An overview of directional options in Beltone hearing aids

Now including CrossLink Directionality 4 and Ultra Focus 2

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Beltone™

INTRODUCTION

Directional microphones in hearing aids were once a single component that provided an unchanging response. As technology advanced, users could manually select the directional response. Today's digital hearing aids provide much greater sophistication, both in the sound processing as well as in the way the directional response is automatically activated. This paper describes the many directional fitting options that Beltone offers across the product portfolio.

Directional microphones in hearing aids remain the only proven technology that improves speech recognition in noise[1-4] with evidence reaching back to the 1970s.[5] The principle on which this key benefit is based is the improvement in signal-to-noise ratio (SNR) for sound coming from a particular direction, usually in front of the user. Directional technology in hearing aids has evolved dramatically throughout the decades, while still preserving this fundamental benefit. There have been major technical advances that have optimised SNR improvement, improved sound quality, increased usability, and helped to make the technology more beneficial in everyday environments. As a result, Beltone offers a plethora of directional features and options in our product portfolio. This paper provides an overview of directional options available in Beltone hearing aids.

Because this paper is intended to be used as a reference, the directional options are organised and discussed according to their purpose. The directional options cover three broad categories, as shown in Figure 1. One category contains the set of holistic features which control the directional modes. These features follow a rationale to automatically apply different settings such that user benefit is optimised in everyday situations. They make it easier for users to benefit from the advanced technologies without needing to understand how they work. In simple terms, these represent the "how" that describes the way different modes are applied. Another category includes the actual directional modes, the sound processing strategies that create the directional response and result in an improved SNR for the hearing aid user. Each of these is the "what" that can be automatically controlled by the "how" features. The third category covers features that help in reducing or eliminating drawbacks of conventional directional processing (i.e. low frequency roll-off and compensation,[6] increased wind noise,[7,8] and poorer localisation[9]). These are the "facilitation" features that help users enjoy the benefits of directionality without having the distracting downsides.

AUTOMATIC CONTROL FOR EASE OF USE

In everyday life, people naturally and subconsciously use different listening strategies depending on the characteristics of the environment and what their intentions and goals are in the given situation. Because the way a person listens is different depending on the situation and their listening goals, hearing aid technology should be designed to support different ways of listening rather than imposing rigid schemes. Although directional microphones can improve hearing in noise, they can also interfere with listening when desired sounds are moving or not directly in front of the user. Beltone continually refines its approach to using directional technology in a way that considers how a listener will experience it in real-life. A hearing aid



AUTOMATIC CONTROL FOR EASE OF USE

- CrossLink Directionality 4
- CrossLink Directionality 3
- CrossLink Directionality 2
- CrossLink Directionality with Personal Sound ID
- CrossLink Directionality
- Spatial Directionality
- Speech Spotter Pro

IMPROVED SNR

- Ultra Focus 2
- Ultra Focus
- Weighted binaural beamformer
- Smart Beam
- Adaptive Directionality
- Fixed Hypercardioid

SOUND QUALITY AND SPATIAL HEARING

- M&RIE
- Personal Sound ID
- Band-Split Directionality

Figure 1. Beltone directional options can be organised into three broad categories according to their purpose.

user is not just the sum of their two ears. A person's ears work within the framework of the entire auditory system. Therefore, the entire human auditory system is considered in the design, from the acoustic effects of the shape and location of the external ears on the head to the power of binaural processing by the brain. The goal is for a hearing aid user to effortlessly engage in auditory social behaviors in the same way as a normal hearing individual, and thereby have a natural and transparent hearing experience.

Beltone developed an approach to automatically applying directionality based on binaural hearing that supports natural listening strategies. It uses analysis of the acoustic environment to steer bilaterally fit hearing aids among three different listening modes with the most optimum settings to support different listening strategies that people naturally use. We call these modes Spatial Cue Preservation, Binaural Listening, and Speech Intelligibility.

- The Spatial Cue Preservation mode emphasizes naturalness and overall sound quality. Although directional microphones help hearing in noise by improving SNR for speech in front of the user, they may not be preferred in less complex environments. This mode aims to provide the best and most enjoyable listening conditions in environments that are relatively quiet or with few overlapping sound sources.

- The Binaural Listening mode is based on the observation that a listener can take advantage of the location of the ears on each side of the head to either enhance or suppress sounds in the environment at will. When the environment is moderately complex, the listener shifts away from relying primarily on spatial cues, relying instead on the ear that has the best representation of the desired sound – the "better ear".

- The Speech Intelligibility mode is activated in complex listening environments where individual talkers blend into the mix of background sound. In that type of environment, it is likely that a listener would employ a listening strategy where they face a conversation partner to maximise visual cues as well as the audibility of the person's voice.

Support for these listening modes is the strategy Beltone has followed for more than a decade. Each successive generation has enhanced how well this could be done as new technologies became available. Table 1 provides an overview of how the strategy has evolved.

Feature	Introduced	Uses ear-to-ear communication	Spatial Cue Preservation	Binaural Listening	Speech Intelligibility
Spatial Directionality	Beltone True™ (2010)	No	N/A	Focus ear: Directional Monitor ear: Omnidirectional	N/A
CrossLink Directionality	Beltone Promise™ (2012)	**Yes**	Omnidirectional	Focus ear: Directional Monitor ear: Omnidirectional	**Bilateral directional**
CrossLink Directionality with Personal Sound ID	Beltone Legend™ (2015)	Yes	**Personal Sound ID**	Focus ear: Directional Monitor ear: Omnidirectional	Bilateral Directional
CrossLink Directionality 2	Beltone Trust™ (2017)	Yes	Personal Sound ID	Focus ear: Directional Monitor ear: **Enhanced omnidirectional**	Bilateral Directional
CrossLink Directionality 2	Beltone Amaze™ (2018)	Yes	**Personal Sound ID***	Focus ear: Directional Monitor ear: Enhanced omnidirectional	Bilateral Directional
CrossLink Directionality 3	Beltone Imagine™ (2020)	Yes	**M&RIE** or Personal Sound ID**	Focus ear: **Weighted binaural beamformer** Monitor ear: Enhanced omnidirectional	**Weighted binaural beamformer**
CrossLink Directionality 4	Beltone Achieve™ (2022) Beltone Serene™ (2023)	Yes	M&RIE or Personal Sound ID**	Focus ear: Weighted binaural beamformer Monitor ear: **True omnidirectional with ear-to-ear streaming**	**High resolution weighted binaural beamformer**

*Binaural Compression performance was improved
**Depending on receiver

Table 1. Overview of how the Beltone binaural hearing strategy for applying directional technology has evolved. The bolded text indicates the improvements for each successive generation.

CrossLink Directionality 4

Role

Adjusts hearing aid microphone patterns according to a binaural hearing strategy and based on acoustic analysis of the environment.

Benefit

Better hearing with less effort in all daily life situations.

Details

CrossLink Directionality 4 is the most advanced version of the Beltone strategy for controlling directionality. Compared to previous versions, the improvements included in CrossLink Directionality 4 include further improved SNR with a higher resolution weighted binaural beamformer, and streaming of sound from the directional to the omnidirectional side when in Binaural Listening mode.

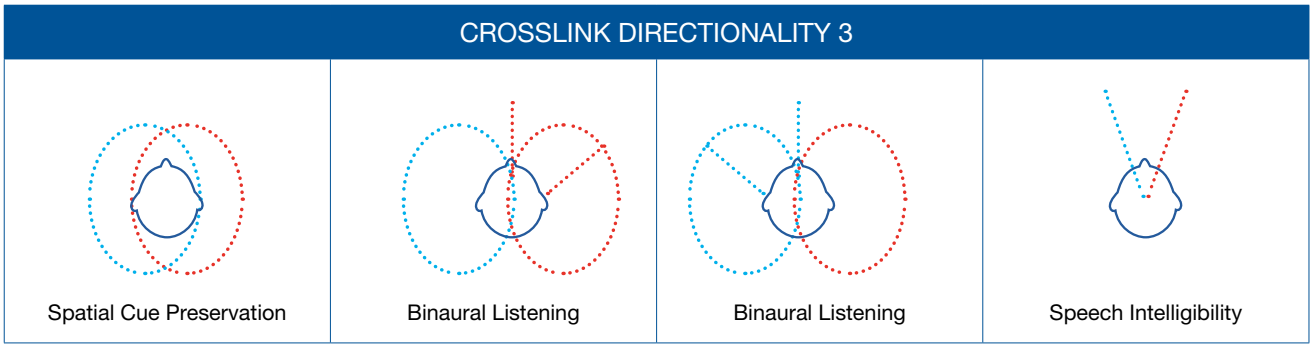


Figure 2. Three different listening modes are automatically applied to support the listening strategies that people naturally use in different types of environments. Ear-to-ear data exchange and a binaural connection enable this advanced processing.

How to use it

CrossLink Directionality 4 is the default program in some premium hearing aids, such as the Beltone Achieve and Beltone Serene.

Further reading on CrossLink Directionality 4 and CrossLink Directionality 3

Empowering hearing aid users with directionality designed for the real world

Enhanced directional strategy with new binaural beamformer leads to vastly improved speech recognition in noise

The evolution of the Beltone binaural hearing strategy: CrossLink Directionality 3 and Ultra Focus

Further reading on CrossLink Directionality with Personal Sound ID

CrossLink Directionality with Personal Sound ID

Effect of directionality strategy on the audibility of sounds in the environment for varying hearing loss severity

Further reading on CrossLink Directionality

CrossLink Directionality: Facilitating true binaural auditory processing

Proven benefits of Beltone CrossLink Directionality

Further reading on Spatial Directionality

Spatial Directionality brings Beltone Rely users the great hearing they deserve

Speech Spotter

Role

Smoothly switches between omnidirectional and directional mode depending on the sound environment.

Benefit

Can provide directional benefit in noisy situations without the user needing to switch programs. Does not require a binaural fit so a user who wears only one hearing aid can benefit.

Details

Speech Spotter is the most basic way of automatically controlling directionality. Depending on the specific product, it activates Adaptive Directionality, Smart Beam with selectable beamwidth, or Smart Beam Steering whenever there is noise present and speech detected in front of the user. For devices with ear-to-ear communication, Speech Spotter can be synchronised such that both hearing aids always switch at the same time. Speech Spotter has slow transition times to ensure that the switching between the omnidirectional and directional modes is not distracting for the user.

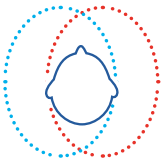
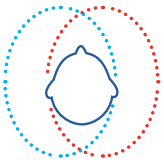
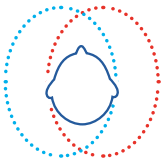
SPEECH SPOTTER MICROPHONE MODES					
Signal in front	Speech	Speech	Speech	Noise	Noise
Signal behind	Quiet	Speech Babble	Noise	Noise	Speech
MICROPHONE RESPONSE	 Omni	 Directional	 Directional	 Omni	 Omni

Figure 3. Speech Spotter follows a conventional approach for automatically controlling directional microphones.

OPTIONS THAT IMPROVE SNR

Weighted binaural beamformer with spatial cue preservation

Role

Improves SNR for sound in front of the user while preserving important localisation cues. Enhances the speech on the less noisy side in environments where the noise surrounding the user is not equal.

Benefit

Strikes a balance between maximizing SNR for speech in front of the user, preserving access to off-axis sound, and preserving spatial hearing cues to allow re-orienting to new or moving target speech.

Details

The weighted binaural beamformer uses the four microphones on bilaterally fitted hearing aids to form a narrow directional beam. Compared to other Beltone directional features that improve SNR, the binaural beamformer has the potential to increase articulation index-weighted directivity index (AI-DI)[10] by approximately 2 dB. The weighting of the signal from the side with the least noise provides better performance in environments where the noise background is not the same on both sides of the user. Figure 4 shows how binaural beamforming is limited to the mid frequency region to preserve some spatial hearing cues and sound quality.

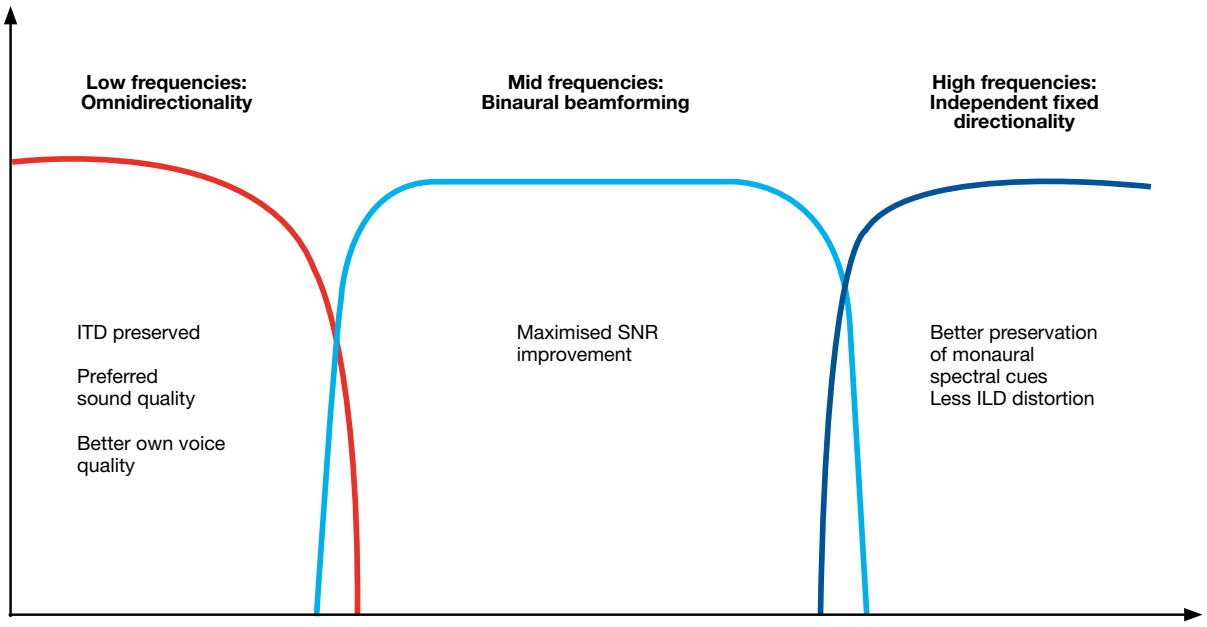


Figure 4. The Beltone binaural beamformer applies strong directionality in the mid-frequency range, while preserving spatial hearing cues in the low and high frequency bands.

How to use it

The weighted binaural beamformer is automatically incorporated in CrossLink Directionality 4 and CrossLink Directionality 3. In addition, the user selectable Ultra Focus 2 and Ultra Focus features are based on this technology.

Further reading

The evolution of the Beltone binaural hearing strategy: CrossLink Directionality 3 and Ultra Focus

Ultra Focus and Ultra Focus 2

Role

Maximise speech understanding in noise.

Benefit

Gives the user a selectable option to override automatic control of microphone modes to get the best improvement in directional benefit for speech in front.

Details

Both Ultra Focus and Ultra Focus 2 use the weighted binaural beamformer with a low Mixing Point Frequency setting to provide the best possible SNR for speech in front. Other advanced features are also customised to preserve the clarity of the sound. Ultra Focus 2 uses an improved, higher resolution weighted binaural beamformer that gives a 4.3 dB improvment in SNR compared to the technology used in Ultra Focus.

How to use it

Ultra Focus 2 and Ultra Focus can be assigned as a dedicated listening program. They are the default directional setting in the “Hear in Noise” program. Users can easily activate it via the on-board pushbutton, a remote control, or the Beltone HearMax app when they are in a situation where they only want to focus on what is in front of them.

Further reading

The evolution of the Beltone binaural hearing strategy: CrossLink Directionality 3 and Ultra Focus

Enhanced directional strategy with new binaural beamformer leads to vastly improved speech recognition in noise

Smart Beam with Selectable Beamwidth, Smart Beam Steering and Adaptive Directionality

Role

Improves SNR for speech in front of the user. Adjusts polar pattern shapes to cancel noise most effectively in the rear plane.

Benefit

Improves speech understanding in dynamic, noisy situations.

Details

The adaptive directional features are multiband, meaning that they apply different polar patterns depending on frequency. As an example of how this could be helpful, the adaptive directional features can adjust to effectively reduce the buzz of a group conversation occurring in the background while at the same time reducing the clatter of dishes and cutlery off to one side.

In addition to adaptation for sound coming from the rear plane, Smart Beam Steering and Smart Beam with Selectable Beamwidth offer adjustments of the focus to the front, called “beamwidth”. Smart Beam Steering adjusts beamwidth as the intensity of speech in front of the user increases. Smart Beam with Selectable Beamwidth offers three beamwidth settings, Narrow, Medium and Wide. Adaptive Directionality sets the beamwidth to Medium.

How to use it

Depending on technology level, one of these three adaptive directional features will be default in the Hear in Noise program. They are well-suited to any environment where the user will want to listen solely to speech coming from the front.

Further reading

Beltone Technology White Paper Series: 2010

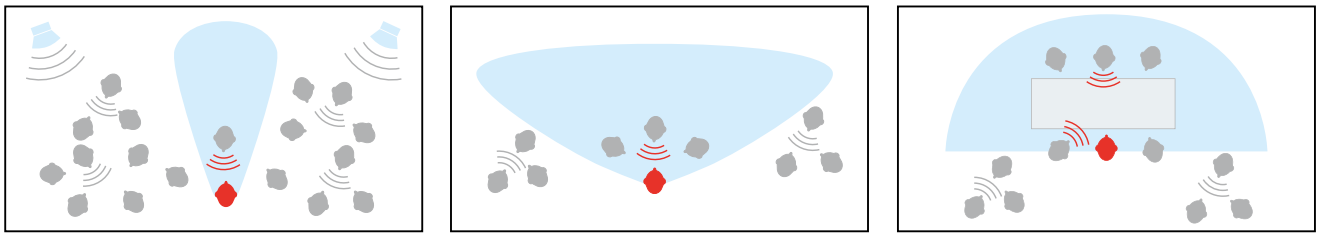


Figure 5. These illustrations show conceptually how different beamwidths may help improve listening in different types of noisy backgrounds. When listening to one person directly in front, a narrow focus is desirable (left panel). As the number and location of the participants in the conversation increases (middle and right panels), a wider beamwidth may be optimal. Smart Beam Steering continually adapts the beamwidth according to the intensity of the speech directly in front. Smart Beam with selectable beamwidth offers three beamwidth settings.

Fixed Hypercardioid

Role

Improves SNR for speech in front of the user.

Benefit

Improves speech understanding in noisy situations.

Details

Directional microphone systems in Beltone digital hearing aids are dual microphone systems, where two omnidirectional microphones are positioned on the device, and digital delays are applied to one of the microphones to create the desired spatial directivity patterns. Fixed Hypercardioid uses the dual microphones on the hearing aid to create a static hypercardioid response. This type of response would be observed with a traditional directional microphone with two sound ports. A key difference is that a prescribed Mixing Point Frequency is also applied to balance sound quality and directional benefit. Fixed Hypercardioid is the simplest directional option in that the directional characteristics do not adapt to different noise environments.

How to use it

Fixed Hypercardioid may be a default setting in some lower technology products. It is an available option at all technology levels. Because of its invariant directional characteristics, it is well-suited for verification measurements of directionality in the test box or real ear.

SOUND QUALITY AND SPATIAL HEARING OPTIONS

M&RIE

Role

Places a microphone in the receiver module for receiver-in-ear devices to take advantage of the user's unique ear shape to filter and collect sound in the most natural location.

Benefit

An immersive an individualised hearing experience with greater depth and direction, sense of space and localisation.

Details

M&RIE, which means "Microphone-and-receiver-in-ear", is technically not a directional microphone. However, it preserves the natural directional hearing that occurs due to the acoustic effects of the outer ear, head and body. M&RIE can be used with compatible Receiver-in-Ear (RIE) hearing aids from Beltone. It is integrated in the CrossLink Directionality 4 and the CrossLink Directionality 3 programs, where it is active in quiet and moderately complex listening environments. M&RIE can also be selected for a customised listening program. Because the microphone location in the ear canal provides some natural protection from wind noise, M&RIE is a good choice for a listening program intended for outdoor use. When M&RIE is active in a binaural fitting, binaural compression is also applied. Binaural compression aligns the gains at the two ears to best preserve natural level differences between the ears resulting from the acoustic shadow created by the head. Known as Interaural Level Difference (ILD), this is a significant high frequency cue for localisation.



Figure 6. The M&RIE is a receiver module that includes a microphone in the ear canal that helps maintain the ear's natural directional characteristics and spatial hearing cues.



Figure 7. When fit with a M&RIE receiver, the canal microphone is active by default when in CrossLink Directionality 4 or CrossLink Directionality 3. In other programs, "M&RIE" can be selected in the Advanced Features screen.

How to use it

The M&RIE is a hardware solution. When hearing aids are fit with M&RIE, the receiver is automatically recognised by the Solus Max fitting software and incorporated in CrossLink Directionality 4 or CrossLink Directionality 3. As mentioned, it can also be selected in a dedicated listening program.

Further reading

An innovative RIE with microphone in the ear lets users "hearing with their own ears"

M&RIE receiver preferred for sound quality and localisation

Beltone Imagine with M&RIE reduces listening effort

Less wind noise with M&RIE leads to better sound quality

Localization with M&RIE improves with experience

Personal Sound ID

Role

Emulates spatial hearing cues normally provided by the natural sound filtering of the outer ear that are disrupted when the hearing aid microphones are placed above the ear.

Benefit

Better localisation compared to omnidirectionality, especially for sounds in the horizontal plane, and improved sound quality.

Details

Personal Sound ID was designed to compensate for the disadvantageous location of the microphones above the ear in RIE and Behind-the-Ear (BTE) hearing aids. It uses the directional microphone system to achieve a response for sounds in the horizontal plane that is similar to the average adult ear. This type of feature is generically known as "pinna compensation" or "pinna restoration" in reference to its purpose in compensating for lost acoustic cues from the pinna. Thus, it emulates the response of an omnidirectional microphone with placement within the ear canal. As the name suggests, Personal Sound ID is automatically incorporated in CrossLink Directionality with Personal Sound ID. Furthermore, it is incorporated in CrossLink Directionality 2, as well as in CrossLink Directionality 4 and CrossLink Directionality 3 in fittings where the M&RIE receiver is not used. Personal Sound ID can also be selected as the directional setting in a dedicated program where natural sound quality is prioritised, such as a program for music listening or outdoor use. In a binaural fitting, Personal Sound ID incorporates binaural compression as described above in the section on M&RIE. In dual microphone custom hearing aids with ear-to-ear communication, the pinna compensation is not needed, but binaural compression is still applied when CrossLink Directionality with Personal Sound ID, CrossLink Directionality 3 or CrossLink Directionality 4 is selected.

How to use it

Personal Sound ID is automatically incorporated in CrossLink Directionality with Personal Sound ID, CrossLink Directionality 2, and CrossLink Directionality 3 and 4 when not using M&RIE. Like M&RIE, Personal Sound ID can be selected for a dedicated listening program.

Further reading

CrossLink Directionality with Personal Sound ID

Band-Split Directionality

Role

Splits the sound into low and high frequencies, applying directional processing only to the high band.

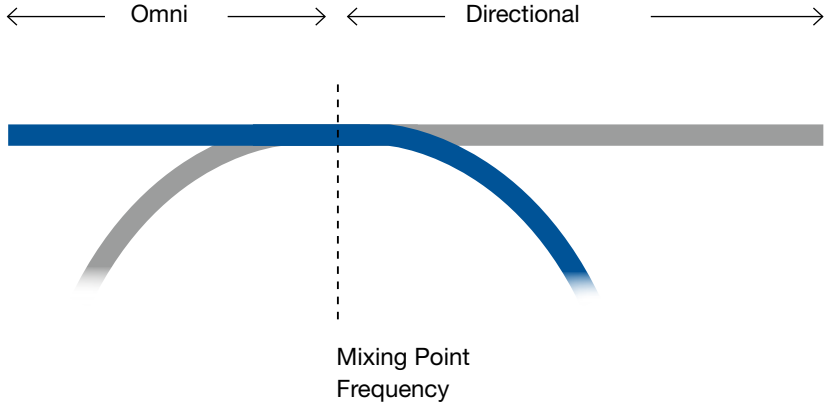


Figure 8. The Mixing Point Frequency splits the sound into 2 bands. Directionality is applied to the high band.

Benefit

Improved sound quality compared to full band directionality and preserved low frequency interaural timing differences (ITD), for improved localisation.

Details

All directional processing in Beltone hearing aids uses Band-Split Directionality. This processing minimises the impact on sound quality of the inherent low frequency roll-off associated with directional microphones, which can cause a tinny sound quality. Directional processing is carried out in the frequency region that is most important for understanding speech. This provides directional benefit to the user without affecting sound quality compared to other microphone modes. This is critical for a seamless transition when an automatic switching feature is active, such as CrossLink Directionality 4 or Speech Spotter. Sound quality and directional benefit are balanced for each individual based on low frequency hearing threshold levels and the spacing between microphones on the device. People with worse low frequency hearing are prescribed a lower Mixing Point Frequency (a lower crossover frequency between the low and high bands; see Figure 8). Devices with closer microphone spacing have higher crossover frequencies for each Mixing Point Frequency setting than those with greater spacing. This is because the relationship between microphone spacing and wavelength of the sound affects the frequency at which the inherent roll-off occurs. Closer microphone spacing results in a higher frequency for the roll-off.

In addition to balancing sound quality and directional benefit, Band-Split Directionality also preserves low frequency ITD cues, which are disrupted by full-band directionality.[9]

How to use it

The Mixing Point Frequency is automatically calculated for each individual. In some products, it is also available for fine-tuning in the Advanced Features screen of Beltone Solus Max™. Although it is rare to change this setting, the user complaints that might prompt a change are:

- Limited benefit understanding speech in noisy situations: *decrease* Mixing Point Frequency setting to lower the frequency where directional processing begins.
- Intermittent noisiness or tinny sound quality and the user is fit with a feature that automatically changes microphone modes, such as CrossLink Directionality 4 or Speech Spotter: *increase* Mixing Point Frequency setting.

Further reading:

Beltone Technology White Paper Series: 2010

Møller K, Jespersen C. The Effect of Bandsplit Directionality on Speech Recognition and Noise Perception. Hearing Review Products. 2013 Jun:8-10.

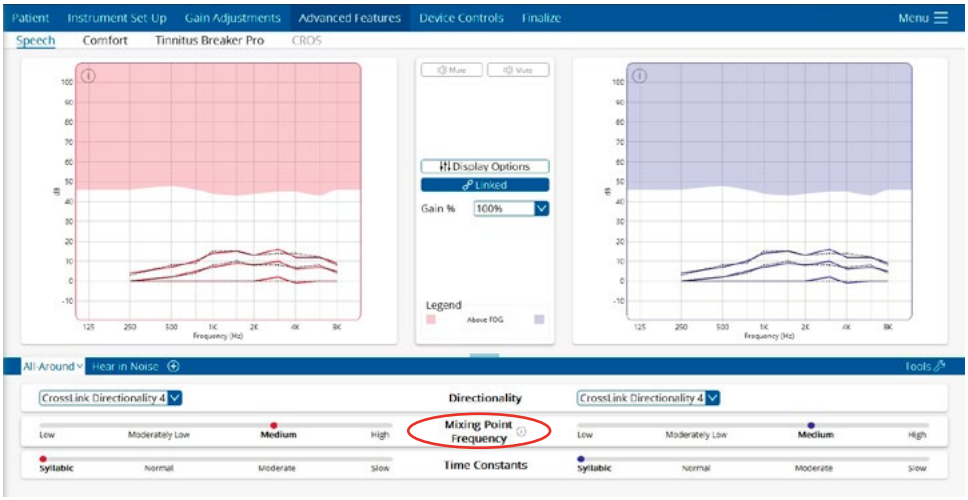


Figure 9. Some products allow adjustment of the Mixing Point Frequency in the Advanced Features screen.

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