Technical Report

Remembering the role of "Sound Level Indicators"

The current sound level meter standard, BS 61672, was introduced back in 2002 with its two defined performance classes of instrument, known as engineering and precision devices. This replaced the original standard from the previous century with its additional lower Grade 3 sound level indicators, referred to as SLIs. The fact that they have disappeared from the standards does not mean that SLIs have faded away, quite the opposite there are very many models on the market covering a price range of less than £100 to over £500. However, following the absence of any kind of quality control guidance for over a quarter of a century some care is needed now to ascertain that the level of uncertainty that can be given to the results they provide.

Noise control has now become a key topic for medical, environmental and engineering professionals and concepts of legal metrology underpin the ensuing regulations; whilst codes of practice control the actual measurement methods. These controls do increase the cost which keeps this market close to the acoustic professionals; however, there are many applications where lower degrees of accuracy may well be acceptable. Certainly, for those new to the measurement of noise, SLI's are a good place to start. The ensuing absence of any guidance has resulted in a kind of specification creep where SLI manufacturers are making partial claims to conformance that could become confusing. Claims such as "*has frequency weightings as per BS 61672*" or "*fast and slow time constants as per British Standards*" could be misunderstood as a claim of conformance to the current standards.

One of the considerations relative to the initial acquisition of a SLI is, of course, its basic accuracy and stability. For sure with sound being an intangible energy form, we can't get hold of it, and with the human reaction to it being highly subjective makes it difficult for the beginner to quantify. Normally a reference sound source is used to "set" a sound level meter, SLM, to the international reference sound level of 94 dB at a frequency of 1k Hz, (1 Newton pressure level relative to the human threshold of hearing) before each measurement sequence. An initial observation is that SLIs, unlike SLMs, rarely have an associated sound calibrator with them so this alignment to the international dB scale is not regularly made. So, it follows that any natural temporal and environmental drift will go unnoticed over time. The reason for this omission is to some extent driven by the relative cost between the reference sound calibrator and the basic cost of the SLI, and that the calibrator itself has cost associated with keeping it in calibration. This does indicate that some form of external reference calibration should be undertaken on SLIs, certainly at least annually. So, using a sound calibrator to re-align the SLI to the dB scale and if possible, to also check its frequency response, as this is the parameter that most often drifts out of specification, would seem a sensible cost-effective service for a calibration laboratory to offer.

Before progressing this suggestion, a couple of observations relating to associated sound calibrators need to be considered. These devices generate a sound pressure in a closed cavity into which the SLI microphone is inserted thereby exposing it to a known sound pressure level, to which it can be adjusted. A fact of physics is that the sound level generated in the cavity is dependent on the equivalent volume of the microphone inserted into it, so different models of microphone will produce different sound pressure levels. The result is also dependent on the barometric pressure, so it is also possible to have different results on different days. Hence the term "associated" sound calibrator, it must be suitable for the SLI it is to be used with. There are alternative types of sound calibrators that have more complex electronics that allow for them to compensate for different volume loadings and to correct for barometric pressure. These are generally known as laboratory sound calibrators, and many can operate at more than one sound level and at different frequencies. Using a suitable reference sound calibrator not only allows the basic accuracy of the SLI to be set but also by checking at different frequencies will confirm that the most delicate component, the microphone, has not been damaged. So, setting the international dB scale and verifying the relative frequency response to that

Figure 1
Using sound pressure calibrations can cause systemic errors at high frequencies.

reference would seem to be a good basic annual calibration procedure for a SLI. On the downside these laboratory reference sound calibrators cost many thousands of pounds and require expensive traceable reference calibration. Hence, an annual subcontracted service would seem to be the best approach to supporting a SLI in the field. In investigating this proposal in more detail, we come across a problem associated with the fact that sound calibrators produce sound pressure waves in a cavity whilst the actual sound measurements are made in acoustic free field conditions; and in free-field conditions microphones behave differently to when they are in an enclosed cavity. This stems from the fact that the introduction of the measurement microphone into the free-field will alter the sound field that we are trying to measure. This is because as the sound field impinges on the measurement microphone it will be reflected away and diffracted around its body thereby changing the sound field we are trying to measure. This effect becomes more noticeable as the wavelength (frequency) of the sound approaches the diameter of the of the microphone face. For a standard ½ inch measurement microphone it is just an increase of around 0.25 dB at 1k Hz, but this error increases to approximately 9 dB at the higher audio frequencies. Also, the magnitude of these errors is microphone type specific, although the general shape of the response is similar the detail of the over-reporting of the sound pressure level varies with different designs of same size microphones. Figure 2 shows how microphones will respond in both pressure and free-fields, the solid line is the response in the closed pressure field response, which is essentially flat with changes in frequency. The dotted lines show how the different designs of ½ inch pressure microphones will respond in a free-field as the frequency increases. This spread of results is due to both the variation of the acoustic impedance of the microphones diaphragm and the detail of the protection grid fitted on the front of the microphone. The important point is that the microphone will over report the sound level in a free-field, and that the magnitude of this error is microphone type dependent.

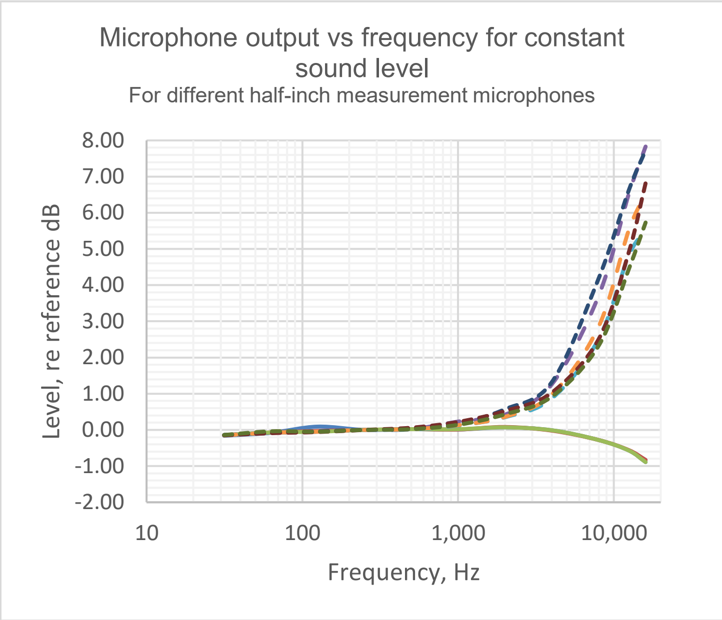

Figure 2
Effect of acoustic reflections errors on microphone response

Microphone designers get around this problem by altering the pressure response of the microphone so that it is no longer flat with frequency, but it falls off in exact mirror of how the free-field response rises with increasing frequency. So, referring again to figure 2, they take one of the six examples shown with dotted lines and then engineer its pressure response, the solid line, so that it falls by the same number of dB that the free-field response, the dotted line, increased at each frequency. The result will be that for that one model of microphone it will now have a flat frequency response in a free-field. Just what we need for a sound level measurement, the downside is that the pressure response will no longer be flat with frequency, hence our relative frequency response provided by the closed cavity reference sound calibrator report lower sound levels with increasing frequency. With SLMs this problem is solved by the microphone manufacturer providing correction tables that show the amount that needs to be added to the result to compensate for the free-field correction that has been built in, unfortunately this statistically derived information is difficult to produce with acceptable uncertainties so is hardly ever available for SLIs. As a result, the SLI will seriously under report the dB levels at mid- and higher frequencies.

The discussions above relate to just the microphone, but then this is mounted on the body of the sound level indicator, which then also further reflects the sound waves, these reflections will interact with the original sound wave in both constructive and destructive manner depending on the relative phase of the incident and reflected sound waves. This is shown in Figure 3, the curve on the left shows the free-field response of the microphone only in the sound field whilst that on the right shows the same microphone mounted on the complete SLI located in the same field. This shows the extent of the effect of the sound reflections from the case affecting the results. These additional deviations use up nearly all the permitted tolerances on the SLIs frequency response, so the case reflections are an important element to consider in the verification of the calibration of an SLI.
For SLMs the manufacturers put a lot of effort into the design of the case profile and publish correction figures based on measurements of a representative sample of each model, with uncertainties, so that case reflections

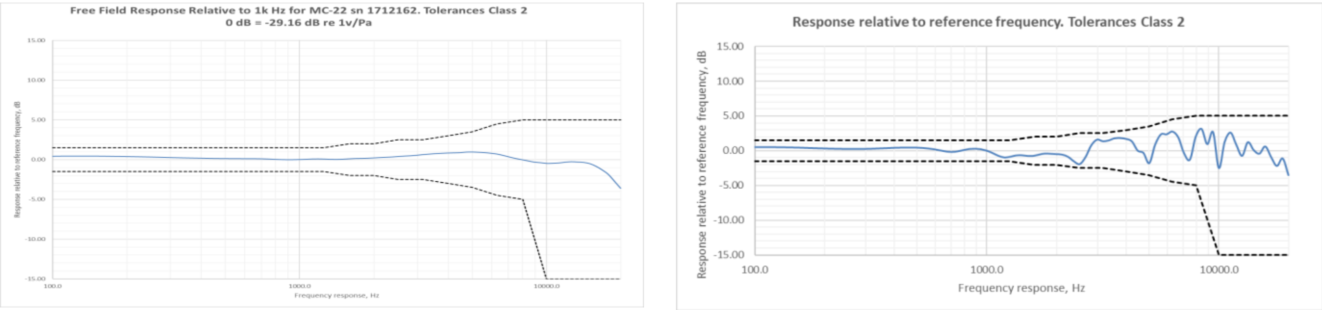

Figure 3
Left graph microphone only mounted in sound field. Right graph same microphone but mounted on SLI.

can be accounted for in the calibration. In the example chosen it was a SLI with a sensible case design, figure1 right hand side, with a conical front to minimise these reflections. But there are examples of SLIs with flat surfaces, and these will produce much more marked case reflections.

Summarising in respect of a SLI calibrations based on closed coupler pressure measurements; they will achieve the first requirement of ensuing that the alignment to the international reference level is correct but for frequencies above 1k Hz that the uncertainties will increase and will quickly be as large as even the more relaxed tolerances of the old BS 60651 class 3 standard. As we have seen this is due to the uncertainties that relate to microphone pressure to free-field effects, that are microphone type dependent, as well as case reflections, that are case profile dependent. To improve on the mid to high frequency calibration in the absence of the necessary technical information from the SLI manufacturer's it would be necessary for the SLI owner to source the information themselves. This can be achieved by placing the complete SLI in an anechoic chamber and measure its overall free-field response. Which would provide the combined result of both the free-field and case reflection effects. From this information it is possible to calculate the necessary corrections for the higher frequency pressure measurements. So, as we have already ensured that the reference level is correctly aligned to the national standard, we would then have all the information we need for the calibration certificate of the reference level and relative frequency response, so we then have a comprehensive initial calibration document. If the pressure coupler calibrations at the mid and higher frequencies are now also carried out all the information to calculate the free field corrections would be to hand allowing any future re-calibration to be carried out using the lower cost method.

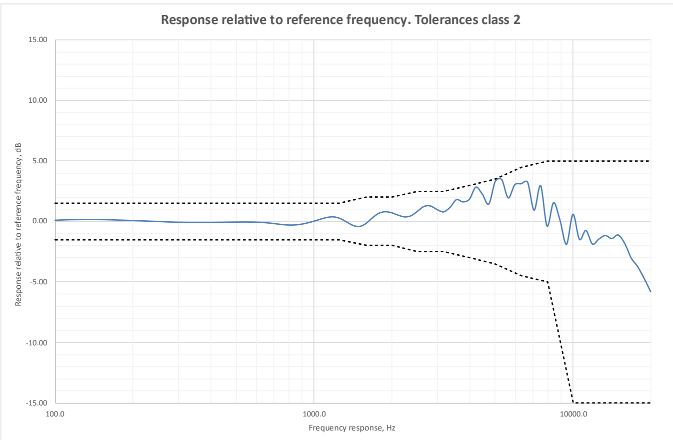

Figure 4
Typical SLI free-field calibration result

As there have been advances in the methods available for making free-field calibrations which allow for a degree of automation,although it is still necessary to mount the instrument in a free acoustic space but once that is done the process can be automatic. It does require the SLI in question have the necessary mounting and test points, so it is not suitable for all instruments but does give a route to reasonable uncertainties to be obtained for the calibration of SLIs at mid to higher frequencies with documented uncertainties. An example of a free-field calibration of a suitable SLI is shown in figure 4, this result has 93 measurement points over the frequency range of the instrument and in this case is shown with the class 2 tolerance from the current standard. The expanded uncertainty associated with this type of measurement is 0.38 dB at low, 0.76 dB at mid and 0.99 dB at high frequencies, which would be more than adequate to confirm compliance with the tolerances discussed; even so in this case it shows this SLI to be in the grey zone at 5k Hz. The calibration certificate will also have a statement confirming the necessary corrections to apply to the pressure calibration figures at higher frequencies to compensate for the combined effect of the free-field and case reflection errors, thereby allowing any future re-calibration to take advantage of the less expensive procedure.

Where the SLI is not suitable for direct free-field measurements extending the calibration beyond the setting of the reference level is difficult to justify on technical grounds. To evaluate these potential errors, we have examined the SLI free-field responses that we have in our calibration library and selected just the ones that relate to instruments with sensible sound level meter profiles and standard ½ inch microphones and from these produced a "typical free-field and case reflection" correction. The object of this exercise is to examine the expanded uncertainty of these results to give an indication if some statistical data based on a larger sample of results would be precise enough to validate conformance to the relative frequency response tolerances given in the standards. The expanded uncertainty of the mean of this sample was 3.03 dB at 8k Hz and 5.5 dB at 12.5 k Hz., including these additional items in the overall measurement uncertainty budget would probably give an expanded uncertainty more than the allowed 6 dB BS 60651 tolerances above 8k Hz. For some users may be happy to accept these potential errors in the absolute measurements at mid and high frequencies and rely on just being able to detect a relative change between calibrations; the knowledge that a change in results was an instrument error and not a change in noise emissions may have value to them. Figure 5 shows a typical relative frequency response constructed from the 11 octave measurements of the coupler sound pressure measurements as the pressure response; these have then been extended by the estimated "typical" correction figures discussed above. This initially seems to show that it moves from a fail to a pass condition. However, the tolerances will need to be adjusted to accommodate the expanded uncertainty of the dataset used to correct for the missing data.

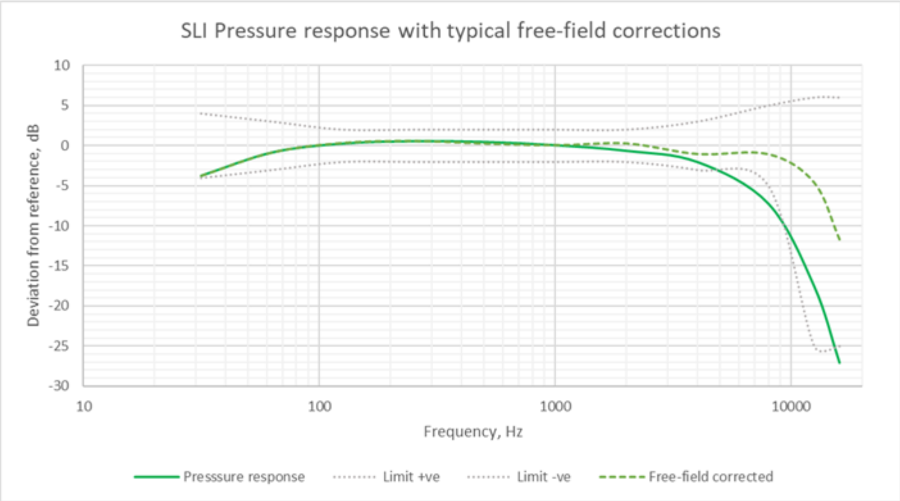

Figure 5
Pressure calibration with estimated free-field and case correction data.
Limits require adjustment to accommodate correction uncertainties

To summarize we have tried to show an economical yet technically sound method of providing calibration support for sound level indicators that do not claim full conformance to the current BS61672 type 2-meter standard. Notwithstanding full compliance the SLI has a valuable role in certain sectors of acoustics, its limitations in respect of staying within reference calibration and its frequency response conforming to the stated relative frequency response can be addressed by an initial free-field calibration and ensuing calibrations using simplified pressure calibrations. It is estimated that the initial free-field calibration would cost approximately £225 with the ensuing pressure calibrations at £140. For SLIs that are not suitable for free-field calibration or where the full costs cannot be justified just the pressure coupler calibrations may be made and due allowance made for the added uncertainty following from correction data at mid and high frequencies not being available.

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Notes: We refer to the original BS 60651 which has been withdrawn so this is used for reference only. The limits allowed in it for Class 3 meters, SLIs, generally have limits on their relative frequency responses that are around ±1 dB wider than the current standard. SLIs also differ from SLMs in their environmental stability, in their ability to handle high crest factor and wide dynamic range signals and only provide simple exponentially averaged indices. So even with equivalence in terms of the absolute calibration and relative frequency response, there are other reasons why an SLI and SLM would give differing results.