Antinoise Creates the Sounds of Silence

Computer-generated "antisounds" are stilling the roar of engines and the whine of fans—and that's just for starters

NOISE IS UBIQUITOUS, AND THERE'S SO much of it that it's become one of the nation's top occupational and environmental health problems. In fact, if current noise-control research succeeds, there will be even more of it in the air—and yet the world will be a quieter place because of it.

This pacific paradox is promised—indeed, it's already being delivered—by an innovative application of the digital arts termed active noise control (ANC). Already ANC systems are quieting industrial air conditioning, heating systems, and ventilating fans, and this year should see the silencing of grain-loading equipment, refrigerators, and even magnetic resonance imagers (MRIs). By 1993 several luxury cars will be equipped with ANC mufflers, and further down the road some researchers even envision personal headphones—the polar opposite of personal stereos—that would create private zones of silence.

"We're talking about a technology that could make a significant impact on reducing unwanted, and oftentimes dangerous, noise in the home, on the street, and on the job," says Irene Lebovics, president of NCT Personal Quieting, a division of Noise Cancellation Technologies in Stamford, Connecticut. She adds that this technology could easily become a multibillion-dollar industry. "Electronic mufflers [alone] is a billion-dollar market," she says.

And it's not only the true believers who speak this highly of ANC systems. "This technology is certainly going to be a big deal," says James Alexander, an analyst at Donaldson, Lufkin & Jeanrette in New York. "The auto industry is trying to shave ounces off the weight of a car, and here's a technology that can save pounds. Plus, you improve efficiency. It's a winner."

Industry in the United States already spends well over $1 billion a year to control noise in the workplace, according to Donna Costlow, spokeswoman for the National Association of Manufacturers. That figure could skyrocket if the Occupational Safety and Health Administration (OSHA) makes its noise control regulations stricter—and OSHA officials see controlling noise as an urgent priority.

John Steelnack, an industrial hygienist at OSHA, explains why his agency might well go after noise: Work-related hearing loss, he says, "is one of our biggest concerns. And with workman's compensation costs for hearing problems skyrocketing," he adds, "and with more stringent inspections on our part, there is a growing demand for better noise-control technologies."

If active noise-control systems turn out to be the answer, it won't be because they are merely the Great White (Noise) Hope of the noise-pollution industry. Active noise control does not simply mask nasty sounds with nice ones—offering your mind a soporific while the assault goes on. Nor does it rely—as most noise control does today—on soundproofing, which is bulky, heavy, and effective at deadening only high-frequency noise, not the low-frequency rumble that is the biggest problem in industry. Instead, ANC actually erases sound with sound.

It turns out that when sound waves of equal amplitude and frequency but opposite phase collide, they cancel each other, leaving behind nothing but silence. This is not a new idea. The technique behind ANC was first studied in the 1870s by Lord Rayleigh, who experimented with canceling sound from a pair of organ pipes using tones generated by an electric tuning fork. Paul Lueg, a German engineer, won the first patent for a crude sound-cancellation device in 1933.

> ***"It's not just the faster computer chips and powerful programming algorithms. It's also the great interplay between the programmers and the people studying the acoustics."***
>
> —R.A. GREINER OF THE UNIVERSITY OF WISCONSIN-MADISON

But though the theory is straightforward, as Rayleigh and Lueg demonstrated, pulling it off is another matter. "In principle, the idea of active noise control is simple," says James D. Jones, assistant professor at Purdue University's Ray W. Herrick Acoustics Laboratory. "In application, though, it's a very complex and difficult problem."

The challenge has been to analyze the complex brew of sound frequencies making up noise and to create a precise mirror image of each component. Until the microelectronics revolution, that challenge could be met only on a blackboard. And until recently, even the ubiquitous chip wasn't by itself sufficient to permit the design of a practical machine. "A decade ago, we would have needed a $100,000 minicomputer to do the signal processing," says Larry J. Eriksson, vice president for research at Nelson Industries Inc., in Stoughton, Wisconsin, whose Digisonix division makes ANC systems.

What distinguishes today's noise controllers from far less effective devices built even 5 years ago is the use of powerful, low-cost digital signal processors that can convert analog sounds into digital signals and then analyze those signals, all on one chip. "Today we can do the same processing with a single chip costing less than a thousand dollars, and next year we'll probably be able to do more for even less," Eriksson says enthusiastically.

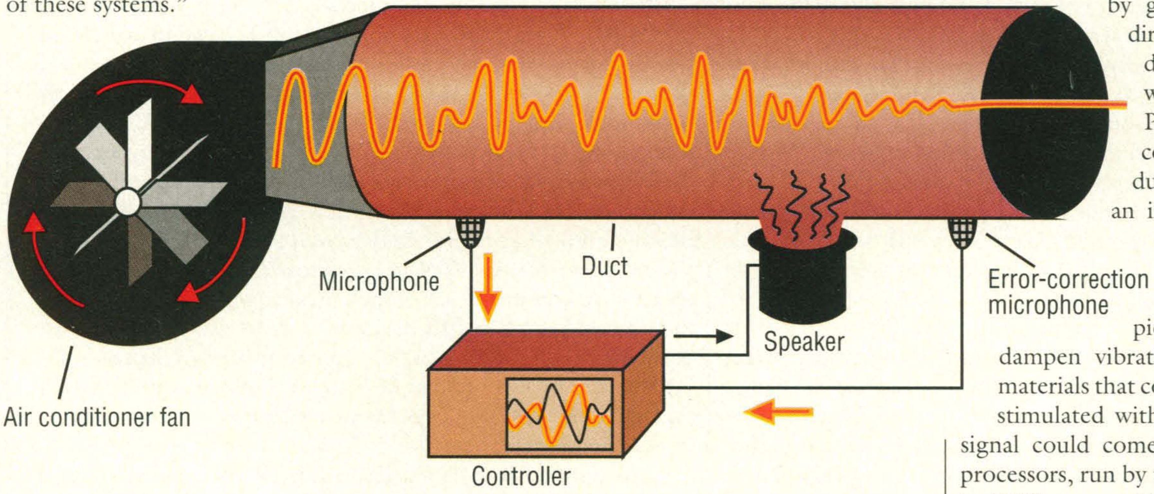
The ANC systems built around such chips typically consist of two microphones and one or more speakers, together with the processor. The first microphone picks up the offending noise close to its source and feeds the signals into the digital processor. Besides analyzing the signals, the processor is programmed with a representation of the real acoustic world, be it a fan duct, muffler pipe, airplane cabin, or whatever—programming that is known in the acoustics trade as a filter.

The filter enables the chip to predict how the characteristics of the sound will change as it travels away from the source toward the ears of long-suffering humans. In a matter of microseconds, the computer generates the appropriate "anti-noise," to be broadcast from speakers located away from the input microphone. The second microphone, which sits near the speakers, provides error correction feedback, enabling the processor to adjust its signals to improve noise cancellation.

It's easy to credit Texas Instruments and Motorola for creating the chips that orchestrate all this, but honors also must go to the acoustic scientists in both academia and industry who have harnessed these chips' power. To develop the computer programs that govern the production of the mirror-image sounds, these researchers have studied how sound behaves in thousands of different settings—from ones as simple and benign as a heating duct to others as complex and hostile as an engine exhaust manifold.

"It's not just the faster computer chips and powerful programming algorithms that are driving this field forward so quickly today," says R.A. Greiner, professor of electrical engineering at the University of Wisconsin-Madison. "It's also the great interplay that's going on between the programmers and the people who are studying the acoustics of these systems."

Controlling Sound With Sound



Noises off. *A computer-controlled system for quieting a ventilator analyzes noise* (orange/yellow line) *and eliminates it by generating mirror-image "antinoise"* (black lines).

The first fruits of this collaboration are already reaching the marketplace: ANC systems for controlling fan hum in heating, ventilation, and air conditioning ducts. Digisonix, for example, has installed its ANC system in dozens of factories, office buildings, hospitals, and recording studios since 1987. The Digisonix model has two sound-eliminating filters. The first dampens the pure tones produced by certain kinds of fans—which can be particularly damaging to hearing—by more than 25 decibels (dBs), or more than 70%. The second filter cuts random broadband noise by another 10 to 15 dBs. Installed together, the two filters can reduce the noise of a fan from well over 100 dBs to as low as 70 dBs. That will more than satisfy OSHA: current regulations call for a 90 dB limit.

A smaller emerging market for ANC devices, but one with life-saving potential, is in quieting MRIs. While physicians have been thrilled with MRIs' diagnostic capabilities, their patients have been less than delighted with the tremendous din these machines produce. Some patients, in fact, balk at having MRI scans done because of the noise.

NCT has developed an electronic headphone that can create a zone of silence around the patient's head, reducing perceived noise by an average of 25 dBs. In November, both Siemens Medical Systems, in Iselin, New Jersey, and Toshiba America in San Francisco approved the NCT system, which sells for about $25,000, for use as an accessory product with their MRI machines. In the future, ANC headphones could find use on construction sites, inside helicopters, and even in the home—imagine a headset designed to tune out barking dogs or screaming children. Eventually, a similar system could be built into car headrests; the filters would cut road noise to a bare whisper, while leaving honks, sirens, screams, and conversation unaffected.

The ride might be quieter than now even without the headrest, thanks to electronic mufflers, the next ANC product likely to hit the marketplace. NCT has successfully tested a prototype and has signed a contract with Walker Manufacturing, a division of Tenneco in Racine, Wisconsin, to produce the mufflers for 1994 model cars. Digisonix has also tested an electronic muffler, though its effort lags behind NCT's.

The auto industry is eager to install ANC mufflers because, unlike conventional mufflers, the devices quiet exhaust noise without generating back pressure, thereby improving power and performance while cutting fuel consumption by 2% to 5%. That may seem a minor improvement, but it is no small matter for engineers trying to bring an entire fleet into line with government fuel economy standards.

Cars and trucks represent but a small part of the potential muffler market. Industrial engines of all kinds produce objectionable, even dangerous noise. For example, CSX Transportation in Baltimore had a severe noise problem with its grain-loading equipment. An NCT electronic muffler cut noise levels by 80%, bringing them well below OSHA standards and eliminating employee complaints. By doing away with back pressure and the need for sound-deadening materials, the muffler also improved fuel efficiency by 20% and cut equipment costs, according to Lebovics.

In the long run the best way to cut noise in some applications may be to catch it before it is emitted—to eliminate the machine vibrations that generate sound waves. A variant of ANC may be able to do just that by generating antivibrations directly on the noise-producing object. "Not only would this cut noise," says Purdue's Jones, "but it could improve an object's durability since vibration is an important cause of wear and tear."

He and his students are studying the use of piezoceramic actuators to dampen vibrations. Piezoceramics are materials that contract and expand when stimulated with an electric signal. The signal could come from the same digital processors, run by the same programs, used in ANC systems. "If we can get this to work, it may be possible to install piezoceramic actuators directly on a surface that vibrates, and control at least that part of the vibration that is capable of generating acoustic radiation," says Jones.

If noise could be nipped in the bud by antinoise and antivibrations, workers, managers, OSHA inspectors, and the public at large could lead calmer and healthier lives. "Like any new technology, we have to be careful not to sell it as a panacea for all noise and vibration problems," says Eriksson of Digisonix. But such caution is not enough to stop Eriksson and others from envisioning ANC systems on a grander scale than present technology permits: ones that might purge a house or an entire concert hall of specific kinds of noise, letting ordinary conversation or a delicate sonata come through loud and clear. ■ JOE ALPER

Joe Alper is a free-lance science writer based in St. Paul, Minnesota.

ADDITIONAL READING:

"Computer-Aided Silencing: An Emerging Technology." L.J. Eriksson. *Sound and Vibration*, volume 2, part 1, 653-600, July 1990.

"Active Attenuation of Acoustic Noise: Past, Present, and Future." David C. Swanson. *ASHRAE Transactions*, volume 95, part 2, 3259-3272, 1989.

"The State-of-the-Art in Active Noise Control." J. Stevens and K. Ahuja. *AIAA-90-3924-CP*, a publication of the American Institute of Aeronautics and Astronautics, 1-13, 1990.