In general, active

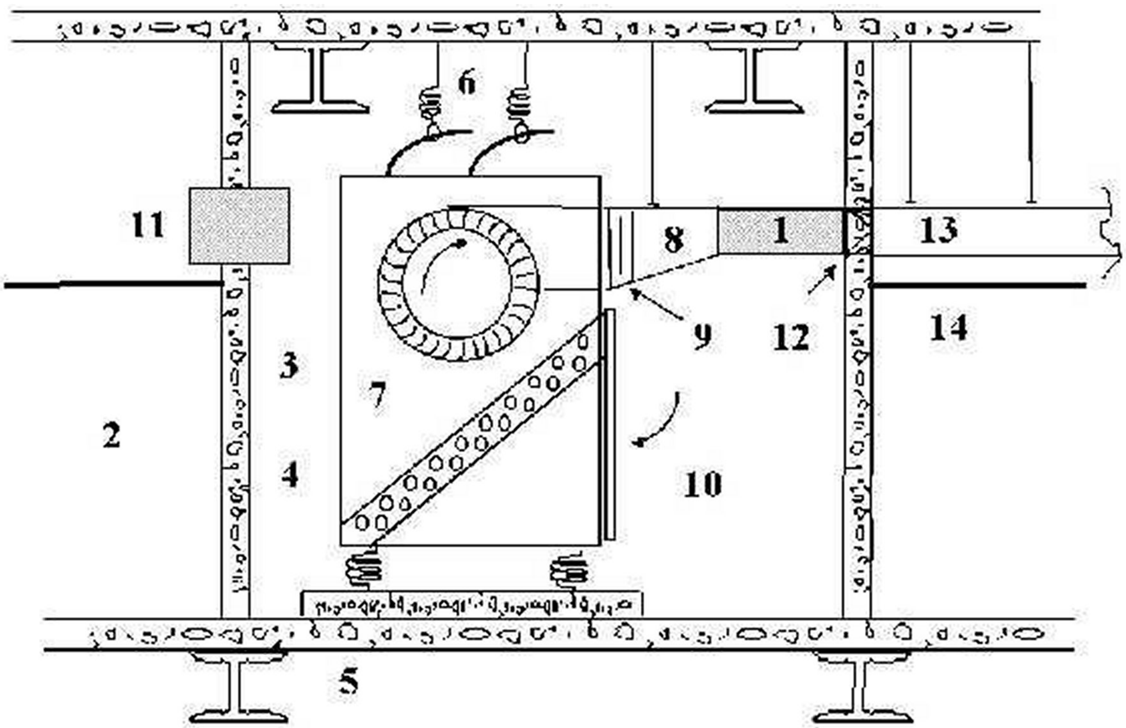

Figure 2: Typical mechanical room (MER) layout, with noise and vibration paths enumerated.

duct silencers will reduce any fan noise, within the frequency range of effect, to this residual level. This for a given fan noise spectrum, the attenuation will be less at higher velocities as shown in Figure 4 below. A louder spectrum, especially for example the strong blade pass frequency of a backward inclined fan, will provide a strong signal relative to the turbulence, and attenuation will be high even at excess velocities.

The turbulence is not simply a direct function of velocity. In a long straight duct, the turbulent energy may be 1% of the total dynamic head, but in tortured flow paths, it could be 5% or more, with a corresponding increase in the pseudo-SPL. Therefore, the active duct silencers incorporate some special means of turbulence suppression for the microphones [3].

Predicting the noise in an HVAC system with active duct silencers is easier than would first appear. The beginning step for the engineer designers of the HVAC system is to consult with the active duct silencer manufacturer to select a design velocity that will allow cancellation down to the desired in-duct SPL. Then, the anticipated active attenuation will be given as an average value, with a ± 5 dB spread. This is not a design tolerance that must be added to uncertainties in the fan sound power. Rather, the active attenuation will, in effect, compensate for louder fan noise. If the fan is louder than predicted, the cancellation will increase because of the improved acoustic signal.

Below is a summary of an installation of 20 nominally identical air handlers. The test standard for fan noise data at 63 Hz has an acknowledged tolerance of ± 6 dB. As installed, the fans also delivered a wide spread of incident sound power levels to the active silencer. But the active systems achieved greater cancellation on the noisier fans, so the spread of residual, in-duct sound power levels was an acceptable ± 2 dB tolerance. Thus the designer can, with confidence, use average fan noise and silencer attenuation values in predictions.

	63 Hz Active Off	*Active Attenuation*	*63 Hz Active On*
Average dB	95.1	18.1	76.9
Std. Dev.	2.6	2.3	1.2
Minimum	88	13	75
Maximum	101	23	79
Scatter	+6 / -7	+5 / -5	+2 / -2

Table 2: Summary of measured results (in-duct SPL) for 20 "Identical" AHUs and active duct silencers.

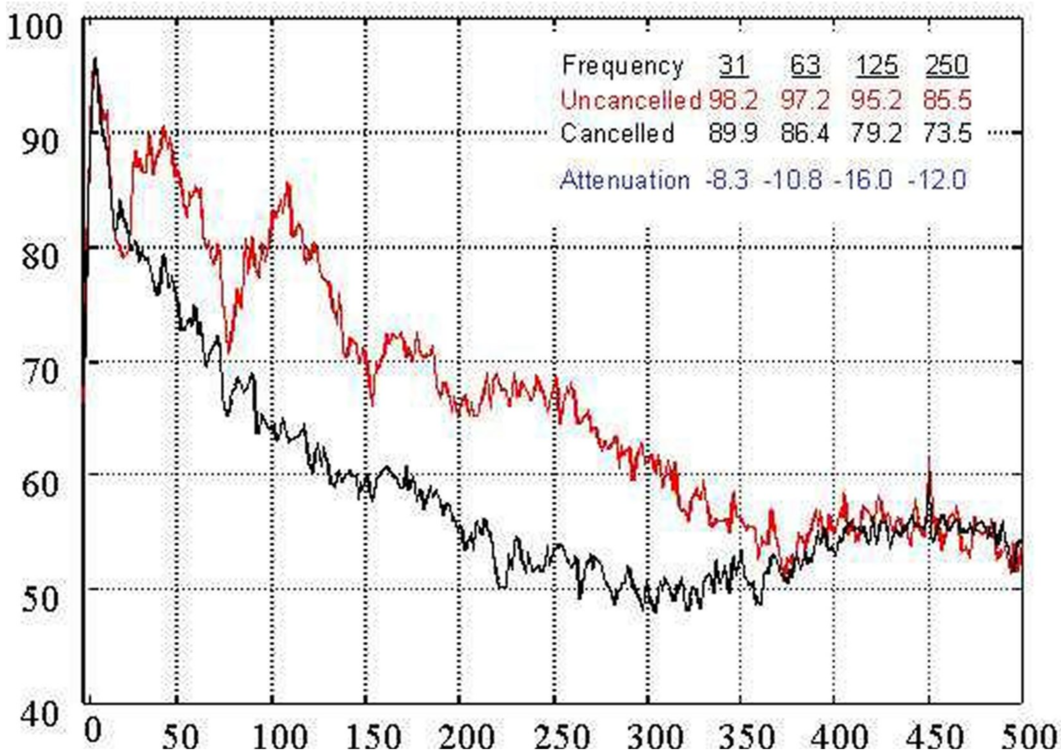

Figure 3: In-duct attenuation for 550 mm × 550 mm modules on forward-curved fan.

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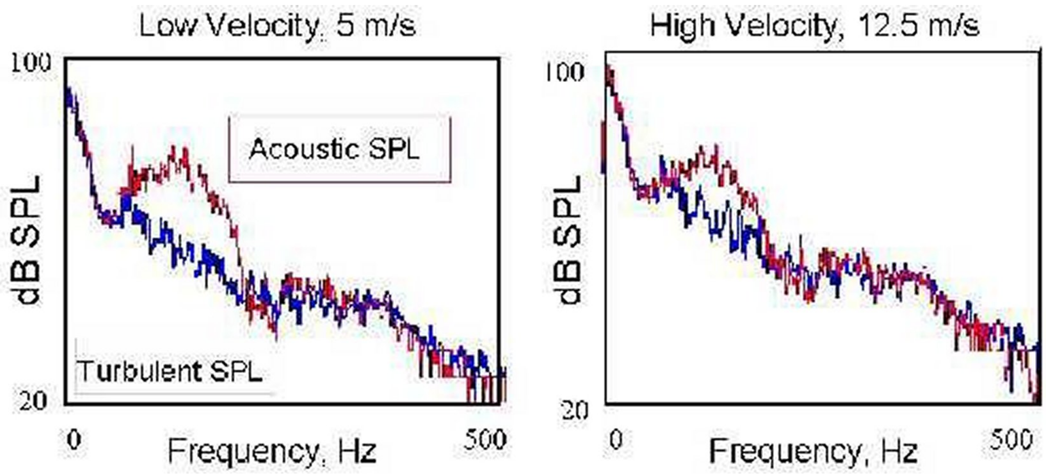

Figure 4: Effects of air turbulence on residual noise level after cancellation.