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Acoustic Calibrators - a new "old" design

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ABSTRACT

When IEC standard 60942: 2003 [1] for Acoustic Calibrators was published, it offered a significant improvement in accuracy over previous versions. Not only were the tolerances tightened, but measurement uncertainties were included. As the accuracy of the acoustic calibrator controls the final measuring accuracy of a sound level meter, this was an important step forward.

The general opinion at the time was that the new standard would make obsolete traditional calibrators that simply used a stabilised oscillator to power a transducer, and would most likely be met by a feedback design where a precision microphone is used to control the acoustic pressure in the cavity.

In the event, the new technology of the feedback design gave new problems that were far less easy to solve than at first thought; but by paying attention to fine details and by correcting for static pressure and temperature, the more traditional design could easily meet the new requirements.

In 2008, five years after the standard was published only one commercial design appeared to have been formally Pattern Approved as meeting IEC 60942 : 2003 at both Class 1 and Class 2 accuracy and this is a simple, reliable design using a small microcontroller to make the various corrections needed. A special transducer was designed for the calibrator as existing ones were inadequate for reliable, long-term accuracy.

The paper describes the steps taken to produce the device and gives results showing the stability after the first full year of operation.

1. INTRODUCTION

In essence, a conventional acoustic calibrator has to do one thing and one thing alone. It has to produce a pure 1kHz sine wave at a pressure of 1Pa and it has to do this over as wide a range of external influences possible. What could be simpler? The 'accuracy' of the acoustic calibrator sets the best measuring accuracy of the whole measuring chain and is in many ways the most critical link in the chain. Despite this, from the time the first sound standard IEC 60123 was published in 1961, there was a delay of a quarter century before the first international standard for acoustic calibrators, IEC 942 [2], was published and in that time manufacturers had to reply on themselves to provide their calibrator 'standard'.

2. HISTORY

There have been many interesting methods used to make acoustic calibrators. At least three manufacturers produced a “Falling Ball” device, where thousands of small ball bearings were

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dropped onto a mica membrane to give a broad band noise. The more scientific approach was to produce a pistonphone where two opposing pistons rapidly change the volume of the microphone cavity and from this a reproducible and calculable pressure change results. These devices, being mechanical, were limited in practical terms to frequencies below about 250Hz and this gave a huge added uncertainty when A-frequency-weighted measurements were being made, as the actual attenuation at 250Hz of the sound level meter being calibrated was not likely to be known. Nevertheless, the pistonphone is still regarded in some countries as a serious device for field use.

By 1970, after the publication of the Walsh-Healey Act in the USA, at least 20 new sound level meter companies were formed and many of them produced a sound calibrator. Being mostly American, these start-ups wanted an all-electronic solution for the calibrator and of the devices designed, two stand out: those designed designed by Quest Technology – now part of 3M - and Pulsar Instruments - now part of Scientific Measurements group. Both these companies produced an acoustic calibrator using the same critical part - a transducer originally meant for a divers helmet microphone. Many other companies used the same device as it was ideally suited to the known requirements.

The Pulsar calibrator had as its oscillator a Wien Bridge, the level of which was controlled by a small filament bulb intended as an aircraft cockpit indicator. This could hold the output level well, but being thermally operated, was very susceptible to ambient temperature changes. In about 1977 this was solved by the addition of a small thermistor as a temperature correction and the new device was branded Cirrus. This device was probably one of the most copied devices in acoustics and we have found at least 20 manufacturers with a “replica copy” of this. By 1982, tests at a government laboratory suggested that while the temperature correction worked, improvements could still be made. In addition the circuitry, using very old components, was becoming expensive to manufacture and so while the Wien Bridge remained, the control circuitry was improved. The stabilising element became a Field Effect Transistor operating in its variable resistance mode and a voltage reference source was included along with a comparator to control the stabilising element. The reference voltage source could be manipulated to correct for the transducer temperature curve and the effects of static pressure change could be corrected by means of an external barometer. See Figure 1.

Figure 1: CR:511F with Barometer

In this form, the calibrator was externally tested against the first edition of the IEC 942 standard and was given a formal EU Pattern Approval certificate, PTB 21.51 – 00.03. It was still just recognisable as the same basic device designed in 1970, but with many incremental improvements. However, for the SMI group, the fact that there were so many apparently identical copies that did not comply with IEC 942 made the designers think again.

3. IEC 60942 : 2003

A. A new design

When the third edition of IEC standard 60942 for Acoustic Calibrators was published in 2003, it offered a significant improvement in accuracy over previous editions. Not only were the tolerances tightened, but many uncertainties of testing were included. As the accuracy of the acoustic calibrator controls the final measuring accuracy of a sound level meter, this was an important step forward. The international standard for sound level meters, IEC 61672 [3], requires that any SLM submitted for periodic verification testing must be accompanied by a calibrator certified to the requirements of IEC 60942, making it essential that calibrators conforming to the new standard are provided in sound level meter measurement kits.

The general opinion at the time was that the new standard would make obsolete the traditional calibrators that simply used a stabilised oscillator to power a small transducer in the microphone cavity. It was thought that the new “high accuracy” standard would most likely only be met by a feedback design, where a precision microphone is used to control the acoustic pressure in the cavity. This was despite the fact that many designers had vast experience in the "traditional" type and very few had ever designed a feedback device. It is clear that a feedback design has many advantages, such as better control over the equivalent volume, but it has the huge disadvantage that the accuracy relies almost totally on the feedback microphone. As microphones of the required performance tend to cost more than the purchase price of a calibrator, this disadvantage became the key point.

In the event, the new technology of the feedback design also gave new problems that turned out to be far less easy to solve than at first thought; while by paying attention to the fine details and by correcting for static pressure, temperature and humidity, the more traditional design could easily meet the new requirements - and so it proved.

At Cirrus Research plc. the decision was made to design the new calibrator by evolution, not revolution. The arguments for and against such an approach were many, but came down to the fact that while every engineer knows that they can design a better device than his predecessors, they often fail to see the problems with a “clean sheet” approach, with the result that unforeseen problems arise. The more cautious approach chosen reflected the view that after 30 years of incremental improvement, almost all the weak points and potential “bear traps” of the existing design were known to the design team – all they had to do was to solve known problems. This is far less exciting for the engineer, but far more productive.

B. Problem parameters

For an acoustic calibrator, the known major problem points are the changes in output due to external influences, particular static pressure, humidity and temperature.
Table 1 shows the tolerances in IEC 60942: 2003 for level over the specified ranges of temperature, humidity and static pressure.

Table 1: *Level tolerances within specified environmental conditions*

Frequency (Hz)	Tolerance Class LS (dB)	Tolerance Class 1 (dB)	Tolerance Class 2 (dB)
31.5 to >160	-	0.5	-

160 to 1k25	0.2	0.4	0.6
>1k25 to 4k	-	0.6	-
>4k to 8k	-	0.8	-
>8k to 16k	-	1	-

These limits apply over the static pressure range from 65 to 108 kPa with humidity from 25% to 90% for all types, while the temperature limits are shown in Table 2:

Table 2: *Temperature ranges for different performance Classes*

Class	Lower limits degrees Celsius	Higher limit degrees Celsius
LS	.+16	.+30
1	-10	.+50
2	0	.+40

To a practical person, Class 2 units, intended to be used in the field should logically have a wider temperature range, albeit at increased tolerance, but the working group decided otherwise.

Such matters as frequency drift, the purity of the sine wave, the actual level and such classic matters, were not considered serious problems as they had all been resolved on the existing Pattern Approved Class 1 device the CR:511E and there was significant leeway on each effect. For example, a change up to 1% in the frequency is permitted, i.e. 10Hz, but with crystal clocks today, a change of 1 part in 10^6 would be considered more normal. Also in IEC 60942, great stress is made of supply voltage fluctuations, that is change of output as the battery is discharged. These must be less than 0,1 dB, or about 1%. In the 21st century this should be an inconsequential task and it could be far tighter than this. The main problem was – and is – static pressure and humidity.

4. REALISATION OF THE NEW “OLD” DESIGN

The most important matter was the choice of a suitable transducer. The divers' helmet unit used since 1970 was now obsolete and no similar device was found. In any event, the old transducer had several problems. It was designed like a conventional loudspeaker with a wound coil and this was hard to screen against magnetic fields. The performance with varying temperatures was very marginal in that the units were not as repeatable as we would have liked. As the tolerances of IEC 60942 were tightened, this disparity between devices became a significant problem. If a transducer has large changes due to an external effect, these can be compensated for, but if there are wide unit-to-unit differences compensation is far harder. With a computer based design, almost anything can be corrected-for but the more the disparity, the more testing needs to be done and the cost increases. Accordingly, the decision was taken to design and manufacture a new device. A ceramic disk design was chosen and this resolved almost all the previous, known problems. The performance of the new transducer with temperature and static pressure was found to be highly consistent and repeatable [4]. The rest of the design closely followed previous models but with the addition of static pressure sensors to avoid the need for a barometer and a small microprocessor to make the required corrections and generate the signals needed.

It was interesting to note that, had the low cost static pressure sensor been available when the previous devices were designed, they probably could have met the latest static pressure requirements without the use of a barometer.

The use of a microprocessor to control everything gives many advantages, especially in testing. Should a newly-manufactured unit not comply with every parameter, corrections can be written into the internal memory. For example, if on a particular device, at very low static pressure, the level is too near the tolerance limit, it is logically easy to add a calibration constant to the program. While logically easy, this means that every unit needs to be tested at many static pressure points and this of course significantly increases the cost of testing. Each unit would have to be put in a pressure chamber and individually adjusted by a controlling computer, so it is important that the basic design has as little natural dispersion as possible from the design centre. The same applies for temperature performance. If the device has very wide natural variations, many more points need to be checked on every unit than if the temperature performance was better known. Eventually, a set of tests was devised so that the ISO 95% confidence level could be easily reached.

On the old CR:511E calibrator one major issue was the use of mechanical switches, where the switch directly controlled the circuitry. With a computer based design, the mechanical switches need only send a digital signal to the computer and so all the signal lines can be better protected against humidity; indeed, this was one of the break-though points.

The finished product is shown in Figure 2. The lack of feedback microphone yields a small, lightweight unit. The robust plastic case cushions the transducer and electronics from rough handling in everyday use.

Figure 2: CR:514 Acoustic calibrator

5. RESULTS

Some performance data for the new calibrator designs (named CR:514 for Class 2 and CR:515 for Class 1) is shown below.

The mean, uncorrected, static pressure response of a batch of transducer assemblies is shown in Figure 3. 95% of newly-manufactured units lie within the upper and lower lines. The curve shape is highly consistent, making software correction simple.

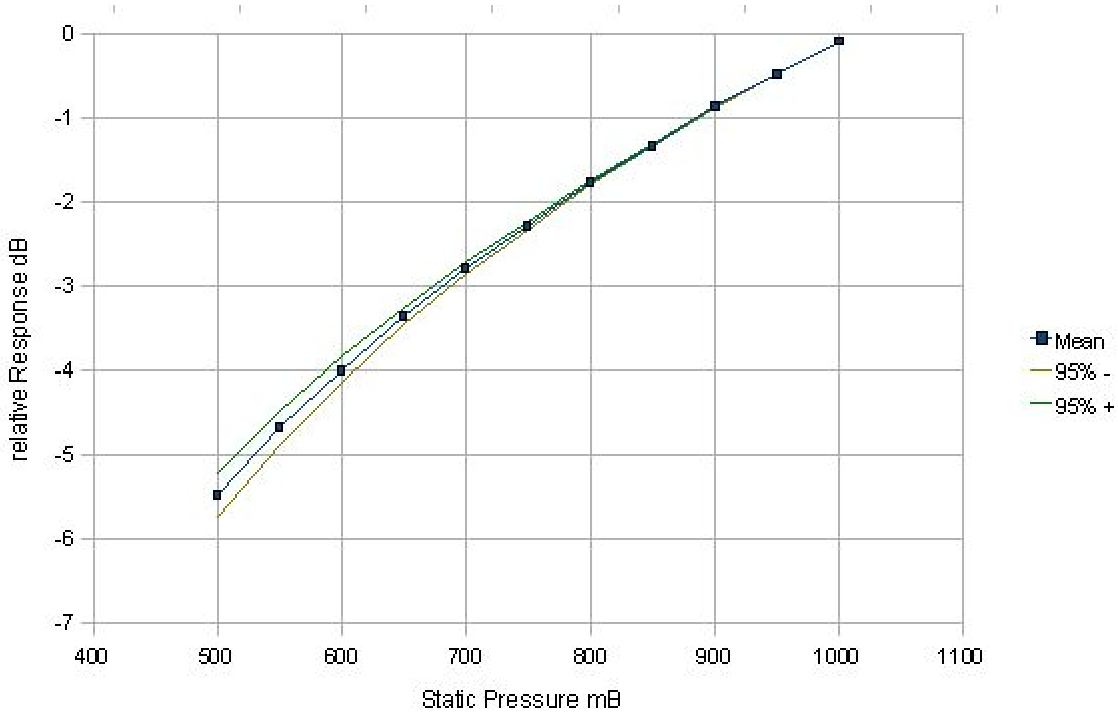

Figure 3: Mean static pressure performance of transducer assemblies

Temperature characteristics of three Class 1 CR:515 calibrators are shown in Figures 4, 5 and 6. There are small variations in temperature performance between units, and some hysteresis can be seen - although the results are all well within the required tolerances. The tests extend above and below the specified temperature range of -10 to +50 degrees C.

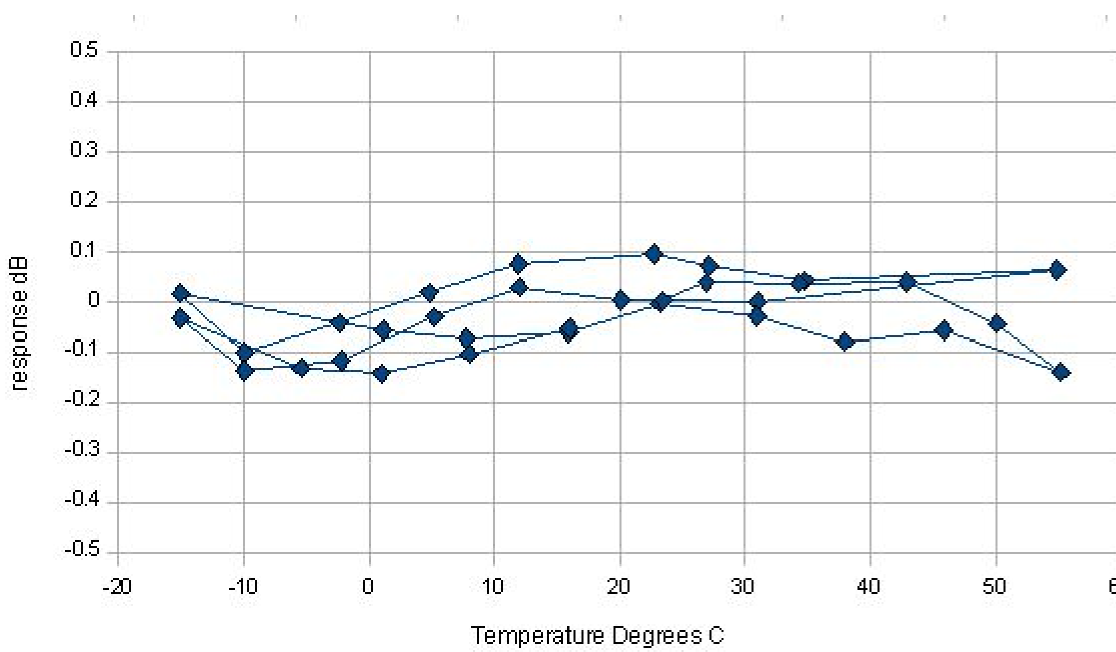

Figure 4: Temperature response - Unit A

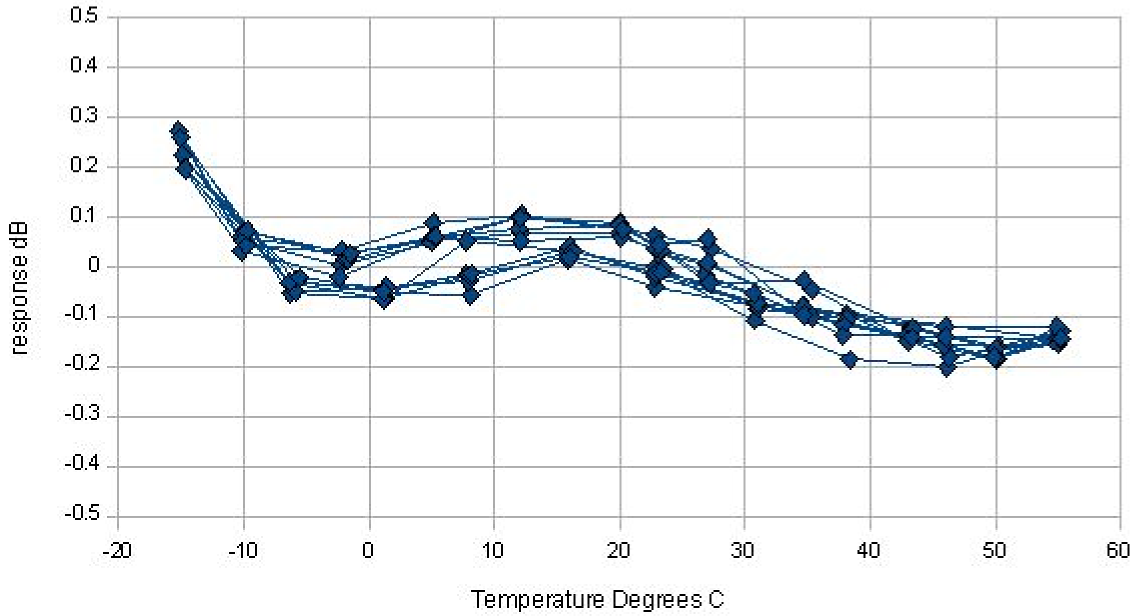

Figure 5: Temperature response - Unit B

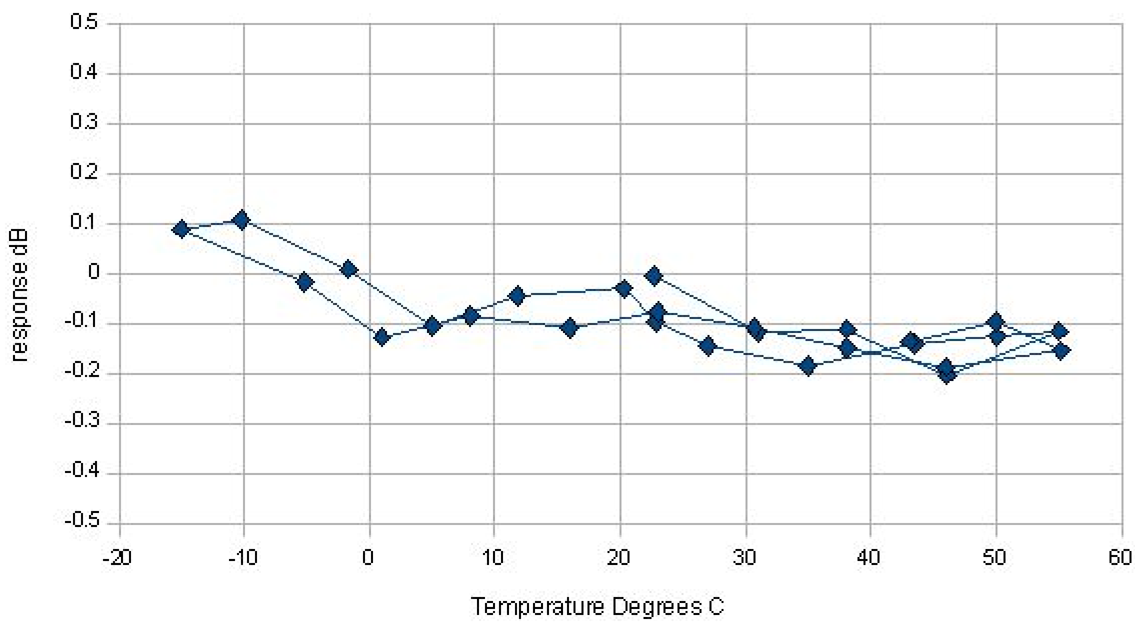

Figure 6: Temperature response - Unit C

The long-term drift of two calibrators is shown in Figure 7. These units are used as everyday factory-floor reference Working Standards. The expanded uncertainty of measurement here is 1.2dB. No long-term drift trends can be discerned in this data.

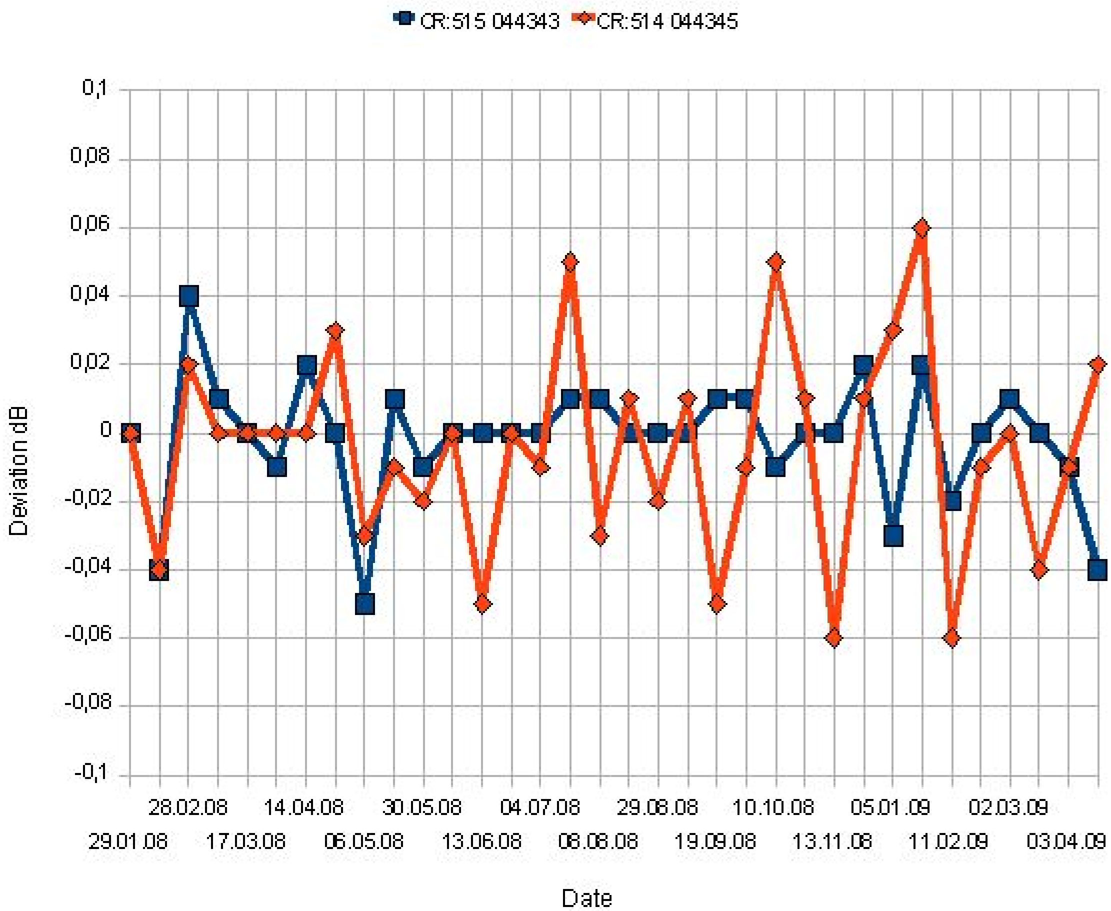

Figure 7: Long-term drift of two Working Standard calibrators

Tables 3 and 4 show sample results of pattern evaluation tests on the influence of air temperature and relative humidity, according to the requirements of IEC 60942:2003.

Table 3: Influence of air temperature (5.4, A.5.3 and A.5.5 of IEC 60942:2003)

Measured temperature °C	Measured frequency Hz	Measured output voltage from microphone mV	Actual expanded uncertainty of voltage meas. dB	Absolute value of difference between SPL at reference conditions and measured SPL	Tolerance limits dB
0.0	1000.01	11.363	0.20	0.24	0.60
10.0	1000.03	11.169	0.20	0.38	0.60
23.0	1000.04	11.368	0.20	0.20	0.60
30.1	1000.04	11.351	0.20	0.20	0.60
40.0	1000.03	11.238	0.20	0.28	0.60

Table 4: Influence of relative humidity (5.4, A.5.3 and A.5.6 of IEC 60942:2003)

Measured relative humidity %	Measured output voltage from microphone mV	Actual expanded uncertainty of voltage meas. dB	Absolute value of difference between SPL at reference conditions and measured SPL	Tolerance limits dB
25.9	11.438	0.20	0.21	0.60
50.3	11.424	0.20	0.20	0.60
69.5	11.407	0.20	0.21	0.60
79.8	11.450	0.20	0.23	0.60
89.3	11.477	0.20	0.25	0.60

6. CONCLUSION

When the 2003 version of IEC 60942 was published, expert opinion suggested that it was going to be fairly easy to meet. However, mature reflection then suggested that it was going to be more difficult than supposed and for 5 years no company managed to obtain Pattern Approval, despite several new designs being introduced; all except the unit described here appearing to be feedback devices. This was logical, as the same expert opinion initially held that only feedback or "controlled" devices would be able to meet the standard. The present design shows that this is not so, and a traditional simple device, well engineered, is more than adequate for the task with enough tolerance in hand for drift over life.

In 2008 the first units meeting IEC 60942 : 2003 were Pattern Approved by the PTB, the Cirrus Research CR:515 at Class 1 level and the CR:514 at Class 2 level with approval number PTB - 21.5 – 08.01. Similar instruments were also approved for Pulsar Instruments in the UK (21.5 - 08.03), Cesva in Spain (21.5 - 08.02) and ACO Pacific in California (21.5 – 08.04).

Since the abstract for this paper was written, a feedback design has also been approved, showing that the tolerance limits in IEC 60942 : 2003 are sensible and practical and indeed can be met using different technologies. It seems to follow that some parameters can reasonably be tightened at the next revision of IEC 60942 to further improve overall measurement accuracy.

Table 5 gives details of the calibrators pattern approved by PTB, to June 2009.

Table 5: PTB Type Approvals to IEC 60942:2003 (excerpt)

Type	Manufacturer	Characteristics	Type approval
CR:515	Cirrus Research	Electrodynamic drive, uncontrolled; Class 1; 94 dB at 1000 Hz	21.5 - 08.01
CR:514	Cirrus Research	Electrodynamic drive, uncontrolled; Class 2; 94 dB at 1000 Hz	21.5 - 08.01
CB006	Cesva Instruments	Electrodynamic drive, uncontrolled; Class 1; 94 dB at 1000 Hz	21.5 - 08.02

CB004	Cesva Instruments	Electrodynamic drive, uncontrolled; Class 2; 94 dB at 1000 Hz	21.5 - 08.02
Model 105	Pulsar Instruments	Electrodynamic drive, uncontrolled; Class 1; 94 dB at 1000 Hz	21.5 - 08.03
Model 106	Pulsar Instruments	Electrodynamic drive, uncontrolled; Class 2; 94 dB at 1000 Hz	21.5 - 08.03
521	ACO Pacific	Electrodynamic drive, uncontrolled; Class 1; 94 dB at 1000 Hz	21.5 - 08.04
SV30A	SVANTEK	Electrodynamic drive, controlled; 94 dB and 114 dB at 1000 Hz	21.5 - 08.05
SV31	SVANTEK	Electrodynamic drive, controlled Class 1; 114 dB at 1000 Hz	21.5 - 08.05

REFERENCES

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3. *Electroacoustics – Sound level meters – Part 3: Periodic tests,* International Standard IEC 61672-3:2006, International Electrotechnical Commission, Geneva, Switzerland, 2006.
4. R. Wright and D. Cartman, “Design of a new non-feedback calibrator for sound level meters “, in Proceedings of Internoise 2006, paper no. 429.