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Low Costs Electrical Calibration System of SLM with the Uncertainty Measurements Compared with Primary System Platform Brūel & Kjær type 3630

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ABSTRACT

Sound level meter (SLM) calibration according to IEC61672-1, 2, 3: 2013 is an essential step in the measurement process. It ensures that the SLM meets its specifications. There is a strong need for an efficient and cheap calibration system device for the electrical calibration of SLM since it avoids the body effect and angle sensitivity of the microphone membrane to the sound incidence angle for free field calibration. As well as, it avoids leakage errors due to the microphone fitting in the coupler and the coupler effect in pressure field calibration. This work gives an alternative system device used in the electrical calibration of SLM. This system consists of individual tools; PULSE signal generator, universal frequency counter, HP Dynamic signal analyzer, and DMM voltmeter. All system tools are complying with the IEC17025. The calibration procedures follow the second edition of IEC61672-2. Calibration measurements of frequency, time-weightings, and linearity of range parameters as the major features of SLMs are tested in the frequency range of 31.5 Hz to 16 k Hz. The calibration was repeated 5 times on different days and different warm-up times for devices to estimate the associated uncertainty measurement values in accordance with Part 2 and Part 3 of IEC 61672. The obtained results show that, the calibration measurement deviations are in the allowable tolerance of the IEC 61672-1 and they are comparable with that obtained from the primary **B**rüel & **K**jær (**B** & **K**) platform 3630. The computed uncertainty of measurements is in accepted limits that are required by IEC 61672-1 which is determined to the level of confidence of 95%, using coverage factor 2.

Key words Calibration system for SLM; frequency- and time-weightings; toneburst; range of linearity test; noise measurement; uncertainty of measurements.

1. INTRODUCTION

A sound level meter (SLM) is the most usable device for acoustics measurements in the field. In general, an SLM consists of; a microphone, a preamplifier, a signal processor, and a display device [1]. Frequency-weighting and time-weighting are the most common quantities for sound measurements or calibrations. The frequency weighting is an electric integrated filter inside a sound level meter where it correlates the objective measurements with the human subjective response. Three filter types of frequency weightings, namely; A-, C-, and Z-weighting are applicable in sound level meters. Commonly, dB(A), dB(C), or dB(Z) indicate the measurements in A-, C- or Z-weighting, respectively [2]. A-weighting is mandator parameter in SLMs and refers to what humans are physically capable of hearing. Also, this weighting is used for occupational noise surveys and for measurements of hearing damage risk [3]. C-weighting is flat in the frequency range of 31.5 Hz - 8 kHz, it responds to the human ear at high-level sounds (more than 100 dB) and it is used in the measurement of impulse noise. Therefore, C-weighting is used for machine- and jet-noise measurements. The Z-weighting is zero correction and has a flat frequency response of 20 Hz to 20 kHz, it is often used in octave band analysis and determining environmental noise.

SLMs are commonly fitted with three detector time weightings [4], [5] are often; Fast, Slow, and Impulse-time weightings. The Fast - weighting corresponds to a 125 ms time constant the Slow- weighting corresponds to a 1 second time constant and Impulse- weighting has a time constant of 35 ms. They may also be fitted with Peak-weighting having a time constant of less than 100 μs. All these components of SLM construction need to be verified test (calibration). So, a regular recalibration SLM is essential to ensure that all of the features and functions are working as intended by the manufacturer and remain accurate and compliant with the requirements of reference standards IEC/ISO.

The calibration of SLM in accordance with international standards can be achieved using different calibration instrument systems. However, the realization of calibration with a system instrument is acceptable if it satisfies the limits of IEC 61672-1-3 2013 [6], [7], [8] and in accordance with the ISO/IEC 17025 standard [9]. Podgórski [10] describes the measurement station for the calibration of instruments for sound measurements in AP 146 laboratory in Poland (which belongs to Svantek and is accredited by the Polish Center for Accreditation (PCA)). Zhong et al. [11] implemented an automatic calibration system using image recognition, in which the result is automatically obtained from the indication on the sound level meter screen. it uses a different calibration method, in which an anechoic chamber is required to calibrate in a free field the frequencies from 500 Hz to 20 kHz, an active coupler to calibrate in a pressure field the frequencies from 10 Hz to 500 Hz, and a laboratory standard microphone to obtain reference field responses, which increases the cost. Such operation makes this a much more versatile system, with which reports with calibration results can also be generated automatically.

Brüel & Kjær developed a compact calibration system [12], which allows periodic calibration and measurement uncertainty estimation for B & K sound level meters and also other brands. In addition, it offers the possibility of calibrating in automatic mode (if the sound level meter has a serial interface), semi-automatic (if the sound level meter has an analog output that corresponds satisfactorily with the indication on the screen), and manual (if the sound level meter does not have any output. analog), with sequences predefined or customized by the user. It has an integrated customer and instrument database, allowing traceability of calibration intervals for working standards.

The process of verification and calibration of SLMs in accordance with international standards is in general divided into an electrical part and an acoustical part. The acoustical SLM calibration in accordance with international standards obeys the free field calibration method and coupler method. The coupled technique is considered as one of the most convenient required by the standard, especially for the secondary laboratory. Dwisetyo, et al., [13] compare the SLM calibration for the frequency weighting parameter by coupler method using the standard instruments (multifunction acoustic calibrator and a working standard of pressure microphone (WS2-P Microphone)).

Electrical calibration of the sound level meter is useful since it avoids the body effect and angle sensitivity of the microphone membrane to the sound incidence angle for free field calibration, as well as the coupler effect in pressure field calibration. Electrical tests are achieved by replacing the microphone with an electrostatic actuator (an equivalent electrical circuit to the microphone) and using an acoustic input signal. The primary standard systems for electrical SLM calibration, which comply with all relevant international standards and recommendations are highly cost. Due to the complexity issue and business priority, especially for the private calibration laboratories and the growing of industrial needs to SLM calibration, it is urgently needs to develop a qualified and cheap instrumentation system for electrical SLM calibration.

The present work aims to test and verify a cheap and accurate electrical SLM calibration system instrument. This system is realized using; a PULSE signal generator, universal frequency counter, HP Dynamic signal analyzer, and DMM voltmeter. All system tools are complying with the IEC 17025. Frequency weighting, time weighting, and linearity measurements are tested for B&K SLM 2235. The results of calibration using these systems are compared to the reference value required by IEC 61672-1. Also, this work aims to provide an estimation of the expanded uncertainty in accordance with the Guide to the expressions of Uncertainty in Measurement (GUM) [14], [15] for a coverage probability 95% and compared to the limit values required by IEC 61672-1 2013 (Annex B).

This work gives a comparison of electrical calibration results obtained from the primary system ***B***&***K*** type 3630 laboratory standard system and commercial system of individual tools used to calibrate SLM type 2260 over the frequency range 31.5 Hz to 16kHz.

2. INSTRUMENTAION

2.1. Calibration System Devices Under Specification

The necessary instruments of the commercial electrical calibration system and their technical specifications used for SLM calibration are;

2.1.1 Waveform generator:

Sinusoidal signal generator: frequency range shall be at least 20 Hz to 20 kHz, the error of output frequency is less than 0.25 %.

2.1.2 Signal Analyzer

Dual-channel Dynamic Signal Analyzer 35665a of the following specifications:
Real-time Frequency Ranges:

- 1/1 OCTAVE RANGE (at centers): 0.0613 Hz to 16 kHz
- 1/3 OCTAVE RANGE (at centers): 0.08 Hz to 32 kHz
- 1/12 OCTAVE RANGE (at centers): 0.09145 Hz to 12.338 kHz.

Source type: Sine, swept-sine, random, burst, burst random, pink noise, curve fit and synthesis, arbitrary source

- Precision multimeter, 3458A: Low internal noise, and excellent short-term stability, linearity has been measured within ± 0.05 ppm of 10 volts, transfer accuracy for 10 volts DC is 0.1 ppm over 1 hour ± 0.5 °C. Internal noise has been reduced to less than 0.01 ppm rms yielding 8.5 digits of usable resolution. The total relative error at the operating temperature of 28 °C = 42 μV
- Reference multi-meter FLUKE 8508A: Ranges:
  DC voltage; 10 mV to 1000 V with maximum resolution 1nV; DC current 10 μA to 30 A, with maximum resolution 1pA.
  AC voltage 10 mV to 1000 V with maximum resolution 1nV; AC current 10 uA to 30 A, with maximum resolution 1pA.
- Frequency counter:
- Attenuator: Attenuation range of 60 dB, resolution (minimum scale) is better than 0.1 dB, the maximum expanded uncertainty less than 0.2 dB.
- Toneburst signal generator: toneburst signal frequency is 4 kHz, and the duration shall be at least 0.25ms to 1000 ms.

Different items of equipment listed above have certificates of traceability and uncertainty. The calibration certificate is traceable to the international system of units maintained at the National Institute of Standards (Egypt), with a measurement uncertainty of ±0.08 dB. This reported uncertainty is based on a standard uncertainty multiplied by a coverage factor, k = 2.

2.2. Brüel & Kjær's Platform Type 3630A

In order to verified the proposed system for capabilities of SLM calibration, there has been comparative study using the worldwide standard **B&K** Platform Type 3630A (Figure 1) carried out to adhere to the 1st class SLM type 2236 B&K. This calibration system generates test signals in fulfil the requirements of relevant international standards IEC 60651 and IEC 60804. The system PULSE analyzer capable of analyzing FFT, 1/n-octave filters and overall levels. The system includes an integrated digital voltmeter DMM Agilent 34970 and B&K's Multifunction Acoustic Calibrator Type 4226 guarantee the measurement chain. The IEC61672 tests calibration available as an upgrade with the default acceptance limits set in accordance with IEC type 1 SLMs.

The calibration procedure and test modes controlled through an interface of special windows for operator instructions, system setup and test results.

Figure 1: Platform B & K calibration system type 3630 A (Source: user manual of the system type 3630)

2.3. Device under test (DUT)

The device under calibration test is a B&K precision integrating SLM type 2236, S/N 2015543, it is a type 1 model SLM complying with the most recent standards (e.g. IEC 61672-2013, ANSI, and others). The Adapted impedance WA0302-D with serial no. 2800216 of 20pF is used in electrical calibration (replace the condenser microphone). The reference level range of maximum value, 160 dB. (which is specified and defined by the manufacturer).
For an SLM that has an electrical output that is to be used for the periodic tests, the indications obtained from the electrical output and the corresponding indications on the display device of the SLM shall be confirmed to be identical within the tolerance limits given in IEC 61672-1: 2013.

3. METHODOLOGY

This work implies, the IEC 61672-2 2013, **clause 9** as the basis guide for electrical calibration in according to which the results were obtained**.** Electrical signals are inserted into the sound level meter through an input equivalent device, that gives signals equal to that signal generated from the microphone.

The explanation of the electrical calibration method using the aforementioned standards will be discussed in this part of the work. The most interesting electrical verification parameters for electrical calibration are Frequency Weightings (A, C, Lin), Time Weightings ((Fast, Slow, Impulse, Peak), level range control, Linearity Rang, Electrical Inherent Noise, Toneburst (ref. freq. 4kHz). However, the calibration test is performed for items that are available in the device under test.

3.1. Frequency-Weighting Calibration Test

In this test, the frequency-weightings are specified relative to the response at 1 kHz, using sinusoidal electrical signals. Two methods can be applied for electrically calibration of SLM [16], these methods can be implemented by using several instrument standards required by the IEC standard. However, the realization of calibration with a system instrument is acceptable if it is satisfying the limits of IEC 61672-1-3: 2013. The SLM calibration conducted in accordance with the test procedures of IEC61672-2, for A- and C- frequency weighting at the frequency range of 31.5 Hz ~ 16 kHz [10].

3.1.1. Constant input signal level

The test procedure for this method requires that, the level of the input sinusoidal electrical signal be adjusted to display an indication that is 125 dB (less than the maximum range of the reference level by 35 dB) on the reference level range to the device under test at a frequency 1k Hz and maintained it constant. The voltage as root mean square (rms) of the Sound Analyzer is recorded as a reference value. The level of the electrical input signals in rms and the indication of the corresponding level on the display are recorded for each test frequency other than 1 kHz of the 1/3 octave in the range from 31.5 Hz to 12.5 kHz for the frequency weighting A or C.

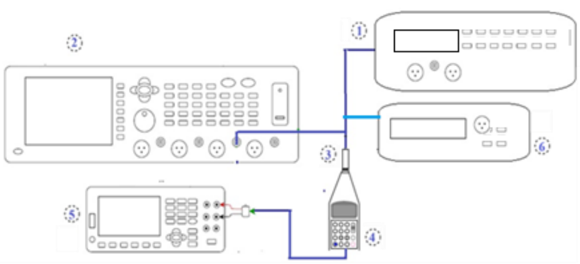
For frequency weighting (A or C), the relative electrical signal is calculated by subtracting the level indicated at 1kHz from the level indicated at a test frequency. The obtained values should be comparable with the specification of SLM as specified in the IEC 61672-1: 2013 and the difference must be within the tolerance given by this standard. This method is greater sensitive to level linearity error, but it does not account for the level of overload error.

Calculate the difference value corresponding reference level and draw the response curve to get Z, A, and C frequency-weighted characteristics. The steps should be repeated at least 5 times and take the average at each frequency, the standard uncertainty of measurements is also estimated.

3.1.2. Fixed display indication

Figure 2 shows the experimental set up for frequency weightings test. The test procedure for this method requires that, the level of the input sinusoidal electrical signal be adjusted to display an indication that is 94 dB on the reference level range to the device under test at a frequency 1k Hz. At each frequency of a frequency-weighting (A or C), the level of the input signal is adjusted to produce the same indication on the display as of the reference signals at frequency 1k Hz. The levels of the input signals and the corresponding indications on the display device shall be recorded. Differences between electrical input signal levels may be determined from the differences in the settings of an input signal attenuator or from ***20 log*** ($\mathbf{V}_f/\mathbf{V}_{ref}$) where $\mathbf{V}_f$ and $\mathbf{V}_{ref}$ are the root-mean-square voltages measured for a frequency weighing and for the frequency weighting that was selected for the tests reference signals, respectively. This method accounts for the level of overload error.

NOTE *input signals may be measured as root-mean-square voltages or as the settings, in decibels, of an input signal attenuator.*



Keys
1. Sinusoidal Signal Generator
2. HP 35665a Dynamic Signal Analyzer
3. B & K WA0302-D Adapted Impedance
4. B & K SLM type 2236
5. 8508A Digital Multimeter
6. HP Frequency Counter

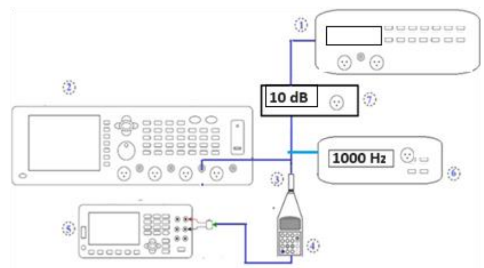
Figure 2: Experimental set up for frequency weightings test

3.2. Level Linearity Test

Figure 3 shows the experimental set up for the level linearity test. The level linearity is tested in accordance with IEC 61672-2 (Clause 9.8) by using a steady sinusoidal electrical signal at a frequency of 31.5Hz, 1kHz, and 16 kHz, for class 1 and at a frequency of 31.5Hz, 1kHz, and 8 kHz, for class 2 SLM. The SLM under test shall be set to ***A***- frequency weighted, ***Fast***-time weighting (or time-averaged sound level), and at the reference level range.

The signal generator shall supply SLM under test with sinusoidal signal at specific frequency, and adjusted level to the level reference. The input test signal level shall be changed increasing or decreasing in steps (of 1 dB to 10 dB) using an attenuator (or by signal generator). The level linearity deviation is the difference between the indicated sound level on SLM and the corresponding anticipated sound level of test signal generator. For each frequency, the linearity is tested in steps from the starting point on the reference range up to the first indication overload and then in downward to the first indication of under-range passing through the starting point.

The measured value should be the arithmetic mean of at least five test results by which the standard uncertainty of measurement is determined. The measure level linearity errors must be within tolerance limits given by IEC 61672-1: 2013.



keys
1. sinusoidal signal generator
.
.
7. Attenuator

Figure 3: Experimental set up for the level linearity test

3.3. Level Range Control Test

The test is performed with steady sinusoidal electrical input signals at 1 kHz, by recording the sound level display on SLM in different level range control. The difference between different level ranges should be within the allowable tolerance of IEC 61672-1. This test applicable to multiple level ranges.

3.4. Time-Weightings *F*, *S*, and *I* for SLM

Time Weighting**:** refers to the exponential averaging method used to adjust a measurement instrument's response to fluctuating signals over time. Time weighting essentially applies a "filter" to the signal, emphasizing or deemphasizing certain aspects of the signal based on the chosen time constant**.**

Sound Level time-weighted is defined as the time period over which the root mean square signal level is calculated (response speed). There are three speeds used on most SLMs namely; **Fast**, which the time response is 125ms (1/8 Sec.), **Slow**, which the time response is 1000ms (one second), and **Impulse** which, the time response is 35ms averaging times. The choice of ***F*** and ***S*** settings to use depends on the signal. The time-weight is given by [6],

$$L_{f_{w\tau}}(t) = 10 \log \left[\frac{(1/\tau) \int_{-\infty}^{t} P_f^2(\varepsilon)\, e^{-(t-\varepsilon)/\tau} d\varepsilon}{P_0^2} \right] dB \quad (1)$$

where

f_w is the frequency weighting A, C, or Z
τ is the exponential time constant in seconds for either the ***F***, ***S***, or ***I*** time weighting,
ξ is a dummy variable of time integration from some time in the past as indicated by -∞ for the lower limit of the integral to the time of observation, t,
$Pf_w(\xi)$ is the instantaneous sound pressure signal of frequency-weighted (A, C, or Z), and
P_0 is the reference pressure value of 20 µPa.

For the F time-weighting the applied input signal frequency is at 4 kHz, while for the S time-weighting check the applied input signal frequency is at 1 kHz as specified by IEC61672-2 Clause 9.11. The input signal level is adjusted to indicate a sound level that is less 5 dB than the upper limit of level linearity on the reference level range for at least ten seconds, then the input signal is shut off and the decay time is recorded using a stopwatch. Figure 4 shows the experimental set up for the time-weighting tests.

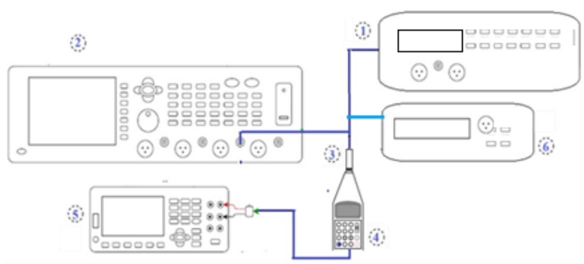


Figure 4: Electrical calibration system for time-weighting

3.5. Toneburst Response Test

This test checks the response of SLMs to short-duration signals with 4 kHz tone bursts that start and stop at zero crossing. The test implemented using a sinusoidal signal generator, which applies 4 kHz sinusoidal signal to the SLM under test, with adjusted input signal level such that the SLM display indication 3 dB less than the upper limit of primary indicator range, and use this indication as a reference level. Figure 5 shows the experimental set up for the toneburst test.

The purpose of time-weighting SLMs, with reference 4 kHz tonebrust response δ_{ref} for maximum time-weighted sound levels can be calculated from equation (2).

$$\delta_{ref} = 10\log\left(1 - e^{-T_b/\tau}\right), \quad (2)$$

where

T_b is the specific duration of a tonebrust in second,
τ is a standard exponential time constant,

and the sound exposure level of tonebrust can be calculated using the approximation in equation (3)

$$\delta_{ref} = 10\log\left(T_b/T_o\right) \quad (3)$$

where

T_b is the specific duration of a tonebrust in second,
T_o is a reference time valued 1 second.

The toneburst responses and applicable accepted limits for the shorter tonebrust are given by IEC-61672-1 2013.

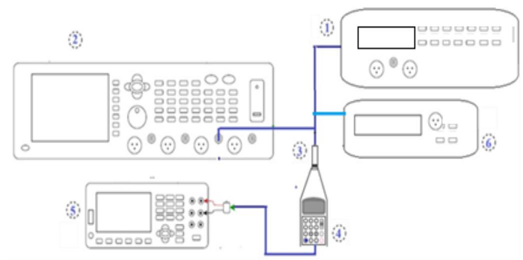


Figure 5: Electrical calibration system for toneburst response

3.6. Overload Indication

The overload indication tests the differences between the levels of the positive half ***Lp*** and negative half-cycle ***Ln*** for input signal that burst caused the displays of overload indication. The overload indication tested for both ***Fast***- and ***Slow***-time weighting. Sinusoidal electrical signals at frequencies of 31.5 Hz, 1 kHz, and 4 kHz are applied to the device as specified by IEC61672-2 Clause 9.15. The overload indication test was performed on the reference range of the device under test.

4. ENVIRONMENTAL CONDITIONS

The environmental conditions namely; static air pressure, temperature, and relative humidity are given in IEC 16072-1 as 23 oC, 101,325 kPa, and 50%, respectively. Standard operating ranges of environmental conditions: 80 kPa to 105 kPa for static air pressure, 20 °C to 26 °C for air temperature, and 25 % to 70 % for relative humidity can be applied. The specifications for the influence of the environmental conditions are summarized in Table 1.

Table 1: Influence of the environmental conditions

Item parameter	Class model	Tolerance	Uncertainty
Temperature	*Class 1*	± 0.8 dB	0.3 dB
	Class 2	± 1.3 dB	
Relative Humidity	*Class 1*	± 0.6 dB	0.3 dB
	Class 2	± 1.2 dB	
Static Pressure	*Class 1*	± 0.7 dB	0.3 dB
	Class 2	± 1.0 dB	

In the present work, the environmental conditions were recorded continuously during the calibration test (at the start of each set of measurements and at the end of each set of measurements), Table 2.

Table 2: The average laboratory conditions

Item parameter	Average	Standard Deviation	Standard Uncertainty
Pressure	101.3 kPa	0.45	0.15
Temp	23.5	0.75	0.15
R. H.	57.5	0.65	0.15

5. UNCERTAINTY BUDGETS OF MEASUREMENT

The uncertainty measurement budget related to any calibration test is strongly needed, ISO-17025 [9]. Therefore, this work aims also to provide the evaluation of the uncertainty measurement associated with the electrical calibration of SLM using the proposed calibration system in this article following the Guide to the expressions of Uncertainty in Measurement (GUM) [17], [18] and JCGM guides [19], [20], [21].

The budget of uncertainty is classified into two categories, A-type and B-type. Type A, which usually can be obtained by applying some measurement series and generally solving with a statistical procedure, such as the standard deviation obtained in a repeatability study; and Type B, which is the method of uncertainty evaluation by means other than statistical analysis. Values belonging to this category (type B) are evaluated by all available scientific information, such as a calibration certificate, previous measurement data, manufacturer's specifications or deduced from personal experience [22]. The values of the uncertainty type A decrease with the increasing number of repeated measurements, while the values of type B uncertainties are independent on the repeated measurements. The standard uncertainties of type A and B are combined to give the combined uncertainty [23], as the following relation:

$$u_c(x) = \sqrt{u_A^2 + u_B^2}, \tag{4}$$

where u_A is the standard uncertainty of type ***A***, and u_B is the standard uncertainty of type ***B***.

3.1 Principal of Determination of the Uncertainty to the Understudy SLM Calibration System U_A

Factors that can be considered in assessing the uncertainty measurement associated with a sound level meter operation were discussed and analyzed in a verification study by the National Physical Laboratory, UK [24]. The error correction values of the different factor contributions in type ***A*** uncertainty measurement to the sound level meter are summarized in the following corrections: The correction associated with the frequency-weighting network δ_{fr}, and the correction associated with the linearity on the sound level meter reference range δ_{lin}. the correction associated with the detector characteristics δ_{rms}, the correction associated with the time weighting function (***fast*** or ***slow***) δ_{time}, the correction associated with the resolution of the display (for the devices with the standard numerical display with the resolution of 0,1 dB), δ_{res} and the correction associated with the linearity on other range settings of sound level meter, δ_{dl}. The type ***A*** uncertainty measurement is determined as;

$$u_A = \sqrt{\sum_{i=1}^{6} u_i^2}, \tag{5}$$

The standard uncertainty of type ***B*** are coming from all possible error sources assessed from manufacturers data and from calibration certificates of all devices used in calibration test [25]. The values of uncertainty type ***B*** can be estimated using the following relation

$$u_B = \sqrt{\sum_{i}^{N} u_i^2(x)}, \tag{6}$$

where; ***N*** is the different individual contributions errors and u_i is the i^{th} uncertainty contribution of factor i^{th}.
An expanded uncertainty of measurement *U*, obtained by multiplying the combined standard uncertainty u_c by a coverage factor *k*,

$$U = k\, u \tag{7}$$

If high reliability is connected with the value of the measured quantity, normal (Gaussian) distribution can be attributed to the measurand, and the standard extension coefficient (coverage factor) $k = 2$ shall be used. The assigned expanded uncertainty corresponds to a coverage probability of approximately 95%. Also, the maximum uncertainty permitted is given by IEC 61672-1 [7].

The measurement uncertainty of sound level meters calibration contains at least the following components:
The measurement uncertainty from the calibration certificate of the standard instruments of calibration system, the uncertainty resulting from any environmental effects, the repeatability of measurements, and uncertainty due to the limited resolution of the sound level meter under test.

6. ELECTRICAL TESTS RESULTS

6.1. Frequency-weighting Results

Using the proposed cheap calibration system, the measurement data of the frequency weighting to the SLM under test are represented in Table 3, and the electrical characteristics of the A- and C-weightings are shown in Figure 6. The measured value is the arithmetic mean of five measurement results. The measurements are conducted for A- and C- frequency-weightings, and the time-weight is set to **Fast**. The individual devices of the system measurement is warmed up according to the time specified by the manufacturer. Method used in this work is the steady level of the input electrical signals, The C-weighting curve produces almost flat response.

Table 3: Frequency-weighting test results

Freq [Hz]	Expected (A) [SL dB]	Expected (C) [SL dB]	Measured SL (A) F [SL dB]	Measured SL (C) F [SL dB]	Deviation (A) [dB]	Deviation (C) [dB]	Accepted Limits (A) [dB]	Accepted Limits (C) [dB]	Expand Unc.(u) (A) [dB]	Expand Unc.(u) (C) [dB]	Accept. Limit u dB
1000	**125.0**	**125.0**	**124.8**	**124.8**	**0.0**	**0.0**	**±1.1**	**±1.1**	**0.2**	**0.25**	**0.4**
25	80.3	120.5	79.9	120.9	-0.4	0.4	±2.0	±0.2	0.35	0.35	0.5
31.5	85.5	121.9	85.0	122.3	-0.5	0.4	±1.5	±0.1	0.35	0.35	0.5
40	90.3	122.9	90.0	123.2	-0.3	0.3	±1.5	±0.1	0.35	0.35	0.5
50	94.7	123.6	94.3	123.9	-0.4	0.3	±1.5	±0.1	0.35	0.35	0.5
63	98.7	124.1	98.2	124.3	-0.5	0.2	±1.5	0.1	0.35	0.35	0.5
80	102.4	124.4	102.0	124.6	-0.4	0.2	±1.5	0.0	0.35	0.35	0.5
100	105.8	124.6	105.5	124.9	-0.3	0.3	±1.0	-0.1	0.35	0.35	0.5
125	108.8	124.7	108.5	125.0	-0.3	0.3	±1.0	0.0	0.3	0.3	0.5
160	111.5	124.8	111.2	125.0	-0.3	0.2	±1.0	0.1	0.3	0.3	0.5
200	114.0	124.9	113.6	125.0	-0.4	0.1	±1.0	0.0	0.3	0.3	0.4
250	116.3	124.9	116.0	125.1	-0.3	0.2	±1.0	-0.1	0.3	0.3	0.4
315	118.3	124.9	118.0	125.1	-0.3	0.2	±1.0	-0.1	0.3	0.3	0.4
400	120.1	124.9	119.8	125.0	-0.3	0.1	±1.0	-0.1	0.3	0.3	0.4
500	121.7	124.9	121.4	125.1	-0.3	0.2	±1.0	-0.1	0.3	0.3	0.4
630	123.0	124.9	122.7	125.1	-0.3	0.2	±1.0	0.0	0.3	0.3	0.4
800	124.1	124.9	123.9	125.0	-0.2	0.1	±1.0	-0.1	0.3	0.3	0.4
1250	125.5	124.9	125.3	125.1	-0.2	0.2	±1.0	0.0	0.3	0.3	0.4
1600	125.9	124.8	125.7	125.1	-0.2	0.3	±1.0	0.0	0.3	0.3	0.6
2000	126.1	124.7	125.8	124.9	-0.3	0.2	±1.0	0.0	0.3	0.3	0.6
2500	126.2	124.6	125.9	124.8	-0.3	0.2	±1.0	-0.1	0.3	0.35	0.6
3150	126.1	124.4	125.9	124.6	-0.2	0.2	±1.0	0.0	0.35	0.35	0.6
4000	125.9	124.1	125.6	124.3	-0.3	0.2	±1.0	0.0	0.35	0.35	0.6
5000	125.4	123.6	125.2	123.9	-0.2	0.3	±1.5	0.1	0.35	0.4	0.6
6300	124.8	122.9	124.5	123.2	-0.3	0.3	+1.5,-2.0	0.0	0.4	0.4	0.6
8000	123.8	121.9	123.6	122.2	-0.2	0.3	+1.5,-2.5	0.0	0.4	0.4	0.6
10000	122.4	120.5	122.1	120.7	-0.3	0.2	+2.0,-3.0	0.0	0.4	0.4	0.6

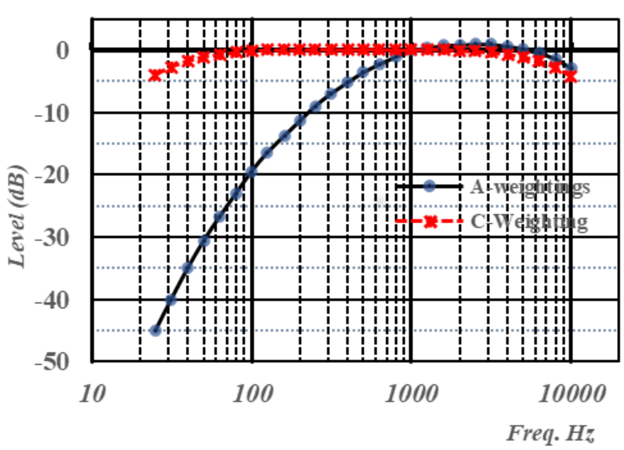


Figure 6: The electrical test of the A- and C-weightings

The frequency weighting C curve produces an almost flat response but with a roll-off below 31.5Hz and above 8000Hz.

6.2. Level Linearity Test Results

This test is implemented using a steady sinusoidal electrical signal at a frequency of 1 kHz with the sound level meter set to frequency weighting A. The signal amplitude is adjusted to indicate 94 dB on the reference level of 94 dB The signal is kept constant and switching the instrument for different ranges and the readings at each range are checked. Repeat the previous with increasing the signal amplitude in steps of 5 dB on the reference level range up to within 5 dB of the upper limit of the first indication of overload. For each step, the readings at each range are checked.

Also, the tests are performed with the signal decreasing in 5 dB steps down starting from the 94 dB till above the specified lower limit of the range within 5 dB. Measured values are the arithmetic mean of five test results, the measured data are represented in Table 4 and linearity level is shown in figure 7.

Table 4: Linearity level range, at1 kHz, and SPL of 5 dB steps

Expected SPL(dB)	Measured SPL (dB)	Deviation (dB)	Tolerance (dB)	Unc (dB)
130	129.9	-0.1	±0.3	0.25
129	128.9	-0.1	±0.3	0.25
124	124.1	0.1	±0.3	0.25
119	118.9	-0.1	±0.3	0.25
114	113.9	-0.1	±0.3	0.25
109	108.9	-0.1	±0.3	0.25
104	104	0	±0.3	0.25
99	98.9	-0.1	±0.3	0.25
94	94	0	±0.3	0.25
89	89	0	±0.3	0.25
84	84	0	±0.3	0.25
79	79	0	±0.3	0.25
74	74	0	±0.3	0.25
69	69	0	±0.3	0.25
64	64	0	±0.3	0.25
59	58.9	-0.1	±0.3	0.25
54	53.9	-0.1	±0.3	0.25
52	51.9	-0.1	±0.3	0.25

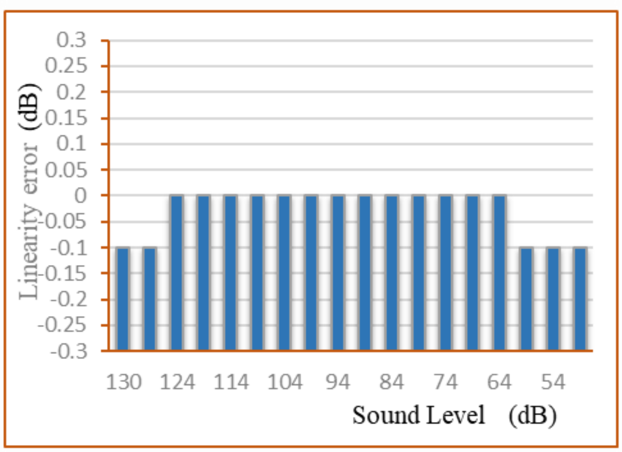


Figure 7: Linearity level

6.3. Toneburst Response Test Results

The SLM is set at the reference level range and frequency weighting A. The indicated sound level may be an F-time-weighted sound level, an S-time-weighted sound level or a time averaged sound level. Tone-burst responses were measured for tone-burst durations; 200ms, 2ms, and 0.25ms (IEC 61672-1). The deviations of measured tone burst responses from the corresponding reference tone burst must be within the accepted limits specified in IEC 61672-1.

The test implemented using a sinusoidal signal generator, which applies 4 kHz sinusoidal signal to the SLM under test, with adjusted input signal level such that the SLM display indication 3 dB less than the upper limit of primary indicator range, and use this indication as a reference level. The SLM is set at the reference level range and frequency weighting A. The indicated sound level may be an F-time-weighted sound level, an S-time-weighted sound level or a time averaged sound level.

A single 4k Hz tone-burst with too short-durations signals with 4 kHz tone bursts that start and stop at zero crossings and are extracted from steady 4 kHz sinusoidal input signals is applied to SLM under test. For **Fast** time-weighting, signal of time-duration, 200 ms, 2 ms and 0.25 ms are applied while for Slow time-weighting, a single 4k Hz tone-burst with durations of 200 ms and 2 ms, are applied.

The tone burst response can be calculated by subtracting the corresponding F-weighting sound level indicated for the steady signals from the maximum tone-burst signals F-weighting. The measured value is the arithmetic mean of five measurement results, the measured data are represented in Table 5 (F-weighting) and in Table 6 (S-weighting).

Table 5: Tone-burst response, ***F***-weighting

	Expect dB	**Meas.** dB	**δ_{ref}** dB	**Limits** dB	**Dev.** dB	**Uncer.** dB
Ref. Sig.	135	135	0.0	±0.5	0.0	0.25
200ms	135	134.8	-1.0	±0.5	-0.2	0.25
2 ms	117	116.5	-18.0	+1,0; -1,5	-0.5	0.25
0.25ms	106	105.2	-27.0	+1,0; -3,0	-0.8	0.25

Table 6: Tone-burst response, Time-weighting, ***S***

	Expect dB	**Meas.** dB	**δ_{ref}** dB	**Limits** dB	**Dev.** dB	**Uncer.** dB
Ref. Sig.	135	135	0.0	±0.5	0.0	0.25
200ms	127.6	127.2	-7.4	±0.5	-0.4	0.25
2 ms	108	107.1	-27.0	+1,0; -1,5	-0.9	0.25

6.4. Self-noise Generated Check Test Results

The sound level meter is sited at the maximum-sensitive level range at specific frequency-weighting. The self-generated noise is measured at different frequency-weightings, A, C and Z-weighting of time interval 60 s. It is preferably measured as a time-averaged sound level with an averaging time of at least 30s. Measured values are the arithmetic mean of five test results, the measured data are represented in Table 7.

Table 7: self-noise measured level

	Max	**Meas.**	**Uncer.**
	dB	dB	dB
A-weighted	13.5	10.5	0.5
C-weighted	20.6	13.8	0.5
Z-weighted	20.6	16.5	0.5

6.5. Overload indication test

The overload detector of the sound level meter is verified with different voltage signals at levels around the limit of overload indication. A signal at a level corresponding to 5 dB below the maximum level of the sound level meter is applied starting at 1 kHz. The frequency of the signal is then lowered in 1/3-octave steps, and at the same time the level of the signal is increased so as to keep the same A-frequency-weighted level, until an overload is detected or the acceptance limits of the routine are exceeded.

This test of overload indication is only to be performed for sound level meters capable of displaying time-average sound levels. Overload indication is tested on the reference level range with the sound level meter set to display A-weighted time-average sound level. Measured values are the arithmetic mean of five test results, the measured data are represented in Table 8.

Table 8: Overload indication results

Frequency Hz	Expected [dB SPL]	Measured [dB SPL]	Accept Limit [dB]	Deviation [dB]	Uncertainty [dB]
1000 (Ref Freq)	135.0	134.8	±1.0	-0.2	0.35
800Hz	134.8	134.8	1.0	0.0	0.35
630Hz	134.8	134.8	1.0	0.0	0.35
500Hz	134.8	134.8	1.0	0.0	0.35
400Hz	134.8	134.8	1.0	0.0	0.35
316Hz	134.8	134.8	1.0	0.0	0.35

6.6. Time weighting test

Sound level meters perform the verification of the time weighting characteristic under the electric characteristic test. Input duration of 200 ms time (F) and 500 ms (S) and 2k Hz single tone to sound level meters. The difference between maximum display value and the display value of sinusoidal wave that is continuous and has equal amplitude shall meet the requirements in Table 9. The measured value is the arithmetic mean of five measurement results.

Apply 2k Hz sinusoidal signal through the equivalent resistance the same as microphone to sound level meters. Adjust input signal amplitude to sound level meters display the indication 4 dB below upper limit of primary indicator range and use this indication as reference level.

Apply a duration of 200ms (F) and duration of 500ms (S) at 2kHz tone burst to sound level meters.

Table 9: The response to test tone burst

Indicator	Time Duration test of tone burst (ms)	Max. response to continuous signal (dB)	Limits (Type 1) (dB)
Fast	200	-1.0	±1.0
Slow	500	-3.1	±1.0

6.7. Calibration Results Using the B & K Type 3630

The A-weighting frequency response of the SLM to sinusoidal voltage signals at 1 kHz and at other frequencies is registered in Table 10.

Table 10: B&K type 3630 calibration system test results for frequency-weighting (A)

	Expected [dB SPL]	Measured [dB SPL]	Accept - Limit [dB]	Accept + Limit [dB]	Deviation [dB]	Uncertainty [dB]
1000Hz <Ref>	125.0	124.9	-1.0	1.0	-0.1	0.12
10Hz	54.5	54.1	-100.0	3.0	-0.4	0.12
12.58Hz	61.5	61.4	-100.0	3.0	-0.1	0.12
15.84Hz	68.2	68.2	-100.0	3.0	0.0	0.12
19.95Hz	74.4	74.5	-3.0	3.0	0.1	0.12
25.19Hz	80.2	80.4	-2.0	2.0	0.2	0.12
31.623Hz	85.5	85.6	-1.5	1.5	0.1	0.12
39.811Hz	90.3	90.4	-1.5	1.5	0.1	0.12
50.119Hz	94.7	94.8	-1.5	1.5	0.1	0.12
63.096Hz	98.7	98.8	-1.5	1.5	0.1	0.12
79.433Hz	102.4	102.4	-1.5	1.5	0.0	0.12
100Hz	105.8	105.7	-1.0	1.0	-0.1	0.12
125.89Hz	108.8	108.8	-1.0	1.0	0.0	0.12
158.49Hz	111.5	111.6	-1.0	1.0	0.1	0.12
199.53Hz	114.0	114.0	-1.0	1.0	0.0	0.12
251.19Hz	116.3	116.2	-1.0	1.0	-0.1	0.12
316.23Hz	118.3	118.2	-1.0	1.0	-0.1	0.12
398.11Hz	120.1	120.0	-1.0	1.0	-0.1	0.12
501.19Hz	121.7	121.6	-1.0	1.0	-0.1	0.12
630.96Hz	123.0	123.0	-1.0	1.0	0.0	0.12
794.33Hz	124.1	124.0	-1.0	1.0	-0.1	0.12
1258.9Hz	125.5	125.5	-1.0	1.0	0.0	0.12
1584.9Hz	125.9	125.9	-1.0	1.0	0.0	0.12
1995.3Hz	126.1	126.1	-1.0	1.0	0.0	0.12
2511.9Hz	126.2	126.1	-1.0	1.0	-0.1	0.12
3162.3Hz	126.1	126.1	-1.0	1.0	0.0	0.12
3981.1Hz	125.9	125.9	-1.0	1.0	0.0	0.12
5011.9Hz	125.4	125.5	-1.5	1.5	0.1	0.12
6309.6Hz	124.8	124.8	-2.0	1.5	0.0	0.12
7943.3Hz	123.8	123.8	-3.0	1.5	0.0	0.12
10000Hz	122.4	122.4	-4.0	2.0	0.0	0.12
12589Hz	120.6	120.7	-6.0	3.0	0.1	0.12
15849Hz	118.3	118.3	-100.0	3.0	0.0	0.12

The C-weighting frequency response of the SLM to sinusoidal voltage signals at 1 kHz and at other frequencies is registered in Table 11.

Table 11: B&K type 3630 calibration system test results for frequency-weighting (C)

	Expected [dB SPL]	Measured [dB SPL]	Accept - Limit [dB]	Accept + Limit [dB]	Deviation [dB]	Uncertainty [dB]
1000Hz <Ref>	125.0	124.9	-1.0	1.0	-0.1	0.12
10Hz	110.6	110.1	-100.0	3.0	-0.5	0.12
12.58Hz	113.7	113.6	-100.0	3.0	-0.1	0.12
15.84Hz	116.4	116.4	-100.0	3.0	0.0	0.12
19.95Hz	118.7	118.8	-3.0	3.0	0.1	0.12
25.19Hz	120.5	120.8	-2.0	2.0	0.3	0.12
31.623Hz	121.9	122.2	-1.5	1.5	0.3	0.12
39.811Hz	122.9	123.1	-1.5	1.5	0.2	0.12
50.119Hz	123.6	123.7	-1.5	1.5	0.1	0.12
63.096Hz	124.1	124.2	-1.5	1.5	0.1	0.12
79.433Hz	124.4	124.5	-1.5	1.5	0.1	0.12
100Hz	124.6	124.7	-1.0	1.0	0.1	0.12
125.89Hz	124.7	124.8	-1.0	1.0	0.1	0.12
158.49Hz	124.8	124.8	-1.0	1.0	0.0	0.12
199.53Hz	124.9	124.9	-1.0	1.0	0.0	0.12
251.19Hz	124.9	124.9	-1.0	1.0	0.0	0.12
316.23Hz	124.9	124.9	-1.0	1.0	0.0	0.12
398.11Hz	124.9	125.0	-1.0	1.0	0.1	0.12
501.19Hz	124.9	125.0	-1.0	1.0	0.1	0.12
630.96Hz	124.9	124.9	-1.0	1.0	0.0	0.12
794.33Hz	124.9	124.9	-1.0	1.0	0.0	0.12
1258.9Hz	124.9	124.9	-1.0	1.0	0.0	0.12
1584.9Hz	124.8	124.8	-1.0	1.0	0.0	0.12
1995.3Hz	124.7	124.8	-1.0	1.0	0.1	0.12
2511.9Hz	124.6	124.7	-1.0	1.0	0.1	0.12
3162.3Hz	124.4	124.4	-1.0	1.0	0.0	0.12
3981.1Hz	124.1	124.1	-1.0	1.0	0.0	0.12
5011.9Hz	123.6	123.7	-1.5	1.5	0.1	0.12
6309.6Hz	122.9	123.0	-2.0	1.5	0.1	0.12
7943.3Hz	121.9	122.0	-3.0	1.5	0.1	0.12
10000Hz	120.5	120.6	-4.0	2.0	0.1	0.12
12589Hz	118.7	118.7	-6.0	3.0	0.0	0.12
15849Hz	116.4	116.4	-100.0	3.0	0.0	0.12

The response of the SLM to sinusoidal voltage signals is registered for various levels covering the reference level range, including a level nominally corresponding to $\mathbf{L_{ref}}$ at the measurement frequency. From this the response at the other levels is calculated relative to the response at the level corresponding to L_{ref}. The relative response is compared to the anticipated relative response. For each level the difference between the responses at the level and at the previous level is also calculated in order to determine differential level linearity, the measured data are registered in Table 12.

Table 12: B&K type 3630 calibration system test results for linearity range, IEC60651, 4000 Hz, SPL 10 dB steps

	Expected [dB SPL]	Measured [dB SPL]	Accept - Limit [dB]	Accept + Limit [dB]	Deviation [dB]	Uncertainty [dB]
94 dB	94.0	94.0	-1.0	1.0	0.0	0.12
52 dB. Rel. Ref.	52.0	52.0	-0.7	0.7	0.0	0.12
60 dB. Rel. Ref.	60.0	60.0	-0.7	0.7	0.0	0.12
60 dB. Diff.	60.0	60.0	-0.4	0.4	0.0	0.12
70 dB. Rel. Ref.	70.0	70.0	-0.7	0.7	0.0	0.12
70 dB. Diff.	70.0	70.0	-0.4	0.4	0.0	0.12
80 dB. Rel. Ref.	80.0	79.9	-0.7	0.7	-0.1	0.12
80 dB. Diff.	80.0	79.9	-0.4	0.4	-0.1	0.12
90 dB. Rel. Ref.	90.0	89.9	-0.7	0.7	-0.1	0.12
90 dB. Diff.	89.9	89.9	-0.4	0.4	0.0	0.12
100 dB. Rel. Ref.	100.0	99.9	-0.7	0.7	-0.1	0.12
100 dB. Diff.	99.9	99.9	-0.4	0.4	0.0	0.12
110 dB. Rel. Ref.	110.0	109.9	-0.7	0.7	-0.1	0.12
110 dB. Diff.	109.9	109.9	-0.4	0.4	0.0	0.12
120 dB. Rel. Ref.	120.0	119.9	-0.7	0.7	-0.1	0.12
120 dB. Diff.	119.9	119.9	-0.4	0.4	0.0	0.12
130 dB. Rel. Ref.	130.0	129.8	-0.7	0.7	-0.2	0.12
130 dB. Diff.	129.9	129.8	-0.4	0.4	-0.1	0.12

The maximum reading of the SLM under test when exposed to single tonebursts is registered for various burst durations. The toneburst response of the SLM is calculated as the maximum reading relative to the response of the SLM to a steady sinusoidal signal with the same frequency and peak voltage as the tonebursts. The response of the SLM to a single burst is tested and compared to the anticipated response, the measured data for time-weighting ***F*** are given in Table 13, and in Table 14 for time-weighting ***S.***

Table 13: B&K type 3630 calibration system test results of time-weighting, response to single burst, 200 ms, **F**

	Expected [dB SPL]	Measured [dB SPL]	Accept - Limit [dB]	Accept + Limit [dB]	Deviation [dB]	Uncertainty [dB]
Ref. 126 dB	126.0	125.9	-1.0	1.0	-0.1	0.20
Burst Meas. 126 dB	124.9	125.0	-1.0	1.0	0.1	0.20
Ref. 116 dB	116.0	115.9	-1.0	1.0	-0.1	0.20
Burst Meas. 116 dB	114.9	115.0	-1.0	1.0	0.1	0.20
Ref. 106 dB	106.0	105.9	-1.0	1.0	-0.1	0.20
Burst Meas. 106 dB	104.9	105.1	-1.0	1.0	0.2	0.20
Ref. 96 dB	96.0	96.0	-1.0	1.0	0.0	0.20
Burst Meas. 96 dB	95.0	95.1	-1.0	1.0	0.1	0.20
Ref. 86 dB	86.0	86.0	-1.0	1.0	0.0	0.20
Burst Meas. 86 dB	85.0	85.2	-1.0	1.0	0.2	0.20
Ref. 76 dB	76.0	76.0	-1.0	1.0	0.0	0.20
Burst Meas. 76 dB	75.0	75.1	-1.0	1.0	0.1	0.20
Ref. 66 dB	66.0	66.0	-1.0	1.0	0.0	0.20
Burst Meas. 66 dB	65.0	65.1	-1.0	1.0	0.1	0.20
Ref. 56 dB	56.0	56.0	-1.0	1.0	0.0	0.20
Burst Meas. 56 dB	55.0	55.2	-1.0	1.0	0.2	0.20

Table 14:. B&K type 3630 calibration system test results for time-weighting, Response to Single Burst, 500 ms, S

	Expected [dB SPL]	Measured [dB SPL]	Accept - Limit [dB]	Accept + Limit [dB]	Deviation [dB]	Uncertainty [dB]
Ref. 126 dB	126.0	125.9	-1.0	1.0	-0.1	0.25
Burst Meas. 126 dB	121.8	122.1	-1.0	1.0	0.3	0.25
Ref. 116 dB	116.0	115.9	-1.0	1.0	-0.1	0.25
Burst Meas. 116 dB	111.8	112.1	-1.0	1.0	0.3	0.25
Ref. 106 dB	106.0	105.8	-1.0	1.0	-0.2	0.25
Burst Meas. 106 dB	101.7	102.1	-1.0	1.0	0.4	0.25
Ref. 96 dB	96.0	95.9	-1.0	1.0	-0.1	0.25
Burst Meas. 96 dB	91.8	92.1	-1.0	1.0	0.3	0.25
Ref. 86 dB	86.0	86.0	-1.0	1.0	0.0	0.25
Burst Meas. 86 dB	81.9	82.2	-1.0	1.0	0.3	0.25
Ref. 76 dB	76.0	75.9	-1.0	1.0	-0.1	0.25
Burst Meas. 76 dB	71.8	72.2	-1.0	1.0	0.4	0.25
Ref. 66 dB	66.0	66.0	-1.0	1.0	0.0	0.25
Burst Meas. 66 dB	61.9	62.3	-1.0	1.0	0.4	0.25
Ref. 56 dB	56.0	56.0	-1.0	1.0	0.0	0.25
Burst Meas. 56 dB	51.9	52.3	-1.0	1.0	0.4	0.25

The function of the overload detector of the SLM is verified with different voltage signals at levels around the limit of overload indication. A signal at a level corresponding to 5 dB below the maximum level of the sound level meter is applied starting at 1 kHz. The frequency of the signal is then lowered in 1/3-octave steps, and at the same time the level of the signal is increased so as to keep the same A-frequency-weighted level, until an overload is detected or the acceptance limits of the routine are exceeded. the observed data are registered in Table 15.

Table 15: B&K type 3630 calibration system test results for overload indication, Sine signal, Inverse A

	Expected [dB SPL]	Measured [dB SPL]	Accept - Limit [dB]	Accept + Limit [dB]	Deviation [dB]	Uncertainty [dB]	
1000Hz <Ref>	135.0	134.8	-1.0	1.0	-0.2	0.31	
794.33Hz	134.8	134.8	-1.0	1.0	0.0	0.31	
630.96Hz	134.8	134.8	-1.0	1.0	0.0	0.31	
501.19Hz	134.8	134.8	-1.0	1.0	0.0	0.31	
398.11Hz	134.8	134.8	-1.0	1.0	0.0	0.31	
316.23Hz	134.8	134.8	-1.0	1.0	0.0	0.31	Overload

7. CONCLUSION

The proposed device system for the SLM calibration in this work complies with the requirements of the allowed maximum tolerance and expanded uncertainties given by the IEC61672-1, low cost if we compare the other system calibration of SLM of B &K type 3630, It does not need an anechoic chamber. At most frequencies, the values of the expanded uncertainties of the primary B&K system are one-half of the corresponding values of the commercial system. This is because, as the number of instruments used in calibration process increases, the uncertainty of measurements increases. The proposed system offering fast calibration, it takes around 30 minutes for the SLM calibration.

Conflicts of Interest

The author declares that they have no potential conflicts of interest with respect to the research and authorship

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