Recent experiences with electronic acoustical enhancement in concert halls, opera houses, and outdoor venues

David Griesinger

Lexicon Inc.

3 Oak Park, Bedford, MA 01730

www.lexicon.com/links

Steve Barbar

Lares Associates,

Columbia,MD 21045

www.lares-lexicon.com

Major Message:

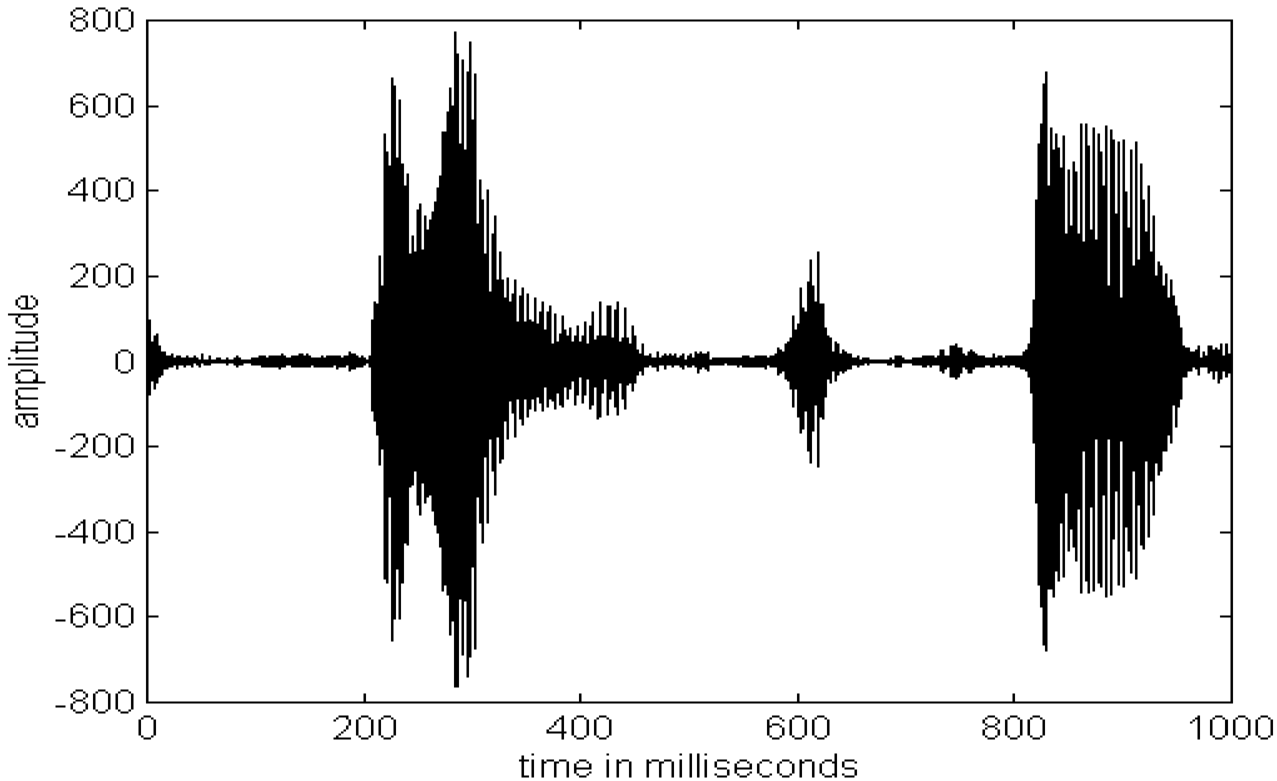
- Many halls - especially opera houses or halls with fewer than 1000 seats - have problems that can only be solved with a combination of absorption and electronic acoustical enhancement.
- For world-class performance you need high clarity and high envelopment at the same time in all seats.
- The best results come from a dual-slope decay above 500Hz, and high reverberant level below 500Hz.
- High reverberant level requires high resistance to feedback.

Contents:

Acoustic Perceptions

- Primary Perceptions:
  - Lighting, Color scheme
  - Musical Balance
    - High instruments vs Bass instruments
    - Voices vs Orchestra
  - Loudness
  - Intelligibility (Clarity)
- Subconscious Perceptions
  - Envelopment (Spaciousness)
    - This one REALLY works!
  - Early Hall Sense (Depth, Blend)
    - Subtle, but nice

Intelligibility



1250Hz 1/3 octave filtered speech - Note the phones typically have a rapid rise, with gaps of 150ms or more.

We localize the rising edges, and hear envelopment during the gaps.

Physiology of Intelligibility

- When there is noise or reverberation, speech comprehension is limited by the ability to separate sound events (phones) from each other.
- Ideally we need to distinguish both the start and end of a phone.
- reflected energy in the 50-150ms range is maximally disturbing.
- we want to minimize reflections in this time range!
- Frequencies above 700Hz are of primary importance to speech (and music) intelligibility.

Localization

- Rising edges of acoustic events are preferentially detected and localized.
- Speech phones and notes from soloists often rise in < 10ms.
- Thus speech and soloists are easily localized.
- Legato strings are often broadened.
- ASW - Apparent Source Width - depends strongly on the rise time of the source!

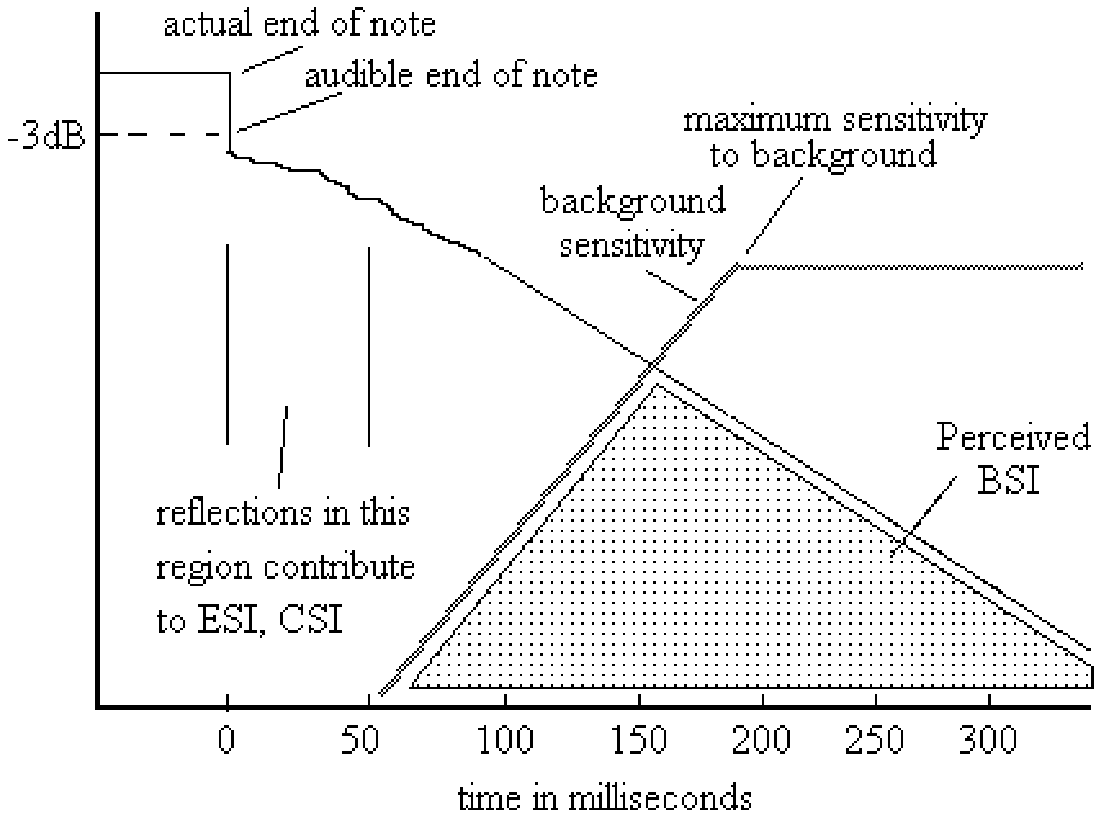
Envelopment - the Holy Grail of acoustics

– Envelopment draws the listener into the music or scene.
  - An essential part of modern cinema sound
– Envelopment takes training to reliably perceive.
  - Most music listeners (and critics) perceive only loudness, balance, intelligibility, and localization.
– The effect is unconscious but powerful.
  - In a recent blind test there was a consistent bias for high envelopment.
– frequencies below 500Hz are the most important.

Physiology of Envelopment

- is primarily derived from the spatial properties of the background sound between notes.
- Thus envelopment depends on the neural process that separates foreground and background.
- Determining the end of a sound event often takes >100ms.
- Reflected energy 150ms or more after the end of a sound event contributes to envelopment.
- Envelopment depends on the absolute level of the reflected sound.
- Frequencies below 500Hz are particularly important.

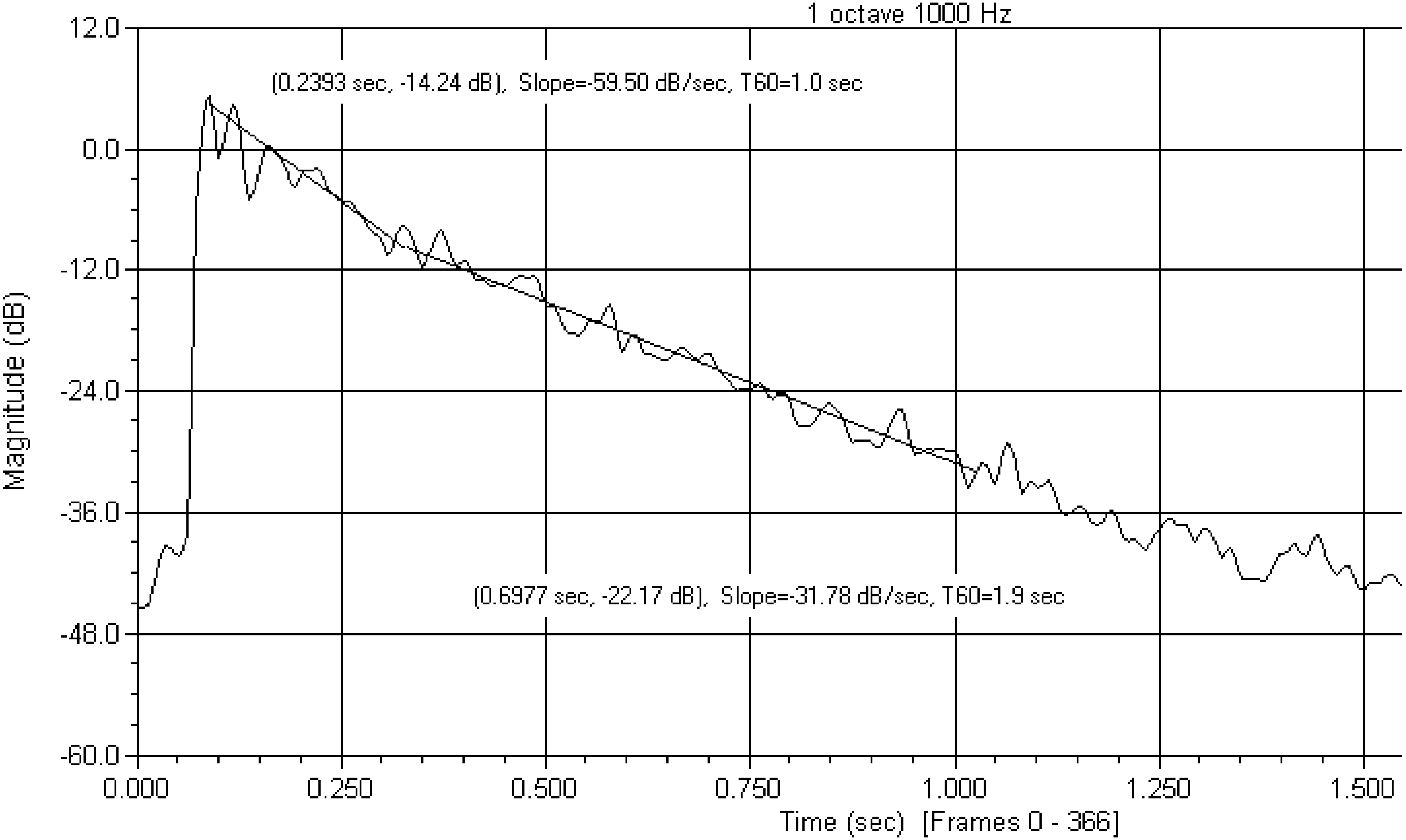
Perception of envelopment depends on detecting the ends of notes



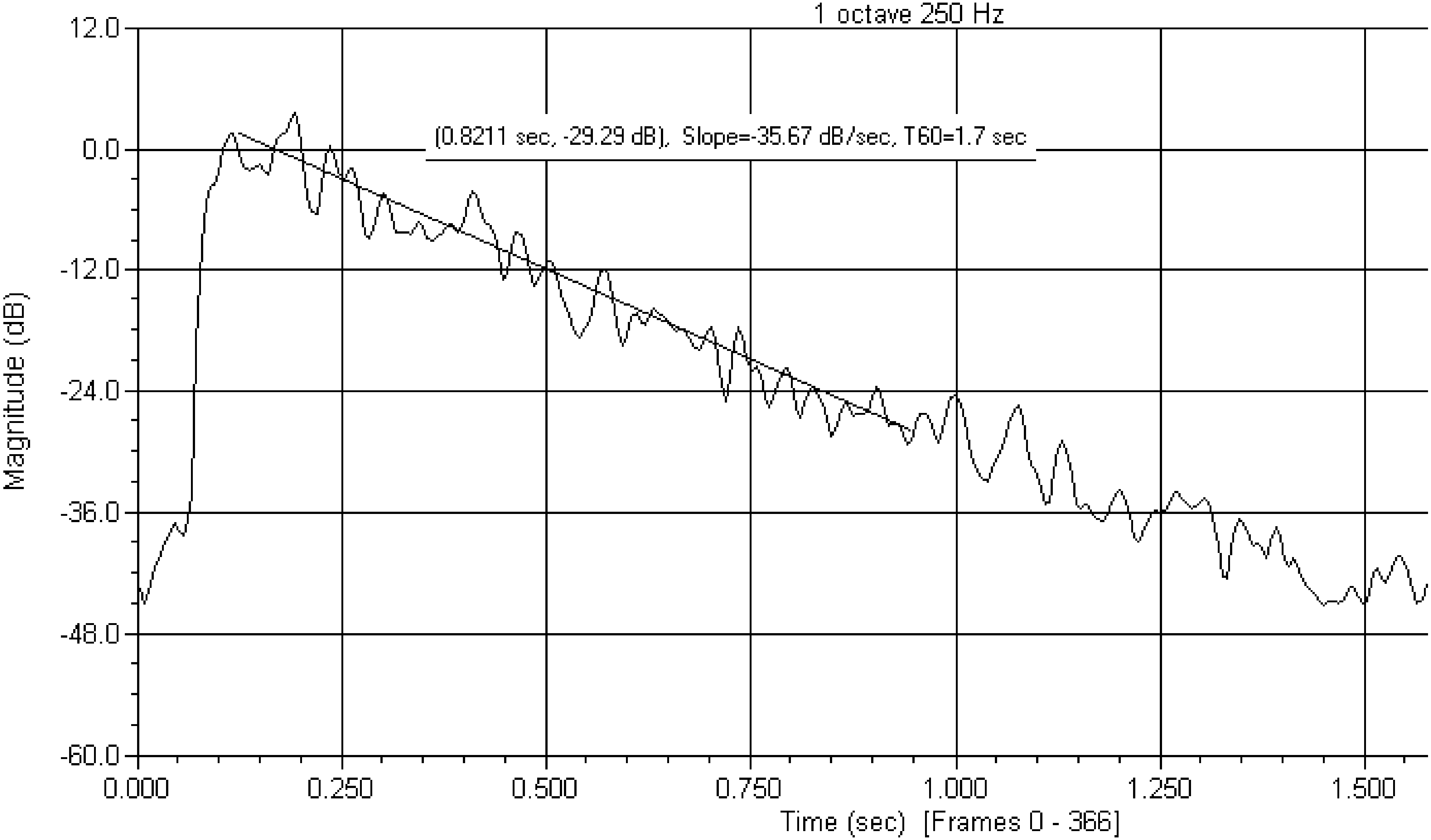
Clarity and envelopment at the same time

- may require a dual-slope decay above 500Hz
- with a single-slope decay below 500Hz.

Boston Symphony Hall, occupied, stage to front of balcony, 1000Hz

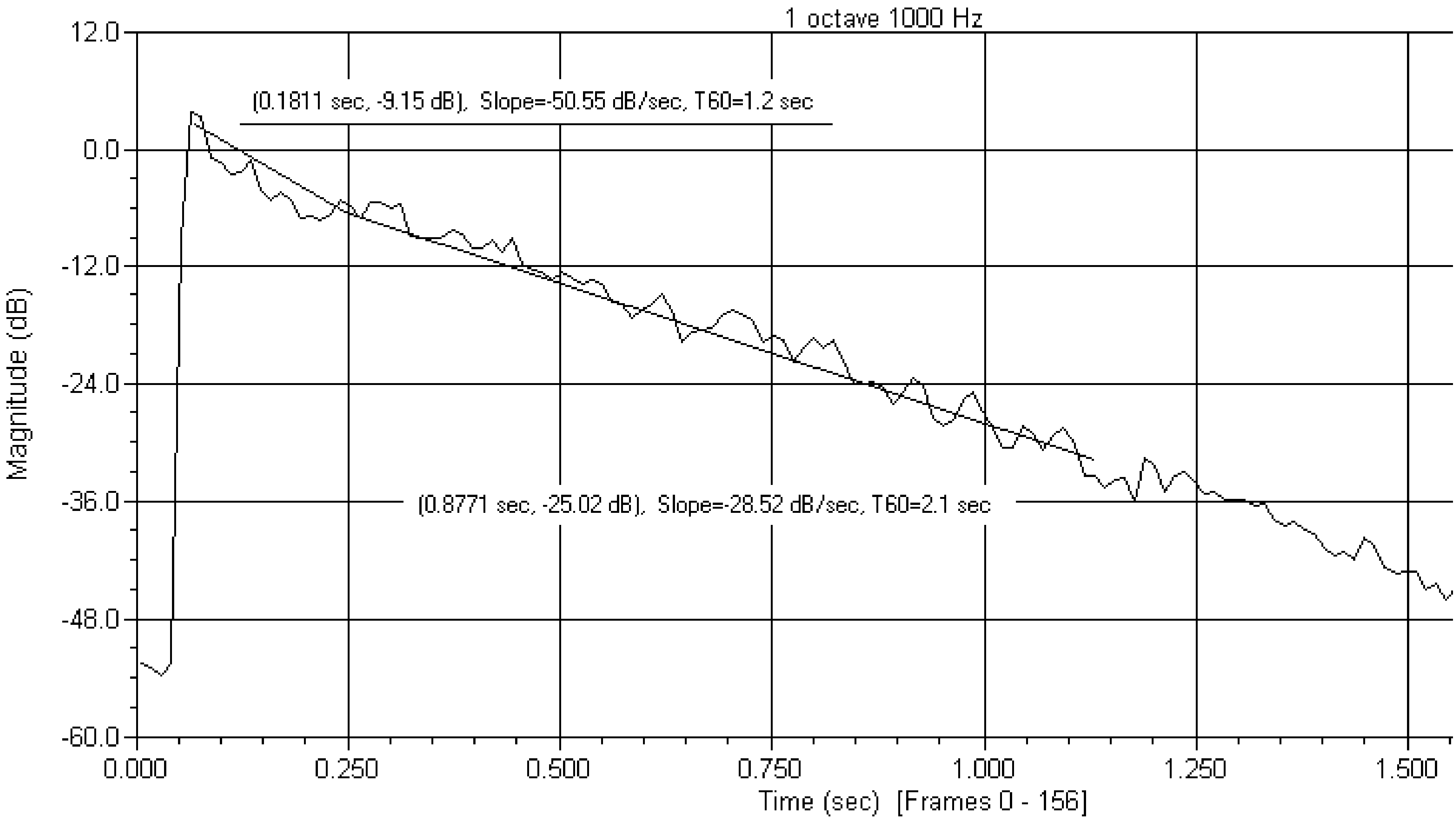


Boston Symphony Hall, occupied, stage to front of balcony, 250Hz

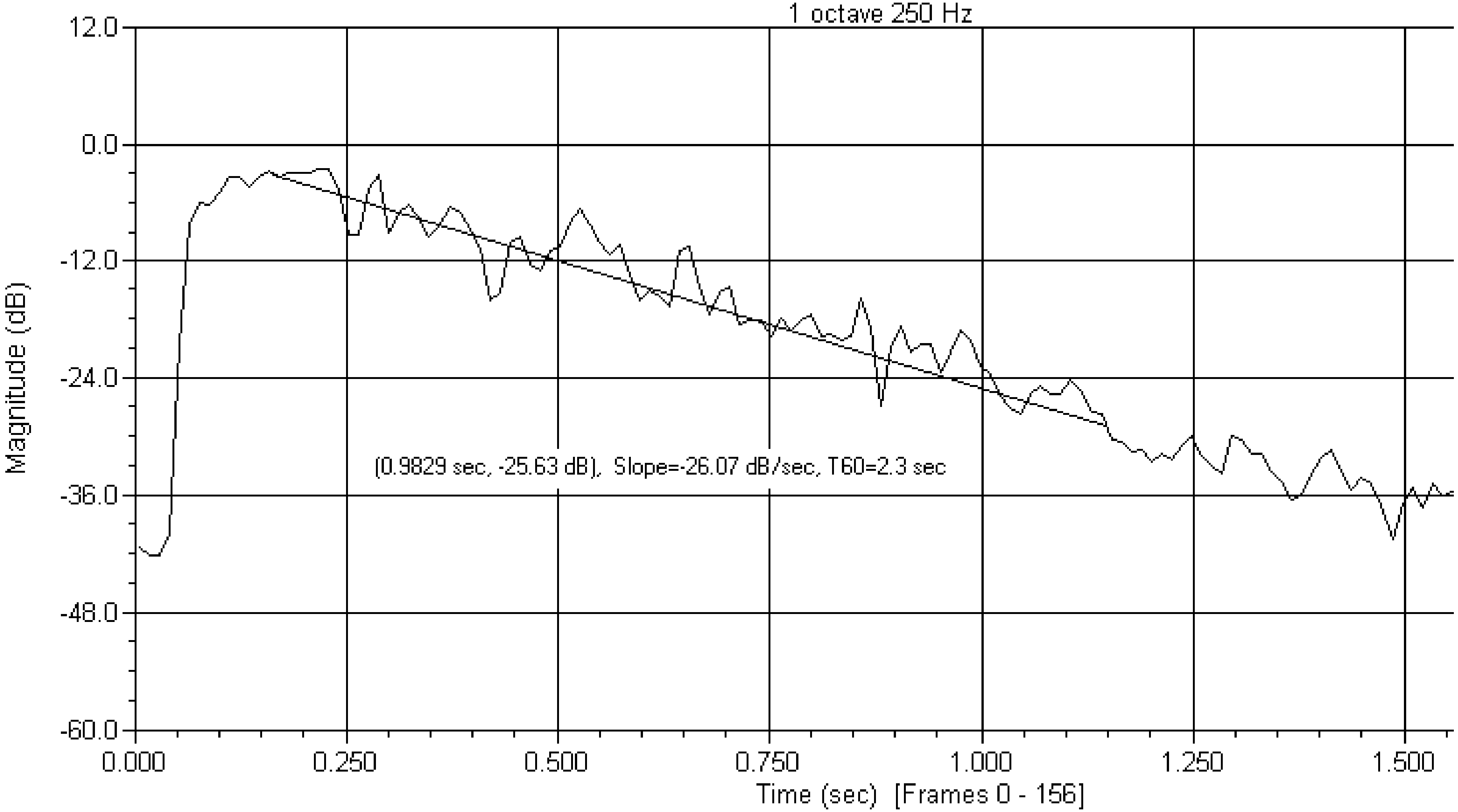


Adelade - Festival Center Theater

Adelaide Festival Center Theater, unoccupied, system on, stage to row R, 1000Hz

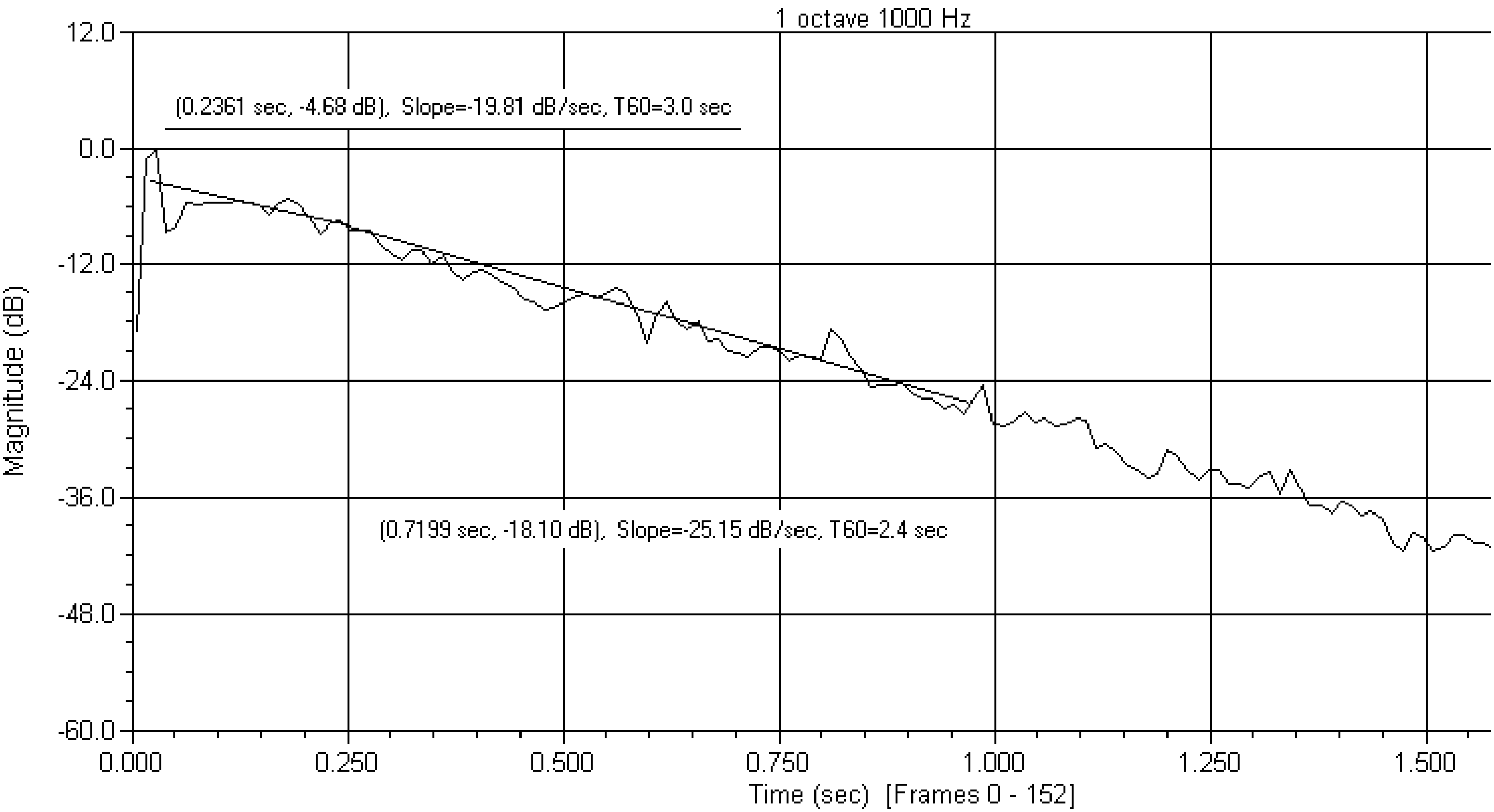


Adelaide Festival Center Theater, unoccupied, system on, stage to row R, 250Hz

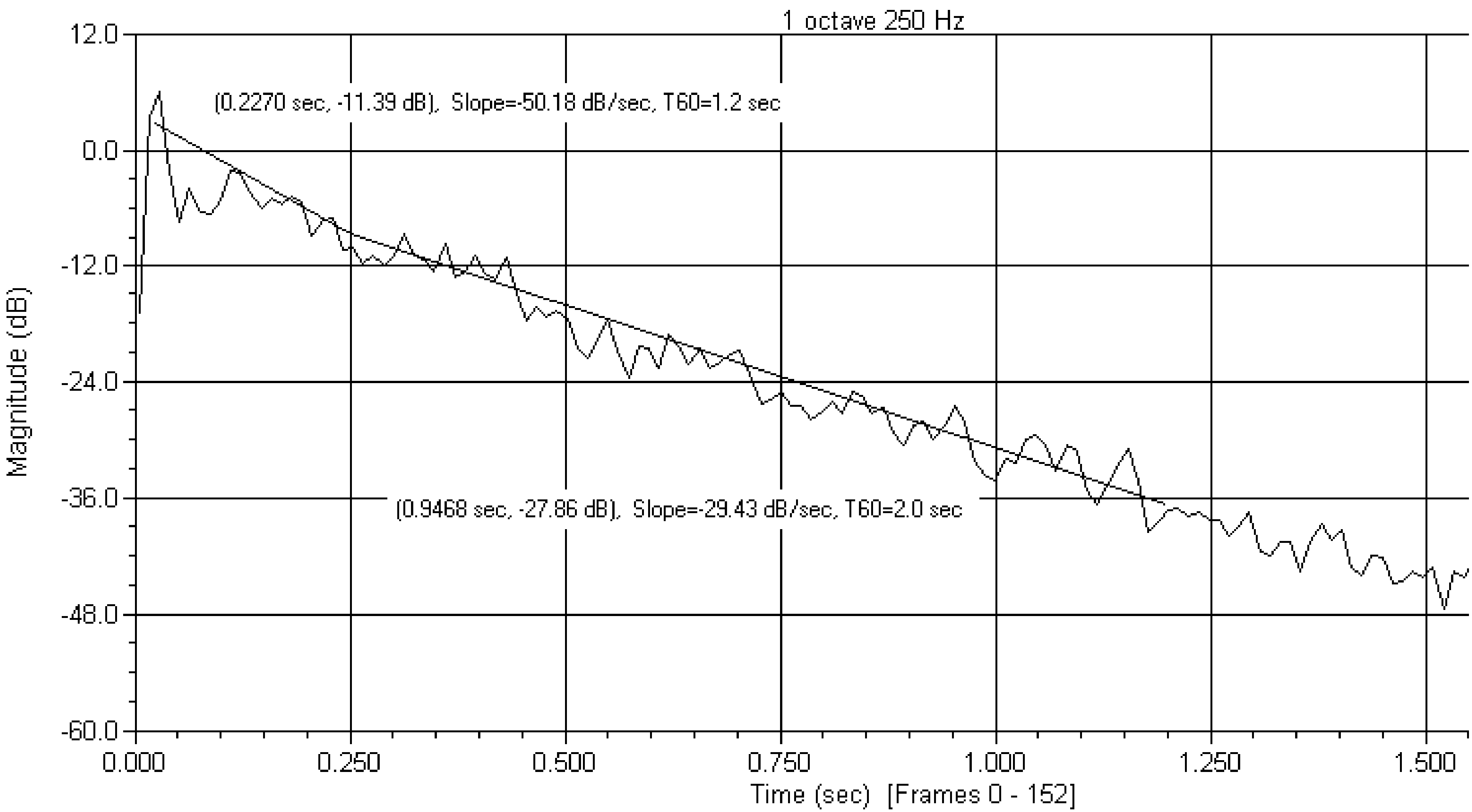


Sydney Symphony Hall

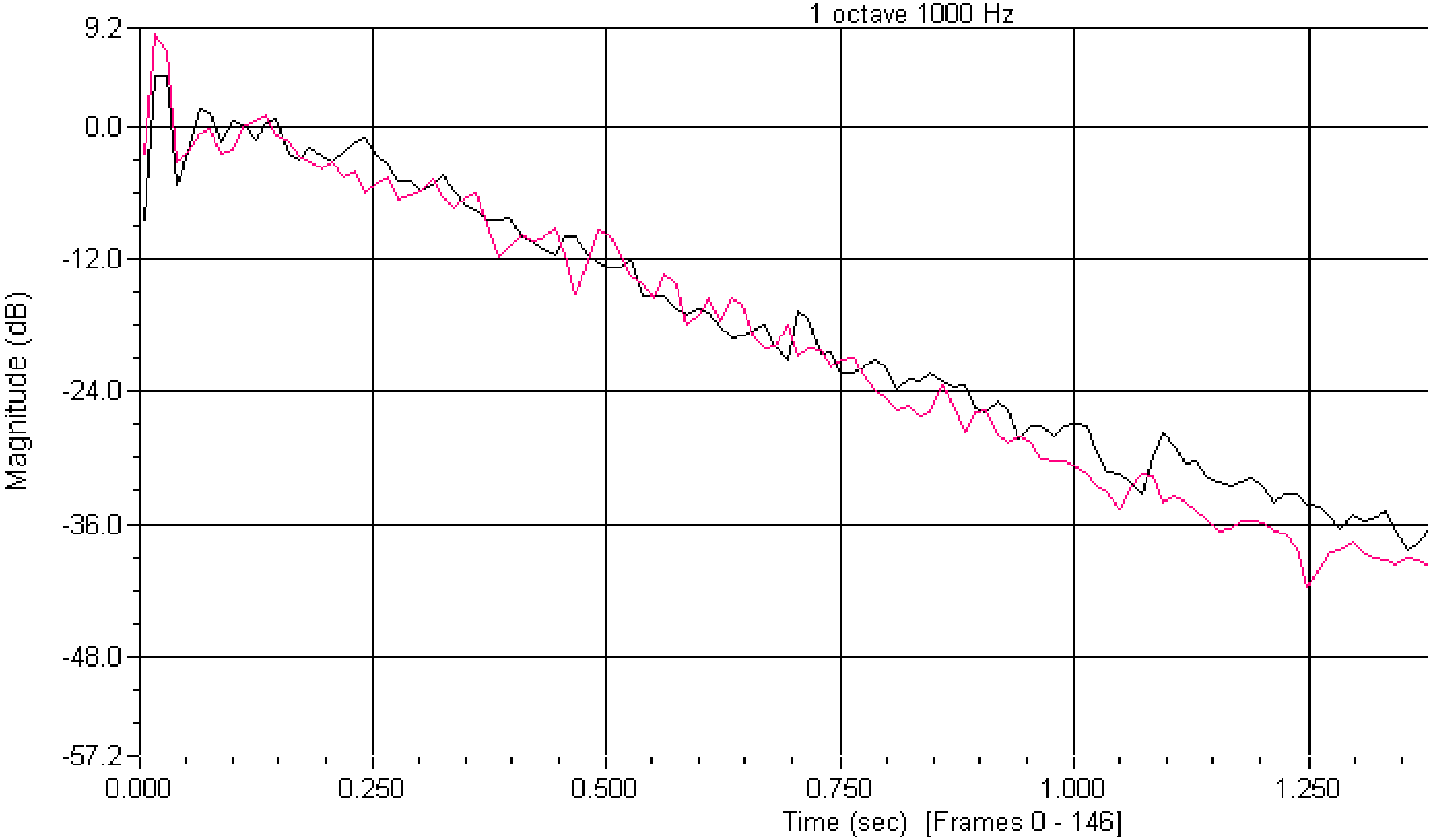
Sydney Symphony Hall, unoccupied, front desk to row R, 1000Hz



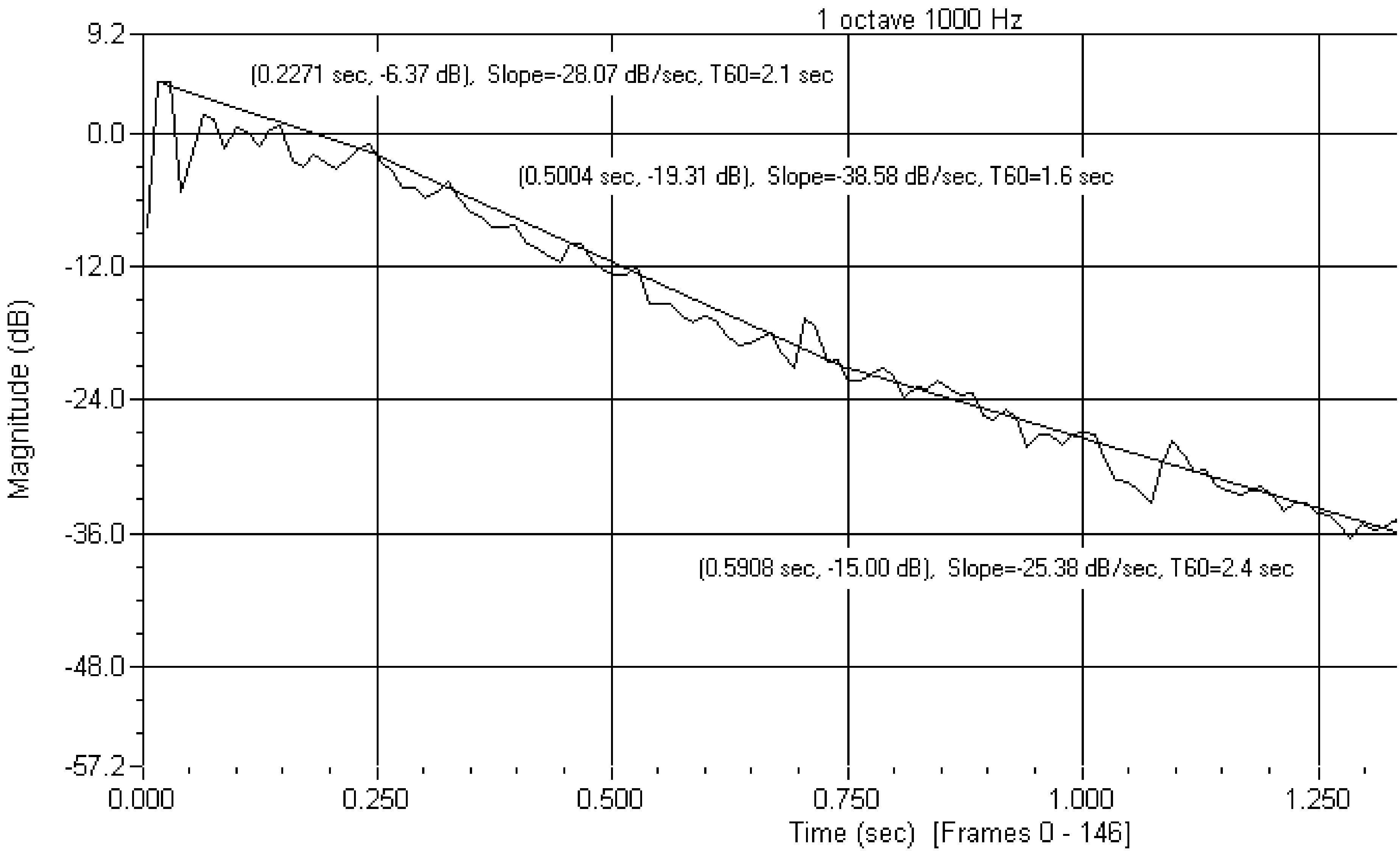
Sydney Symphony Hall, unoccupied, front desk to row R, 250Hz



Opera house, unoccupied, system on/off, front of stage to row N, 1000Hz



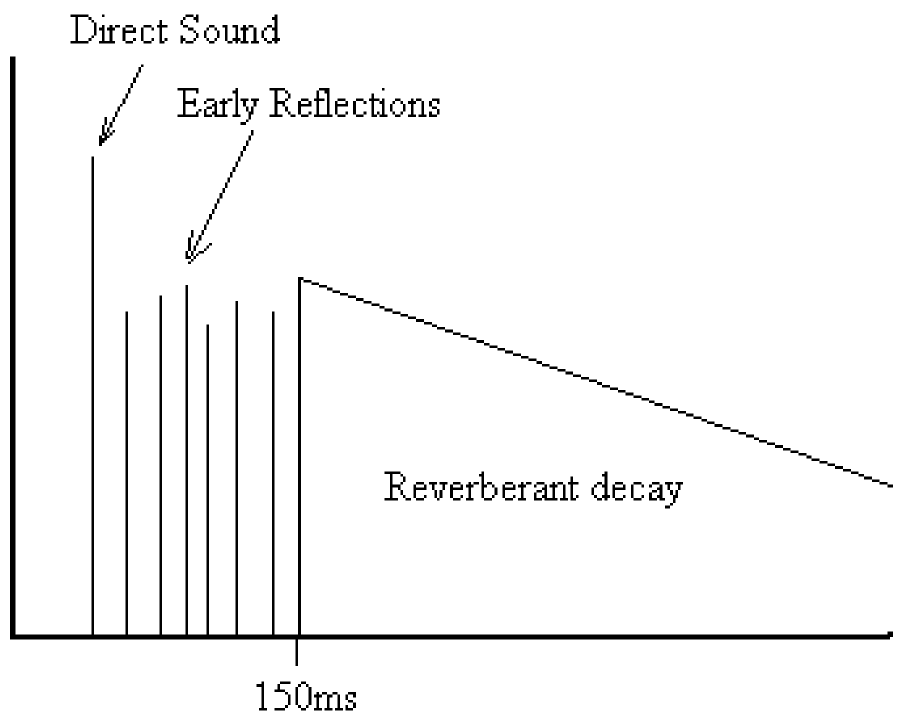
Opera house, unoccupied, system on, front of stage to row N, 1000Hz



Physiology of Early Spatial Impression - (Blend or Depth)

- Lateral reflected energy in the 10ms to 50ms range reduces the “closeness” of the sound image
- While this perception is pleasant, it is not musically essential.
- too much energy in this time range can cause image broadening, timbre coloration, etc.
- The ideal is to have the total energy in this time range two to four times less than the direct sound.

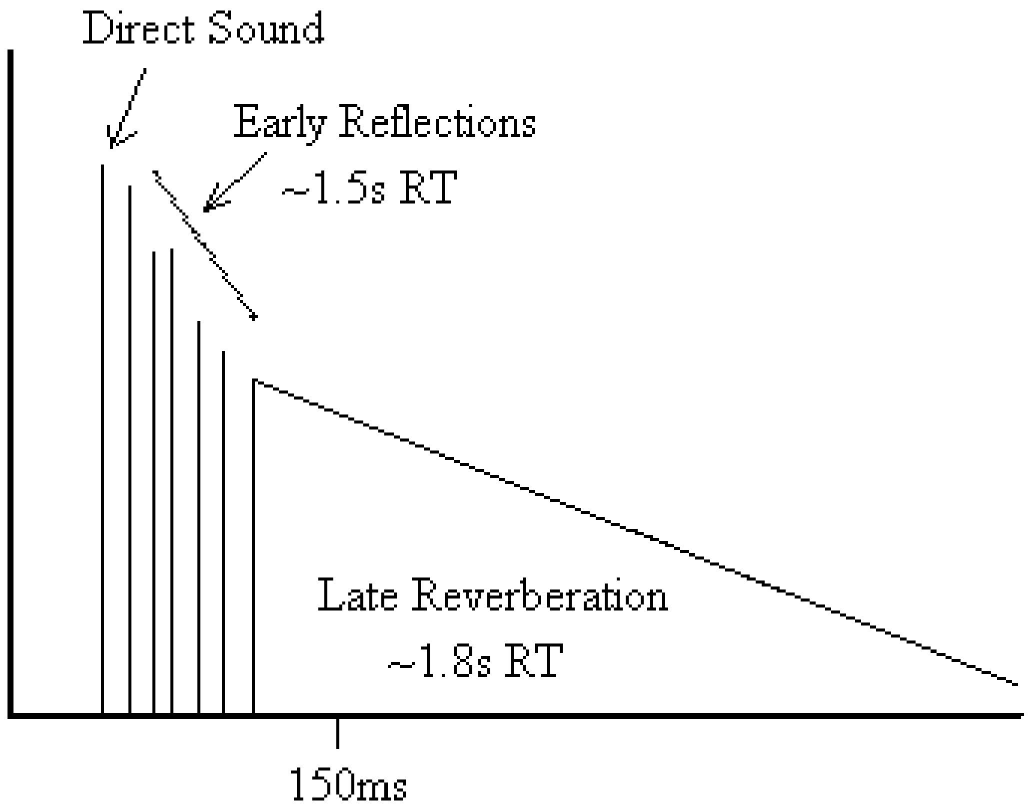
Acoustics of Large Spaces



Note the low level of reflections in the 50-150ms range, and the substantial energy in the later reverberant decay.

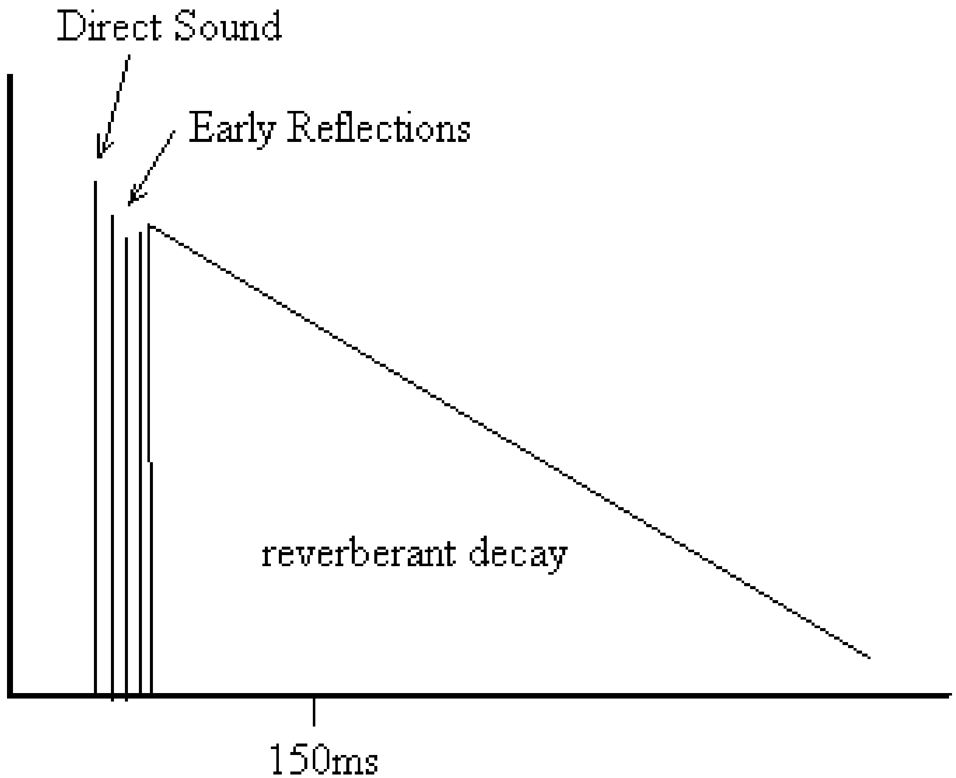
This hall will combine clarity and envelopment.

Large space with stage house



– Example - Boston Symphony Hall

Acoustics of Small spaces

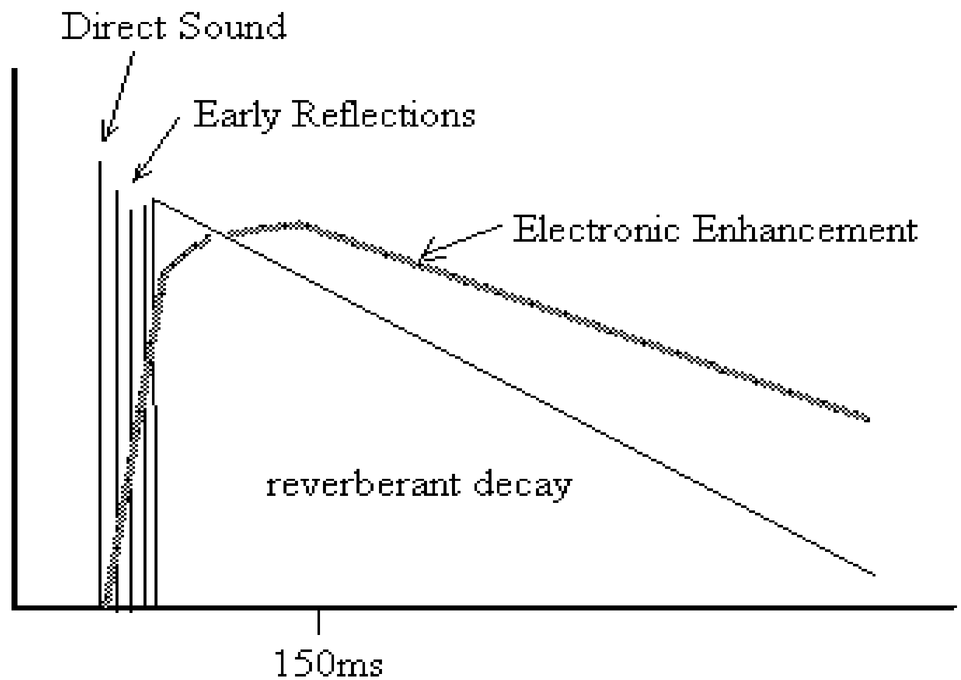


Note the high level of early reflections, and the early onset of reverberant decay. The high energy in the 50-150ms time results in poor intelligibility and coloration.

Electronic Enhancement in small spaces

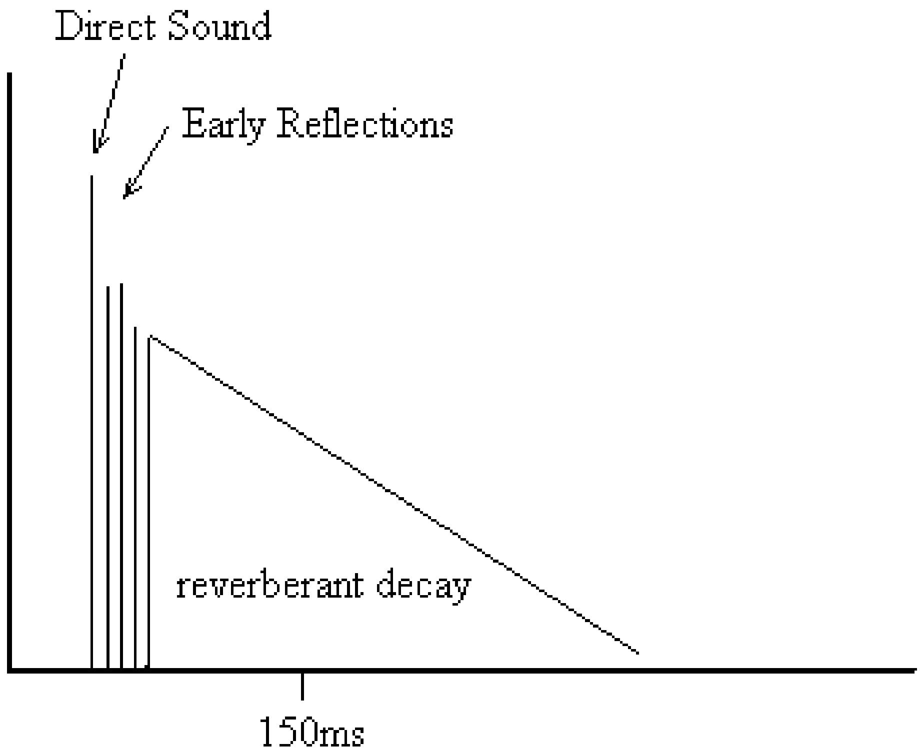
- works best when the strong early reflections are controlled with adequate absorption.
- electronics are used to supply later reverberation at the proper level.
- The result is clear, uncolored direct sound, supported and augmented by envelopment.

We can add electronic enhancement but...



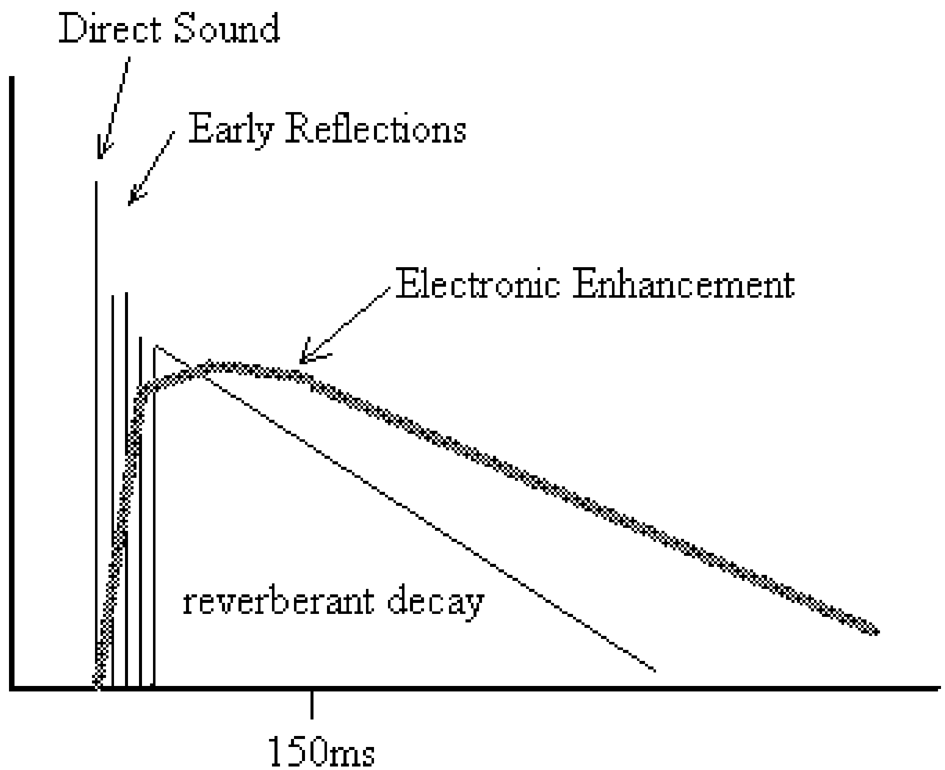
– Enhancement increases envelopment, but there is too much energy from 50-150ms,
– and the sound is muddy.

Results of added absorption



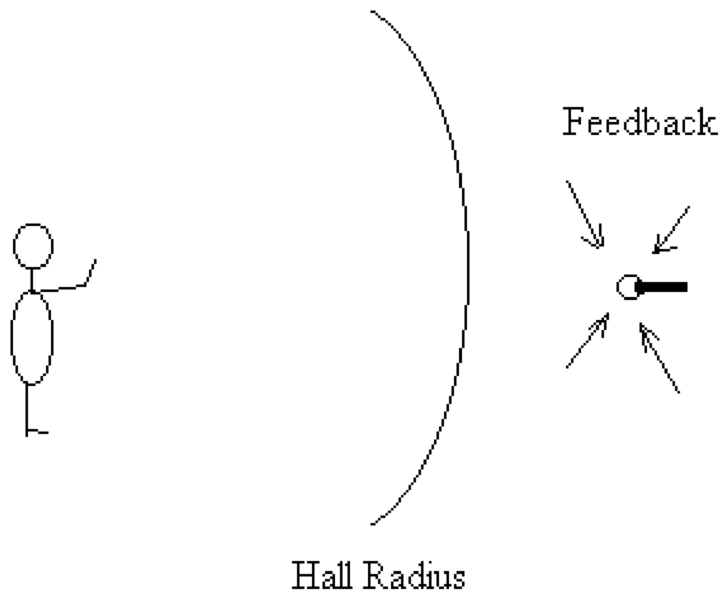
– absorption reduces the strength of the reflections in the 50-150ms time range

Now add electronic enhancement



– electronic enhancement supplies the missing late reflections and envelopment.

Feedback is the dominant problem!



– when the microphone is beyond the hall radius
– adding more microphones does not (usually) help

Electronic Acoustic Enhancement

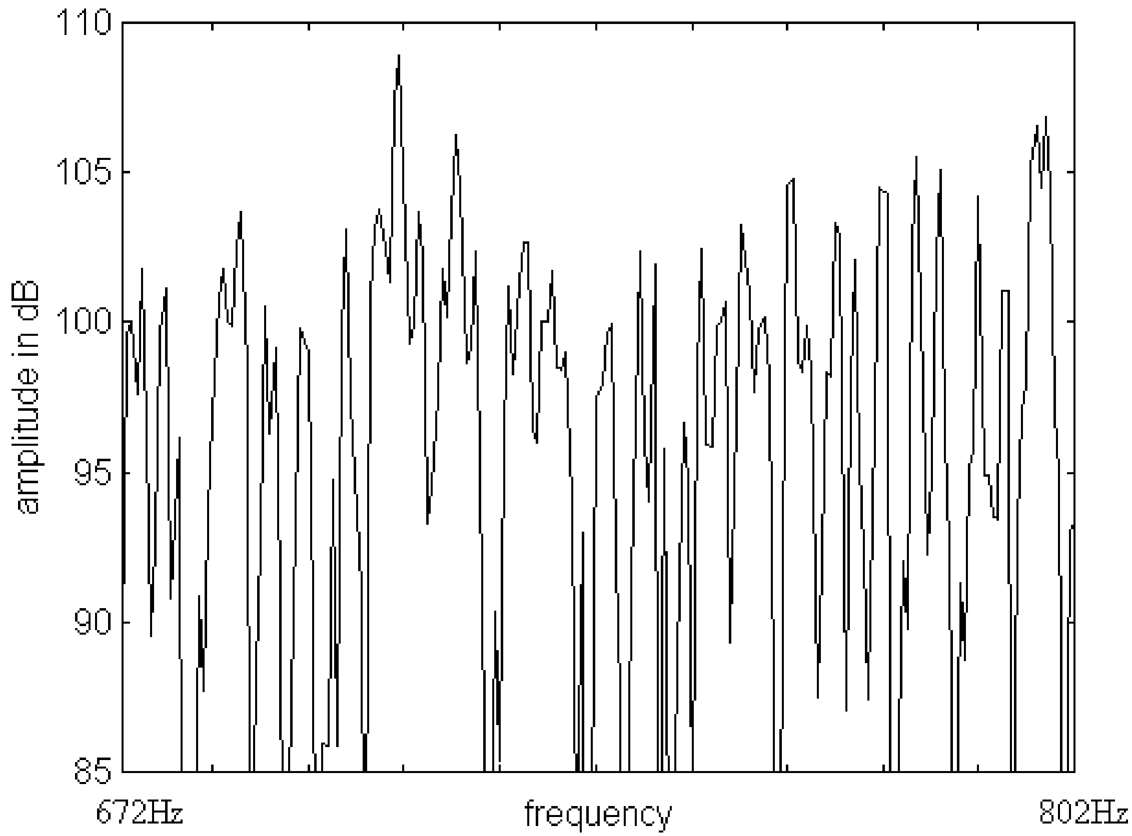
- Electronics allows us to separately manipulate reflected energy in different time ranges
- But ONLY if the microphones are close to the source!
- Acoustic feedback is the dominant feature in enhancement systems.
- The amount of feedback is determined by the ratio of the source-microphone distance to the enhanced critical distance (hall radius)!
- In a single channel system feedback must be below -20dB or there will be audible coloration.
- This means for a 3 meter critical distance the microphones must be within .3m meters of the source!

Coloration

- Acoustic feedback is not frequency linear!
- The transfer function between loudspeaker and microphone is uneven, with peaks and dips.
- Overall peaks and dips can be equalized flat with an analyzer such as JBL Smaart and a parametric equalizer. This must be done as a first step.
- Once overall equalization is flat, there remains a fine structure of peaks and dips that is inherent in natural reverberation, and depends on the reverberation time.
- Feedback will occur at the peaks of this fine structure, and will occur at system gains far below an average loop gain of zero dB.

Fine structure of the transfer function

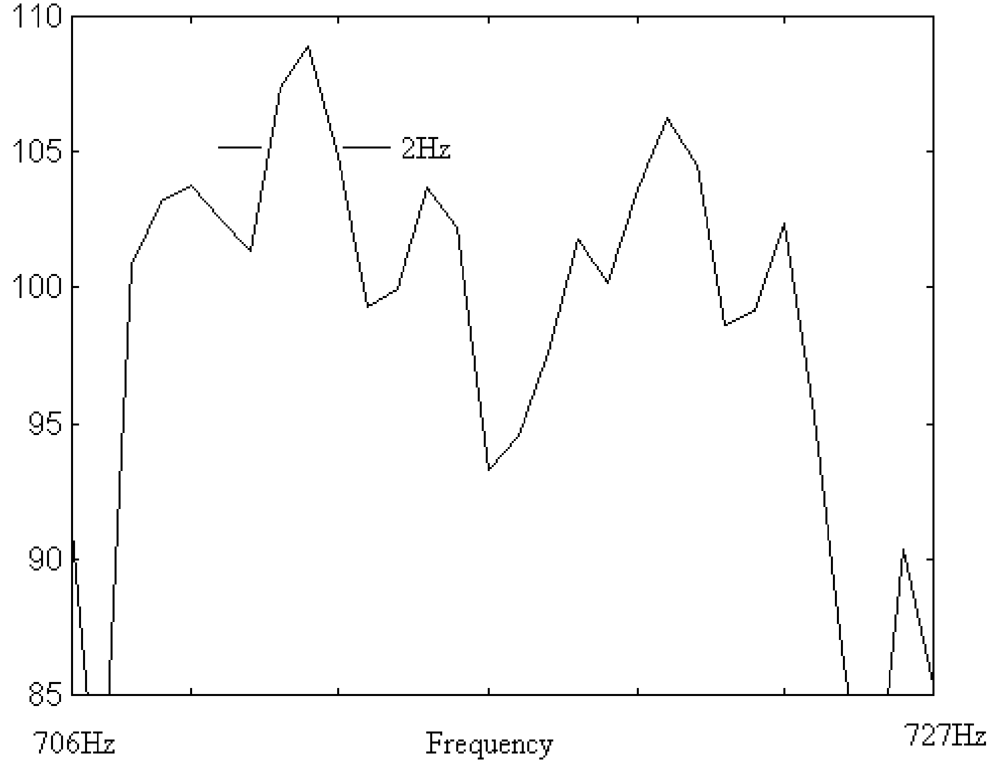
- The height and width of the peaks depend on the combined natural and enhanced reverberation times.
- The peak height and frequency vary chaotically with small changes in temperature, occupancy, etc.
- These peaks lengthen the RT of selected frequencies and are HIGHLY AUDIBLE.
- Coloration is reduced by using multiple microphones, speakers, and amplifiers - but only if the microphones and speakers are separated by the critical distance. (MCR)
- In an MCR system the Loop gain (feedback) is reduced by the sqrt of the # of channels.
- An MCR system with 16 channels requires a microphone distance of 1.2 meters or less. (Much better than .3m, but not very useful!)



Transfer function from the stage of Boston Symphony Hall to row N. Note the ~12dB peak to average ratio.

Feedback around this path will increase the RT at the peak frequencies.

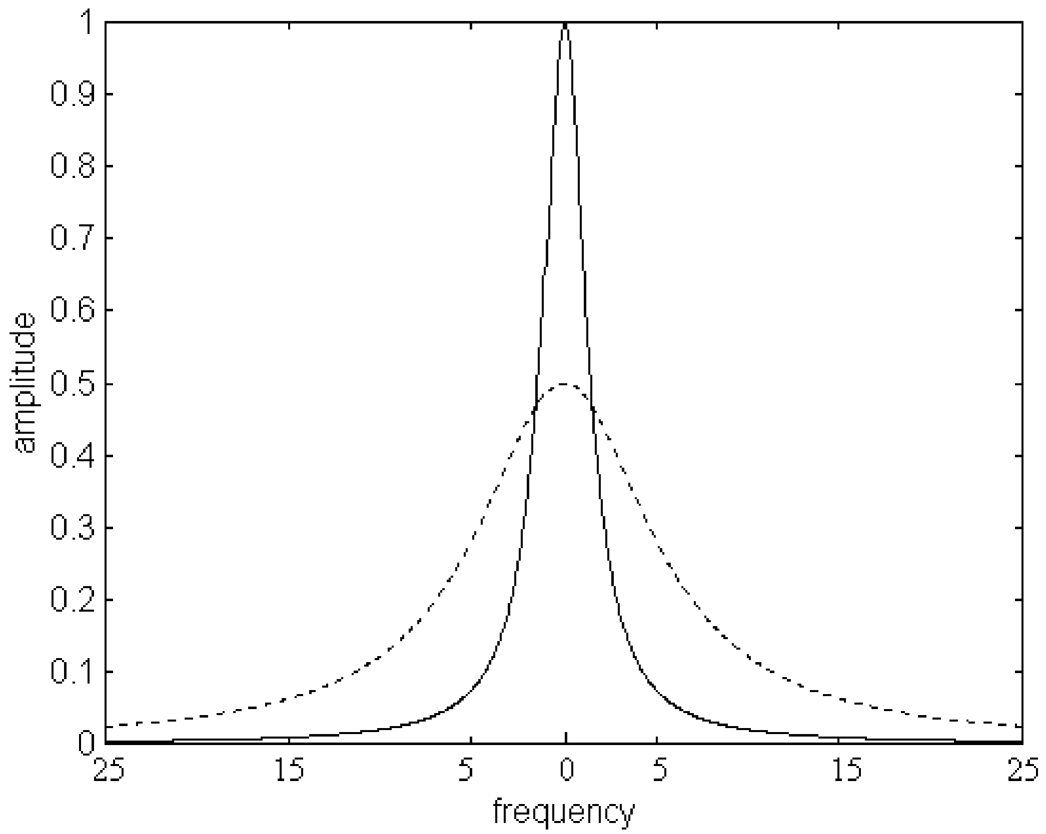
Fine scale frequency response in Boston Symphony



Note the ~2Hz peak width. This width is approximately 4/RT. We can use phase modulation to broaden this peak and lower its amplitude. Note the ~2Hz peak width. This width is approximately 4/RT. We can use phase modulation to broaden this peak and lower its amplitude.

Peak to average ratio

- can be reduced through phase modulation
- as much as 6dB of peak reduction can be achieved



Phase modulation and pitch-shift

- Phase modulation is associated with pitch-change.
- Not all methods that produce phase modulation are the same.
- There are methods that produce adequate phase modulation over a wide frequency range, with minimal pitch shift.
- With care a 6dB increase in stability can be achieved.
- This 6dB gives an enormous improvement in coloration!
- In our experience phase modulation is essential for producing low coloration even in a 16 channel system.

Multiple Time Variant Reverberators - MTVR

- allows a small number of microphones and a large number of loudspeakers.
- Up to 18dB of feedback reduction can be achieved with two Lares frames - (each with 8 independent reverberators.)
- source-microphone distance (cardioid) =
- 2*.17*sqrt(#reverbs)/critical distance ~= 10meters!
  - The factor of 2 is the 6dB gain from phase modulation
  - The factor .17 is the cardioid directivity factor reduced by the -20dB necessary for low coloration. Assume 16 channels.
- When phase modulation is NOT used: ~=0.5meters!
- With MTVR envelopment can be dramatically increased without artificial coloration. (but you need all the tricks.)

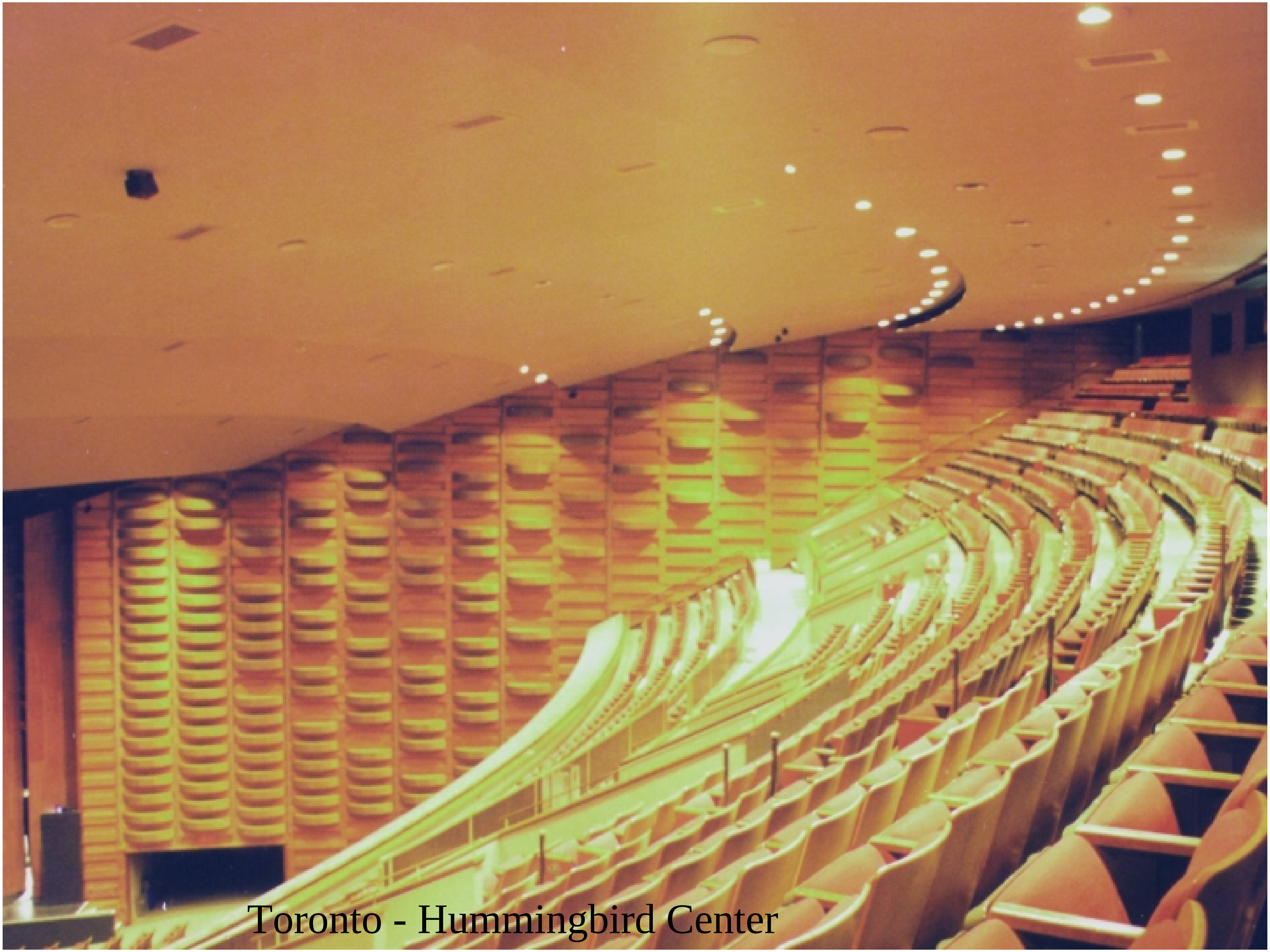
Berlin - Deutches
Staatsoper

Deutches Staatsoper - Berlin

- 0.9 seconds reverberation time
- small, highly damped stage house
- 4 audience rings
- high intelligibility, intimate seating - excellent dramatic connection between actor and audience.
- low reverberance, poor envelopment. Orchestra sounds small, confined to the pit. Singers get no hall return.
- OK for Mozart, poor for Wagner
- Similar to Zurich, London, Vienna, etc.

Lares system

- installed by the house Tonmeister, Albrecht Krieger
- 8 speakers in the ceiling were added
- 2 subwoofers on either side of the dome
- 40 speakers in the ring system
- frequency dependent equalization - 6dB more level below 300Hz.
- 1.7 seconds RT below 500Hz for opera. High envelopment, excellent hall return. Wagner lives!
- 2.0 seconds RT broadband for Ballet.
- System in continuous use for more than two years, with excellent reviews.


Toronto - Hummingbird Center

Hummingbird Center - Toronto

- large hall with 3200 seats, 1.2 seconds RT
- Lares system has 4 Lares frames, 312 loudspeakers, 4-6 B&K microphones.
- Direct sound is augmented in the front, under the balconies and in the back of the hall.
- Reverberant level and decay time are adjustable above and below the balconies.
- Similar equalization as the Staatsoper for opera.

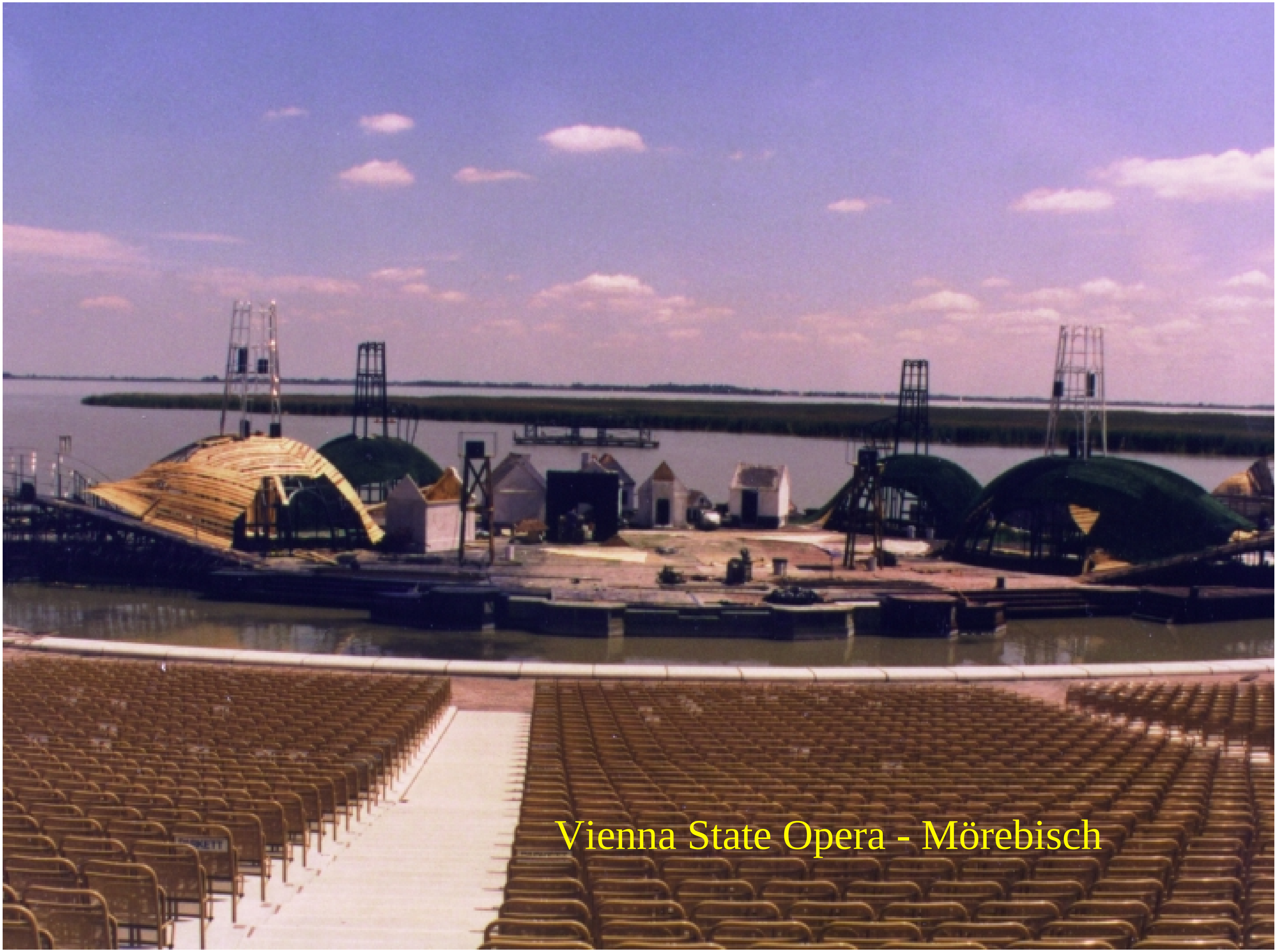

Indianapolis - Circle Theater

Circle Theater, Indianapolis

- Former Vaudeville house, now the Indianapolis Symphony Hall
- System installed with Paul Scarborough of Jaffe, Holden, Scarborough.
- Lares system (three frames) augments both the late reverberation and early lateral reflections.
- Early reflection augmentation increases “Blend”.
- Later reverberation increases warmth, envelopment.
- Reviews have been very good.

Adelaide Festival Center Theater

- 2200 seats, 1.2 seconds RT. System design by Steve Barbar of Lares Associates.
- 350 sq. meters absorption added to stage house, 250 sq. meters to stalls, carpets removed from the floors.
- after treatment intelligibility was good
- five Lares frames, 244 loudspeakers



Vienna State Opera - Mörebisch