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Lab Notes

Volume 10, Issue 1 **March 2017**

Electroacoustics & Audio

- *Consulting*
- *Design / Testing*
- *Training*

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Training Services

CJS Labs also offers customized in-house training. Our design experience, proven processes, and measurement expertise will make your product development more efficient. Learn how to optimize both your designs and test routines. Having a thorough understanding of fundamentals, correct terminology, and proper techniques will also enable you to make more informed decisions and communicate more effectively with your customers and vendors as well as within your own organization. Understand why certain failure modes are problematic, even if they are not obvious or audible. Sample course outlines and details are available on our website:
http://www.cjs-labs.com/training_seminars.html

Contact us to schedule a training course for your organization.

West Coast Headphone Seminars

In late February and early March, CJS Labs participated in a series of free seminars with G.R.A.S. and Listen demonstrating electroacoustic test methods and instrumentation for headphones and headsets. The seminars in Seattle, WA, Santa Clara, CA and Glendale, CA were well attended. Listen and G.R.A.S. products were featured while I described the details of various standards and test methods. Attendees were encouraged to bring their own devices to be measured. Quite a number of interesting topics came up in the Q&A sessions. I was also fortunate to meet face-to-face with many of the attendees.

News and Recent Developments

IEC TC-29 – Milano

I will be in Milano, Italy 27-31 March as Head of the US Delegation to IEC TC-29 Electroacoustics.

ISO TC-43 – Copenhagen

ISO TC-43 Acoustics meets 15-19 May in Copenhagen, Denmark. I will be there to participate in several working group meetings.

AES in Berlin

The AES 142nd Convention will take place 20-23 May in Berlin.
http://www.aes.org/events/142/

Joint ASA/EAA Meeting in Boston

I will be at the joint meeting of the Acoustical Society of America and the European Acoustical Association in Boston 25-29 June. ASA Standards meetings will take place Sunday and Monday.

http://acousticalsociety.org/content/acoustics-17-boston#

Let us know if you plan to attend any of these events and would like to set up a meeting to discuss your projects.

Please contact us and let us know how we can be of service to you and your organization.

Christopher J. Struck

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Volume 10, Issue 2 **June 2017**

Electroacoustics & Audio

- *Consulting*
- *Design / Testing*
- *Training*

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Europe Headphone Seminars

CJS Labs followed up its successful US West Coast headphone seminars with G.R.A.S. and Listen with seminars in the U.K., Denmark and Germany in May. These events were well attended. I had the opportunity to meet many persons interested in headphone design, manufacturing and testing. My presentation focused on test methods, target response, and applicable standards. The Q&A sessions generated some interesting queries and provided useful feedback.

News and Recent Developments

IEC & ISO Standards

I was Head of the US Delegation to IEC TC-29 Electroacoustics at the meeting in Milano, Italy in March. I participated in the Ear Simulator, Hearing Aids, and Microphones working groups. I also participated in the ISO TC-43 meetings in May in Copenhagen.

AES in Berlin

I attended the AES 142nd Convention in Berlin in May. I attended a number of interesting sessions and met with clients and other persons in the industry. I also gave a tutorial lecture on headphone measurements: http://www.aes.org/events/142/tutorials/?ID=5400

Joint ASA/EAA Meeting in Boston

I will be at the joint meeting of the Acoustical Society of America and the European Acoustical Association in Boston 25-29 June. ASA Standards meetings will take place Sunday and Monday.

http://acousticalsociety.org/content/acoustics-17-boston#

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Averaging Time, Measurement Uncertainty, and Confidence Limits — Part 2

Lab Notes Vol. 8, Issue 2 discussed averaging time and confidence limits. Recall that the standard deviation for a measurement of Gaussian noise is

$$\sigma = \frac{1}{2\sqrt{BT_A}}$$

where B is the bandwidth, T is the averaging time and $BT >> 1$. A Coverage Factor of $k = 1$ is equivalent to an uncertainty of $P(L) = 68\%$; for $k = 2$, $P(L) = 95.4\%$; and for $k = 3$, $P(L) = 99.7\%$.

For a measurement in 1/3 octave bands, bandwidth is related to the filter center frequency as

$$B = 0.2307675 f_C$$

The uncertainty [in dB] in terms of Bandwidth, Averaging Time and Coverage Factor is given by

$$L_\sigma = 20\log_{10}\left(1 \pm \frac{k}{2\sqrt{BT}}\right)$$

Fig. 1 shows the uncertainty for a measurement of noise in 1/3 octave bands for $k = 2$, for various averaging times.

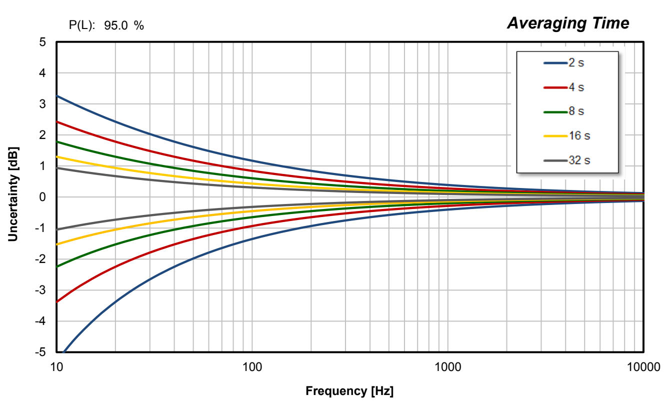

Fig. 1. Uncertainty for noise in 1/3 octave bands.

Note that the uncertainty interval is symmetric about the mean value, however, the interval is logarithmically stretched when converted to dB. The minimum averaging time for a given coverage factor and confidence interval is given by

$$T_{MIN} = \frac{\dfrac{1}{\left(\dfrac{2\left(10^{\frac{L_\sigma}{20}} - 1\right)}{k}\right)^2}}{B}$$

This is plotted in Fig. 2 for a measurement of noise in 1/3 octave bands, with $P(L) = 95$ %, and a confidence interval of ± 1 dB.

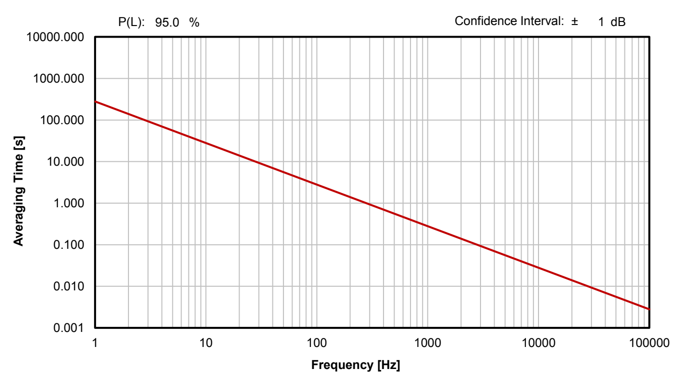

Fig. 2. Uncertainty for noise in 1/3 octave bands.

As expected, the required averaging time increases for measurements at lower frequencies, where the bandwidth is narrower.

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Sample Rate Conversion

Digital audio signals exist at many different sample rates, depending upon the application: Pro audio uses 48 kHz, 88.2 kHz, 96 kHz, 176.4 kHz and 192 kHz; Consumer audio uses 44.1 kHz; streaming audio and voice band communication systems use lower sample rates. In order to interconnect digital devices or to perform measurements and analyses, both the output and input audio must be at the same sample rate. Dedicated hardware and software sample rate converters are used to perform this function. Synchronous conversion uses a fixed integer ratio, L/M, between the two sample rates, e.g., to convert between 44.1 kHz and 48 kHz, $L/M = 147/160$.

The steps in performing sample rate conversion are shown in Fig. 1.

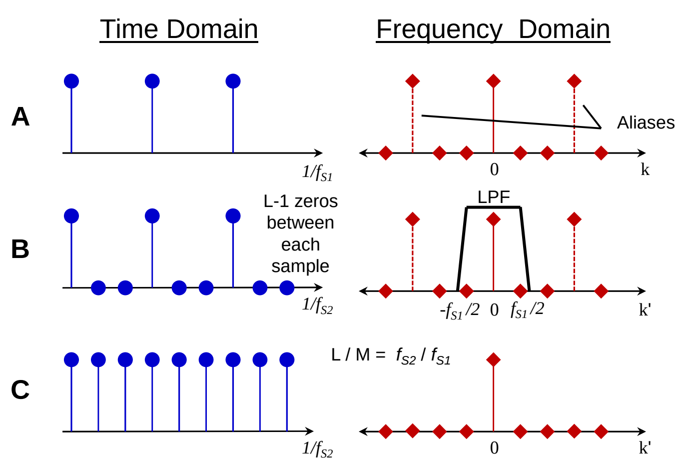

Fig. 1. Sample rate conversion process.

Fig. 1 A shows the digital signal at its original sample rate in both the time and frequency domains.

For conversion to a higher sample rate, L - 1 zeros are inserted between each of the samples of the original signal. This signal is then low pass filtered. The cut off frequency of the low pass filter is at one-half the lower sample rate (Fig. 1 B).

Every M^{th} sample from the filtered output is then selected to obtain the new signal at the higher sample rate (Fig. 1 C).

To convert from a higher sample rate to a lower sample rate, the values of L and M are simply reversed. Alternatively, sample rate conversion can be performed by interpolation, however, both methods are mathematically identical as selection of the low pass filter function is equivalent to selecting an interpolation function.

For high bandwidth, real-time applications, asynchronous sample rate converters can accept input signals with dynamically changing sample rates and output an uninterrupted signal at a different sampling rate. For most test and measurement applications, however, the stimulus signals are very short and sample rate conversion can be performed as a simple post-process operation.

Sample rate conversion is typically required when testing asynchronous digital electroacoustic devices such as USB or Bluetooth® headsets. The 16 kHz sample rate microphone output is typically converted to 44.1 kHz or 48 kHz for analysis, even though the microphone response only extends to 8 kHz. A second sample rate conversion is usually also necessary to align the actual sample rate of the device under test—which has an asynchronous master clock that may be running slightly slow or fast — to the sample rate of the analysis. This ensures frequency accuracy in the measured response.

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Volume 10, Issue 3 **September 2017**

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ASA Standards Award

In June, I received an award at the spring ASA meeting in Boston this for chairing S3 Working Group 37, which completed the revision of the ANSI/ASA S3.7 Method for Measurement and Calibration of Earphones standard. The work took about 18 months and the standard was balloted and published last November.

ASA Standards Manager Neil Stremmel presented the award after the S3 meeting.

News and Recent Developments

AES New York

The AES 143rd Convention takes place 18-21 October in New York City. I will be presenting a tutorial entitled "***Headphones, Headsets & Earphones: Electroacoustic Design & Verification***", Session PD01 on Wed. 18 Oct. at 10:45am. http://www.aes.org/events/143/productdevelopment/?ID=5537

ISEAT—Shenzhen

I will be presenting the keynote address, entitled ***"Why Is Headphone Audio So Poor, and What Can Be Done About It?"*** at the ISEAT symposium in Shenzhen, China 4-5 November. I'm also giving a master class on Loudspeaker Design. http://www.iseat.org/en/

ASA Meeting in New Orleans

The Acoustical Society of America meets in New Orleans 4-8 December. I am co-chairing Special Session 3aID at 7:45am on Wed. 6 Dec. entitled ***"Standards: Practical Applications in Acoustics"***. This session will also be live streamed. Stay tuned for details. http://acousticalsociety.org/content/174th-meeting-acoustical-society-america#overlay-context=content/174th-meeting-acoustical-society-america

Let us know if you plan to attend any of these meetings and would like to set up a meeting to discuss your project.

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CJS Labs is a consulting firm based in San Francisco, CA. We specialize in audio and electroacoustics applications. With over 30 years of industry experience in engineering and technology management, our areas of expertise include transducers, acoustics, system design, instrumentation, measurement and analysis techniques, hearing science, speech intelligibility, telephonometry, and perceptual coding. We also offer project management, technology strategy, patent & IP evaluation, and training services

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Insertion Gain of Earphones

In general, it is not possible to measure the acoustic response of earphones directly in the free field in the same manner as a loudspeaker, nor would such a measurement have any meaning. Measurements are normally performed on a manikin with an ear simulator at the equivalent of the ear drum. This response, however, does not directly represent the effective or net gain of the device, as some portion of the comparable response in a sound field would occur naturally due to head diffraction effects and the ear canal resonance. Therefore, the effective response of an earphone as perceived by the listener is correctly represented as an ***insertion gain***. The conceptual process for determining the insertion gain is shown in Fig. 1.

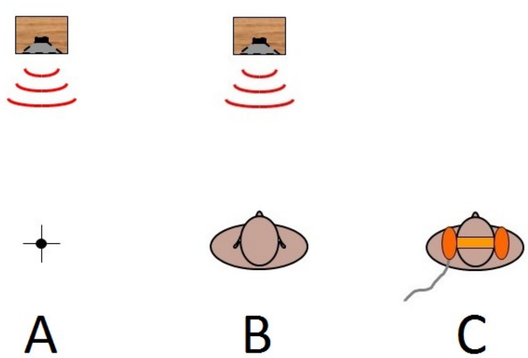

Fig. 1. Insertion gain measurement process.

First, the sound source is measured at the reference position (A). Next, the response at the ear drum is measured (B). Lastly, the earphone response is measured at the ear drum (C). Typical resulting responses are shown in Fig. 2.

Note the rise in the open ear response in the range centered at 2.8 kHz due to head diffraction and the

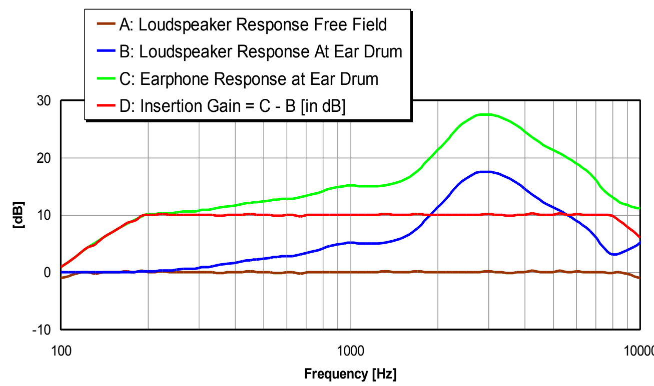

Fig. 2. Measurements for determining the insertion gain of an earphone.

ear canal resonance. In order for the earphone to have a flat perceived response, this feature must appear in the earphone response when measured at the ear drum. The insertion gain of the earphone under test is the difference between the measured ear phone response in the ear simulator and the open ear response, in dB. In this example, the open ear response is free field, on-axis, but this could be diffuse field or some other appropriate target. The desired result is a "flat" insertion gain across the bandwidth of interest, as shown in Fig. 2, curve D.

Therefore, it is the insertion gain that maps to perceived response. This means that if the appropriate target response at the ear drum is met, the result will be the desired flat insertion gain, and measurements on the device under test need only be performed using a manikin with an ear simulator. Both free and diffuse field data are readily available.

Please contact us for more information.

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Volume 10, Issue 4 **December 2017**

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ISEAT 2017—Shenzhen, China

In November, I presented a Master class on loudspeaker design and the closing keynote lecture entitled ***"Why Is Headphone Audio So Poor, and What Can Be Done About It?"*** at the ISEAT 6th International Symposium on Electroacoustic Technologies in Shenzhen, China. Both presentations were well received. I had excellent support from the organizer, Prof. Yong Shen, of Nanjing University, his student, Hongyi Zhu, and the ISEAT staff.

News and Recent Developments

AES 143rd New York

In October, I attended the AES 143rd Convention October in New York City. In addition to the exhibition and papers, I presented a tutorial entitled "***Headphones, Headsets & Earphones: Electroacoustic Design & Verification***". I included new material on testing wireless devices. Not surprisingly, there were a lot of questions afterwards.

ASA 174th Meeting in New Orleans

The Acoustical Society of America met in New Orleans in December. I chaired 2 standards meetings and co-chaired a Special Session entitled ***"Standards: Practical Applications in Acoustics"***. I also made two presentations: *"An overview of ANSI/ASA S3.7-2016: Method for measurement and calibration of earphones"* and *"Measurement uncertainty and its application to standards in acoustics"*. The session was live streamed and recorded. The recorded presentations are available at:

https://attendee.gotowebinar.com/register/3937864997797067522

Please contact us to discuss your projects and let us know how we can be of service to you.

Happy New Year!

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Efficiency Bandwidth Product for Loudspeaker Drivers

Richard Small, in his seminal JAES papers laid out the mathematical foundation in engineering terms for the design of closed box, ported, and passive radiator systems. The parameters of the simplified lumped parameter electro-mechano-acoustic circuit model bear his name along with that of Neville Thiele, who's work Small's papers is based upon. These have long been a *de facto* industry standard.

The parameters may be measured on a given driver using a variety of methods (e.g., added volume, added mass, SPL sensitivity plus electrical impedance, or laser velocity plus electrical impedance). Many manufacturers provide this data on their specification sheets as well with their samples (see Fig. 1).

Parameter	Symbol	Value	Unit
Driver Surface Area	S_D	83.32	cm²
Voice Coil DC Resistance	R_E	3.71	ohms
Resonant Frequency	f_S	87.22	Hz
Impedance Maximum at Resonance	Z_{MAX}	36.34	Ω
Impedance Minimum	Z_{MIN}	3.75	Ω
Mechanical Quality Factor	Q_{MS}	7.526	
Electrical Quality Factor	Q_{ES}	0.857	
Total Quality Factor	Q_{TS}	0.769	
Equivalent Compliance Volume	V_{AS}	3.17	liters
Mechanical Compliance	C_{MS}	0.3261	mm/N
Mechanical Effective Moving Mass	M_{MS}	10.21	grams
Mechanical Damping	R_{MS}	0.7435	N·s/m
Magnetic Flux Density · Coil Length Product (Force Factor)	Bl	4.93	T·m
Voice Coil Inductance	L_E	0.058	mH
Efficiency	η_0	0.237	%
Sensitivity		89.2	dB SPL at 1m

Fig. 1. Thiele-Small parameters for a driver.

In addition to modeling the small signal behaviour of the loudspeaker system, the suitability of a particular driver for use in a closed or ported system can be determined by its parameters.

The Efficiency Bandwidth Product (EBP) is calculated as

$$EBP = \frac{f_s}{Q_{ES}}$$

or, simply the quotient of the resonant frequency and the electrical quality factor.

In general, drivers with an EBP < 60 are best suited for use in a closed box system. The more compliant suspension is supplemented by the stiffness of the air in the enclosure to provide additional restoring force — the force required to bring the driver back to its zero displacement rest position when the input voltage crosses through zero.

Drivers with an EBP > 90 are best suited for use in a ported box (or band pass) system. In this case, since the enclosure is open to the outside, a stiffer suspension is required, as the driver must supply its own restoring force.

Drivers with an 60 < EBP < 90 provide flexibility with respect to the choice of closed box vs. ported / band pass enclosure, but are not optimum for either.

If the EBP is not provided with the other parameters, it is usually the first step in the design process in order to evaluate the driver, particularly if a particular system design is required.

Please contact us for more information.