

HEARING GLASSES

AN INNOVATIVE APPROACH TO BEAT THE COCKTAIL PARTY EFFECT >>> DOI 10.1051/epn:2008405

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One often hears complaints from hearing-impaired people that their hearing aid is useless – or even counter-productive - under conditions where they need it most. This is strange. A hearing aid should make listening easier, not worse. How is this possible? The answer to this question has been known for a very long time. It is related to the fact that hearing impairment is often caused by reduced sensitivity and bandwidth of hearing, due to a reduced sensory-neural response of the ear caused by age, high noise levels or a disease.

This has two consequences. First, the threshold of hearing is raised. To compensate for this a hearing aid is an ideal companion, because it can amplify the sound that enters the ear. The second consequence is more difficult to handle. Mainly due to the reduced frequency bandwidth, a higher speech to noise ratio will be needed to understand speech. This is where many hearing aids fail, because they amplify wanted and un-

wanted sound by the same amount, leaving the speech to noise ratio unchanged. Under noisy conditions the sounds are often not just too weak; the problem is that the wanted sound simply cannot be distinguished from the noise. This is known as the cocktail party effect. Already in 1978 Plomp [1] published on this phenomenon and from his paper the conclusion can be drawn that the speech to noise ratio should be increased by at least 6 dB to give a hearing-impaired person the same ease of understanding speech under noisy conditions as a healthy person. However, research has shown that traditional hearing aids often amplify unwanted sound even more than wanted sound. This is mainly due to the directional characteristics of such a hearing aid when it is worn on the head.

This directly explains why the traditional ‘omnidirectional’ hearing aids turn out to be useless under noisy conditions. What one needs is adequate directional selectivity.



▲ FIG. 1: Water waves reveal the position of the source by the direction in which they move.

Looking for an innovative solution

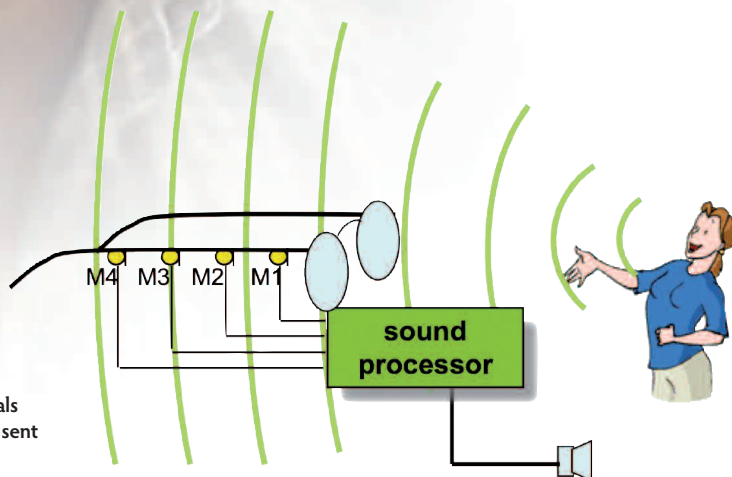
The answer to the problem seems easy: simply make a hearing aid directional, at least for situations where the wearer needs a better speech intelligibility. When facing a speaking person one needs amplification of sounds from the front, and attenuation of sounds from all other directions. This is at least a good solution when the speaker is near, such that the direct sound from the speaker is dominant over reflections and reverberation. This solution is well known in principle but not easily obtained in practice. What we need is a directional microphone (or *two*, for both ears). Moreover, to obtain directivity one needs to sample the sound field spatially over distances of several wavelengths. This may be compared with water waves (fig. 1). The position of the source (the disturbances caused by a stone thrown into the water) can be found by looking at the water surface and simultaneously observing the waves at different positions. It is not sufficient just to look at one point of the surface. This is exactly the problem that a hearing aid faces: for a good directivity it needs to observe or sample the sound field over some distance. But hearing aids are usually so small that it is almost impossible to do so.

This knowledge, plus the fact that there is a great need for good speech intelligibility in the hearing-impaired community, were the basis for a long term project at Delft University of Technology. Indeed, this topic became the subject of two successive PhD-thesis projects [2, 3].

It was clear from the start that microphone arrays had to be invoked to achieve a highly directional response, and that spectacles would be the ideal location for the microphone arrays. Since the spectacles are fixed to the head, the arrays turn automatically in the direction in which the wearer is looking. Looking at the speaker is not only polite: it also offers the possibility of lip-reading assistance!

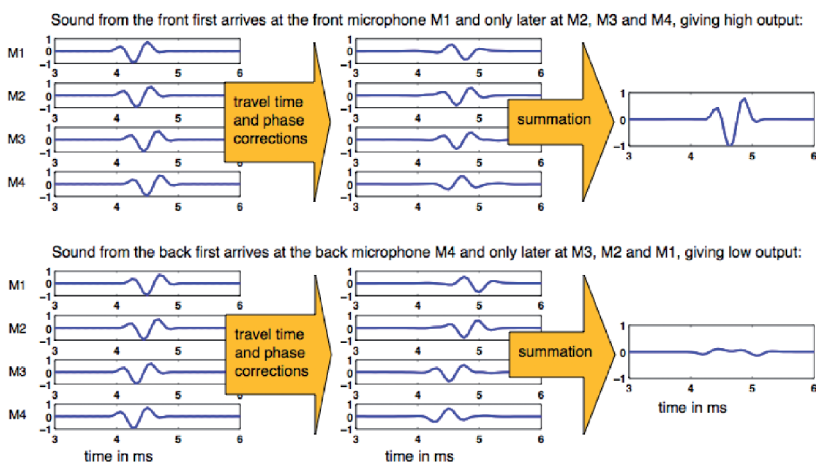
Early prototypes were downright ugly, but the hearing glasses which are now on the market have a fashionable design and look like normal spectacles (fig. 2). Each 'temple' (horizontal leg) of the spectacles contains four tiny microphones whose signals are fed to a chip for real-time signal processing, as shown in the block diagram of figure 3.

The first part of the signal processing is the so-called beam forming of the microphone array, which amplifies sounds from



▲ FIG. 2: The Varibel hearing glasses as worn with ear fittings.

► FIG. 3: Block diagram of the hearing glasses. The microphone signals are especially processed for high directional selectivity before being sent to the ears.



◀ FIG. 4: Principle of the directional beam former.

the front, *i.e.*, the direction in which the wearer is looking, while attenuating sound from the sides and from the back. The signal processing also includes frequency-dependent amplification and compression, necessary to obtain a comfortable listening level of the signals that are sent to the ears. This is achieved by small loudspeakers that are connected to the spectacles and feed the signals through tiny tubes to the ears (fig. 2).

Physical background

The operation of the hearing glasses relies mainly on the fact that differences in direction of incoming sound waves can be directly translated into differences in travel time to the microphones in the array. Obviously, this is done more accurately if there is a larger distance between the microphones. The temples of the spectacles offer sufficient spacing for this to be achieved with sufficient precision.

The principle of operation is further explained in figure 4. Sound coming from the front is processed in such a way that the microphone signals line up and their phases are optimized. In this case there is a high output. When applying this same processing to sounds coming from other directions, the signals do not line up and the output is low. This is illustrated in the figure for sound coming from the back.

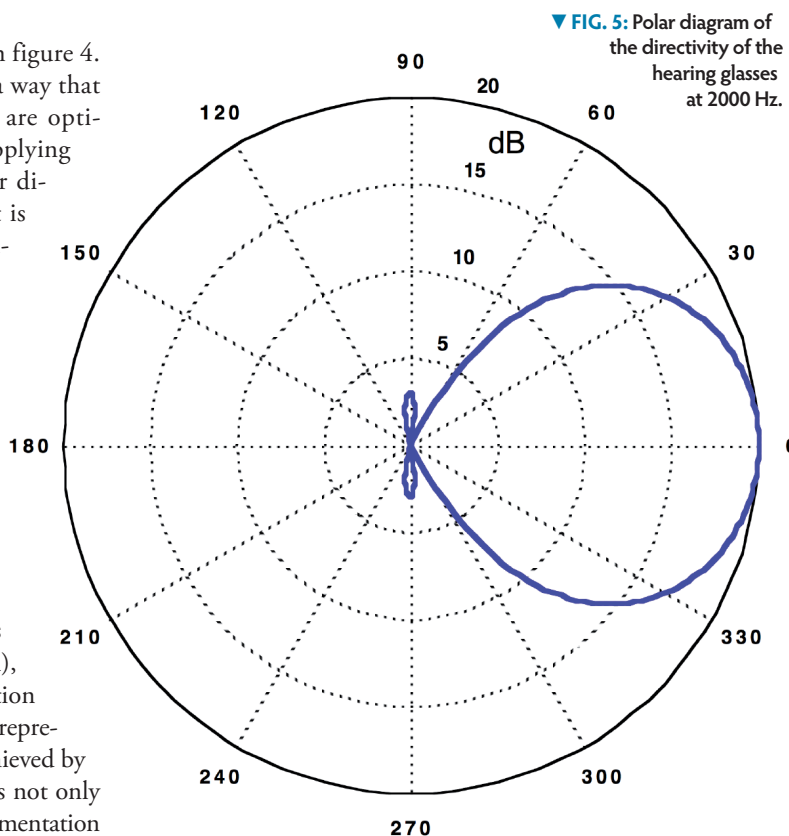
It must be noted that the array processing used here is not a simple delay and summation procedure, where signals are only time shifted for a desired listening direction. This well known principle would not be sufficient here, because the length of the microphone arrays of 72 mm is still small in relation to the wavelengths over a large frequency range. (The wavelength of a 1 kHz sound is 0.34 m). Instead, a much more sophisticated principle is used here, called optimized beam forming. In this method not the output from sound in a desired direction is maximized (as delay-and-sum beam forming would), but the ratio between sound from the desired direction and sound that enters randomly from all directions (representing the unwanted noise) is maximized. This is achieved by using specially designed phase shifts. This principle is not only more sophisticated; it also requires a very precise implementation

of the filters that are needed in the microphone channels. This task cannot be carried out with sufficient accuracy by analogue techniques. Therefore we had to delay product development until low-energy digital signal processing (DSP) chips having the required functionality became available in the hearing aid industry.

Performance

With our optimized beam-forming method a very high directivity can be obtained, as shown in figure 5 for a frequency of 2 kHz.

The gain in directivity is expressed in the so-called directivity index or *DI*. Since the *DI* is frequency dependent it is usually weighted over the frequency range which is important for speech intelligibility. It is then called the speech-intelligibility-weighted directivity index *DI_w*. It is a measure for the attenuation of unwanted sounds from random directions as compared to the sensitivity in the forward direction. The processing of the hearing glasses gives a *DI_w* of 8 dB, which is extremely high for such a small microphone array of only 4 microphones over a length of 72 mm. Notice that this is significantly higher than the necessary increase in speech to noise ratio of 6 dB as found by Plomp [1]. Conventional directional hearing aids often use only two microphones that have to be placed close together, ▶



▼ FIG. 5: Polar diagram of the directivity of the hearing glasses at 2000 Hz.

- ▶ because they must fit into the hearing aid. They usually do not show a DI_w higher than 3 dB.

The hearing glasses offer several user modes for different acoustic environments. In situations where a high directivity is not needed, a reduced directivity can be chosen by the wearer at will. In this mode the user can listen more easily to sounds from all directions, which is safer in traffic, and is also preferred for listening to music.

In conclusion

Hearing glasses provide the innovative answer to the demand from society for a highly directional hearing aid. It represents the result of a long-time research effort, carried out at the Laboratory of Acoustical Imaging and Sound Control of Delft University of Technology. Use is made of optimized beam forming

by microphone arrays that are placed in the temples of a pair of spectacles. The signal processing is carried out with dedicated low-energy DSP-chips. The hearing glasses yield an effective directivity index up to 8 dB, which makes understanding speech much easier under noisy conditions. These hearing glasses have been on the market since April 2006 and are manufactured by the Dutch company Varibel. ■

References

- [1] R. Plomp, *J. Acoust. Soc. Am.*, **63**(2), 533, 1978.
- [2] W. Soede, “*Improvement of speech intelligibility in noise*”, PhD Thesis TU Delft, 1990.
- [3] I.L.D.M. Merks, “*Binaural application of microphone arrays for improved speech intelligibility in a noisy environment*”, PhD Thesis TU Delft, 2000.