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Development of Test Signals for the EIA-426-B Loudspeaker Power Rating Compact Disk

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ABSTRACT

The EIA-426-B standard: "Loudspeakers, Optimum Amplifier Power" (April 1998) specifies a test CD that contains the calibration and test signals for all the tests defined in the standard. This CD is intended to improve the consistency and convenience of the standard and will be made available through the EIA and other sources. This paper describes the development process of the signals placed on the CD with emphasis on the spectral-shaped random noise signal used for life testing and the variable-rate sine-wave sweep test signal used for power compression tests. All signals were generated analytically using a signal processing and data analysis program. In the process of creating the signals, a couple of errors were detected in the standard in its description of the method for generating the variable-rate sweep signal. The paper also develops the math for generating variable-rate sweeps whose spectrums roll-off at an arbitrary given rate. Complete statistics and measurements are described for the signals as placed on the CD and for the signals as played back on a typical CD player. Also described are a series of 6.5-cycle shaped tone bursts that are included on the CD. These are intended for use as a test stimulus for short-term power assessment of loudspeakers and electronics, and for testing the frequency response, energy decay and narrow-band phase/polarity of systems.

INTRODUCTION

With the advent of relatively inexpensive mastering, production, and cost of compact discs (CD), the EIA working group which revised the EIA RS-426 loudspeaker power test standard, choose to offer the test signals defined in the standard on CD. This distribution form is highly usable, readily available, very convenient, and minimizes the use of expensive signal-generation test equipment.

This paper describes the development process of the signals placed on the CD and their characteristics, both as recorded and played back on a typical CD player.

The standard specifies several test signals including: 1) an amplitude calibration 1 kHz tone, 2) an accelerated life test signal consisting of band-limited random noise with a prescribed spectrum and crest factor, 3) a power compression test signal consisting of a variable-sweep-rate warble-like sinewave test signal of constant amplitude which has the same approximate spectrum as the life-test noise, and 4) a series of pure tone distortion test signals.

This paper also describes a number of additional bonus test-signal tracks placed on the CD which are not specified in the standard. These tracks include additional higher-frequency pure tones and a series of shaped tone bursts at various frequencies. The bursts are intended for use as a test stimulus for frequency-dependent short-term peak power assessment and headroom of loudspeakers and electronics[1 - 4], and for testing the frequency response, energy decay and narrow-band polarity of systems [4 - 7].

These tone bursts are also available on other commercially available CDs [2, 3, 9].

DESCRIPTION OF EIA–426-B STANDARD: ”LOUDSPEAKERS, OPTIMUM AMPLIFIER POWER”

The standard’s forward states very well the intent and scope of the revision of the RS-426 standard and is reproduced here:

Forward From Standard

“1.1 This standard was developed by the EIA R-3 Audio Systems Committee working group for study and revision of EIA-426-A, in response to a survey of loudspeaker manufactures which indicated a need to re-examine the current standard in the areas of test signal spectrum, test duration, and the calculation of power. EIA-426-A comprises an “accelerated life” test of full-range systems.”

“1.2 This document extends 426-A to include standards for performance with respect to power compression and distortion at the optimum amplifier power, and provides for a test signal on a compact disc, to improve test reliability and to facilitate and encourage wider use of the standard. The procedures are organized in three sections: Section A contains the procedure for testing power compression, Section B contains the procedure for testing distortion, Section C contains the procedure for the accelerated Life Test. The optimum amplifier power is the maximum input power at which the product under test is rated to meet the stated EIA criteria for acceptability under all three categories – power compression, distortion, and accelerated life.”

“1.3 Whereas EIA-426-A rated the ability of a loudspeaker to handle power – a concept of little practical use – the revised standard, 426-B, recommends the maximum power rating for an amplifier to be connected to the loudspeaker. This could be considered to be an “optimum” power match, as this is the most power which can be delivered to the speaker while permitting the speaker to operate within acceptable limits of performance as defined by EIA in this standard under the categories of power compression, distortion, and accelerated life testing.”

DEVELOPMENT OF TEST SIGNALS

This section describes the development of each of the signals on the CD. Each subsection starts with the standards specification of the signal, followed by a detailed description of the generation of the signal as placed on the CD.

All tracks were generated as PC WAV files using the data analysis and graphing program Igor Pro Version 4.0 by WaveMetrics, Inc., (www.wavemetrics.com). The draft (non-production) version of the CD was mastered using Sound Forge Version 4.5 by Sonic Foundry, Inc., (www.sonicfoundry.com).

Amplitude Calibration Tone (Track 1)

Specification

Track 1 is specified to contain a 1000-Hz constant-amplitude calibration tone that lasts for one minute (60 seconds). The tone is intended for use as an amplitude calibration signal for all the test signals that follow on the disk. The following power-compression swept-sine signal and distortion test tones are recorded at the same level as the calibration tone, and the life-test noise signal is recorded at an rms level 3-dB lower than the calibration tone. A ramp is specified to reduce pops and clicks.

Development

The specification was followed exactly with the peak level set to 6-dB down referenced to the CD’s 16-bit digital maximum of ±32,767 counts (0 dBFS). The –6-dB-peak level corresponds to a maximum count of ±16,384 for the sinewave. The resultant rms level of the sinewave is therefor –9 dBFS. A four-cycle half-Hann ramp was added to the start and finish of the tone to minimize start/stop transients. Signal length was set to 60 seconds. Figure 1 illustrates the resultant waveform of the signal for a short 20-ms example signal (not recorded on the CD, for example only!).

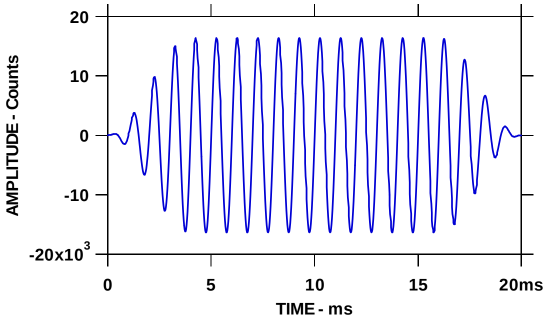

Fig. 1. Example 20-ms 1000-Hz pure-tone waveform with four-cycle half-Hann ramps added at the beginning and end to minimize start-stop transients.

Band-limited Noise for Life Testing (Track 2)

Specification

For the accelerated life test track 2, the standard specifies spectral-weighted Gaussian noise, soft clipped to a crest factor of 6 dB and lasting for 30 minutes.

The specified weighting (as measured by a constant percentage bandwidth analyzer), bandlimits the noise to 40 Hz and 10 kHz, is flat between 40 Hz and 1 kHz, and then rolls off at 3 dB/octave (10 dB/decade) between 1 kHz and 10 kHz. The band limiting is accomplished by a 40-Hz high-pass filter of at least 6th-order minimum and a 10-kHz low-pass filter of at least 4th-order minimum, both maximally-flat Butterworth types.

Its rms level is specified to be 3-dB lower that that of the calibration tone on track 1. With its specified 6-dB crest factor, this means that the peak level of the noise will be the same as the peak level of the calibration tone.

Development

The following steps were required to generate the life test noise:

1. Create data wave: Create a 2^19 = 524,288 point signal using double-precision floating-point numbers. Set point spacing to 1/44100 seconds (≈ = 22.7 uS), thus creating a signal of roughly 11.89 seconds (= 524288/44100) duration. Note that this wave size is a power of two which makes the following convolutions easier to accomplish using FFT techniques.

2. Fill with noise: Fill signal with Gaussian random numbers using Igor’s gnoise function to yield a simulated white noise with a standard deviation of 8000 (this number is arbitrary due to the following normalization in step 4). The FFT spectrum of the noise is flat from 0 to 22 kHz. Note that although this noise signal is not maximal-length sequence based, its length is sufficiently long to insure good signal statistics.

The following lists the signal's statistics as generated by Igor's "WaveStats" operation (see Appendix A for definition of variables):

V_npnts = 524288; V_numNaNs = 0; V_numINFs = 0;
V_avg = -1.67141; V_sdev = 8001.51; V_rms = 8001.5;
V_adev = 6383.49; V_skew = 0.00286879; V_kurt = -0.00168316;
V_minloc = 10.2661; V_min = -37260; V_maxloc = 8.18866;
V_max = 36603.2;

Figure 2 shows the histogram or amplitude distribution of the data at this point. The data is accumulated into 200 bins ranging from –40k to +40k in amplitude. Note the Gaussian shape (as expected). The calculated crest factor is 13.4 dB $\left(=20\,Log\left(\frac{37260}{8001.5}\right)\right)$.

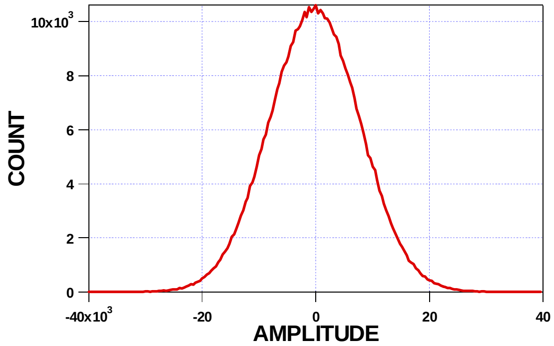

Fig. 2 Histogram amplitude distribution of raw noise data before processing. Data has an RMS value of 8000.

3. Bandlimit noise to 40 Hz and 10 kHz: Bandlimit the noise between 40 Hz and 10 kHz by convolving the data with the impulse response of a 40-Hz 6th-order Butterworth high-pass filter cascaded with a 10-kHz 6th-order Butterworth low-pass filter.

4. Convert noise spectrum to pink between 40 Hz and 1 kHz and –10 dB/octave rolloff at higher frequencies: This was done by convolving the data with the impulse response of a half-order low-pass filter at 40 Hz cascaded with a half-order low-pass filter at 1 kHz. The half-order low-pass filter provides a –10 dB/octave response roll-off above a certain cutoff with the following transfer function:

$$H_{\text{half-order}}(s)=\frac{\sqrt{\omega_0}}{\sqrt{s+\sqrt{\omega_0}}}$$

where s complex variable
ω_0 cutoff frequency

Figure 3 shows the 524,288 point FFT spectrum of this band-limited and shaped noise.

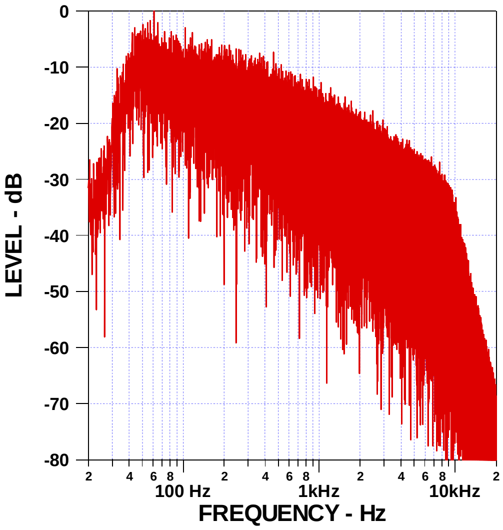

Fig. 3. FFT spectrum of band-limited and shaped noise. The spectrum is bandpassed between 40 Hz and 10 kHz and has a rolloff of –10 dB/octave between 40 Hz and 1 kHz with an additional –10 dB/octave rolloff at higher frequencies.

5. Soft clip noise: The noise data was then soft clipped so that its crest factor was set to 6 dB. The soft clipping was accomplished using the following input-output soft-clip function that is intended to mimic diode full-wave soft clipping:

$$y=\begin{cases}=\left(\dfrac{x^k}{x^k+1}\right)^{\frac{1}{k}} & \text{for } x\geq 0\\[2ex] =\left(\dfrac{(-x)^k}{(-x)^k+1}\right)^{\frac{1}{k}} & \text{for } x<0\end{cases} \qquad \text{Eq. (1)}$$

where x = input
y = output
k = rounding parameter

This function provides a static non-linearity that limits the output to one irregardless of the input value. For small values of input ($|x|\leq 0.1$) the input-output relationship is linear with a slope of one.

For larger values of input, the output approaches one but does not exceed it. The rounding parameter *k* controls the amount of rounding at the corner where the input approaches and exceeds one (*k* = 1 quite rounded, *k* = 4 typical rounding, *k* = 100 hard clip, etc.).

In operation, the input data must be scaled up or down to appropriately clip the data at the proper level and then scaled back to provide the desired peak levels. Figure 4 shows a plot of this function for four different rounding parameters.

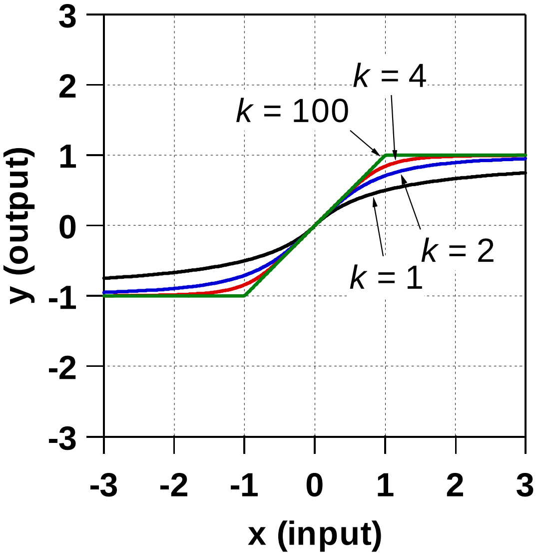

Fig. 4. Plot of the soft-clip function of eq. (1) for four different rounding parameters: k = 1 very rounded, k = 2 somewhat rounded, k = 4 typical rounding, and k = 100 hard clipping.

The data was soft clipped with a rounding value of k = 4 and the peak level set to 16,384 (-6 dB peak for a 16-bit signal).

The following lists the signal's statistics after the rounding operation as generated by Igor's "WaveStats" operation (see Appendix A for definition of variables):

V_npnts = 524288; V_numNaNs = 0; V_numINFs= 0;
V_avg = 3.44821; V_sdev = 8200.96; V_rms = 8200.95;
V_adev = 6886.05; V_skew = -0.00158713; V_kurt = -0.931479;
V_minloc = 9.87426; V_min = -16356; V_maxloc = 4.3683;
V_max = 16384;

Figure 5 shows the histogram or amplitude distribution of this final data. Note the truncated Gaussian shape that the clipping operation provides. Also note added roughness.

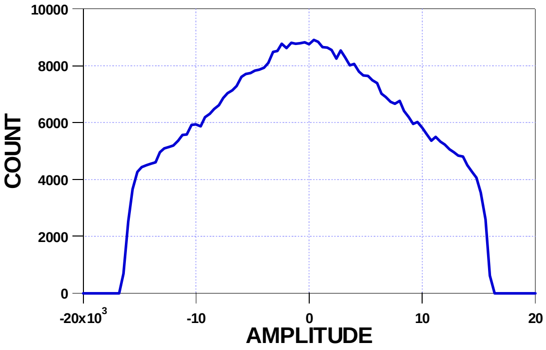

Figure 5. Histogram amplitude distribution of final band-limited shaped and clipped noise data.

The calculated crest factor is 6.0 dB $\left(=20Log\left(\frac{16384}{8200.95}\right)\right)$ as desired.

Figure 6 shows the calculated one-third-octave spectrum of the noise data which conforms to the desired spectral shape specified in the standard.

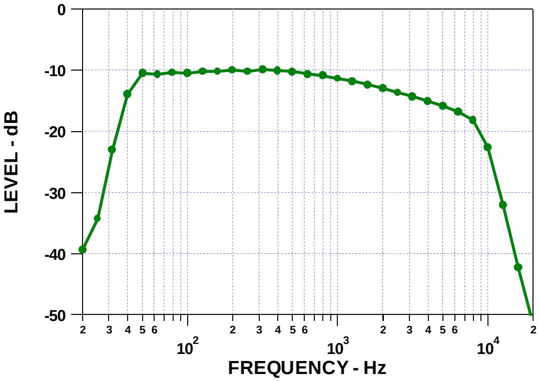

Figure 6. Calculated one-third-octave spectrum of final noise data.

7. Create 30-minute long signal: The previously created 524,288 point noise signal of about 11.89 seconds length was then looped end to end for 152 repetitions and then truncated to create the desired 30-minute long signal.

8. Convert to WAV file: The double-precision floating-point data values were then converted to 16-bit word values and then written out to a PC WAV file.

Variable Rate Sweep for Compression Testing (Track 3)

Specification

On track 3, the standard specifies a variable-rate swept sine wave of constant amplitude with a power spectrum that matches the spectrum of the life test noise on track 2 and lasts for 10 minutes. The signal is composed of a sequence of 0.5-second up-down sweeps whoes duration is "chosen to be fast enough not to burn out tweeters, but not so fast as to produce modulation artifacts."

A single 0.5-second up-down sweep is to be composed of a 0.25-second 40 Hz to 10 kHz upsweep followed by a 0.25-second 10 kHz to 40 Hz downsweep. The standard further specifies that the variable-rate sweep "requires a sweep rate proportional to the square root of frequency from 40 Hz to 1 kHz and directly proportional to frequency from 1 kHz to 10 kHz. The sweep rate function of frequency is continuous at the 1 kHz transition."

Note: Subsequent investigation revealed that the standard's underlined quote in the previous paragraph is incorrect, and should read: requires a sweep rate *directly proportional to frequency from 40 Hz to 1 kHz and proportional to the square of frequency from 1 kHz to 10 kHz.*

Development

The following steps were required to generate the variable-rate sweep signal.

1. Create data waves: Create a 0.5-second signal of 22050 points using double-precision floating-point numbers to contain the single up-down sweep.

2. Generate log sweep from 40 Hz to 1 kHz: A log sweep provides a sweep rate that is directly proportional to frequency and a spectrum which provides constant energy per percentage bandwidth, identical to pink noise (rolls off at –10 dB/octave in reference to white noise). Appendix B describes the log sweep in more detail.

3. Generate square sweep from 1 kHz to 10 kHz: A square sweep provides a sweep rate that is directly proportional to the square of frequency and a spectrum which rolls off at –10 dB/octave in reference to pink noise (rolls off –20 dB in reference to white noise). Appendix B describes the square sweep in more detail. A slight amount of over sweep to 10.25 kHz was required so that the spectrum better matched the roll off of the shaped noise on track 2.

4. Form 0.25-second up sweep: Combine the log sweep and square sweep created in steps 2 and 3 into a single up sweep.

Note that the only way to control the relative spectral levels of each of the sweeps is to vary their relative sweep times because their sweep amplitudes are equal by definition. I determined experimentally that a log-sweep time of 0.1925 seconds followed by a much shorter square sweep time of 0.0575 seconds (making a total 0.25 second up sweep), was required to provide a good spectral match at the 1 kHz transition where the two sweeps are connected.

In addition, the starting phase of the square sweep was forced to match the ending phase of the preceding log sweep to provide a seamless transition between the sweeps.

Figure 7 shows the FFT spectrum of the up sweep.

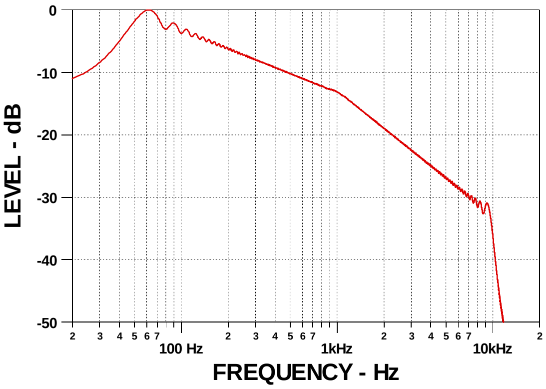

Fig. 7.FFT spectrum of 0.25-second constant-amplitude up sweep. Note the “Gibbs phenomena”-like ripples at the ends of the spectrum.

5. Form final 0.5-second up-down sweep: A single up-down sweep was formed by appending a time-reversed version of the up-sweep to the end of the up sweep. To allow for seamless sequences of up-down sweeps formed in the next step, the down sweep was inverted in phase and shifted over one-half period of its highest frequency. Figure 8 shows the FFT spectrum and Fig. 9 shows the one-third-octave spectrum of the up-down sweep. Figure 10 shows the time waveform of the up-down sweep.

Interestingly, the spectrum of the up-down sweep (Fig. 8) exhibits a picket fence effect and low-frequency below-100-Hz anomalies that are not present in the spectrum of the up sweep (Fig. 7). At low frequencies, the nulls in the spectrum are spaced at 2 Hz and the spacing increases at higher frequencies. I have no explanation for this effect other than its possibly an interference between the spectrums of the up sweep and the delayed and time-reversed down sweep.

The following lists the 0.5-second up-down sweep statistics as generated by Igor’s “WaveStats” operation (see Appendix A for definition of variables):

V_npnts= 22050; V_numNaNs= 0; V_numINFs= 0;
V_avg= -0.0429478; V_sdev= 11583.4; V_rms= 11583.1;
V_adev= 10428.9; V_skew= 1.10978e-05; V_kurt= -1.49972;
V_minloc= 0.0163039; V_min= -16384; V_maxloc= 0.00591837;
V_max= 16384;

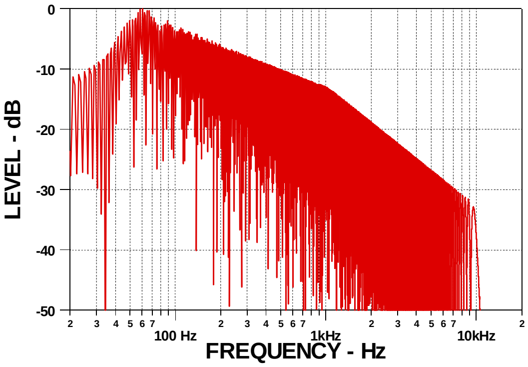

Fig. 8 FFT spectrum of 0.5-second constant-amplitude up-down sweep.

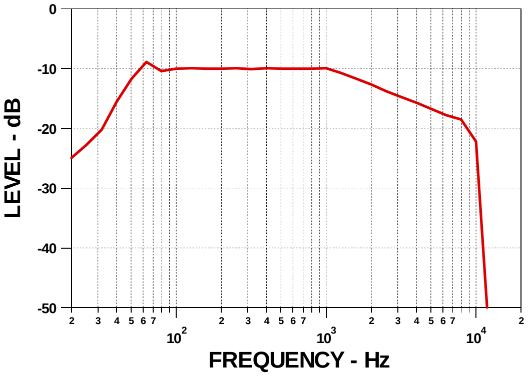

Fig. 9 Calculated one-third-octave spectrum of 0.5-second constant-amplitude up-down sweep.

6. Create 10-minute long signal: The 0.5-second up-down sweep was then looped end to end for 1200 repetitions to form a 10-minute long signal.

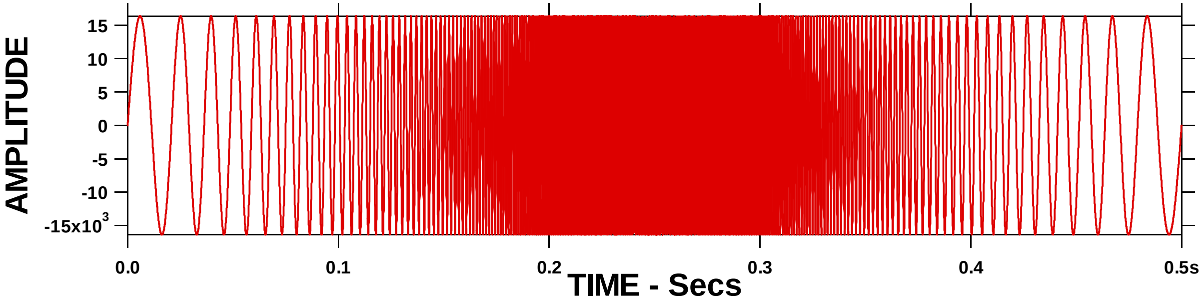

Fig. 10. Time waveform of 0.5-second constant-amplitude up-down sweep. The first half of the signal is composed of a 40 Hz to 1 kHz log sweep from 0 to 0.1925 seconds, and a 1 kHz to 10.25 kHz square sweep from 0.1925 seconds to 0.25 seconds. The last half is an inverted time-reversed version of the first half.

7. Convert to WAV file: The double-precision floating-point data values were then converted to 16-bit word values and then written out to a PC WAV file.

Pure Tones for Distortion Tests (Tracks 4 – 34)

Specification

The standard specifies that the CD contain pure tones for distortion testing at all the IEC standard one-third-octave center frequencies ranging from 20 Hz to 5 kHz. These tracks are to contain 15 seconds of tone followed by 5 seconds of silence and be recorded at a level equal to the calibration tone on track 1.

For completeness, I choose to include the rest of the pure tones on the CD ranging from 6.3 kHz to 20 kHz as bonus tracks.

Development

As with the calibration tone on track 1, the peak level of each tone was set to –6 dB which corresponds to a maximum count of ±16,384 for the sinewave. For each tone, the signal was on for 15 seconds and off for 5 making a total track time of 20 seconds. A four-cycle half-Hann ramp was added to the start and finish of each tone to minimize start/stop transients (see Fig. 1 for an example of four-cycle half-Hann ramps added to a signal at the beginning and end).

Shaped Tone Bursts for Peak Power and Headroom Tests (Tracks 35 – 68)

Specification

Additional bonus tracks were included on the CD which contain 6.5-cycle shaped tone bursts whose energy is constrained to a one-third-octave bandwidth. These bursts are intended for use as a test stimulus for frequency-dependent short-term peak power assessment and headroom of loudspeakers and electronics, and for testing the frequency response, energy decay and narrow-band phase/polarity of systems.

The tone burst tracks should cover the frequency range from 10 Hz to 20 kHz at all the preferred IEC standard one-third-octave center frequencies. The bursts are repeated at one burst per second on the left channel and one burst per 10 seconds (0.1 burst per second) on the right channel. Each track lasts for 30 seconds. The low-repetition rate on the right channel makes these signals more suitable for systems that have long energy decay (reverberation) times such as large rooms and concert halls.

Development

A 6.5-cycle Hann-weighted (or raised-cosine envelope) tone burst was chosen given by the following equation [3]:

$$f(t)=\begin{cases}\left(1-\cos\dfrac{2\pi f_0 t}{6.5}\right)\dfrac{\sin 2\pi f_0 t}{2} & \text{for } 0\le t\le \dfrac{6.5}{f_0}\\ 0 & \text{otherwise}\end{cases} \qquad \text{Eq.(2)}$$

Where t = time, seconds
f_0 = center frequency of burst, Hz

Note that the number of cycles is constant, thus holding the spectrum width to a constant percentage of the center frequency f_0.

The waveform is symmetrical about its center with its highest amplitude (+1.000) occurring at the center ($t = 3.25/f_0$). The highest negative peaks of about -0.944 (-0.5 dB) occur symmetrically around the center of the burst. The positive peak level of the bursts were set to a maximum level of 32,767 counts on the CD (0 dBFS).

Figure 11 shows the waveshape of an example 1-kHz 6.5-cycle burst, while Fig. 12 shows its FFT spectrum. The spectrum of the 1-kHz burst is 3-dB down at 889 and 1111 Hz, which is very close to one third of an octave. The side lobes are greater than 40-dB down an octave away from the center frequency.

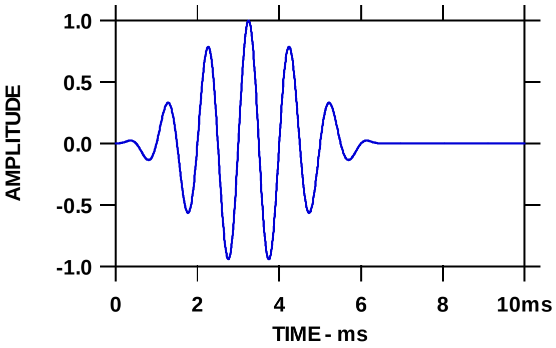

Fig. 11 Waveshape of a 1-kHz 6.5-cycle Hann-weighted tone burst with its peak amplitude normalized to one.

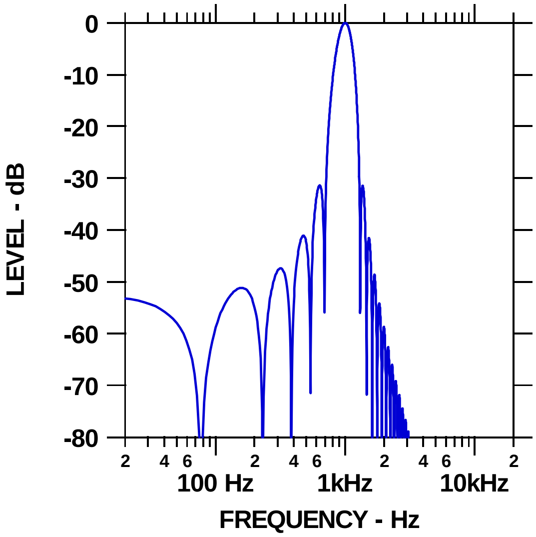

Fig. 12. FFT spectrum of the tone burst of Fig. 11. The burst's energy is confined to a one-third-octave bandwidth at its center frequency.

If this burst is repeated end-to-end with no space between bursts, the crest factor is approximately 7.3 dB. Note: the crest factor of the tone-burst recorded on the CD is higher due to the added silence between the bursts. As the burst frequency increases, the signal's crest factor also increases due to the shortening of the burst in relation to the fixed repetition period of once per second.

The crest factor increases by exactly one dB for each 1/3rd-octave increase in frequency, ranging from 9.1 dB at 10 Hz to 42.1 dB at 20 kHz for the left channel, and is 10 dB higher at each frequency in the right channel. Each track's crest factor is listed in APPENDIX C: CD TABLE OF TRACK CONTENTS.

Figure 13 shows the waveform of track number 35 the 10-Hz tone-burst on the CD. The track lasts for 30 seconds with the bursts repeating at one burst per second on the left channel and one burst per 10 seconds on the right (0.1 burst per second). Note that the bursts are exactly left-right synchronized on both channels every ten bursts.

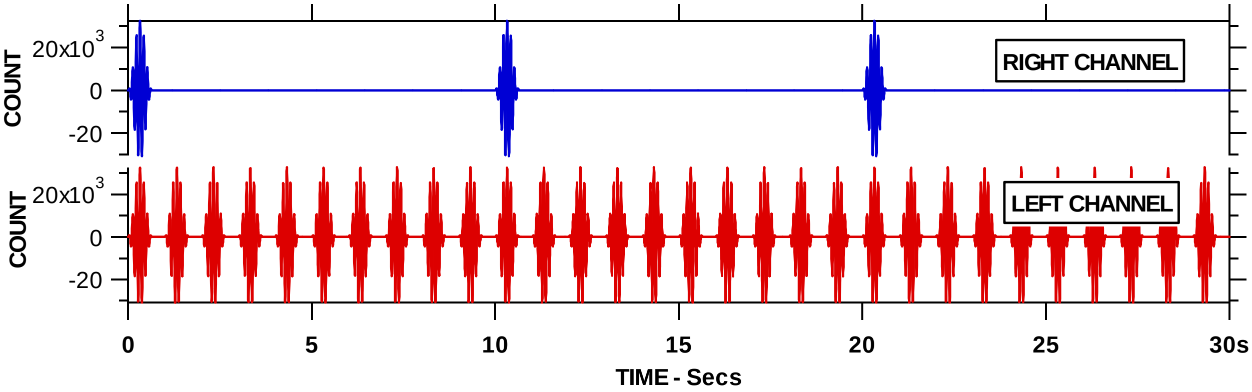

Fig. 13. Waveform of the 10-Hz tone-burst on track number 35. The track lasts for 30 seconds with the bursts repeating at one burst per second on the left channel and one burst per 10 seconds on the right.

USE OF TEST SIGNALS

Only brief comments on the use of the signals defined in the standard are included here. Refer to the standard for a complete description of the use of the signals defined in the standard. In-depth comments are included here only for the tone-burst test signals.

Amplitude Calibration Tone (Track 1)

The 1-kHz calibration signal provides a reference for all the following test signals on the CD. Quoting the standard: “Therefore, the signal level need be set only once to achieve the proper levels for all tests, and power calculations may be based on this setting.”

Band-limited Noise for Life Testing (Track 2)

The band-limited spectrally-shaped noise signal provides a test stimulus for accelerated life tests of loudspeakers. Again quoting the standard: “This procedure simulates the working life of the speaker by testing its ability to withstand a test signal at half the optimum amplifier power for an extended duration without suffering an irreversible and unacceptable change in performance parameters or integrity.” ….. “The criterion for passing this test is that the speaker not acquire a permanent shift in parameters such as free-air resonance frequency.” The standard defines an “extended duration” as eight hours.

Variable Rate Sweep for Compression Testing (Track 3)

The variable-rate sinewave sweep test provides a test signal to assess the degree to which the acoustic output of the speaker is compressed as the input level is raised. The low crest factor of the sine sweep maximizes amplifier power.

The standard specifies that the speaker passes the power-compression test if it is tested at its rated optimum amplifier power and suffers no more than 6-dB of compression in each one-third-octave band from 40 Hz to 10 kHz or through the bandwidth specified by the manufacturer. The reference for this test is a spectrum gathered when the input to the speaker is 20-dB below the optimum amplifier power.

Pure Tones for Distortion Tests (Tracks 4 to 34)

Quoting from the standard: “This procedure measures harmonic distortion at the optimum amplifier power using sinewave test signals at one-third-octave spaced IEC center frequencies.” ….. “Apply the sequence of sine wave test signals to the speaker at the optimum amplifier power. Within its specified bandwidth, the speaker shall generate harmonics whose RMS amplitude is less than that of the fundamental.”

Shaped Tone Bursts (Tracks 35 to 68)

The shaped tone bursts provide a test signal suitable for many different types of tests. These include use as a test stimulus for frequency-dependent short-term peak power assessment and headroom of loudspeakers and electronics, and for testing the frequency response, energy decay and phase/polarity of systems. The test signal has a spectrum that covers a one-third-octave bandwidth, with a time duration that decreases as frequency rises.

The peak level of the bursts on the CD are adjusted to reach just under 0 dBFS. Used as an excitation signal, the bursts essentially use up all the available dynamic range of a system being tested, while their energy stays constrained to a narrow one-third-octave bandwidth. As test signal, the highly-energetic tone burst stimulates system behaviors that simple sine waves do not. The bursts are more like the transient nature of music.

Subjectively, the tone bursts do not sound particularly loud as much as their peak levels might imply. This has to do with the integration time of the ear that requires a signal to exist for 80 to 300 milliseconds for full subjective loudness to be attained. Because the bursts are quite short, they sound much less loud than a sinewave of the same peak amplitude. The tone bursts are exceptionally hard to reproduce, because their very-high short-term level fully exercises anything it drives, while their narrow bandwidth makes any resultant distortion very audible.

Peak Power Tests of Loudspeakers

The low duty cycle of the tone bursts provides an excellent test signal for high-power short-term peak-power testing of loudspeakers. Figure 10 of [1] (reproduced here as Fig. 14) shows typical measurements of the peak electrical input power and peak acoustic SPL of a high-quality domestic bookshelf loudspeaker at each one-third-octave frequency from 20 Hz to 20 kHz. The duty-cycle of the test signal is low enough so that the long-term thermal characteristics of the speaker under test are not exercised at all.

The test consists of determining the maximum peak electrical input power and resultant peak output sound pressure levels in the range of 20 Hz to 20 kHz using the setup of Fig. 15. A very high-power power amplifier (more powerful than any speaker that might be tested) is used to drive the speaker. The peak input power was calculated by assuming the measured peak voltage is applied to a resistor whose value is the speaker’s rated impedance.

The test sequence consists of determining how high the burst signal can be raised before either 1) the output sounds objectively distorted or 2) the acoustic output waveform (as observed on an oscilloscope) appears unacceptable distorted, which ever occurs first. At each burst frequency, the maximum peak input voltage and the corresponding peak acoustic sound pressure (usually at one meter on axis) are recorded. The measurement data is in turn plotted on a graph versus frequency similar to Fig. 14.

The data of Fig. 14 is very useful because it tells how much power that speaker can handle and how loud it will play on a short-term basis in each frequency band.

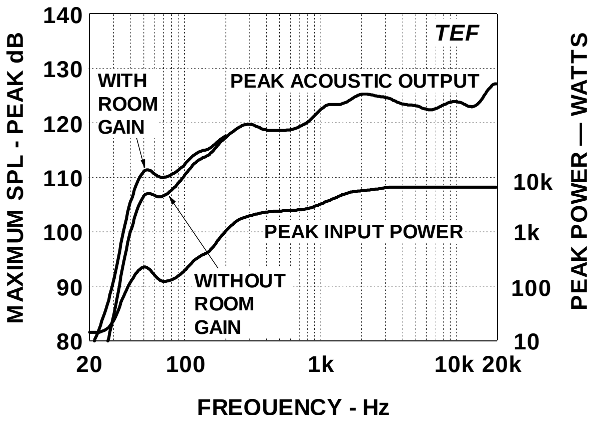

Fig. 14. Typical peak input-output measurements of a high-quality bookshelf loudspeaker using the shaped tone burst.

Peak Power Tests of Amplifiers

The tone burst is quite good for measuring the short-term peak power output of amplifiers. A plot of the amplifiers maximum peak voltage, current, and power versus frequency and various loads is quite informative [5]. At high frequencies, slew rate limits might be reached, while at low frequencies output device protection circuits may be triggered, both of which result in reduced peak power output.

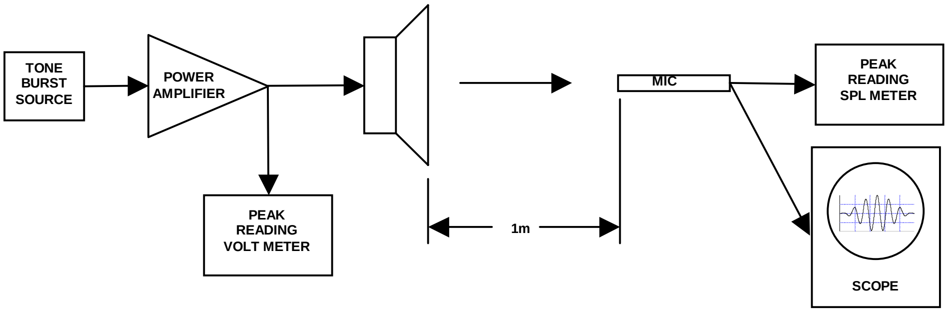

Fig. 15 Setup for measuring the peak electrical input and peak acoustic output of a loudspeaker.

Headroom Tests (Boink Tests)

The tone burst can be used to assess the overload point and headroom of a sound system [2, 3]. At each frequency, the sound level is turned up to the point at which the burst just starts sounding distorted. The level is then turned down slightly so that the sound is relatively undistorted. This level is then measured by a peak-reading sound level meter whose value then represents the maximum undistorted peak sound pressure level at that frequency.

An optimum system design would match the measured peak sound pressure frequency response with the expected spectral content of the program material played through the system. This allows the system to play the program material at the loudest level with equal likelihood of overload in each frequency band. In addition, each intermediate stage in a properly designed sound system should reach overload at roughly the same input level to the system.

Frequency Response and Energy Decay Tests

As Linkwitz points out [4], the shaped tone bursts are excellent for measuring the frequency response of loudspeakers. Armed only with a tone burst source (such as the CD described here), a power amplifier, a calibrated microphone, a microphone preamplifier and an oscilloscope; one can perform free-field measurements in a reflective environment in a manner similar to time delay spectrometry (TDS) or maximal length sequence (MLS) based tests.

It’s only necessary to measure the peak (or peak-to-peak) amplitude of the first received burst (which is presumably the direct sound) on the oscilloscope before the first echo arrives. The distinctive shape of the tone burst makes identifying the echoes relatively easy. As Linkwitz points out, “The low-frequency limit for free-field measurements is reached when the difference in propagation time between the direct and the first reflected signal equals the burst length.” This low-frequency limit is the same limit reached by all measurement techniques that attempt to make free-field measurements in reflective environments.

The envelope of the burst response as approximately seen on the scope screen or computed by taking the absolute value of the response and plotting on a logarithmic vertical scale shows roughly how the energy decays in a room, the so-called “Energy Time Curve” or ETC [4, 8]. The individual envelope decays at each frequency can be combined to form a 3D display of level versus time and frequency[6].

Polarity Tests

The shaped tone burst can also be used to measure phase distortion [4] and so-called “band-limited polarity” [7]. For this application, the information is contained not in the envelope of the burst but in the relationship between the position of the cycles of the carrier in relationship to the envelope. Phase changes at and near the tone burst’s center frequency do not change the burst’s envelope but only the position of the cycles in relationship to the envelope.

MEASUREMENTS

A number of measurements were taken at the line output of a compact disc player playing the EIA test CD. A Stanford Research Systems model SR785 two-channel dynamic signal analyzer was used to analyze its output. These measurements follow.

Amplitude Calibration Tone (Track 1)

Narrow-Band FFT Spectrum

Figure 16 shows the measured FFT spectrum of the 1-kHz amplitude calibration tone on track 1 with the peak normalized to 0 dB. Low-frequency noise or DC offset below 100 Hz is evident, presumably due to the CD player. Above 200 Hz, the distortion and noise is 90 dB or more below the 1-kHz peak.

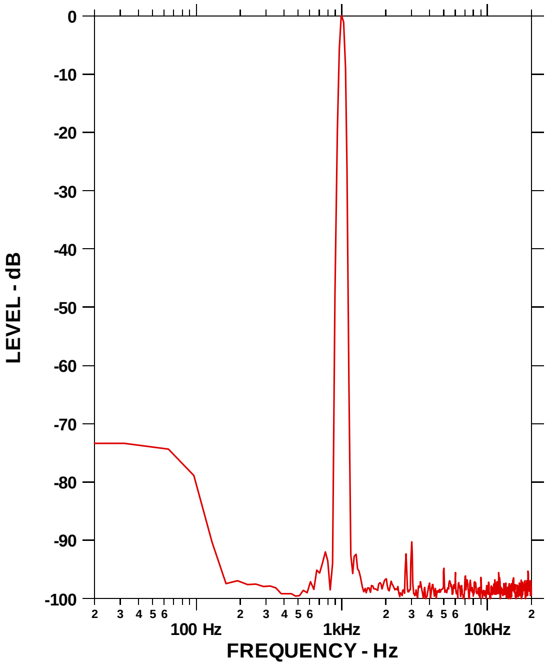

Fig. 16. Measured FFT spectrum of the 1-kHz calibration tone on track 1 with peak normalized to 0 dB.

Histogram Amplitude Distribution

Figure 17 shows the amplitude histogram of the 1-kHz calibration tone on track 1. The data was gathered in mid waveform excluding the half-Hann start-end ramps. A 12 Sec data gathering time was used with a 30.5 uS sampling time (393 kSamples total). The histogram exhibits the typical characteristics of a sine wave with the waveform spending most time near the peaks. The peaks measure somewhat higher than the expected 1.414 V for a –6dB recorded tone.

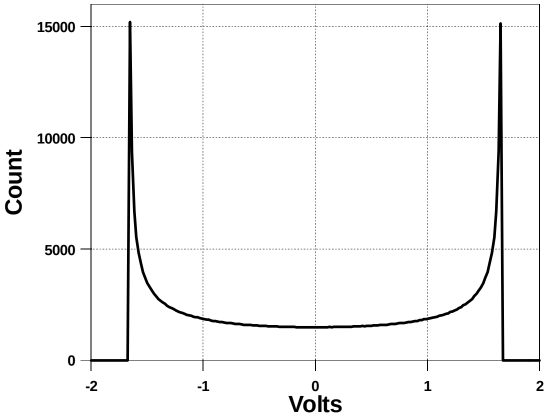

Fig. 17. Measured amplitude histogram of the 1-kHz calibration tone on track 1.

Band-limited Noise for Life Testing (Track 2)

One-Third-Octave Spectrum

Figure 18 shows the measured one-third-octave spectrum of the life-test noise on track 2. The analyzer was set to a 32 second exponential averaging mode and run until the spectrum was stationary.

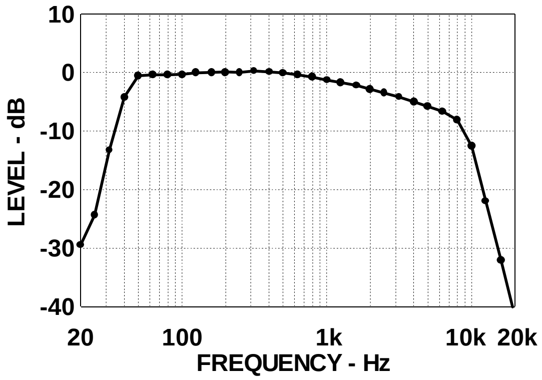

Fig. 18. Measured one-third-octave spectrum of the life-test noise on track 2.

Histogram Amplitude Distribution

Figure 19 shows the measured amplitude histogram of the life-test noise on track 2. A 12 Sec data gathering time was used with a 30.5 uS sampling time (393 kSamples total). Note that the peak levels above ±1.5 Volts are smoothly rounded off and constrained to less than ±1.65 Volts. Again the CD player's output is somewhat high because the highest peaks should be only about ±1.414 Volts.

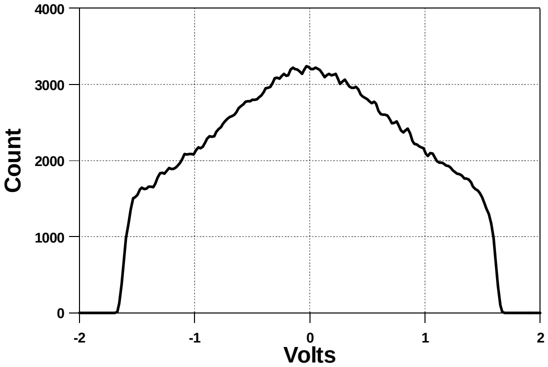

Fig. 19. Measured amplitude histogram of the life-test noise on track 2.

Variable Rate Sweep for Compression Testing (Track 3)

One-Third-Octave Spectrum

Figure 20 shows the measured one-third-octave spectrum of the variable-rate sweep on track 3. The analyzer was set to a 32 second exponential averaging mode and run until the spectrum was stationary.

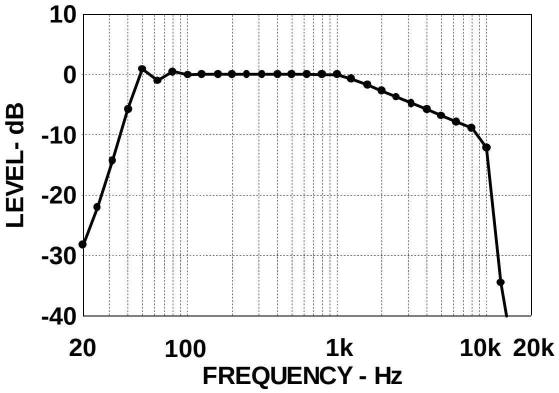

Fig. 20. Measured one-third-octave spectrum of the variable-rate sweep on track 3 used for compression tests. Level is normalized to 0 dB at 500 Hz.

One-Twelfth-Octave Spectrum

Figure 21 shows a narrower constant-percentage bandwidth spectrum of the variable-rate sweep on track 3. Note the spectral anomalies below 100 Hz that occured when the down sweep is attached to the up sweep (see comments earlier in the sweep development section). Data is not displayed above 6 kHz because the analyzer did not generate it in twelfth-octave mode.

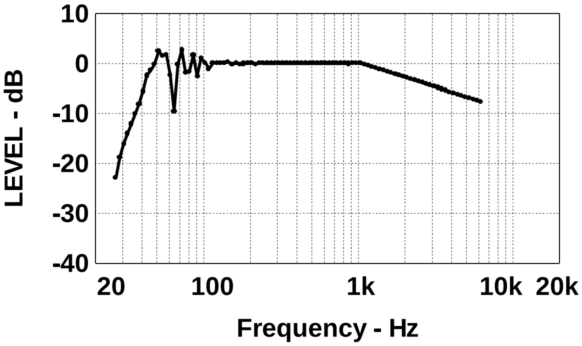

Fig. 21. Measured one-twelfth-octave spectrum of the variable-rate sweep on track 3 used for compression tests. Level is normalized to 0 dB at 500 Hz.

Histogram Amplitude Distribution

Figure 22 shows the measured amplitude histogram of the variable-rate sweep on track 3. A 12 Sec data gathering time was used with a 30.5 uS sampling time (393 kSamples total). Note this histogram is essentially that same as the histogram of the 1-kHz sinewave calibration tone on track 1. This demonstrates that the variable-rate sweep is in fact a sinewave.

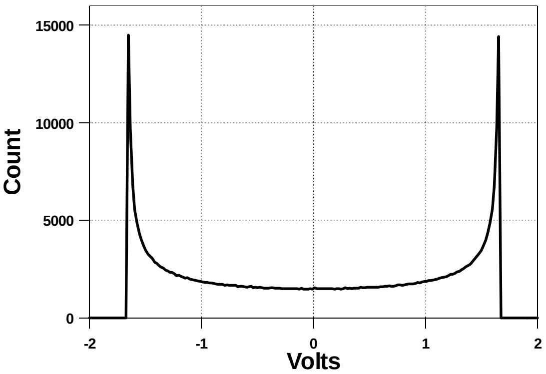

Fig. 22. Measured amplitude histogram of the variable-rate sweep test signal on track 3.

Pure Tones for Distortion Tests (Tracks 4 to 34)

The measurement results for these tones essentially duplicate the results for the 1-kHz calibration tone and are not shown.

Shaped Tone Bursts for Peak Power and Headroom Tests (Tracks 35 to 68)

Waveshape

Figure 23 shows the measured waveform of the 80-Hz shaped tone burst on track 44.

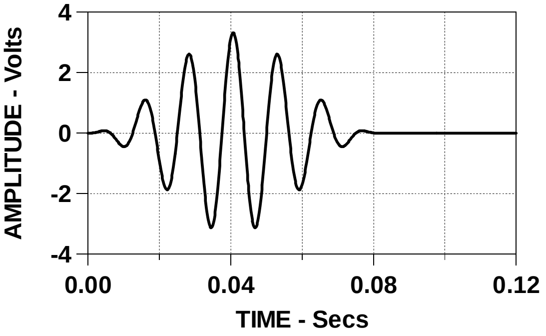

Fig. 23 Measured waveform of 80-Hz shaped tone burst on track 44.

One-Third-Octave Spectrum

Figure 24 shows the measured one-third-octave spectrum of the 500-Hz shaped tone burst on track 52. Note that the spectrum is at least 50 dB down at frequencies greater than an octave away from its center frequency.

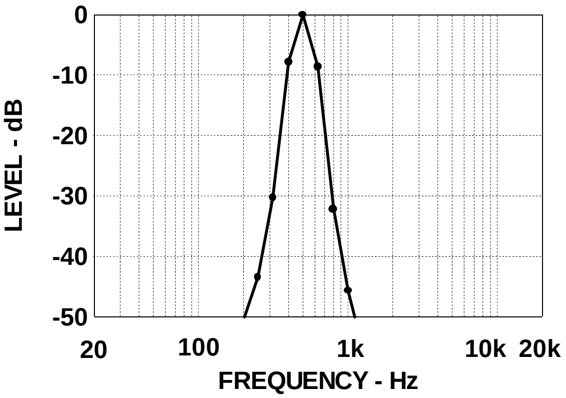

Fig. 24. Measured one-third-octave spectrum of the 500-Hz shaped tone burst on track 52. Peak level is normalized to 0 dB.

Histogram Amplitude Distribution

Figure 25 shows the measured amplitude histogram of the 10-Hz tone burst on the left channel of track 35. A 12 Sec data gathering time was used (12 bursts) with a 30.5 uS sampling time (393 kSamples total). Due to the inter-burst silence periods, the count at zero volts is very high. The histogram shape clearly indicates the varying levels of the individual cycles in the burst with spikes at and near the peak levels of each cycle. The outermost spikes just beyond ±3 Volts indicate the highest level peaks of the burst. The positive spike should theoretically be at 2.828 Volts (the peak level of a 2 Vrms sinewave) but the CD player’s output is somewhat high.

CONCLUSIONS

The development of the test signals on this CD were much more challenging and laborious than I originally predicted. The final product was well worth the effort however. The signals recorded on the CD met the specifications in the standard as evidenced by the final measurements The standard, along with the CD, will go a long way towards improving the consistency, convenience of measuring, and specifying the power ratings of loudspeakers and amplifiers.

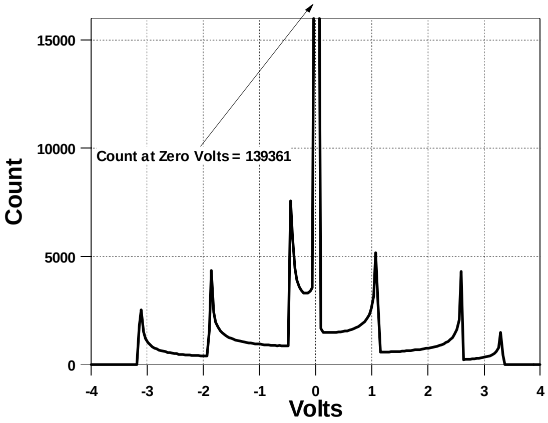

Fig. 25. Measured amplitude histogram of the 10-Hz tone-burst on the left channel of track 35.

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[1] D. B. Keele, Jr., "Platinum Audio Studio 2 Speaker," An equipment review appearing in *Audio Magazine*, May 1999, page 58.

[2] T. Holman, "Boink Test," TMH Corporation, 2500 Wilshire Blvd., Suite 750, Los Angeles, CA 90057 USA. (213) 201-0030 voice, (213) 201-0031 fax, (www.thmlabs.com)

[3] The Hollywood Edge, "Test and Measurement Disk Series,' and accompanying instruction manual, The Hollywood Edge, 7080 Hollywood Blvd., Suite 519, Hollywood, CA 90028 USA, 1-800-292-3755 (www.hollywoodedge.com).

[4] S. Linkwitz, "Shaped Tone-Burst Testing," J. Audio Eng. Soc., vol. 28, no. 4 (1980).

[5] D. B. Keele, Jr., "Peak Power Measurements of Crown Macro Reference Amplifier," Report prepared for Crown International, Dated May 22, 1992. (Report available from the author.)

[6] D. B. Keele, Jr., "Time-Frequency Display of Electroacoustic Data Using Cycle-Octave Wavelet Transforms" presented at the 99th Convention of the Audio Engineering Society (1995 October), preprint Number: 4136.

[7] D. B. Keele, Jr., "Measurement of Polarity in Band-Limited Systems,' presented at the 91st Convention of the Audio Engineering Society (1991 October), preprint 3168.

[8] D. B. Keele, Jr., The Analytic Impulse and the Energy-Time Curve: The Debate Continues," presented at the 93rd Convention of the Audio Engineering Society (1992 October), preprint 3399.

[9] SynAudCon, "Test CD for Sound Reinforcement Systems," Synergetic Audio Concepts, 8780 Rufing Road, Greenville, IN 47124 USA, (812) 923-0174. (www.synaudcon.com)

[10] D. B. Keele, Jr., "Log Sampling in Time and Frequency: Preliminary Theory and Application'" presented at the 97th Convention of the Audio Engineering Society (1994 November), preprint 3935 (K-1).

APPENDIX A: IGOR'S WAVESTATS FUNCTION

All graphs in this paper and all tracks on the CD were generated using the data analysis and graphing program Igor Pro Version 4.0 by WaveMetrics, Inc., (www.wavemetrics.com).

Igor's WaveStats operation computes several values associated with the named wave. WaveStats returns the statistics in the automatically created global variables:

V_npnts	number of points. Doesn't include NaN or INF points.
V_numNans	number of NaNs.
V_numINFs	number of INFs.
V_avg	average of Y values.
V_sdev	standard deviation of Y values, ("Variance" is V_sdev2.)
V_rms	RMS of Y values
V_adev	Average deviation
V_skew	Skewness
V_kurt	Kurtosis
V_minloc	X location of minimum Y value.
V_min	minimum Y value.
V_maxloc	X location of maximum Y value.
V_max	maximum Y value.

APPENDIX B: DESIGN OF CONSTANT-AMPLITUDE VARIABLE-RATE SINEWAVE SWEEPS FOR SPECIFIED SPECTRAL ROLLOFFS

Specification of Sweep

The sweep is specified by assuming that the sweep rate ($S=\frac{d\omega}{dt}$) varies as a power n of the sweep frequency:

$$S = \frac{d\omega}{dt} = \omega^n \,. \qquad \text{Eq.(3)}$$

Without proof, the sweep's spectral roll-off rate $\Re$ (in dB/octave) is proportional to the value of the exponent n, as follows:

$$\Re = 3n \,. \qquad \text{Eq.(4)}$$

Specific values of n yield the following sweeps:
n = 0: sweep rate constant. This is a linear sweep which exhibits no rolloff, the same as white noise;
n = 1: sweep rate proportional to frequency. This is a log or exponential sweep which rolls off at 3dB/octave or 10dB/decade, the same as pink noise;
n = 2: sweep rate proportional to the square of the frequency. This is a square sweep which rolls off at 6dB/octave or 20dB/decade, etc;
$n \geq 3$: sweep rate proportional to higher powers of frequency. These higher rates exhibit higher spectral rolloff rates in direct proportion.

Plan of Attack

Differential equation (3) is solved for various values of n by separation of variables to yield the equations that give the frequency as a function of time $\omega(t)$ and the phase rate as a function of time $\phi(t)$.

The phase rate is simply the time integral of the frequency function:

$$\theta(t) = \int \omega(t)dt \,.$$

The sweep waveform is then given by:

$$y(t) = ASin(\theta + C).$$

The complete sweep is specified by computing various constants after setting the start and stop frequencies ω_1, ω_2 ($\omega_1=2\pi f_1$, $\omega_2=2\pi f_2$) and sweep duration τ. Note that sweep starts at frequency f_1 at t=0 and ends at frequency f_2 at $t = \tau$.

Solve For n = 0, Linear Sweep (Flat spectrum, same as white noise)

This differential equation is solved by separation of variables as follows:

$$S = \frac{d\omega}{dt} = a\omega^0 = a$$

$$\frac{1}{\omega^0} d\omega = adt$$

both sides can then be integrated:

$$\int \frac{1}{\omega^0} d\omega = \int adt = a\int dt = at + c$$

$$\int d\omega = at + c$$

or

$$\omega(t) = at + c \qquad \text{Eq.(7)}$$

where a and c are constants.

The phase rate is then:

$$\theta(t) = \int \omega(t)dt = \frac{at^2}{2} + ct + \theta_1$$

where θ_1 is an arbitrary constant that sets the initial phase.

Eq.(7) may be solved for a and c given specific start and stop frequencies ω_1, ω_2 and sweep duration τ yielding:

$$a = \frac{\omega_2 \text{-} \omega_1}{\tau}, \text{ and}$$

$$c = \omega_1.$$

Solve For *n* = 1, Log or Exponential Sweep (3-dB/octave rolloff, same as pink noise)

In like manner, the following shows the results for n = 1:

$$\omega(t) = ce^{at}, \text{ and}$$

$$\theta(t) = \frac{c}{a}e^{at} + \theta_1$$

where

$$a = \frac{1}{\tau}\ln\left(\frac{\omega_2}{\omega_1}\right), \text{ and}$$

$$c = \omega_1.$$

Solve For *n* = 2, Square Sweep (6-dB/octave rolloff)

In like manner, the following shows the results for n = 2:

$$\omega(t) = \frac{1}{at + c}, \text{ and}$$

$$\theta(t) = \frac{1}{a}\left(\ln(at + c) - \ln(c)\right) + \theta_1$$

where

$$a = \frac{\left(\frac{1}{\omega_2} - \frac{1}{\omega_1}\right)}{\tau}, \text{ and}$$

$$c = \frac{1}{\omega_1}.$$

This is a so called square sweep that provides a spectrum that rolls off at 6 dB/octave or 20 dB/decade (rolls off at 3 dB/octave faster than pink noise). Note that the phase is a function of the natural log of time. This was called a log sweep in [10] where the frequency varied inversely with time.

Solve For *n* = 3 and Higher

Likewise, the following shows the general results for $n \geq 3$ (note: n need not be an integer):

$$\omega(t) = \left[(1-n)\left(at + c\right)\right]^{\frac{1}{1-n}}, \text{ and}$$

$$\theta(t) = \frac{\left[(1-n)(at + c)\right]^{\frac{2-n}{1-n}}}{(2-n)a} + \theta_1$$

where

$$a = \frac{1}{\tau(1-n)}\left(\omega_2^{1\text{-n}} \text{-} \omega_1^{1-n}\right), \text{ and}$$

$$c = \frac{\omega_1^{1-n}}{1-n}.$$

APPENDIX C: CD TABLE OF TRACK CONTENTS

TRACK NUM.	**DESCRIPTION**	**PEAK LEVEL dB** ***Both Channels***	**RMS LEVEL dB** ***Both Ch. or Left, Right***	**CREST FACTOR dB** ***Both Ch. or Left, Right***	**TRACK TIME Min:Secs**
1	Reference Tone: 1 kHz.	-6.0	-9.0	3.0	1:00.00
2	Spectrally Shaped Random Noise for Life Tests: Band-limited 40 Hz to 10 kHz.	-6.0	-12.0	6.0	30:00.00
3	Variable-Rate Sinewave Sweep for Power Compression Tests: 0.5 second cycle time. Spectrum same as Life Test Noise (Track 2).	-6.0	-9.0	3.0	10:00.00
4	Pure Tone: 20 Hz	-6.0	-9.0	3.0	0:20.00
5	Pure Tone: 25 Hz	-6.0	-9.0	3.0	0:20.00
6	Pure Tone: 31.5 Hz	-6.0	-9.0	3.0	0:20.00
7	Pure Tone: 40 Hz	-6.0	-9.0	3.0	0:20.00
8	Pure Tone: 50 Hz	-6.0	-9.0	3.0	0:20.00
9	Pure Tone: 63 Hz	-6.0	-9.0	3.0	0:20.00
10	Pure Tone: 80 Hz	-6.0	-9.0	3.0	0:20.00
11	Pure Tone: 100 Hz	-6.0	-9.0	3.0	0:20.00
12	Pure Tone: 125 Hz	-6.0	-9.0	3.0	0:20.00
13	Pure Tone: 160 Hz	-6.0	-9.0	3.0	0:20.00
14	Pure Tone: 200 Hz	-6.0	-9.0	3.0	0:20.00
15	Pure Tone: 250 Hz	-6.0	-9.0	3.0	0:20.00
16	Pure Tone: 315 Hz	-6.0	-9.0	3.0	0:20.00
17	Pure Tone: 400 Hz	-6.0	-9.0	3.0	0:20.00
18	Pure Tone: 500 Hz	-6.0	-9.0	3.0	0:20.00
19	Pure Tone: 630 Hz	-6.0	-9.0	3.0	0:20.00
20	Pure Tone: 800 Hz	-6.0	-9.0	3.0	0:20.00
21	Pure Tone: 1 kHz	-6.0	-9.0	3.0	0:20.00
22	Pure Tone: 1.25 kHz	-6.0	-9.0	3.0	0:20.00
23	Pure Tone: 1.6 kHz	-6.0	-9.0	3.0	0:20.00
24	Pure Tone: 2 kHz	-6.0	-9.0	3.0	0:20.00
25	Pure Tone: 2.5 kHz	-6.0	-9.0	3.0	0:20.00
26	Pure Tone: 3.15 kHz	-6.0	-9.0	3.0	0:20.00
27	Pure Tone: 4 kHz	-6.0	-9.0	3.0	0:20.00
28	Pure Tone: 5 kHz	-6.0	-9.0	3.0	0:20.00
29	Pure Tone: 6.3 kHz	-6.0	-9.0	3.0	0:20.00
30	Pure Tone: 8 kHz	-6.0	-9.0	3.0	0:20.00
31	Pure Tone: 10 kHz	-6.0	-9.0	3.0	0:20.00
32	Pure Tone: 12.5 kHz	-6.0	-9.0	3.0	0:20.00
33	Pure Tone: 16 kHz	-6.0	-9.0	3.0	0:20.00
34	Pure Tone: 20 kHz	-6.0	-9.0	3.0	0:20.00
35	Tone Burst: 10 Hz	0.0	-9.1, -19.1	9.1, 19.1	0:30.00
36	Tone Burst: 12.5 Hz	0.0	-10.1, -20.1	10.1, 20.1	0:30.00
37	Tone Burst: 16 Hz	0.0	-11.1, -21.1	11.1, 21.1	0:30.00
38	Tone Burst: 20 Hz	0.0	-12.1, -22.1	12.1, 22.1	0:30.00
39	Tone Burst: 25 Hz	0.0	-13.1, -23.1	13.1, 23.1	0:30.00
40	Tone Burst: 31.5 Hz	0.0	-14.1, -24.1	14.1, 24.1	0:30.00
41	Tone Burst: 40 Hz	0.0	-15.1, -25.1	15.1, 25.1	0:30.00
42	Tone Burst: 50 Hz	0.0	-16.1, -26.1	16.1, 26.1	0:30.00
43	Tone Burst: 63 Hz	0.0	-17.1, -27.1	17.1, 27.1	0:30.00
44	Tone Burst: 80 Hz	0.0	-18.1, -28.1	18.1, 28.1	0:30.00
45	Tone Burst: 100 Hz	0.0	-19.1, -29.1	19.1, 29.1	0:30.00
46	Tone Burst: 125 Hz	0.0	-20.1, -30.1	20.1, 30.1	0:30.00
47	Tone Burst: 160 Hz	0.0	-21.1, -31.1	21.1, 31.1	0:30.00
48	Tone Burst: 200 Hz	0.0	-22.1, -32.1	22.1, 32.1	0:30.00
49	Tone Burst: 250 Hz	0.0	-23.1, -33.1	23.1, 33.1	0:30.00
50	Tone Burst: 315 Hz	0.0	-24.1, -34.1	24.1, 34.1	0:30.00
51	Tone Burst: 400 Hz	0.0	-25.1, -35.1	25.1, 35.1	0:30.00
52	Tone Burst: 500 Hz	0.0	-26.1, -36.1	26.1, 36.1	0:30.00
53	Tone Burst: 630 Hz	0.0	-27.1, -37.1	27.1, 37.1	0:30.00
54	Tone Burst: 800 Hz	0.0	-28.1, -38.1	28.1, 38.1	0:30.00
55	Tone Burst: 1 kHz	0.0	-29.1, -39.1	29.1, 39.1	0:30.00
56	Tone Burst: 1.25 kHz	0.0	-30.1, -40.1	30.1, 40.1	0:30.00
57	Tone Burst: 1.6 kHz	0.0	-31.1, -41.1	31.1, 41.1	0:30.00
58	Tone Burst: 2 kHz	0.0	-32.1, -42.1	32.1, 42.1	0:30.00
59	Tone Burst: 2.5 kHz	0.0	-33.1, -43.1	33.1, 43.1	0:30.00
60	Tone Burst: 3.15 kHz	0.0	-34.1, -44.1	34.1, 44.1	0:30.00
61	Tone Burst: 4 kHz	0.0	-35.1, -45.1	35.1, 45.1	0:30.00
62	Tone Burst: 5 kHz	0.0	-36.1, -46.1	36.1, 46.1	0:30.00
63	Tone Burst: 6.3 kHz	0.0	-37.1, -47.1	37.1, 47.1	0:30.00
64	Tone Burst: 8 kHz	0.0	-38.1, -48.1	38.1, 48.1	0:30.00
65	Tone Burst: 10 kHz	0.0	-39.1, -49.1	39.1, 49.1	0:30.00
66	Tone Burst: 12.5 kHz	0.0	-40.1, -50.1	40.1, 50.1	0:30.00
67	Tone Burst: 16 kHz	0.0	-41.1, -51.1	41.1, 51.1	0:30.00
68	Tone Burst: 20 kHz	0.0	-42.1, -52.1	42.1, 52.1	0:30.00

APPENDIX D: PEAK VOLTAGE MEASURING ADAPTER FOR DIGITAL VOLT METER (DVM)

Description

Test instruments that measure instantaneous peak voltages are quite rare. With the exception of analog oscilloscopes and the more recent digital oscilloscopes including portable ones that have waveform measuring capabilities, I no of none except for some of the old Bruel & Kjaer measurement amplifier/meters and sound level meters.

The following schematic Fig. 26 shows the circuit of a passive half-wave rectifier adapter that goes between the output of a power amplifier, that drives a loudspeaker, and a digital volt meter. The adapter is designed to drive a DVM set to a DC scale with a 10 meg input impedance. The adapter charges a capacitor which holds the peak voltage long enough for the DVM to measure it. A discharge switch is provided to reset the adapter.

Internally, a high-quality high-voltage 10 uF capacitor is charged through a diode and series surge limiting resistor, which is then discharged through a 100 meg ohm resistance composed of a 90 meg ohm resistor in series with the 10 meg ohm input of the DVM. This output circuit forms a divide by 10 attenuator which means the *DVM reading must be multiplied by 10* to get the actual peak voltage. The large RC time constant of this combination (RC = 100 meg x 10 uF = 100 x 10^{+6} x 10 x 10^{-6} = 1000 seconds = 16.67 minutes) holds the reading for a sufficient time to be measured accurately with the DVM. The 0.6V voltage drop of the diode can be neglected for peak input voltages above about 10 Volts.

Parts List

C1: Capacitor, 10 uF, 300 WVDC or higher, ±20% tolerance, low-leakage (Note: oil-bath style AC motor starting caps may work OK.)

D1: Diode, high peak reverse voltage (PRV > 500V) (Note: the original version of this adapter used a small-signal 1N645 diode that worked well for many years, although its rated characteristics seemed anemic for this application.)

R1: Resistor, 15 Ohm, ½ Watt, 10% tolerance

R2: Resistor, 220 Ohm, ½ Watt, 10% tolerance

R3: Resistor, 90 meg Ohm, 0.1 Watt, 1% tolerance (Note: nine each 10 meg Ohm, 0.1 Watt, 1% tolerance resistors wired in series may be substituted).

S1: Switch, SPDT, push button or momentary toggle

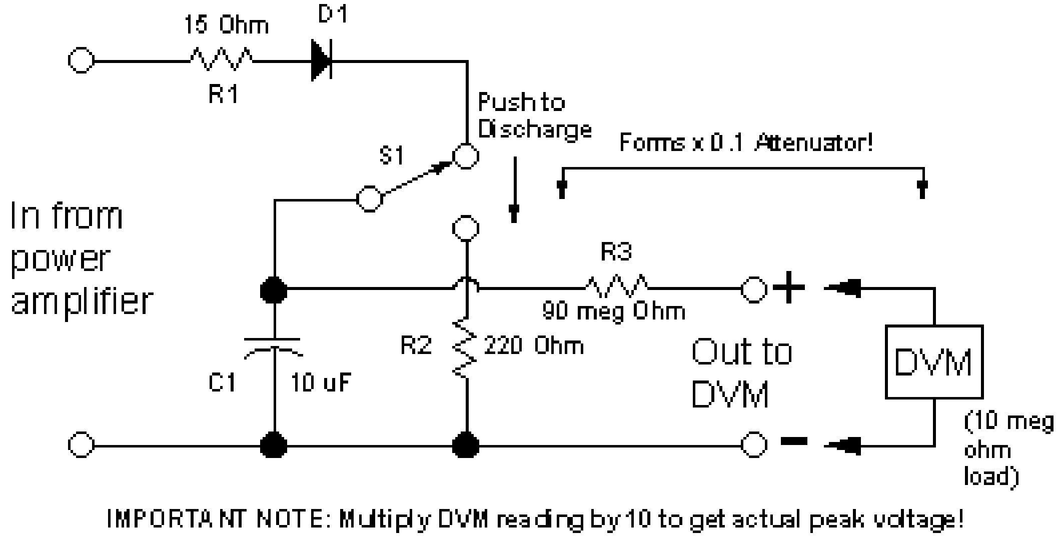

Fig. 26. Schematic of peak voltage measuring adapter.