CJS Labs

Technology · Research · Strategy · Solutions

Lab Notes

NCAC
National Council of Acoustical Consultants
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Volume 4, Issue 1 **February 2011**

Audio & Electroacoustics

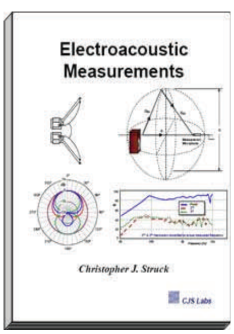
- *Consulting*
- *Design / Testing*
- *Training*

Inside this issue:

"Electroacoustic Measurements" Book

***THE** essential reference for making proper electroacoustical transducer measurements. A 300+ page, bound, fully annotated compendium of slides and notes from the CJS Labs training seminars. Literature references for each chapter are also included. Ordering information:*

http://www.cjs-labs.com/sitebuildercontent/sitebuilderfiles/OrderingCourseNotes.pdf



Electroacoustics Seminar A Success!

The *"Fundamentals of Electroacoustic Measurements"* seminar was held at the Grand Hyatt, San Francisco on 8 November 2010, immediately after the AES 129th Convention. Attendees came from a wide variety of industries and academia to learn about electroacoustic principles and applications. In addition to the course material presented, there was animated Q&A, with participants exchanging practical information and experiences from the 'front lines'.

HATS & Handset Positioner Added to Arsenal

A Brüel & Kjær Type 4128 Head And Torso Simulator and Type 4606 Handset Positioner has been added to the CJS Labs arsenal of test equipment. This industry standard test fixture significantly enhances our capabilities for telephonometry measurements, and handset and headset design and testing. Contact us for more information.

Recent News & Upcoming Events

IEEE 1329-2010

The latest revision of the IEEE 1329 hands-free telephone testing standard was published in August 2010 and is available from IEEE:

http://standards.ieee.org/findstds/standard/1329-2010.html

American Academy of Audiology:

Audiology NOW!® 2011

AudiologyNOW!® 2011, the annual conference for the American Academy of Audiology, will be held in Chicago, IL 6-9 April 2011. More info at:

http://www.audiologynow.org/

We plan to attend. Please contact us if you would like to set up a meeting.

161st Meeting of the Acoustical Society of America

The next ASA meeting is in Seattle, WA 23-27 May 2011. Registration and hotel info is available at: http://acousticalsociety.org/

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

Best regards,

Christopher J. Struck

CEO & Chief Scientist

CJS Labs

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CJS Labs is a consulting firm based in San Francisco, California. We specialize in audio and electroacoustics applications. With over 25 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, and training services

Back issues of Lab Notes are available on our website at:

http://www.cjs-labs.com/lab_notes_links.html

Random & Bias Errors in Measurements

Just as a model is only a limited approximation of the behaviour of a system, measurements are generally only estimates of the true system response. For measurements of linear systems using signals that may contain noise, the results can contain both bias and random errors.

A **Bias Error** is a systematic error introduced in the measurement, analysis, or post-processing. **Random Error** is the standard deviation of the estimates and is due to the fact that averaging is not performed over an infinite number of records, or over an infinitely long measurement time. Fig. 1 illustrates the effects of random and bias errors in the estimate of a measured value.

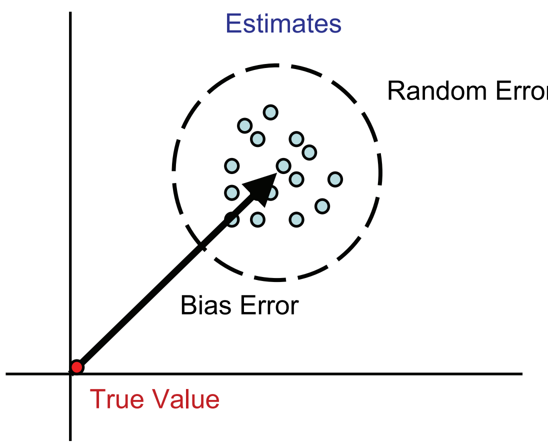

Fig. 1. Vector representation of a measurement as estimates in relation to the true value.

Accuracy, in this context, describes the closeness of an estimate to the true value. **Precision** is the degree to which measurements repeated under the same conditions produce the same result. Increasing the number of estimates or averages can improve the precision, but not the accuracy.

Certain bias errors can be corrected for by using *apriori* knowledge of the effect, if known. Bias errors in the estimates can be due to a number of different effects, such as:

1. Incorrect calibration
2. Random noise at the system input and/or output
3. Limited resolution or spectral leakage (i.e., use of incorrect time window function
4. Correlated noise, e.g., reflections
5. Uncompensated propagation delay from input to output
6. Non-linearities

If a random Gaussian amplitude distributed signal is measured and averaged over an infinitely long time, the result will converge to the true mean RMS value, μ. For a finite averaging time, however, there will be some uncertainty about the true mean value. This can be described in terms of **Confidence Limits** or statistical probability: There is a probability P(L) of 68% that the measured signal level will be within the limits of ± one Standard Deviation, σ; a probability of 95% of being within ±2σ, and a probability of 99.7% of being within ±3σ. In acoustical measurements, these are referred to as Confidence Limits. The value of $2 \times 3 = 6\,\sigma$ gives a good indication of the total spread ($L_{MAX} - L_{MIN}$).

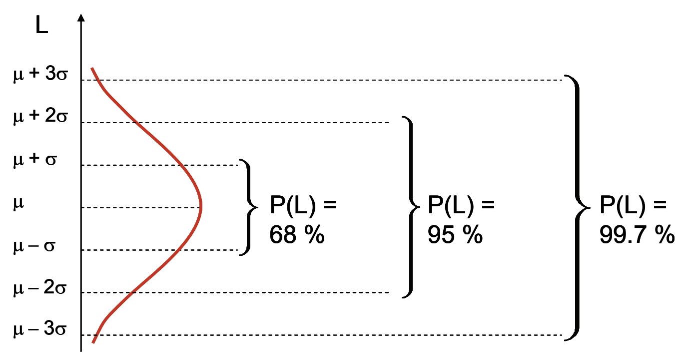

Fig. 2. Gaussian amplitude distribution showing typical measurement confidence limits.

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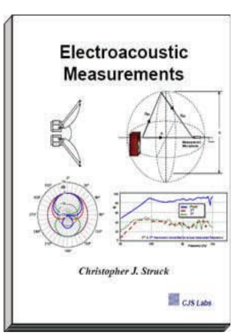

AES San Francisco Microphone Clinic

On 14 June 2011, CJS Labs will set up our simulated free field test rig, automated turntable and custom designed free field 'Point Source' for microphone measurements for the AES – San Francisco chapter meeting at Dolby Laboratories.

http://www.aessf.org/index.htm

The first 10 persons to register and bring their pro audio recording microphone (and mic stand adaptor) to the meeting can have their unit measured during the meeting and receive a print out certificate of the response, sensitivity, and polar pattern. Between tests, I will be on hand to discuss the test system, measurement technique, and hardware, as well as the limits of its applicability. I'll also show alternative methods and supplemental measurements and take questions from the audience on these topics. I hope to see you there.

Audiology NOW!® 2011

The AudiologyNOW!® conference took place in Chicago 6-9 April 2011. On the first day of the convention, I attended the meeting of the ANSI S3WG48 Working Group on Hearing Aid Measurements. The exhibits featured the latest in digital signal processing hearing instruments and fitting systems from all of the major manufacturers. I met with a number of you there. By all accounts, it was a huge success.

Recent News & Upcoming Events

Binaural Cable Car

A binaural recording of a San Francisco cable car is posted on our home page. Listen with headphones to hear the spatial effect.
http://www.cjs-labs.com/sitebuildercontent/sitebuilderfiles/CableCarBinaural.mp3

How It's Made: Microphones

Are you curious about how high-end microphones are made? This fascinating episode showing how the Sennheiser U87 is manufactured and tested originally aired back in August of 2009 on the Science Channel HD. It is definitely worth a closer look:
http://science.discovery.com/videos/how-its-made-microphones.html

161st Meeting of the Acoustical Society of America

ASA will be meeting in Seattle, WA 23-27 May 2011. Registration and hotel info is available at:
http://acousticalsociety.org/
We plan to attend. Please contact us if you would like to set up a meeting.

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

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Correlated and Uncorrelated Noise Errors

In Lab Notes, Vol. 1, Issue 2 (May 2008), we discussed the difference between signal addition on a power basis and signal addition on a vector basis (including phase). Applications of transducer measurements frequently encounter both of these effects as noise corruption.

Generally, it is desired to measure only the direct sound from the transducer without influence from the room environment or other noise sources. In practice, this is may be difficult to achieve without a specially treated room or special signal processing.

In addition to the direct sound component in an ordinary room, sound also reaches the measurement microphone via reflected sound paths. This can be considered **correlated noise** to the measurement, as it is a delayed and attenuated version of the direct sound.

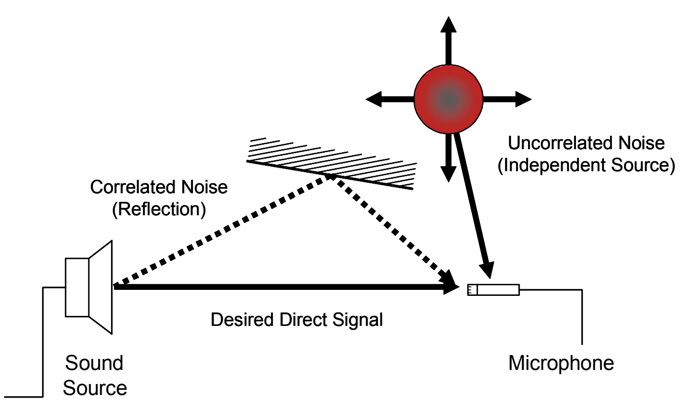

Fig. 1. Typical test set up showing desired signal and noise components.

Furthermore, **uncorrelated noise** sources, e.g., fans, background noise, speech, etc, can affect the measurement. Both types of noise can be mitigated with the proper choice of test technique.

Fig. 2 shows the error due to the effect of a single reflection on an otherwise flat frequency response. In this example, the reflection is -10 dB relative to the direct sound. Note, however, that the reflection is correlated and therefore interferes on a signal basis (i.e., in phase), not on a power basis. Response dips

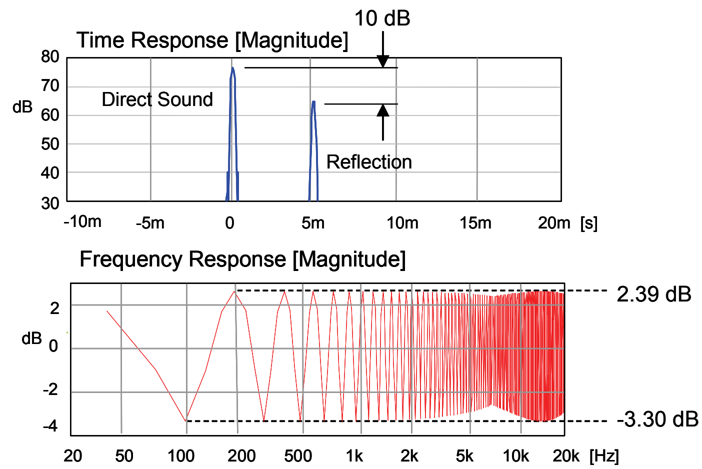

Fig. 2. Effect of a single reflection at -10 dB.

occur at N/τ and response peaks occur at (1+ 2N)/(2τ), where τ is the reflection delay and N = {0,1,2,3,4…}.

Another aspect of correlated noise errors is that the error is independent of test level, i.e., simply increasing the stimulus level does not improve the measurement S/N as it does for uncorrelated noise (at a fixed level).

So what conclusions can be drawn from this? For ± 0.5 dB measurement error, uncorrelated noise must be –10 dB relative to the desired signal. Reflections, however, must be -25 dB relative to the desired signal. Conversely, the influence of uncorrelated noise at -25 dB on the resulting measured level is less than 0.01 dB. For most steady state background noise, this is easily achievable, particularly band-by-band. For ± 0.1 dB measurement error, however, correlated reflections must be at least -40 dB relative to the desired signal!

In practice, this means having adequate stimulus level, filtering, using a treated room or test chamber, performing the measurement in a closed cavity or coupler, performing a near field measurement, and/or the use of gated or simulated free field techniques.

Contact us for more information.

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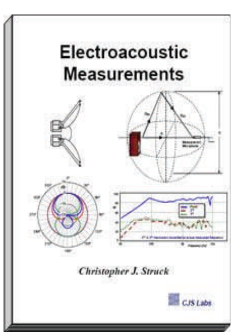

Fundamentals of Electroacoustic Measurements

CJS Labs will offer its 1-day "Fundamentals of Electroacoustic Measurements" seminar on Monday, 24 October 2011 in New York city, immediately after the AES 131st Convention.

This course focuses on measurements of electroacoustic transducers, including instrumentation, data interpretation, and information on how to perform appropriate tests. Techniques for diagnosing problems in design and QC are shown. Practical demonstrations are provided throughout the course. It is intended for technical persons who are responsible for the electroacoustical performance of loudspeakers, microphones, headphones, telephones, hearing aids, or transducer-equipped media devices. R&D, Q.C/Q.A., and Production related topics are covered. The level and content are appropriate for both novices and persons with some test and measurement experience. This training will enable you to perform accurate measurements and provide you with the necessary tools to understand and correctly interpret the results.

Space is limited to 15 persons. Your space is not guaranteed until payment is received. The course fee includes a buffet lunch and a printed set of the course notes. More info at:

http://www.cjs-labs.com/sitebuildercontent/sitebuilderfiles/1-DaySeminarOverview2011.pdf

Email or phone today to reserve a place.

Recent News

AES-SF Mic Clinic

On 14 June 2011, CJS Labs set up our simulated free field test rig, automated turntable and custom designed free field 'Point Source' for microphone measurements for the AES – San Francisco chapter meeting at Dolby Laboratories.

http://aessf.org/meetings/20110614.htm

A number of persons brought their recording mics in, and these were tested during the meeting. The mic owners received a print out certificate of the response, sensitivity, and polar pattern. Between tests, I presented information about the test system, measurement technique, and hardware, as well as the limits of its applicability. Alternative methods and supplemental measurements were also shown, followed by a lively Q&A session.

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Acoustic Impedance Measurements

Acoustic impedance is defined as

$$Z = \frac{p}{u} \quad \text{[Pa·s·m}^{-3}\text{]} \qquad [1]$$

where p is sound pressure and u is volume velocity. This is simply Ohm's Law and is analogous to electrical impedance where the pressure represents voltage and volume velocity represents current. Using the Norton equivalency for a current source, a small high impedance source (e.g., hearing aid receiver, or condenser microphone driven as a transmitter) is essentially a constant volume velocity source when fired into a small enclosed volume, such as a tube or ear canal, and assuming the wavelength of sound, $\lambda \gg 4r$, where r is the radius of the tube. At low frequencies

$$Z = \frac{\gamma P_0}{j\omega V} \qquad [2]$$

where γ = ratio of specific heats (ca. 1.4 for air)
P_0 = static pressure [in Pa]
V = volume [in m^3]

Continuing the electrical analogy, a constant volume represents a capacitance and an inertance or acoustic mass (e.g., small slit, tube, or opening, where the air is essentially non-compressible) represents an inductance. It is convenient when measuring equivalent volumes to measure impedance times frequency, as a constant volume appears as a flat response on a log-log or dB vs. log frequency axis. Therefore

$$|Z| \cdot j\omega = \gamma P_0 \frac{1}{V_{EQ}} \qquad [3]$$

So impedance times frequency is inversely proportional to the equivalent volume. The equivalent volume and the physical volume may or may not be the same at higher frequencies, depending upon the complexity of the system under investigation. However, in most cases, the modulus of the equivalent volume and the physical volume converge as $f \to 0$, i.e., at DC. This also means that for a high acoustic impedance source, sound pressure is inversely proportional to the load volume

$$p = u \cdot \frac{\gamma P_0}{j\omega V_0} \qquad [4]$$

So the volume velocity can be found from a pressure measurement into a known volume, or

$$u = \frac{p_0(f)\,\gamma P_0}{j\omega V_0} \qquad [5]$$

where $p_0(f)$ is the resulting sound pressure into a known calibration volume, V_0. Therefore, the acoustic impedance of an unknown element can be found by repeating this same measurement to find $p_1(f)$ with the unknown impedance substituted for the calibration volume

$$Z = \frac{p_1(f)}{\dfrac{p_0(f)\gamma P_0}{j\omega V_0}} \qquad [6]$$

Generally, this is measured as the modulus (magnitude, neglecting phase) of the inverse of equivalent volume as

$$|Z| \cdot f = \frac{p_1(f)}{p_0(f)} \cdot \frac{\gamma P_0}{2\pi V_0} \quad \text{[Pa·m}^{-3}\text{]} \qquad [7]$$

Working with SPL measurements in dB, this becomes

$$20\log_{10}\left(|Z| \cdot f\right) = 20\log_{10}\left(\frac{p_1(f)}{p_0(f)} \cdot \frac{\gamma P_0}{2\pi V_0}\right) \qquad [8]$$

or

$$|Z| \cdot f\ [in\ dB] = L_{p_1}(f) - L_{p_0}(f) + 20\log_{10}\left(\frac{\gamma P_0}{2\pi V_0}\right) \qquad [9]$$

The last term is a scaling constant (moving the entire result up or down a constant value of decibels).

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Volume 4, Issue 4 November 2011

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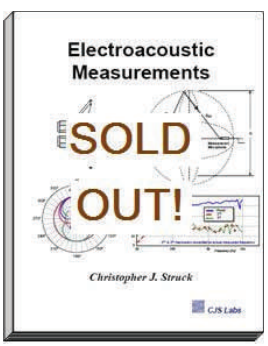
"Electroacoustic Measurements" Book: OUT OF PRINT!



THE essential reference for making proper electroacoustical transducer measurements. A bound, fully annotated compendium of slides and notes from the CJS Labs training seminars. Literature references for each chapter are also included. A new and expanded revision is planned for 2012. Contact us to reserve your copy!

Telephony Tutorial at AES 131st in New York City

On Saturday 22 October 2011, I will be presenting a Tutorial at the AES 131st Convention in New York entitled, "Telephonometry: The Practical Acoustics of Handsets, Headsets, and Mobile Devices"

http://www.aes.org/events/131/tutorials/?ID=2881

The basic concepts of Telephonometry on analog and digital telephones, including both subjective and objective methods will be explained. The historical concept of Loudness Rating and standard methods for its calculation are also reviewed. Standard objective measurements of send, receive, sidetone and echo response are explained. Selection and use of appropriate instrumentation, including ear and mouth simulators will be detailed. Techniques for the evaluation of handsets, headsets, speakerphones, and other hands-free devices will be presented. Applications of these measurements to analog, digital, cellular, and VoIP devices will be shown. Various methods specified in the ITU-T, IEEE, TIA, ETSI, and 3GPP standards will also be explained.

Please contact us if you are attending AES in New York and would like to set up a meeting. We hope to see you there.

Recent News & Upcoming Events

162nd Meeting of the Acoustical Society of America

ASA will be meeting in San Diego, CA at the Town and Country Hotel and Convention Center 31 October - 4 November. Registration and hotel info is available at: http://acousticalsociety.org/

On Wednesday 2 November 2011 at 1:15pm, I will be giving an invited presentation/paper entitled "Modern Tools for the Development of Acoustical Standards"

(Session 3pIDb).

Please contact us if you are attending ASA in San Diego and would like to set up a meeting.

ANSI/ASA S3 Chair

I am very pleased to announce that I have been selected to Chair the ANSI/ASA S3 Standards Committee on Bioacoustics, overseeing the development of national standards in bioacoustics and related fields. My 3-year term begins in May 2012. I will also continue to chair working groups S3WG67 (Manikins) and S3WG37 (Ear Simulators & Couplers).

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

Best regards,

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Directivity Index

With the exception of very small measurement microphones, most practical electroacoustic systems are not equally sensitive in all directions. Fig. 1 shows the polar response of various 1st order systems in one plane, normalized to the frontal on-axis response. These could be sources or receivers. In this case, the

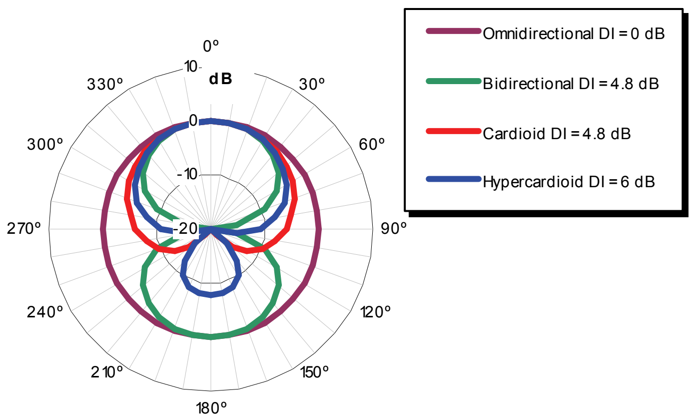

Fig. 1 First-order directional systems

polar responses are axially symmetric, i.e., they are 3-D 'balloon' shapes, where these plots outline a horizontal cross-section. An **Omnidirectional** source or receiver has equal sensitivity in all directions. Polar response in practical systems is typically frequency dependent. The directivity of a source, such as a loudspeaker, typically increases with increasing frequency as the wavelength of sound becomes small compared to the size of the source. Microphones can be made directional by the addition of a second port open to the rear of the diaphragm. Alternatively, two Omnidirectional microphones can be scaled and summed to form a first order directional pattern.

Directivity, Q, is the power ratio of the Free Field reference axis response to the Diffuse Field (Random Incidence) response. This applies to either sources or receivers.

$$Q(f) = \frac{4\pi |p_{ax}|^2}{\int_0^{2\pi}\int_0^{\pi} |p(\theta,\phi)|^2 |\sin\theta| \, d\theta \, d\phi}$$

The numerator in the expression for Directivity, Q, is simply the mean square pressure (or power) of the ideal point source radiating spherically into a free field. This is usually the on-axis response of the device under test, but could be chosen to be at some other reference angle or elevation. The denominator is the mean square pressure (or power) of the diffuse field response, i.e., a weighted summation of the energy in all directions, in 3 dimensions. Symmetry can (and should) be used to simplify the calculation and data gathering. The Directivity Index, DI, is the Q expressed in dB, e.g., a Q of 1 equals a DI of 0 dB (omnidirectional).

$$DI = 10 \log_{10} Q \quad [in\ dB]$$

Directivity can easily be calculated from the free field polar response *if* the response is axially symmetric. However, directivity is *always* in 3-dimensional space.

This also implies that for complex systems without axial symmetry, the Directivity Index can also be obtained from just two measurements: The on-axis free field response and the random incidence response, measured in a diffuse field.

Note also that a DI < 0 does not imply *less* directivity (as a DI

$$DI(f) = 10\log_{10}\left[\frac{10^{\frac{H_0(f)}{10}}}{10^{\frac{H_{diffuse}(f)}{10}}}\right] = H_0(f) - H_{diffuse}(f) \quad [in\ dB]$$

of 0 is omnidirectional and is the theoretical minimum). On the contrary, in this case, the directivity is simply not in the chosen reference axis.

In practice, the data is gathered with an automated turntable system and the polar plots and DI calculation are performed as a post-processing. Please contact us for more information.