APPLICATION NOTE AN29

PROTECTING MICROPHONES FROM WIND NOISE PICKUP

Microphones are highly sensitive to wind noise, limiting their performance when used outdoors. A properly designed wind protector can significantly reduce this noise level. Mechanically reducing the wind noise enables further noise reduction using software, expands opportunities for using microphones. The design of the wind protection is not intuitively obvious, careful design is needed create protection that is both unobtrusive and effective. This document provides some recommended designs and the theory behind them.

OVERVIEW

As intelligent audio devices are becoming more portable, they are more likely to be used in windy situations. The microphones in electronic devices are more directly exposed to the wind than our eardrums, making them more sensitive to wind noise. Wind noise interferes with hearing other sounds, making speech harder to understand and environmental sounds harder to detect.

Microphone booms have been used to improve the SNR by moving the microphone closer to the mouth. However, many users now want to have that same speech performance, without having an intrusive boom.

Well-written software algorithms can reduce the perceived wind noise by more than 20 dB. However, these algorithms cannot do their job well if the speech to noise ratio (SNR) is already well below 0 dB before processing.

A good wind screen gives the algorithms a much better signal to work with, improving SNR by as much as 30 dB. The noise reduction can be achieved with no degradation of speech, improving the effectiveness of speech recognition systems. A wind screen also improves the ratio of environmental sounds to wind noise, which is helpful for preserving environmental awareness. It is quite difficult (if not impossible) for an algorithm to reduce wind noise while preserving environmental sounds with their spatial cues.

A good wind screen works not only by keeping wind from directly hitting the microphone diaphragm, but also by keeping the source of the wind noise far from the microphone. The main source of wind noise is the turbulent motion that occurs when the airflow is disturbed, such as by our bodies and our electronic devices. How to control and shape this turbulent airflow is often not intuitively obvious.

The next couple figures help give an idea of the problem caused by wind noise. Figure 1 shows the speech SNR for a simple headset with no wind protection. This was measured using the experimental headset shown next to the graph. The SNR calculation assumes a speech level of 65 dB at the ear. The SNR goes below -30 dB for when walking outdoors in a gentle breeze.

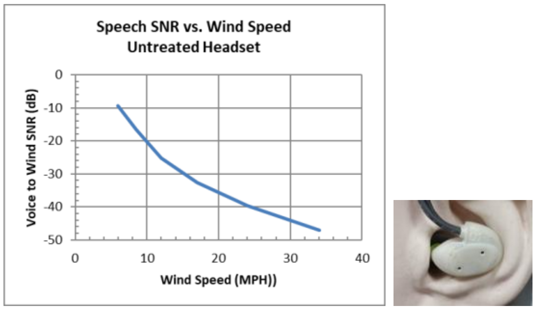


Figure 1 Typical speech SNR in wind for an untreated headset, and an image of the headset used

Figure 2 shows how the spectrum of the noise varies with wind speed. At low wind speeds the energy is concentrated at low frequencies, where it does not interfere much with speech. At higher wind speeds, the wind spectrum covers the entire audio band

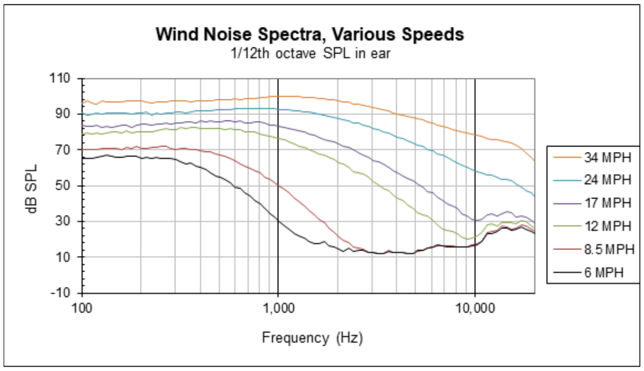


Figure 2 Level and high frequency content of wind noise increases with wind velocity

THEORY OF WIND NOISE GENERATION

Wind noise mainly comes from the turbulent action within the airflow. Turbulent vortices are created by anything that creates sufficient shear within the airflow. Any change in the speed or direction of the overall airflow will create shear within it. Objects that block airflow create turbulence, and sharp edges on the leading edge of that object intensify the vortex shedding. Even when wind travels parallel to a perfectly flat and smooth surface there will be shear in the airflow, since the air velocity along the object boundary must be zero.

The turbulence forms a series of tiny vortices, which are blown past the object. To a microphone, this turbulence looks like a collection of tiny monopole signal sources passing by quickly and traveling very close to the microphone port, each of which is producing different pressure. The net effect is random noise with a rapidly fluctuating envelope. The higher the wind velocity, the greater the amount of noise will be, and the greater the proportion of high frequency content.

A simplified sketch of turbulence is shown in Figure 3. Colors are used to indicate wind speed, with red being fast and blue being slow. Wind flowing past a headset is squeezed and slowed near the boundary. This in turn causes the airflow to curl up and start spinning into vortices of airflow. A quiet zone also forms near the surface of the shape that is further downwind due to the drag along the boundary. Vortices are farther from the boundary in this area.

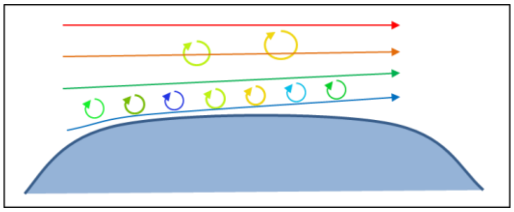


Figure 3 Example of turbulence caused by an obstruction to air flow. Color of arrows indicates wind velocity.

Once triggered, the vortices flow downstream from the source. If airflow is blocked by a barrier, a portion of the vortices will drift into the shadow of the airflow barrier and linger there. This creates low frequency buffeting noise in zones where the net velocity of the airflow is small.

Barriers that gradually redirect airflow tend to create vortices that are lower in energy, and have a thicker quiet zone layer between the vortices and the barrier, both of which reduce microphone wind noise pickup. Sharper disruptions not only trigger vortices closer to the disrupting surface, but their noise has broader bandwidth and more energy. Smoother, less turbulent disruptions produce mostly low frequency energy.

The noise level drops rapidly with the distance between the vortices and the microphone. Placing a wind screen in front of the microphone lets us control that distance. The vortices will be concentrated along the surface of the wind screen. The amount of attenuation with distance follows the principles for a monopole sound source. The level drop with distance depends on the solid angle over which the sound can escape. If sound can escape in all directions in 3 dimensions, the level drops with square of distance, for a level drop of 6 dB per doubling of distance. If sound escapes mainly in 2 dimensions, such as along a surface, the level drops proportional to distance, for only 3 dB per doubling of distance. If sound travels in one dimension, such as within a tube, there is no reduction with distance.

Another important fundamental principle is that the overall air velocity behind commonly used treatment materials (metal mesh, foam, felt) is practically zero, and does not directly contribute to microphone noise. For protection materials of at least a moderate density, all of the noise from the microphone is due to modulation of the air pressure caused by the traveling vortices, not by some portion of the undisturbed outer air flow leaking through the protection material and striking the microphone diaphragm. It also does not matter if the path between the protection layer and the microphone diaphragm is direct or convoluted. Redirecting the sound between the protection layer and the microphone through a longer path will not reduce the wind noise unless the wind noise has a means to escape from that path.

Following this model, several key guidelines can be deduced:

1. The level of vortices created and their penetration into the material are inverse to the density of the protection material. Very low density material, such as fur, creates virtually no vortices, but requires great thickness to keep the wind away from the microphone. If size is not a factor, this is the best option. Denser materials, such as low density foam, will create somewhat more energetic vortices, but they will be confined to the outer portion of the material. Higher density materials of foam or felt and screens keep the vortices at the outer layer of the material. For the thinnest designs, use a thin, rigid, porous screen as the outermost layer of protection.
2. Different types of protection material will have the same vortex penetration and vortex generation. Differences in material thickness, density, mean free path length, and the presence or lack of a hollow interior portion will have little effect on noise reduction provided the material keeps wind out at all. Differences in density of the protection material mostly define how far turbulence penetrates into the material, effectively reducing distance between noise source and mic port. If a hollow interior exists, the shape of the protection layer primarily determines the noise picked up by the mic. Any screen resistance between 25 Rayl and 170 Rayl is likely to be effective. Avoid very high density or low porosity materials, as they are likely to block high frequency speech. Felt and open cell foam rubber offer good damping with low speech loss, but will need protection from moisture absorption. 100 micron filter felt has been shown to work well.
3. Spacing between vortices and microphone is critical in thin designs, with effectiveness increasing 6 dB for each doubling of distance up to around 4 mm. Beyond that thickness, other factors tend to reduce the effectiveness of increased spacing.
4. One should minimize trapping of sound energy between wind screen and mic port. The ideal shape is a streamlined 3-D bubble around the microphone. However, this can rarely be done except on the tip of a boom. A more compact but useful shape is large shallow depression on a surface. The walls of the depression should be angled to trap as little energy as possible. The worst possible shape is a tube.
5. The protected area should be as large as is practical. The thickness of the shear layer increases with distance along the direction of air flow, so the leading edge of the protected zone should be at least 2 mm upstream of microphone port, 4 mm would be better.
6. Energy in the vortices should be minimized to minimize noise. Turbulence is caused by presence of any sudden changes in velocity.

Disturbances should be minimized, and their distance from the mic port maximized. Sharp corners, protrusions of the earphone housing and wind screen, and surface texture of the wind screen are factors. All edges of the earphone exposed to wind should have radii >2 mm, preferably >4 mm. Vortex energy is reduced if the surface of the material is smooth, but there is an inherent minimum drag that creates vortices regardless of material choice.

7. A highly streamlined shape will steer vortices further away from touching the shell, effectively increasing the protection thickness.
8. A microphone placed on the rear side of the earphone (in the concha bowl) where there is little wind will show good reduction of wind noise. Performance can be comparable to a well-protected microphone on the outer surface of the earphone, within the limits of sound trapping covered in point #2.
9. Using multiple ports with one microphone can reduce wind noise, provided the ports are spaced at least 3 mm apart. The noise at each port opening is uncorrelated, so the combined pressure of the ports will provide spatial averaging. For widely spaced openings, the SNR increases proportional to the square root of the number of ports. This provides a benefit of 3 dB for each doubling of ports.
10. Since vortices create uncorrelated sources of pressure, even relatively closely spaced microphones will show low correlation in their noise. Microphones spaced at least 3 mm apart can support wind noise reduction algorithms that depend on low correlation.

EXAMPLE DESIGNS

The following figures and graphs describe some simple prototype designs. Figure 4 and Figure 5 show an example design where a large screen is used to protect the microphone. Red arrows show the paths the wind noise follow as it disperses from a vortex just over the mic port. While sound cannot escape straight downward, sound traveling at even small angles from this direction can reflect from the earphone shell and escape into free space.

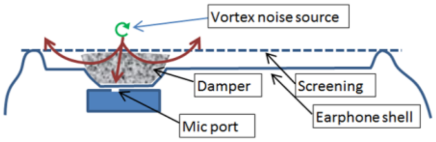


Figure 4 Sound escaping from a vortex

Figure 5 Appearance experimental headset

Figure 6 shows this device provides 20 dB of wind attenuation over a wide range of frequencies. The black curve shows the noise with no wind screen, and the red curve shows the noise spectrum with a wind screen and a felt damper behind the screen. The felt damper quiets any vortices that may penetrate the metal screening. This damper has little effect if the wind is travelling parallel to the screen, but may offer some additional protection if the wind blows directly at the screen. One weakness of this particular headset is that the edges of the screen area are fairly sharp, creating significant turbulence.

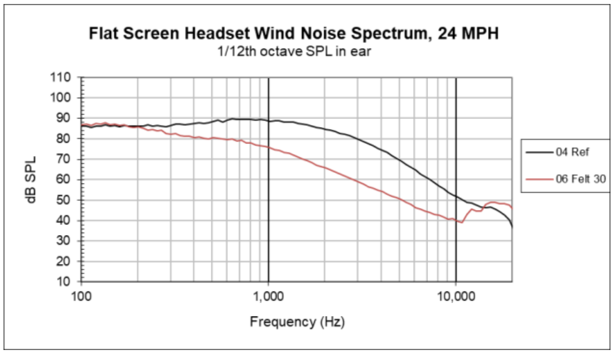


Figure 6 Wind noise reduction using large screen and felt damper.

Placing a large screen over multiple microphones will reduce their directivity. The shared volume between screen and microphones will tend to have a uniform pressure, interfering with beam forming. If multiple microphones will be behind a common barrier, a divider should be placed between microphones to create separate chambers, as is shown in Figure 7.

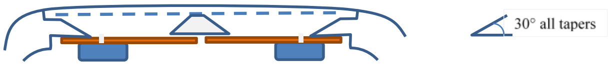


Figure 7 Isolated chambers should be made for each microphone behind the wind screen

The next example shows the impact of using a more streamlined wire mesh over the mic openings (Figure 8). The gentle radius upwind of the mic ports helps increase the thickness of the boundary layer between the turbulent flow and the wind screen over the mic port opening. Figure 9 shows this design provides 35 dB of noise reduction over a wide range of frequencies.

This example is an extreme design, using a very large wire mesh. A smaller mesh area should provide similar results, provided the same smooth shaping is preserved, and wind noise is not trapped at the edges of the screen area.

Figure 8 Appearance of streamlined headset. Middle picture shows felt lining over headset body.

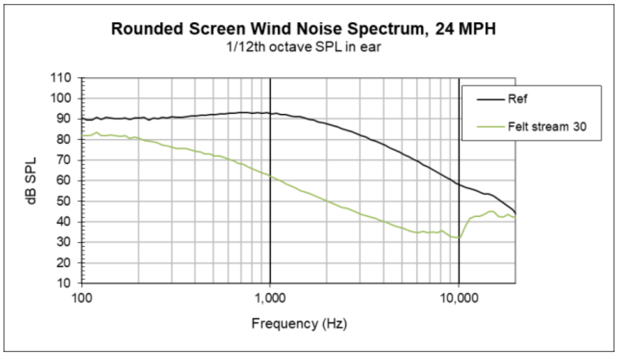


Figure 9 Streamlined cover works best. Mesh resistance not critical, but 30 Rayl shows slight advantage

Sometimes is not practical to create a large wind screen on the outer surface of a headset. A useful alternative is to put the microphone in a location that is sheltered from the wind. The side of the headset facing the concha bowl is just such a location. Figure 10 shows examples of sheltered microphone implementations. The device on the left is made without a screen. Ribs are used to keep the mic port from accidentally sealing to the skin. The device on the right has a screen added for additional wind and sweat protection.

Figure 11 shows the wind noise performance of these designs. The sheltered location provides about 25 dB of wind protection. The green curve shows that adding the wind protection screen over the sheltered microphone entrance offers only a little improvement. It still is useful, both for protection from sweat and for protection in case wind coming from certain angles is able to get behind the earphone.

Placing a microphone adjacent to the skin adds some risks. The microphone may seal against the skin, occluding the port. Providing ridges, as shown in the left side of Figure 10 prevents unwanted occlusion. The microphone may be also become contaminated by sweat, dirt, or other contaminants, so should use a waterproof or water repelling screen over the opening. Another risk is that the microphone picks up scraping noises as the headset slides against the skin. This can be controlled by using a sports lock to hold the earphone in place, or to provide larger clearance from the skin near the mic opening. The concha bowl has resonances, so some equalization may be needed to preserve the natural tone of the speech. Figure 12 shows the difference in voice pickup on a Kemar ear for the external and concha side microphone positions. These curves were measured by using the artificial voice of the Kemar as a signal source. This particular combination of signal source, headset and ear produces peaks near 5 kHz and 15 kHz, and a dip near 10 kHz. The results in other setups may be quite different, so unique corrective equalization must be created for each new design.

Figure 10 Sheltered mic without and with screen protection. Ribs prevent port from sealing against skin.

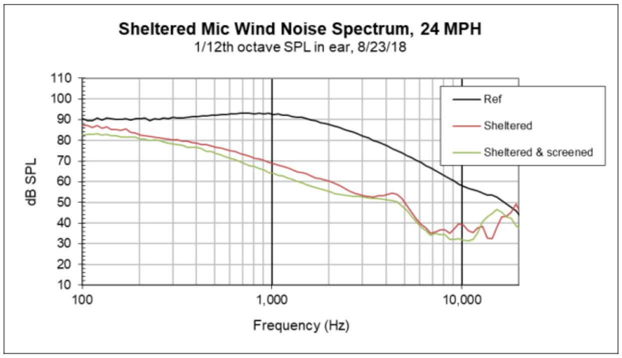


Figure 11 Sheltered microphone position works almost as well as a well-protected external mic

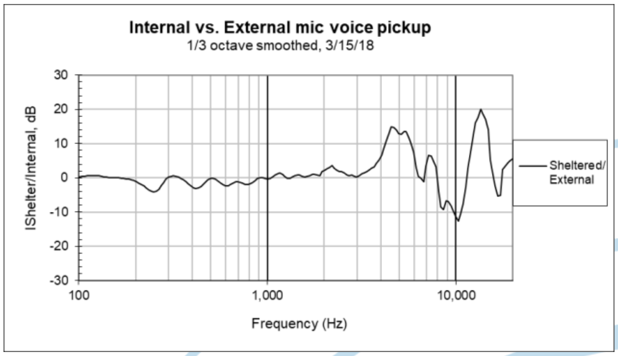


Figure 12 Difference in mic pickup, external vs. sheltered

In summary, the most important factors in wind protection are geometry and distance. It is critical to create as large a separation between turbulence and the mic port, and to allow noise to escape freely in all directions from the protected zone. The distance of separation is controlled both by the distance between the wind screen and the microphone, and by using streamlining to divert air flow away from the microphone screen. Turbulence should be minimized by using highly rounded shapes, with radii of at least 2 mm, and preferably greater than 4mm.

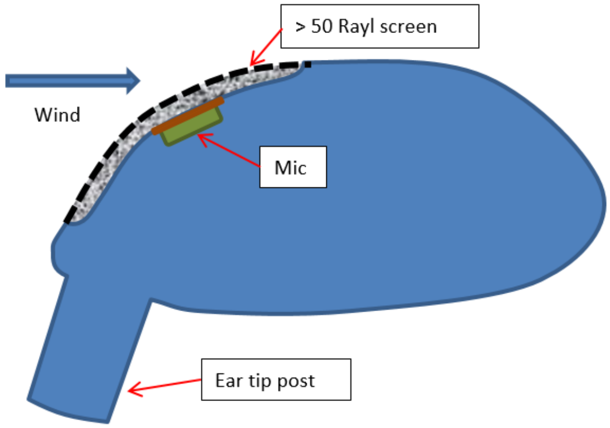
The actual selection of materials has only a minor influence on the level of wind protection, with higher density and resistance materials offering somewhat greater benefit. Hydrophobic meshes will reduce the impact of sweat and rain on the headset.

RECOMMENDED PROTECTIONS

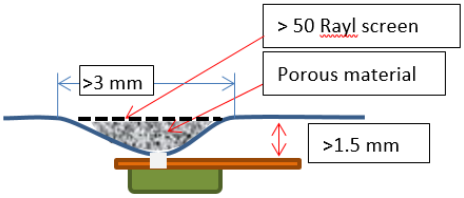
Below are a couple geometries that should work well. They provide good protection in a reasonably compact design.

1. **Best case, streamlined headset, long wire mesh**

- Wire mesh and pocket below it is at least 8 x 4 mm. Preferably covers most of exposed surface.
- Gap between mic and mesh is at least 1.5 mm, preferably >2 mm
- Radius of housing is >2mm, preferably >4 mm
- Leading (upwind) edge of pocket is >4 mm, from mic port
- Mesh is >50 Rayl, preferably >100 Rayl
- Optional damping material placed between screen and housing
- Edge of screen is flush with housing

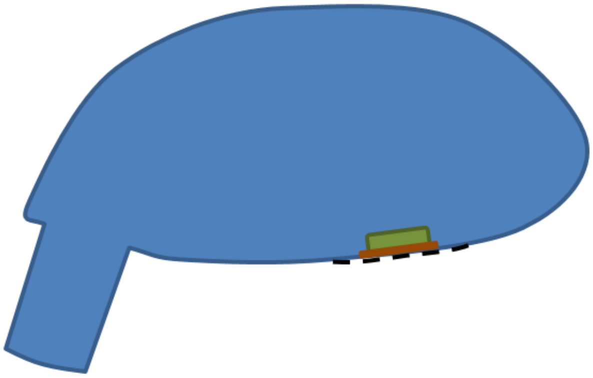


2. **Simpler setup with reduced protection. Dimple in middle of flat or curved surface**



3. **Sheltered microphone position**

- Place microphone in the concha bowl, sheltered from direct wind
- Use raised ridges to prevent sealing against skin
- Optionally cover opening with wind screen



CONCLUSION

A good wind screen can provide substantial wind noise protection, improving sound quality at a given wind speed, and allowing use in higher wind speeds than if not fully protected. It both provides a better sounding unprocessed signal, and enables the use of signal processing for further improvements.

Good wind screen design can be surprisingly difficult. It is hard to estimate both the vortex generation and how that sound will be picked up by the microphones. A good design considers both the fluid flow near the protection, and the propagation of sound within the protected area. The smaller the design, the more difficult it becomes to predict the performance. It is a good idea to mock up and test ideas early in the design process to refine the design.

REVISION HISTORY

Revision	Description	Date
1	Initial Release	11/25/18