

# Assessing FM transparency, FM/HA ratio with digital aids

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The advantages of frequency modulation (FM) systems are well recognized.<sup>1</sup> In an ideal situation, an FM system that is connected to a hearing aid (HA) maintains the frequency-output characteristics of the hearing aid and enhances the signal-to-noise ratio (SNR) of the listening environment.

That said, a clinician who works with FM and hearing aids must evaluate if the addition of the FM results in the optimal use of the FM-HA combination. Specifically, the clinician must verify that: (1) the electroacoustics of FM and HA meet specifications (i.e., sufficiently broad bandwidth, no evidence of distortion, etc); (2) the coupling of the FM does not change the frequency response of the hearing aid in the various FM receiver positions (such as HA, FM, FM+HA) for the same stimulus input (i.e., transparency); and (3) the ratio of the FM output to the hearing aid output, when used in the FM+HA mode, is favorable.

This last verification goal is also known as the SNR advantage of the FM in the FM+HA mode. It is important for clinicians working with these two devices to know how to determine the FM/HA

ratio and, when necessary, to adjust the sensitivity of the devices to achieve the optimal ratio. The implicit expectation is that the FM+HA mode will increase wearer satisfaction.

Clinicians have sought to standardize the verification of FM systems when used with hearing aids. However, with the advent of digital signal processing (DSP) hearing aids, the parameters and protocols previously used to verify FMs and HAs may be inadequate. Digital processing can interact with the type and duration of the stimulus used, resulting in equivocal results. Furthermore, the type of FM system used, as well as the hearing aid analyzer used to measure transparency and FM/HA ratio, may affect the outcome of the verification.

Kuk and Keenan evaluated the impact of stimulus duration and stimulus type on the reliability and validity of verification.<sup>2</sup> Integrating their findings, we will present in this article a three-step protocol for measuring both the transparency and the FM/HA ratio in one measurement session. Specifically, we will describe the protocol, provide

a brief overview of Kuk and Keenan's findings pertinent to the measurements at hand, and demonstrate implementation of the protocol with two commercial hearing aid analyzers and a new FM system.

## WHAT NEEDS VERIFICATION?

### *Transparency*

If a wearer's hearing aid has been adjusted for optimal frequency response, its use with an FM system should not change that response. An FM system that does not alter the frequency-response characteristics of the hearing aid at a chosen input level is said to be transparent at that input level.

A transparent FM system will ensure consistent audibility, whether the hearing-impaired patient uses the HA alone, the HA with the FM connected but in the HA-alone mode, the HA with the FM connected but in the FM-alone mode, or the HA with the FM connected in the FM+HA mode—provided that audibility is assured in the HA-alone mode. Transparency

must be verified because real-ear verification of the FM/HA combination can be done with the coupler in the simulated mode only as long as real-ear verification of the HA-alone condition proves sufficient. Although many newer FM systems are transparent, some earlier ones were not, which meant that the frequency output of the hearing aids coupled to the FMs was significantly different from their output in the stand-alone position.<sup>3</sup>

### *FM/HA ratio*

An FM system, when used with a hearing aid in the FM-alone mode, yields an SNR advantage greater than 20 dB. But when it is used in the FM+HA mode, the SNR is generally poorer because both the FM transmitter microphone and the hearing aid microphone are active. A study by Hawkins revealed no difference in children's word-recognition scores between the FM+HA mode and the HA-alone mode (i.e., the FM failed to improve the SNR).<sup>4</sup> The outcome might have been different if the output of the FM had been higher than that of the HA.

*"... with the advent of digital signal processing (DSP) hearing aids, the parameters and protocols previously used to verify FMs and HAs may be inadequate..."*

It is important for clinicians to have an effective way to verify and adjust the relative gain settings between the FM and the HA if they wish to optimize both the FM input (e.g., the teacher's voice) and the hearing aid input (e.g., from classmates, own voice, environmental sounds).

The American Speech-Language-Hearing Association (ASHA) evaluated the issue of optimal FM/HA ratio and recommended a +10-dB SNR advantage of the FM output (over the HA output) in an FM+HA mode.<sup>5</sup> For example, the output of the FM system from an 80-dB SPL input signal should be 10 dB more than the output of the HA from a 65-dB SPL input when the FM is in the FM+HA mode. A 65-dB SPL input level is chosen to represent the level of conversational speech, while the 80-dB SPL signal reflects the level of the conversational speech of the speaker (i.e., the teacher) as measured at the FM microphone in the chest or lapel mic position.

While the +10-dB advantage may be a good compromise, it may not always be achievable when the FM is in its default position. Furthermore, the FM/HA wearer may require a lower ratio to perceive environmental sounds and classmates' voices (from the HA mic) or a higher ratio to further enhance the teacher's voice (or attenuate classmates' voices). Thus, knowing how to verify and adjust the FM/HA ratio will be beneficial.

### THE THREE-STEP PROTOCOL

Clinicians may follow this protocol to assess both the transparency and the FM/HA ratio of an FM-HA combination in a single measurement session using only coupler measurements.

❖ Step I: Obtain a reference. Measure the output of the hearing aid in the FM+HA mode with a 65-dB SPL speech or speechlike stimulus presented to the hearing aid for 8 to 10 seconds.

Step II: Transparency. Measure the output of the hearing aid in the FM+HA mode with a 65-dB SPL speech or speechlike stimulus presented to the FM mic for 8 to 10 sec-

onds. The frequency-output curves obtained in Steps I and II should be similar if the FM is transparent.  
+ Step III: FM/HA ratio. Measure the output of the hearing aid in the FM+HA mode with an 80-dB SPL speech or speechlike stimulus presented to the FM mic for 8 to 10 seconds. The difference in output between Steps III and I defines the FM/HA ratio (or relative output of the FM/HA combination).

### *Basis for the recommendations*

Given the definitions of transparency and FM/HA ratio, it is intuitive why the difference between Steps I and II should reflect transparency (or the lack thereof) and why the difference between the steps should reflect the FM/HA ratio. However, the basis for the specific stimulus

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characteristics (i.e., speech or speechlike stimuli for 8-10 seconds) requires further explanation.

A key difference between today's DSP hearing aids and traditional analog linear hearing aids is the use of non-linear signal processing, which also includes many adaptive features. Rather than responding instantaneously to the input signals as in linear processing, non-linear signal processing requires time to effect change.

For example, the attack time on a compression hearing aid decides how long the hearing aid takes to reach a stable, reduced gain state. The longer the attack time, the longer it takes the non-linear hearing aid to reach the compressed state. In a fast-acting compression system, it may take less than a second for the output to stabilize, whereas in a slow-acting compression system, it may take as long as 2

seconds to stabilize. Furthermore, the use of a modulated signal (such as the digital speech signals used on the Frye) could take as long as 8 seconds to reach a stable, compressed state. For a single procedure to be useful for most compression systems and most signal types, the selected stimulus must be longer than 8 seconds.

The action of noise-reduction algorithms in many DSP hearing aids can confound the results in two ways: introducing variability in the output and reducing the output. These algorithms evaluate the modulation characteristics of the input signals to decide if additional gain reduction should occur. It is necessary to use either a modulated signal (speech or speechlike signals) or a non-modulated signal shorter than the activation time of the noise-reduction algorithm to prevent the hearing aid from initiating additional gain reduction. For Widex hearing aids with such an algorithm, the duration of a continuous signal must be no longer than 15 seconds to avoid the action of the noise-reduction algorithm.

The action of an active feedback-cancellation mechanism must be considered as well. These algorithms examine the input signals over time and identify repetitive signals or sinusoidal signals as feedback. The use of speech or speechlike stimuli or signals shorter than 10 seconds will bypass the action of these algorithms and result in a reliable output.

The action of an adaptive directional microphone may also affect the outcome of the evaluation. The azimuth of stimulus presentation, the nature of the stimulus (continuous versus modulated), and the duration of the stimulus can all affect the measured output. This is especially critical when measuring the output of the hearing aid alone in its normal mode of operation. In such a case, a modulated signal of 8-10 seconds presented at the correct azimuth yields the most reliable response. However, since some hearing aids, including the Widex Senso Diva, change to an omnidirectional mic in the FM+HA mode during the evaluation, no special considerations are necessary to bypass this feature during FM evaluation.

These considerations prompted us to choose a speech or speechlike signal to

bypass the noise-reduction and feedback algorithms, and a signal duration of 8-10 seconds to ensure a stable output.

### Implementation of the protocol

The FM system used in this illustration is the Scola, an FM system recently introduced by Widex that is compatible with most behind-the-ear hearing aids. Like many other FM systems today, it uses a miniature FM receiver that can be coupled to the base of a BTE. However, a transparent audio shoe is used with a slide-on plug instead of the Euro-plug for a firmer attachment to hearing aids. Furthermore, the sensitivity of the FM input can be adjusted via a screw potentiometer on the receiver.

The FM transmitter is a hand-held device with several directional-microphone options. During evaluation, the FM transmitter's microphone must be set to the omnidirectional mode and it must directly face the sound outlet of the hearing aid analyzer for a reliable output. The protocol described should be applicable to other FM systems as well.

The Diva BTE hearing aid is used in the demonstration. This is an advanced DSP hearing aid with 15 channels of independent enhanced dynamic range compression, each with an adaptive attack and release time (SoundStabilizer™). A noise-reduction algorithm, a fully adaptive directional microphone, and an active feedback-cancellation algorithm are among the non-linear adaptive features that must be controlled during the HA and FM measurements.

To avoid output variability, one can set the hearing aid to a special test mode (Test Mode 2) and deactivate some of the features during real-ear/coupler measurements. However, doing so requires the hearing aid to be programmed to that condition. This may be difficult for clinicians who lack the software for the programming of a special test mode. In acknowledgment of clinical realities, the current protocol was written so that the hearing aid can be in either its normal mode or the special test mode. Because this recommendation is based on the Diva hearing aids, minor deviations may occur with other hearing aids. However, we believe this recommendation is inclusive enough to be suitable for most of today's hearing aids, both digital and analog.

### DEMONSTRATION WITH THE AUDIOSCAN SYSTEM

The Audioscan Verifit is a hearing aid analyzer that allows real-ear, simulated real-ear, and coupler measurement of hearing aids and FM systems. The output is displayed with a 1/3-octave bandwidth. This system allows the use of real-life speech stimuli (child, female, male) and ICRA digitally distorted speech stimulus, as well as a continuous pink noise as stimuli for evaluation. Each speech stimulus is about 10 seconds in duration, and the output of the hearing aid can be "captured" or averaged over the course of the stimulus.

For a reliable output, it is important to use averaging by pressing the "continue" function. The "capture" function captures the instantaneous output spectrum of the hearing aid at only one point in time. This can be extremely variable over time. Because the spectra of various real-life stimuli differ significantly, we choose ones whose spectra may be similar to those available on other hearing aid analyzers. For this reason, we recommend the "female speech" and the "ICRA" signals on this system for verification purpose.

### Pre-evaluation

In the following example, the Audioscan is used in the "simulated real-ear" mode for ease of implementation. This is a recommended mode to use after the output of the hearing aid alone has been verified to meet one's criteria of acceptability (e.g., meeting a particular prescriptive gain target, ensuring that soft sounds are above thresholds) using real-ear or other measurement tools. If the FM is transparent to the HA, the real-ear output of the FM+HA should be similar to the real-ear output of the hearing aid alone.

When considering a criterion of acceptability, it is important to realize that many prescriptive gain/output targets have not considered the issue of channel summation in their formulation. Thus, the target values may be higher than the intended values.<sup>6</sup> Rather than matching the average output to the gain targets for conversational level sounds, one may instead estimate how much of the softer signal is above the wearer's threshold as a criterion estimate of audibility. Any adjustment of the hearing aid to achieve this audibility should be made at this stage.

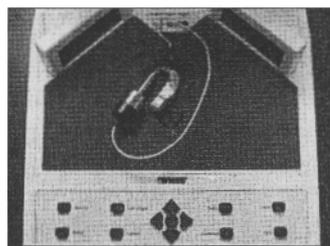
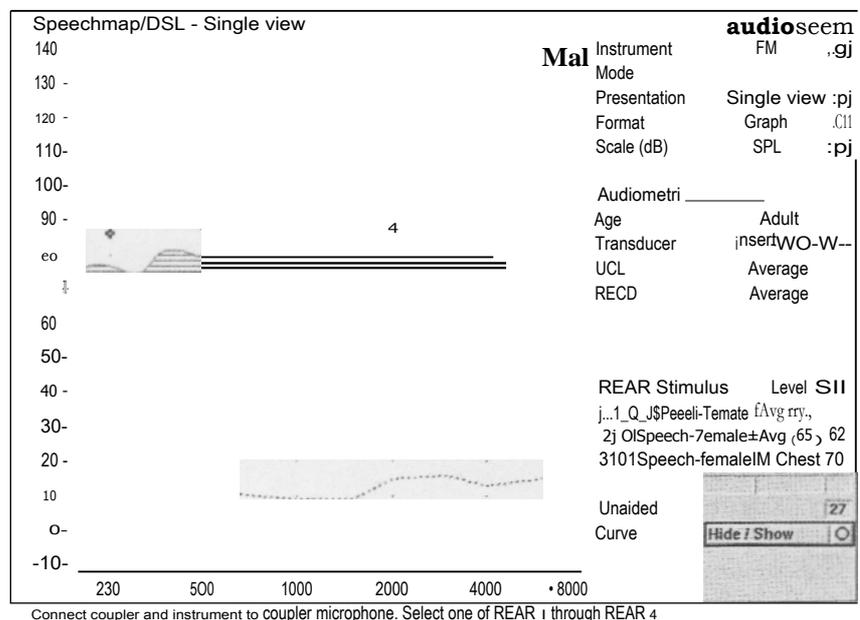


Figure 1. (A) Placement of hearing aid in the Audioscan test chamber. The female speech signal was presented from the left loudspeaker. (B) Output of the Senso Diva with a 65-dB SPL female speech signal averaged over the course of 10 seconds with the signal presented to the hearing aid (in FM+HA).



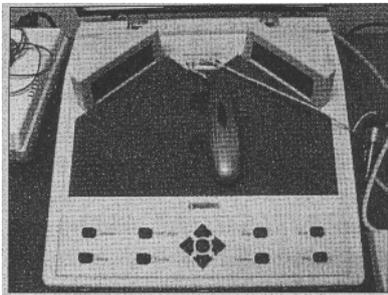
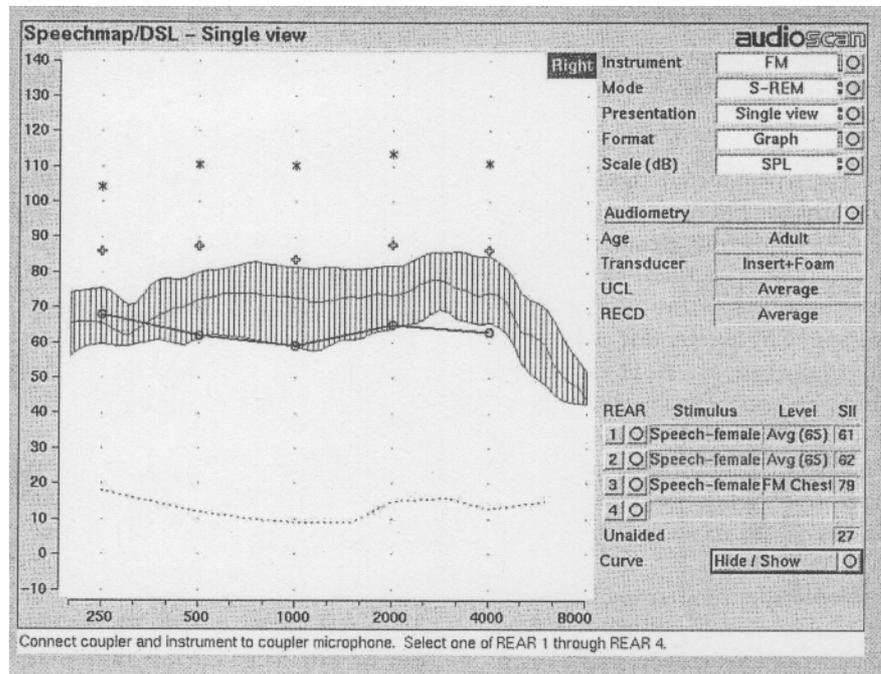


Figure 2. (A) Recommended position of the Scola Fiti 1 mic/transmitter in the Audioscan test chamber. The FM mic should be in the omnidirectional mode, (8) Output of the Diva with a 65-dB female speech signal averaged over the course of 10 seconds with the signal presented to the FM mic (in FM+HA).



## Evaluation

Step II of the three-step protocol is, as is explained above, to obtain a reference. Figure 1A shows the position of the hearing aid (connected to the FM receiver) in the test chamber. A 65-dB SPL female speech signal is directed to the hearing aid microphone with the FM receiver in the FM+HA position. The female speech signal is presented in its entirety (about 10 seconds) and the "continue" option is selected to average the output over time. Figure 1B shows the output of the hearing aid. The FM transmitter is in the omnidirectional mode and positioned outside the test chamber. Since the FM microphone is active, it is important to perform this testing in a quiet environment.

Step II of the protocol is to determine transparency. Replace the hearing aid (and FM receiver) with the FM mic/transmitter and position it in the test chamber as illustrated in Figure 2A. The position of the FM transmitter is critical in avoiding potential baffle or shadow effects. In addition to the illustrated position, the FM mic may be placed in parallel to the signal source. Also, the FM mic should be set in the omnidirectional mic mode. Once properly placed, the 65-dB SPL female speech signal may be presented in its entirety (using the "continue" option) and the output from the HA measured. Meanwhile, the hearing aid is connected to the HA coupler and left outside the test chamber. The output is shown in Figure 2B.

If one examines Figures 1B and 2B, they appear to be very similar. Indeed, if one superimposes the two curves, they are within 1-2 dB of each other. When the curves determined in Steps I and II are identical, transparency of the FM system (with the HA) is confirmed.

Step III is to measure the FM/HA ratio. With the hearing aid outside the test box and the FM transmitter still inside the test chamber, select "FM" and choose the appropriate stimulus to present to the FM transmitter. Since the FM mic used in this example is designed to be worn on the chest, a "chest mic" position should be selected to correct for the increase in sound pressure level as the microphone is moved closer to the talker. Another alternative is the "boom mic," which incorporates different corrections.

One may also wonder if the same stimulus (i.e., female speech) should be presented as the signal of interest. For example, one may argue that if a child's teacher is a man, the clinician should select male speech as the stimulus to represent the real-life situation more accurately.

However, there are two other considerations. First, female speech is selected because it is closer in spectral characteristics to the characteristics recommended by ANSI 3.42. Choosing the signal would result in a different audibility estimate. Secondly, because of the spectral difference between stimuli, the use of different stimuli for FM and HA would confound

the estimated FM/HA ratio. In this case, it would be lower than if the same stimulus was used in both measures. For these reasons, the same female speech in the chest position is recommended.

Figure 3 shows the output of the hearing aid when the input is presented to the FM mic in the chest position and the FM mic/transmitter is positioned as in Figure 2A. When the curve obtained in Step III is superimposed on the curve obtained in Step I, one obtains an estimate of the FM/HA ratio as the difference between the two curves. In this case, the estimated ratios vary from 0 to 12-dB across frequencies, with the most typical difference around 9 dB.

The Audioscan also offers another way of estimating the FM/HA ratio through the use of a table display (Figure 4), which lists the numeric output at several frequencies. In this example, REAR 1 is the numeric output at the specific frequencies when the signal is presented to the hearing aid; REAR 2 is the output when the signal is presented to the FM; and REAR 3 is the output of the HA when the female speech is measured at the FM-chest position. The difference between REAR 1 and REAR 3 defines the FM/HA ratio at a particular frequency.

## Adjustments in direct audio input sensitivity

The previous steps reveal the FM/HA ratios at the default setting of the FM.

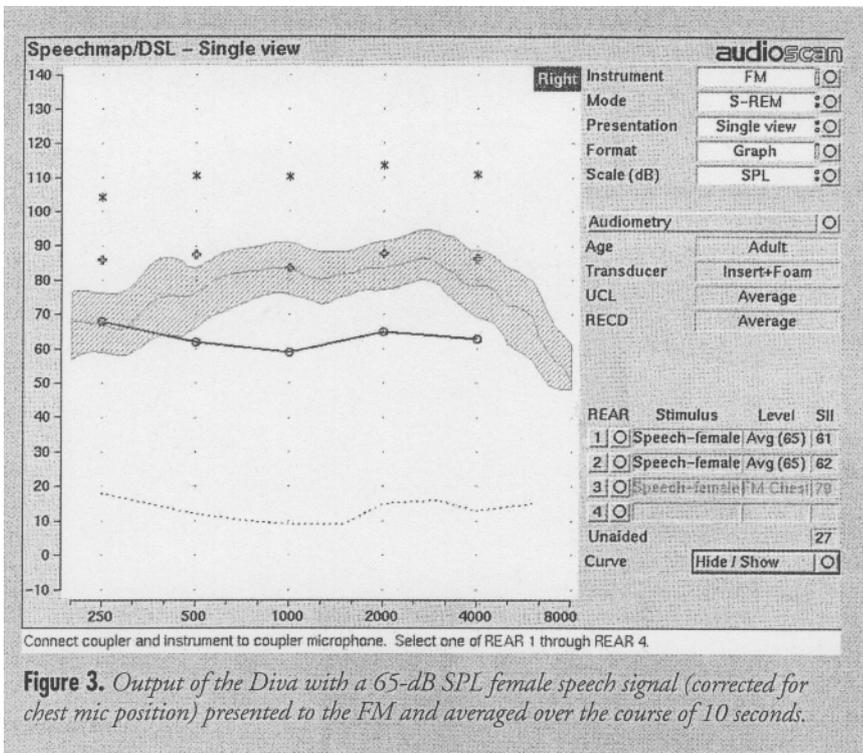


Figure 3. Output of the Diva with a 65-dB SPL female speech signal (corrected for chest mic position) presented to the FM and averaged over the course of 10 seconds.

However, a +10-dB FM SNR may not always be obtainable or desirable. Fortunately, today's FM receivers frequently have gain controls/potentiometers that allow adjustments to the sensitivity of the FM microphone or output of the FM. For example, the Scola receiver incorporates a gain parameter that can be adjusted by +/-7 dB. The above measurement (Step III) can be repeated after an adjustment to the FM receiver sensitivity to achieve the desired FM/HA ratio. In some hearing aids, such as the Senso Vita BTE, one may also adjust the direct audio input (DAI) sensitivity directly through the hearing instrument using the fitting software.

### DEMONSTRATION WITH THE FRYE SYSTEM

The Frye Fonix 6500 system typically allows coupler and real-ear measurements using primarily composite (or synthetic complex) signals that are speechlike. These signals include the "speech-shaped composite noise" (or composite), which is a continuous signal with spectral characteristics that comply with ANSI 53.42-1992 specifications; the digital speech-ANSI signals, which are modulated signals (randomly, about four times a second, to approximate the temporal patterns of speech) that have the spectra of the speech signal specified by ANSI; and digital speech-ICRA signals, which have the

spectra of the speech signal specified by the International Collegium of Rehabilitative Audiologists. Output from the hearing aid is displayed using a 100-Hz fixed bandwidth.

Once the output of the hearing aid is stabilized, the clinician presses a stop button on the control panel to freeze the frequency-output response. Although both ANSI- and ICRA-weighted digital speech

are speechlike signals, we recommend the ANSI-weighted speech signal because it is similar in spectrum to the female speech used in the Audioscan system.

### Pre-evaluation

Again, it is important to ensure that the settings on the hearing aid alone meet one's criteria of acceptability when using real-ear measurement. As explained before, if the real-ear results are acceptable, a transparent FM system will also result in an acceptable output, even though coupler measurements are conducted with the FM-HA combinations. Real-ear output of the hearing aid alone should be measured and displayed on the SPL-O-gram screen to estimate acceptability before proceeding to FM measurements.

Figure 5 is a real-ear display of the hearing aid output (SPL-O-Gram) from the Frye 6500 system. The output of the hearing aid with 50-dB and 65-dB SPL, ANSI-weighted digital speech signals is displayed in relation to the patient's thresholds and UCLs. The signal was presented for 8 seconds at 0° azimuth. One can see that the output for the softer stimulus was above the thresholds of the wearer through 4000 Hz, ensuring the criterion of audibility. Adjustments may be made on the hearing aid at this stage to reach one's criterion of acceptability. Afterwards, all subsequent evaluation may be done in a coupler.

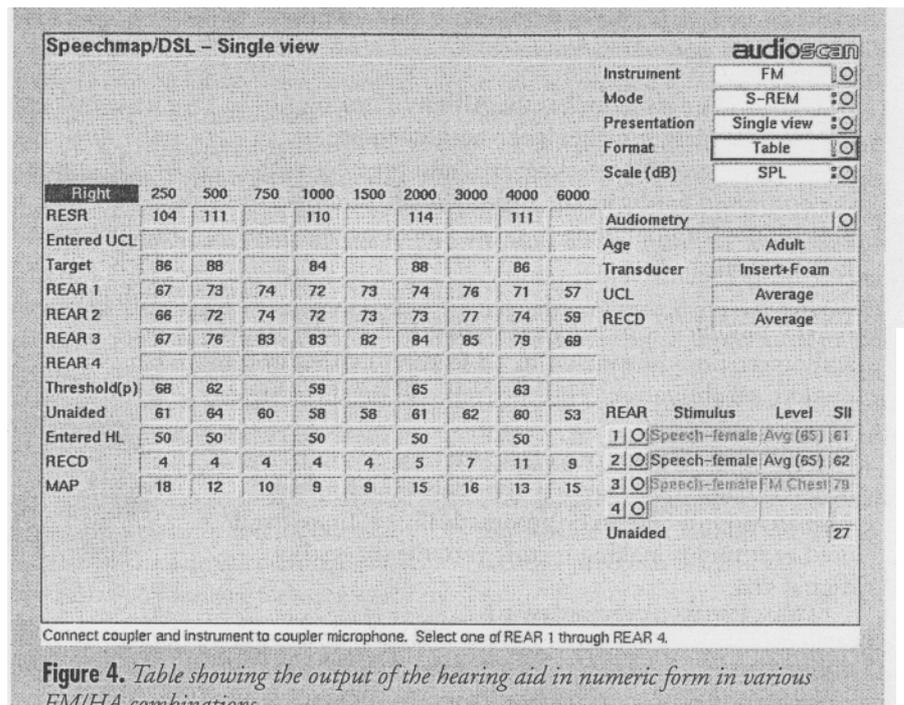


Figure 4. Table showing the output of the hearing aid in numeric form in various FM/HA combinations.

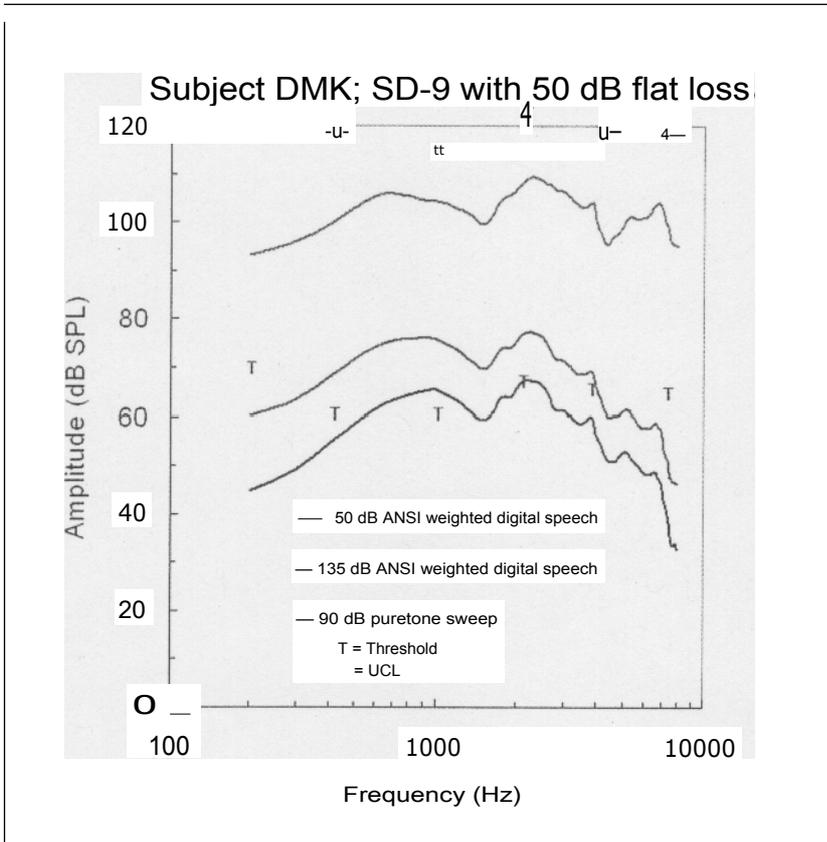


Figure 5. Real-ear output of the Diva evaluated with the Fiye 6500.

**Evaluation**

Step I: Obtain a reference. Figure 6A shows the position of the hearing aid (connected to the FM receiver) in the test chamber. A 65-dB SPL ANSI-weighted digital speech signal is directed to the hearing aid microphone with the FM receiver in the FM+HA position. The modulated ANSI-weighted digital speech signal is presented for 8 seconds to allow the output of the hearing aid to stabilize. The stop button is pressed to freeze the screen and capture the response.

Figure 6B shows the output of the hearing aid. The FM transmitter is in the omnidirectional mode and positioned outside the test chamber. Since the FM microphone is active, it is important to perform this testing in a quiet environment.

Step II: Determine transparency. Replace the hearing aid (and FM receiver) with the FM mic/transmitter and position it in the test chamber as illustrated in Figure 7A. Because the signals are presented from a loudspeaker underneath the device being evaluated, the position of the FM transmitter is less critical as long as the microphone is within the indicated circle in the test box. In addition, the FM

mic should be set in the omnidirectional mic mode. Once properly placed, the 65-dB SPL ANSI-weighted speech signal may be presented for 8 seconds and its output from the HA measured. Meanwhile, the hearing aid is connected to the HA coupler and left outside the test chamber. The

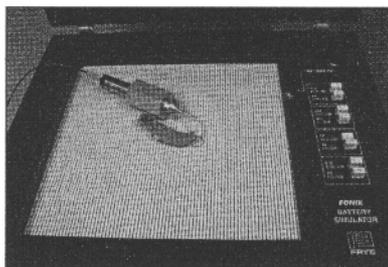
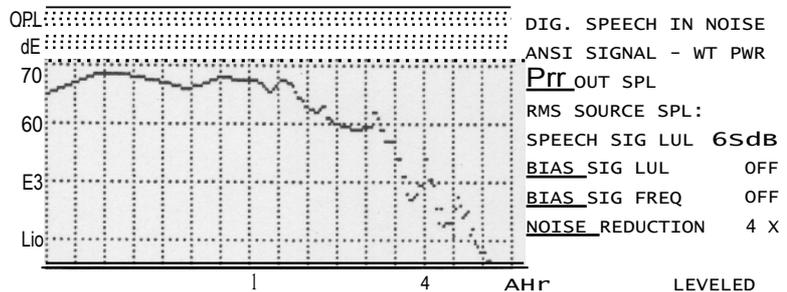


Figure 6. (A) Placement of hearing aid in the Frye test chamber. The 65-dB SPL ANSI-weighted digital speech signal was presented from the loudspeaker underneath the hearing aid. (B) Output of the Diva with a 65-dB SPL ANSI-weighted digital speech signal captured after it has been presented for 8 seconds to the hearing aid (in .17M+HA).

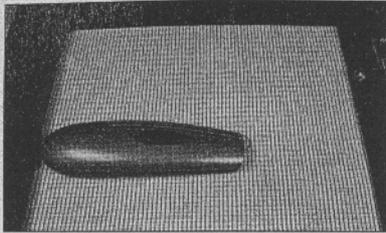


output is shown in Figure 713.

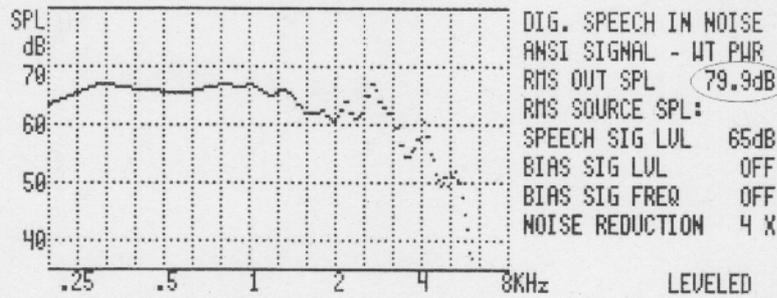
If one compares Figures GB and 7B, they appear to be very similar. Indeed, if one superimposes the two curves, they are within 1-2 dB of each other. When the curves determined in Steps I and II are identical, transparency of the FM system (with the HA) is verified. An advantage of the Frye system is that it also reports the overall output level on the right-hand side. In this case, the output in Step I is 79.6 dB and 79.9 dB in Step II.

Step III: Measure the FM/HA ratio. With the hearing aid outside the test chamber and the FM transmitter still inside the test chamber, increase the level of the ANSI-weighted digital speech signal to 80 dB SPL and present it to the FM transmitter for 8 seconds. Freeze the screen when a stable response is reached. This level of stimulus intensity is selected to correct for the increase in sound pressure level as the microphone is moved closer to the speaker.

Figure 8 shows the output of the hearing aid when the input is presented to the FM mic at 80 dB SPL and the FM/transmitter is positioned as in Figure 7A. When the curve obtained in Step III is superimposed to the curve obtained in Step I, an estimate of the FM/HA ratio is obtained as the difference between the two curves. Furthermore, one may subtract the overall levels reported on the right-hand side between Steps I and III. In this case, the estimated ratio was 8 dB



**Figure 7.** (A) Recommended placement of the Scola FM mic/transmitter in the Frye test chamber. The FM mic should be in the omnidirectional mode. (B) Output of the Diva with a 65-dB SPL ANSI-weighted digital speech signal captured after it has been presented for 8 seconds to the FM mic (in FM+HA).



(87.6-79.6). Note that this level is reported as an overall level change (i.e., across all frequencies and not 1/3-octave frequencies, as reported in the Audioscan). One may adjust the FM receiver to achieve a more desirable FM/HA ratio.

(Note: Frye Electronics offers software called "Press and Go" that allows automated testing of the FM/HA ratio similar to the test described in this paper when the Frye system is connected to a personal computer via an RS232 cable.)

## CONCLUSIONS

Despite the difference in stimuli used in the two hearing aid analyzers (one female speech and one ANSI-weighted speech-shaped noise), the estimated transparency and FM/HA ratios measured in the FM-HA combination are remarkably similar. For both the Audioscan and the Fonix,

the output spectrum obtained in Step II was similar to that in Step I, suggesting transparency. In addition, the FM/HA ratio was 8 to 9 dB for both test systems, although it is important to note that the Audioscan reports in 113-octave levels and Frye reports an overall level.

The result may differ if different stimuli are used during the evaluation. Indeed, during our evaluation, we realized that the use of different stimuli from the same hearing aid analyzer or use of the "same" stimulus on different hearing aid analyzers often yielded a different estimate of the FM/HA ratio.

This raises an important question for clinicians to consider. If the noted FM/HA ratio varies depending on test stimuli and test systems, which stimulus (and test system) should be used to obtain results that best represent the real-life performance of

the FM-HA combination? While more research is necessary to reach a consensus, clinicians should use the same equipment, test stimulus, and test method each time they make the measurements in order to avoid matching one FM/1-1A ratio target in the first test session and another FM/HA ratio target in the next test session.

Prior to making hearing aid program changes to accomplish a desired FM advantage, the clinician should, whenever possible, supplement results with performance-based measures.

Although it is impossible to eliminate all sources of error when making these measurements, using a consistent test method will at least limit the variability that would otherwise occur. The three-step procedure described in this article is a sequential approach that can achieve both the goals of assessing transparency and of determining a beneficial FM/HA ratio. Although results displayed were obtained with the Widex hearing aids and FM system and only two commercial hearing aid analyzers, its principles should be applicable to other hearing instruments and hearing aid analyzers.

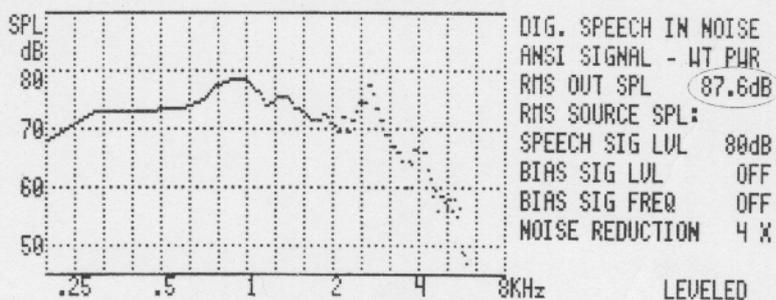
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**Figure 8.** Output of the Diva with an 80-dB SPL ANSI-weighted digital speech signal presented to the FM (in FM+HA) for 8 seconds.