Phonak Insight

Binaural directionality

Wireless communication opens the door to a completely new approach in directional multi-microphone systems

Introduction

Phonak has the distinction of being the inventor of multi-microphone technology in hearing instruments. As early as the 1990s, hearing instruments with AudioZoom directional microphone technology were setting new standards in speech clarity in background noise. With the emergence of digital hearing instruments, multi-microphone technology was adopted by all manufacturers and has been evolving ever since. Multi-microphone technology is now standard and expected in all hearing instruments. The specific physical limits imposed by the use of only two microphones have remained an obstacle to even greater enduser benefits. ZoomControl made it possible for the first time to produce new microphone patterns by allowing an interactive exchange of data between the left and right hearing instruments. It became possible for the enduser to selectively focus to the right, to the left or to the back. Phonak has now taken another major step forward in directional microphone technology. By combining our exclusive ability to transmit the full audio signal between hearing instruments with directional microphone functionality, Phonak can now offer a binaural beamforming system. Completely new microphone beam patterns can be generated. Using real-audio wireless exchange, the microphones of both hearing instruments work together to focus with even greater accuracy on sound sources coming directly from the front while minimizing competing noise from all directions. The result is a significantly improved signal-to-noise ratio (SNR), which offers far better speech comprehension in difficult listening situations than has been possible before.

Natural hearing focus

The human hearing system is able to localize numerous acoustic sound sources to within a few degrees of each other. This is possible by making use of miniscule differences in transmission time and signal level entering each ear. This localization process normally occurs subconsciously and can be used to focus on specific sounds. . Incoming signals from every direction are evaluated in the brain for their apparent importance, and subjected to an auditory scene analysis. Depending on the results of this evaluation, certain sounds are either emphasized, or suppressed. When hearing loss is present this mechanism is disrupted and less effective resulting in difficulty locating sound sources and suppressing background noise when the acoustic signals are being processed in the inner ear and the brain. Modern technology attempts to restore these abilities, but because it is not able to intervene in the inner ear or the brain, it operates by emphasizing signals considered to be important and suppressing others regarded as irrelevant or even intrusive.

In hearing instruments, multi-microphone technology is the most significant and effective method of differentiating between wanted and unwanted signals. It makes use of the fact that an individual typically looks in the direction of the desired audio signal. By connecting the directional characteristics of the two microphones, signals from the front are typically emphasized and those from other directions are suppressed.

The limits of dual microphone systems

Simple dual microphone systems have specific limits that are determined by the laws of physics. Figure 1 shows various possible characteristics of a two-microphone system. The beam or polar plot possibilities range from a pure omni-directional characteristic to a figure-eight shape. For hearing instruments, the main focus is always to the front, if we disregard the pure figure-eight pattern which is not normally used. There is only a single principal direction and the sensitivity with which the hearing instrument reacts in each direction is not very precise. The result is that in addition to signals coming directly from the front, those within a forward angle of roughly +/- 60° are also effectively included. Depending on the listening situation, this is not always desirable.

To overcome this phenomena the beam must be made narrower and more sensitive, which can be accomplished by increasing the distance between the two microphones.

There are limits to this strategy as well because the housings of today's hearing instruments are very small. Attempts to increase the number of microphones connected in series, can also create a narrower beam, have been met with little success. Although connecting a number of microphones in series makes it possible in principle to generate new directional characteristics, the challenge is that this can only be accomplished with second order directional microphone systems.

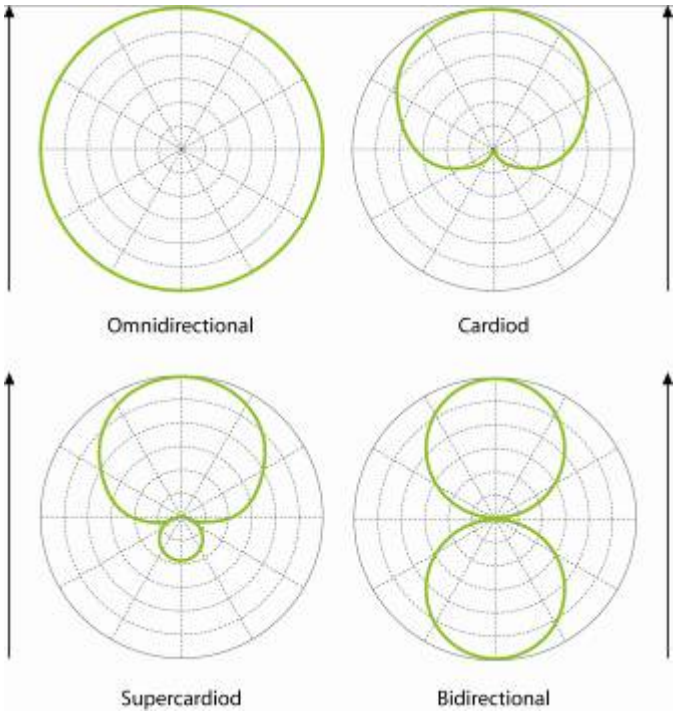

Fig. 1: Polar diagrams showing the theoretical microphone patterns which can each be continuously attained through use of two microphones.

The effects of "order"

A single directional microphone is also known as a "first order microphone". For physical reasons, a directional microphone operates using frequency-dependent sensitivity, which means that it transmits lower frequencies less effectively than higher frequencies. Sensitivity declines by 6 dB per octave as the frequency drops; if uncorrected this can result in light or thin sound because of poor bass transmission. Adjusting the frequency response to offset this phenomenon raises the internal noise level which can cause problems, particularly when input signals are faint because the internal noise can become audible. Dual microphone systems often employ two omni-directional microphones to achieve a first order directional characteristic. The result is that multi-microphone systems in digital hearing instruments often operate only omni-directionally at low frequencies and directionally for higher frequencies. Directionality for all frequencies is sometimes employed in specific acoustic situations where it can be assumed that the raised level of internal noise is not audible or does not affect intelligibility of the other desired signals. Although modern hearing systems offer multiple frequency channels which can minimize these issues, this solution is still not fully satisfactory.

The challenge of increased internal noise at low frequencies is exacerbated in higher-order directional microphone systems including triple and serial multiple microphone arrangements. For example, sensitivity can decline by up to 12 dB per octave at low frequencies in a triple-microphone system (see Figure 2). As a result, in three microphone instruments, only two microphones operate simultaneously in the low-frequency range. The third microphone is active only for signals above 1 kHz.

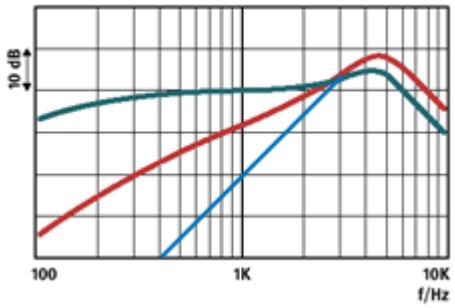

Fig. 2: Sensitivity levels of a single microphone (green line) a dual microphone system (red line) and a triple microphone system (blue line).

Realistic directional characteristics

It should be noted that some of this discussion of dual/multi-microphone technology is only theoretical. In the case of a dual microphone system, the theoretical curves mentioned earlier can only be achieved if we imagine the hearing instrument is completely unobstructed within a free sound field. Results obtained from when wearing hearing instruments in real listening environments will of course be different. In a typical BTE for example, sound can enter the microphones with relatively little interference from one side only. On the other side is the listener's head, and this produces a shadow effect (Figure 3). The net effect of diffraction caused by the head shadow is less severe for low frequencies and increases in higher frequencies. The result is that, in practice, directivity is generally poorer for lower frequencies.

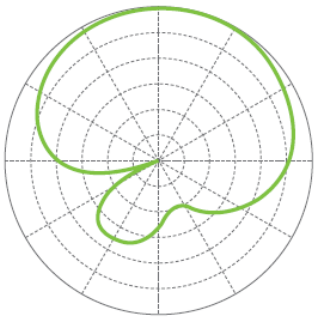

Fig. 3: Measured directional head characteristics showing the head shadow effects.

Developments with ZoomControl

The development of ZoomControl in Phonak hearing instruments represented the next stage in multi-microphone systems. For the first time ever, a hearing instrument wearer could choose to focus hearing in a direction other than the

front. ZoomControl applies the principles of dual microphones already discussed, but with the ability to focus to the back as well as the front. Where a beam to the right or the left is required in a dual microphone system, the arrangement of the microphones needs to be altered, placing them in parallel instead of in series (Figure 4). This is theoretically possible with a binaural fitting, because the front and rear microphones of two instruments together could achieve this arrangement. All that remains is to link the microphones to each other which can be accomplished using wireless radio technology, for example, in a HIBAN (Hearing Instrument Body Area Network) system, for example. If the beam is to be oriented to the right, the forward right-hand microphone could take over the role of the front microphone, and the left-hand microphone could take on the role of the rear microphone. It is not quite so simple because in practice, the presence of the head shadow effect can mean that there is no suitable signal on the opposite side which would help in the differentiation process. With ZoomControl, a slightly different approach was taken to achieve an effective focus to the side.

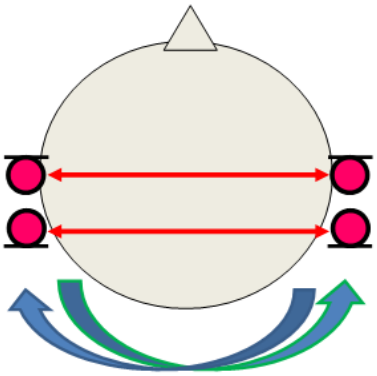

Fig. 4: Microphones placed in parallel

If the user decides to use ZoomControl and direct his focus to the right, several events occur simultaneously. The sensitivity of the left microphone is attenuated so that it does not pick up signals from the left, while the right hearing instrument adopts a setting which ensures the best possible signal reception from the right. The signals from the right hearing instrument are transmitted wirelessly and in real time to the left hearing instrument where they are amplified with the gain model of the left hearing instrument. As a result, the enduser hears the signal optimized for signals from the right amplified at appropriate levels in both ears. The effect is remarkable: the enduser experiences a directional focus just as he would with a regular beamformer, but it is oriented to the chosen side.

ZoomControl is an independent program which is activated via the onboard program button or remote control. Until now, the enduser had to select the focus direction and manually alter it if the situation changed. In the Spice Generation, this unique Phonak innovation has become even more advanced. Now, when the listener wishes to focus in a direction other than the front, he needs only to select the auto ZoomControl program. From there, the hearing instruments select the direction of the dominant speech signal and automatically adjust the focus direction if and when the signal source direction changes.

Microphone arrays

Complex microphone setups using numerous microphones are in widespread practical use. Along with modern computer technology these microphone arrays make it possible to detect and track virtually any moving sound source with precision. Although an array of this type is not feasible in hearing instruments the opportunities it offers interest both hearing professionals and technology developers. A simple arrangement with which a person could acoustically "see" in any direction is shown in Figure 5. Connecting the single microphones (M1 – M4) in a suitable manner provides directions Z1 – Z4. If microphones M2 – M4 are connected to a "virtual" microphone M5, direction Z5 is also possible. It is easy to see that this arrangement of microphones is able to focus in any direction. Unfortunately size and space limitations prevent this from being used in hearing instruments.

Nevertheless, these ideas form the basis for the development of an improved beamformer in a hearing instrument. The fact is that when both ears are fitted with hearing instruments, there are four microphones present, so why not use them to develop a directional characteristic that is an improvement over current systems?

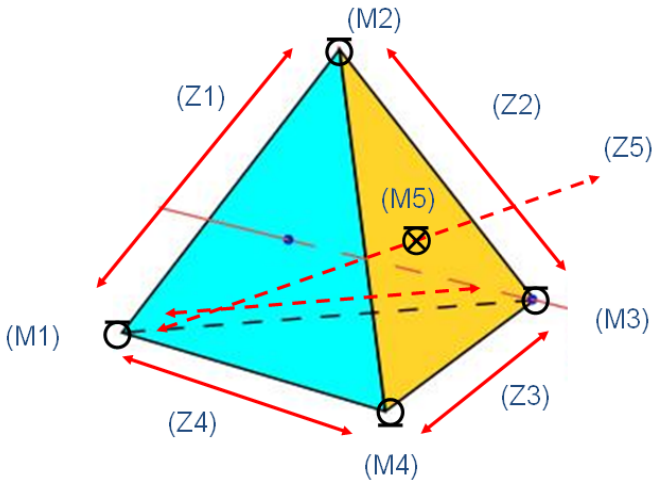

Fig. 5: A theoretical arrangement of microphones (m) forming an array which allows precise focus in any direction (z).

StereoZoom– the new microphone array linked by wireless technology

In hearing instruments, a three-dimensional arrangement of the microphones is not as important, because most significant sound events happen in the plane around us. It is therefore possible to employ the long-proven arrangement of microphones in hearing instruments which allows signal level directional characteristics to be created. The fundamental idea behind the new StereoZoom system developed by Phonak is the desire to make use of the formation of the beam. This is accomplished by linking the microphones of each hearing

instrument, via wireless technology, in other words, the dual microphone system on one side is linked to the dual microphone system on the other side. In practice, this allows for a new beam pattern to be created that is "sharper" than before and which also offers an even better SNR. The beamforming process in the lower frequencies is improved even further by the increased spacing between the microphones. At the same time, the null settings of the beam can be moved much further to the front, which produces a very narrow beam and the potential for a more favorable SNR. Figure 6 shows this condition as it works in a speech in noise situation. With a conventional beamforming system, all three of the individuals (represented by the mouth icons) in the general area in front of the listener would be amplified equally. But if the listener wanted to hear only one of these three speakers, the other two could cause interference if they were talking among themselves. With StereoZoom, it is now possible to narrow the beam focus to just one individual, with the result that the listener is now able to concentrate fully on that conversation.

Fig. 6: Monaural directional microphones have a broad forward focus (grey beam) StereoZoom creates a highly focused beam (green) to the front to focus on a single voice in a crowd.

Program placement

More than five years of field testing conducted during the development of StereoZoom, showed that it makes little sense to integrate StereoZoom in the automatic mode of a hearing instrument. The effect of the very narrow directional beam provided by StereoZoom is only appropriate for very specific listening situations where a listener wishes to focus on only one speaker in the presence of competing noise. As a result, StereoZoom is available as an independent program which can be activated by the enduser when required, either via the push button on the hearing instruments or by remote control. It is intended for use in complex, difficult listening environments where conventional directional microphone systems do not provide sufficient benefit.

New chip technology

Binaural beamforming with StereoZoom is only made possible due to sophisticated processing technology and the capacity to stream the full audio signal between hearing instruments in real time. This unique wireless functionality and processing capacity is provided by the newest audio-processing chip, and StereoZoom is available in all the premium wireless hearing instruments of the Phonak Spice Generation.

Summary

Phonak continues the leadership position in the area of directional microphone technology. With StereoZoom, another significant milestone in the development of beamforming technology has been achieved which goes far beyond the conventional directional microphone technology available in most hearing instruments. The objective was to construct a microphone array that not only uses the two microphones on each hearing instrument independently but that creates a network of microphones from both instruments in a binaural fitting. This allows new and narrower beam patterns to be created and applied to specific, challenging listening environments. By wirelessly linking the hearing instruments and exchanging audio signals in real time, it is now possible to narrow the focus to one particular individual, reducing interfering noise coming not only from the back and sides but now, for the first time, from near the front as well.

This new era of binaural beamforming is possible due to the astonishing capacity of the new Spice chip platform, which offers far superior performance compared to existing platforms. StereoZoom is an independent program activated by the enduser when required, either via the push button on the hearing instrument or by using the remote control. It offers improved forward directivity, and thus a noticeable improvement in SNR in unusually challenging situations which, until now, were not manageable for wearers of hearing instruments.