ELEC 407
DSP Project

Algorithmic Reverberation – A Hybrid Approach

Combining Moorer's reverberator with simulated room IR reflection modeling

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Reverb

Natural reverberation is the “ambience” of a room. From any source there is sound that reaches the listener in a direct path, as well as sound that reaches the listener indirectly through reflections in the acoustic space. Reverb is the indirect sound that we hear as it interacts with the acoustics of the environment.

The purpose of artificial reverb is to add the impression of ambience to an acoustic signal that was recorded in a “dry” environment – the ultimate goal is to simulate natural reverb.

Early Reflections + Late Reverb

Early Reflections – the first reflections that we hear within about 100ms of hearing the direct sound of the source.

Late Reverberation– the reverberant sound field after about 100ms, until it fully decays. Late reverb is characterized by a dense texture of diffused reflections that reach our ears from many different paths. These diffused reflections are out of phase with one another, causing us to hear the comb filtering effect.

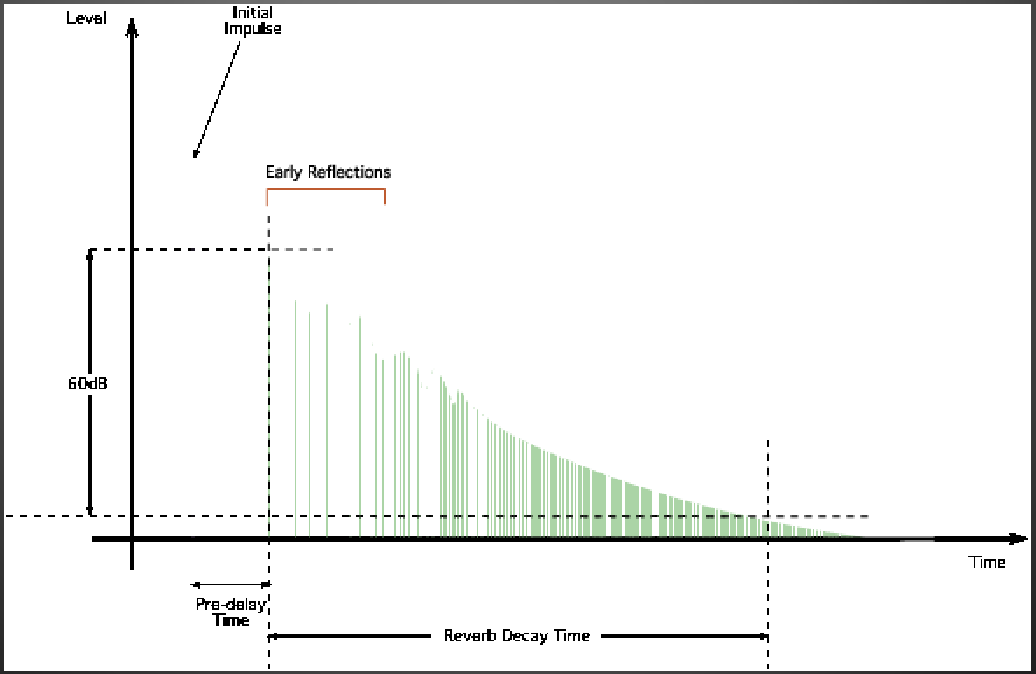


Figure 1: Typical impulse response of a room, highlighting the ITDG, early reflections, and RT60 [2].

Two Important Acoustic Parameters

•**Initial Time Delay Gap (ITDG)** – the time gap between the arrival of the direct sound that we hear, and the first early reflection. This gives us an impression of intimacy with relationship to walls in a room.

•**RT60 -** the *reverb time, RT60,* is the time it takes for the acoustic signal to decay by 60dB (typically different measured at each frequency). RT60 is defined by the volume of the room and the absorption of sound energy inside the room.

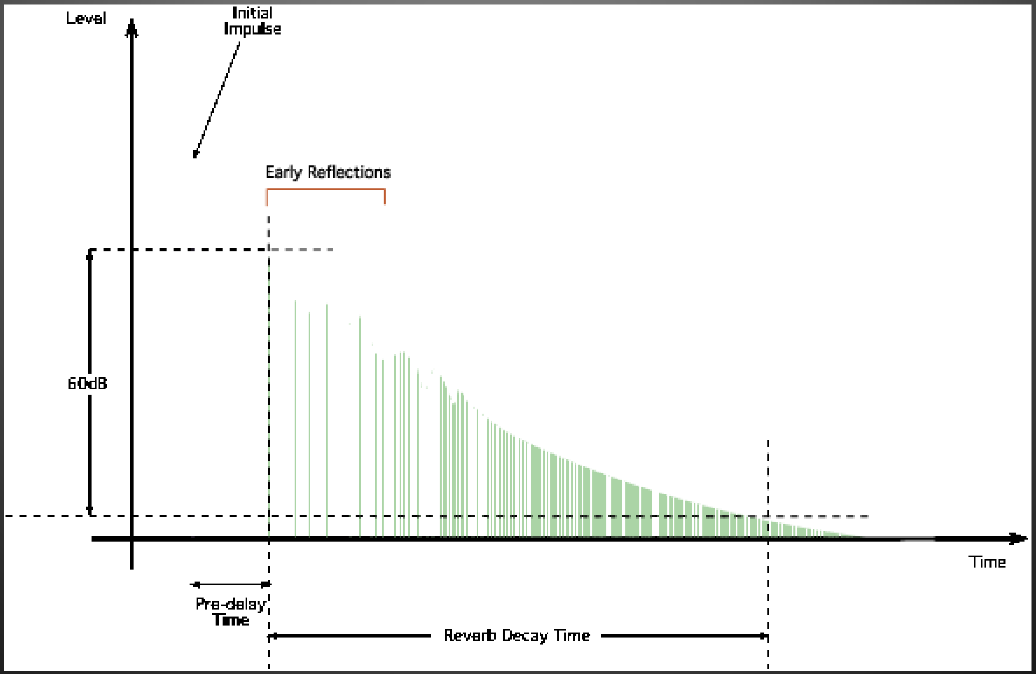


Figure 1: Typical impulse response of a room, highlighting the ITDG, early reflections, and RT60 [2].

Moorer's Reverberator

<u>Stage A</u>

•Tap delay line FIR network to simulate early reflections

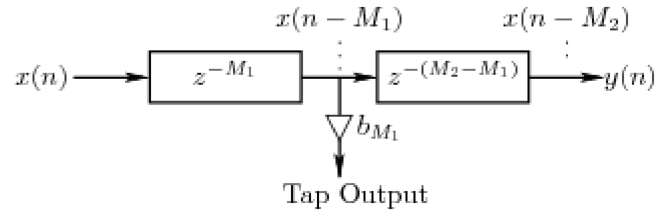
<u>Stage B (Schroeder's Reverberator)</u>

•Parallel comb filters followed by first order lowpass filters to simulate a smooth decay with high frequency roll off as time progresses

• Allpass filter to increase echo density without adding colouring to the magnitude frequency response.

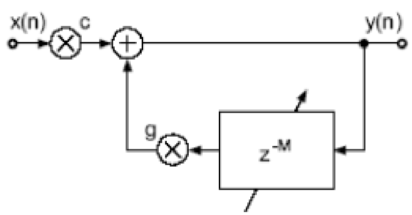
Moorer's Reverberator

Tap Delay Line



[4]

IIR Comb Filter



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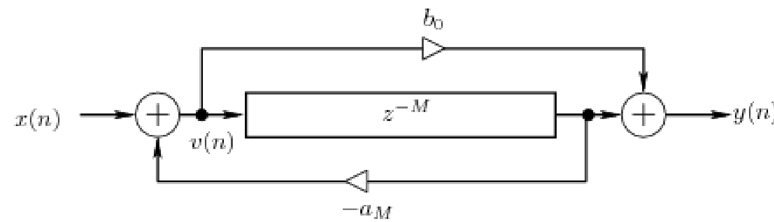
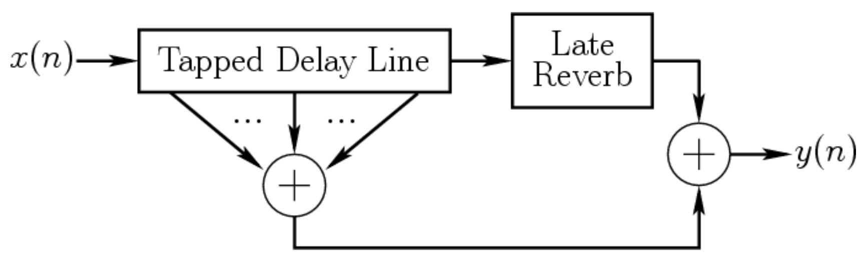
Allpass Filter

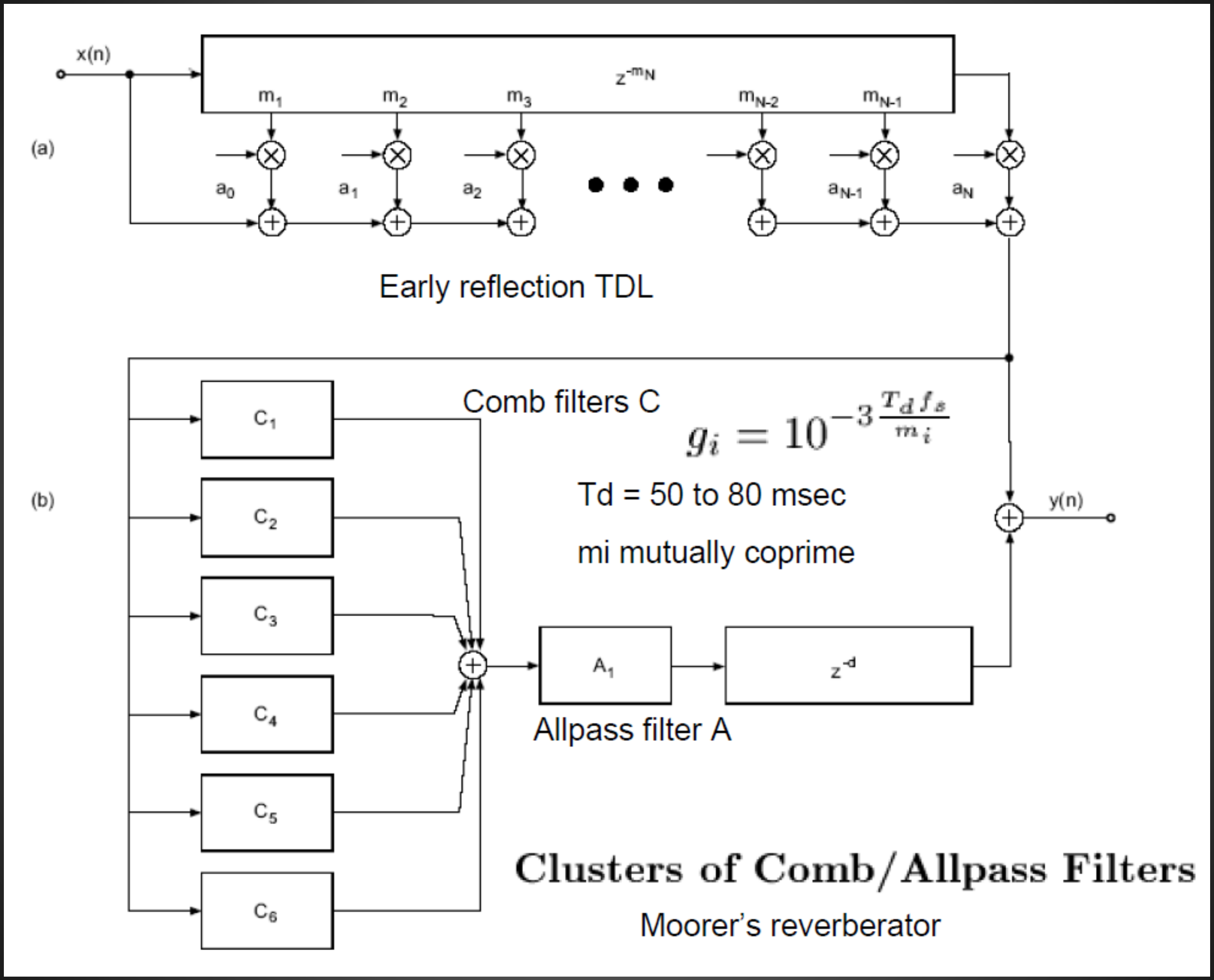


Combination IIR/FIR comb filter becomes an allpass filter when $b_0 = a_M$ [4]

<u>Moorer's Reverberator: Tap Delay Line with Late Reverb (Schroeder's Reverberator)</u>



Moorer's Reverberator



Moorer's reverberator block diagram [3]

Revised Design

Modeling Early Reflections with a Simulated Room Impulse Response

• Replace Tap Delay Network with an FIR filter that simulates the impulse response of a basic rectangular room model.

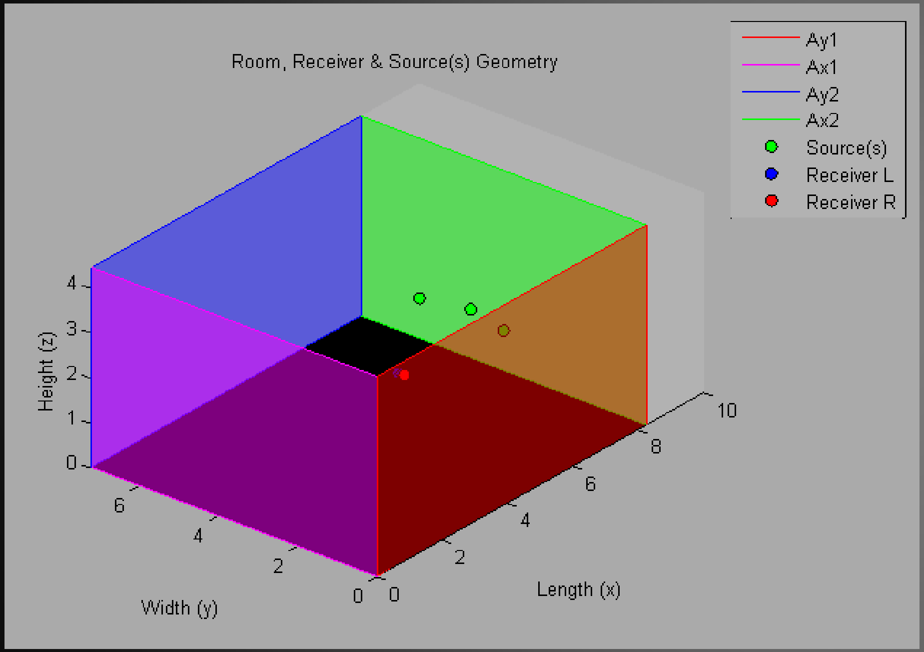
• Convolve the dry signal with the simulated room IR to obtain a more realistic representation of the early reflections. *For added speed, FFT convolution was used*.

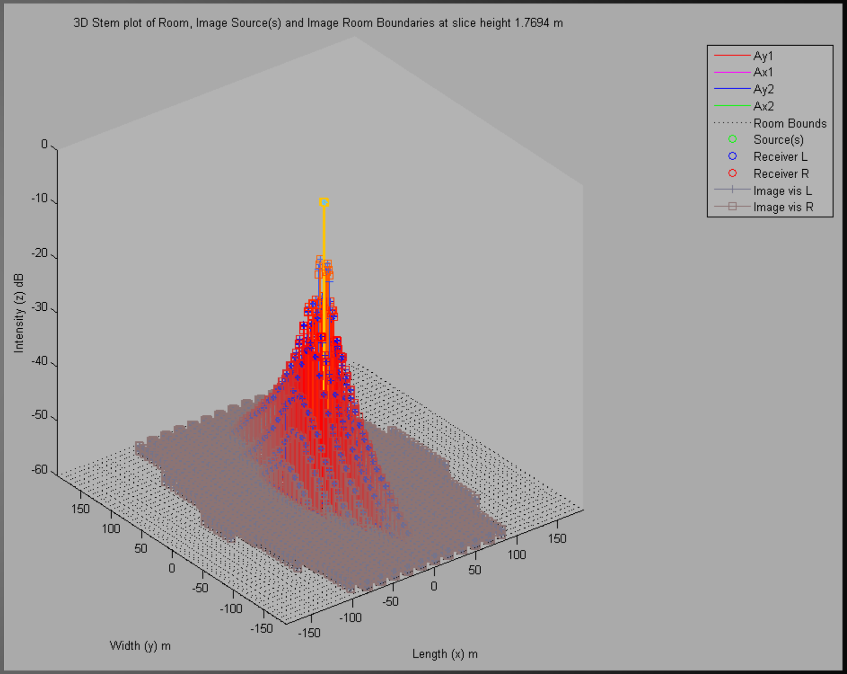
• Feed a mix of the convolved signal with early reflections and dry signal into the late reverb stage (Stage B).

Using this concept, a reasonably realistic reverb can be achieved in a way that is less computationally intensive than pure convolution reverb (convolution of a dry signal with the measured the IR of a real room, or a high order FIR filter).

Revised Design

Modeling Early Reflections with a Simulated Room Impulse Response





Simulated rectangular room layout with 3 sound sources as seen in RoomSim [5] (left), percieved location of early reflections plotted for room layout, (stem height is sound intensity height)[5]

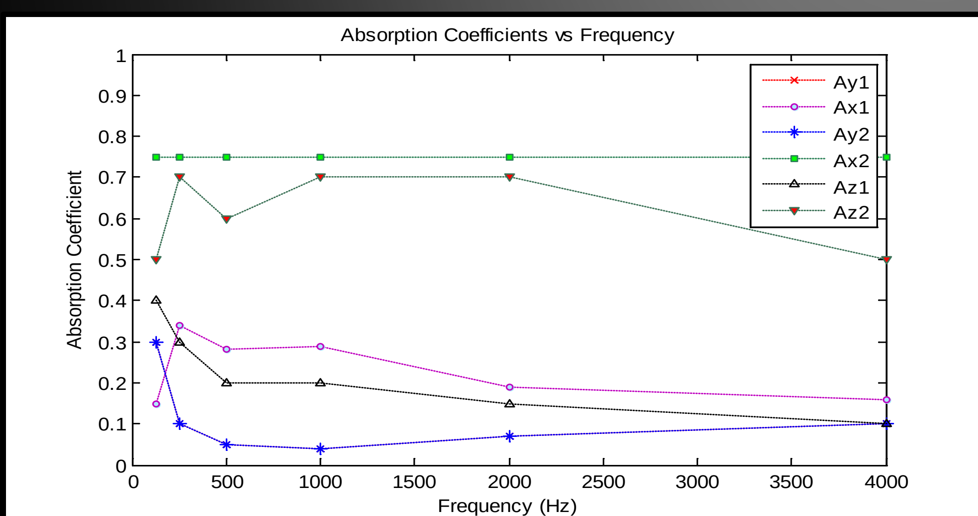
The coefficients for the simulated IR were chosen by applying suitable absorption coefficients to RoomSim [5].

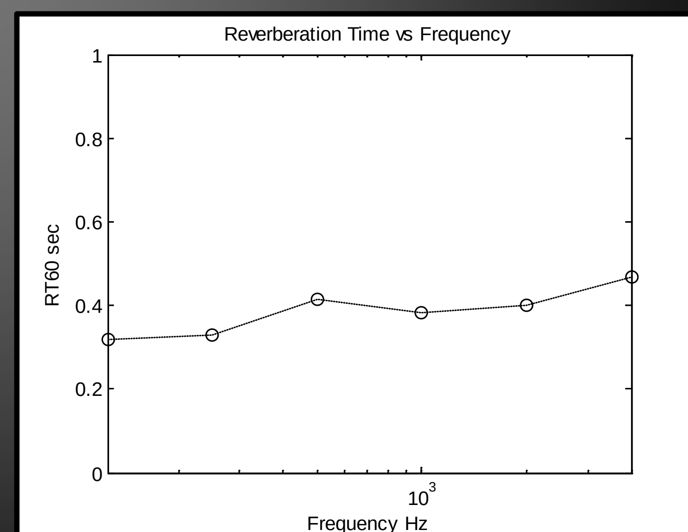
Revised Design

Modeling Early Reflections with a Simulated Room Impulse Response

Table 1: Absorption coefficients used in RT60 and IR simulation

Surface	**Main Surface Material Simulated**	**125 Hz**	**250 Hz**	**500 Hz**	**1000 Hz**	**2000 Hz**	**4000 Hz**
Back Wall (Ax1)	RPG Skyline diffusor (attenuation at 125 Hz added)	0.15	0.34	0.28	0.29	0.19	0.16
Front Wall (Ax2)	hypothetical 50% broadband attenuation (acoustic foam and glass)	0.75	0.75	0.75	0.75	0.75	0.75
Side Wall 1 (Ay1)	gypsum wallboard	0.3	0.1	0.05	0.04	0.07	0.1
Side Wall 2 (Ay2)	gypsum wallboard	0.3	0.1	0.05	0.04	0.07	0.1
Floor (Az1)	varnished cork parquet on joists (floating)	0.15	0.11	0.10	0.07	.0.06	0.7
Ceiling (Az2)	acoustic tile (suspended)	0.5	0.7	0.6	0.7	0.7	0.5





Revised Design

Modeling Early Reflections with a Simulated Room Impulse Response

$$d_{ijk} = \sqrt{x_i^2 + y_j^2 + z_k^2}$$

is the distance to each virtual source

$$u_{ijk}(t) = t - \frac{d_{ijk}}{c}$$

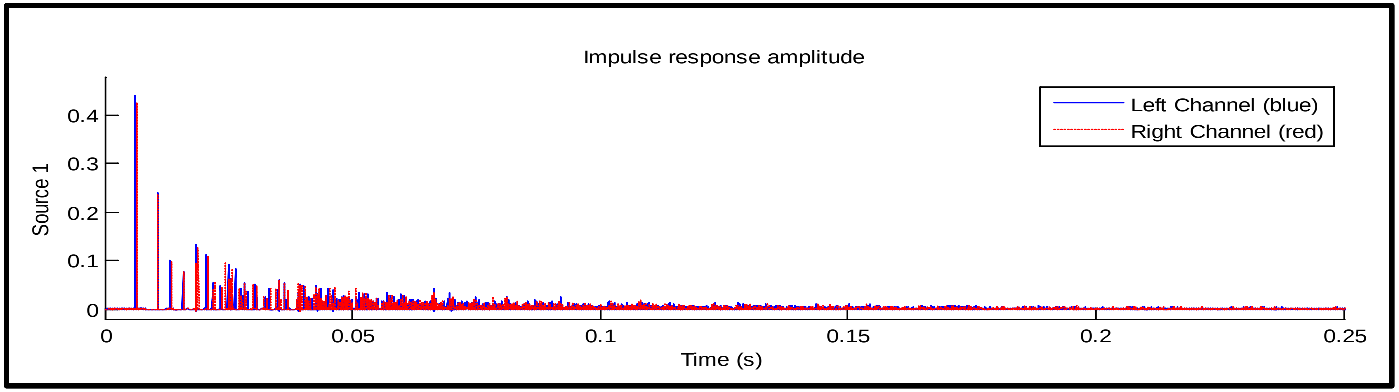
is the unit impulse function of each virtual source

$$h(t) = \sum_{i=-n}^{n} \sum_{j=-n}^{n} \sum_{k=-n}^{n} a_{ijk} e_{ijk}$$

[6]

where $a_{ijk}(u_{ijk}) = \begin{cases} 1, & \text{if } u_{ijk} = 0 \\ 0, & \text{otherwise} \end{cases}$

and $e_{ijk} = b_{ijk} r_{ijk}$ is the magnitude of each echo, and *r* is the total reflection coefficient of the surface (inverse of the absorption coefficient) and

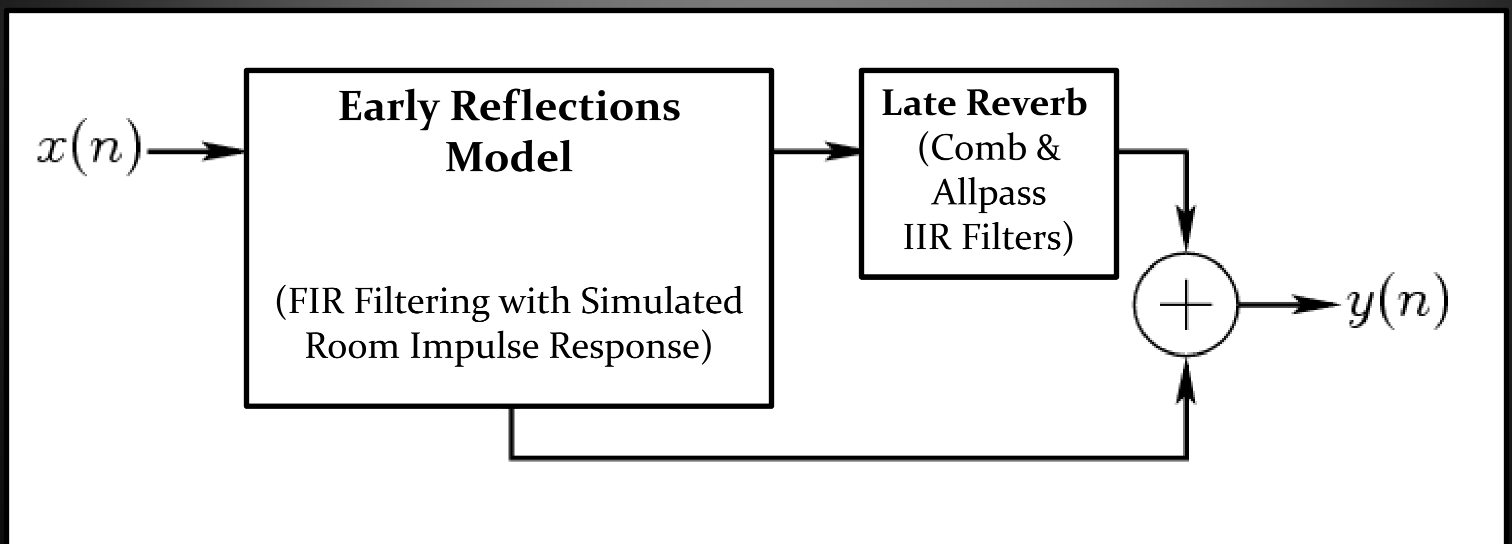


Impulse response for rectangular room model with selected coefficients

Revised Design – A Hybrid Approach

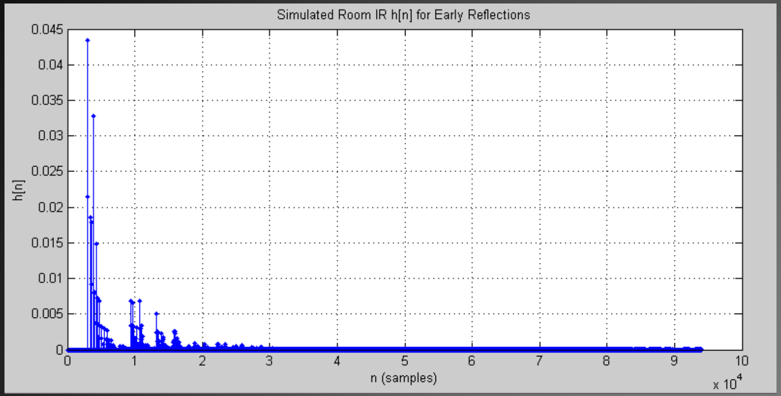
Combining Moorer's reverberator concept with simulated room IR reflection modeling

- Low order FIR filter to model early reflections of simulated room
- IIR based algorithm for late reverb using comb, lowpass, and allpass filters



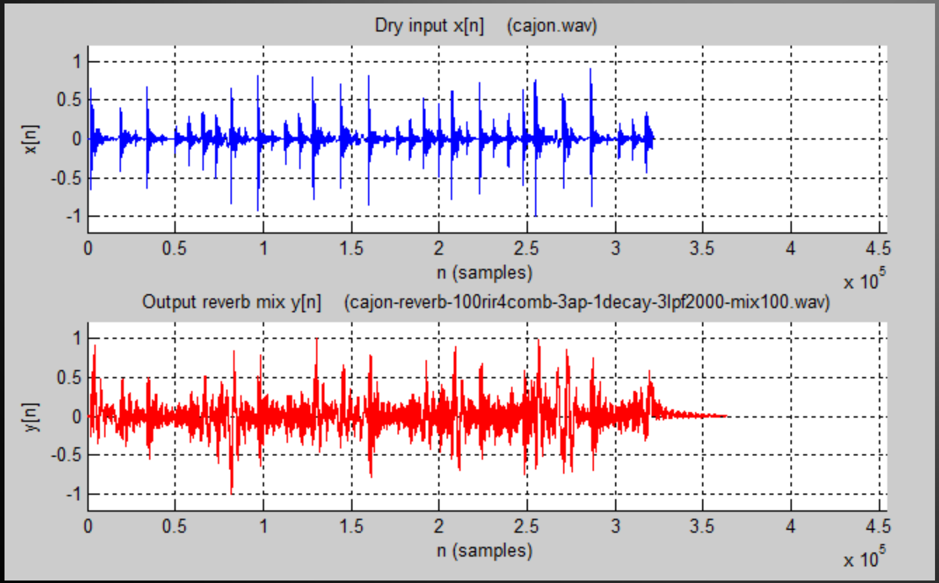
Revised Design – A Hybrid Approach

Stage A: simulated room IR reflection modeling



- Low order FIR filter to model early reflections of simulated room

Stage B: IIR comb, lowpass & allpass filters



- IIR based algorithm for late reverb using comb, lowpass, and allpass filters

References

[1] Leo L. Baranek, " Concert Hall Acoustics—2008*," J. Audio Eng. Soc.,, vol. 56, no. 7/8, pp. 532-544, 2008 July/August.

[2] Sound on Sound, Online Image, 2006 [2009 July 26], Available at FTP: http://www.soundonsound.com/sos/may00/articles/reverb.htm

[3] Udo Zölzer, *DAFX*., (John Wiley & Sons, 2002., West Sussex)

[4] Julius O. Smith (23 July 2009), Spectral Audio Signal Processing, Center for Computer Research in Music and Acoustics (CCRMA) Department of Music, Stanford University, Available at FTP: http://ccrma.stanford.edu/~jos/sasp/

[5] Campbell, D. (06 June 2007), RoomSim acoustic toolbox

[6] McGovern, Stephen G. A Model for Room Acoustics, 2004