Integrating Real Ear Measurement into Destiny™ and Zōn™ Hearing Instruments

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Starkey®

Figure 1a: The Destiny 1600 product line spans all hearing instrument types from BTE to CIC.

Figure 1b: The Zōn product line shown in each of six available colors.

Starkey's Destiny and Zōn devices and the associated software were developed based on a commitment to evidence-based design and scientific method. Rigorous data collection supported the initial design of features and continued throughout all stages of development. Data in two categories – benchmarking data in the laboratory and clinical data from hearing aid wearers – provided the foundation for the final digital algorithms. The result is two families of digital hearing instruments with unparalleled features and benefits, sculpted to the needs of each patient. Figure 1a shows the Destiny product family and Figure 1b shows Zōn in six available colors.

We will not exhaustively review all features of Starkey products here. For reviews of some features and their scientific underpinnings, we direct interested readers to several other publications (Merks et al., 2006; Howes and Olson, 2006; Banerjee, Recker, and Paumen, 2006; Banerjee, Olson, Recker and Pisa, 2006; Olson and Pisa, 2006; Yanz, Pisa and Olson, 2007; Yanz, Preves and Howes, 2008; Yanz and Galster, 2008). Ultimately, the full functionality of any Starkey product will be appreciated as hearing professionals work with these revolutionary products.

This paper will discuss Integrated Real Ear Measurement (IREM) and the direct benefits it offers to the hearing professional and the hearing aid wearer. As mentioned earlier Starkey's commitment to evidence-based design requires that attention is paid to clinical best practice recommendations. These recomendations are a part of the evidential support for the integration of real ear into Destiny and Zōn products. In order to ensure that the benefits of Integrated Real Ear Measurement reach as many patients as possible, this feature is available in the Destiny 1600, 1200, 800 and 400, as well as the Zōn, .7, .5, and .3 techology levels.

Integrated Real Ear Measurement

Destiny and Zōn devices introduce a major technologic advancement to the fitting of hearing instruments by incorporating real-ear measurement capability into the hearing aid itself. Integrated Real Ear Measurement improves the accuracy of fitting initially, when a hearing instrument is programmed to a prescriptive target, and subsequently, when the instrument is fine-tuned to meet patient preferences.

Performing real-ear measurements (REM) represents the standard of care for objectively verifying the performance characteristics of a hearing instrument (Valente et al., 2006). Nonetheless, relatively few hearing professionals use real-ear equipment routinely (Strom, 2005; Kirkwood, 2006), offering various reasons, among them expense, time limitations and the feeling that the equipment is cumbersome to use. Survey data show that roughly sixty percent of hearing professionals perform REM less than half the time (Kirkwood, 2006).

Typical steps in a conventional REM evaluation are as follows (Figure 2):

1. Enter the audiogram into the REM equipment. It calculates target gain as a function of frequency, according to the selected prescriptive formula, and plots it on a graph.

2. Insert the microphone probe tube into the ear canal and measure the real-ear unaided response (REUR).

3. Insert the hearing instrument alongside the probe tube, turn it on and measure the real-ear aided response (REAR).

4. Subtract the REUR from the REAR to derive the real-ear insertion gain (REIG).

5. Evaluate the accuracy of the REIG relative to the prescriptive target and adjust hearing instrument response parameters to optimize the fit.

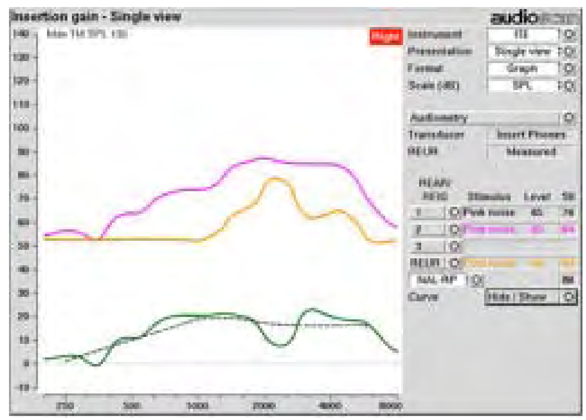

Figure 2. Sample real-ear measurements from a commercial real-ear analyzer (Audioscan Verifit). Dashed black line: insertion gain target; yellow: real-ear unaided response; pink: real-ear aided response; green: real-ear insertion gain.

In this typical protocol the probe tube must remain in the patient's ear throughout the procedure, while repeated measures are made as the hearing aid response is adjusted. The patient must remain quiet and in the proper position relative to the loudspeaker presenting test signals. Furthermore, the process must be repeated following fine-tuning adjustments.

The acoustic behavior of a hearing instrument can be quantified in a standard 2-cm^3 coupler, and coupler responses are used routinely to represent performance relative to manufacturer specifications, using procedures described in the ANSI standard (ANSI, 2003). However, that coupler response fails to predict the behavior of the hearing instrument in a real ear because its volume and acoustic impedance are not representative of a real ear.

A timesaving alternative to conventional probe tube measures, with accuracy beyond the coupler response, is available. The real-ear response of a hearing instrument can be approximated if the coupler response and the difference between the coupler response and the real-ear response are known. This quantity is known as the *real ear-to-coupler difference* (RECD), and it can be measured in three steps (Figure 3).

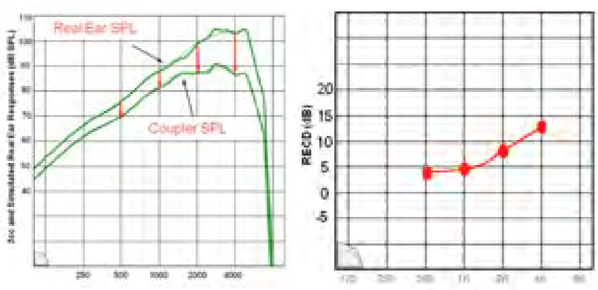

Figure 3. Derivation of RECD. Left panel shows SPL as a function of frequency in a 2cc coupler and in an ear canal, generated by the same transducer, driven by the same voltage. The right panel shows the RECD as a function of frequency, calculated as real-ear SPL minus coupler SPL.

1. Place an acoustic signal source in the coupler and measure its output.
2. Place the same acoustic source in the ear, without changing its driving voltage, and measure its output again in the patient's ear canal with a probe tube and microphone.
3. Calculate the RECD by subtracting the coupler SPL from the real-ear SPL.

Once the RECD is known, adding it to a known coupler response predicts the individual real-ear response.

The RECD is used routinely in a couple ways. First, it is often used in pediatric hearing instrument fittings. Knowledge of the hearing aid acoustic response is especially important in pediatric fittings because the smaller size of a child's ear generates a higher output SPL than an adult ear. Also, objective acoustic verification is especially important at an early age, when conventional behavioral measures of performance are difficult. Furthermore, a child is unlikely to sit quietly in one position for the time required to adjust a hearing aid response while monitoring its output with a probe tube in his or her ear.

RECD offers a helpful shortcut when testing children. After making one quick measure of SPL in the child's ear, the hearing instrument can be fitted to a prescriptive target by monitoring and adjusting its response in a coupler. This technique provides an accurate custom fit and avoids the challenge of trying to hold a young child still while making probe tube measurements and adjusting a hearing instrument to match a target.

In a second application, hearing instrument manufacturers routinely use an approximation to the RECD in their fitting software to calculate the predicted or simulated real-ear response, which is then displayed graphically on the computer screen. Also stored in the fitting software is the coupler response of the aid, and adding the average RECD to a known coupler response allows the software to predict the hearing instrument response in the average patient's ear.

ACCURACY OF AVERAGE RECDS

An important difference between these two applications of RECD is that the pediatric application uses a measured RECD, whereas programming software typically uses an average RECD. However, an individual RECD measurement, considered essential for the pediatric application, is also helpful in improving fitting accuracy in adults in lieu of real-ear measurements.

Even in an adult population, the RECD varies considerably from one ear to another (e.g., Bagatto et al., 2002; Fikret-Pasa and Revit, 1992; Munro and Toal, 2005). Another way of demonstrating this point is to couple the same hearing aid to a number of different ears, without changing any settings, and observe the extent to which the response of the aid varies, as measured by a probe microphone. Such a comparison, conducted in our laboratories, is shown in Figure 4, in which the output of the same open instrument was measured in the ears of nine subjects. SPL generated in these nine ears varies considerably, due once again to differences in the acoustic characteristics of the ear canals. In summary, to the extent that an average RECD fails to accurately represent an individual RECD, the predicted real-ear response, and the fit to target based on that response, will fail to accurately fit a prescriptive target based on a patient's audiogram.

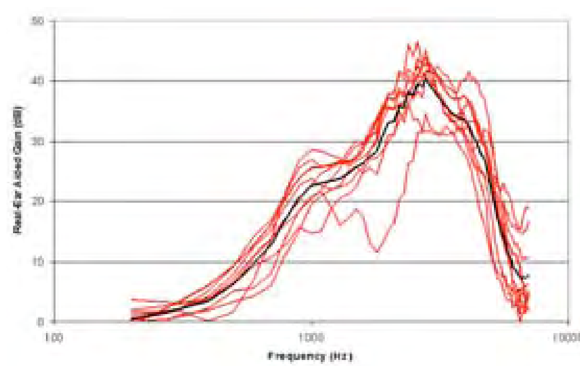

Figure 4. Real-ear aided gain from nine ears in response to the same hearing aid at the same settings, demonstrating the variability across ears. Measurements were done with Audioscan Verifit REM system.

A new solution: Integrated Real Ear Measurement. In Destiny and Zōn devices, Starkey's development team has created a unique data collection and processing scheme that allows the hearing instrument itself to measure the individual RECD and use those data to accurately predict the real-ear aided response. This capability allows an accurate fit to the prescriptive target and accurate quantification of subsequent changes in programmable parameters.

During the Integrated Real Ear Measurement procedure, the microphone and receiver of the hearing instrument temporarily perform operations different from their usual transduction of sounds into and out of the hearing

Figure 5. Probe tube attached to the Integrated Real Ear Measurement adaptor on a Zōn hearing instrument.

Figure 6. Destiny ITE and BTE in patients' ears with programming cable and probe tube in place. Attached to the BTE is a special earhook with a channel that allows the probe tube tip to attach to the microphone port. The orange band around the BTE case seals the rear port of the directional microphone to reduce ambient noise.

instrument circuitry. The receiver becomes a signal source, which sends a calibrated broadband signal to the ear canal. The microphone in turn becomes a probe microphone that measures the resulting signal generated in the ear canal. The two transducers essentially become the calibrated signal source and measurement microphone described earlier to perform a conventional RECD measurement.

The Integrated Real Ear Measurement calibration is initiated as part of the automated initial fitting protocol called Auto Path or by pressing the Integrated Real Ear icon on the Inspire® OS screen. (This initial step should be done prior to placing the probe tube in the patient's ear to avoid creating feedback as a result of the direct path through the probe tube from the ear canal back to the hearing aid microphone.) A dialog box appears instructing the operator in the necessary steps. After attaching the probe tube to the microphone and inserting its opposite end into the ear canal, the operator presses *Begin*. The receiver emits a calibrated tonal complex for eight seconds. This standard signal generates a sound pressure in the ear canal, which is then measured by the hearing aid microphone with a probe tube. This is the essential step that enables the hearing aid to measure SPL in the ear canal, and these data are then used to derive the individual RECD.

To prepare for the RECD measurement, the tip of a proprietary probe tube is attached to the microphone port of the hearing aid (Figures 5 and 6). The opposite end of the probe tube is inserted into the ear canal, either through the vent or alongside the shell or earmold. (If a Destiny or Zōn is ordered real-ear ready, the probe tube will already be in place and ready to go when the aid is received.) Care must be taken to make sure the tip of the probe tube extends at least 5 mm beyond the sound bore of the hearing instrument, to ensure accurate measurement at frequencies beyond about 4 kHz. The probe tube is marked to assist in proper placement.

The result of running the Integrated Real Ear Measurement is displayed in Figure 7. The graphs show the average RECD used by the Inspire OS software, based on published research by (Seewald et al., 1996) and the measured RECD for each ear of this patient.

Figure 7. Integrated Real Ear window in Inspire OS, showing average RECD (black dashed line) and individual RECDs for right and left ears (blue line).

As discussed earlier, the RECD allows us to predict real-ear SPL from coupler SPL. However, the SPL generated in an ear canal by a hearing aid – the real-ear aided response (REAR) – is also affected by microphone location effects (MLE), which differ from one hearing aid style to another. Since this effect is small, in comparison to RECD variability across ears, and quite consistent from one head to another (Bentler and Pavlovic, 1989), one set of corrections for MLEs as a function of frequency is stored in the Inspire OS software for each hearing aid model (Figure 8).

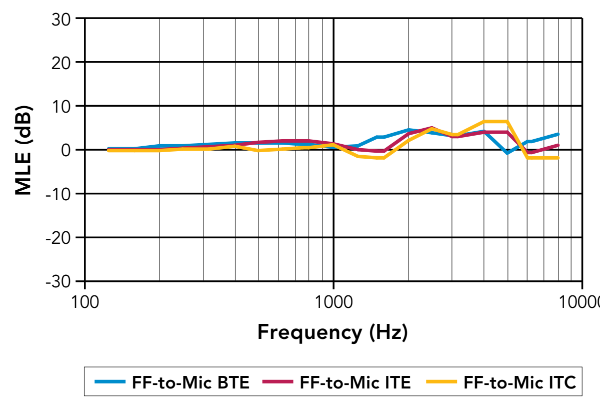

Figure 8. Microphone location effects for three hearing instrument styles.

The coupler response of each hearing aid model and matrix – the essential starting point in the derivation of REAR – is stored in the hearing instrument at the time of manufacture.

Based on the quantities discussed, an accurate prediction of the real-ear aided response is achieved according to the following formula, also illustrated in Figure 9.

REAR = Coupler response + RECD + MLE

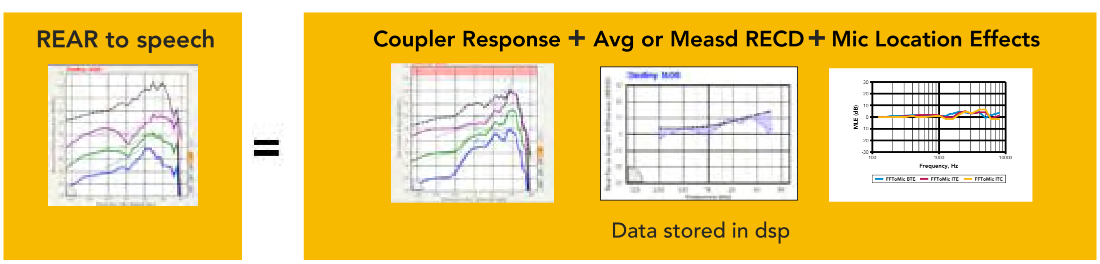

Figure 9. Derivation of individual REAR. Coupler response is the response to a known standard input.

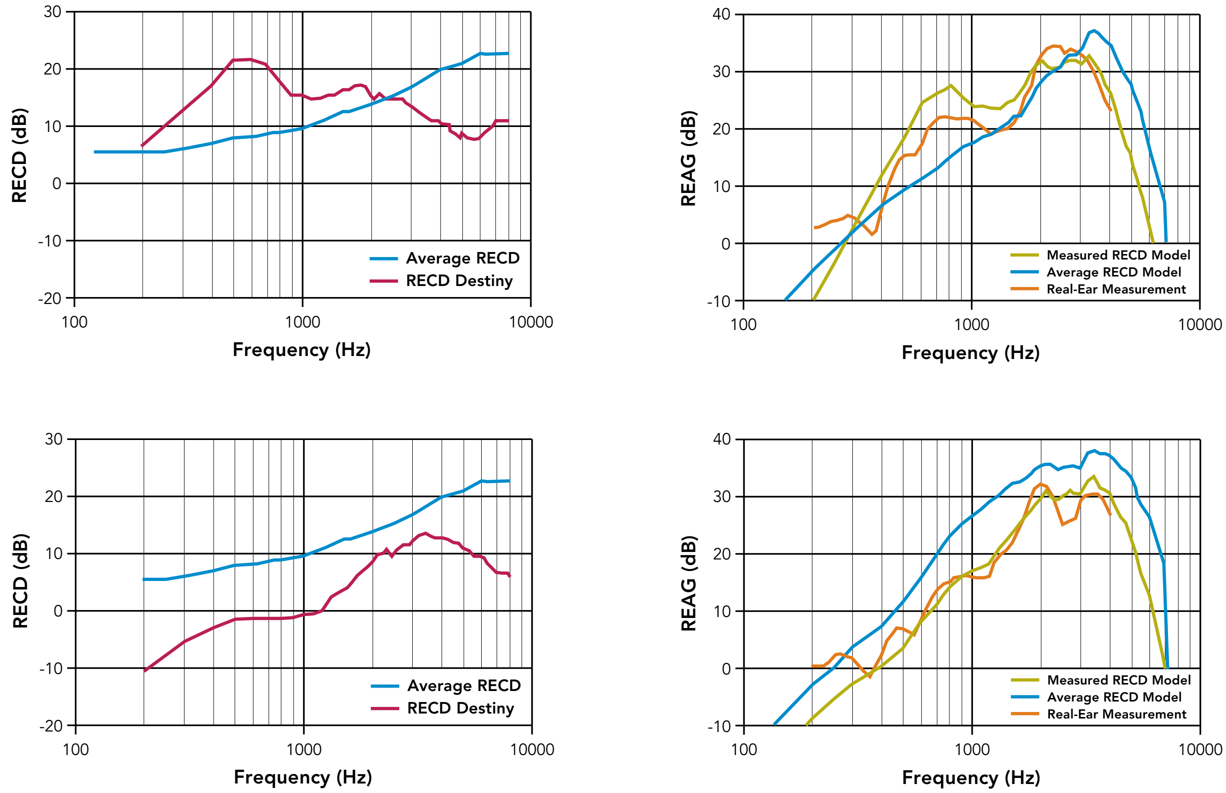

Figure 10. Insertion gain as a function of frequency for two subjects. Left panels: Average RECD (blue) and RECD measured by Destiny 1600 (red). Right panels: Predicted real-ear aided gain based on average RECD (blue) and based on measured RECD (green). Actual real-ear aided gain (orange) was measured with a commercial REM system.

BENEFITS OF INTEGRATED REAL EAR MEASUREMENT

The benefits of completing Integrated Real Ear Measurement include increased accuracy in the initial fit of the hearing instrument response to a prescriptive target and increased accuracy of subsequent fitting adjustments. Two examples of initial fitting accuracy are shown in Figure 10. The left panels show the average RECD and the individual RECD measurement. The right panels show two predicted real-ear aided gains – one based on the average RECD and the other based on the measured RECD for each patient. To assess the accuracy of these predictions, the real-ear aided response was measured using the AudioScan Verifit system. In both cases the predicted real-ear gain agrees more closely with the measured real-ear gain when the measured RECD is used.

The accuracy of the Integrated Real Ear Measurement system was evaluated in 52 ears. Destiny 1600 instruments were fit to each ear using average RECDs and RECDs measured with Integrated Real Ear Measurement. The acoustic response was then measured with the Audioscan Verifit Real Ear Measurement system. It was found that through the use of measured RECD the mean of all fittings fell closer to the prescriptive target than when the average RECDs were used. With Integrated Real Ear Measurement, the average deviation from target was less than 3 dB (Figure 11).

Analysis of the test-retest results indicates that the reliability of Integrated Real Ear Measurement is excellent. In Figure 12, individual data are plotted with a bold line indicating the mean test-retest reliability.

After the measurement of the individual RECD during the initial fitting, the probe tube is removed, and the Inspire OS screen displays an accurate estimate of the real-ear output, since the measured RECD is stored in the hearing instrument. As the Inspire OS software tracks adjustments in response variables, such as overall gain, channel gain and compression characteristics, it displays an ongoing, updated representation of the hearing aid output in the patient's ear, not only at the first visit but at follow-up visits as well. Integrated Real Ear Measurement would only need to be repeated in the event of an acoustic change to the hearing aid performance, such as vent or shell modification or replacement of a receiver or microphone.

As our data have shown, employing a measured RECD in the programming software has several benefits. First and foremost, the software can execute a more accurate fit to the chosen prescriptive target because the calculation of the hearing aid response is now based on the acoustic characteristics of the individual ear. Second, parameter adjustments to fine-tune the hearing aid to user preferences are displayed accurately. These steps in the fitting process can be performed after the probe tube has been removed from the patient's ear canal. With Integrated Real Ear Measurement available in the majority of Destiny and Zōn products both patients and practitioners can experience these benefits at many different technology levels.

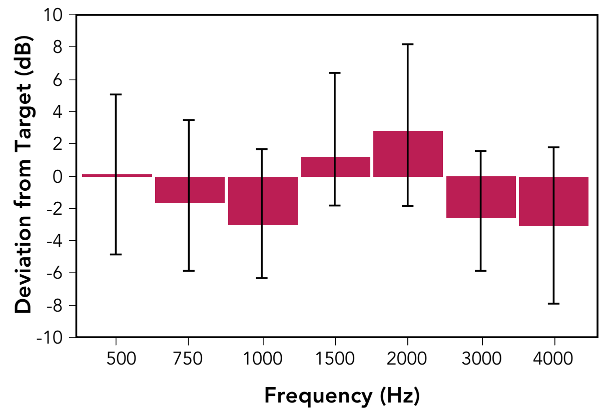

Figure 11. Mean deviation from NAL-R target as a function of frequency, after calibration with Integrated Real Ear Measurement. Error bars represent standard deviations.

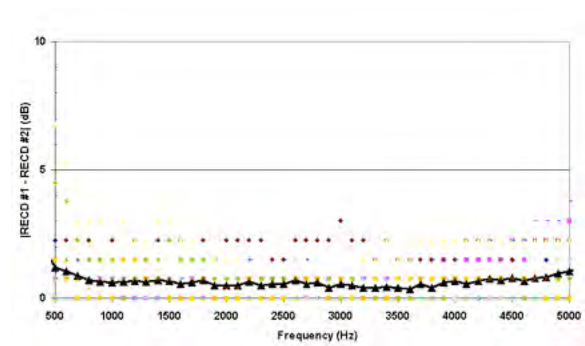

Figure 12. Test-retest reliability for RECD measurement using Integrated Real Ear Measurement in a Destiny 1600 CIC custom hearing aid.

Speech Mapping

The integration of real-ear measurement into Starkey hearing instruments directly supports a feature of the Inspire software called Speech Mapping. In conventional speech mapping procedures, the probe tube required for real-ear verification is placed in the patient's ear canal to measure the hearing aid response to any live or recorded signal, and the resulting output is displayed on a monitor. Now with speech mapping integrated into both the hearing aid and programming software, the aid's microphone functions as a transducer capable of monitoring the level of any acoustic inputs. By extracting data directly from the hearing aid, both the unaided input to the hearing aid and the aided output of the hearing aid can be displayed in the Inspire software. Destiny and Zōn devices with Inspire OS offer calibrated Speech Mapping.

Cunningham et al. (2002) offer data on the efficacy of using speech mapping to improve efficiency of hearing aid fittings. For digital hearing aid wearers, the use of a live speech map reduced the number of post-fitting return visits by about 50 percent, reflecting a decreased need for adjustments and further counseling.

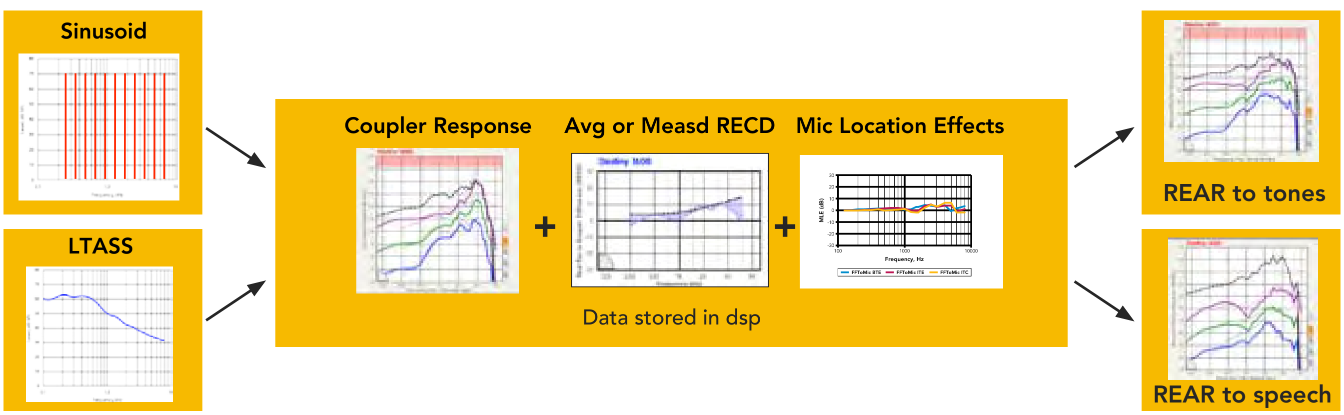

Figure 13. Components used to accurately predict real-ear aided response in an Integrated Real Ear Measurement.

Integrated Real Ear Measurement and Speech Mapping offer related but different information. Both measurements rely on knowledge of certain essential data stored in the digital signal processor, as shown in Figure 13: the instrument's coupler response to a standard input, either tonal or speech-shaped, the effects of programmed response parameters on the coupler response, the RECD measured in this patient's ear and the microphone location effects for this instrument type.

With this common starting point, Integrated Real Ear Measurement and Speech Mapping differ in what they use as the input signal. Integrated Real Ear Measurement, which creates the graphed Measured Real-Ear Response in dB SPL, assumes a standard input, either pure tones or a speech-shaped broadband signal based on the long-term average speech spectrum (LTASS) (Figure 13).

Speech Mapping, on the other hand, does not assume a standard input signal, but rather uses whatever signal reaches the hearing aid microphone as its input (Figure 14). Thus Speech Mapping reflects performance in response to whatever is happening at each moment. The graphed Speech Map in Figure 14 shows the real-time response to incoming speech (red bars) and a captured 10-second sample of speech, shown as a median level (magenta line) and range around the mean.

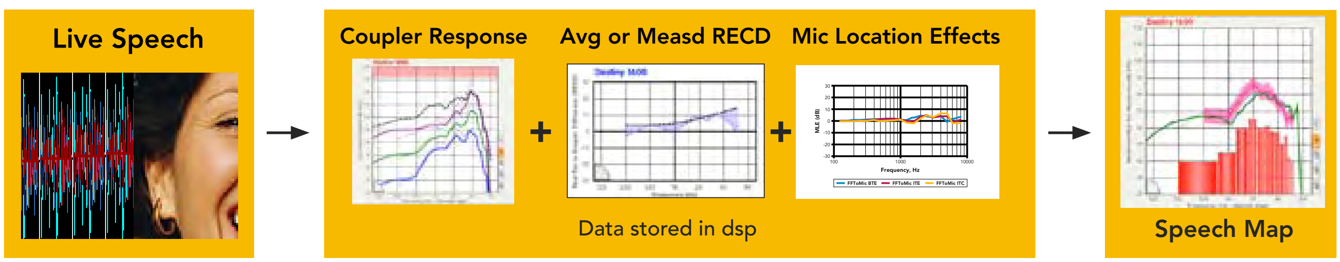

Figure 14. Components used to accurately predicting real ear aided response in Speech Mapping.

Speech Mapping offers several benefits to hearing professionals and patients. It allows the operator to monitor the hearing aid's response shape as programmable parameters are adjusted and adaptive features activate and deactivate. More important, by using live input to the hearing aid, rather than tones and noises, it has the potential to be used as a counseling tool, educating patients and engaging them in the fitting process.

Speech Mapping monitors the acoustic environment in real time. If music plays, the patient *hears* it and *sees* it. If a spouse speaks, that voice shows up on the graph. The hearing professional can plot the patient's audiogram on the Speech Mapping graph and superimpose the spouse's voice both unamplified, below threshold of audibility, and amplified, within the audible range above the hearing thresholds, at the same time the patient hears the voice.

Bringing real-world signals into the fitting process results in greater understanding of hearing loss and how hearing instruments work. The patient hears changes and simultaneously sees them on the computer screen, and the live visual display engages not only the patient, but also family members or friends who are important supporters of the rehabilitative process. The face validity of the fitting process is likely to increase, and both patient and family come away with a better understanding of what the hearing instruments are doing.

Summary

We have described in this paper the functionality and accuracy of Integrated Real Ear Measurement, a major feature that distinguishes Destiny and Zōn devices as state-of-the-art digital hearing instruments. This feature assists the patient and hearing professional in optimizing hearing aid benefit at the time of fitting and adjustment.

To the hearing professional, these features offer unprecedented accuracy in setting and adjusting hearing instruments, based on data collected with the hearing aids in the patient's ears. To the hearing aid wearer, they offer a means of becoming more fully engaged in the fitting process and reassurance about how the instruments work and the nature of the benefit they provide. For both the patient and professional these features enhance the exchange of information and the counseling process that is so important to a successful rehabilitative outcome.

Many thousands of hearing aid wearers have experienced the benefits of this technology in the Destiny and Zōn product lines. New hearing aid wearers are adapting easily to first-time hearing aid use. This success is the result of careful scrutiny in the laboratory and in the field, to ensure demonstrable patient benefit prior to product release.

The scope of this paper does not include all of the features of the Destiny and Zōn hearing instruments or the Inspire OS software that programs them. Rather, it provides an overview of Integrated Real Ear Measurement and Speech Mapping. A full understanding of these products will come from personal experience.

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