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Objective Testing of High-End Audio Systems

The high-end audio equipment market is filled with extraordinary products. Although the engineering and the materials utilized are often the finest available, the quality control of such systems is frequently done subjectively, rather than objectively. This article shows some best practice examples of how to deploy effective quality measurement systems through the complete life cycle (R&D, QC, installation, and repair) of high-end audio systems.

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When looking at the high-end audio market, there’s a variety of products ranging from well-designed top-notch audio devices with solid technical specifications to gadgets that appear rather esoteric and whose results cannot be objectively evaluated. The latter are not within the scope of this article. Only audio devices and systems that are designed based on solid audio engineering work are considered. Although there are a few reputable large enterprises that have a high-end audio product line, the majority of high-end audio companies are small with only a few employees. As a result, quite often a single person takes on several technical responsibilities, ranging from R&D, purchasing, incoming Quality Control (QC), assembly, end-of-line (EOL) testing, as well as service, maintenance, and QC management. Also, more often than not, small companies have only limited access to appropriate testing resources (e.g., acoustically optimized testing facilities).

One way to overcome the lack of proper measurement is to communicate the performance of a high-end audio system on an emotional rather than a technical level, using colorful but nebulous language. After all, high-end audio systems are life-style products. Leading companies sustain market share by emphasizing longevity in the mechanical design and sound quality. Besides the sound experience, the customer also wants a piece of equipment that is designed to please the eye. Both the sound and the appearance are subjective qualities to the customer (see Photo 1).

Following the maxim that a quality product is easier to sell, the sound quality can be quantified by appropriate objective measurements. This article describes best practice examples of
objective measurements on high-end audio devices. The measurement applications that follow are viewed from two angles.

The first view describes the typical measurements on the various devices along the signal chain, from the signal source to the amplifier over the cables to the loudspeakers and finally the room in which the system is installed. The main concern is to provide a very linear, low-noise and low-distortion signal through the entire signal chain.

The second view covers the distinctive measurements at different life-cycle stages of the various devices, from R&D to incoming QC, end-of-line (EOL) QC, and installation of the system as well as service and maintenance.

R&D

The R&D phase builds the foundation of a high-quality product. Any shortcomings not solved or managed at this early stage of the product development will be passed through to all the later stages. This applies to the complete signal chain covered by the product.

Electrical Signal Path

Any unwanted noise before or within the amplifier will be irreversibly audible at the loudspeakers. This means it is essential to keep the signal clean from the very beginning of the signal chain.

Distortion—In most systems, distortion is an unwanted effect and is avoided at all costs as it affects the perception of sound quality. It’s important to realize that distortion is mainly a result of the system reaching an upper limit of operation. Thus, the testing shall be executed close to these limits. The distortion can be quantified as total harmonic distortion (THD) or as individual harmonic distortion values.

Some tube amplifiers produce a significant amount of even-numbered harmonic components (k2, k4, and k6). Advocates argue that this creates a more pleasant sound.

Hum & Noise—The presence of noise or hum can cover fine details of sound. So, providing a low-noise circuit design is one of the most important tasks in the R&D phase. Noise can be measured with or without the presence of a test signal. In either case, it is important to realize that amplifier stages amplify both, the signal and the noise. Therefore, a high signal-to-noise ratio (SNR) is desired. When using balanced analog audio channels, it is important to measure the Common Mode Rejection Ratio (CMRR) as this determines the ability to cancel out cable-induced noise or hum. Noise and especially hum can also be introduced from the system power supply. Therefore, it is recommended to perform these measurements with different mains-power conditions and settings.

Bandwidth—The bandwidth is measured with a frequency response measurement. The measured level has to be within the expected limits throughout the specified frequency bandwidth. Modern sound systems cover bandwidths up to ultra-sonic frequencies.

Linearity—All the previously mentioned measurements can be influenced by the amplitude of the input signal, as well as the power of the output signal. An appropriate way to verify this system behavior is to run an amplitude sweep signal at the system input. The amplitude shall range from zero to the maximum allowed input signal. The output signal is measured with level and distortion and shall be within the expected limits through the input signal range.

Channel Balance and Separation—The spatial awareness of the listener is based on having more than one sound source (e.g., stereo). It is vital that all channels behave as uniformly as possible. All the previously mentioned measurement results shall be compared for all channels of the system.

Furthermore, the influence of one channel on other channels (e.g., caused by unwanted electro-magnetic induction or capacitive coupling) must be checked. This is done with a Crosstalk measurement.

Acoustic Signal Path

In the R&D phase, the developer has to contend with loudspeaker drivers as well as loudspeaker systems. Besides the acoustical parameters, the electrical parameters are of interest. However, before any measurement results can be assumed to be reliable, new bass and midrange loudspeakers need to be operated for a certain time in order to have the suspension material reach its final characteristics.

Woofer and Midrange Driver Conditioning—Several burn-in procedures for loudspeaker drivers are known. The proposed test signals range from noise to music. Practical experience at Art Déco Acoustics showed that a low-frequency sine wave signal delivered excellent results. The loudspeakers’ suspension is displaced in a very controlled and predictable way, while not producing bothersome loud noise.
Burn-In Signal Frequency
The signal shall be at a low frequency, so that the driver suspension gets properly displaced. Also, the frequency shall have ample distance from the free air resonance frequency, so that the generator can properly control the driver. For bass loudspeakers,

\[ f_{\text{burn-in}} = f_0 \times 0.33 \]

For midrange loudspeakers,

\[ f_{\text{burn-in}} = f_0 \times 0.50 \]

whereas:
- \( f_{\text{burn-in}} \) is the signal frequency in Hertz (Hz)
- \( f_0 \) is the free-air resonance frequency of the loudspeaker in Hertz (Hz)

Burn-In Signal Power
The required power for exciting the loudspeaker to the desired \( X_{\text{max}} \) value in a controlled way can be calculated with this formula:

\[ P_{\text{burn-in}} = \left( \frac{x_{\text{max}}^2 \times Z_i}{(C_{\text{ms}} \times BL)^2} \right) \times 2 \]

whereas:
- \( P_{\text{burn-in}} \) is the power of the burn-in signal in watts (W)
- \( x_{\text{max}} \) is the peak displacement in one direction in meters (m)
- \( Z_i \) is the rated impedance in ohms (Ω)
- \( C_{\text{ms}} \) is the mechanical compliance in meters/NEWTONS (m/N)
- \( BL \) is the force factor NEWTONS/Amperes (N/A)

Burn-In Duration
The goal of the burn-in process is to achieve settled and stable mechanical conditions. The required period of time to reach those conditions is different for each loudspeaker model, and therefore, must be individually evaluated. A practical way to proceed is to apply the burn-in signal and measure the \( f_0 \) (free-air resonance frequency) and \( R_0 \) (free-air resonance impedance) values initially and then every two hours, until they become settled. To avoid interference with the loudspeakers thermal behavior, it is advised to allow the loudspeaker to cool off before performing \( f_0 \) and \( R_0 \) measurements (see Figure 1 and Figure 2).

Depending on the individual loudspeaker model, typical burn-in times are 6 to 36 hours for bass loudspeakers, and 6 to 24 hours for midrange loudspeakers.

Loudspeaker Measurements—The R&D phase requires all of the classic loudspeaker measurements. The bass, midrange, and high-frequency drivers are rated individually, electrically, and acoustically. The Thiele-Small (T-S) parameters of the drivers are used to determine and optimize the loudspeaker’s housing dimensions. The system’s acoustic performance shows the interaction of all individual components. It is characterized by measuring frequency response, distortion response, and sensitivity. Also the directional characteristic of the complete system can be measured and optimize in the R&D phase.

All acoustic measurements must be executed in a defined and reproducible acoustic environment. The use of a calibrated measurement microphone is recommended. The microphone distance and position relative to the loudspeaker must be
kept constant. In case of frequency response ripples caused by imperfections of the testing environment, a smoothing filter (e.g., 1/3 octave bandwidth) can be applied.

**Income QC**

Electrical Components—IQC testing of electrical components is required when the component plays a critical role in the signal path, and the headroom of the component’s specified vs. requested accuracy is low. Quite often, these are parts used in the loudspeaker crossover network, such as:

- Inductance inductor value, distortion vs. current, distortion vs. frequency, and capacitance vs. capacitor value

Depending on long-term experience and significance, these tests can be either executed as sample tests (e.g., a few components from one batch delivered) or as a 100% income test.

Acoustic Components—While in less sensitive markets a loudspeaker system will eventually reach its final characteristics during its normal usage, this is not an option for high-end audio manufacturers. Therefore, a crucial initial procedure for all new incoming bass and midrange loudspeakers is to perform the burn-in procedure as previously described.

Loudspeaker Pairing—The settled results of the burn-in test can be used to place loudspeakers into groups with similar behavior. This is important for using more than one driver of the same type in one loudspeaker, as well as building left and right loudspeaker pairs that show identical behavior. The accepted deviation of \( f_0 \) and \( R_0 \) within the same group depends on the enclosure in which the loudspeaker will be used:

- Vented enclosures or horn enclosures: \( f_0 \) within 2 Hz, \( R_0 \) < 15% relative different

- Not vented enclosures: \( f_0 \) within 10 Hz, \( R_0 \) < 50% relative different

**Manufacturing QC**

**Device Testing**

In this stage, the individual devices of the high-end audio system are tested against their specifications.

- Amplifier Final Test—The completed amplifier devices run through a thorough set of tests, such as frequency response, output power, distortion response, hum and noise rejection ratio, channel separation ratio, spectral noise analysis, channel balance, inter-channel phase, slew rate, and common mode rejection ration (CMRR). This set of tests is performed at several gain settings. Where applicable, user controls (e.g., LED, switches, or dial controls) are tested for mechanical and functional performance.

- Loudspeaker Final Test—The final assembled loudspeakers are electrically tested for impedance response. Special attention is paid to the device resonance frequencies and resonance impedances. The acoustic test for final assembled loudspeakers contain frequency response, distortion response, diversity, sensitivity and Rub & Buzz. The latter is especially crucial as even the slightest objectionable audible effects would not be accepted by the customer.

Although each individual loudspeaker driver has already been tested for Rub & Buzz, this stage of testing reveals any noise coming from problems in the mechanical assembly of the loudspeaker, such as vibrating pieces or air leakages in sealed cavities. As in all previous acoustic test stages, it is vital to have a test fixture that allows reproducible results with minimum influence from outside noise.

- Acceptance Limit Finding—The applied limits for passing or failing a measurement have to be calculated for each individual measurement function. Whenever possible, absolute limits evaluated from a component’s datasheet are preferred. However, some measurement functions are not suitable for absolute limits. This is often the case for acoustic measurements (e.g., Rub & Buzz) when either no specification is available, or the acoustic conditions during test are different than those used for specification.

- For such measurement functions, one or several reference measurements are taken and overlaid with a headroom. The amount of headroom depends on the number of references taken, and the allowed mean variation.

**System Testing**

Finally, the individual devices get put together to the final system configuration. In this final stage, the test depth can be reduced as the individual system devices are already tested thoroughly. The interaction between amplifier, left and right loudspeaker is tested with a few simple acoustic sensitivity and frequency response measurement. At this point, it is also appropriate to perform a subjective listening test at a defined listener position, using well-known listening material.
**Installation**

All the efforts of manufacturing a perfect high-end audio system can become worthless when the system is used in an environment that is not suitable for listening.

Reverberation—Too much of reverberation in a listening room can ruin the listening experience, likewise an absence of reverberation is also not pleasing to the ear. The optimum reverberation depends on the room size. For typical living room size applications, a RT60 time of 0.3 to 0.5 s for all frequency bands is recommended. The RT60 measurement is determined by either using a gated pink noise signal applied to the sound system, or alternatively an impulsive sound (e.g., a bursting balloon).

**Room Reflections**

Low frequencies/standing waves—The room resonance frequency can be calculated:

\[ f_0 = \frac{v_s}{2 \times l} \]

whereas:

- \( f_0 \) is room resonance frequency in Hertz (Hz)
- \( v_s \) is speed of sound in meters/seconds (m/s)
- \( l \) is room dimension in meters (m) (length/width/height)

For typical living room sizes, resonance frequencies will appear in the range of 20 Hz to 100 Hz. The presence of room resonances can be measured by applying the room resonance frequency to the sound system, and then measure the acoustic level at different positions in the room. If the measurement varies greatly, low frequency reflections are present and need to be eliminated by applying appropriate acoustic treatments for low frequencies to the room.

Mid and High Frequencies—Reflections of mid and high frequencies appear as a comb filter effect. This effect is not only audible, but also easily measurable. To identify comb filter effects in a room, white noise is applied to the sound system. Then, the spectrum of the sound is measured in the room, using a high-resolution fast Fourier transform (FFT). When the spectrum of the room with linear scaled X-axis shows equi-distance notches, this is an indication for room reflections (see Figure 3).

**Ambient Noise**

Since high-end systems are supposed to...
reproduce every little detail of the original sound, overlapping hum or noise from the environment is not acceptable. The ambient noise can be measured as a simple A-weighted sound level reading.

A more sophisticated way is to use noise curves measurements. Noise curves follow the sound level vs. octave band course where the loudness of noise is perceived equally.

Recommended noise criteria (NC) level values for Recording Studios, Concert halls and similar listening applications are NC 15-20 (see Figure 4).

**Repair & Service**

With repair or service of a high-end audio system, the existing set of measurements from manufacturing QC testing can be applied to identify a faulty system component. Usually the failed measurement indicates the type of failure. When fault diagnostics on circuit board level is required, an audio analyzer with standard functionality such as level, distortion, and FFT is most useful.

When critical parts are exchanged, it is important to match the characteristics of the replaced part. After the repair, the regular device tests defined before are performed for the repaired device. Before shipping, the manufacturing QC system test is executed.

**Quality Control Management Aspects**

**Test Environment**

For acoustic measurements in the R&D, incoming QC, and manufacturing QC, an acoustically stable test environment is the foundation for reliable and reproducible test data. Exact positioning of all loudspeaker models as well as the measurement microphone are crucial. Ambient noise should be held as low as possible. Reflections from room boundaries or obstacles must be covered with acoustic treatment material, or managed by the test system by applying time-window functionality.

**Documentation**

Every measurement procedure in each phase of the product must be documented in a clear and unambiguous manner, making it executable by any technician in the company. When a measurement is performed, the data shall be logged with the serial number of the device or system under test. This allows comparison of results in case of a repair and also indicates the quality of the products over the course of time. Having a complete and traceable set of significant measurement data for each product ever shipped is an important and valuable asset to a company.

**Calibration**

To ensure the accuracy of the measurement system, all relevant devices such as the audio analyzer and the measurement microphone should be calibrated according to the manufacturer’s recommendation. Measurement microphone are sensitive to temperature and humidity changes. Therefore, a more frequent periodic calibration with a microphone calibrator is advised.

**Wrap Up**

Consistent and appropriate measurements during the complete high-end audio product life cycle lead to high, objective, and constant product quality. Measurements shall comprise the complete signal path from the signal source to the loudspeakers. Objective measurement values are a better selling proposition than imaginative descriptions. A suitable measurement system covers all requirements for electric and acoustic measurements. And finally, a complete set of measurement data of all shipped products is a valuable company asset.

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**About the Authors**

Gregor Schmidle is Product Manager at NTI Audio in Schaan, Liechtenstein. He completed a Bachelor of Science degree at the Interstate University of Applied Sciences of Technology in Buchs, Switzerland in 1992 and a Master of Science degree at the University of Applied Sciences in Dornbirn, Austria in 2004. Gregor has been in the audio and acoustic Test & Measurement Industry for more than 25 years. After working several years at NEUTRIK as a hardware and software developer, he continued his career at NTI Audio as an applications support engineer. In his current position, Gregor is in charge of NTI Audio’s industrial key customers worldwide.

Gerd Köck started his carrier as a telecommunication technician at Siemens AG in Stuttgart until 1981. Then he studied BSEE (till 1986), Computer Science at Esslingen (DE) University with focus on digital signal processing, switching to technology and numerical analysis. He was responsible for the development (analog, power, DSP algorithms) and final acceptance of a main power disturbance and net quality event recorder system for electrical power nets (1998). He then directed to sales at Infineon (an automotive controller and power till 2001), and Conti (an automotive infotainment and instrument cluster till 2007). At Telt Wireless, he introduced the automotive grade 2G/3G wireless modules (till 2009). From 2009 on, Gerd founded Art Déco Acoustics and started development of loudspeakers and amplifiers. In parallel, he worked as freelance consultant in the automotive industry in wireless and lighting technologies.

Brian MacMillan is General Manager for NTI Audio US office in Portland, OR. Brian has worked in sound and vibration instrumentation for more than 25 years in local sales and support and as a Product Manager. He has worked with a variety of customers and markets in the US, Denmark, and the United Kingdom.