United States Department of Commerce
National Institute of Standards and Technology

NIST Technical Note 1286

Response of Personal Noise Dosimeters to Continuous and Impulse-Like Signals

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Prepared for:

Occupational Safety and Health Administration
U.S. Department of Labor

June 1991

U.S. Department of Commerce
Robert A. Mosbacher, Secretary

National Institute of Standards and Technology
John W. Lyons, Director

National Institute of Standards and Technology
Technical Note 1286
Natl. Inst. Stand. Technol.
Tech. Note 1286
156 pages (June 1991)
CODEN: NTNOEF

U.S. Government Printing Office
Washington: 1991

For sale by the Superintendent of Documents
U.S. Government Printing Office
Washington, DC 20402

ABSTRACT

A study of the capabilities of noise dosimeters to measure personal exposure to time-varying and impulse-like noises was carried out. Ten commercial noise dosimeters were obtained. A laboratory reference noise dosimeter was constructed to provide a demonstrably accurate basis with which to compare the commercial noise dosimeters. Each commercial dosimeter, when ordered from the manufacturer, was specified to have: (1) a threshold A-weighted sound level of 80 dB, (2) a criterion sound level of 90 dB, and (3) an exchange rate of 5 dB and/or 3 dB. A preliminary series of tests employing electrical input signals was performed to check the stability and gain linearity of each dosimeter as well as its ability to process (1) signals having moderate (up to 10 dB) crest factors and (2) an input signal that should cause the output signal of the detector to repeatedly cross the threshold sound level. All but one dosimeter was able to approximate closely the percentage criterion exposures of the preliminary tests. Seven of the ten dosimeters were selected for further testing, involving electrical and electroacoustical frequency response, electrical linearity, and electrical response to tone-burst sequences with burst durations of 0.01, 0.1, and 1.0 s and crest factors of 10, 20, and 30 dB. The performance of the commercial dosimeters was compared with theory and with results obtained from the reference dosimeter. Additional electrical tone-burst sequence tests, employing a wider range of burst durations and crest factors, were performed using the reference dosimeter and the results of these tests were compared with theoretical calculations. Except in a few isolated cases, the commercial dosimeters were in general agreement with the performance specification of the appropriate American National Standard and with OSHA regulations.

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1. Introduction

1.1 Background

Present Federal regulations, promulgated under the authority of the Occupational Safety and Health Act and the Coal Mine Safety Act, specify limits on the noise exposure of workers during their working day [1-3][1]. The intent of these regulations is to reduce the risk of permanent noise-induced hearing damage. Such present and future regulations must depend upon the capabilities of the instruments that are needed to measure noise exposure.

A noise measuring instrument that can be carried or worn throughout the work period to measure the sound exposure of a given individual is termed a personal sound exposure meter or personal noise dosimeter (often called simply a dosimeter). In situations where a worker is exposed to unpredictable time-varying noise, a personal noise dosimeter is frequently used to establish worker noise dose. In general, the noise environment of a worker may contain noise which is, at least in part, impulsive in character. As a consequence of Occupational Safety and Health Administration (OSHA) interest in the accuracy of dosimeter measurements, the National Institute of Standards and Technology (NIST), then the National Bureau of Standards, was consulted as an impartial authority and requested to examine systematically the capabilities of commercial dosimeters.

Functionally, a personal noise dosimeter (as specified in ANSI S1.25-1978, "Specification for Personal Noise Dosimeters")[2] consists of a sound level metering section, an exposure integration section, and an indicator (see Fig. 1). A microphone [MIC] senses the sound pressure and the (typically amplified) output voltage from the microphone is fed into an A-weighting network which filters the signal [A-WTG AMP]. The signal is then squared [SQR], exponentially averaged (with a 1-s time constant) [AVG], and converted to a level equivalent to the A-weighted (slow-response) level that would be read on a sound level meter. The output of the sound level metering section is then fed into the exposure integration section (containing an exponentiation [EXP] circuit, threshold circuit [THLD], and integrator [INT]) which performs the algorithm necessary to compute percentage criterion exposure, according to a particular exchange rate, threshold sound level, and criterion sound level. The dosimeter processes the output of the exposure integration section throughout the measurement duration and indicates a percentage criterion exposure [Indicator] corresponding to the accumulated data at the completion of the measurement.

A brief definition of the following terms, intrinsic to the description of the operation of personal noise exposure meters, and to noise exposure measurement and analysis, is provided here for clarity. The reader is referred to Appendix A of this report, or to ANSI S1.25-1978, for further definition of these terms.

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[1]Numbers in brackets indicate references cited in Sec. 7.1 at the end of this report.

[2]References to American National Standards are cited in Sec. 7.2 at the end of this report.

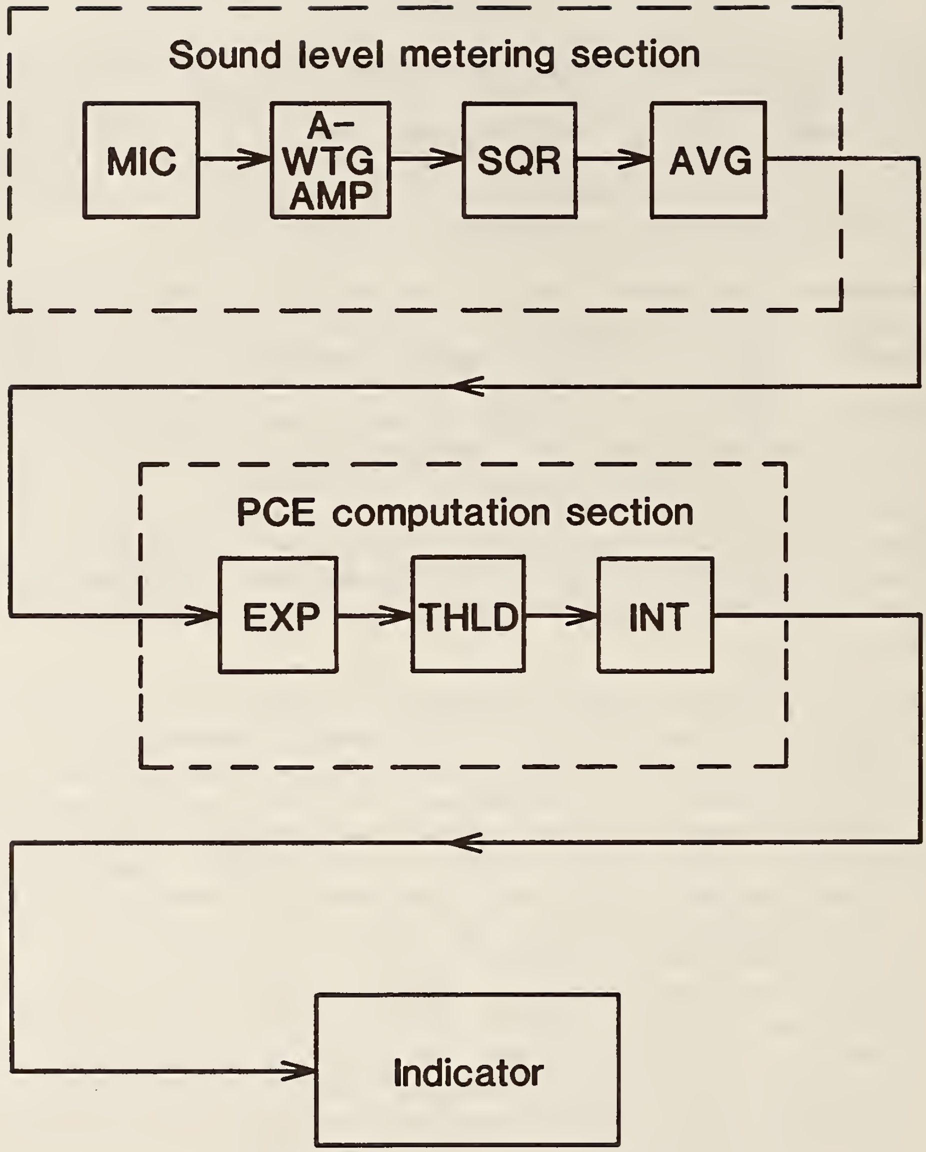

Figure 1. Functional block diagram of a personal noise exposure meter, after ANSI S1.25-1978, "Specification for Personal Noise Dosimeters." While a specific noise dosimeter may, or may not, consist of circuits homomorphic with those given in the diagram, the performance of such a dosimeter should be equivalent to that of a hypothetical instrument constructed as shown.

Sound pressure level: ten times the logarithm to the base ten of the ratio of the mean-square sound pressure to the square of a reference sound pressure of 20 μPa.

Voltage level commensurate with sound pressure level: ten times the logarithm to the base ten of the ratio of the mean-square voltage to the square of the product of (1) the nominal microphone sensitivity of a personal noise exposure meter and (2) a reference sound pressure of 20 μPa.

A-weighted sound level: the sound pressure level of a signal measured using an A-weighting network (filter) and (for the purposes of this report) a slow (1 s) exponential-time-averaging constant.

Sound exposure: the time integral, over a stated time or event, of the slow exponential-time-averaged, squared, A-weighted, sound pressure signal when the 3-dB exchange rate is used. For the 5-dB exchange rate, it is the time integral of approximately the 0.6 power of the slow exponential-time-averaged, squared, A-weighted, sound pressure signal. Sound exposure is measured only when a sound level exceeds the threshold sound level.

Criterion sound exposure: The product of the criterion duration (i.e., 8 h) and the mean-square sound pressure corresponding to the criterion sound level when the 3-dB exchange rate is used. The product of the criterion duration and approximately the 0.6 power of the mean-square sound pressure corresponding to the criterion sound level when the 5-dB exchange rate is used.

Percentage criterion exposure (also referred to as "dose"): the ratio of a given sound exposure to the criterion sound exposure, expressed as a percentage.

Criterion sound level: the A-weighted, time-averaged, 8-h sound level that produces a percentage criterion exposure of 100 percent.

Exchange rate: for a given measurement duration, the decibel increase in a continuous uniform sound level corresponding to a doubling of percentage criterion exposure.

Threshold sound level: the upper limit of sound levels to be excluded from the computation of percentage criterion exposure. Note: this definition of threshold sound level is consistent with the definition given above and in ANSI S1.25-1978 for sound exposure in that only sound levels in excess of the threshold sound level contribute to sound exposure. However, it is inconsistent with the formula given in ANSI S1.25-1978 for the calculation of percentage criterion exposure when the measured slow A-weighted sound level equals the threshold sound level (see also the formulae given in Appendices A and B for the calculation of percentage criterion exposure).

Equivalent level: the average sound level equivalent to a given percentage criterion exposure and measurement duration.

Slow response: the response characteristic of a root-mean-square detector that includes an exponential averaging device with a time constant of 1 s.

Crest factor: a dimensionless ratio of the peak to root-mean-square values of the dependent variable of a periodic waveform, with time the independent variable. Unless otherwise noted, signal crest factors have been expressed logarithmically in terms of decibels in this report, i.e., twenty times the logarithm to the base ten of the ratio of peak to rms waveform values. The reader is cautioned that both linear and logarithmic representations of crest factor have appeared in the literature.

1.2 Objective

The objective of this study was to examine the capability of commercial noise dosimeters to respond accurately to noise with impulsive content. This study did not address such issues as the appropriateness of the use of an A-weighting filter, a slow response, or a 5-dB exchange rate in a personal noise exposure meter. No effort was made to characterize the dosimeters in conformance with any particular instrument standard.

1.3 Approach

A variety of dosimeters was tested using sets of well-defined and replicable signals which approximated, in level and form, signals typical of an acoustic environment in which a dosimeter might be exposed to noise of an impulsive character (see Sec. 5.2). Steady-state signals at various levels were used to calibrate the dosimeters or to test aspects of the response of the dosimeters which might prove beneficial in analyzing the response of the dosimeters to impulsive signals. The principal measure of performance of the dosimeters with respect to impulsive signals was considered to be "percentage criterion exposure" as defined in American National Standard (ANSI) S1.25-1978, "Specification for Personal Noise Dosimeters," and, for the tests involving the use of a 5-dB exchange rate, the Code of Federal Regulations, Title 29, Part 1910, Section 95, "Occupational noise exposure" [1].

Ten commercially available noise dosimeters were obtained for testing. These dosimeters were selected to provide a sample of either previously tested or current design engineering, including some instruments that have been widely used by OSHA. The operational characteristics of the dosimeters were as defined in ANSI S1.25-1978 with the criterion A-weighted sound level equal to 90 dB, the threshold sound level equal to 80 dB, and the exchange rate equal to either 3 or 5 dB, depending on the test and instrument capabilities.

A laboratory reference noise dosimeter was assembled, from commercially available laboratory-grade instruments, and evaluated in order to provide a basis with which to compare the commercial noise dosimeters. For this purpose, the reference dosimeter (laboratory reference noise dosimeter) could be set to comply to the general specifications of ANSI S1.25-1978 and, in particular, to current OSHA regulations.

The approach used in the investigation incorporated thee related areas of effort: (1) analytical/computational studies to predict or confirm the response of a dosimeter to signals with nominal crest factors ranging from 3 to 30 dB; (2) experimental studies employing a measuring amplifier which, when used in conjunction with a measuring microphone and microphone preamplifier, constituted a precision laboratory-grade sound level meter that also functioned as the "front end" of a superior quality reference dosimeter; and (3) experimental studies employing portable commercial dosimeters.

A series of preliminary electrical tests and a series of electrical tests employing signals having moderate-to-high crest factors were performed using the reference dosimeter and commercial dosimeters. Additionally, electrical frequency response and linearity tests were performed using the commercial dosimeters, and electroacoustical response tests were performed using the reference dosimeter and commercial dosimeters. A brief description of these tests follows. Full descriptions of the tests are given in the appropriate sections below.

In this report, the responses of the commercial dosimeters (ten in the case of the preliminary tests and seven in the other tests) are examined, discussed, and compared with measurements using the reference dosimeter and with theoretical calculations. The response of the reference dosimeter to tone-burst sequences is further compared with the results of theoretical calculations.

1.3.1 Electrical Frequency Response and Linearity Tests

The electrical frequency response of the commercial dosimeters was tested at octave intervals from 31.5 Hz to 8 kHz with additional measurements made at 20 Hz and 10 kHz. A continuous sine wave at 135 dB (SPL) was applied to each dosimeter at each test frequency. "SPL," as used in this report to describe electrical input signals used in performing electrical tests, denotes the unweighted voltage levels equivalent to the sound pressure levels given. For those dosimeters that could be operated as a sound level meter (i.e., the dosimeter could be set to display an A-weighted sound level using a slow time constant in the exponential averaging device), the results were read as A-weighted sound levels. For the remaining dosimeters (which had only percentage-criterion-exposure display capabilities), a set of tests was developed with the length (measurement duration) of the tests varying depending on the A-weighted level of the signal and the exchange rate of the dosimeter. The test results were read as a percentage criterion exposure which was converted to an equivalent level.

The electrical linearity of the commercial dosimeters was tested at 1 and 10 kHz and 10 dB increments from 135 to 85 dB (SPL) and at 31.5 Hz at 135 and 125 dB (SPL).

1.3.2 Electroacoustical Response Tests

The electroacoustical low-frequency response of the reference dosimeter and commercial dosimeters was tested at octave intervals from 63 Hz to 1 kHz in an acoustic coupler which, depending on the dosimeter under test, was fitted with either a 1/2-inch or 3/8-inch microphone adapter. The acoustic coupler contained an electrodynamic transducer that provided the sound source. The outer diameter of the dosimeter microphone was increased, when needed, by wrapping tape around it until a proper seal was made with the coupler adapter. The sound pressure in the coupler cavity, for a given frequency and drive voltage at the coupler electrical terminals, was established using a calibrated laboratory measuring microphone. The pressure sensitivity of the reference dosimeter was calibrated using a pistonphone which in turn had been calibrated using insert voltage techniques and NIST-owned laboratory standard microphones. Each of the commercial dosimeters was calibrated in the acoustic coupler using a 1-kHz sine wave at a calibration level specified by the manufacturer. The procedure followed during the calibration of the commercial dosimeters was that given in the dosimeter operating or instruction manual for calibration of the instrument with an acoustic calibrator. Each of the dosimeters was tested separately at a constant A-weighted sound level of 85 dB at each of the test frequencies using a continuous sine wave. The output of the reference dosimeter rms detector was recorded and converted to an A-weighted sound level.

After each of the commercial dosimeters had been calibrated in the acoustic coupler as noted above, the electroacoustical high-frequency responses of the laboratory reference dosimeter and the commercial dosimeters were tested in the large NIST reverberation chamber at octave intervals from 500 Hz to 10 kHz. The dosimeters were located at one of four locations within the reverberation chamber with an 1/8-inch laboratory measuring microphone as a reference at a fifth position. The sound pressure levels at the four test locations relative to the measuring microphone reference location were measured at each of the test frequencies using the reference microphone measuring system (1/8-inch measuring microphone, microphone preamplifier, power supply, and measuring amplifier). The unweighted (flat response) gain of the reference dosimeter was calibrated using a pistonphone and two acoustic calibrators inside the reverberation chamber. The test signal was pink noise that was filtered by a bandpass filter, centered on the test frequency, with a bandwidth of 3 percent of the test frequency. The filtered noise was amplified, as needed, to maintain an A-weighted sound level of approximately 85 dB at each dosimeter location. The A-weighted level indicated on the reference dosimeter measuring amplifier was recorded during the time that the noise was generated and, upon completion of each of the tests, the recorded readings were averaged and converted into A-weighted sound levels. The commercial dosimeters were adjusted to display percentage criterion exposure and were exposed to the test signals for a measurement duration corresponding to a nominal 12 percent criterion exposure (depending on the sound pressure level at the microphone location, the exchange rate of the instrument, and the duration of the test). The percentage criterion exposure was read and converted to an equivalent level, based on the measurement duration (defined to be equivalent to the length of time that the noise was generated electrically during the test).

1.3.3 Preliminary Electrical Tests

A preliminary series of tests employing electrical input signals was performed using all ten of the commercial noise dosimeters obtained for testing. These tests checked the stability over time and the gain linearity of the noise dosimeters as well as their ability to: (1) process a signal with a moderate (10-dB) crest factor and (2) determine the percentage criterion exposure of a tone-burst signal which should cause the output of the exponential averaging device of the dosimeter (as shown in Fig. 1) to cross the threshold sound level repeatedly. The preliminary tests were used to examine the basic performance of the commercial dosimeters and, if possible, to restrict the number of dosimeters to be subjected to subsequent tests. If a unit performed poorly for these less demanding but essential preliminary tests, it was eliminated from the extensive series of more demanding tests.

The electrical signals used in the preliminary tests were individually applied to each noise dosimeter after its gain had first been calibrated using a 1-kHz sine wave at a voltage level calculated from the acoustical calibration sound pressure level specified by the manufacturer and the nominal sensitivity of the microphone of the dosimeter. Nine of the ten dosimeters were set to a 5-dB exchange rate and one was set to a 3-dB exchange rate.

The reference dosimeter measured each test signal twice with each of the measurement durations equal to an integral number of fundamental periods of the test signal. An 8-h percentage criterion exposure, extrapolated from the data obtained during the first measurement of each of the test signals, was computed using a 5-dB exchange rate; and an 8-h percentage criterion exposure, extrapolated from the data during the second measurement of each of the test signals, was computed using a 3-dB exchange rate. After comparing the responses of the commercial dosimeters to the preliminary test signals with measurements made using the reference dosimeter and with theoretical calculations, thee of the ten dosimeters were eliminated from further testing. In the descriptions of the other tests that appear below, the phase "commercial dosimeters" refers to the remaining seven commercial dosimeters selected for further testing.

1.3.4 Electrical Tests Employing Signals with Moderate-to-High Crest Factors

A set of tone-burst sequence test signals was developed in order to measure noise dosimeter response to an extensive array of time-varying signals. The tone-burst sequences had burst durations ranging from 0.010 to 10 s and crest factors ranging from 4.8 to 30 dB. The tone bursts were comprised of an integral number of cycles of a sine wave having a fixed voltage amplitude equivalent to 120 dB (SPL) and a frequency of either 100 Hz or 1 kHz. The crest factors were derived by varying the repetition period of the burst sequence for a given burst duration. A set of tests, employing both 5-dB and 3-dB exchange rates, was developed for the commercial dosimeters from a subset of these tone-burst sequence test signals. In addition to the tests employing tone-burst sequences, the commercial dosimeters were tested using a continuous 1-kHz sine wave at voltage levels of 90 and 120 dB (SPL).

The reference dosimeter was used to measure each of the tone-burst sequence test signals twice, with each of the measurement durations equal to an integral number of fundamental periods of the test signal. The 8-h, 5-dB and 3-dB exchange rate, percentage criterion exposures corresponding to each of the tone-burst sequence test signals were computed from the reference dosimeter measurement results, with a 5-dB exchange rate applied to the first measurement and a 3-dB exchange rate applied to the second measurement.

As in the case of the preliminary electrical tests, the electrical signals having moderate-to-high crest factors were individually applied to each commercial noise dosimeter after its gain was calibrated using a 1-kHz sine wave. The commercial dosimeters were used in both the 5-dB and 3-dB exchange rate tests, providing the instrument had the capability of selecting (via programming or DIP switch position changes) the exchange rate used to compute the percentage criterion exposure; otherwise the dosimeters were used only in those tests in which the exchange rate of the test agreed with the exchange rate of the instrument as it was received at NIST. The measurement duration of each of the tone-burst sequence tests was selected such that, based on the reference dosimeter results, the percentage criterion exposure would remain constant at 100 percent. The measurement durations selected for the tests that used a continuous 1-kHz sine wave were the time periods required to produce a theoretical percentage criterion exposure of 3 percent at 90 dB (SPL) and 100 percent at 120 dB (SPL).

2. Signal Source and Measuring Instruments

2.1 Electrical Test Signal Source

2.1.1 Description

The equipment comprising the signal source along with measuring instruments used in the electrical tests is shown in Figs. 2 and 3 within the dashed box denoted "Electrical Signal Source System With Monitoring Equipment". (Note: slight modifications, as noted below, in the measuring instrumentation from that which is indicated in Figs. 2 and 3 were made in the case of the tone-burst sequence tests that were used in the preliminary electrical tests and the electrical tests employing signals having moderate-to-high crest factors.)

A sine wave was produced and, depending upon the test, either held constant or periodically gated by the function generator. The output of the function generator [FCN GEN] was followed by a wide-band linear amplifier [AMP]. Digital multimeter 1 [DMM 1] monitored the dc voltage offset at the output of the amplifier. The frequency counter [Counter], connected in parallel with digital multimeter 1, monitored the frequency of the amplified sine wave produced by the function generator. A matching resistor [RES] was placed at the amplifier output so that the precision attenuator [ATT] input was driven from a matching source impedance at 1 kHz. The voltage at the input of the precision attenuator was monitored by an oscilloscope [Scope] containing a sample-and-hold module and an analog-to-digital converter which enabled the peak amplitude of the waveform to be displayed to four digits. The signal was then selectively attenuated to the nearest 0.1-dB by the precision passive attenuator. The output of the precision attenuator was loaded with an impedance matching network [NET] which was constructed so that, at 1 kHz, the dosimeter under test was driven from the proper source impedance and the precision attenuator was terminated with the proper load impedance. Finally, digital multimeter 2 [DMM 2] monitored the voltage at the input to the dosimeter under test. The computer [COMP] was connected via an interface bus [IEEE 488] (IEEE Std 488-1978), either to the measuring amplifier [MA] of the laboratory reference noise dosimeter as shown in Fig. 2 or to the function generator as shown in Fig. 3. When connected to the measuring amplifier, the computer acted as part of the laboratory reference noise dosimeter. When connected to the function generator, the computer acted as part of the signal source system by controlling the output of the generator and thus determining the duration of the commercial dosimeter tests as needed.

The signal source and measuring instruments used during the preliminary tests were as described in the preceding paragraph except that the frequency counter was not connected since the only frequency produced by the function generator during these tests was 1 kHz, the accuracy of which had been calibrated against the NIST Gaithersburg 1-kHz standard frequency. The signal source and measuring instruments used in the remaining electrical tests that involved the use of continuous sine waves (e.g., frequency response tests or dosimeter calibrations) were the same as described in the preceding paragraph. The frequency of the function generator's continuous (not gated) sine wave output was either varied as needed in the case of the frequency response and linearity tests or held constant at 1 kHz as was the case in the preliminary tests. During the tone-burst sequence tests which were not part of the preliminary tests, digital

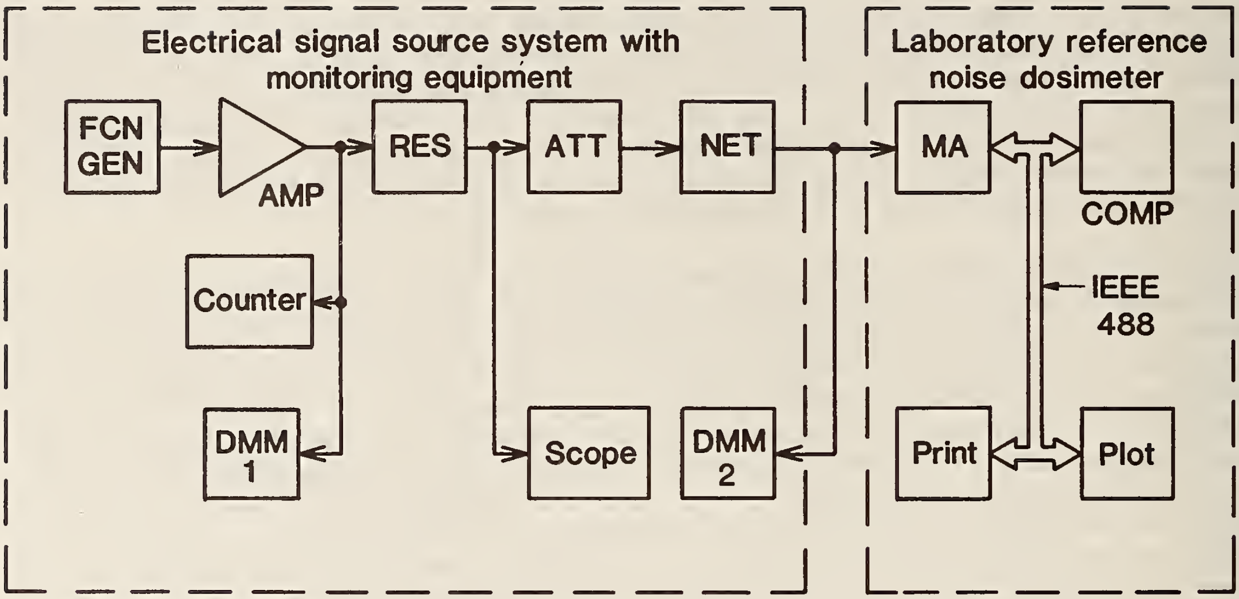

Figure 2. Electrical signal source system and laboratory reference dosimeter.

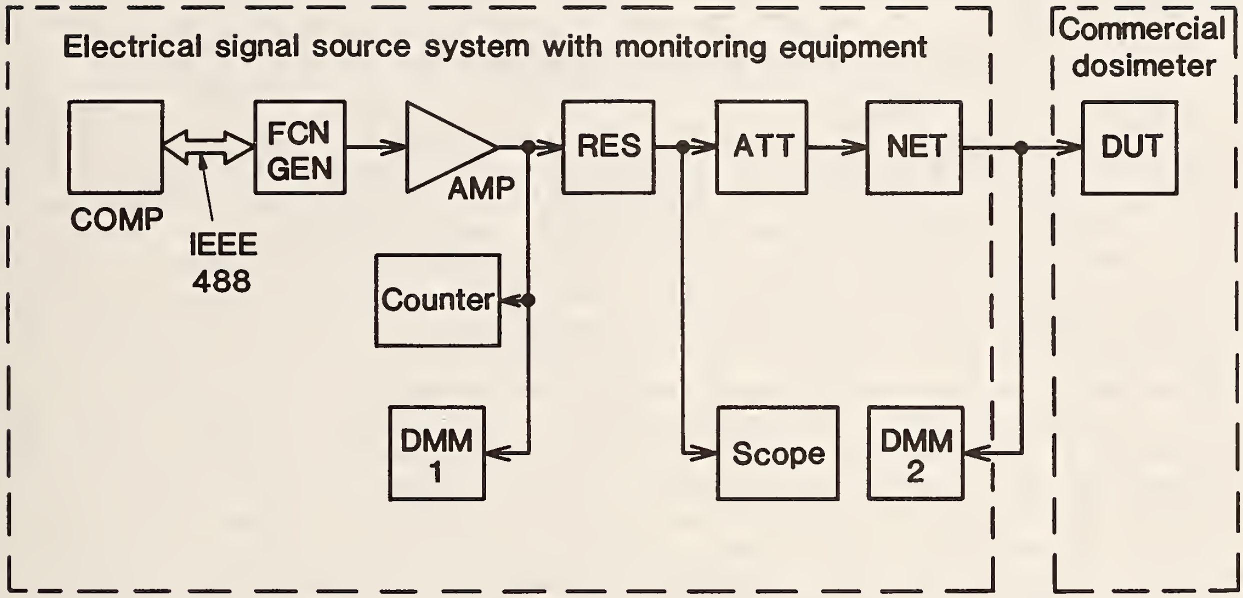

Figure 3. Electrical signal source system and commercial dosimeter under test [DUT].

multimeter 1 and 2, as well as the frequency counter, were disconnected to avoid any possibility of damage to these measuring instruments or of impedance anomalies occurring in the signal source circuitry as a result of the input impedance of the measuring instruments changing in response to the high crest factor signals of short duration to which they would normally not be exposed (e.g., temporary input impedance changes occurring in the measuring instrumentation during automatic range switching).

2.1.2 Calibration

The function generator and oscilloscope were calibrated for amplitude and time base accuracy, using a precision laboratory ac calibration source, calibrated pulse generators, and/or counters that had been checked against NIST Gaithersburg standard frequency sources available in the laboratory. The frequency counter used in the signal source instrumentation was calibrated against the NIST Gaithersburg 1-kHz standard frequency. The digital multimeters were calibrated for amplitude accuracy and filtering characteristics using precision laboratory ac and dc calibration sources. The precision attenuator was calibrated for attenuation accuracy using insert voltage techniques in conjunction with a precision laboratory ac calibration source. The signal-to-noise ratio and stability of the test system in its entirety were measured and verified to be adequate for the purposes of the tests. The total harmonic distortion plus noise was individually measured for the function generator and the signal source system at low, mid and high frequencies. An analysis of the levels of individual harmonics relative to their respective fundamentals was performed on the low-frequency distortion measurements using a low-distortion measurement system in conjunction with an adjustable center frequency, 1-percent band-limited, filter. The total harmonic distortion plus noise and the A-weighted levels of the individual harmonics relative to the low-frequency fundamentals were found to be negligibly small for the purposes of the tests. The time base of the computer was calibrated against the NIST Gaithersburg 100-Hz standard frequency for a time period equal to the longest measurement duration used in the tone-burst sequence tests.

2.2 Low-Frequency Acoustical Test Signal Source

2.2.1 Description

The equipment comprising the signal source along with measuring instruments used in the acoustical low-frequency response tests is shown in Figs. 4, 5, and 6 within the dashed box denoted "Low-Frequency Acoustical Signal Source System with Monitoring Equipment." A continuous sine wave was produced by the function generator and amplified by a wide-band linear amplifier [AMP]. The frequency counter monitored the frequency of the amplified sine wave produced by the function generator. A matching resistor was placed at the amplifier output so that the precision attenuator input was driven from a matching source impedance at 1 kHz. The waveform at the input of the precision attenuator was monitored by the oscilloscope. The signal was then selectably attenuated to the nearest 0.1 dB by a precision passive attenuator. The output of the precision attenuator was terminated with a matching network which consisted of a load resistor in parallel with a high impedance variable resistor (multiturn

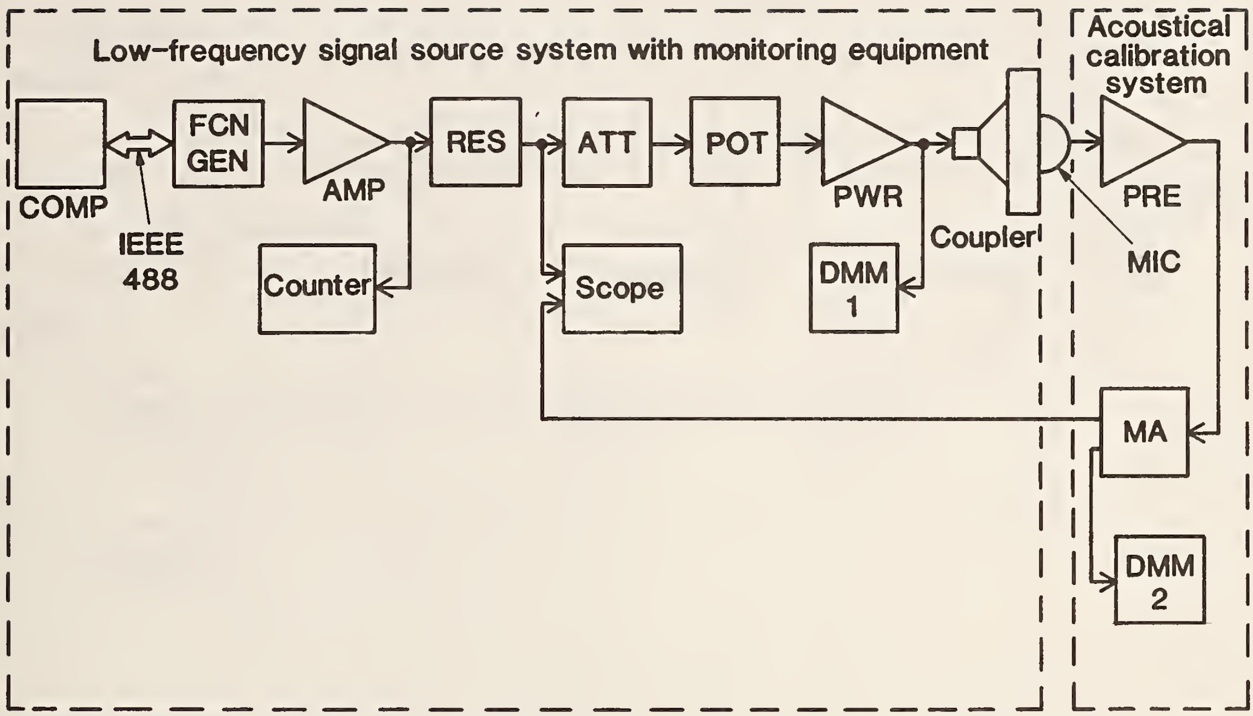

Figure 4. Low-frequency acoustical signal source system and acoustical calibration system.

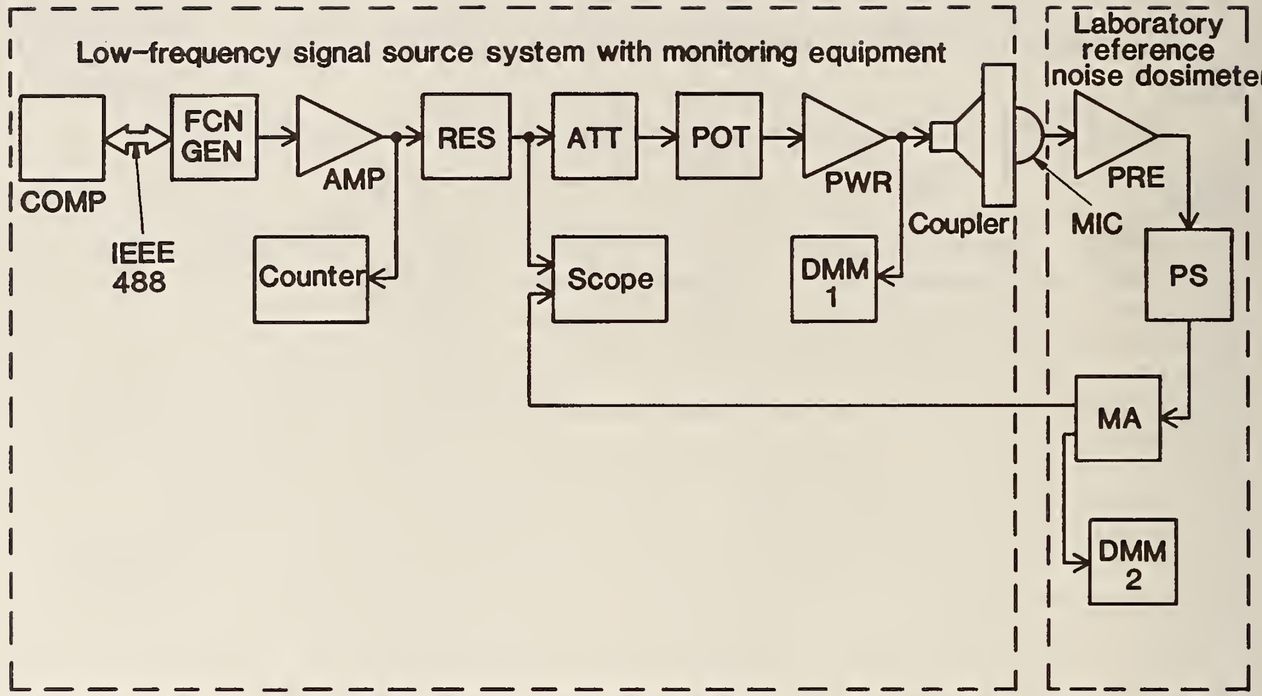

Figure 5. Low-frequency acoustical signal source system and laboratory reference noise dosimeter.

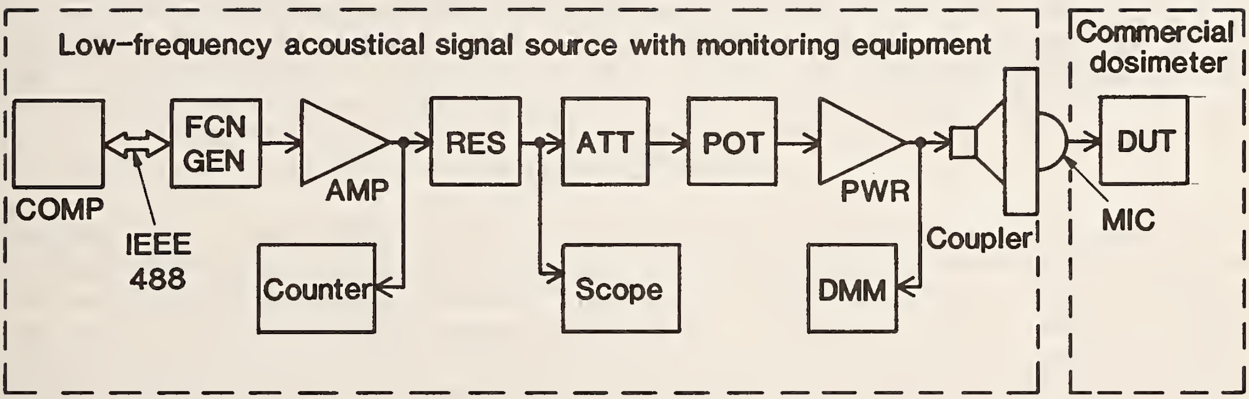

Figure 6. Low-frequency acoustical signal source system and commercial dosimeter under test [DUT].

potentiometer [POT]) which adjusted the drive voltage of a power amplifier to obtain the desired voltage at the acoustic-coupler electrical input terminals. The sine wave was amplified by the power amplifier [PWR] to produce a voltage equivalent to an A-weighted sound level of 85 dB within the acoustic coupler [Coupler]. Digital multimeter 1 monitored the acoustic coupler ac drive voltage and the dc offset voltage produced by the power amplifier. Either a 1/2-inch or 3/8-inch adapter was fitted into the acoustic coupler in order to adapt the orifice of the coupler to the size of the microphone of the dosimeter under test. As was the case in the commercial dosimeter tests involving the use of electrical input signals, the computer was connected to the function generator to time the test measurement durations.

2.2.2 Calibration

The measuring instruments used to calibrate the sound pressure level versus drive voltage of the acoustic coupler are shown in Fig. 4 within the dashed box denoted "Acoustical Calibration System." The sound pressure produced by the acoustic coupler (without the 1/2-inch or 3/8-inch adapters that were used with the reference and commercial dosimeters) was measured by a 1/2-inch laboratory measuring microphone [MIC] which was fit with a Type L (as defined in ANSI S1.12-1967, "Specification for Laboratory Standard Microphones") adapter. The output of the measuring microphone was amplified by a preamplifier [PRE] the output of which was further amplified by the measuring amplifier [MA]. (Note: this was the same measuring amplifier that was used in the laboratory reference noise dosimeter (see Fig. 2).) When the measuring amplifier was used as part of the acoustical calibration system shown in Fig. 4, the A-weighting network of the laboratory reference dosimeter was replaced with a high-pass filter having a nominal cut-off frequency of 22 Hz. The ac output of the measuring amplifier was monitored by the oscilloscope and the waveform compared with that of the input to the precision attenuator. The logarithmic dc output of the rms detector of the measuring amplifier was measured by digital multimeter 2 and the voltage converted into a sound pressure level expressed in decibels to a resolution of 0.01 dB.

The computer, function generator, oscilloscope, frequency counter, and precision attenuator used in the "Low-Frequency Acoustical Signal Source System With Monitoring Equipment" were the same as those used in the "Electrical Signal Source System With Monitoring Equipment" and the descriptions of the calibrations of these instruments contained in Sec. 2.1.2 apply to the low-frequency acoustical signal source calibrations as well. Descriptions of the calibrations performed on the measuring amplifier are found in Sec. 3.2.

In addition to these calibrations which are referenced in other parts of the report, the digital multimeters were calibrated for amplitude accuracy using precision laboratory ac and dc calibration sources. The signal-to-noise ratio and stability of the test system in its entirety were measured and verified to be adequate for the purposes of the tests.

The total harmonic distortion plus noise of the low-frequency signal source system was measured at each of the frequencies used in the acoustical low-frequency response tests and also at 40, 50, 80, and 100 Hz using the acoustical calibration system shown in Fig. 4 and a low-distortion measuring system. An analysis of the level of the individual harmonics relative to each of the fundamental frequencies used in the overall low-frequency response tests was performed using the acoustical calibration system with a low distortion measurement system and a tunable bandpass filter with a bandwidth equal to 1 percent of the center frequency of the filter. The sound pressure levels produced by the acoustic coupler during the test-frequency harmonic distortion measurements were the same as those produced by the coupler during the dosimeter response testing.

The impulse response of the acoustic coupler was measured using a pulse generator, power amplifier, laboratory measuring microphone and preamplifier, measuring amplifier, and oscilloscope with camera. The linearity of the acoustic coupler was measured over the range of 80 to 120 dB (SPL) at 1 kHz using a sine wave generator, power amplifier, laboratory measuring microphone and preamplifier, measuring amplifier, and digital multimeters.

The pressure sensitivity of the acoustical-calibration-system measuring microphone was determined by the reciprocity method using procedures consistent with those given in ANSI S1.10-1966, "Method for the Calibration of Microphones," for absolute pressure calibration of microphones. The pressure sensitivity of the acoustical calibration system was determined using acoustic calibrators which in turn had been calibrated by comparison with calibrated microphones. The calibrations of these microphones were traceable to NIST Type L laboratory standard microphones that had been calibrated by the reciprocity method using procedures consistent with those given in ANSI S1.10-1966 for absolute pressure calibration of microphones.

The reader is referred to chapters 3 and 4 for a description of the use of the low-frequency signal source system with the reference and commercial dosimeters (see Figs. 5 and 6).

2.3 High-Frequency Acoustical Test Signal Source

2.3.1 Description

The acoustical high-frequency response tests were performed in the large reverberation chamber at NIST Gaithersburg. The characteristics of this chamber were such that a reasonable approximation to a random incident sound field was produced at the test locations, given the frequency spectrum and random character of the sound produced by the horn and compression driver [4-7]. A diagram of the signal source and measuring instruments used in these tests is shown in Fig. 7 within the dashed area denoted "High-frequency acoustical signal source system with monitoring equipment." The measuring system used to establish the sound pressure levels inside the reverberation chamber is shown within the dashed box denoted "Acoustical reference system." (The laboratory reference noise dosimeter and a commercial dosimeter are also shown schematically in Fig. 7.)

The signal was comprised of pink noise which was produced by a noise generator [N GEN], shaped by a bandpass filter with a bandwidth equal to 3 percent of the center frequency of the filter [FLTR], and amplified by a power amplifier [PWR]. The signal could be turned on or off with a switch following the noise generator output and the test measurement durations were determined using this switch and a stop watch. An oscillator and frequency counter (not shown in Fig. 7) were

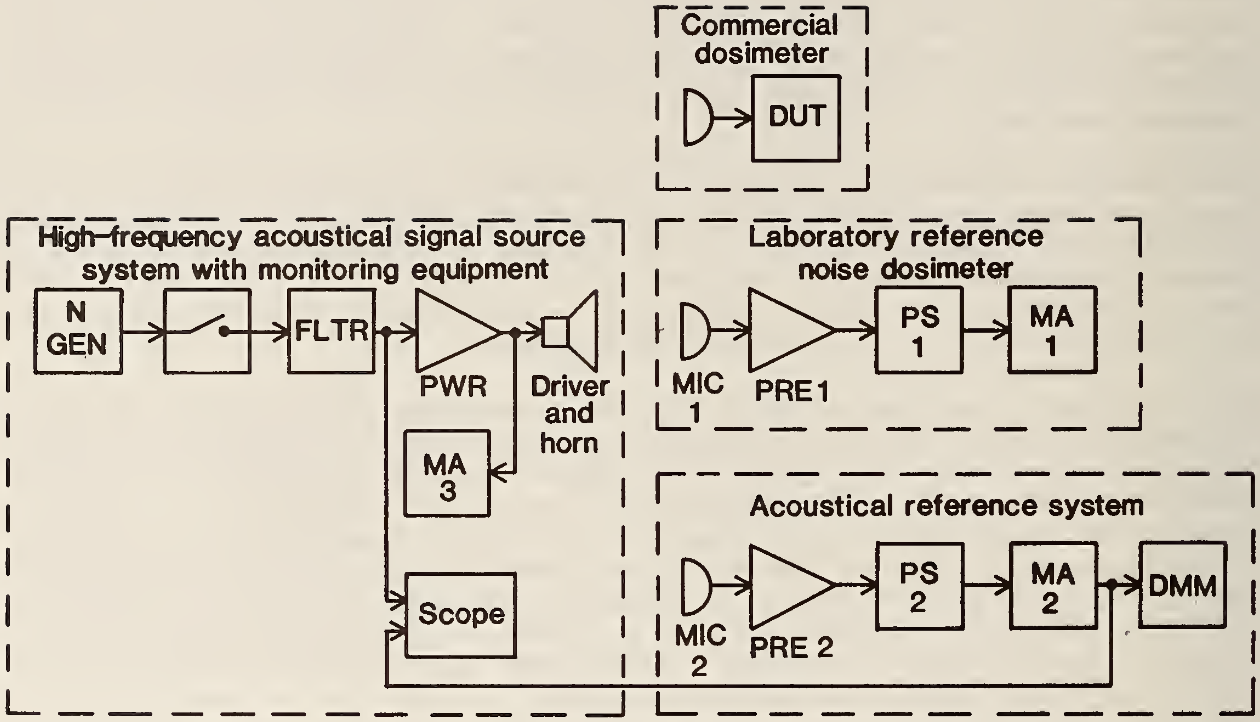

Figure 7. High-frequency acoustical signal source system, commercial and reference noise dosimeters, and acoustical reference system.

used to match the center frequency of the filter with the desired test frequency. The noise was monitored at the input of the power amplifier by the oscilloscope [Scope] and at the output of the power amplifier by measuring amplifier 3 [MA y3] which had a 100-second rms detector averaging time. The sound in the reverberation chamber was produced by a compression driver coupled to a constant directivity horn. The nominal coverage pattern (-6 dB relative to axial response) of the horn was equal to 90 × 40 degrees. The driver and horn combination were approximately 1.2 m above the floor, supported by a bass-reflex loudspeaker cabinet (not connected electrically), and were positioned such that the mouth of the horn was facing the intersection of two of the walls of the chamber at a distance of about 1.1 m. The reverberation chamber turning vanes rotated continuously throughout the tests at an average rate of 6.2 rpm and were oriented at an angle of 22.5 degrees with respect to vertical. Twelve sound absorbing panels, designed for maximum absorption at 100 Hz, were located randomly on the walls and ceiling of the chamber. The ambient conditions in the reverberation chamber during the period of time that the tests took place were (1) barometric pressure: within the range 99.0 to 101.5 kPa with typical fluctuations during the duration of any given test of less than 0.1 kPa (2) temperature: within the range 22 to 26 °C with typical fluctuations during the duration of any given test of less than 0.2 °C and (3) relative humidity: 37 to 47 percent with typical fluctuations during the duration of any given test of less than 1 percent.

The measuring instruments in the acoustical reference system used to establish the sound pressure levels at the reference-system microphone position in the chamber during the tests were a calibrated 1/8-inch measuring microphone [MIC 2], preamplifier [PRE 2], power supply [PS 2], measuring amplifier [MA 2], and digital multimeter [DMM]. The averaging time of the rms detector in measuring amplifier 2 was set at 100 s and the linear dc-voltage output of the rms detector was monitored by the digital multimeter which retained the maximum and minimum voltage values obtained during the measurement duration of each of the tests. The output of measuring amplifier 2 could be set such that the ac input voltage of the rms detector could be viewed on the oscilloscope and compared with the input voltage of the power amplifier.

2.3.2 Calibration

The relative frequency response of the 1/8-inch microphone, preamplifier, power supply, and measuring amplifier of the acoustical reference system were calibrated (as a system) by the electrostatic actuator method. The absolute sensitivity was calibrated at one frequency by methods traceable to laboratory standard microphones calibrated by the reciprocity method. The frequency response and meter linearity of measuring amplifier 2 were measured using an oscillator and calibrated digital voltmeter and the digital multimeter was calibrated using a precision laboratory dc calibration source. The pressure sensitivity of the acoustical reference system was calibrated using a pistonphone as well as acoustic calibrators which in turn had been calibrated by comparison with microphones that had received calibrations traceable to laboratory standard microphones calibrated by the reciprocity method. The signal-to-noise ratio and the stability of the signal source system were measured and verified to be adequate for the purposes of the tests.

3. Laboratory Reference Noise Dosimeter

As noted in Sec. 1.3, one of the three major areas of effort in approaching the issues addressed by this study was the construction and evaluation of a laboratory reference noise dosimeter. The laboratory reference noise dosimeter (also referred to in this report as "laboratory reference dosimeter" or simply "reference dosimeter") provided a superior quality dosimeter with which to compare the commercial dosimeters. The superior quality of the reference dosimeter also enabled extensive studies, involving a variety of input signals, to be performed in a relatively short period of sampling time using an instrument approaching an "ideal" dosimeter (as set forth in ANSI S1.25-1978, "Specification for Personal Noise Dosimeters").

3.1 Description

The reference dosimeter utilized basically two configurations: one configuration for the electrical input signals used in the tests employing continuous or gated sine waves (the preliminary electrical tests and the electrical tests employing signals having moderate-to-high crest factors), and one configuration for the acoustical input signals used in the acoustical response tests. The electrical-test-signal configuration shown in Fig. 2 consisted of a measuring amplifier [MA], a computer [COMP], a digital plotter [PLOT], and a printer [PRINT]. The acoustical-test-signal configuration shown in Figs. 5 and 7 consisted of a 1/2-inch laboratory measuring microphone [MIC] (designed for essentially uniform [flat] pressure response with respect to frequency), a microphone preamplifier [PRE], a power supply [PS], and the same measuring amplifier that was used in the electrical-test-signal configuration. For the acoustical low-frequency response tests (see Fig. 5), a digital multimeter [DMM 2] was added to read the logarithmic dc-voltage output of the measuring amplifier rms detector. The computer was not needed for the acoustical response measurements since the detector output of the measuring amplifier, which was essentially constant during these measurements, was read as an analog output and ultimately expressed as an A-weighted sound level, not a percentage criterion exposure.

The measuring amplifier included the A-weighting network, amplifiers, squaring device, and exponential averaging device of the reference dosimeter. (Note: see Sec. 1.1.1 for the relation of the A-weighting network, amplifiers, squaring device, and exponential averaging device to a personal noise dosimeter.) The measuring amplifier was set to conform to ANSI S1.25-1978, with one exception as regards the exponential averaging time constant: during the acoustical high-frequency response measurements when a 30-s time constant was used in order to average the random character of the input signal.

The measuring amplifier also contained an analog-to-digital converter that sampled the output of the exponential averaging device once every 10 ms and, when the reference dosimeter was in the electrical-test-signal configuration, sent this information via an interface bus ([IEEE 488] in Fig. 2) to the computer for processing. The computer was programmed to store the digital output samples of the measuring amplifier for a time period selected by the operator and then to perform a numerical integration of the stored data in accordance with the formula given for calculating percentage criterion exposure in ANSI S1.25-1978 (see Appendix A). The values employed for the exchange rate and threshold sound level were as selected by the operator, while the criterion sound level was fixed in the computer program at 90 dB (SPL), where "SPL" designates a voltage level defined as the equivalent of a sound pressure level of 90 dB re 20 μPa. For the preliminary electrical tests and the electrical tests employing signals having moderate-to-high crest factors, the exchange rate (per doubling of exposure duration) was either 5 or 3 dB and the threshold sound level was 80 dB (SPL).

3.2 Calibration

The pressure response of the 1/2-inch measuring microphone was calibrated by the reciprocity method in accordance with procedures given for the calibration of microphones in ANSI S1.10-1966, "Method for the Calibration of Microphones." The pressure response was found to be uniform (flat) to within ± 0.6 dB over the frequency range of 50 Hz to 10 kHz. The free-field response of the 1/2-inch measuring microphone was calibrated by the reciprocity method in accordance with procedures given in ANSI S1.10-1966. The free-field response of the 1/2-inch microphone was also calibrated by comparison with other NIST reference microphones (the free-field response of which had been calibrated by the reciprocity method). The frequencies used in the free-field response calibrations of the 1/2-inch measuring microphone and the other NIST laboratory reference microphones included 2, 4, 8, and 10 kHz. The microphone polarization voltage produced by the power supply was measured and adjusted to the value specified by the microphone manufacturer to better than 0.1 percent using a calibrated digital voltmeter. The combined frequency response of the microphone preamplifier, power supply and measuring amplifier was measured and found to be flat to better than 0.05 dB in the frequency range of 20 Hz to 100 kHz using a precision laboratory ac-voltage calibration source and a digital voltmeter. The sensitivity of the acoustical test configuration of the reference dosimeter was determined using a pistonphone and acoustic calibrators which in turn had been calibrated using insert voltage techniques and calibrated microphones. The calibrations of the NIST laboratory standard microphones, used in the calibration of the acoustic calibrators and pistonphone, were traceable to NIST Type L laboratory standard microphones that had been calibrated by the reciprocity method in accordance with procedures given in ANSI S1.10-1966.

The impulse response of the internal A-weighting filter of the measuring amplifier was measured using a pulse generator and transient capture device. The impulse response of the A-weighting filter was determined between the input to the internal-filter buffer amplifier (denoted "Output From Ext Filter" on the measuring amplifier) and the measuring-amplifier ac-voltage output (denoted "1 V FSD" on the measuring amplifier). The results of this measurement were plotted against the theoretical impulse response of an A-weighting network (see Fig. 8). The theoretical A-weighting-network impulse response was based on calculations made using formulas derived from the poles and zeros of an A-weighting filter given in Sec. 5.2 and Appendix C of ANSI S1.4-1983, "Specification for Sound Level Meters," and in ANSI S1.42-1986,"Design Response of Weighting Networks for Acoustical Measurements." The slight differences between the measured and theoretical impulse responses are considered attributable to the experimental uncertainties in the impulse response measurement, and to the idealized nature of the theoretical calculation, which did not attempt to include

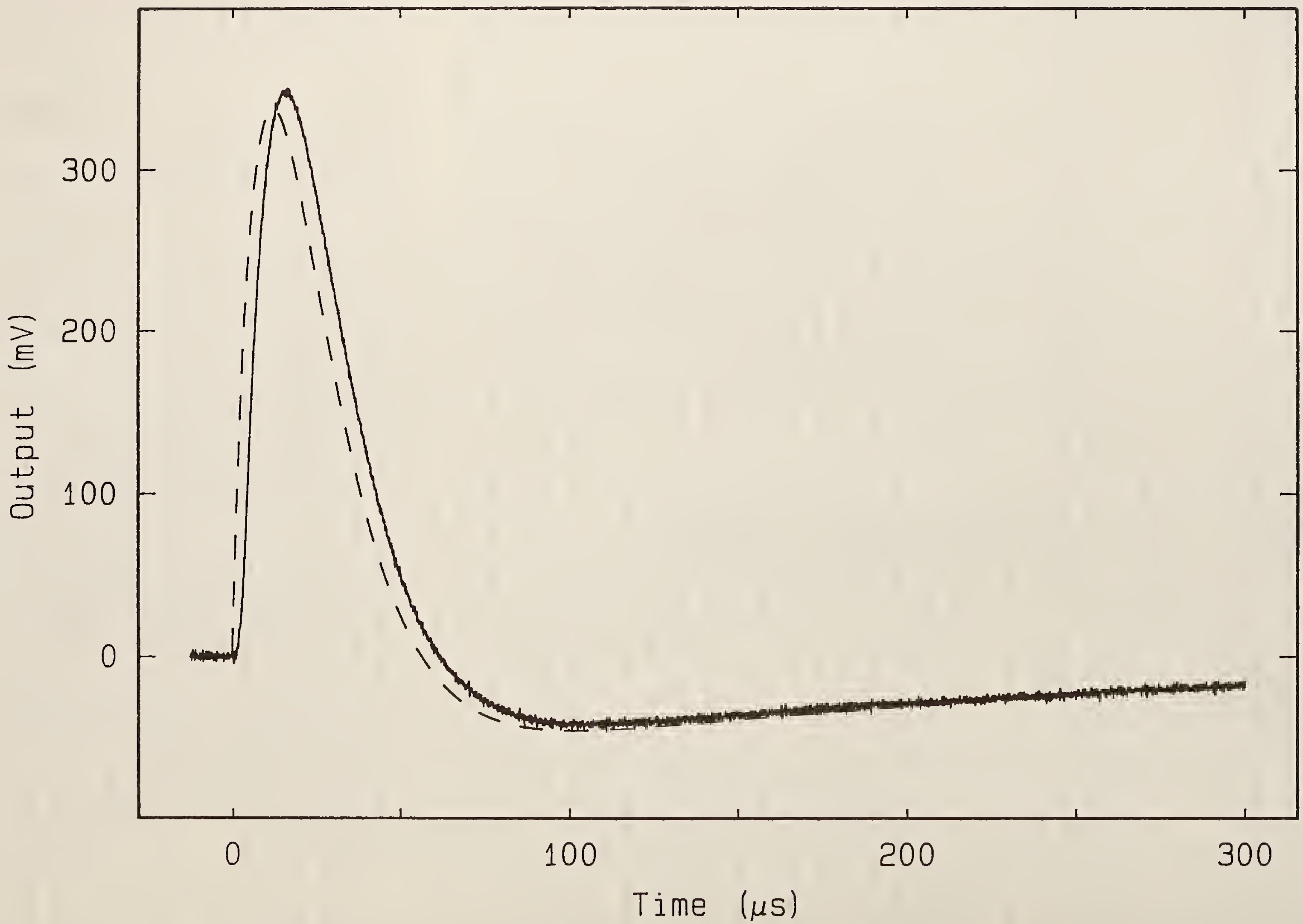

Figure 8. Theoretical (dashed) and reference-dosimeter (solid) A-weighting network impulse responses.

the ultrasonic upper frequency limits (well beyond the audio frequency range) of the measuring amplifier and its realization of the A-weighting network.

Both the A-weighted and the unweighted (flat) amplitude and phase response of the measuring amplifier were tested, as a function of frequency, in 1/3-octave increments using a low distortion oscillator, frequency counter, phase meter, and calibrated digital voltmeters. The amplitude and phase responses were determined relative to an essentially constant voltage at the direct input of the measuring amplifier. The amplitude response of the measuring amplifier was determined at the dc-voltage output of the rms detector and the phase response of the measuring amplifier was determined at the ac voltage output ("1 V FSD"). Theoretical values for the amplitude and phase response of an A-weighting network, as a function of frequency, were determined from formulas derived from the poles and zeros of an A-weighting network referenced above. The A-weighted amplitude response of the measuring amplifier relative to 1 kHz was found to agree with theoretical values to better than +0.1 or -0.2 dB in the frequency range of 10 Hz to 20 kHz and better than ±0.1 dB in the frequency range of 20 Hz to 10 kHz. The A-weighted phase response of the measuring amplifier was found to agree with theoretical values to better than +50 or -20 deg in the frequency range 10 Hz to 20 kHz and better than ±20 deg from 20 Hz to 10 kHz. The flat (unweighted) amplitude response of the measuring amplifier relative to 1 kHz was better than ±0.1 dB and typically better than ±0.05 dB in the frequency range 20 Hz to 10 kHz. The unweighted phase response of the measuring amplifier was better than ±10 deg in the frequency range 20 Hz to 10 kHz. (Note: the amplitude/phase response and the impulse response were made at different inputs to the measuring amplifier: the direct input and the input to the buffer amplifier of the internal filter section. From measurements of the amplitude and phase response of the measuring amplifier using the two different inputs, the direct input to the amplifier [which added, according to the block diagram for the instrument, a stage of amplification relative to the buffer amplifier input] gave the A-weighted amplitude and phase responses that more nearly approximated the theoretical A-weighted response, particularly at very low frequencies.)

The linearity of the measuring amplifier rms detector and analog amplifiers relative to full scale deflection was measured in increments of 10 dB over a range of 60 dB using a 1-kHz precision ac-voltage calibration source. During these measurements, the input and output sections of the measuring amplifier were set for unity gain and the dc-voltage output of the rms detector of the measuring amplifier was read using a calibrated digital voltmeter. The linearity of the measuring amplifier rms detector and analog amplifiers measured under these conditions was found to be better than ±0.05 dB.

The rms detector and exponential averaging time constant were tested essentially in accordance with procedures given under "Time-Averaging Characteristics" in Secs. 8.4.1 and 8.4.2 of ANSI S1.4-1983. These tests were performed at one range level setting of the measuring amplifier: that of unity gain in the input and output sections of the amplifier. During the tests performed in accordance with Sec. 8.4.1, the level of the rms detector was read using the analog meter movement of the measuring amplifier; during the tests performed in accordance with Sec. 8.4.2, the logarithmic dc output voltage of the rms detector was read using a calibrated digital multimeter and then converted to decibels to a resolution of 0.01 dB.

The measuring amplifier met requirements given for a Type 0 instrument for all the test signals in "TABLE VIII" of ANSI S1.4-1983 using both a fast and slow exponential time weighting. The measuring amplifier also met maximum overshoot requirements given for a Type 0 instrument in "TABLE IX" of ANSI S1.4-1983. The overshoot tests were performed at 100 Hz, 1 kHz, and 8 kHz using both a fast and slow exponential time weighting, with the maximum level of the test signal 4 dB below full scale deflection (tests using stepped input signals having a lesser maximum level were not performed).

The measuring amplifier met, typically by an order of magnitude, the requirements given for a Type 0 instrument in "TABLE VII" of ANSI S1.4-1983 when tested in accordance with Sec. 8.4.2 of ANSI S1.4-1983. The crest factors of the signals used in these tests were: (1) less than 3, (2) greater than 3 but less than 10, and (3) equal to 10. (Note: crest factor has been expressed here as a linear dimensionless ratio in order to be consistent with its usage in ANSI S1.4-1983. Unless otherwise noted, elsewhere in the report crest factor is expressed logarithmically in terms of decibels.) The tests were performed using a slow exponential time weighting at a level 2 dB below full scale deflection and in 10-dB increments below this level over a range of 50 dB.

An additional test was performed to characterize further the performance of the slow exponential averaging time constant. The results indicated that the error in the slow exponential time averaging constant was less than 10 percent and that the rise and decay time constants were equal to within 1 percent of one another.

A low-distortion measurement system was used to determine the total harmonic distortion plus noise of the measuring amplifier and of the oscillator that was used to determine the frequency and phase response of the measuring amplifier. The total harmonic distortion plus noise of the measuring amplifier was evaluated at 20 Hz and 1 kHz using the A-weighted response mode of operation of the measuring amplifier and at 20 Hz using the unweighted (flat) response mode of operation of the measuring amplifier. The total harmonic distortion plus noise at 20 Hz was found to be more than 35 dB below the fundamental using an A-weighted response and more than 80 dB below the fundamental using a flat response. The total harmonic distortion plus noise at 1 kHz was found to be more than 80 dB below the fundamental using an A-weighted response. The distortion-plus-noise results were obtained with the input and output sections of the measuring amplifier set for unity gain and were measured at the ac output (1 V FSD) of the measuring amplifier. The total harmonic distortion plus noise of the oscillator used to determine the frequency and phase response of the measuring amplifier was evaluated at 15 Hz, 20 Hz, 1 kHz, and 20 kHz and found to be more than 80 dB below the fundamental for frequencies evaluated below 20 kHz and more than 70 dB below the fundamental at 20 kHz.

The operation of the exchange rate(s) and the threshold sound level of the laboratory reference noise dosimeter were tested. The 3-dB, 4-dB, and 5-dB exchange rates were tested by increasing the level of a continuous sine wave (for which an 8-h percentage criterion exposure of 100.0 percent had been computed) by 3, 4, and 5 dB and then computing an 8-h percentage criterion exposure for each of the increased levels using the exchange rate that corresponded to the increase in level, i.e., 3, 4, or 5 dB. The threshold sound level was tested by evaluating the 8-h percentage criterion exposure corresponding to a continuous sine wave at voltage-level equivalents of 80.0 and 80.1 dB (SPL). The test results agreed with theoretical percentage criterion exposures to four significant figures (zero or "dose not calculated" in the case of 80.0 dB (SPL)). In all of these tests, the performance of the laboratory reference dosimeter and its instrumentation very closely approached design centers or ideals (see the comparisons of theoretical calculations with the measured performance of the reference dosimeter in the electrical tests employing continuous or gated sine waves that appear in Sec. 5).

3.3 Acoustical Test Procedures and Results

The acoustical response of the reference dosimeter was tested at octave intervals from 63 Hz to 1 kHz using an acoustic coupler as the signal source, and from 500 Hz to 10 kHz using a compression driver and horn in the large reverberation chamber at NIST Gaithersburg as the signal source. A sine wave was used as the test signal in the low-frequency response tests and filtered pink noise was used as the test signal in the high-frequency tests. A description of the experimental procedures and the results of these tests appear below for the reference dosimeter.

3.3.1 Low-Frequency Acoustical Test Procedures and Results

The low-frequency acoustical response of the reference dosimeter, as shown in Fig. 5, was tested using a continuous electrical sine wave to drive an electrodynamic transducer housed inside an acoustic coupler. The reference dosimeter microphone measured the sound level produced by the transducer in the coupler cavity. A 1/2-inch microphone adapter was used in the coupler to adapt the size of the coupler orifice to the diameter of the reference dosimeter microphone. The frequencies used in these tests were: 63.1, 126, 251, 501, and 1000 Hz which correspond to the preferred frequencies of 63, 250, 500, and 1000 Hz defined in ANSI S1.6-1984, "Preferred Frequencies, Frequency Levels, and Band Numbers for Acoustical Measurements." Before the acoustic coupler measurements were made using the reference dosimeter, the coupler was calibrated at a constant A-weighted sound level of 85 dB at each of the test frequencies, using the acoustical calibration system shown in Fig. 4. (Note: these preliminary calibrations, described in Sec. 2.2.2, were performed without the 1/2-inch coupler microphone adapter inserted in the coupler orifice.) The drive voltages present at the coupler electrical input terminals during the calibration were recorded for each of the test frequencies, when an A-weighted sound level of 85 dB was obtained in the coupler cavity. A 1/2-inch microphone adapter and the 1/2-inch reference dosimeter microphone were then fitted into the coupler and the input voltage of the power amplifier and the frequency of the sine wave produced by the function generator were adjusted to provide an A-weighted sound level of 85 dB at 63.1 Hz in the coupler cavity based on the calibration drive voltage at that frequency. The reference dosimeter microphone was then positioned in the 1/2-inch coupler microphone adapter such that the output level of the microphone was maximized. The logarithmic dc-voltage output of the reference dosimeter measuring amplifier rms detector was recorded and converted to an A-weighted sound level using a gain correction factor determined from the pistonphone calibration value for the system. As in the preliminary 63.1 Hz measurement, the input signal of the acoustic coupler was adjusted to provide, based on the preliminary calibration results, an A-weighted sound level of 85 dB at 126, 251, 501, and 1000 Hz, consecutively. The detector output voltage of the reference dosimeter measuring amplifier was recorded and converted to an A-weighted sound level to the nearest 0.01 dB at each of the frequencies.

The A-weighted sound levels were expressed relative to the applied A-weighted sound level of 85.0 dB, and rounded to the nearest 0.1 dB (see Table 3, Sec. 4.5). The relative frequency response tolerances given for random incident sound in ANSI S1.25-1978 also are included in this table; these tolerances have been included for purposes of comparison only and do not imply that the reference or commercial dosimeters were tested in accordance with ANSI S1.25-1978. The results indicate, based on the coupler calibration measurements, that the reference dosimeter measurements agreed with the applied sound pressure levels to ±0.1 dB in the frequency range of 63 to 1000 Hz. Assuming the equivalence of random incidence and pressure response for the reference dosimeter microphone in this frequency range, these results meet the tolerances given for a Type 0 sound level meter in "TABLE V" of ANSI S1.4-1983. (This statement has been included for purposes of comparison only and does not imply that the reference dosimeter was tested in accordance with procedures or necessarily met the requirements defined in ANSI S1.4-1983 for a Type 0 sound level meter.)

3.3.2 High-Frequency Acoustical Test Procedures and Results

The reference dosimeter microphone was positioned inside the reverberation chamber at one of the four dosimeter test locations, along with three of the commercial dosimeters. The unweighted (flat response) gain of the reference dosimeter was calibrated using a pistonphone and two acoustic calibrators inside the reverberation chamber. The signal source system shown in Fig. 7 was adjusted to produce filtered pink noise that was centered, individually, on each of the test frequencies for a period of approximately 115 min. The bandwidth of the filtered noise was 3 percent of the test frequency. The test frequencies were 0.5, 1, 2, 4, 8, and 10 kHz and the duration of the noise during each test was timed to the nearest second using a calibrated stop watch. The A-weighted level indicated on the reference dosimeter measuring amplifier was periodically recorded during the time that the noise was generated (typically near the beginning, middle, and end of each test) and, upon completion of each of the tests, the recorded readings for each test were averaged and converted into A-weighted sound levels.

Values for the diffuse field sound pressure levels applied during the tests were obtained relative to the measurement results, position, and calibrated actuator response of the acoustical reference system. In order to obtain these values, the assumption was made that the electrostatic-actuator response, diffuse-field response, and random-incidence response of the acoustical reference system were equivalent. The results of the reference dosimeter diffuse-field measurements were analyzed as follows: (1) approximate expressions for the diffuse-field sound pressure levels measured by the reference dosimeter were obtained from the measurement results, the random-incidence electrostatic actuator correction factors given by the microphone manufacturer for the reference-dosimeter microphone with the protection grid in place, and the microphone pressure calibration response levels (re 250 Hz); and (2) the results of (1) were expressed relative to the values obtained for the applied diffuse-field sound pressure levels obtained using the acoustical reference system. The results of this analysis (see Table 3, Sec. 4.5) indicate that the reference dosimeter measurements agreed with the applied sound pressure levels within +0.5 and -0.1 dB in the frequency range of 500 Hz to 10 kHz. Assuming the equivalence of random incidence and diffuse field response for the reference dosimeter microphone in this frequency range, these results meet the tolerances given for a Type 0 sound level meter in "TABLE V" of ANSI S1.4-1983. (This statement has been included for purposes of comparison only and does not imply that the reference dosimeter was tested in accordance with procedures or necessarily met the requirements defined in ANSI S1.4-1983 for a Type 0 sound level meter.)

4. Commercial Dosimeter Testing

4.1 Description

Ten commercially available noise dosimeters were obtained for testing. These dosimeters were selected to provide a sample of either past, current, or previously tested design engineering, including some instruments that have been widely used by OSHA. Nine of the units, when ordered, were specified to be factory wired or programmed to correspond to current OSHA regulations, i.e., a criterion sound level of 90 dB, an exchange rate of 5 dB, and a threshold sound level of 80 dB (one of these units was reprogrammed upon receipt at NIST as a result of battery failure during shipment). The remaining unit was specified to be hard-wired at the factory to evaluate dose (percentage criterion exposure) using the same criteria as the other nine dosimeters except that the exchange rate of the instrument was to be 3 dB instead of 5 dB. Several sets of tests, outlined briefly in the Introduction (Sec. 1.3), were established to examine the response of the instruments to a variety of signals. These tests included: electrical frequency response and linearity tests involving the use of continuous sine waves, electroacoustical frequency response tests involving the use of sine waves and/or filtered pink noise, and a series of electrical tests employing continuous or gated sine waves. A detailed description of the signal source systems used in these tests appears in Sec. 2 and diagrams of the systems, as used with the commercial dosimeters, are shown in Figs. 3, 6, and 7. The descriptions, procedures, and results of the preliminary electrical tests and the electrical tests employing signals having moderate-to-high crest factors appear in detail in Sec. 5, which covers the electrical tests employing continuous or gated sine waves. The electrical frequency response and linearity and the electroacoustical frequency response test descriptions, procedures and results appear below. The preliminary set of electrical tests appearing in Sec. 5 was performed using all ten of the dosimeters but only a selected subset of seven of the dosimeters was used in the remaining tests (see Sec. 5 regarding the preliminary electrical test results for the basis of the selection of the dosimeters used in the remaining tests). Except for the series of electrical tests employing signals having moderate-to-high crest factors, the exchange rates of the dosimeters, when the tests were performed, were as the units were received at NIST. In the case of the series of electrical tests employing signals having moderate-to-high crest factors, the dosimeters for which the exchange rate of the instrument could be adjusted via programming or DIP switch position changes were used in both 5-dB and 3-dB modes of exchange rate operation.

4.2 Signal Application

4.2.1 Electrical Signal Application

In order to obtain the procedure recommended by the factory for substituting an electrical signal in place of the output voltage of the dosimeter microphone, a technical representative of each of the commercial noise dosimeter manufacturers was contacted prior to commencement of testing, except in the case of one instrument for which this procedure was already explicitly specified in the noise dosimeter service instructions.

The noise dosimeter microphone and its associated cable were disconnected and replaced with a length of shielded cable and an electrical connector, except for one case in which the microphone was replaced with an adapter furnished by the noise dosimeter manufacturer.

Individual shielded resistive impedance matching networks were constructed for insertion between the precision attenuator and each noise dosimeter during testing ([NET] in Fig. 3). These matching networks provided the input source impedance specified by the dosimeter manufacturer for their unit and they also provided the load impedance required by the attenuator when the noise dosimeters were connected. The commercial dosimeter source impedances, provided by the matching networks in combination with the attenuator, were measured at 1 kHz using an impedance bridge. The load impedances at the attenuator output, provided by the matching networks in combination with their respective commercial dosimeters, were measured at 1 kHz using the same impedance bridge.

4.2.2 Acoustical Signal Application

The microphones and associated cables that had been removed for the electrical tests of the dosimeters were reconnected to the inputs of the dosimeters. In the case of one dosimeter, an external preamplifier with extension cable, furnished as an accessory to the instrument, was used in the acoustical tests so that the dosimeter microphone could be positioned at a location remote from the case that housed the electronics and display of the dosimeter. Two sets of electroacoustical frequency response tests were performed — one set in the range 63 Hz to 1 kHz and one set in the range 500 Hz to 10 kHz. An acoustic coupler was used as the acoustical signal source in the low-frequency response tests and a compression driver coupled to a constant directivity horn located inside the large reverberation chamber at NIST Gaithersburg was used as the acoustical signal source in the high-frequency response tests (see Figs. 6 and 7 and the sections regarding signal source and measuring instruments).

4.2.2.1 Low-Frequency Acoustical Signal Application

A 1/2-inch or 3/8-inch microphone adapter, appropriate to the diameter of the microphone of the dosimeter to be tested, was fitted into the orifice of the acoustic coupler. In order to insure a proper seal between the outer surface of the microphone and the coupler cavity, the microphones of the dosimeters were wrapped with tape to increase the outside diameter of the dosimeter microphones when needed. Each dosimeter microphone was individually inserted into the acoustic coupler and then, using a 63.1 Hz sine wave, the position of the microphone within the coupler was adjusted until the response of the microphone was maximized.

4.2.2.2 High-Frequency Acoustical Signal Application

Each dosimeter microphone was attached to a support wire with a nominal outside diameter of 4 mm, either by using a clip furnished with the dosimeter (e.g., one intended to attach the microphone to clothing) or with tape. Each of the microphones was positioned at one of four test locations within the reverberation chamber at a nominal height of 1.7 m above the floor and were oriented such that the primary acoustical port of each microphone was facing the ceiling. A random-incidence pressure-response correction adapter was installed on the dosimeter microphone when furnished by the manufacturer of the instrument. The support wires to which the dosimeter microphones were attached were in turn each supported by a 1/2-inch microphone holder and microphone stand at approximately 38 cm below the position of the microphones. The case or body which contained the dosimeter electronics was attached to the microphone stand with tape (Velcro) more than 76 cm below the dosimeter microphone.

4.3 Calibration

4.3.1 Electrical Input Signal Calibration

The electrical gain of each dosimeter was calibrated using a 1-kHz sine wave at a calibration voltage calculated from the acoustical calibration sound pressure level specified by the manufacturer and the nominal sensitivity of the microphone of the dosimeter (See Appendix A). The calibration voltage was obtained by measuring the amplitude of the voltage at the noise dosimeter input with digital multimeter 2 (see Fig. 3) and adjusting the precision attenuator while maintaining approximately 1 V rms at the attenuator input. The calibration procedure was then performed as outlined in the operating manual for the noise dosimeter except that the sound pressure level applied to the microphone had been replaced with its electrical equivalent. In those cases where the noise dosimeter could be used as a sound level meter, the dosimeter calibration potentiometer was adjusted for the appropriate reading using this mode of operation. In the remaining cases, where the noise dosimeter had only a percentage criterion exposure display capability, the calibration potentiometer was adjusted for the percentage criterion exposure reading which corresponded to applying the calibration level for a specified length of time, as given in the noise dosimeter operating manual.

4.3.2 Acoustical Input Signal Calibration

The electroacoustical gain of each of the dosimeters was calibrated in the acoustic coupler using a 1-kHz sine wave at a calibration sound pressure level specified by the manufacturer. The sensitivity (sound pressure level versus drive voltage) of the acoustic-coupler electrodynamic transducer was calibrated at least once each day that the coupler was used. These calibrations were performed using the acoustical calibration system at an A-weighted sound level of 85 dB for each of the low-frequency response test frequencies. Typically, an additional calibration was performed using a 1-kHz sine wave at a higher sound level, usually 114 dB. The procedure used in the coupler calibration(s) was as described in Sec. 2.2, i.e., the drive voltage at the coupler electrical input terminals required to produce a given A-weighted sound level in the coupler cavity without the use of the microphone adapters was determined using the acoustical calibration system. With the dosimeter microphone in the acoustic coupler, a drive voltage corresponding to a calibrated 1-kHz sound pressure level (typically 114 dB re 20 μPa) was applied to the coupler's electrical terminals and the precision attenuator was adjusted relative to the calibrated level setting to obtain the acoustical calibration level of the dosimeter specified by the manufacturer. The calibration procedure was then performed as outlined in the operating manual for the noise dosimeter. For those cases where the noise dosimeter provided a sound level reading, the dosimeter calibration potentiometer was adjusted for the appropriate reading using this mode of operation. In the remaining cases, where the noise dosimeter had only a percentage criterion exposure reading available, the calibration potentiometer was adjusted for the percentage criterion exposure reading which corresponded to application of the calibration level for a specified length of time, as given in the noise-dosimeter operating manual.

4.4 Electrical Frequency Response and Linearity Test Procedures and Results

The electrical frequency response tests were performed individually using the seven dosimeters that were selected for further testing after the completion of the preliminary electrical tests (see Sec. 5.1). The signal source instrumentation used during the tests was the same as that indicated in Fig. 3. The electrical frequency response of the seven dosimeters was tested at the following preferred frequencies (as defined in ANSI S1.6-1984, "Preferred Frequencies, Frequency Levels, and Band Numbers for Acoustical Measurements"): 20 Hz, octave-band center frequencies from 31.5 Hz to 8 kHz, and 10 kHz. Each dosimeter was calibrated as outlined in Sec. 4.3.1. A continuous sine wave at the voltage-level equivalent of 135 dB (SPL) was applied to the dosimeters at each of the test frequencies. The corresponding A-weighted levels were calculated at each test frequency. For those dosimeters that could be operated as a sound level meter, the results were read as A-weighted levels. For the remaining dosimeters (which had only percentage-criterion-exposure display capabilities), a set of tests was developed with the duration of the tests varying depending on the A-weighted level of the signal and the exchange rate of the dosimeter. Except for the test performed at 20 Hz, the measurement durations selected for use in the 5-dB exchange rate tests resulted in percentage criterion exposures in the range of 108 to 174 percent in order that the calculated exposure percentages be of integer value and three significant figures. To avoid an excessively long integration time, the measurement duration selected for the test performed at the preferred frequency of 20 Hz resulted in a calculated percentage criterion exposure of 12 percent. Except for the tests performed at 20 and 31.5 Hz, the measurement durations selected for use in the 3-dB exchange rate tests resulted in percentage criterion exposures that were in the range of 1035 to 1797 percent so that (1) the measurement durations would each be equal to a minimum of 10 s, and (2) the calculated exposure percentages would be of integer value and the same order of magnitude. In order to avoid excessively long measurement times, the durations selected for the tests performed at the preferred frequencies of 20 and 31.5 Hz resulted in calculated percentage criterion exposures of 13 and 14.75 percent. The test results were read as percentages which were converted to equivalent levels.

The results of these frequency response measurements were expressed as equivalent sound levels relative to the calculated A-weighted levels based on the applied voltage level equivalent of 135.0 dB (SPL). These relative response values were rounded to the nearest 0.1 dB and then, in order to compensate for nonlinearities in the gain of the instruments re their respective 1-kHz calibration levels, were normalized at 1 kHz. These results are shown in Table 1. The relative frequency response tolerances given for random incident sound in ANSI S1.25-1978, "Specification for Personal Noise Dosimeters," have also been included in the table of the results of the electrical frequency response tests. These tolerances have been included for purposes of comparison only and do not imply that the reference or commercial dosimeters were tested in accordance with ANSI S1.25-1978. The results indicate that the commercial dosimeter measurements agreed with the applied levels to better than ±5.0 dB and typically to better than ±1.0 dB in the frequency range of 20 Hz to 10 kHz. In all cases, the normalized relative response values are within the relative frequency response tolerances given for personal noise dosimeters in "TABLE I" of ANSI S1.25-1978. (This statement has been included for purposes of comparison only and does not imply that the commercial dosimeters were tested in accordance with procedures or necessarily met the requirements defined in ANSI S1.25-1978 for personal noise dosimeter relative frequency response.)

The electrical linearity of the seven dosimeters was tested at 1 and 10 kHz in 10 dB increments from 135 to 85 dB (SPL) and at 31.5 Hz (preferred frequency) at 135 and 125 dB (SPL), where SPL denotes unweighted voltage levels equivalent to the given sound pressure levels, in dB re 20 μPa. The linearity tests were performed after the frequency response measurements were completed with the test results monitored in the same manner as in the electrical frequency response tests. For those instruments that were operated as a dosimeter to indicate percentage criterion exposure, a brief description of the linearity tests follows. The measurement durations selected for use in the 5-dB exchange rate linearity tests were such that the percentage criterion exposures (calculated from the A-weighted levels of the applied signals and the measurement durations) were greater than 100 and were constant over the range of the linearity tests at each of the frequencies tested provided that the A-weighted level of the applied signal was greater than 85.6 dB. To avoid excessively long integration times, the measurement durations selected for the tests that were performed at A-weighted levels of 85.6 dB or less resulted in calculated percentage criterion exposures in the range of 15 to 27 percent. In the case of the 3-dB exchange rate tests, the measurement durations selected for use in the linearity tests were such that the percentage criterion exposures (calculated from the A-weighted level of the applied signals and the measurement durations) were greater than 1000 and were constant over the range of the linearity tests at each of the frequencies tested provided that the A-weighted level of the signal applied was 102.5 dB or greater. Note: the large values of the percentage criterion exposures resulted, at least in part, from stipulating that the smallest measurement duration be greater than 10 s, i.e., ten time constants of the exponential averaging device. To avoid excessively long integration times, the measurement durations selected for the tests performed at A-weighted levels less than 102.5 dB resulted in calculated percentage criterion exposures in the range of 12 to 17 percent. The test results were read as a percentage criterion exposure which was converted to an equivalent level.

The results of the linearity measurements were expressed as equivalent sound levels. In order to express the linearity response of the dosimeters relative to the criterion sound level of 90.0 dB, the equivalent levels were normalized to the average of the equivalent levels determined for applied levels of 95.0 and 85.0 dB at 1 kHz. The normalized equivalent levels were then expressed relative to the sum of the corresponding applied levels normalized to 90 dB and the frequency response of the dosimeters, relative to 1 kHz, at the applied test

Table 1. Relative electrical frequency response level (dB) of commercial dosimeters.[a]

Nominal Frequency[b] (Hz)	Tolerance[c] (dB)	Commercial Dosimeter (dB)						
		1	2	3	4	5	6	7
20	+5,−∞	2.6	−1.3	0.6	−0.1	0.5	0.7	4.1
31.5	+3.5,−4.0	1.2	−0.7	0.2	−0.6	0.4	0.4	2.8
63	±3.0	0.4	−0.4	0.2	−1.0	−0.3	−0.1	2.0
125	±2.5	0.1	−0.2	0.2	−0.2	−0.1	−0.3	1.8
250	±2.5	0.0	−0.1	0.1	0.0	0.1	−0.3	1.6
500	±2.0	0.0	0.0	−0.3	0.1	0.2	−0.2	1.6
1000	±2.0	0	0	0	0	0	0	0
2000	±3.0	0.0	0.1	−0.1	−0.1	0.3	0.0	0.0
4000	+5.5,−4.5	−0.1	0.4	0.0	−0.3	0.5	−0.2	0.1
8000	±6.5	0.0	0.4	0.5	−0.3	−0.9	−0.4	0.9
10000	+6.5,−∞	0.1	−0.3	0.6	−0.1	−2.0	−0.8	1.4
		Gain Adjustment Factor[d]						
1000	NA	−0.2	0.0	0.1	−0.5	0.0	0.3	−1.8

[a] The dosimeter measurements have been expressed relative to: the voltage level applied to the dosimeters when under test (the electrical equivalent of a constant sound pressure level of 135 dB) plus the theoretical response of an A-weighting filter. The commercial dosimeter results indicated in the table are these relative response values less the relative response values of each of the dosimeters at 1 kHz (gain adjustment factor), e.g., if the response of a particular dosimeter, relative to 135 dB at 1 kHz, was found to be "x" dB, then "x" dB was subtracted from each of the relative response values obtained for that particular dosimeter. The A-weighted frequency response of the reference-dosimeter measuring amplifier relative to 1 kHz, when calibrated over the frequency range indicated above, was better than ±0.10 dB.

[b] Nominal frequencies correspond to preferred frequencies as defined in ANSI S1.6-1984.

[c] The tolerances given are those specified in "TABLE I" of ANSI S1.25-1978 for A-weighted response to randomly-incident sound.

[d] The response relative to a 1-kHz sine wave at an applied voltage level equivalent to a sound pressure level of 135 dB (the gain adjustment factor has been subtracted from each of the relative response values obtained; see footnote a, above).

frequency. The final expressions for the linearity response of the instruments were rounded to the nearest 0.1 dB and are listed in Table 2. The results indicate, based on the calculated A-weighted levels, that the linearity response of the commercial dosimeters was independent of frequency, i.e., the linearity or nonlinearity of the instruments at a given applied level was the same at 31.5 Hz, 1 kHz, and 10 kHz, typically to better than a few tenths of a decibel except: (1) at 10 kHz for applied levels of 95.0 dB (SPL) or less, and (2) except for dosimeter 7 in general. At 10 kHz and levels of 95.0 and 85.0 dB (SPL), the linearity of four of the dosimeters departed from the linearity response at 1 kHz by 2.0 dB or more. In the case of dosimeter 7, the nonlinearity exhibited at 1 kHz at the applied level of 135.0 dB ranged from −2.9 to −0.7 dB in three different applications of the same test and appeared to be a function of the length of time the instrument had been operational prior to performing the test (the battery and instrument calibration were checked repeatedly during these tests). Note, however, that dosimeter 7 had a fixed exchange rate of 3 dB and that the calculated percentage criterion exposure for this test was in excess of 1000 percent, implying the accumulation of a large reading over a relatively short period of time. In the other 1-kHz linearity tests applied at levels of 85 to 125 dB, where the total accumulated percentage criterion exposure was the same but the integration period was longer, the linearity exhibited by the instrument was much better.

4.5 Electroacoustical Test Procedures and Results

The overall (acoustical and electrical) gain of each of the dosimeters tested was calibrated using the acoustic coupler prior to performing the electroacoustical frequency response tests. The signal source system for the low-frequency response tests and the high-frequency response tests was as indicated in Figs. 6 and 7, respectively.

4.5.1 Low-Frequency Acoustical Test Procedures and Results

After the electroacoustical gain of the dosimeter under test was calibrated at 1 kHz, the frequency of the function generator and the drive voltage at the electrical terminals of the acoustic coupler were varied in accordance with the latest coupler sensitivity calibration values (see Sec. 4.3.2) to provide a constant A-weighted sound level at 63.1, 126, 251, 501, and 1000 Hz (corresponding to preferred frequencies of 63, 125, 250, 500, and 1000 Hz as defined in ANSI S1.6-1984). For those dosimeters that could be operated as sound level meters, the results were read as A-weighted levels. For the remaining dosimeters (which had only percentage-criterion-exposure display) a set of tests was developed with the duration of the tests varying depending on the exchange rate of the dosimeter. The duration for each test was such that, based on an applied A-weighted sound level of 85.0 dB, a theoretical percentage criterion exposure of 12.0 percent should be obtained. The test results were read as a percentage criterion exposure which was converted to an equivalent level.

The results of these measurements were taken relative to the applied A-weighted sound level of 85.0 dB and then rounded to the nearest 0.1 dB. These response values were then expressed relative to the 1-kHz response values in order to

Table 2. Electrical linearity (dB) of the commercial dosimeters.[a]

Nominal Frequency[b] (Hz)	Applied Level[c] (dB)	Commercial Dosimeter (dB)						
		1	2	3	4	5	6	7
31.5	135.0	−0.5	+0.0,−0.2	−0.4	0.0	0.0	0.2	2.1
	125.0	−0.5	−0.1	−0.2	−0.1	0.0	0.5	−2.0
1000	135.0	−0.5	0.0	−0.2	0.0	0.0	0.2	−2.0[d]
	125.0	−0.5	0.0	−0.2	0.0	0.0	−0.4	−0.3
	115.0	−0.4	0.0	0.1	−0.1	0.0	−0.5	−0.2
	105.0	−0.2	0.0	−0.2	0.0	0.0	−0.2	−0.1
	95.0	−0.1	+0.0,−0.1	0.1	0.0	0.0	0.1	0.0
	85.0	0.1	0.0	−0.1	−0.1	0.0	−0.1	0.0
10000	135.0	−0.6	0.0	−0.2	0.0	−0.5	0.2	−2.0
	125.0	−0.7	+0.0,−0.1	0.3	−0.2	0.0	−0.4	−1.9
	115.0	−0.5	0.0	−0.2	−0.6	0.5	−0.6	−1.8
	105.0	−0.3	0.0	−0.2	0.1	0.0	−0.7	−1.7
	95.0	0.0	+0.1,−0.0	−1.7	−0.1	−1.0	−0.8	−1.5
	85.0	−0.2	−0.1,−0.0	<−6.4	−1.0	−2.0	−2.1	−1.5

[a] The dosimeter measurements have been normalized to the average of the measurement results obtained at the applied levels of 95 and 85 dB at 1 kHz. The results indicated in the table are these normalized values expressed relative to the sum of the applied levels normalized to 90 dB and the frequency response of the dosimeters relative to 1 kHz.

[b] Nominal frequencies correspond to preferred frequencies as defined in ANSI S1.6-1984.

[c] The applied levels are the voltage levels applied to the dosimeters when under test (the electrical equivalent of sound pressure levels corresponding to the values of the applied levels).

[d] The average of three separate measurement results ranging from −2.9 to −0.7 dB.

compensate for nonlinearities in the gain of the instruments relative to their 1-kHz calibration levels. These results (the measured levels relative to 85.0 dB and to the response levels at 1 kHz) are tabulated in the acoustic-coupler portion of Table 3. Note that in the case of dosimeter 5, the reading displayed during the 1-kHz measurement jittered between 0.0 and +0.5 dB relative to the applied sound level. The value selected to adjust the relative gain of the instrument was +0.5 dB, which tended to give the most uniform relative frequency response for the instrument. The relative frequency response tolerances given for random incident sound in ANSI S1.25-1978 have also been included in Table 3. These tolerances have been included for purposes of comparison only and do not imply that the reference or commercial dosimeters were tested in accordance with ANSI S1.25-1978. The results indicate, based on the coupler calibration measurements, that the commercial dosimeter relative response levels agreed with the applied sound levels to ± 1.6 dB and typically to better than ± 0.5 dB in the frequency range of 63 Hz to 1 kHz. Assuming the equivalence of random incidence and pressure response for the dosimeter microphones in this frequency range, the results of these tests meet the relative frequency response tolerances given for personal noise dosimeters in "TABLE I" of ANSI S1.25-1978. (This statement has been included for purposes of comparison only and does not imply that the commercial dosimeters were tested in accordance with procedures or necessarily met the requirements defined in ANSI S1.25-1978 for personal noise dosimeter relative frequency response.)

4.5.2 High-Frequency Acoustical Test Procedures and Results

During the high-frequency tests, all of the commercial dosimeters tested were set to display percentage criterion exposure. Four dosimeters (four commercial dosimeters or three commercial dosimeters plus the laboratory reference dosimeter) were located inside the reverberation chamber and exposed to 3-percent band-limited pink noise at an A-weighted average sound level of approximately 85 dB for a nominal measurement duration of 115 min. The bandpass filter (see Fig. 6) was sequentially centered on each test frequency (0.5, 1, 2, 4, 8, and 10 kHz), the total measurement duration (period of time that the noise was present at the input of the bandpass filter) timed to the nearest second, and the test results read and converted to an equivalent level. These test signals corresponded to a percentage criterion exposure of approximately 12 percent using a 5-dB exchange rate or 8 percent using a 3-dB exchange rate. Values for the diffuse field sound pressure levels applied during the tests were obtained relative to the measurement results, position, and calibrated actuator response of the acoustical reference system. In order to obtain these values, the assumption was made that the electrostatic actuator response, diffuse field response, and random incidence response of the acoustical reference system were equivalent. The results of the commercial-dosimeter diffuse field measurements were analyzed and are given in Table 1 as follows: (1) the equivalent sound levels measured by the commercial dosimeters were expressed relative to the values obtained for the average applied diffuse-field sound levels at their respective test locations and (2) the response levels obtained in (1) were normalized to the relative response of the dosimeters at 1 kHz as measured in the acoustic coupler (gain adjustment factor). These results are tabulated in the reverberation chamber portion of Table 3. The results indicate, based on the values obtained for the applied sound levels using the acoustical reference system, that the commercial dosimeter normalized-equivalent levels agreed with

Table 3. Relative electroacoustical frequency response level (dB) of reference and commercial dosimeters.[a]

Nominal[b] Frequency (Hz)	Tolerance[c] (dB)	Reference[d] Dosimeter (dB)	Commercial Dosimeter[e] (dB)						
			1	2	3	4	5	6	7
			Acoustic Coupler						
63	±3.0	−0.1	0.0	−0.2	−1.5	−0.6	−0.5	1.6	−0.9
125	±2.5	0.1	0.1	0.3	−0.3	0.0	0.0	1.6	0.1
250	±2.5	0.1	0.0	0.4	0.2	0.0	0.0	1.2	0.3
500	±2.0	0.0	0.0	0.3	0.2	0.0	0.0	0.8	0.3
1000	±2.0	0.0	0	0	0	0	0	0	0
			Reverberation Chamber						
500	±2.0	0.5	0.1	0.0	−0.3	−0.4	0.2	1.0	0.4
1000	±2.0	0.3	−0.1	−0.1	−0.5	−0.5	−0.8	0.0	0.3
2000	±3.0	0.4	0.0	0.0	0.1	−0.4	−0.2	−1.2	−0.1
4000	+5.5,−4.5	0.1	−0.7	−0.7	−0.8	−1.1	0.6	−2.6	−1.2
8000	±6.5	0.3	2.5	1.5	−0.1	−0.2	8.2	−1.5	1.5
10000	+6.5,−∞	−0.1	<−5.2	−4.3	<−4.3	−0.7	3.5	<−6.3	<−4.8
			Gain Adjustment Factor[f]						
1000	NA	NA	0.5	−0.1	0.0	0.0	0.5[g]	0.0	0.0

[a] The dosimeter measurements have been expressed relative to the A-weighted sound pressure levels applied to the dosimeters when under test (nominally 85 dB).

[b] Nominal frequencies correspond to preferred frequencies as defined in ANSI S1.6-1984.

[c] The tolerances given are those specified in "Table I" of ANSI S1.25-1978 for A-weighted response to randomly-incident sound.

[d] The laboratory reference dosimeter reverberation chamber response results have been expressed, at each of the frequencies listed, as the dosimeter response relative to the applied A-weighted sound pressure level minus (1) the random incidence correction specified by the microphone manufacturer and (2) the pressure response of the microphone relative to 250 Hz.

[e] The commercial dosimeter results have been expressed as the response of each dosimeter relative to the applied A-weighted sound pressure level minus the relative response value obtained for each dosimeter at 1 kHz when measured in the acoustic coupler (gain adjustment factor), e.g., if the response of a particular dosimeter, relative to 85 dB at 1 kHz, was found to be "x" dB, when

(Table 3, cont'd.)

measured in the acoustic coupler, then "x" dB was subtracted from each of the relative response values obtained in the acoustic coupler and in the reverberation chamber for that particular dosimeter.

[f] The response relative to that for a 1-kHz sine wave at an applied sound pressure level of 85 dB when measured in the acoustic coupler (the gain adjustment factor has been subtracted from each of the relative response values obtained; see footnote e above).

[g] The indicated result is based on one of two readings (see Sec. 4.5.1).

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the applied sound levels to better than ±1.5 dB in the frequency range 500 Hz to 1 kHz and, with the exception of one result, better than ±3 dB in the frequency range 2 to 8 kHz. The relative response of dosimeter 5 measured +8.2 dB at 8 kHz. This measurement was verified by operating the dosimeter in the sound-level-meter mode and reading A-weighted sound level with: (1) the microphone mounted as in the initial response measurement, (2) the primary acoustic port of the microphone in the same position as in the initial measurement but mounted differently (suspended from above rather than supported from below), and (3) the microphone attached to the shirt collar of the observer with a clip furnished for this purpose by the instrument manufacturer. The sound field was sampled by the observer in the area of the reverberation chamber used for the frequency response measurements and the results compared with readings obtained from three other dosimeters operated as sound level meters and located in the area sampled. These additional measurements were made after first checking that the calibration of dosimeter number 5 had not shifted significantly. All of the measurements that were made using dosimeter 5 tended to confirm that the relative diffuse-field response of the dosimeter was at least +8.0 dB at 8 kHz.

The electroacoustical response of the majority of the dosimeters at 10 kHz was such that the applied sound level, when combined with the response of the instruments, was less than the threshold sound level of the dosimeters, thereby making the exact response indeterminate when using this test procedure. Assuming the equivalence of random incidence and diffuse field response for the commercial dosimeter microphones in this frequency range, the results of these tests meet the relative frequency response tolerances given for personal noise dosimeters in "TABLE I" of ANSI S1.25-1978 except in the case of dosimeter 5 at 8 kHz. (This statement has been included for purposes of comparison only and does not imply that the commercial dosimeters were tested in accordance with procedures or necessarily met the requirements defined in ANSI S1.25-1978 for personal noise dosimeter relative frequency response.)

5. Electrical Tests Employing Continuous or Gated Sine Waves

A series of preliminary electrical tests and a series of electrical tests involving input signals of moderate-to-high crest factor were performed using the laboratory reference dosimeter and the commercial dosimeters. The signals used in these tests were composed of a sine wave that either remained continuous, or was periodically gated, over the measurement duration of the tests. When gated, the sine wave formed a series of tone bursts, each of which began on a positive zero crossing and ended on a negative zero crossing of the sine wave. The burst durations were equal to an integral number of periods of the frequency of the sine wave that composed the bursts.

The preliminary set of electrical tests was performed using all ten of the commercial dosimeters (denoted 1 through 10) but only a selected subset of seven of the commercial dosimeters (denoted 1 through 7) was used in the electrical tests that employed signals of moderate-to-high crest factor. The exchange rates of the commercial dosimeters, when used in the series of preliminary electrical tests, were as the units were received at NIST with one exception (see parenthetical note below). In the case of the series of electrical tests involving input signals of moderate-to-high crest factor, the dosimeters that had the capability of selecting the exchange rate of the instrument via programming or DIP switch position changes were used in both 5-dB and 3-dB modes of exchange-rate operation. (Note: one dosimeter was received at NIST that had to be reprogrammed as a result of battery failure during shipment. This instrument was programmed for a slow criterion sound level of 90 dB, an exchange rate of 5 dB, and a threshold sound level of 80 dB prior to its use in making measurements of the preliminary electrical test signals.) A threshold sound level of 80 dB was used to evaluate a percentage criterion exposure from all measurements made of the test signals in the case of either the commercial or reference dosimeters. The electrical tests were performed separately for each of the dosimeters with the appropriate impedance matching network, described in Sec. 4.2.1, inserted in the test system as shown in Fig. 3. The reader is referred to Secs. 2, 3, and 4 for details regarding the techniques of signal application and calibration of the instruments that were used in these tests.

5.1 Preliminary Electrical Tests Employing Continuous or Gated Sine Waves

Two sets of preliminary electrical tests (one set based on a 5-dB exchange rate and one set based on 3-dB exchange rate) were performed using a continuous or gated 1-kHz sine wave. The preliminary tests were performed in order to characterize the fundamental operation of the group of ten dosimeters received for testing and, if possible, to reduce the total number of dosimeters subjected to more extensive testing. The electrical signals employed in the preliminary tests were sampled by the laboratory reference dosimeter and 8-h percentage criterion exposures were obtained for each of the test signals, using both 5-dB and 3-dB exchange rates. Theoretical percentage criterion exposures were obtained for each of the preliminary electrical tests that were performed using the commercial dosimeters. The measurement results of the laboratory reference and commercial dosimeters, obtained when using the preliminary electrical test signals, are summarized and compared with theoretical results.

5.1.1 Description

The signals used in the preliminary electrical tests are described below and shown schematically in Figs. 9 through 12. The levels given in the descriptions and plots of the test signals refer to voltage levels equivalent to rms sound pressure levels re 20 μPa. Below the test signal plots appear plots of the theoretical steady-state detected output of a dosimeter (conforming to ANSI S1.25-1978, "Specifications for Personal Noise Dosimeters") when exposed to each of the test signals. The term "steady state" refers to a time sufficiently long that all transients at the detected output of the dosimeter, resulting from the response of the dosimeter to the input signal occurring after an initial state of rest, have effectively decayed to zero. In the case of the laboratory reference dosimeter, the detected response of the dosimeter was allowed to approximate a steady-state condition by applying each of the test signals a minimum of 20 s (20 times the slow exponential averaging time) prior to sampling the detector output. (Note: for the cases in which the detector output varied with time, i.e., for the cases in which the test signal was a sine wave that was gated to form a tone-burst sequence, the output level of the theoretical rms detector was calculated in 10-ms increments using the mathematical model described in Appendix B. The theoretical expression for the input signal to the detector was obtained by using the mathematical model to A-weight a tone-burst sequence which corresponded to the test signal.) The measurement (test) durations and the theoretical percentage criterion exposures corresponding to the preliminary electrical tests, performed using the input signals shown in the figures, are indicated in Table 4 for both 5-dB and 3-dB exchange rates. (Note: the measurement durations given in the test descriptions, and table apply only to the commercial dosimeters. In the case of the laboratory reference dosimeter, the signals described below were sampled for 1 s, if the test signal was a continuous sine wave, or 6 s, if the test signal was a gated sine wave [tone-burst sequence with a burst repetition period of 3 s].)

The preliminary electrical test signals (see Figs. 9 through 12) were:

Signal P1: a continuous 1-kHz sine wave at a level of 90.0 dB.

Signal P2: a continuous 1-kHz sine wave at a level of 130.0 dB.

Signal P3: a 1-kHz sine wave at a level of 130.0 dB that was gated to form a tone-burst sequence with the duration of each of the bursts equal to 0.6 s and the repetition period of the bursts equal to 3.0 s. The signal level during each of the bursts was equal to 130.0 dB and during the time period (2.4 s) between each of the bursts was less than 65 dB (the unweighted residual noise level of the signal source system when measured over the frequency range of 2 Hz to 200 kHz using a slow exponential time constant). This constituted a periodic input signal with a fundamental period of 3 s and a nominal crest factor of 10 dB.

Signal P4: a 1-kHz sine wave at a level of 85.0 dB that was gated to form a tone-burst sequence with the duration of each of the bursts equal to 1.5 s and the repetition period of the bursts equal to 3.0 s. The signal level during each of the bursts was equal to 85.0 dB and during the time period (1.5 s) between each of the bursts was less

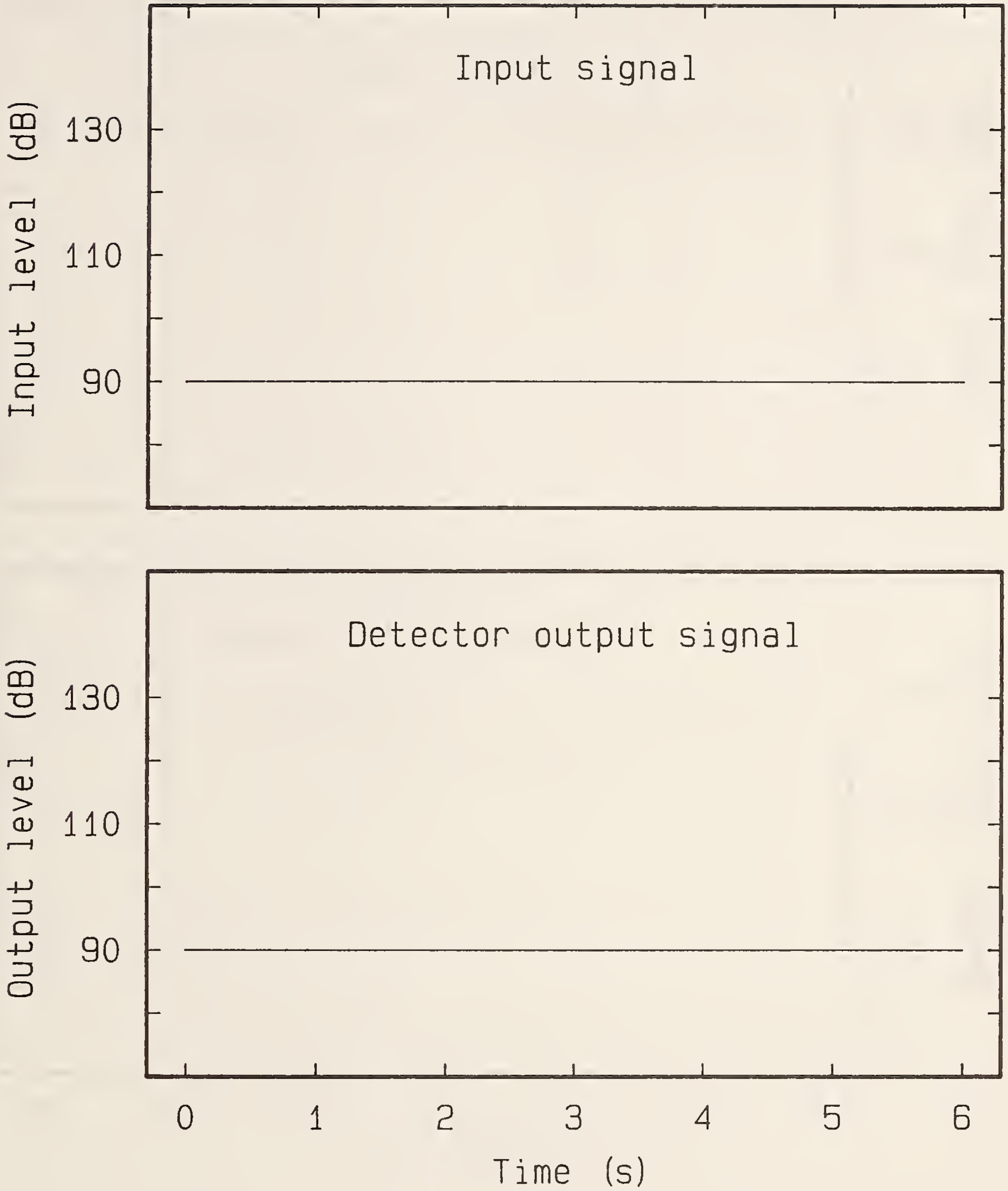

Figure 9. Preliminary electrical input (test) signal P1 (a continuous 1-kHz sine wave having a nominal crest factor of 3 dB), and the corresponding theoretical output from the detector. (Input levels are voltage-level equivalents of sound pressure levels and output levels are theoretical equivalents of A-weighted sound levels.)

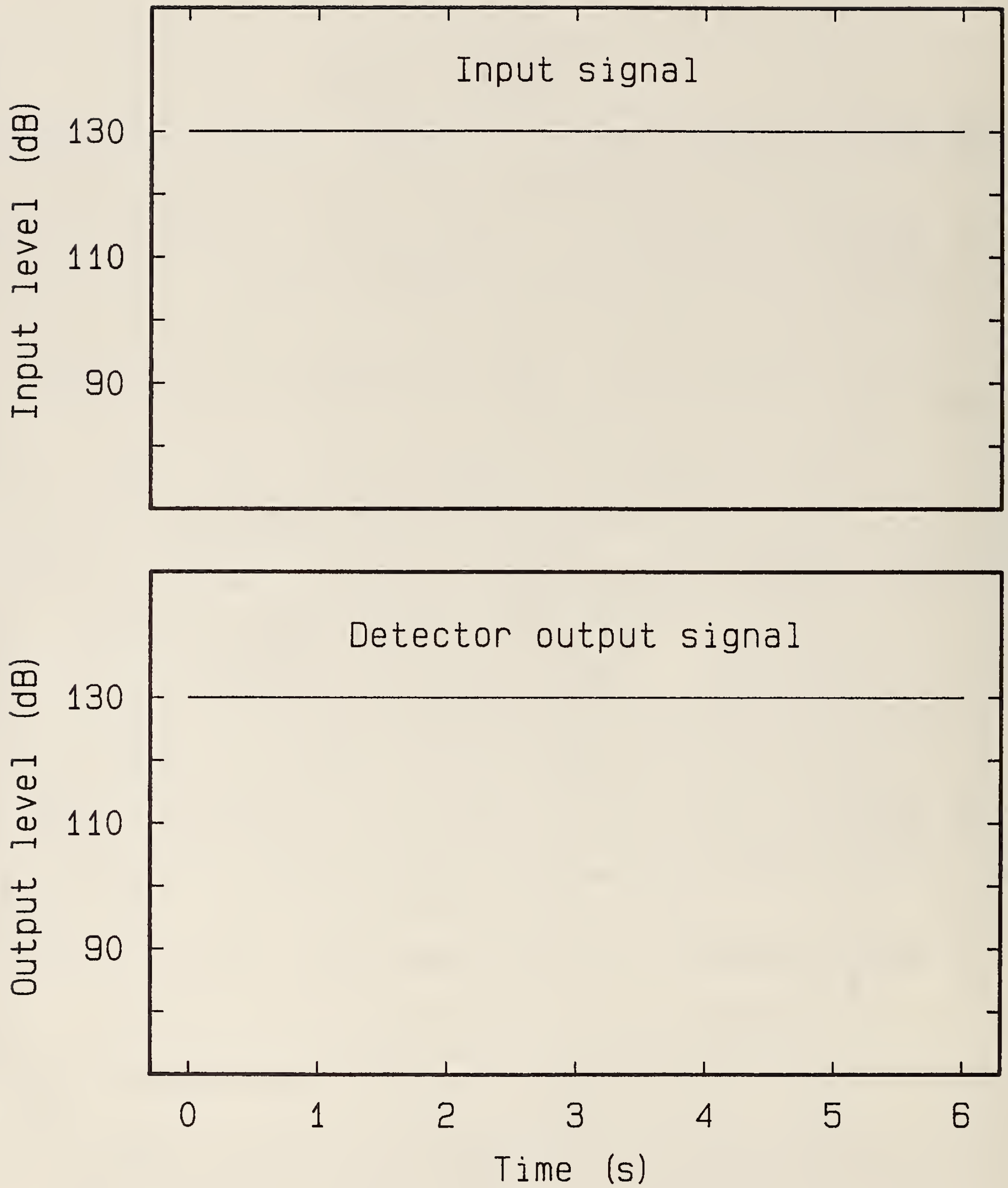

Figure 10. Preliminary electrical input (test) signal P2 (a continuous 1-kHz sine wave having a nominal crest factor of 3 dB), and the corresponding theoretical output from the detector. (Input levels are voltage-level equivalents of sound pressure levels and output levels are theoretical equivalents of A-weighted sound levels.)

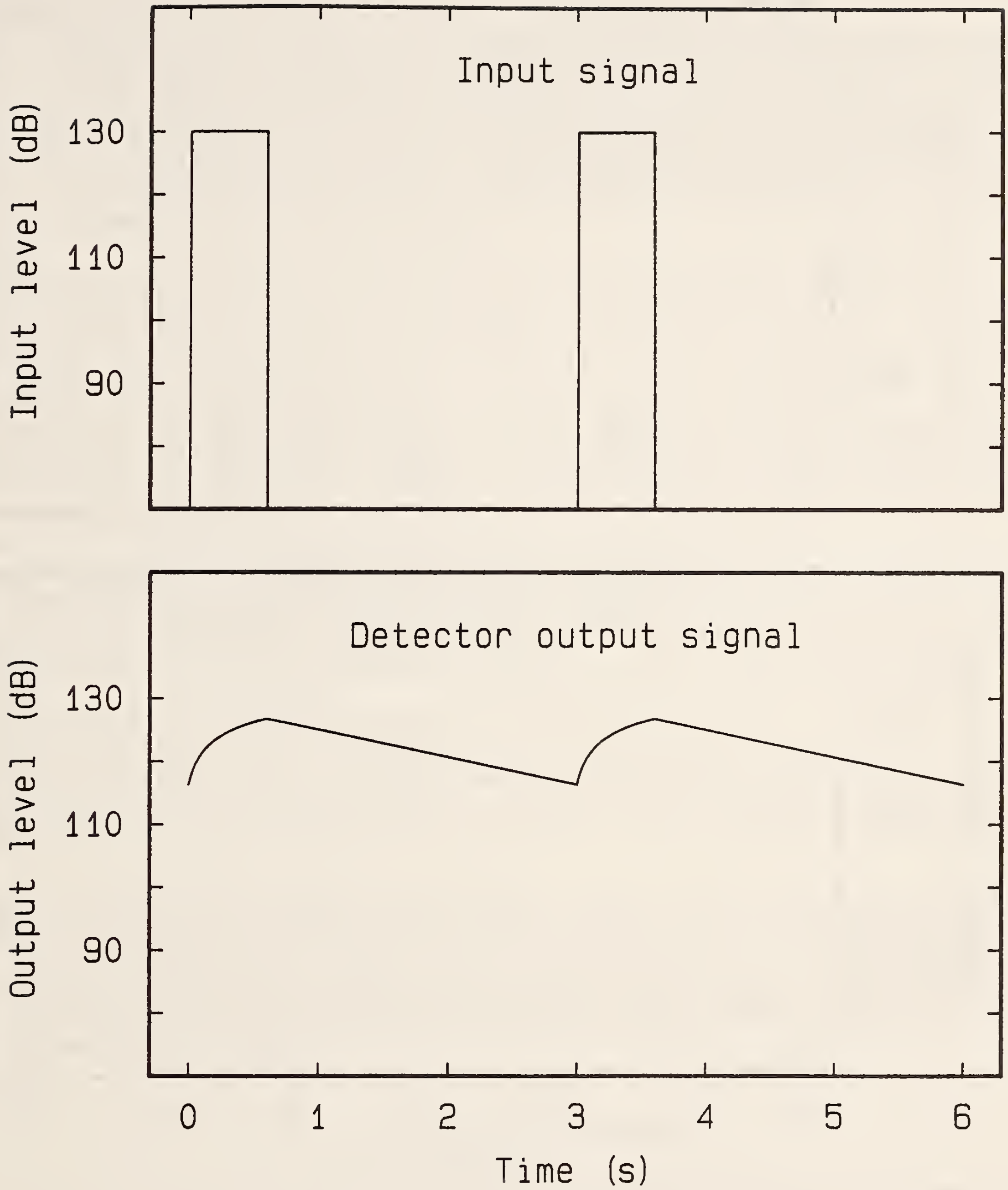

Figure 11. Preliminary electrical input (test) signal P3 (a 1-kHz sine wave gated to form a tone-burst sequence having a burst duration of 0.6 s, a repetition period of 3.0 s, and a nominal crest factor of 10 dB), and the corresponding theoretical output from the detector. (Input levels are voltage-level equivalents of sound pressure levels and output levels are theoretical equivalents of A-weighted sound levels.)

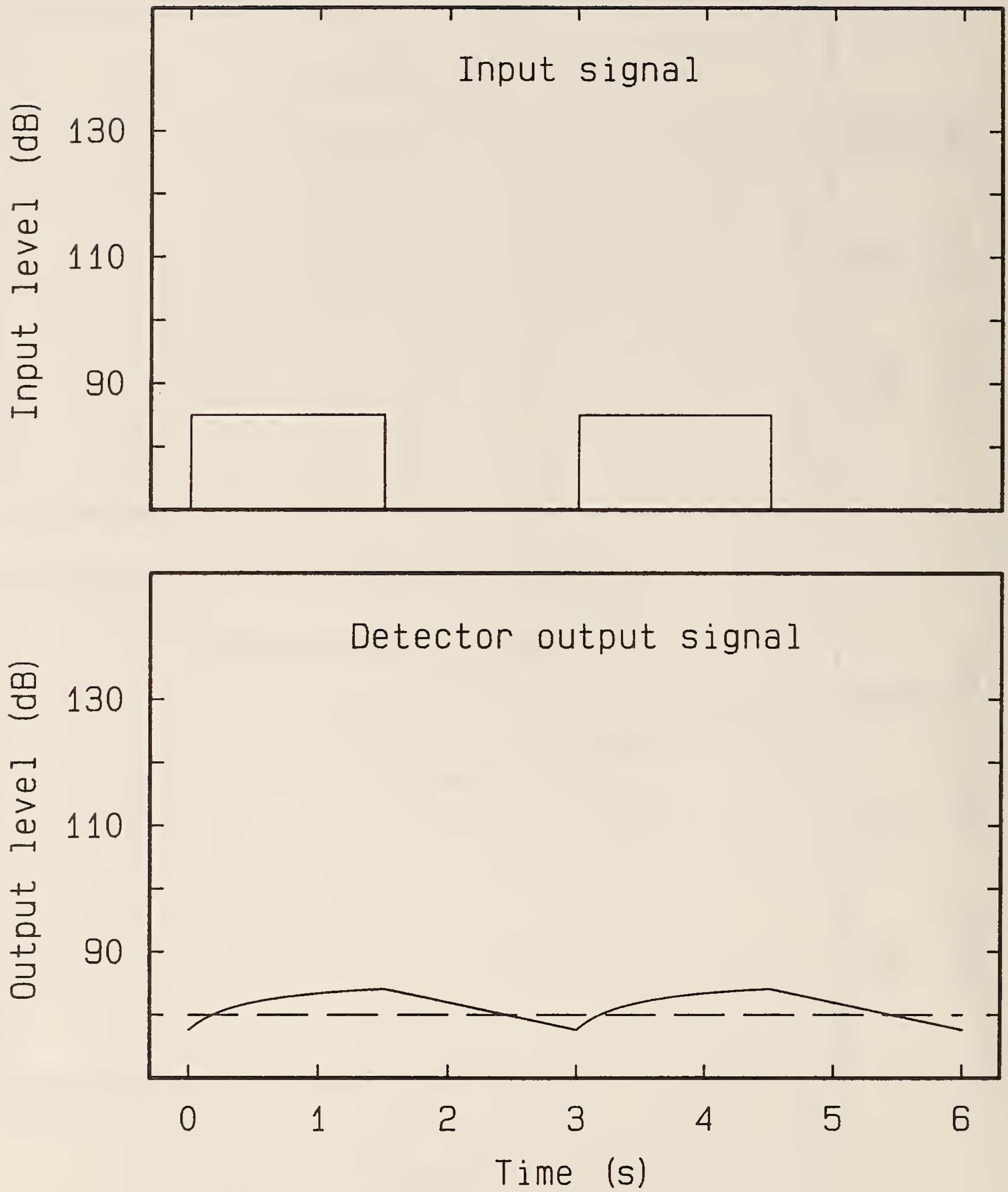

Figure 12. Preliminary electrical input (test) signal P4, (a 1-kHz sine wave gated to form a tone-burst sequence having a burst duration of 1.5 s, a repetition period of 3.0 s, and a nominal crest factor of 6 dB), and the corresponding theoretical output from the detector. (The dashed line indicates the threshold sound level of 80 dB. Input levels are voltage-level equivalents of sound pressure levels and output levels are theoretical equivalents of A-weighted sound levels.)

than 65 dB. This constituted a periodic input signal with a fundamental period of 3 s and a nominal crest factor of 6 dB. Notice that for this test signal, the extreme values of the output of the theoretical rms detector were approximately +4 and −2 dB relative to the threshold sound level, with one positive-slope crossing and one negative-slope crossing of the threshold sound level during each 3-s period of the test signal.

The preliminary electrical tests using the signals described above were:

1. Test signal P1 for 0.2400 h, resulting in a theoretical percentage criterion exposure of 3.00 percent for both 5-dB and 3-dB exchange rates.

2. Test signal P1 for 8.000 h, resulting in a theoretical percentage criterion exposure of 100 percent for both 5-dB and 3-dB exchange rates. This checked the long term measurement stability of the commercial dosimeters relative to Test 1 above.

3. Test signal P2 for 0.2400 h using a 5-dB exchange rate, or 0.006144 h using a 3-dB exchange rate, resulting in a theoretical percentage criterion exposure of 768 percent for both 5-dB and 3-dB exchange rates. This checked the linearity of the dosimeters relative to Test 1 and Test 2 above.

4. Test signal P3 for 0.8000 h using a 5-dB exchange rate, or 0.03692 h using a 3-dB exchange rate, resulting in a theoretical percentage criterion exposure of 923 percent for both 5-dB and 3-dB exchange rates. This checked the capability of the dosimeters to process a signal having a moderate crest factor.

5. Test signal P4 for 8.000 h, resulting in theoretical percentage criterion exposure of 27.1 percent using a 5-dB exchange rate, or 13.9 percent using a 3-dB exchange rate. This checked the capability of the dosimeters to process a signal that should cause the detected output of the instruments to cross the threshold sound level a considerable number of times over a long measurement duration.

5.1.2 Experimental Procedure

The signal source system was as shown in Fig. 2 for the reference dosimeter and Fig. 3 for the commercial dosimeters except: (1) the frequency counter was not connected since the frequency of the sine wave output of the function generator had been determined at 1 kHz by calibration as noted in Sec. 2, and (2) digital multimeter 2 was disconnected during the tests that involved the use of a gated sine wave (tone-burst sequence). (Note: the computer was connected to the measuring amplifier of the reference dosimeter to evaluate the test signals when the computer functioned as part of the reference dosimeter, and was connected to the function generator to time the measurement durations when the commercial dosimeter tests were performed.)

5.1.2.1 Laboratory Reference Noise Dosimeter Experimental Procedure

Initially, a 1-V rms reference (continuous 1-kHz sine wave) was maintained at the input of the attenuator and reduced by 50 dB at the output of the attenuator (see Fig. 2). This level (-50 dB re 1 V rms) was defined to be 90.0 dB (SPL) in the laboratory reference dosimeter computer program so that the input voltage sensitivity of the reference dosimeter approximated that of the commercial noise dosimeters.

The reference dosimeter sampled test signal 1, a continuous 1-kHz sine wave at a voltage level equivalent to 90.0 dB (SPL), for a period of 1 s (one sample every 10 ms) and evaluated the 8-h percentage criterion exposure corresponding to the signal, using a 5-dB exchange rate. The measurement was repeated and an 8-h percentage criterion exposure was evaluated from the results using a 3-dB exchange rate.

With 1 V rms (continuous 1-kHz sine wave) remaining at its input, the attenuator was adjusted to provide the equivalent of 130.0 dB (SPL) at the input of the reference dosimeter (test signal 2). The reference dosimeter sampled this level twice, for a period of 1 s each time, and evaluated an 8-h percentage criterion exposure from each of the measurements. An exchange rate of 5 dB was used for the first set of measurement samples and an exchange rate of 3 dB was used for the second set of measurement samples.

As in the previous two tests, each of the following test signals was measured twice, with the 8-h percentage criterion exposure corresponding to the first set of data evaluated using an exchange rate of 5 dB, and with the 8-h percentage criterion exposure corresponding to the second set of data evaluated using an exchange rate of 3 dB.

The function generator was set to provide a sequence of counted bursts of 600 cycles each (600-ms burst duration), with a fundamental (repetition) period of 3.00 s, so that the interval between the end of one burst and the start of another was 2.4 s. The voltage level at the input of the reference dosimeter during each burst was the same as in the 130.0-dB case above. During the intervals between bursts, the residual noise of the test system (less than the equivalent of 65 dB (SPL) in the frequency range 2 Hz to 200 kHz) comprised the input signal. The reference dosimeter sampled this waveform (test signal 3) twice, for a period of 6 s each time, and evaluated an 8-h percentage criterion exposure from each of the measurements.

Lastly, the function generator was set to provide a sequence of counted bursts of 1500 cycles each (1.5 s duration) with a fundamental (repetition) period of 3.00 s. The attenuator was adjusted so that the voltage at the input of the reference dosimeter during each burst was equivalent to 85.0 dB (SPL). During the intervals between bursts the signal at the reference dosimeter input was the residual noise of the test system. The reference dosimeter sampled this sequence of tone bursts (test signal 4), twice, for 6 s each time, and evaluated an 8-h percentage criterion exposure from each of the measurements.

5.1.2.2 Commercial Dosimeter Experimental Procedure

The preliminary electrical tests based on a 5-dB exchange rate, described in Sec. 5.1.2 and indicated in Figs. 9 through 12, were performed using the nine dosimeters specified to have a 5-dB exchange rate; the preliminary electrical tests, based on a 3-dB exchange rate, were performed using the one dosimeter specified to have a 3-dB exchange rate. The electrical gain of each commercial dosimeter was calibrated using a 1-kHz sine wave, essentially in accordance with the procedures outlined in the operator's manual for the instrument. The signal levels used to calibrate the instruments were based on the nominal microphone sensitivities of the noise dosimeters and the calibration sound levels specified by the dosimeter manufacturers (see Appendix A). Each of the four test signals was separately applied to the commercial dosimeters for the measurement durations given in the test descriptions. The voltage levels of the input signals, based on the nominal microphone sensitivities of the dosimeters, were equivalent to the sound levels given in the test descriptions. The function generator and attenuator were adjusted to obtain the desired test signal as described in the case of the reference dosimeter, i.e., they were adjusted to provide a continuous sine wave or a sequence of counted tone bursts at voltage levels appropriate to the nominal microphone sensitivity of the unit under test. Each dosimeter was set to display percentage criterion exposure and the display readings were recorded at the completion of each of the measurement durations.

5.1.3 Results

5.1.3.1 Reference Dosimeter Results

Plots of the difference between synchronized samples of the output of the detector of the reference dosimeter, and the theoretical detector output of a dosimeter conforming to the specifications given in ANSI S1.25-1978, are shown in Figs. 13 through 16 for preliminary electrical test signals P1 through P4. The level differences correspond to the reference-dosimeter measurement results, from which the 8-h percentage criterion exposures were calculated using a 5-dB exchange rate, referenced to the theoretical detected output levels for the test signals. Below each of the difference plots appear corresponding plots of the theoretical detected output for the length of time that the reference dosimeter sampled the test signals (the values used for the detected output levels in these plots and difference calculations were the same as those used in the detector output plots that appear in the description of the test signals). For those cases in which the detector output varied with time, i.e., for the cases in which the test signal was a sine wave that was gated to form a tone-burst sequence, the theoretical detector plots begin 10 ms (one data point) prior to the point that the slope of the theoretical detected output becomes positive. In general, the measurements made by the reference dosimeter began at an arbitrary point on these time-varying theoretical detector output curves. The time-varying detected outputs, those measured by the reference dosimeter and those calculated for a dosimeter conforming to ANSI S1.25-1978, were synchronized in time (±5 ms) as follows. Since the measured detector output levels were obtained in intervals of 10 ms and the theoretical detector output levels were calculated in intervals of 10 ms, the total number of measured and calculated data points were equal for any given interval of time. The measured data points were synchronized with the beginning of the calculated data at the first data point in the sample period that the measured output of the detector of the reference dosimeter changed

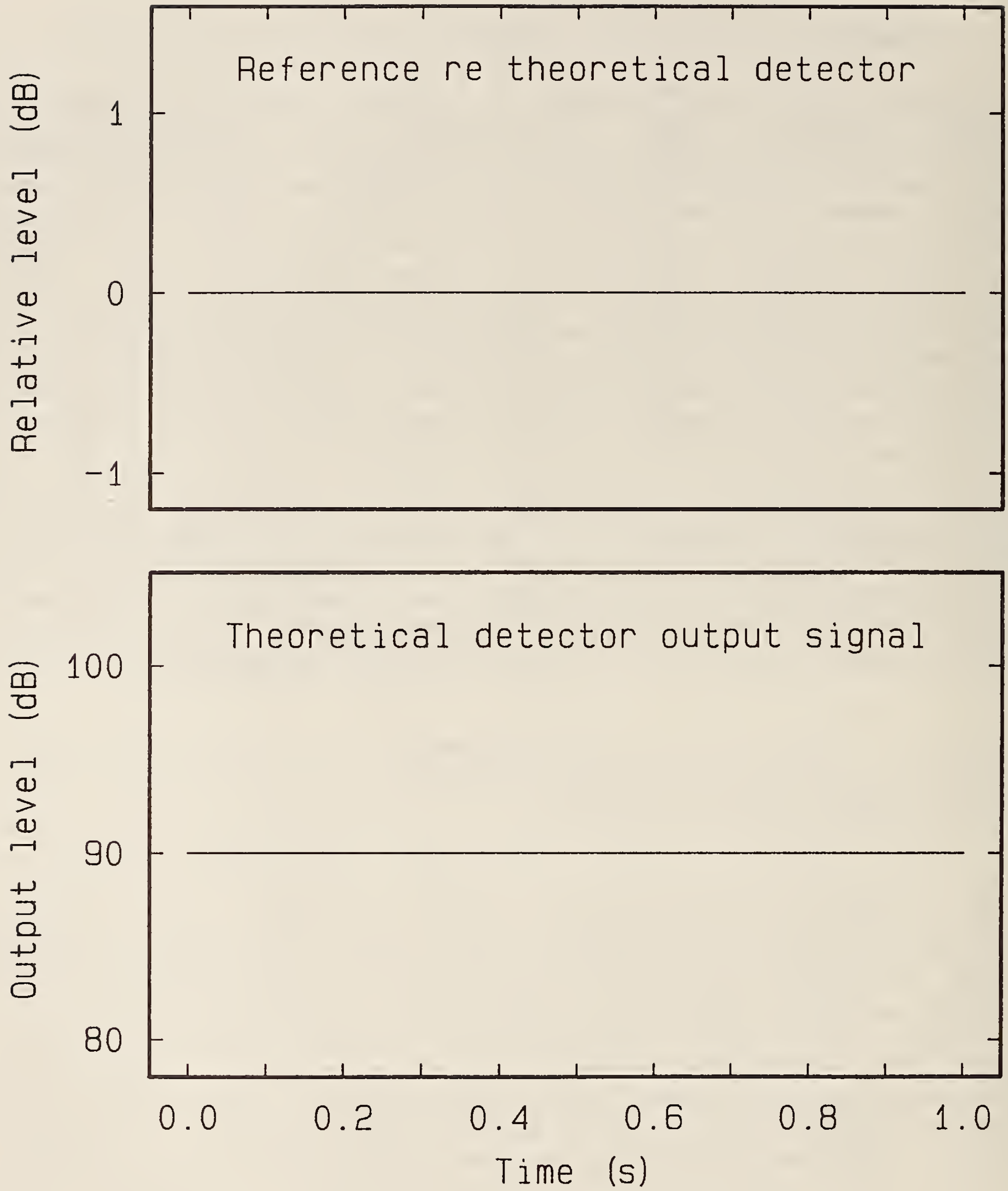

Figure 13. Relative and theoretical steady-state detector output levels due to preliminary electrical test signal P1 (a continuous 1-kHz sine wave having a nominal crest factor of 3 dB). The lower plot shows the expected (theoretical) level. The upper plot shows the measured level from the reference dosimeter, relative to the expected level. (Reference dosimeter and theoretical detector output levels are equivalents of A-weighted sound levels.)

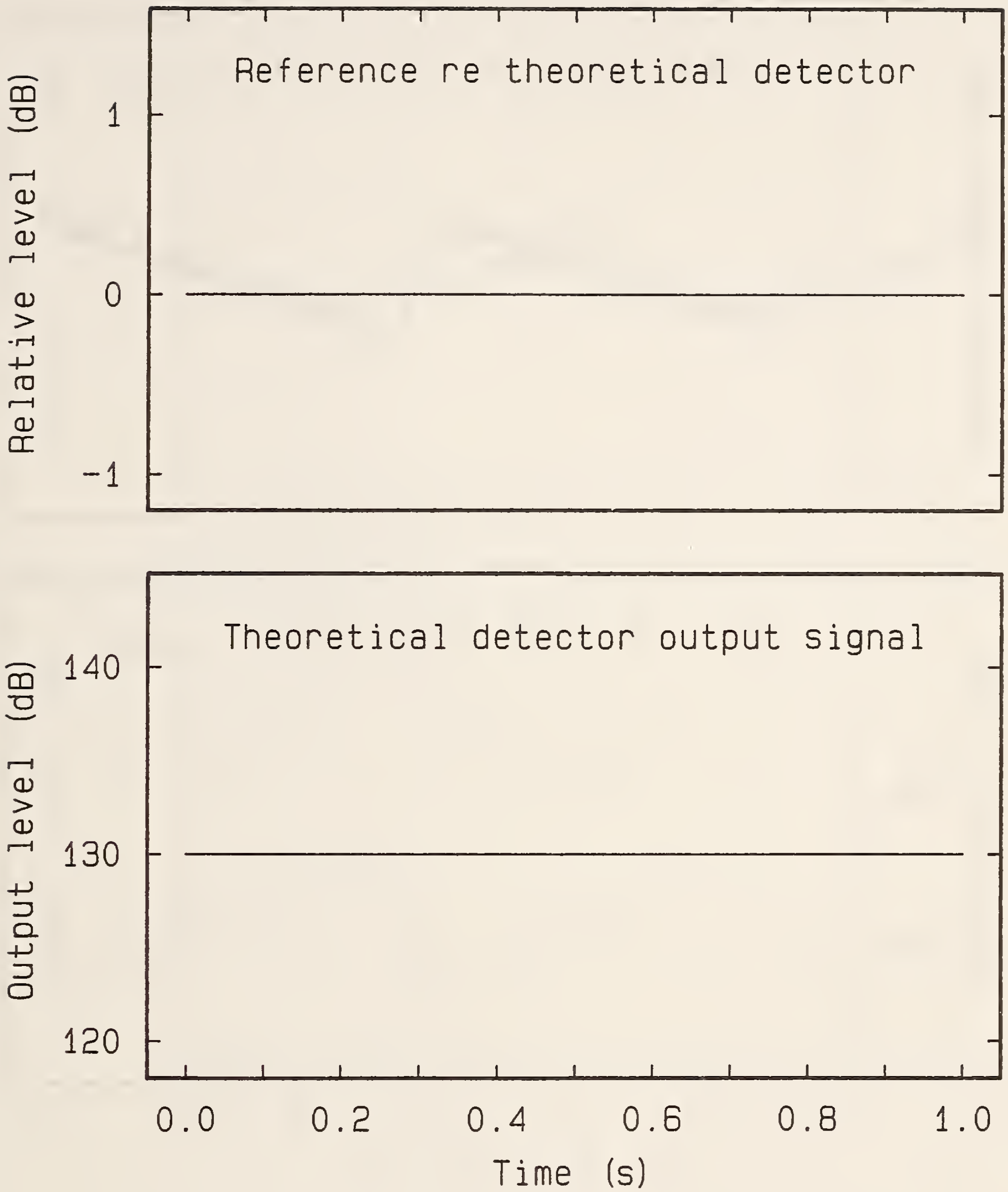

Figure 14. Relative and theoretical steady-state detector output levels due to preliminary electrical test signal P2 (a continuous 1-kHz sine wave having a nominal crest factor of 3 dB). The lower plot shows the expected (theoretical) level. The upper plot shows the measured level from the reference dosimeter, relative to the expected level. (Reference dosimeter and theoretical detector output levels are equivalents of A-weighted sound levels.)

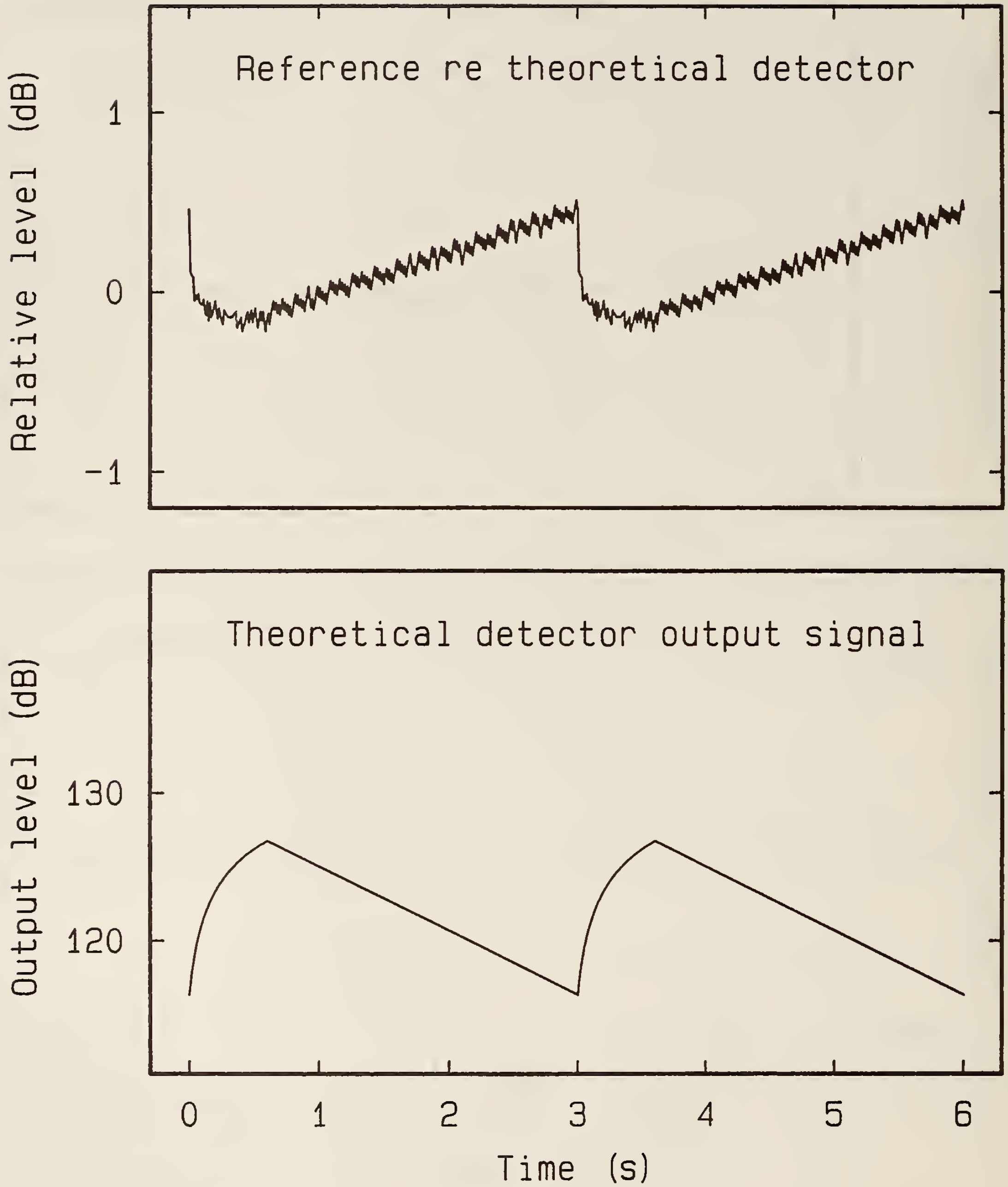

Figure 15. Relative and theoretical steady-state detector output levels due to preliminary electrical test signal P3 (a 1-kHz sine wave gated to form a tone-burst sequence having a burst duration of 0.6 s, a repetition period of 3.0 s, and a nominal crest factor of 10 dB). The lower plot shows the expected (theoretical) level. The upper plot shows the measured level from the reference dosimeter, relative to the expected level. (Reference dosimeter and theoretical detector output levels are equivalents of A-weighted sound levels.)

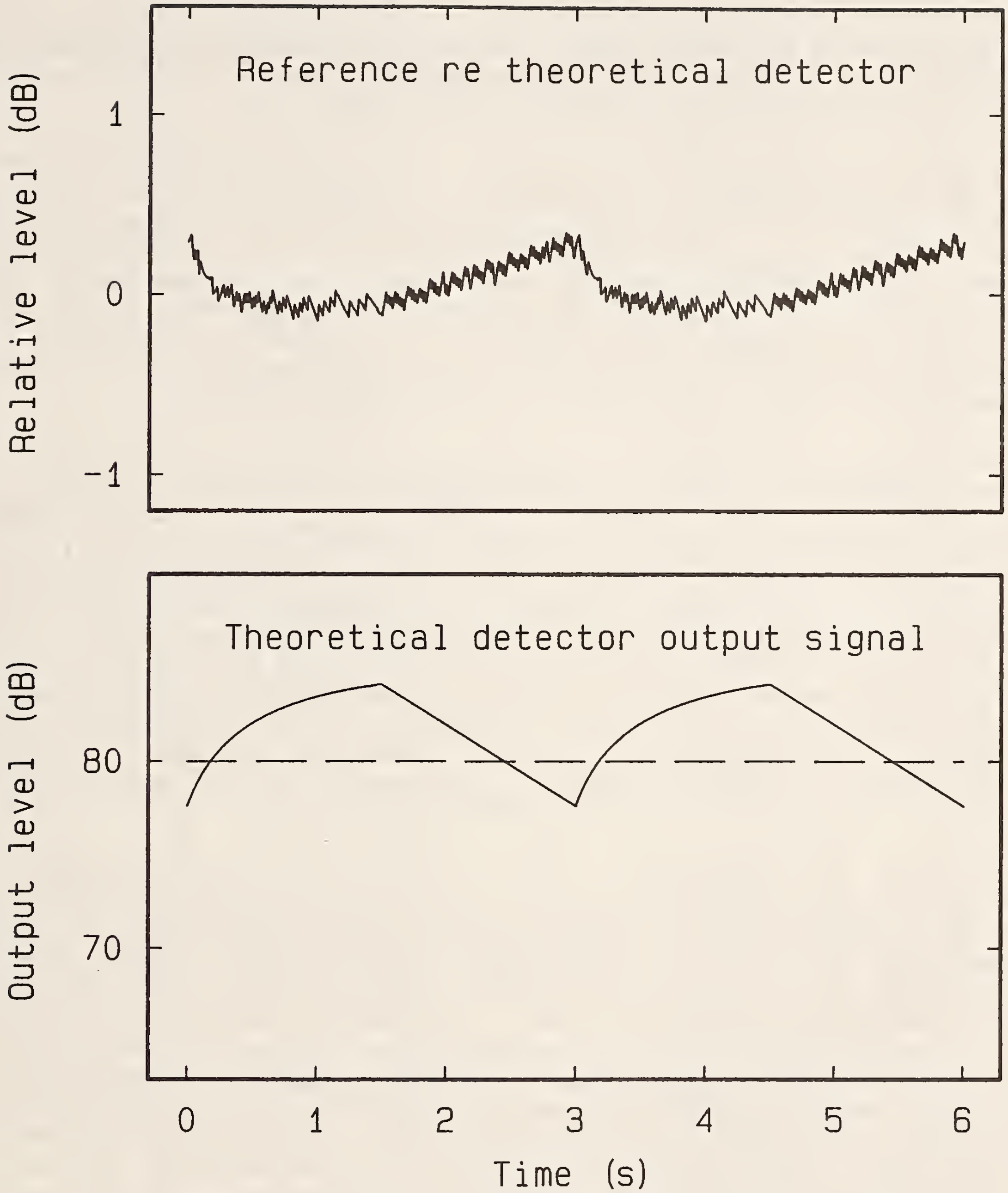

Figure 16. Relative and theoretical steady-state detector output levels due to preliminary electrical test signal P4 (a 1-kHz sine wave gated to form a tone-burst sequence having a burst duration of 1.5 s, a repetition period of 3.0 s, and nominal crest factor of 6 dB). The lower plot shows the expected (theoretical) level. The upper plot shows the measured level from the reference dosimeter, relative to the expected level. (The dashed line indicates the threshold sound level of 80 dB. Reference dosimeter and theoretical detector output levels are equivalents of A-weighted sound levels.)

from a negative to a positive slope. The measured data that were obtained prior to the point of synchronization were appended to the end of the measured data as though the data had been obtained contiguously.

A theoretical percentage criterion exposure value was calculated for each of the tests using formulae given in Appendix A, in the case of those test signals composed of a continuous sine wave, and in Appendix B, in the case of those test signals composed of a gated sine wave. Each of the 8-h percentage criterion exposure values, obtained for the test signals from the reference dosimeter measurement results, was extrapolated to values corresponding to the length of time that the test signals were applied to the commercial dosimeters. These percentage criterion exposures, as well as the results of the commercial dosimeter tests, are given in Table 4 to the nearest integer.

The percentage criterion exposure results of the reference dosimeter and the commercial dosimeters were expressed relative to theoretical exposure values using the formula given in Appendix A for calculating, in a simplified form, the difference between the equivalent levels of a test signal based on exposure values obtained from measurement results and those obtained from theoretical calculations. The number of digits used to perform the relative response calculations was five, in the case of the theoretical values, four, in the case of the reference dosimeter values, and, in the case of the commercial dosimeter values, was the number of digits available in the display of the instruments for any given combination of test result and instrument (the minimum number of digits was two except for dosimeters 4, 5, and 10 which had less than two in the case of the 3 percent exposure test). The results of the relative response calculations are given in Table 5 to the nearest 0.1 dB.

The plots of the synchronized samples of the output of the detector of the reference dosimeter relative to the output of the theoretical detector calculated in 10-ms intervals for signals P1 through P4 indicate that the reference-dosimeter and theoretical detector outputs agreed to better than 1 dB (see Figs 13 through 16). In cases of a time-varying detector output (test signals P3 and P4), the differences in level between the reference dosimeter and theoretical detector output levels became increasingly larger during the time period(s) that the detector output decayed from a maximum. This is consistent with the calibration of the exponential averaging time constant of the reference-dosimeter measuring amplifier indicating a decay time constant of about 1.06 s or approximately 6 percent greater than the 1-s value used for the exponential averaging time constant in the theoretical calculations. In all cases, the reference dosimeter and the theoretical detector output levels were in agreement to within a few tenths of a decibel during the time period when the detector output was the largest, i.e., the time period when the detector output level influenced the value of the percentage criterion exposure the most. (Note: see Sec. 5.2.3.1 for a more detailed discussion of the differences between measured and calculated detector output levels.)

The reference-dosimeter equivalent levels (based on percentage criterion exposures calculated from the sampled output of the reference-dosimeter detector), when expressed relative to theoretical values for signals P1 through P4, indicate differences in equivalent levels of 0.1 dB, or less, between the

Table 4. Percentage criterion exposures (percent) measured in the preliminary electrical tests involving the use of a continuous or gated 1-kHz sine wave.[a]

Burst Level[b] (dB)	Test Duration[c] (h)	Burst Duration[d] (s)	Crest Factor[e] (dB)	Theory[f] (%)	Reference Dosimeter (%)	Commercial Dosimeter (%) 1	2	3	4	5	6	7	8	9	10
5-dB Exchange Rate															
90	0.2400	cw	3	3	3	3	3	3	2	3	3	...[g]	3	3	3
90	8.000	cw	3	100	100	104	100	103	95	99	103	...	100	92	100
130	0.2400	cw	3	768	768	743	764	750	719	766	836	...	741	727	768
130	0.8000	0.60	10	923	929	898	919	931	808	952	939	...	929	921	657
85	8.000	1.5	6	27	27	34	29	29	23	28	27	...	29	29	0
3-dB Exchange Rate															
90	0.2400	cw	3	3	3	...	...	...	...	...	...	3[h]	...	...	...
90	8.000	cw	3	100	100	...	...	...	...	...	...	102	...	...	...
130	0.006144	cw	3	768	768	...	...	...	...	...	...	731	...	...	...
130	0.03692	0.60	10	923	909	...	...	...	...	...	...	895	...	...	...
85	8.000	1.5	6	14	14	...	...	...	...	...	...	112	...	...	...

[a] The values of the percentage criterion exposures, in percent, have been expressed to the nearest integer. The sine wave, when gated, comprised a tone-burst sequence such that the duration and repetition period of the bursts were each equal to an integral number of cycles of the sine wave, and each burst began and ended on a "zero crossing" of the sine wave, with the repetition period of the tone bursts equal to 3 s.

[b] The rms level of the 1-kHz sine wave when continuous.

[c] The time period, to four significant figures, that each of the commercial dosimeters was exposed to the test signal. For the reference dosimeter, the detector output was sampled in 10-ms intervals for a period of 1 s in the case of a continuous sine wave, and 6 s (two tone-burst repetition periods) in the case of a gated sine wave.

(Table 4 cont'd.)

[d] The time period that the sine wave, when gated, was present during each cycle (repetition period) of the burst sequence (denoted cw when the sine wave was not gated).

[e] The nominal crest factor of the test signal.

[f] Theoretical values for the tests were obtained by multiplying the theoretical 8-h percentage criterion exposure results, computed for each of the test signals and expressed to five significant figures, by the ratio of the measurement duration to eight hours.

[g] "..." indicates that no measurement was made for a given combination of dosimeter and exchange rate.

[h] Average of two measurement results with the percentage criterion exposures agreeing within 0.08 percentage points.

Table 5. Equivalent levels (dB) relative to theoretical values, calculated for the preliminary electrical tests involving the use of a continuous or gated 1-kHz sine wave.[a]

Burst Level[b]	Test Duration[c]	Burst Duration[d]	Crest Factor[e]	Reference Dosimeter	Commercial Dosimeter (dB)									
(dB)	(h)	(s)	(dB)	(dB)	1	2	3	4	5	6	7	8	9	10
				5-dB Exchange Rate										
90	0.2400	cw	3	0.0	0.3	0.0	0.0	−2.9	0.0	0.0	...[f]	0.0	−0.6	0.0
90	8.000	cw	3	0.0	0.3	0.0	0.2	−0.4	−0.1	0.2	...	0.0	−0.6	0.0
130	0.2400	cw	3	0.0	−0.2	0.0	−0.2	−0.5	0.0	0.6	...	−0.3	−0.4	0.0
130	0.8000	0.60	10	0.0	−0.2	0.0	0.1	−1.0	0.2	0.1	...	0.0	0.0	−2.5
85	8.000	1.5	6	0.1	1.6	0.5	0.5	−1.2	0.2	−0.1	...	0.6	0.5	...
				3-dB Exchange Rate										
90	0.2400	cw	3	0.0	...	...	...	...	...	...	0.2[g]	...	...	...
90	8.000	cw	3	0.0	...	...	...	...	...	...	0.2	...	...	...
130	0.006144	cw	3	0.0	...	...	...	...	...	...	−0.2	...	...	...
130	0.03693	0.60	10	−0.1	...	...	...	...	...	...	−0.1	...	...	...
85	8.000	1.5	6	−0.1	...	...	...	...	...	...	9.1	...	...	...

[a] The percentage criterion exposure test results were expressed relative to the theoretical 8-h percentage criterion exposures, calculated for each of the test signals and expressed to five significant figures. The formula given in Appendix A was then used to compute, in a simplified form, the difference between the equivalent level of each test signal based on exposure values obtained from measurement results and that obtained from theoretical calculations. The number of digits in the test results, used to perform the relative response calculations, was the number of digits available in the display of the instruments for any given combination of test result and instrument (the minimum number of digits was two except for dosimeters 4, 5, and 10 which had less than two in the case of the 3 percent exposure test). The values obtained in the relative response calculations have been tabulated to the nearest tenth of a decibel.

[b] The rms level of the 1-kHz sine wave when continuous.

(Table 5, cont'd.)

[c] The time period, to four significant figures, that each of the commercial dosimeters was exposed to the test signal. In the case of the reference dosimeter, the output of the rms detector was sampled in 10-ms intervals for a period of 1 s in the case of a continuous sine wave, and 6 s (two tone-burst repetition periods) in the case of a gated sine wave.

[d] The time period that the sine wave, when gated, was present during each cycle (repetition period) of the burst sequence (denoted cw when the sine wave was not gated).

[e] The nominal crest factor of the test signal.

[f] "..." indicates that the relative response was not calculated either because of a null measurement result or because no measurement was made for a given combination of dosimeter and exchange rate.

[g] 0.2 and 0.1 dB when calculating the relative response using the two measurement results obtained rather than their average (see Table 4, footnote g).

reference-dosimeter and theoretical results when using either a 5-dB or 3-dB exchange rate (see Table 5).

5.1.3.2 Commercial Dosimeter Results

The differences between the relative responses of the dosimeters when applying test signal P1 for 0.2400 versus 8.000 h were less than 0.5 dB except in the case of dosimeter 4 (see Table 5). (Note: the relative response values that pertain to the measurements of test signal P1 for a duration of 0.2400 h are not significant to a tenth of a decibel for dosimeters 3, 4, 5, 6, 8, and 10 in the sense that the number of digits available in the displays of these instruments for this test was insufficient to provide a value for an equivalent level of the test signal that was significant to a tenth of a decibel. In the case of dosimeter number 4, the relative response value of -2.9 dB that was obtained for test signal 1 given a measurement duration of 0.2400 h is significant only to approximately ±1 dB because of the number of digits that were in the display of the instrument for this test result. Notice that when the same test signal was applied to dosimeter 4 for a longer measurement duration, i.e., 8 h, the relative response of the instrument was equal to -0.4 dB.) The response of the dosimeters to test signal 1 for measurement durations of 0.2400 and 8.000 h did not indicate any significant difference in the performance of the instruments when given short versus long measurement durations.

The differences between the relative responses of the dosimeters to a continuous sine wave at 90 dB (test signal 1) and at 130 dB (test signal 2) were less than 0.5 dB (based on the results of the 8-h measurements of test signal 1). These results indicate that the combined linearity of the amplifiers and display circuitry of each of the instruments was better than ±0.5 dB for this test.

The absolute value of the relative responses of the dosimeters to a signal with a nominal crest factor of 10 dB (test signal P3) was 1.0 dB or less and typically less than 0.3 dB in all cases except dosimeter 10 which exhibited a relative response of -2.5 dB with respect to this signal.

The absolute value of the relative responses of the dosimeters to test signal P4, i.e., a signal that should cause the detected outputs of the dosimeters to cross the threshold sound level a large number of times over the measurement duration of the test (8 h), was less than 1.5 dB except in the cases of dosimeters 1, 7, and 10. The relative responses of dosimeters 1 and 7 in this test were +1.6 dB and +9.1 dB, respectively. In the case of dosimeter 10, the instrument indicted a null response to test signal P4, i.e., 0 percent. Further investigation, using a continuous sine wave at a voltage level equivalent to 85 dB (SPL), indicated that the threshold sound level of dosimeter 10 was at a level in excess of 85 dB. This would explain the response of the instrument in test five given that measurements made of test signal P4 using the reference dosimeter and theoretical calculations made for test signal P4 both indicated that A-weighted slow detected sound levels for this signal should be less than 84.2 dB.

In the case of dosimeters 3 and 8, and dosimeters 6 and 9, the dosimeters were of the same manufacturer but were a different model. In comparing the performance of dosimeters 3 and 8, it was decided to discontinue the testing of one of the dosimeters since the response of the two dosimeters in the tests were similar enough that it appeared that testing both dosimeters would be a duplication of effort. In comparing the performance of dosimeters 6 and 9, it was decided to discontinue the testing of dosimeter 9 since the overall performance of this unit was not generally as good as dosimeter 6 (the more recent design of the two models).

For reasons stated in the preceding paragraph and because of an apparent problem with the threshold sound level of dosimeter 10, it was decided at the completion of the preliminary electrical tests to eliminate dosimeters 8, 9, and 10 from further testing.

5.2 Electrical Tests Employing Signals Having Moderate-to-High Crest Factors

Industrial noise which is impulsive in nature and produced predominantly by a process involving impact(s) such as forging, stamping, or hammering (explosive processes such as gun fire are excluded from this analysis) appears, to first approximation, as a train of damped sinusoidal excitations with a fundamental repetition period which is regular, irregular, or intermittent depending on the nature of the source. The maximum (peak) unweighted sound pressure level produced by a loud industrial process of the type discussed could typically range from 110 to 135 dB SPL_{peak} when measured at the location where a worker spends the majority of time exposed to the noise source [8-11]. In order to quantify noise dosimeter response to stimuli similar to, but less complex than, the in-situ measurements discussed above, a set of electrical test signals was developed utilizing tone-burst sequences that had burst durations ranging from 10 ms to 10 s and signal crest factors ranging from 4.8 to 30 dB (see Table 6). Two sets of tone-burst sequences were measured by the laboratory reference dosimeter. One set had burst durations and signal crest factors corresponding to the complete set of test signals with each burst comprised of counted bursts of an integral number of cycles of a 100-Hz sine wave. The other set had burst durations and signal crest factors corresponding to a limited subset of the test signals with each burst comprised of counted bursts of an integral number of cycles of a 1-kHz sine wave. A series of electrical tests was devised for the commercial dosimeters using a total of nine signals (referred to in the text that follows as test signals 1 through 9). One of the test signals was a continuous 1-kHz sine wave, and eight of the test signals constituted a set of sequences of counted bursts of a 1-kHz sine wave that had burst durations and signal crest factors the same as those of eight of the signals measured by the reference dosimeter (indicated in Table 6 by bold-faced type with the test signal number appearing in parentheses). The text that follows is a description of the signals and measurement results of, essentially, three groups of tests where two of the groups pertain to measurements performed using the reference dosimeter to measure a set of test signals consisting of counted bursts of either a 100-Hz or 1-kHz sine wave. The third group of tests pertains to measurements performed using the reference and commercial dosimeters to measure a set of signals consisting of a 1-kHz sine wave that either remained continuous or was gated to form sequences of counted bursts, with the signals in this group denoted test signals 1 through 9.

5.2.1 Description

The tone bursts used in the electrical tests involving signals with a moderate-to-high crest factor were comprised of an integral number of cycles of a sine wave at a voltage level equivalent to 120 dB (SPL) and a frequency of either 100 Hz or 1 kHz. The crest factors of the signals were derived by varying the repetition period of the burst sequence for a given burst duration. As in the case of the preliminary series of electrical tests described in Sec. 5.1 above, two series of tests, one based on a 5-dB exchange rate, and one based on a 3-dB exchange rate, were performed for each group of tests. The parameters (burst durations, burst repetition periods, and crest factors) of the tone-burst sequences are shown in Fig. 17 and Table 6. Fig. 17 shows the tone-burst duration versus repetition period for each of the tone-burst sequences along lines of constant crest factor. The tone-burst sequence parameters used in the test signals are indicated by circles or dots with the dots representing the tone-burst sequence parameters that were used in the tests performed using both the commercial and the reference dosimeters (test signals 2 through 9). Table 6 indicates the tone-burst repetition period, in seconds, for each of the tone-burst sequences as a function of the burst duration and crest factor of the test signals. The tone-burst repetition periods that are bold-faced indicate the tone-burst sequence parameters that were used in the commercial-dosimeter test signals 2 through 9.

5.2.1.1 Laboratory Reference Noise Dosimeter Test Description

Two sets of test signals were configured using the tone-burst sequence parameters referenced above. One set of tone-burst sequence test signals was configured using an integral number of cycles of a 100-Hz sine wave such that the number of cycles, divided by 100, was numerically equal to the desired burst duration in seconds. A second set of tone-burst sequence test signals was configured using an integral number of cycles of a 1000-Hz sine wave such that the number of cycles, divided by 1000, was equal to the desired burst duration. All of the tone-burst sequence test parameters shown in Fig. 17 and Table 6 were used for the set of 100-Hz sine-wave test signals. However, only those parameters shown in Figs. 17 and Table 6 that corresponded to tone-burst sequences with burst durations of 1 s, or less, were used for the set of 1-kHz sine-wave test signals. Both sets of these tests consisted of two subsets of tests, one based on a 5-dB exchange rate, and one based on a 3-dB exchange rate.

5.2.1.2 Commercial Dosimeter Test Description

A set of tests, employing both 5-dB and 3-dB exchange rates, was created for the commercial dosimeters using a continuous or gated sine wave at a voltage level equivalent to 120 dB (SPL). The sine wave, when gated, formed tone-burst sequences with the parameters indicated for test signals 2 through 9 that are given in Fig. 17 and Table 6. The signals used in these tests are described below and shown schematically in Figs. 18 through 26. The levels given in the descriptions and plots of the test signals refer to voltage levels equivalent to rms sound pressure levels referenced to 20 μPa. Below each plot of a test signal appears a plot of the corresponding theoretical steady-state detector output (see Sec. 5.1.1 above for a description of what is meant by "steady-state"). (Note: for the cases in which the detector output varied with time,

Table 6. Burst repetition periods as a function of burst duration and crest factor, for the tone-burst sequences applied to the reference and commercial dosimeters during the electrical tests using signals of moderate-to-high crest factor. The bold-faced values, with the test signal numbers given in parentheses, indicate the signals that were applied to the commercial dosimeters.

Burst Duration (s)	Burst Repetition Period (s)				
	Crest Factor (dB)				
	4.8	6.0	10	20	30
0.010	0.015	0.020	**0.050**(2)	**0.5**(5)	**5.0**(8)
0.020	0.030	0.040	0.10	1.0	10
0.050	0.075	0.10	0.25	2.5	25
0.10	0.15	0.20	**0.50**(3)	**5.0**(6)	**50**(9)
0.20	0.30	0.40	1.0	10	100
0.50	0.75	1.0	2.5	25	250
1.0	1.5	2.0	**5.0**(4)	**50**(7)	500
2.0	3.0	4.0	10	100	...
5.0	7.5	10	25	250	...
10	15	20	50	500	...

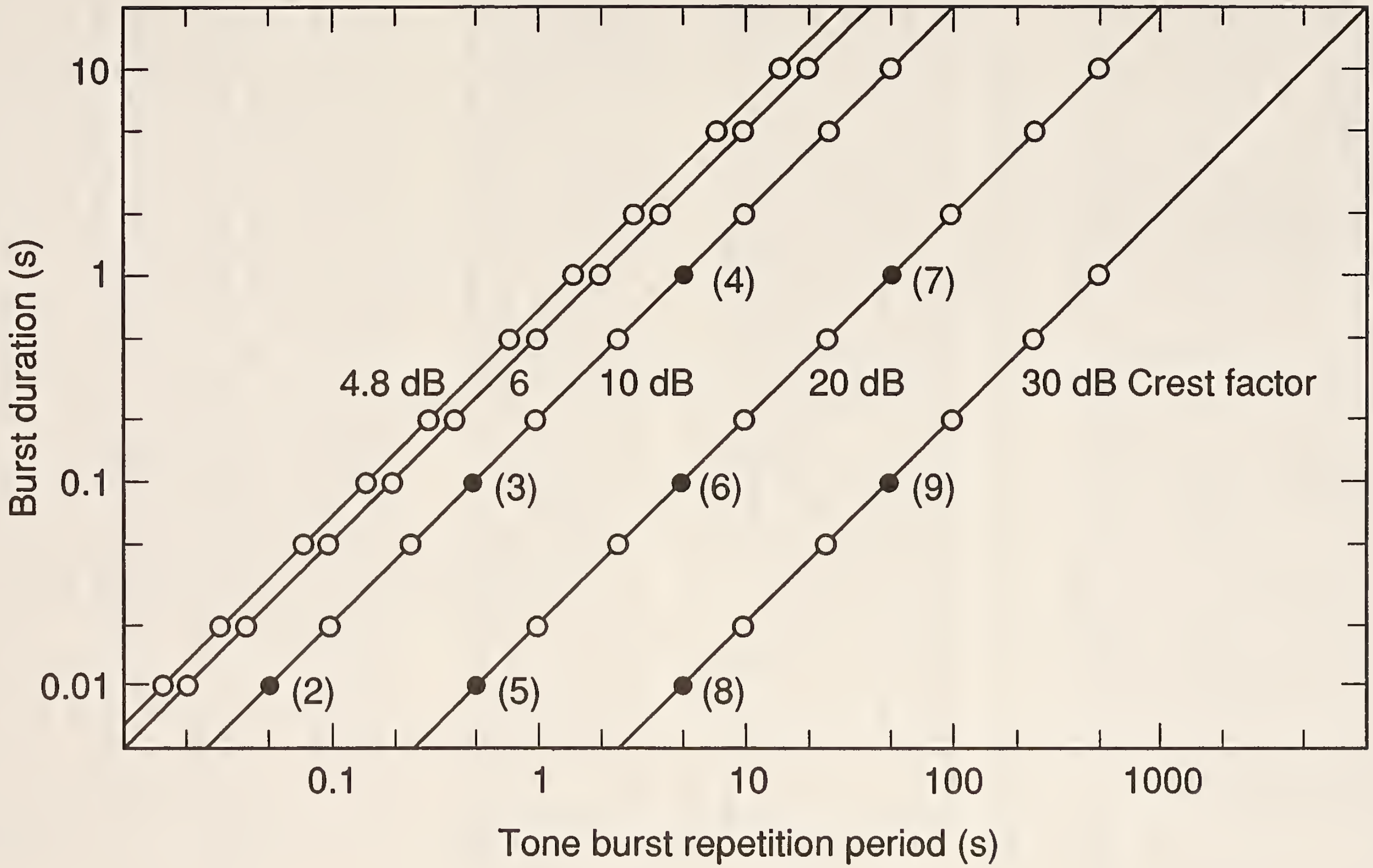

Figure 17. The parameters (burst durations, repetition periods,and crest factors) of the tone-burst sequences applied to the commercial dosimeters (solid circles) and the reference dosimeter (open and solid circles) during the electrical tests using signals of moderate-to-high crest factor. The test signal numbers are indicated in parentheses to the right of the corresponding solid circle.

i.e., for the cases in which the test signal was a sine wave that was gated to form a tone-burst sequence, the output level of the theoretical rms detector was calculated in 10-ms increments using the mathematical model described in Appendix B. The mathematical expression for the input signal to the theoretical detector was obtained by using the mathematical model to theoretically A-weight a tone-burst sequence which corresponded to the test signal. The measurement durations given in the test descriptions and table apply only to the commercial dosimeters. In the case of the laboratory reference dosimeter, the signals described below were sampled for 1 s, if the test signal was a continuous sine wave. If the test signal was a gated sine wave [tone-burst sequence] it was sampled by the reference dosimeter for a period of 1 s or two repetition periods, which ever was greater.) The measurement duration of each of the tests was selected such that, based on the reference dosimeter results (not theoretical calculations), the percentage criterion exposure would remain constant at 100 percent.

The electrical test signals having nominal crest factors in the range of 3 to 30 dB (see Figs. 18 through 26) were:

Signal 1: a continuous 1-kHz sine wave at a level of 120.0 dB.

Signal 2: A 1-kHz sine wave at a level of 120.0 dB that was gated to form a tone-burst sequence with the duration of each of the bursts equal to 0.010 s and the repetition period of the bursts equal to 0.050 s. The signal level during the time period (0.040 s) between each of the bursts was less than 65 dB (the unweighted residual noise level of the signal source when measured over the frequency range of 2 Hz to 200 kHz using a slow exponential time constant). This constituted a periodic input signal with a fundamental period of 50 ms and a nominal crest factor of 10 dB.

Signal 3: A 1-kHz sine wave at a level of 120.0 dB that was gated to form a tone-burst sequence with the duration of each of the bursts equal to 0.10 s and the repetition period of the bursts equal to 0.50 s. The signal level during the time period (0.40 s) between each of the bursts was less than 65 dB. This constituted a periodic input signal with a fundamental period of 500 ms and a nominal crest factor of 10 dB.

Signal 4: A 1-kHz sine wave at a level of 120.0 dB that was gated to form a tone-burst sequence with the duration of each of the bursts equal to 1.0 s and the repetition period of the bursts equal to 5.0 s. The signal level during each of the bursts was equal to 120.0 dB and during the time period (4.0 s) between each of the bursts was less than 65 dB. This constituted a periodic input signal with a fundamental period of 5.0 s and a nominal crest factor of 10 dB.

Signal 5: A 1-kHz sine wave at a level of 120.0 dB that was gated to form a tone-burst sequence with the duration of each of the bursts equal to 0.010 s and the repetition period of the bursts equal to 0.50 s. The signal level during the time period (0.49 s) between each of the bursts was less than 65 dB. This constituted a periodic input signal with a fundamental period of 500 ms and a nominal crest factor of 20 dB.

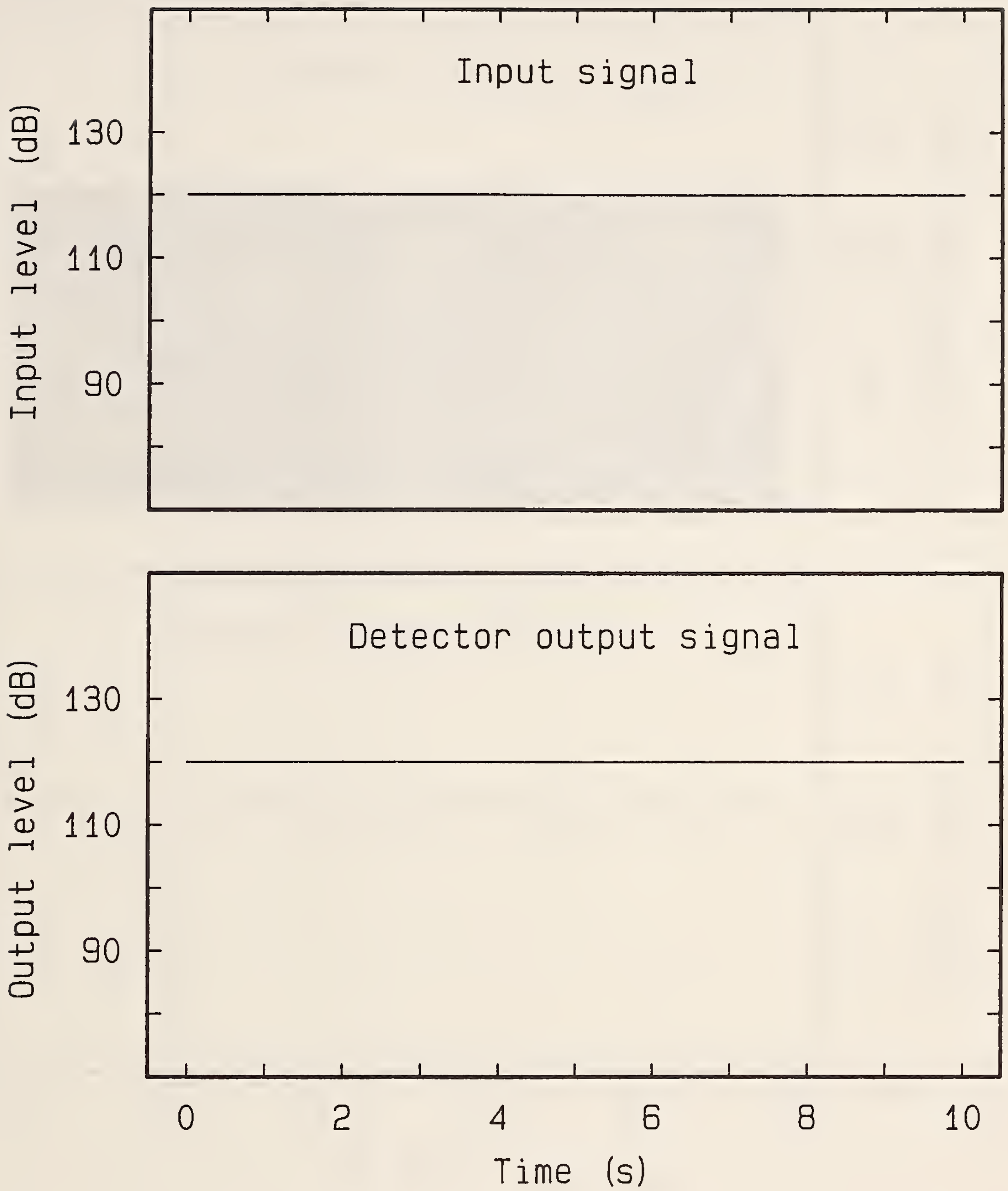

Figure 18. Electrical input (test) signal 1 (a continuous 1-kHz sine wave having a nominal crest factor of 3 dB), and the corresponding steady-state detector output of a theoretical dosimeter. (Input levels are voltage-level equivalents of sound pressure levels and output levels are theoretical equivalents of A-weighted sound levels.)

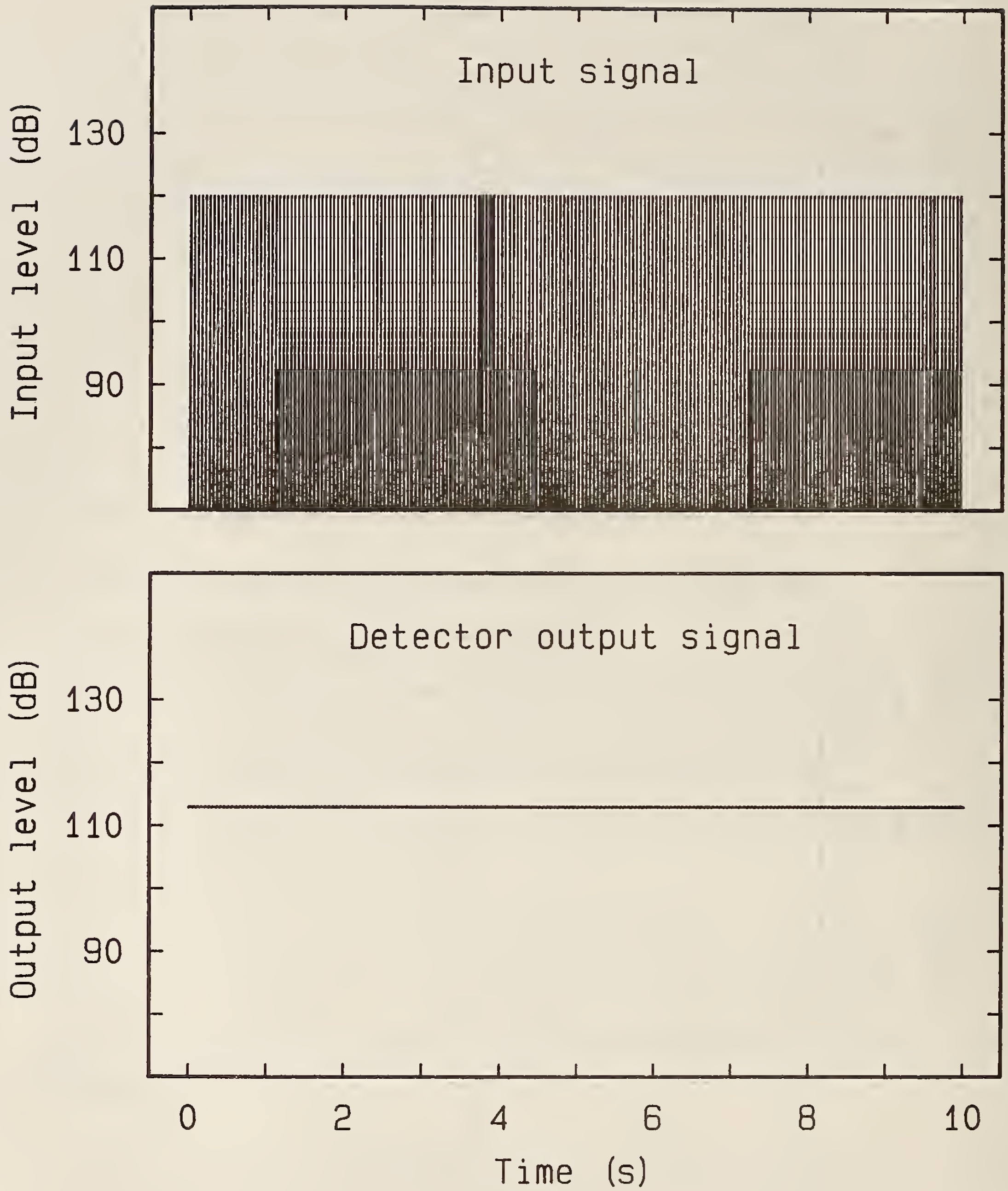

Figure 19. Electrical input (test) signal 2 (a 1-kHz sine wave gated to form a tone-burst sequence having a burst duration of 0.01 s, a repetition period of 0.05 s, and a nominal crest factor of 10 dB), and the corresponding steady-state detector output of a theoretical dosimeter. (Input levels are voltage-level equivalents of sound pressure levels and output levels are theoretical equivalents of A-weighted sound levels.)

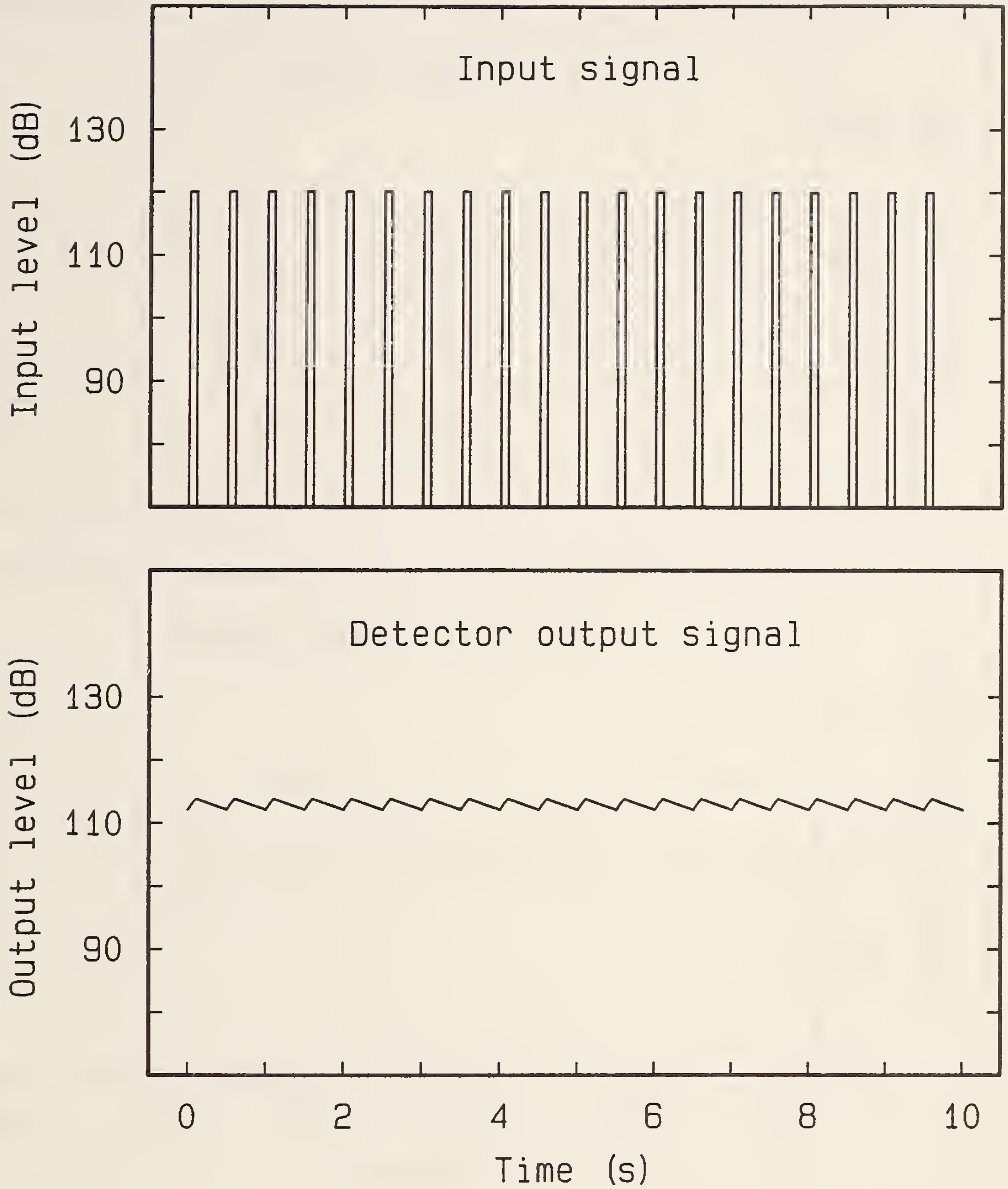

Figure 20. Electrical input (test) signal 3 (a 1-kHz sine wave gated to form a tone-burst sequence having a burst duration of 0.1 s, a repetition period of 0.5 s, and a nominal crest factor of 10 dB), and the corresponding steady-state detector output of a theoretical dosimeter. (Input levels are voltage-level equivalents of sound pressure levels and output levels are theoretical equivalents of A-weighted sound levels.)

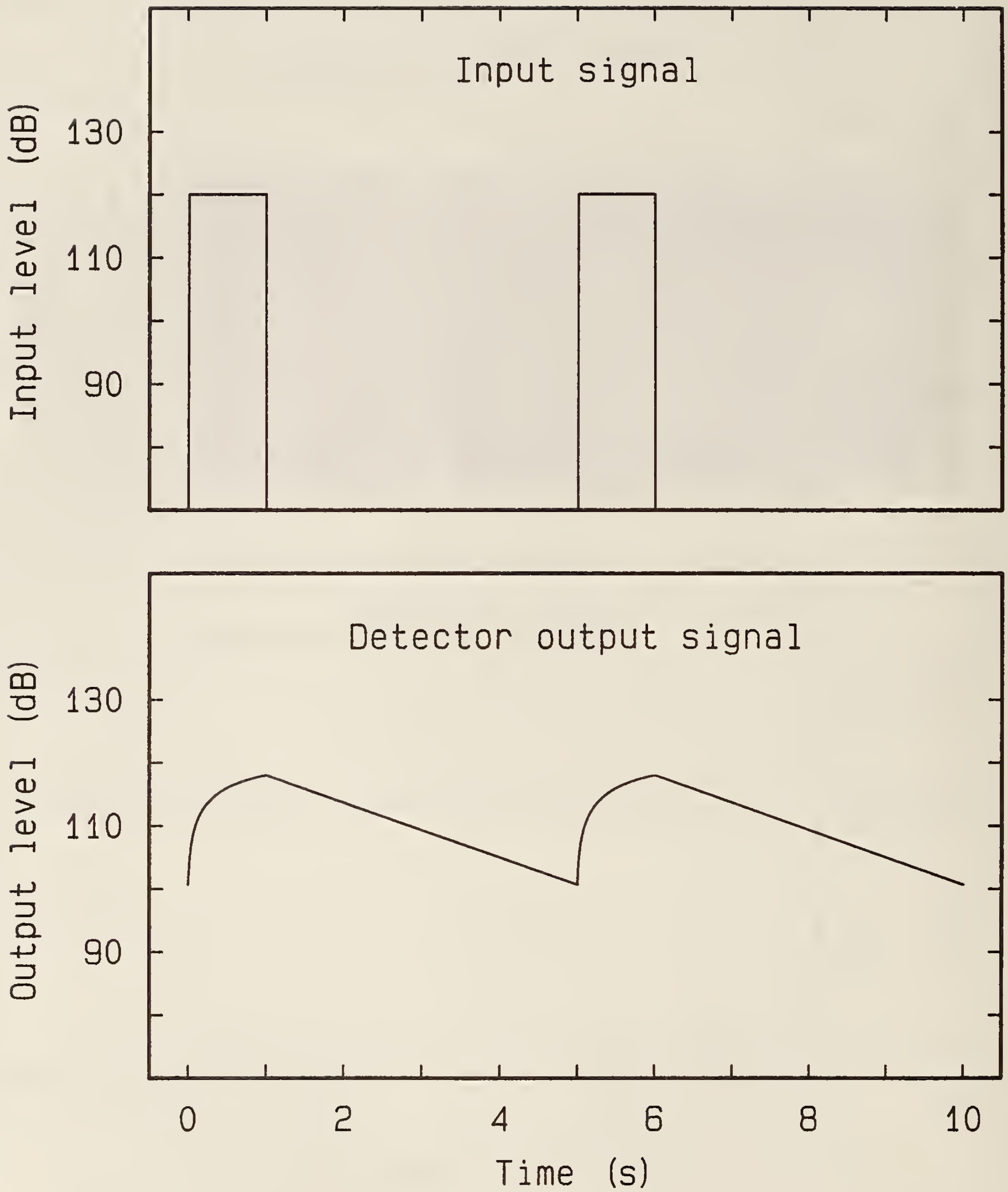

Figure 21. Electrical input (test) signal 4 (a 1-kHz sine wave gated to form a tone-burst sequence having a burst duration of 1.0 s, a repetition period of 5.0 s, and a nominal crest factor of 10 dB), and the corresponding steady-state detector output of a theoretical dosimeter. (Input levels are voltage-level equivalents of sound pressure levels and output levels are theoretical equivalents of A-weighted sound levels.)

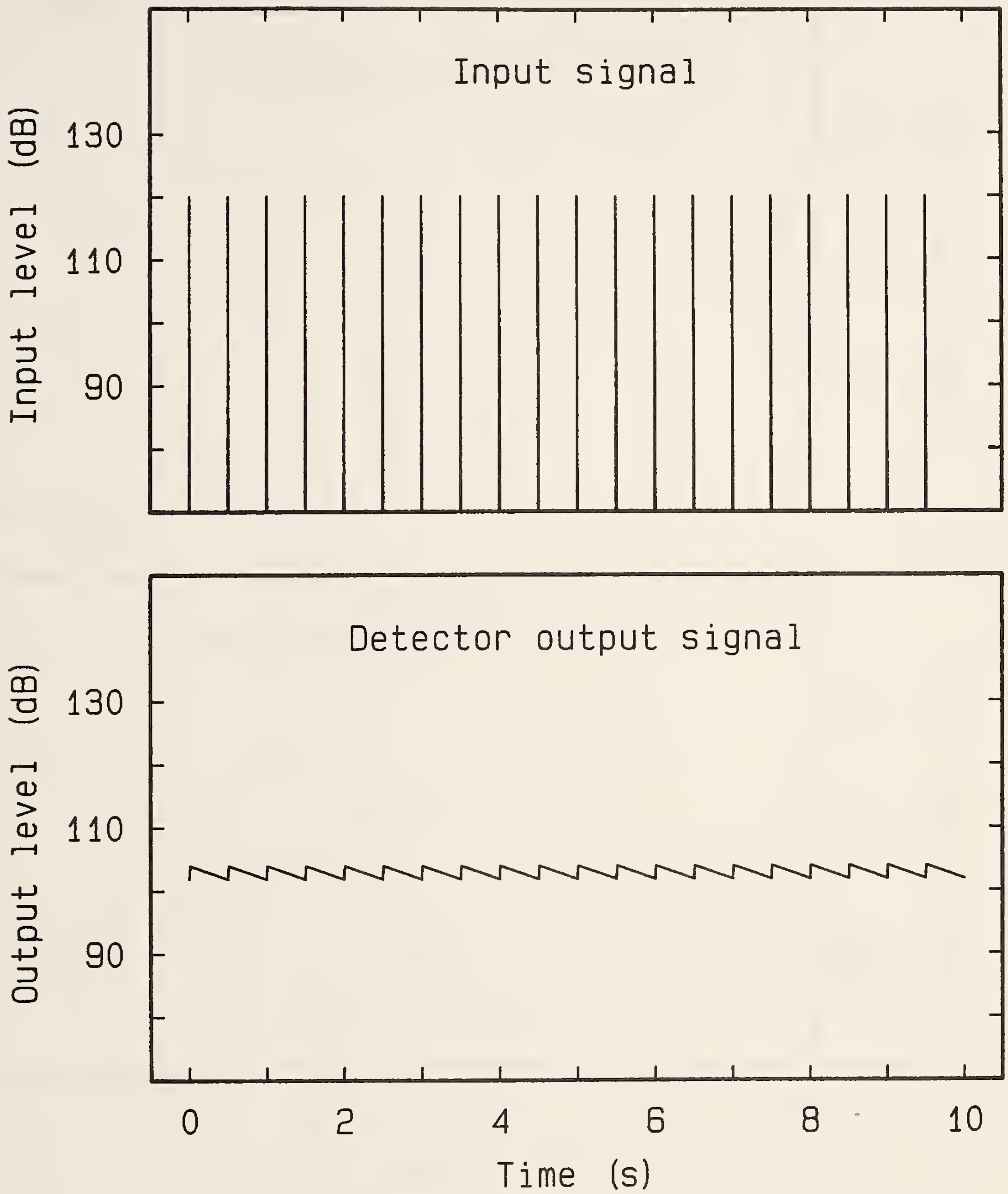

Figure 22. Electrical input (test) signal 5 (a 1-kHz sine wave gated to form a tone-burst sequence having a burst duration of 0.01 s, a repetition period of 0.50 s, and a nominal crest factor of 20 dB), and the corresponding steady-state detector output of a theoretical dosimeter. (Input levels are voltage-level equivalents of sound pressure levels and output levels are theoretical equivalents of A-weighted sound levels.)

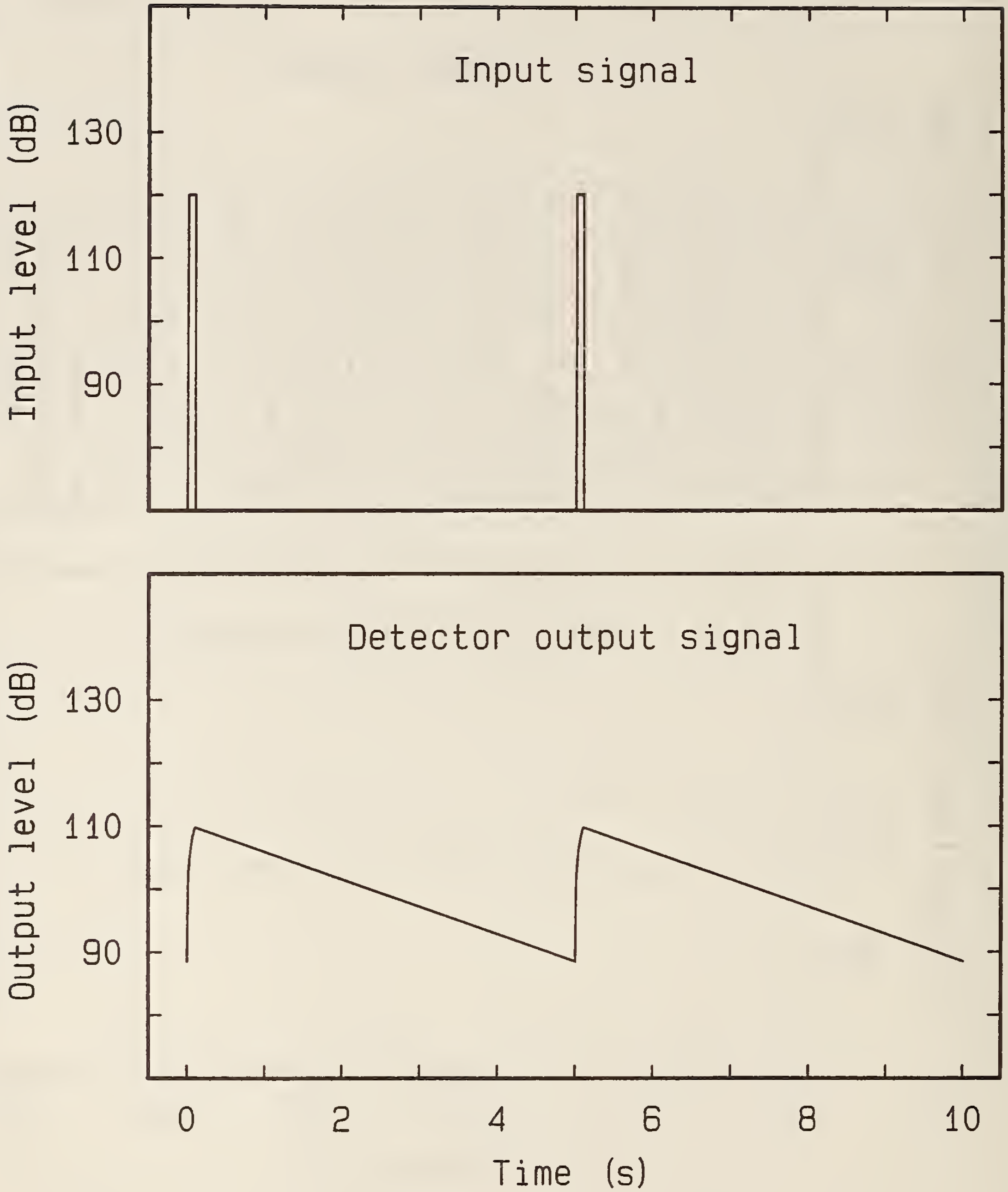

Figure 23. Electrical input (test) signal 6 (a 1-kHz sine wave gated to form a tone-burst sequence having a burst duration of 0.1 s, a repetion period of 5.0 s, and a nominal crest factor of 20 dB), and the corresponding steady-state detector output of a theoretical dosimeter. (Input levels are voltage-level equivalents of sound pressure levels and output levels are theoretical equivalents of A-weighted sound levels.)

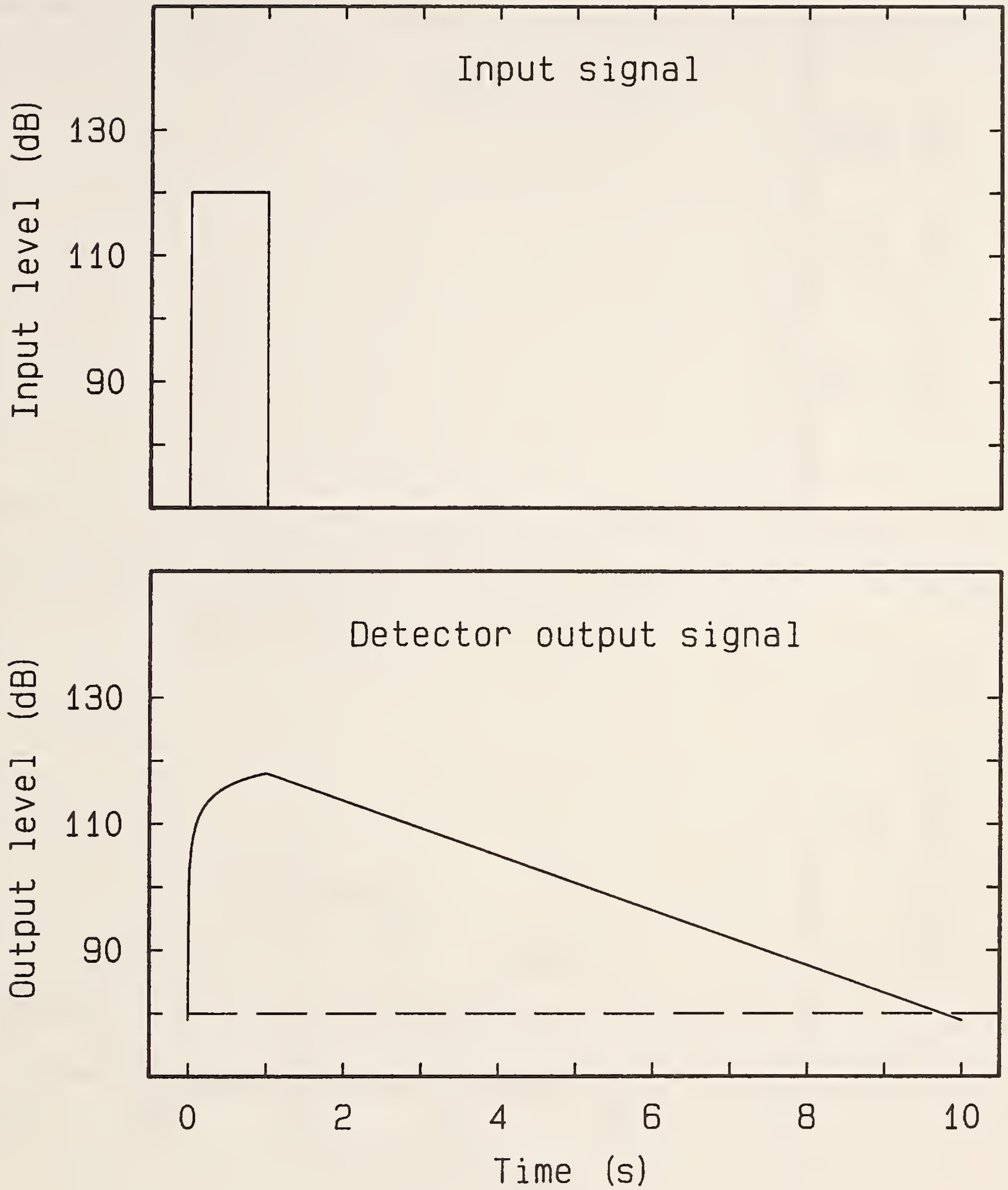

Figure 24. Electrical input (test) signal 7 (a 1-kHz sine wave gated to form a tone-burst sequence having a burst duration of 1.0 s, a repetition period of 50 s, and a nominal crest factor of 20 dB), and the corresponding steady-state detector output of a theoretical dosimeter. (The dashed line indicates the threshold sound level of 80 dB. Input levels are voltage-level equivalents of sound pressure levels and output levels are theoretical equivalents of A-weighted sound levels.)

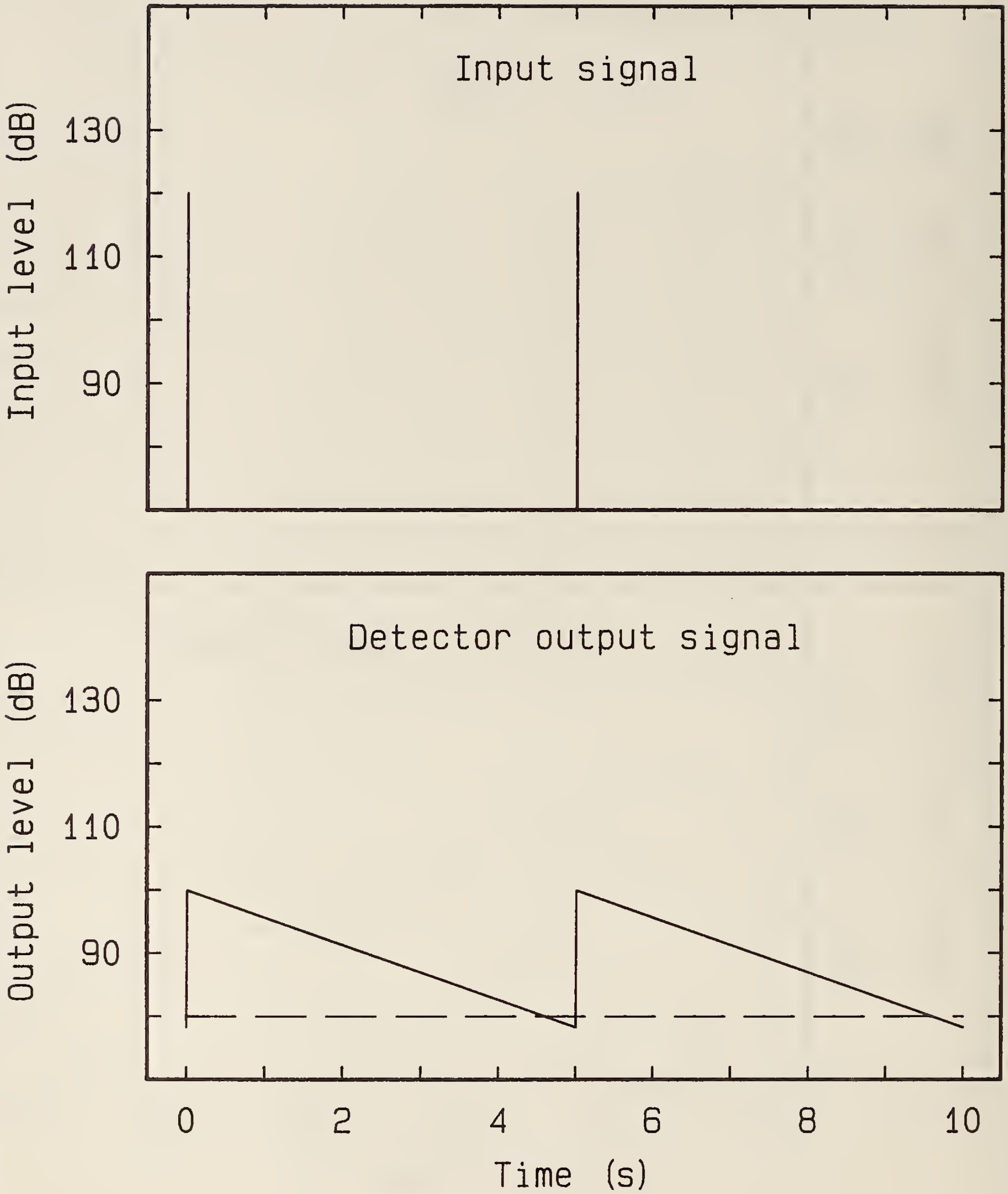

Figure 25. Electrical input (test) signal 8 (a 1-kHz sine wave gated to form a tone-burst sequence having a burst duration of 0.01 s, a repetition period of 5.0 s, and a nominal crest factor of 30 dB), and the corresponding steady-state detector output of a theoretical dosimeter. (The dashed line indicates the threshold sound level of 80 dB. Input levels are voltage-level equivalents of sound pressure levels and output levels are theoretical equivalents of A-weighted sound levels.)

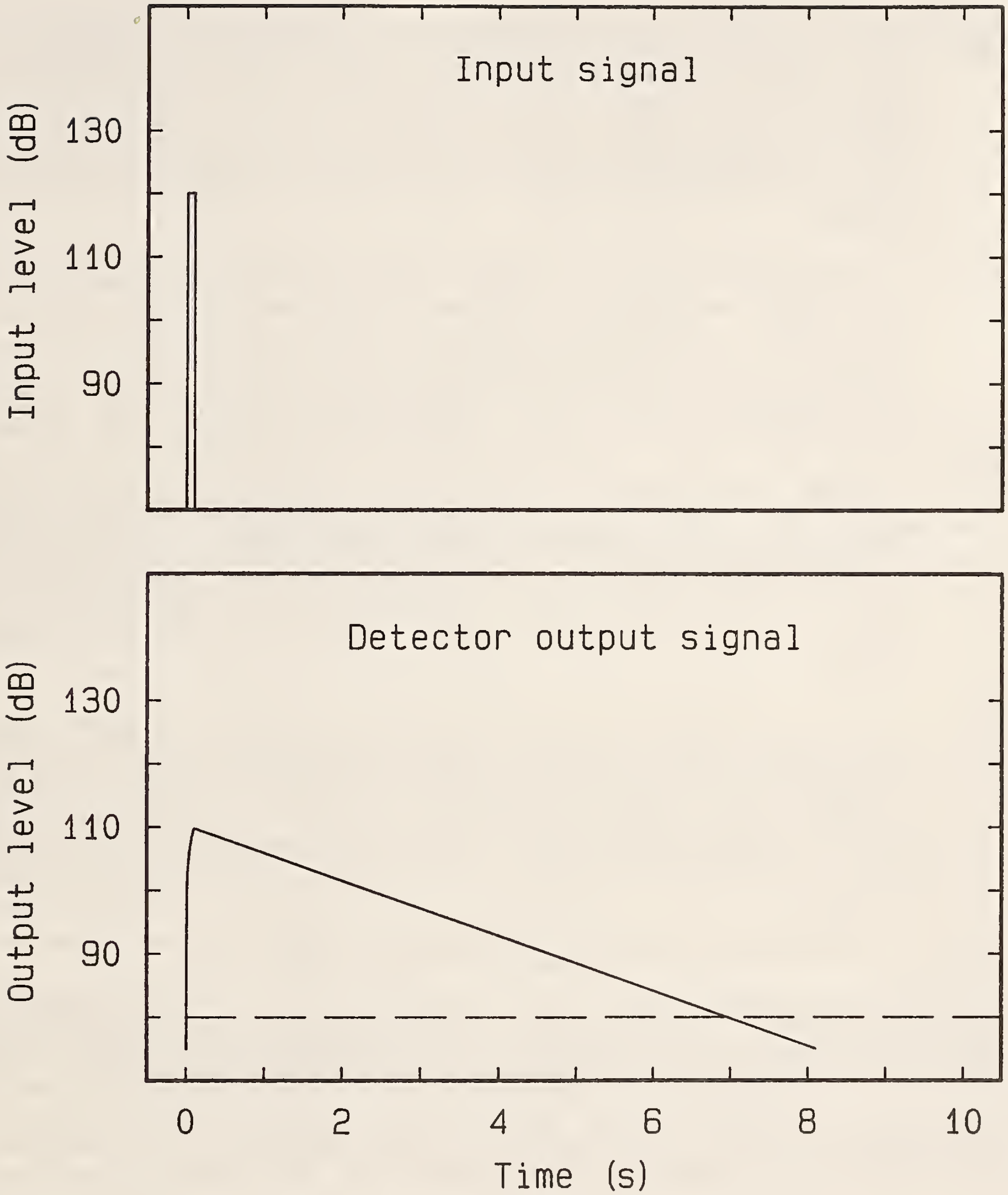

Figure 26. Electrical input (test) signal 9 (a 1-kHz sine wave gated to form a tone-burst sequence having a burst duration of 0.1 s, a repetition period of 50 s, and a nominal crest factor of 30 dB), and the corresponding steady-state detector output of a theoretical dosimeter. (The dashed line indicates the threshold sound level of 80 dB. Input levels are voltage-level equivalents of sound pressure levels and output levels are theoretical equivalents of A-weighted sound levels.)

Signal 6: A 1-kHz sine wave at a level of 120.0 dB that was gated to form a tone-burst sequence with the duration of each of the bursts equal to 0.10 s and the repetition period of the bursts equal to 5.0 s. The signal level during the time period (4.9 s) between each of the bursts was less than 65 dB. This constituted a periodic input signal with a fundamental period of 5.0 s and a nominal crest factor of 20 dB.

Signal 7: A 1-kHz sine wave at a level of 120.0 dB that was gated to form a tone-burst sequence with the duration of each of the bursts equal to 1.0 s and the repetition period of the bursts equal to 50 s. The signal level during the time period (49 s) between each of the bursts was less than 65 dB. This constituted a periodic input signal with a fundamental period of 50 s and a nominal crest factor of 20 dB.

Signal 8: A 1-kHz sine wave at a level of 120.0 dB that was gated to form a tone-burst sequence with the duration of each of the bursts equal to 0.010 s and the repetition period of the bursts equal to 5.0 s. The signal level during the time period (4.49 s) between each of the bursts was less than 65 dB. This constituted a periodic input signal with a fundamental period of 5.0 s and a nominal crest factor of 30 dB.

Signal 9: A 1-kHz sine wave at a level of 120.0 dB that was gated to form a tone-burst sequence with the duration of each of the bursts equal to 0.10 s and the repetition period of the bursts equal to 50 s. The signal level during the time period (49.9 s) between each of the bursts was less than 65 dB. This constituted a periodic input signal with a fundamental period of 50 s and a nominal crest factor of 30 dB.

The electrical tests using the signals described above were:

1. Test signal 1 for 0.1250 h using a 5-dB exchange rate, or 0.008000 h using a 3-dB exchange rate, resulting in a theoretical percentage criterion exposure of 100 percent for both 5-dB and 3-dB exchange rates.

2. Test signal 2 for 0.3364 h using a 5-dB exchange rate, resulting in a theoretical percentage criterion exposure of 101 percent.

3. Test signal 3 for 0.3325 h using a 5-dB exchange rate, resulting in a theoretical percentage criterion exposure of 101 percent.

4. Test signal 4 for 0.3700 h using a 5-dB exchange rate, resulting in a theoretical percentage criterion exposure of 100 percent.

5. Test signal 5 for 1.341 h using a 5-dB exchange rate, or 0.4103 h using a 3-dB exchange rate, resulting in a theoretical percentage criterion exposure of 101 percent for both 5-dB and 3-dB exchange rates.

6. Test signal 6 for 1.558 h using a 5-dB exchange rate, resulting in a theoretical percentage criterion exposure of 99 percent.

7. Test signal 7 for 3.490 h using a 5-dB exchange rate, or 0.4072 h using a

3-dB exchange rate, resulting in a theoretical percentage criterion exposure of 99 percent for a 5-dB exchange rate and 102 percent for a 3-dB exchange rate.

8. Test signal 8 for 6.405 h using a 5-dB exchange rate, resulting in a theoretical percentage criterion exposure of 99 percent.

9. Test signal 9 for 15.13 h using a 5-dB exchange rate, resulting in a theoretical percentage criterion exposure of 100 percent.

5.2.2 Experimental Procedure

The signal source system was as shown in Fig. 2 for the reference dosimeter and in Fig. 3 for the commercial dosimeters, except for the tests that employed a gated sine wave (during these tests, the frequency counter and the two digital multimeters were disconnected). (Note: the computer was connected to the measuring amplifier to evaluate the test signals when used as part of the reference dosimeter, and was connected to the function generator to time the measurement durations when the commercial dosimeter tests were performed.)

5.2.2.1 Laboratory Reference Noise Dosimeter Experimental Procedure

Eight-hour percentage criterion exposures were obtained for all of the signals measured by the reference dosimeter employing both 5-dB and 3-dB exchange rates. Each test signal was measured twice, with the 8-h percentage criterion exposure corresponding to the first set of data evaluated using an exchange rate of 5 dB, and with the 8-h percentage criterion exposure corresponding to the second set of data evaluated using an exchange rate of 3 dB. In all cases, the percentage criterion exposures, evaluated from measurement results obtained using the reference dosimeter, are based on a threshold sound level of 80 dB.

Prior to applying the sets of tone-burst sequence test signals to the reference dosimeter, a 1 V rms continuous sine wave of either 1 kHz or 100 Hz was maintained at the input of the attenuator and reduced by 20 dB at the output of the attenuator. The frequency of the continuous sine wave applied to the input of the attenuator depended upon the set of tone-burst-sequence test signals that was to be used. This level (-20 dB re 1 V rms at the input of the reference dosimeter) was defined in the reference dosimeter computer to be 120.0 dB when the frequency of the sine wave was 1 kHz, and an A-weighted sound level of 100.86 dB when the frequency of the sine wave was 100 Hz. These A-weighted levels kept the A-weighted sensitivity of the reference dosimeter the same as in the preliminary electrical tests where -50 dB re 1 V rms was defined to be 90.0 dB (SPL re 20 μPa) at 1 kHz. During the tone-burst sequences, the equivalent unweighted sound pressure level at the input of the reference dosimeter was 120 dB during the tone bursts and less than 65 dB (residual noise level of the signal source) during the time interval between tone bursts. Both sets of test signals (the tone-burst sequences comprised of counted bursts of a 100-Hz sine wave, and the tone-burst sequences comprised of counted bursts of a 1-kHz sine wave) were measured using a slow exponential averaging time constant.

The following is a detailed description of the application (to the reference dosimeter) of test signals 1 through 9, described in Sec. 5.2.1.2 above. In the case of the test signals for which a detailed description of signal application has been omitted, the test signals were applied to the reference dosimeter in a manner similar to that given below, i.e., (1) the level of the sine wave comprising the tone bursts at the input of the reference dosimeter was equivalent to an unweighted rms sound pressure level of 120 dB re 20 μPa, (2) the burst duration and repetition period were varied as needed to obtain the desired tone-burst sequence parameters, and (3) the test signal was sampled for a time period that was an integral multiple of the fundamental (repetition) period of the tone-burst sequence. As was the case in the preliminary electrical test signals, each of the test signals was applied to the reference dosimeter for a minimum of 20 s prior to sampling the output of the detector in order to allow the detector to approach a steady-state condition of response.

In all of the tests described below, the exponential averaging time constant of the reference dosimeter was slow and the frequency of the test signal sine wave (continuous or gated) was 1 kHz. (Note: for clarity the second measurement of each of the signals [from which the 8-h percentage criterion exposure for the 3-dB exchange rate was evaluated] has been omitted from the signal application descriptions which follow when the evaluation of the test signal using a 3-dB exchange rate was not included as part of the series of tests performed using the commercial dosimeters.)

Initially, a continuous 1-kHz sine wave at a level of -20 dB re 1 V rms was applied to the reference dosimeter and defined to be the equivalent of 120.0 dB (A-weighted sound level) in the reference dosimeter computer program. The reference dosimeter sampled this signal for a period of 1 s two separate times and evaluated an 8-h percentage criterion exposure for each of the measurements.

The function generator was then set to provide a sequence of counted bursts of 10 cycles each (0.010 s burst duration) with a fundamental (repetition) period of 0.050 s. As was the case in the other tests, the attenuator remained fixed at the reference setting so that the voltage at the input of the reference dosimeter during each of the bursts was equivalent to 120.0 dB (SPL) and, during the intervals between bursts, was the residual noise of the test system. The reference dosimeter sampled this sequence of tone bursts for a period of 1 s and evaluated an 8-h percentage criterion exposure for the measurement.

With the number of cycles in the burst remaining fixed at 10 (0.010 s burst duration), the function generator was set to provide a fundamental (repetition) period of 0.50 s. The reference dosimeter sampled this sequence of tone bursts twice for a period of 1 s each time and evaluated an 8-h percentage criterion exposure for the measurements using a 5-dB and 3-dB exchange rate.

Again with the burst duration remaining fixed at 0.010 s, the function generator was set to provide a fundamental period of 5.0 s. The reference dosimeter sampled this sequence for a period of 10 s and evaluated an 8-h percentage criterion exposure for the measurement, using a 5-dB exchange rate.

The function generator was then set to provide a sequence of counted bursts of 100 cycles each (0.10 s burst duration) with a fundamental (repetition) period of either 0.50, 5.0, or 50 s. The reference dosimeter sampled these tone-burst sequences for 1, 10, or 100 s, respectively, and evaluated an 8-h percentage exposure criterion using a 5-dB exchange rate for each of the test signals.

The function generator was then set to provide a sequence of counted bursts of 1000 cycles each (1.0 s burst duration) with a fundamental (repetition) period of 5.0 s. The reference dosimeter sampled this signal for a period of 10 s and evaluated an 8-h percentage criterion exposure for the measurement, using a 5-dB exchange rate.

With the burst duration remaining fixed at 1.0 s, the function generator was set to provide a fundamental (repetition) period of 50 s. The reference dosimeter sampled this signal twice for a period of 100 s each time and evaluated an 8-h percentage criterion exposure for the measurements using a 5-dB and 3-dB exchange rate.

5.2.2.2 Commercial Dosimeter Experimental Procedure

The electrical tests described in Sec. 5.2.1.2 were performed using commercial dosimeters 1 through 7 (those dosimeters selected for additional testing after the completion of the preliminary electrical tests). The microphones and associated cable of the dosimeters were removed and the dosimeters were calibrated using the procedures described in Secs. 4.2.1 and 4.3.1. The dosimeters were tested in both the 5-dB and 3-dB exchange rate modes, providing the instrument had the capability of selecting the exchange rate used to compute the percentage criterion exposure; otherwise the dosimeters were used only in those tests in which the exchange rate of the test agreed with the exchange rate of the instrument as it was received at NIST. Four of the seven instruments tested (dosimeters 2, 3, 5, and 6) had the capability of selecting the exchange rate used by the dosimeter to compute percentage criterion exposure. For these units, the 5-dB exchange rate tests were performed, the exchange rate of the dosimeter under test was changed to 3 dB, and then the 3-dB exchange rate tests were performed. For the three remaining dosimeters, the 5-dB exchange rate tests were performed using dosimeters 1 and 4, and the 3-dB exchange rate tests were performed using dosimeter 7. A threshold sound level of 80 dB was used to determine percentage-exposure-criterion values. The signal source instrumentation during the tests was the same as that indicated in Fig. 2 except that during tests employing a gated sine wave (signals 2 through 9), the frequency counter and the two digital multimeters were disconnected. The computer was connected to the function generator to time the tests and to turn the generator output "on" at the beginning, and "off" at the end, of each test. Each dosimeter was set to display percentage criterion exposure and the display reading was recorded at the completion of each of the measurement (test) durations.

5.2.3 Results

Theoretical 8-h percentage criterion exposure values were calculated for tone-burst sequences having the parameters shown in Fig. 17 and Table 6, using both 5-dB and 3-dB exchange rates with a threshold sound level of 80 dB (SPL). Theoretical exposure values were obtained, utilizing formulae given in Appendix B, for sequences of tone bursts that were comprised of either a 1-kHz or a 100-Hz sine wave at a level defined to be 120 dB (SPL). Equivalent levels were also obtained. (For purposes of analyzing these theoretical results, equivalent levels based on a threshold sound level of 20 dB (SPL) were determined as well and appear in Sec. 6.) For those cases in which the tone-burst sequences were measured by the reference dosimeter, the percentage-criterion-exposure results obtained using the reference dosimeter were expressed relative to the theoretical exposure values (see formula A5 given in Appendix A). The number of digits used to perform the relative response calculations was five, in the case of the theoretical values, and four, in the case of the reference dosimeter values. The results of these calculations are given in Tables 7 through 16, and are grouped according to the crest factor of the signal (tone-burst sequence) and the frequency of the sine wave comprising the tone bursts.

Plots of the difference between synchronized samples of the output of the detector of the reference dosimeter, and the theoretical detector output of a dosimeter conforming to the specifications given in ANSI S1.25-1978, are shown in Figs. 27 through 35 for electrical test signals 1 through 9 (the test signals that were used in the electrical tests of the commercial dosimeters employing signals having moderate-to-high crest factors). The level differences correspond to the reference-dosimeter measurement results, from which the 8-h percentage criterion exposures were calculated using a 5-dB exchange rate, referenced to the theoretical detected output levels for the test signals. (Note: the difference between a measured and theoretical result was not plotted if the theoretical detector output level was less than 75 dB, i.e., more than 5 dB below the 80-dB threshold sound level that was used in determining a percentage criterion exposure value corresponding to the test signal [see Figs. 33 and 35].) Below each of the difference plots appear corresponding plots of the theoretical detected output levels for the length of time that the reference dosimeter sampled the test signals (the values used, in these plots, for the theoretical detected output levels and difference calculations were the same as those used in the detector output plots that appear in the description of the test signals). For those cases in which the detector output varied with time, i.e., for the cases in which the test signal was a sine wave that was gated to form a tone-burst sequence, the theoretical detector output plots begin 10 ms (one data point) prior to the point that the slope of the theoretical detected output becomes positive, or at 75 dB [Figs. 33 and 35], whichever level was greater. In general, the measurements made by the reference dosimeter began at an arbitrary point on these time-varying theoretical detector output curves. The time-varying detected outputs, those measured by the reference dosimeter and those calculated for a dosimeter conforming to ANSI S1.25-1978, were synchronized in time (±5 ms) as follows. Since the measured detector output levels were obtained at intervals of 10 ms and the theoretical detector output levels were calculated at intervals of 10 ms, the total number of measured and calculated data points were equal for any given interval of time. The measured data points were synchronized with the beginning of the calculated data at the first data point in the sample period that the measured output of the detector of the reference dosimeter changed from a negative to a positive slope. The measured data that were obtained prior to the point of synchronization were appended to the end of the measured data as though the data were obtained contiguously.

A theoretical percentage criterion exposure value was calculated, for each of the electrical tests of the commercial dosimeters that were performed using electrical test signals 1 through 9, utilizing formulae given in Appendix A, in the case of the test signal composed of a continuous sine wave, and Appendix B, in the case of those test signals composed of a gated sine wave. The 8-h

Table 7. Theoretical percentage criterion exposures and equivalent levels for the tone-burst sequences having a nominal crest factor of 4.8 dB that were used in the electrical tests involving signals of moderate-to-high crest factor with the frequency of the sine wave comprising the tone bursts equal to 1 kHz at a level of 120 dB and the threshold sound level of the mathematical-model dosimeter equal to 80 dB.[a]

Burst Duration (s)	Theory				Reference Dosimeter re Theoretical Equivalent Level[d] (dB)	
	8-h PCE[b] (%)		Equivalent Level[c] (dB)			
	Exchange Rate (dB)					
	5	3	5	3	5	3
0.010	4966	65610	118.2	118.2	-0.1	-0.1
0.020	4990	66140	118.2	118.2	0.0	0.0
0.050	5004	66450	118.2	118.2	0.0	0.0
0.10	5009	66560	118.2	118.2	-0.1	-0.1
0.20	5011	66610	118.2	118.2	-0.1	-0.1
0.50	5010	66650	118.2	118.2	-0.1	-0.1
1.0	5001	66660	118.2	118.2	-0.1	-0.1
2.0	4969	66660	118.2	118.2	...[e]	...
5.0	4829	66670	118.0	118.2	...	...
10	4642	66670	117.7	118.2	...	...

[a] Only the signals having burst durations of 1 s or less were applied to the reference dosimeter.

[b] Calculated from a numerical integration of the rms detector output of the mathematical model dosimeter performed over a single repetition period for each of the tone-burst sequences and extrapolated to 8 h.

[c] The equivalent level, to the nearest tenth of a decibel, of the corresponding 8-h percentage criterion exposure when expressed to five significant figures (see Appendix A for the formula used to perform the calculation).

[d] For those cases in which the percentage criterion exposures corresponding to the test signals were measured, the 8-h percentage criterion exposure results obtained using the reference dosimeter have been expressed relative to the theoretical 8-h percentage criterion exposures using the formula given in Appendix A for computing, in a simplified form, the difference between the equivalent levels of a test signal based on exposure values obtained from measurement results and those obtained from theoretical calculations. The number of significant figures in the percentage criterion exposures used to perform the calculations was four, in the case of the reference dosimeter values, and five, in the case of the theoretical values.

[e] "..." indicates that a measurement result was not obtained for the test signal using the reference dosimeter.

Table 8. Theoretical percentage criterion exposures and equivalent levels for the tone-burst sequences having a nominal crest factor of 6 dB that were used in the electrical tests involving signals of moderate-to-high crest factor with the frequency of the sine wave comprising the tone bursts equal to 1 kHz at a level of 120 dB and the threshold sound level of the mathematical-model dosimeter equal to 80 dB.[a]

Burst Duration (s)	Theory: 8-h PCE[b] (%)		Theory: Equivalent Level[c] (dB)		Reference Dosimeter re Theoretical Equivalent Level[d] (dB)	
	Exchange Rate (dB)					
	5	3	5	3	5	3
0.010	4176	49210	116.9	116.9	−0.1	−0.1
0.020	4196	49600	117.0	117.0	−0.1	−0.1
0.050	4208	49840	117.0	117.0	−0.1	−0.1
0.10	4208	49920	117.0	117.0	0.0	0.0
0.20	4213	49960	117.0	117.0	−0.1	−0.1
0.50	4205	49980	117.0	117.0	0.0	−0.1
1.0	4176	49990	116.9	117.0	0.0	−0.1
2.0	4079	50000	116.8	117.0	...[e]	...
5.0	3762	50000	116.2	117.0	...	...
10	3504	50000	115.7	117.2	...	...

[a] Only the signals having burst durations of 1 s or less were applied to the reference dosimeter.

[b] Calculated from a numerical integration of the rms detector output of the mathematical model dosimeter performed over a single repetition period for each of the tone-burst sequences and extrapolated to 8 h.

[c] The equivalent level, to the nearest tenth of a decibel, of the corresponding 8-h percentage criterion exposure when expressed to five significant figures (see Appendix A for the formula used to perform the calculation).

[d] For those cases in which the percentage criterion exposures corresponding to the test signals were measured, the 8-h percentage criterion exposure results obtained using the reference dosimeter have been expressed relative to the theoretical 8-h percentage criterion exposures using the formula given in Appendix A for computing, in a simplified form, the difference between the equivalent levels of a test signal based on exposure values obtained from measurement results and those obtained from theoretical calculations. The number of significant figures in the percentage criterion exposures used to perform the calculations was four, in the case of the reference dosimeter values, and five, in the case of the theoretical values.

[e] "..." indicates that a measurement result was not obtained for the test signal using the reference dosimeter.

Table 9. Theoretical percentage criterion exposures and equivalent levels for the tone-burst sequences having a nominal crest factor of 10 dB that were used in the electrical tests involving signals of moderate-to-high crest factor with the frequency of the sine wave comprising the tone bursts equal to 1 kHz at a level of 120 dB and the threshold sound level of the mathematical-model dosimeter equal to 80 dB.[a]

Burst Duration (s)	Theory				Reference Dosimeter re Theoretical Equivalent Level[d] (dB)	
	8-h PCE[b] (%)		Equivalent Level[c] (dB)			
	Exchange Rate (dB)					
	5	3	5	3	5	3
.010	2405	19680	112.9	112.9	−0.1	−0.1
.020	2417	19840	113.0	113.0	−0.1	−0.1
.050	2423	19940	113.0	113.0	−0.1	−0.1
.10	2422	19970	113.0	113.0	0.0	−0.1
.20	2412	19980	113.0	113.0	0.0	−0.1
.50	2341	19990	112.7	113.0	0.0	0.0
1.0	2157	20000	112.2	113.0	0.0	0.0
2.0	1848	20000	111.0	113.0	...[e]	...
5.0	1522	20000	109.6	113.0	...	...
10	1401	20000	109.0	113.0	...	...

[a] Only the signals having burst durations of 1 s or less were applied to the reference dosimeter.

[b] Calculated from a numerical integration of the rms detector output of the mathematical model dosimeter performed over a single repetition period for each of the tone-burst sequences and extrapolated to 8 h.

[c] The equivalent level, to the nearest tenth of a decibel, of the corresponding 8-h percentage criterion exposure when expressed to five significant figures (see Appendix A for the formula used to perform the calculation).

[d] For those cases in which the percentage criterion exposures corresponding to the test signals were measured, the 8-h percentage criterion exposure results obtained using the reference dosimeter have been expressed relative to the theoretical 8-h percentage criterion exposures using the formula given in Appendix A for computing, in a simplified form, the difference between the equivalent levels of a test signal based on exposure values obtained from measurement results and those obtained from theoretical calculations. The number of significant figures in the percentage criterion exposures used to perform the calculations was four, in the case of the reference dosimeter values, and five, in the case of the theoretical values.

[e] "..." indicates that a measurement result was not obtained for the test signal using the reference dosimeter.

Table 10. Theoretical percentage criterion exposures and equivalent levels for the tone-burst sequences having a nominal crest factor of 20 dB that were used in the electrical tests involving signals of moderate-to-high crest factor with the frequency of the sine wave comprising the tone bursts equal to 1 kHz at a level of 120 dB and the threshold sound level of the mathematical-model dosimeter equal to 80 dB.[a]

Burst Duration (s)	Theory				Reference Dosimeter re Theoretical Equivalent Level[d] (dB)	
	8-h PCE[b] (%)		Equivalent Level[c] (dB)			
	Exchange Rate (dB)					
	5	3	5	3	5	3
.010	599.9	1968	102.9	102.9	0.0	0.0
.020	598.6	1984	102.9	103.0	0.0	0.0
.050	573.8	1994	102.6	103.0	0.0	0.0
.10	510.2	1997	101.8	103.0	0.0	0.0
.20	405.1	1998	100.1	103.0	0.1	−0.1
.50	288.9	1999	97.7	103.0	0.0	−0.1
1.0	227.7	2000	95.9	103.0	0.0	−0.1
2.0	185.1	2000	94.4	103.0	...[e]	...
5.0	152.2	2000	93.0	103.0	...	...
10	140.1	2000	92.4	103.0	...	...

[a] Only the signals having burst durations of 1 s or less were applied to the reference dosimeter.

[b] Calculated from a numerical integration of the rms detector output of the mathematical model dosimeter performed over a single repetition period for each of the tone-burst sequences and extrapolated to 8 h.

[c] The equivalent level, to the nearest tenth of a decibel, of the corresponding 8-h percentage criterion exposure when expressed to five significant figures (see Appendix A for the formula used to perform the calculation).

[d] For those cases in which the percentage criterion exposures corresponding to the test signals were measured, the 8-h percentage criterion exposure results obtained using the reference dosimeter have been expressed relative to the theoretical 8-h percentage criterion exposures using the formula given in Appendix A for computing, in a simplified form, the difference between the equivalent levels of a test signal based on exposure values obtained from measurement results and those obtained from theoretical calculations. The number of significant figures in the percentage criterion exposures used to perform the calculations was four, in the case of the reference dosimeter values, and five, in the case of the theoretical values.

[e] "..." indicates that a measurement result was not obtained for the test signal using the reference dosimeter.

Table 11. Theoretical percentage criterion exposures and equivalent levels for the tone-burst sequences having a nominal crest factor of 30 dB that were used in the electrical tests involving signals of moderate-to-high crest factor with the frequency of the sine wave comprising the tone bursts equal to 1 kHz at a level of 120 dB and the threshold sound level of the mathematical-model dosimeter equal to 80 dB.

Burst Duration (s)	Theory				Reference Dosimeter re Theoretical Equivalent Level[c] (dB)	
	8-h PCE[a] (%)		Equivalent Level[b] (dB)			
	Exchange Rate (dB)					
	5	3	5	3	5	3
0.010	123.9	196.2	91.5	92.9	0.1	−0.1
0.020	96.36	197.4	89.7	93.0	0.0	−0.1
0.050	68.50	199.0	87.3	93.0	0.0	−0.1
0.10	52.67	199.5	85.4	93.0	0.0	−0.1
0.20	40.51	199.7	83.5	93.0	0.0	−0.1
0.50	28.89	199.9	81.0	93.0	0.0	−0.1
1.0	22.77	200.0	79.3	93.0	0.0	−0.1

[a] Calculated from a numerical integration of the rms detector output of the mathematical model dosimeter performed over a single repetition period for each of the tone-burst sequences and extrapolated to 8 h.

[b] The equivalent level, to the nearest tenth of a decibel, of the corresponding 8-h percentage criterion exposure when expressed to five significant figures (see Appendix A for the formula used to perform the calculation).

[c] The 8-h percentage criterion exposure results obtained using the reference dosimeter have been expressed relative to the theoretical 8-h percentage criterion exposures using the formula given in Appendix A for computing, in a simplified form, the difference between the equivalent levels of a test signal based on exposure values obtained from measurement results and those obtained from theoretical calculations. The number of significant figures in the percentage criterion exposures used to perform the calculations was four, in the case of the reference dosimeter values, and five, in the case of the theoretical values.

Table 12. Theoretical percentage criterion exposures and equivalent levels for the tone-burst sequences having a nominal crest factor of 4.8 dB that were used in the electrical tests involving signals of moderate-to-high crest factor with the frequency of the sine wave comprising the tone bursts equal to 100 Hz at a level of 120 dB and the threshold sound level of the mathematical-model dosimeter equal to 80 dB.

Burst Duration (s)	Theory				Reference Dosimeter re Theoretical Equivalent Level[c] (dB)	
	8-h PCE[a] (%)		Equivalent Level[b] (dB)			
	Exchange Rate (dB)					
	5	3	5	3	5	3
0.010	376.6	904.6	99.6	99.6	−0.1	−0.1
0.020	365.6	861.3	99.4	99.4	0.0	0.0
0.050	358.0	831.8	99.2	99.2	0.0	0.0
0.10	355.4	822.1	99.1	99.1	0.0	0.0
0.20	354.2	817.0	99.1	99.1	0.0	0.0
0.50	353.2	814.1	99.1	99.1	0.0	0.0
1.0	352.3	813.2	99.1	99.1	0.0	0.0
2.0	349.9	812.6	99.0	99.1	0.0	0.0
5.0	340.0	812.4	98.8	99.1	−0.1	−0.1
10	326.5	812.2	98.5	99.1	0.1	0.0

[a] Calculated from a numerical integration of the rms detector output of the mathematical model dosimeter performed over a single repetition period for each of the tone-burst sequences and extrapolated to 8 h.

[b] The equivalent level, to the nearest tenth of a decibel, of the corresponding 8-h percentage criterion exposure when expressed to five significant figures (see Appendix A for the formula used to perform the calculation).

[c] The 8-h percentage criterion exposure results obtained using the reference dosimeter have been expressed relative to the theoretical 8-h percentage criterion exposures using the formula given in Appendix A for computing, in a simplified form, the difference between the equivalent levels of a test signal based on exposure values obtained from measurement results and those obtained from theoretical calculations. The number of significant figures in the percentage criterion exposures used to perform the calculations was four, in the case of the reference dosimeter values, and five, in the case of the theoretical values.

Table 13. Theoretical percentage criterion exposures and equivalent levels for the tone-burst sequences having a nominal crest factor of 6 dB that were used in the electrical tests involving signals of moderate-to-high crest factor with the frequency of the sine wave comprising the tone bursts equal to 100 Hz at a level of 120 dB and the threshold sound level of the mathematical-model dosimeter equal to 80 dB.

Burst Duration (s)	Theory				Reference Dosimeter re Theoretical Equivalent Level[c] (dB)	
	8-h PCE[a] (%)		Equivalent Level[b] (dB)			
	Exchange Rate (dB)					
	5	3	5	3	5	3
0.010	317.9	682.8	98.3	98.3	0.0	0.0
0.020	307.5	646.0	98.1	98.1	0.0	0.0
0.050	301.1	623.9	98.0	98.0	0.0	0.0
0.10	298.9	616.5	97.9	97.9	0.0	0.0
0.20	297.8	612.8	97.9	97.9	0.0	0.0
0.50	296.6	610.6	97.8	97.9	0.0	0.0
1.0	294.2	609.9	97.8	97.9	0.1	0.0
2.0	287.2	609.5	97.6	97.8	0.1	0.0
5.0	264.4	609.1	97.0	97.8	0.1	0.0
10	244.7	608.6	96.5	97.8	0.1	0.0

[a] Calculated from a numerical integration of the rms detector output of the mathematical model dosimeter performed over a single repetition period for each of the tone-burst sequences and extrapolated to 8 h.

[b] The equivalent level, to the nearest tenth of a decibel, of the corresponding 8-h percentage criterion exposure when expressed to five significant figures (see Appendix A for the formula used to perform the calculation).

[c] The 8-h percentage criterion exposure results obtained using the reference dosimeter have been expressed relative to the theoretical 8-h percentage criterion exposures using the formula given in Appendix A for computing, in a simplified form, the difference between the equivalent levels of a test signal based on exposure values obtained from measurement results and those obtained from theoretical calculations. The number of significant figures in the percentage criterion exposures used to perform the calculations was four, in the case of the reference dosimeter values, and five, in the case of the theoretical values.

Table 14. Theoretical percentage criterion exposures and equivalent levels for the tone-burst sequences having a nominal crest factor of 10 dB that were used in the electrical tests involving signals of moderate-to-high crest factor with the frequency of the sine wave comprising the tone bursts equal to 100 Hz at a level of 120 dB and the threshold sound level of the mathematical-model dosimeter equal to 80 dB.

Burst Duration (s)	Theory				Reference Dosimeter re Theoretical Equivalent Level[c] (dB)	
	8-h PCE[a] (%)		Equivalent Level[b] (dB)			
	Exchange Rate (dB)					
	5	3	5	3	5	3
0.010	183.1	273.1	94.4	94.4	0.0	0.0
0.020	177.1	258.4	94.1	94.1	0.0	0.0
0.050	173.4	249.5	94.0	94.0	0.0	0.0
0.10	171.9	246.6	93.9	93.9	0.0	0.1
0.20	170.5	245.1	93.8	93.9	0.0	0.0
0.50	165.0	244.2	93.6	93.9	0.1	0.0
1.0	152.0	243.9	93.0	93.9	0.1	0.0
2.0	126.5	242.8	91.7	93.9	0.1	0.0
5.0	105.6	243.3	90.4	93.9	0.1	0.0
10	97.88	243.5	89.8	93.9	0.1	0.0

[a] Calculated from a numerical integration of the rms detector output of the mathematical model dosimeter performed over a single repetition period for each of the tone-burst sequences and extrapolated to 8 h.

[b] The equivalent level, to the nearest tenth of a decibel, of the corresponding 8-h percentage criterion exposure when expressed to five significant figures (see Appendix A for the formula used to perform the calculation).

[c] The 8-h percentage criterion exposure results obtained using the reference dosimeter have been expressed relative to the theoretical 8-h percentage criterion exposures using the formula given in Appendix A for computing, in a simplified form, the difference between the equivalent levels of a test signal based on exposure values obtained from measurement results and those obtained from theoretical calculations. The number of significant figures in the percentage criterion exposures used to perform the calculations was four, in the case of the reference dosimeter values, and five, in the case of the theoretical values.

Table 15. Theoretical percentage criterion exposures and equivalent levels for the tone-burst sequences having a nominal crest factor of 20 dB that were used in the electrical tests involving signals of moderate-to-high crest factor with the frequency of the sine wave comprising the tone bursts equal to 100 Hz at a level of 120 dB and the threshold sound level of the mathematical-model dosimeter equal to 80 dB.

Burst Duration (s)	Theory				Reference Dosimeter re Theoretical Equivalent Level[c] (dB)	
	8-h PCE[a] (%)		Equivalent Level[b] (dB)			
	Exchange Rate (dB)					
	5	3	5	3	5	3
0.010	45.67	27.31	84.3	84.4	−0.2	0.0
0.020	43.86	25.84	84.1	84.1	0.0	0.0
0.050	36.29	23.23	82.7	83.7	0.2	0.1
0.10	29.80	22.83	81.3	83.6	0.1	0.0
0.20	24.76	23.51	79.9	83.7	0.1	0.0
0.50	18.82	24.02	78.0	83.8	0.1	0.0
1.0	15.27	24.19	76.4	83.8	0.1	0.0
2.0	12.65	24.28	75.1	83.9	0.1	0.0
5.0	10.56	24.33	73.8	83.9	0.1	0.0
10	9.788	24.35	73.2	83.9	0.1	0.0

[a] Calculated from a numerical integration of the rms detector output of the mathematical model dosimeter performed over a single repetition period for each of the tone-burst sequences and extrapolated to 8 h.

[b] The equivalent level, to the nearest tenth of a decibel, of the corresponding 8-h percentage criterion exposure when expressed to five significant figures (see Appendix A for the formula used to perform the calculation).

[c] The 8-h percentage criterion exposure results obtained using the reference dosimeter have been expressed relative to the theoretical 8-h percentage criterion exposures using the formula given in Appendix A for computing, in a simplified form, the difference between the equialent levels of a test signal based on exposure values obtained from measurement results and those obtained from theoretical calculations. The number of significant figures in the percentage criterion exposures used to perform the calculations was four, in the case of the reference dosimeter values, and five, in the case of the theoretical values.

Table 16. Theoretical percentage criterion exposures and equivalent levels for the tone-burst sequences having a nominal crest factor of 30 dB that were used in the electrical tests involving signals of moderate-to-high crest factor with the frequency of the sine wave comprising the tone bursts equal to 100 Hz at a level of 120 dB and the threshold sound level of the mathematical-model dosimeter equal to 80 dB.

Burst Duration (s)	Theory				Reference Dosimeter re Theoretical Equivalent Level[c] (dB)	
	8-h PCE[a] (%)		Equivalent Level[b] (dB)			
	Exchange Rate (dB)					
	5	3	5	3	5	3
0.010	1.738	0.7492	60.8	68.7	−1.3	−0.9
0.020	3.201	1.580	65.2	72.0	−0.2	−0.2
0.050	3.354	2.094	65.5	73.2	0.0	−0.1
0.10	2.964	2.265	64.6	73.6	0.1	0.0
0.20	2.476	2.351	63.3	73.7	0.1	0.0
0.50	1.882	2.402	61.3	73.8	0.1	0.0
1.0	1.527	2.419	59.8	73.8	0.1	0.0

[a] Calculated from a numerical integration of the rms detector output of the mathematical model dosimeter performed over a single repetition period for each of the tone-burst sequences and extrapolated to 8 h.

[b] The equivalent level, to the nearest tenth of a decibel, of the corresponding 8-h percentage criterion exposure when expressed to five significant figures (see Appendix A for the formula used to perform the calculation).

[c] The 8-h percentage criterion exposure results obtained using the reference dosimeter have been expressed relative to the theoretical 8-h percentage criterion exposures using the formula given in Appendix A for computing, in a simplified form, the difference between the equivalent levels of a test signal based on exposure values obtained from measurement results and those obtained from theoretical calculations. The number of significant figures in the percentage criterion exposures used to perform the calculations was four, in the case of the reference dosimeter values, and five, in the case of the theoretical values.

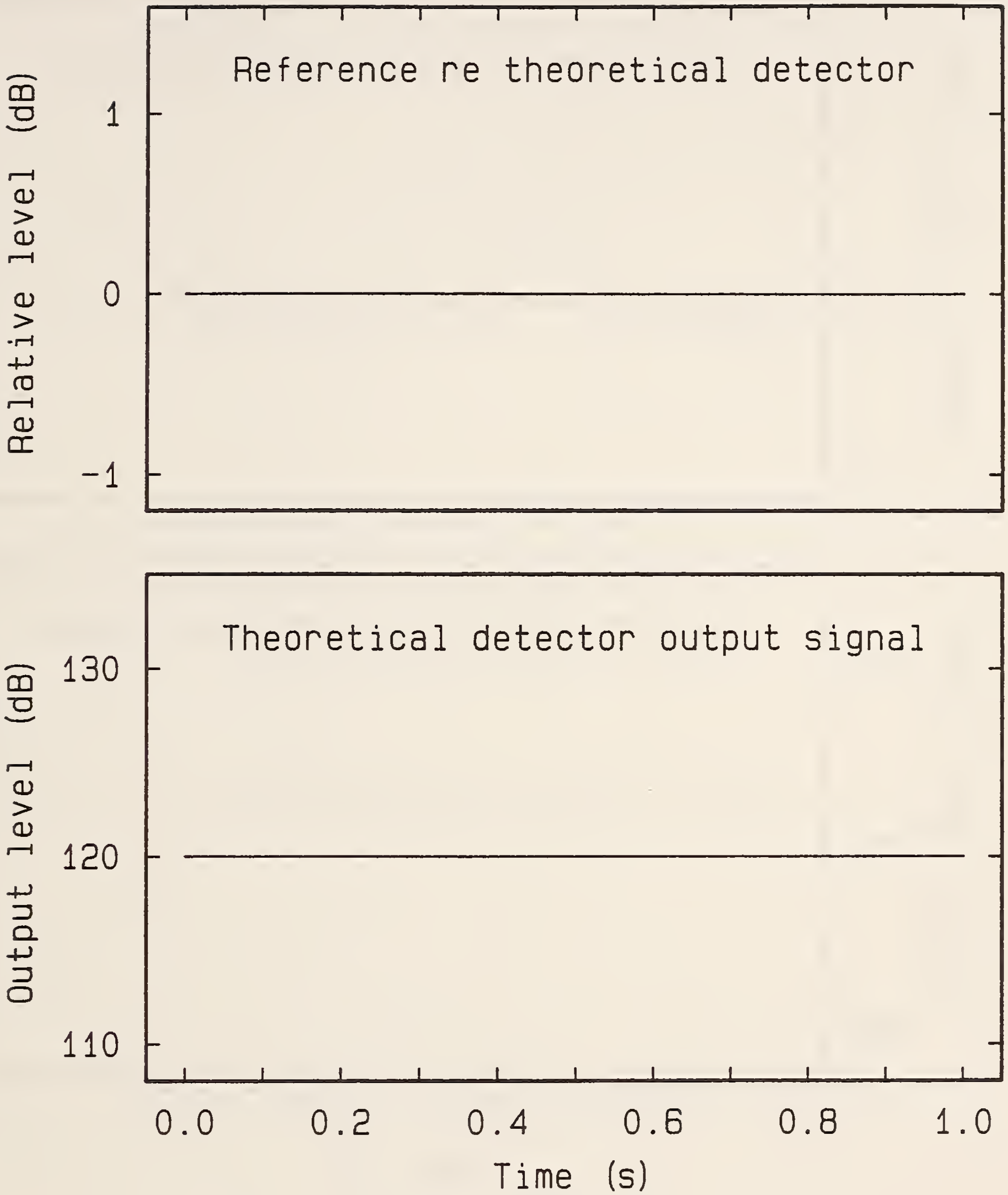

Figure 27. Relative and theoretical steady-state detector output levels due to electrical test signal 1 (a continuous 1-kHz sine wave having a nominal crest factor of 3 dB). The lower plot shows the expected (theoretical) level. The upper plot shows the measured result from the reference dosimeter, relative to the expected level. (Reference dosimeter and theoretical detector output levels are equivalents of A-weighted sound levels.)

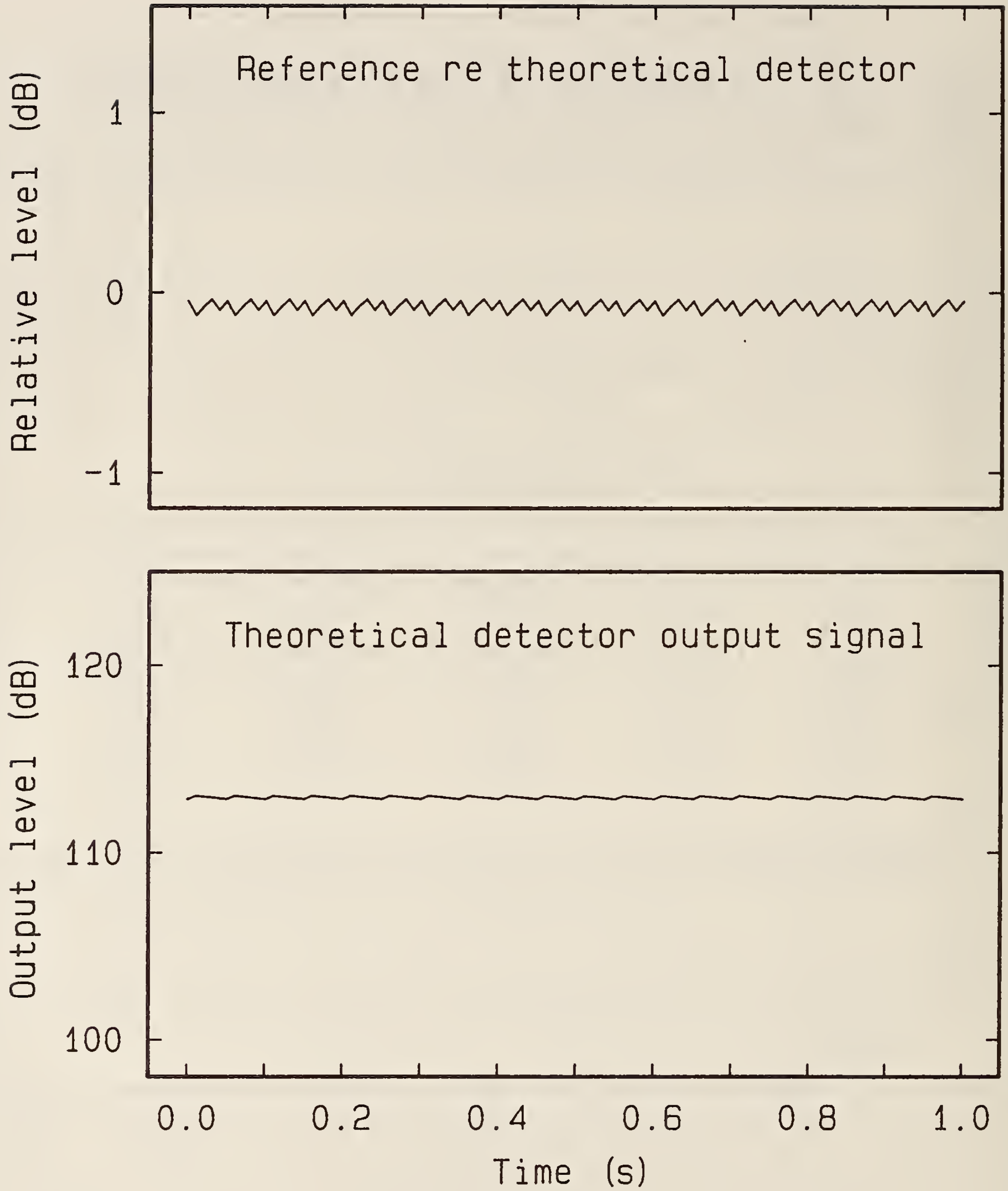

Figure 28. Relative and theoretical steady-state detector output levels due to electrical test signal 2 (a 1-kHz sine wave gated to form a tone-burst sequence having a burst duration of 0.01 s, a repetition period of 0.05 s, and a nominal crest factor of 10 dB). The lower plot shows the expected (theoretical) level. The upper plot shows the measured result from the reference dosimeter, relative to the expected level. (Reference dosimeter and theoretical detector output levels are equivalents of A-weighted sound levels.)

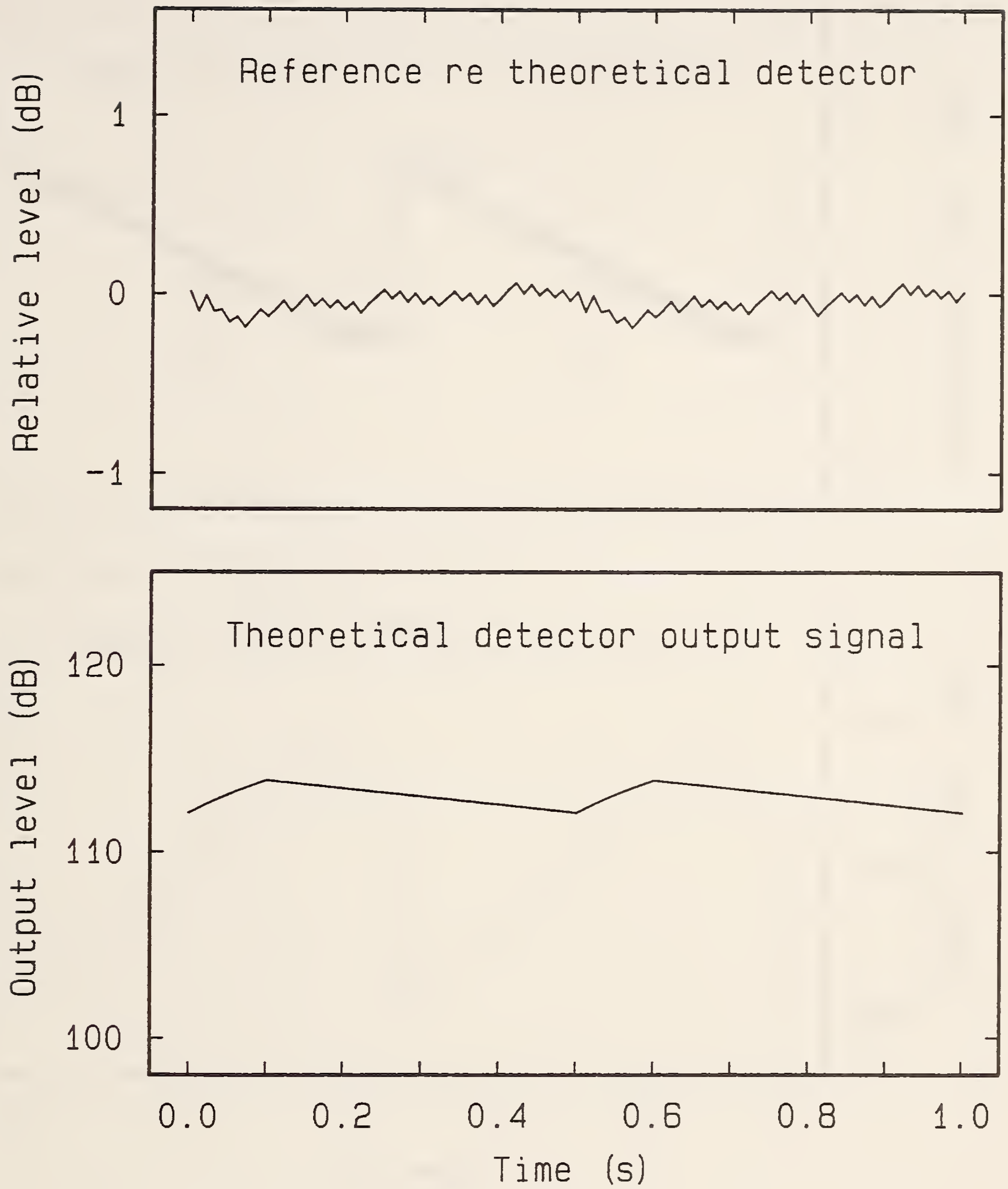

Figure 29. Relative and theoretical steady-state detector output levels due to electrical test signal 3 (a 1-kHz sine wave gated to form a tone-burst sequence having a burst duration of 0.1 s, a repetition period of 0.5 s, and a nominal crest factor of 10 dB). The lower plot shows the expected (theoretical) level. The upper plot shows the measured result from the reference dosimeter, relative to the expected level. (Reference dosimeter and theoretical detector output levels are equivalents of A-weighted sound levels.)

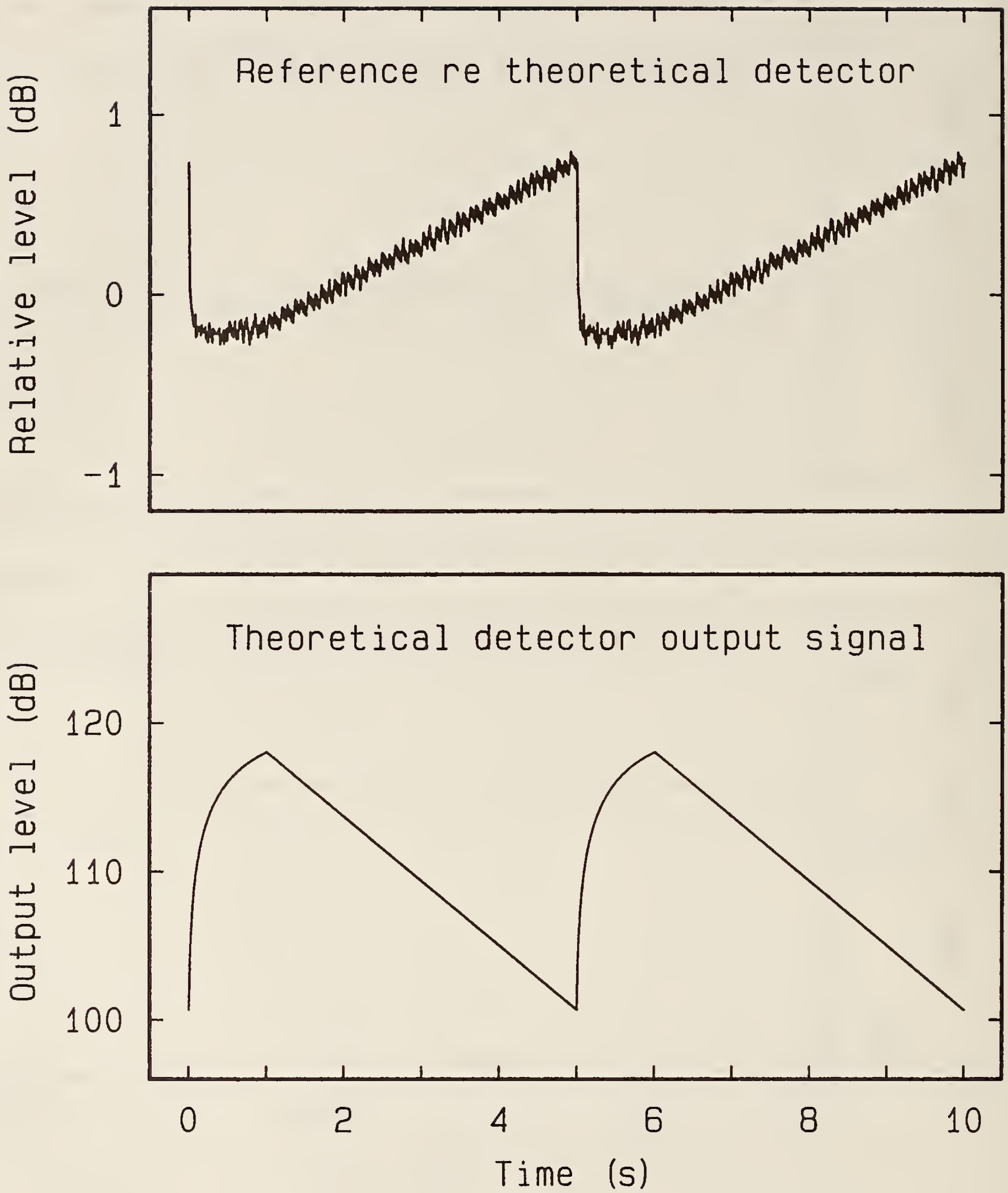

Figure 30. Relative and theoretical steady-state detector output levels due to electrical test signal 4 (a 1-kHz sine wave gated to form a tone-burst sequence having a burst duration of 1.0 s, a repetition period of 5.0 s, and a nominal crest factor of 10 dB). The lower plot shows the expected (theoretical) level. The upper plot shows the measured result from the reference dosimeter, relative to the expected level. (Reference dosimeter and theoretical detector output levels are equivalents of A-weighted sound levels.)

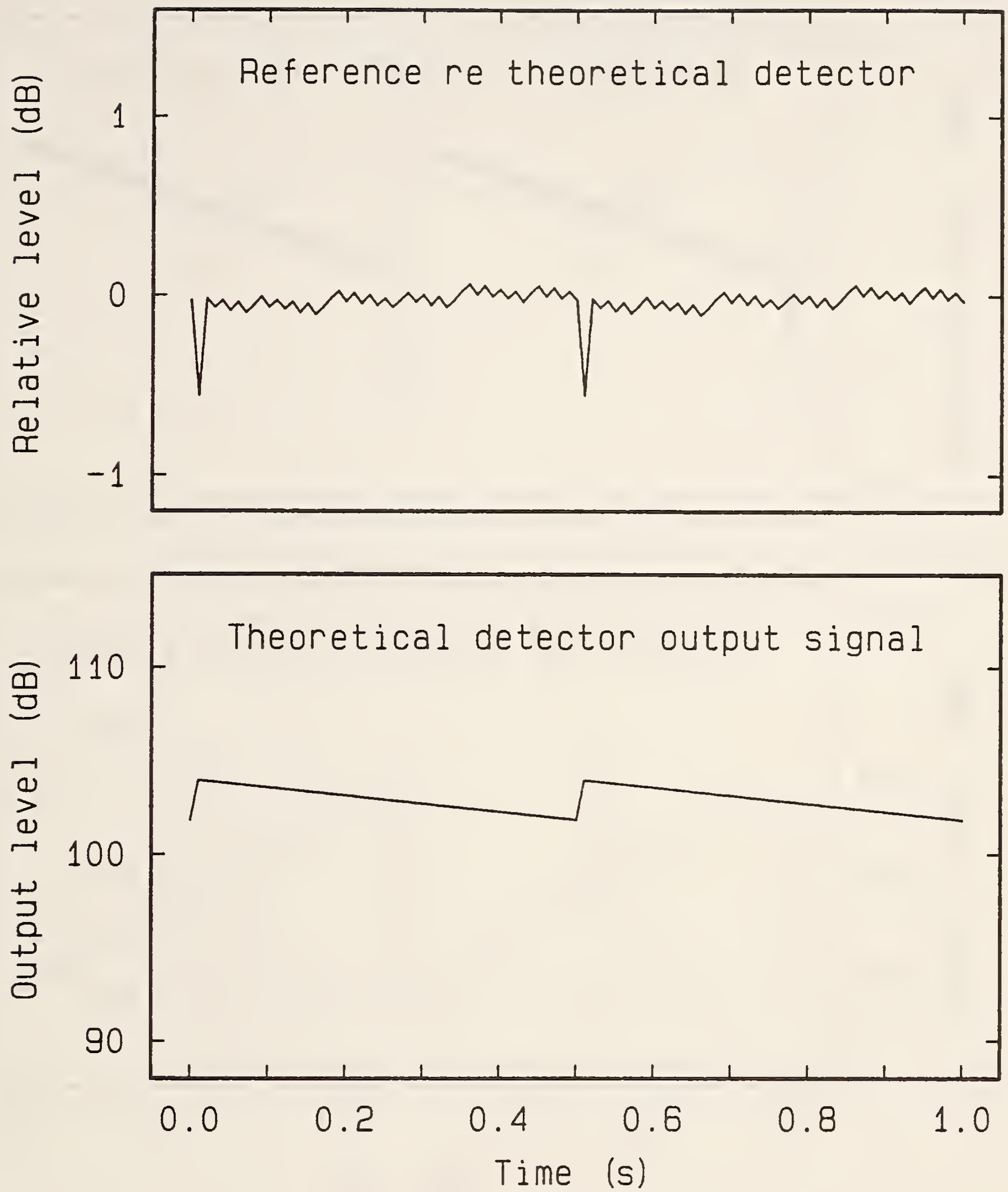

Figure 31. Relative and theoretical steady-state detector output levels due to electrical test signal 5 (a 1-kHz sine wave gated to form a tone-burst sequence having a burst duration of 0.01 s, a repetition period of 0.50 s, and a nominal crest factor of 20 dB). The lower plot shows the expected (theoretical) level. The upper plot shows the measured result from the reference dosimeter, relative to the expected level. (Reference dosimeter and theoretical detector output levels are equivalents of A-weighted sound levels.)

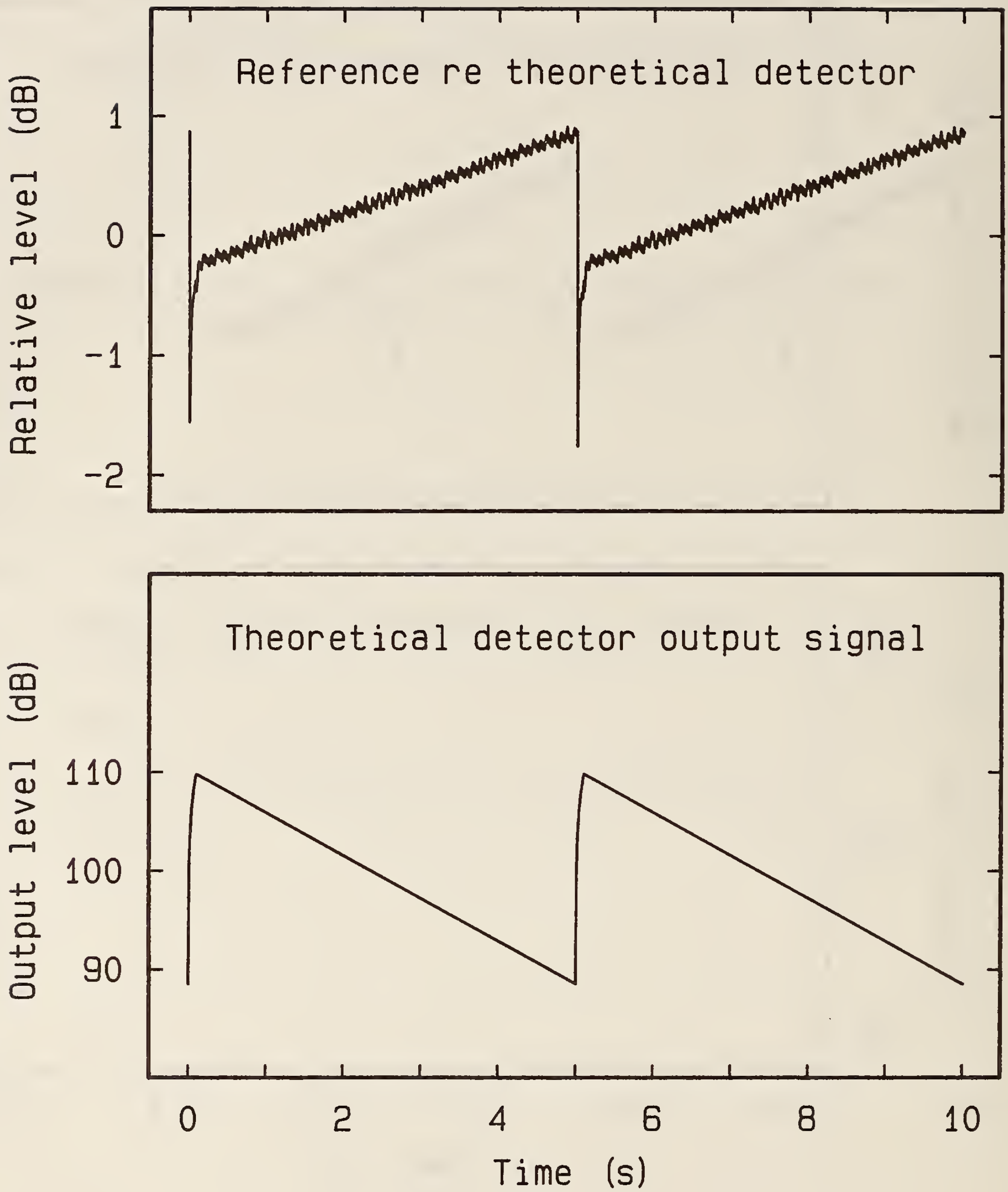

Figure 32. Relative and theoretical steady-state detector output levels due to electrical test signal 6 (a 1-kHz sine wave gated to form a tone-burst sequence having a burst duration of 0.1 s, a repetition period of 5.0 s, and a nominal crest factor of 20 dB). The lower plot shows the expected (theoretical) level. The upper plot shows the measured result from the reference dosimeter, relative to the expected level. (Reference dosimeter and theoretical detector output levels are equivalents of A-weighted sound levels.)

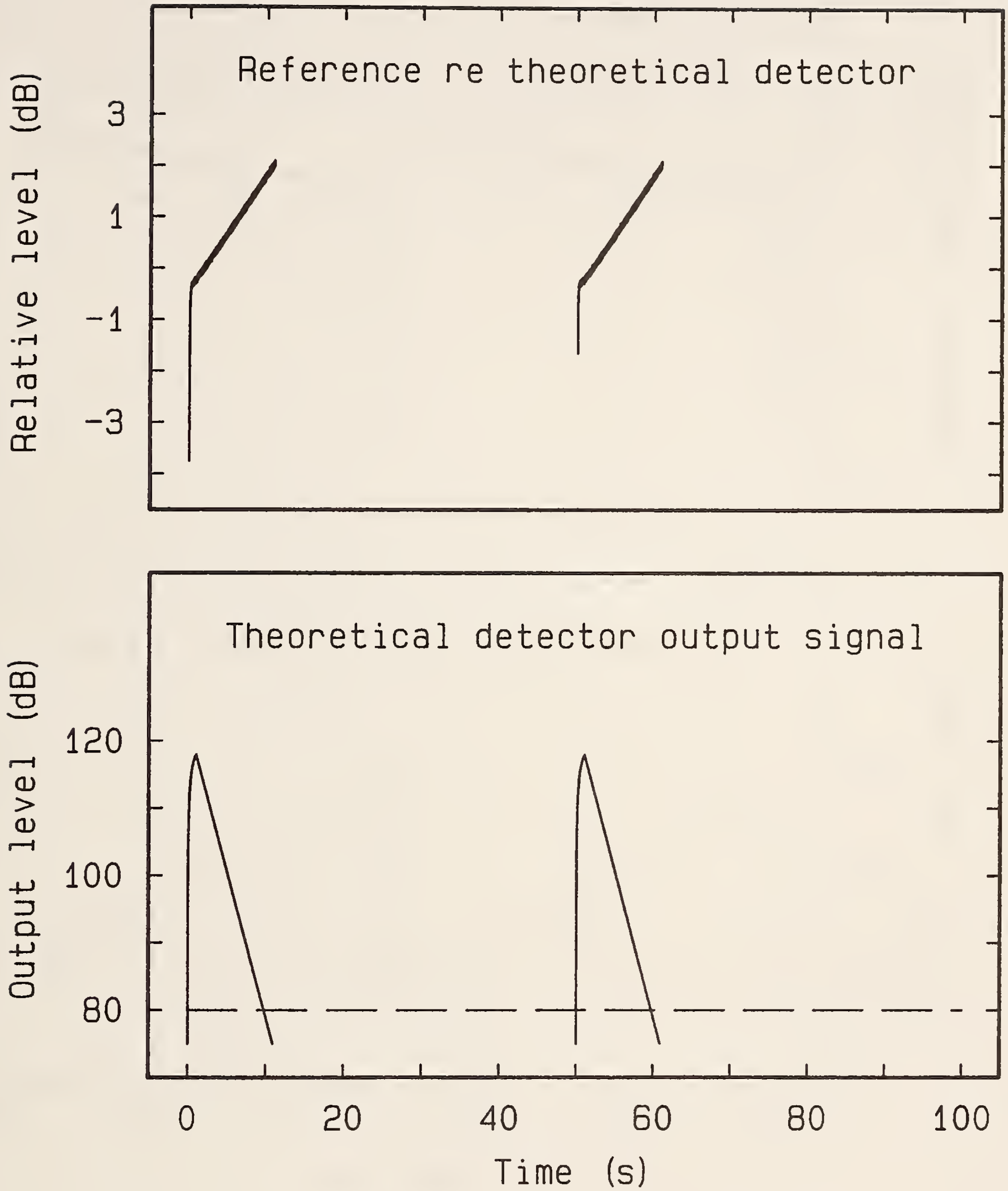

Figure 33. Relative and theoretical steady-state detector output levels due electrical test signal 7 (a 1-kHz sine wave gated to form a tone-burst sequence having a burst duration of 1.0 s, a repetition period of 50 s, and a nominal crest factor of 20 dB). The lower plot shows the expected (theoretical) level. The upper plot shows the measured result from the reference dosimeter, relative to the expected level. (The dashed line indicates the threshold sound level of 80 dB. Reference dosimeter and theoretical detector output levels are equivalents of A-weighted sound levels.)

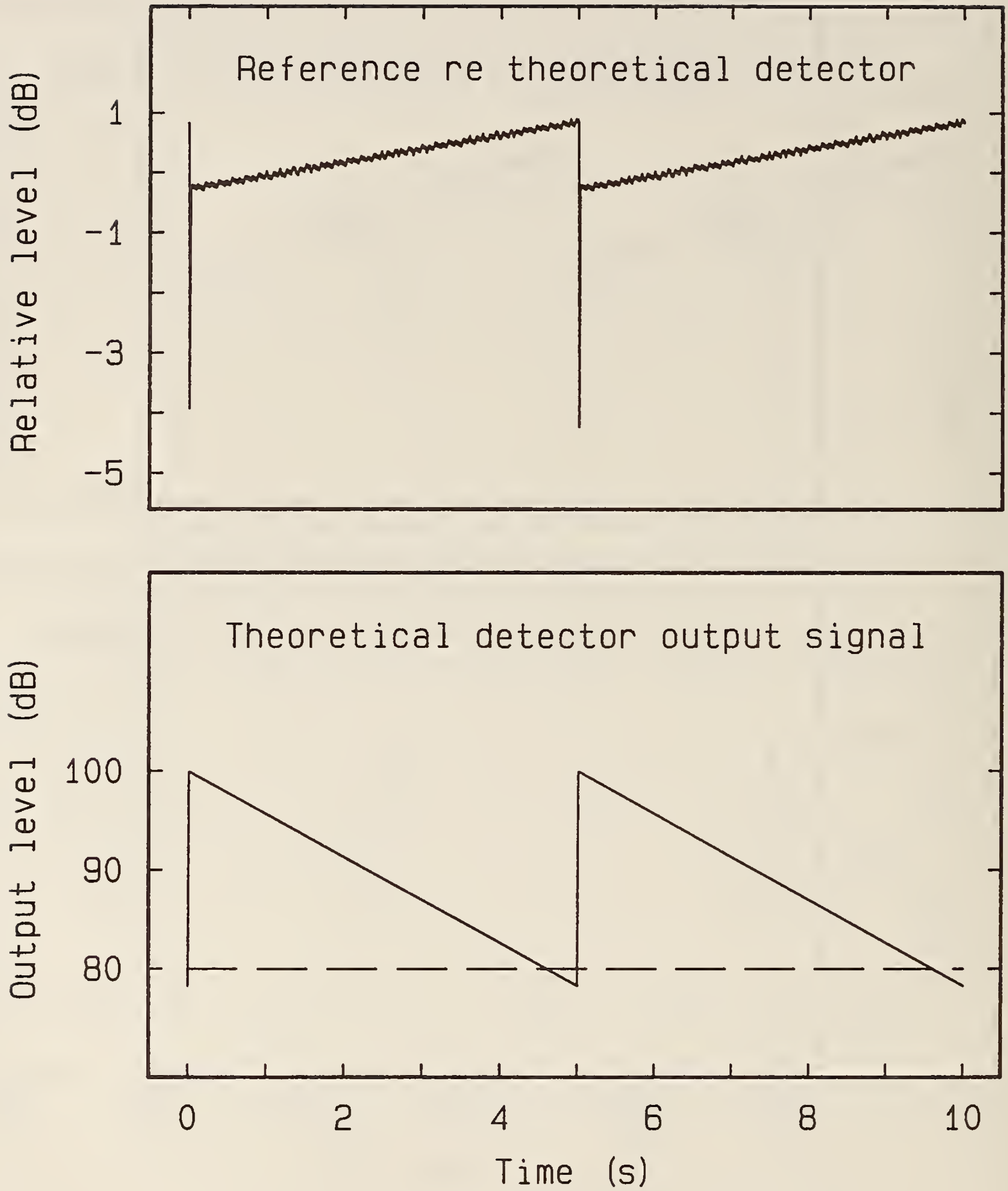

Figure 34. Relative and theoretical steady-state detector output levels due to electrical test signal 8 (a 1-kHz sine wave gated to form a tone-burst sequence having a burst duration of 0.01 s, a repetition period of 5.0 s, and a nominal crest factor of 30 dB). The lower plot shows the expected (theoretical) level. The upper plot shows the measured result from the reference dosimeter, relative to the expected level. (The dashed line indicates the threshold sound level of 80 dB. Reference dosimeter and theoretical detector output levels are equivalents of A-weighted sound levels.)

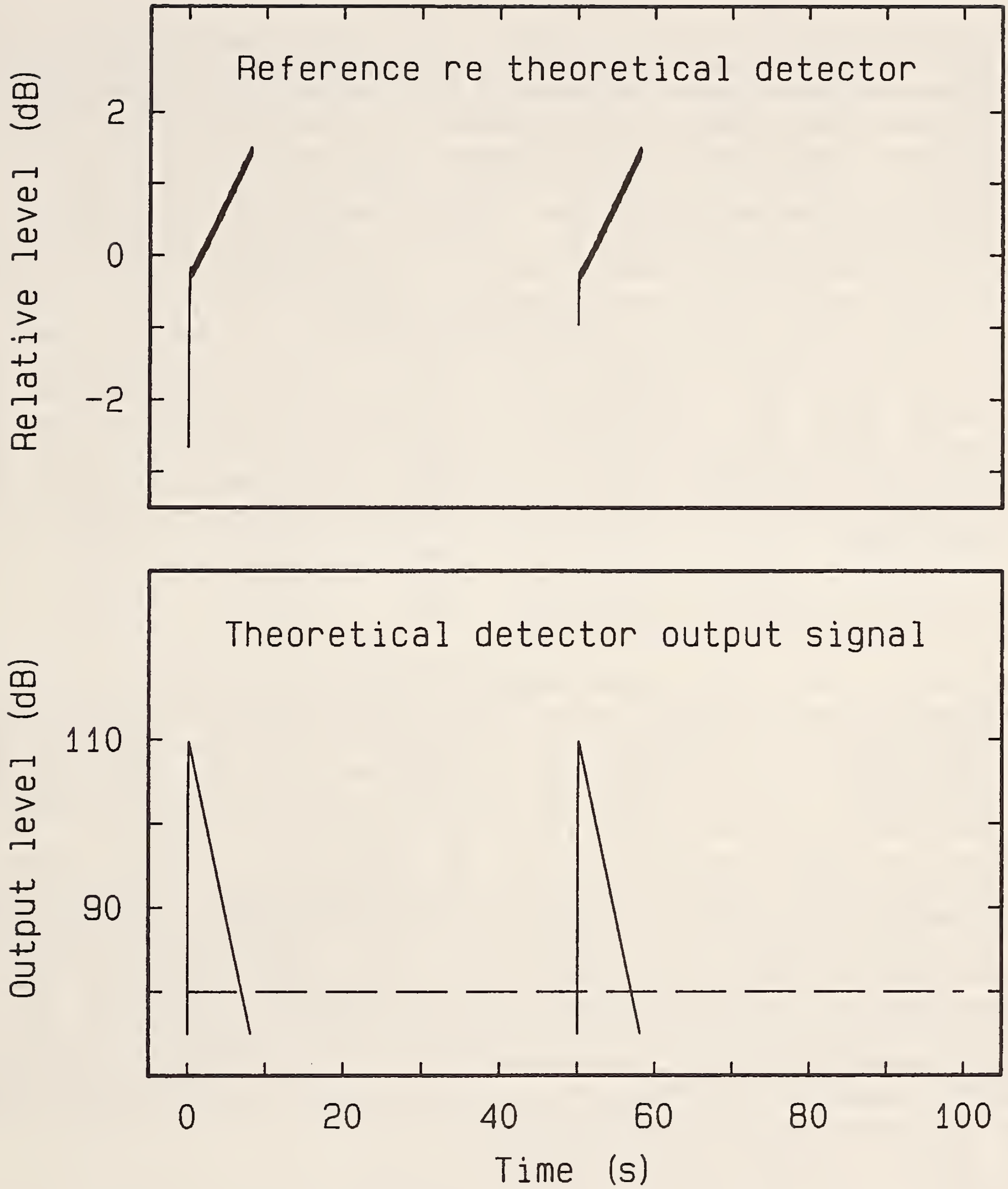

Figure 35. Relative and theoretical steady-state detector output levels due to electrical test signal 9 (a 1-kHz sine wave gated to form a tone-burst sequence having a burst duration of 0.1 s, a repetition period of 50 s, and a nominal crest factor of 30 dB). The lower plot shows the expected (theoretical) level. The upper plot shows the measured result from the reference dosimeter, relative to the expected level. (The dashed line indicates the threshold sound level of 80 dB. Reference dosimeter and theoretical detector output levels are equivalents of A-weighted sound levels.)

percentage criterion exposure values, obtained for electrical test signals 1 through 9 from the reference dosimeter measurement results, were extrapolated to values corresponding to the length of time that the test signals were applied to the commercial dosimeters. The percentage criterion exposures obtained from theoretical calculations and measurements made using the laboratory reference dosimeter, as well as the results of the commercial dosimeter tests, are given in Table 17 to the nearest integer. The percentage criterion exposure results of the reference dosimeter and the commercial dosimeters have been expressed relative to theoretical exposure values using the formula given in Appendix A for calculating the difference between the equivalent levels of the test signals based on the test results, and the levels based on theoretical results. The number of digits used to perform the relative response calculations was five, in the case of the theoretical values, four, in the case of the reference dosimeter values and, in the case of the commercial dosimeter values, was the number of digits available in the display of the instruments for any given combination of test result and instrument (the minimum number of digits was two). The results of the relative response calculations are given in Table 18 to the nearest 0.1 dB.

5.2.3.1 Reference Dosimeter Results

The plots of the synchronized samples of the output of the detector of the reference dosimeter relative to the output of the theoretical detector calculated in 10 ms intervals for signals 1 through 9 indicate that the reference-dosimeter and theoretical detector outputs typically agreed to better than 1 dB (see Figs 27 through 35). Only in cases in which the maximum and minimum output levels of the theoretical detector differed by more than 20 dB was the difference between the reference dosimeter and the theoretical detector output levels greater than 1 dB, with the relatively large differences occurring during the time period that there was the greatest change in the shortest period of time in the output level of the detector(s), i.e., during the time period of the largest positive slope in the measured and calculated detector output curves. These relatively large differences may be attributed, at least in part, to the fact that the sampled output of the detector was not synchronized to better than 5 ms with that of the mathematical model (e.g., if the slope of the theoretical detector output at a particular point in time was on the order of 1 dB/ms then the disagreement between the measured and theoretical output levels could be of the order of 5 dB for this data point).

The data set acquired by the reference dosimeter for a 5-dB exchange rate, when synchronized in time (±5 ms) with the data set acquired by the reference dosimeter for a 3-dB exchange rate, typically agreed at each synchronized data point within 0.1 dB. Again, only during periods of large positive slopes in the detector output curves were there significant differences in the measured data files, the extreme value of the difference between any two data files of the same signal being less than 12 dB.

Notice that the differences in level between the reference dosimeter and theoretical detector output levels become increasingly larger during the time period(s) that the detector output decays from a maximum. This is consistent with the calibration of the exponential-averaging time constant of the reference-

Table 17. Percentage criterion exposures (percent) measured in the electrical tests of the commercial dosimeters that involved the use of a continuous or gated 1-kHz sine wave to produce signals having moderate-to-high crest factors.[a]

Test Duration[b] (h)	Burst Duration[c] (s)	Crest Factor[d] (dB)	Theory[e] (%)	Commercial Dosimeter (%) 1	2	3	4[f]	5	6	7
				5-dB Exchange Rate						
0.1250	cw	3	100	98	101	102	91[g]	98	100	...[h]
0.3364	0.010	10	101	99	101	103	93	101	101	...
0.3325	0.10	10	101	98	101	103	92	101	95	...
0.3700	1.0	10	100	97	105	99	81	102	97	...
1.341	0.010	20	101	96	99	101	93	104	94	...
1.558	0.10	20	99	89	103	96	75	105	97	...
3.490	1.0	20	99	85	106	94	76	95	99	...
6.405	0.010	30	99	67	104	86	80	104	119	...
15.13	0.10	30	100	63	114	88	71[i]	84	101	...
				3-dB Exchange Rate						
0.008000	cw	3	100	...	103	100	...	99	104	95
0.4103	0.010	20	101	...	101	103	...	109	89[j]	93
0.4072	1.0	20	102	...	112	97	...	84[k]	98	82

[a] The values of the percentage criterion exposures have been expressed to the nearest integer. The voltage level of the sine wave, when continuous or during the "on" portion of the gated signals, was equivalent to a sound pressure level of 120 dB. When gated, the sine wave comprised a tone-burst sequence such that the duration and repetition period of the bursts were equal to an integral number of cycles of the sine wave, and each burst began and ended on a "zero crossing" of the sine wave. The repetition periods of the tone-burst sequences used in the tests are given in Table 6 (test signals 2 through 9).

[b] The time period, to four significant figures, that each of the commercial dosimeters was exposed to the test signal. In the case of the reference dosimeter, the output of the rms detector was sampled in 10-ms intervals for a period of 1 s or two repetition periods, whichever was greater.

[c] The time period that the sine wave, when gated, was present during each cycle (repetition period) of the burst sequence (denoted cw when the sine wave was not gated).

[d] The nominal value of the crest factor of the test signal.

[e] Theoretical values for the tests were obtained by multiplying the theoretical 8-h percentage criterion exposure results, computed for each of the test signals and expressed to five significant figures, by the ratio of the indicated measurement duration to 8 h.

(Table 17, cont'd.)

[f] Unless otherwise noted, the results are for measurements performed after the second of two calibration adjustments of the instrument.

[g] 89 percent was obtained when the test was performed prior to the second calibration of the instrument.

[h] "..." indicates that no measurement was made for a given combination of dosimeter and exchange rate.

[i] Result was obtained prior to the second calibration of the instrument.

[j] 85 percent was measured when the test was repeated under the same conditions.

[k] 95 percent was measured when the test was repeated using a new battery (the test of the battery, performed at the end of the first measurement using the battery-check internal to the dosimeter, indicated that the condition of the battery was such that it [the battery] could be used reliably to make additional measurements).

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dosimeter measuring amplifier indicating a decay time constant of about 6 percent greater than 1 s, the value used for the exponential averaging time constant in the theoretical calculations (see Sec. 3.2). A 1.06 s time constant would result in an increase in the measured relative to theoretical detector output levels of about 1 dB every 4 s of decay time.

In all cases, the reference dosimeter and the theoretical detector output levels were in agreement to within a few tenths of a decibel during the time period when the detector output was the largest, i.e., the time period when the detector output level influenced the value of the percentage criterion exposure the most.

The reference-dosimeter equivalent levels (based on percentage criterion exposures calculated from the sampled output of the reference-dosimeter detector), when expressed relative to theoretical values, indicate differences of 0.1 dB,or less, between the reference-dosimeter and theoretical results for all the tone-burst sequences when using either a 5 or 3 dB exchange rate - providing that the number of cycles of the sine wave comprising the tone bursts in the sequence was greater than five (see Tables 7 through 16). If the number of cycles of the sine wave comprising the tone bursts in the sequence was 5 or less, the relative response of the reference dosimeter still was ±0.1 dB, or less, providing that the nominal crest factor of the input signal (tone-burst sequence) was less than 20 dB (see Tables 12 through 14). If the number of cycles of the sine wave comprising the tone burst was 5 or less, and the nominal crest factor of the input signal was 20 dB, the relative response of the reference dosimeter was ±0.2 dB, or less (see Table 15). If the number of cycles of the sine wave comprising the tone bursts was greater than one, and the nominal crest factor of the input signal was 30 dB, the relative response of the reference dosimeter was −0.2 to +0.1 dB (see Table 16). If a single cycle sine wave comprised the tone bursts, and the nominal crest factor of the input signal was 30 dB, the relative response of the reference dosimeter was on the order of −1 dB (see Table 16).

Table 18. Equivalent levels (dB) relative to theoretical values, calculated for the electrical tests of the commercial dosimeters involving the use of a continuous or gated 1-kHz sine wave to produce signals having moderate-to-high crest factors.[a]

Test Duration[b] (h)	Burst Duration[c] (s)	Crest Factor[d] (dB)	Reference Dosimeter (dB)	Commercial Dosimeter (dB)						
				1	2	3	4[e]	5	6	7
5-dB Exchange Rate										
0.1250	cw	3	0.0	−0.2	0.1	0.1	−0.7[f]	−0.1	0.0	...[g]
0.3364	0.010	10	−0.1	−0.2	0.0	0.1	−0.6	0.0	0.0	...
0.3325	0.10	10	0.0	−0.2	0.0	0.1	−0.7	0.0	−0.4	...
0.3700	1.0	10	0.0	−0.2	0.4	0.0	−1.5	0.2	−0.2	...
1.341	0.010	20	0.0	−0.3	−0.1	0.0	−0.6	0.2	−0.5	...
1.558	0.10	20	0.0	−0.8	0.2	−0.3	−2.0	0.4	−0.2	...
3.490	1.0	20	0.0	−1.1	0.5	−0.4	−1.9	−0.3	0.0	...
6.405	0.010	30	0.1	−2.8	0.3	−1.0	−1.6	0.3	1.3	...
15.13	0.10	30	0.0	−3.3	0.9	−0.9	−2.4[h]	−1.2	0.1	...
3-dB Exchange Rate										
0.008000	cw	3	0.0	...	0.1	0.0	...	−0.1	0.2	−0.2
0.4103	0.010	20	0.0	...	0.0	0.1	...	0.3	−0.5[i]	−0.4
0.4072	1.0	20	−0.1	...	0.4	−0.2	...	−0.8[j]	−0.2	−0.9

[a] The percentage criterion exposure test results were expressed relative to the theoretical 8-h percentage criterion exposures, calculated for each of the test signals and expressed to five significant figures. The formula given in Appendix A was then used to compute, in a simplified form, the difference between the equivalent level of each test signal based on exposure values obtained from measurement results and that obtained from theoretical calculations. The number of digits in the test results, used to perform the relative response calculations, was the number of digits available in the display of the instruments for any given combination of test result and instrument (the minimum number of digits in any of the values used in the calculations of the relative response was two). The values obtained in the relative response calculations have been tabulated to the nearest tenth of a decibel.

[b] The time period, to four significant figures, that each of the commercial dosimeters was exposed to the test signal. In the case of the reference dosimeter, the output of the rms detector was sampled in 10-ms intervals for a period of 1 s or two repetition periods, whichever was greater.

[c] The time period that the sine wave, when gated, was present during each cycle (repetition period) of the burst sequence (denoted cw when the sine wave was not gated).

[d] The nominal value of the crest factor of the test signal.

(Table 18 cont'd.)

[e] Unless otherwise noted, the values given for the relative response of the instrument were calculated using results obtained from measurements performed after the second of two calibration adjustments of the instrument.

[f] -0.8 dB using the value of the result obtained when the test was performed prior to the second calibration of the instrument.

[g] "..." indicates that a relative response was not calculated due to the fact that a measurement result was not obtained for a given combination of dosimeter and exchange rate.

[h] Response based on a measurement result obtained prior to the second calibration of the instrument.

[i] -0.8 dB based on the measurement result obtained when the test was repeated under the same conditions.

[j] -0.3 dB based on the measurement result obtained when the test was repeated using a new battery.

The equivalent levels, corresponding to the percentage criterion exposures that were based on measurement results obtained for electrical test signals 1 through 9 using the reference dosimeter, agreed with theoretical values to ±0.1 dB, or better (see Table 18).

5.2.3.2 Commercial Dosimeter Results

The response of the commercial dosimeters to electrical test signals 1 through 9 agreed with theoretical equivalent levels calculated for the signals to within ±2 dB, and typically to within ±1 dB, for signals having a nominal crest factor of 20 dB or less, and to within ±4 dB for signals having a nominal crest factor of 30 dB (see Table 18). No difference greater than 0.5 dB, and typically no more than 0.1 dB to 0.2 dB, was detected between the performance of the commercial dosimeters when they were used in the 5-dB versus 3-dB exchange-rate mode of operation. The gain of dosimeter 4 was adjusted twice, with test 1 performed after each of the two gain adjustments, test 9 performed after the initial gain adjustment, and the remaining tests performed after the second gain adjustment (see Table 17, footnotes g and h, and Table 18, footnotes f and g). It was noted in the case of dosimeter number 5 when using a 3-dB exchange rate that the response of the instrument to test signal 7 was more nearly equal to the theoretical percentage criterion exposure when a fresh battery was used to make the measurement. (A test of the condition of the battery was made at the completion of the initial measurement of test signal 7 using the battery-check internal to the dosimeter. The results of the test of the battery indicated that the condition of the battery was such that it could be used reliably to make additional measurements. See Tables 17 and 18, footnotes k and j, respectively.) Test 5 was performed twice using dosimeter 6, set to an exchange rate of 3 dB.

The second measurement was made consecutively with the first measurement and resulted in a percentage-criterion-exposure value approximately 4 percentage points lower than that obtained in the first measurement (see Table 17, footnote j, and Table 18, footnote i).

6. Discussion of Results

6.1 Theoretical Response to Signals of Moderate-to-High Crest Factor

The theoretical equivalent levels given in Tables 7 through 16 for the tone-burst sequences with moderate-to-high crest factors, are, in general, not constant for a given crest factor but vary as a function of the bandwidth of the frequency spectrum of the test signals, the exchange rate(s), and the threshold sound level (80 dB). In order to examine the effect of a threshold sound level of 80 dB, the theoretical model described in Appendix B was used to calculate equivalent levels, for the test signals, using a threshold sound level of 20 dB. The results of these calculations are summarized in Tables 19 and 20. The theoretical results for a threshold sound level of 80 dB are compared in Tables 21 and 22 with the results for a 20-dB threshold level for those signals that resulted in the output of the theoretical rms detector becoming less than 80 dB during the time period between tone bursts.

6.1.1 Comparison of 5-dB and 3-dB Exchange Rates

The use of a 5-dB exchange rate results in equivalent levels for the tone-burst sequences that are equal (to the nearest 0.1 dB) to the levels based on the A-weighted power spectrum of the sequences (see Appendix B, Sec. B.5), providing that the period between bursts (T – N/f) is on the order of the time constant of the exponential averaging device, or less. As the period between bursts becomes larger than the time constant of the exponential averaging device, the time-weighted levels become increasingly smaller than those based on the A-weighted power spectrum of the input waveform (independent of whether or not the output of the rms detector becomes less than the threshold sound level). In the case of a 3-dB exchange rate, however, the equivalent levels are independent of the period between the bursts, i.e., for signals containing bursts comprised of a large number of cycles of a sine wave (N > 10), the levels are constant for a given crest factor (see Table 7 through 16).

6.1.2 Comparison of 80-dB and 20-dB Threshold Sound Levels

Variations in an equivalent level due to effects caused by the output level of the rms detector of a dosimeter becoming less than the threshold sound level depend, at least in part, upon the maximum output level of the rms detector relative to the threshold sound level, the exchange rate of the dosimeter, and the ratio of (1) the period of time that the output signal of the rms detector is above the threshold sound level to (2) the period of time that the signal is below threshold. Here the term "variation" refers to a change in an equivalent level caused by the level of the detector output becoming less than the threshold sound level (see Tables 21 and 22).

The tone-burst sequences having moderate-to-high crest factors for which the output signal of the rms detector of a personal noise exposure meter should theoretically cross below a threshold sound level of 80 dB are (see also Tables 21 and 22):

Table 19. Theoretical equivalent levels (dB) for the tone-burst sequences that were used in the electrical tests involving signals of moderate-to-high crest factor with the frequency of the sine wave comprising the bursts equal to 1 kHz at a level of 120 dB and the threshold sound level of the mathematical-model dosimeter equal to 20 dB.[a]

Burst Duration (s)	Crest Factor (dB)									
	4.8		6.0		10		20		30	
	Exchange Rate (dB)									
	5	3	5	3	5	3	5	3	5	3
0.010	118.2	118.2	116.9	116.9	112.9	112.9	102.9	102.9	91.7	92.9
0.020	118.2	118.2	117.0	117.0	113.0	113.0	102.9	103.0	90.0	93.0
0.050	118.2	118.2	117.0	117.0	113.0	113.0	102.6	103.0	87.4	93.0
0.10	118.2	118.2	117.0	117.0	113.0	113.0	101.8	103.0	85.5	93.0
0.20	118.2	118.2	117.0	117.0	113.0	113.0	100.2	103.0	83.6	93.0
0.50	118.2	118.2	117.0	117.0	112.7	113.0	97.7	103.0	81.1	93.0
1.0	118.2	118.2	116.9	117.0	112.2	113.0	96.0	103.0	79.4	93.0
2.0	118.2	118.2	116.8	117.0	111.0	113.0	94.5	103.0	...	...
5.0	118.0	118.2	116.2	117.0	109.7	113.0	93.0	103.0	...	...
10	117.7	118.2	115.7	117.0	109.1	113.0	92.4	103.0	...	...

[a] See Tables 7 through 11 for theoretical equivalent levels based on a threshold sound level of 80 dB. Equivalent levels were not calculated for sequences having a crest factor of 30 dB and burst durations greater than 1.0 s.

Table 20. Theoretical equivalent levels (dB) for the tone-burst sequences that were used in the electrical tests involving signals of moderate-to-high crest factor with the frequency of the sine wave comprising the bursts equal to 100 Hz at a level of 120 dB and the threshold sound level of the mathematical-model dosimeter equal to 20 dB.[a]

Burst Duration (s)	Crest Factor (dB)									
	4.8		6.0		10		20		30	
	Exchange Rate (dB)									
	5	3	5	3	5	3	5	3	5	3
0.010	99.6	99.6	98.3	98.3	94.4	94.4	84.3	84.4	73.1	74.4
0.020	99.4	99.4	98.1	98.1	94.1	94.1	84.1	84.1	71.2	74.1
0.050	99.2	99.2	98.0	98.0	94.0	94.0	83.6	84.0	68.4	74.0
0.10	99.1	99.1	97.9	97.9	93.9	93.9	82.7	83.9	66.4	73.9
0.20	99.1	99.1	97.9	97.9	93.8	93.9	81.0	83.9	64.4	73.9
0.50	99.1	99.1	97.8	97.9	93.6	93.9	78.6	83.9	62.0	73.9
1.0	99.1	99.1	97.8	97.9	93.0	93.9	76.8	83.9	60.2	73.9
2.0	99.0	99.1	97.6	97.9	91.9	93.9	75.3	83.9	...	...
5.0	98.8	99.1	97.0	97.9	90.5	93.9	73.9	83.9	...	...
10	98.5	99.1	96.5	97.9	89.9	93.9	73.3	83.9	...	...

[a] See Tables 12 through 16 for theoretical equivalent levels based on a threshold sound level of 80 dB. Equivalent levels were not calculated for sequences having a crest factor of 30 dB and burst durations greater than 1.0 s.

Table 21. Equivalent levels (dB) based on a threshold sound level equal to 80 dB expressed relative to equivalent levels based on a threshold sound level of 20 dB for the tone-burst sequences that were used in the electrical tests involving signals of moderate-to-high crest factor with the frequency of the sine wave comprising the bursts equal to 1 kHz at a level of 120 dB.[a]

Burst Duration (s)	Crest Factor (dB)									
	4.8		6.0		10		20		30	
	Exchange Rate (dB)									
	5	3	5	3	5	3	5	3	5	3
0.010	---	---	---	---	---	---	---	---	−0.2	0.0
0.020	---	---	---	---	---	---	---	---	−0.3	0.0
0.050	---	---	---	---	---	---	---	---	−0.1	0.0
0.10	---	---	---	---	---	---	---	---	−0.1	0.0
0.20	---	---	---	---	---	---	−0.1	0.0	−0.1	0.0
0.50	---	---	---	---	---	---	0.0	0.0	−0.1	0.0
1.0	---	---	---	---	---	---	−0.1	0.0	−0.1	0.0
2.0	---	---	---	---	---	---	−0.1	0.0	...	...
5.0	---	---	---	---	−0.1	0.0	0.0	0.0	...	...
10	---	---	0.0	0.0	−0.1	0.0	0.0	0.0	...	...

[a] Relative equivalent levels have been indicated by "---" in the case of those signals for which the output of the rms detector of the mathematical-model dosimeter did not become less than the threshold sound level of 80 dB. See Tables 7 through 11 and Table 19 for the values of the equivalent levels upon which the relative levels given in this table are based. Equivalent levels were not calculated for sequences having a crest factor of 30 dB and burst durations greater than 1.0 s.

Table 22. Equivalent levels (dB) based on a threshold sound level equal to 80 dB expressed relative to equivalent levels based on a threshold sound level of 20 dB for the tone-burst sequences that were used in the electrical tests involving signals of moderate-to-high crest factor with the frequency of the sine wave comprising the bursts equal to 100 Hz at a level of 120 dB.[a]

Burst Duration (s)	Crest Factor (dB)									
	4.8		6.0		10		20		30	
	Exchange Rate (dB)									
	5	3	5	3	5	3	5	3	5	3
0.010	---	---	---	---	---	---	---	---	–12.3	–5.7
0.020	---	---	---	---	---	---	---	---	–6.0	–2.1
0.050	---	---	---	---	---	---	–0.9	–0.3	–2.9	–0.8
0.10	---	---	---	---	---	---	–1.4	–0.3	–1.8	–0.3
0.20	---	---	---	---	---	---	–1.1	–0.2	–1.1	–0.2
0.50	---	---	---	---	---	---	–0.6	–0.1	–0.7	–0.1
1.0	---	---	---	---	---	---	–0.4	–0.1	–0.4	–0.1
2.0	---	---	---	---	–0.2	0.0	–0.2	0.0	...	...
5.0	---	---	0.0	–0.1	–0.1	0.0	–0.1	0.0	...	...
10	0.0	0.0	0.0	–0.1	–0.1	0.0	–0.1	0.0	...	...

[a] Relative equivalent levels have been indicated by "---" in the case of those signals for which the output of the rms detector of the mathematical model dosimeter did not become less than the threshold sound level of 80 dB. See Tables 12 through 16 and Table 20 for the values of the equivalent levels upon which the relative levels given in this table are based. Equivalent levels were not calculated for sequences having a crest factor of 30 dB and bursts durations greater than 1.0 s.

in the case of the 1000-Hz sine-wave sequences,

- none of the signals with a crest factor of 4.8 dB,
- signals with a crest factor of 6.0 dB and burst durations greater than 5 s,
- signals with a crest factor of 10 dB and durations greater than 2 s,
- signals with a crest factor of 20 dB and durations greater than 0.1 s, and
- all of the signals with a crest factor of 30 dB; and

in the case of the 100-Hz sine-wave sequences,

- signals with a crest factor of 4.8 dB and burst durations greater than 5 s,
- signals with a crest factor of 6.0 dB and burst durations greater than 2 s,
- signals with a crest factor of 10 dB and burst durations greater than 1 s,
- signals with a crest factor of 20 dB and burst durations greater than 0.02 s, and
- all of the signals with a crest factor of 30 dB.

In particular, of the tone-burst sequences used in testing the commercial dosimeters, preliminary electrical test signal P4 and moderate-to-high crest-factor electrical test signals 7, 8, and 9 should have resulted in the detector output crossing below the threshold sound level (see also Figs. 12, 24, 25, and 26).

The theoretical mathematical model described in Appendix B was used to calculate and compare the equivalent levels corresponding to these signals, given a threshold sound level of 80 dB, with equivalent levels based on a threshold sound level of 20 dB (see Tables 21 and 22). Note that not all signals for which the output of the rms detector crossed below the threshold sound level produced a difference between these two equivalent levels of a 0.1 dB or more. In general, the effects of the threshold sound level on a equivalent level corresponding to a signal that results in the output of the rms detector crossing below the threshold sound level will be manifested differently for different exchange rates. In particular, these effects may be obscured when they occur in combination with other effects that cause a change in the equivalent level, e.g., in the case of a 5-dB exchange rate when the equivalent level is changing as a result of the period between bursts being greater than the time constant of the exponential averaging device. The following observations apply only to the results based on the tone-burst sequences examined in this report and may or may not be true for other time-varying input signals.

The relative levels shown in Tables 21 and 22 indicate that the difference in equivalent levels based on a threshold sound level of 20 dB, versus 80 dB, increases as the maximum output level of the theoretical rms detector approaches the threshold sound level of 80 dB. This is demonstrated in the general trend of the level differences increasing with decreasing burst duration for a given signal crest factor, with increasing signal crest factor for a given burst duration, and with a decrease in the A-weighted level of the sine wave comprising the tone bursts. This trend is moderated by the magnitude of the ratio of the period of time that the detector output is greater than the threshold sound level to the period of time that the detector output is below the threshold.

For example, in the case of the 20-dB crest-factor sequences comprised of a 100-Hz sine wave given in Table 22, notice that the magnitude of the difference in levels based on the two threshold sound levels increases with decreasing burst duration except in the case of the sequence with burst durations equal to 0.050 s. The maximum (not equivalent) theoretical levels of the detector output for the 20-dB crest-factor sequences comprised of bursts of a 100-Hz sine wave given burst durations of 0.050, 0.10, and 0.20 s were found to be 88, 91, and 93 dB, respectively. However, the ratios of the period of time that the detector output was greater than the threshold sound level to the period of time that the detector output was less than the 80-dB threshold sound level as measured by the reference dosimeter for these signals, were 1.5, 1.1, and 0.5, respectively. Specifically:

- for the sequence having burst durations equal to 0.050 s, the maximum output level of the rms detector of the reference dosimeter was on the order of 8 dB above the threshold sound level (80 dB), and the ratio of the length of time that detector output was greater than the threshold sound level to the length of time that detector output was less than the threshold sound level was approximately 1.5;

- for the sequence having burst durations of 0.10 s, the maximum output level of the rms detector of the reference dosimeter was on the order of 11 dB above the threshold sound level, but the ratio of the length of time that detector output was greater than the threshold sound level to the length of time that detector output was less than the threshold sound level was approximately 1.1;

- for sequences having burst durations greater than 0.10 s or less than 2.0 s, the maximum output level of the rms detector of the reference dosimeter increased to a level approximately 18 dB above the threshold sound level while the ratio of the length of time that detector output was greater than the threshold sound level to the length of time that detector output was less than the threshold sound level decreased to approximately 0.1; and

- for sequences having burst durations greater than 1.0 s, the rms-detector output level of the reference dosimeter reached a maximum level that was 20 dB or more above the threshold sound level with ratios of the length of time that detector output was greater than the threshold sound level to the length of time that detector output was less than the threshold sound level that were less than 0.1.

Notice also, that the influence on the magnitude of the difference in equivalent levels based on the two threshold sound levels is manifested differently for a 5-dB exchange rate than for a 3-dB exchange rate.

6.1.3 Summary of Theoretical Response

Given that the output of the rms detector of a personal noise exposure meter does not become less than the threshold sound level then, for tone-burst sequences of a given crest factor in which the interval between bursts is less than the time constant of the exponential averaging device, the equivalent level computed from the percentage criterion exposure resulting from a given signal is independent of the exchange rate used to calculate the percentage criterion exposure. In other words, the equivalent level computed for a signal from different values of percentage criterion exposure will be equal for different exchange rates provided that the period between the bursts is less than the time constant of the exponential averaging device and the detector output does not become less than the threshold sound level. In general, the equivalent levels computed from percentage criterion exposure results based on a 3-dB exchange rate appear to be independent of the exchange rate (i.e., do not change as result of the period between bursts exceeding the value of the time constant of the exponential averaging device) and are equal to the A-weighted power spectrum levels except for effects due to the detector output crossing below the threshold sound level. Equivalent levels that are based on a 3-dB exchange rate may not be constant for a set of signals (tone-burst sequences) that have the same crest factor, and that have bursts comprised of a sine wave of the same frequency and amplitude, but may vary as a function of the power spectrum distribution corresponding to the signal upon which the equivalent level is based.

Effects on an equivalent level resulting from the output level of the rms detector becoming less than the threshold sound level appear to be a function of the maximum level of the output of the detector relative to the threshold sound level, and of the ratio of the time period that the detector output is above the threshold level to the time period that the detector output is below the threshold level. Increasing the ratio of the period of time that the detector output is greater than the threshold sound level to the period of time that the detector output is less than the threshold sound level decreases the effects on a equivalent level that result from the detector output becoming less than the threshold sound level.

6.2 Reference Dosimeter Response to Signals of Moderate-to-High Crest Factor

The response of the laboratory reference dosimeter was typically ±0.1 dB relative to the theoretical equivalent levels calculated for the signals measured by the reference dosimeter (see Tables 7 through 16). One notable exception to this was in the case of the tone-burst sequence comprised of bursts of a single cycle of a 100-Hz sine wave, having a crest factor of 30 dB. For this tone-burst sequence, the response of the reference dosimeter was on the order of −1 dB relative to the theoretical equivalent level corresponding to the tone-burst sequence.

6.3 Commercial Dosimeter Response to Signals of Moderate-to-High Crest Factor

Results of the tests of the electrical and electroacoustical A-weighted response of the commercial dosimeters relative to the theoretical response of an A-weighting filter, using continuous bands of pink noise and/or sine waves in the frequency range of 250 to 2000 Hz, indicated that the relative response of the commercial dosimeters, after applying a gain correction factor, was better than ±2.0 dB and typically better than ±0.5 dB in this frequency region (see Tables 1 and 3). Results of the electrical linearity tests on the commercial dosimeters at 1000 Hz, when performed over the range of applied levels from 85 to 125 dB and normalized to the average of the measurement results obtained at the applied levels of 85 and 95 dB ("applied levels" refers to the electrical equivalent of sound pressure levels), indicated that the commercial dosimeters were linear at 1 kHz within this range to better than ±1.0 dB and typically better than ±0.5 dB (see Table 2). Given that 99 percent of the energy of the signals used in testing the commercial with signals of moderate-to-high crest factor dosimeters was in the frequency range of 450 to 1550 Hz for the tone-burst sequences with burst durations equal to 0.010 s, 900 to 1100 Hz for the tone-burst sequences with burst durations equal to 0.10 s, and 990 to 1010 Hz for the tone-burst sequences with burst durations of 1.0 s, and given that the rms level of the sine wave comprising the waveforms used in these tests corresponded to a sound pressure level of 120 dB, the frequency response and linearity test results indicate that the frequency content (spectrum) and level of the waveforms used in testing the commercial dosimeters were within the normal operating limits of the instruments.

Figures 36 and 37 show, as a function of signal crest factor, the test results obtained using commercial dosimeters 1 through 7 expressed relative to the theoretical percentage criterion exposures and equivalent levels that correspond to the test signals when using a 5-dB exchange rate. Figures 38 and 39 show, as a function of signal crest factor, the test results obtained using commercial dosimeters 1 through 7 expressed relative to the theoretical percentage criterion exposures and equivalent levels that correspond to the test signals when using a 3-dB exchange rate. The triangles, circles, and squares shown in Figs. 36-39 correspond to test signals having burst durations equal to 0.01, 0.1, and 1.0 s, respectively.

The relative percentage criterion exposures and equivalent levels shown in Figs. 36, 37, 38, 39 indicate that the relative response of the dosimeters tend to converge, independent of burst duration, to the value of the relative response of the dosimeters to a continuous sine wave. This suggests that no significant anomalies are occurring with respect to the frequency content of the waveforms used in testing, i.e., the response of the dosimeters is independent of the bandwidth of the frequency spectrum of the test signals. There is a general tendency, however, for the response of the commercial dosimeters to diverge from the theoretical response with increasing signal crest factor. However collectively, i.e., as a group, the response of the commercial dosimeters does not appear to tend towards being greater than or less than the response of a theoretical personal noise exposure meter that conforms to the specifications outlined in ANSI S1.25-1978, nor does there appear to be any systematic tendency in the response of the commercial dosimeters to be different for longer or shorter burst durations.

As regards the tests performed using a 5-dB exchange rate, the response of the commercial dosimeters agreed with theoretical values to ±2.0 dB, or less, (typically within ±1.0 dB) for signals having a crest factor of 20 dB, and to within ±4.0 dB (typically within ±2.0 dB) for signals having a crest factor of 30 dB (see Table 18). These relative equivalent levels correspond to relative

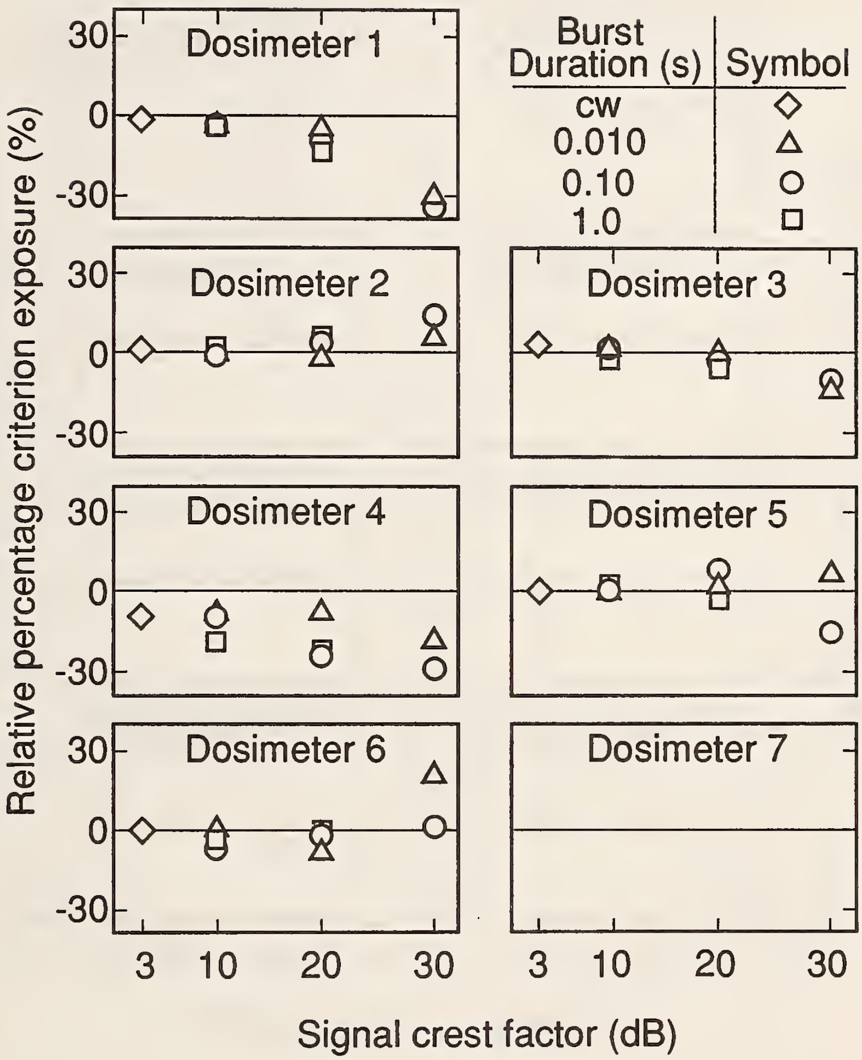

Figure 36. Relative percentage criterion exposures, based on a 5-dB exchange rate, for commercial dosimeters as a function of crest factor for test signals 1 through 9. The relative exposures plotted are the differences between measured and theoretical percentage criterion exposures. (See Table 17 for the measurement results upon which the plots are based. The plot for dosimeter 7 has been left blank since no measurement results were obtained for this dosimeter using a 5-dB exchange rate.)

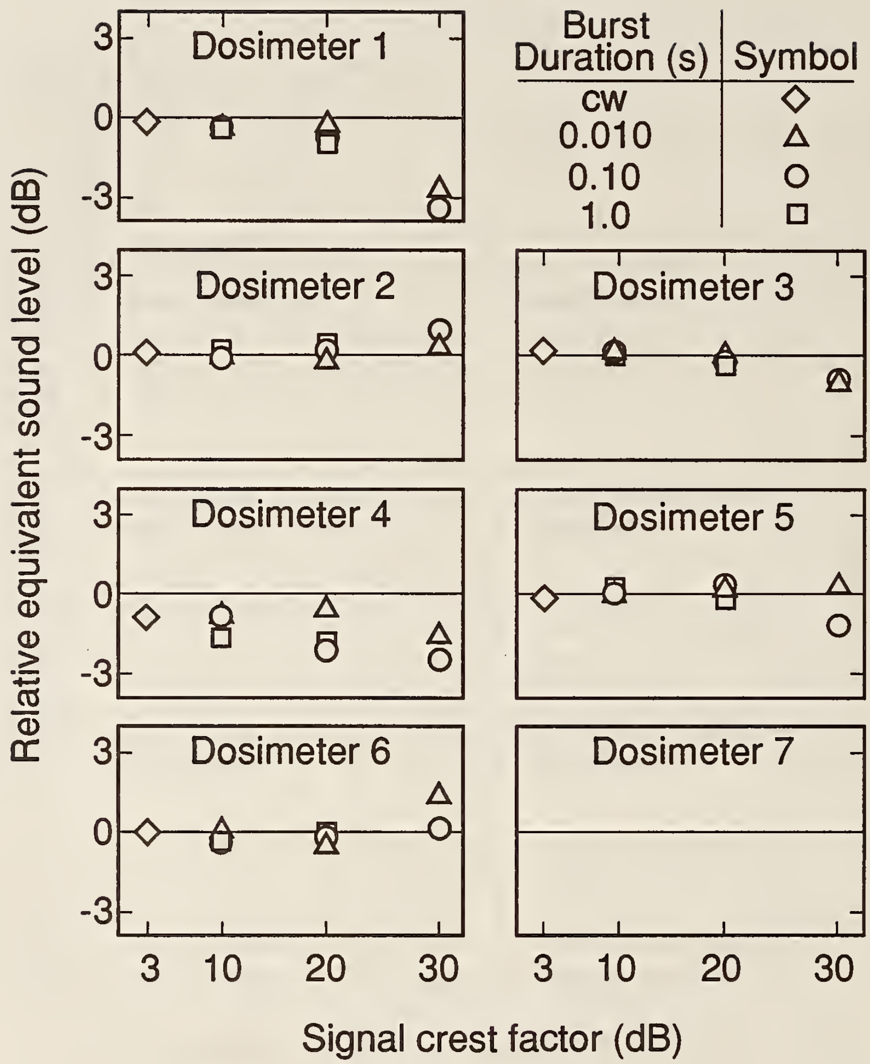

Figure 37. Relative equivalent levels corresponding to measurement results, based on a 5-dB exchange rate, obtained for commercial dosimeters as a function of crest factor for test signals 1 through 9. The levels plotted are the differences, in decibels, between measured and theoretical equivalent levels. (See Table 18 for the numbers upon which the plots are based. The plot for dosimeter 7 has been left blank, since no measurement results were obtained for this dosimeter using a 5-dB exchange rate.)

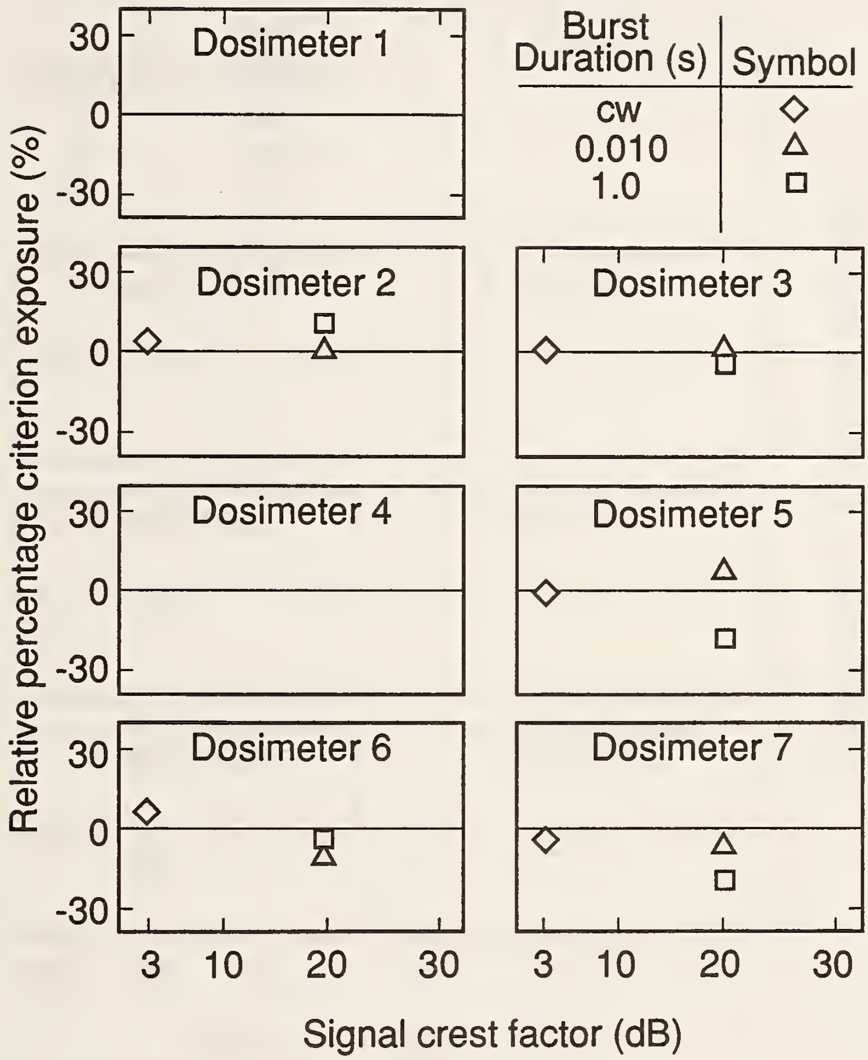

Figure 38. Relative percentage criterion exposures, based on a 3-dB exchange rate, for commercial dosimeters as a function of crest factor for test signals 1, 5, and 7. The relative exposures plotted are the differences between measured and theoretical percentage criterion exposures. (See Table 17 for the measurement results upon which the plots are based. The plots for dosimeters 1 and 4 have been left blank since no measurement results were obtained for these dosimeters using a 3-dB exchange rate.)

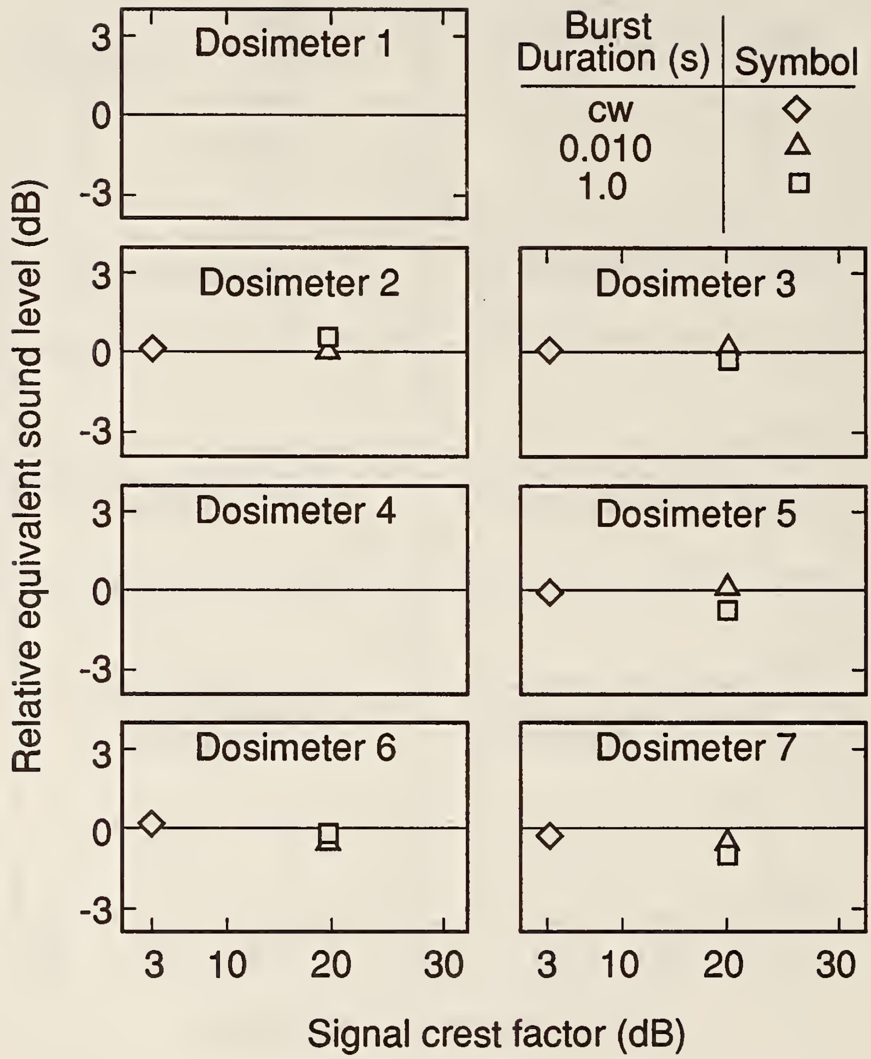

Figure 39. Relative equivalent levels corresponding to measurement results, based on a 3-dB exchange rate, obtained for commercial dosimeters as a function of crest factor for test signals 1, 5, and 7. The levels plotted are the differences, in decibels, between measured and theoretical equivalent levels. (See Table 18 for the numbers upon which the plots are based. The plots for dosimeters 1 and 4 have been left blank since no measurement results were obtained for these dosimeters using a 3-dB exchange rate.)

percentage criterion exposures on the order of ±20 percent, for signals having a crest factor of 20 dB or less, and ±40 percent, for signals having a crest factor of 30 dB.

For the tests performed using a 3-dB exchange rate, the relative equivalent levels of the commercial dosimeters were within ±1.0 dB and the relative percentage criterion exposures were within ±20 percent.

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7.2 American National Standards

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[3]This document is currently in the process of revision.

Appendix A. Symbols and Terminology

This appendix is a listing of symbols and mathematical definitions for terms appearing in this report. Dimensional units are given in square brackets.

p Instantaneous sound pressure [Pa]

p_{rms} Root-mean-square sound pressure [Pa]

p_{peak} Peak sound pressure - the maximum absolute value of p over a given time interval [Pa]

v_{rms} Root-mean-square voltage [V]

M The sensitivity of the microphone of a personal noise exposure meter [V/Pa]

p_o Reference sound pressure, 20 μPa

Sound pressure level (SPL):

$$SPL = 10 \log(p_{rms}^2/p_o^2) \text{ [dB]}$$

Peak sound pressure level (SPL_{peak}):

$$SPL_{peak} = 10 \log(p_{peak}^2/p_o^2) \text{ [dB]}$$

Voltage level commensurate with sound pressure level (VL_{spl}):

$$VL_{spl} = 10 \log[v_{rms}^2/(M\ p_o)^2] \text{ [dB]}$$

t Time [h]

T Measurement duration [h]

T_c Criterion sound duration [h]

L(t) The A-weighted sound level at the output of the sound level metering section of a personal noise exposure meter containing an exponential averaging device with a slow response characteristic (1-s time constant) [dB]

L_c Criterion sound level [dB]

L_t Threshold sound level [dB]

Q Parameter that defines the exchange rate (ER) of a personal noise exposure meter (Q is normally defined by a given exchange rate)

$Q = ER/\mathrm{Log}_{10}(2)$ [dimensionless]

For a 5-dB exchange rate, $Q = 5/\mathrm{Log}_{10}(2) = 16.60964...$

For a 3-dB exchange rate, $Q \equiv 10$

(For the so-called "3-dB" exchange rate, the actual exchange rate is $ER = 10\ \log_{10}(2) = 3.010299...$, so that Q = 10 by definition, in conformance with ANSI S1.25-1978)

Sound exposure (SE):

$$SE = \int_0^T \left[p_o^2\ 10^{L(t)/10} \right]^{10/Q} dt \qquad [(\mathrm{Pa})^{20/Q}\ \mathrm{h}] \qquad \text{(A1)}$$

<u>where only those values of L(t) in excess of the threshold level are included in the integration</u>, i.e., if $L(t) \le L_t$, the integrand is set equal to zero.

Criterion sound exposure (CSE):

$$CSE = T_c \left[p_o^2\ 10^{L_c/10} \right]^{10/Q} \qquad [(\mathrm{Pa})^{20/Q}\ \mathrm{h}] \qquad \text{(A2)}$$

Percentage criterion exposure (PCE):

$$PCE = 100\ \frac{SE}{CSE} = \frac{100}{T_c} \int_0^T \left[10^{(L(t)-L_c)/10} \right]^{10/Q} dt \qquad [\%] \qquad \text{(A3)}$$

Equivalent level (L_{eq}):

$$L_{eq} = L_c + Q \log_{10} \left[\frac{PCE}{100} \frac{T_c}{T} \right] \quad [dB] \qquad (A4)$$

Note that this definition of equivalent level is consistent with the definition appearing at the end of Sec. 4.7 of ANSI S1.25-1978, in that Q may assume a value corresponding to an arbitrary exchange rate. However, the reader is cautioned that the terms "equivalent level," "average level," and "equivalent time-weighted average level" appear in the literature with the use of the terms restricted to a 3-dB exchange rate.

Relative equivalent level ($L_{eq\text{-}rel}$):

$$L_{eq\text{-}rel} = Q \log_{10} \left[\frac{PCE}{PCE_{ref}} \frac{T_{ref}}{T} \right] \quad [dB] \qquad (A5)$$

where PCE_{ref} and T_{ref} are the respective reference percentage criterion exposure and reference measurement duration (e.g., theoretical values) relative to which an equivalent level is being expressed.

Crest factor (CF):

$$CF = 20 \log_{10} \left[\frac{x(t)_{peak}}{x(t)_{rms}} \right] \quad [dB] \qquad (A6)$$

where $x(t)_{peak}$ and $x(t)_{rms}$ are the maximum absolute value and the root-mean-square value, respectively, of the dependent variable of a periodic waveform, with time the independent variable. Unless otherwise noted, crest factor is expressed logarithmically in terms of decibels using the formula given above. The reader is cautioned that both linear $[(x(t)_{peak}/x(t)_{rms}]$ and logarithmic representations of CF appear in the literature.

Appendix B. Analytical Representation of the Response of a Noise Dosimeter to Periodic Signals

B.1 Introduction

As described in Sec. 1, a noise dosimeter can be represented by the following elements, which sequentially modify the input signal:

1) A-weighting network,
2) squaring circuit,
3) exponential time-averaging circuit, and
4) exponentiator and integrator.

In this Appendix, the response of each of these elements to a periodic input signal is considered. Section B.2 provides both the frequency-domain and the time-domain analytical representations of an ideal A-weighting network. Sections B.3 and B.4 provide two different approaches to the analytical representation of the response of a noise dosimeter to periodic signals. In each approach, the periodic input signal is first appropriately combined with the analytical representation of the A-weighting network to obtain an explicit expression for the output signal from the A-weighting network. This expression is then squared to yield an expression for the output signal from the squaring circuit. This signal, in turn, is used as the input signal to an exponential (RC) time-averaging circuit, corresponding to the "slow" response of a sound level meter, and expressions are derived for the output, or "detected," signal.

Analytical expressions are thus obtained for the response of the A-weighting network, the squaring circuit, and the exponential time-averaging circuit. For the final stage of the noise dosimeter, the "exponentiator" and integrator, numerical integration is used in order to handle arbitrary exchange rates.

In Sec. B.3, effectively the approach is to trace each Fourier component of the periodic input signal through the various elements of the noise dosimeter. For the A-weighting network and the exponential time-averaging circuit, this is done by convolving the Fourier series expansion of the input signal to the circuit element with the impulse response of that element. The analytical expressions obtained are valid for any arbitrary periodic input signal. Specific results are given for the case wherein the input signal to the dosimeter is taken to be an infinite train of tone bursts, each consisting of an integral number of cycles of a pure sine wave, with the "on-period" beginning at a positive zero crossing and ending on a negative zero crossing, followed by an "off-period" with no input signal.

In Sec. B.4, the progression of the signal through the various elements of the dosimeter is not analyzed in terms of the various Fourier components. Rather, the signal is represented by one function during the on-period and by another function during the off-period, with continuity of signal in going from the on-period to the off-period and then to the next on-period.

B.2 A-Weighting Network Representation

B.2.1 Frequency Domain

The frequency-domain transfer function for an ideal A-weighting network is given by [B1-B2][1]

$$W(j\omega) = \frac{K\omega^4}{(j\omega+\omega_1)^2(j\omega+\omega_2)(j\omega+\omega_3)(j\omega+\omega_4)^2} , \qquad \text{(B1)}$$

where $j^2 = -1$, $\omega = 2\pi f$, and f is frequency. There are four finite zeroes at $\omega = 0$, and there are six poles on the real axis, with double poles at $\omega_1 = 2\pi f_1$ and $\omega_4 = 2\pi f_4$ and single poles at $\omega_2 = 2\pi f_2$ and $\omega_3 = 2\pi f_3$. The pole frequencies are $f_1 = 20.599$, $f_2 = 107.65$, $f_3 = 737.86$, and $f_4 = 12194$ Hz. The constant K normalizes the transfer function to unit amplitude at 1000 Hz.

The amplitude response of the A-weighting network is

$$|W(j\omega)| = [W(j\omega)W^*(j\omega)]^{1/2}$$

$$= \frac{K\omega^4}{\left[(\omega^2+\omega_1^2)^2(\omega^2+\omega_2^2)(\omega^2+\omega_3^2)(\omega^2+\omega_4^2)^2\right]^{1/2}} , \qquad \text{(B2)}$$

where the asterisk denotes the complex conjugate.

The phase response associated with $W(j\omega)$ is

$$\theta(\omega) = \arctan\left[\frac{\mathrm{Im}[W(j\omega)]}{\mathrm{Re}[W(j\omega)]}\right]$$

$$= 2\pi - 2\arctan\frac{\omega}{\omega_1} - \arctan\frac{\omega}{\omega_2} - \arctan\frac{\omega}{\omega_3} - 2\arctan\frac{\omega}{\omega_4} . \qquad \text{(B3)}$$

B.2.2 Time Domain

Expanding Eq. (B1) into a sum of partial fractions and taking the inverse Laplace transformation of each term yields the time-domain impulse response of the A-weighting network,

$$h(t) = \sum_{i=1}^{4} (A_i + B_i t)e^{-\omega_i t} , \qquad \text{(B4)}$$

[1]Number in brackets indicate references cited in Sec. B.7 of this appendix.

where

$$A_1 = \frac{-K\omega_1^4}{(\omega_2-\omega_1)(\omega_3-\omega_1)(\omega_4-\omega_1)^2} \left\{ \frac{4}{\omega_1} + \frac{1}{\omega_2-\omega_1} + \frac{1}{\omega_3-\omega_1} + \frac{2}{\omega_4-\omega_1} \right\} , \qquad \text{(B5a)}$$

$$A_2 = \frac{K\omega_2^4}{(\omega_1-\omega_2)^2(\omega_3-\omega_2)(\omega_4-\omega_2)^2} , \qquad \text{(B5b)}$$

$$A_3 = \frac{K\omega_3^4}{(\omega_1-\omega_3)^2(\omega_2-\omega_3)(\omega_4-\omega_3)^2} , \qquad \text{(B5c)}$$

$$A_4 = \frac{-K\omega_4^4}{(\omega_1-\omega_4)^2(\omega_2-\omega_4)(\omega_3-\omega_4)} \left\{ \frac{4}{\omega_4} + \frac{2}{\omega_1-\omega_4} + \frac{1}{\omega_2-\omega_4} + \frac{1}{\omega_3-\omega_4} \right\} , \qquad \text{(B5d)}$$

$$B_1 = \frac{K\omega_1^4}{(\omega_2-\omega_1)(\omega_3-\omega_1)(\omega_4-\omega_1)^2} , \qquad \text{(B5e)}$$

$$B_2 = B_3 = 0, \qquad \text{(B5f)}$$

$$B_4 = \frac{K\omega_4^4}{(\omega_1-\omega_4)^2(\omega_2-\omega_4)(\omega_3-\omega_4)} . \qquad \text{(B5g)}$$

B.3 Fourier Series Approach

B.3.1 A-Weighting Network Response

If an input signal, $x(t)$, passes through a physically realizable linear filter having an impulse response $h(t)$, the output signal from the filter is given by the convolution integral

$$y(t) = \int_{-\infty}^{t} h(t-\tau)\, x(\tau)\, d\tau . \qquad \text{(B6)}$$

Let the input signal be periodic, of period T, and have as its Fourier expansion

$$x(t) = \sum_{n=0}^{\infty} [a'_n \cos n\beta t + b'_n \sin n\beta t] , \qquad \text{(B7)}$$

where $\beta = 2\pi/T$, (B8a)

$$a'_o = \frac{1}{T}\int_0^T x(t)\,dt \quad , \tag{B8b}$$

$$b'_o = 0 \quad , \tag{B8c}$$

$$a'_n = \frac{2}{T}\int_0^T x(t)\cos n\beta t\,dt \quad , \qquad n \neq 0, \tag{B8d}$$

$$b'_n = \frac{2}{T}\int_0^T x(t)\sin n\beta t\,dt \quad , \qquad n \neq 0. \tag{B8e}$$

Substitution of Eq. (B7) into Eq. (B6) yields, after integration, the Fourier expansion for the A-weighted signal,

$$y(t) = \sum_{n=0}^{\infty} [a_n \cos n\beta t + b_n \sin n\beta t] \quad , \tag{B9}$$

where

$$a_o = a'_o \sum_{i=1}^{4} \left[\frac{A_i}{\omega_i} + \frac{B_i}{\omega_i^2} \right] \equiv 0 \quad , \tag{B10a}$$

$$b_o = 0 \quad , \tag{B10b}$$

$$a_n = \sum_{i=1}^{4} \left[\frac{\omega_i a'_n - n\beta b'_n}{\omega_i^2 + n^2\beta^2} A_i + \frac{(\omega_i^2 - n^2\beta^2)a'_n - 2\omega_i n\beta b'_n}{(\omega_i^2 + n^2\beta^2)^2} B_i \right] , \tag{B10c}$$

$$b_n = \sum_{i=1}^{4} \left[\frac{n\beta a'_n + \omega_i b'_n}{\omega_i^2 + n^2\beta^2} A_i + \frac{(\omega_i^2 - n^2\beta^2)b'_n + 2\omega_i n\beta a'_n}{(\omega_i^2 + n^2\beta^2)^2} B_i \right] . \tag{B10d}$$

For the special case wherein the input signal consists of N cycles of a pure tone of unit amplitude and circular frequency $\omega = 2\pi f$, with the on-period beginning at a positive zero crossing and ending at a negative zero crossing,

$$x(t) = \begin{cases} \sin \omega t & , \quad 0 \le t \le N/f \\ 0 & , \quad N/f \le t \le T \end{cases} \tag{B11}$$

and the Fourier coefficients become, from Eqs. (B8),

$$a'_o = b'_o = 0 \quad , \tag{B12a}$$

$$a'_n = \begin{cases} \dfrac{fT}{\pi(f^2T^2-n^2)} [1 - \cos(2n\pi N/fT)] \quad , & n \neq fT \\ 0 \quad , & n = fT \end{cases} \tag{B12b}$$

$$b'_n = \begin{cases} \dfrac{-fT}{\pi(f^2T^2-n^2)} [\sin(2n\pi N/fT)] \quad , & n \neq fT \\ N/fT \quad , & n = fT \end{cases} \tag{B12c}$$

The result obtained by substituting Eqs. (B12) into Eqs. (B10) was independently checked by taking the inverse Laplace transform of the product of the (forward) Laplace transform of Eq. (B6) and the transfer function of an A-weighting network (Eq. (B1)). Note: both transient and steady-state terms were obtained using the Laplace transform technique with only the steady-state terms (general solution of the homogeneous equation) used in the check.

B.3.2 Squaring Circuit Response

Squaring the expression (Eq. (B9)) for the signal at the input to the squaring circuit yields

$$y^2(t) = \sum_{k=0}^{\infty} \sum_{\ell=0}^{\infty} (a_k \cos k\beta t + b_k \sin k\beta t)(a_\ell \cos \ell\beta t + b_\ell \sin \ell\beta t) \quad . \tag{B13}$$

Carrying out the indicated multiplications and using trigonometric identities results in

$$y^2(t) = \frac{1}{2} \sum_{k=0}^{\infty} \sum_{\ell=0}^{\infty} [(a_k a_\ell + b_k b_\ell) \cos(k-\ell)\beta t + (a_k a_\ell - b_k b_\ell) \cos(k+\ell)\beta t$$
$$+ (a_k b_\ell + b_k a_\ell) \sin(k+\ell)\beta t + (b_k a_\ell - a_k b_\ell) \sin(k-\ell)\beta t] \quad . \tag{B14}$$

Collecting terms for $n = k-\ell$ and for $n = k+\ell$ leads to the following Fourier expansion for the output signal from the squaring circuit:

$$y^2(t) = \sum_{n=0}^{\infty} [c_n \cos n\beta t + d_n \sin n\beta t] \quad , \tag{B15}$$

where

$$c_o = a_o^2 + \frac{1}{2} \sum_{m=1}^{\infty} (a_m^2 + b_m^2) \;, \tag{B16a}$$

$$d_o = 0, \tag{B16b}$$

$$c_n = \frac{1}{2} \sum_{m=0}^{n} (a_m a_{n-m} - b_m b_{n-m}) + \sum_{m=n}^{\infty} (a_m a_{m-n} + b_m b_{m-n}) \quad , \; m \neq 0 \quad , \tag{B16c}$$

$$d_n = \sum_{m=0}^{n} a_m b_{n-m} + \sum_{m=n}^{\infty} (b_m a_{m-n} - a_m b_{m-n}) \quad , \; m \neq 0 \quad . \tag{B16d}$$

B.3.3 Exponential Time-Averaging Circuit Response

The exponential time-averager in a noise dosimeter consists of a single-pole low-pass filter having as its impulse response

$$h(t) = \alpha e^{-\alpha t} . \tag{B17}$$

For a "slow" response detector, as required by OSHA regulations, $\alpha = 1\ s^{-1}$. (For "fast" response, $\alpha = 8\ s^{-1}$.)

Substituting Eqs. (B15) and (B17) into Eq. (B6) and performing the indicated integration leads to the Fourier expansion of the output signal from the detector,

$$z(t) = \sum_{n=0}^{\infty} [p_n \cos n\beta t + q_n \sin n\beta t] \quad , \tag{B18}$$

where

$$p_n = \frac{\alpha(\alpha c_n - n\beta d_n)}{\alpha^2 + n^2\beta^2} \tag{B19a}$$

$$q_n = \frac{\alpha(n\beta c_n + \alpha d_n)}{\alpha^2 + n^2\beta^2} \quad . \tag{B19b}$$

B.4 Two-Region Approach

B.4.1 A-Weighting Network Response

If a periodic signal, $x(t) = x(t \pm nT)$, is passed through a realizable linear filter of impulse response $h(t)$, the output signal is, from Eq. (B6),

$$y(t) = \int_0^t h(t-\tau)\, x(\tau)\, d\tau + \sum_{n=0}^{\infty} \int_{-(n+1)T}^{-nT} h(t-\tau)\, x(\tau)\, d\tau$$

$$= \int_0^t h(t-\tau)\, x(\tau)\, d\tau + \sum_{n=0}^{\infty} \int_0^T h[t+(n+1)T-\tau]\, x(\tau)\, d\tau. \qquad \text{(B20)}$$

Substituting the impulse response of the A-weighting network, from Eq. (B4), into Eq. (B20), the A-weighted periodic signal is

$$y(t) = \sum_{i=1}^{4} y_i(t) \quad , \qquad \text{(B21)}$$

where

$$e^{\omega_i t} y_i(t) = (A_i + B_i t) I_i(t) - B_i J_i(t)$$

$$+ \sum_{n=0}^{\infty} \left\{A_i + B_i[t + (n+1)T]\right\} e^{-\omega_i (n+1)T} I_i(T)$$

$$- B_i \sum_{n=0}^{\infty} e^{-\omega_i (n+1)T} J_i(T) \quad , \qquad \text{(B22)}$$

$$I_i(t) = \int_0^t e^{\omega_i \tau} x(\tau)\, d\tau \quad , \qquad \text{(B23)}$$

$$J_i(t) = \int_0^t \tau e^{\omega_i \tau} x(\tau)\, d\tau \quad . \qquad \text{(B24)}$$

Substituting

$$\sum_{n=0}^{\infty} e^{-\omega_i (n+1)T} = \frac{e^{-\omega_i T}}{1 - e^{-\omega_i T}}$$

and

$$\sum_{n=0}^{\infty} (n+1)T\, e^{-\omega_i (n+1)T} = \frac{T e^{-\omega_i T}}{\left[1 - e^{-\omega_i T}\right]^2}$$

into Eq. (B22) yields

$$y_i(t) = \left\{ \frac{I_i(t) + [I_i(T) - I_i(t)] e^{-\omega_i T}}{1 - e^{-\omega_i T}} \right\} A_i e^{-\omega_i t}$$

$$+ \left\{ t[I_i(t) - I_i(T)] + \frac{[t + (T-t) e^{-\omega_i T}] I_i(T)}{\left[1 - e^{-\omega_i T}\right]^2} \right.$$

$$\left. - \frac{J_i(t) + [J_i(T) - J_i(t)] e^{-\omega_i T}}{1 - e^{-\omega_i T}} \right\} B_i e^{-\omega_i t} \quad , \qquad \text{(B25)}$$

where the terms have been arranged to facilitate demonstration of periodicity, i.e.,

$$y_i(0) = y_i(T) = \left[\frac{I_i(T)}{1 - e^{-\omega_i T}} \right] A_i e^{-\omega_i T}$$

$$+ \left[\frac{T I_i(T)}{(1 - e^{-\omega_i T})^2} - \frac{J_i(T)}{1 - e^{-\omega_i T}} \right] B_i e^{-\omega_i T} . \qquad \text{(B26)}$$

Equations (B21), (B25), (B23), and (B24) provide the output of the A-weighting network for an arbitrary periodic input signal, $x(t)$.

For the special case of a tone burst, as defined by Eq. (B11), Eqs. (B23) and (B24) yield

$$
I_i(t) = \begin{cases} \dfrac{e^{\omega_i t}}{\omega_i^2 + \omega^2} \left(\omega_i \sin \omega t - \omega \cos \omega t + \omega e^{-\omega_i t}\right) & , \quad 0 \le t \le N/f \\[2ex] -\dfrac{\omega}{\omega_i^2 + \omega^2} \left[e^{\omega_i N/f} - 1\right] & , \quad N/f \le t \le T) \end{cases} \tag{B27}
$$

and

$$
J_i(t) = \begin{cases} \dfrac{e^{\omega_i t}}{(\omega_i^2 + \omega^2)^2} \Big\{[(\omega_i^2+\omega^2)\omega_i t - (\omega_i^2-\omega^2)] \sin \omega t \\ \qquad - [(\omega_i^2+\omega^2)\omega t - 2\omega_i \omega] \cos \omega t - 2\omega_i \omega e^{-\omega_i t}\Big\} & , \quad 0 \le t \le N/f \\[2ex] -\dfrac{2e^{\omega_i N/f}}{(\omega_i^2 + \omega^2)^2} \left[(\omega_i^2+\omega^2)N\pi - \omega_i \omega(1-e^{-\omega_i N/f})\right] & , \quad N/f \le t \le T) \end{cases} \tag{B28}
$$

Combining Eqs. (B21), (B25), (B27), and (B28), the A-weighted tone burst signal is described by

$$
y(t) = \begin{cases} D \sin \omega t + E \cos \omega t + F(t) + tG(t) & , \quad 0 \le t \le N/f \\ U(t) + tV(t) & , \quad N/f \le t \le T) \end{cases} \tag{B29}
$$

where

$$
D = \sum_{i=1}^{4} \left[\frac{\omega_i A_i}{\omega_i^2 + \omega^2} + \frac{(\omega_i^2 - \omega^2) B_i}{(\omega_i^2 + \omega^2)^2} \right] , \tag{B30a}
$$

$$
E = \sum_{i=1}^{4} \left[- \frac{\omega_i A_i}{\omega_i^2 + \omega^2} - \frac{2\omega_i \omega B_i}{(\omega_i^2 + \omega^2)^2} \right] , \tag{B30b}
$$

$$
F(t) = \sum_{i=1}^{4} F_i e^{-\omega_i t} \tag{B30c}
$$

$$
F_i = \zeta_i(T) A_i + \eta_i(T) B_i \quad , \tag{B30d}
$$

$$G(t) = \sum_{i=1}^{4} G_i e^{-\omega_i t} \tag{B30e}$$

$$G_i = \zeta_i(T) B_i \ , \tag{B30f}$$

$$U(t) = \sum_{i=1}^{4} U_i e^{-\omega_i (t - N/f)} \tag{B30g}$$

$$U_i = e^{-\omega_i N/f} \left[\zeta_i(0) A_i + \eta_i(0) B_i \right] \ , \tag{B30h}$$

$$V(t) = \sum_{i=1}^{4} V_i e^{-\omega_i (t - N/f)} \ , \tag{B30i}$$

$$V_i = e^{-\omega_i N/f} \zeta_i(0) B_i \ , \tag{B30j}$$

$$\zeta_i(t) = \frac{\omega}{\omega_i^2 + \omega^2} \ \frac{1 - e^{-\omega_i (t - N/f)}}{1 - e^{-\omega_i T}} \ , \tag{B30k}$$

$$\eta_i(t) = \frac{1}{(\omega_i^2 + \omega^2)\left(1 - e^{-\omega_i T}\right)} \left[2N\pi e^{-\omega_i (t-N/f)} + \frac{2\omega_i \omega \left(1 - e^{-\omega_i (t-N/f)}\right)}{\omega_i^2 + \omega^2} - \frac{\omega T (e^{\omega_i N/f} - 1) e^{-\omega_i T}}{1 - e^{-\omega_i T}} \right] . \tag{B30ℓ}$$

Note that when U_i is substituted into U(t) and V_i into V(t), the $\exp(\omega_i N/f)$ factor drops out. These definitions of U_i and V_i are used to simplify certain equations which follow in Sec. B.4.3, below.

B.4.2 Squaring Circuit Response

Squaring Eq. (B29) yields

$$y^2(t) = \begin{cases} D^2\sin^2\omega t + E^2\cos^2\omega t + F^2(t) + t^2G^2(t) + 2DE \sin \omega t \cos \omega t \\ \quad + 2DF(t)\sin \omega t + 2DtG(t)\sin \omega t + 2EF(t)\cos \omega t \\ \quad + 2EtG(t)\cos \omega t + 2tF(t)G(t) \quad , \qquad 0 \le t \le N/f \\ \\ U^2(t) + t^2V^2(t) + 2tU(t)V(t) \quad , \qquad N/f \le t \le T \end{cases} \tag{B31}$$

as the output of the squaring circuit.

B.4.3 Detector Response

The output of the detector circuit, obtained by substitution of Eq. (B17) into Eq. (B6), can be written as

$$z(t) = \left[\alpha I(t)e^{-\alpha t} \right] + \left[\alpha I(T)e^{-\alpha T} \right] \frac{e^{-\alpha t}}{1 - e^{-\alpha T}} \quad , \tag{B32}$$

where

$$I(t) = \int_0^t e^{\alpha\tau}\, y^2(\tau)\, d\tau \quad . \tag{B33}$$

The form of Eq. (B32) facilitates demonstration of the fact that $z(0) = z(T) = \alpha I(T)e^{-\alpha T}/(1 - e^{-\alpha T})$. Substitution of Eq. (B31) into Eq. (B33) leads, after considerable algebra, to

$$\alpha I(t)e^{-\alpha t} = \begin{cases} \dfrac{D^2 + E^2}{2} + He^{-\alpha t} + P \sin 2\omega t + Q \cos 2\omega t \\ \quad + R(t) \sin \omega t + S(t) \cos \omega t + X(t) \quad , \quad 0 \le t \le N/f \\ \\ \left[\alpha I(N/f)e^{-\alpha N/f} + Y\right]e^{-\alpha(t - N/f)} + Z(t) \quad , \; N/f \le t \le T \end{cases} \tag{B34}$$

where

$$H = \frac{2\alpha\omega DE - (\alpha^2 + 2\omega^2)E^2 - 2\omega^2 D^2}{\alpha^2 + 4\omega^2} + \sum_{i=1}^{4} \alpha\phi_i(0) - \sum_{i=1}^{4}\sum_{j=1}^{4} \alpha\theta_{ij}(0) \quad , \qquad \text{(B35a)}$$

$$P = \frac{\alpha^2 DE + \alpha\omega(E^2 - D^2)}{\alpha^2 + 4\omega^2} \quad , \qquad \text{(B35b)}$$

$$Q = \frac{\alpha^2(E^2 - D^2) - 4\alpha\omega DE}{2(\alpha^2 + 4\omega^2)} \quad , \qquad \text{(B35c)}$$

$$R(t) = \sum_{i=1}^{4} \alpha e^{-\omega_i t}\left[\frac{2[(\alpha-\omega_i)D + \omega E](F_i+G_i t)}{(\alpha-\omega_i)^2 + \omega^2} - \frac{2[(\alpha-\omega_i)^2-\omega^2]D + 4(\alpha-\omega_i)\omega E}{\left[(\alpha-\omega_i)^2 + \omega^2\right]^2} G_i\right] \quad , \qquad \text{(B35d)}$$

$$S(t) = -\sum_{i=1}^{4} \alpha e^{-\omega_i t} \phi_i(t) \quad , \qquad \text{(B35e)}$$

$$X(t) = \sum_{i=1}^{4}\sum_{j=1}^{4} \alpha e^{-(\omega_i+\omega_j)t} \theta_{ij}(t) \quad , \qquad \text{(B35f)}$$

$$Y = -\sum_{i=1}^{4}\sum_{j=1}^{4} \alpha\psi_{ij}(N/f) \quad , \qquad \text{(B35g)}$$

$$Z(t) = \sum_{i=1}^{4}\sum_{j=1}^{4} \alpha e^{-(\omega_i+\omega_j)t} \psi_{ij}(t) \quad , \qquad \text{(B35h)}$$

$$\phi_i(t) = \frac{2[\omega D-(\alpha-\omega_i)E](F_i+G_i t)}{(\alpha-\omega_i)^2 + \omega^2} + \frac{2\left[(\alpha-\omega_i)^2-\omega^2\right]E - 4(\alpha-\omega_i)\omega D}{\left[(\alpha-\omega_i)^2 + \omega^2\right]^2} G_i \quad , \qquad \text{(B35i)}$$

$$\theta_{ij}(t) = \frac{F_iF_j}{\omega_{ij}} + \frac{2F_iG_j}{\omega_{ij}^2}(\omega_{ij}t-1) + \frac{G_iG_j}{\omega_{ij}^3}(\omega_{ij}^2t^2 - 2\omega_{ij}t + 2) \quad , \tag{B35j}$$

$$\psi_{ij}(t) = \frac{U_iU_j}{\omega_{ij}} + \frac{2U_iV_j}{\omega_{ij}^2}(\omega_{ij}t-1) + \frac{V_iV_j}{\omega_{ij}^3}(\omega_{ij}^2t^2 - 2\omega_{ij}t + 2) \quad , \tag{B35k}$$

$$\omega_{ij} = \alpha - \omega_i - \omega_j \quad . \tag{B35ℓ}$$

B.5 Mean-Square Values

The mean-square value of a periodic input signal, $x(t)$, is

$$\langle x^2 \rangle = \frac{1}{T}\int_0^T x^2(t)\, dt \quad , \tag{B36}$$

where T is the period. For a tone burst of unit amplitude, as defined by Eq. (B11),

$$\langle x^2 \rangle = \frac{1}{T}\int_0^T \sin^2(t)\, dt = \frac{N}{2fT} \quad . \tag{B37}$$

The quantity N/fT is the "duty factor" of the signal, i.e., the fraction of the period during which the tone is "on."

Alternatively, Eq. (B7) can be substituted into Eq. (B36), yielding

$$\langle x^2 \rangle = a_o'^2 + \frac{1}{2}\sum_{n=1}^{\infty}(a_n'^2 + b_n'^2) \quad , \tag{B38}$$

in conformance with Parseval's theorem. For a tone-burst sequence, the values for a_n' and b_n' from Eqs. (B12) result in

$$a_n'^2 + b_n'^2 = \begin{cases} \left[\dfrac{2\sin(n\pi N/fT)}{\pi fT(1 - n^2/f^2T^2)}\right]^2 \quad , & n \neq fT \\ \dfrac{N^2}{f^2T^2} \quad , & n = fT. \end{cases} \tag{B39}$$

In the limit as the duty factor approaches unity (i.e., the tone is on most of the time), the frequency spectrum given by Eq. (B39) becomes quite narrow, approaching that of the pure tone. As N/fT becomes small, approaching zero, the frequency spectrum of the tone burst becomes quite broad, with power spread over a wide range of frequencies.

The mean-square value of an A-weighted periodic signal is, by analogy to Eq. (B38),

$$\langle y^2 \rangle = \frac{1}{2} \sum_{n=1}^{\infty} (a_n^2 + b_n^2) \quad . \tag{B40}$$

Substitution of Eqs. (B12) and (B10) into Eq. (B40) would, after simplification, yield

$$\langle y^2 \rangle = \frac{1}{2} \sum_{n=1}^{\infty} W_n^2 (a_n'^2 + b_n'^2) \quad , \tag{B41}$$

where W_n is given by Eq. (B2), evaluated at $\omega = 2\pi n/T$. Thus, as seen by comparison of Eqs. (B38) and (B41), each spectral component of the input signal is modified by the squared amplitude response of the A-weighting network at the corresponding frequency. Thus the power spectrum of a weighted tone-burst sequence is given by Eq. (B41), with $(a_n'^2 + b_n'^2)$ given by Eq. (B39).

B.6 Computation of Percentage Criterion Exposure

For the case of a 3-dB exchange rate, the exponentiation and integration circuit of an ideal dosimeter yields a result that is simply proportional to the mean-square value of the signal, provided that the detected signal level does not fall below the threshold level. If the threshold is crossed, it is necessary to integrate the output of the exponential time-averaging circuit over the time period(s) when it is above the threshold value. For the case of a 5-dB exchange rate, analytical integration is not possible and it is necessary to use numerical integration in all cases, whether or not the detected level falls below the threshold level.

Computer programs (in FORTRAN) were written to compute the A-weighted, squared, and detected signal using:

1. Fourier Series Approach (Eq. (B18))

2. Two-Region Approach (Eq. (B32)).

The results of these two programs agreed to better than 0.01 dB provided sufficient terms were included in the Fourier series approach. Since the computations for the two-region approach took much less time than those for the Fourier series approach, Eq. (B32) was used for the theoretical results presented in this report.

A computer program using a proprietary numerical integration routine was written to carry out the exponentiation and integration of the detected signal, resulting in either a percentage criterion exposure or an equivalent level. In accordance with Eq. (A1), the integration only summed in the detected signal when its level was equal to or greater than the equivalent of the threshold sound level (see Sec. 1, p. 2, regarding an inconsistency in ANSI S1.25-1978 as to how signal levels equal to the threshold sound level are to be handled).

B.7 References

[B1] American national standard specification for sound level meters, ANSI S1.4-1983 (ASA 47). New York, NY: American National Standards Institute, Inc. (American Institute of Physics for the Acoustical Society of America); 1983. 18 p.

[B2] American national standard design response of weighting networks for acoustical measurements, ANSI S1.42-1986 (ASA 64). New York, NY: American National Standards Institute, Inc. (American Institute of Physics for the Acoustical Society of America); 1986. 9 p.

Appendix C. Laboratory Apparatus

The following list of equipment has been included in order to document the laboratory apparatus that was utilized in performing the tests and procedures addressed in this technical note. The identification of the equipment listed does not imply recommendation or endorsement of the equipment by the National Institute of Standards and Technology, nor does it imply that the equipment identified is necessarily the best available for the purpose.

The blocks and other symbols in Fig. 2 correspond to the following specific equipment:

Electrical signal source system with monitoring equipment

FCN GEN:	Hewlett Packard Model 3314A Function Generator.
AMP:	Hewlett Packard Model 467A Power Amplifier/Supply.
Counter:	Soltec Model 6003 Counter.
DMM 1:	Fluke Model 8060A Digital Multimeter.
RES:	600 Ω (nominal) resistor.
ATT:	Daven Type VT 795 G Attenuation Network.
Scope:	Tektronix 7704 Oscilloscope with 7A18 Dual Trace Amplifier, M2 Sample/Hold Module, 7D12 A/D Converter, 7B53 Delaying Time Base, and 7B70 Time Base.
NET:	A resistor, or network of resistors, providing a nominal 600 Ω load at the output of the attenuation network (ATT).
DMM 2:	Keithley Model 172 Digital Multimeter.

Laboratory reference noise dosimeter

MA:	Brüel and Kjaer Type 2636 Measuring Amplifier.
COMP:	Hewlett Packard Model 9836A Technical Computer.
Print:	Hewlett Packard printer.
Plot:	Hewlett Packard Model 9872T Graphics Plotter.

The equipment for Fig. 3 was the same as that listed for Fig. 2 except add:

COMP:	Hewlett Packard Model 9836A Technical Computer.
DUT:	Device (commercial dosimeter) under Test

The equipment for Fig. 4, Fig. 5, and Fig. 6 was as follows:

Low-frequency signal source system with monitoring equipment.

COMP:	Hewlett Packard Model 9836A Technical Computer.
FCN GEN:	Hewlett Packard Model 3314A Function Generator.
AMP:	Hewlett Packard Model 467A Power Amplifier/Supply.
Counter:	Soltec Model 6003 Counter.
RES:	600 Ω (nominal) resistor.
ATT:	Daven Type VT 795 G Attenuation Network.
Scope:	Tektronix 7704 Oscilloscope with 7A18 Dual Trace Amplifier, M2 Sample/Hold Module, 7D12 A/D Converter, 7B53 Delaying Time Base, and 7B70 Time Base.
POT:	Precision potentiometer and resistor providing a nominal 600 Ω load at the output of the attenuation network (ATT).
PWR:	Crown Model D-60 Dual-Channel Power Amplifier.
DMM 1:	Fluke Model 8860A Digital Multimeter.
Coupler:	GenRad Transducer Assembly. The coupler was the same as that normally used as the "Transducer Assembly" in a GenRad Model GR 1986 Omnical Sound Level Calibrator, and included a transducer cable and housing (top and bottom), desiccant kit, transducer, gaskets, and screws.

Acoustical calibration system

MIC:	Brüel and Kjaer Type 4134 Condenser Microphone Cartridge fitted with Brüel and Kjaer Adapters DB 0225 and DB 0111.

PRE: Brüel and Kjaer Type 2619 Microphone Preamplifier.

MA: Brüel and Kjaer Type 2636 Measuring Amplifier.

DMM 2: Fluke Model 8060A Digital Multimeter.

Laboratory reference noise dosimeter

MIC: Brüel and Kjaer Type 4134 Condenser Microphone Cartridge.

PRE: Brüel and Kjaer Type 2619 Microphone Preamplifier.

PS: Brüel and Kjaer Type 2801 Microphone Power Supply.

MA: Brüel and Kjaer Type 2636 Measuring Amplifier.

DMM 2: Fluke Model 8060A Digital Multimeter.

The equipment for Fig. 7 was as follows:

High-frequency acoustical signal source system with monitoring equipment.

N GEN: Brüel and Kjaer Type 1402 Random Noise Generator.

FLTR: Brüel and Kjaer Type 2121 Frequency Analyzer.

PWR: McIntosh MC 2100 Power Amplifier.

MA 3: Brüel and Kjaer Type 2607 Measuring Amplifer

Scope: Tektronix 434 Storage Oscilloscope.

Driver and horn: JBL Model 2445J Compression Driver and Model 2380 Bi-Radial Horn.

Laboratory reference noise dosimeter

MIC 1: Brüel and Kjaer Type 4134 Condenser Microphone Cartridge.

PRE 1: Brüel and Kjaer Type 2619 Microphone 78Preamplifier.

PS 1: Brüel and Kjaer Type 2801 Microphone Power Supply.

MA 1:	Brüel and Kjaer Type 2636 Measuring Amplifier.

Acoustical reference system

MIC 2:	Brüel and Kjaer Type 4138 Condenser Microphone Cartridge.
PRE 2:	Brüel and Kjaer Type 2618 Microphone Preamplifier.
PS 2:	Brüel and Kjaer Type 2801 Microphone Power Supply.
MA 2:	Brüel and Kjaer Type 2607 Measuring Amplifier.
DMM:	Fluke Model 8860A Digital Multimeter.

NIST-114A
(REV. 3-89)

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NATIONAL INSTITUTE OF STANDARDS AND TECHNOLOGY

BIBLIOGRAPHIC DATA SHEET

1. PUBLICATION OR REPORT NUMBER
NIST/TN-1286

2. PERFORMING ORGANIZATION REPORT NUMBER

3. PUBLICATION DATE
June 1991

4. TITLE AND SUBTITLE
Response of Personal Noise Dosimeters to Continuous and Impulse-Like Signals

5. AUTHOR(S)
D. J. Evans, D. R. Flynn, V. Nedzelnitsky, and E. D. Burnett

6. PERFORMING ORGANIZATION (IF JOINT OR OTHER THAN NIST, SEE INSTRUCTIONS)
U.S. DEPARTMENT OF COMMERCE
NATIONAL INSTITUTE OF STANDARDS AND TECHNOLOGY
GAITHERSBURG, MD 20899

7. CONTRACT/GRANT NUMBER

8. TYPE OF REPORT AND PERIOD COVERED
Final

9. SPONSORING ORGANIZATION NAME AND COMPLETE ADDRESS (STREET, CITY, STATE, ZIP)
OSHA
Room N3653
200 Constitution Ave., NW
Washington, DC 20210

10. SUPPLEMENTARY NOTES

☐ DOCUMENT DESCRIBES A COMPUTER PROGRAM; SF-185, FIPS SOFTWARE SUMMARY, IS ATTACHED.

11. ABSTRACT (A 200-WORD OR LESS FACTUAL SUMMARY OF MOST SIGNIFICANT INFORMATION. IF DOCUMENT INCLUDES A SIGNIFICANT BIBLIOGRAPHY OR LITERATURE SURVEY, MENTION IT HERE.)
A study of the capabilities of noise dosimeters to measure personal exposure to time-varying and impulse-like noises was carried out. Ten commercial noise dosimeters were obtained. A laboratory reference noise dosimeter was constructed to provide a demonstrably accurate basis with which to compare the commercial noise dosimeters. Each commercial dosimeter, when ordered from the manufacturer, was specified to have: (1) a threshold A-weighted sound level of 80 dB, (2) a criterion sound level of 90 dB, and (3) an exchange rate of 5 dB and/or 3 dB. A preliminary series of tests employing electrical input signals was performed to check the stability and gain linearity of each dosimeter as well as its ability to process (1) signals having moderate (up to 10 dB) crest factors and (2) an input signal that should cause the output signal of the detector to repeatedly cross the threshold sound level. All but one dosimeter was able to approximate closely the percentage criterion exposures of the preliminary tests. Seven of the ten dosimeters were selected for further testing, involving electrical and electroacoustical frequency response, electrical linearity, and electrical response to tone-burst sequences with burst durations of 0.01, 0.1, and 1.0 s and crest factors of 10, 20, and 30 dB. The performance of the commercial dosimeters was compared with theory and with results obtained from the reference dosimeter. Additional electrical tone-burst sequence tests, employing a wider range of burst durations and crest factors, were performed using the reference dosimeter and the results of these tests were compared with theoretical calculations. Except in a few isolated cases, the commercial dosimeters were in general agreement with the performance specification of the appropriate American National Standard and with OSHA regulations.

12. KEY WORDS (6 TO 12 ENTRIES; ALPHABETICAL ORDER; CAPITALIZE ONLY PROPER NAMES; AND SEPARATE KEY WORDS BY SEMICOLONS)
Acoustical instrumentation; dosimeter; impulsive noise; noise dosimeter; noise exposure; noise measurement; occupational noise; sound exposure

13. AVAILABILITY

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- [x] ORDER FROM NATIONAL TECHNICAL INFORMATION SERVICE (NTIS), SPRINGFIELD, VA 22161.

14. NUMBER OF PRINTED PAGES
156

15. PRICE

ELECTRONIC FORM

☆ U.S. GOVERNMENT PRINTING OFFICE: 1991 — 281-557/40450

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