# FLOWN SUBWOOFERS DO NOT GENERATE MORE NOISE POLLUTION THAN GROUND-STACKED SUBWOOFERS

Flown and ground-stacked subwoofers offer the possibility of noise pollution reduction at low frequencies:

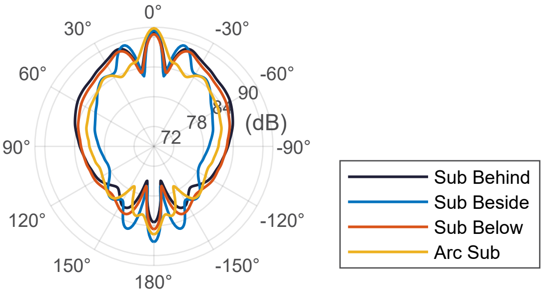
- Stage sides: best reduction for subwoofers flown besides the main system (A-weighted, octave 63 Hz); the ground-stacked Arc Sub provides only benefits in the octave 31.5 Hz, which is rarely inspected in isolation in noise pollution regulation.
- Stage rear: the rejection can be improved by flying subwoofers behind the main system and using cardioid subwoofer configurations.
- Ground-stacked subwoofers are more likely to be influenced by inhomogeneous atmospheric conditions than flown subwoofers. When ground-stacked subwoofers are used, their bandwidth must be limited.

## NOISE POLLUTION

Noise pollution issues are increasingly considered in large-scale sound reinforcement for outdoor events. The noise pollution is due to the Sound Pressure Level (SPL) generated by the loudspeaker system at large distances. One of the most effective measures to limit annoyance is to choose the stage orientation so that it does not directly face the nearest neighbors. As so, noise pollution issues are mostly limited to the sides and rear directions of the stage. At medium and high frequencies, the noise pollution reduction is achieved by controlling the directivity of the source. At low frequencies, noise pollution can be reduced by subwoofers positioning relative to the full range system.

## SYSTEMS COMPARISON

### Observations in free field



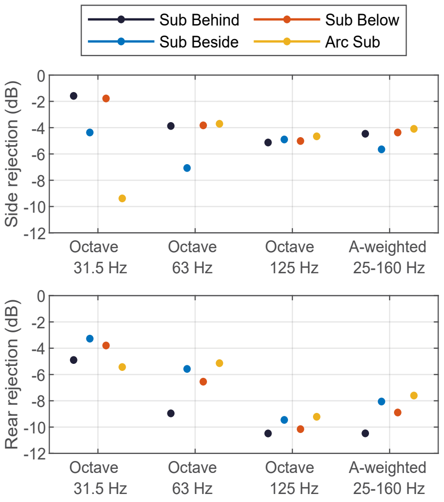
**Polar response***

Four subwoofer deployments are compared associated with the main system (see annex 1 for more details on tested setups). The figure besides shows the polar response at 250 m, in the 20 – 160 Hz frequency band.

In the frontal direction (see Annex 2), all design choices create almost the same SPL. The difference between the loudest (Sub Behind) and the lowest level (Arc Sub) is around 1 dB.

**Rejection**

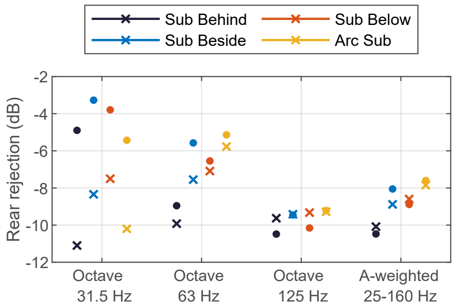
This figure shows the rejection at the rear and on the sides of the stage (see Annex 2).



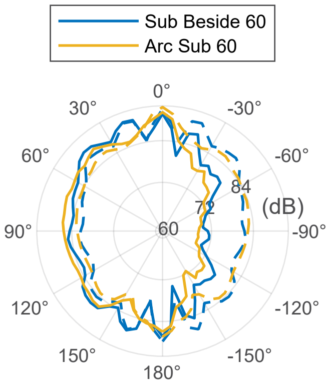
- **On the sides** of the system, the Arc Sub reaches the best rejection in the octave 31.5 Hz but does not perform well in the 63 and 125 Hz octave bands. Consequently, the arc sub presents the worst side rejection in the A-weighted 20 – 160 Hz frequency band.
- **The Sub Beside** has the best side rejection in the 63 Hz octave band. This configuration is also better than other left/right subwoofer configurations in the 31.5 Hz centered octave. This configuration has the best side rejection considering the A-weighted band.
- **At the rear,** the Sub Behind has the best rejection in the overlap octave (63 Hz). The combination of the main system and the subwoofers creates a cardioid configuration that enables significantly reducing the level at the rear.

### Cardioid subwoofer configurations

- If noise pollution must be reduced at the rear of the system, cardioid subwoofer configurations can be used. The figure beside presents the rear rejection of the subwoofer configurations with either the standard preset (points) or the cardioid extended preset (x) (3/1 sub ratio).
- The rejection is improved with the cardioid configurations, particularly in the 31.5 Hz octave band, whatever the subwoofer positioning.
- The benefit of using a cardioid extended preset is the most important with the flown subwoofers.



## Accounting for various atmospheric conditions



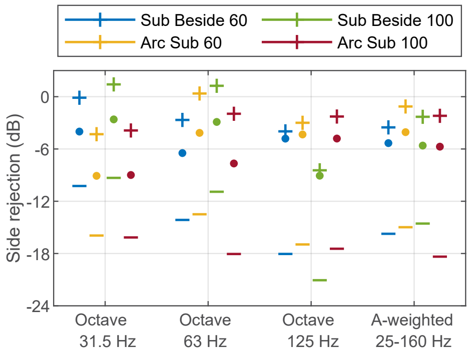
Simulations in free field assume homogeneous atmospheric conditions. However, during open-air events, atmospheric conditions are usually inhomogeneous (see Annex 3 for details).

To illustrate the impact of the wind, a lateral wind is simulated (wind toward the 90° direction). Its impact on the side SPL is studied. Two systems are particularly worth inspecting: Sub Beside and Arc Sub. Results are observed with the original crossover around 60 Hz (Sub Beside 60 and Arc Sub 60), and with a crossover shifted toward 100 Hz (Sub Beside 100 and Arc Sub 100).

The figure beside presents the polar response for Sub Beside 60 and Arc Sub 60. The level increases on the downwind* side (left side) and decreases on the upwind* side (right side) for both configurations. The influence of the wind is higher for the Arc Sub 60, especially upwind.

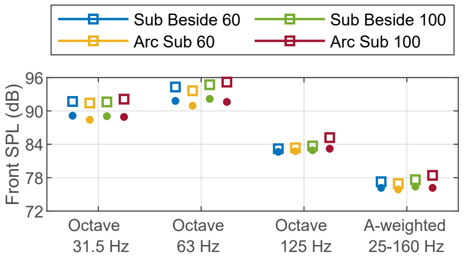
The next figure compares the side rejection of the systems: the points represent the values without wind, the "+", the values on the downwind side, and the "-", the values on the upwind side.

- Octave 31.5 Hz: best side rejection with Arc Sub configurations whatever the wind conditions.
- Octave 63 Hz: the rejection of the Sub Beside 60 is better than the Arc Sub 60, especially under downwind conditions; the Arc Sub 100 presents the best side rejection without wind; this rejection is, however, widely impacted by the wind and the benefit is lost downwind compared to Sub Beside 60.
- Octave 125 Hz: Sub Beside 100 has the best side rejection; this rejection is stable downwind.
- A-weighted 25 – 160 Hz band: the Arc Sub 60 presents the worst side rejection.



The influence of the temperature inversion* is studied by comparing the front SPL during the day (points) and the night (squares). The temperature inversion increases the level in all studied octave bands.

- During the day, the level at the front is slightly smaller with arc sub configurations.
- During the night, the temperature inversion makes the Arc Sub 100 the loudest configuration at the front of the system.



# GLOSSARY

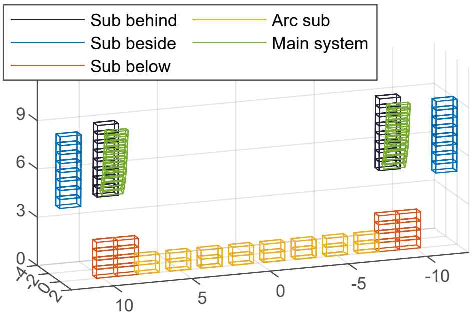
- **Polar response:** shows the variability of the average banded SPL around the system.
- **Downwind:** when the wind goes from the source to the receiver, in the propagation direction.
- **Upwind:** when the wind goes from the receiver to the source, opposing the propogation direction
- **Temperature inversion:** positive temperature gradient, generally observed during the night

# ANNEX 1 - TESTED SYSTEM CONFIGURATIONS

## Main and subwoofer systems

The main system is composed of 12 L-Acoustics K2 per side, spaced 18 m apart, flown at 9 m. The arrays are mechanically optimized to cover an audience area of 60 m long per 45 m. Four subwoofer configurations are proposed, with 16 L-Acoustics KS28 each:

- **Sub Behind:** flown left/right configuration with a vertical line of 8 subwoofers per side, flown at 9 m, 1.7 m behind the main system.
- **Sub Beside:** flown left/right configuration with a vertical line of 8 subwoofers per side, flown at 9 m, 3 m besides, at the exterior of the main system.
- **Sub Below:** ground-stacked left/right configuration with a matrix of 2 columns of 4 subwoofers on each side, stacked below the main system.
- **Arc Sub:** ground-stacked horizontal line with 8 columns of 2 subwoofers, spaced of 2 m. Delays are applied on subwoofer columns, by pair, from interior to exterior: 0, 0.7, 2.4, and 6.2 ms.



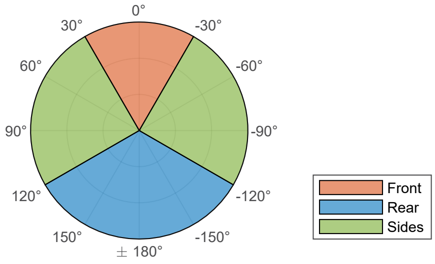
The summation of the main system with subwoofers is optimized at position [30;4], namely at half the total length of the audience and slightly off-axis. The original crossover between K2 and KS28 (KS28_60 preset) is around 60 Hz. For investigation purposes, the crossover is additionally shifted toward 100 Hz using a high-pass filter on the K2 (LR24 at 100 Hz) and a preset KS28_100 for the subwoofers.

## Normalization

Loudspeaker system designs can only be compared for noise pollution if they provide a similar audience experience. A drive signal is computed for each system so that they reach the same typical target spectrum at 40 m of the system (averaged along the audience width) with a level of 99 dB(A) or 112 dB(C).

# ANNEX 2 - COMPARISON METRIC

Design choices are compared with their polar response, computed at 250 m from system origin. The polar response is calculated by averaging the normalized frequency responses in the corresponding frequency bands across the entire 20 – 160 Hz frequency.



For further analysis, the space is divided into three angular portions, see the figure beside

**1.** Front, defined as the 60° around the sound system axis, corresponds to a typical audience width

**2.** Rear, 120° around the back of the system.

**3.** Sides, all other angles on either side of the system

For a more detailed analysis, front level, rear, and side rejection are calculated by octave bands as the difference between respectively the level at the rear or on the sides and the level at the front.

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[1] Defined in "Simulating low-frequency noise pollution using the parabolic equations in sound reinforcement loudspeaker systems" (Link)

# ANNEX 3 - INHOMOGENOUS ATMOSPHERIC CONDITIONS

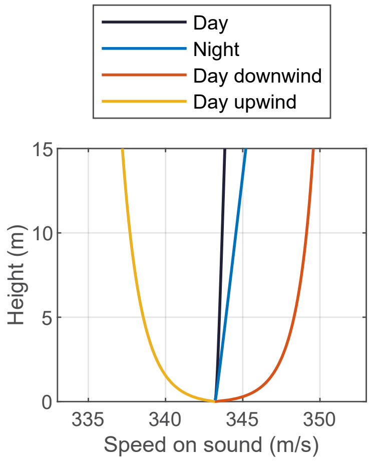
## Wind and temperature gradient

In open-air events, atmospheric conditions are usually inhomogeneous: wind and temperature are not constant with altitude.

- Usually given at a certain height, the wind is slowed down close to the ground by obstacles and the ground roughness.
- On a sunny day, the sun heats the ground, heat is transferred to adjacent air, and it makes the temperature warmer close to the ground; on the contrary, during the night, the heat is absorbed by the ground, the air is cooled close to the ground and the temperature increases with the altitude (temperature inversion)

The wind and temperature influence the speed of sound:

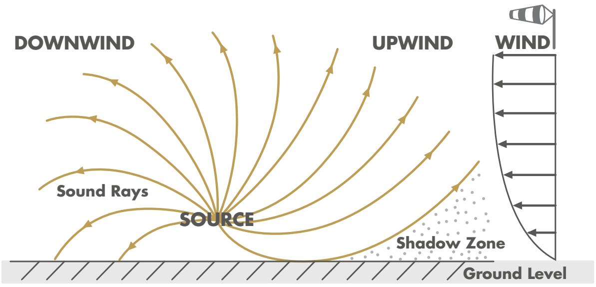
- Downwind conditions increase the speed of sound while upwind conditions decrease the speed of sound.
- The speed of sound is proportional to the square root of the absolute temperature.
- These inhomogeneous atmospheric conditions create a sound speed gradient.

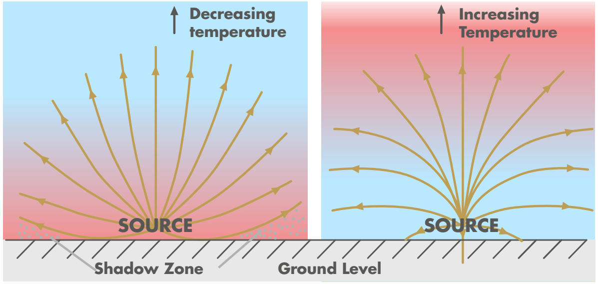


## Impact on sound propagation

In ray acoustics theory, a straight line going from a source to a receiver in a homogeneous atmosphere is replaced by a curved ray, in the presence of a speed of sound gradient. This phenomenon is known as refraction and is described in the figure:

- Downwind conditions or positive temperature gradients contribute to an increase in the speed of sound with altitude. It creates downward refraction. The sound is then reflected off the ground and refracted back toward the ground. The sound is thus concentrated close to the ground, creating higher SPL and higher noise pollution.
- On the contrary, upwind conditions or a negative temperature gradient contribute to a decrease in the speed of sound with altitude. It causes upward refraction. It leads to lower SPL, even shadow zone, and lower noise pollution.





## Simulation Method

Parabolic equations (PE) are used to simulate inhomogeneous atmospheric conditions. A complete description of the method is available in the AES convention paper “Simulating low-frequency noise pollution using the parabolic equations in sound reinforcement loudspeaker systems” (link). PE is a very accurate method to simulate complex sources, accounting for variable ground impedance and vertical celerity profiles, with a reduced computational cost compared to other advanced computational methods such as the Finite Element Method (FEM) and increased accuracy compared to ray acoustics methods, especially at low frequencies.