# ACTIVE CANCELLATION OF SMALL COOLING FAN NOISE FROM OFFICE EQUIPMENT

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## INTRODUCTION

Small axial cooling fans on office equipment are common annoying noise sources in the workplace. The acoustic spectra of such fans are characterized by a broadband sound superimposed with a series of discrete frequency tones. Those audible tones make the sound substantially more objectionable than it would be without the tones [1]. In the past, efforts were made to reduce the discrete frequency tones by both conventional passive measures [2] and active cancellation techniques [3, 4]. The active cancellation systems reported were mostly of a laboratory-testing nature. They consisted of a fan and a loudspeaker mounted on a large baffle with an error microphone placed in front of the baffle. Such arrangements are not very practical. In the real world, the loudspeaker and error microphone have to be installed in the same enclosure as the fan.

In this paper, a practical cancellation system is introduced. The system has a fan, a loudspeaker and an error microphone all installed in an enclosure similar to the ones for office equipment. A substantial noise reduction is achieved all around the system. The paper discusses the acoustical requirements for such a global noise reduction. It also describes a testing system for determining the magnitude and phase of a fan's noise field. Testing results are also presented.

## SOUND PRESSURE FIELD OF A SMALL AXIAL FAN

A simple active cancellation system consists of a fan speed sensor, an error microphone, a controller, and a cancellation sound source (a loudspeaker). The controller generates a cancellation sound and adjusts the phase and magnitude of the sound to minimize the resultant sound pressure at the error microphone. It has been proven that when the sound source and the cancellation source are both monopoles and the distance between the two sources is much less than the wavelength, forcing the sound pressure at the error microphone to a minimum also reduces the sound pressure at all other locations around the two sources and a global sound reduction is achieved [5]. Thus, if a small cooling fan's sound pressure field has the characteristics of a monopole, then its noise can be globally reduced by a single loudspeaker.

We developed a system to explore the sound pressure field of a small axial fan at its blade passing tone (or a harmonic) by measuring the instantaneous sound pressure wave form. The system consists of an optical rotation speed sensor, two microphones, a digital signal processor, including A/D and D/A converters and a dual channel oscilloscope (see Figure 1). The optical sensor traces the fan shaft speed. The shaft speed is used to synchronize the sample rate of the A/D converters. The microphones pick up the sound pressure signals at two locations, and send the signals through the A/D converters to the processor, where discrete Fourier Transforms are executed. The Fourier Transforms at the blade passing frequency (or any chosen harmonic) are selected and the reverse Fourier Transforms are then calculated to reconstruct the sound pressure wave forms at that frequency. The reconstructed wave forms are converted back to analog signals and sent to the oscilloscope. This process is performed continuously and the sound pressure at the two locations are shown on the oscilloscope as two sine waves. By comparing the magnitude and phase of the two sine waves, the difference between the sound pressures is determined.

Using this system, we measured the sound pressure field of a 4 inch Dayton axial fan at its blade passing frequency. The fan has 5 blades and runs at 3060 rpm. During the measurement, the fan was mounted in an enclosure (see Figure 2) and blew air outward. A strip of wood was placed across the fan discharge to simulate a typical safety grid. With the strip, the fan has strong tones at its blade passing frequency and the first harmonic. Using the testing system described above, we measured the sound pressure magnitude and phase on hemispheres centered at the fan's geometric center. On hemispheres with radii 18 inches or larger, the magnitude of the sound pressure level is almost uniform. On hemispheres with radii between 3 to 18 inches, the sound pressure is weakest at 90 from the fan's normal direction and strongest at an angle 30 from the fan's normal. The sound pressure has a constant phase on a hemisphere larger than 3 inches in radius. Due to the air flow from the fan, measurement cannot be done within 3 inches of the fan.

Using the same system we also measured the sound pressure field of a 3 inch loudspeaker. The speaker was installed in the same enclosure as the fan (see Figure 2). During the measurement, a tone of the fan's blade passing frequency was fed to the loudspeaker and the measurement system was synchronized to the fan shaft frequency. On a 2 inch radius hemisphere, the sound pressure is about twice as strong at the normal direction of the speaker than at 90 from the normal direction. At further distances, the sound pressure becomes more uniform. On hemispheres larger than 6 inches radii, the sound pressures are about the same everywhere. The phase on a hemisphere is constant.

From the measurement results we conclude that, for a fan mounted in an enclosure such that the sound radiated from the front does not interfere with sound radiated from the back, its sound pressure field, at radii of 18 inches or more in the half space in front of the enclosure, is that of a monopole. At radii less than 18 inches, the sound pressure has the same phase everywhere on a hemisphere, but the magnitude is different at different angles. This conclusion also applies to a speaker, except that the critical distance is 6 inches rather than 18.

Since the error microphone cannot be located 18 inches from the fan, because the enclosure for typical office equipment is not that big, a location needs to be found where the sound pressure ratio between that location and a location more than 18 inches away is the same for both the fan and the speaker. When the error microphone is located at this location, a global sound reduction can be achieved. Using the testing system, we found such a location for our demonstration system. It is at about four and half inches from the edge of the fan and one inch under the line between the fan and the speaker (see Figure 2).

## THE CANCELLATION DEMONSTRATION SYSTEM AND TEST RESULTS

The cancellation demonstration system consists of a 12" x 15" x 18" plywood enclosure with an open back. The fan and speaker are both mounted inside the front surface of the enclosure with their edges almost touching (see Figure 2). The microphone is located as described above. The fan is the 4 inch Dayton fan described above. A 3 inch speaker and a half inch microphone were used. In selecting microphone locations it is important to avoid direct air flow on the microphone. Fortunately, on the enclosure surface, where the microphone is mounted, air flow is minimal. The optical sensor and the active cancellation controller are mounted inside the enclosure.

The sound pressure levels at the error microphone with and without cancellation are shown in Figure 3. Sound reductions of 19 dB and 12 dB were achieved at the blade passing tone (255 Hz) and the first harmonic (510 Hz), respectively. It seems that when the front side of the speaker cancels the front side fan noise, the back side of the speaker also cancels the back side fan noise. Sound reductions of 23 dB and 6 dB were measured inside the enclosure behind the fan at the blade passing tone and the first harmonic, respectively. The sound pressure levels measured along a 36 inch radius horizontal circle around the enclosure at 15 increments are shown in Figure 4. The front of the enclosure is labeled as zero degrees. It can be seen that the sound reduction at the blade passing tone is between 19 dB and 11 dB.

The sound reduction at the first harmonic was not significant. More sound reduction was achieved in the front and the back of the enclosure than on the sides. At a few locations, sound pressure increased.

When one monopole is used to cancel the sound of another monopole by minimizing the sound pressure along the center line between the two monopoles, the sound reduction around the two monopoles can be calculated theoretically [5]. When the sound wavelength is 16 times the distance between the monopoles, sound reductions at 45 and 90 from the center line are 22 dB and 16 dB, respectively. When the wavelength is 8 times the distance, the reduction at 45 and 90 are 11 dB and 5 dB. When the wavelength is 4 times the distance, the sound will be reduced only at angles within 45 of the center line and sound will increase by 6 dB at 90 from the center line. For the demonstration system presented here, at the blade passing tone (255 Hz) and the first harmonic (510 Hz), the wavelengths are about 14 and 7 times the distance between the center of the fan and the center of the speaker. The sound reductions achieved with the system approximately agree with the theoretical values.

## CONCLUSIONS

The demonstration system showed that it is possible to globally cancel the tones of a small axial fan by using a single loudspeaker and a simple controller to minimize the sound pressure at an error microphone. This technique only works with tones at low frequencies and when the distance between the fan center and the speaker center is much less than the wavelength. This means that the technique only works when the fan has strong tones at low frequencies, say, under 500 Hz for 4 inch fans. The broadband noise from a fan is random in phase and magnitude [3] and thus cannot be canceled using the technique presented here.

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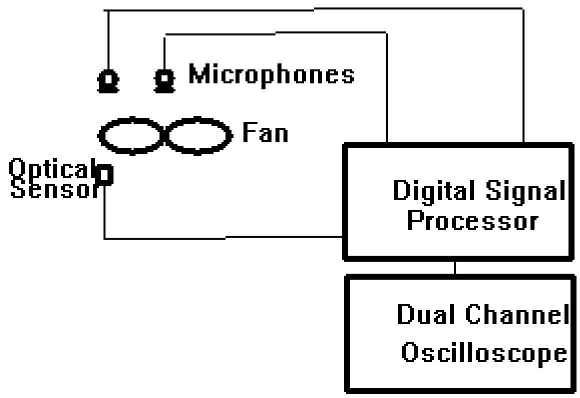


Figure 1. Sound Field Testing System.

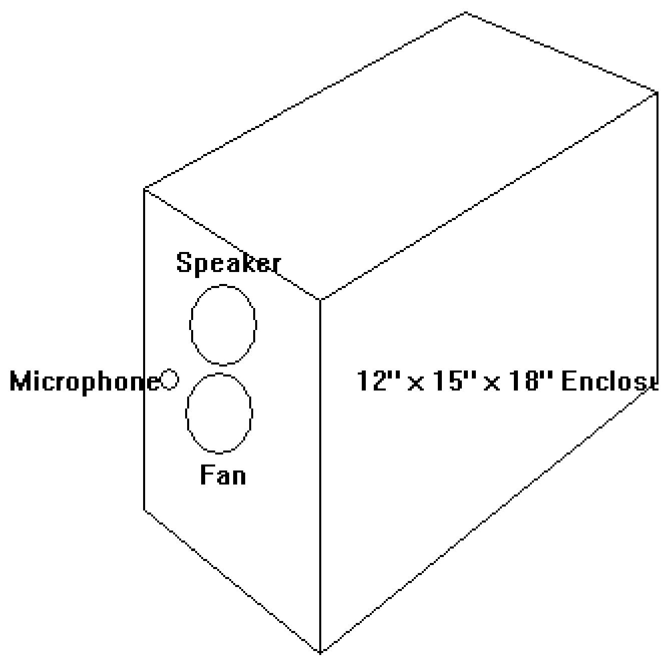


Figure 2. Cancellation Demonstration System.