GN ReSound

HUMAN RESOLUTION WARP™

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As part of the development of future hearing instruments, it is necessary to continually evaluate the approach used to implement such things as compression. This is especially true when incorporating more advanced signal processing and different fitting options. Frequency warping is one approach that engineers have developed to improve frequency resolution and sound quality while also decreasing distortion. GN ReSound was the first to implement frequency warping into hearing instruments with WarpOpen that is used in the ReSoundAIR and Canta7 Open hearing instruments (Groth & Pedersen, 2003).

In 2005, GN ReSound released the second generation of hearing instrument warp processors, Human Resolution Warp™. The Human Resolution Warp™ provides frequency resolution similar to the human auditory system, with minimal delay, and a high sound quality. Further, the ReSound Metrix™ microprocessor is faster and more powerful to allow for 17, frequency-warped channels to accomplish such things as hearing-loss compensation (compression), noise reduction, and environment recognition.

MULTI-CHANNEL PROCESSING

Kates & Arehart (2005) described the three fundamental approaches taken in designing multi-channel processing for digital hearing intruments. These are multi-channel filter banks, Fast Fourier Transformation (FFT) based processing, and utilization of a side branch to the audio signal path for frequency analysis. In each of these approaches, the primary goal is to match the frequency resolution of the digital system to the frequency resolution of the human auditory system.

Multi-channel filter banks use combinations of low-pass and high-pass filters to separate the input signal into multiple channels for independent processing. This technique emulates the traditional analog band-spilt filterbank into digital technology. The filters are either finite-impulse response (FIR) or infinite-impulse response (IIR). The FIR filter banks are beneficial for hardwired (not software upgradeable) microprocessors. While this filter type can be power efficient the tradeoff is relatively long processing delays that are not acceptable for open fittings. The IIR filter banks again lead well to power-efficient hardwired microprocessors. While a low processing delay is often measured for the high-frequency channels, a greater processing delay occurs for lower frequencies. The variation in processing delay across frequencies will substantially decrease the directionality. For both FIR and IIR filter banks, the channels are processed independently and then combined together. This increases negative channel interactions including issues with calculation errors at crossover frequencies, decreased sound quality and reduced directionality.

The frequency analysis technique (FFT) provides great sound quality, however it has other challenges for effective implementation. The FFT technique is based on a uniform spacing of frequency components while the auditory system is based on a logarithmic spacing. The human ear's ability to resolve sounds is best modeled by a system in which the bandwidth of the frequency analysis is nearly constant at lower frequencies and increases proportionally at higher frequencies (Moore & Glasberg, 1983). This is due to the logarithmic frequency coding on the basilar membrane.

The hearing instrument channels can be matched to the auditory system channels but, is accomplished at the expense of processing efficiency. For example, in an FFT-based system, the uniformly spaced bands can be combined to provide bandwidths similar to the auditory system. This approach can provide an excellent representation of auditory system; however it requires a high-resolution FFT to achieve the necessary low-frequency resolution (see Figure 1). This high-resolution FFT results in unnecessarily narrow high-frequency bandwidths and excessive signal processing. While this approach can provide excellent sound quality, the required processing can delay the output from the hearing instrument. If this processing

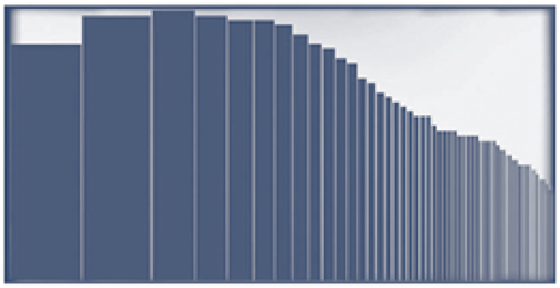

Figure 1.
An FFT-based system can provide the necessary low-frequency resolution but only at the expense of unnecessary narrow high-frequency bandwidths.

delay is too long, the hearing instrument might have a negative user perception (e.g. an echo).
A multi-channel design technique which provides logarithmic frequency representation with high efficiency is frequency warping. A mathematical warping function defines how individual frequency components and different frequency ranges are mapped on the logarithmic scale. The ReSound Metrix Human Resolution Warp™ uses parameters that closely correspond to the auditory Bark scale (Smith & Abel, 1999). The Bark scale incorporates the critical bandwidth as the scale unit (Zwicker et

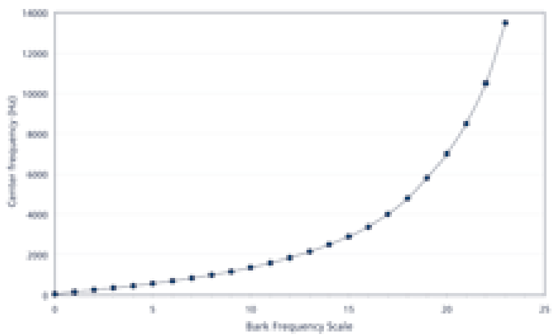

Figure 2.
The bark scale units correspond to the center frequencies of the auditory system's critical bands. As the bark value increases, the bandwidth of the critical band increases exponentially.

al, 1957). Figure 2 illustrates the logarithmic nature of the bark scale.
GN ReSound is the only hearing instrument manufacturer that uses frequency warping in a product. However, this technique is preferred for other audio applications where accurate but efficient frequency representation corresponding to the auditory system is required. These include Linear Predictive Coding of Speech (Strube, 1980), design of loudspeaker equalization filters (Wang et al, 2000; Karjalainen et al, 1996), modeling the acoustic properties of musical instruments, and modeling the head-related transfer function for synthesis of 3-D sound localization cues (Karjeleinen & Smith, 1996).

HUMAN RESOLUTION WARP™

The GN ReSound Human Resolution Warp™ (first used in the ReSound Metrix) is a side-branch type processor in which frequency warping is used for both the signal path filters as well as frequency analysis (see Figure 3). This is a parallel processing system for the audio path and the analysis path. The audio path uses frequency-warped FIR filters and the signal remains as a time waveform. The non-audio

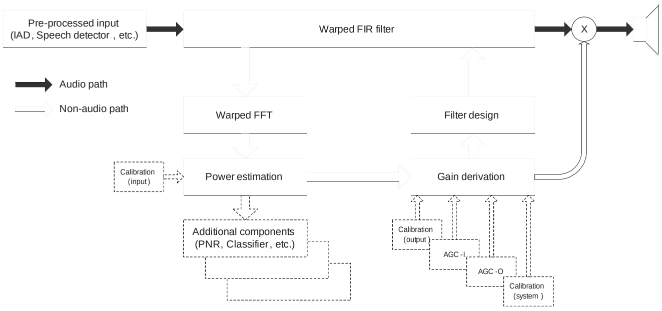

Figure 3.
The ReSound Metrix Human Resolution Warp™.

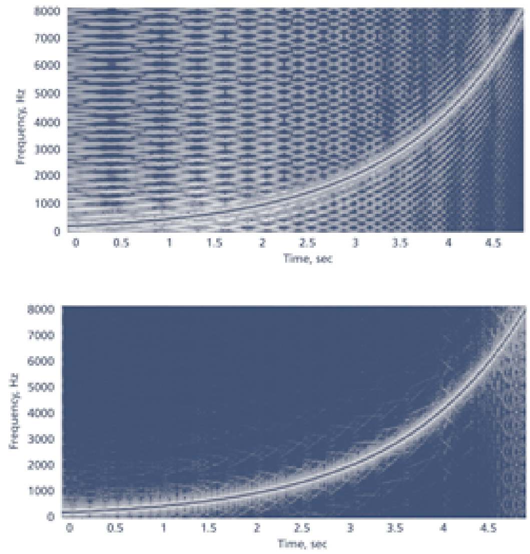

Figure 5.
Spectrogram showing the responses for a swept tone for an FFT-based processor (left panel) and the Warp™ processor (right panel). Non-linear distortion is indicated by a lattice pattern in the measurement. The Warp™ processor shows extremely little non-linear distortion.

path uses frequency-warped FFT-analysis and channel-specific decisions (e.g. gain) are determined.

The frequency warped FFT spectrum results in 17, smoothly overlapping frequency bands separated by approximately 1.3 Bark as illustrated in Figure 4. In

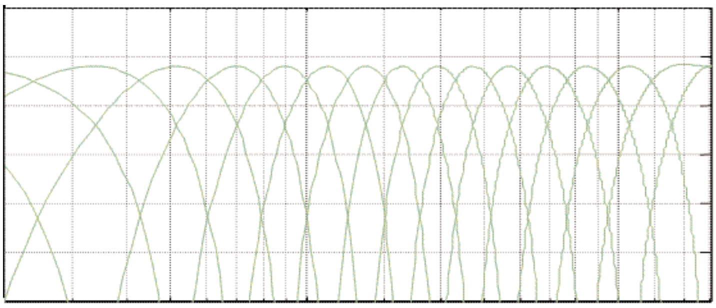

Figure 4.
The Warp™ processor has 17 overlapping frequency bands. The frequency warping results in non-uniform band spacing corresponding closely to the auditory Bark scale. The degree of overlap between the bands provides a smooth, artifact-free frequency response.

addition to closely emulating auditory system frequency resolution, the overlapping structure of the bands also minimizes band edge effects, contributing to superior sound quality. An extra sound quality benefit of the Warp™ processor is that it has negligible non-linear distortion, as can be seen in Figure 5.

HUMAN RESOLUTION WARP™ AND OPEN FITTINGS

An additional unique characteristic of the Human Resolution Warp™ processor is that it is well-suited to fitting nearly any hearing loss with any venting strategy. As described above, this system provides an exceptional match to the human auditory system with virtually no distortion.

For open fittings, the greatest benefit of frequency warping is that the efficient manner in which it is utilized significantly diminishes processing delay. Minimizing the time it takes from sound entering the hearing instrument microphone until it exits the receiver is considered crucial for open hearing instrument fittings. For any digital hearing instrument, sound processing delay affects coloration of the sound, or timbre, and as it increases will result in the perception of echoes. For fittings in which the ear is relatively unoccluded, propagation delay is even more critical as direct and amplified sound mix in

the wearer's ear canal.
The Human Resolution Warp™ processor design introduces delays that are shorter than required to ensure no disturbing perceptual effects both for conventional and open fittings (Groth & Soendergaard, 2004; Dillon et al, 2003; Agnew & Thornton, 2000; Stone & Moore, 1999). While frequency variant delay may also give rise to deleterious perceptual effects, the across-frequency delay associated with the Warp™ processor was found to be inaudible for both normal-hearing and hearing-impaired listeners (Kates & Arehart, 2005). Because the flexibility of the Warp™ processor allows fitting all hearing loss configurations, the ReSound Metrix product line incorporates many innovative earmold and shell solutions for open fittings.

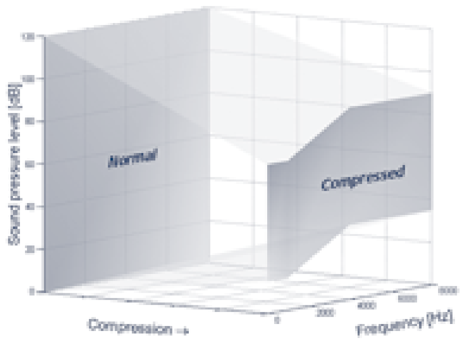

Figure 6.
Cochlea Dynamics comprises of a set of compression characteristics that resemble the cochlear function. The wide dynamic range compression squeezes the normal range of sound levels into the reduced dynamic range of the hearing impaired individual.

COCHLEA DYNAMICS AND HUMAN RESOLUTION WARP™

In 1989, GN ReSound pioneered multi-band full dynamic range compression and was the first to introduce this type of compression in a commercial hearing instrument. Termed Cochlea Dynamics, this compression strategy was based on a design by Villchur (1973) to address the recruitment problems of individuals with sensorineural hearing losses. GN ReSound has continued its legacy of Cochlea Dynamics with Human Resolution Warp™ processing, included as part of the ReSound Metrix™.

Cochlea Dynamics encompass a set of compression characteristics intended to compensate for the loss of the ear's natural compressive non-linearity, which is a result of outer hair cell damage in the cochlea. The compression characteristics include fast syllabic attack and release times, low-compression thresholds, and compression ratios ranging from 1:1 to 3:1 (Figure 6). In addition, GN ReSound hearing instruments have employed overlapping bands to emulate the critical bands of the human auditory system. The physiologic rationale for Cochlea Dynamics is described in more detail by Edwards et al (1998).

SUMMARY

The Human Resolution Warp™ used in the ReSound Metrix hearing instruments is a 17-channel system that provides an excellent match to human auditory perception. The frequency warping technique decreases the low frequencies providing greater resolution and releases processing of unnecessarily narrow high frequency bandwidths. The relationships adhere closely to the auditory Bark scale. Added benefits of the frequency warping technique and band structure include extremely low distortion and sound artifact, which ensures superior sound quality. Furthermore, the Warp™ compressor's short processing delay is suitable for open fittings.

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