ANSI S3.42-1992
(ASA 103-1992)

AMERICAN NATIONAL STANDARD

TESTING HEARING AIDS WITH A BROAD-BAND NOISE SIGNAL

Accredited Standards Committee S3, Bioacoustics

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AMERICAN NATIONAL STANDARD
Testing Hearing Aids with a Broad-Band Noise Signal

ACCREDITED STANDARDS COMMITTEE S3, BIOACOUSTICS

ABSTRACT

This standard describes techniques for characterizing the steady-state performance of hearing aids with a broad-band noise signal. The need for such a standard arises from the importance of assessing the performance of hearing aids in environments more nearly representing their real-world use. The noise test signal specified herein has been employed by the National Bureau of Standards for over 20 years in testing hearing aids. Among the tests described are noise saturation sound pressure level, noise gain, frequency response, family of frequency response curves and output versus input characteristic. Additionally, the appendix recommends use of the coherence function to indicate the validity of frequency response measures and distinguishes between use of random and pseudo-random noise and asynchronous versus synchronous analysis.

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FOREWORD

[This Foreword is not a part of American National Standard ANSI S3 42-1992—Testing Hearing Aids with a Broad-Band Noise Signal, ASA Catalog No. 103-1992.]

American National Standards have traditionally utilized pure tone signals to test hearing aids. However, new types of hearing aids have been developed over the last few years with increasingly complex and non-linear signal processing algorithms. The salient features of these devices are often not well characterized by pure tone measurements. Thus, the use of pure tones to assess the performance of these newer hearing aids is limited to quality control purposes. This document represents an initial effort to develop a national standard for the measurement of hearing aid performance with a steady-state complex input signal. The signal recommended herein is a random noise that has been spectrally shaped to represent the short-term average speech spectrum.

In addition to addressing methods of expressing gain, saturation sound pressure level and frequency response using the noise input signal, the use of the coherence function is recommended to validate the frequency response, and indirectly as an indicator of the amount of noise and distortion produced by a hearing aid.

This standard has been developed under the jurisdiction of Accredited Standards Committee S3, Bioacoustics, using the American National Standards Institute (ANSI) Accredited Standards Committee Procedure. The Acoustical Society of America provides the Secretariat for Accredited Standards Committee S3, Bioacoustics.

Accredited Standards Committee S3, Bioacoustics, under whose jurisdiction this standard was developed, has the following scope:

> Standards, specifications, methods of measurement and test, and terminology, in the fields of psychological and physiological acoustics, including aspects of general acoustics, shock and vibration which pertain to biological safety, tolerance, and comfort

At the time this Standard was submitted to Accredited Standards Committee S3, Bioacoustics, for approval, the membership was as follows:

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Suggestions for improvements in this Standard will be welcomed They should be sent to **Accredited Standards Committee S3 at the Standards Secretariat, in care of the Acoustical Society of America, 335 East 45th Street, New York, NY 10017-3483. Telephone (212) 661-9404.**

CONTENTS

American National Standard Testing Hearing Aids with a Broad-Band Noise Signal

0 INTRODUCTION

The frequency response of electroacoustic systems has traditionally been obtained with a swept pure tone input signal whose level is held constant while the system output is monitored over the frequency range of interest. Heretofore, this has also been the method of testing hearing aid frequency response. However, another procedure has evolved for obtaining frequency responses of electronic systems as a result of the recent proliferation of digital spectrum analyzers which utilize steady-state broad-band noise as one of their test signals. A time-stationary, steady-state broad-band noise, which is more typical of the complex input signals that hearing aids are required to process in non-laboratory real-world environments, may be a more suitable test signal for depicting performance, particularly for those heaing aids with level dependent gain circuity. However, to date, no standardized document exists that denotes procedures for testing hearing aids with a broad-band input signal.

For those hearing aids which do not have automatic gain control (AGC) or other forms of adaptive signal processing circuitry, or for hearing aids having such circuitry but tested with input levels below their activation point, the same frequency response should result whether a swept pure tone is used or a broad-band noise is used, as long as the hearing aid is operating linearly and the signal-to-noise ratio is adequate. The intent of the present ANSI hearing aid testing standard S3.22-1987 is to describe the frequency response of hearing aids in their linear mode regardless of whether automatic signal processing such as AGC is incorporated or not. However, a method is needed to demonstrate the change in steady-state frequency response of AGC or other adaptive circuit action as a function of input signal level because of the effect it may have on the speech recognition abilities of hearing aid wearers. Knowledge of such effects may be used to provide a better selection of frequency-gain characteristics for hearing aid fitting purposes. Care in selecting the most appropriate methods for characterizing AGC systems is but one manifestation of a growing awareness in hearing aid measurements: the more sophisticated signal processing techniques are employed such as, for example, frequency-selective input or output compression, the more the selection of appropriate measurement signals and measurement techniques becomes crucial to realizing the goal of obtaining meaningful performance measures.

Frequency response curves developed for hearing aids with level dependent frequency response, or for AGC hearing aids with frequency dependent compression threshold using swept pure tones at varying input levels may not be representative of the response using complex signals. This occurs with the swept-tone method because only one frequency is presented at a time and the control system responds to each frequency individually. In the case of AGC hearing aids with frequency dependent compression threshold tested at high input levels, compression may vary with frequency, producing a flattened frequency response curve not representative of the response obtained with a complex input signal.

For an input signal more representative of real use conditions, such as speech, many frequency components are present simultaneously. There is considerable precedent for testing hearing aids either with linear circuitry or with automatic signal processing circuitry using a shaped, steady-state, broad-band noise for an input signal. The National Institute of Standards and Technology (formerly the National Bureau of Standards) and the Veterans Administration have historically used a broad-band, speech spectrum-like noise input signal to determine performance characteristics of hearing aids. The test signal specified in this standard has spectral characteristics similar to those of the short-term spectrum of speech but is not representative of other important characteristics such as the temporal nature and the amplitude probability distribution of speech. With this signal, an AGC detector will respond to a single level, from contributions at many frequencies, not to the individual frequency components. Thus, with this signal, the individual frequency components affected by an AGC loop will retain their relative amplitude relationships.

Care should be exercised in interpreting measurements made with a steady-state noise signal because hearing aids whose frequency response is changed by the dynamic characteristics of the input signal cannot be fully characterized by this time-invariant signal, e.g., hearing aids that have adaptive AGC time constants based on the temporal pattern of the input signal.

References

ANSI S3.22-1987 Specification of Hearing Aid Characteristics.

ANSI S3.35-1985(R 1990) Method of Measurement of Performance Characteristics of Hearing Aids Under Simulated *in-situ* Working Conditions.

Bendat, J. S. and Piersol, A. G. (1980): *Engineering Applications of Correlation and Spectral Analysis*, Wiley & Sons, New York.

Prokais, J. and Manolakis, D. (1988): *Introduction to Digital Signal Processing*, Macmillan Publishing Company, New York.

Rife, D. and Vanderkooy, J. (1989): Transfer function measurement with maximum-length sequences, J. Audio Eng. Soc., 37, 6: 419–443.

1 SCOPE

The purpose of this document is to define a test method with which to characterize the steady-state frequency response and input/output characteristics of hearing aids as the input level varies. This method is particularly useful for those hearing aids that have automatic gain control or other types of adaptive circuitry.

2 DEFINITIONS

2.1 NSPL90

The NSPL90 is the root-mean-square (RMS) output sound pressure level (SPL) produced by a hearing aid with its gain set at maximum and with a 90 dB RMS speech-weighted noise input SPL. The standard measurement bandwith is limited to 200 to 5000 Hz because of diffraction problems and equipment accuracy tolerances at high frequencies. If a measurement bandwidth other than 200 to 5000 Hz is used, it shall be stated.

2.2 Full-on noise gain

With the gain control on the hearing aid in the full-on position, the noise gain is a single figure expressed in decibels and is derived by subtracting the overall RMS input SPL to the hearing aid from the RMS output SPL produced by the hearing aid. The standard measurement bandwidth is 200 to 5000 Hz. E.g., with a 50 dB RMS noise input sound pressure level, full-on noise gain = output SPL − 50 dB.

2.3 Spectrum

The distribution of amplitude and phase of the components of a signal as a function of frequency.

2.4 Spectrum level

The level of that part of the signal contained within a band 1 Hz wide, centered at the particular frequency.

2.5 Auto-spectrum (power spectrum)

The auto-spectrum represents the power level of either the input signal (G_{AA}) to or the output signal (G_{BB}) from a hearing aid in the frequency domain. It is computed by multiplying the Fourier transform of the signal by the complex conjugate of the Fourier transform of the signal.

2.6 Cross-spectrum

The cross-spectrum (G_{AB}) indicates the degree to which the same signal frequencies are mutually present in the input and output of a hearing aid. It is computed by multiplying the complex conjugate of the Fourier transform of the input signal to the hearing aid by the Fourier transform of the output signal from the hearing aid.

2.7 Coherence

A number ranging from 0 to 1 showing to what degree the output from a hearing aid is correlated to the input. Coherence for a random noise test signal is reduced by nonlinearity and by system noise. For a more thorough definition, see Appendix A.

2.8 Crest factor

The ratio of the peak value of a signal to its root-mean-square (RMS) value as follows:

$$\text{Crest factor (dB)} = 20\log_{10}\left(\frac{\text{peak voltage or pressure}}{\text{RMS voltage or pressure}}\right).$$

2.9 Spectrum analyzer

An instrument generally used to display the power distribution of a signal as a function of frequency. A dual channel analyzer permits calculation of the frequency response function for a hearing aid via a simultaneous analysis of the input to and output from a hearing aid.

2.10 RMS

The root-mean-square (also called "effective") value Y_{RMS} of a function-of-time $y(t)$. It is given by the square root of the mean of the sum of the squares of the instantaneous value of a signal:

$$Y_{RMS} = \sqrt{\left(\frac{1}{T}\int_a^{a+T} y^2(t)dt\right)},$$

where "a" is any value of time, and "T" is the effective averaging time. For periodic functions, T can be an integral multiple of the period, but needn't be if excessively long averaging times are required. For non-periodic functions, T is any time interval that is long enough to make the value "Y" essentially independent of small changes in T.

When $y(t)$ refers to the sound pressure at a point in space, the value of the function is defined as the instantaneous pressure at that point, in the presence of a sound wave, minus the static pressure at that point.

2.11 Butterworth filter

A filter which produces a frequency response that gives the maximum passband flatness. The rolloff is smooth and monotonic at a rate of 20 dB/decade (6 dB/octave) for every pole. The poles of an analog Butterworth filter are uniformly spaced on a circle in the complex s-plane. Thus, the poles of the filter will all have the same natural frequency and this frequency will be the half power (or 3 dB down) frequency for the filter.

2.12 Random noise

Random noise, as used in this document, is understood to be stationary random noise. The actual amplitude and phase at any time are unpredictable, but their time-averaged statistical properties are stable. In particular, the time-averaged probability density function and the time-averaged spectrum are stable over time and repeatable, within estimation error, from one time record to the next.

2.13 Pseudo-random noise

A periodically repeated sequence of amplitudes in a time domain signal, determined by some defined arithmetic stationary process providing an approximately normal (Gaussian) distribution of amplitudes., e.g., composite noise; maximum length sequence. For an example of the application of a maximum length sequence, refer to Rife and Vanderkooy, 1989.

2.14 *In-situ*

From the Latin, meaning "in position," this term refers to measurements made on a hearing aid while it is in the position of normal use, i.e., on the real ear of the wearer. Refer to S3.35-1985.

2.15 Simulated *in-situ*

Referring to *in-situ* hearing aid measurements that use an anatomical model of the human head, torso, pinna, ear canal and eardrum instead of a real human wearer. Refer to ANSI S3.35-1985 for descriptions of various applicable terms and simulated *in-situ* measurements.

2.16 dB SPL

The unit of level, in decibels, of an RMS sound pressure, relative to a reference RMS sound pressure of 20 μPa.

$$\text{dB SPL} = 20\log_{10}\left(\frac{\text{RMS sound pressure}}{20\mu\text{Pa}}\right).$$

2.17 Synchronous analysis

Analysis which is synchronized with the period of the input signal, e.g., with the periodicity of pseudo-random noise.

3 NOISE INPUT SIGNAL (refer to Appendix A)

3.1 Noise type and crest factor

Random noise, modified to provide a nominal crest factor of 12 dB, is the preferred input signal. For the purposes of this document, random noise shall have a normal probability distribution which is truncated so that the maximum signal level will never be more than 15 dB above the RMS level. The crest factor of the noise input signal shall be stated.

The noise should be continuous, i.e., its level should be constant for a sufficiently long time before each analysis period for any adaptive signal processing elements of the hearing aid to stabilize. Many adaptive hearing aids use fast-acting detectors to develop their signal-processing control signals. The amount of signal processing action, which often regulates the amount of gain the hearing aid provides (e.g., AGC aids), therefore may be dependent on the crest factor of the input signal. Because of the relatively large crest factor of the broad-band noise input signal, as compared to that for the traditionally-used pure tones for testing hearing aids, it is expected that there may be more variability in the measurements with broad-band noise inputs having varying crest factors than with pure tone input signals generated by different varieties of signal generators.

The type of noise (random, or pseudo-random and its period) shall be stated.

3.2 Spectrum

The amplitude as a function of frequency of the broad-band noise input signal should be controllable so as to achieve the desired long-term spectrum level of the input signal at the test point to within the values indicated in Table 1 and Figure 1. This may be accomplished by use of an equalizer or by amplitude control of individual components. The nominal mid and high frequency spectrum of the noise input signal shall be equivalent to that of a single pole low pass Butterworth filter (e.g., single resistor-capacitor filter section) having a 3 dB corner frequency at 900 Hz. The 6 dB per octave slope shall continue to at least 5 kHz. Above that frequency, the nominal spectrum level of the input signal shall not increase. The nominal low frequency spectrum for the noise input signal shall be equivalent to a two pole high pass Butterworth filter with 3 dB corner frequency at 200 Hz.

The shape of the power spectrum level of the acoustic noise input signal is given by:

$$S_n = 10 \log_{10} \frac{(f/200)^4}{[1+(f/200)^4]} \times \frac{1}{[1+(f/900)^2]} .$$

The tolerance is ± 3 dB over the frequency range from 200 to 5000 Hz. Below 200 Hz, the lower limit is $-\infty$ and the upper limit is given by:

$$S_{n_{\max}} = 10 \log_{10} \frac{(f/200)^2}{[1+(f/200)^2]} \times \frac{1}{[1+(f/900)^2]} + 3 \text{ dB}.$$

TABLE 1. Nominal values and upper and lower limits for the steady-state, broad-band noise input spectrum corresponding to Figure 1.

Freq. (Hz)	Lower (dB)	Nominal (dB)	Upper (dB)
100	$-\infty$	−12.4	−4.0
125	$-\infty$	−8.9	−2.6
150	$-\infty$	−6.3	−1.6
175	$-\infty$	−4.5	−0.8
200	−6.2	−3.2	−0.2
225	−5.3	−2.4	0.6
250	−4.8	−1.8	1.2
300	−4.2	−1.2	1.8
350	−4.1	−1.1	2.0
400	−4.0	−1.0	2.0
450	−4.1	−1.1	1.9
500	−4.3	−1.3	1.7
600	−4.6	−1.6	1.4
700	−5.1	−2.1	0.9
800	−5.6	−2.6	0.4
900	−6.0	−3.0	0
1 000	−6.5	−3.5	−0.5
1 250	−7.7	−4.7	−1.7
1 500	−8.8	−5.8	−2.8
1 750	−9.8	−6.8	−3.8
2 000	−10.7	−7.7	−4.8
2 250	−11.6	−8.6	−5.6
2 500	−12.4	−9.4	−6.4
3 000	−13.8	−10.8	−7.8
3 500	−15.1	−12.1	−9.0
4 000	−16.2	−13.2	−10.2
4 500	−17.2	−14.2	−11.2
5 000	−18.0	−15.0	−12.0
6 000	$-\infty$	−16.6	−12.0
7 000	$-\infty$	−17.9	−12.0
8 000	$-\infty$	−19.0	−12.0
9 000	$-\infty$	−20.0	−12.0
10 000	$-\infty$	−21.0	−12.0

Above 5000 Hz the upper limit is the upper limit value at 5000 Hz and the lower limit value is $-\infty$.

NOTE: The input spectrum level is subtracted out in the frequency response and gain measurements. Control of the input spectrum is required because the hearing aid may be nonlinear. The upper and lower tolerances on the spectrum are meant to ensure repeatability with respect to the particular operating conditions of the hearing aid under test.

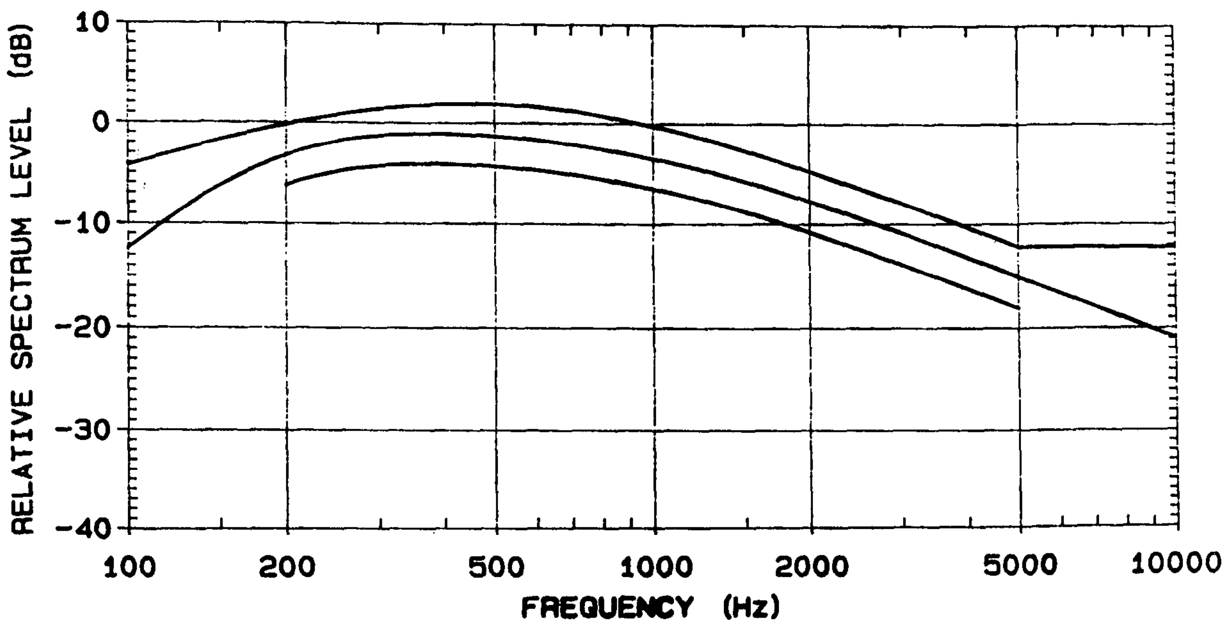

FIG. 1. Nominal, upper and lower limits for the steady-state broad-band noise input spectrum corresponding to the numerical values in Table 1.

4 SPECTRUM ANALYSIS EQUIPMENT

Either a single or dual spectrum analyzer may be used. An analyzer that sweeps a tracking filter across the frequency range is also acceptable. Analyzers of the constant bandwidth type, such as FFT analyzers, shall have analysis points every 250 Hz or less. Analyzers of the relative bandwidth type, such as digital filter analyzers, shall have a bandwidth of 1/3 octave or less. The effective filter analysis bandwidth and smoothing including windowing shall be stated. Dual-channel analysis using the cross-spectrum method (see Appendix A) is preferred. Single channel analysis, which uses the auto-spectrum method, will give equivalent results (to within approximately ± 1 dB) if: a) the sound field has been equalized in accordance with ANSI S3.22-1987, Appendix A or S3.35-1985; b) the hearing aid under test is stable; c) the signal to noise ratio is good (at least 10 dB in each analysis band) and d) the hearing aid under test is operating in a linear mode. Otherwise, results from the two methods may differ.

The test method (auto-spectrum or cross-spectrum with FFT, digital filter or swept tracking filter), averaging time, analysis bandwidth and total frequency range of analysis shall be stated.

NOTE: pseudo-random noise having the same period as the analysis time record is an acceptable input signal. However, if the aid under test is operating nonlinearly, the results may differ from those obtained with random noise.

5 TEST ENVIRONMENT

The test environment shall be as specified in ANSI S3.22-1987 or in ANSI S3.35-1985(R 1990).

The residual noise in the test chamber shall give a signal to noise ratio in each analysis band equal to or greater than 10 dB with a noise input signal as specified in 3.0 at an RMS level of 50 dB SPL. If the residual noise spectrum has the same shape as the noise input signal spectrum, this implies that the RMS level of the residual noise over the bandwidth 200 to 5000 Hz could be as high as 40 dB SPL. If the residual noise spectrum has a different shape, the maximum RMS level would be lower than 40 dB SPL.

The RMS level of the residual noise over a bandwidth of 100 to 5000 Hz must be no greater than 50 dB SPL.