

Application Note



Directionality

Many hearing impaired people have great difficulty understanding speech in noisy environments such as parties, bars and meetings. But speech understanding can be greatly improved if unwanted surrounding sounds are filtered out.

Figure 1 illustrates a listener with a directional hearing aid in a noisy environment.

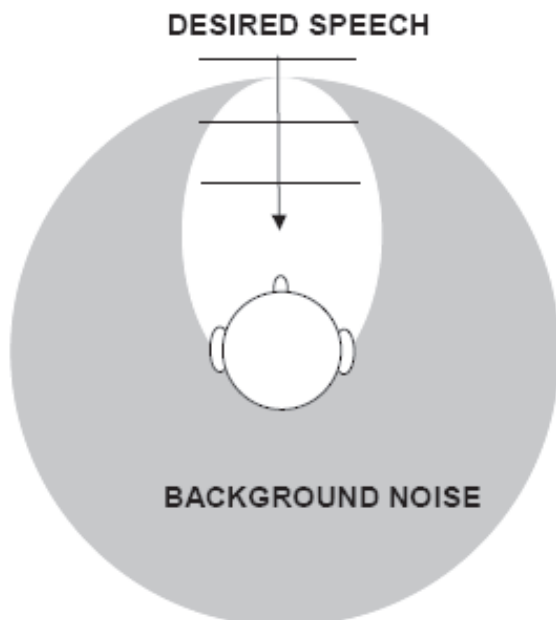


Figure 1. An illustration of a person in a noisy environment.

A directional hearing aid will significantly reduce sounds coming from any other direction than the front. A directional hearing aid requires a directional microphone solution.

In the market today there are two options:

1. A traditional single directional microphone
2. Two microphones with identical responses (matched pair)

Both microphone options work on a similar principle to obtain directionality. The single directional microphone will be used to explain the properties of directionality.

What is directionality?

A microphone is called directional if its output depends on the angle of incidence of the incoming sound (Figure 2).

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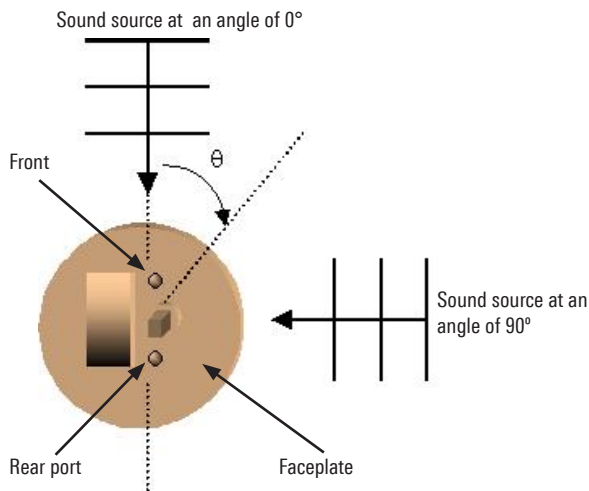


Figure 2. Angle between sound source and sound ports.

Directionality of a microphone or a hearing aid can be expressed using a directivity index or the front-to-back ratio. These measures are a method of expressing the signal to environment noise ratio as it applies to directional microphones and their capability to reduce sounds from certain directions.

Definitions

DI The directivity index is defined as the sensitivity of sounds directly in front of the listener (0°) compared to the average of sounds that come from any other direction. Figure 3 shows the area used for the calculation of the DI.

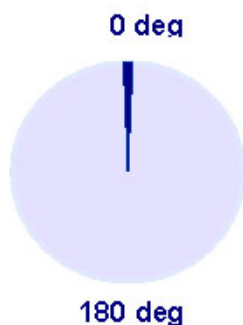


Figure 3. Directivity Index (DI)

UI Unidirectional Index is the ratio between sensitivity of sound from an imaginary front hemisphere (from 270° to 90°) to that from an imaginary rear hemisphere (from 90° to 270°). Figure 4 shows the area used for the calculation of the UI.

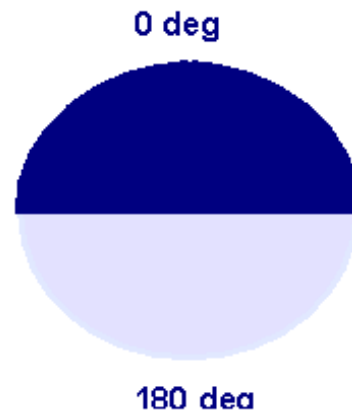


Figure 4. Unidirectional Index (UI)

F/B

The front to back ratio is the ratio between sensitivity for sound coming from the front at an angle of 0° and the sensitivity of sound coming from the rear at an angle of 180° .

AI-DI

The Articulation Index - Directivity Index (AI-DI) is a measure of audible speech across specific frequency bands. The AI can be applied to the DI at different frequencies, resulting in a single number expressed in decibels. This number represents the degree the speech is enhanced compared to background noise. The following weighting factors are used for the calculation: 20% at 500Hz, 23% at 1kHz, 33% at 2kHz and 24% at 4kHz.

Polar plots

Polar plots are measurement plots that show the sensitivity of the directional device at different angles.

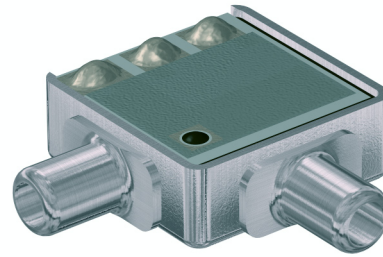
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Single Directional Microphone

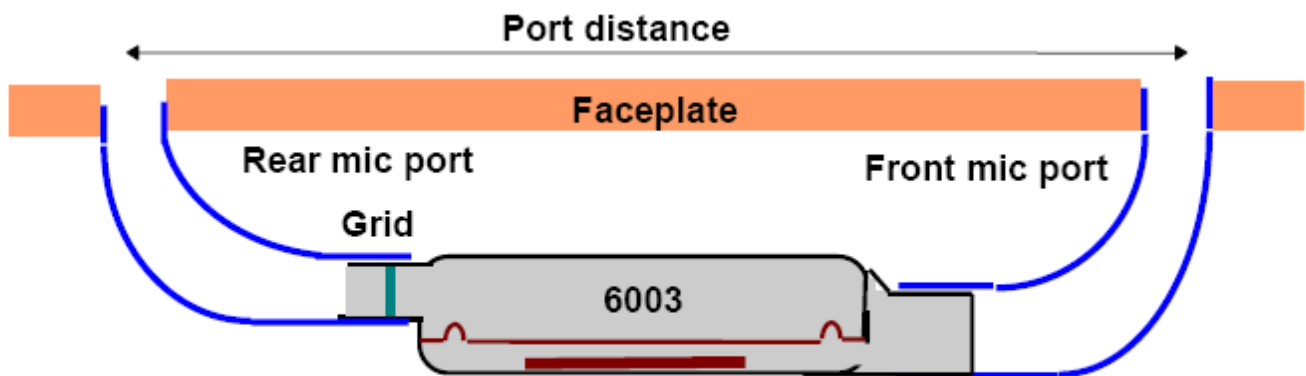
A traditional directional microphone contains two sound inlets, one on either side of the diaphragm. Figure 5 illustrates the use of a directional microphone.

The output of the microphone is proportional to the phase difference between two acoustic signals. The subtraction of the two acoustic signals takes place at the diaphragm. The distance between the sound inlets causes the phase difference. From figure 2 it can be seen that if the angle θ is 90° the phase of the acoustic signals will be equal.

Different directional characteristics such as cardioid or hypercardioid responses can be obtained by changing the distance between the sound ports or changing the grid in the rear sound port. Figure 6 show different polar plots. The formulas used to obtain the correct directivity characteristics can be found in Appendix 2.



Sonion 6001 Directional Microphone



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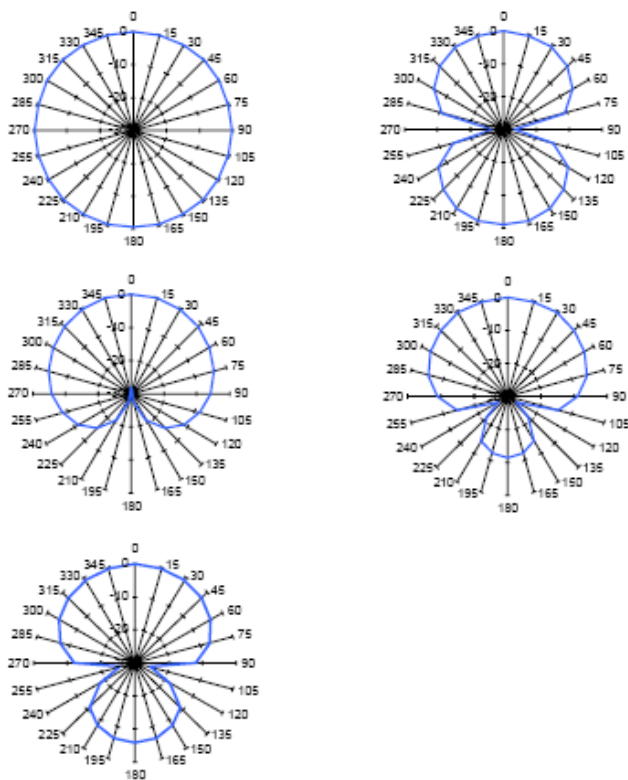


Figure 6. Types of polar directivity patterns (starting left top): omni directional, bi-directional, cardioid, supercardioid and hyper-cardioid. The attenuation is expressed in dB relative to the 0°-output level.

The best polar plot response depends on a listening situation. If an unwanted speaker is standing right behind the hearing aid user, a cardioid response will perform best to reduce the noise from behind. However, when the user finds himself in a 'cocktail party' situation where the background noise is equally strong from all directions, then a hypercardioid response is best suited. Most directional hearing aids are configured to have a hypercardioid polar response, because it has the highest average attenuation of noise sources over all angles of incidence.

Table 1 shows that a hypercardioid pattern achieves the highest possible value for the DI, 6.0 dB. However, a supercardioid pattern has 0.3 dB lower DI, but achieves much higher UI than a hypercardioid response. High UI values are perceived more as a benefit in noisy environments because most people intuitively turn their back to disturbing noise sources. A supercardioid response may then be more beneficial than a hypercardioid response. The table also shows the values for β , which presents the ratio between the internal and the external delay. The acoustical delay of the microphone (Δt) is the internal delay and the propagation delay due to the distance between the sound inlets (d/c) is the external delay.

Metric	Omni directional	Bidirectional	Cardioid	Supercardioid	Hypercardioid
DI [dB]	0	4.8	4.8	5.7	6.0
UI [dB]	0	0	8.4	11.5	8.4
β		0	1	0.57	0.33

Table 1. Theoretical values of DI, UI and β for different directivity patterns.

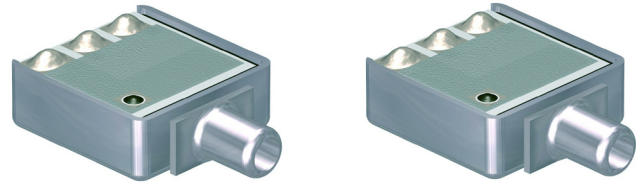
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Directional Microphone Application

The output of a directional microphone is directly related to the distance between its sound inlets. By attaching tubing to the microphone this distance is increased and higher output is obtained. This will make the directional microphone less sensitive to noise. However, the tubing changes the acoustical response of a sound inlet.

The delay time of a directional microphone differ. To chose the correct microphone with the correct delay time (Δt), first the desired polar response (b) needs to be defined as well as the distance between the sound inlets in the hearing aid (d). These two parameters identify he desired delay time of the directional microphone. The design of the microphone may limit the delay times available.

There are some noisy situations such as traffic noise where the user will not benefit from directionality. Therefore, it is very important for the user to have an option of switching from omni to directional mode. Incorporating an omni directional microphone is desirable or the second option is to use two omni directional matched pair microphone. This concept is explained in the next section Matched Pair Microphones.



Sonion 6046 Matched Pair Microphone

The operation principle of matched pair microphones is similar to that of traditional directional microphone. See figure 7 below. The directional output is the difference between two electric signals instead of acoustic signals. The sensitivity and phase response of these microphones must be identical. Any differences in sensitivity or phase will influence the directionality. Freedom of signal manipulation and flexibility of microphone positioning are among the advantages of using a matched pair. For instance different directional characteristics can be achieved by manipulating the electrical delay times. Also to obtain higher output tubing is not required simply increase the spacing between the two signal inlets by placing them further apart.

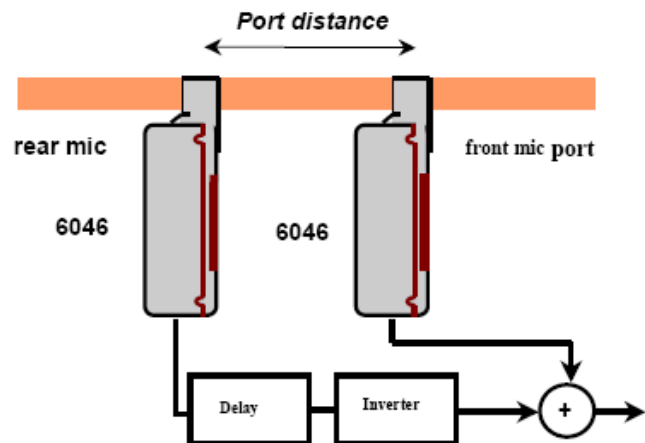


Figure 7. Application of matched pairs.

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Definition of matched pair microphones

Two microphones are considered to be identical when sensitivity and phase match criteria given in Table 2. Sonion is capable of delivering matched pairs within very tight tolerances.

Standard Matching		Sonion Matching		
Frequency (Hz)	Sensitivity max. dev. (dB)	Phase max. dev. (°)	Sensitivity max. dev. (dB)	Phase max. dev. (°)
< 1000	1	2	0.5	1
1000-4000	2	10	2	5

Table 2. Matching criteria of the microphones

Table 3 shows the influence of mismatching sensitivity of the microphones on the DI values when a port distance of 6.4mm is used. The mismatching in sensitivity will have the most influence in the low frequency range. For a matched pair it is possible to reduce the mismatching by tuning the electronic circuitry.

Mismatching (dB)	DI @ 500 Hz	DI @ 1kHz	DI @ 2kHz	DI @ 4kHz
0.0	5.8	5.8	5.8	5.7
0.25	4.8	5.5	5.7	5.7
0.5	3.2	4.8	5.6	5.7
0.75	2.1	4.0	5.2	5.7
1.0	1.4	3.2	4.9	5.6

Table 3. Influence of Sensitivity Mismatching on DI value

Application Note

Matched Pair Application

To obtain best directionality Sonion recommends using the same model and type microphone where both acoustical and electrical characteristics are the same. If mechanical design of the hearing aid demands a change in distance between the sound inlets it is feasible to use tubing, although it results in a slight loss of directionality at higher frequencies (above 4 kHz). Since tubing changes the response of the microphones the same tubing should be attached to both microphones.

Comparison between directional microphone and matched pair microphones

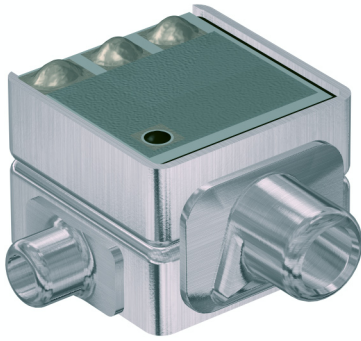
Directional Microphone	Matched Pair Microphone
Better S/N ratio	More flexibility in directionality
Non-flexible directionality behaviour	Electronics needed to obtain directional characteristics
Need of tubing for wider port spacing	No tubing required

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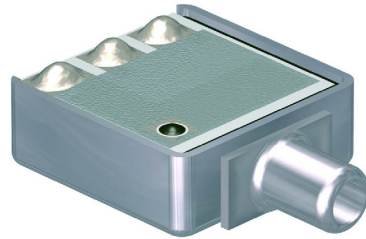
Appendix 1

Examples of directional microphones and matched pairs

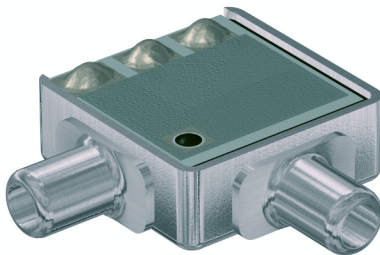
This module is a combination of an omnidirectional microphone and directional microphone in one small package.



Sonion microphone model 6903.



Sonion microphone model 6003.



Sonion microphone model 6001.

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Appendix 2

Calculations

The formulas below can be used to calculate the total output U of the directional microphone and to calculate the ratio b between the acoustical delay of the microphone (Δt) and the propagation delay due to the distance between the sound inlets (d/c).

$$U = A \frac{\omega \cdot d}{c} (\beta + \cos \theta)$$

U = output of the microphone

$$\beta = \frac{c}{d} \cdot \Delta t$$

c = sound velocity

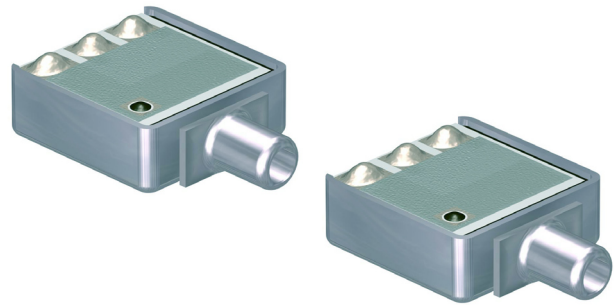
A = sensitivity

ω = angular frequency of sound

d = distance between sound inlets

Δt = delay time of acoustical network of microphone

θ = angle ref. to microphone



Sonion matched pair 6046

This matched pair microphone model contains a superior electronic circuit design which produces extremely close matching of sensitivity and phase.

Note: For a complete list of directional solutions please contact a Sonion representative.