

ALGORITHMIC REVERBERATION VIDEO TUTORIAL



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AES Textbook
hackaudio.com

AUDIO ENGINEERING SOCIETY PRESENTS...



HACK AUDIO

AN INTRODUCTION TO
COMPUTER PROGRAMMING
AND DIGITAL SIGNAL
PROCESSING

A FOCAL PRESS BOOK

ERIC TARR

iconic algorithms

Gain Diffusion Modulation Pre-delay Time HPF LPF Bit Depth Dry/Wet

Schroeder Moorer FDN - Jot Dattorro Gardner

Four Six Eight

Schroeder Reverb

```
graph LR; Input(( )) --> FBCF1[FBCF]; FBCF1 --> APF1[APF]; APF1 --> APF2[APF]; APF2 --> APF3[APF]; APF3 --> Output(( )); FBCF1 --> FBCF2[FBCF]; FBCF2 --> APF1; FBCF1 --> FBCF3[FBCF]; FBCF3 --> APF1; FBCF1 --> FBCF4[FBCF]; FBCF4 --> APF1;
```

all-pass filter

Delay Time Gain

```
graph LR; Input(( )) --> Add1((+)); Add1 --> Delay[Delay]; Delay --> Multi1((x)); Multi1 --> Add2((+)); Add2 --> Multi2((x)); Multi2 --> Gain((Gain)); Multi2 --> -Gain((-Gain)); -Gain --> Add1;
```

1. BACKGROUND

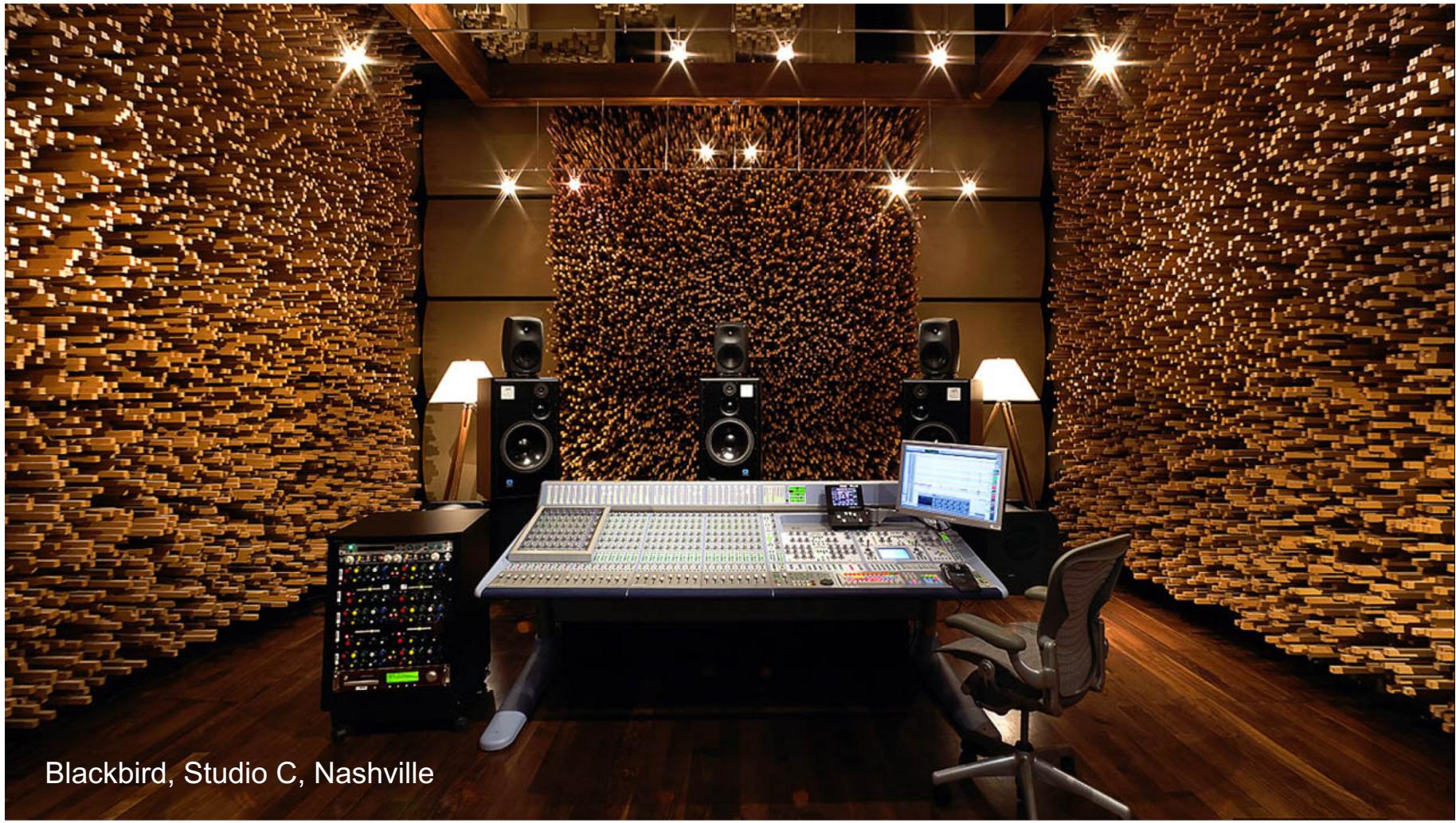
Characteristics of Natural Reverberation



Ocean Way, Studio A, Nashville



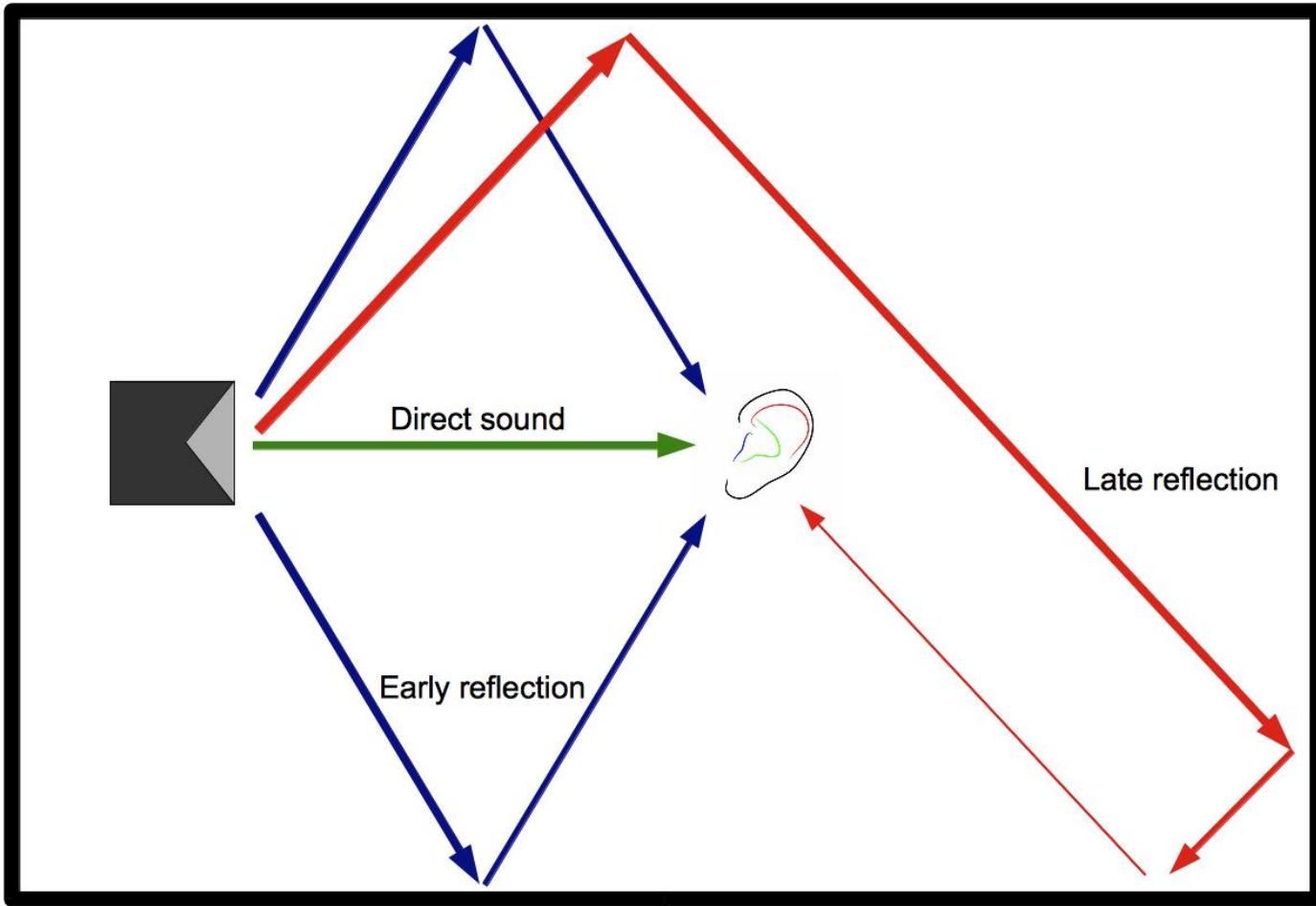
Anechoic Chamber, Belmont

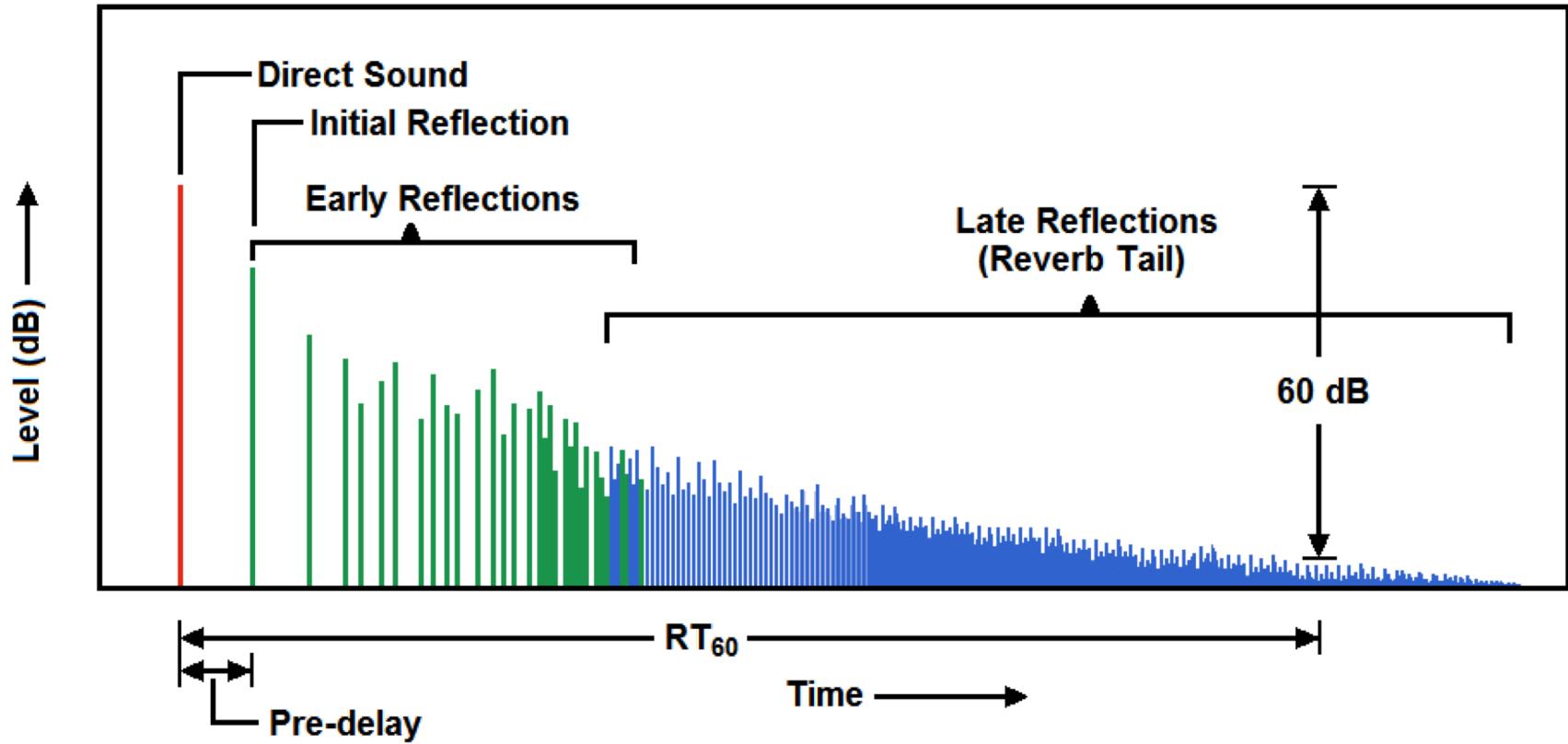


Blackbird, Studio C, Nashville



Racquetball Court





2. DIGITAL REVERB

Algorithms of Artificial Reverb

Digital Reverb

Convolution



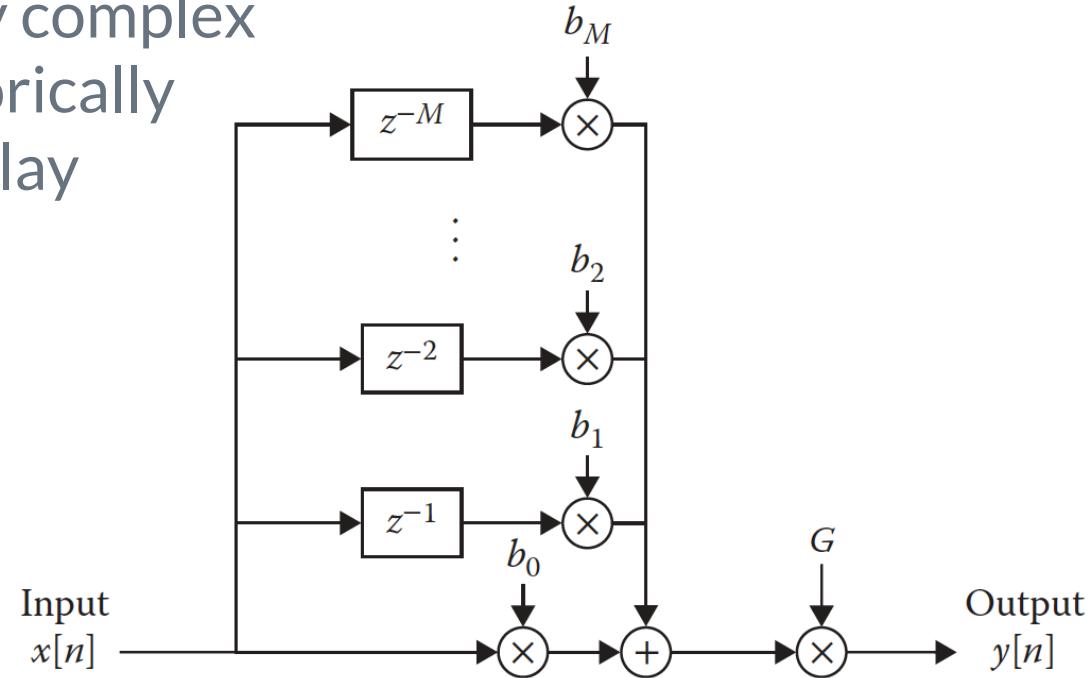
Algorithmic



Digital Reverb

► Convolution using an impulse response (IR)

Computationally complex
Impractical historically
Feedforward Delay



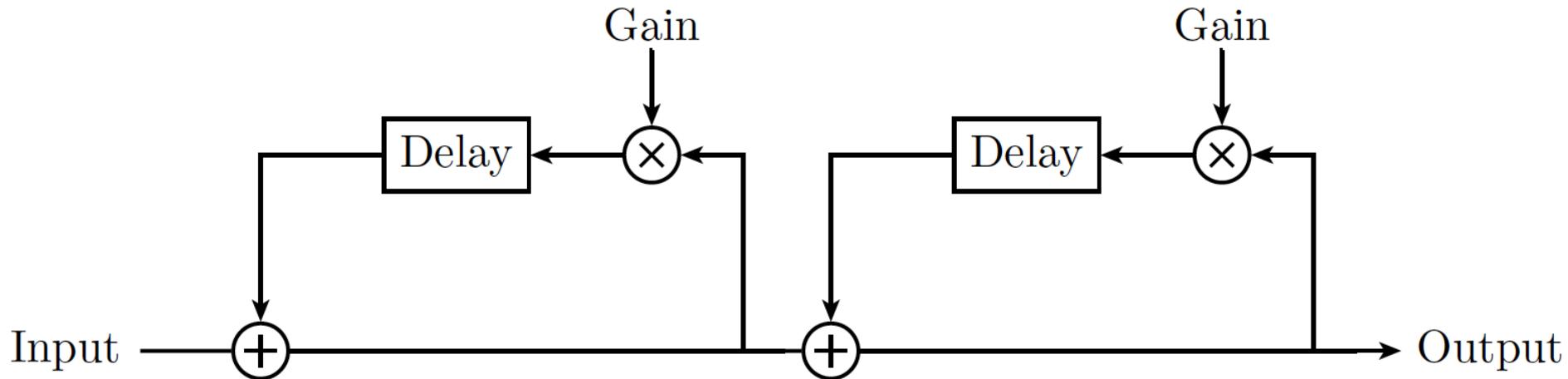
Digital Reverb

▷ Algorithmic Reverb

Computationally efficient

Implemented since 1960s

Feedback Delay



Feedback Comb Filter

- ▷ Multiple repetitions through feedback
- ▷ Frequency response has resonant peaks

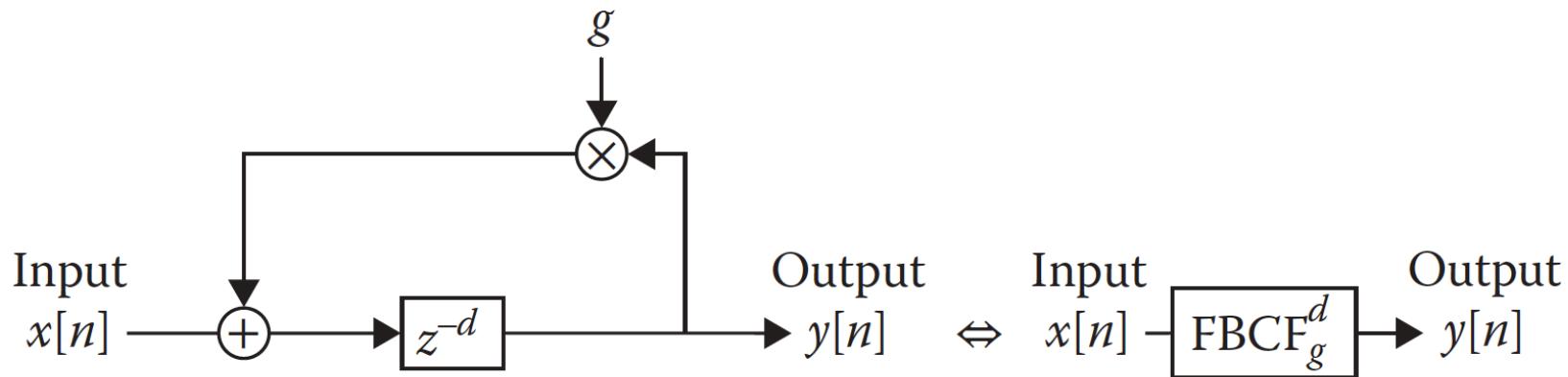


Figure 16.1: Block diagram of feedback comb filter for Schroeder reverb

Combining FBCFs

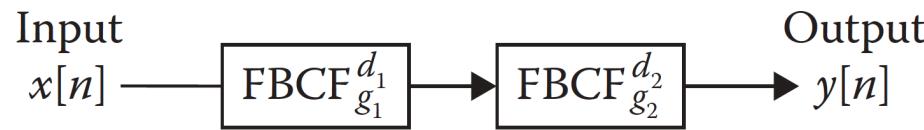


Figure 16.2: Block diagram of series feedback comb filters

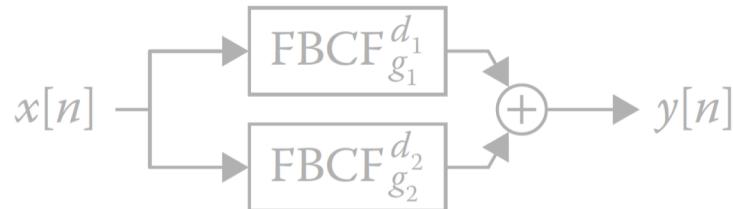


Figure 16.3: Block diagram of parallel feedback comb filters

Combining FBCFs

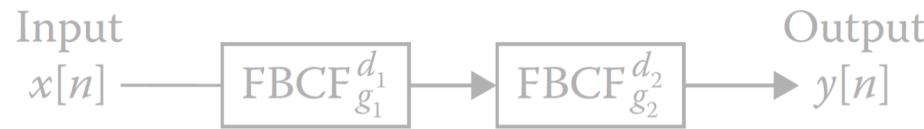


Figure 16.2: Block diagram of series feedback comb filters

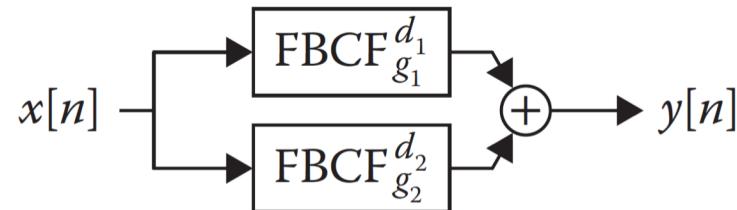


Figure 16.3: Block diagram of parallel feedback comb filters

All-pass Filters

- ▷ Increase density of repetitions
- ▷ Flat frequency response – “Colorless Delays”

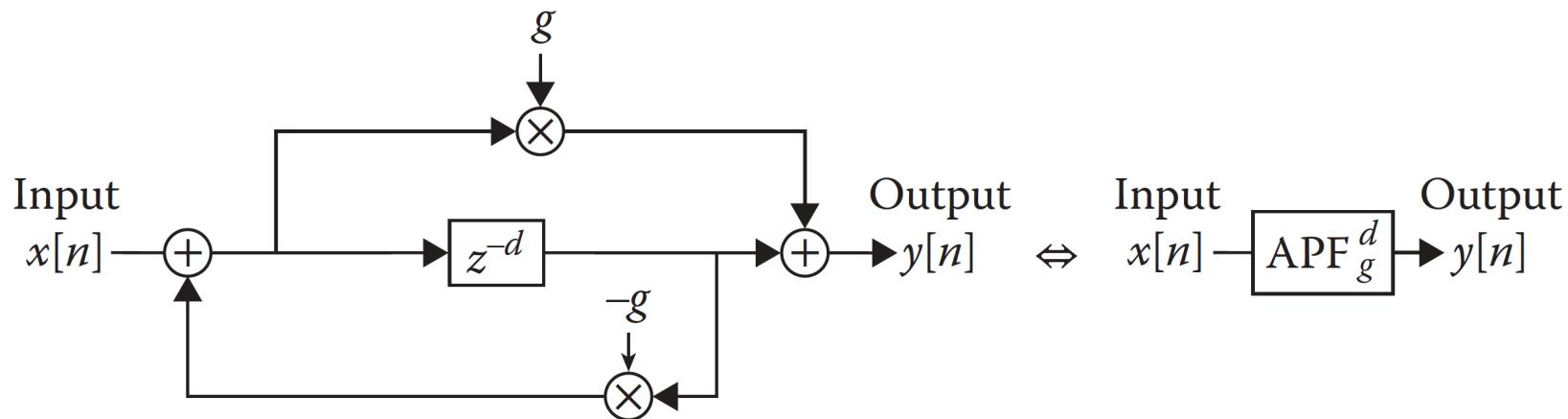


Figure 16.4: Block diagram of all-pass filter for Schroeder reverb

3. ALGORITHMS

Important designs in audio engineering history

Schroeder (1961,1962,1970)

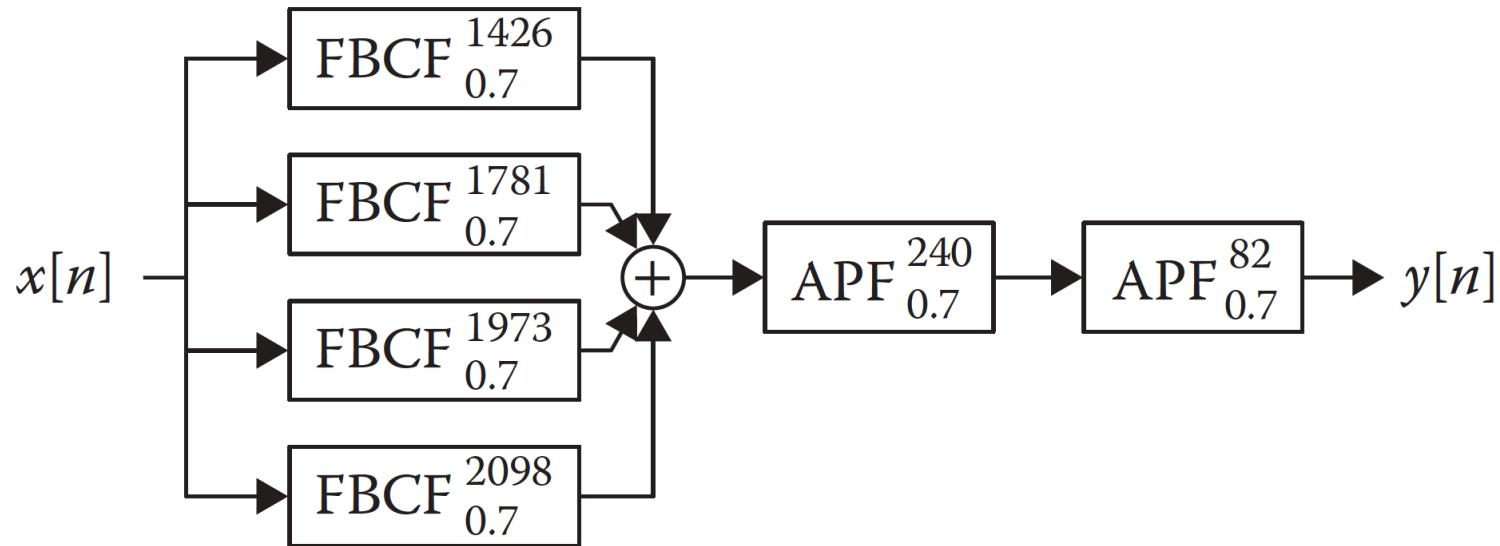


Figure 16.5: Block diagram of Schroeder reverb

Moorer (1979)

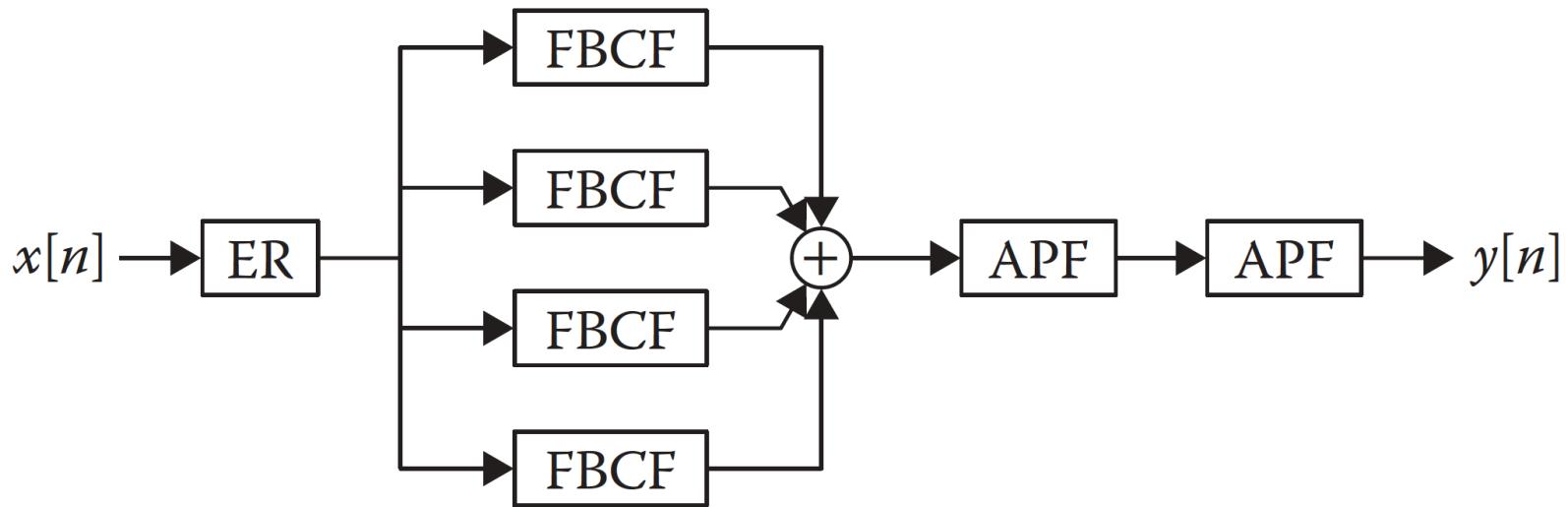


Figure 16.6: Block diagram Moorer reverb

Moorer (1979)

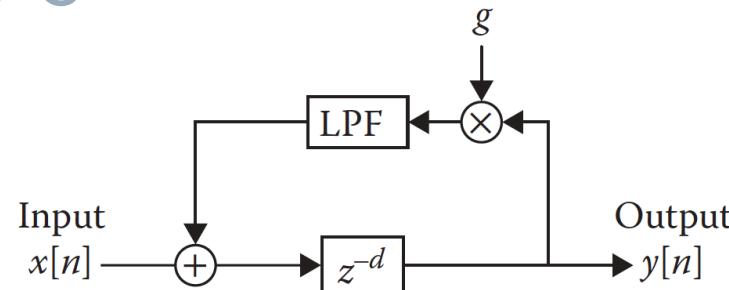


Figure 16.9: Block diagram of low-pass filtered feedback comb filter for Moorer reverb

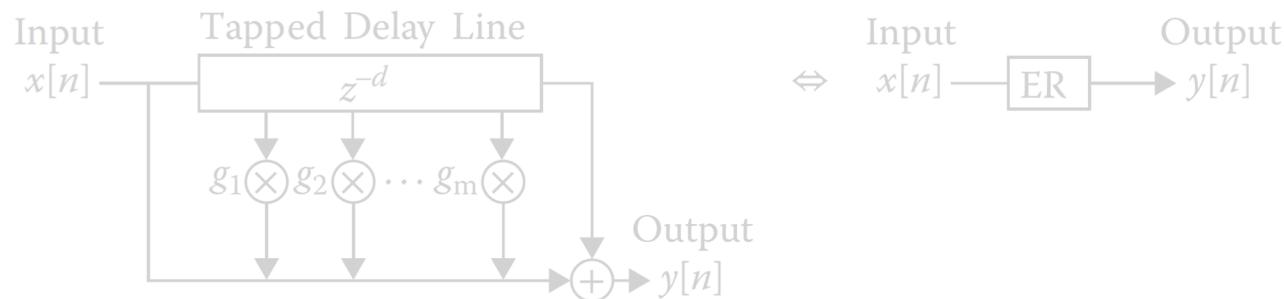


Figure 16.7: Tapped delay line for early reflections

Moorer (1979)

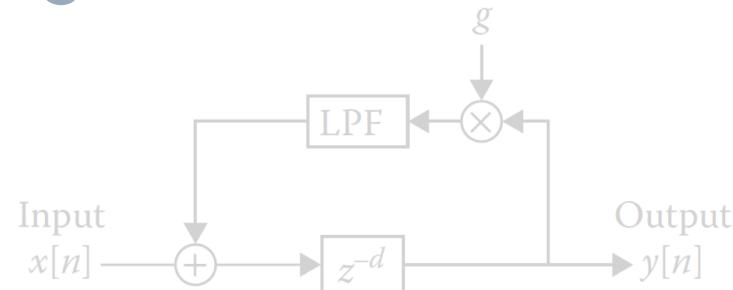


Figure 16.9: Block diagram of low-pass filtered feedback comb filter for Moorer reverb

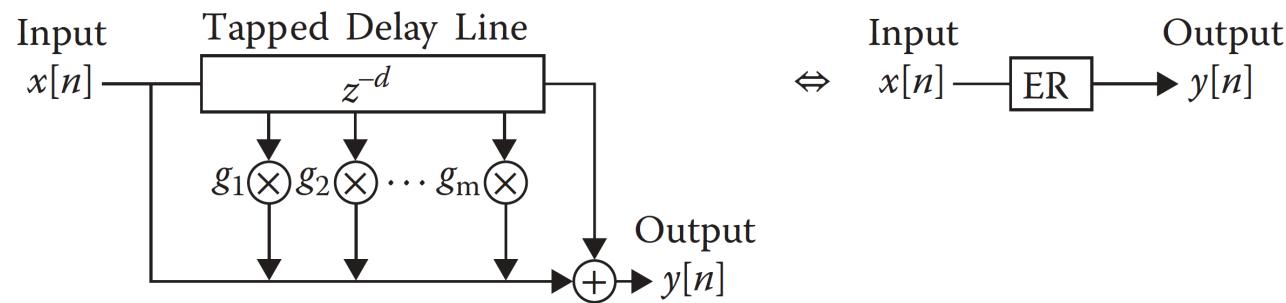
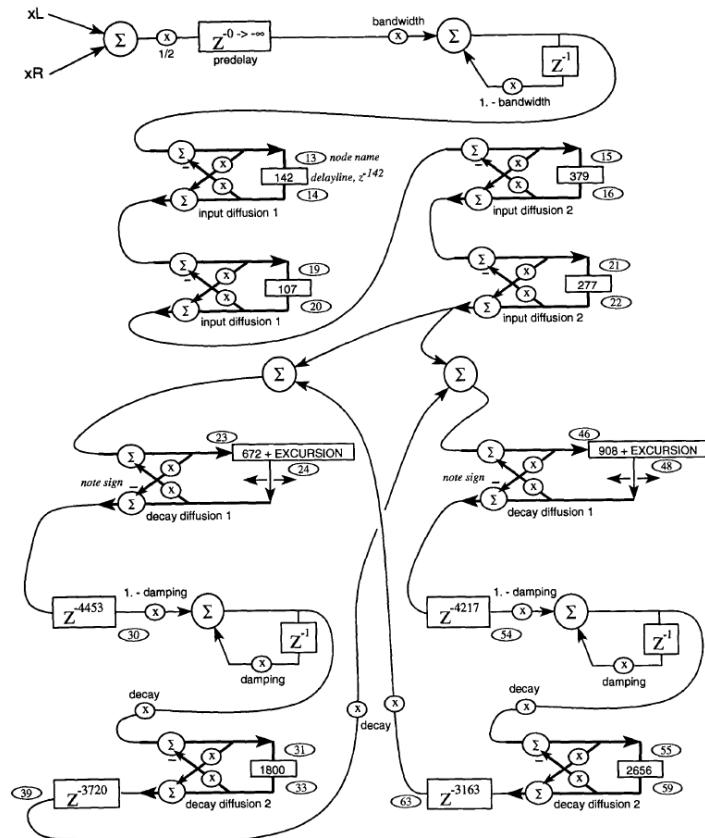
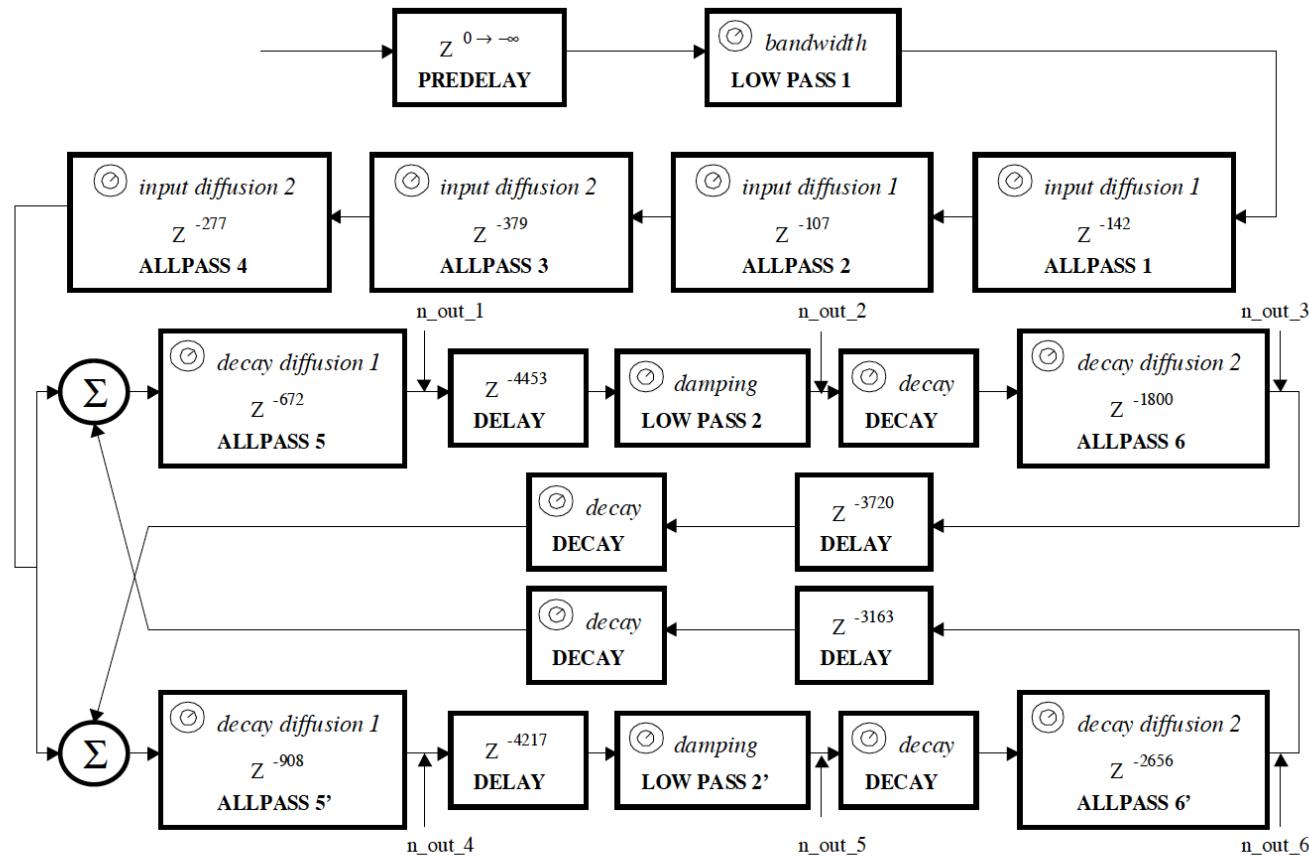


Figure 16.7: Tapped delay line for early reflections

Dattorro Plate (1979)



Dattorro Plate (1979)



Dattorro Plate (1979)

► Output Summing Matrix

Node	Delay	Sign	Node	Delay	Sign
n_out_4	266	+	n_out_1	353	+
n_out_4	2974	+	n_out_1	3627	+
n_out_5	1913	-	n_out_2	1228	-
n_out_6	1996	+	n_out_3	2673	+
n_out_1	1990	-	n_out_4	2111	-
n_out_2	187	-	n_out_5	335	-
n_out_3	1066	-	n_out_6	121	-

Table 1. Left output (left), right output (right).

Gardner (1992)

- ▷ Small, Medium, Large Hall Designs
- ▷ Nested All-pass Filters
- ▷ Schematic Diagrams

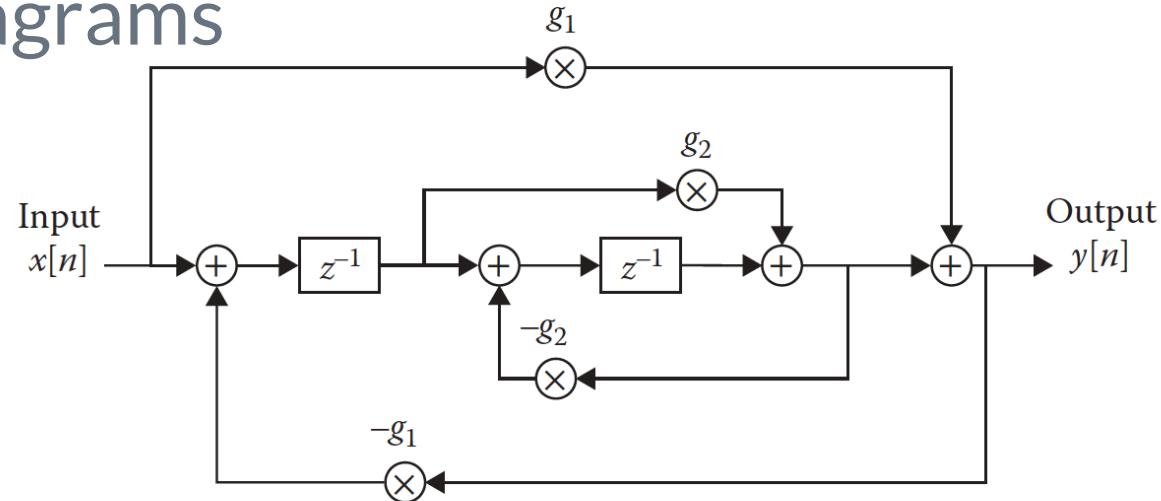


Figure 13.23: Block diagram of Direct Form II nested APF

Gardner (1992)

- ▷ Small, Medium, Large Hall Designs
- ▷ Nested All-pass Filters
- ▷ Schematic Diagrams

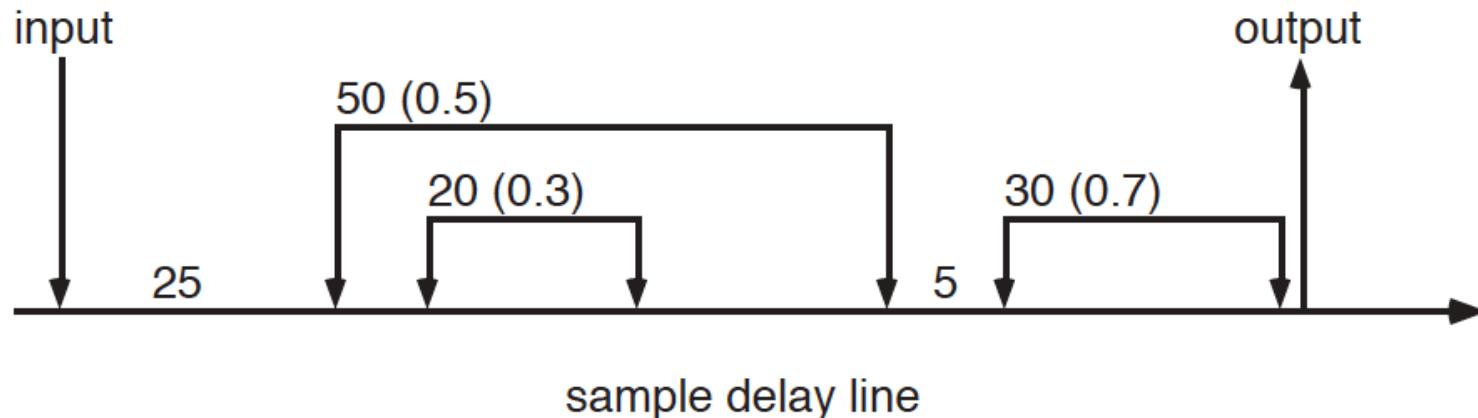
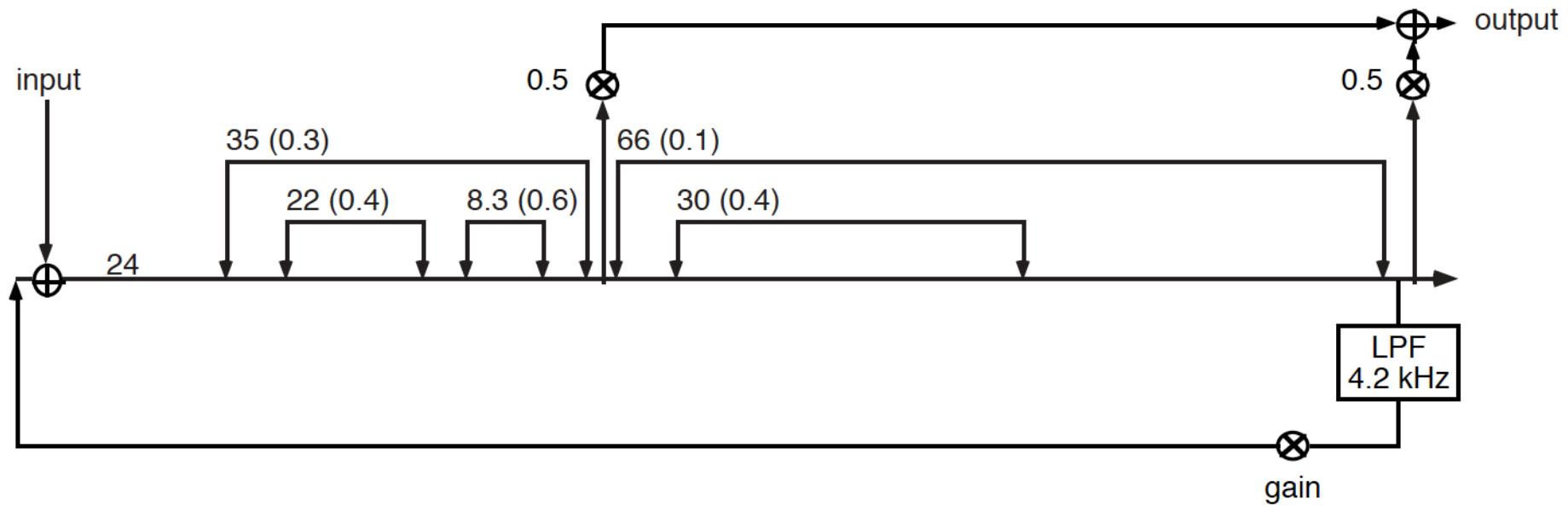
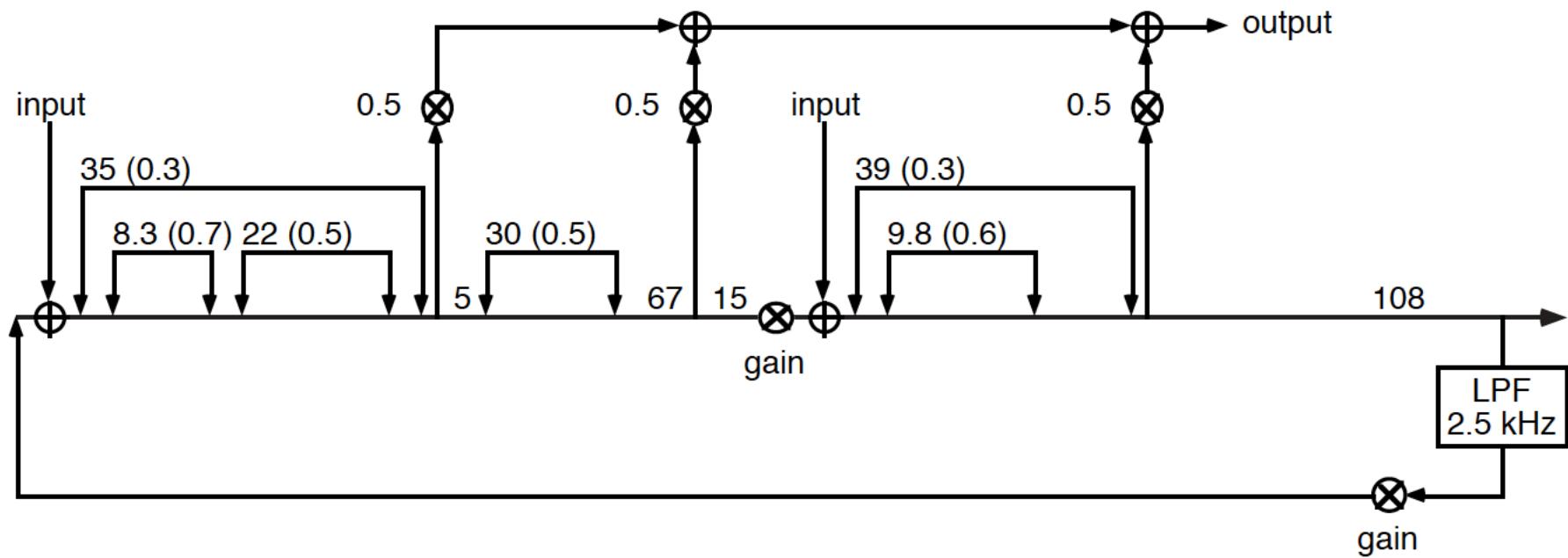


Figure 4.8 Example of schematic representation of an allpass reverberator.

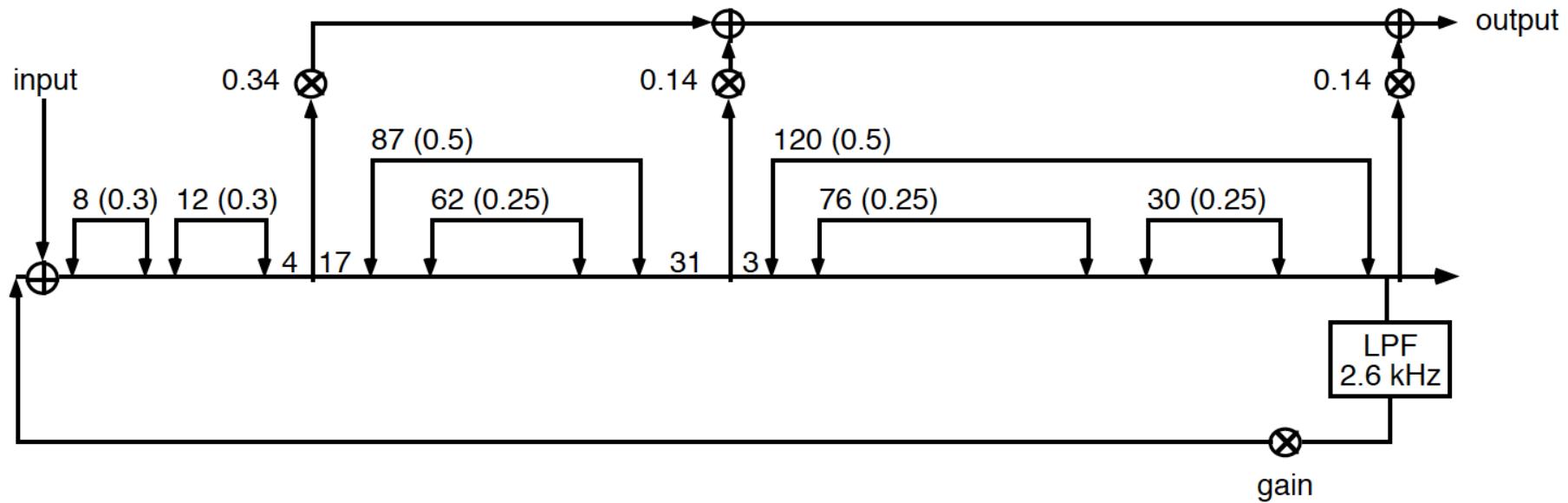
Gardner Small Hall (1992)



Gardner Medium Hall (1992)

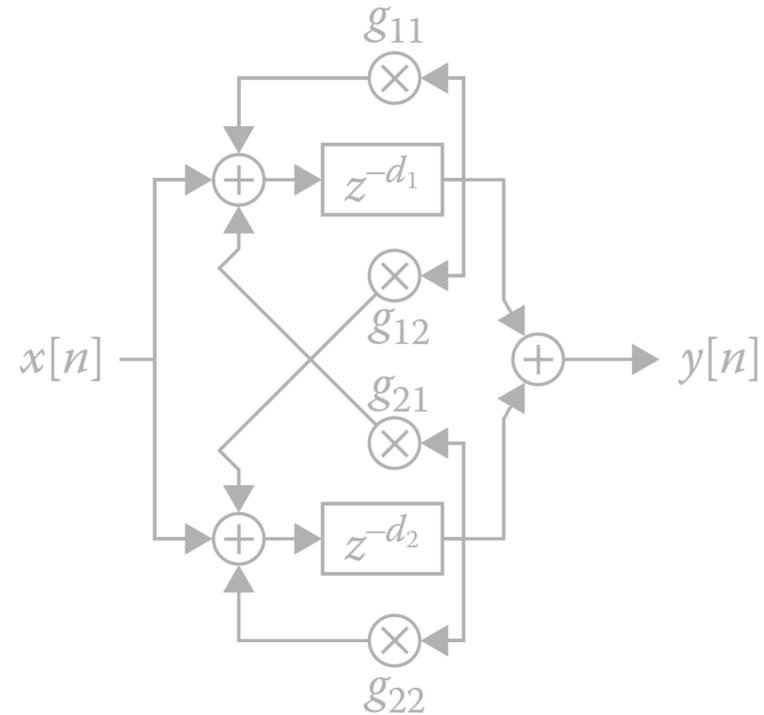
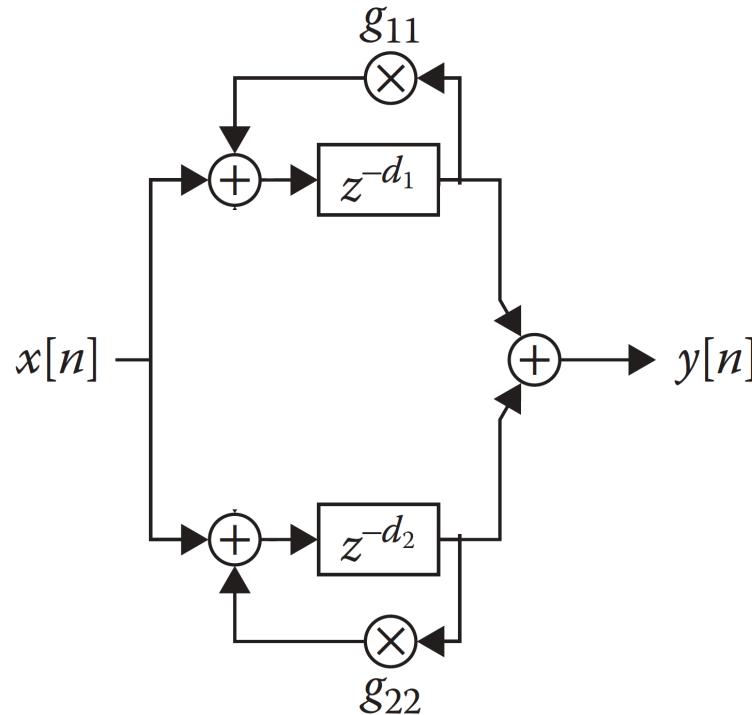


Gardner Large Hall (1992)



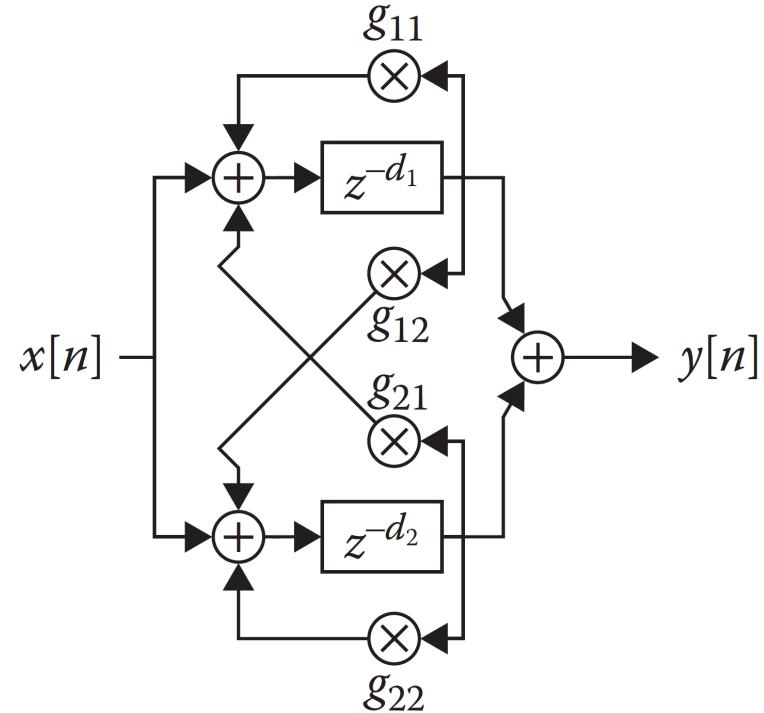
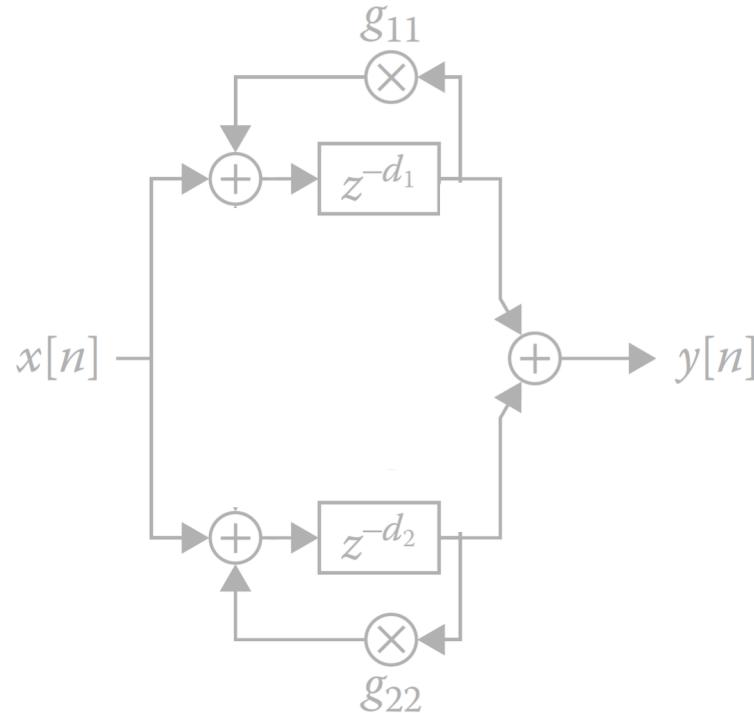
Jot (1992) Feedback Delay Network

▷ Crossover Feedback

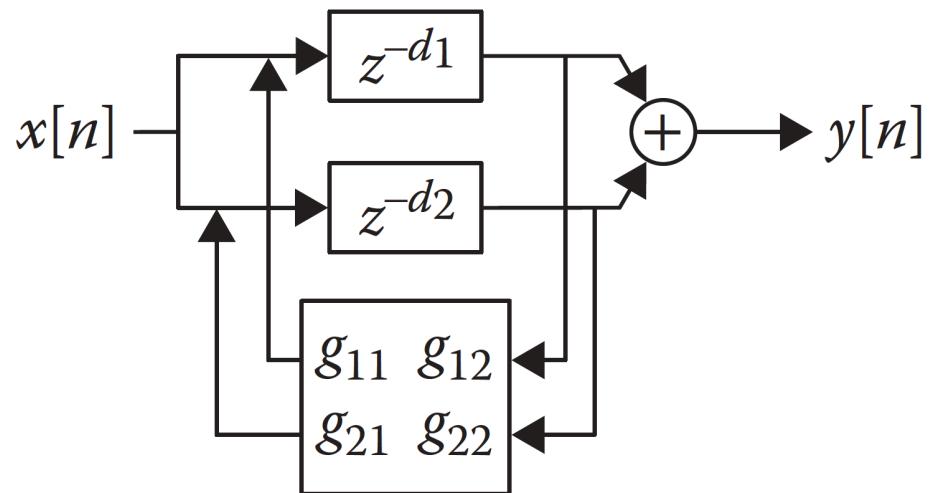
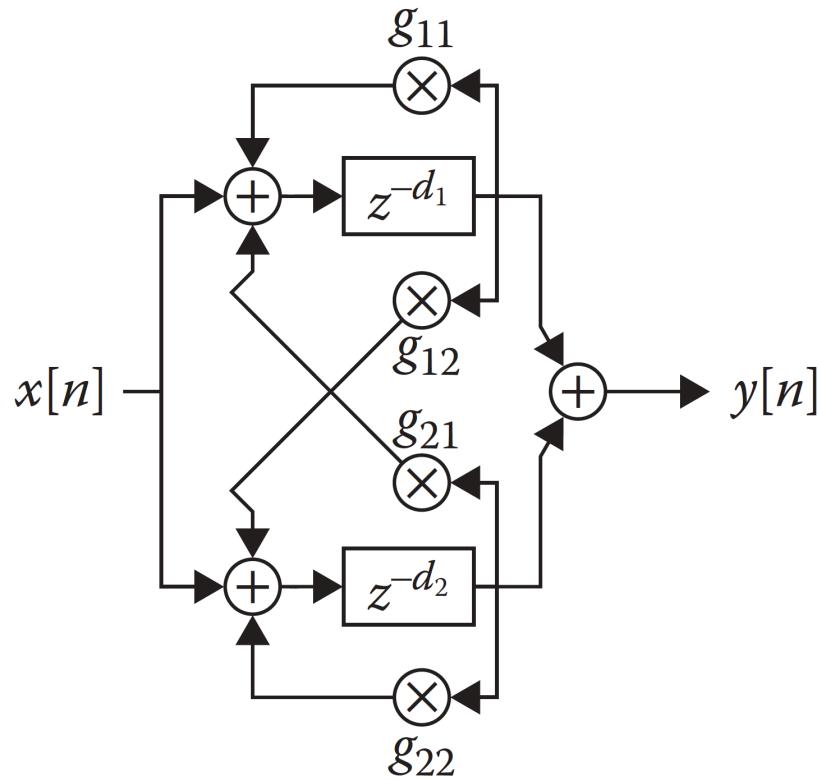


Jot (1992) Feedback Delay Network

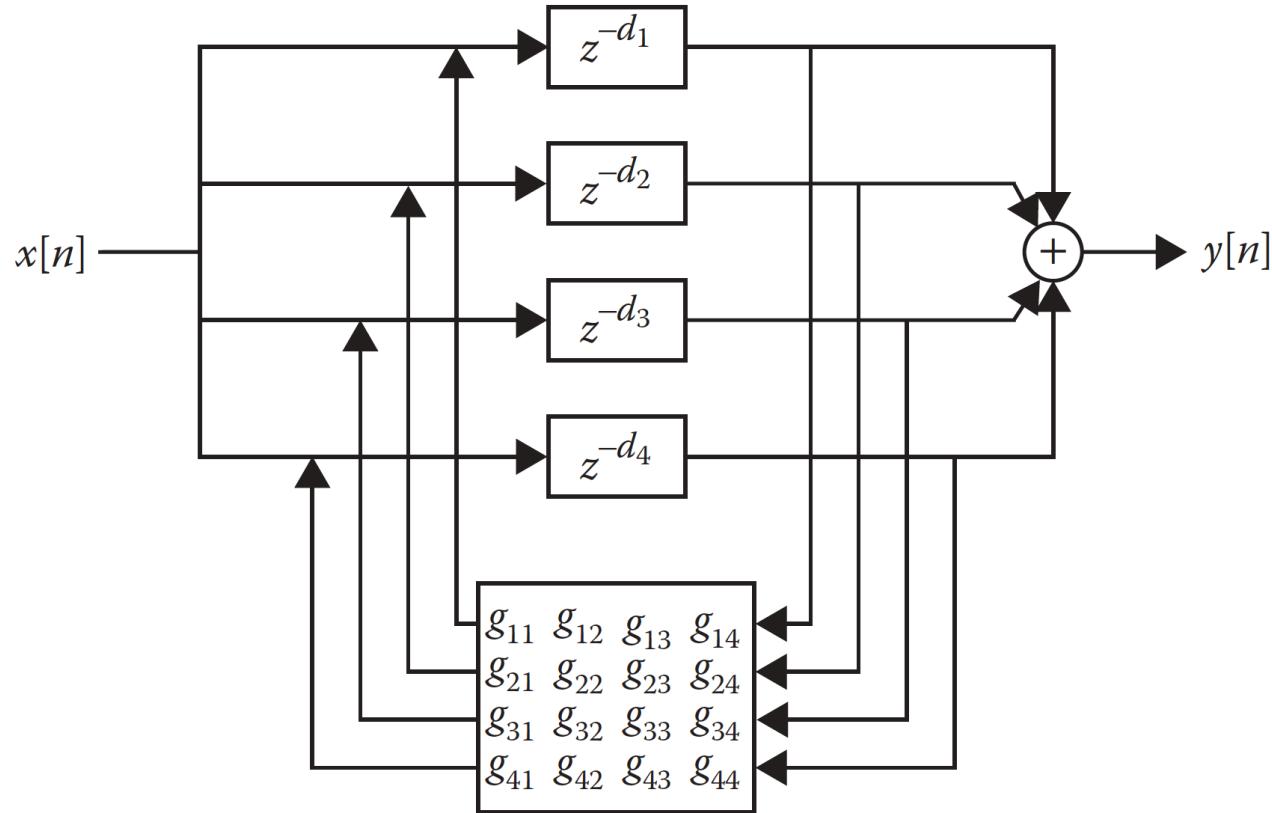
▷ Crossover Feedback



Jot (1992) Feedback Delay Network



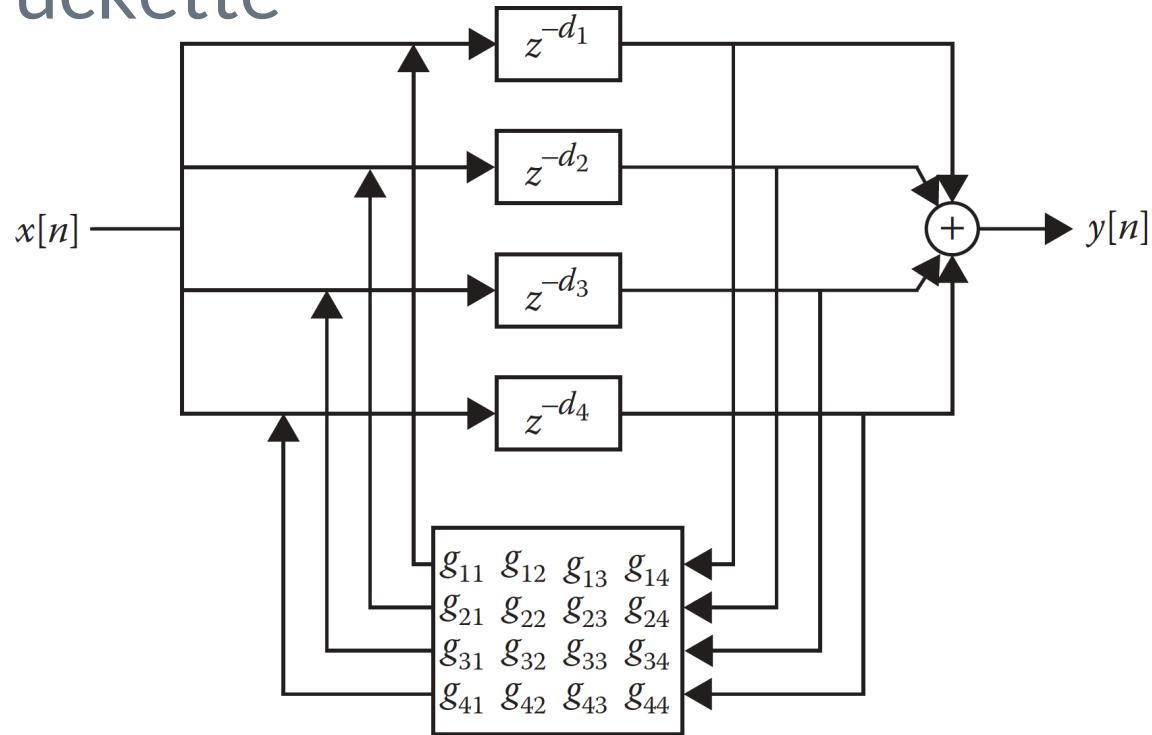
Jot (1992) Feedback Delay Network



Jot (1992) Feedback Delay Network

▷ Stautner and Puckette

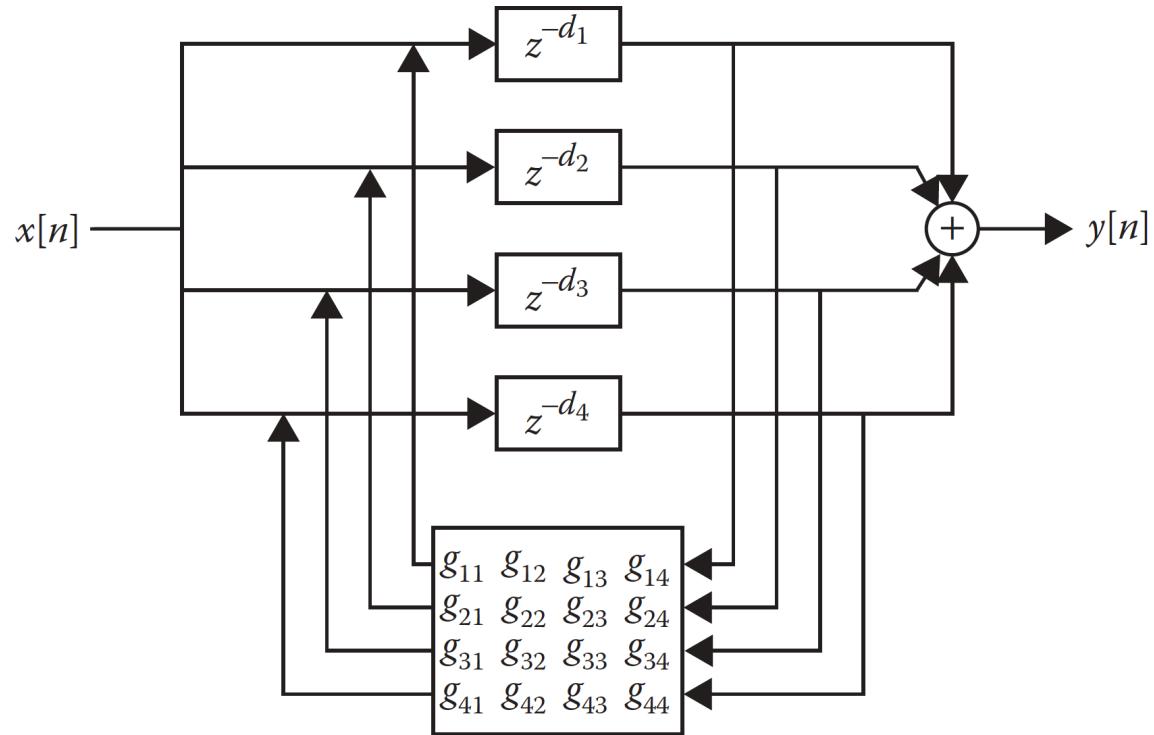
$$\begin{bmatrix} 0 & 1 & 1 & 0 \\ -1 & 0 & 0 & -1 \\ 1 & 0 & 0 & -1 \\ 0 & 1 & -1 & 0 \end{bmatrix}$$



Jot (1992) Feedback Delay Network

▷ Hadamard

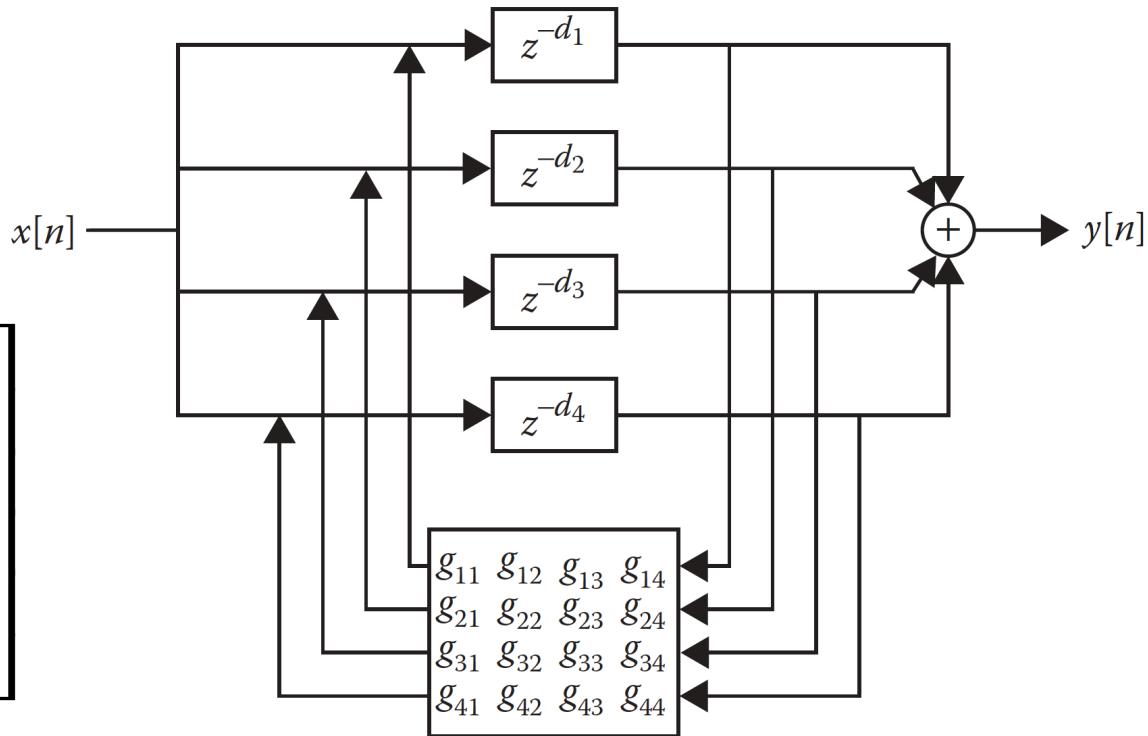
$$\begin{bmatrix} 1 & 1 & 1 & 1 \\ 1 & -1 & 1 & -1 \\ 1 & 1 & -1 & -1 \\ 1 & -1 & -1 & 1 \end{bmatrix}$$



Jot (1992) Feedback Delay Network

▷ Householder

$$\begin{bmatrix} 1 & -1 & -1 & -1 \\ -1 & 1 & -1 & -1 \\ -1 & -1 & 1 & -1 \\ -1 & -1 & -1 & 1 \end{bmatrix}$$



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eric.tarr@belmont.edu

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