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by Brian Csermak
Applications Engineer
Gennum Corporation

A Primer on a Dual Microphone Directional System

There are four basic approaches to building a directional hearing instrument system: 1) One directional microphone; 2) One directional plus one omnidirectional microphone; 3) Two omnidirectional microphones, and 4) A microphone array. Although the first approach has the advantage of being the simplest and smallest, it should not be considered unless some form of mechanical switch is involved allowing for an omnidirectional mode. In fact, one of the main reasons directional microphones failed to gain widespread popularity in the past was the lack of an omnidirectional mode. Microphone arrays are extremely directional systems that can achieve an improvement in the *signal-to-noise-ratio* (SNR) by as much as 12 dB.[1] However, these systems are only possible in a neck-worn apparatus, eyeglass frames or some form of pointer. As a result, most hearing-impaired individuals will usually not consider this as a viable option.

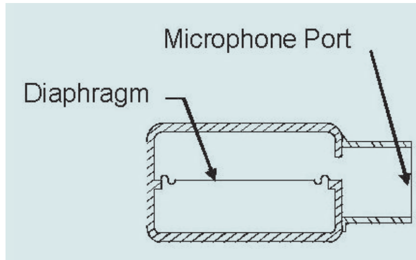

Fig. 1. *Omnidirectional mic function. (Figs. 1 & 2 adapted from Thompson.[1])*

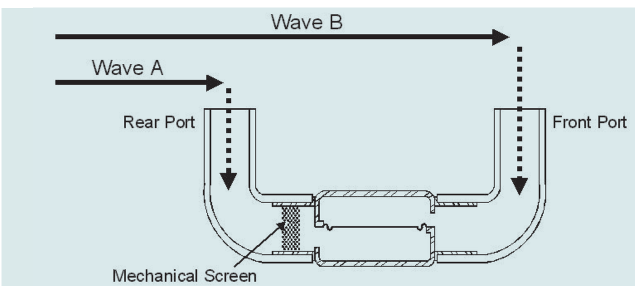

Fig. 2. *A traveling wave and its interaction with a directional microphone.*

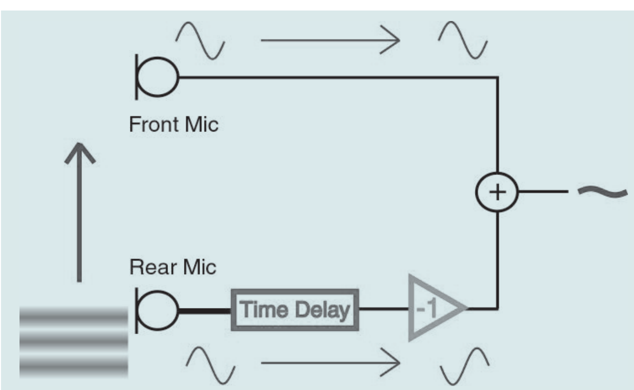

Fig. 3. *Interaction of two omnidirectional mics with a sound wave.*

This leaves the two most common approaches: omni-plus-directional (a term coined by Steve Thompson[2]) and dual microphone systems. The omni-plus-directional approach involves using one omnidirectional microphone and one directional microphone along with some form of switching mechanism that effectively turns one on and the other off. Therefore, at any given time, only one microphone is in operation. The dual microphone approach uses some form of electronic circuit which processes the outputs from two omnidirectional microphones to obtain both an omnidirectional pattern as well as any number of directional patterns. Although, as Thompson has stated, both approaches can achieve exceptional directional results, the dual-microphone approach offers a number of distinct advantages which will be detailed in this article.

This article was submitted by Brian Csermak, applications engineer for Gennum Corp. Correspondence can be addressed to HR or Brian Csermak, Gennum Corp., P.O. Box 489, Sta. A, Burlington, Ontario, Canada L7R 3Y3; e-mail: brian_c@gennum.com.

Directional Microphones

Fig. 1 shows a typical omnidirectional microphone. Sound entering the port causes pressure changes inside the microphone's front chamber. These pressure changes cause the diaphragm to vibrate, which in turn produces an electrical analog signal at the output of the microphone. This signal is then processed by an electronic circuit.

Given that no electronic circuit available today (be it analog or digital) can completely extract speech from background babble[1,3,4], how can we help people hear better in noise? The solution is to keep the noise from getting into the circuit in the first place. One way to do this is with directional microphones.

The operation of a directional microphone is quite simple (Fig. 2). A travelling sound wave originating from directly behind the hearing instrument wearer will reach the rear port of the directional microphone first. A portion of that wave (Wave A) enters the rear port and encounters a mechanical screen that effectively slows down or delays this sound wave. Meanwhile, X seconds later, another portion of the travelling sound wave (Wave B) will reach the front port where it enters the front half of the microphone chamber unimpeded. If the mechanical screen is designed such that it delays Wave A by X seconds, then it will enter the rear half of the microphone chamber at the same time that Wave B enters the front chamber. Since both Wave A and Wave B should simultaneously cause very similar pressure changes in their respective chambers but on opposite sides of the diaphragm, no pressure differential will exist across the diaphragm. Therefore, it will not vibrate and no electrical signal will be produced. Hence, the directional microphone has effectively cancelled the sound wave from the rear and prevented it from entering the circuit.

The effect of a directional microphone can be replicated with two omnidirectional microphones (Fig. 3). Whereas in a directional microphone a mechanical screen is used to delay the sound entering the rear port of the microphone, in this case an electronic filter is used to delay the electrical signal that is produced by the sound entering the rear microphone. Again, if the electronic delay is set to X seconds (the same amount of time it takes sound to travel from the rear mic to the front mic), then the two signals will arrive at point "+" at the same time; they can be subtracted from each other and therefore cancelled.

In both cases, the internal delay element was set to be equal to the time it takes the sound coming from the rear to

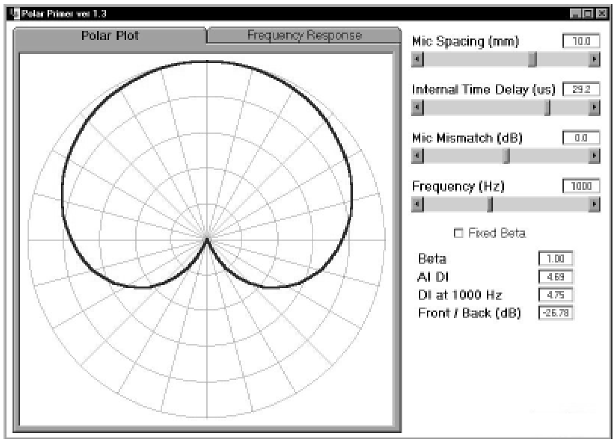

Fig. 4. *A cardioid response derived when beta is equal to unity. (See author's note.)*

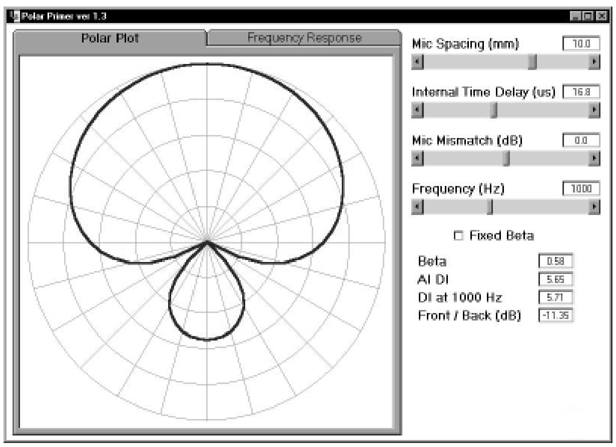

Fig. 5. *Supercardioid pattern, reducing sound from the directions of 125° and 235°, derived from a beta equal to 0.58.*

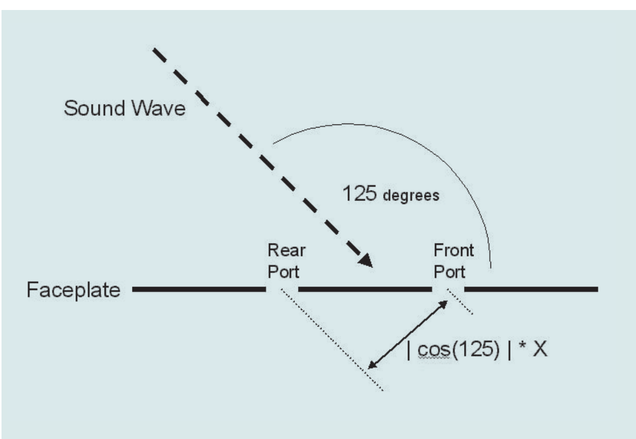

Fig. 6. *A dual microphone faceplate and a sound wave being received from a direction of 125°.*

travel the distance between the two microphone ports (usually referred to as the *external time delay*). The ratio of these two components, the internal time delay divided by the external time delay, is known as *Beta*. In this case, beta equals 1 (X/X = 1). This yields the cardioid response (named for its heart-like shape) shown in Figure 4. *(Author's Note: Fig. 4 displays a screen shot of a free educational software tool called the Polar Primer. This tool can be downloaded at http://frontwave.gennum.com. The Polar Primer allows the user to vary the different elements of a directional system to see its effect on the directional pattern and frequency response.)*

If either element of this ratio is changed, a *different* directional response is produced. Fig. 5 shows what is known as a supercardioid pattern. In this case, sounds originating from directly behind the microphone system are no longer completely cancelled. Instead, sounds arriving from 125° and 235° are reduced the most. Why is this? The answer is because Beta is now equal to 0.58. This means that the *internal* time delay is *0.58 times smaller* than the *external* time delay.

Why does it cancel the sounds arriving from 125° and 235°? Because for sounds arriving from these directions, it only takes 0.58 x X to travel between the two ports. This point can be illustrated better by using some trigonometry and a standard calculator. Fig. 6 shows the faceplate of a dual-microphone hearing instrument and a sound wave arriving from 125°. If the cosine of 125° is utilized, the effective distance that sound coming from this angle travels on its way from the rear mic port to the front mic port can be determined. In this case, it is the *cos(125) x X = 0.58 x X*. Similarly, sound arriving from different angles "see" a different effective microphone port separation. By changing the ratio (beta), the null (the point of greatest sound cancellation) can be "tuned" to any angle between 90° and 270°.

In summary, the directional pattern produced by a directional system is mainly determined by two elements: the distance between the two microphone ports and the internal time delay—the ratio of which is known as Beta.

Advantages of a Dual-Microphone System

• *Flexibility*: In a directional microphone, Beta is fixed by the manufacturer of the microphone. Therefore, only one directional response is achievable. In a dual omnidirectional microphone system, both the port spacing and the internal time delay can be configured by the hearing instrument manufacturer on an individual basis. In fact, in a multi-memory multi-microphone programmable system, such as FRONTWAVE™ from Gennum Corp., different time delays can be programmed into each memory providing the user up to four different directional patterns. This gives wearers the option of switching between directional patterns to the one that gives them the greatest advantage for the particular environment. Of course, one of these memories should always be configured to omnidirectional, as there will be many situations where this will be the best choice.

• *Low-Noise Omnidirectional Mode*: A common complaint of hearing instrument wearers is that they sometimes hear a hiss in quiet environments. This is "circuit noise." In most well-designed hearing instruments, the microphone is the dominant source of this noise. This noise is always less in omnidirectional mode than in directional mode, however, it can still be quite bothersome to some wearers.

A dual microphone system is designed to improve this situation. If the same signal (such as speech) is presented to two omnidirectional microphones, that signal will increase by 6 dB when the outputs of the two microphones are added together. However, since the noise generated by each individual microphone is random and uncorrelated, when it is added together, it only increases by 3 dB at the output. Therefore, a net increase in the SNR of 3 dB is realized. However, if the output of the two microphones is attenuated or reduced by 6 dB to bring the system back to unity gain, a reduction of 3 dB in the microphone noise is realized. A reduction of this magnitude is audible to practically all hearing instrument wearers and should improve comfort and satisfaction in quiet listening conditions.

The flip side of using two microphones is that the internal microphone noise is actually louder by 3 dB (possibly as much as 4.5 dB) in directional mode.[2] However, since the wearer should only be using the directional mode in noisy environments, the environmental noise in these situations will

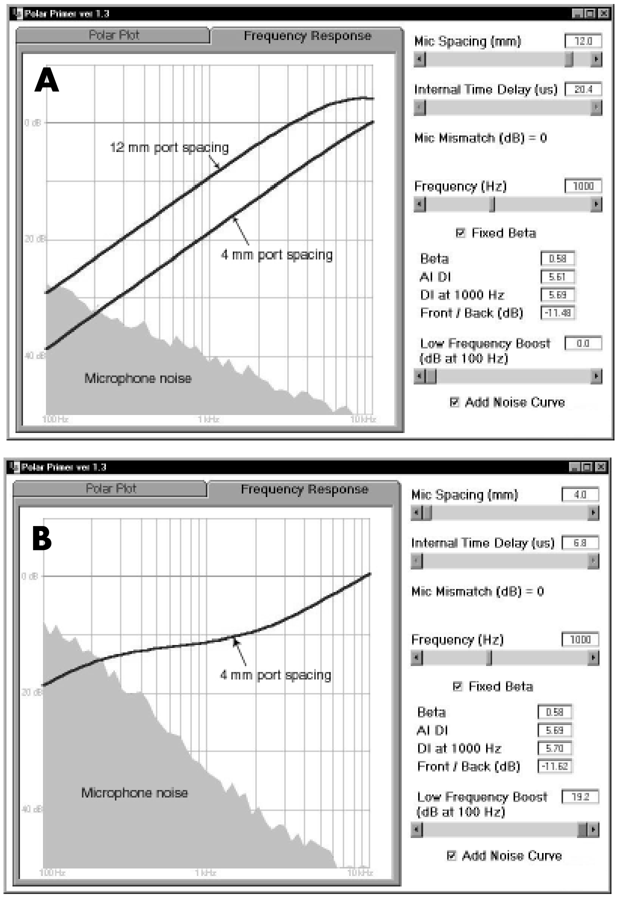

Fig. 7a & b. *(Top) Frequency response of two different systems with different port spacing. (Bottom) Frequency response of a 4 mm port spacing system when 20 dB of gain is applied at 100 Hz.*

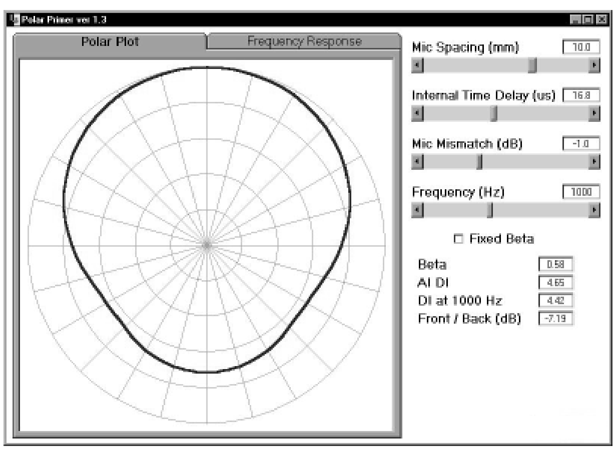

Fig. 8. *Effect of a 1 dB mismatch in microphones in a dual microphone system.*

most certainly dominate any circuit noise so that this becomes a non-issue.

• *Low Frequency Roll-off*: All directional systems, regardless of implementation, suffer the same undesirable side effect of rolling off the low frequencies. (The physics behind this effect are complex and beyond the scope of this article.) This loss of sensitivity in the low frequencies is worse for smaller microphone port separations. Fig. 7a shows the frequency response of two different systems, one with a port spacing of 4 mm and one with a spacing of 12 mm. A comparison of the two responses shows almost 10 dB less sensitivity at 500 Hz for the smaller port spacing, significantly reducing the signal-to-noise ratio.

In some situations (and for some types of hearing losses), this roll-off may be desirable. One example is in an environment where there is a lot of interfering low-frequency energy such as fan noise. However, if the wearer already has a significant low-frequency hearing loss, then reducing the lows even further is undesirable. Of course, gain can always be added to this low frequency region to bring the system back to a flat or equalized response. Unfortunately, this has a problem of its own. Fig. 7b shows the frequency response of the system with a 4 mm port spacing when 20 dB of gain has been applied at 100 Hz. While the applied gain has successfully boosted the sensitivity to the low frequency region, it has also amplified the internal microphone noise. Therefore, the SNR has not improved. This noise, although likely not audible in noisy environments, will definitely become objectionable if the user remains in directional mode in a quiet environment. This is another reason why it is crucial that a directional hearing instrument includes an option to switch to omnidirectional mode.

An advantage of a dual microphone system is that it makes it easier for the hearing instrument manufacturer to space the microphone ports further apart, thereby lessening the amount of low frequency roll-off. It also avoids the need for extension tubing which can affect frequency response.

• *Microphone Mismatch*: In a dual microphone system, it is critical that both microphones be matched in sensitivity and phase. Fig. 8 shows the effect of a 1 dB mismatch in the sensitivities of the two microphones on the supercardioid pattern from Fig. 5. It is apparent that a significant degradation of the directional pattern has occurred. Manufacturers need to ensure that they trim out any sensitivity differences in the microphones in the process of assembling each individual hearing instrument. The FRONTWAVE™ system and its software component is designed to automatically trim out microphone sensitivity mismatches typically to within 0.02 dB.

There has been much discussion about the possibility of "microphone drift"—microphone characteristics changing over time creating a mismatch and degrading directional performance. However, if microphone pairs are used from the same production batch, it is likely that their characteristics will drift together and not apart. Regardless, no evidence to date has been produced which suggests that any drift that might occur is significant enough to have a noticeable effect. Research continues in this area.

• *Cosmetics:* A few years ago, directional hearing instruments (particularly dual microphone systems) were generally only available in BTEs. This was a significant barrier for many users who would only wear the more cosmetically appealing smaller shell models. In the past few years, the benefits of using directional microphone technology in ITEs became evident.[5] There are now available a wide variety of ITE models sporting both omni-plus-directional and dual microphone systems. In fact, one manufacturer has recently launched a dual microphone directional instrument (using the Gennum system) in a mini-canal. Since the dual microphone approach allows the manufacturer a great deal of flexibility in microphone placement, it is somewhat easier to fit them into the smaller shell sizes. They also have the added advantage of one less microphone port than the omni-plus-directional system, resulting in a more cosmetically appealing instrument. ◆

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This article was submitted by Brian Csermak, applications engineer for Gennum Corp. Correspondence can be addressed to HR *or Brian Csermak, Gennum Corp., P.O. Box 489, Sta. A, Burlington, Ontario, Canada L7R 3Y3; e-mail: brian_c@gennum.com.*