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R&D Stories

SPEAKER FOCUS

Thoughts on AES X223 and X241 Speaker Measurement Projects

By
Geoff Hill
(United Kingdom)

I have just returned from the recent Audio Engineering Society (AES) 144th International Convention in Milan, Italy, where I was among many colleagues who are trying to solve one of the outstanding problems of loudspeaker drive units today. Namely, being able to trust the measurements that are being presented to us.

Tetrahedral Test Chambers were demonstrated at the Audio Engineering Society (AES) convention in New York, 2015. Contrary to anechoic chambers, these systems define the geometry, the environment, and a calibration methodology. They minimize internal reflections and standing waves and provide internal measurements in a pressurized environment, which is readily compensated with modern equipment. Finally, they increase the acoustic isolation—making high-quality measurements possible in a production environment.

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I know that is putting it bluntly, however I believe in speaking of things as they are and not as we would like them to be. That is the root of the problem now and in the past—it's crazy when you think about it that loudspeakers are between 90 and 100 years old now (depending on whether you count Jensen or Rice & Kellogg as the first), and we still cannot trust our measurements!

Dealing with Anechoic Chambers

I have been involved with loudspeakers and transducers for the reproduction of sound for most of my career, in the early days, we didn't have access to much equipment and things were initially set up by ear. Later at Bowers & Wilkins and Goodmans, I was introduced to anechoic chambers and proper test equipment. Even then, I thought it seemed odd that soundproofed rooms, usually the size and often the cost of a house, was considered the way of measuring loudspeakers—oddly enough there is not even a lot of theory to back it up! Do we listen to loudspeakers in an anechoic room?

Anyway, I used anechoic chambers to measure loudspeaker systems. These were usually located in the middle of the anechoic space equally-spaced between the wedges of the chambers. Usually this meant mounting big heavy loudspeakers and light delicate microphones on floppy mesh floors situated around one-third of the way up the vertical height of the chamber. The results of this, of course, was that every measurement was different from every other one. Because of the inherent imprecision, I remember being trained to line up the microphone and the loudspeaker using a 1 m rule. And because everything uncontrollably bobbed up and down on the mesh floor, and because of the variable location within the chamber, every result was different from every other chamber, and this would show any and every time I needed to compare results produced by a contractor or sub supplier. Various other unknown factors could interfere (e.g., the one chamber I worked that had an enormous metal plate supported on a steel beam just below the door entrance, in which the loudspeaker drivers were mounted!). Crazily enough, this situation has remained fundamentally the same throughout my career to date.

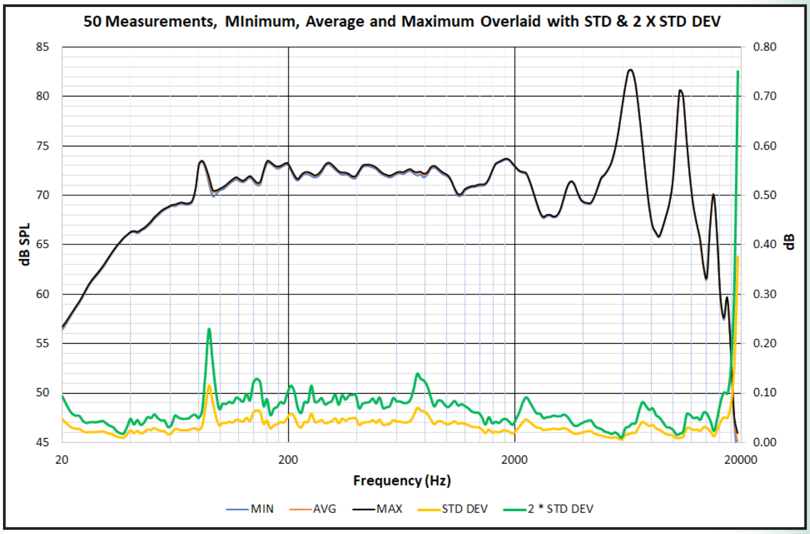
The AES Documents

Many of us in the Audio Engineering Society (AES) have been aware of and working toward a unified solution to this problem for a while. The AES subcommittee on Acoustics assigned the problem to SC-04-03 in 2013, which kicked off project X223 at the 134th convention in New York in October 2013. And, at the 135th convention in Berlin, Germany, in May 2014, it was decided to issue this as an Information Document.

An Information Document is probably best described as an informal standard that has gone through the same full review process that a standard has, but it is more advisory in nature than a full standard, however, it represents our best collective thoughts on a subject.

The problem with Loudspeaker Testing in production is one many of you might have come across at one time or other. In essence it always boils down to the following:

- Production and Sales want to ship as much acceptable product as possible.
- Quality and the Customer only want a perfect product. Neither want any product with any faults as these will cause trouble and usually expensive trouble later.
- As a customer or user, you need to know that you are getting a loudspeaker as close to specification as possible, in an ideal world you might want to accept loudspeaker drive units purely upon measurement data. But can you?
- How do you make a judgment between perfect and acceptable? The standards IEC 60268-5, JIS etc., recommend using an anechoic or free-field environment. This is fine for a one-off or very limited quantities but for production quantities that regularly range from tens to hundreds of thousands if not millions, it is not a practical option.
- Anyway, do you have a chamber? Unlikely, unless you are in the Military, Academia, or in a



Statistical Analysis on 50 measurements made using the same driver on a TTC900 test chambers, without any disturbances, to test the stability of the system. These were within 0.15 dB at 2 dB Standard Deviations over the operating range.

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Research and Development department. Even many loudspeaker companies don't, but they still need to measure the many characteristics of a loudspeaker but in a typically noisy factory environment.

As I said earlier, the AES Subcommittee on Loudspeakers and Headphones SC-04-03, is aware of this problem and has been working toward producing advice in this area.

There are two related Information documents, X223 and X241. Project X223 concentrates on the acoustic test chambers: "To consider factors affecting the interchangeability of measurement data from simple loudspeaker comparison chambers."

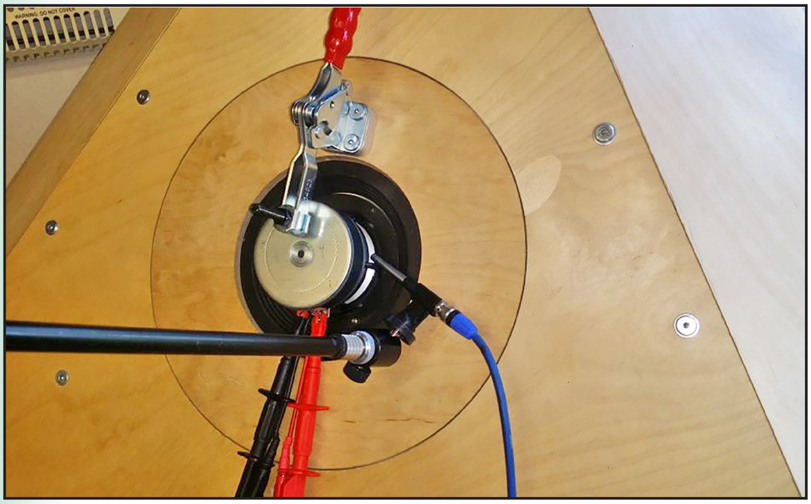
The problem is essentially simple in theory while being complex in practice. Essentially it boils down as follows:

(1) The Standards demand anechoic or free-field measurements but of loudspeakers drivers on baffles (regardless of how they are designed to be used in practice—usually in some enclosure).

(2) Practicalities demand measurement in some form of test box or cabin if only to reduce the external noise produced and to protect workers hearing as well as to stop external noises interfering with test and measurement equipment.

The problem with using a true anechoic or free-field environment is that they are horrendously big and expensive, while simultaneously difficult to set up for precision repeatable measurements especially when measuring small loudspeaker drive units.

Test boxes are notoriously individual—often having significant differences one to another and making it all but impossible to reconcile measurements made in facility with another, often even within a single facility, unless they use common test chambers.



A TTC900 being set up for the first time—then and only then do you need to set up or calibrate the chamber's correction curve.

Project X241 intends to: "Specify parameters and methods of measurement required for end-of-line quality control tests performed on loudspeaker drivers manufactured for automotive, consumer and professional applications. It includes requirements for mechanical setup. It does not consider measurements of loudspeaker systems or multi-driver arrangements."

While X241 originated in Automotive Audio, it looks to wider concerns around all the various factors that can affect any measurement system.

As of course many things can and do change the performance of loudspeaker drive units in practice. These include:

- Temperature—think of how a loudspeaker's surround changes its stiffness between usage in Finland on a winter morning (-30°C), to operating at the height of a summer day in Saudi Arabia (+40°C) being quite possible
- Humidity—paper or fiber diaphragms operating in dry desert conditions (0% RH to moist equatorial rain forests (90% RH)
- Air Pressure
- External Noise
- Capable of operating correctly with wind, rain, etc.

Between them, X223 and X241 tackle these problems and advise current best practice.

The loudspeaker needs to produce its rated output without introducing unwanted distortion or noises and the quality or otherwise is measured using an audio analysis system powering an amplifier, usually a digital Fast Fourier Transform (FFT) system today, and measured by a microphone back to the analysis system. So, it's quite a complex system with an awful lot of ways to go wrong and truthfully just a few ways to get it right.

One of the key characteristics of any measurement system is accuracy and the other is consistency. Both are important and need verification and, ultimately, it is determining how accurate and the level that this accuracy can be trusted to that is the mark of any measurement system.

GageR&R

Yes, I know the spelling is awkward—but that is what it was known as in the Automotive Industry, which developed it as a methodology for controlling the dimensions of individual parts or complete

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components. One of the core concepts in GageR&R is best explained by breaking the name into its component parts:

- Gage is just a shortened version of Gauge
- R for Repeatability
- R for Reproducibility

The key here is that there is a movement away from just a measurement toward a measurement system and the realization that consistency is key. But how do you effectively measure a loudspeaker's parameters? Let's remember that GageR&R was fundamentally developed to handle single-dimensional mechanical data.

Apart from specialized Thiele-Small (T-S) parameters, most loudspeaker data is inherently multi-dimensional simultaneously having frequency vs. amplitude, frequency vs. impedance, frequency vs. distortion, and so on. The key here is that potentially there is a lot of data that needs organizing so that we can clearly see what is going on.

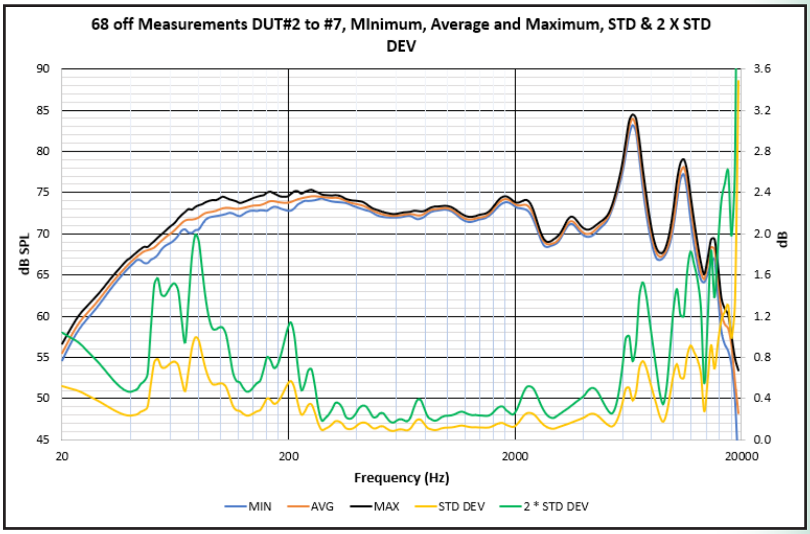
Personally, I first started exploring this area when working for Ericsson's Research Triangle Park in North Carolina in 2000. There, I had to measure and analyze data from batches of thousands at a time. These ideas were later developed into a more general methodology. I outlined some of the principles behind this in a paper I presented to the Association of Loudspeaker Manufacturing & Acoustics (ALMA) International in 2010 in Shenzhen, China. This has been extensively updated in my latest book, *Loudspeaker Design Modeling and Measurement a Practical Guide* to be published by Focal Press in October 2018.

The first requirement is data, and modern FFT-based systems can produce this, however, even today few systems effectively gather and correlate this information. So, what is required?

- A list of known frequencies at which the parameter of interest is measured.
- A list of the value or level of the parameter.
- A means of correlating these measurements to an individual loudspeaker.

We can see the problem clearest if we overlay data from a large series of measurements, if we do so with typical electronics we get very consistent results with relatively small and predictable changes in gain, cut-off frequency etc. A loosed tolerance being say ±5% or ±0.5 dB. With a tight tolerance being ±0.1% or ±0.09 dB.

However, loudspeakers have been notoriously variable and unstable with very wide tolerances



The 68 measurements are of six drivers of the same type but repeatedly measured over the course of half a day and demonstrate the stability of both the measurement system and the variations of this particular drive unit.

commonly accepted. Partly I believe this has occurred for four reasons. A wider tolerance range is easier to meet and causes less rejects. Most acoustical measurements have a large margin of error often ±3 dB is accepted as a tight acoustical tolerance. At low and high frequencies, ±6 dB would be relatively normal. Many loudspeaker test chambers allow large variations in setup, and the ruling standards seem to accept such variations without question.

GageR&R, ANOVA Analysis of Variation, Statistical Analysis-Standard Deviation, Normal distribution, Cpk & Ppk, and other methods, all give us tools to understand the variations present in large samples of data and when we understand these we can potentially control them.

About the Author

Geoff Hill is best described as a passionate engineer and can get frustrated when there is a better way to do something, but nobody else can see it. After qualifying in electronics (City and Guilds FTC in Telecommunications), he co-founded Impulse, a company that made high-efficiency horn loudspeakers at a time when the LS3/5a and Linn Kan were all the rage. Later, Geoff has worked with many companies and along the way he has designed everything to do with sound, including automotive, mobile phones, PA, hi-fi systems, and loudspeaker drivers from 25 mm tweeters up to 18" sub-bass drivers. His latest venture, Hill Acoustics, marks a return to his roots, combining 40-plus years' experience. An active member of the Audio Engineering Society (AES), he has worked with various committees over the years to help and assist where and when he can. He is currently active within AES SC-04-03 on the subject of loudspeaker measurements and is a British member of IEC TC100. Geoff can be reached via www.geoff-hill.com.

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It was lack of consistency in measurements that plagued so many of us through our careers whether in hi-fi, loudspeaker drive units, consumer electronics, or mobile telephony.

In my mind there are two separate questions to answer: Are such variations due to loudspeakers themselves or are they due to the methods and methodologies that we have or are still applying to such measurements?

It is my feeling that it is the methodologies that are primarily responsible for this situation—yes, undoubtedly some loudspeaker drive units have significant variations from ±3 dB to ±6 dB. But let's remember ±6 dB is a 2:1 variation or ±200% tolerance range… Such a tolerance range is difficult to justify today. I believe it is important to ask why this has occurred before we ask what can be done about it.

In loudspeaker drive units, the main causes of variation in sensitivity (loudness) are:

- Magnet material—cheaper materials are either lower spec or more variable—sometimes the grade is subtly changed until the customer notices and complains!
- Thinner or thicker grades of wire being used or more likely poor control of tension while winding. These can change DCR and or wind length.
- Thicker or thinner diaphragm materials together with under/over doping/damping
- Wrong material—rare but has happened.
- Dimensional differences—excessive tolerances especially in the motor unit can lose lots of power.
- Wrong smaller magnet. The inside diameter can be increased reducing the magnet volume. This is hard to detect and only weighing or stripping down the parts reveals exactly what is going on.
- Extra heavy or light dust caps.

Conclusion

As we can see, this is quite a non-exhaustive list but provided the measurement system is stable and accurate, the final sensitivity can be accurately measured. The next point is the accuracy with which the frequency response can be measured—in a free-field or anechoic condition theoretically there are no sources of interference, in practice there are many.

Most are fairly benign and change just the levels due to distance or change the response shape due to the angle and or azimuth of measurement. Or changes of response due to diffraction or reflection and cancellation which are simple to calculate.

However, when we consider measurements inside a test chamber, things get much more complicated as there are now multiple sources including those previously mentioned. Still, test chambers enable us to design and simultaneously control the acoustic environment while pinning down the physical dimensions and enabling precision equalization, thus enabling more accurate measurements to be made that are repeatable and reproducible on a truly industrial scale for the first time.

All of which sounds great but how should we actually go about proving measurement capability? As we already mentioned, we should use statistical tools. Primarily, these decouple the shape or curve of a measurement from the quality or stability of the aggregate of a series of measurements of nominally similar ones, thus, we can separate out variations in loudspeakers themselves from variations due to the measurement process itself or the environmental aspects.

Resources

L. Beranek, *Acoustical Measurements*, Revised Edition, Acoustical Society of America; Revised edition (June 1, 1988)

G. Hill, *Loudspeaker Design Modeling & Measurement—A Practical Introduction*, October 2018.

Project AES-X223 Initiation, "AES-X223, Loudspeaker Driver Comparison Chambers," Audio Engineering Society, October 2014, www.aes.org/standards/meetings/init-projects/aes-x223-init.cfm

Project AES-X241 Initiation, "AES Project X241, End of Line Testing for Production Loudspeaker Drivers, Audio Engineering Society, March 2017, www.aes.org/standards/meetings/init-projects/aes-x241-init.cfm