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Lab Notes

IEEE Consultants' Network of Silicon Valley

NCAC National Council of Acoustical Consultants Member

Audio & Electroacoustics

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

Volume 7, Issue 1 **March 2014**

Inside this issue:

Audio Design Workshop

On 18 March 2014, the AES San Francisco Section, in conjunction with CJS Labs, Texas Instruments, Audio EMC, Oxford Digital, and Prism Sound, will present a free Master Class entitled:

Active Loudspeakers:

Design and Optimization Master Class

This master class will be a unique opportunity to hear from some of the most experienced engineers in the industry, and to hear about their practical experiences in analogue and digital audio design. See the latest developments in technology, and learn from the many decades of collective experience of our panel of experts.

I will be presenting a module on Electroacoustics and Transducers.

The class will be held at:

Cogswell College
1175 Bordeaux Drive
Sunnyvale, CA 94089

Registration is required, as space is limited.

Join us in person or via live or recorded web cast:

http://www.eventbrite.co.uk/e/active-loudspeaker-design-masterclass-live-cogswell-polytechnical-college-registration-10200884119?aff=prism1

We look forward to seeing you there.

News and Recent Developments

ASA 167th in Providence

The 167th Meeting of the Acoustical Society of America will take place 5-9 May 2014 in Providence, RI at the Rhode Island Convention Center and the Omni Hotel.

The meeting program and technical sessions will cover a wide variety of different acoustical disciplines.

I will be attending the standards plenary, ASACOS, and accredited subcommittee meetings as Chair of ANSI Subcommittee 3 on Bioacoustics.

If you will be attending the ASA 167th and would like to set up a meeting, please do not hesitate to contact us.

Information about the ASA 167th Meeting is available at:

http://acousticalsociety.org/meetings/providence

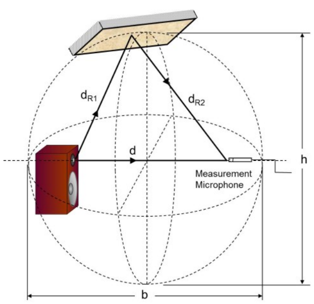
Please contact us and let us know how we can be of service to you and your organization.

Christopher J. Struck

CEO & Chief Scientist

CJS Labs

Electroacoustics Measurements Seminar



Materials for the one-day Electroacoustics Measurements seminar have been extensively revised and updated with additional slides on new topics. An outline is available on our website:

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

Contact us to schedule an in-house training course for your organization.

CJS Labs

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CJS Labs is a consulting firm based in San Francisco, CA. We specialize in audio and electroacoustics applications. With over 27 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

High Resolution of Pure Tone Components using FFT 'Picket Fence' Correction

The effect of measuring the spectrum only at filter (or FFT) centre frequencies is referred to as the "Picket Fence" Effect, since it is similar to viewing the true continuous spectrum through a picket fence with the given measurement bandwidth (see Fig. 1).

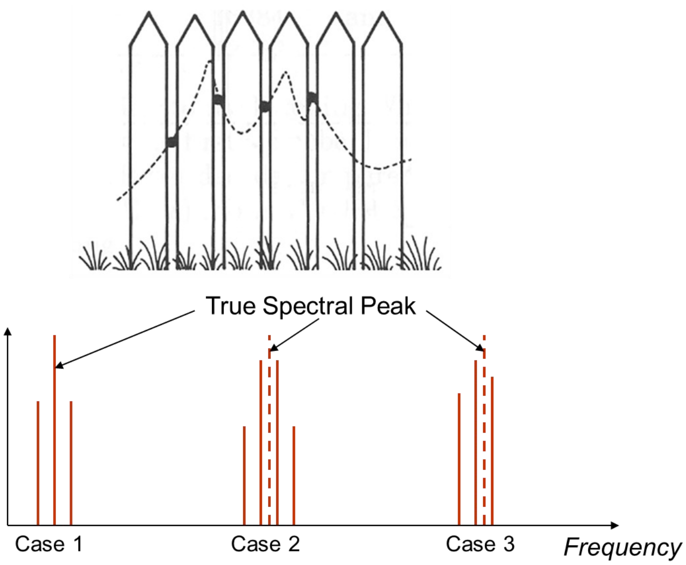

Fig. 1 'Picket Fence' Effect and 3 typical analysis cases for a pure tone component.

Except in the situation where a frequency component exactly coincides with a spectral line (Case 1), there will in general, be an error in both amplitude and frequency (Cases 2 and 3). Assuming the component is a single and stable frequency, these errors can easily be compensated for by interpolation techniques.

Both a frequency and an amplitude correction can be applied using the information from the spectral lines closest to the true spectral peak and knowledge of the time window used in the FFT analysis. The frequency correction Δf_C [in Hz] for Hann weighting is:

$$\Delta f_C = \frac{2 - 10^{(L_1 - L_2)/20}}{1 + 10^{(L_1 - L_2)/20}} \cdot \Delta f$$

where L_1 and L_2 are levels of the highest spectral FFT lines around the peak and Δf is the frequency resolution (FFT line spacing) in the analysis. The amplitude correction, ΔL [in dB] for Hann weighting is:

$$\Delta L = 20\log_{10}\left| \frac{\sin \pi \frac{\Delta f_C}{\Delta f}}{\pi \frac{\Delta f_C}{\Delta f}} \cdot \frac{1}{1 - \left(\frac{\Delta f_C}{\Delta f}\right)^2} \right|$$

ΔL is 0 dB when the true frequency exactly coincides with an analysis line (Case 1). In this case, L_1 - L_2 = 6.0 dB. ΔL = 1.42 dB when L_1 - L_2 = 0 dB, i.e., when the true frequency is exactly between two spectral FFT lines (Case 2). For Rectangular weighting, the frequency correction is:

$$\Delta f_C = \frac{1}{1 + 10^{(L_1 - L_2)/20}} \cdot \Delta f$$

and the amplitude correction is:

$$\Delta L = 20\log_{10}\left| \frac{\sin \pi \frac{\Delta f_C}{\Delta f}}{\pi \frac{\Delta f_C}{\Delta f}} \right|$$

Similar equations can also be derived for any other time window function.

Please contact us for more information.

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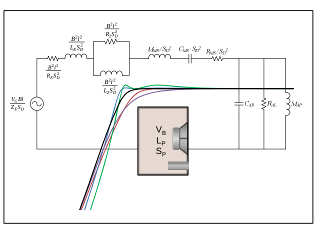
Volume 7, Issue 2 **June 2014**

Inside this issue:

NEW! Loudspeaker Design Seminar



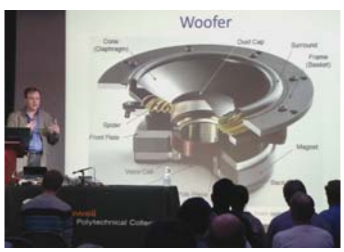
CJS Labs now features its brand new one-day seminar covering drivers and their inherent nonlinearities, enclosures, cabinet vibration, crossover design, Thiele-Small parameters, equivalent circuits, cone break-up, diffraction, and room acoustic effects. Complete design examples are detailed for closed and ported systems. An outline is available on our website:

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

Contact us to schedule a training course for your organization.

Audio Design Workshop Wrap

In March, in conjunction with Texas Instruments, Audio EMC, Oxford Digital, and Prism Sound, I presented a Master Class lecture on Active Loudspeaker Design for the AES San Francisco Section at Cogswell College in Sunnyvale, CA.

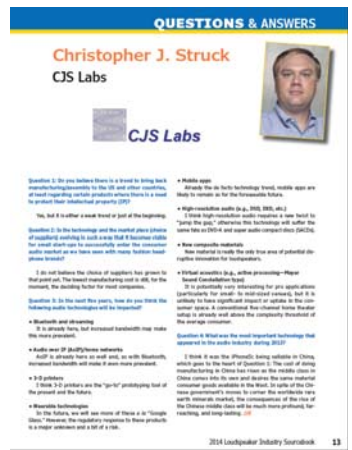


This class was well attended, both in-person and via simultaneous web cast. This enabled Q/A from the audience members in Sunnyvale as well as from persons following the lecture on-line. The entire Master Class was recorded as is available for viewing through the LinkedIn Audio Design Workshop.

http://audiodesignworkshop.org/adwl_home.php

Featured Interview in the 2014 Loudspeaker Industry Sourcebook

My interview regarding industry trends appears in the just released 2014 LIS.



News and Recent Developments

IEEE Honors Iconic Shure Microphone Design

The Shure Unidyne directional cardioid microphone, designed by Benjamin Bauer, and introduced in 1939, has been named an IEEE Milestone.

Read more at:
http://theinstitute.ieee.org/technology-focus/technology-history/iconic-microphone-is-named-an-ieee-milestone

ASA 167th in Providence

I attended the ASA 167th Meeting in Providence, RI in May. I was there primarily for the standards plenary, ASACOS, and accredited subcommittee meetings as Chair of ANSI Subcommittee 3 on Bioacoustics. The meetings were productive, with many standards projects going on this year.

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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Near Field Loudspeaker Measurements

Near field measurements (Keele JAES 1974) are another useful simulated free field technique. The microphone is simply placed extremely close to the source. In this case, the direct sound level is

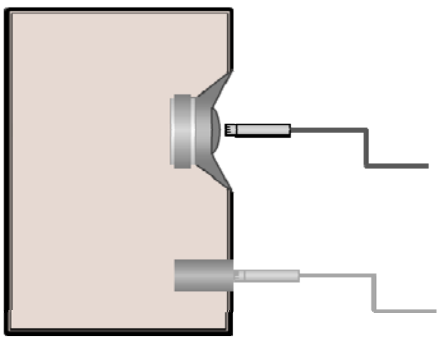

Fig. 1 Mic positioning for near field measurements

considerably above the level of reflections or background noise. Any stimulus may be used. The near field technique can also be used on devices with ports and passive radiators. The individual sources are measured separately (see Fig. 2) and scaled as per Eq. 1, where S_P is the effective radiating area of

$$H(f)_{NF} = H(f)_D + \sqrt{\frac{S_P}{S_D}} \cdot H(f)_P \qquad [1]$$

the port or passive radiator and S_D is the effective radiating area of the driver, and finally complex power summed to yield the overall near field response. This is a complex vector summation (magnitude and phase) and the results are in dB. This overall near field response can then be scaled to obtain the far field response as per Eq. 2, where d is the reference distance to the far field (usually 1m), and a

$$H(f)_{FF} = H(f)_{NF} - 20\log_{10}\left(\frac{4d}{a}\right) \qquad [2]$$

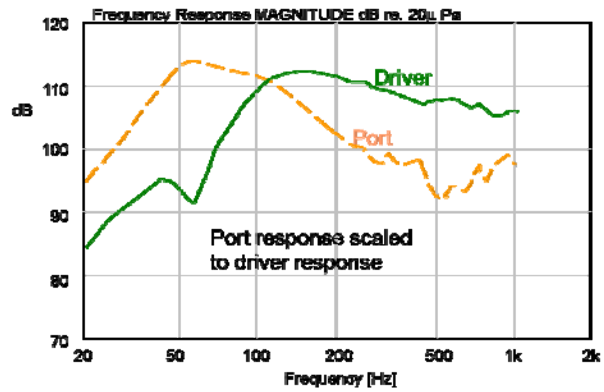

Fig. 2 Near Field Driver and Port measurements

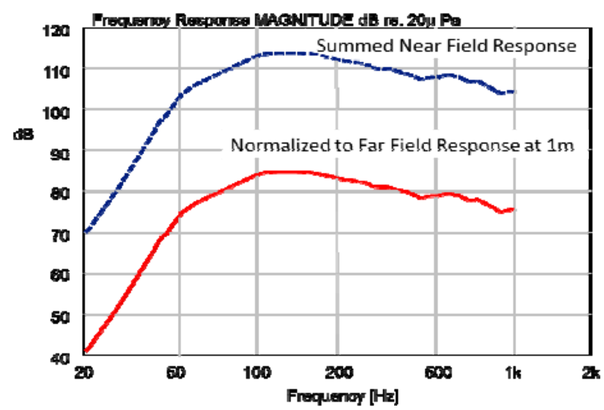

Fig. 3 Near Field and Far Field responses

is the radius of the driver. The result is in dB for a 4π full anechoic space (Fig. 3). For raw drivers mounted in an infinite baffle (2π half-space), the *4d* factor in the numerator becomes *2d*. This technique is valid up to *ka* = 1.6 with errors of less than 1 dB, however, the microphone distance must be less than 0.11 times the radius. At higher frequencies, the shorter wavelength and modal behaviour cause greater errors. Please contact us for more information.

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Volume 7, Issue 3 **September 2014**

Electroacoustics & Audio

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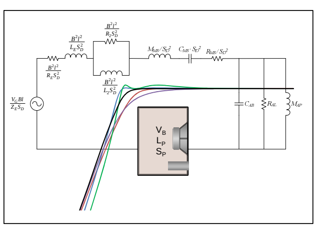
Inside this issue:

NEW! Loudspeaker Design Seminar



CJS Labs now features its brand new one-day seminar covering drivers and their inherent nonlinearities, enclosures, cabinet vibration, crossover design, Thiele-Small parameters, equivalent circuits, cone break-up, diffraction, and room acoustic effects. Complete design examples are detailed for closed and ported systems. An outline is available on our website:

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

Contact us to schedule a training course for your organization.

Loudspeaker Design Master Class at AES 137th in Los Angeles

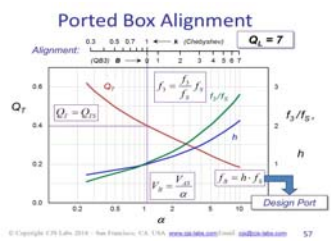
The AES 137th Convention will be held 9-12 October 2014 at the Convention Center in Los Angeles. Info at:

http://www.aes.org/events/137/

At the AES 137th, I will be presenting a Master Class entitled "***Almost Everything You Ever Wanted to Know About Loudspeaker Design***" on Thu. 9 Oct. at 9:00 AM. Info at:

http://www.aes.org/events/137/tutorials/?ID=4191

This Master Class will walk the attendees through complete enclosure and



crossover designs utilizing Thiele-Small data from actual drivers. Equivalent circuits, cabinet effects, time alignment, and Zobel compensation are detailed. Performance tradeoffs and limitations in both the small and large signal domains are shown. If you will be at the AES 137th in Los Angeles and would like to arrange a meeting, please contact us.

1-Day Electroacoustics Training Course

In conjunction with Listen, Inc., I will be presenting the 1-day *Fundamentals of Electroacoustic Measurements* training course on **Monday 6 October 2014** in Santa Clara, CA. Info and registration details are available at:

http://www.listeninc.com/us/news_events/training_classes.html

News and Recent Developments

Training Seminar in Shanghai

I was in China in August where I was engaged for 4 days of seminars and training. Attendees came from all over Asia, including Beijing, Shenzhen, Seoul, Taipei, and Shanghai.

The sessions were interactive, with Q&A throughout, as well as many practical examples. The food and hospitality were also outstanding. I'm sure Anthony Bourdain would approve...

Appointment as Resource Expert to U.S. TAG

As a result of voting earlier this year, I am pleased to announce that I have been appointed as a Resource Expert for the United States Technical Advisory Group (TAG) to IEC Technical Committee 29 — Electroacoustics. I will be responsible for review of draft IEC standards and providing guidance and recommendations for the US vote.

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

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

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Closed & Ported Loudspeaker Maximum Output

In his seminal papers on closed and vented loudspeaker enclosure design (JAES 1973), Richard Small showed that the maximum output of either design was limited by the volume displacement of the system, i.e., the amount of air that can be moved at low frequencies. This is governed by two parameters: The driver surface area, S_D, and the maximum driver excursion, x_{MAX}, the product of these yielding the displacement volume. The low frequency response of a direct radiator loudspeaker system is high pass, with sound power output proportional to the square of the product of volume displacement and frequency — also proportional to cone acceleration. Displacement, mechanically, is the double integral of acceleration — a multiplication by frequency squared — and hence low pass. For comparison, assuming the highest efficiency alignment for each system (2nd and 4th order Chebyshev, respectively), Small derived the following simple expressions for the maximum power output of each system:

$$P_{AR\,(Closed\,)\,MAX} = 0.85\, f_3^{\,4} S_D^{\,2} x_{MAX}^{\,2} \qquad [1]$$

$$P_{AR\,(Ported\,)\,MAX} = 3.0\, f_3^{\,4} S_D^{\,2} x_{MAX}^{\,2} \qquad [2]$$

where P_{AR} is the acoustical sound power [in Watts]. The papers also feature families of plots for these expressions as a function of corner frequency f_3 and volume displacement, $S_D x_{MAX}$. Figs. 1 and 2 show these graphs re-plotted as SPL at 1m [in dB]. The difference between closed and ported systems is simply the ratio of the leading coefficients: A 5.5 dB increase for the ported system. The conclusion is that to play loud at low frequencies, you need to move more air. This means an overall larger system, which the Marketing Dept. may not be too happy about...

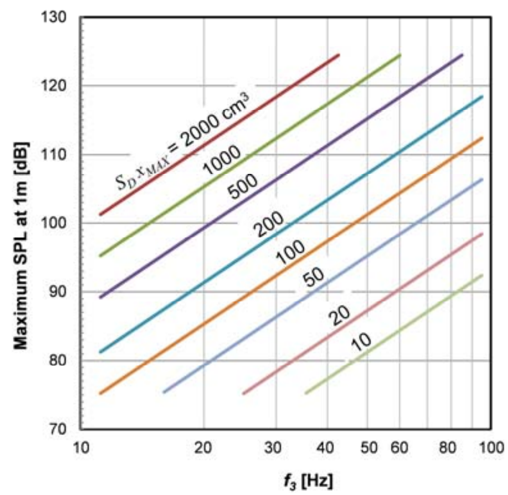

Fig. 1 Maximum output SPL for a closed box system.

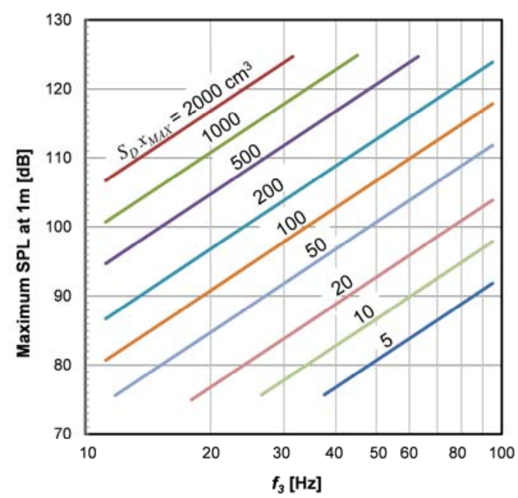

Fig. 2 Maximum output SPL for a ported box system.

Please contact us for more information.

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Volume 7, Issue 4 **December 2014**

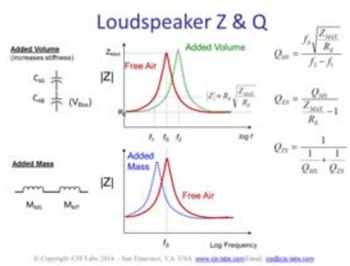
Inside this issue:

Loudspeaker Design Seminar at ALMA Winter Symposium 2015

Winter ALMA will take place 3-4 January 2015 at the Tuscany Suites & Casino in Las Vegas, NV just before CES. I will be presenting a seminar entitled "***An Overview of Loudspeaker System Design***" on Sunday, 4 January 2015 at 2:00 PM. Info at:

http://www.almainternational.org/events/winter_symposium_2015_announcements__information

This seminar will cover closed and ported enclosures, designs utilizing Thiele-Small parameters, crossovers, equivalent circuits, diffraction effects, time alignment, basic nonlinearities, modal behaviour, and cone break up. Performance tradeoffs and limitations in both the small and large signal domains are explained. A complete ported system design will be shown step-by-step. This course is recommended for anyone new to loudspeaker system design or as a refresher of fundamental concepts.



I will also be participating in the Inter-Organizational Standards Forum on Sunday morning.

If you will be at CES or Winter ALMA in Las Vegas and would like to arrange a meeting, please contact us.

Training Seminars

CJS Labs also offers customized in-house training. Our design experience, proven processes, and measurement expertise will make your development more efficient. Learn how to optimize both your designs and test routines. Having a thorough understanding of the 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.

News and Recent Developments

AES 137th - Los Angeles

Over 70 persons attended my Master Class "*Almost Everything You Wanted To Know About Loudspeaker Design*". A large amount of information was presented in the 2-hour session, but participants remained engaged throughout. The class materials have been edited and supplemented and are posted to the password protected part of our website. Contact us if you would like have a copy.

Electroacoustics Training Course - Santa Clara, CA

The *Fundamentals of Electroacoustic Measurements* training course held in conjunction with Listen, Inc. in October was a huge success, with over 20 persons attending. The Q&A was very interactive and we received very positive feedback about the seminar.

Happy Holidays!

Christopher J. Struck

CEO & Chief Scientist

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Acoustic Helmholtz Resonators

Analogous to an RLC circuit or a Single-Degree-Of-Freedom (SDOF) mass-spring-damper mechanical system, an acoustical network can also behave as a Helmholtz resonator. The acoustic compliance is typically a contained volume of compressible air. The acoustic mass is usually a slug of non-compressible air trapped in a tube or aperture. To demonstrate this with a physical example, we can model an empty Perrier bottle as a Helmholtz resonator (see Fig. 1). The volume can be found by filling the bottle up with water to just below the bottom of the neck and using a measuring cup or graduated cylinder. In MKS (SI) units, the compliance is calculated as

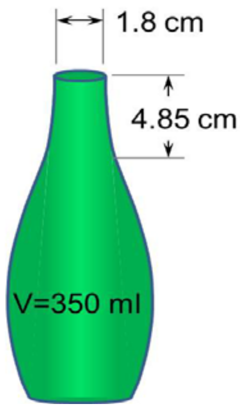

Fig. 1 Perrier Bottle

$$C_A = \frac{V}{\rho_0 c^2} = \frac{0.00035}{1.18 \cdot (344.8)^2} = 2.495 \times 10^{-9} \left[\frac{m^4 s^2}{kg} \right]$$

The surface area of the neck opening is

$$S = \pi r^2 = \pi \, (0.009)^2 = 2.545 \times 10^{-4} \; m^2$$

Given the taper to the inside, the length of the neck is somewhat more ambiguous. Nonetheless, one 'straight' *end correction* should be applied. Using a length of 4.85 cm, the effective length is found as

$$L_{effective} = L + 0.613 r$$
$$= 0.0485 + 0.613 \cdot 0.009 = 0.05402 \; m$$

The acoustic mass is then calculated as

$$M_A = \frac{L_{effective} \;\; \rho_0}{S} = \frac{0.05402 \cdot 1.18}{2.545 \times 10^{-4}} = 250.5 \left[\frac{kg}{m^4} \right]$$

From this, the resonant frequency can be calculated as

$$f_0 = \frac{1}{2\pi \sqrt{M_A C_A}} = 201.3 \, Hz$$

This simple model for adiabatic conditions follows the methodology given in Beranek (1954, rev, 1993). pg. 131, or Beranek & Mellow (2012), pg. 123.

Blowing on the bottle and recording the signal, an FFT analysis (see Fig. 2) reveals a resonant frequency of 201.31 Hz, verifying the calculation.

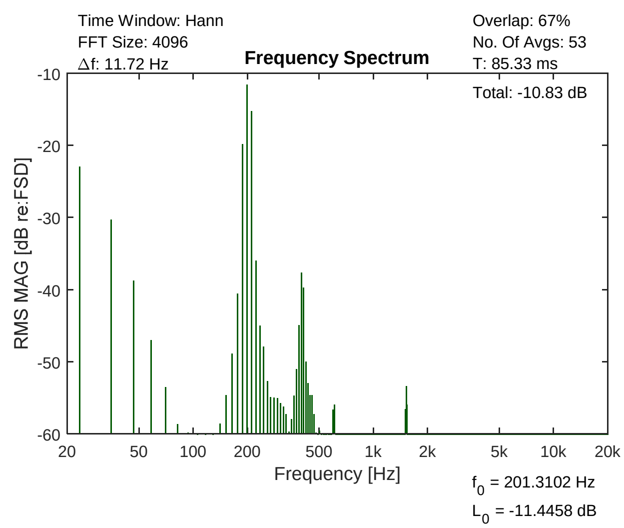

Fig. 2 FFT analysis of the open bottle resonance .

Note that the resonance lies between two FFT lines, so the 'Picket Fence' correction algorithm (*Lab Notes: Vol. 7, No. 1 - March 2014*) is used to find the exact frequency. This measurement could therefore be performed first and then used to solve for the acoustic mass and effective length of the neck.

Please contact us for more information.