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# What Can "Go Wrong" in Acoustic Measurements: Common Errors, Hardware Failures and Mistakes

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## ABSTRACT

Making acoustic measurements is challenging. A lot of things can go wrong: microphones can fail or be damaged, animals can gnaw cables, clocks will drift, weather conditions can change, details about the measurement can be lost, even highly competent people can make mistakes. New capabilities in sound level meters & computers and small changes in working practice can avoid, mitigate, salvage or at least understand "what went wrong." This presentation will share experiences and lessons learned from working with instrumentation designers and users in industry and government. Please come willing to share your experiences so others can learn.

## 1 INTRODUCTION

I have had the opportunity to work in test and measurement for multiple decades. That has allowed me to make many mistakes. For much of that time, my jobs have involved either direct or indirect support of customers and colleagues using my employer's measurement equipment. That has allowed to benefit from seeing others' mistakes.

Many of my mistakes and others' mistakes are not unique. They are often common problems that are unfortunately are easy to repeat. Some are inherent in the technology used in sound level meters. For example condenser microphones are fragile and can be easily damaged. Other problems are like incorrect settings are common but features like pre-defined configurations are available but not always used.

There is an old proverb:

- The wise man learns from someone else's mistakes,
- the smart man learns from his own,
- and the stupid one never learns.

I also had the opportunity to find ways to salvage measurements and make recommendations on how to avoid making the same mistake again. This paper is an attempt to share to make others "wise."

## 2 MICROPHONE

The microphone is really the fundamental part of sound level meter. It is also the first part of the measurement chain.

### 2.1 Microphone Physical Damage – Avoid

The capacitive microphone is a miracle of transduction.

Small changes in pressure induce very small movements in a thin diaphragm. Unfortunately, this sensitivity to very small changes in pressure causes a capacitive microphone to be fragile. In addition, the microphone needs to be located away from the sound level meter's body to correctly measure a sound field. So much like a dog, a sound level meter leads with its most sensitive element.

The first way to avoid microphone damage is never to remove the protective grid. It seems like an obvious statement, but unfortunately the threat of the grid cap is the same direction as the threat of the capsule on the preamplifier. It is very easy to unintentionally remove the grid cap when you are intending to remove the microphone capsule.

The next obvious way to avoid damage is not to drop the sound level meter. Most sound level meters come with a lanyard to minimize risk of accidentally dropping the sound level meter.

When not in use make sure to store the mic and pre-amplifier in their case. Be careful with the preamplifier its round and it rolls.

Use the manufacturer supplied windscreen. It protects the microphone from inadvertent impacts with obstacles like wall, tripods, car doors, etc. It also helps with wind noise.

### 2.2 Microphone Physical Damage – Detect

To be able to detect damage in a capacitive microphone, it is first helpful to understand how damage affects the microphone. When viewed from the side the microphone is much like a trampoline. An impact will distort the outer ring of microphone, which will lead to a reduction in the tension of the microphone diaphragm.

The reduction in tension causes an increase in deflection of the diaphragm in response to sound. The microphone will become more sensitive. Normally, more sensitivity is desirable. Unfortunately, a reduction in tension changes sensitivity and the frequency response.

It is difficult to test the frequency response outside a calibration laboratory. It is important to notice significant increases in a microphone's sensitivity. An increase in sensitivity in indicative of damage.

During yearly calibration at a calibration laboratory, a change in frequency response is directly detected. The frequency response is compared to the limits for the sound level meter's class.

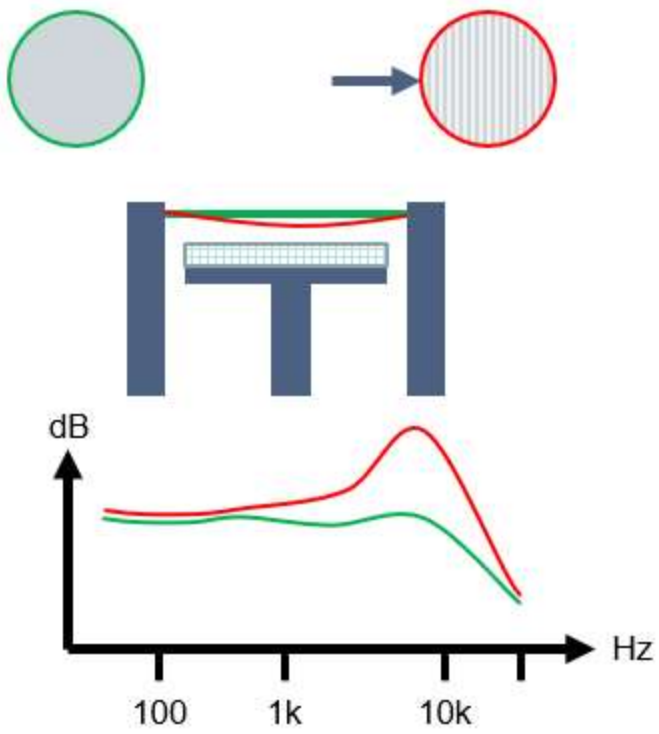


***Figure 1:*** *Increased sensitivity and change in frequency response caused by damage on a condenser microphone*

### 2.3 Microphone Loss of Pre-polarization Voltage – Detect

A less common problem with modern microphones is the failure of the polarization voltage. It is now common to use pre-polarized microphones. These microphones have a charged material on their back plate to create an electric condenser. Over time, the pre-polarization can begin to fail. The microphone then becomes less sensitive. This is a manufacturing defect, no way for a user to avoid. Fortunately, it is problem which has largely been overcome by manufacturers.

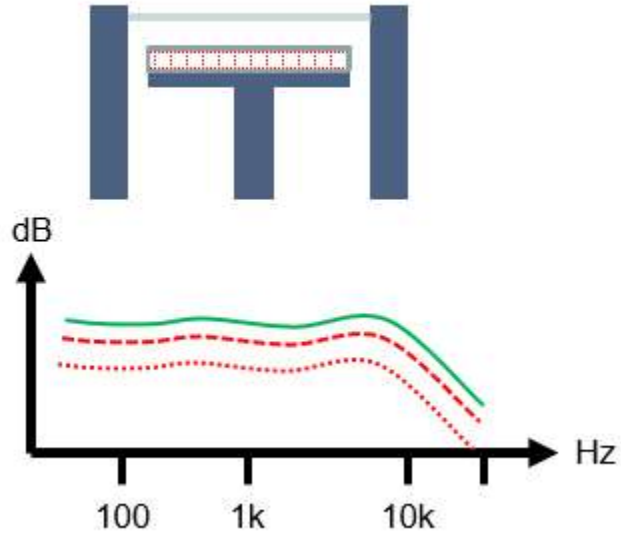


***Figure 2:*** *Reduced sensitivity caused by failing pre-polarization voltage*

### 2.4 Microphone – Detect

Monitoring a microphone sensitivity overtime is an important way to detect both damage and loss of pre-polarization voltage. This is why it is important to regularly calibrate microphones in field and at a longer intervals at a calibration laboratory.

As discussed earlier, physical damage to the microphone causes a sudden and typically large increase in sensitivity. It is the most common problem with a microphone and is easy to detect.

A loss in polarization voltage is more difficult to detect since it occurs slowly over time, it might not be noticed from one field calibration to the next. It is important to track the current calibration relative to the last factory calibration. Only by monitoring this value, is it possible to detect a slow failure in the polarization voltage.

Controversially, some, myself included, recommend not using the field calibrator to change the sensitivity stored in the sound level meter. Frequent field calibrations will slowly track the loss of sensitivity caused by a loss in calibration. Better to measure and even store the calibration tone frequently.

Another problem with using the calibration function on sound level meter is it typically only shows the broadband level. Almost all class 1 and class 2 sound level meters include 1/1- or 1/3-octave filters. Being familiar with spectrum of your calibrator's tone is useful for detecting other sound level meters problems like increased noise floor.

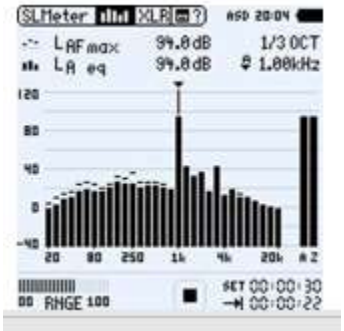


***Figure 3:*** Typical calibration tone in 1/3-octave spectra

## 3 PREAMPLIFIER

### 3.1 Preamplifier – Avoid problems

Keep the preamplifier connected to the sound level meter whenever possible. Keeping the preamplifier connected to the sound level meter protects the electrical connector by keeping out dirt and moisture. An unattached preamplifier being a cylinder, it has a tendency to roll.

### 3.2 Preamplifier – Detect

Becoming familiar with the calibration tone's spectrum is helpful in detecting problems in a preamplifier. Electrical noise tends to be white in nature, this means that higher frequency 1/3 octaves, with wider bandwidths, will be the most sensitive to higher than normal electrical noise.

Ideally you would have a very quiet space to test the noise floor of a preamplifier or a dummy microphone. This is often not practical. At some frequencies the calibrator acts as a "quiet box."

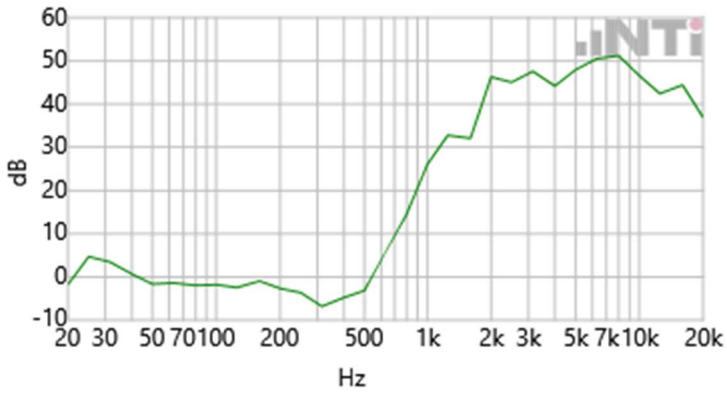


***Figure 4:*** *Attenuation of a calibrator as a function of frequency*

Just like any wall or partition the walls of the calibrator is most effective at high frequencies. Store the spectrum of the microphone in the calibrator, which the calibration turned off, when the system is new or after a recent laboratory calibration. The system's noise floor is tested both at time of manufacture during laboratory calibration. Having the "known good" reference, it is possible to detect an increase in noise at high frequencies. Of course, the walls act as an attenuator to the surrounding noise, so being as quiet a space as possible when taking this measurement is required.

Some electrical is not constant but is impulsive. Most sound level meters have the capability to listen to the signal through headphones. It is useful to listen using this capability to detect any kind of pops or hiss is that are caused by electrical problems in the preamplifier.

## 4 A/D CONVERTER

### 4.1 A/D Converter – Avoid problems

Analog to digital, A/D, converters are an area where technology has improved the most. Not long ago an 80 dB dynamic range was the norm. Now 100 dB is common and through the ability to stack two A/D converters it is possible to achieve a single range sound level meter covering over 120 dB.

If your sound level meter still has multiple ranges, use predefined setups that store your appropriate range for the measurement. For example, in building acoustics, have a predefined setup with the range set high for the source room level measurement. In the receiving room, have a different predefined set up with range set too low to measure the background noise.

### 4.2 A/D Converter – Detect

Overloads and under loads our problems well covered within the sound level meter standards ANSI/ASA S1.4 and IEC 61672. These standards require that overloads and underloads are marked in data.

Another way to detect a problem with noise is compare the background noise like L90 or L99.9 to the expected noise floor of the system. A high value of logged L90, even during quiet portions of an evening, indicates a noise problem.

## 5 STORAGE – AVOID PROBLEMS

Storage or memory has greatly increased over the years. In the past, storage capacity was measured in kilobytes, KB, but now gigabytes, GB, is common. A full 24 hours of 24-bit, 48-kHz single channel audio is approximately 12 GB.

Besides being more plentiful and inexpensive, storage has also become more reliable. It is now more likely that human error will lose data instead of storage failure. To avoid accidently erasing overwriting data, if at all possible, never work from the original master, only from a copy. Alternatively, make the first step in processing data copying the data to a location that is automatically backed up such as a cloud drive. Preferably a location that automatically archives past versions if there are any changes.

It is good practice to regularly reformat cards using formatting tools recommended by the sound level meter's manufacturer; almost always not the default formatting tool included in Windows and MAC operating systems.

One benefit of inexpensive memory cards is it is not expensive to have spares or even single-use memory cards. The frequency of replacement is a function of the value of the data that would be lost in a failure. Certainly, after two or three years of faithful service, every memory card deserves retirement.

If you have several memory cards, it is hard to tell them apart. It is helpful to either add a label with the date of purchase, a real challenge on microSD cards, or change the name of the card to encode the data of purchase. A file with this information on the card is another alternative but can be easily lost during periodic reformats.

Finally, don't be cheap, buy name brand cards when possible. Even name brand cards can fail but you will have controlled what you can by buying quality cards to begin with. Some sound level meter manufacturers offer tested memory cards that have been tested and verified. Continuously storing over week or month to a memory card, as in logging measurements, is not a typical application for memory cards. Some card's internal controllers have low level functions to periodically move data on the card. When the card controller is moving data around the card's write speeds drops significantly.

## 6 BATTERIES – AVOID PROBLEMS

### 6.1 Li-Ion

Most sound level meters use Li-ion batteries. Li-ion batteries are a huge improvement in battery technology that has enabled significant advances in portable electronics.

Li-ion batteries howeverhave known issues. Their storage capacity decreases over time both as a function of the number of charge-discharge cycles, but also as a function of age. After about 3-4 years, most Li-ion batteries have lost significant storage capacity and should be replaced. Think about a four-year-old mobile phone, reduced battery life is significant issue that drives phone replacement.

Most sound level meters are expected to have a much longer career than 3-4 years. Unlike many phones, the Li-ion batteries are intended to be replaced but the owner. Like with memory cards, it is useful to put the date on a new battery. Especially in organizations with multiple sound level meters where batteries can be swapped between older and newer units.

Like other electronics, avoid storing the sound level meter in hot locations such as car trunks in summer. The electronics will be fine but the Li-ion battery can be damaged by excessive heat.

When a Li-ion starts to fail, they tend to swell. Occasionally check installed batteries. If you detect swelling, replace the battery immediately or increase the checking frequency. Swollen batteries can eventually fail and lead to well know Li-ion fires.

### 6.2 Alkaline batteries

Alkaline batteries are no longer as common since they have lower capacity per volume.

Although not a fire risk, alkaline batteries can also cause damage to electronics. Alkaline batteries contain acid. If they are left in devices for long periods, the acid can leak and destroy the electronics.

If you have alkaline battery powered devices you do not use regularly, it is best to remove the batteries between use.

## 7 OPERATOR – AVOID PROBLEMS

Not expectedly, the operator is often the "weak link" in the measurement system. Even experienced and skilled operators make mistakes. Especially in field measurements that are done in unfamiliar environments sometimes with clients asking lots of questions.

### 7.1 Misconfiguring the measurement parameters

Modern sound level meters have greatly increased capabilities over earlier models. Sound level meters from 30-40 years had all their settings clearly visible on the instruments front panel, it helped that they did not have much functionality and that they were typically large

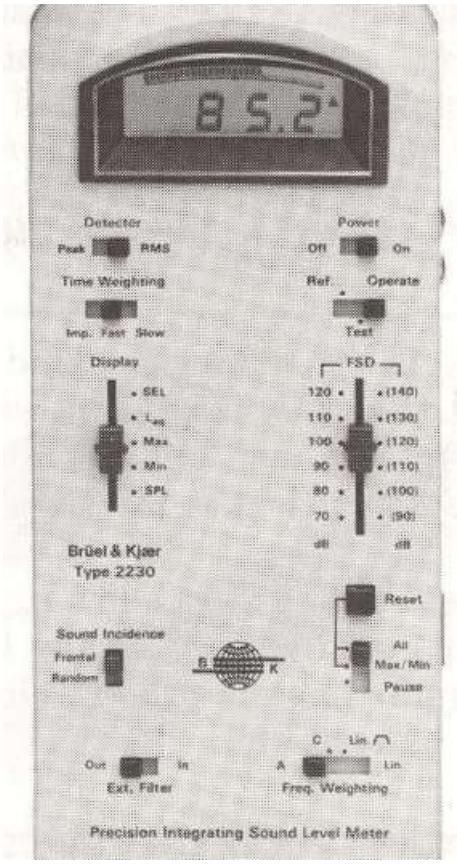


***Figure 5:*** *Front panel of a Brüel & Kjær Type 2230 from the early 1980'st*

The operator could simply look at the unit and see what its settings were. Of course, mistakes still happened.

With the increase of functionality on sound level meters in the 1990s, some settings need to be hidden when not be checked or changed. From then on, it was not as clear how a unit is configured. Sound level meters retain their settings between sessions. That is helpful and avoids setting up the unit for each session, retained settings can be a false friend especially in

organizations that share units. You may have left the unit correctly configured after your last use, but that doesn't mean your colleague returned the favor.

As they became more setting rich, sound level meters added the capability to store and recall measurement configurations. This feature goes by a variety of names: settings, configurations, profiles, etc. Figure out what your meter's name is for this feature and use it. For new consultants, give them a list of pre-defined configurations to use for each standard test.

As discussed earlier, memory is now cheap and plentiful. When storage capacity was measured in KB, logging setups traded-off between the number of parameters (e.g. LAeq, LCpeak, 1/3-octave), logging interval (e.g. once a hour, once a minute) and total measurement time. Now in the days of GB storage capacity, reducing parameter and logging interval to extend measurement time has largely passed. Even in long-term monitoring (e.g. weeks), the advent of remote access to download results to free up memory has reduced the need to budget the memory.

This is relevant to avoiding operator error. A frequent operator error is not configuring the sound level to store needed parameters. Sometimes needs change, a client comes with a new request or post analysis raises questions that could have been answered if additional parameters had been stored, but often it is a simple error of not considering what parameters should be stored at initial setup. Things get hectic and there is not always time to plan each new job. Again, a case for pre-defining common measurement setups.

| Logging item | Data /s | Use case 1 (Live 1) | Use case 2 (Live 2) | Use case 3 (Env 1) | Use case 4 (Env 2) | Use case 5 (Env 3) |
|---|---|---|---|---|---|---|
| SLM with 10 levels | 1.2 kB/s | ✓ | ✓ | ✓ | ✓ | ✓ |
| Spectral logging (1/3rd oct) | 12 kB/s | | | ✓ | ✓ | ✓ |
| Compressed Audio | 12 kB/s | | ✓ | | ✓ | |
| Uncompressed Audio 24 Bit / 48kHz | 144kB/s | | | | | ✓ |
| Standard SD XL2 8 GB | | 81 d | 7.4 d | 7.4 d | 3.9 d | 0.6 d |
| Extended SD XL2 32 GB | | 323 d | 29.4 d | 29.4 d | 15.4 d | 2.5 d |
| Archiv Disk 2TB | | 56 y | 5.2 y | 5.2 y | 2.7 y | 5.2 m |

***Figure 6:*** *Memory usage for a typical SLM with 100 ms loggingt*

### 7.2 Data usage for 100 ms logging

The above table is for a sound level meter that stores broadband SLM and spectral data natively as ASCII. ASCII data storage is becoming more common because of plentiful storage. ASCII data takes more space then proprietary binary, by a factor of about eight, but can be easier to work with for post-analysis. Audio data is typically stored as WAV, with different sampling rates, bit depths and compression, or MP3.

Broadband parameters take very little storage space, a subset of 10 broadband levels or parameters takes on 1.2 KB/s for a 100 ms, 10 times a second, logging rate. Increasing the number of parameters to the 50 available (parallel A-, C-, Z-weightings, eq, max, min, peak) increases

memory usage to 6 KB/s. Organizations can decide if the extra memory usage of all logging 50 parameters is worthwhile in the pre-defined logging configuration

Logging spectral data is more memory intensive at 12 KB/s at 100 ms logging rate. Logging 10 broadband parameters plus spectral data at a 100 millisecond rate would fill a 8 GB memory card in a week or a 32 GB card in just under a month. If the logging rage is reduced to once per second, the total measurement times increase to 74 and 294 days respectively.

Logging interval plays significantly changes memory usage but with storage capacities in GB, the question is now intervals of 100 millisecond or 1 second instead 1 minute or 1 hour from the days of storage capacities in KB. Faster logging intervals are useful in logging situations where there are multiple possible noise sources. Especially noise monitoring where there are both noise sources coming from the monitored property but also from outside the property. A classic example is monitoring a construction site along a busy road near an airport. Having a one second or faster logging intervals allow external noises to be removed or excluded. This is an improvement over the previous method where one-hour logging intervals were supplemented by measuring the amplitude and duration of "events" for later exclusion. "Events" worked for eq measurements but was problematic for max, peak and level statistics.

Which broadband and spectral parameters, logging interval, and data storage format define the memory usage rate for the traditional parameters measured and reported by noise consultants. Modern electronics and increases in available storage have enabled storing the actual audio as a WAV or MP3.

Storing audio is currently an area where memory budgeting is often still needed. However as available storage shifts from GB to TB, this will become less of an issue. A 2 TB memory device can hold 5+ months continuous audio recording at 24-bit resolution and 48 kSamples/sec sampling rate. There will issues "downstream" of working with and archiving TB recordings, but similar issues were overcome in the past with GB recordings and are currently being pioneered by those working with high resolution video.

For now, the initial question is what will audio recordings be used:

A. Identifying noise source
B. Re-analysis of sound

For identifying whether a sound is caused by construction work, vehicle pass-by, or aircraft flyover; recordings with reduced sampling rates, bit depths and other compression techniques are typically sufficient. Even for some forms of re-analysis, like pure tone detection by FFT, compressed audio works. Reduced sampling rates sacrifice higher frequencies but high frequencies are attenuated much faster over distances. Reduced bit rates sacrifice dynamic range but it is the high amplitudes that are of interest. MP3 compression is more problematic for pure tone analysis by FFT. MP3 compression has its own model of frequency masking, high amplitude tones "masking" nearby lower amplitude tones, which may or may not match the standards model for such masking or audibility.

Since the ability to record high resolution recordings is relevantly recent, applications for it are uncommon Possibly, automatic noise source identification based on artificial intelligence would benefit from high resolution recordings, but the field is still in its early days. Data transmission rates are improving but these are still an issue when dealing with high resolution recording.

Back to the topic of avoiding operator errors. When recording audio first became possible in electronics, memory was still scarce. To conserve memory, it was common to trigger recording only when a sound level exceeded a threshold. It was very challenging to budget memory usage for an unknown amount of audio recordings.

If the recording threshold was set too high, you risked missing recordings when something of interest was happening. The consultant then needed to fall back on noise source identification through amplitude, duration and possible 1/3-octave spectra. This was never an easy task, even for experienced consultants. The conclusions could be easily be challenged since the underlying data was very limited.

If the recording threshold was set too low, the sound level meter could run out of memory, which would end the long-term early; a significant loss of data.

Now with large amounts of storage and compressed audio, it possibly to budget memory usage including recording. Simply record compressed audio for the entire measurement. If downstream arching of large recordings is an issue, simply delete the separate audio files after the analysis, reporting and acceptance is done.

### 7.3 Other human errors, hardware configuration

Setting up the hardware is another avoidable source of human error. Sometimes the error is obvious, a recording with noise from a missing windscreen is painful to listen to, knowing that the measured sound level parameters also include this extra wind noise. Sometimes the hardware errors are more subtle, measurement levels being affected by being too close to the operator holding the device or building or variations caused by wind coming from different directions and amplitude over the course of a long-term monitoring session.

Here are some suggestions to avoid hardware human errors:

- Always use a windscreen
- For quick measurements, mount the sound level or microphone on a tripod or monopod "walking stick"
- For long-term measurements, directly measure windspeed and direction onsite or have a method to review wind variations from publicly available sources
- For measurements where the sound level meter is inside a case, lock the controls before closing the lid. Even well-designed cases can inadvertently stop or pause a measurement by hitting a button or large touch screen

A final source of avoidable human error is having great data, but not knowing the location or context. It seems obvious when the data is being stored where the measurement was taken and any special conditions. It may not be as obvious later on for you or a co-worker.

The data and the time of the measurement can be helpful for later "detective" work; "where was I the evening of August 30?" Notes on paper or phone are useful, but can become easily "separated" from the data. It is better to use the voice annotation feature available on most sound level meters. Built-in GPS on sound level meters which will help with the "where" if not always the "what."

## 8 OPERATOR – SALVAGE PROBLEMS

The below table describes some common operator errors and how to at least partially recover.

**Table 1:** Common errors and ways to recovert

| Error | How to recover | Comments |
|---|---|---|
| Wrong calibration value | Calculate difference in sensitivity in dB, add correction | A recorded calibration tone helps |
| Wrong weighting spectrum (e.g. Z- instead of A-weighting) | Apply known spectral weighting as dB | Careful with tones especially at low frequencies, the weighting spectral weighting is at the 1/3-octave center frequency |
| Wrong weighting broadband (e.g. Z- instead of A-weighting) | Sum from corrected spectrum | |
| Erroneous sounds (e.g. helicopter) | Remove those samples from average | Audio recording helps and high logging rate |

### 8.1 Salvaging Operator errors – the last option

If a required parameter was not measured (e.g. spectral data), it is best to go remeasure it. Sometimes data is truly irreplaceable, so direct remeasurement is not an option.

With parallel recording of the audio becoming more common, it is sometimes possible re-analyze a measurement from the recording. This type of re-analysis is definitely not officially compliant with any instrument standards, even if re-analysis is done through playback into a sound level meter. Any such re-analysis should be clearly explained and documented.

Here are some other considerations:

- If the recording was made with automatic gain control (AGC) re-analysis not possible
- Re-analysis is limited to the frequency range of the recording
- For re-analysis through playback into a sound level meter, it will take as long to re-measure as the original recording. An hour-long recording takes at least an hour to re-analyze, a week long recording would take at least a week
  - Re-analysis into a PC can be faster than real-time but the functionality of a sound level meter needs to be acutely reproduced in software
- Calibration of the system is challenging. Even when the WAV files scaling is known, the gain in the playback system needs to be known or compensated for. A recording of the calibration tone is very helpful

Again, remeasuring is the best and correct solution.

## 9 SUMMARY

Thank you for getting to the end. Hopefully there was something mentioned that will help you avoid problems in your measurements or more easily recover from any problems you encounter.

If there is one thing, I would like readers to take away from this paper, it would be start using their sound level meter's "store and recall of pre-defined configurations" feature.

That is the best and easiest way to join the "wise."