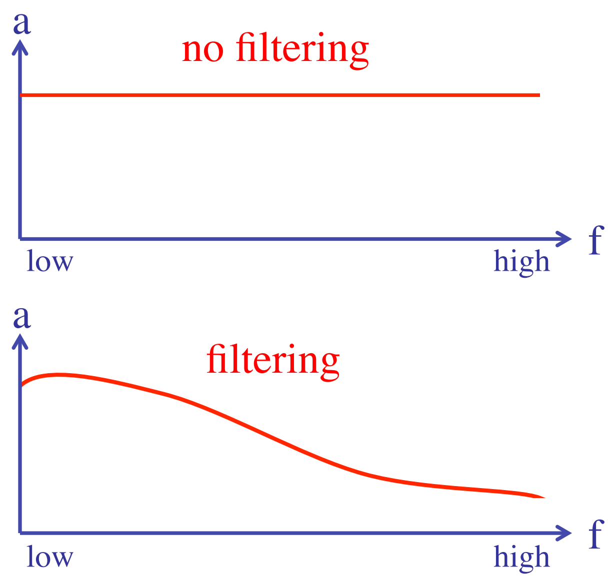
Basic Filters
And
Reverberators

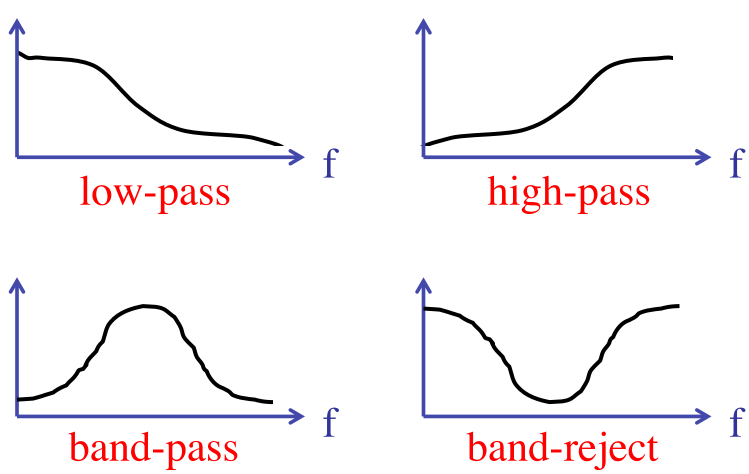
Filter: a frequency-dependant attenuator

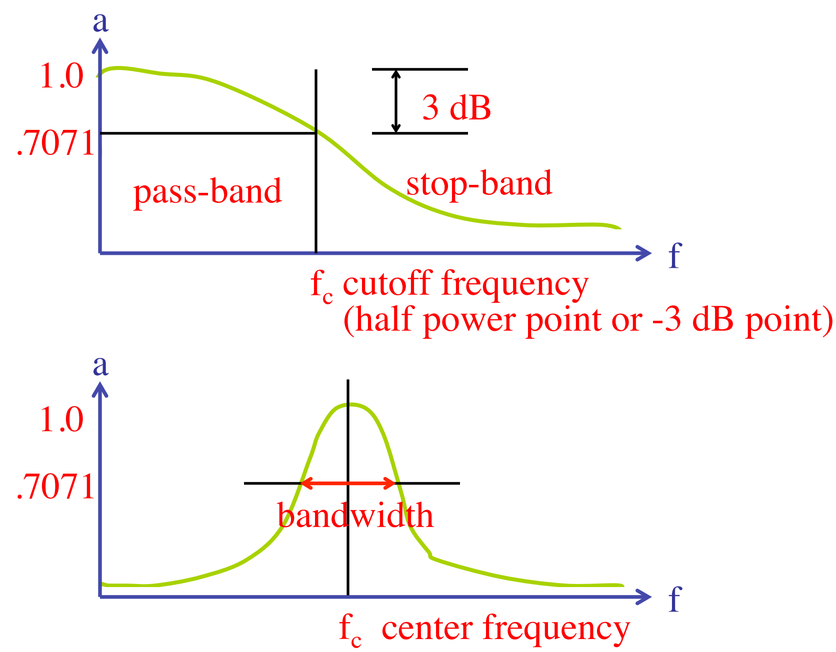
It enhances some frequencies and
diminishes others.

Amplitude Response

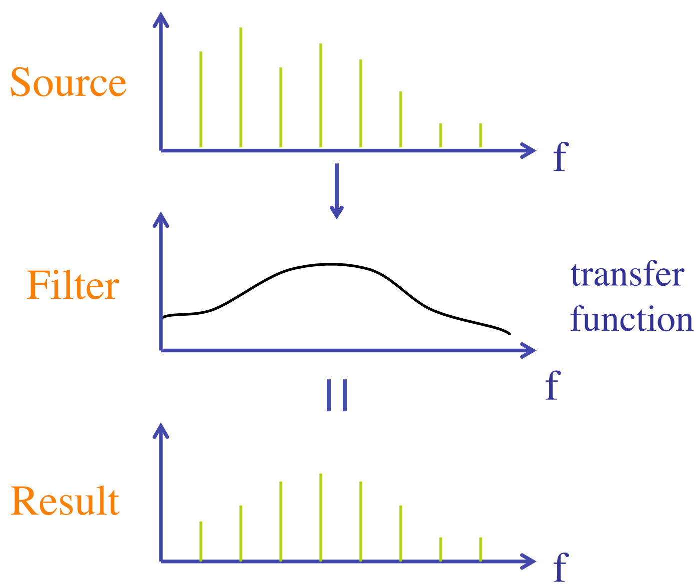


Basic Types of Amplitude Response

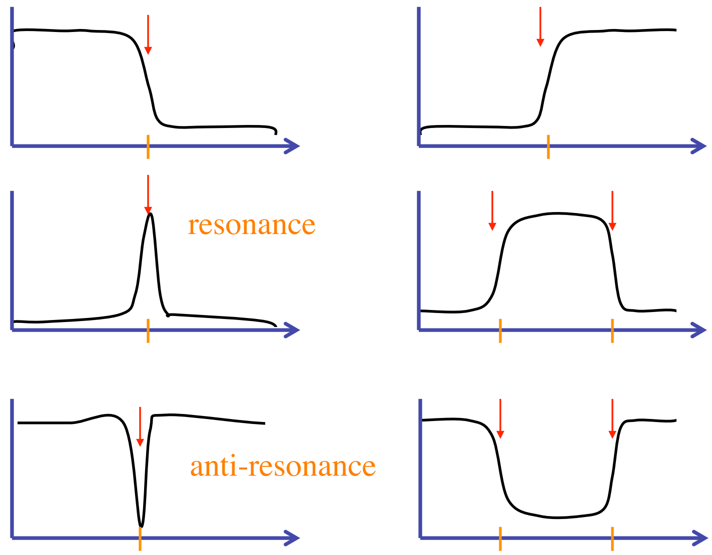




Source/Filter Interaction

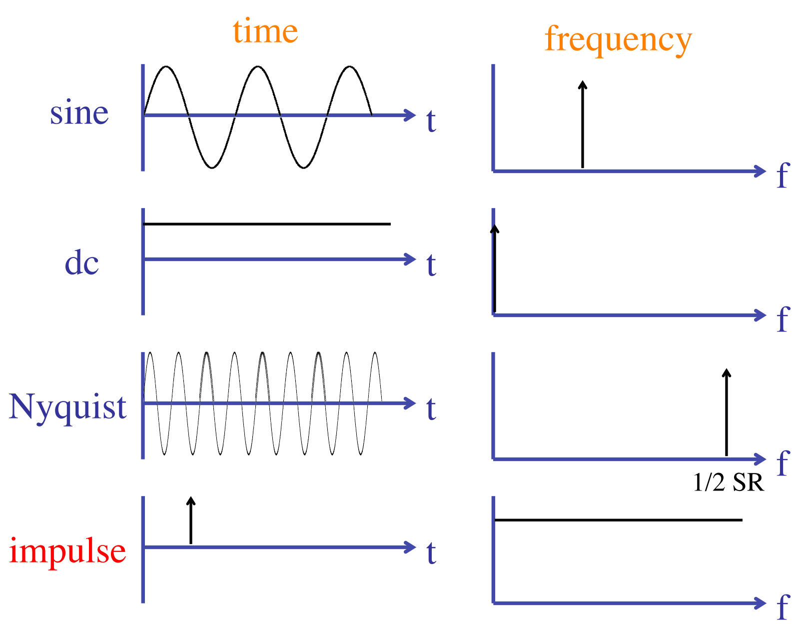


How are they perceived?

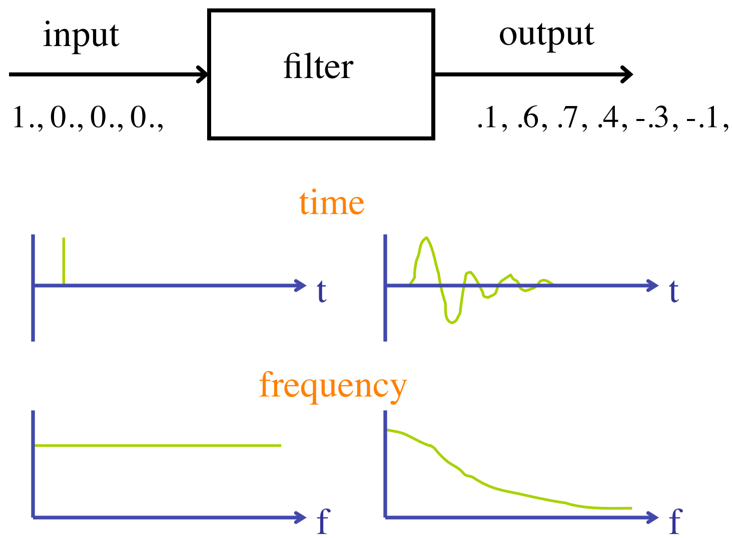


Induced pitch

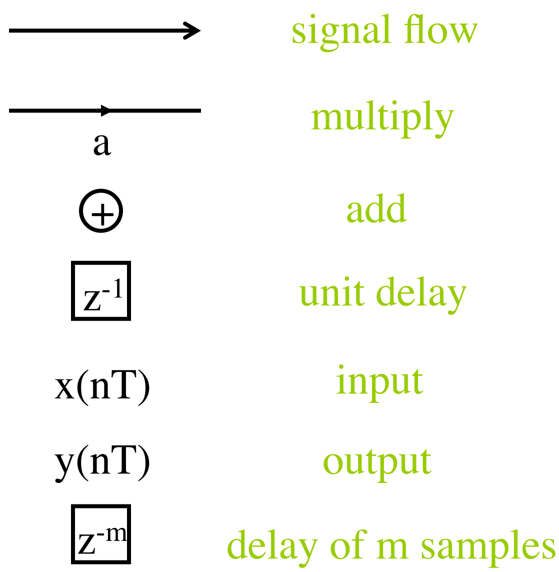
Special Signals



Impulse Response



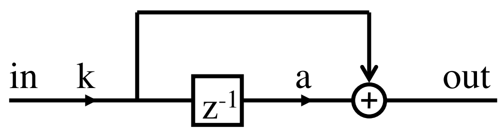
Graphic Symbols



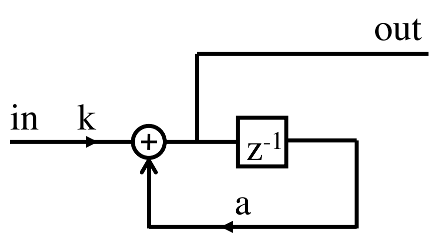
Digital Filters

Two Types

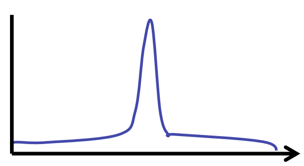
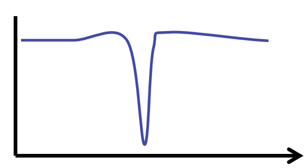
<u>non-recursive</u>
feed forward
"notches"
FIR



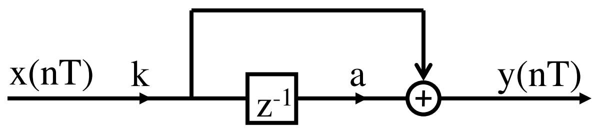
<u>recursive</u>
feed back
"peaks"
IIR



first-order filters

spectral features		
filter type	recursive (poles)	non-recursive (zeros)
acoustic analog	stored energy resonance	cancelled energy anti-resonance

non-recursive



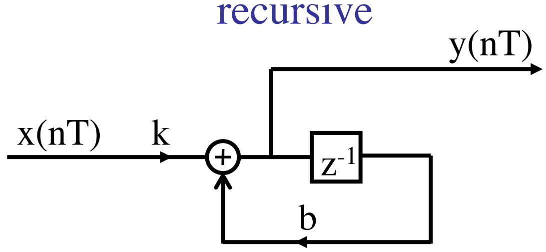
a = 1

n	x(nT)	y(nT)	x(nT)	y(nT)
0	1	1	1	1
1	1	2	-1	0
2	1	2	1	0
3	1	2	-1	0
4	1	2	1	0

a = -1

n	x(nT)	y(nT)	x(nT)	y(nT)
0	1	1	1	1
1	1	0	-1	-2
2	1	0	1	2
3	1	0	-1	-2
4	1	0	1	2

recursive



b = .9

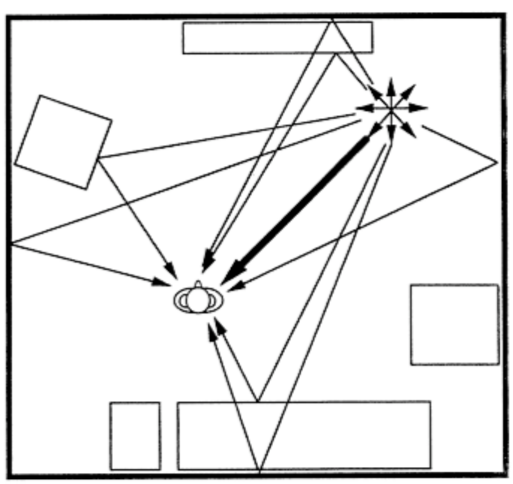
n	x(nT)	y(nT)	x(nT)	y(nT)
0	1	1.0	1	1.0
1	1	1.9	-1	-.10
2	1	2.7	1	.91
3	1	3.4	-1	-.18
4	1	4.1	1	.84
5	1	4.7	-1	-.25

Environmental Acoustics and Computational Simulation

Also known as

REVERB

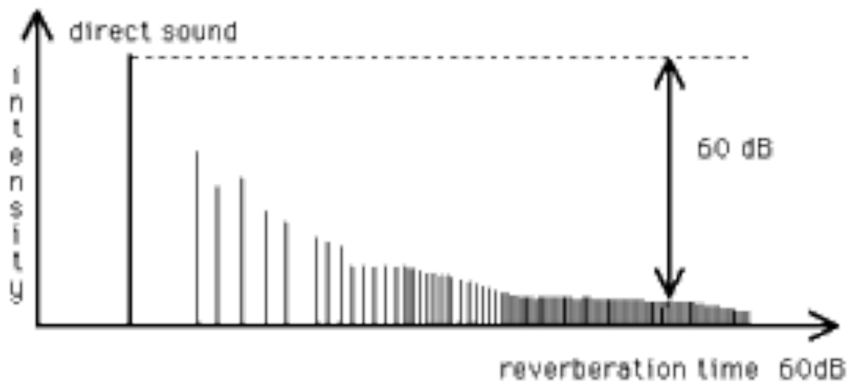
Indirect Sound



Indirect sound exists in all environments though we may not attend to it consciously.

Large-Space Acoustics

We are most able to attend to indirect sound in large-spaces like concert halls or cathedrals.



Reverberation time is the duration in which the indirect sound decreases to -60 dB of the direct sound.

Large-Space Acoustics

Typical reverberation times:

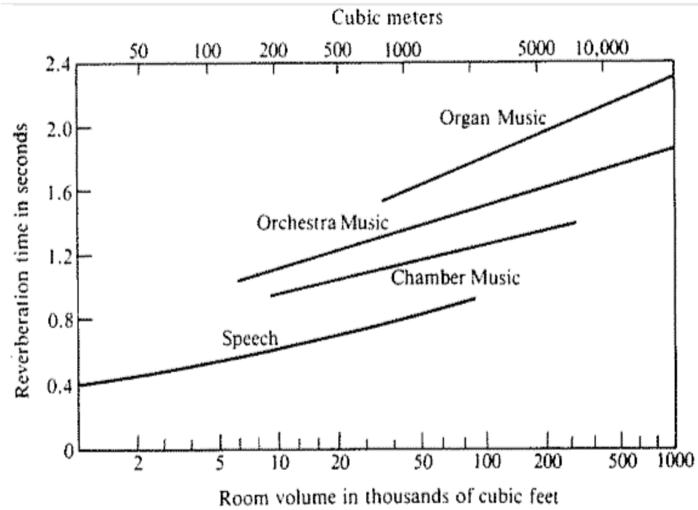
TABLE 23.3 Acoustical characteristics of concert halls

	Year built	Volume (m^3)	Area (m^2)	Number of seats	t_1 (ms) Floor	Balc.	RT (s) 125	500	2000 Hz
Symphony Hall, Boston	1900	18,740	1550	2630	15	7	2.2	1.8	1.7
Orchestra Hall, Chicago	1905	15,170	1855	2580	40	24	—	1.3	—
Severence Hall, Cleveland	1930	15,700	1395	1890	20	13	—	1.7	1.6
Carnegie Hall, New York	1891	24,250	1985	2760	23	16	1.8	1.8	1.6
Opera House, San Francisco	1932	21,800	2165	3250	51	30	—	1.7	—
Arie Crown Theatre, Chicago	1961	36,500	3265	5080	36	14	2.2	1.7	1.4
Royal Festival Hall, London	1951	22,000	2145	3000	34	14	1.4	1.5	1.4
Royal Albert Hall, London	1871	86,600	3715	6080	65	70	3.4	2.6	2.2
Concertgebouw, Amsterdam	1887	18,700	1285	2200	21	9	2.2	2.1	1.8
Kennedy Center, Washington	1971	19,800	1220	2760	—	—	2.5	2.2	1.9

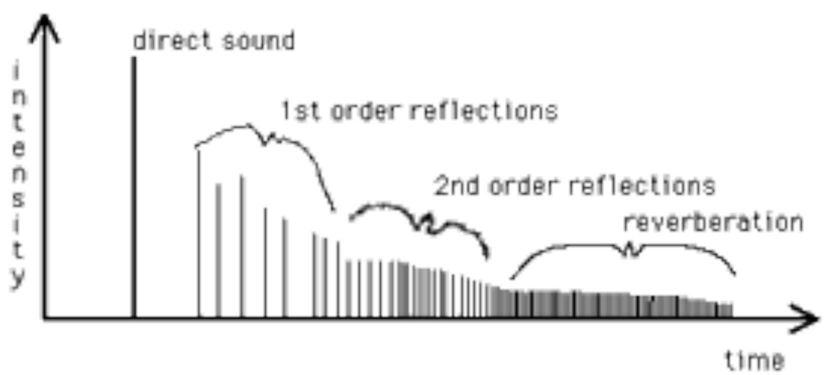
Source: After Beranek (1962).

Large-Space Acoustics

Different kinds of music and sound are best presented with different reverberation times.



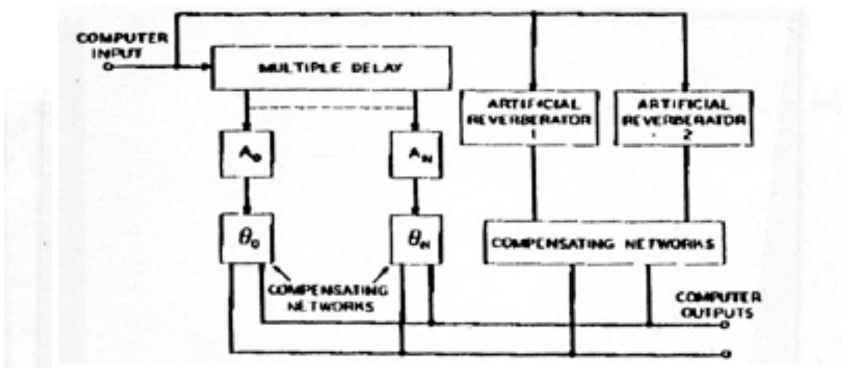
Large-space Acoustics



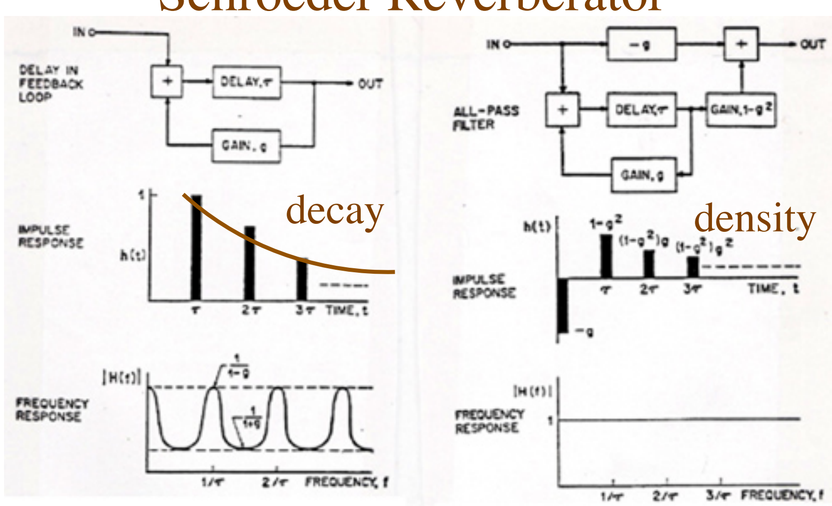
Indirect sound that reflects off of one wall is called a **first-order reflection**, off two walls a **second-order reflection**, etc. As the density of reflections increases, the higher-order reflections merge into the continuous sound with at least 1000 reflections/sec we call **reverberation** or the **late field**.

Reverberation Simulation

By 1963 Manfred Schroeder has perfected the first digital reverberator. His purpose was to simulate concert hall acoustics including a multiple delay line to simulate the initial first- and second-order reflections.

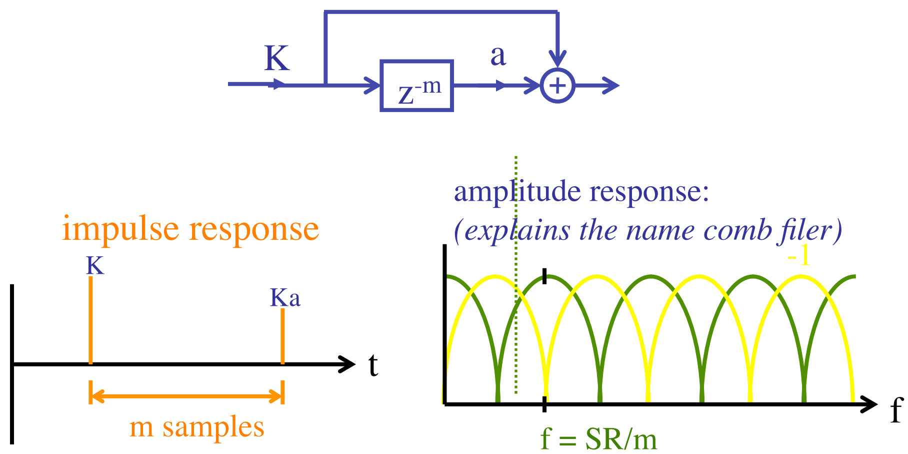


Schroeder Reverberator

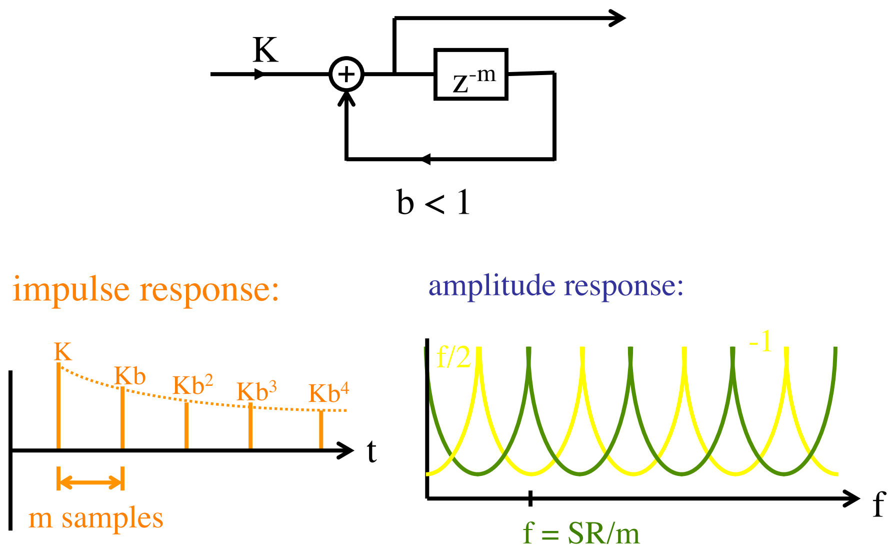


Schroeder's basic building blocks were the **delay line** (a **non-recursive comb filter**), the **recursive comb filter** and the **all-pass comb filter**.

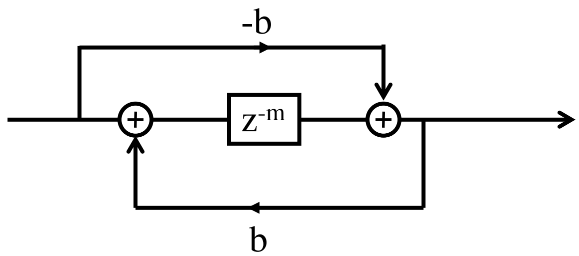
Delay line: Non-recursive Comb Filter



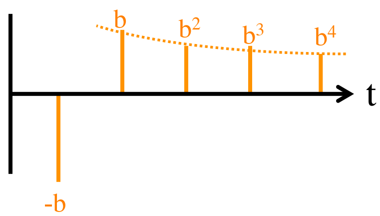
Recursive Comb Filter



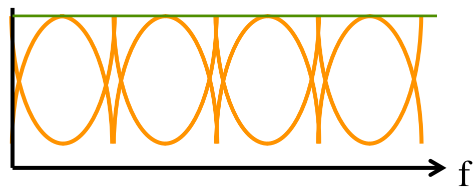
All-pass Comb Filter



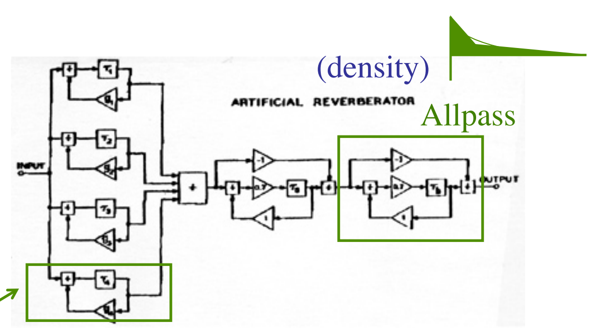
impulse response



amplitude response is constant:
(recursive and non recursive parts cancel each other)

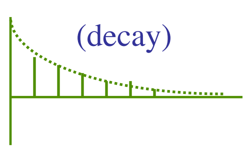


Schroeder Reverberator

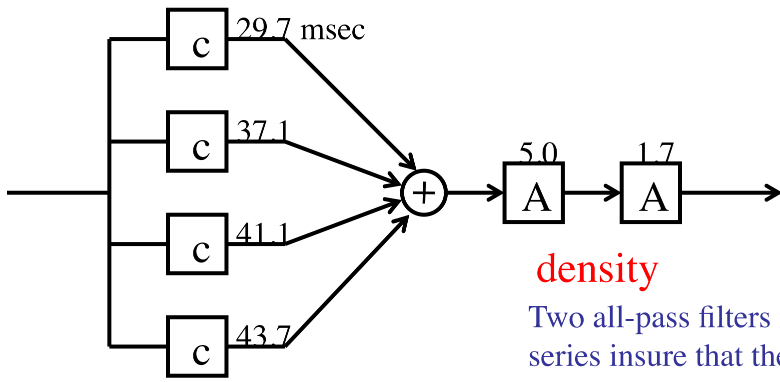


Block diagram of a single channel (monophonic) reverberator

recursive comb



Schroeder Reverberator



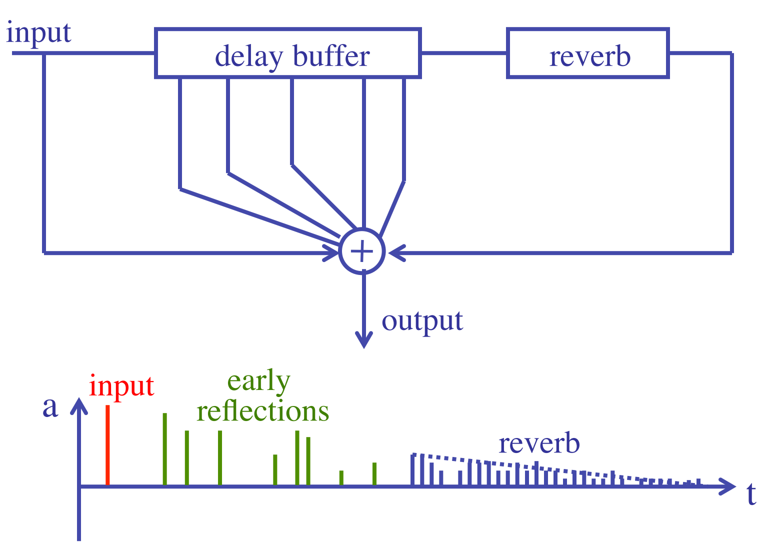
decay

Four recursive comb filters in parallel determine the reverb time

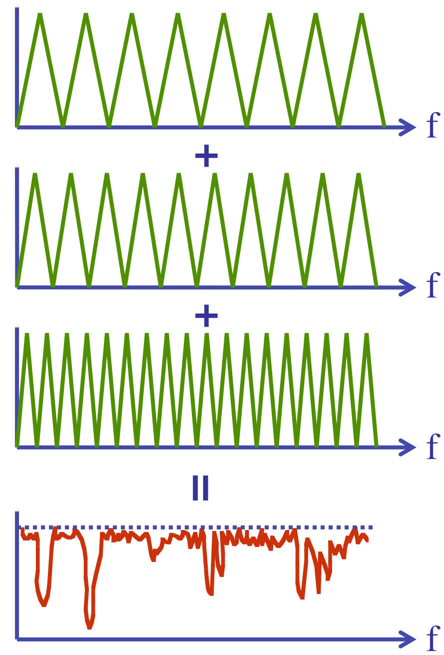
density

Two all-pass filters in series insure that there are 1000 reflections/sec.

Early Reflections



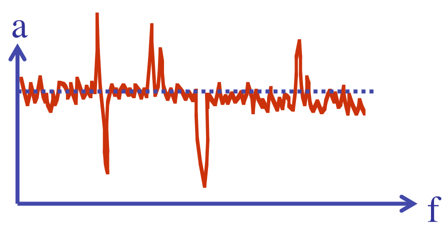
Summation of recursive comb filters should approximate a flat response



Problems

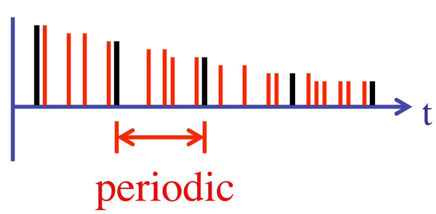
1)

Response is not flat



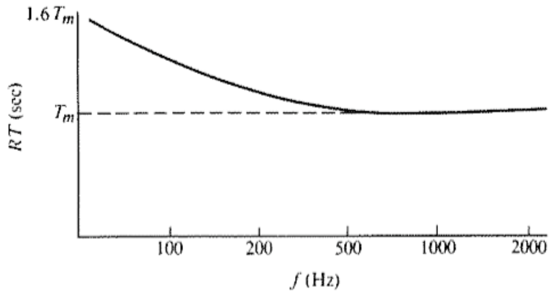
2)

Impulse response has periodicities that produce pitch percepts



Air and Wall Absorption

Air and wall absorption combine to create a reverberation time that is frequency dependent. For concert halls the low-frequency reverberation time is longer:



Air and Wall Absorption

TABLE 23.2 Sound absorption by people and seats, and air absorption

Material	125	250	500	1000	2000	4000	8000	Unit*
					Frequency (Hz)			
Wood or metal seats, unoccupied	0.014	0.018	0.020	0.036	0.035	0.028		m^2
Upholstered seats, unoccupied	0.13	0.26	0.39	0.46	0.43	0.41		m^2
Audience in upholstered seats	0.27	0.40	0.56	0.65	0.64	0.56		m^2
Air absorption (per m^3):								
20°C, 30%	—	—	—	—	0.012	0.038	0.136	
20°C, 50%	—	—	—	—	0.010	0.024	0.086	

Air absorption and the absorption of walls, seats and people help to shape the reverberation.

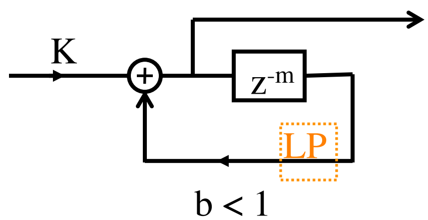
Air and Wall Absorption

In everyday environments the building materials have a strong impact on reverberation of the acoustic environment.

TABLE 23.1 Absorption coefficients for various materials

	Frequency (Hz)					
Material	125	250	500	1000	2000	4000
Concrete block, unpainted	0.36	0.44	0.31	0.29	0.39	0.25
Concrete block, painted	0.10	0.05	0.06	0.07	0.09	0.08
Glass, window	0.35	0.25	0.18	0.12	0.07	0.04
Plaster on lath	0.14	0.10	0.06	0.05	0.04	0.03
Plywood paneling	0.28	0.22	0.17	0.09	0.10	0.11
Drapery, lightweight	0.03	0.04	0.11	0.17	0.24	0.35
Drapery, heavyweight	0.14	0.35	0.55	0.72	0.70	0.65
Terrazzo floor	0.01	0.01	0.02	0.02	0.02	0.02
Wood floor	0.15	0.11	0.10	0.07	0.06	0.07
Carpet, on concrete	0.02	0.06	0.14	0.37	0.60	0.65
Carpet, on pad	0.08	0.24	0.57	0.69	0.71	0.73
Acoustical tile, suspended	0.76	0.93	0.83	0.99	0.99	0.94
Acoustical tile, on concrete	0.14	0.20	0.76	0.79	0.58	0.37
Gypsum board, one-half inch	0.29	0.10	0.05	0.04	0.07	0.09

Air and Wall Absorption



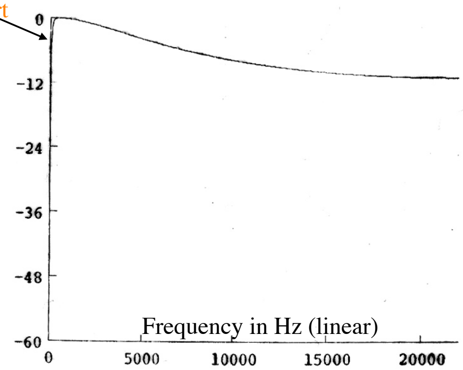
Moorer suggests putting low-pass filter in the feedback loop of the recursive comb filter in order to simulate air and wall absorption. This causes the high frequencies in the reverberation to die out before the low frequencies.

Air & wall absorption filter

Usually the low-pass filter inserted into the recursive comb filter is a first-order filter. Here is a second-order filter that is more accurate.

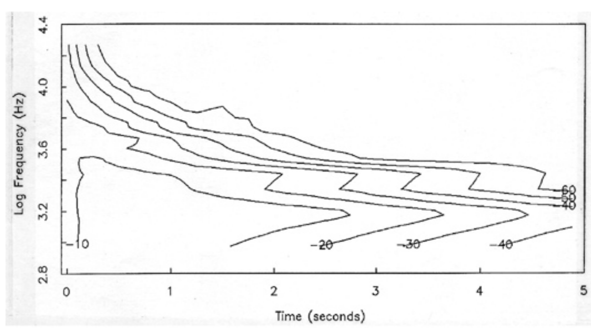
Low-frequency loss (not present in concert halls but present in other kinds of construction)

Power in dB

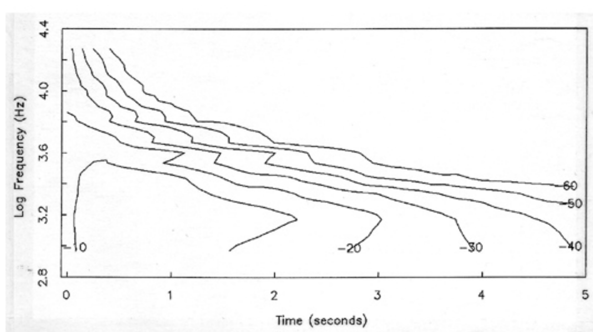


Comparison of simulated and actual rooms

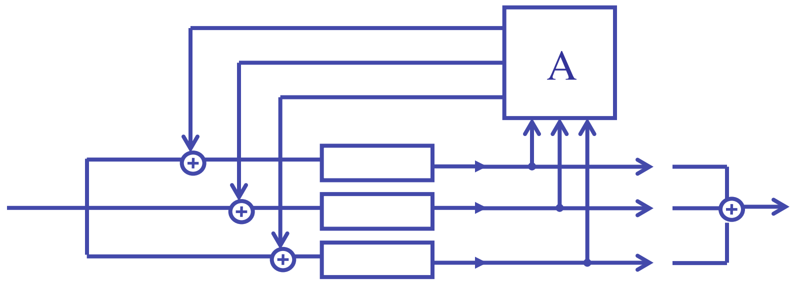
simulated



real

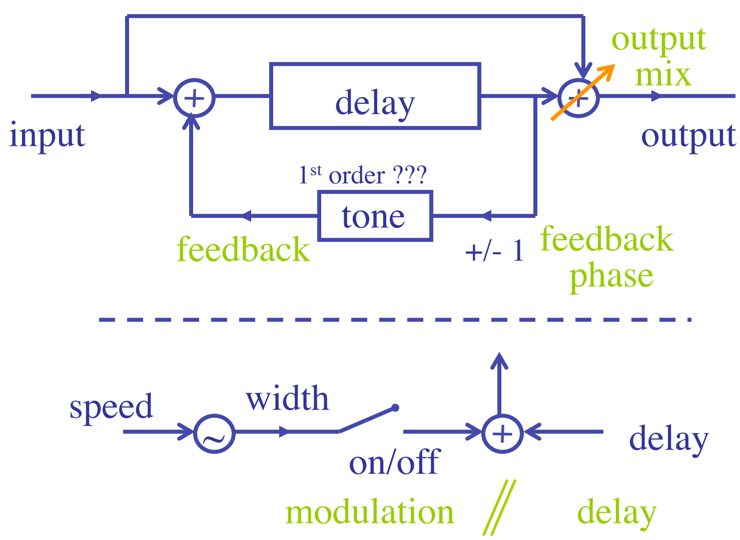


Feedback Matrix

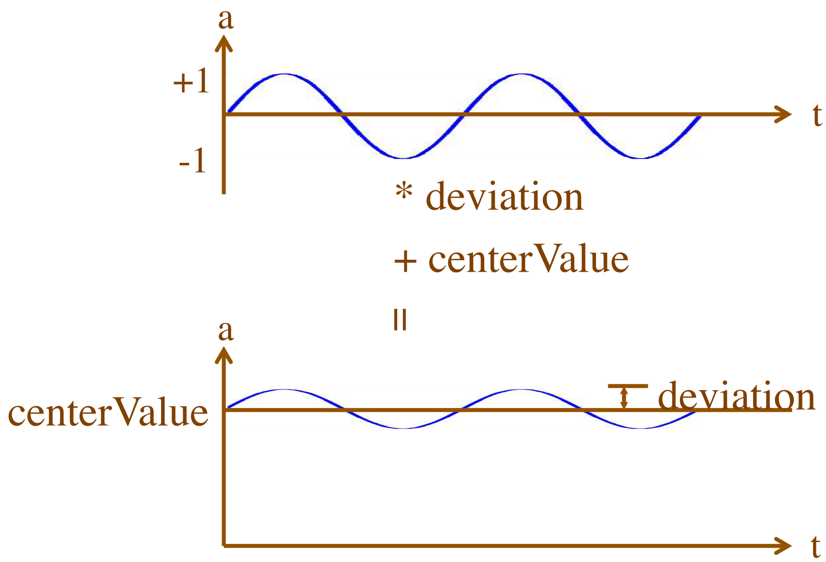


Strautner & Puckette 1982
Jot & Chaigne 1991

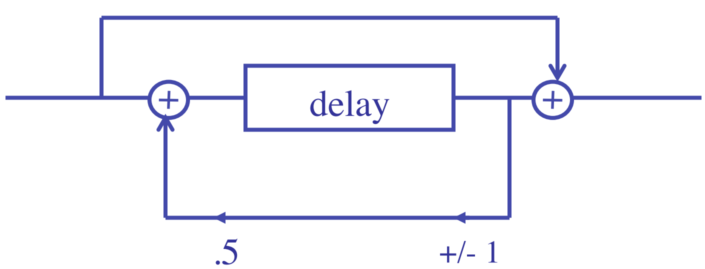
Generic Effects Processor



Control Signals/Modulators



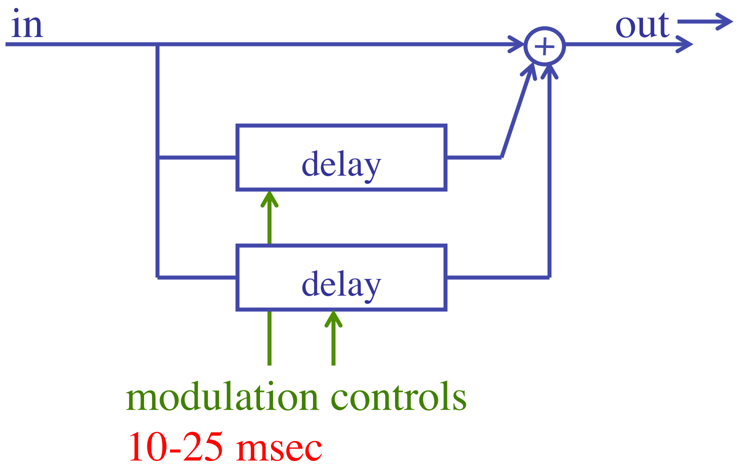
"Flanging"



+1 metallic, zingy
-1 whoosh, hollow

delay	
5 ms	200 Hz
↕	
20 ms	50 Hz

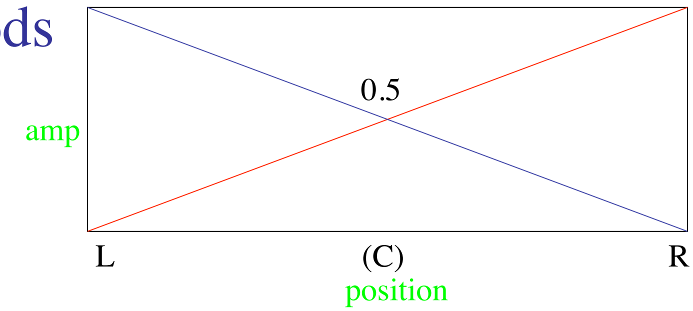
Chorusing



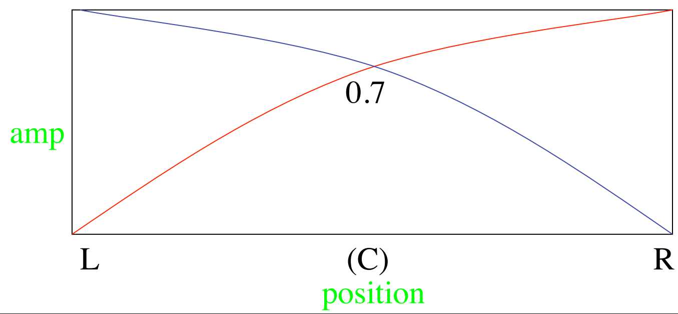
Panning and Positioning

Panning Methods

Amplitude Panning



Intensity or Power Panning



Panning Methods

Near-field Monitoring:

Greatest accuracy:

Low Frequencies:
amplitude panning

High Frequencies:
power panning

Large-space Monitoring:

power panning