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.

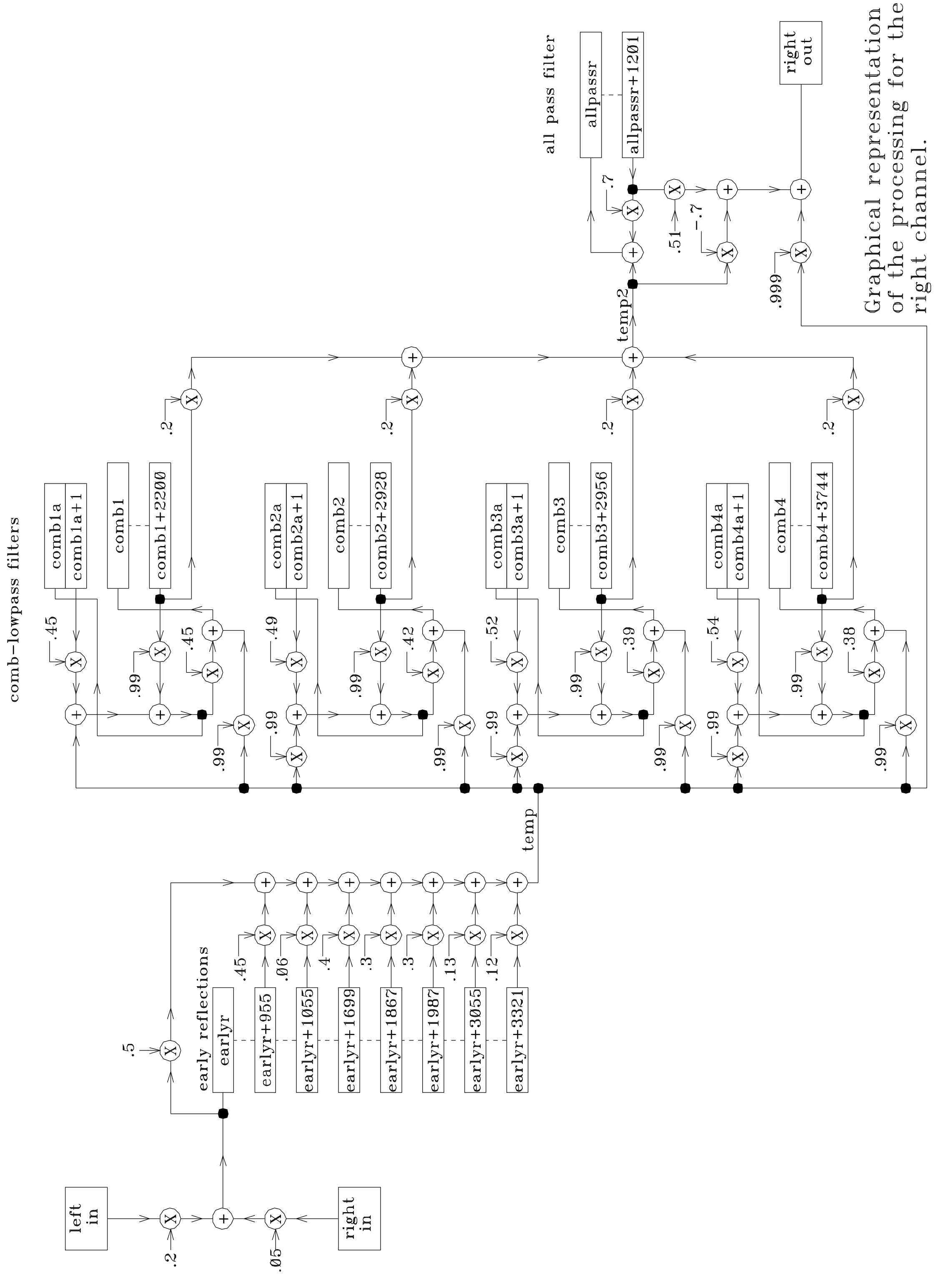
Algorithm

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.

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.

Source code

```
; File:         AN3201-04.ASM
; Description:  Example reverb program
; Author:       Frank Thomson
; Copyright 2001 Wavefront Semiconductor
;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;
MEM    earlyr       3321         ; Early reflections right channel
MEM    comb1        2200
MEM    comb1a       1
MEM    comb2        2928
MEM    comb2a       1
MEM    comb3        2956
MEM    comb3a       1
MEM    comb4        3744
MEM    comb4a       1
MEM    allpassr     1201
MEM    temp                      ; Temp register
MEM    temp2        1            ; Temp register
MEM    earlyl       3321         ; Early reflections left channel
MEM    comb1l       2200
MEM    comb1la      1
MEM    comb2l       2928
MEM    comb2la      1
MEM    comb3l       2956
MEM    comb3la      1
MEM    comb4l       3744
MEM    comb4la      1
MEM    allpassl     1201
;NOTE: memory locations are referenced by:
;      name         Start of memory block
;      name'        End of memory block
;      name"        Middle of memory block
;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;
;Read ADC in and write to the early reflection memory
RZP    ADCR         K=0.2
RAP    ADCL         K=0.05
WAP    earlyr       K=0.5
RAP    earlyr+955   K=0.45
RAP    earlyr+1055  K=0.06
RAP    earlyr+1699  K=0.4
RAP    earlyr+1867  K=0.3
RAP    earlyr+1987  K=0.3
RAP    earlyr+3055  K=0.13
RAP    earlyr'      K=0.12       ; Early reflection plus dry in accumulator
;
; Comb filters
; Comb filter 1
WAP    temp         K=0          ;Save accumulator
RAP    comb1a'      k=.45        ;tail * k + acc
RAP    comb1'       k=.99
WAP    comb1a       k=0
WZP    temp2        k=.45
RAP    temp         k=.99
WAP    comb1        k=0          ;write to head
; Comb filter 2
RZP    temp         K=.99
RAP    comb2a'      k=.49        ;tail * k + acc
RAP    comb2'       k=.99
WAP    comb2a       k=0
WZP    temp2        k=.42
RAP    temp         k=.99
WAP    comb2        k=0          ;write to head
```

```
; 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 accumulater
RAP    comb1la'      k=.45         ;tail * k + acc
RAP    comb1l'       k=.99
WAP    comb1la       k=0
WZP    temp2         k=.45
RAP    temp          k=.99
WAP    comb1l        k=0           ;write to head
; Comb filter 2
RZP    temp          K=.99
RAP    comb2la'      k=.49         ;tail * k + acc
RAP    comb2l'       k=.99
WAP    comb2la       k=0
WZP    temp2         k=.42
RAP    temp          k=.99
WAP    comb2l        k=0           ;write to head
```

```
; Comb filter 3
RZP    temp          K=.99
RAP    comb3la'      k=.52        ;tail * k + acc
RAP    comb3l'       k=.99
WAP    comb3la       k=0
WZP    temp2         k=.39
RAP    temp          k=.99
WAP    comb3l        k=0          ;write to head
; Comb filter 4
RZP    temp          K=.99
RAP    comb4la'      k=.54        ;tail * k + acc
RAP    comb4l'       k=.99
WAP    comb4la       k=0
WZP    temp2         k=.38
RAP    temp          k=.99
WAP    comb4l        k=0          ;write to head
;
; Sum outputs of comb filters
RZP    comb1l'       k=.2
RAP    comb2l'       k=.2
RAP    comb3l'       k=.2
RAP    comb4l'       k=.2
;
; All-pass
WAP    temp2         k=0
RAP    allpassl'     k=.7
WZP    allpassl      k=0
RZP    temp2         k=-.7
RAP    allpassl'     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
```

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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