Lecture 7: Filters & Reverb

1. Filters & EQ
2. Time delay effects
3. Reverb

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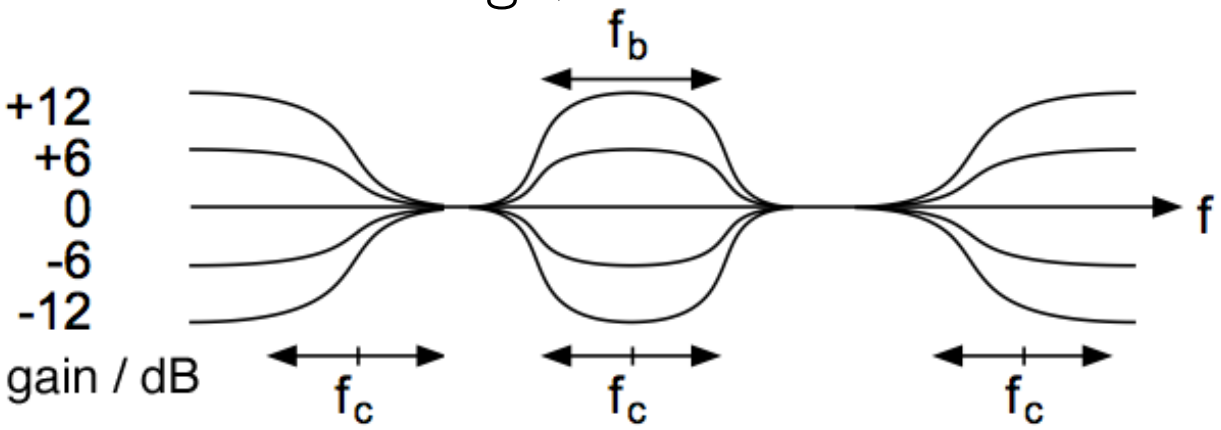
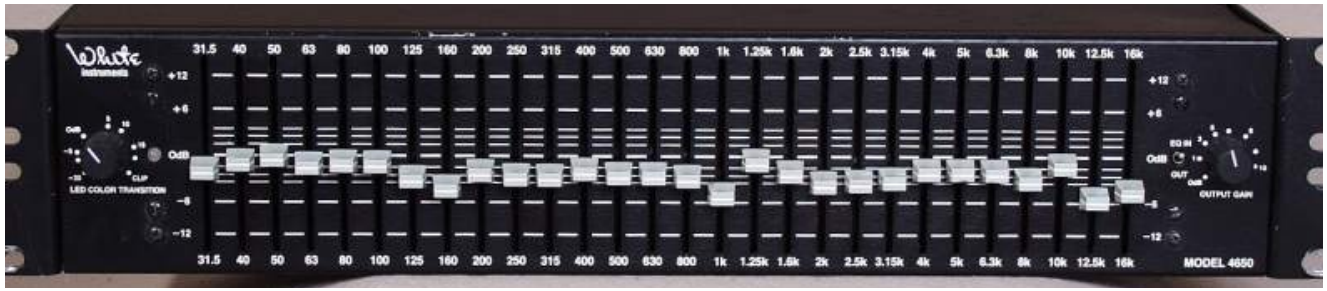
1. Filters & EQ

- EQ is a critical tool in audio mixing
  - boost/cut on single control
  - each instrument has its own "space"
- Different formats
  - Low/Mid/High, Parametric

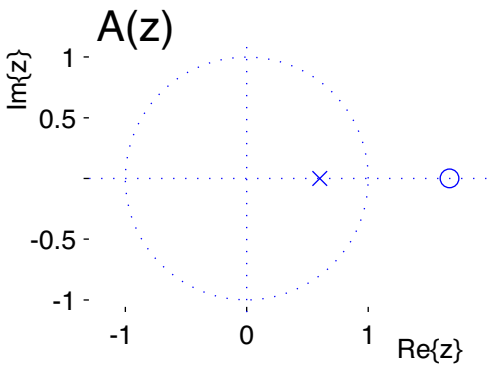


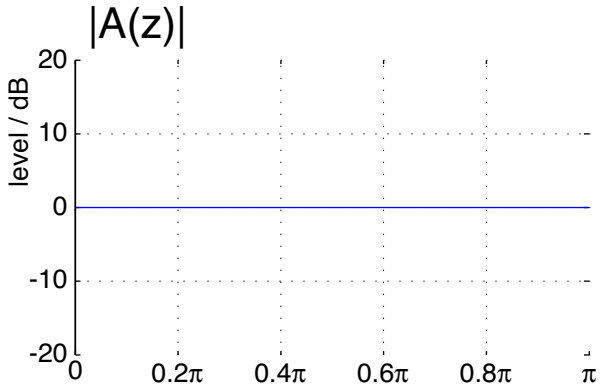
- Graphic EQ

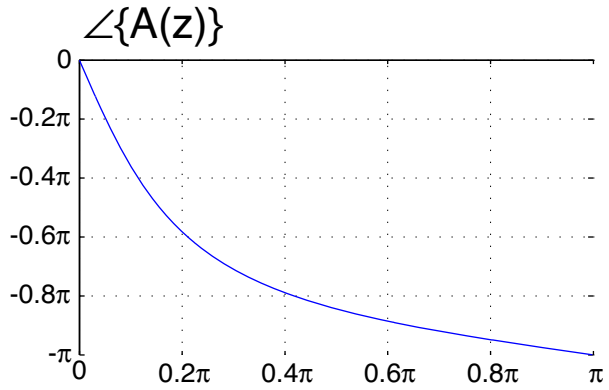


EQ filters

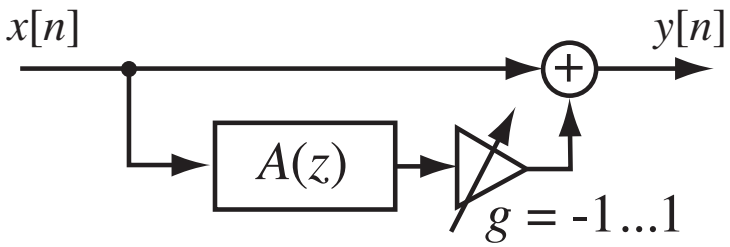
- How to get boost + cut from a single filter?
  - use allpass

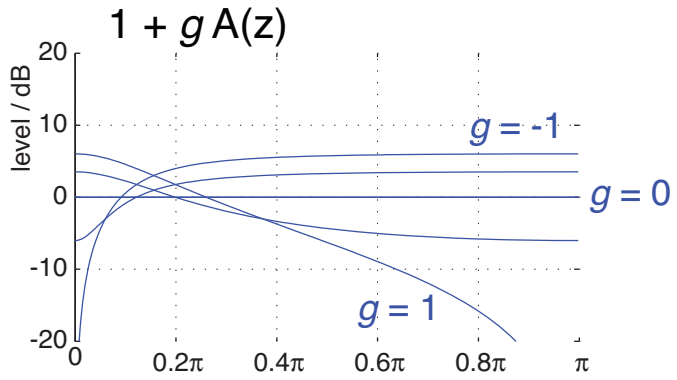






  - then +/- to get phase cancellation/reinforcement





pd~

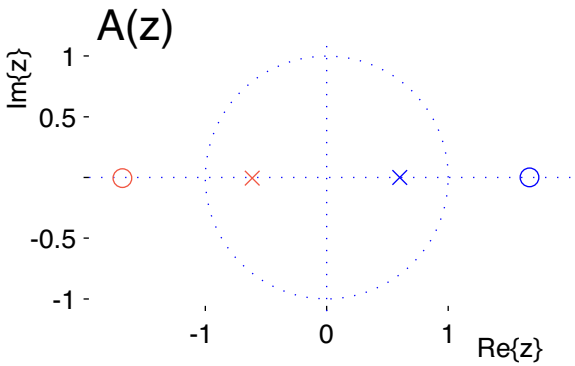
s03-allpass1.pd

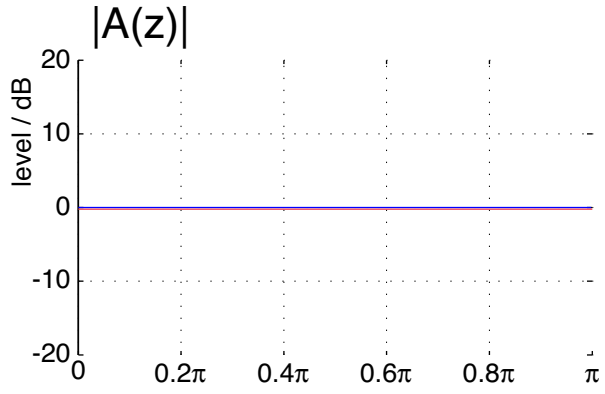
Allpass Filters

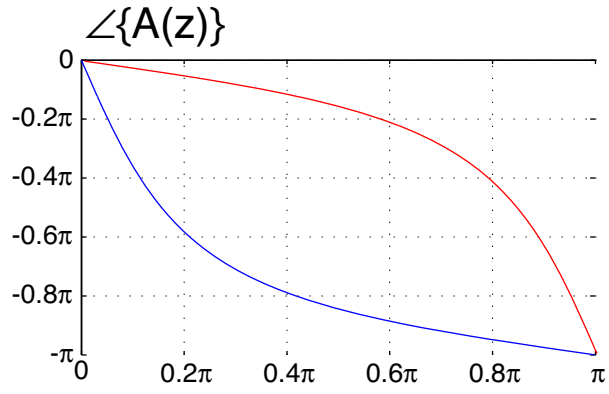
- Allpass filters have flat gain: $|A(e^{j\omega})| = 1$
  - from mirror-image numerator and denominator:

$$A(z) = \frac{z^{-m} D_m(z^{-1})}{D_m(z)}$$

  - e.g. for $D_m(z) = 1 - 0.6z^{-1} \quad \Rightarrow A(z) = \frac{-0.6 + z^{-1}}{1 - 0.6z^{-1}}$







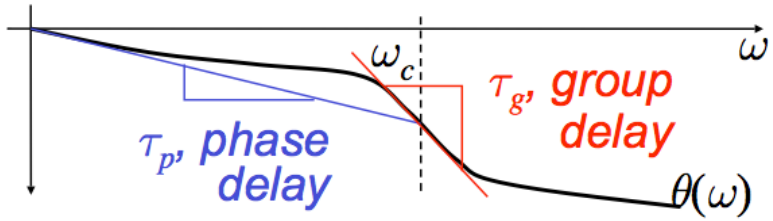
  - slope governs phase interactions, group delay

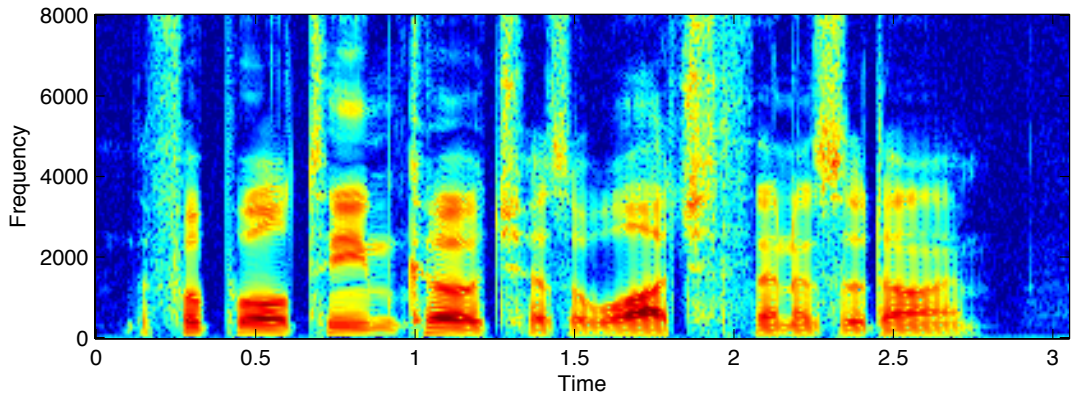
$$\tau_g(\omega_c) = -\frac{d\theta(\omega)}{d\omega}\bigg|_{\omega=\omega_c}$$

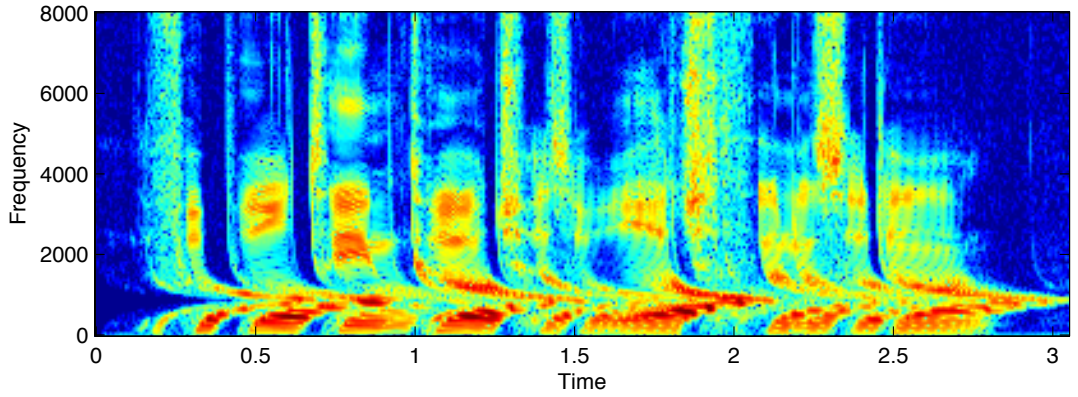
Group Delay

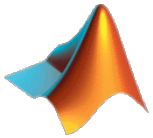
- Local phase change of $H(z)$ governs effective delay of that frequency region: "group delay"

$$\tau_g(\omega_c) = -\frac{d\theta(\omega)}{d\omega}\Big|_{\omega=\omega_c}$$



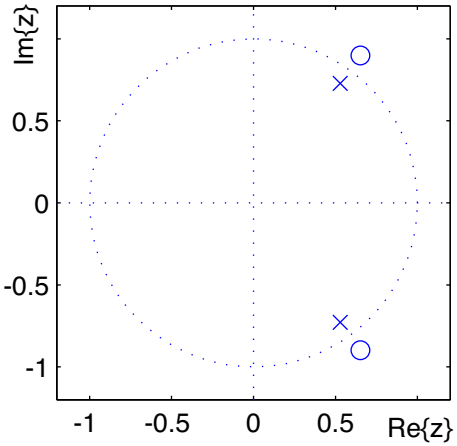


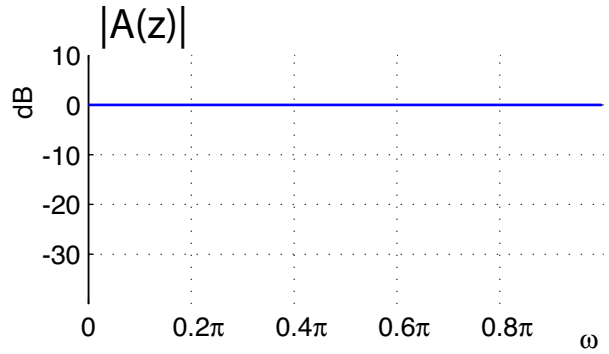


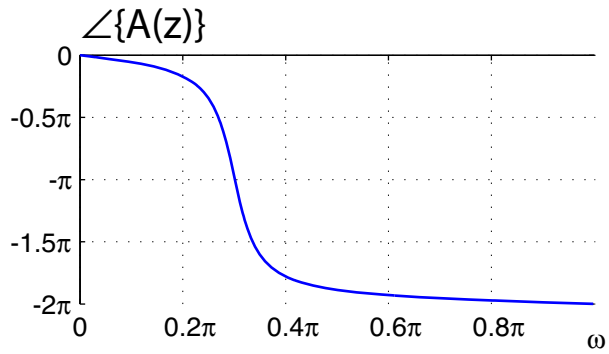


Parametric EQ

- 2nd order Allpass → slope & place $\theta(\omega) = \pi$

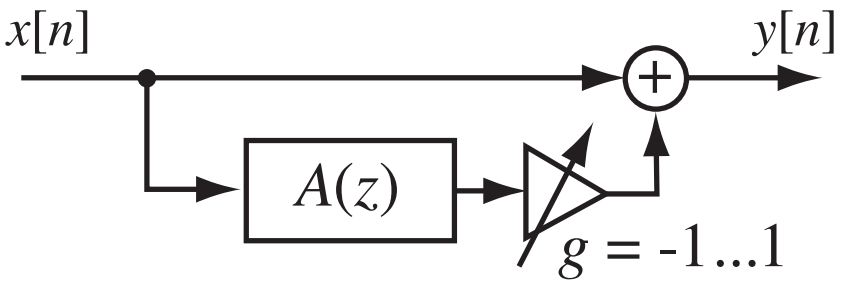


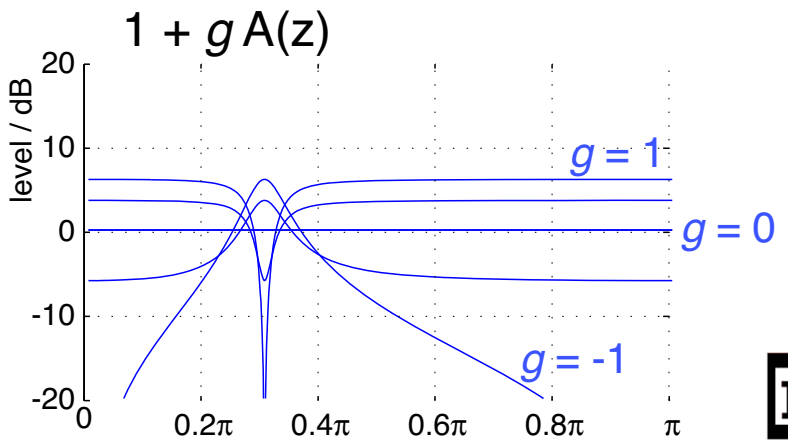




  - angle → frequency
  - radius → slope → bandwidth

- Same structure for EQ



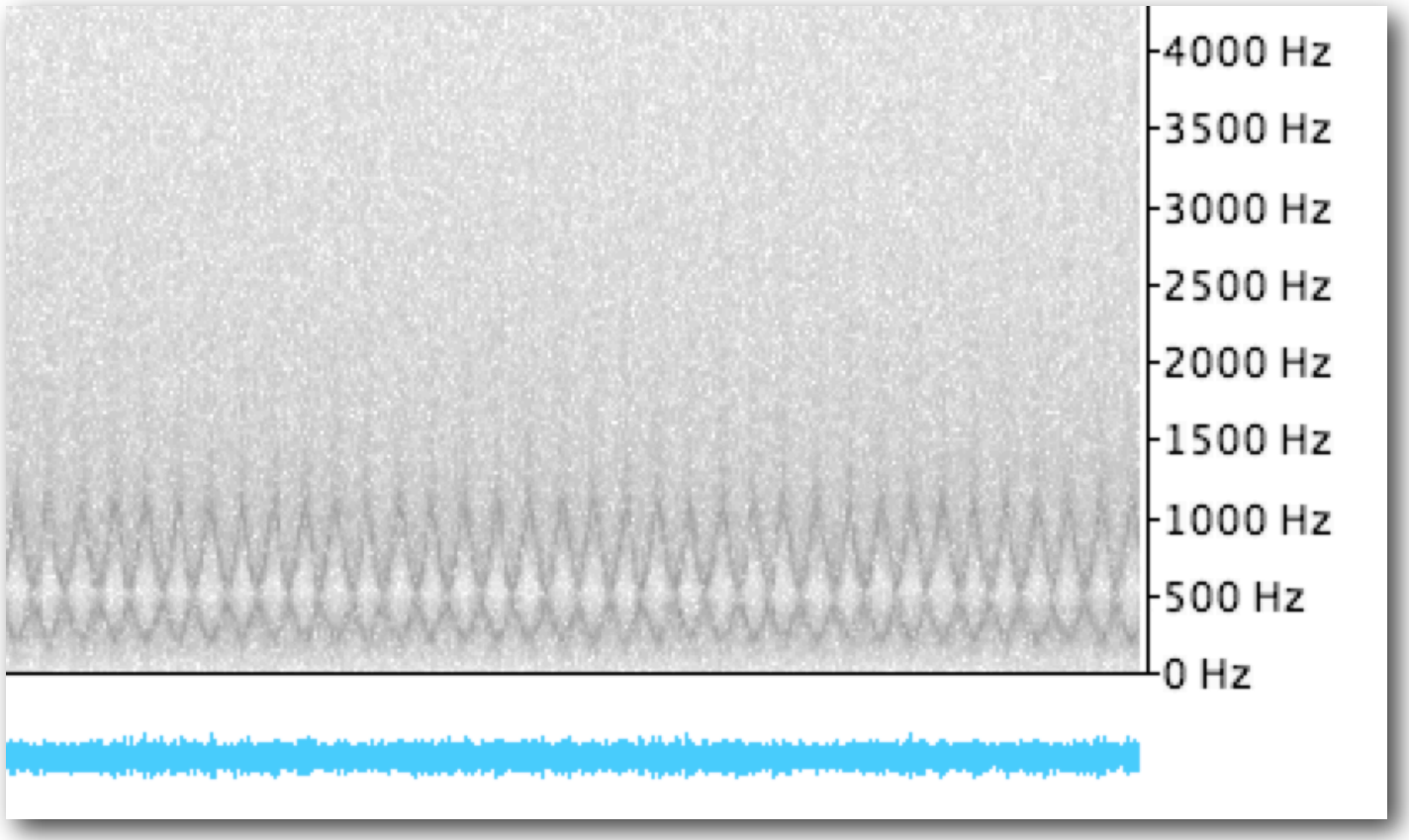


pd~

s06-allpass2.pd

Time-Varying Filters

- Classic Wah-Wah ?



- Iterated Filters...

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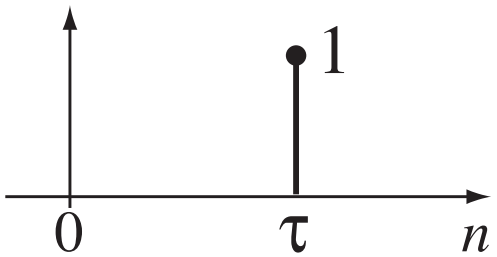
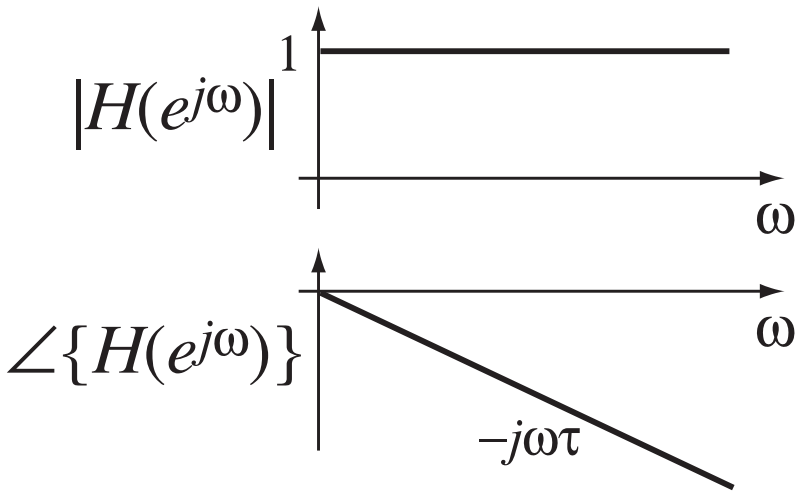
s07-wahwah.pd

2. Time Delays

- Delays correspond to sound propagation
  - 340 m/s ≈ 1 foot / ms
- Delays are a simple kind of filter
  - can analyze from Fourier perspective...

$$h[n] = \delta[n - \tau]$$
$$\Rightarrow H(e^{j\omega}) = e^{-j\omega\tau}$$

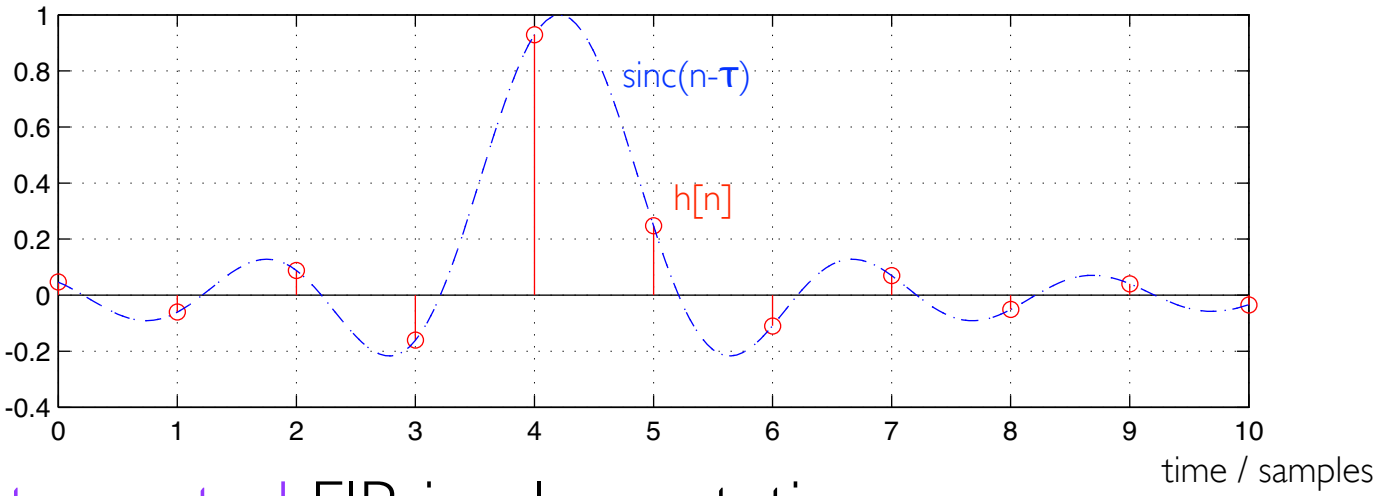




Fractional Delays

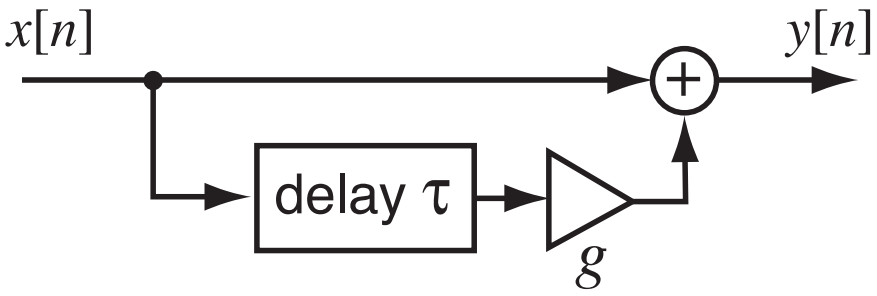
- For short delays, one sample quantization may be too coarse
  - 1 sample @ 44.1 kHz = 22.7 μs
- Fractional delay can be recovered from Fourier domain

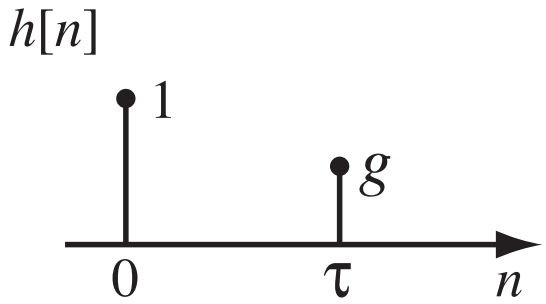
$$e^{-j\omega\tau} \Leftrightarrow \frac{\sin \pi(n-\tau)}{\pi(n-\tau)} = \mathrm{sinc}(n-\tau)$$



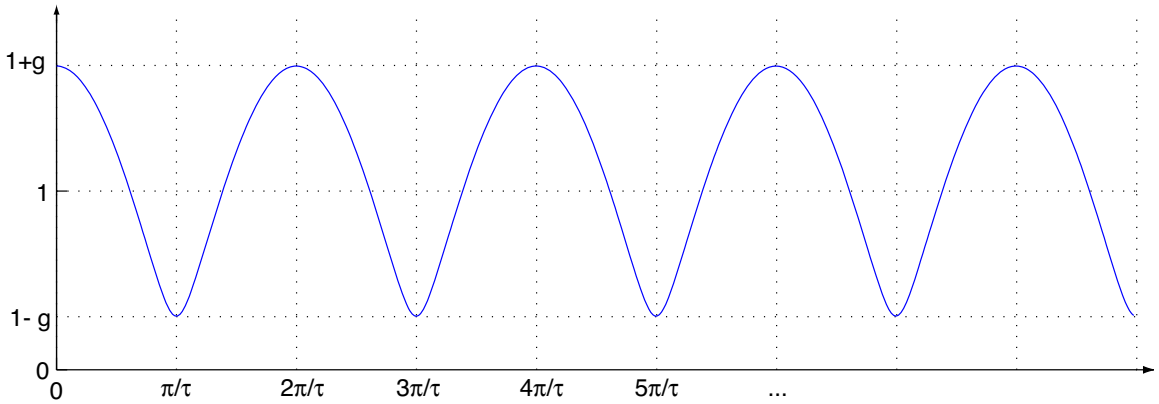
  - truncated FIR implementation

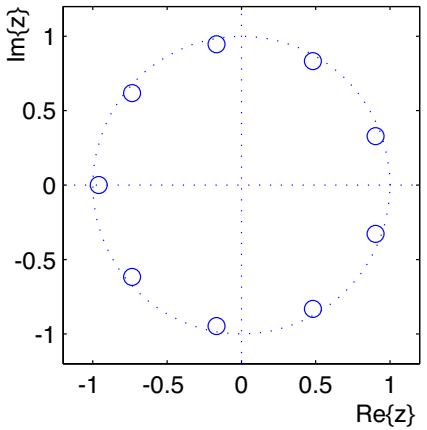
Comb Filters





- Delay added to direct path causes "comb"
  - .. from phase interactions



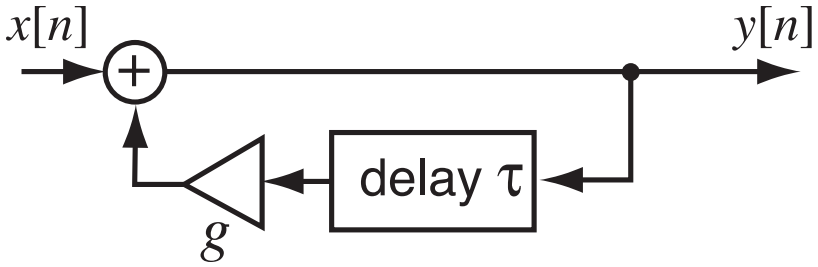


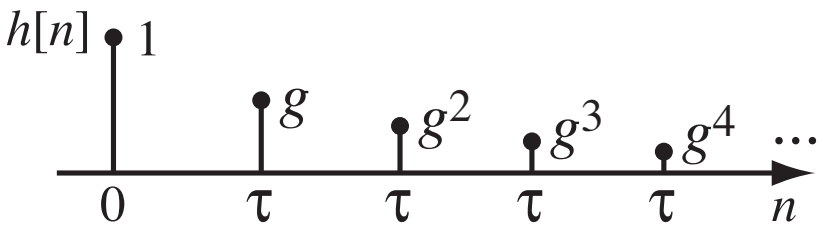
- Range of perceptual effects
  - < 10 ms - phasing (spectral structure)
  - 20-100 ms - chorus/doubling
  - > 100 ms - echo

pd~
s10-comb.pd

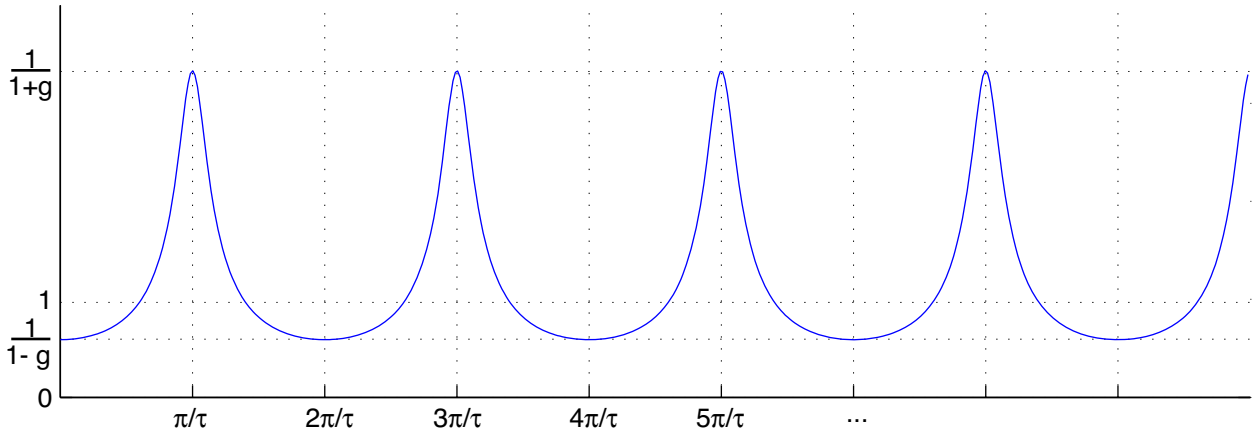
IIR Comb Filters

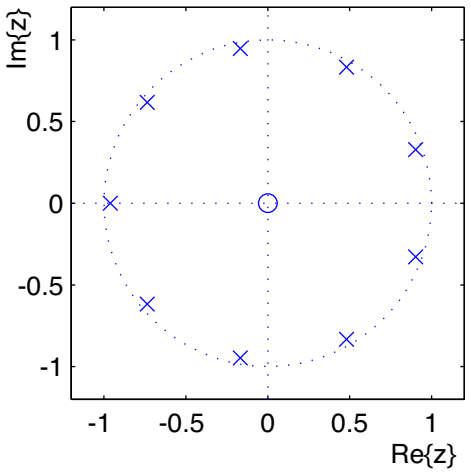
- Feedback delay spreads out more in time





- Poles can give unbounded gain

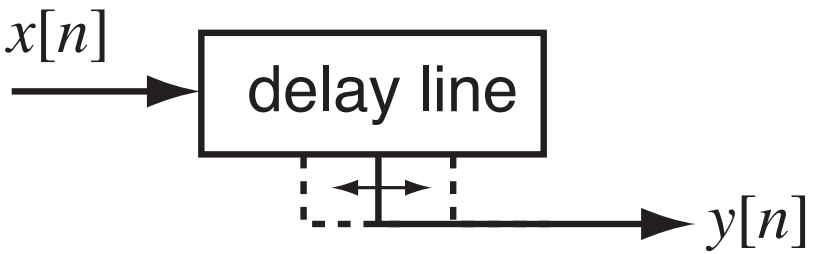




s11-iircomb.pd

Time Varying Delay

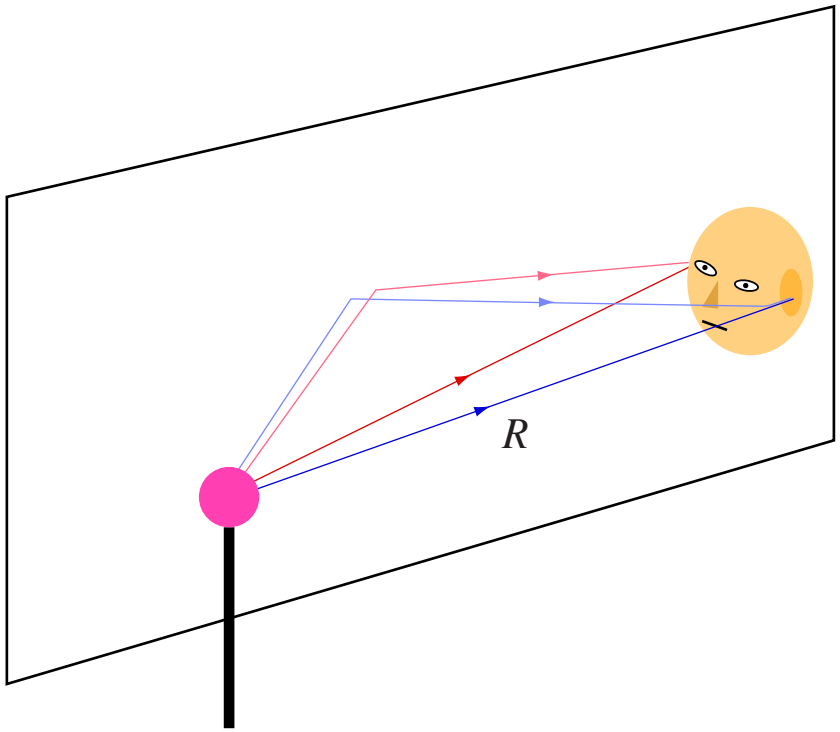
- Periodic variation over large range
  ⇒ Pitch modulation
  - analogous to Doppler shift



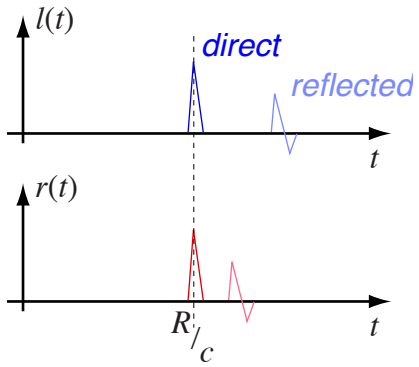
- Random (but smooth) shift over short delay
  ⇒ Chorus
  - pattern of cancellation "notches" like detuned voices

pd~
s12-vardelay.pd

3. Reverberation

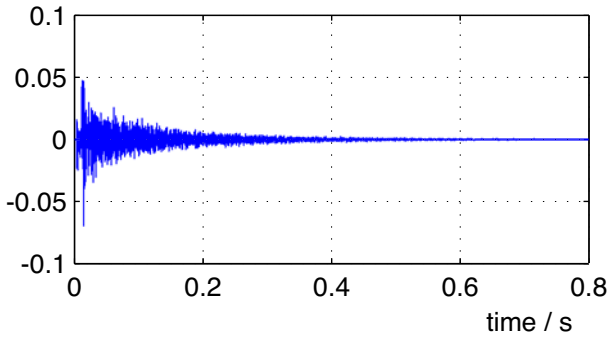


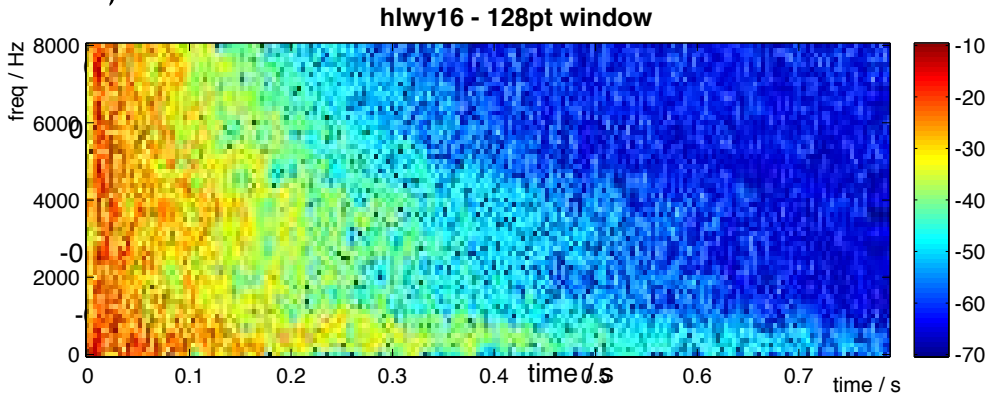
- Received sound is direct path + reflections

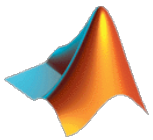


- delayed relative to direct path
- different at each ear
- Direct-to-Reverberant...

- Source→Ear is ~ LTI
  - can use impulse response, convolution

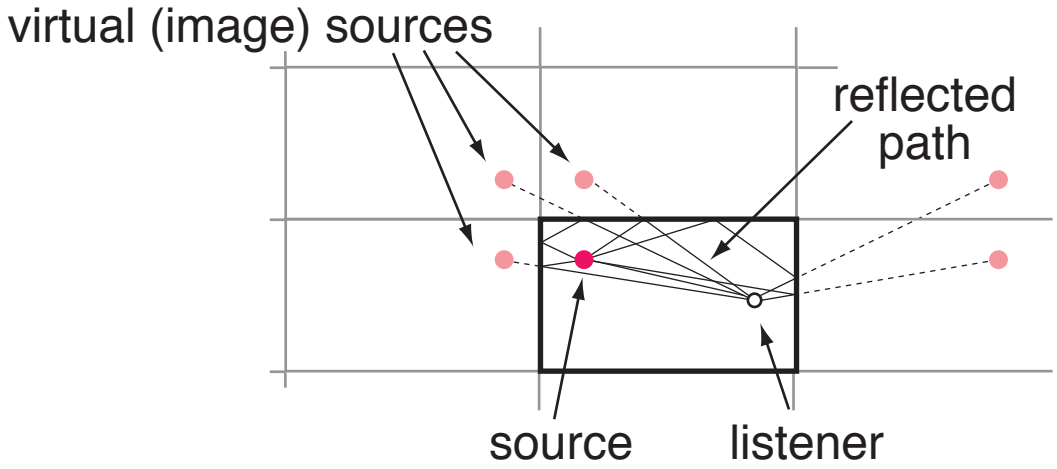






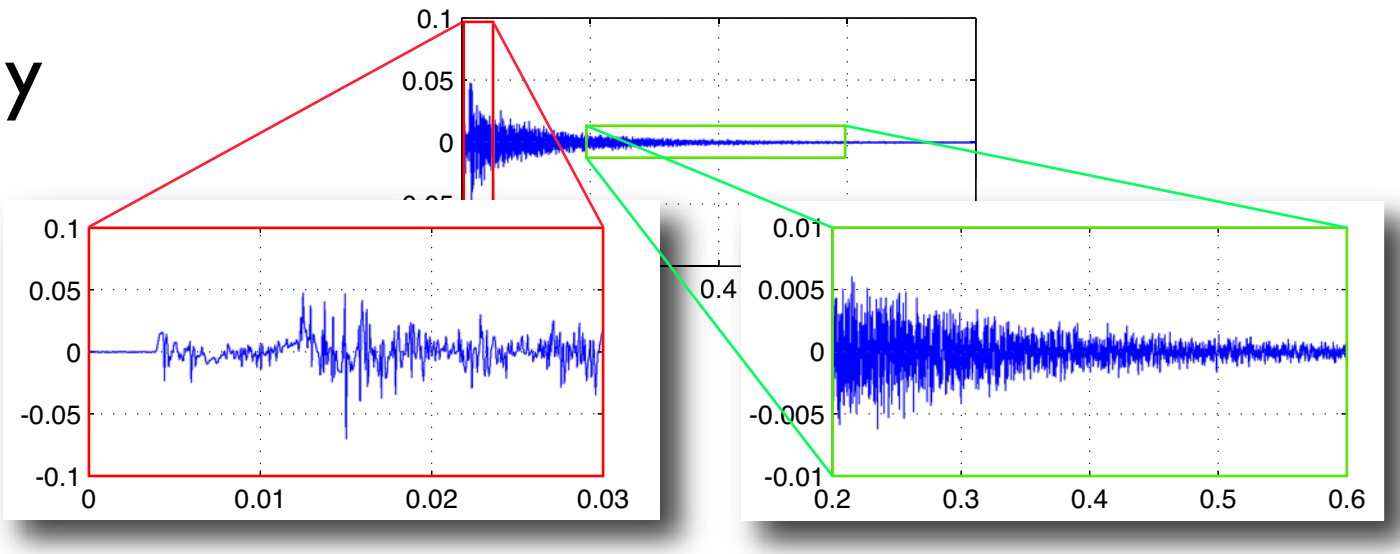
Early Echoes & Late Reverb

- Reflected paths are like "virtual sources"



  - first part of reverberant IR is sparse

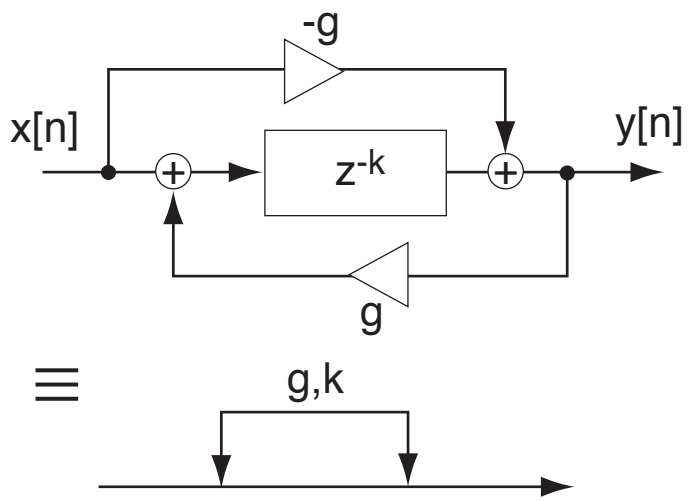
- Reflections quickly build up & merge
  - later part of reverb is like decaying noise



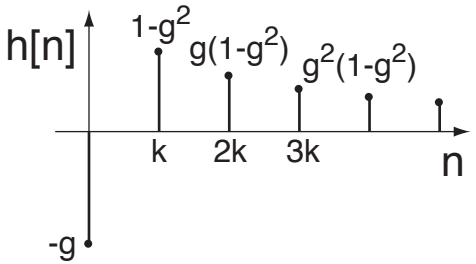
Nested Allpass

- Allpass efficiently creates decaying response
  - multiple, combined filters for complex patterns

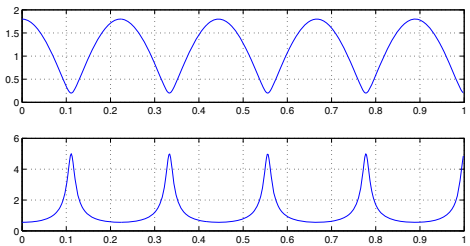
Allpass



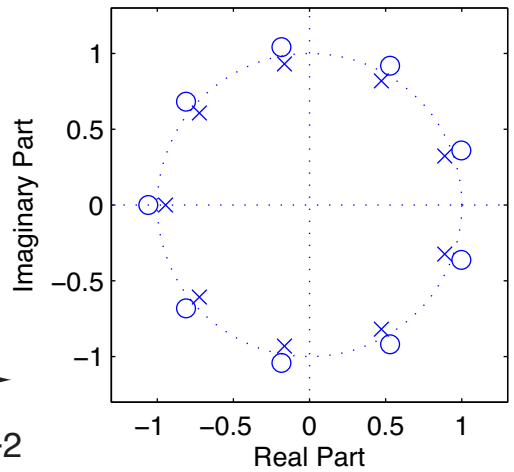
$$H(z) = \frac{z^{-k} - g}{1 - g \cdot z^{-k}}$$



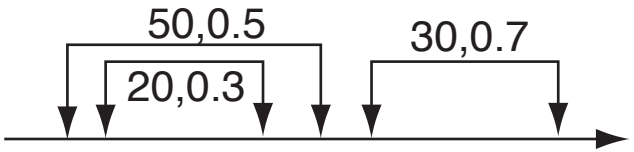
FIR Comb



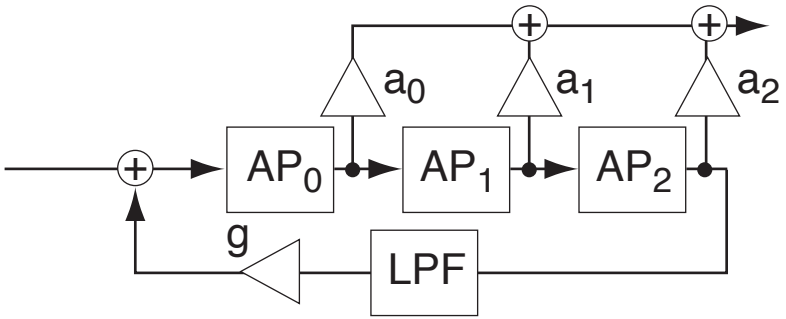
IIR Comb



Nested+Cascade Allpass



Synthetic Reverb

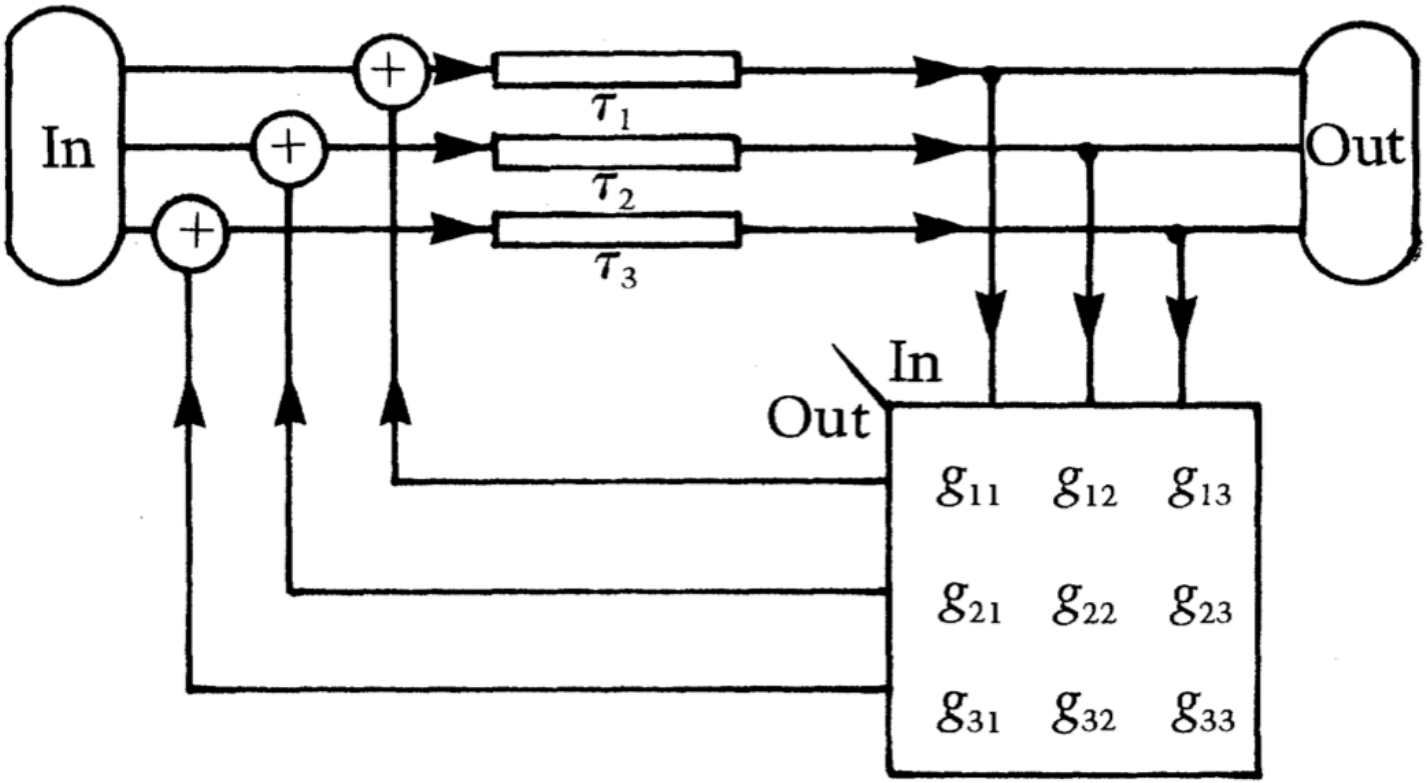


pd~

s15-gardnerverb.pd

Feedback Delay Network

- Matrix of feedbacks gives even more complex patterns
  - "Unitary" matrix ensures decay



from Stauter & Puckette 1982

pd~

s16-reverb.pd

Summary

- Filters:
  EQ used to balance mixes
  Varying filters gives effects e.g. Wah-wah

- Delays
  Wide range of effects: phasing ... echo
  Fractional delays

- Reverb
  Just a complex pattern of echoes
  Discrete early echoes → reverberant tail