The Effect of Analysis Methods and Input Signal Characteristics on Hearing Aid Measurements

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Section 1: Common Source Types

FONIX analyzers contain two main signal types: Pure-tone and Broadband. In a pure-tone sweep, the analyzer produces a tone at each frequency, takes a measurement, and moves onto the next frequency. Each tone in the sweep is presented with the same input amplitude that is either set by the user or pre-defined by an automated test sequence such as ANSI.

There are six different pure-tone source types:

- LONG: Pure-tone sweep using 64 different frequencies. This signal is the most detailed pure-tone sweep used by FONIX analyzers.

- NORMAL: Pure-tone sweep using 49 different frequencies. This signal is the standard pure-tone sweep to use for more pure-tone measurements.

- SHORT: Pure-tone sweep using 10 different frequencies. This signal is mostly used in real-ear measurements to test with an input level of 90 dB SPL.

- FAST: Repeating pure-tone sweep using 16 different frequencies. This signal is a "real-time" version of a pure-tone sweep.

- SINGLE: Single pure-tone at frequency set by user. This signal is used to obtain the hearing aid response at a particular frequency.

- AVG: Three frequency pure-tone mini sweep. This signal is mostly used in test sequences such as ANSI.

There are two main types of broadband signals:

- Composite: A continuous broadband signal consisting of 79 different frequencies presented simultaneously.

- Digital Speech: A modulated version of the Composite signal that turns itself off and on in order to simulate speech, thus preventing advanced digital hearing aids from going into noise suppression mode.

Section 2: Speech Weighting

During a typical pure-tone sweep, an equal amount of intensity is presented to each frequency of the pure-tone sweep. This intensity is equal to the average intensity of the signal. That is, if the source type is set to 65 dB SPL, a pure-tone signal is presented at 200 Hz at 65 dB, and a measurement is taken. Then a 300 Hz signal is presented at 65 dB, and a measurement is taken. The sweep progresses until all frequencies have been presented and measured.

The arithmetic used in calculating hearing aid gain is very simple when testing with puretone sweeps. If the test output is 90 dB at a certain frequency, and the input signal is 65 dB, then the gain is 25 dB. As a result, when a clinician examines puretone test results in terms of output (dB SPL), it's very easy to quickly determine how much gain the hearing aid is producing. When testing with broadband signals, however, the arithmetic is much more complicated.

When a broadband signal is used, the signal consists of multiple frequencies presented simultaneously. Usually when testing hearing aids, broadband signals are "speech weighted." That is, the lower frequencies of the signal contain more energy than the higher frequencies of the signal. See Figure 1 for an example of the Composite signal using the speech weighting defined by the ANSI S3.42 standard. The total energy of this signal is 65 dB SPL.

Notice that while the total energy of the signal is 65 dB SPL, the energy of the individual frequencies starts at 54 dB at 200 Hz and decreases to 35 dB at 8000 Hz. This can be confusing to even experienced clinicians.

To explain the phenomenon, imagine a single speaker outputting a 65 dB signal. Now add a second speaker outputting the same amount of energy. Basic physics tells us that doubling the energy adds 3 dB to the signal. Therefore, the total energy of the two speakers combined is 68 dB. The Composite signal can be thought of as a series of 79 different speakers, each outputting energy. When the energy is summed, it equals the desired input level of the signal. However, the energy of the signal at any single frequency is much less than the total energy of the entire broadband signal.
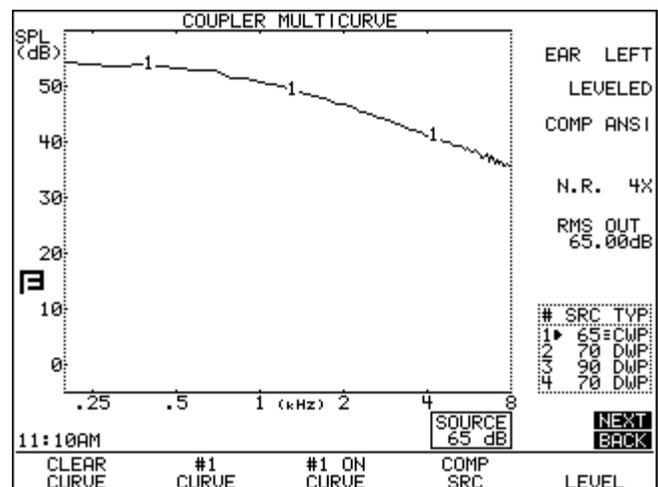

Figure 1: *ANSI Speech-weighted composite signal with an RMS output of 65 dB SPL*

When viewing test results in terms of dB Gain, the speech weighting of the input signal does not usually have a large impact on test results because it is subtacted out when the input is subtracted from the output. (See Section 3 for information on how it *can* affect test results.)

However, when viewing test results in terms of output (dB SPL), the speech weighting of the input signal has a very large impact on the displayed test results. Figure 2A is an example of a Gain graph of a hearing aid measured with a Composite signal (Curve 1) and a puretone sweep (Curve 2). Figure 2B shows the same measurements with the test results displayed in dB SPL. An inexperienced clinician may be tempted to examine the Composite signal test results in Figure 2B and mentally caculate that the hearing aid is only producing 27 dB of gain (92-65) at 2000 Hz, when in reality the hearing is actually producing 45 dB of gain.

As Figures 2A and 2B demonstrate, it is critical that the clinician performing the hearing aid measurements is aware of the characteristics of the input signal and how it may affect test results, particularly when viewing results in terms of dB SPL.

Fortunately, both the FONIX 7000 and FP35 hearing aid analyzers will automatically convert almost all measurements quickly between dB Gain and dB SPL, making mental arithmetic gymnastics unnecessary.

Section 3: Speech Weighting and Compression Characteristics

The term "speech weighting" when used with hearing aid measurements usually refers to the use of a broadband signal in which the low frequencies of the signal have more energy than the high frequencies of the signal.

The ANSI S3.42 standard defines a particular type of speech weighting that is commonly used in broadband signals used to test hearing aids. Figure 1 shows a 65 dB broadband signal with the ANSI S3.42 speech weighting.
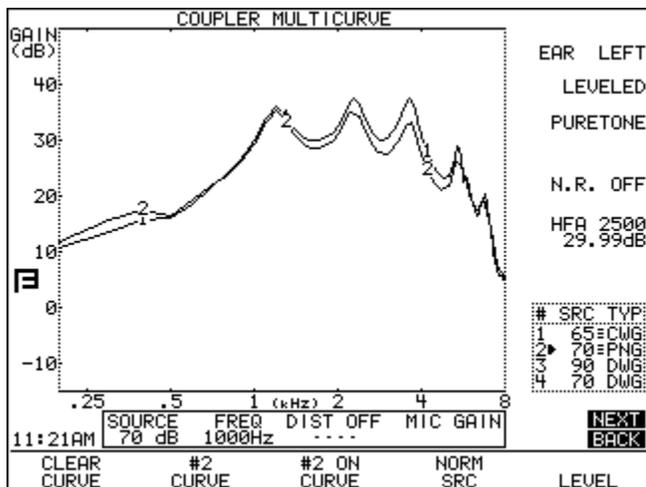
On FONIX hearing aid test equipment, ANSI speech weighting (or "filter") refers to this type of signal.

Another common speech weighting is called ICRA. The International Collegium of Rehabilitative Audiologists (ICRA) developed a CD of sounds that represent simulated speech. This CD of sounds was used in the development of many early digital hearing aids. Frye Electronics determined the ICRA speech weighting by performing a spectrum analysis of the adult male speech track on the ICRA CD. This analysis was turned into the ICRA filter used by FONIX hearing aid testing equipment. See Figure 3 for a comparison of the ANSI S3.42 and the ICRA speech weighting. Notice ICRA has more energy in the low frequencies but less energy in the high frequencies than the ANSI S3.42 signal.

The ANSI and the ICRA speech weighted signals have the same amount of total intensity. However, the distribution of that intensity is different: ANSI has more energy in the high frequencies and less energy in the low frequencies than ICRA. When testing hearing aids with sophisticated automatic compression, this difference can affect the shape of the resulting frequency response. Some hearing aids may actually produce more gain in the high frequencies when exposed to a signal with ICRA speech weighting than when exposed to a signal with ANSI weighting. This is because the hearing aid detects less energy in the high frequencies of the ICRA signal and may seek to amplify those frequencies more than it would an ANSI-weighted signal with greater energy in the same frequencies.

Figure 4A illustrates the difference between a hearing aid tested with an ANSI weighted broadband signal (Curve 1) and an ICRA weighted broadband signal (Curve 2). Test results are shown in gain. Notice the ICRA-weighted signal produces more gain in the high frequencies than the ANSI-weighted signal. Figure 4B shows the same responses in terms of dB SPL. The ICRA-weighted signal produces more output in the lows
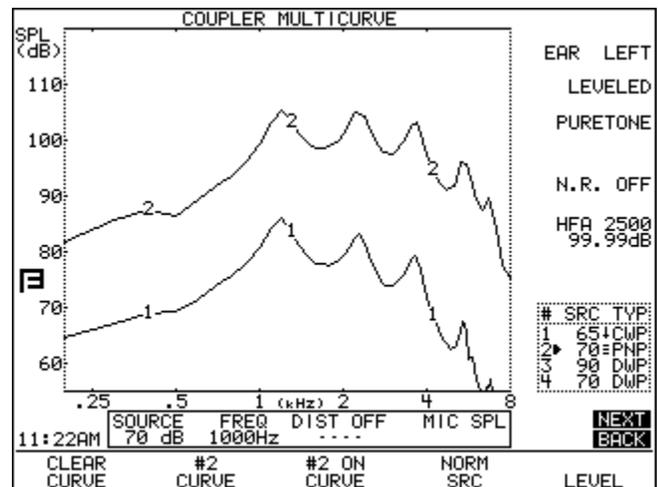

Figure 2A: Gain comparison of hearing aid measurement using a Composite signal (Curve 1) and a puretone sweep (Curve 2).

Figure 2B: Output (dB SPL) comparison of hearing aid measurement using a Composite signal (Curve 1) and a puretone sweep (Curve 2).

than the ANSI-weighted signal, but equal output in the high frequencies. The overall RMS OUT values from the ANSI and ICRA weighted signals are equal.

Section 4: Modulated Signals

Many advanced hearing aids have "speech enhancement" or "noise suppression" features that attempt to eliminate background noise in the environment while amplifying speech noises. In order to determine which part of the signal is noise and which part of it is speech, the hearing aid responds to modulations in the input signal. The idea is that constant sounds are probably noise whereas sounds that are changing (modulated) are probably speech or otherwise important to amplify.

Most traditional signal types used to test hearing aids are pure-tone sweeps or continuous broadband signals. The noise suppression technology in hearing aids tends to categorize such signals as noise instead of speech. Therefore, it is necessary to use modulated test signals in order to determine the hearing aid's frequency response to speech.

The Digital Speech signal was developed by Frye Electronics as a test signal for digital hearing aids. Digital Speech is a modulated version of the continuous Composite signal. Instead of being presented continuously, the Digital Speech signal is turned on for a set period of time and off for a random period of time. This modulation makes the hearing aid treat the signal as if it were a speech signal instead of a noise signal.

The "on" time is dependent upon the aid type setting since some hearing aids may require this signal to be on for a longer period of time in order to get an accurate measurement than other hearing aids. For linear hearing aids, this time is 20 ms. For AGC hearing aids, this time is 100 ms. For Adaptive AGC hearing aids, this time is 200 ms. This time can be further customized by adjusting the Misc Meas delay. The signal "off" time is random between 100 and 300 milliseconds and cannot be adjusted.

Figure 3:   A comparison of the ANSI-weighted Composite signal (Curve 1) and the ICRA-weighted Composite signal (Curve 2).

Since the characteristics of the Digital Speech signal are similar to the Composite signal (except for the modulation), it is possible to do a direct comparison of the hearing aid's frequency response to the two signals. Figure 5 shows a comparison of a the frequency response of a digital hearing aid tested with a Digital Speech signal (Curve 1) and a Composite signal (Curve 2). This type of comparison can be used to show how much the hearing aid suppresses unwanted noise.

Section 5: Bias Signals

Many advanced hearing aids have noise suppression technology that attempts to decrease noise in the environment while amplifying speech. With the FONIX 7000 Hearing Aid Test System, the user can introduce a noise at a particular frequency and find out how noise in one channel of the hearing aid may affect the frequency response in other channels.

The Digital Speech signal, as explained in Section 4 above, is a modulated signal that turns on and off. When enabled, the Bias Signal is added during the "off" times of the Digital Speech signal. That is, the Digital Speech
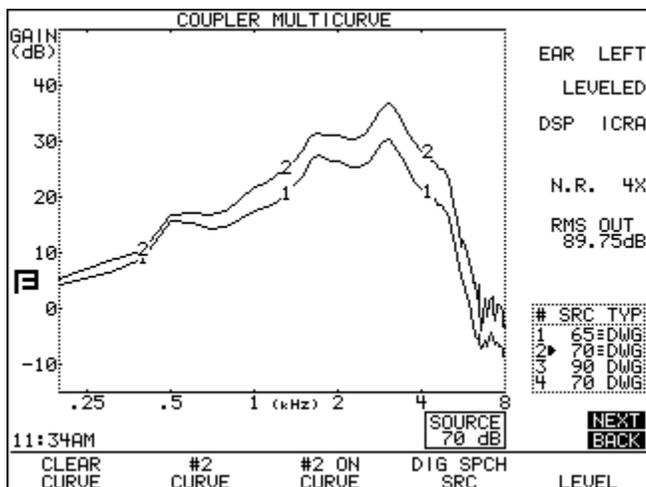
Figure 4A: Gain results of a WDRC hearing aid measured with the ANSI-weighted Composite signal (Curve 1) and the ICRA-weighted Composite signal (Curve 2).
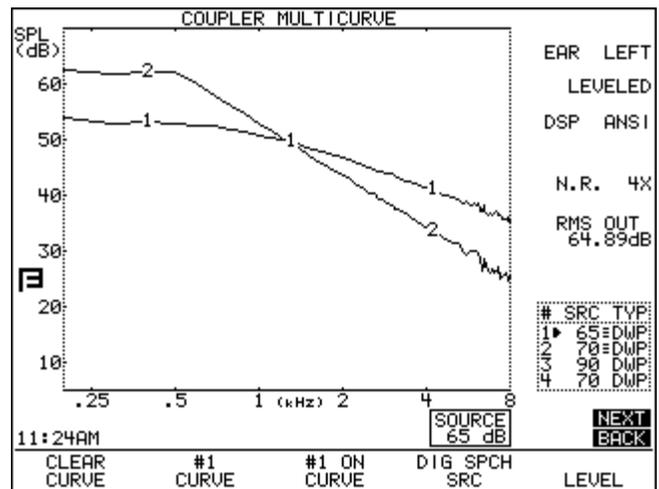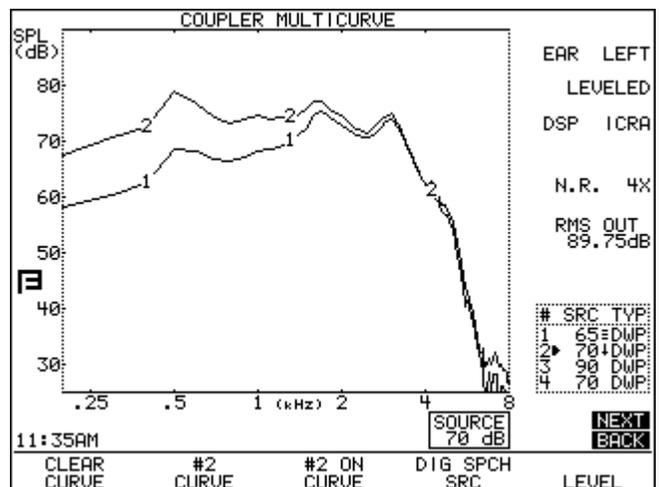
Figure 4B: Output (dB SPL) results of a WDRC hearing aid measured with the ANSI-weighted Composite signal (Curve 1) and the ICRA-weighted Composite signal (Curve 2).
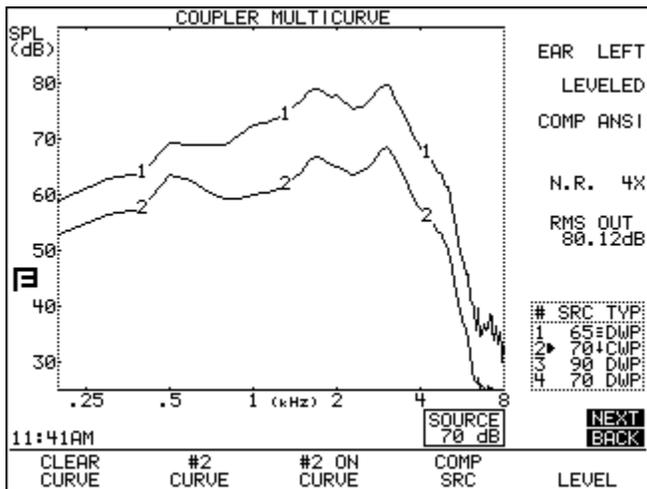
Figure 5: *Comparison of hearing aid measurement using a Digital Speech signal (Curve 1) and a Composite signal (Curve 2).*

Figure 6: *Hearing aid measurements using Digital Speech with Bias signal at 500 Hz (Curve 1), 1000 Hz (Curve 2), and 4000 Hz (Curve 3).*

signal alternates between a broadband signal and a pure-tone signal. Since the broadband signal consists of a combination of all pure-tone signals available on the FONIX 7000, there is constantly a signal at the frequency of the Bias Signal. If the Bias Signal level is close to the level of the broadband signal, the hearing aid may interpret the test signal as continuous at the Bias Tone frequency and decrease the amplification at that frequency.

The Bias Signal amplitude can be changed from 40-90 dB SPL in 5 dB increments. Its frequency can be set in 100 Hz intervals.

Figure 6 contains an example of an advanced digital hearing aid tested using the Digital Speech signal with a Bias Signal at 500 Hz (Curve 1), 1000 Hz (Curve 2), and 4000 Hz (Curve 3). Curve 4 shows the frequency response of the hearing aid to the Digital Speech signal when no Bias Signal is present. Notice how the hearing aid provides less amplification in the channel where the Bias Signal is present, but maintains the level of the frequency response in the other channels.
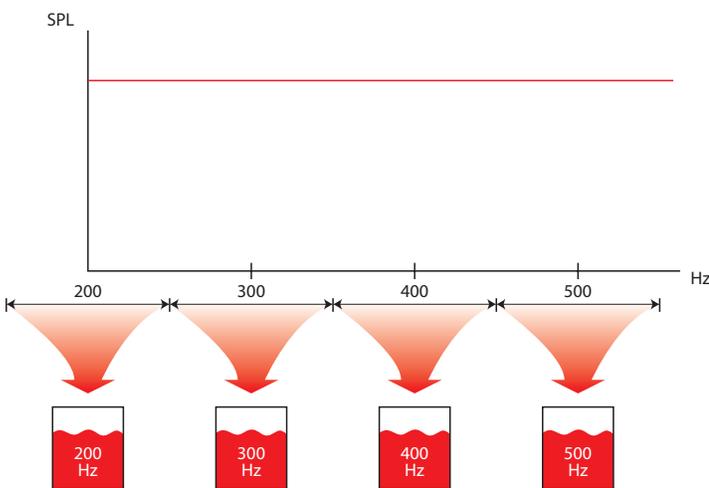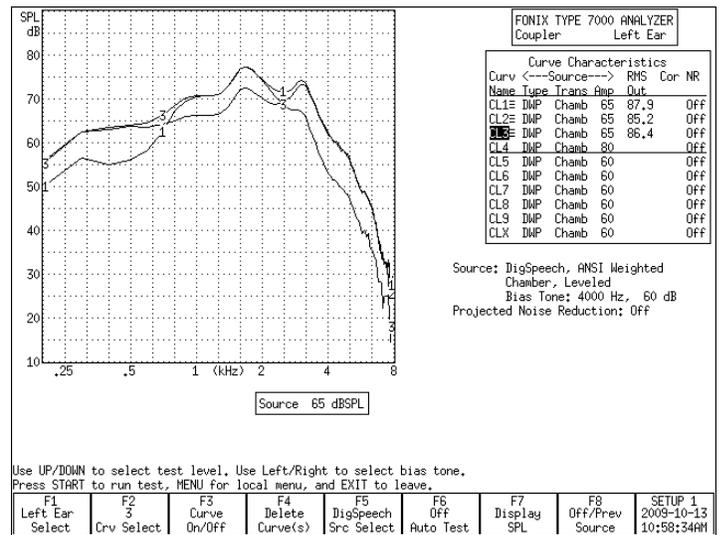
Section 6 Effects of Analysis Type in Output Measurements

When viewing test results of broadband signal in output (dB SPL), the analysis type and resolution has a large effect on the measurement results.

A broadband signal contains energy at frequencies across the 200-8000 Hz frequency spectrum. During the analysis process, the analyzer takes the hearing aid signal from the time domain and figures out what its frequency components are by transforming it into the frequency domain and dividing up the resulting signal into frequency components.

FONIX hearing aid analyzers perform a 100 Hz resolution FFT on the test signal. That is, after the signal has been transformed to the frequency domain, it is divided up into 79 equally spaced "bins" 100 Hz apart from 200-8000 Hz. For instance, to determine the frequency
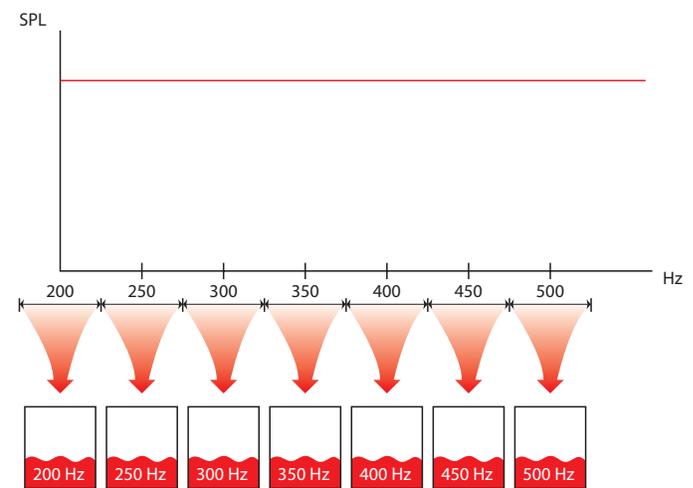

Figure 7A: *Part of a frequency response curve decomposed into 100 Hz "bins."*

Figure 7B: *Part of a frequency response curve decomposed into 50 Hz "bins."*
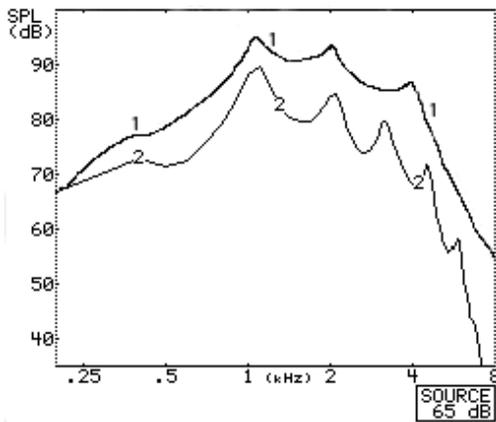
Figure 8: *Curve 1 is measured with 1/3 octave analyzis. Curve 2 is measured with 100 Hz FFT.*

response of the signal at 500 Hz, the analyzer includes all components of the signal from 450-550 Hz. All the energy of the signal that is contained at any frequency between 450 and 550 Hz is called "500 Hz" and graphed.

If the energy of the signal was something tangible that could be physically divided up, it might look something like Figure 7A. The top part of this figure is part of a frequency graph that is totally flat at some arbitrary level. In the bottom part of the figure, the frequency energy has been divided up into separate bins labeled as 200, 300, 400, 500, and 600 Hz.

If the analyzer were to perform an FFT with 50 Hz resolution instead of a 100 Hz resolution, the bins would be spaced 50 Hz apart. To determine the frequency response at 500 Hz, the analyzer would use all components of the signal between 475-525 Hz. Since there are more "bins" into which to put the energy, the amplitude of each bin will be smaller even though the total energy of the signal is the same. See Figure 7B.

If the frequency response of a hearing aid is analyzed with 100 Hz resolution, the level of each data point is going to be higher than if the analysis used 50 Hz resolution because there are fewer frequency bins in which to divide up the energy of the signal.

This phenomenon is only evident when you view test results in terms of output (dB SPL). If the hearing aid is producing 10 dB of gain, you would see 10 dB of gain in

both 50 Hz resolution and 100 Hz resolution analysis. However, the output of the 100 Hz resolution analysis would be greater than the output of the 50 Hz resolution analysis.

Some competing analyzers use third octave analysis. In third octave analysis, the signal is separated into 17 different bins. The size of each bin varies according to the frequency. The 1/3 octave frequencies between 200-8000 Hz are: 200, 250, 315, 400, 500, 630, 800, 1000, 1250, 1600, 2000, 2500, 3150, 4000, 5000, 6300, and 8000.

Compared to the 100 Hz FFT, third octave analysis has slightly higher resolution in the low frequencies and much lower resolution in the high frequencies. Since there are overall fewer bins into which to put the energy of the signal, almost all bins will have higher levels than the corresponding frequency in the 100 Hz FFT analysis.

When examining a graph of a frequency response, the third octave analysis will have higher output levels than the same response analyzed with 100 Hz resolution FFT. The rate of this difference is 3 dB per octave. In Figure 8, Curve 2 shows the 100 Hz resolution frequency response of an unamplified ANSI-weighted composite signal. Curve 1 shows the 1/3 octave resolution frequency response of the same signal.

The use of third octave analysis and 100 Hz analysis methods is equally correct. It is important, however, for the clinician to be aware of the differences between these methods in order to account for them when performing any kind of comparisons between test equipment.

Note 1: When performing a frequency response of a pure-tone signal, in both third octave analysis and 100 Hz FFT analysis, all of the energy of the signal is contained in a single bin. Therefore, a pure-tone response in third octave analysis will be identical to the same signal's response in 100 Hz FFT. The 3 dB per octave difference only occurs with broadband signals.

Note 2: When viewing test results in terms of dB Gain, in which the input signal is subtracted from the output signal, the resulting response is independent of analysis type. That is, a hearing aid frequency response should have identical results in dB Gain. The 3 dB difference is only seen when viewing results in terms of dB SPL.