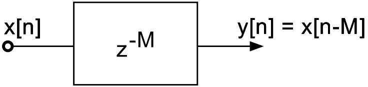
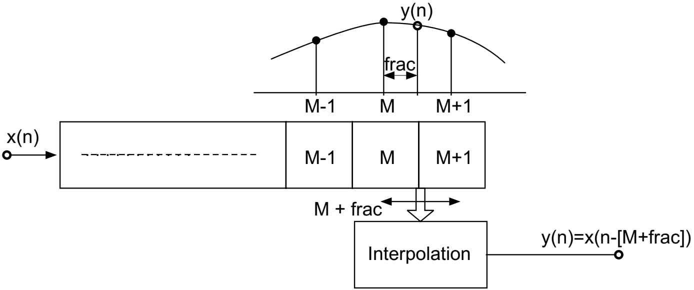
# E85.2607: Lecture 3 – Delay-based effects

# Basic delay




- Delay signal by $M$ samples (or $\tau = M/f_s$ seconds)
- Not much to hear on its own
- Useful for compensating for other delays
  - Acoustic delays in sound reinforcement
  - Processing delays in e.g. long FIR filter
- Implement using *delay line* or buffer
- Poles and zeros? Frequency response?

# Fractional delays




- What if $M$ is not an integer?
- Use *interpolation* to simulate *fractional delay*
  - Estimate the value of sample that doesn't exist

# Fractional delays – strategies

1. Linear interpolation

$$y[n] = x[n-(M+1)]\mathrm{frac} + x[n-M](1-\mathrm{frac})$$

   What kind of filter is this?

2. Allpass interpolation

$$y[n] = x[n-(M+1)]\mathrm{frac} + x[n-M](1-\mathrm{frac}) - y[n-1](1-\mathrm{frac})$$

3. Sinc interpolation, Many more...

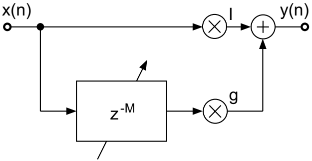
# FIR comb filter

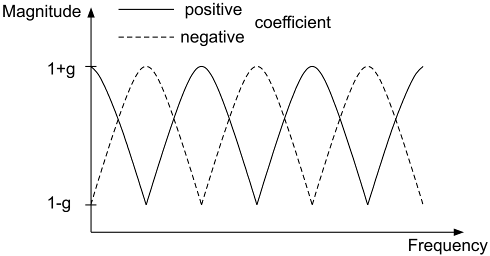
Mix input with a delayed version of itself:

$$y[n] = x[n] + g\,x[n - M]$$

$$H(z) = 1 - g\,z^{-M}$$

# FIR comb filter – frequency response



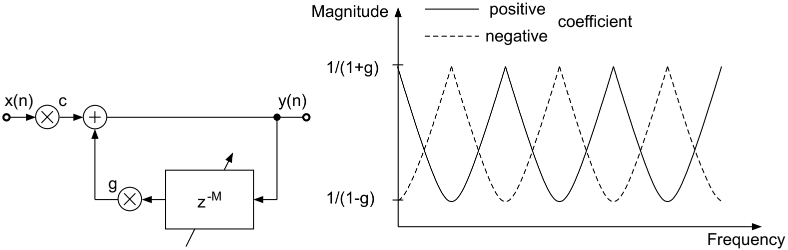
# IIR comb filter

Mix input with a delayed version of filter output:

$$y[n] = c\,x[n] + g\,y[n-M]$$

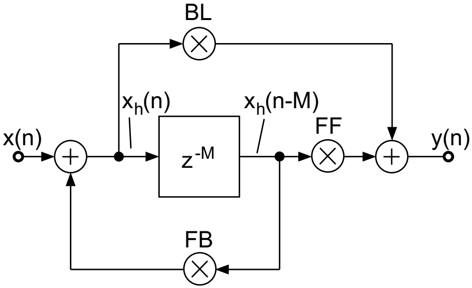
$$H(z) = \frac{c}{1 + g\,z^{-M}}$$

# IIR comb filter – frequency response



# Universal comb filter

Combine FIR and IIR comb filters into a single structure




| | BL | FB | FF |
|---|---|---|---|
| FIR comb filter | X | 0 | X |
| IIR comb filter | 1 | X | 0 |
| allpass | $a$ | $-a$ | 1 |
| delay | 0 | 0 | 1 |

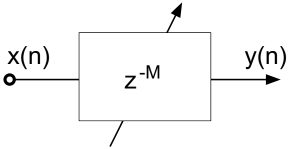
# What do these comb filters sound like?

PD time...

# Delay-based effects: Echo

- Mix input with a long delay ($> 50$ms)
  - FIR comb filter...
- Haas/Precedence Effect
  - If the same sound comes from two different locations, the sound will seem to come from the direction of the sound which arrives first. Our sensory system ignores subsequent sounds.
  - If the delay is larger than about 50 ms, the sounds will be heard as distinct events.
- Different delays lead to different effects
  - Slapback/doubling: echo with short delay $<< 50$ms
- Lets build one

# Delay-based effects: Vibrato

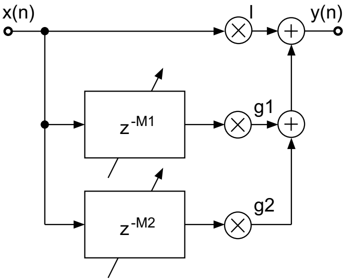



- Time-varying delay (5–10 ms)
- LFO to control delay variation (5–14 Hz)

# Delay-based effects: Flanger

- Time varying slapback (delay $< 15$ ms)
- Use low-frequency oscillator to vary the delay ($\sim 1$ Hz)

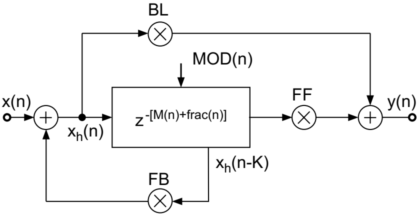
# Delay-based effects: Chorus




- Mix input with randomly delayed versions of itself
- Sounds like a *chorus* of sounds that are not quite in sync

# Bringing it all together

Common universal comb filter structure:




Typical parameters:

| | BL | FF | FB | DELAY | DEPTH | MOD |
|---|---|---|---|---|---|---|
| Vibrato | 0 | 1 | 0 | 0 ms | 0-3 ms | 0.1-5 Hz Sine |
| Flanger | 0.7 | 0.7 | 0.7 | 0 ms | 0-2 ms | 0.1-1 Hz Sine |
| (white) Chorus | 0.7 | 1 | (-0.7) | 1-30 ms | 1-30 ms | lowpass noise |
| Doubling | 0.7 | 0.7 | 0 | 10-100 ms | 1-100 ms | lowpass noise |

# Reading

- *Introduction to Digital Filters*
    - Analysis of a Digital Comb Filter
    - through "Pole-Zero Analysis"
- *DAFX*, Chapter 3 (if you have it)