

Lateral Sound Energy and Small Halls for Music

Concert Hall Research Group Summer
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Session II: Chamber Music Halls

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“It’s about the music.”

Enjoyment of music is the goal.

Good acoustics contributes to getting us there.

How do we get to good/great music halls?

The acoustic design path

What are good acoustic halls?

Why are they good? Can they be measured?

What physical acoustic properties result in good acoustics? and, result in measurements indicative of good acoustics?

How can we design structure to result in those physical acoustic properties? (Note: Not the acoustic measures themselves.)

Concert Hall Acoustics Research

The search for improvement. Not new.

“during recent years, many attempts have been made to look for new acoustical criteria of a room; there are so many that it is impossible to refer to all of them.”

Not a quote from the recent past, but from Erwin Meyer, (*“Definition and Diffusion in Rooms,” Journal of the Acoustical Society of America, Vol. 26, No. 5, September, 1954*).

Concert Hall Acoustics Before 1965

Measures/Elements considered important:

Reverberation Time

Diffusion, Diffusivity

Initial Time Delay Gap (ITDG)

Concert Hall Acoustics Research after 1965

Measures/Elements considered important:

Reverberation Time (T30)

Early Decay Time (EDT)

Initial Time Delay Gap, (ITDG)

Clarity, C50, C80

Lateral sound Energy

Lateral Sound Energy

Earliest ASA reference: **Robert .S. Shankland** (Case Institute of Technology)

Referred to work by **Fritz Winckel** (Case Institute of Technology), and by **Erwin Meyer** (Gottingen University),

“that suggest that there may be a considerable difference in the psychological effect on a listener when early reflected sounds come predominantly from above as compared to the effects of early reflections that approach the listener more nearly in a horizontal plane.”

(Letter to the editor of the Journal of the Acoustical Society of America, 1963)

Harold Marshall, (Institute of Sound and Vibration Research, The University, Highfield, Southampton, England), 1967,

While conducting personal subjective preference studies, concluded that lateral reflections were preferred, and that their effect was to enhance a spatial effect of the room that he initially called spatial response (SR), and later (with Barron) termed “Spatial Impression” (SI) [2] 1967.

Manfred Schroeder , (Göttingen University, studies beginning in 1969) with **Dieter Gottlob**, **Karl-Friederich Siebrasse**, then **Yoichi Ando**

Conducted listener preference studies also showing that increased lateral sound reflections were preferred by music listeners.

Refs [5, 6, 7, 8, 9]

Ando's portion of the studies

Determined:

1. Inter-Aural-Cross-Correlation Coefficient (IACC): to be a more important measurement of concert hall "preference" and quality than the other "most important" acoustical qualities of 1) reverberation time, 2) initial time delay gap, 3) clarity (C80), and 4) strength (loudness, G).
2. Most optimum angle for reception of lateral sound energy reception was approximately 55 degrees.
3. Time delay of the *strongest* reflection was more important than the delay of the *first* reflection. [6, 7]

Soon (after 1980), the desirability of lateral sound reflections was generally accepted.

Subsequently, research seemed to concentrate on the *detail* of the lateral sound, breaking it into component parts:

“Early Lateral Sound” arriving 0-80 msec after the Direct Sound. The term Apparent Source Width (ASW) began to be applied to this portion.

“Late Lateral Sound” arriving after 80 msec after the Direct Sound. The term Envelopment (ENV) began to be applied to this portion.

Subjective Qualities of Spatial Impression

Harold Marshall, (1967) [2]

“Spatial Responsiveness”

Observed that,

“while many halls without the effect might be described as "good" halls, halls described as," the best halls ," always had it.”

"To aid in the identification of the quality sought, it is observed that:

“a), as a property of the sound, it is related to loudness attributes;

“b), as a property of the hall, it carries the “idea of spatial responsiveness” to the music;

“c), for the listener, it generates a “sense of envelopment” in the sound and of “direct involvement” with it in much the same way that an observer is aware of his involvement with a room he is in.”

"A note on the importance of room cross section in concert halls", Journal of Sound and Vibration, Vol. 5, No. 1, (1967) [2]

Paul Vaneklassen and Jerald Hyde (1969) [3]

“Spatial Impression” (SI)

“in an "auditorium synthesis listening system", the acoustical image was "found to “focus on the source” during quiet passages,

while it “broadened as the passages became louder”, creating a feeling of "envelopment" by the sound, and a broadening of the images source."

“Auditorium Synthesis - early results of listener preference,” JASA, 1969 [3]

Harold Marshall and Michael Barron (1981) [10]

The term "Spatial Impression" was now used.

“The effect of lateral reflections referred to here as spatial impression is unmistakable in a simulation. As the lateral reflection level is increased, the “source appears to broaden” and the music gains body and fullness.

“One has the impression of “being in a three dimensional space” (though without any real sensation of the size of the space).

“For high level lateral reflections, one experiences the sensation of “being somewhat enveloped” by the sound.

“The description by the manager of the Concertgebouw Orchestra of Amsterdam reported by Marshall deserves repetition: “the sensation of spatial impression corresponds to the difference between "feeling inside the music" and "looking at it, as through a window.”””

*"Spatial impression due to early lateral reflections in concert halls: the derivation of a physical measure,"
Journal of Sound and Vibration, Vol. 77, No. 2, 1981. [10]*

Personal Experience

1. “Source broadening” I have experienced more as a broadening of the sound from the “area” of the source. The individual sound sources do not broaden themselves. However, the “sound stage” seems to broaden to the extent that one feels closer, more involved, with the stage, making it seem audibly wider than the distance would otherwise indicate.
2. In addition, the depth of the sound stage can often be sensed as well as the width, especially during quieter music periods. The relative positions of the instruments on the stage can be sensed more readily. The sound of individual instruments seems to be more easily isolated and heard individually, both during quieter and louder periods, as if there is more definition to the instruments. The spatial effect seems to some degree almost two dimensional (width and depth). The sensing of this effect may relate to the detail and spatial location (both width and depth) of musicians as described by subjective reviewers when a stereo recording is reproduced on the very finest, audiophile-level, sound reproducing equipment.

Smaller Music Halls

Music Hall Construction and Cost

All communities deserve high performing halls.

Budgets may be restricting.

Does this mean that acoustical goals should be reduced? *No.*

Does this mean that certain acoustic goals can not be achieved? *Maybe, maybe not.*

Lateral Sound in Small Halls

Takayuki Hidaka and Leo Beranek measured newer acoustic parameters of concert and opera halls 1990-2000.

Hidaka with **Noriko Nishihara** extended the measurements to chamber music halls (2002-2004). 16 halls were measured.

These studies were undertaken to evaluate the more recently developed acoustic measures, including the IACC, for these venue types, hopefully to determine their significance, and potentially the importance of design methods that enhance those beneficial acoustic characteristics.

The following parameters were determined for the halls:

Length/Width Ratio range: 1.4 – 3.2

Seat capacity range: 300 – 844

Median RT should be 1.5 to 1.7 sec.

Gm and Gl for European halls was 10-14 dB
Gl was 10 to 15 dB.

Bass Ratio of 1.07 to 1.24.

ITD : 9 ms - 26 msec. (suggested 20 msec or less)

IACC_E 0.28 – 0.35, (suggested 0.30-0.40 max)

Kaul Auditorium

Reed College

Portland, Oregon

Completed: 1998 Total Building Cost: \$4.7 mill

Length: 92' Width: 64' Height: 45' (at peak)

Volume: 207,000 ft³ Seats: 760 Volume/Seat: 272 ft³

L/W: 1.4 2H/W: 1.4 (1.2)

Primary Venue for : *Chamber Music Northwest*

Portland Baroque Orchestra













Acoustics Measurements for Example Halls

Acoustic parameters were measured “approximately,” using a high quality, 11”x6”x6”, two-way loudspeaker, generally omnidirectional, source. A 14 second, 40-20,000 Hz sweep tone was reproduced and recorded using a Type 1 sound level meter with a 1/2” diameter microphone. Recorded .WAV files were deconvolved to determine the impulse responses (IR).

For approximate IACC determination, IR’s were determined holding the microphone of the sound level meter next to each ear on successive sweeps. Resulting IR files were matched within 0.05 msec (approximately 1/2”).

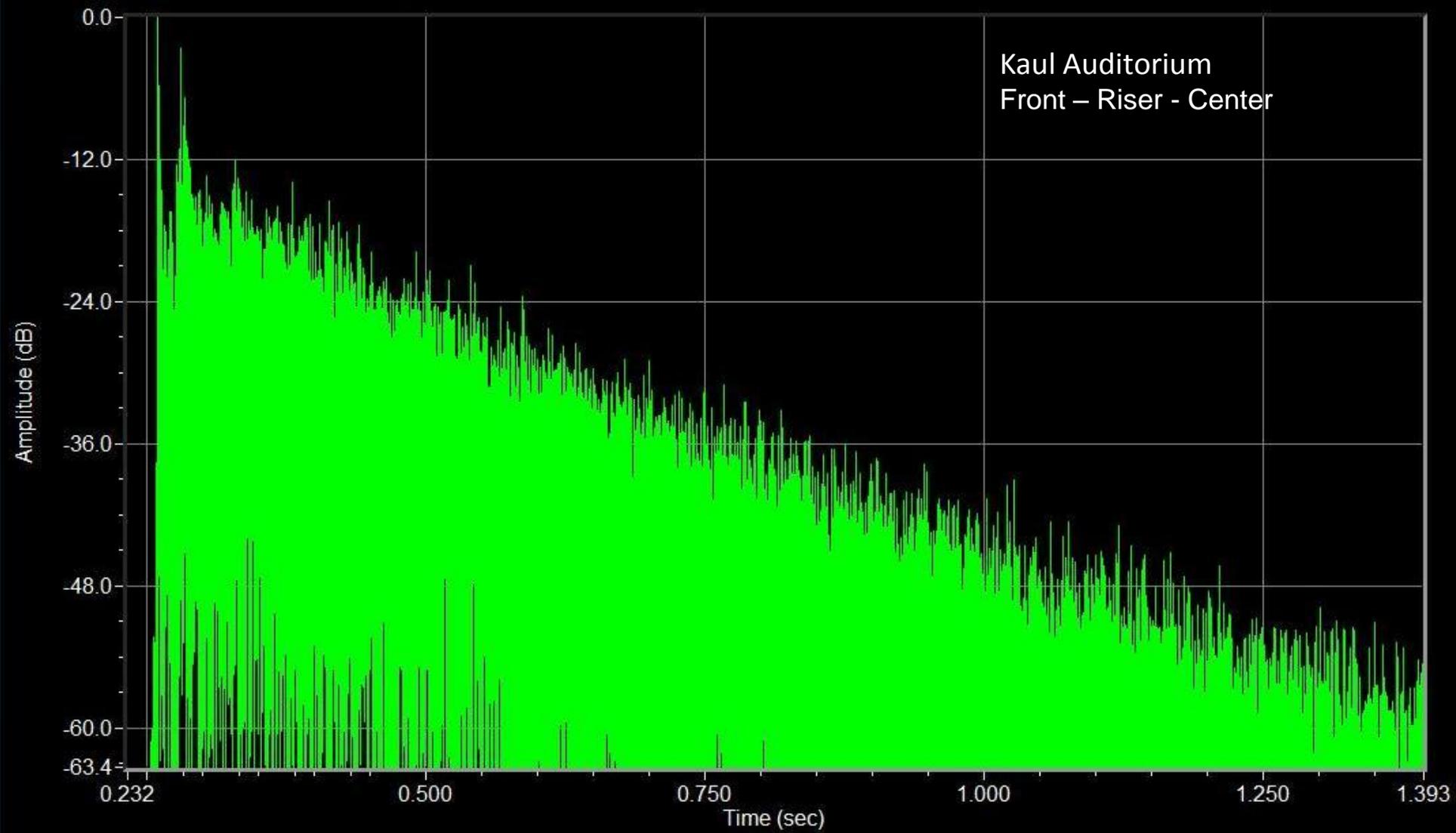
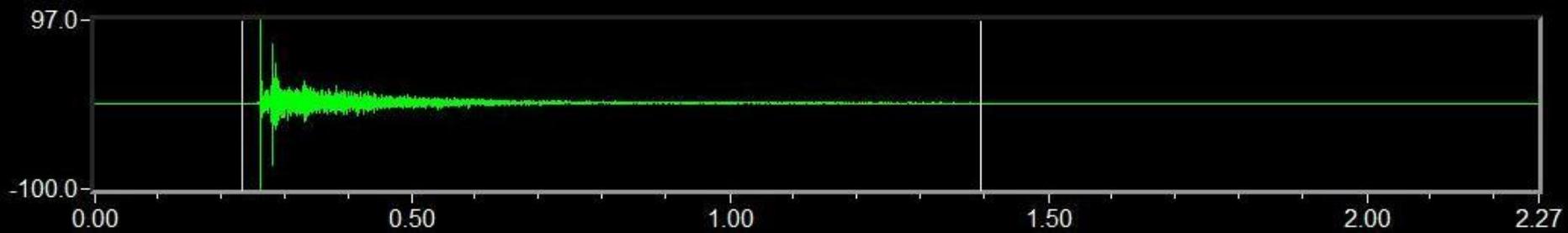
Note: measurements were not extensive. Multiple iterations were not made and averaged. Measurements were made to obtain a general comparison.

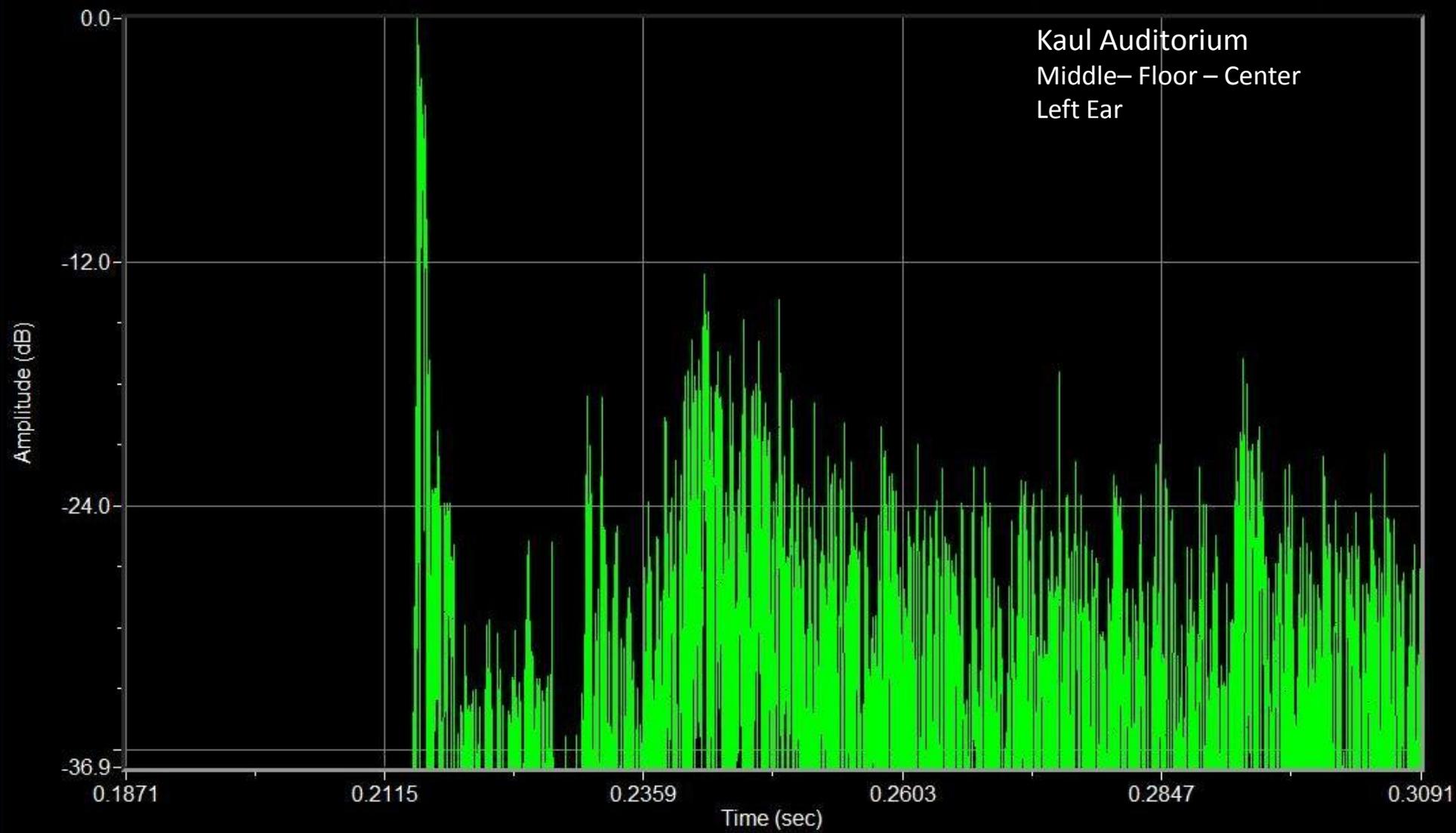
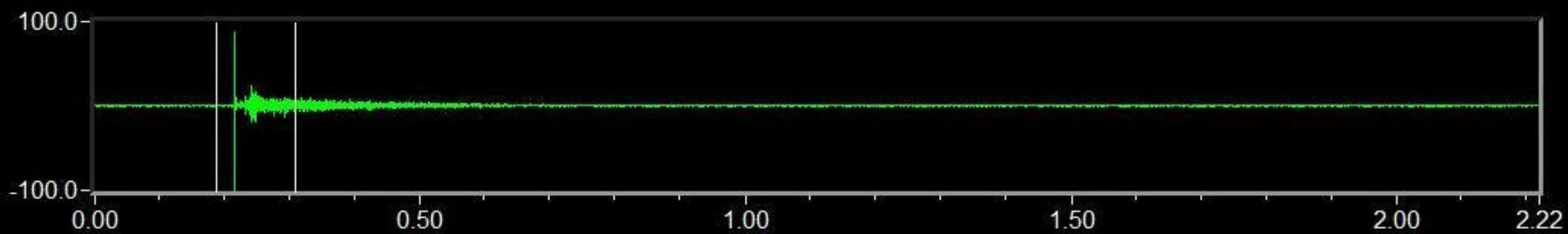
Kaul Auditorium, Reed College

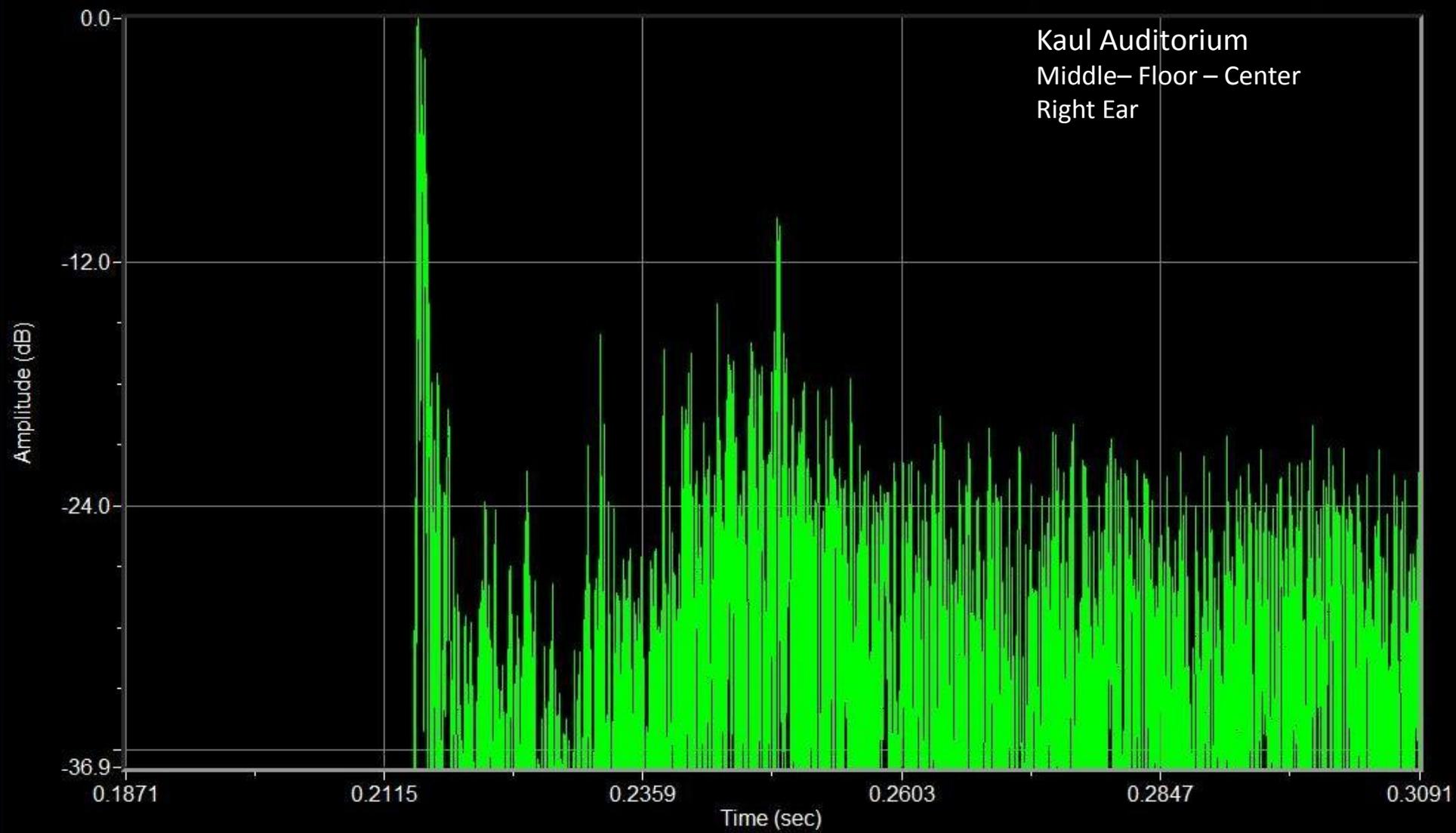
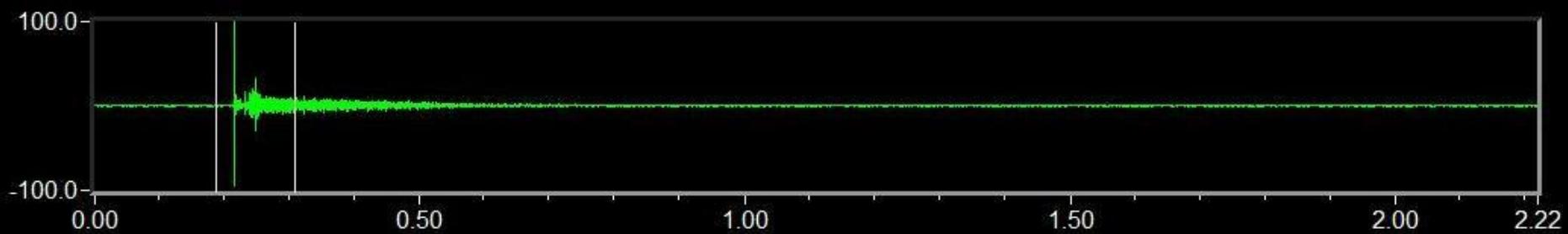
Acoustic Measures (Unoccupied)

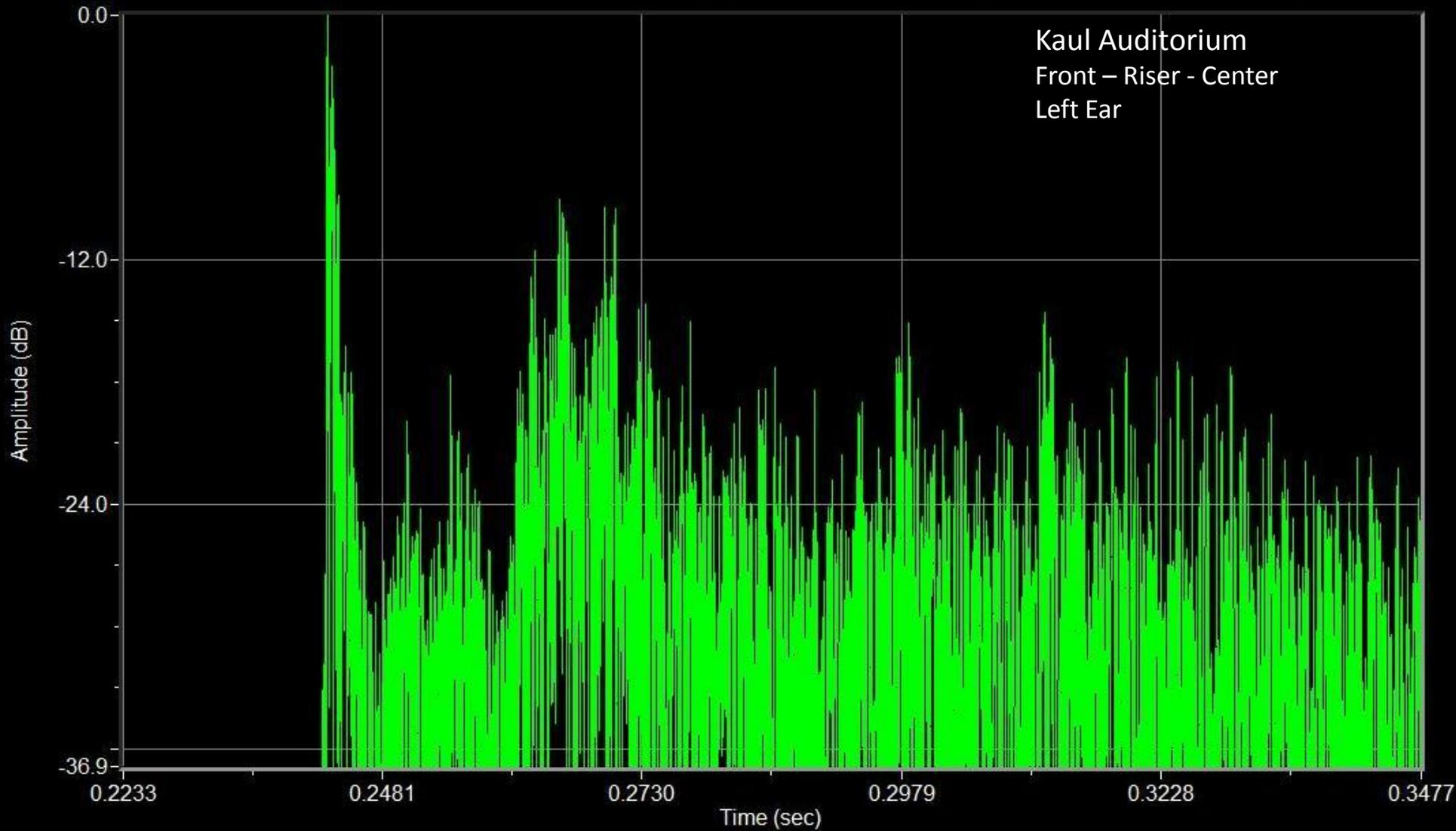
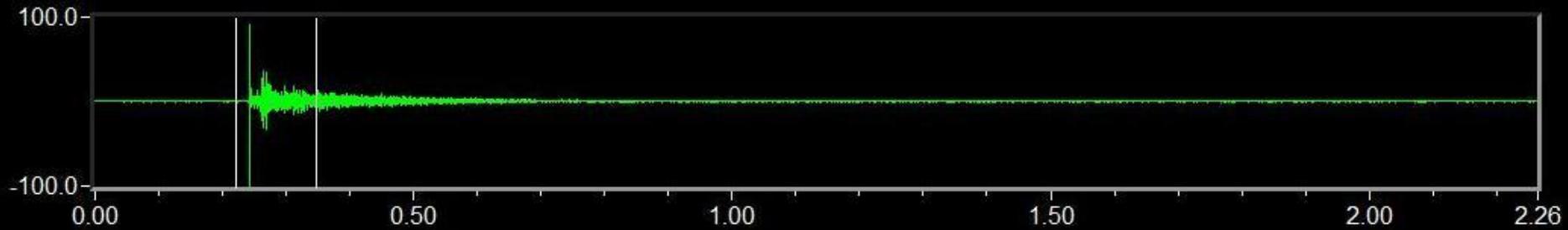
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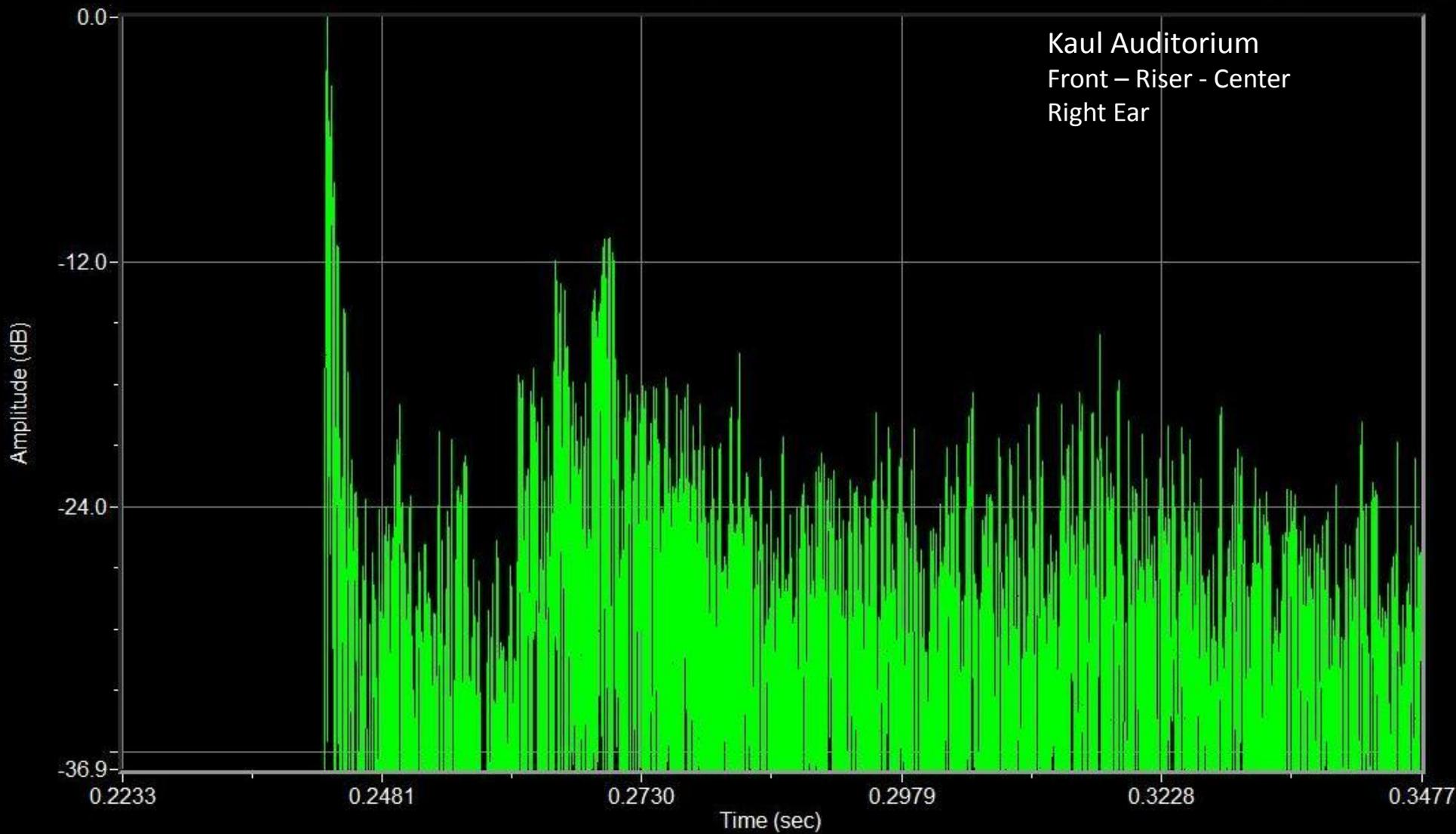
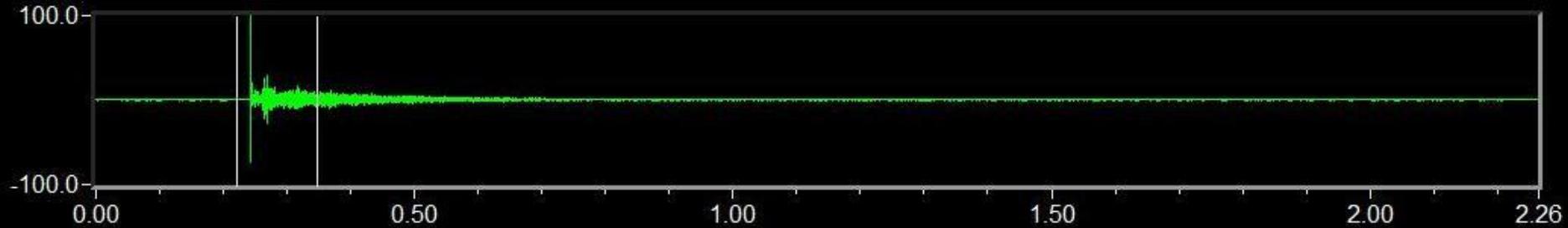
Measure	125	250	500	1000	2000	4000	8000
T30 sec	2.22	1.96	1.88	1.74	1.59	1.37	1.05
T30 sec (Est. Occupied)	2.05	1.96	1.65	1.54	1.29	1.19	0.94
EDT sec			1.86	1.59	1.48	1.29	0.97
C80 dB		-5.80	0.36	1.20	2.15	2.03	4.85
C50 dB		-9.00	-1.31	-2.19	-0.97	-0.24	2.07
ITDG		20 msec					











IACC_E Kaul Auditorium, Reed College

Seat		250	500	1000	2000	4000
E16	Front-Floor-Center	0.70	0.47	0.55	0.65	0.48
E5	Front-Floor-Side	0.81	0.60	0.47	0.45	0.29
K16	Middle-Floor-Center	0.68	0.43	0.42	0.64	0.38
K5	Middle-Floor-Side	0.71	0.38	0.31	0.58	0.28
DD16	Front-Riser-Center	0.80	0.41	0.12	0.38	0.21
DD5	Front-Riser-Side	0.88	0.29	0.13	0.38	0.21
KK16	Back-Riser-Center	0.77	0.53	0.23	0.43	0.22
KK5	Back-Riser-Side	0.83	0.49	0.13	0.46	0.34

IACC Trends of the Measurements

IACC typically decreases as frequency increases.

IACC typically decreases as measurement moves farther off center.

IACC typically is higher at front seat locations.

Note the atypical increase in IACC at 2000 Hz; potentially due to effects of loudspeaker crossover at approximately 2.5 KHz.

IACC_E Kaul Auditorium, Reed College

Seat		250	500	1000	2000	4000
E16	Front-Floor-Center	0.70	0.47	0.55	0.65	0.48
E5	Front-Floor-Side	0.81	0.60	0.47	0.45	0.29
K16	Middle-Floor-Center	0.68	0.43	0.42	0.64	0.38
K5	Middle-Floor-Side	0.71	0.38	0.31	0.58	0.28
DD16	Front-Riser-Center	0.80	0.41	0.12	0.38	0.21
DD5	Front-Riser-Side	0.88	0.29	0.13	0.38	0.21
KK16	Back-Riser-Center	0.77	0.53	0.23	0.43	0.22
KK5	Back-Riser-Side	0.83	0.49	0.13	0.46	0.34
IACC_{E3} Average			All - 0.41		2000 Adjust - 0.35	
IACC_{E3} Average W/O Front seats			All – 0.37		2000 Adjust - 0.30	

Application to smaller, even more budget restricted, Rooms - High School Auditoria

Yoichi Ando (1977) [6, 7] suggested that the time delay of the strongest reflection is more important than the first reflection.

Helmut Haas (1949) determined that the arrival of a second reflection could dominate the directionality of an earlier arriving reflection, if the second reflection was sufficiently loud, relative to the time delay between them.

Harold Marshall (1967) [2], suggested that, “Diffuseness in the ceiling degrades the strength of the main ceiling reflection and thus lowers the masking level, perhaps sufficiently to allow the wall reflections to count. Second, it may provide lateral directionality to the overhead reflections which will decrease the stage area masking and generally improve the masking situation.”

This research suggests the benefit of sound diffusing/scattering ceilings while maintaining strength of side wall sound reflections. How can this be cost effectively accomplished?

Clackamas High School Auditorium

Clackamas, Oregon

Completed: 2001

Length: 75' Width: 70' Height: 28'

Volume: 139,000 ft³ Seats: 595 Volume/Seat: 232 ft³
(below ceiling clouds)

L/W: 1.1 2H/W: 0.8





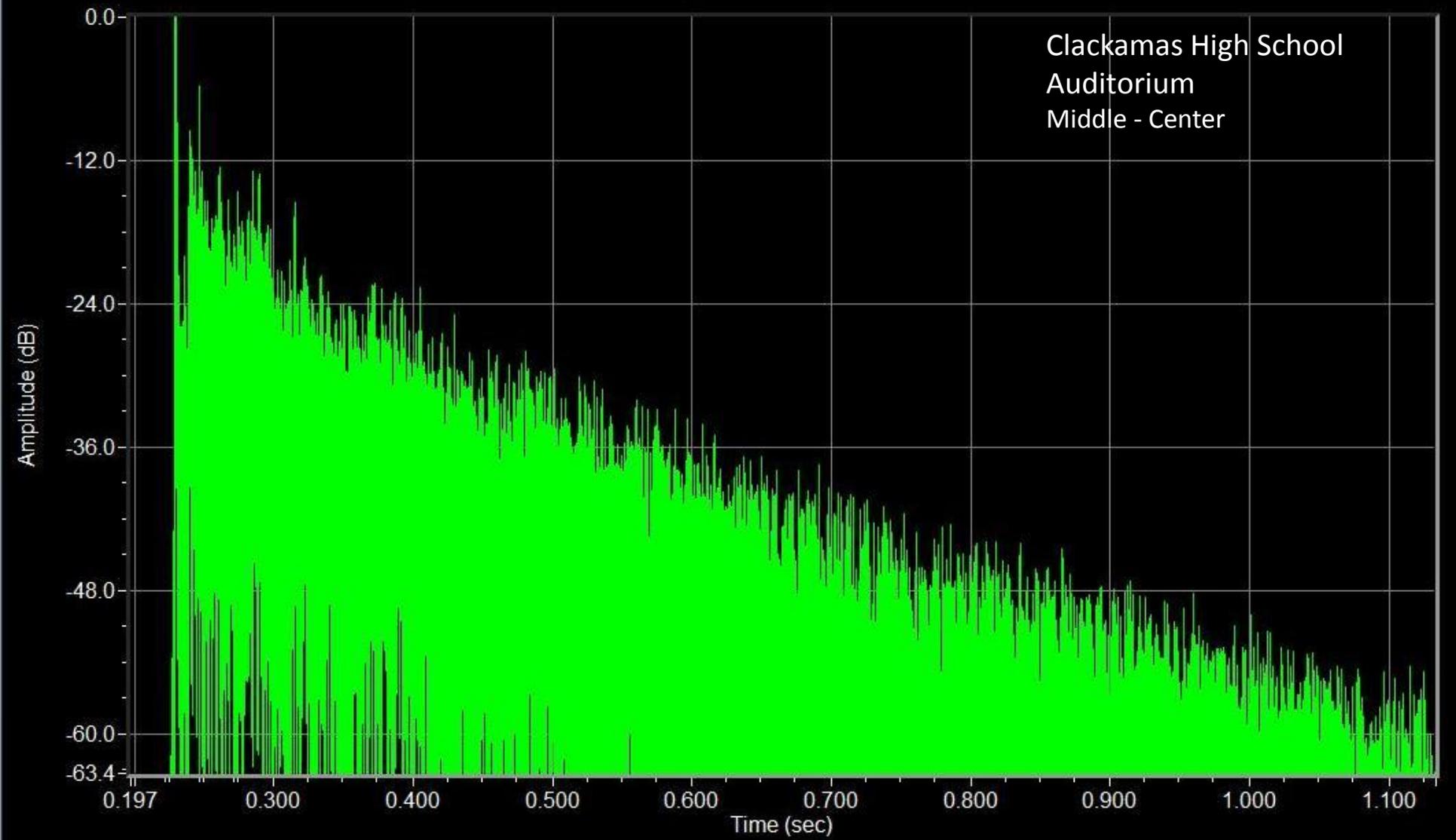
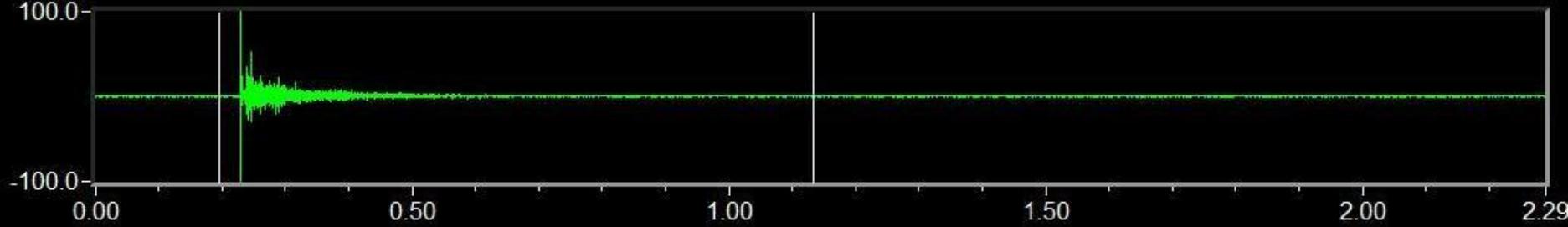


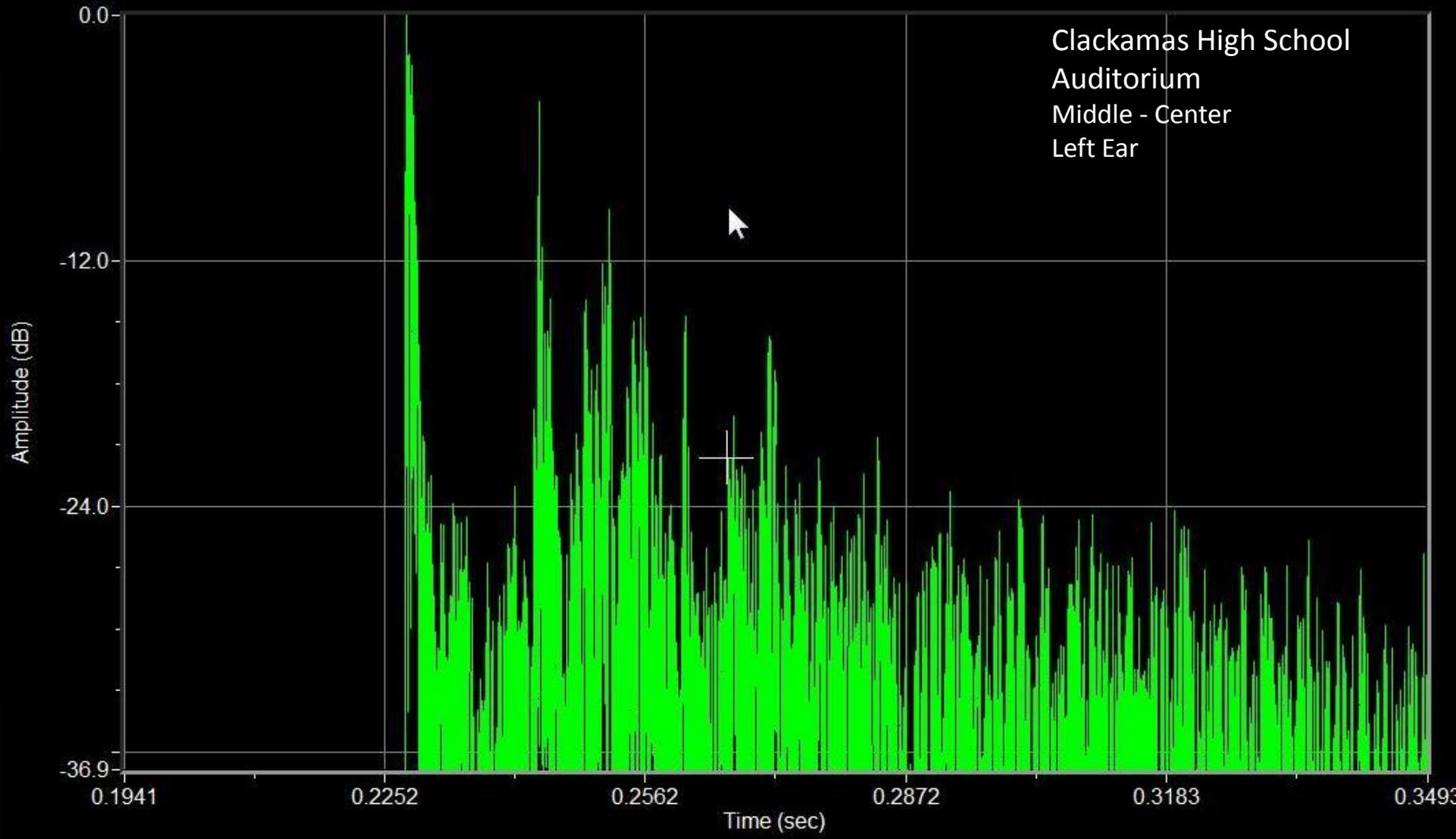
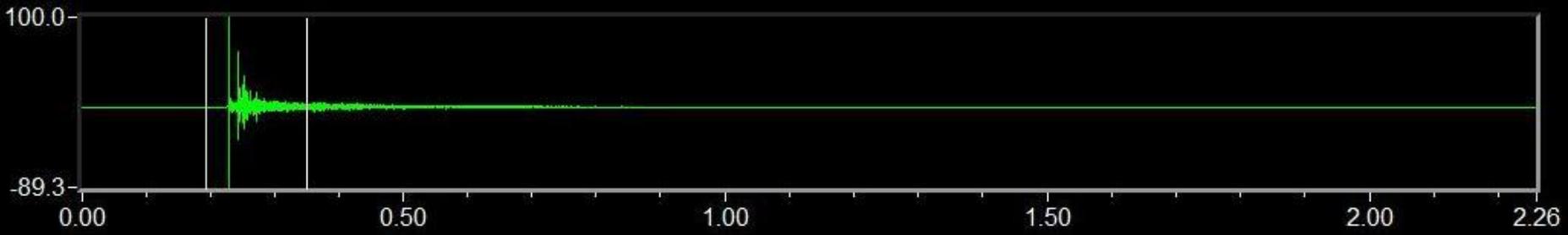
Clackamas High School Auditorium

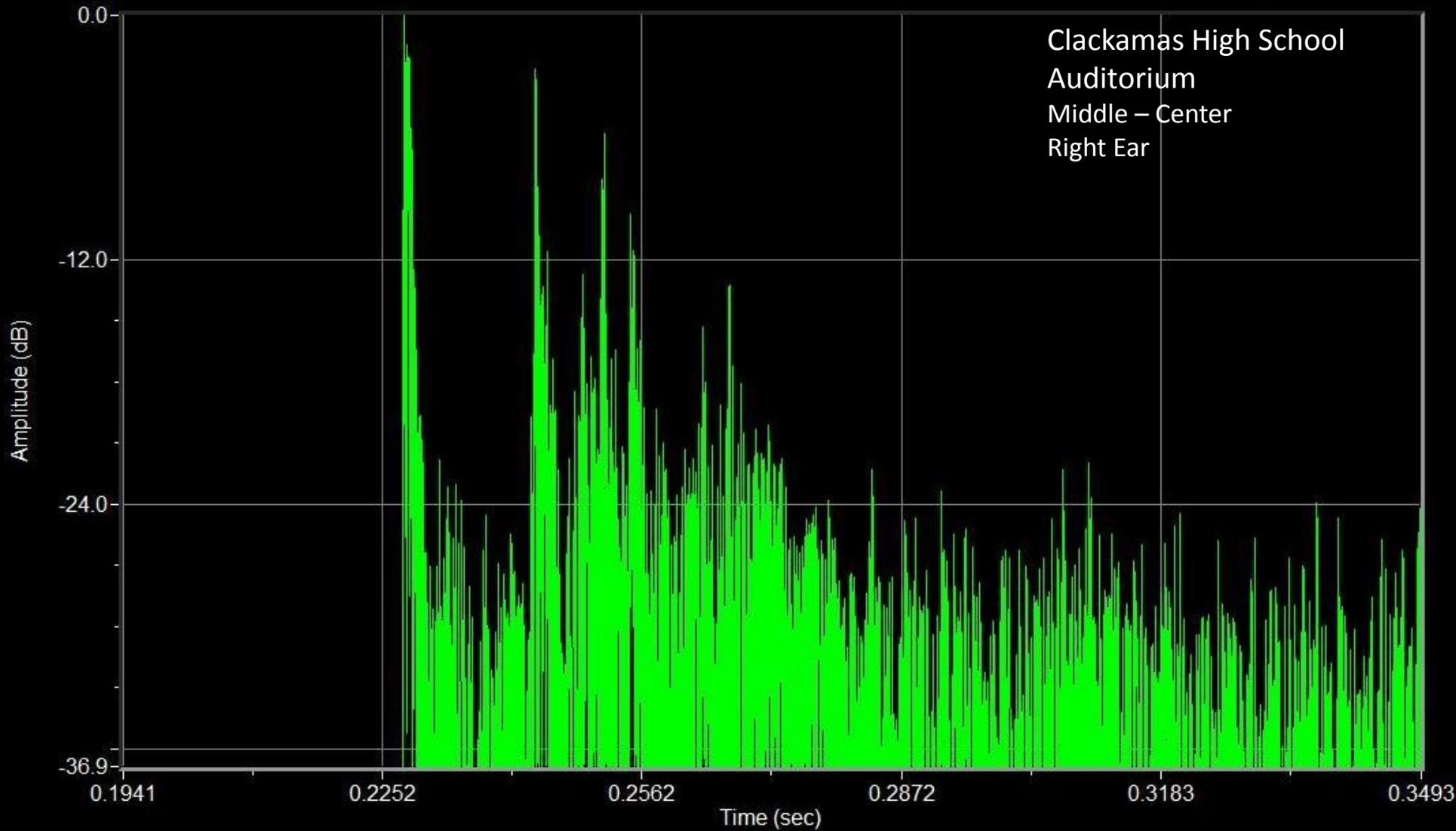
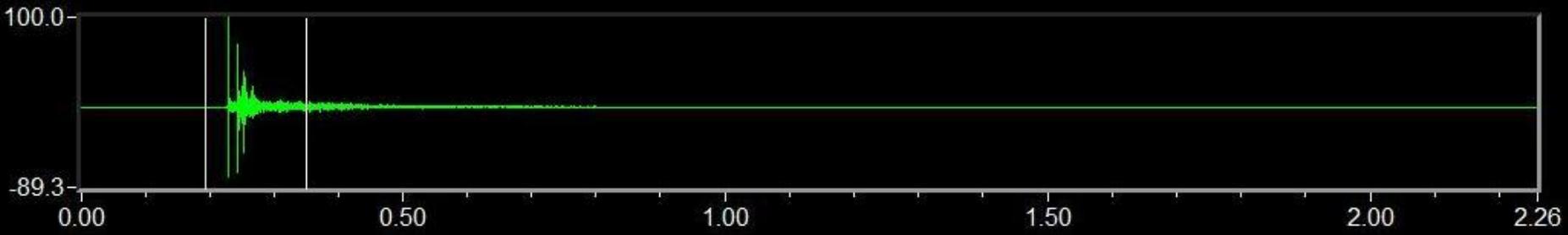
Acoustic Measures (Unoccupied)

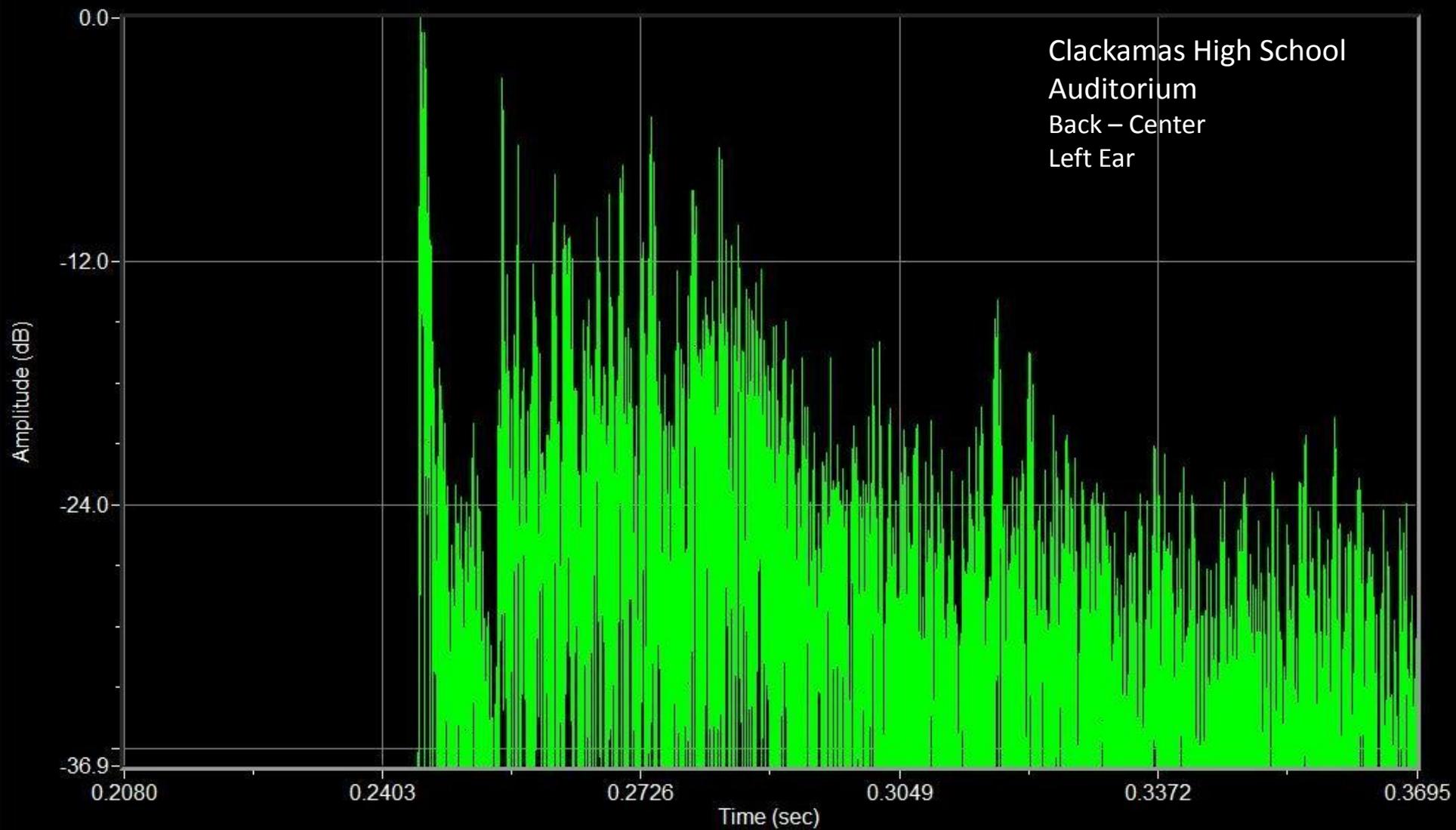
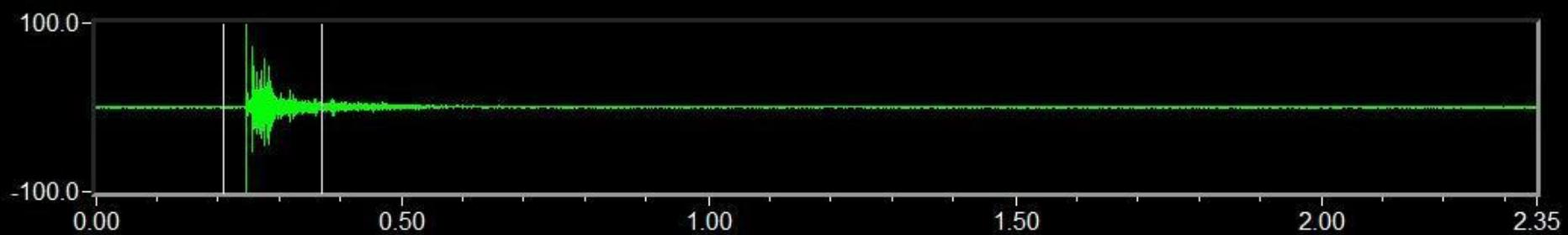
In Octave Frequency Bands (Hz)

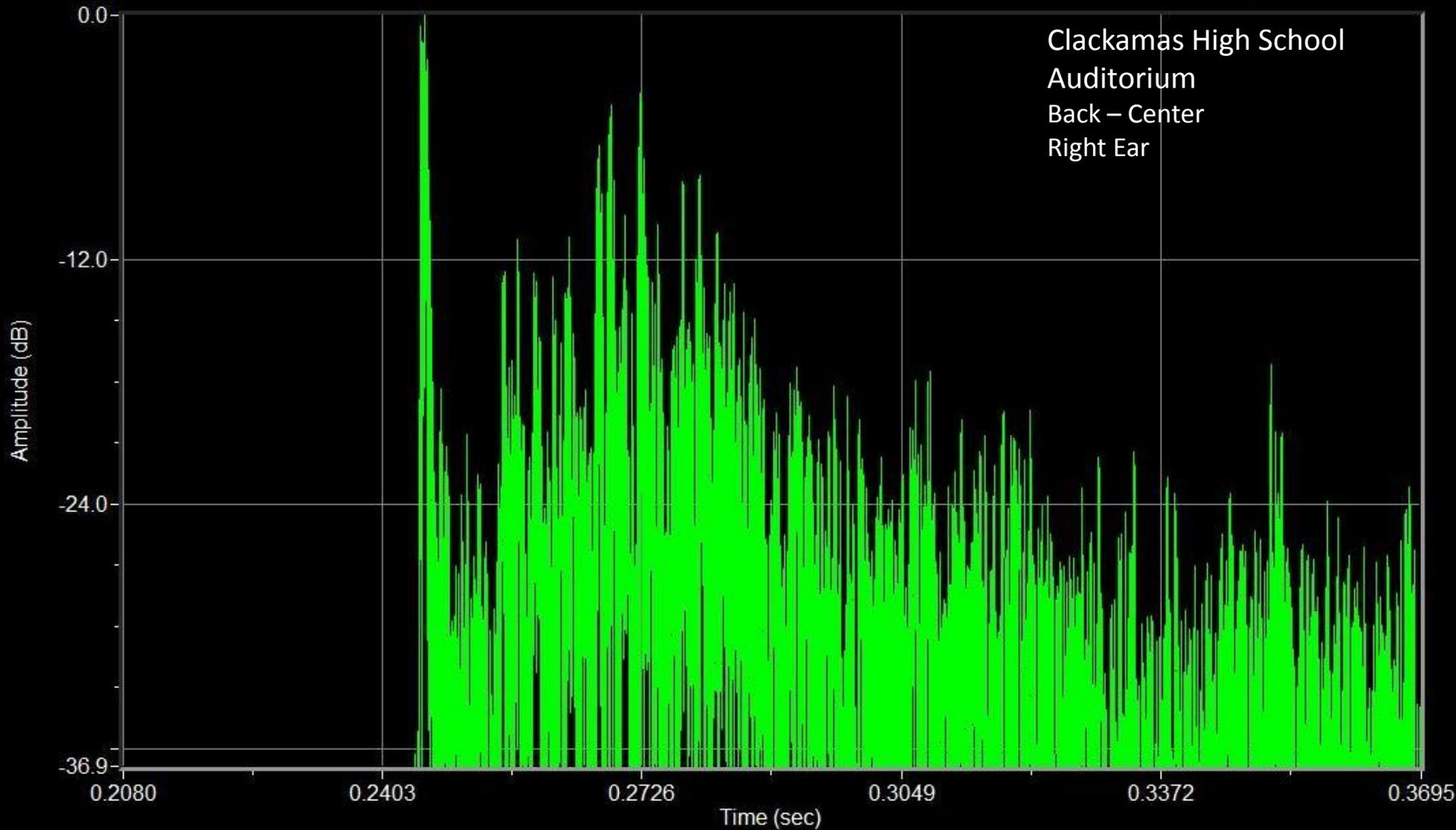
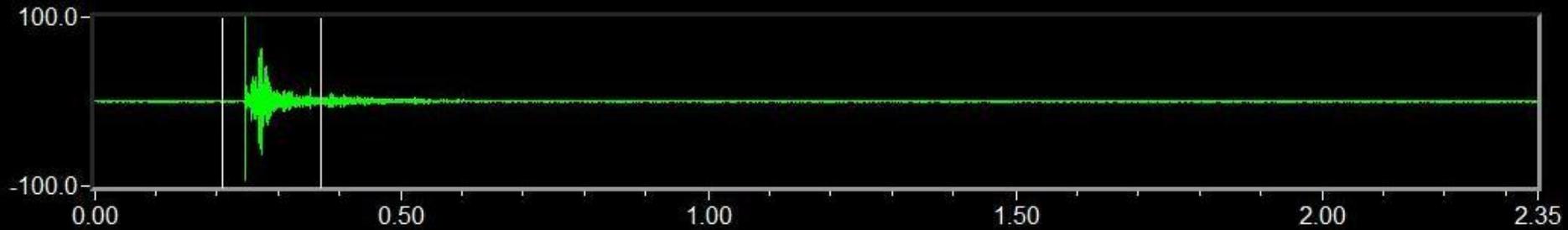
Measure	125	250	500	1000	2000	4000	8000
T30 sec	1.70	1.27	1.45	1.45	1.37	1.17	0.86
T30 sec (est. occupied)	1.58	1.27	1.29	1.29	1.10	1.01	0.77
EDT sec	1.20	1.30	1.10	0.95	0.54	0.55	0.32
C80 dB		2.88	5.70	6.80	9.86	9.24	13.16
C50 dB		0.04	3.06	4.57	8.48	7.18	10.97
ITDG		16 msec					











IACC_E Clackamas High School

Seat		250	500	1000	2000	4000
E106	Middle Front					
F06	Front-Side	0.74	0.42	0.47	0.48	0.39
L106	Middle-Center	0.85	0.56	0.48	0.75	0.24
M06	Middle-Side	0.75	0.46	0.37	0.62	0.26
Q106	Back-Center	0.69	0.37	0.27	0.39	0.36
Q06	Back-Side	0.72	0.18	0.43	0.58	0.36
	IACC_{E3} Average		All - 0.46		2000 Adjust - .39	

Battleground High School Auditorium (Cafetorium)

Battleground, Washington

Completed: 2009

Length: 97' Width: 72+' Height: 38'

Volume: 261,000 ft³ Seats: 650 Volume/Seat: 401 ft³
(including above ceiling clouds)

L/W: 1.3 2H/W: 1.1

Renovation of cafeteria with high barrel vault ceiling (sound absorbed) for a presentation auditorium with platform stage.





CAFE

MARKET

MARKET

PIZZA

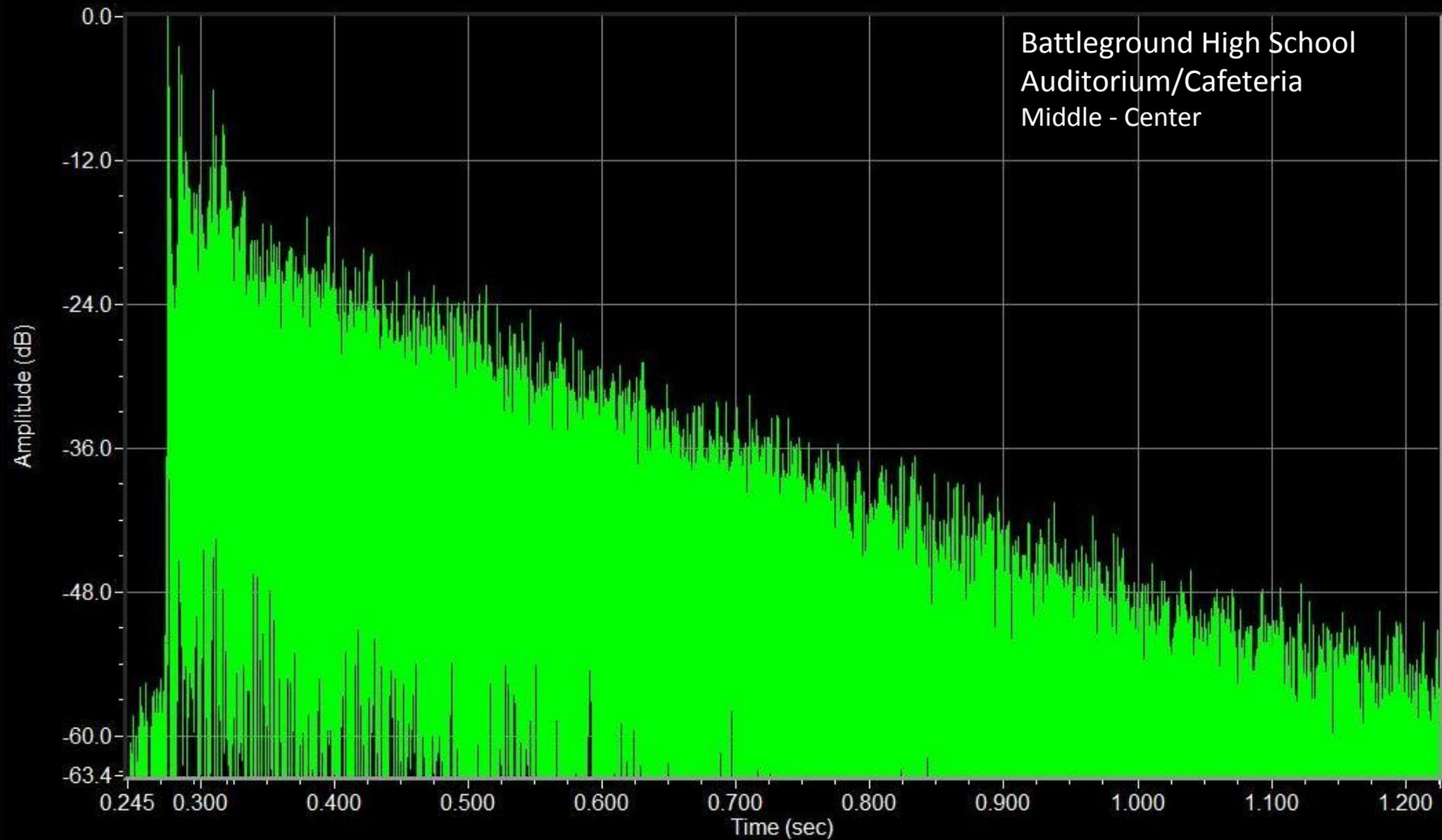
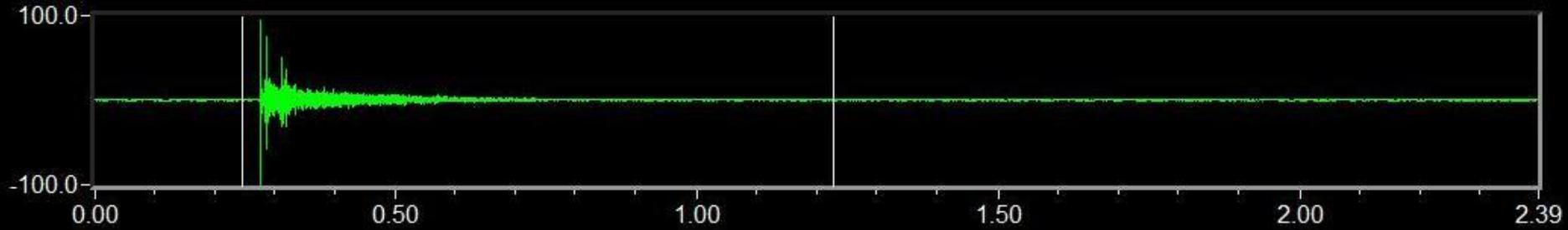


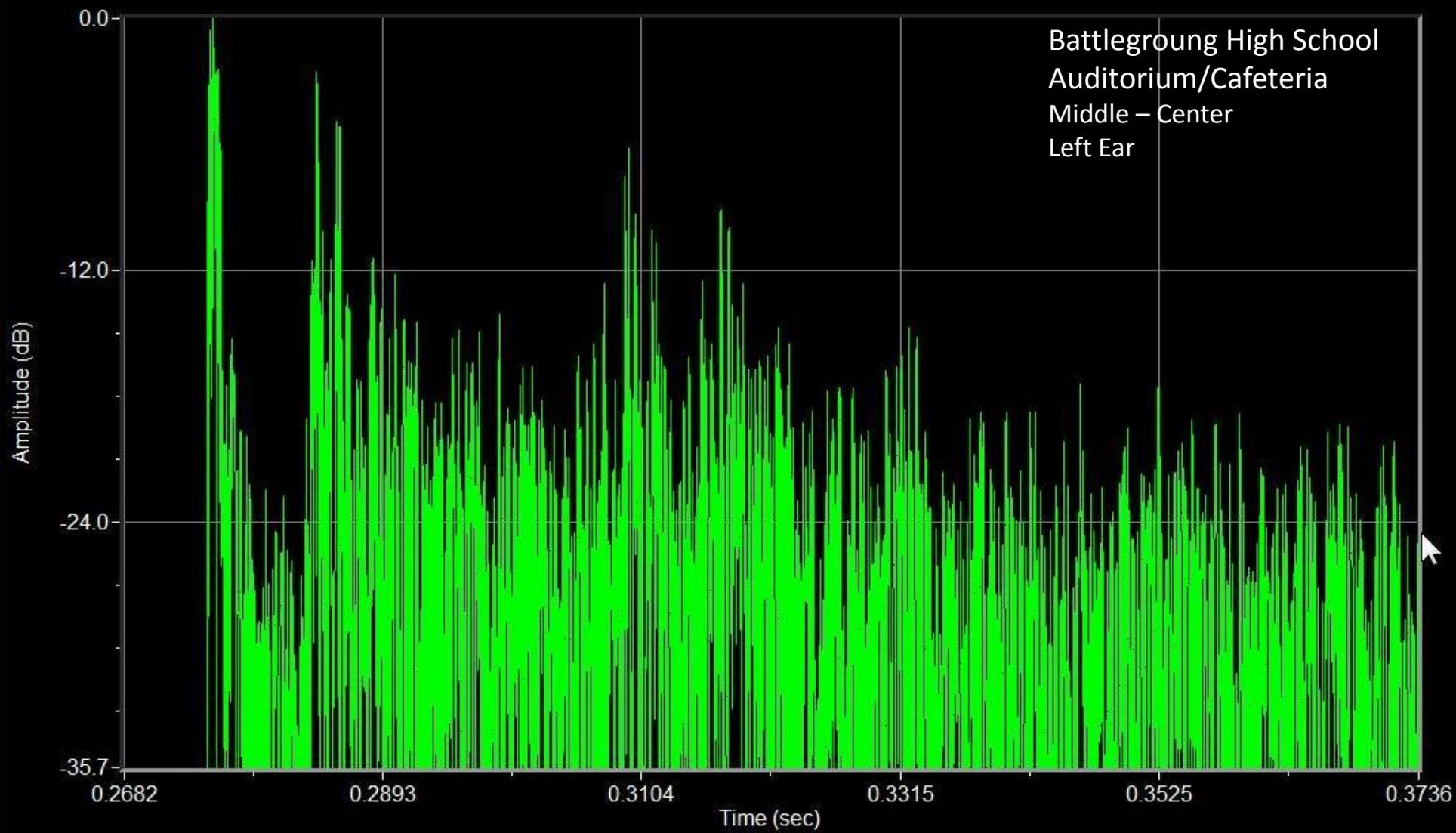
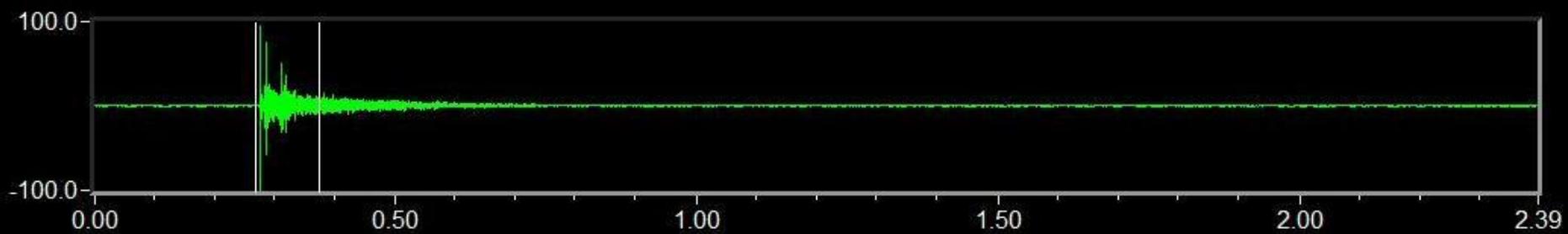
Battleground High School Auditorium

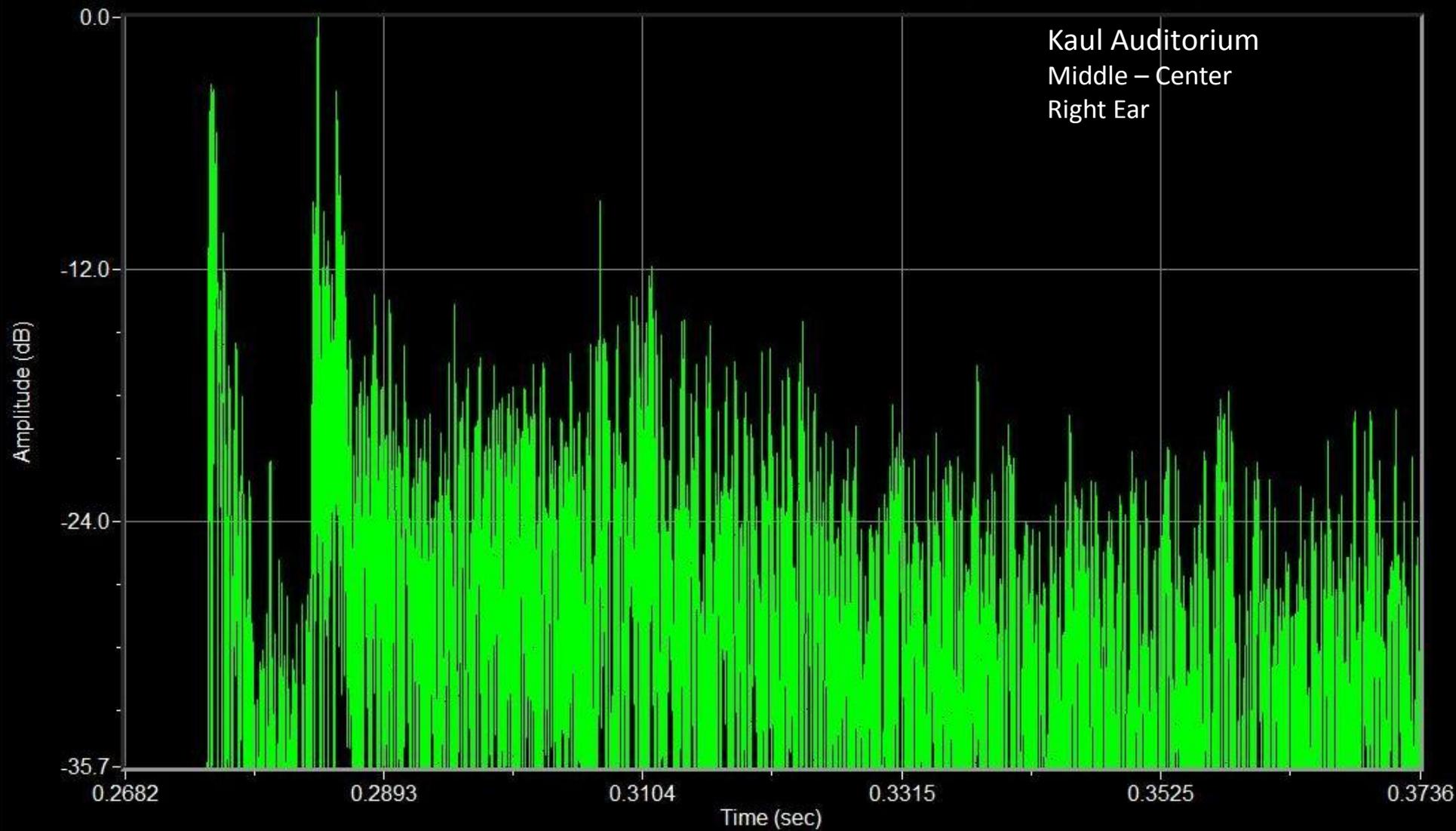
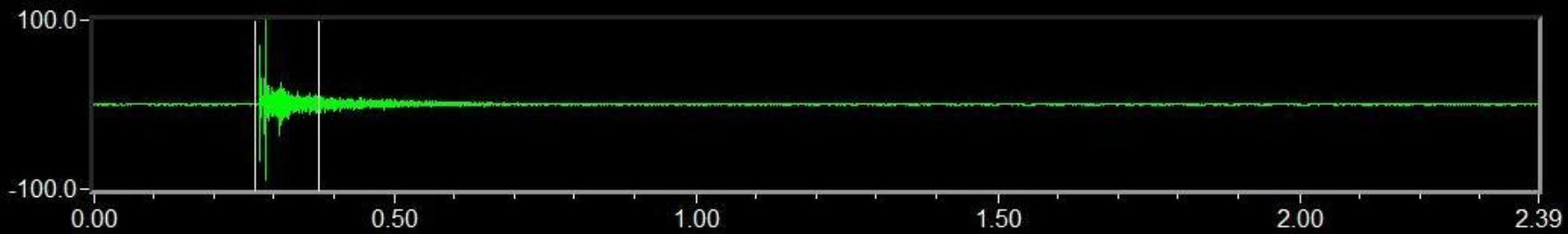
Acoustic Measures (Unoccupied)

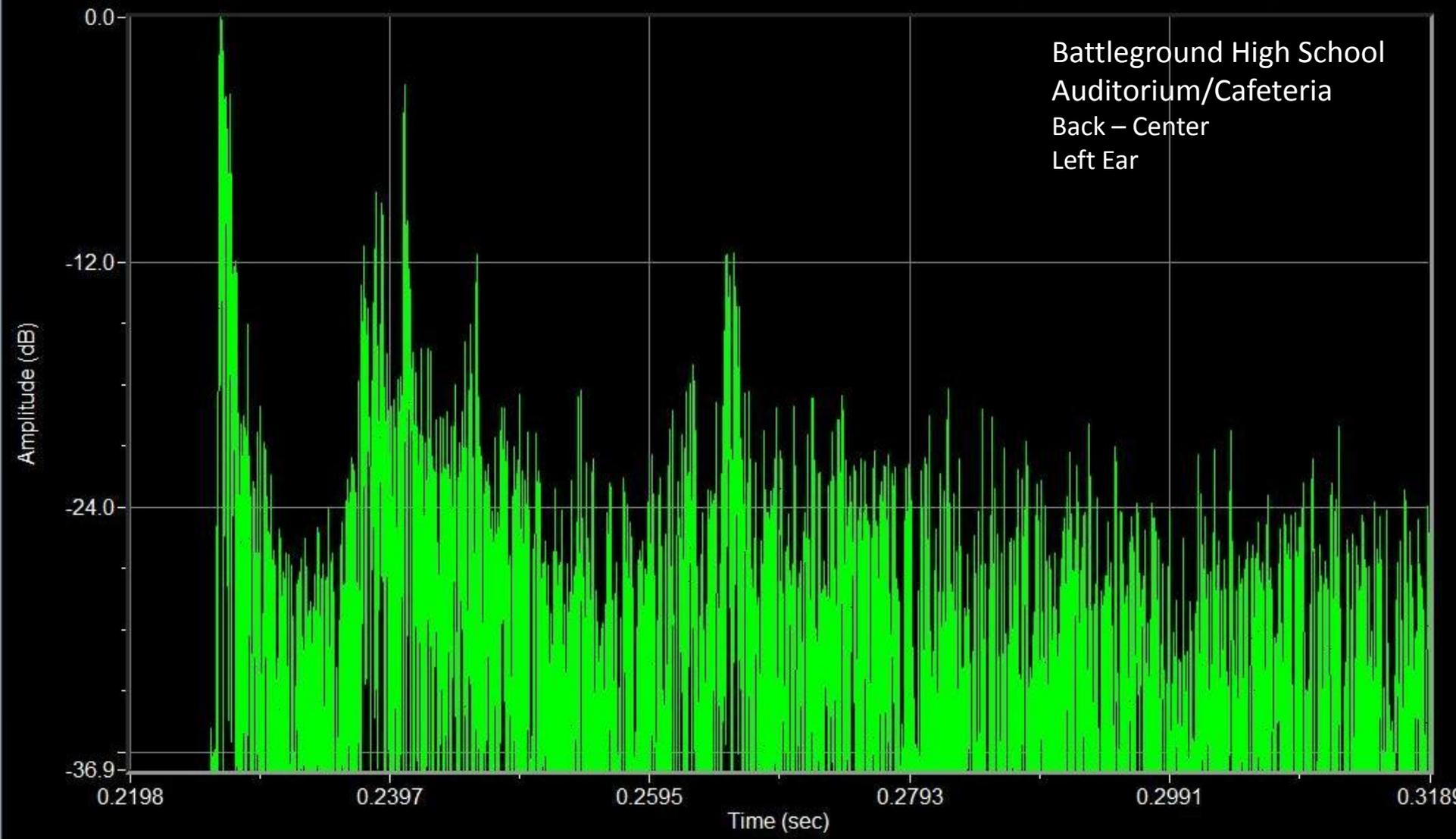
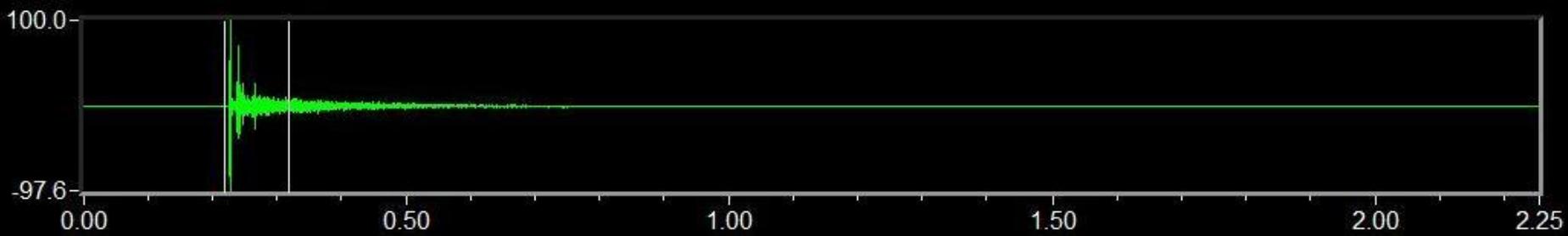
In Octave Frequency Bands (Hz)

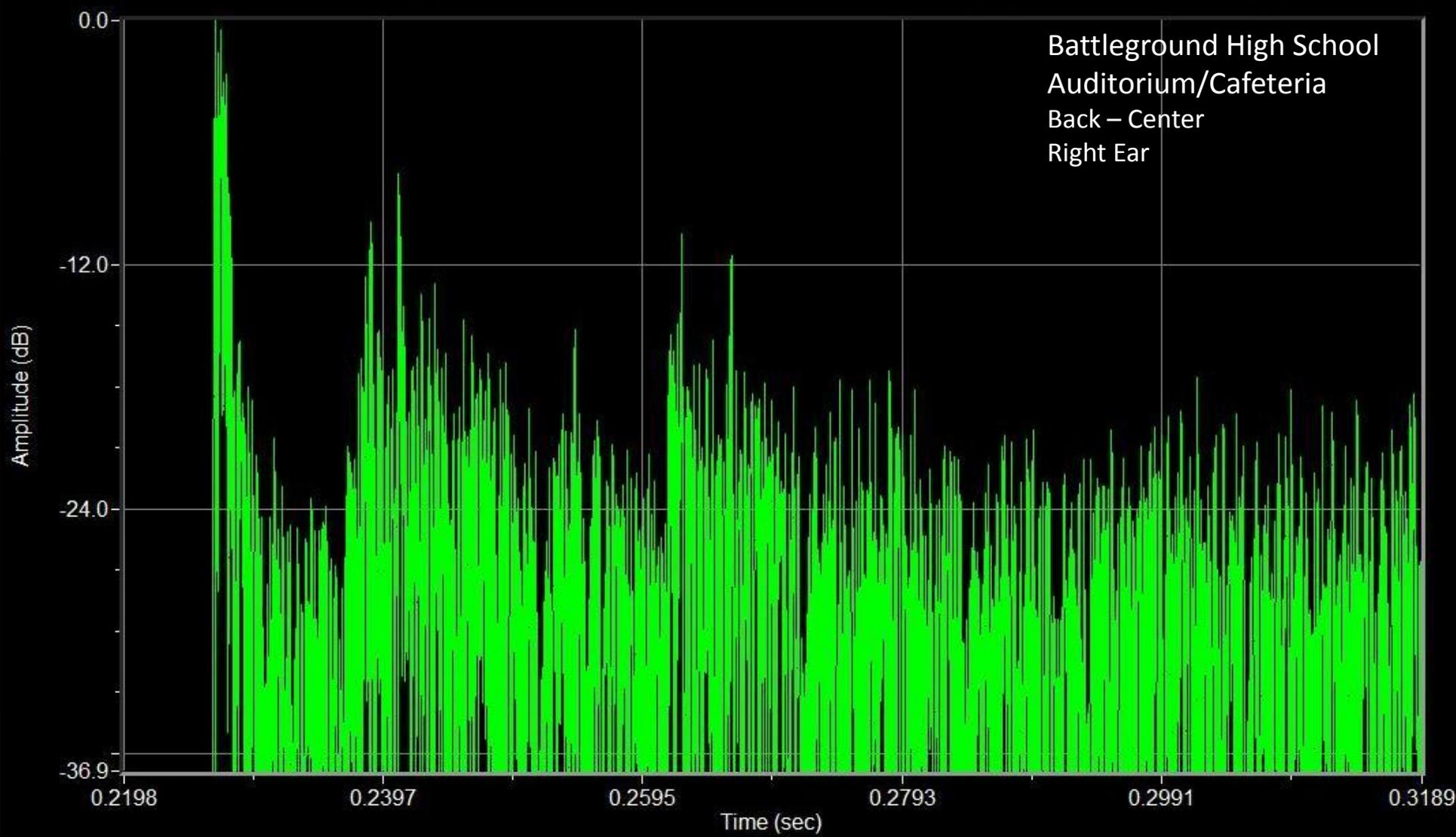
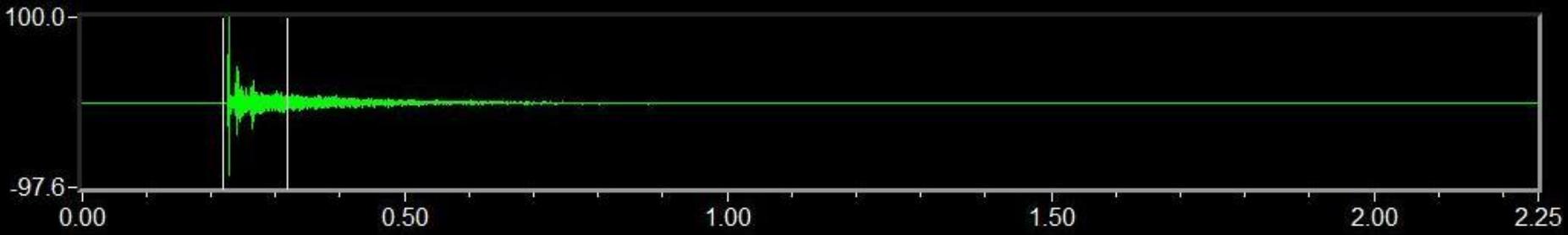
Measure	125	250	500	1000	2000	4000	8000
T30 sec	1.51	1.58	1.47	1.58	1.49	1.34	1.00
T30 sec (Occupied)	1.46	1.58	1.38	1.47	1.31	1.30	0.93
EDT sec	1.75	1.30	1.47	1.36	1.23	1.22	0.80
C80 dB		0.41	0.12	2.93	3.98	2.94	6.98
C50 dB		-2.28	-1.15	1.22	2.21	0.71	4.86
ITDG		11 msec					











IACC_E Battleground High School

Seat	250	500	1000	2000	4000
Front – Center	0.69	0.77	0.78	0.65	0.50
Front – Side	0.73	0.45	0.33	0.56	0.35
Middle – Center	0.77	0.10	0.40	0.58	0.26
Middle – Side	0.85	0.43	0.49	0.56	0.35
Back – Center	0.79	0.51	0.55	0.57	0.34
Back – Side	0.82	0.31	0.39	0.59	0.30

IACC_{E3} Average

All - 0.50

2000 Adjust - 0.45

Further Small Music Room Considerations

Henrik Moller and Jerald Hyde, 2007 [13]

Studied 28 Finnish halls <800 seats. Measured Strength G and Lateral Fraction LF.

Strength G was usually high at +6 dB to +12 dB (concert halls G = 5dB to +6 dB)

Early Lateral Energy, also generally high (measured Lateral Energy Fraction (LF))

LF was found to generally decrease as room width increased.

Fan shaped halls, LF<15%

Almost rectangular, 15%<LF<20%

Rectangular LF=20%

	G	LF
Concert Hall	+2 dB to +6 dB	15% to 20% good
Chamber Orchestra	+7 dB to +8 dB	10% to 15% acceptable
Small Ensembles	10+ dB	10% to 15% adequate
Small Ensembles	10+ dB	15% to 20% acceptable
Chamber Orchestra	10+ dB	15% to 20% loudness saturation

Suggested a reduction in G for larger ensembles using variable acoustics, but maintain LF.

Sandy High School Auditorium

Sandy, Oregon

In Design

Projected Completion: 2012

Smaller room (500 seats). Design includes a more open ceiling to the volume above in order to reduce the sound strength for larger music groups (concert band and orchestra).

Questions: (And opinions, not answers)

Can there be too much Lateral Sound Energy?

The amount of “early lateral sound” energy does not seem to be a issue.

Too much “total early sound” energy may be an issue, especially where large music groups are involved in smaller music halls.

Is emphasis on Lateral Sound Energy useful or detrimental to speech acoustics?

Clarity Factor C50 seems to be the primary factor for speech intelligibility. The direction of the early sound may not be significant. Although, experience seems to indicate the desirability for at least some straight-on, ceiling sound reflection.

Is the pursuit of Lateral Sound Energy a useful direction? Yes.

Does emphasis on lateral sound solve the spatial impression issue? Probably Not.

Is there a bigger picture to spatial Impression? Most assuredly.

Is the pursuit of maximizing the IACC a useful direction? Probably Not.

Measurement of the IACC might be used for general indication of the presence of strong lateral sound energy.

Is the pursuit of duplicating the IACC of another hall a useful direction? The acoustics of a hall can not be duplicated by designing to duplicate the values of acoustics measurements for that hall. There are far too many variables.

Are IACC, or, LF the optimum measures for spatial impression? Probably not, but they are what we currently have.

What are the limitations of the IACC measurement?

How much difference in level, or, time delay, between the reception of sound reflections at the two ears is significant to the IACC measurement? More importantly, how much difference is significant to our listening? Is there some point beyond which that no greater difference is important?

Limitations of loudspeaker source: Even dodecahedron loudspeakers are not omnidirectional above a certain frequency. They are also not equally symmetrical in all directions, i.e. front to back, compared to side to side, etc.

Limitations of the receiving system: In a comparison measurement, such as the IACC (or the Lateral Energy Fraction), departure from perfect frequency response and directivity become important. Differences in frequency response, sensitivity, calibration, and directivity between individual microphones, even with a “matched pair,” may be significant.

Limitations of seat choice for measurement: The determination of the currently quoted “average IACC” for a hall varies depending on how many, and the location, of the seats chosen for measurement. With varying hall size and shape, the presence of balconies or not, etc., the determination of a “standard” procedure for accurate hall comparison is probably not possible.

The IACC is not subjectively definitive. With all the other acoustic factors involved (probably many that we have not yet defined), it is difficult at this time to center on the use of the IACC as a predictor of a specific amount of “spatial impression” in a room.

Final Comment:

Research leads to understanding. As consultants and designers of room acoustics, we need more of both. We especially need more information on the detailed frequency effects of sound scattering and diffusing so that accurate reflected sound levels from specifically dimensioned, building structural elements can be predicted.

Remember:

It's not really about the hall.

“It's about the music.”

It doesn't really matter how the hall tests,
if listeners enjoy the concerts.

There is something about listening to music that makes us almost obsessed to achieve the best listening conditions that we can, whether they be with the latest portable listening device, a \$100,000 audio system, or, a \$200 million concert hall.

In music hall design, the most that we, as consultants, can do is try to remove the impediments to listening to the music in its pure form; to allow the sensations of tone, harmony and timing of the music to have their true impact on us as listeners.

References:

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