CHAPTER 38
SOUND LEVEL METERS*

George S. K. Wong
Institute for National Measurement Standards
National Research Council Canada
Ottawa, Ontario, Canada

1 INTRODUCTION

Sound level meters are designed to measure sound over a range of frequencies and levels comparable to the range of the human ear. The human ear can sense sound in the frequency range from about 15 to 16,000 Hz and pressure changes in a range with a ratio in excess of 1 to 1×10^7. Sound level meters measure and display changes in sound pressures in a systematic manner. Sound pressures are compressed logarithmically so that the 1 to 1×10^7 ratio range is expressed as 0 to 140 dB. The display, whether a ballistic meter movement or a digital display that updates only a few times a second, does not show sound pressure changes instantaneously. Instead, it averages the changes in one of several methods to produce a readable number. The two principal methods are exponential averaging and integrating averaging. Optional features that may be included in sound level meters (SLMs) include peak level, peak hold, maximum level, minimum level, noise dose, sound exposure, events, and exceedance levels with statistical distributions and time histories.

*This chapter is based on Chapter 155, Sound Level Meters, by R.W. Krug, in Volume 4, pp. 1845–1854 of *Encyclopedia of Acoustics*, edited by Malcolm J. Crocker, Wiley, New York, 1997.

1.1 Principles of Operation

Exponential-averaging meters (see Fig. 1) measure sound pressure from a microphone. The microphone, amplifier, and weighting circuit limit the frequencies to a prescribed range. The signal is then squared, so positive and negative pressure changes are converted to the square of the input signal.

The time constant is a single-pole low-pass filter with an exponential time constant. The meter may be graduated directly in decibels (uneven scale), which compresses the low end of the scale and expands the high end, or the logarithm of the signal is taken to produce a linear display in decibels.

Integrating-averaging SLMs (see Fig. 2) detect, frequency weight, and square the sound pressure level similar to exponential-averaging SLMs. The squared signal is integrated. The logarithm of the integrated signal has the logarithm of time subtracted from it. Thus, the level is divided by time or averaged over a time period. The level is then displayed on a meter movement or digital display.

Apart from the microphone and amplifier (including preamplifier) shown in Figs. 1 and 2, a computer can emulate nearly all of the succeeding functions with a microprocessor or with a lap-top computer configured as sound pressure level measuring equipment.

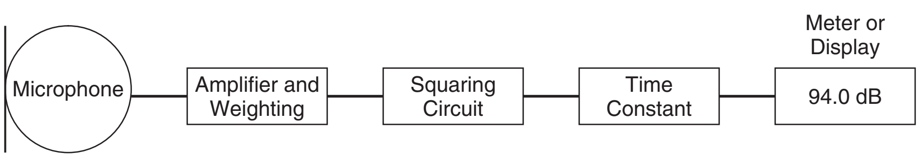

Figure 1 Exponential-averaging SLM.

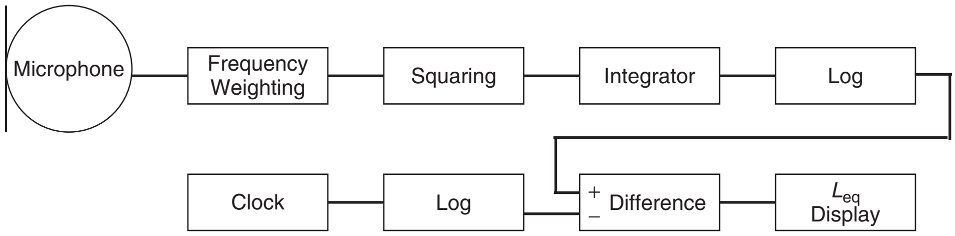

Figure 2 Integrating-averaging SLM.

Handbook of Noise and Vibration Control. Edited by Malcolm J. Crocker

1.2 National and International Standards

Standard specifications are required to ensure the sound is measured in a systematic and reproducible manner. Any number of frequency weightings, time constants, and integration methods could be used. Standards prescribe specific methods of measuring sound, and each generation of standards that have different tolerance limits for measurements, such as A-weighted levels, will make it difficult to correlate data on hearing conservation collected with older SLMs that satisfied the standards of the day. In view of the existence of a large number of older SLMs that are still operational and may be in use, it may be worthwhile to discuss briefly the requirements of some older standards. Some of the older and more recent SLM standards are listed below:

ANSI Sl.4-1983[1] and ANSI S1.4A-1985 Amendment to S1.4: Specification for sound level meters
ANSI Sl.25–1978, 1991[2]: Specification for personal noise dosimeters
IEC 60651-1979[3]: Sound level meters
IEC 60804-1984[4]: Integrating-averaging sound level meters
IEC 61252-2002[5]: Specifications for personal sound exposure meters
IEC 61672-1, 2002[6]: Sound level meters—Part 1: Specifications
IEC 61672-2, 2003[7]: Sound level meters—Part 2: Pattern evaluation tests
IEC 61672-3, 200X (under development): Sound level meters—Part 2: Periodic verification

The above International Electrotechnical Commission (IEC) 61672 series have superseded some of the older SLM standards, and the American National Standards Institute (ANSI) S1.4 is currently under revision. Terminology used in this chapter has been defined in the above standards.

The ANSI S1.4–1978 and the IEC 60651-1979 both specify exponential-averaging SLMs. They are similar except for the directional specifications of the microphone (see Section 2.2). Both specify three accuracy types of meters: type 0, type 1, and type 2. Type 0 instruments are the most accurate and are intended as laboratory standards. Type 1 instruments are intended for laboratory or field use where the acoustical environment can be closely specified and/or controlled. Type 2 SLMs are suitable for general field applications. Type 3 SLMs are specified in IEC 60651-1979. They are of low accuracy and are intended for sound surveys and with little capability to measure impulsive sounds.

The IEC 60804-1984 specifies type 0, type 1, type 2, and type 3 integrating-averaging SLMs. The ANSI S1.25–1991 personal noise dosimeter and the personal sound exposure meter specify instruments intended to be worn on a person to measure noise exposure. They specify only limited-range, single-frequency-weighting, type 2 instruments.

The IEC 61672-1, 2002, specifies class 1 and class 2 instruments. This relatively new standard eliminated type 0 and type 3 instruments. Although the design goal of the A-weighting requirements are unchanged but the tolerance limits for class 1 SLMs has been changed to minus infinity at high frequency above 16 kHz (see Section 3.2). This reduces the capability to capture higher harmonics during measuring impulsive sounds.

2 MICROPHONES

Microphones are transducers that convert changes in sound pressure to an electrical signal. As is typical of many transducers, the microphone is likely to be the most critical, fragile, and expensive part of the instrument. Its response is likely to change with frequency, direction, temperature, absolute pressure, time, and several other factors. As such, it is important to appreciate the limitations and work with them to achieve accurate and reliable response. The selection of microphones[8] is very important for acoustical measurement. For critical applications it is important to understand that the sensitivity of condenser microphones varies with barometric pressure, and this variation that changes with frequency can be corrected.[9,10]

2.1 Types

Sound level meters use several different microphone types. Three types are most commonly used: piezoelectric (ceramic) and two types of air condensers (polarized and electret). In view of the importance of potential hearing loss due to high-frequency sounds[11] the MEM (microelectromechanical) microphone may be used in future high-frequency SLMs that are under development in Germany.

Ceramic Ceramic microphones operate on the principle that piezoelectric materials will generate a voltage when subject to force changes. Ceramics are relatively low cost, have relatively low internal electrical noise, and, compared to other microphones, are quite rugged. They are quite sensitive to vibrations if not mounted properly. The frequency response of ceramic microphones is not as flat as other types, and, as a result, they are often only used with type 2 SLMs.

Condenser The capacitance will change if the separation between two plates is changed. Condenser or capacitor microphones are constructed with one plate of the capacitor made with a very light material that can move when subjected to changes in air pressure. A high voltage is connected via a high impedance to the other plate of the capacitor. Since charge on a capacitor is equal to the capacitance times the voltage, if the capacitance changes and the charge remains constant, the voltage also will change. Condenser microphones tend to be accurate and stable and have a wide, well-defined frequency bandwidth. They are relatively fragile and must be protected from hostile environments and high humidity.

Polarized air condenser microphones require an external voltage often in the range of 200 V. Sensitivity is a function of this voltage that must be well regulated.

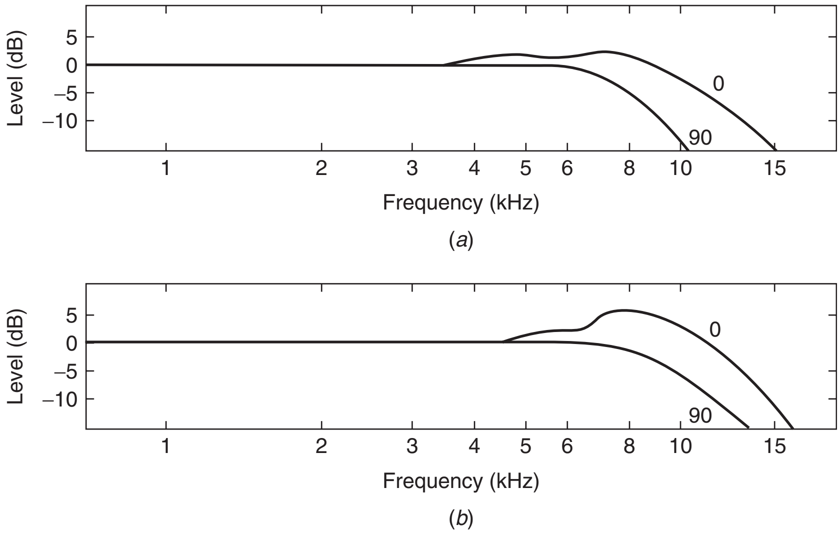

Figure 3 Examples of (*a*) free-field and (*b*) random-incidence half-inch microphones at 0° and 90° used in type 2 SLMs.

Permanent charged or electret microphones have permanent charge built into a plastic membrane. Response is similar to the polarized microphones.

MEM These microelectromechanical systems (MEMS) microphones have not been used in SLMs as such, but with their fast progress in development it is worth mentioning here to anticipate future possible application in miniaturization and special high-frequency sound level meters. MEMS are tiny microphones (as small as 1.6 × 2.8 × 6 mm) with their diaphragm edged from a single piece of silicon. With sophisticated chemical edging techniques, microphone backplate and possibly other electronics can be incorporated in a very small package and mass produced at a very low cost. There are many problems to be solved such as internal noise, frequency response, sensitivity stability, and dynamic range. Nonetheless, the development of a SLM the size of a matchbox may be closer than we anticipated.

2.2 Microphone Response

Microphone response changes with frequency. Microphones roll off below a couple of hertz to zero sensitivity at 0 Hz. At high frequencies the diameter of the microphone diaphragm is an appreciable part of a wavelength. As a result, the microphone rolls off at high frequencies and changes with the direction in which the microphone is pointed relative to the sound source. In general, microphones with smaller dimensions have better high-frequency response but also less sensitivity.

Free Field Free-field microphones are intended to measure sound in an open space free from reflections. The microphone should be pointed directly at the noise source at a 0° incidence. At 0° incidence the frequency response is close to flat over the widest frequency range. High-frequency sound arriving from other angles may be somewhat attenuated (see Fig. 3). The IEC[3,4,6,7] specifies SLMs with free-field microphones.

Random Incidence Random-incidence microphones are intended to measure sound in a diffuse field where the sound is arriving from all directions such as inside a noisy plant or in an area with many reflections. Random-incidence microphones have the flattest response if pointed at about a 70° angle to the noise source. High-frequency noise arriving at angles less than 70° will cause the SLM to read somewhat higher, while angles greater than 70° will generally read somewhat lower (see Fig. 3). The ANSI specifies that SLMs shall use random-incidence microphones. (For more information on free-field and random-incidence measurement, see Chapters 6 and 17 in Ref. 8.)

Pressure Pressure microphones are intended to measure sound in a closed cavity. Its response is often similar to the response of a random-incidence microphone. SLMs are sometimes designed with special circuitry to correct a free-field microphone for random-incidence application.

3 FREQUENCY WEIGHTING

3.1 Standard Weightings

Frequency weightings have been standardized.[12] SLM standards IEC 60651-1979 and ANSI S1.4–1983 specify standard frequency-weighting networks such as A-, B-, and C-weighting (see Fig. 4).

A-weighting is intended to simulate the response of a nominal human ear at 40 phons. It is also considered by many regulations in many countries to be the best weighting for predicting hearing loss due to noise exposure. The SLMs, personal sound exposure meters,

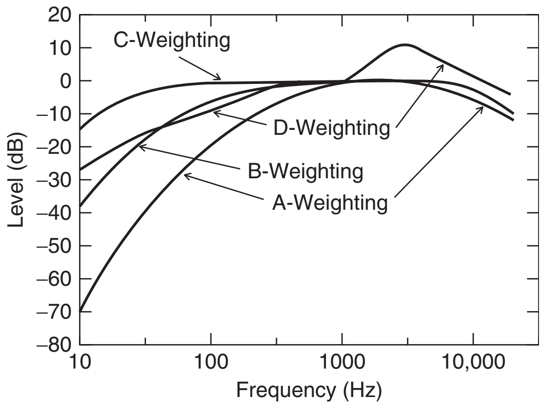

Figure 4 Frequency weighting curves.

and noise dosimeters use A-weighting to determine the effects of noise on humans. See Eq. (2).

B-weighting is intended to simulate the response of a nominal human ear at 70 phons. It is not widely used and has been omitted in the new standards.

C-weighting is intended to simulate the response of a nominal human ear at 100 phons. It is flat over most of the audible frequencies and is down 3 dB at 31.6 and 8000 Hz. Since it is flat over the audible range, it is often used to measure acoustical emission of machinery. It is also used to specify hearing protectors and to measure peak sound pressure level. See Eq. (1).

D-weighting was developed to measure noise from jet aircraft that have a perceived noise level that is higher than the level measured with A-weighting. It is not widely used and it has been dropped from current standards.

Flat or linear response is sometimes included in SLMs. Its frequency response is normally flat between two frequencies. The frequency response is very similar to C-weighting, with the response rolling off at the low end at a couple of hertz and at the high end at several tens of kilohertz. It has been replaced by the Z-weighting in current standards.

In IEC 61672, the A- and the C-weightings are specified, and the **Z-weighting** (or flat) defines a flat response with cutoff frequencies selected by the manufacturer of the SLM.

3.2 A-Weighting Tolerance Limits

In A-weighted level measurements it is important to understand the tolerance limits of an SLM. These tolerance limits play an important role in the indicated sound pressure level that may be quite different from the actual sound pressure level being measured. The class 2 tolerance limits (IEC 61672 and ANSI S1.4) are shown in Fig. 5. The design goal of the A-weighting

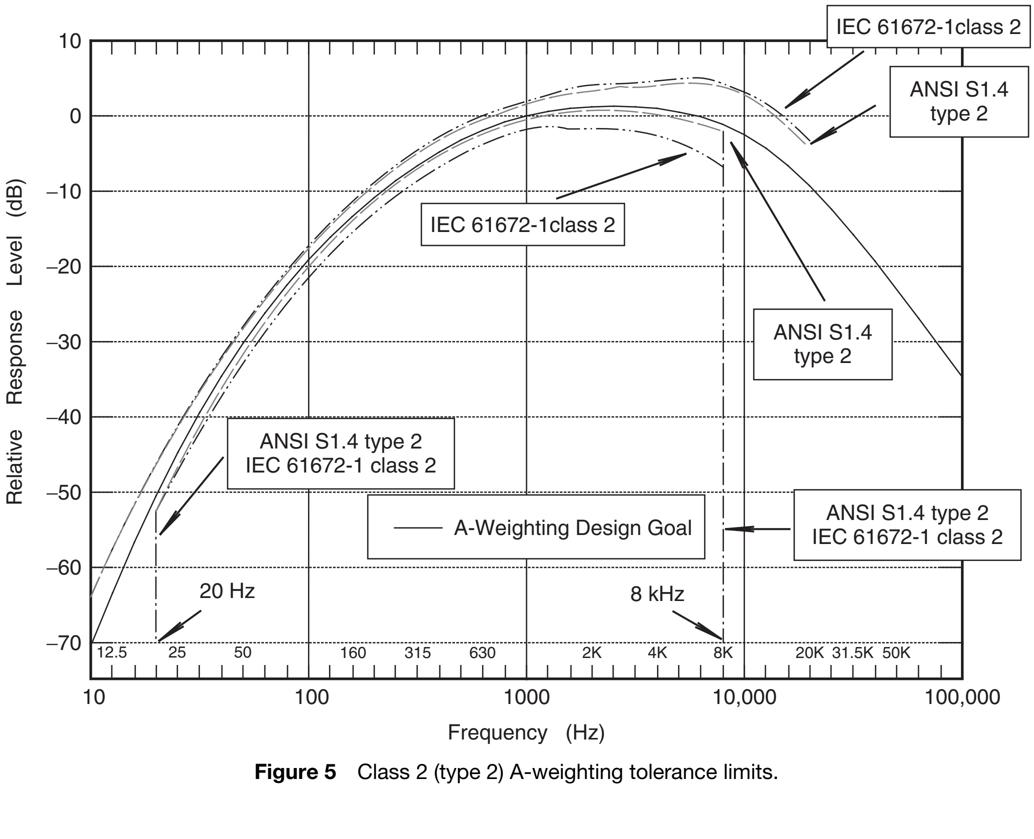

Figure 5 Class 2 (type 2) A-weighting tolerance limits.

is shown by the full line of the graph to 100 kHz. However, after 8 kHz the tolerance limit is at minus infinity. The sound energy above 8 kHz may be lost depending on the capability of the microphone and the electronic circuit. Since class 2 instruments are the workhorse of noise measurement related to hearing conservation and noise control program, one can imagine the result obtain with a class 2 instrument during the survey of factories and mines that usually have sounds of impulsive nature with harmonics that well exceed 8 kHz. The level measured by a class 2 instrument in an impulsive environment will be much lower. The A-weighting tolerance limits for class 1 instruments are shown in Fig. 6. For IEC 61672, after 16 kHz the tolerance limit is at minus infinity, which is an improvement from class 2 instruments. However, there is evidence[11] pointing to hearing loss due to high-frequency sounds. Removing the harmonics after 16 kHz is not helping hearing conservation programs that rely on SLMs to provide the correct sound pressure levels. It is important to point out that for ANSI S1.4A the A-weighted tolerance limits are much tighter, and it is capable of capturing sound energy beyond 20 kHz. See Fig. 6.

3.3 Weighting Equations

The equations for frequency responses for A- and C-weighting are

$$W_C(f) = 20\log\left[\frac{f_4^2 f^2}{(f^2+f_1^2)(f^2+f_4^2)}\right] - W_{C1000} \quad (1)$$

$$W_A(f) = 20\log\left[\frac{f_4^2 f^4}{\begin{array}{c}(f^2+f_1^2)(f^2+f_2^2)^{1/2}\\ \times (f^2+f_3^2)^{1/2}(f^2+f_4^2)\end{array}}\right] - W_{A1000} \quad (2)$$

where W_{C1000} and W_{A1000} the normalization constants, rounded to the nearest 0.001 dB, are -0.062 and -2.000 dB, respectively, representing the attenuation necessary to provide frequency weighting of zero decibels at 1000 Hz for the C- and the A-weightings, respectively, and $f_1 = 20.60$ Hz, $f_2 = 107.7$ Hz, $f_3 = 737.9$ Hz, and $f_4 = 12194$ Hz.

4 SQUARING AND AVERAGING

The instantaneous level at the input of the squaring circuit is converted to a level proportional to the square of the level. It is interesting to note that if the input

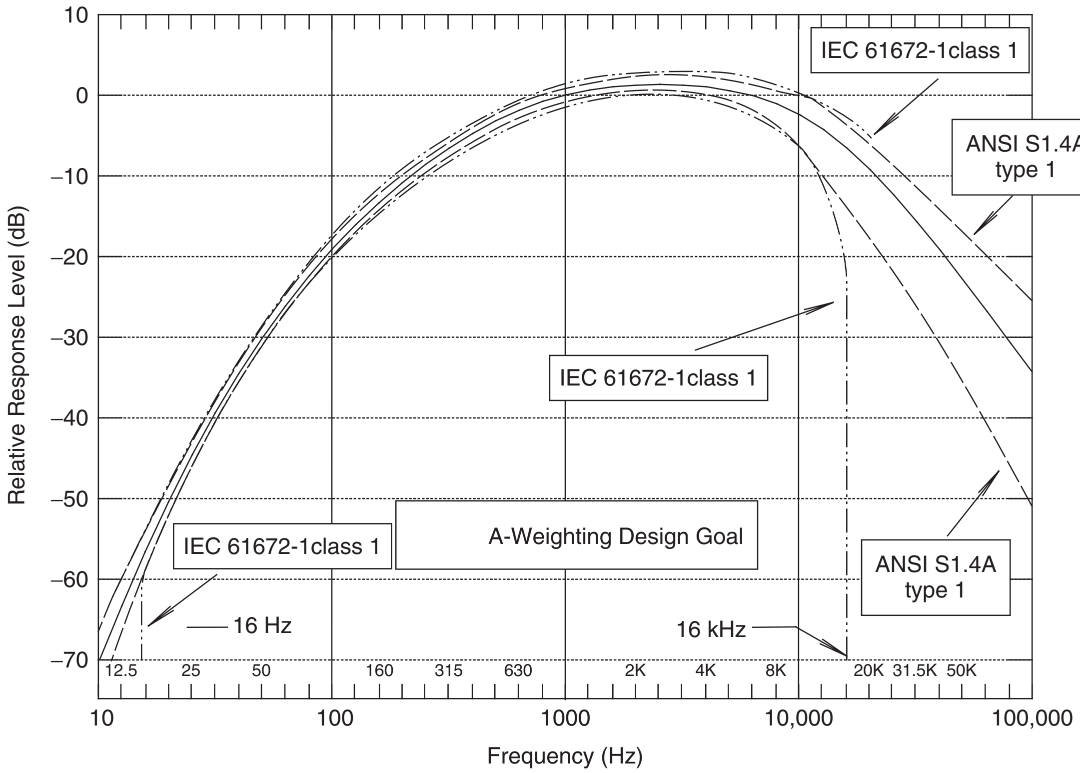

Figure 6 Class 1 (type 1) A-weighting tolerance limits.

pressure varies over 60 dB or 1000 : 1, the output must vary over a range of 1: 1×10^6.

The parameter p_a at the output of the squaring circuit can be found as

$$L_{\text{inst}} = 10 \log(p_a^2/p_o^2) \tag{3}$$

where L_{inst} is the instantaneous level in decibels and (p_a^2/p_o^2) is the ratio of the squared instantaneous A-weighted sound pressure to the squared reference sound pressure at 20 μPa.

4.1 Exponential Averaging

A low-pass filter is placed after the squaring circuit to smooth out the instantaneous fluctuation and make it possible to read the level on a meter or digital display. Fast and slow responses are specified by several SLM standards and impulse response I, which is no longer specified in IEC 61672-1, but imbedded in many existing SLMs, can be found in IEC 60651–1979.

Time Constants *Slow (or S)* is specified as a 1-s time constant. Slow is used for measuring sound where an estimate of the average sound level is needed and the fluctuations are too fast to follow with a fast time constant. Slow is specified by the Occupational Safety and Health Administration (OSHA) and the Department of Defense (DOD) in the United States for measuring noise dose.

Fast (or F) is specified as a 0.125-s time constant. Fast follows fluctuations in sound levels better than slow but may fluctuate too much to be read. Fast is often used to measure transient noise such as vehicle passby noise.

Impulse (*or I*) is specified in IEC 60651-1979 as a 0.035-s time constant followed by a peak detector with a 1.5-s decay time such that the indicator will rise very rapidly to increasing levels but decay slowly when the level decreases. It is used primarily in Germany and a few other countries to measure highly impulsive noise.

4.2 Peak, Maximum, or Minimum Hold

Sound level meters often include additional functions to measure the highest instantaneous level as well as the highest and lowest level after the time constant circuit. These functions can normally be reset to allow detection of the next level.

Peak is the highest instantaneous level. Peak is detected before the time constant circuit. It may have a different frequency weighting than the weighting used to calculate sound pressure level and other levels. Peak signals respond to pulses as short as 50 μs. For a sine wave, the peak level is 3 dB higher than the root-mean-square (rms). level. The tone burst shown in Fig. 7 would have a peak reading of 103 dB.

Maximum and minimum levels are the highest and lowest levels detected after the time constant circuit. The tone burst shown in Fig. 7 has, after a few cycles, a fast maximum of 100 dB and a slow maximum of 96.6 dB. The minimum level for fast is 65.3 dB and for slow is 90.1 dB.

Response to Tone Burst On a logarithmic scale, the time constant will cause the display to change faster for an increase in level than for a decrease in level [see Eqs. (4) and (5)]. The maximum rates of decay for a big decrease in level are 4.34 dB/s for slow, 34.74 dB/s for fast, and 2.90 dB/s for impulse. The maximum response to a single tone burst relative to

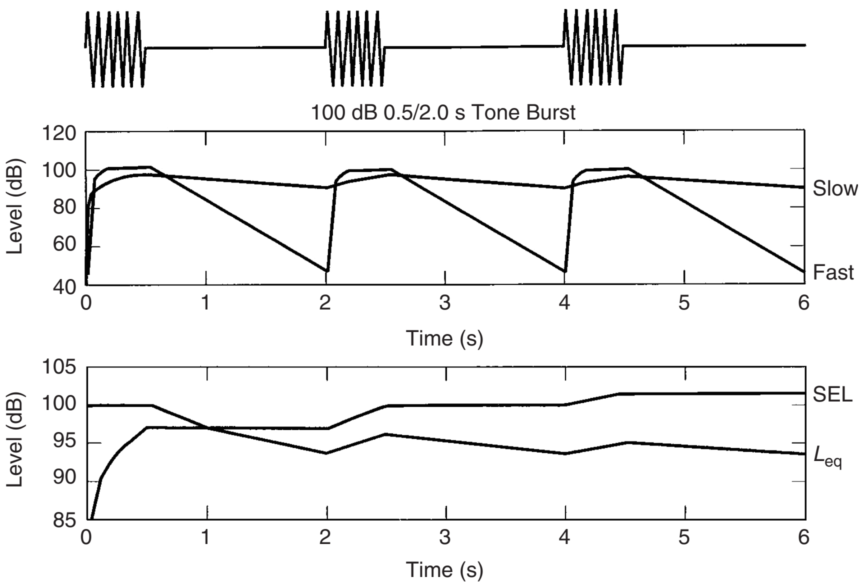

Figure 7 Slow, fast, SEL, and L_{eq} responses to tone burst.

the continuous level of the same tone is

$$L_{\text{on}} = L_{\text{tb}} - 10\log(1 - e^{-T_1/\tau}) \tag{4}$$

The response when a tone is turned off is

$$L_{\text{off}} = L_{\text{on}} - 10\log(1 - e^{-T_2/\tau})$$

$$L_{\text{off}} = L_{\text{on}} - 4.3429448\frac{T_2}{\tau} \tag{5}$$

The integrated sound level of an integral number of tone bursts is

$$L_{\text{eq}} = L_{\text{tb}} - 10\log\left(\frac{T_1}{T}\right) \tag{6}$$

where L_{tb} is the level of tone burst, T_1 the duration of tone burst, T_2 the time from the end of a continuous tone, T the time from the start of one tone burst to the start of the next tone burst (= 1 per repetition frequency), and τ an exponential time constant.

4.3 Integrating Averaging

Equivalent Sound Pressure Level Integrating SLMs, combine all the sound pressures between the start and end of an integration period. [See Eq. (7).] The equivalent sound pressure level (L_{eq}) is the logarithmic average of the squared instantaneous pressures. While the exponential-averaging SLM display depends on what the sound level was immediately preceding the time it was read, integrating-averaging SLMs weigh equally all the sound from the start to the end of the integration time. As can be seen in Fig. 7, exponential-averaged SLMs keep changing when measuring discontinuous sound. Equivalent sound pressure level meters quickly settle to an average level. As a rule of thumb, the L_{eq} level should be within 0.1 dB of the final value after as many minutes as the time between impulses in seconds.

In theory, integrating do SLMs not have a time constant. In practice, some do exponentially average the squared pressure before doing the integration. If the integration time period is long compared to the time constant, the exponential circuit makes little difference. If a loud noise occurred shortly before the start time or shortly before the end time, part of that noise may be included or excluded:

$$L_{\text{eq}} = L_{\text{Aeq},T} = 10\log\frac{1}{T}\int_{T_1}^{T_2}\frac{p_a^2(t)}{p_o^2}dt \tag{7}$$

$$\text{SEL} = L_{\text{EA},T} = 10\log\int_{T_1}^{T_2}\frac{p_a^2(t)}{p_o^2}dt \tag{8}$$

where p_a is the instantaneous A-weighted sound pressure (for weighting other than A-weighting the subscript is changed) and T is the time between the start and end times T_1 and T_2 (for the sound exposure level (SEL) the time is always in seconds).

Sound Exposure Level The SEL is similar to L_{eq} in that pressure is integrated over the measurement period [See Eq. (8).] The SEL measures the total energy and normalizes it to 1 s. The SEL is equal to L_{eq} after 1 s. If the L_{eq} is steady with time, the SEL will be 3 dB greater than L_{eq} after 2 s and 6 dB greater after 4 s, and increase by 3 dB whenever time doubles. The SEL is used to measure the total energy in an event independent of the time duration of the event.

Short Equivalent Sound Pressure Level Short L_{eq} is an L_{eq} value computed at very short intervals, perhaps every $\frac{1}{8}$ or $\frac{1}{16}$ s, and stored in memory for later analysis. Data in memory can then be used to calculate a number of sound describers such as L_{eq}, SEL, exposure, exceedance levels, sound pressure level, and maximum and minimum levels.

Equivalent Sound Pressure Level per Day and Time-Weighted Average The term $L_{\text{ep},D}$ is the equivalent sound level per day, and TWA is the time-weighted average. Both $L_{\text{ep},D}$ and TWA are similar to SEL except the integration is averaged over 8 h instead of 1 s. The level will be less than the L_{eq} level for time periods less than 8 h and greater than the L_{eq} level after 8 h. The $L_{\text{ep},D}$ and TWA are used to measure worker noise exposure during a work day. It is assumed that workers who work less than 8 h can be exposed to higher noise levels during the time they are working without increasing their risk of noise-induced hearing loss. The parameter $L_{\text{ep},D}$ is used in the European community while TWA is used in the United States. If the level is constant, $L_{\text{ep},D}$ will increase by 3 dB if the time is doubled. Also, $L_{\text{ep},D}$ is 44.59 dB less than SEL. The TWA may use different doubling or exchange rates. For OSHA compliance, it will increase by 5 dB if the time is doubled.

5 OPERATING RANGE

Ideally, an SLM should accurately measure all sounds from the noise floor to overload regardless of the temporal nature of the sound. While SLMs are available that accurately measure all sounds over a wide range, many SLMs that meet the older standards have very limited range, particularly when measuring transients.

In IEC 60651-1979 and ANSI S1.4-1983, the requirements for steady and transient response are very limited. Accurate steady-level response is only required over a 10-dB range, and transient response is only required for one tone burst. As many instruments made since these standards were issued barely meet the minimum requirements of the standards, much of the data taken with these instruments may be of little value.

The standards IEC 60651-1979 and ANSI S 1.4-1983 state that the accuracy of instruments shall be within ±0.4, ±0.7, and ±1.0 dB for types 0, 1, and 2 instruments, respectively. This accuracy is required only for steady-tone sounds arriving from the reference direction under reference conditions of pressure, temperature, and humidity. Also, it is required only on one primary indicator range over a 10-dB span.

The SLM standards requirements for tone burst require only that type 1 and type 2 instruments be within tolerance at one point. On fast response only 0.2-s tone bursts and on slow response only 0.5-s tone bursts are required to be accurately measured. Unfortunately, there are many instruments on the market that only meet the standard for this one tone burst. If a noise burst is shorter than specified by the standard, the instruments read low or ignore the burst completely.

The standard IEC 60804-1984 expands the linearity range to 70, 60, and 50 dB for type 0, 1, and 2 instruments, respectively. It also requires tone bursts, as short as 0.001 s to be measured within $\pm 0.5, \pm 0.5$, and ± 1.0 dB for type 0, 1, and 2 instruments, respectively. The standards for personal sound exposure meters and noise dosimeters follow the IEC 60804-1984 type 2 specifications. While this range may not be accurate for very short duration sound burst or for wide level changes, it is sufficient for most noise measurements.

The new IEC 61672-1 specifies only class 1 and class 2 instruments. The tolerance limits for performance include allowances for the expanded uncertainties of measurement that was tabulated for each requirement discussed in the standard. For example, at 250 Hz, the tolerance limits specified for weighted measurements for class 1 instruments is$\pm$1.4 dB. The corresponding expanded uncertainty allowed is 0.4 dB. (The corresponding tolerance limits specified in IEC 60651 is $\pm$1.0 dB without allowance for uncertainty of measurement). At 1 kHz (the reference frequency), the design goal for all frequency weightings is 0 dB with corresponding tolerance limits (with expanded uncertainties of measurements included) of $\pm$1.1 dB for class 1 and $\pm$1.4 dB for class 2 instruments.

5.1 Linearity Operating Range

The linearity range is specified for continuous sound pressure levels. Ideally the instrument should meet the linearity requirements on all ranges, although additional tolerance is allowed on ranges other than the primary indicator range. With IEC 60651, instruments are required to be linear over a range of frequencies from 31.5 Hz to 8 kHz.

In IEC 61672, level linearity applies over the total range for any frequency within the frequency of the sound level meter and for any frequency weighting or frequency response provided. At 1 kHz, on the reference level range the linear operating range shall be at least 60 dB, and the adjacent ranges shall overlap by at lease 30 dB for SLMs that measure time-weighted sound levels, and at least 40 dB for SLMs that measure time-average sound levels or sound exposure levels. These new level linearity requirements have eliminated the discussion on dynamic range.

5.2 Dynamic Range

With previous standards such as IEC 60651 and IEC 60804, dynamic range, often called pulse range, determines the meter's performance when the sound level is not continuous. Ideally, it should be the same as the linearity range. Integrating SLMs are required to have 70, 60, or 50 dB pulse range for types 0, 1, and 2 meters, respectively. Exponential-averaging meters may be very limited in dynamic range capabilities.

5.3 Overload Indicators

Integrating-averaging SLMs and exponential-averaging SLMs are required to have overload detectors to indicate when an overload has occurred. The overload can occur at several places in the meter, and the overload detector may be required to measure several points. Different SLMs have their own implementation for overload indicators. It is best to consult the operating manual to obtain more details on their operation.

5.4 Noise Floor

The lowest level an instrument can read is determined by the noise floor. Noise may be generated in the microphone, its preamplifier, or the electronics of the meter. As a general rule, the lowest level an SLM can measure with 1-dB accuracy is 6 dB above the noise floor. For 0.1-dB accuracy the level must be 16 dB above the noise floor. If the noise floor is well behaved, it is possible to measure lower levels and calculate the actual noise level by logarithmically subtracting the noise from the signal on a mean-square basis. This technique is most useful when measuring sound that can be turned on and off, such as calibrating pure-tone audiometers [see Eq. (9)]:

$$L = 10\log(10^{(L+N)/10} - 10^{N/10}) \qquad (9)$$

where N is the noise floor, $L+N$ the measured level including the noise, and L the level without the noise.

5.5 Threshold Circuits

It is sometimes desirable not to include sounds below a threshold level in the noise calculations. An example is excluding background noise when measuring the noise of an aircraft flyover. The OSHA regulations allow exclusion of noise below certain threshold levels.

Thresholds of noise dosimeters are placed after the time constant circuit and are well defined. Other threshold levels are not well defined, and the user must consult the meter-operating manual to determine exactly how the threshold works.

5.6 Reference Environmental Conditions

IEC 61672-1 specifies reference conditions for specifying of SLMs performance as:

Air temperature: 23°C,
Static pressure: 101.325 kPa
Relative humidity: 50%

6 DISPLAYS AND OUTPUTS

6.1 Analog and Digital

Conventional SLMs use an analog ballistic meter movement to display the sound level. Historically, the conversion to decibels was accomplished by scale graduations. This resulted in a scale with the numbers very close together on the left or lower end and separated on the high or upper end. Such scales were only useful over about a 20-dB range. When meter manufacturers included the logarithmic conversion in the meter electronics, analog meter scales of 30 or more decibels are possible with equal space per decibel. Although digital displays are now widespread, many users still prefer the analog display for ease of reading and detecting changes.

Digital displays offer wide range, and the numbers are easy to read down to a fraction of a decibel. These displays are difficult to read and interpret when used with exponential-averaging meters. If the sound level is not constant, the display will be different each time it updates. It is also necessary to consult the owner's manual to determine if the displayed number is the maximum level, the average level, or the level at the end of the update. Since a display that updates once a second can change 30 or more decibels during that second, it is important to know what is displayed.

6.2 Auxiliary Equipment

Auxiliary outputs are sometimes provided to connect the SLM to other equipment. Consult the operating manual before connecting to make sure the two pieces of equipment are compatible. In general, if a class 2 device such as a filter is connected to a class 1 SLM, the combination is considered as class 2.

7 CALIBRATION

It is recommended that SLMs be checked before and after every use with an acoustical calibrator. Manufacturers' recommendations should be followed. Normally, checking consists of removing the windscreen if any, carefully sliding the calibrator over the microphone, and reading the level. Care must be taken to ensure there is a good seal between the microphone and the calibrator or errors will result. If a calibration has changed by a few tenths of a decibel, it can normally be adjusted to the correct level.

Acoustical calibrators check only the reading at one or at a few frequencies and levels. It is possible for a check to detect no change at one frequency and the SLM can be out of tolerance at another. If a microphone develops a pin hole air leak, the level may not change dramatically at 1000 Hz but may change considerably at other frequencies. Therefore, if daily checks require more than a few tenths of a decibel of corrections, it may be a sign of a much larger deviation at other frequencies. Good procedure recommends SLMs be calibrated at regular time intervals, such as yearly depending on the usage, by an accredited laboratory to ensure the instrument remains within the tolerance required by standards.

8 OTHER TYPES OF SOUND LEVEL METERS

8.1 Dosimeters and Personal Sound Exposure Meters

A special type of meter for measuring noise is the dosimeter or personal sound exposure meter. A block diagram of a noise dosimeter is shown in Fig. 8. An exposure meter would have a similar block diagram except the time constant, threshold, and exponent circuits would be omitted.

The instruments measure noise according to

$$E = \int_0^T p_a^2 \, dt \tag{10}$$

$$\text{DOSE} = \frac{100}{T_c} \int_0^T 2^{(L-L_c)/ER} \, dt \tag{11}$$

where E is exposure, p_a the A-weighted sound pressure, T_c the criterion time (normally 8 h), L_c the criterion level, and ER the exchange rate or doubling. In SI (International System units, exposure is measured in pascal-squared seconds ($\text{Pa}^2 \cdot \text{s}$). For convenience, exposure in personal sound exposure meters is expressed in pascal-squared hours. Exposure to 85 dB for 8 h is approximately equal to one pascal-squared hour ($\text{Pa}^2 \cdot \text{h}$).

Dose is another method of measuring noise exposure, with the results expressed as a percentage of a criterion exposure. In the United States, OSHA, defines 100% dose as the equivalent of a level of 90 dB for 8 h with a 5-dB exchange rate after the time constant. Other regulations may use different criterion levels and

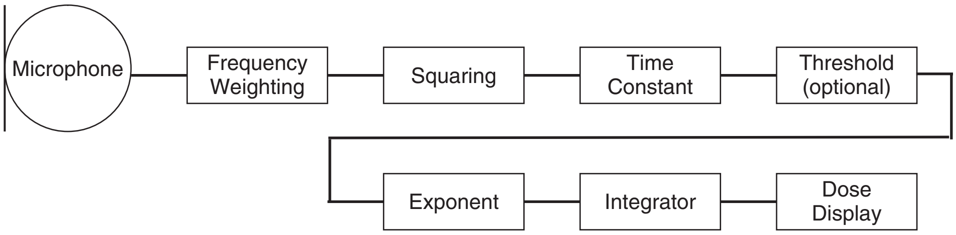

Figure 8 Noise dosimeter.

exchange rates. Since dose combines different levels with 5-dB (OSHA) or 4-dB (DOD) exchange rates, after the time constant circuit, the time constant will change the calculated dose. A slow time constant will produce a higher dose than a fast or no time constant if the sound level is not constant. While Eqs. (10) and (11) appear quite different, they are similar. If the exchange rate is 3 dB, the criterion level is 90 dB, and criterion time is 8 h, then 100% dose = 3.2 $Pa^2 \cdot h$.

9 OPTIONS

A number of additional devices may be built-in or connected to SLMs to expand their performance. Some of the measurements and options include acceleration, velocity, displacement, reverberation, signal analysis such as fast Fourier transform (FFT) and narrow band analysis, structural analysis, data acquisition, time capture, tracking filters, sound intensity, and sound power.

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