

Application Note AN3201-04: Reverberation Algorithm **by Frank Thomson and Chris Maple**

Introduction

There are several approaches to designing a reverb algorithm, of which three are predominant. The first is to model a physical space, whether it corresponds to a real space or not (see Application Note AN3201-05). Another is to create a complex digital filter using plenty of delay, adjusting it to create the desired sonic characteristics without regard to a physical model. A third approach – illustrated in this application note – is a blend of the first two, modeling reality to some extent but not requiring the resulting algorithm to emulate a defined physical space.

The reverb algorithm shown here was derived from information freely available from various sources on the internet, and is similar to the Schroeder-Moorer model. There are three sections:

- i) An early reflection simulator, which combines the direct sound with seven weighted and delayed versions to mimic first arrival sounds
- ii) A room mode simulator, consisting of a bank of four parallel comb filters with various delay times, gain, and with embedded lowpass filters
- iii) An allpass filter to increase the reflection density by smearing and decorrelating the output of the comb/lowpass filter bank.

Multiplier and delay coefficients were chosen to provide a good scattering of values while using up most of the available delay memory.

Our experience in designing this algorithm is instructive, and typical of much of this type of development. During our listening tests, for example, we found that the overall gain had to be reduced to eliminate audible clipping. Even so, the reverb sounded muddy and boomy. To correct for this, the ratio of dry to reflected audio was increased, which cleaned up the sound, leaving it intelligible with satisfying reverb. Finally, a signal generator and oscilloscope were used to further wring out the program, resulting in some additional gain reduction to prevent clipping in most circumstances.

Algorithm

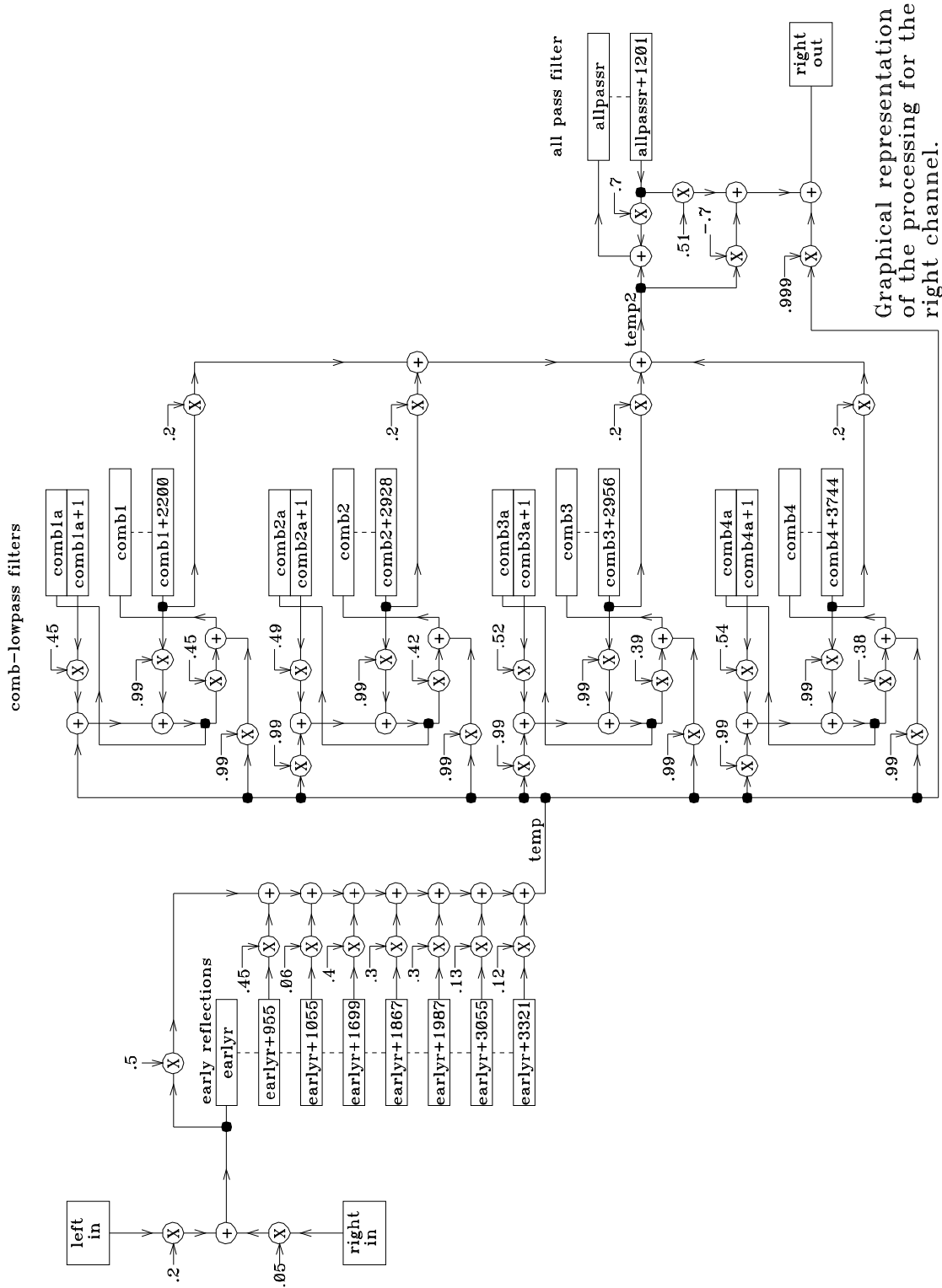
To start off, 25% of the left input is added to the right input and vice versa. This is reasonable considering the amount of mixing that will actually occur in an acoustical environment. From there, each channel is treated completely independently, even for room reverberant modes.

The early reflection section consists of a 3321 stage delay line with weighted taps at various delays ranging from 955 to 3321 sample periods (at 48kHz this gives delays from 20.7 to 69.2 ms, corresponding to 22.4 to 78 feet, assuming 0% relative humidity and 70°F). These reflection signals are summed with the dry signal and fed to the four comb/lowpass filters, which model room reverberant modes. Delays in these filters run from 2200 to 3744 samples, corresponding to dimensions of 51.7 to 87.9 feet. Depending upon room shape and listener positioning, the actual room dimensions associated with the filters could be half those lengths, because the full cycle of a reverberant mode is from a wall to the opposite wall and back again.

The output of the four comb-lowpass filters are summed and the result fed through an allpass filter which is, in turn, added to the "dry + early reflection" audio and sent to the output.

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The allpass filter does not correspond to common physical features, but it works well in electronic reverbs. The summing of early reflections, along with the summing of room mode signals, leads to large peaks and very substantial dips in the frequency response, all to the effect of some nice echoes. To prevent clipping on the peaks, gain must be reduced and thus the overall signal-to-noise ratio suffers. The phase shift of the allpass filter helps smooth some of the peaks, at the same time adding to the apparent “density” of the reverberant soundfield.



Graphical representation of the processing for the right channel.


```

; Comb filter 3
RZP temp K=.99
RAP comb3a' k=.52 ;tail * k + acc
RAP comb3' k=.99
WAP comb3a k=0
WZP temp2 k=.39
RAP temp k=.99
WAP comb3 k=0 ;write to head
; Comb filter 4
RZP temp K=.99
RAP comb4a' k=.54 ;tail * k + acc
RAP comb4' k=.99
WAP comb4a k=0
WZP temp2 k=.38
RAP temp k=.99
WAP comb4 k=0 ;write to head
;
;Sum outputs of comb filters
RZP comb1' k=.2
RAP comb2' k=.2
RAP comb3' k=.2
RAP comb4' k=.2
;
; All-pass
WAP temp2 k=0
RAP allpassr' k=.7
WZP allpassr k=0
RZP temp2 k=-.7
RAP allpassr' k=.51
;
; Add in early reflections
RAP temp k=0.999
;
; Write to the output
WAP OUTR K=0 ;Write it to the DAC
;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;
;Read ADC in and write to the early reflection memory
RZP ADCL K=0.2
RAP ADCR K=.05
WAP earlyl K=.5
RAP earlyl+955 K=.45
RAP earlyl+955 K=.06
RAP earlyl+1699 K=.4
RAP earlyl+1867 K=.3
RAP earlyl+1987 K=.3
RAP earlyl+3055 K=.13
RAP earlyl' K=.12 ; Early reflection plus dry in accumulator
;
; Comb filters
; Comb filter 1
WAP temp K=0 ;Save accumulator
RAP comb11a' k=.45 ;tail * k + acc
RAP comb11' k=.99
WAP comb11a k=0
WZP temp2 k=.45
RAP temp k=.99
WAP comb11 k=0 ;write to head
; Comb filter 2
RZP temp K=.99
RAP comb21a' k=.49 ;tail * k + acc
RAP comb21' k=.99
WAP comb21a k=0
WZP temp2 k=.42
RAP temp k=.99
WAP comb21 k=0 ;write to head

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; Comb filter 3
RZP  temp      K=.99
RAP  comb31a'  k=.52      ;tail * k + acc
RAP  comb31'   k=.99
WAP  comb31a   k=0
WZP  temp2     k=.39
RAP  temp      k=.99
WAP  comb31    k=0      ;write to head
; Comb filter 4
RZP  temp      K=.99
RAP  comb41a'  k=.54      ;tail * k + acc
RAP  comb41'   k=.99
WAP  comb41a   k=0
WZP  temp2     k=.38
RAP  temp      k=.99
WAP  comb41    k=0      ;write to head
;
; Sum outputs of comb filters
RZP  comb11'   k=.2
RAP  comb21'   k=.2
RAP  comb31'   k=.2
RAP  comb41'   k=.2
;
; All-pass
WAP  temp2     k=0
RAP  allpass1' k=.7
WZP  allpass1  k=0
RZP  temp2     k=-.7
RAP  allpass1' k=.51
;
; Add in early reflections
RAP  temp      k=0.999
;
; Write to the output
WAP  OUTL      K=0      ;Write it to the DAC
;::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
RZP  0x00      K=0      ;Add a bunch of reads for refresh
RZP  0x40      K=0
RZP  0x80      K=0
RZP  0xc0      K=0
RZP  0x100     K=0
RZP  0x140     K=0
RZP  0x180     K=0
RZP  0x1c0     K=0
RZP  0x200     K=0
RZP  0x240     K=0
RZP  0x280     K=0
RZP  0x2c0     K=0
RZP  0x300     K=0
RZP  0x340     K=0
RZP  0x380     K=0
RZP  0x3c0     K=0      ; End of AN3201-04.ASM

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Closing thoughts

The reverb described in this application note is easily modified by reference to the block diagram, explanatory text, and the software listing. Although not sophisticated enough to be a true simulation, it provides a passable approximation of a reverberation field based on room size and absorption characteristics. Experimenters may easily alter the timing and strength of early reflections, as well as the room mode parameters in order to achieve desired results.

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