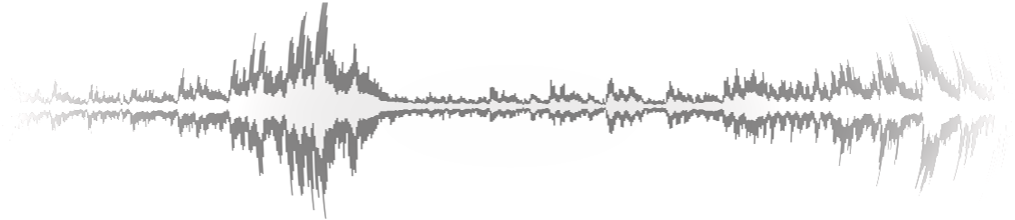
Digital Signal Processing for Music

Part 19: Modulated Effects

alexander lerch



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modulated effects
introduction

- modulated effects belong to the probably oldest class of audio effects
- often used for guitars
- examples
  - delay-line modulation:
    - Vibrato
    - Chorus, Flanger
  - other
    - Phaser
    - Wah-Wah

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modulated effects

introduction: delay line

$$x(i) \longrightarrow \boxed{z^{-M}} \longrightarrow y(i)$$

implementation

input (write) — output (read)

i	x_{i-1}	x_{i-2}	x_{i-3}	$\cdots$	x_{i-M+1}	x_{i-M}
i+1	x_{i}	x_{i-1}	x_{i-2}	$\cdots$	x_{i-M+2}	x_{i-M+1}
i+2	x_{i+1}	x_{i}	x_{i-1}	$\cdots$	x_{i-M+3}	x_{i-M+2}

modulated effects

introduction: delay line

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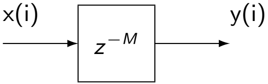

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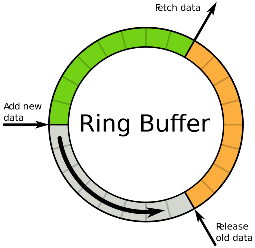
modulated effects

introduction: ring buffer

- **idea**
  - do not move buffer contents
  - instead, increment write and read positions
- **implementation**
  - buffer length L: $L \geq M$
  - store current write index n_w and read index n_r

$\Rightarrow$ for a simple delay: $mod(n_\mathrm{w} - n_\mathrm{r}, L) = M$



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						$\uparrow n_\mathrm{r}$			$\uparrow n_\mathrm{w}$
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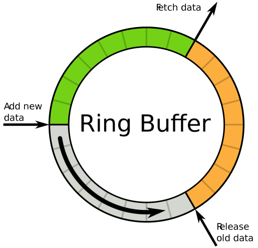

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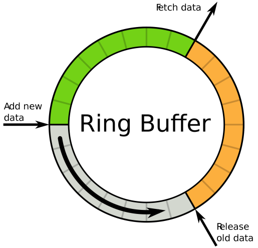

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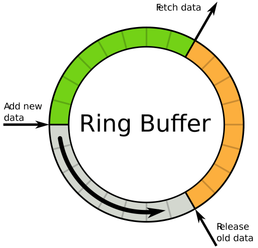

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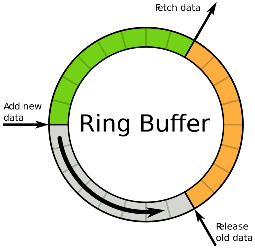

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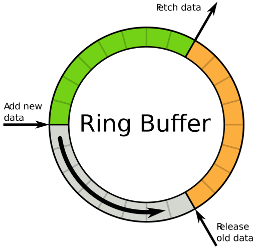

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i+1									
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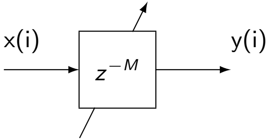
modulated effects

introduction: modulated delay line

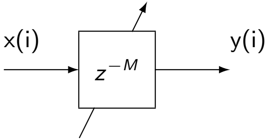


$$n.frac = M + A \cdot \sin\left(2\pi \frac{f_{mod}}{f_s} i\right)$$

- M: static delay in samples
- A: modulation amplitude in samples
- f_{mod}: modulation frequency in Hertz
- sin: oscillator function

modulated effects

introduction: modulated delay line



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modulated effects

introduction: fractional delay line 1/4

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- **problem**
    - (modulated) read index may be *between* samples
    - rounding to integer index causes artifacts

$$\hat{y}(i) = x(i - n.frac)$$

- **solution**
    - interpolate
        - linear interpolation
        - all pass interpolation
        - cubic, sinc, etc. interpolation

modulated effects

introduction: fractional delay line 1/4

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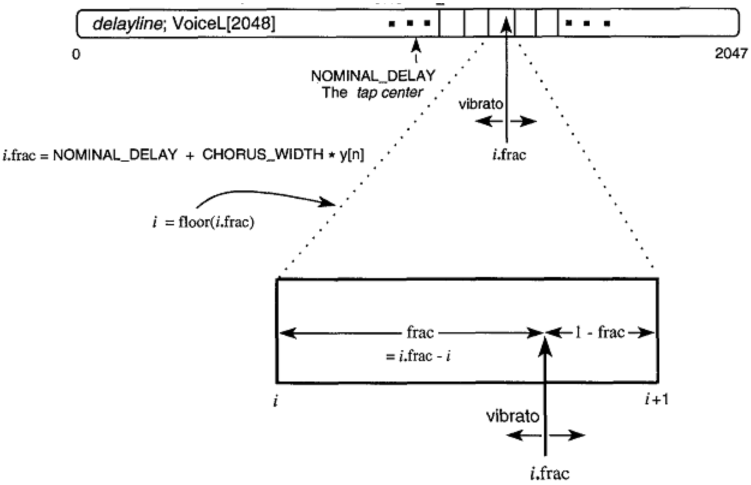
modulated effects

introduction: fractional delay line 2/4



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linear interpolation

- simple to implement
- works well if $f_{mod} << f_s$
- target delay: $i.frac$

$$\begin{aligned}
\hat{y}(i) &= x(i - n.frac) \\
n &= floor(n.frac) \\
frac &= n.frac - n \\
\hat{y}(i) &= x(i - n + 1) \cdot frac + x(i - n) \cdot (1 - frac)
\end{aligned}$$

modulated effects

introduction: fractional delay line 3/4

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introduction: fractional delay line 3/4

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modulated effects

linear interpolation: audio examples

- **original**:
- **6% speed-up**:
- **6% slow-down**:

modulated effects

vibrato

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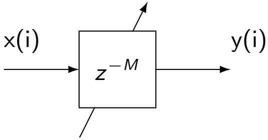
$$x(i) \longrightarrow \boxed{z^{-M}} \longrightarrow y(i)$$

- $M = any$
- $A = 200\,\mathrm{samples}$
- $f_{mod} = 1\,\mathrm{Hz}$

modulated effects
vibrato



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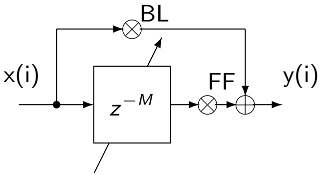
modulated effects

vibrato + input signal



modulated effects

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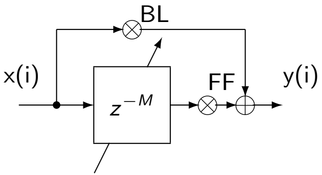
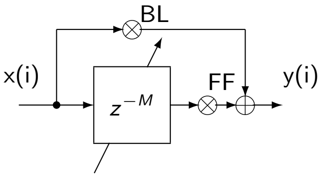


slapback

- $f_{mod} = 0$
- $A = 0$
- $M = 20\,\mathrm{ms}$
- $BL = 0.7$
- $FF = 0.7$

modulated effects

vibrato + input signal



simple echo

- $f_{mod} = 0$
- $A = 0$
- $M = 50\,\mathrm{ms}$
- $BL = 0.7$
- $FF = 0.7$

modulated effects

vibrato + input signal

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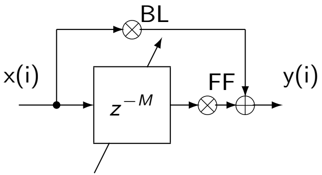

simple flanger

- $f_{mod} = 0.2\,\mathrm{Hz}$
- $A = 2\,\mathrm{ms}$
- $M = 0$
- $BL = 0.7$
- $FF = 0.7$

modulated effects

vibrato + input signal

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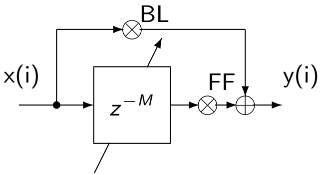
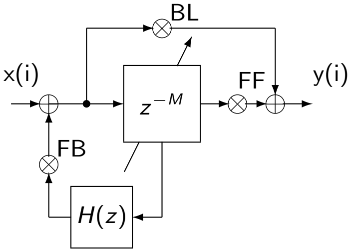


simple chorus

- $f_{mod} = 1.5\,\mathrm{Hz}$
- $A = 2\,\mathrm{ms}$
- $M = 2\,\mathrm{ms}$
- $BL = 1.0$
- $FF = 0.7$

modulated effects

modulated effect with feedback path



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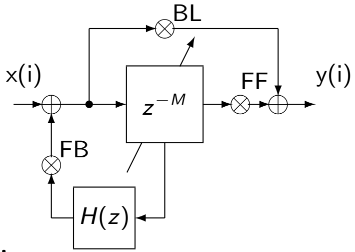

simple flanger with feedback

- $f_{mod} = 0.1\,\mathrm{Hz}$
- $A = 5\,\mathrm{ms}$
- $M = 0$
- $BL = 0.7$
- $FF = 0.7$
- $FB = -0.7$

modulated effects

modulated effect with feedback path

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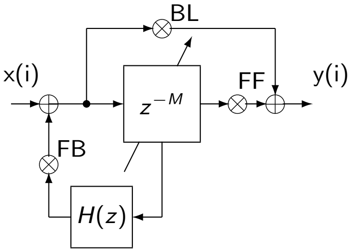
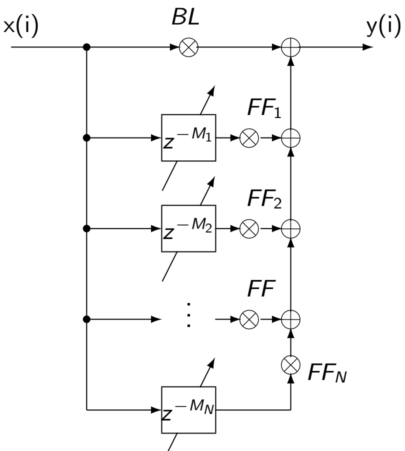


white chorus

- $f_{mod} = 1.5\,\mathrm{Hz}$
- $A = 2\,\mathrm{ms}$
- $M = 2\,\mathrm{ms}$
- $BL = 0.7$
- $FF = 1.0$
- $FB = -0.7$

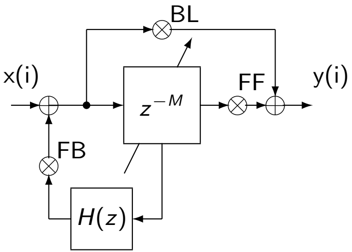
modulated effects

chorus: implementation variant



modulated effects

modulated effects: typical variants



- add low pass/transfer function to feedback path
- use stereo feedback

modulated effects

modulated effects: modulation signal

- **shape**
  - low frequency
  - *sinusoidal* (typically) or *noise* (low pass filtered)
- **phase**
  - **phase response** becomes perceptually relevant when
    - 2 or more signals are added
    - phase is time-variant
    - phase shift between channels (localization)

modulated effects

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modulated effects

modulated effects: phaser

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- sounds similar to delay line effects
- but: different implementation
  - notch filters

  - all pass filters

$f_{mod} = 1\,\mathrm{Hz}, N = 5, M = 2ms, d = 0.5, e = 0.5, fb = 0.5$

modulated effects

modulated effects: phaser

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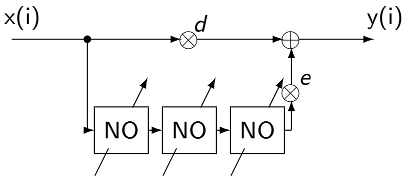

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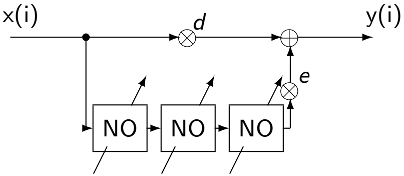
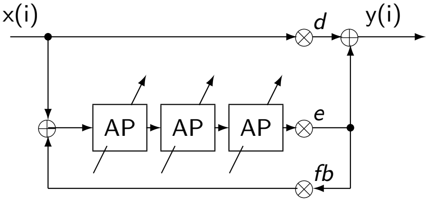


  - all pass filters



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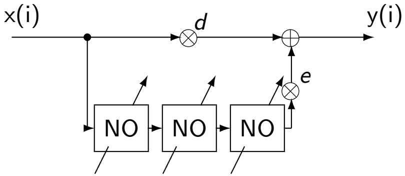
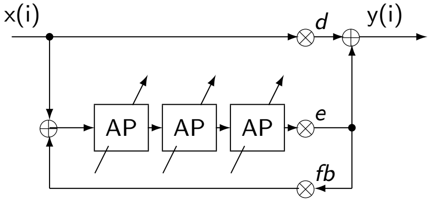


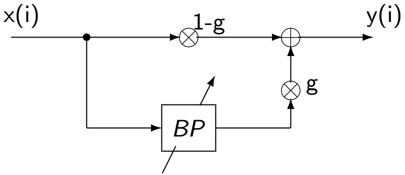
  - all pass filters



$f_{mod} = 1\,\mathrm{Hz}, N = 5, M = 2ms, d = 0.5, e = 0.5, fb = 0.5$

modulated effects

modulated effects: wah-wah



- 'modulated' by pedal
- often a biquad implementation
- not really a bandpass
    - changes shape depending on frequency (resonant at low freqs, broad at high freqs)

modulated effects

summary

- most modulated effects are based on **delay lines**:
  - input signal is added to a delayed version of itself
  - delay time is modulated
- modulation is at very low frequencies (or manually controlled)
  - often sinusoidal
- filters can also be used to create wanted phasing artifacts
  - all-pass and notch filters for phaser
  - band-pass for wah-wah

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