Sonic Spotlight

Frequency Transfer – Providing Audibility For High-Frequency Losses

Through the years, hearing care professionals have become good prognosticators. With one look at the audiogram, we can nearly predict our future relationship with the patient sitting before us. For patients with thresholds up to a moderate degree of loss, we envision a relatively easy, effortless journey together, fueled by our nifty 'tool bag' of conventional hearing aid remedies. However, when thresholds climb to a severe degree of loss, especially in the high frequencies, a heightened sense of concern starts to grow within us. Rightfully so, we anticipate the steep challenges and obstacles looming ahead on the long road to amplification success. For these complex cases, Sonic aims to equip hearing care professionals with yet another simple, effective, easy-to-use tool in the amplification arsenal. Meet Frequency Transfer, and lower everything except your expectations.

How We Hear

Hearing sensitivity occurs following a long chain of intricate events. Sound waves collected from the pinna of the outer ear travel through the ear canal and strike the tympanic membrane. In response, the ossicles (malleus, incus, and stapes) behind the eardrum move to air pressure fluctuations (compression, rarefaction) and amplify the vibrations they receive. The last component of the ossicular chain, the stapes, is in direct contact with the bony, fluid-filled cochlea of the inner ear via the oval window. When sound vibrations travel through the middle ear, the footplate of the stapes pushes on the oval window and causes movement of the cochlear fluid throughout the inner ear. The basilar membrane within the cochlea reacts to the movement and, with its tonotopically arranged fibers, responds according to the frequency of incoming sounds: low-frequency stimulation causes an internal displacement at the apex of the cochlea; high-frequency excitation produces displacement at the basal end. Lying on the basilar membrane is the organ of Corti, which holds sensory receptors, bundles of stereocilia made up of outer and inner hair cells (Figure 1). These hair cells, when healthy, receive the fluid vibrations caused by sound waves and contact the overlying tectorial membrane. Disturbances of the hair cells transform mechanical energy into electrical impulses that stimulate the cochlear nerve. Finally, the auditory cortex of the brain encodes the electrical potentials into meaningful sound, based on the spectral and temporal characteristics it receives.[1]

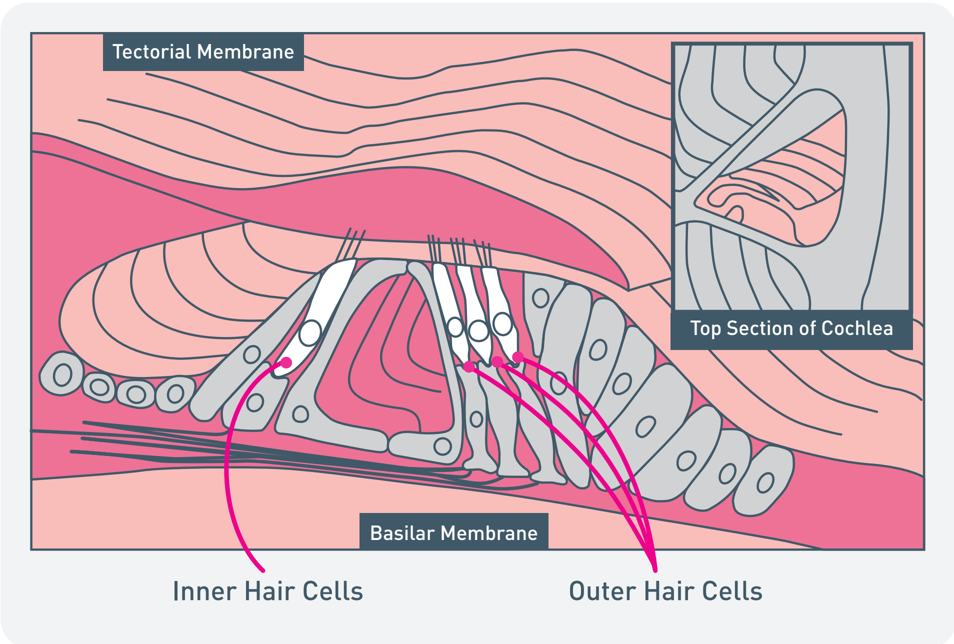

Figure 1: Organ of Corti

Pathophysiology of Sensorineural Hearing Loss

Unlike problems in the outer or middle ear that cause conductive hearing loss, damage to the inner ear hair cells is the major cause of sensorineural loss. Damage occurs from a multitude of sources: noise exposure, ototoxic medication, disease, hereditary factors, and age, for example.[2] The motile outer hair cells, responsible for mechanically amplifying soft sounds (up to about 50 dB) that enter the cochlea, are most vulnerable to the accumulative effects of these factors, especially in the high frequencies. They can become bent or broken, and fail to make contact with the tectorial membrane above. Unfortunately, the loss is permanent; they do not regenerate or grow back. The inner hair cells – which transform the vibrations they receive from the outer hair cells into the electrical signals that continue on to the brain – are just as susceptible to damage. When these hair cells are affected, an increased risk of cochlear dead regions occurs. Cochlear dead regions are areas in the cochlea where inner hair cells cannot adequately transfer sound to the brain.[3] The amount of damage is reflected in the degree of thresholds obtained on the audiogram: up to a moderate hearing loss indicates outer hair cell damage; a severe to profound loss indicates inner hair cell damage.

The Cochlear Amplifier

Healthy functioning ears provide us with more than the capability to hear a wide range of frequencies. They also amplify the volume of sounds we hear in a non-linear fashion. The term 'cochlear amplifier' describes this organic process, where outer hair cells act as a 'pre-amplifier', and apply more amplification to weaker sounds than louder sounds.[4] This explains how a small, snail-shaped organ, restricted to displacing hair cells within a limited anatomical space, enables perception of both a wide range of frequencies from low to high and sound pressure levels from soft to loud.

It follows then, that damage to the outer hair cells will cause not only a reduction in hearing sensitivity at frequency-specific locations, but will also disrupt the cochlear amplifier's ability to apply the appropriate amplification for soft and medium levels of sound. The hearing 'window' becomes much narrower and can lead to recruitment, where moderate to loud sounds grow rapidly louder in sensation level, compared to softer ones. In other words, sounds can become uncomfortable rather quickly, compared to normal tolerance ranges.

Problems with Conventional Amplification

Much of our receptive speech understanding comes from hearing high-frequency consonants, compared to the lower-frequency formants heard in vowel sounds. With high-frequency hearing loss, the ability to hear soft, high-frequency consonants crucial for speech intelligibility (e.g., /s, sh, z/) is reduced. The high-frequency fricative /s/ is particularly important in the English language, as a frequently occurring plural, tense or possessive language marker.[5] These linguistic cues plus many others occurring at or beyond 4,000 Hz, are among the most difficult sounds to restore with amplification for high-frequency losses. Today's state-of-the-art digital hearing instruments outshine technology used in the past. But certain limitations still exist, especially when treating greater degrees of hearing impairment. Most instruments can supply enough gain to adequately treat a moderate to severe hearing loss. However, when attempting to provide greater amounts of gain for severe to profound losses, especially in the high frequencies, problems start to occur.

Receiver Roll-Off

One shortfall of conventional amplification is that the frequency response typical of most receivers starts to 'roll off', or slope downwards, in the high frequencies. That means the least amount of gain is available in the area where the hearing loss is greatest. Even the extended bandwidths provided by today's most advanced digital signal processors have roll-off in the highest frequencies. This restricts the availability, and therefore the effectiveness, of delivering greater gain to this region. The frequency response curve in Figure 2 illustrates the problem area, shaded in blue.

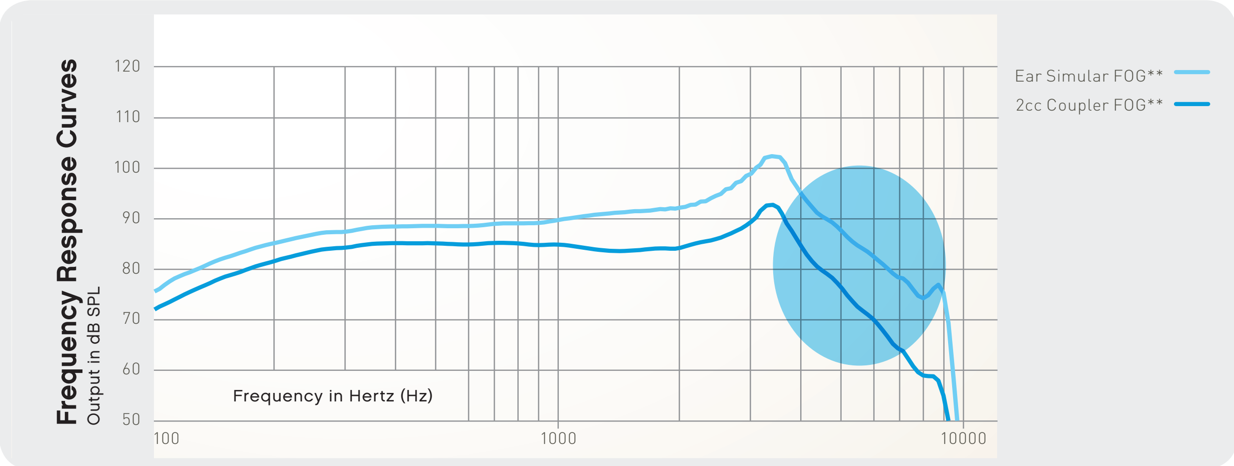

Figure 2: High-frequency roll-off typical of hearing instrument receivers.

Feedback

When the frequency response can successfully provide the appropriate gain necessary for severe losses, two scenarios may occur. The supplied gain is often in a 'hot spot', meaning a critical zone susceptible to feedback. Increased amounts of gain in these high frequencies become a trigger for feedback to occur. Sophisticated adaptive feedback cancellation systems work well, but only within the specified limits of the fitting range. When pushing those amplification boundaries for severe losses, the hearing aid can enter a sub-oscillatory feedback mode that can negatively impact the sound quality of amplification (Figure 3).

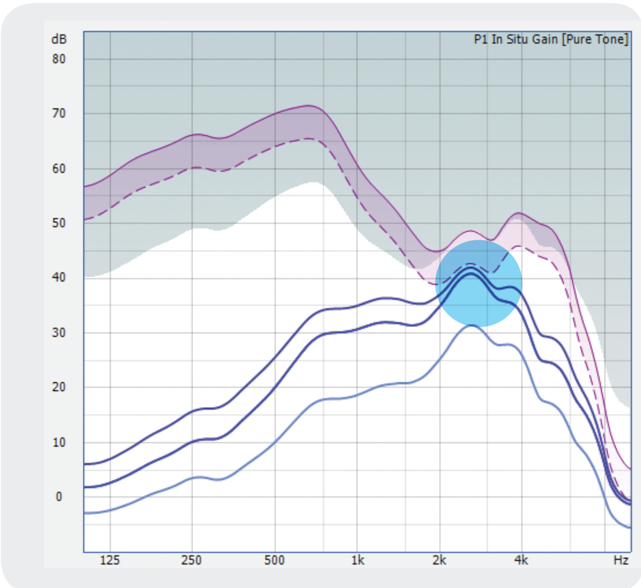

Figure 3: High-gain feedback limits common in the high frequencies.

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Recruitment

Another situation that can occur with conventional amplification is recruitment, or an abnormal growth in loudness perception, which presents in the frequency region of a severe to profound loss. In these cases, the dynamic range is reduced, requiring amplification of soft, medium and loud sounds to be compressed within close proximity together. Sound quality suffers, especially when trying to keep amplified sound from becoming uncomfortably loud, and can lead to rejection of amplification.

Cochlear Dead Regions

Finally, cochlear dead regions can occur with severe to profound hearing loss. A study by Vinay and Moore (2007) concluded that sensorineural hearing loss exceeding 70 dB HL can indicate the likelihood of their presence.[6] Clinical tests such as the Threshold Equalizing Noise (TEN) Test or psychophysical tuning curves (PTC) can identify cochlear dead regions, if suspected. Regarding amplification strategies for this population, studies from the past suggested to reduce high-frequency amplification in the presence of dead regions; however, a more recent study by Cox et al. (2011) actually found the opposite to be true – that those with dead regions are likely to benefit from high-frequency amplification.[7]

Frequency-lowering Solutions

For many years, hearing aid manufacturers have recognized the problems of high-gain/high-frequency amplification and have developed methods to combat them. As a result, many approaches now exist to treat the problem. Known collectively as 'frequency lowering', these methods include: linear frequency transposition; frequency compression; non-linear frequency compression; and envelope warping. Although all are successful in lowering high frequencies to areas with better residual hearing, some performance limitations still exist.

For example, many of the processing strategies limit the full bandwidth of the original signal. Research has shown that frequency-lowering techniques are more effective – whether or not cochlear dead regions exist – when the bandwidth of the original signal remains intact.[8] Additionally, some frequency-lowering systems copy only partial high-frequency cues. Finally, some systems are always on regardless of the hearing loss, whereas others are always off in combination with open fittings.

Frequency Transfer from Sonic

Frequency Transfer is the newest frequency-lowering solution available from Sonic. It improves upon each of the limitations described above. First, the configuration of the audiogram determines if Frequency Transfer is necessary, and only activates the technology if required. High-frequency input from a designated region shifts to a lower frequency region that has better residual hearing. In this way, Frequency Transfer improves the access — and therefore the audibility — of these speech cues. Importantly, the bandwidth of the original signal remains intact. This not only preserves the robust amplification on the original signal, but also promotes a smooth and seamless sound. Finally, Frequency Transfer can be used in conjunction with closed or open fittings alike.Figure 4 shows Frequency Transfer in action. The graph on the left shows the output in dB SPL of a first fit without Frequency Transfer (green line). The amplified input signal /s/ resides at a frequency inaudible for the hearing loss, indicated by its location within the hearing threshold levels in grey. The graph on the right shows the same fitting, but with Frequency Transfer active. The feature copies and relocates the amplified /s/, now the orange peak, to a lower frequency region where better hearing can access the sound. Lastly, the full high-frequency bandwidth of the amplified signal remains intact, as evidenced by the extended blue line following the transfer.

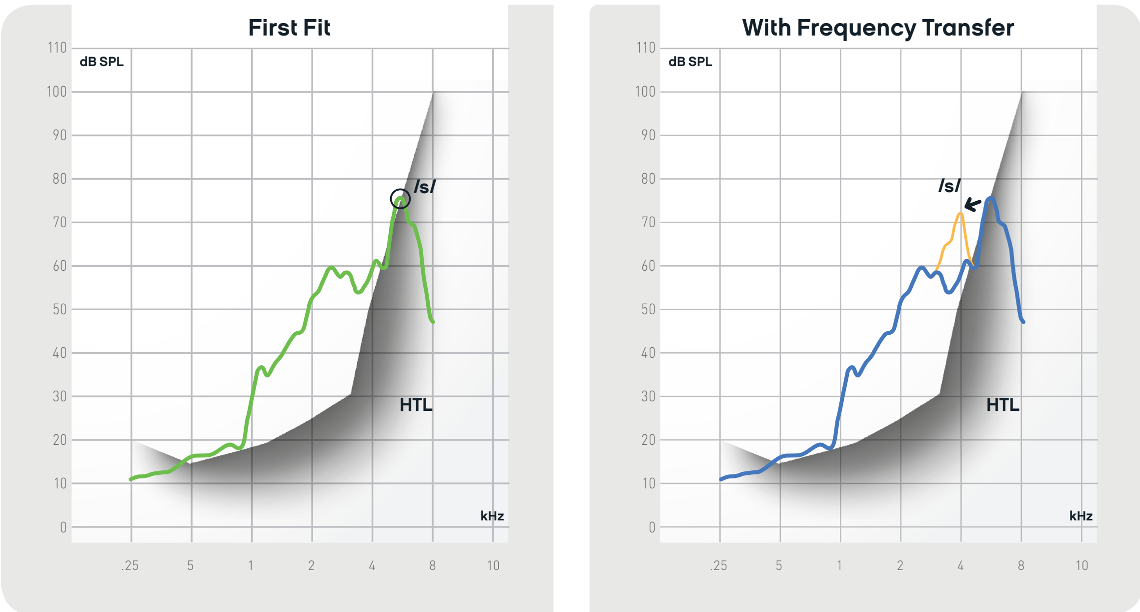


Figure 4: Hearing aid output for the phoneme /s/ with Frequency Transfer off (left) versus on (right).

Specifically, Frequency Transfer works by detecting high-frequency cues in a designated range, the 'source' region. The source region is the location where high-frequency amplification would be insufficient with conventional processing.

Figure 5a shows the source area of an example fitting, indicated by the vertical grey bands. Frequency Transfer copies the selected high-frequency input within the source region and replicates it so that no information is lost.

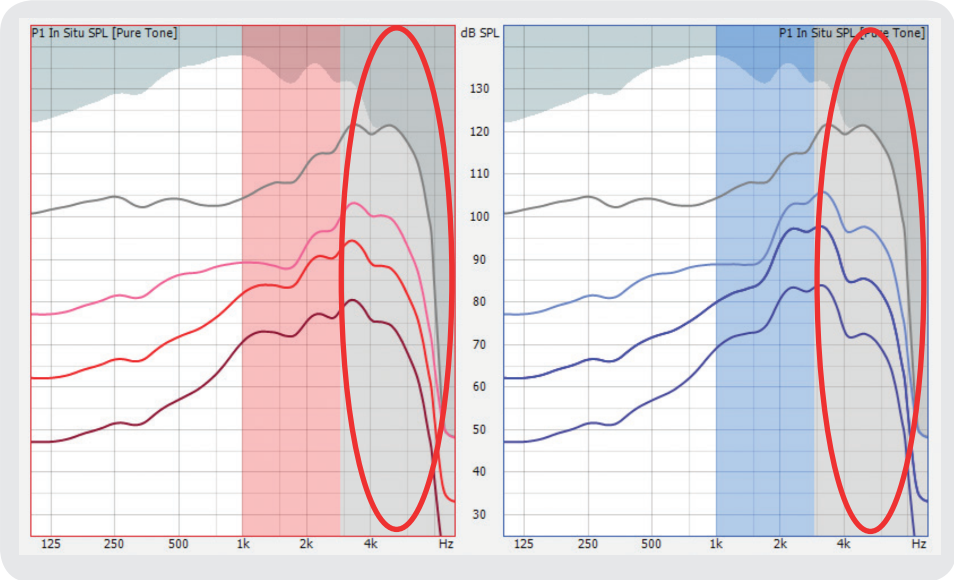


Figure 5a: Example 'source' region using Frequency Transfer.

Next, the frequency content is compressed, then shifted onto a pre-selected, lower 'transfer' region (Figure 5b). The transfer region is where residual hearing is better, based on the audiogram.

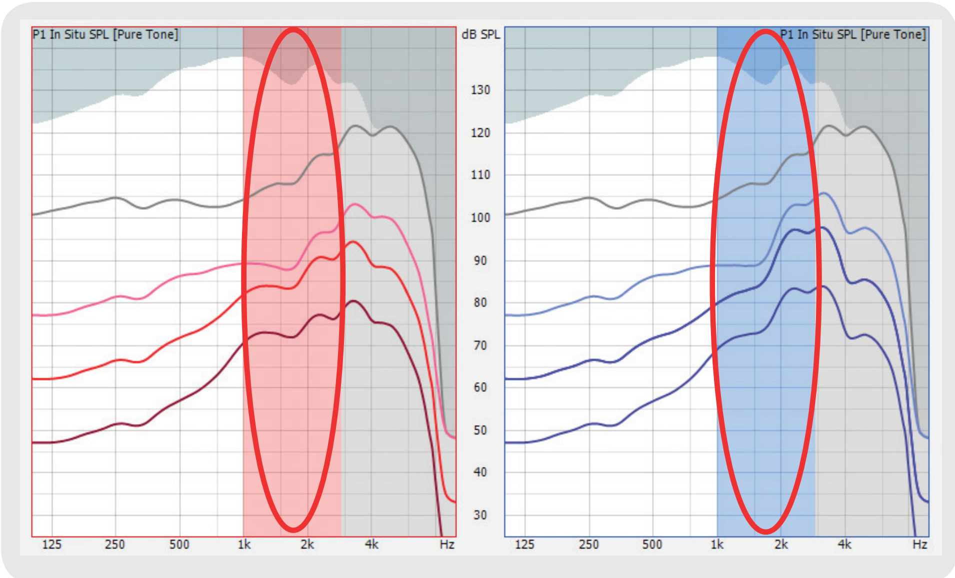


Figure 5b: Example 'transfer' region in red and blue, respectively, for right and left fittings using Frequency Transfer.

By design, the bandwidth of the original signal is never truncated. All of the frequencies in the grey shaded zones still receive the necessary amount of amplification prescribed by the fitting rationale.

Frequency Transfer Verified

Verifying new features is necessary to ensure that the technology performs as intended. Concerning Frequency Transfer, that means two things: 1) high-frequency information should be lowered to a suitable destination and intensity level for the hearing loss; and 2) no part of the signal should be lost during processing.

Spectrograms

Spectrograms provide one useful way to confirm the performance. Figure 6 shows the output of a sentence containing low- and high-frequency sounds. The varying shades of brightness on the left panel represent the intensity of spectral information from low to high frequencies, as seen over time. The bright yellow areas indicate the most intense vocal energy, whereas the light purple areas indicate the least intense energy. Once Frequency Transfer becomes activated (right panel), the spectrogram shows additional areas of brightness, indicated by the arrows, that are not present on the left. This verifies that the targeted high frequencies have been transferred to the lower frequencies, and are now at a greater intensity, as intended. Furthermore, the graph on the right shows no change in brightness within the upper bracketed area. The spectral content is indeed present, in the same amount, in the high frequencies. This proves that the full bandwidth remains intact with the feature on.

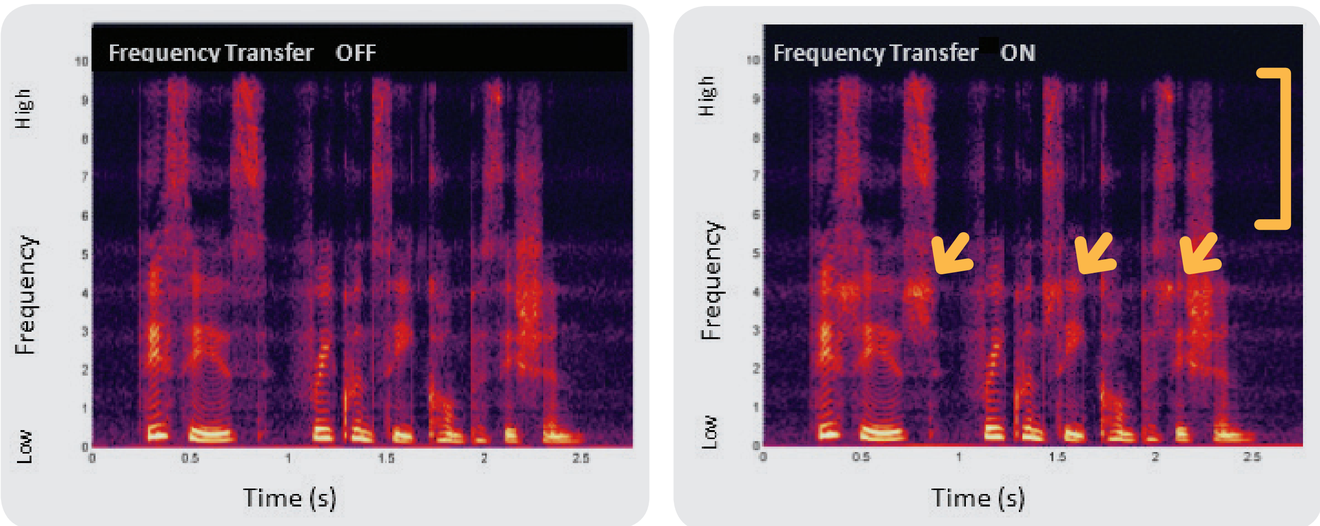


Figure 6: Spectrograms with Frequency Transfer off (left) versus on (right).

Testbox Measures

Testbox measurements also verify Frequency Transfer. For example, Audioscan's Verifit offers four different high-frequency input signals (LTASS Speech3150, 4000, 5000 and 6300) for this purpose (Figure 7). These signals can confirm that the lowered signal is at the appropriate transfer region and intensity level for a patient's needs.

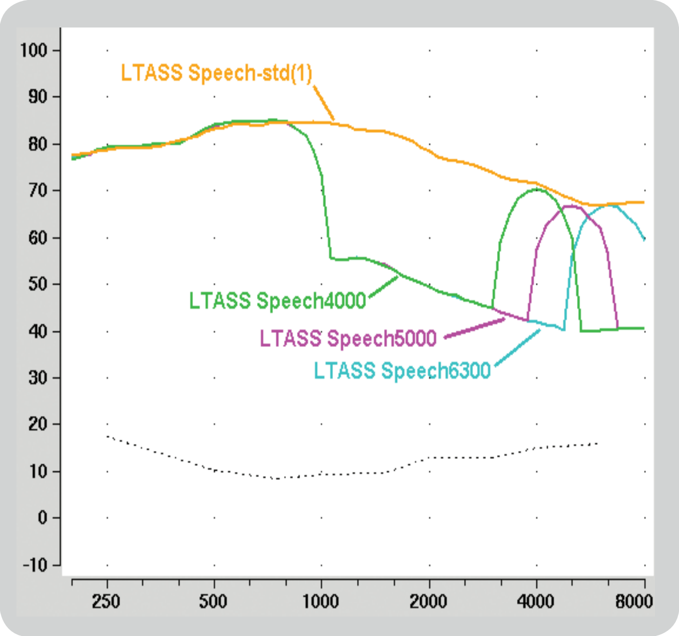


Figure 7: Verifit input signals help to assess frequency lowering.

With this verification method, you can see the stimulus in relation to the audiogram. Figure 8 shows four measurements with the LTASS Speech5000 signal at 65 dB SPL. Each measurement corresponds to a different Frequency Transfer intensity level: off, weak, medium, and strong. If the output of the signal falls below the hearing thresholds (red line), then the signal is too soft. If it falls at or above the hearing thresholds, then audibility has been achieved. In this example, the green line represents Frequency Transfer 'off'; the pink line represents 'weak'; the blue line represents 'medium'; and the orange line represents 'strong'. The green and pink measurements show that the Speech5000 signal is not audible for the loss when Frequency Transfer is off or at the weak intensity level. The blue line shows that the signal becomes audible for the medium intensity level, while the orange line shows that 'strong' is the best intensity level for the signal. In this respect, it is easy to see how verification supports fine-tuning efforts to ensure the transferred signal is comfortably audible above thresholds.

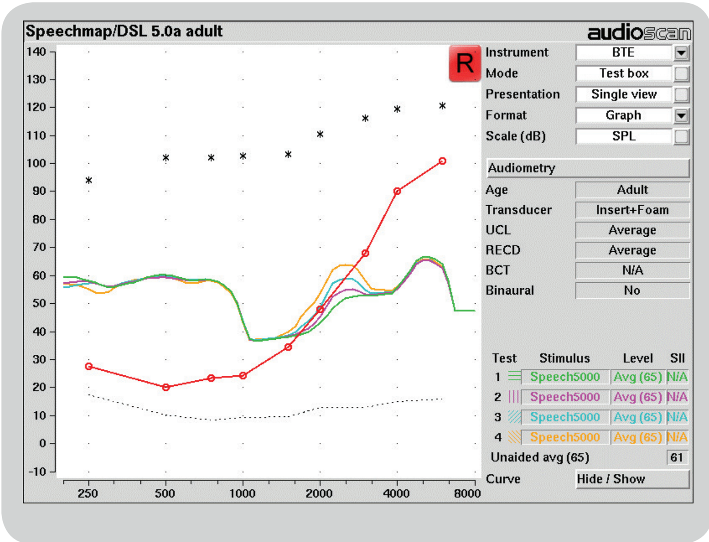


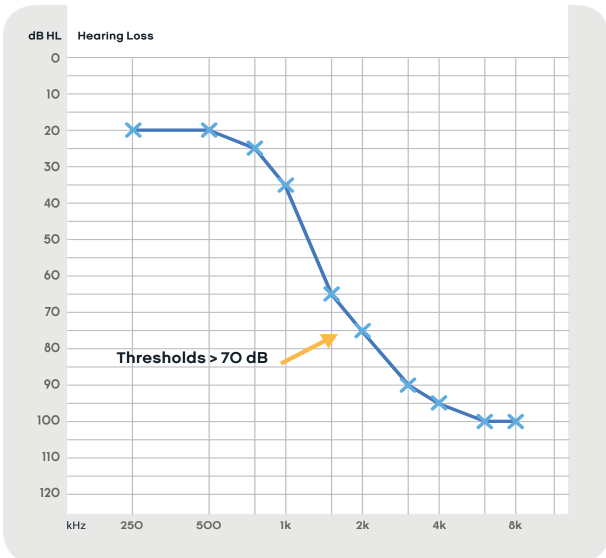
Figure 8: Frequency Transfer intensity levels.

Frequency Transfer in EXPRESS*fit*

Frequency Transfer is easy to use, due to the default settings established in the EXPRESS*fit* fitting software. Read on to find out how Frequency Transfer's default settings are applied, or how to customize fitting flexibility when required.

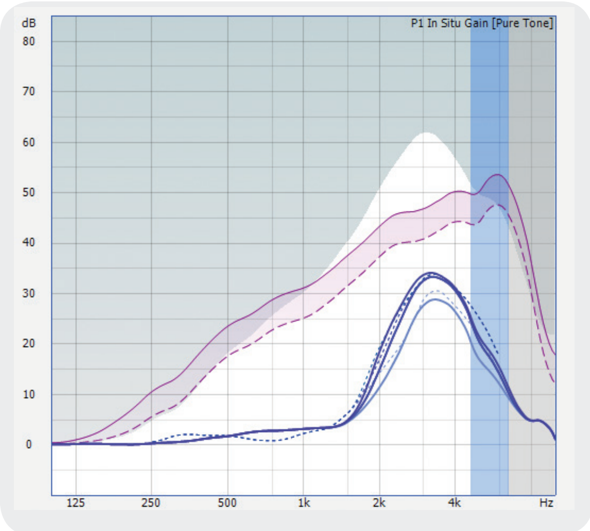
Candidacy

Patients with severe to profound high-frequency hearing loss are candidates for Frequency Transfer. EXPRESS*fit* applies Frequency Transfer by default only when certain audiogram configurations are present. Criteria include high-frequency sensorineural hearing thresholds greater than 70 dB HL.

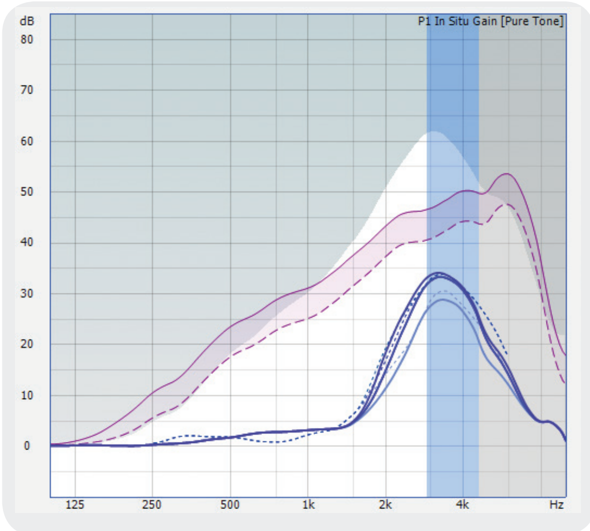


Transfer Regions

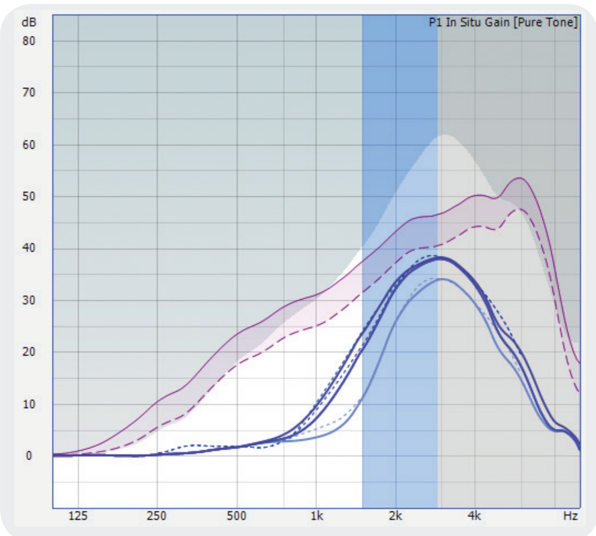
The default settings in EXPRESS*fit* take the guesswork out of which Frequency Transfer region to choose for your patient. Depending on the degree and slope of the thresholds on the audiogram, and the product selected, one of four frequency ranges for the region of Frequency Transfer will be applied.



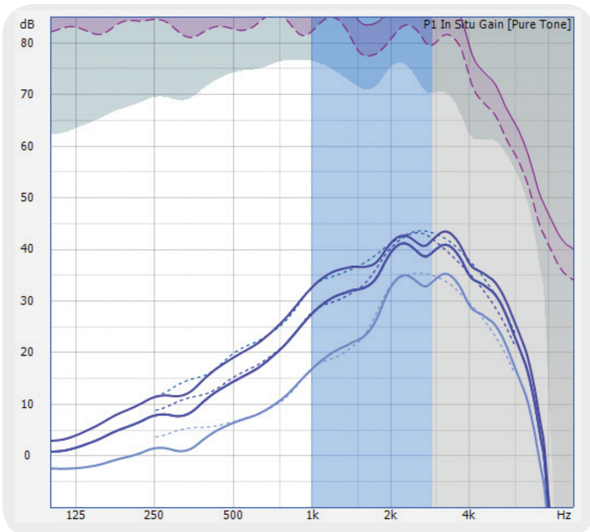
4.6 – 6.5 kHz When the suspected area of the cochlear dead region is small, a mild Frequency Transfer shift occurs, from 4.6 – 6.5 kHz.



2.9 – 4.6 kHz When the suspected area of the cochlear dead region is larger, a moderate Frequency Transfer shift occurs, from 2.9 – 4.6 kHz.



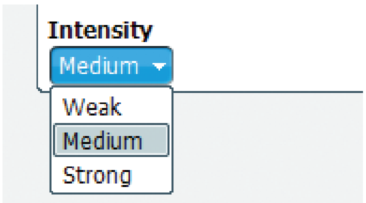
1.5 – 2.9 kHz When the suspected area of the cochlear dead region is very large, a strong Frequency Transfer shift occurs, from 1.5 – 2.9 kHz.



1.0 – 2.9 kHz When the suspected area of the cochlear dead region is extreme, the maximum Frequency Transfer shift occurs, from 1.0 – 2.9 kHz. Note: This range is only available on Super Power products.

Intensity Levels

Three Frequency Transfer Intensity levels are available in EXPRESS*fit*: Weak, Medium, or Strong. In order to optimize the strength of the transferred frequencies, EXPRESS*fit* automatically selects Medium as the default starting point.



Customization

Frequency Transfer allows you to change either the default transfer region or intensity level, if needed. Changes may be necessary depending on any of the following patient-specific outcomes:

- Real ear verification
- Aided speech testing
- Validation measures
- Acclimatization period

Select from the drop-down menus on the Frequency Transfer screen to adapt to your patient's individual needs. For best results, adjust only the intensity, and keep the levels matched in binaural fittings. Changes to the transfer region are not recommended, unless hearing thresholds change.

Note! Frequency Transfer may be turned off, if necessary. Further, it is deactivated with telecoil-only inputs, when the Adaptive Feedback Canceller is off, and in the Music program.

Benefits of Frequency Transfer

Frequency Transfer aims to improve the audibility of speech for patients with severe to profound high-frequency hearing loss. With Frequency Transfer:

- High-frequency sounds are lowered to a region of the audiogram with better hearing
- Audiometric criteria initiate default settings
- Open fittings are supported
- High-frequency cues are copied and transferred so no part of the signal is lost
- The full extended bandwidth of the signal remains intact
- Customization is possible for individual needs
- Drawbacks of conventional amplification are reduced

Frequency Transfer helps patients hear the full, rich spectrum of everyday sounds. It is available in all Celebrate and Journey products from Sonic.

For a demonstration or to learn more, please contact your local Sonic provider.

References

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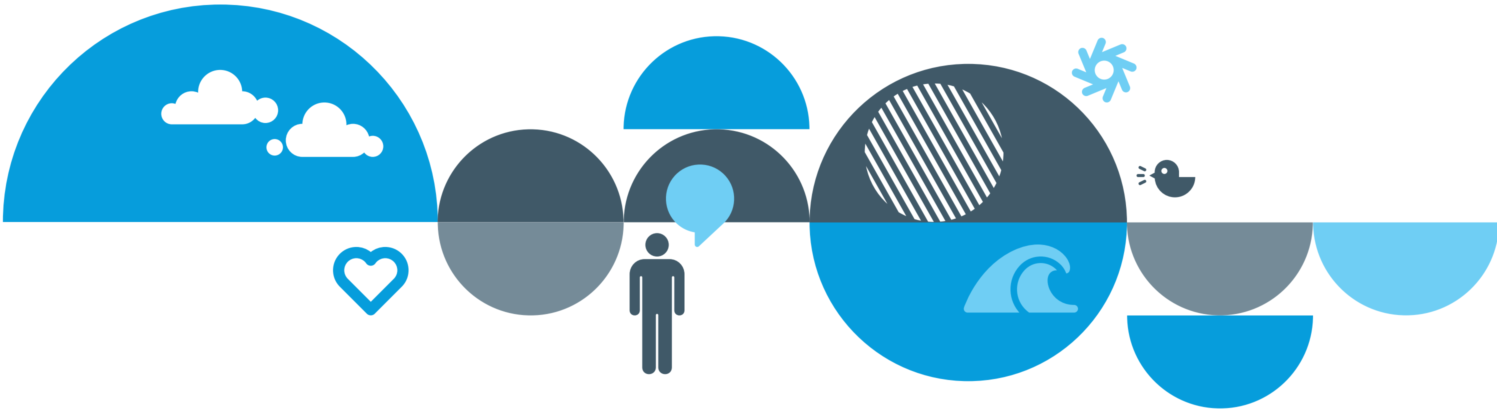

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