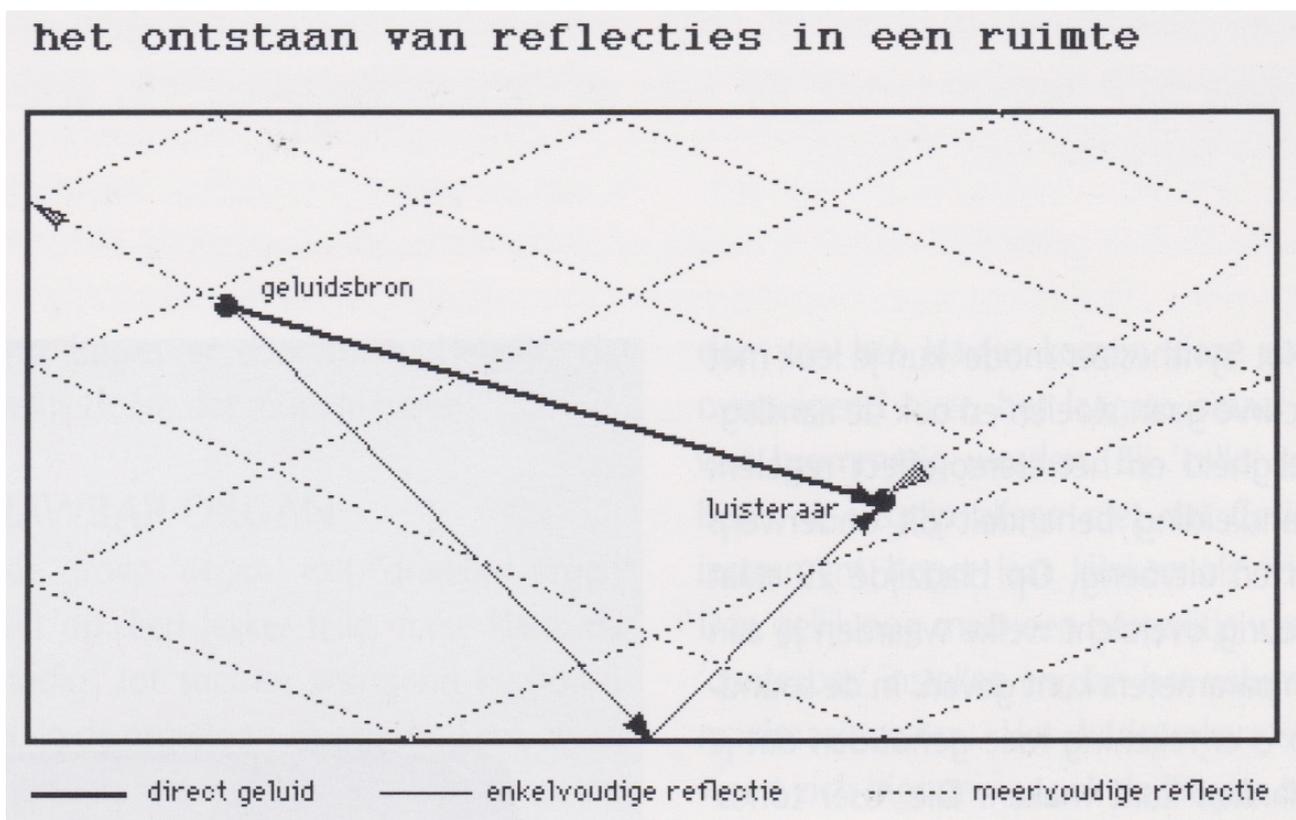


Mother of all Artificial Reverberations

Martin Schroeder's Reverb Schematic (1962) Based on comb filters and all pass filters, variants of the time delay element

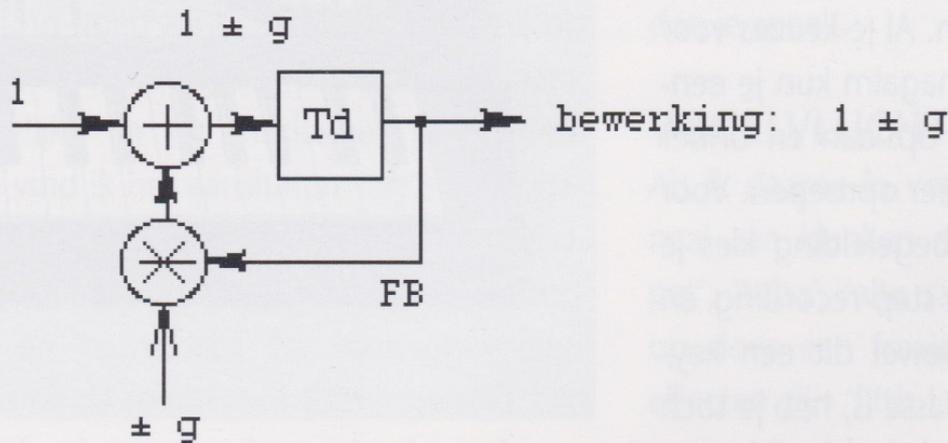
Echoes

Simply put, we can say that reverberation in a room is caused by reflections of the sound by walls, ceiling and floor. These reflections can be regarded as separate echoes, which over time are increasing in density so that in the end we experience it as one diffuse reverberation. In the image below a simplified version of how that happens. First of all we hear the direct signal from the source. Then the simple, early reflections. Subsequently multiple reflections arise, the three-dimensional reflections through walls, ceiling and floor.

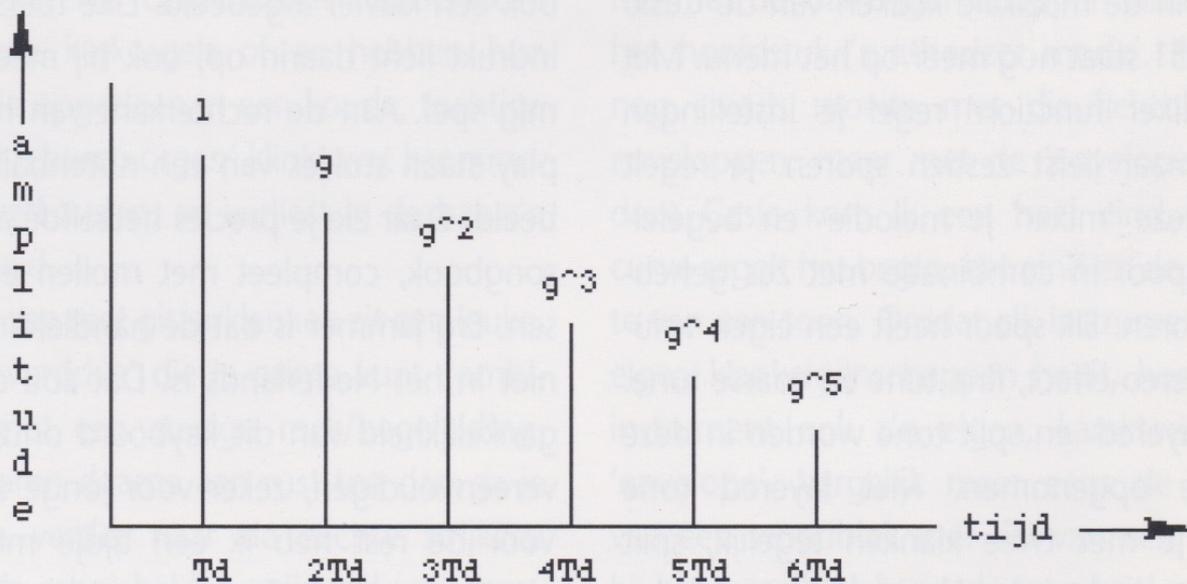


Comb filter

With only one comb filter simple echoes can be simulated. The heart of such a comb filter is formed by a time delay (T_d). In the picture we see the basic diagram that indicates how such a comb filter is composed. The bottom picture shows the so-called impulse response (the echoes) over time. At the height of the bars we see how the echo signal decreases over time in volume. We also see that these echoes are totally regular: in time intervals that are only determined by the chosen time delay values.



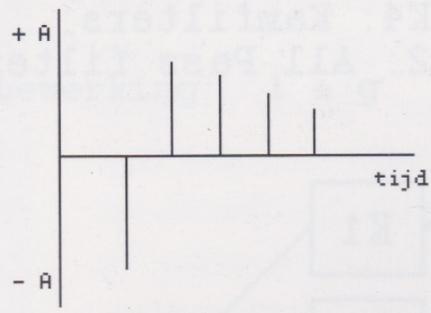
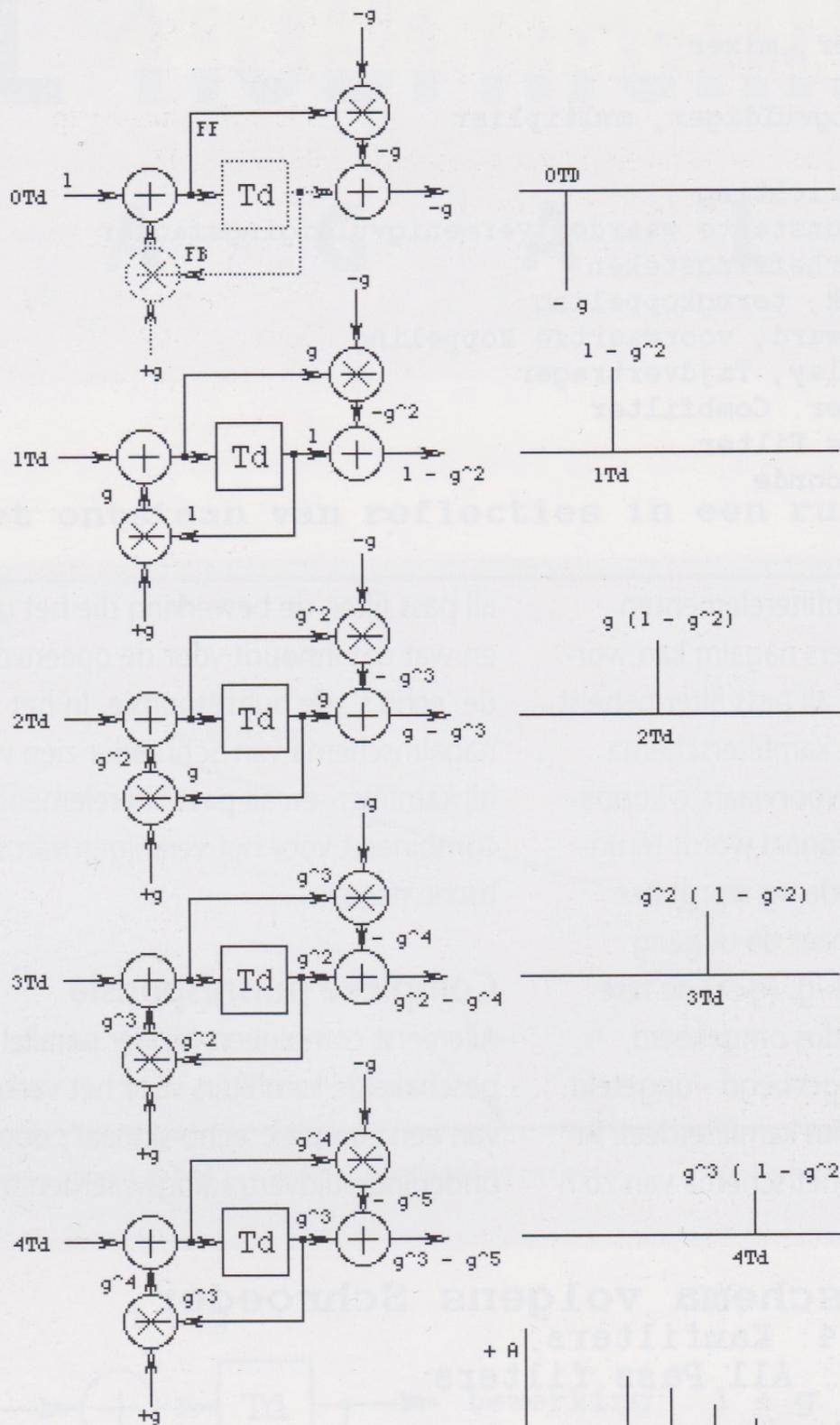
Time delay, pulsresponsies bij positieve feedbackwaarde van g



Schroeder's artificial reverberation

Manfred Schroeder was the first to publish a diagram showing how reverberation can be achieved with multiple comb filter elements in combination with all pass filters. Such an all pass filter entails an extension of the comb filter scheme with a so-called feed forward link.

all pass filter, werking en pulsresponsie-volgorde

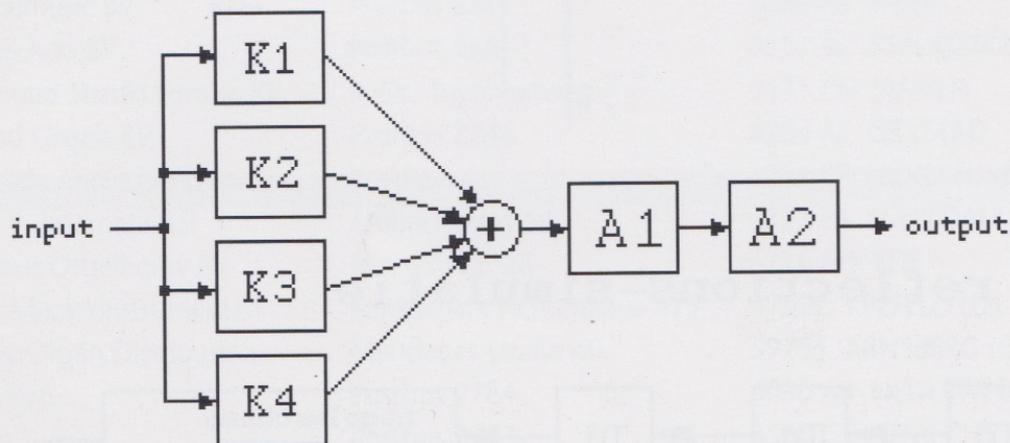


Besides that the signal is returned with the value $+g$, the input signal is also fed directly to the output with a value $-g$ ($g < 1$). The phase is thus reversed and merged, summed, with the output of the comb filter part.

In the illustration we see the diagram of such an all pass filter, the operation it performs and what that means for the successive 'echoes', the impulse response. In Schroeder's reverberation scheme, we see how he combines comb filter and all pass filter elements to obtain synthetic reverberation.

nagalmschema volgens Schroeder

K1 t/m K4: Kamfilters;
A1 en A2: All Pass filters



instellingen voor een middelgrote concertzaal:

K1, 29,7 ms
K2, 37,1 ms
K3, 41,1 ms
K4, 43,7 ms
A1, 5,0 ms
A2, 1,7 ms

formule voor de nagalmtijd: $T_n = 60/g * T_d$

T_n : nagalmtijd
 T_d : tijdsvertraging
 g : verzwakking in dB's

Complex impulse response

First of all, he combines four parallel-connected comb filters to obtain a complex 'echo signal', by choosing the respective time delay values. He relates the mutual time delay settings according to prime number ratios. This is important in order to avoid as much as possible coloration in the simulated reflections.

Coloring

With simple time delay ratios these can easily arise. For example, we propose the following four time relationships: 1, 2, 3 and 4 milliseconds. This gives us a self-repeating echo pattern of $1 \times 2 \times 3 \times 4 = 24$. The pattern is repeated after 24 ms. A number of impulse responses of the various comb filters coincide and thus reinforce each other. This produces an annoying audible phenomenon: coloring.

Prime number ratios

This is prevented by choosing, as stated, prime number ratios. With values from the example of Schroeder, 29.1, 37.1, 42.1 and 43.7 we obtain a pattern that is 1912431.95 ms long. That amounts to a repetition time of almost 32 minutes. Plus, there are no coincident pulse responses! Part of the reverberation problem has now been solved. In this way Schroeder has realized such a complex reflection pattern that it passes as an approach to an acoustic reality.

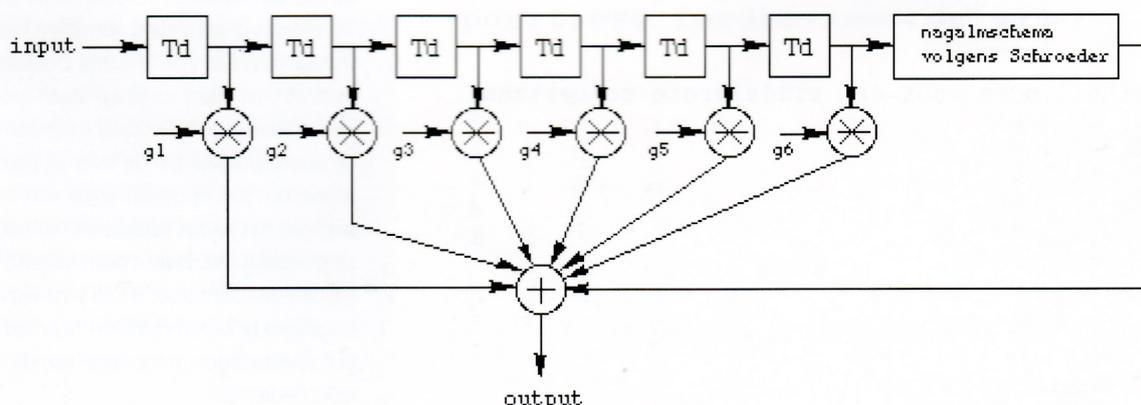
Increasing reflection density

However, what has not yet been solved is the diffusivity of the reflections, increasing the density of the successive impulse responses. Schroeder uses two all pass filters in series for this purpose. The complex impulse response of the four comb filters is fed to these all pass filters. The signal will appear directly at the output via the forward link. Because the all pass filters are switched sequentially, in series or in cascade, the pulse response of the two all pass filters are not added, but multiplied. In this manner, the total number of reflections increases greatly. By choosing successively smaller values for the all pass time delays, Schroeder realizes a consecutive increase in reflection density.

Early reflections

There still remains a problem: there aren't any credible early reflections yet. However, these are very essential for a realistic reverberation experience. Schroeder proposes a scheme for this, which consists of a number of simple time delay elements, which are connected in series and after each time delay are branch off and mixed together. This is now placed for the original reverberation scheme. The whole can be further improved by including low pass filters in the feedback loop of the comb filters. In this way we can realize an increasing absorption of the higher frequencies.

cascade delay t.b.v. early reflections-simulatie



10 ms: reflectieweg van 3,45 meter

realistische waarden voor vroege reflecties (early reflections): 10 - 100 ms

verklaring van de symbolen en afkortingen



opteller, mixer



vermenigvuldiger, multiplier



signaalrichting

g : gain, constante waarde, vermenigvuldigingsfactor

^ : machtverheffingsteken

FB: feedback, terugkoppeling

FF: feedforward, voorwaartse koppeling

Td: Time delay, Tijdvertrager

K : Kamfilter. Combfilter

A : All Pass Filter

ms: milliseconde

Further reading

http://www2.ece.rochester.edu/~zduan/teaching/ece472/reading/Schroeder_1962.pdf

https://en.wikipedia.org/wiki/Manfred_R._Schroeder

Internet

MTurboReverb tutorials (highly recommended)

[https://www.youtube.com/watch?](https://www.youtube.com/watch?reload=9&v=o9eMmpuhz1M&index=4&list=PLDzk3D8LGAAnBLegmUTS1PPRKY9BYwZD1)

[reload=9&v=o9eMmpuhz1M&index=4&list=PLDzk3D8LGAAnBLegmUTS1PPRKY9BYwZD1](https://www.youtube.com/watch?reload=9&v=o9eMmpuhz1M&index=4&list=PLDzk3D8LGAAnBLegmUTS1PPRKY9BYwZD1)

Valhalla DSP:

<https://valhalladsp.com/2011/01/21/reverbs-diffusion-allpass-delays-and-metallic-artifacts/>

Gearslutz Reverb Subculture forum:

<https://www.gearslutz.com/board/geekslutz-forum/380233-reverb-subculture-23.html>