The Use of a High Frequency Emphasis Microphone for Musicians

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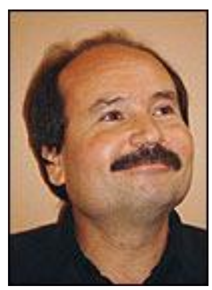
The HF microphone as a low-tech solution for performing musicians and "ultra-audiophiles"

Of the many differences between speech and music as an input to a hearing aid, the one that is perhaps the most important is the intensity. Whether the music is being played by a hard-of-hearing musician or listened to by a hard-of-hearing novice, the higher intensities of the input to the hearing aid can result in problems.

Speech at average conversational levels is typically in the 65-70 dBSPL range with more intense components being up to the mid-80 dBSPL region. Shouted speech can be slightly more intense but typically only in the lower frequency regions (on the vowels and other sonorants). In contrast, even quiet instrumental music can be in excess of 90 dBSPL with sustained levels greater than 105 dBSPL. This is true of both classical and popular forms of music. A Wagnerian opera can have



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instrumental levels in excess of 120 dBSPL.

A related issue is that the crest factors of a speech signal and that of instrumental music are also different. The crest factor is the difference in decibels between the peak of the signal and its average or RMS (Root Mean Square). For speech, typical crest factors are about 12 dB, meaning that the peaks of the signal are about 12 dB more intense than the average. If average conversational speech is 65 dBSPL, then one would expect that the peaks are about 77 dBSPL (65 +12). This figure of 77 dBSPL should sound familiar to those designing and fitting hearing aids—it is the amount that one subtracts from the OSPL90 to obtain the reference test gain of a hearing aid.

In contrast to a speech signal, music has a crest factor that can be greater. Estimates vary, but depending on the physical characteristics of the musical instrument, the crest factor can range from 14 dB to over 20 dB (with an average of 18 dB). This means that, on average, the peaks emanating from a musical instrument are about 18 dB more intense than the average or RMS of the playing intensity. There is less inherent damping in a hard-walled musical instrument such that the peaks are "peakier" relative to the RMS. This difference has ramifications for setting the OSPL90 of a hearing aid program for music versus speech (-6 dB) and also the required gain (-6 dB). That is, the output and the gain of a "music program" in a hearing aid should be 6 dB lower than for the "speech-in-quiet program." This has been covered elsewhere and the reader is directed to Chasin[1] for more information.

The A/D Converter and the 96 dB Music Input Barrier

Given these two differences between speech and instrumental music as an input to a hearing aid, a problem with modern digital hearing aids comes into focus. Modern digital hearing aids typically use a 16-bit A/D converter that limits the dynamic range to about 96 dB at best. Stated differently, most A/D converters found in modern hearing aids will overload when presented with signals in excess of 96 dB SPL—producing distortion at the front end of the hearing aid. Once the input signal is distorted, there is no "music program" in the world that can clean up the signal in the later signal processing stages of the hearing aid. This 96 dB dynamic range is more than sufficient for speech input because the loudest components of shouted speech are less than 96 dB; however, the same cannot necessarily be said of instrumental music as an input to this A/D converter.

Instrumental music, whether related to its overall higher intensity or its greater crest factor, tends to overdrive the front end of the hearing aid because of the limited available dynamic range on the given A/D converters. This entire issue of *The Hearing Review* is dedicated to getting around this and other problems with hearing aids.

Interestingly enough, traditional analog hearing aids that, of course, have no need for an A/D converter, such as the K-AMP, were much better positioned to handle louder music. The input dynamic range was typically limited only by the input transducer(s) and in some cases input compressors aimed at keeping the front end signal clean. The K-AMP, introduced in 1989, is a 20-year-old innovation.

High Frequency Hearing Loss

In many cases, hard-of-hearing musicians and audiophiles may have only a high frequency hearing loss with relatively good hearing at 1000 Hz and below. In these cases, a non-occluding BTE hearing aid fitting would be the style of choice. This is a fitting issue related to a balance of sufficient gain and a minimization of the occlusion effect. In non-occluded fittings such as these, lower frequency sounds, which tend to be more intense, enter the non-occluded ear canal directly, bypassing the hearing aid. Mid and high frequency sounds enter the hearing aid microphone and are transduced through the hearing aid circuitry. On the surface, this sounds like an optimal arrangement, and *for speech* it may be; however, this is certainly not the case for more intense music.

While it is true that a significant amount of low frequency (intense) sound enters the non-occluded ear canal directly, this same low frequency sound is picked up by the hearing aid microphone and is transduced through the hearing aid to the ear. Ultimately, this amplified low frequency sound is, of course, vented out of the ear canal and never reaches the eardrum. The frequency response is one of minimal gain below 1000 Hz. However, this low frequency (intense) sound overdrives the front end A/D converter of the hearing aid causing significant distortion. The lower frequency components are not heard (because of the vent), but the higher frequency harmonics are still effectively transduced to the ear and create a low-fidelity sound.

One Solution: The HF Microphone Hearing Aid

A simple alteration to this hearing aid would be to use a microphone that is less sensitive to the lower frequencies: a High Frequency (HF) microphone. Such a HF microphone would not alter the final frequency response measured in the ear with this non-occluding BTE fitting since a low frequency signal, such as 500 Hz, would not be amplified and transduced to the ear in either case—whether it was transduced by the hearing aid and lost from the ear because of the vent, or never transduced in the first place because of a microphone that was less sensitive to low frequency sounds. However, the benefit of using a HF microphone (ie, less low-frequency sensitivity) would be that the intense low frequency music would only enter the non-occluded ear directly and not via the hearing aid, thereby minimizing audio signals that can potentially overload the front end A/D converter, causing distortion problems.

Potential Drawbacks

Technically, there are advantages for using a broadband microphone typically found in non-occluding hearing aids and there is some concern that these advantages would not be present if a HF microphone, such as the one suggested, were to be used. These factors pertain to:

1. Microphone noise floor versus sensitivity
2. Transient response
3. Optimized directional characteristics
4. Reduced available fitting range

For these technical reasons, hearing aid manufacturers have been hesitant to substitute an HF microphone for the broadband microphone typically found in non-occluding BTE hearing aids.

1) Microphone noise floor versus sensitivity. The base noise floor of a HF emphasis microphone will be roughly the same as a broadband microphone from the same model family. What is, of course, different on the HF mic is the sensitivity to low frequency sounds. Thus, the signal-to-noise ratio (SNR) in the low frequencies for the HF mic is poorer than the broadband version.
When the HF mic is applied in a given hearing instrument system—if more gain is applied in the low frequencies for a given fitting to achieve the same result that a broadband mic would yield in the lows—the noise floor of the microphone will be amplified accordingly. This results in higher audible noise for the user. This is not unlike the situation that occurs when directional microphone systems are compensated for gain in the low frequencies.

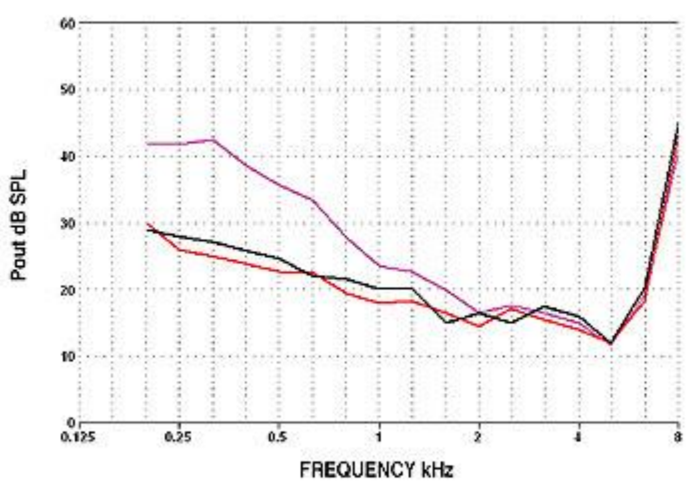

FIGURE 1. One-third octave noise measure for a given fitting: red = broadband microphone system; violet = high frequency (HF) emphasis microphone system; and black = high frequency emphasis microphone system plus adjusted low level expansion thresholds or noise compensation.

"Low level expansion" is a typical signal processing feature on most, if not all, modern digital hearing aids and can be easily used to reduce the audible noise floor. The trade-off of low level expansion is reduced gain for low level inputs in the given frequency region. This trade-off, however, should not be a user issue, as little or no amplification is required in the low frequency regions. For reference, Figure 1 shows the internal noise for three conditions: 1) a broadband microphone typically found with non-occluding BTEs; 2) an HF microphone with less low frequency sensitivity, and 3) an HF microphone with the low level expansion circuitry optimized for the HF microphone.

Also, when listening to music that is inherently more intense, the signal is sufficiently high enough that it would mask the low frequency microphone-related noise. Anecdotally, those who have been fit with this non-occluded BTE modification have not noticed this increase in noise floor even in quiet environments. This may be related to the expansion circuitry setting.

2) Better transient response. As measured at the output of the hearing aid receiver, those devices with a flat or uniform frequency response tend to possess a better transient response, which is beneficial for appreciating some of the percussive aspects of music. While the frequency response of the non-occluding BTE as measured at the eardrum would be identical in both cases (broadband and HF microphones), the output of the broadband microphone would be flatter at the receiver output than the HF microphone. If true, this would have ramifications for using such a HF microphone while listening to percussive musical sounds. Figures 2a-b show the transient response for both types of microphones (2a is for a broadband microphone and 2b is for a HF microphone). As can be seen, there is minimal difference.

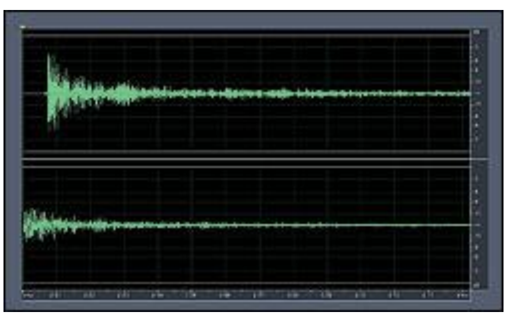

FIGURE 2a-b. Transient response for a broadband microphone. Top (2a): Output from a broadband microphone.

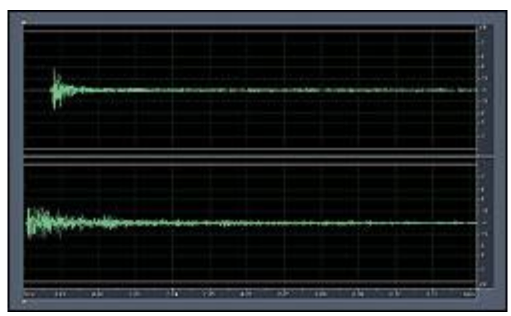

FIGURE 3a-b. Transient response for a high frequency (HF) microphone. Top (3a): Output from HF microphone.

Bottom (2b): "Knife hitting Ceramic" input to a broadband microphone (boosted 20 dB).

Bottom (3b): "Knife hitting Ceramic" input to HF microphone (boosted 20 dB).

3) Optimized directional characteristics. The third aspect of using a broadband microphone is that the matching of microphone pairs for the purposes of creating a directional hearing aid system is more easily controlled due to the matching process that focuses on low frequency matching. Although HF microphone pairs can be matched, the process is a little more challenging. If a HF microphone pair were to be substituted for a broadband microphone pair, then there is a concern that the characteristics would be altered.

This is a complex issue; despite a significant amount of research, it is still not known which directional characteristics are optimal for any given situation. While listening to music, the SNR tends to be very good because the music can be on the order of 90 dB and the background noise in the venue about 70 dB. An SNR of at least +20 dB is quite sufficient for most uses, and a degradation in the directional characteristics may be a non-issue. There may be a more significant issue, however, if the hard-of-hearing person is using this hearing aid for speech with a more adverse noise situation. Anecdotally, however, this has, so far, not been observed.

4) Reduced available fitting range. Due to the reduced low frequency sensitivity of the HF microphone, it is clear that the fitting range of the given instrument will be reduced as compared with its broadband counterpart. Having said this, it is most likely not an issue for most of the applicable fittings for which this modified instrument is targeted.

Using Non-occluding BTEs for More Significant Hearing Losses

It is well known from the study of equal loudness contours (such as those from Fletcher and Munson[2]) that people with a sensorineural hearing loss require less amplification as the input level increases. While a person would require 30 dB for soft speech, they may require only 20 dB for louder speech, and as little as 15 dB for even louder music.

In many cases, hard-of-hearing people can remove their hearing aids when listening to loud music, and this may be optimal for some people. In other cases, where a slight bit of amplification is still required, the use of a non-occluding BTE for just playing (or listening to) loud music may be quite useful. The use of a non-occluding BTE with a HF microphone may be useful for those with more significant hearing losses despite the apparent mismatch between their audiogram and the non-occluding modified microphone hearing aid fitting.

Final Thoughts

The use of a HF microphone in conjunction with a non-occluding BTE hearing aid may not be a *perfect* solution. For playing or listening to loud music, however, it provides the perfect "low tech" innovation that hearing care professions can add to their clinical tool boxes.

References

1. Chasin M. Hearing aids and musicians. *Hearing Review.* 2006;13(3):24-31.
2. Fletcher H, Munson W. Loudness, its definition, measurement, and calculation. *J Acoust Soc Amer.* 1933;5:82-108.

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