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EOL Testing of Acoustic Devices

A Truly Multidisciplinary Task

My job at NTi Audio enables me to support numerous acoustic device manufacturing places worldwide. While many things are handled individually, there are also a lot of common procedures and challenges found in almost every acoustic Quality Control (QC) environment. This article summarizes the major considerations for running a single or multiple-line acoustic QC test that is worthwhile, reliable, and reproducible.

By
Gregor Schmidle
NTi Audio

Keeping up consistent yield and quality in a high-volume acoustic device production environment requires well-designed end-of-line (EOL) manufacturing and test processes. However, there are many possible reasons for variations in measurement results. Within a single production line, variations can be caused by fluctuations in the quality of subcomponent material, changes in the manufacturing and assembly processes, as well as variance in environmental influences.

To ensure accuracy, the test system must be periodically calibrated or characterized in a system calibration. This is especially important when several production lines of the same type are operated in parallel, introducing line-to-line deviations. In many cases, these production lines are also spread across multiple facilities. When common limits are in use on different production lines, the mechanical differences between the test jigs introduce additional deviations in acoustic behavior. Further reasons for unwanted deviations are operator handling errors and wear and tear of test system components (e.g., electrical contacts). Another important topic is a recovery plan in case of an IT disaster (e.g., the loss of a hard drive).

What and How to Measure

Defining appropriate measurement parameters and functions for the EOL test lays out the groundwork for an efficient test system. There are two fundamental, yet conflicting requirements to fulfill:

- The test must be as detailed as necessary to reliably test the desired quality.
- The test must be fast enough to ensure no bottleneck in production.

Typical measurement functions (e.g., in a passive loudspeaker EOL test) are frequency response, impedance response, harmonic distortions in various configurations, sound pressure levels (SPLs) at different frequency bands, resonance frequency, Thiele-Small (T-S) parameters, speaker polarity, and Rub & Buzz measurement.

Technically, all those measurements can be executed by a single glide-sweep stimulus signal. However, in many test applications it is necessary to execute some measurement functions (e.g., frequency response, SPL, and all electrical measurements) with the nominal level of the tested device, whereas the Rub & Buzz test is typically executed at a higher level. Besides considering the measurement function, it is also necessary to set the test signal levels high enough for a proper signal-to-noise ratio (SNR) above environmental noise, but also low enough to not damage the test system operator's hearing. The latter can be diminished by suppressing the test level at higher frequencies to which the human ear is more susceptible.

For loudspeakers, the start and stop frequencies of test signals must not only cover the loudspeaker's transmission band but also adequately include the resonance frequency. If the driver's DC resistance is determined by an extrapolation of the impedance response, it is advised to set the lower frequency far enough away from the resonance. The start and stop frequency of the Rub & Buzz test signal is typically set to the loudspeaker's low-frequency range to trigger any electro-mechanical problems.

Defining Good and Bad

There are various methods and strategies to define limits when testing an acoustic device. The first major decision is whether to work with absolute limits or to use one or several reference samples. The diagram illustrates the decision process.

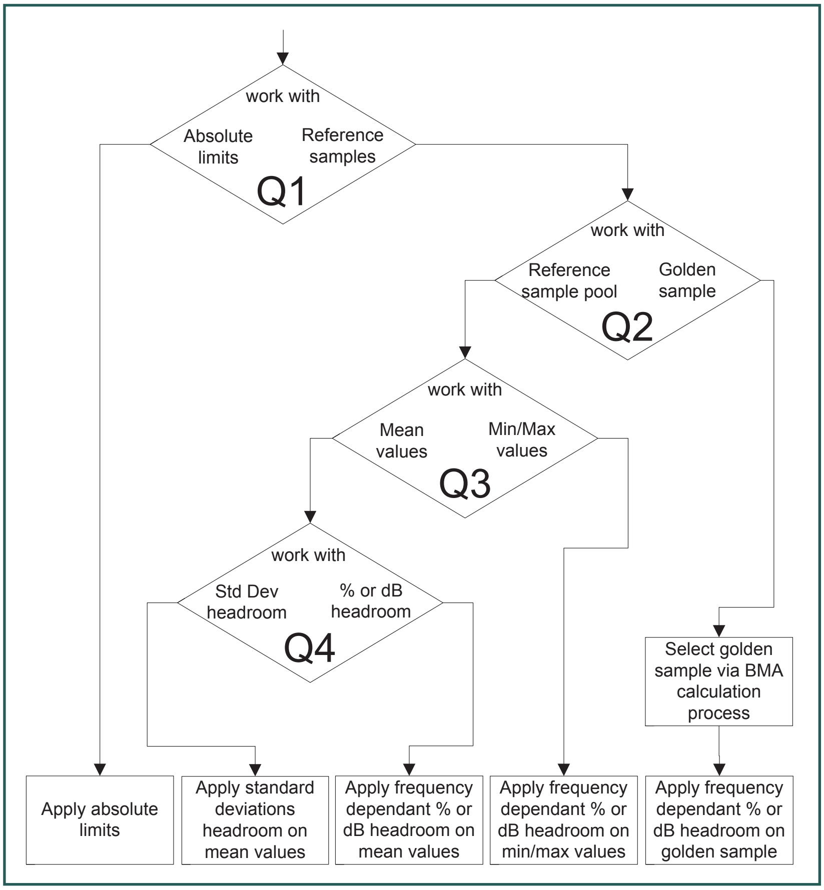
The limit finding strategy should be separately evaluated for each measurement function. Typical measurement functions suitable for the application of absolute limits are frequency and distortion response, as well as all electrical measurements such as impedance response and its derivative results. When using absolute limits for acoustic measurements, it is important to know the conditions under which the limits are valid (e.g., free field). If the conditions in the EOL test are different, the measurement result must be corrected accordingly. Reference samples are usually used when no specification is available (e.g., for Rub & Buzz).

Test Jig Considerations

The ideal test jig would be an anechoic chamber. However, in real life this is not feasible. Nonetheless, the test jig has to fulfill certain characteristics:

- Place the DUT in a defined position relative to the microphone.
- Tightly attach the DUT to the test jig.
- Create a reproducible acoustic situation.
- Avoid acoustic reflections.

A factory worker at Eighteen Sound uses NTi Audio equipment during the QC stage.



This generic limit calculation decision tree can be used to set up your decision process.

- Provide defined front and/or back cavities for the DUT.
- Shield the microphone from environment noise.
- Shield the microphone from structure-borne noise.
- Shield the operator from high sound pressure exposure.
- Allow efficient loading and unloading of the DUT (manual or automated).
- Allow reliable wiring of the DUT, with correct polarity (manual or automated).
- Allow to quickly change jig for testing different models.

Furthermore, the test jig itself should not introduce noise with resonating walls or rattling parts.

Taking all the points into consideration, the typical design is a massive, asymmetric wooden box shielded with acoustical foam in the inside. Since test jigs usually are not commercially available off the shelf, most manufacturers build their own test jigs.

While building one box is a manageable task, problems often begin when it comes to building multiple test jigs. It is recommended to accurately document all measures (e.g., length, width, distance, etc.), materials, and building processes, as even minor variations can produce measurable differences in the acoustic results.

Multiple Lines and Locations

Frequently, there are several production lines of the same type within one factory. Sometimes, the production lines are in different factories and even in different parts of the world. Yet, it is still necessary to manufacture and test the product in exactly the same way. The products shall be tested with the same test parameters, against the same limits, and, of course, deliver the same quality and yield.

Most of the components in different EOL test systems can be:

- Easily chosen to be identical (audio analyzer and accessories, cables and contacts)
- Parameterized to behave identically (audio amplifier gain and microphone sensitivity)

However, the test jigs also have to be built as identical as possible, since they directly influence acoustic behavior. Although there are mathematical corrections available, these increase the system's complexity.

When limit calculation is based on reference samples, it must be considered that the physical reference samples are only available on one site. However, the calculated limits are applied on multiple lines and sites, mostly without access to the physical reference.

Data Logging and Traceability

Almost every loudspeaker manufacturer, especially when using a quality management system, is required to be able to trace back the EOL test results of their products. For high-quality loudspeakers this might be for every single loudspeaker by using a serial number. On smaller and cost-effective devices, mostly the batch number is available. This typically allows tracing back the factory location, manufacturing date, and production line number.

For the data logging, this means that the EOL test software must be able to log several complementary data besides the measurement results, such as date and time, calendar week, project name, operator name, serial or batch number, and environmental data (e.g., temperature and humidity). Obviously, those log files can become quite large over time. Therefore, it is recommended to periodically start new log files (e.g., every week or at the start of each new production batch).

System Calibration and Maintenance

Calibration of the system ensures its accuracy. In a device calibration, the measurement results of the test device are compared against a highly accurate reference of that result and, if necessary, corrected. Device calibrations are usually performed annually by the device manufacturer. These are standards-traceable calibrations under ISO or other quality systems. Typical devices for a calibration in a loudspeaker EOL tester are the audio analyzer and the measurement microphone.

The sensitivity of a microphone can be calibrated by the system operator by using a microphone calibrator. This process can be executed as part of the system calibration. A

About the Author

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system calibration is a procedure that is executed by the operator with a DUT connected to the test system. It consists of:

- Calibrating the test voltage at the DUT terminal, considering the internal or external amplifier gain setting
- Compensating for the electrical frequency response of said amplifier, thereby ensuring that the test voltage is set over the entire tested frequency band
- Calibration of the microphone sensitivity with a microphone calibrator
- Consideration of microphone to DUT distance (when calibrated for a certain SPL)

Wear and Tear on Parts

Some parts of an acoustic device EOL test system are vulnerable to wear and tear, and should be periodically checked or renewed. Parts that need to be checked include:

The electrical contacts that connect the DUT to the test system often show wear from friction, resulting in increased resistance or total loss of connection.

The measurement microphone membrane can be contaminated by dust and dirt, especially when it is facing upward. This can cause changes in microphone frequency response and sensitivity. An easy prevention is to use a dust cap and periodically exchange it.

The mechanic rest on which the DUT is positioned and fixed for the test is usually made of a soft material (e.g., foam or cork). Sometimes, an arrester system is also in use. Because they are mechanically stressed at the very same position during every unloading/loading process, those parts are in danger of wear from friction or even deformation. This can result in changes of acoustic and electrical measurement results.

When Disaster Strikes

To guarantee high availability, it is advisable to be prepared for disasters. Obviously, it is a good idea to have spare parts of all elements of a test system, especially for the ones that have a high risk of being worn out or damaged. But also, there should be documented procedures on any configuration steps that need to be taken in case of an exchange. For example, when exchanging the microphone, the sensitivity of the new microphone must be configured in the test system. This minimizes the system downtime.

To be prepared for an IT disaster (e.g., a PC or hard disk failure), a regular backup of system and project settings is recommended. This task can be automatically handled by test system software. Again, a documented procedure on how to restore the data helps to set up a new system quickly and efficiently, thus reducing downtime.

Hardware Handling

Common problems with hardware components include accidently unplugged cables, turned knobs, or toggled on/off switches. It is good practice to:

- Use amplifiers integrated into the test instrument with fixed gain.
- If an external amplifier is inevitable, use a model with fixed gain or protected volume wheels.
- Secure and stash cables.
- Protect on/off switches against accidental operation (e.g. rack with door).

Fail-Safe Workflow

The DUT must be loaded in the test jig in a clear and unambiguous way. Both the positioning and the contact process should provide haptic feedback to the operator. If the operator is required to trigger the measurement, the trigger button should be conveniently located next to the test jig, so that it can be pushed immediately after the DUT has been loaded.

Alternatively, the test system can constantly scan the contacts and automatically start the measurement once a connected loudspeaker is detected. The end of the measurement must be

Don't panic when disaster strikes. Make sure you have a plan in place.

Safeguard your system from environmental influences.

clearly displayed to the operator so that he or she can unload it immediately. When highly optimized, the next device in line can already be loaded into a second baffle, alternating with the first one that is currently being tested. This increases the throughput of the test system.

Protect Your Settings

To prevent operator errors, the test system software should have a user role management system. While a system administrator is a skilled user with no restriction, an operator is limited to have access only to the absolute necessary controls. If no configuration at all is required by the operator, interfaces such as the keyboard and the mouse can be stashed.

Troubles from Outside

Naturally, environmental influences to an EOL test should be avoided (see **Photo 3**). However, in reality this is not always possible. Therefore, it is important to be aware of the consequences those influences can have, as well as have ways to deal with them.

Temperature affects mostly the electrical parameters of an acoustic device. For a loudspeaker, this is especially the resonance frequency and its dependents. Variations of temperature can be caused by ambient temperature, but also by manufacturing processes that heat up the DUT and are executed shortly before the end-of-line test. For the latter case, before testing have a cooling phase long enough to bring the DUT to ambient temperature. It is advisable to log environmental data (e.g., temperature, humidity, and air pressure) along with the measurement data.

Manufacturing noise obviously influences the acoustic measurements. This includes air-borne as well as structure-borne noise. While some measurements are less susceptible to noise (e.g., frequency response), the most critical measurement is Rub & Buzz of loudspeakers.

There are noise cancellation methods available in loudspeaker EOL test systems. However, this should be the last line of defense because they only deal with impulsive noise and they increase test time.

The majority of noise should ideally be physically shielded by the test jig. This is especially applicable for all constant background noise (e.g., manufacturing noise and machinery) Such shielding reduces the noise floor inside the test jig enabling you to measure Rub & Buzz effects that would otherwise be undetectable. All impulsive noise that only occurs infrequently can be handled by the noise cancellation algorithms of the EOL test system.

Electromagnetic influences are best handled by keeping audio cables short and using balanced audio (XLR cables). This is especially important for cables with low level and high impedance (e.g., microphone cables).

Wrap Up

Running a worthwhile and reliable EOL quality control for acoustic devices is by no means trivial. It requires considerations from several angles and involves multidisciplinary skills. Reproducible, reliable results can only be achieved with a combination of reliable test instruments operating within an environment that either remains constant or is properly managed. ***LIS***