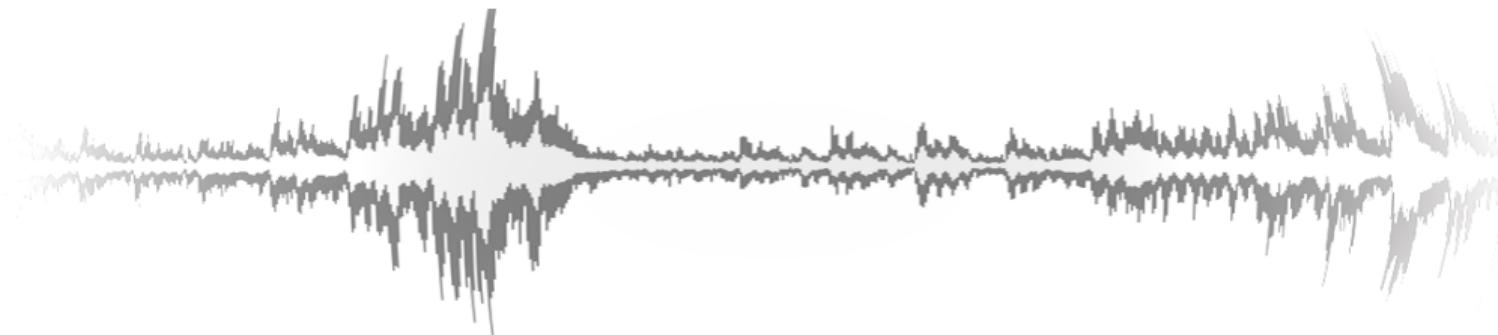


Digital Signal Processing for Music

Part 21: Dynamics Processing

alexander lerch



dynamics processing

introduction

● basic principle

- *apply time-variant audio gain*
- gain depends on signal properties or external factors

● applications

- avoid clipping (unknown input level)
- suppress noise
- adjust playback level (playlist)
- decrease dynamic range (environmental noise)
- increase loudness/energy (commercials)
- adjust (recording) level

dynamics processing

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dynamics processing

introduction: effects

- **(noise) gate**

- suppression of low levels in pauses

- **compressor**

- reduction of the dynamic range

- **expander**

- expansion of the dynamic range

- **limiter**

- limitation of maximum gain

- **AGC (automatic gain control)**

- slow adaptation of recording/payback gain

dynamics processing

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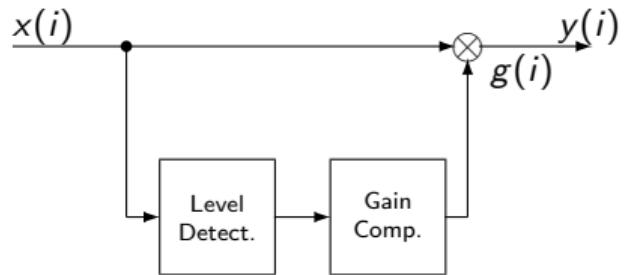
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dynamics processing

overview



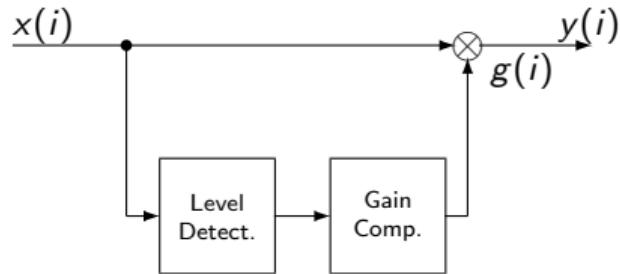
$$y(i) = x(i) \cdot g(i)$$

computation of $g(i)$ usually depends on

- ① input signal *level*
- ② properties & characteristics of the dynamics processor
- ③ time-based control mechanism

dynamics processing

overview



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dynamics processing

level detection

- typical measures

- **peak:**

- physical measure of maximum amplitude

- **rms:**

- physical measure of power level

- **loudness model:**

- models of loudness perception (dBA, Zwicker, BS.1770)

- level computation

$$v_{\text{dB}}(i) = 20 \cdot \log_{10} \left(\frac{v(i)}{v_0} \right)$$

- v_0 : reference constant (0 dB point)
digital: $v_0 = 1 \Rightarrow \text{dBFS}$
- scaling factor: $1 \text{ dB} \approx \text{JNDL}$

dynamics processing

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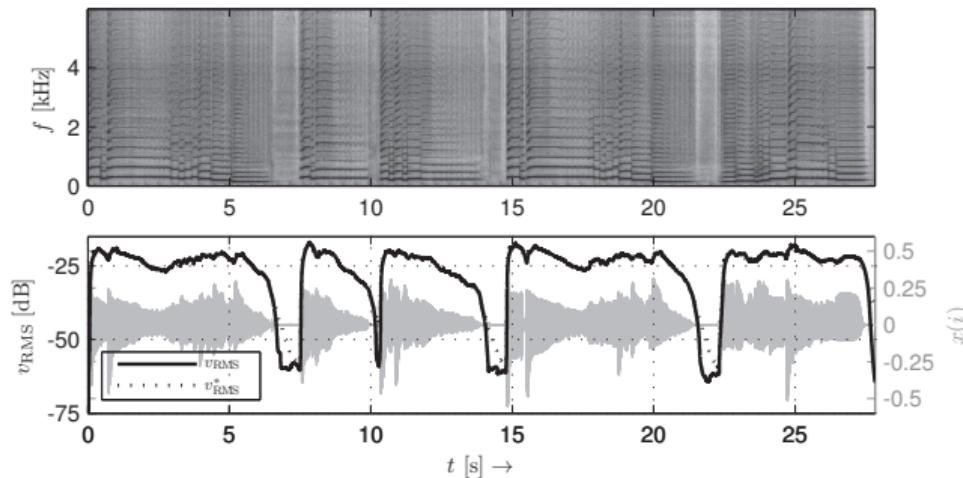
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dynamics processing

level detection: root mean square 1/2

$$v_{\text{RMS}}(n) = \sqrt{\frac{1}{K} \sum_{i=i_s(n)}^{i_e(n)} x(i)^2}$$



dynamics processing

level detection: root mean square 2/2

sample-by-sample processing:

- reduce computational complexity

$$\begin{aligned} v_{\text{RMS}}^2(n) &= \frac{x(i_e(n))^2 - x(i_s(n-1))^2}{i_e(n) - i_s(n) + 1} + v_{\text{RMS}}^2(n-1) \\ v_{\text{RMS}}(n) &= \sqrt{v_{\text{RMS}}^2(n)} \end{aligned}$$

- single pole approximation

$$\begin{aligned} v_{\text{tmp}}(i) &= \alpha \cdot v_{\text{tmp}}(i-1) + (1-\alpha) \cdot x(i)^2 \\ v_{\text{RMS}}^*(i) &= \sqrt{v_{\text{tmp}}(i)} \end{aligned}$$

dynamics processing

level detection: root mean square 2/2

sample-by-sample processing:

- reduce computational complexity

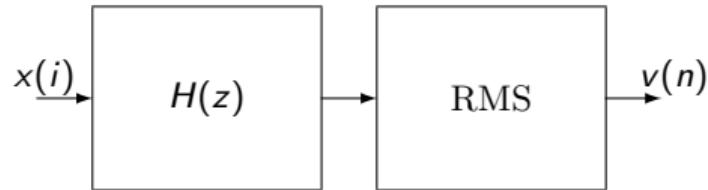
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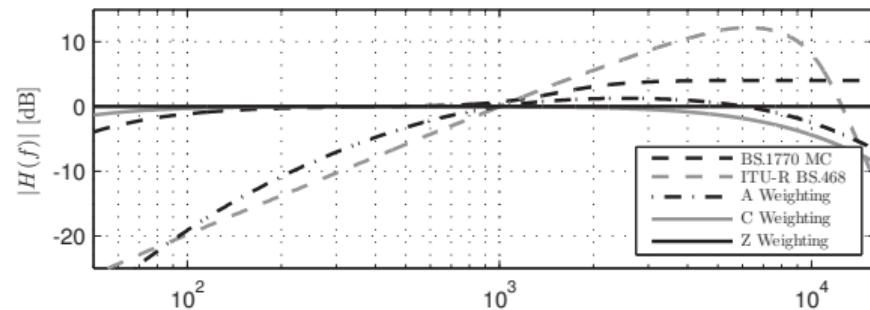
dynamics processing

level detection: weighted root mean square



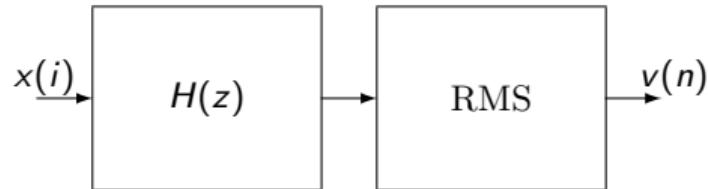
$H(z)$:

- A, B, C weighting
- RLB (BS.1770)
- ...



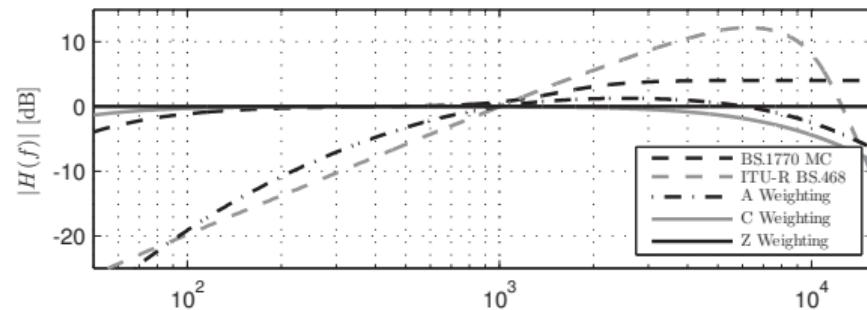
dynamics processing

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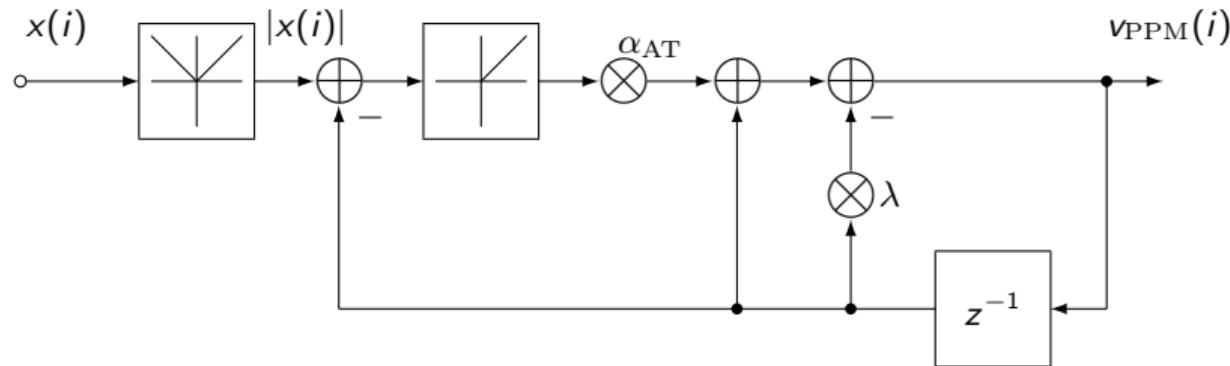
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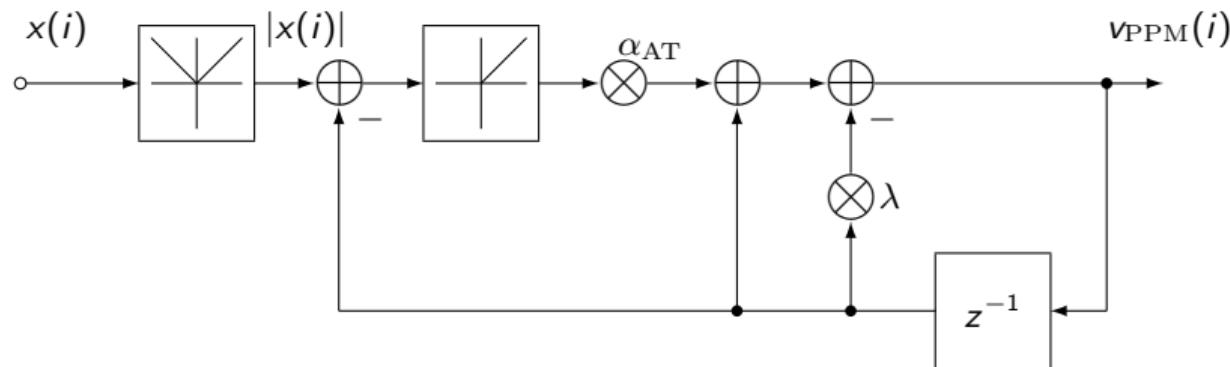
dynamics processing

level detection: peak detection (PPM) 1/2



dynamics processing

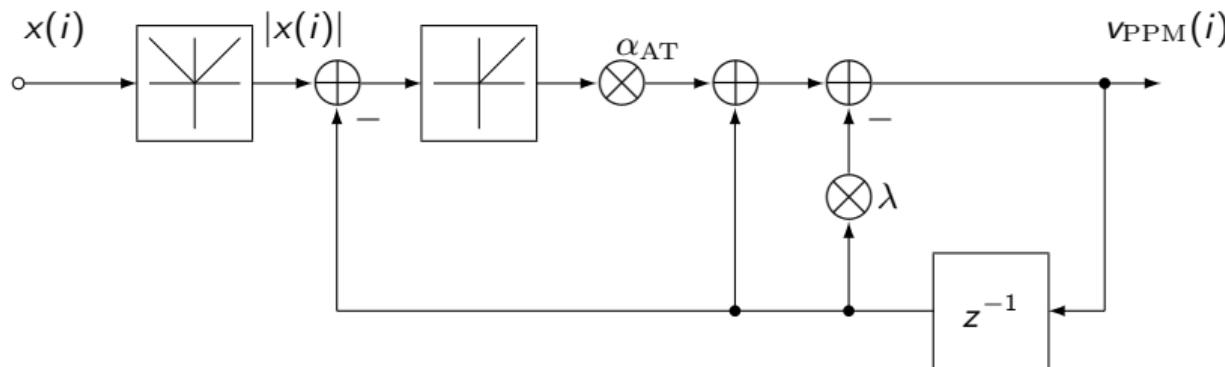
level detection: peak detection (PPM) 1/2



- **release state** ($|x(i)| \leq v_{PPM}(i - 1) \Rightarrow \lambda = \alpha_{RT}$)

dynamics processing

level detection: peak detection (PPM) 1/2

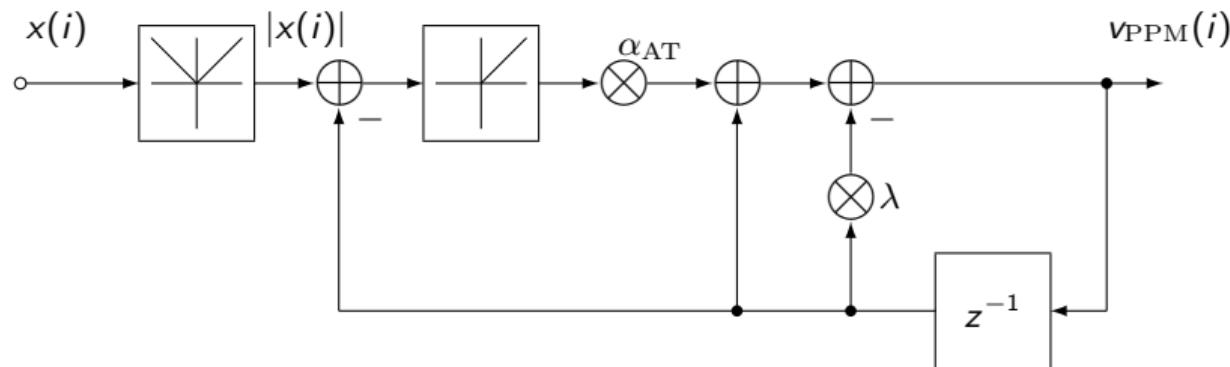


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$$\begin{aligned}v_{PPM}(i) &= v_{PPM}(i-1) - \alpha_{RT} \cdot v_{PPM}(i-1) \\&= (1 - \alpha_{RT}) \cdot v_{PPM}(i-1)\end{aligned}$$

dynamics processing

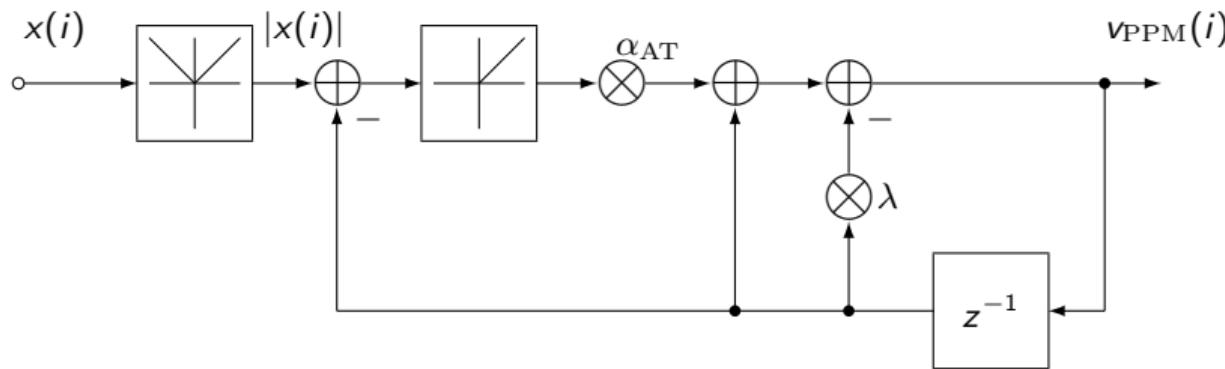
level detection: peak detection (PPM) 1/2



- **attack state** ($|x(i)| > v_{PPM}(i - 1) \Rightarrow \lambda = 0$)

dynamics processing

level detection: peak detection (PPM) 1/2

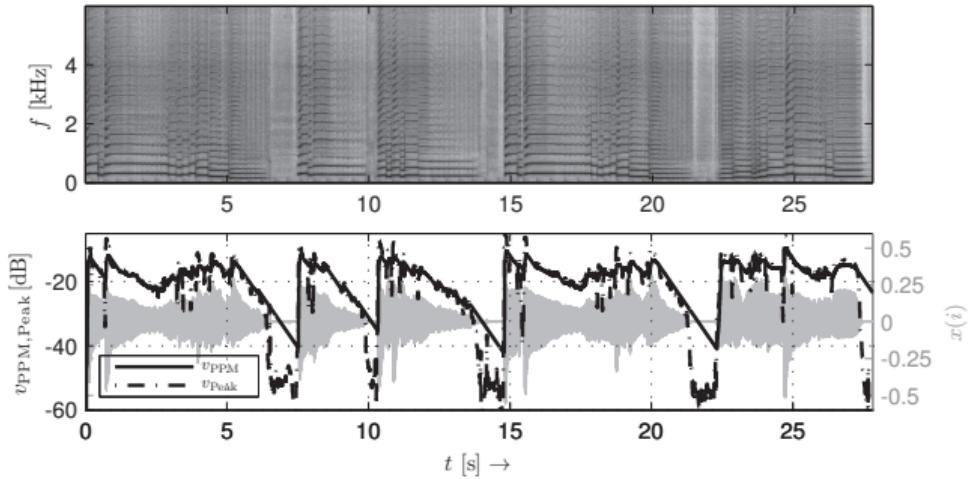


- **attack state** ($|x(i)| > v_{PPM}(i - 1) \Rightarrow \lambda = 0$)

$$\begin{aligned}v_{PPM}(i) &= \alpha_{AT} \cdot (|x(i)| - v_{PPM}(i - 1)) + v_{PPM}(i - 1) \\&= \alpha_{AT} \cdot |x(i)| + (1 - \alpha_{AT}) \cdot v_{PPM}(i - 1)\end{aligned}$$

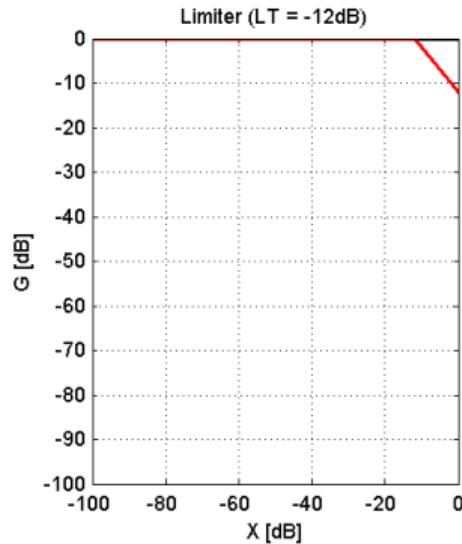
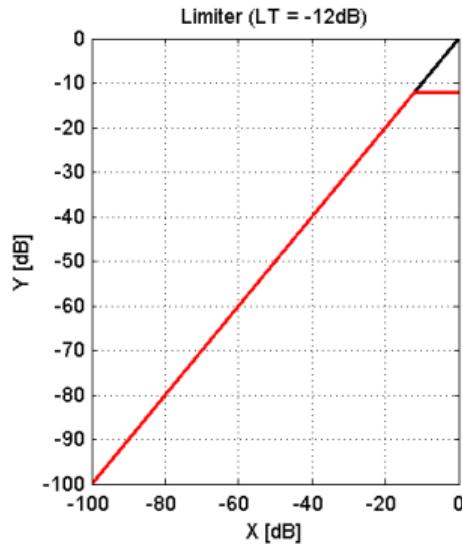
dynamics processing

level detection: peak detection (PPM) 2/2



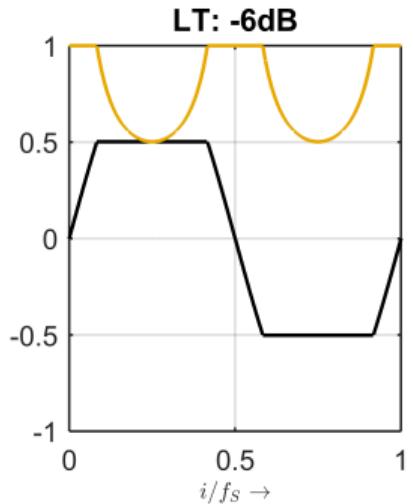
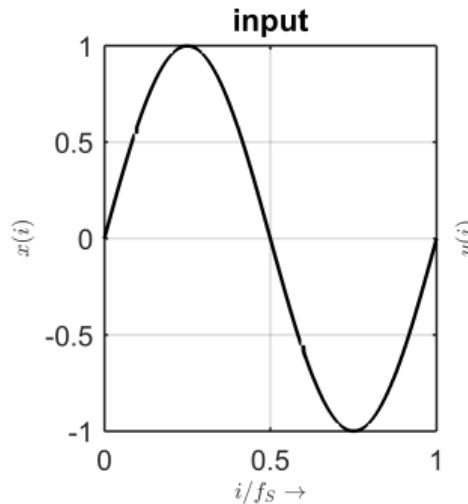
dynamics processing

response curve: limiter



dynamics processing

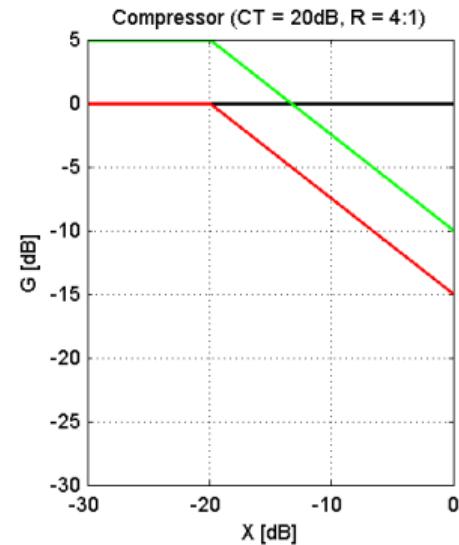
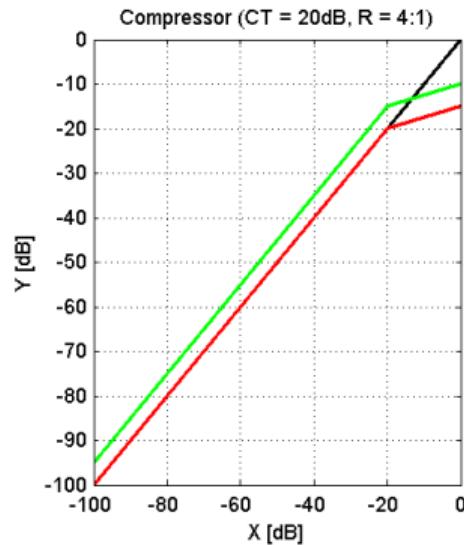
response curve: limiter



param $LT = -9\text{ dB}$

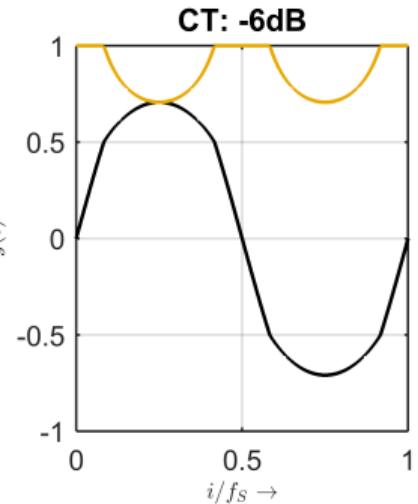
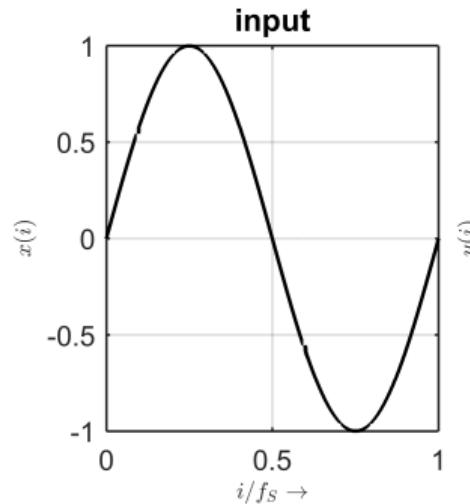
dynamics processing

response curve: compressor



dynamics processing

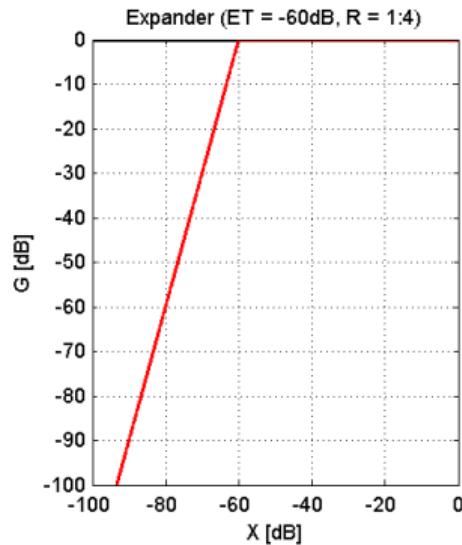
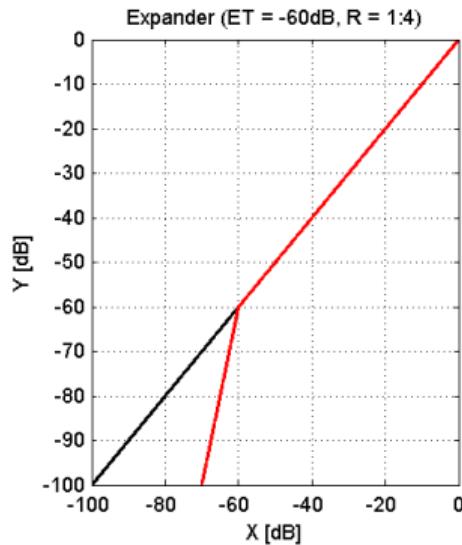
response curve: compressor



param $CT = -9$ dB

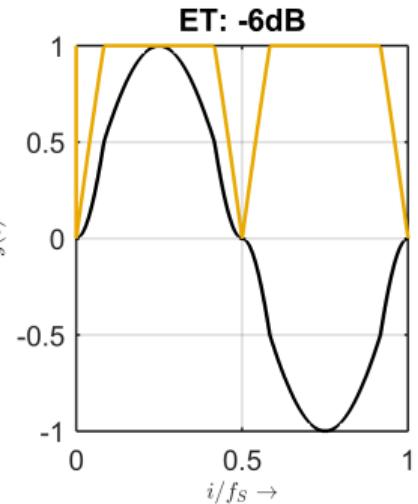
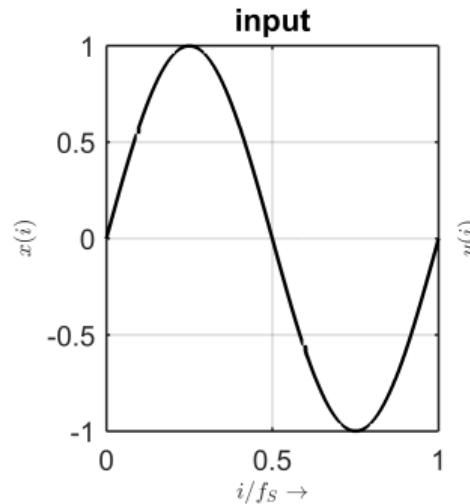
dynamics processing

response curve: expander



dynamics processing

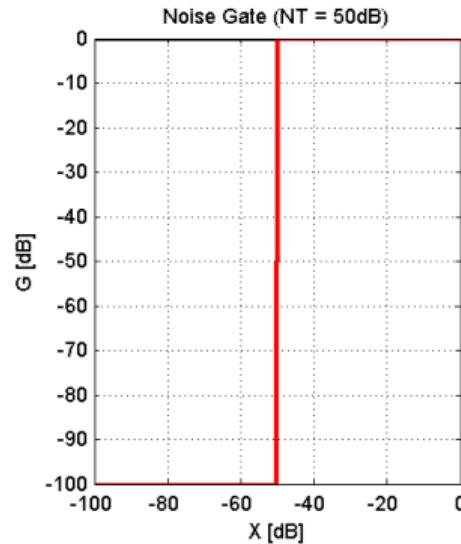
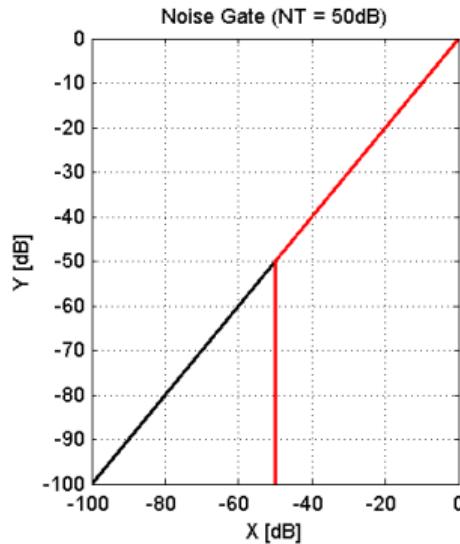
response curve: expander



param $ET = -6\text{ dB}$

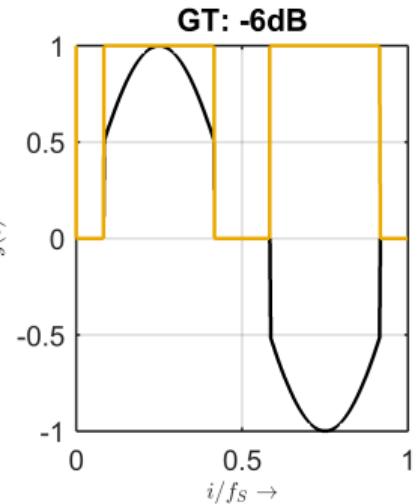
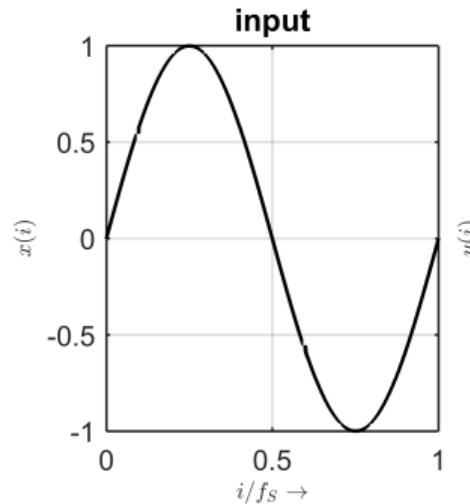
dynamics processing

response curve: noise gate



dynamics processing

response curve: noise gate



param $NT = -12$ dB

dynamics processing

response curve: mathematical description (compressor)

logarithmic description, nonlinear part

- **output:** $Y = g(X) + X$ [dB]
- **ratio:** $R = \frac{\Delta L_i}{\Delta L_o}$
- **slope:** $CS = 1 - \frac{1}{R}$
- **linear equation (offset CT):** $Y = \frac{1}{R}(X - CT) + CT$
- **gain (g = Y - X):**

$$\begin{aligned} g &= \frac{1}{R}(X - CT) + CT - X \\ &= \left(1 - \frac{1}{R}\right) \cdot (CT - X) \\ &= CS \cdot (CT - X) \end{aligned}$$

dynamics processing

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dynamics processing

response curve: mathematical description (summary 1/2)

logarithmic description, nonlinear part

● limiter

$$R = \infty$$

$$Y = LT$$

$$g = LT - X$$

● compressor

$$R > 1$$

$$Y = \frac{1}{R} (X - CT) + CT$$

$$g = \left(1 - \frac{1}{R}\right) \cdot (CT - X)$$

dynamics processing

response curve: mathematical description (summary 1/2)

logarithmic description, nonlinear part

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dynamics processing

response curve: mathematical description (summary 2/2)

logarithmic description, nonlinear part

● expander

$$\begin{aligned} R &< 1 \\ Y &= \frac{1}{R}(X - ET) + ET \\ g &= \left(1 - \frac{1}{R}\right) \cdot (ET - X) \end{aligned}$$

● gate

$$\begin{aligned} R &= 0 \\ Y &= -\infty \\ g &= -\infty \end{aligned}$$

dynamics processing

response curve: mathematical description (summary 2/2)

logarithmic description, nonlinear part

• expander

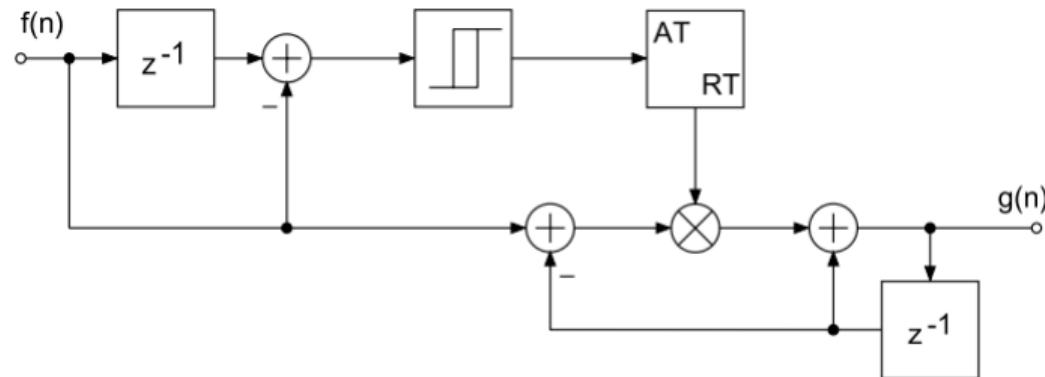
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dynamics processing

smoothing: attack and release 1/2

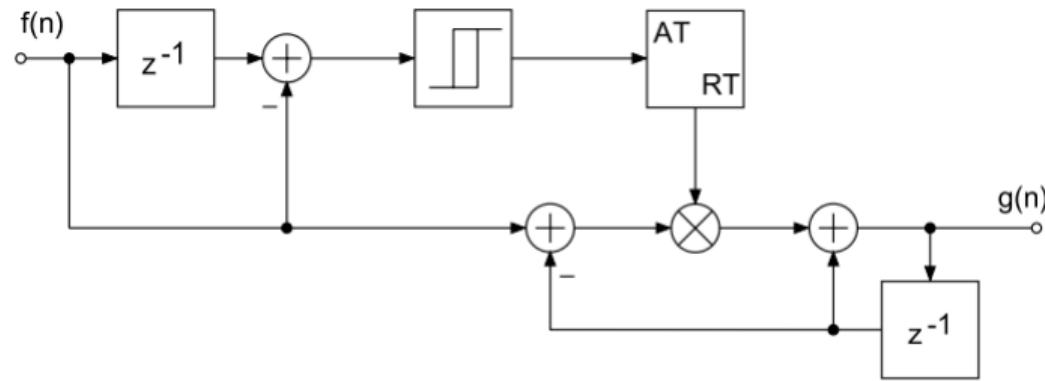


- α_{AT} : attack constant
- α_{RT} : release constant

$$\begin{aligned} g(n) &= \alpha \cdot (f(n) - g(n-1)) + g(n-1) \\ &= \alpha f(n) + (1 - \alpha) \cdot g(n-1) \end{aligned}$$

dynamics processing

smoothing: attack and release 1/2

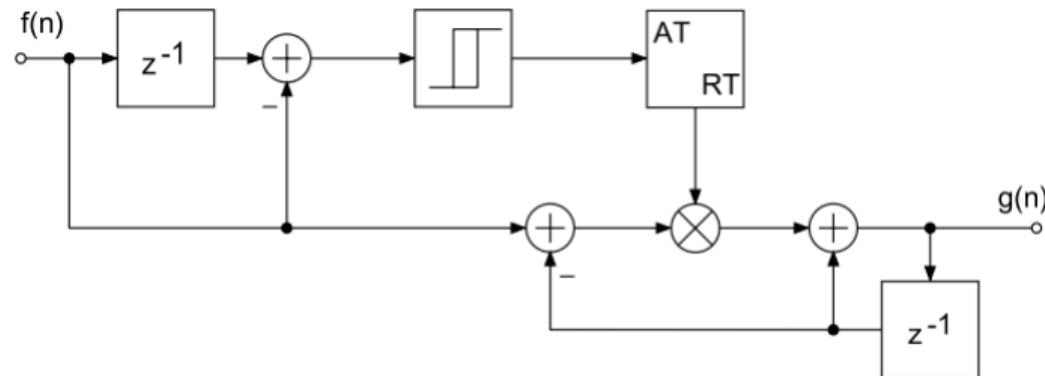


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dynamics processing

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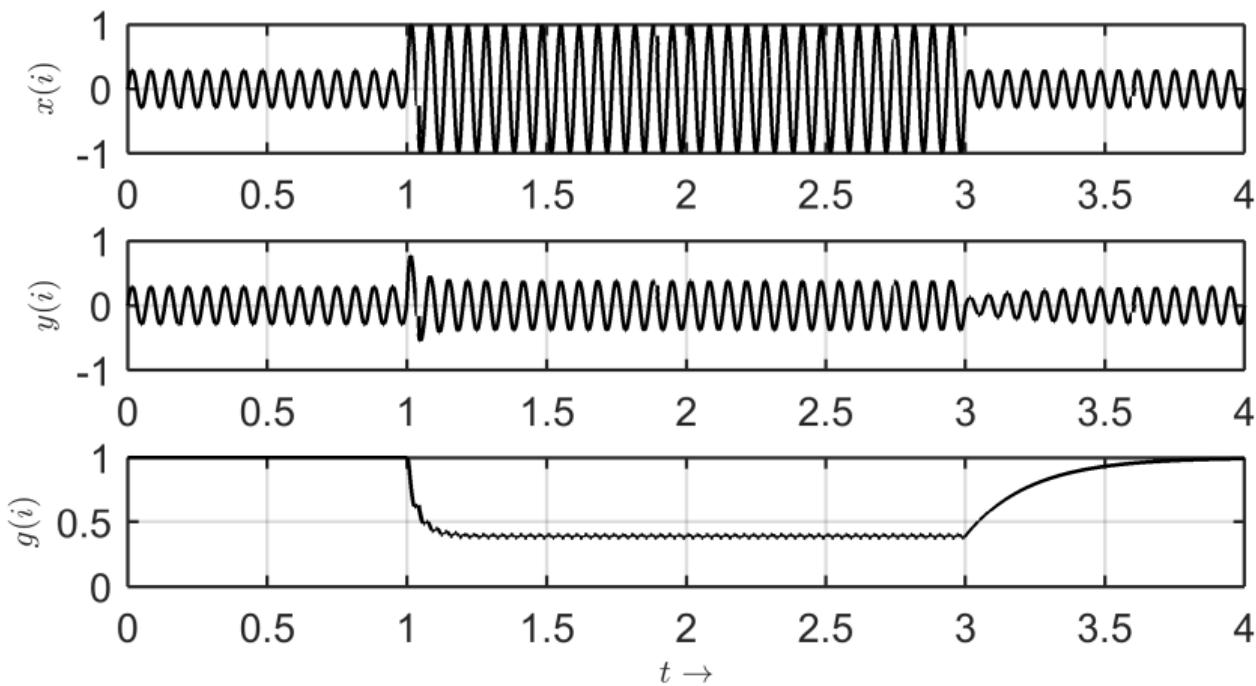


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dynamics processing

smoothing: attack and release 2/2



dynamics processing

smoothing: attack and release coefficients

- single pole step response $\rightarrow g(t) = 1 - e^{\frac{-t}{\tau}}$
- define single pole integration time between 10% and 90%

$$t_I = t_{90} - t_{10}$$

$$0.1 = 1 - e^{\frac{-t_{10}}{\tau}}$$

$$0.9 = 1 - e^{\frac{-t_{90}}{\tau}}$$

$$\Rightarrow 0.9/0.1 = e^{\frac{t_{90}-t_{10}}{\tau}}$$

$$\log(0.9/0.1) = t_{90}-t_{10}/\tau$$

$$t_{90} - t_{10} = 2.197\tau$$

$$\tau \approx t_I/2.2$$

dynamics processing

smoothing: attack and release coefficients

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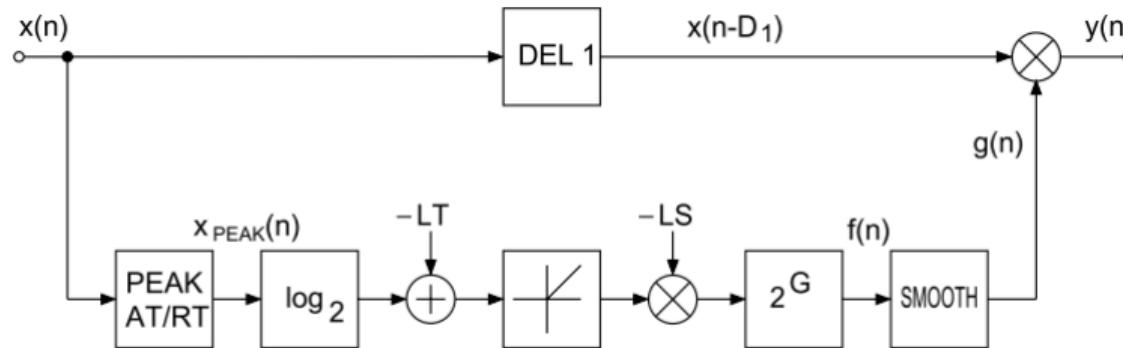
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dynamics processing

overall system: limiter

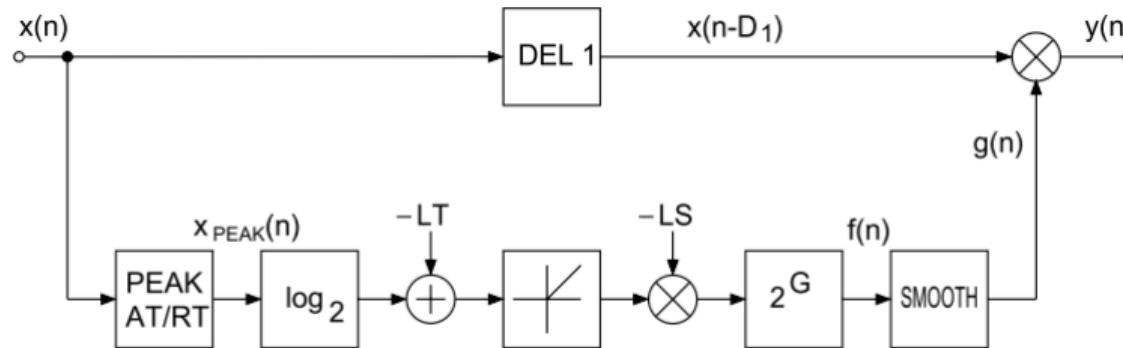


$$CS = 1 - \frac{1}{R} \Rightarrow LS = 1$$

- $X < LT \rightarrow g = 1$
- $X > LT \rightarrow g = (LT - X)$

dynamics processing

overall system: limiter

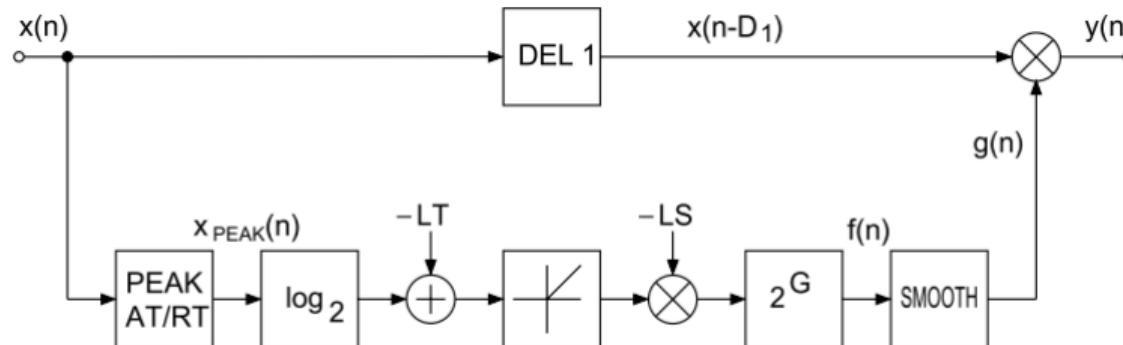


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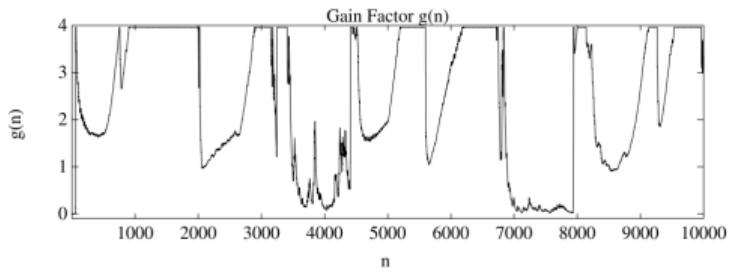
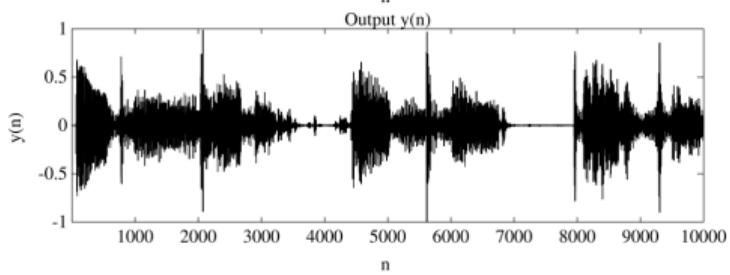
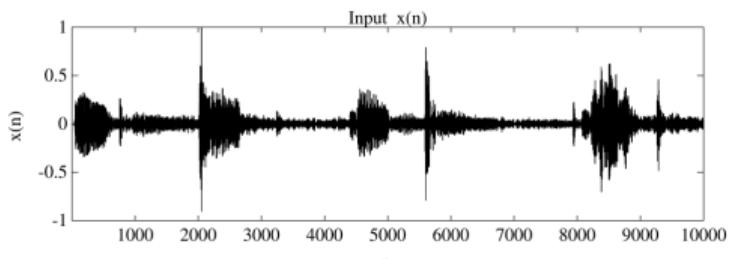


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dynamics processing

gain visualization: combined system



dynamics processing

audio examples



- Gate
- Expander
- Compressor
- Limiter

dynamics processing

variants 1/3

- **attack & release constant selection**

- depending on “abruptness” of change

- **hold time**

- before release, hold gain constant (avoid pumping with low frequency signals)

- **oversampling**

- high time resolution for peak detection

dynamics processing

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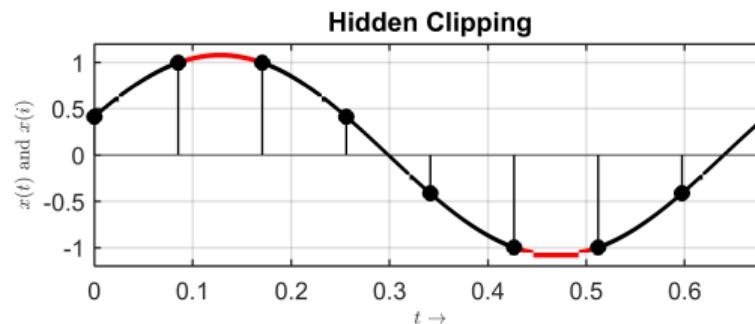
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dynamics processing

variants 2/3

● stereo link

- consider both channels (avoid level-dependent changes of stereo image)
 - one master channel (left or right)
 - mean of both channels
 - channel with higher level (max)

● soft knee

- smooth crossover from linear area to compressed area

potentially noticeable with

- very short attack times
- high compression ratios

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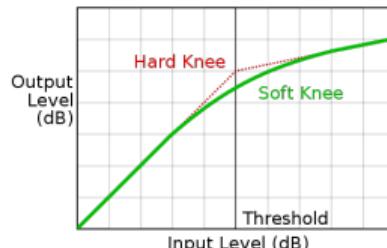
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dynamics processing

variants 3/3

● side chain

- choose different input signal for level control (“ducking”)

● look-ahead

- introduce higher delay in signal path
 - shift gain modification in time
 - combine “future” measurement with current

● multi-band compression

- apply one compressor to each frequency band
- advantages:
 - avoid pumping: varying level in one band (e.g. bass drum) does not influence gain of other bands
 - maximize power, overall loudness

dynamics processing

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dynamics processing

parameter ranges

- **threshold**

-120...0 dB

- **ratio**

0.05...20 (Limiter: ∞)

- **attack**

0...10 ms

- **release**

20...300 ms

- **hold**

0...10 ms

- **stereo-link**

On/Off

- **oversampling**

1...8

- **look-ahead**

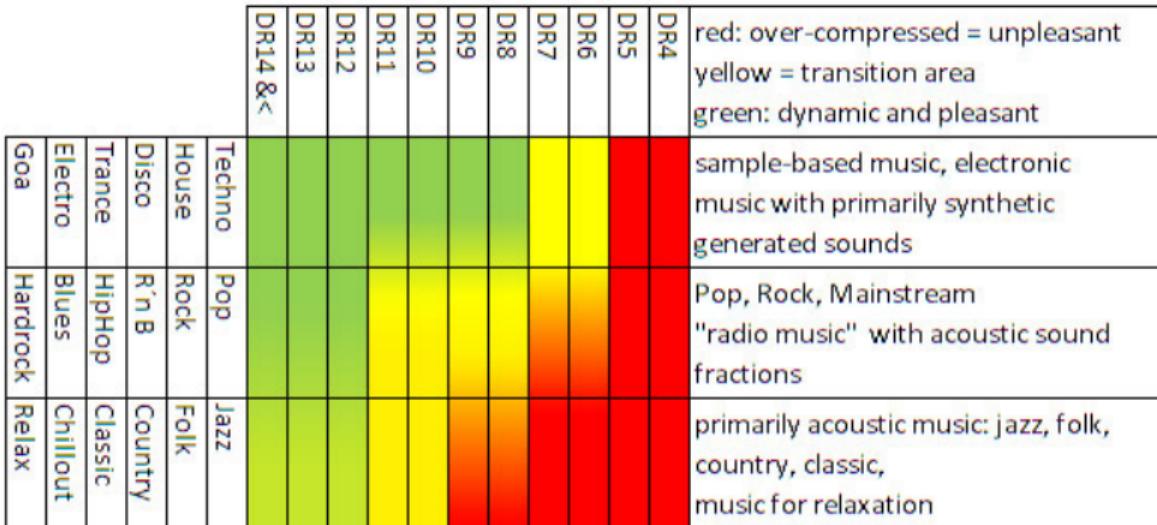
dynamics processing

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dynamics processing

dynamic range target



dynamics processing

summary

dynamics processing systems are

- **time variant:**

gain changes over time

- **signal adaptive:**

gain depends on (input) signal

- sometimes **non-linear:**

at very short attack times (limiting)

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