# Digital Signal Processing for Music

## Part 22: Dynamics Processing

Andrew Beck

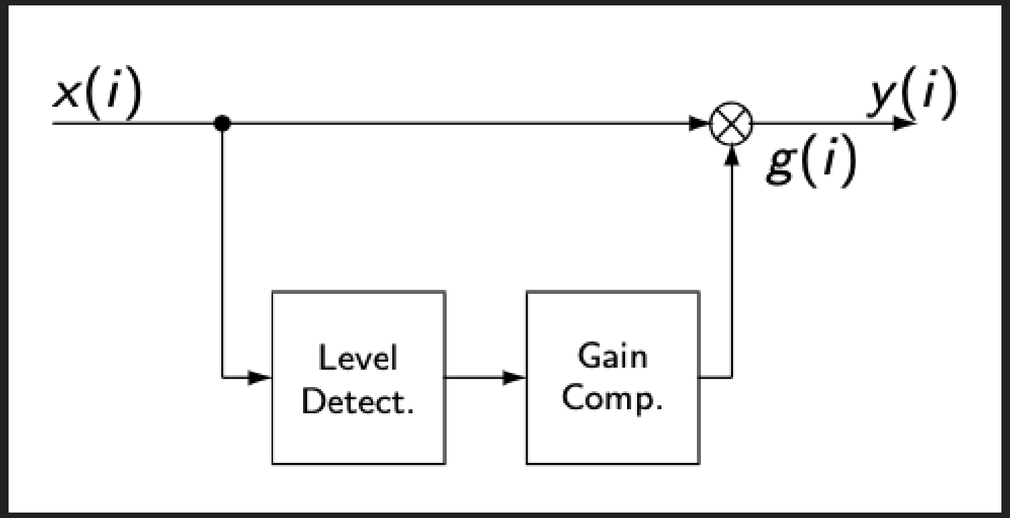
# Intro

- **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 (commericals)
  - Adjust (recording) level

# 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/playback gain

# Overview




Computation of $g(i)$ usually depends on

1. Input signal *level*
2. Properties & characteristics of the dynamics processor
3. Time-based control mechanism

# 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**

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

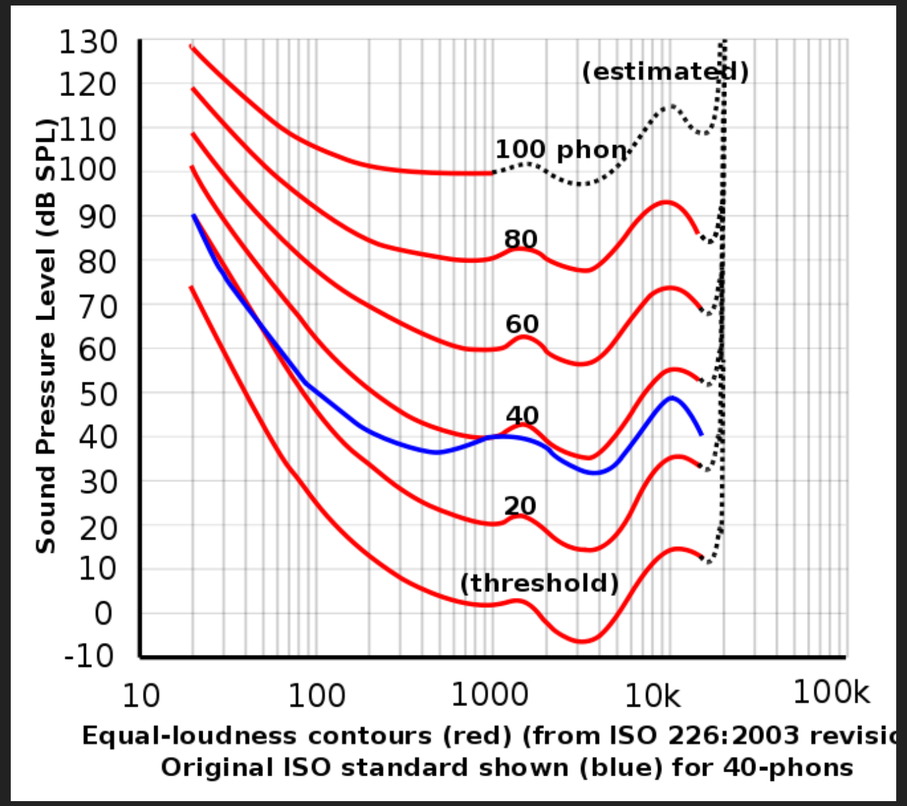
  - $v_0$: Reference constant (0 dB point)
    Digital: $v_0 = 1 \Rightarrow \mathrm{dBFS}$
  - Scaling factor: $1\mathrm{dB} \approx \mathrm{JNDL}$

# Perceptual Loudness

Equal sized steps on the decibel scale not perceived as equal-sized loudness steps

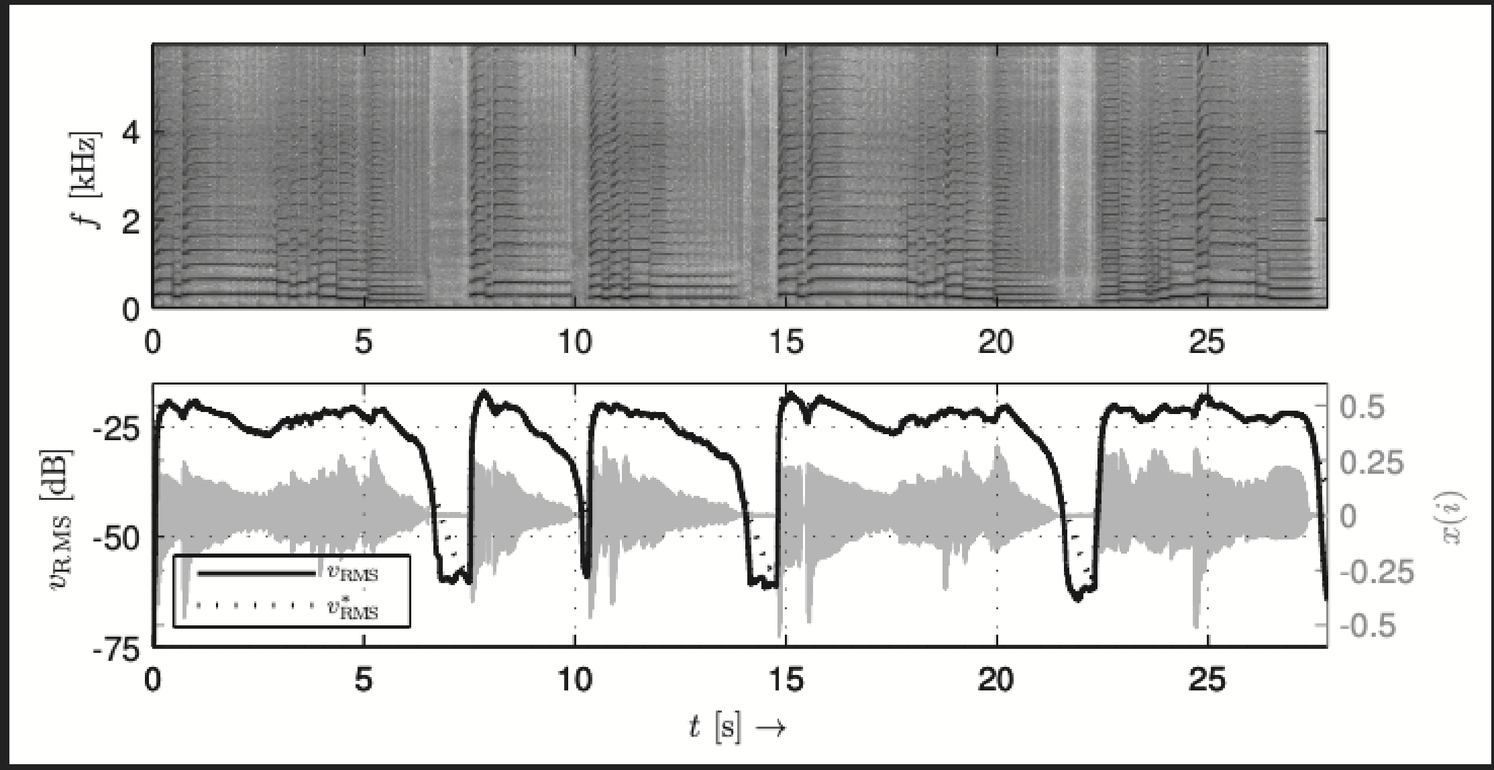
Perceptual loudness depends on

- Frequency
- Cochlear Resolution
- Masking Effects



# Level Detection: Root Mean Square

$$v_{\mathrm{RMS}}(n) = \sqrt{\frac{1}{\mathcal{K}} \sum_{i=i_{\mathrm{s}}(n)}^{i_{\mathrm{e}}(n)} x(i)^2}$$



# RMS: Sample-by-Sample Processing

- Reduce computational complexity

$$v_{\mathrm{RMS}}^2(n) = \frac{x(i_{\mathrm{e}}(n))^2 - x(i_{\mathrm{s}}(n-1))^2}{\mathcal{K}} + v_{\mathrm{RMS}}^2(n-1)$$

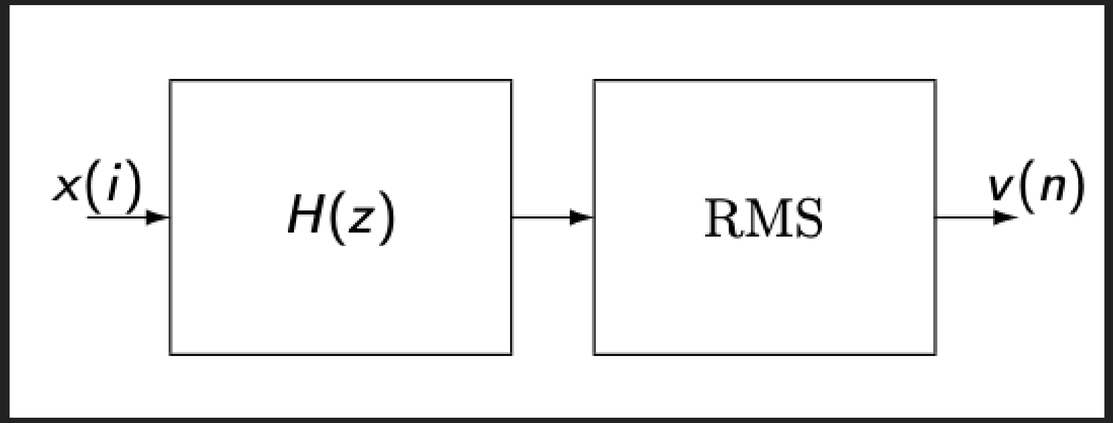
$$v_{\mathrm{RMS}}(n) = \sqrt{v_{\mathrm{RMS}}^2(n)}$$

- Single Pole approximation (no buffering)

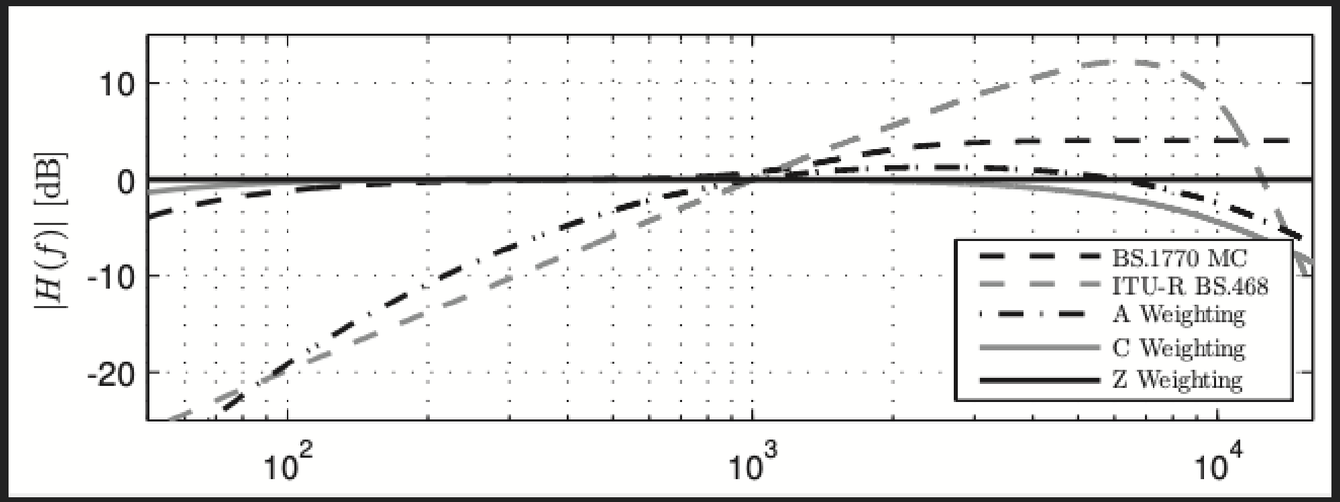
$$v_{\mathrm{tmp}}(i) = \alpha \cdot v_{\mathrm{tmp}}(i-1) + (1-\alpha) \cdot x(i)^2$$

$$v_{\mathrm{RMS}}^*(i) = \sqrt{v_{\mathrm{tmp}}(i)}$$

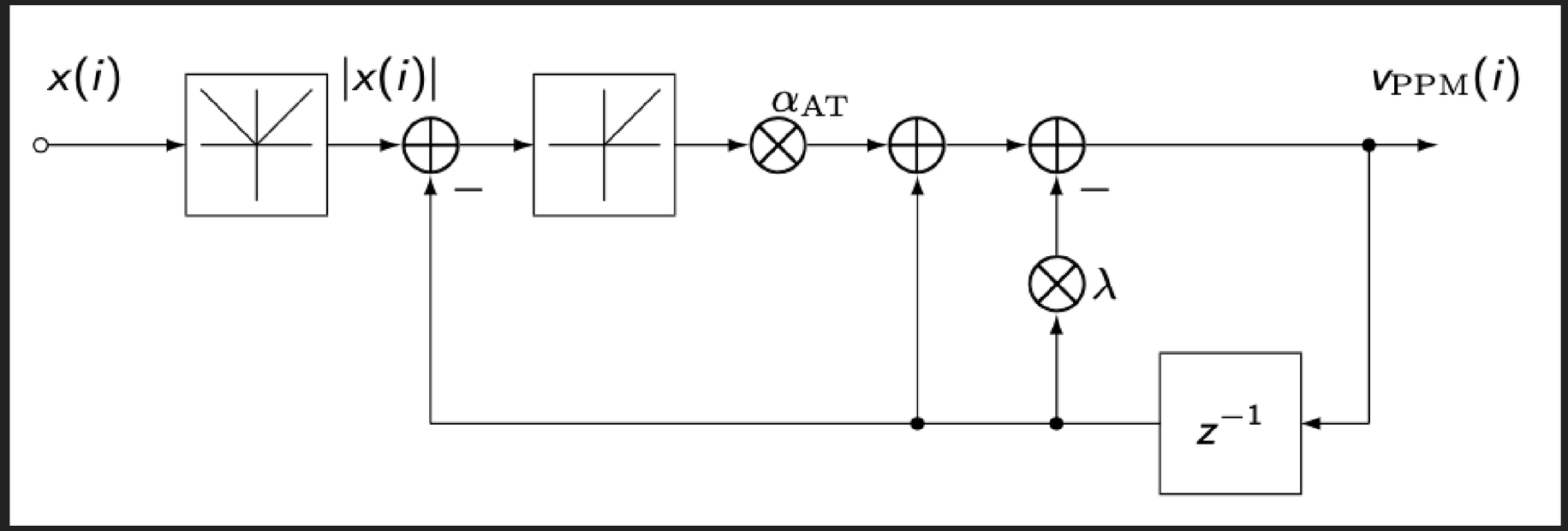
# Level Detection: Weighted RMS




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



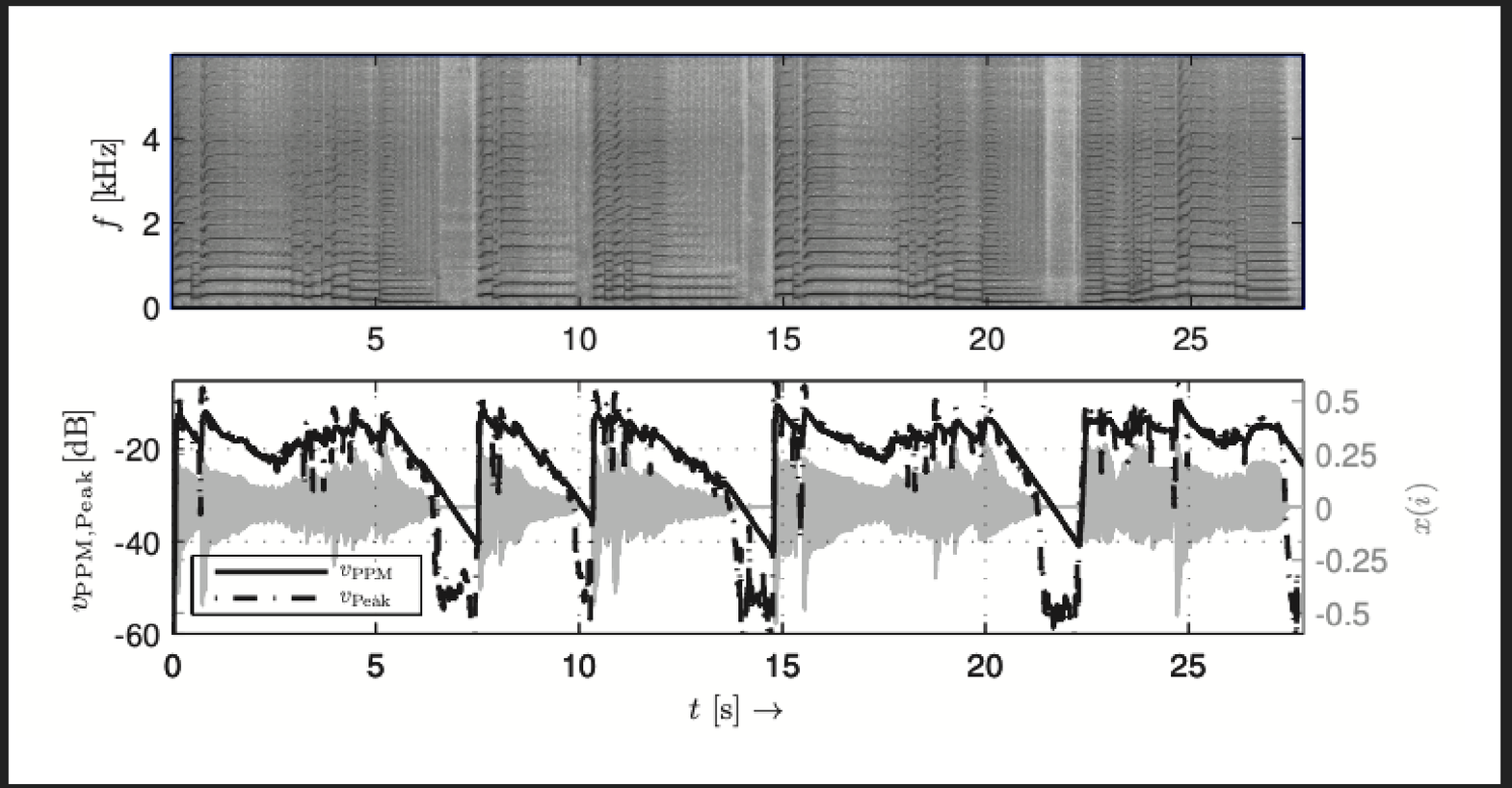
# Peak Detection: PPM (Peak Program Meter)



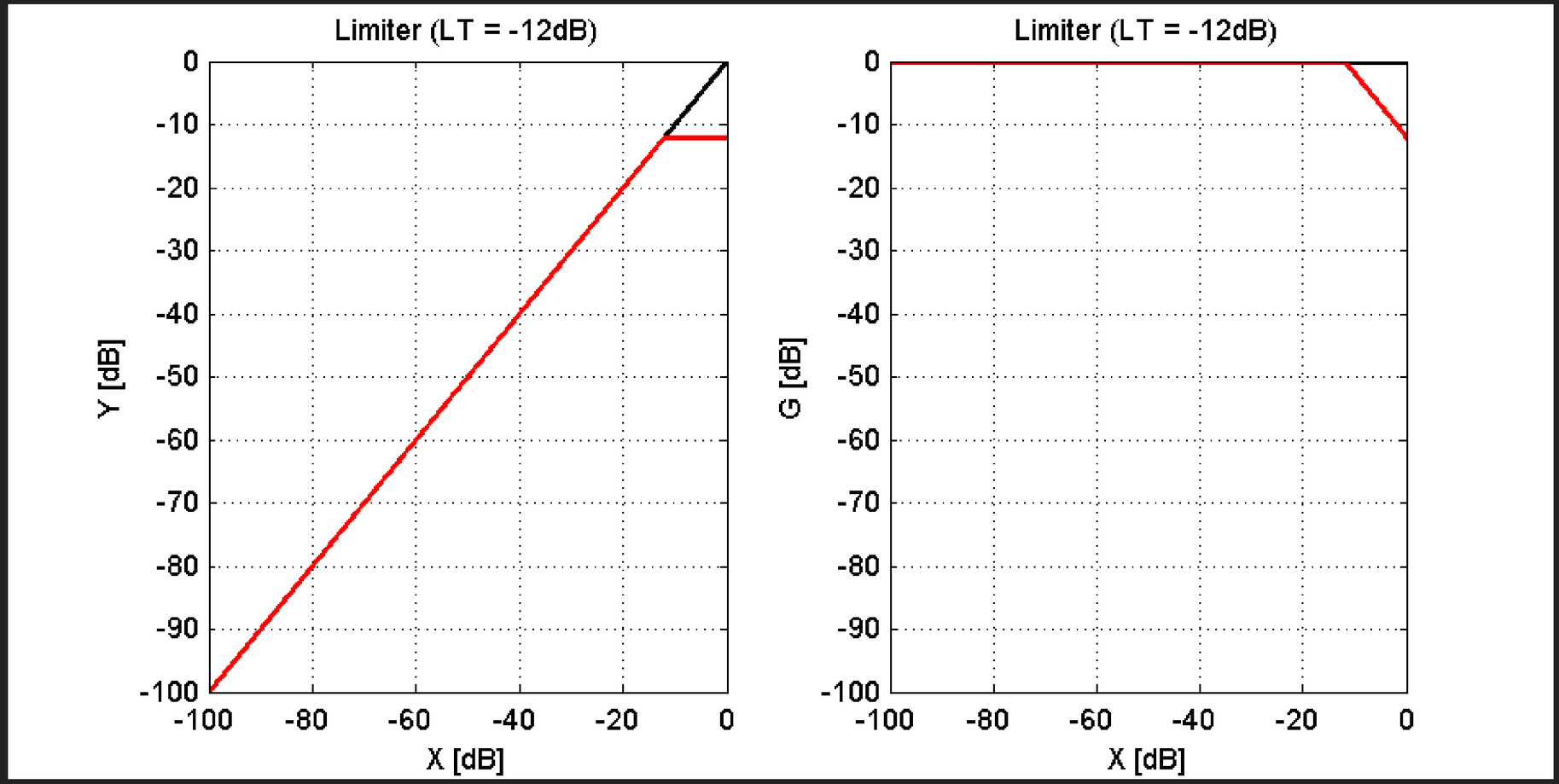

**Attack State** (where $|x(i)| > v_{\mathrm{PPM}}(i-1) \Rightarrow \lambda = 0$)

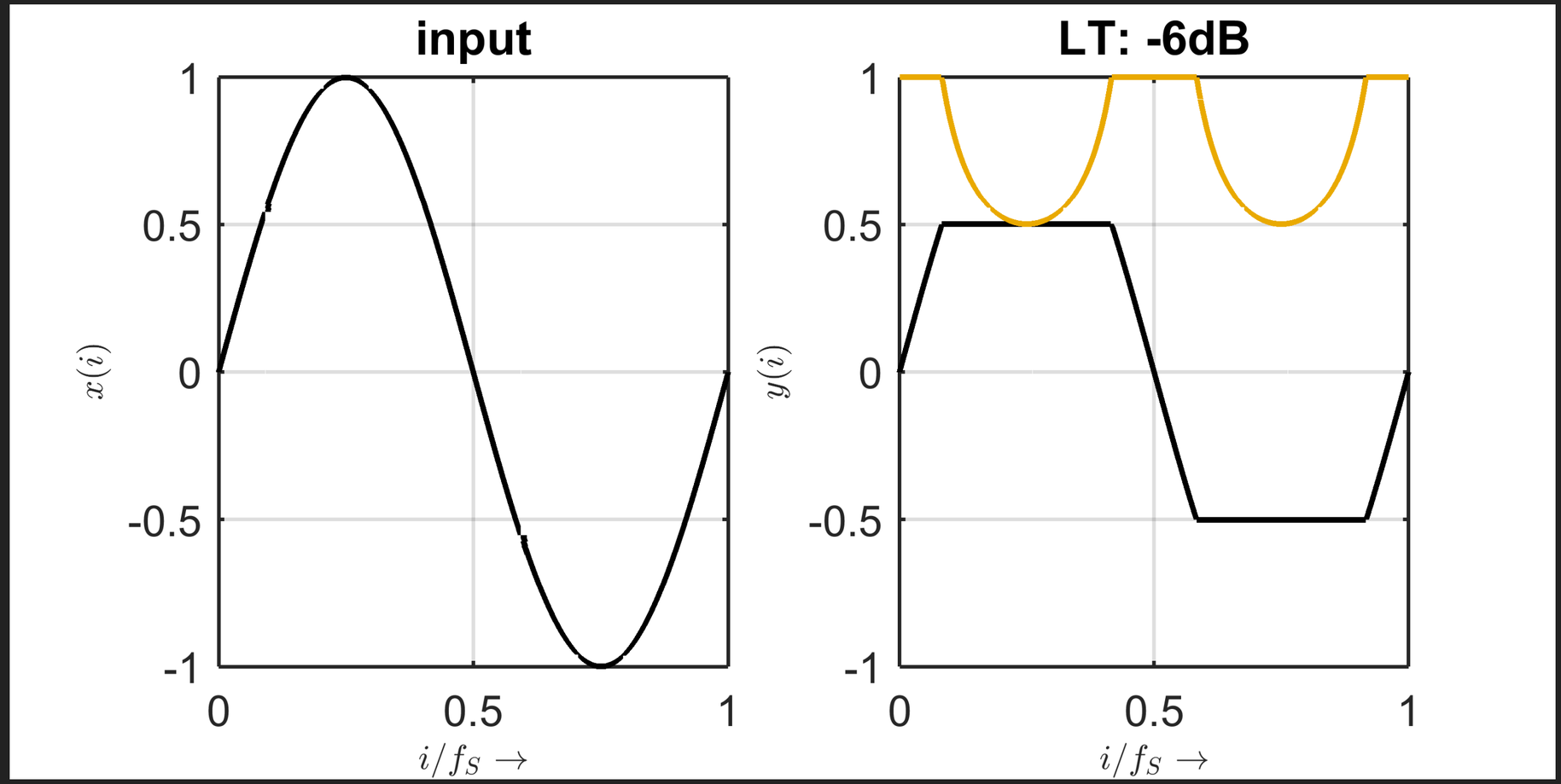
$$
\begin{aligned}
v_{\mathrm{PPM}}(i) &= \alpha_{\mathrm{AT}} \cdot \big(|x(i)| - v_{\mathrm{PPM}}(i-1)\big) + v_{\mathrm{PPM}}(i-1) \\
&= \alpha_{\mathrm{AT}} \cdot |x(i)| + (1 - \alpha_{\mathrm{AT}}) \cdot v_{\mathrm{PPM}}(i-1)
\end{aligned}
$$

# PPM Visualization



# Response Curve: Limiter

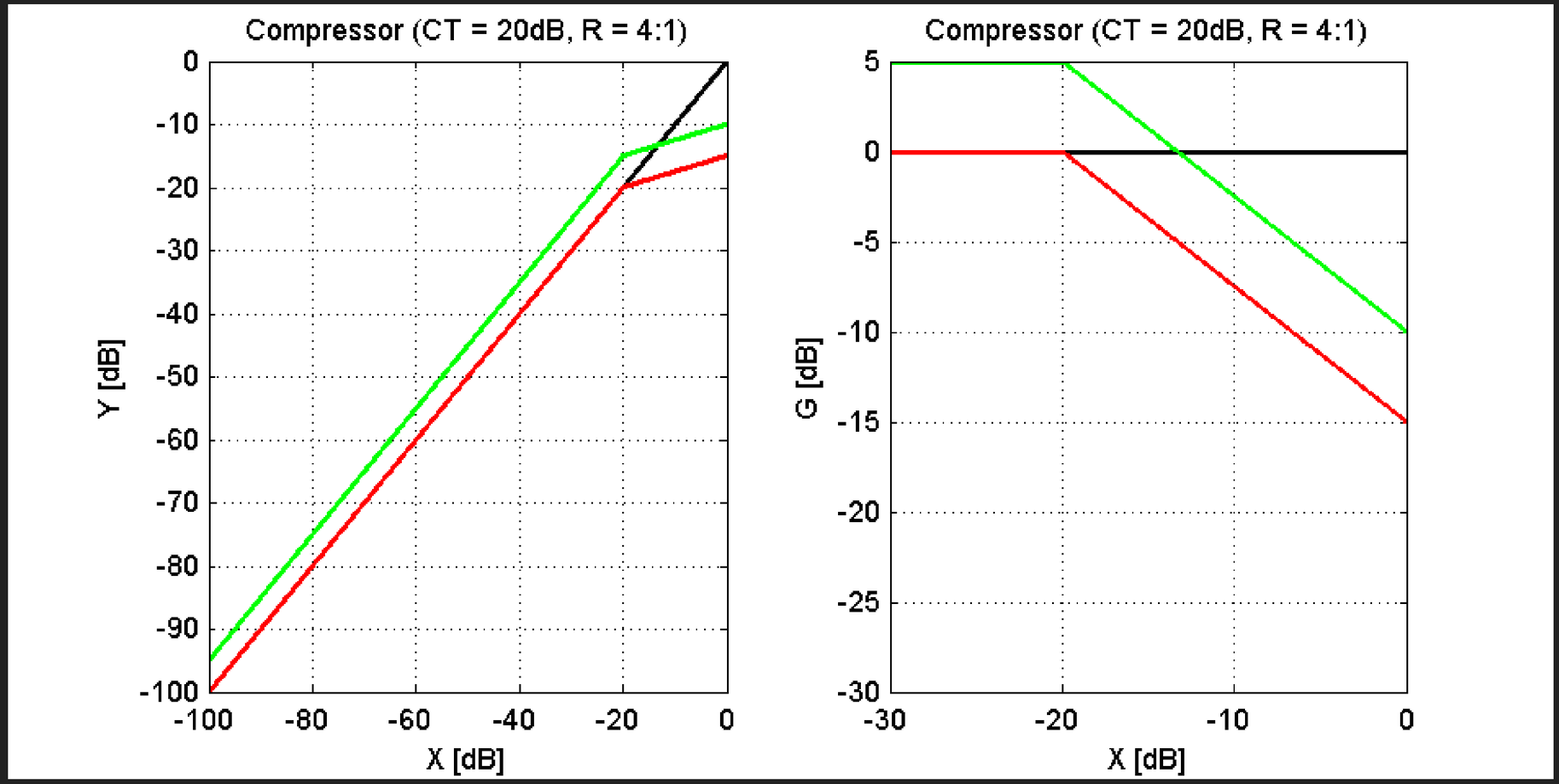


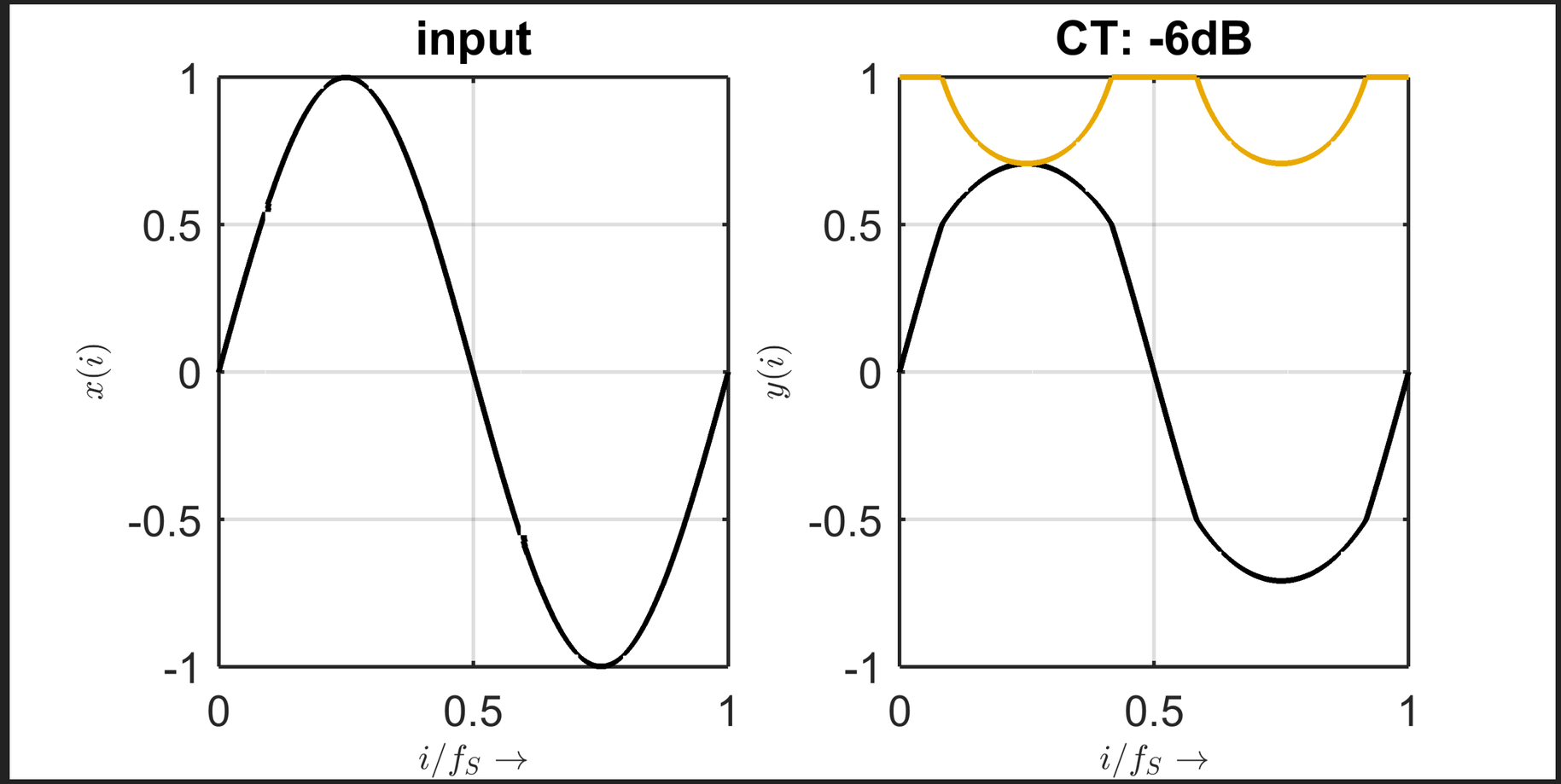



Param *LT* = -9 dB

0:00 / 0:20

# Response Curve: Compressor

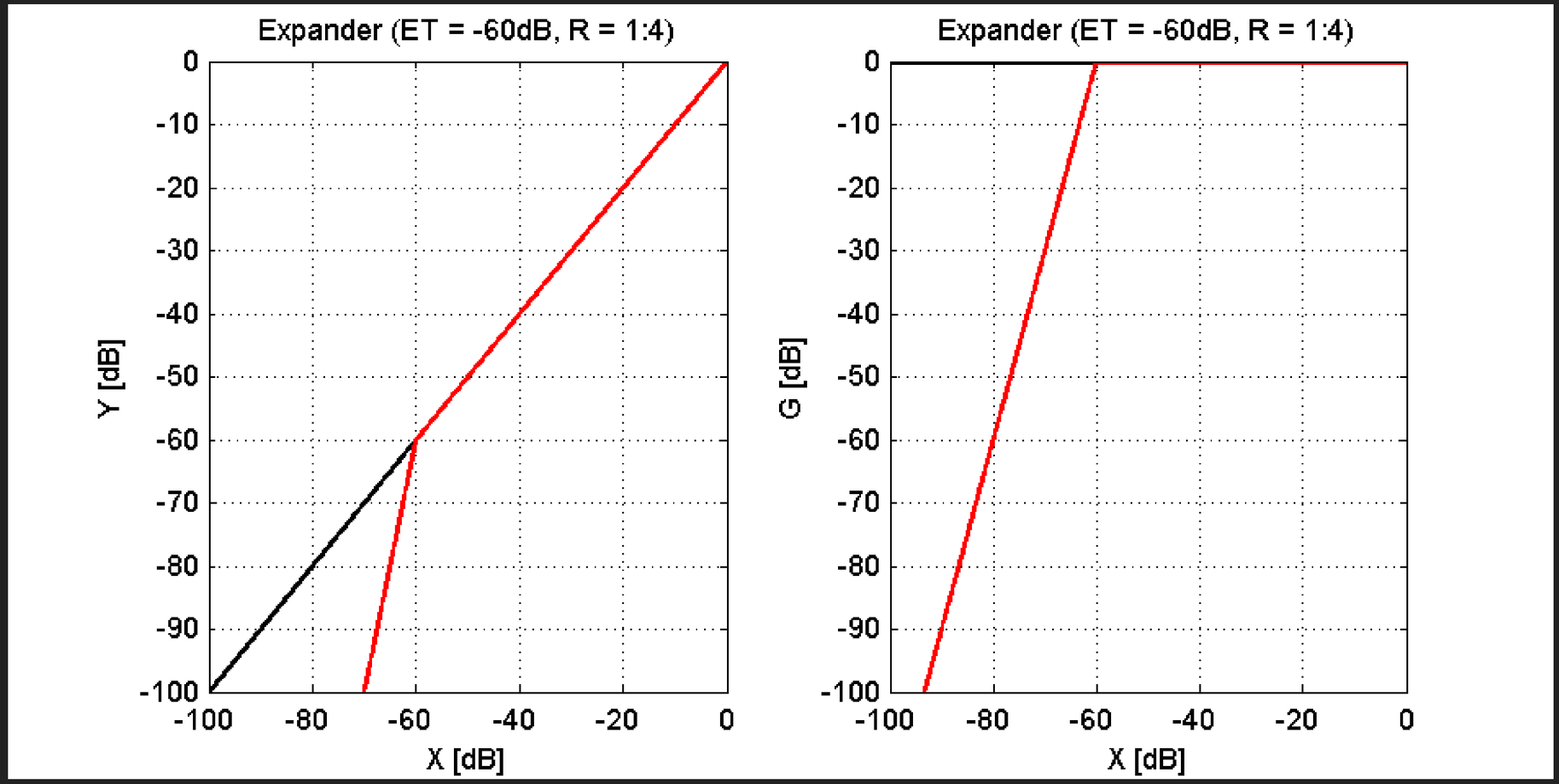


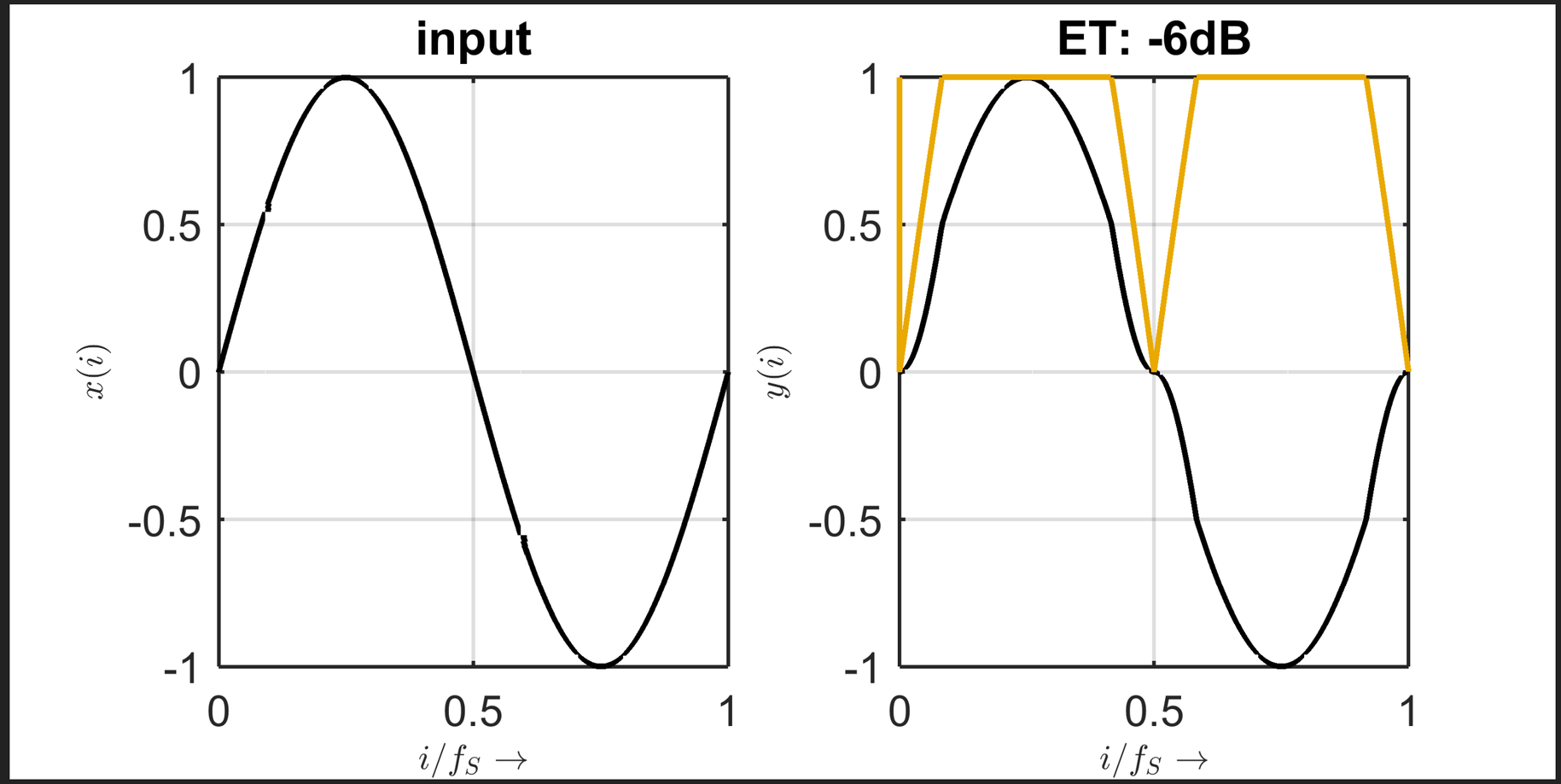



Param *CT* = -9 dB

0:00 / 0:20

# Response Curve: Expander

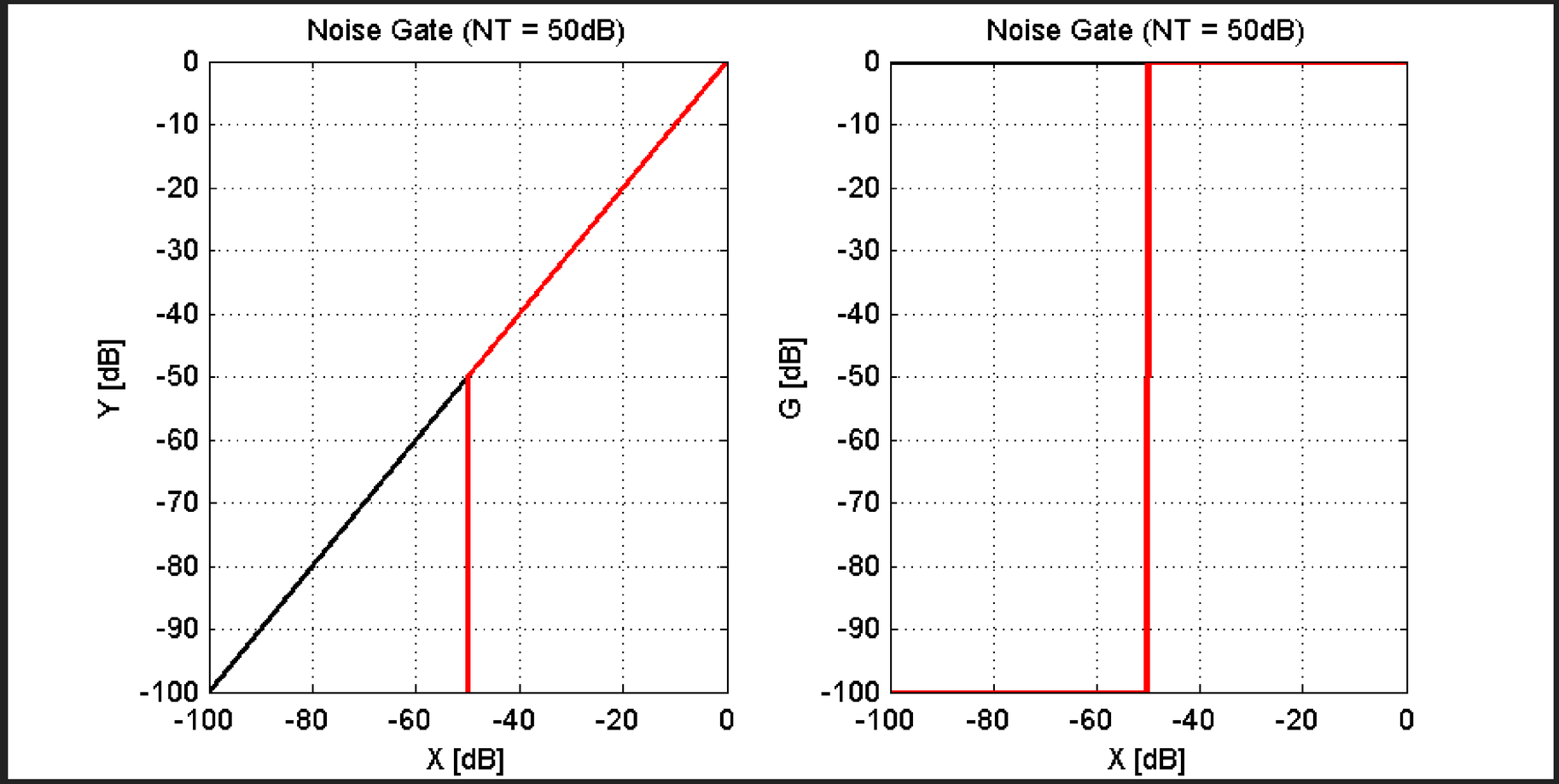


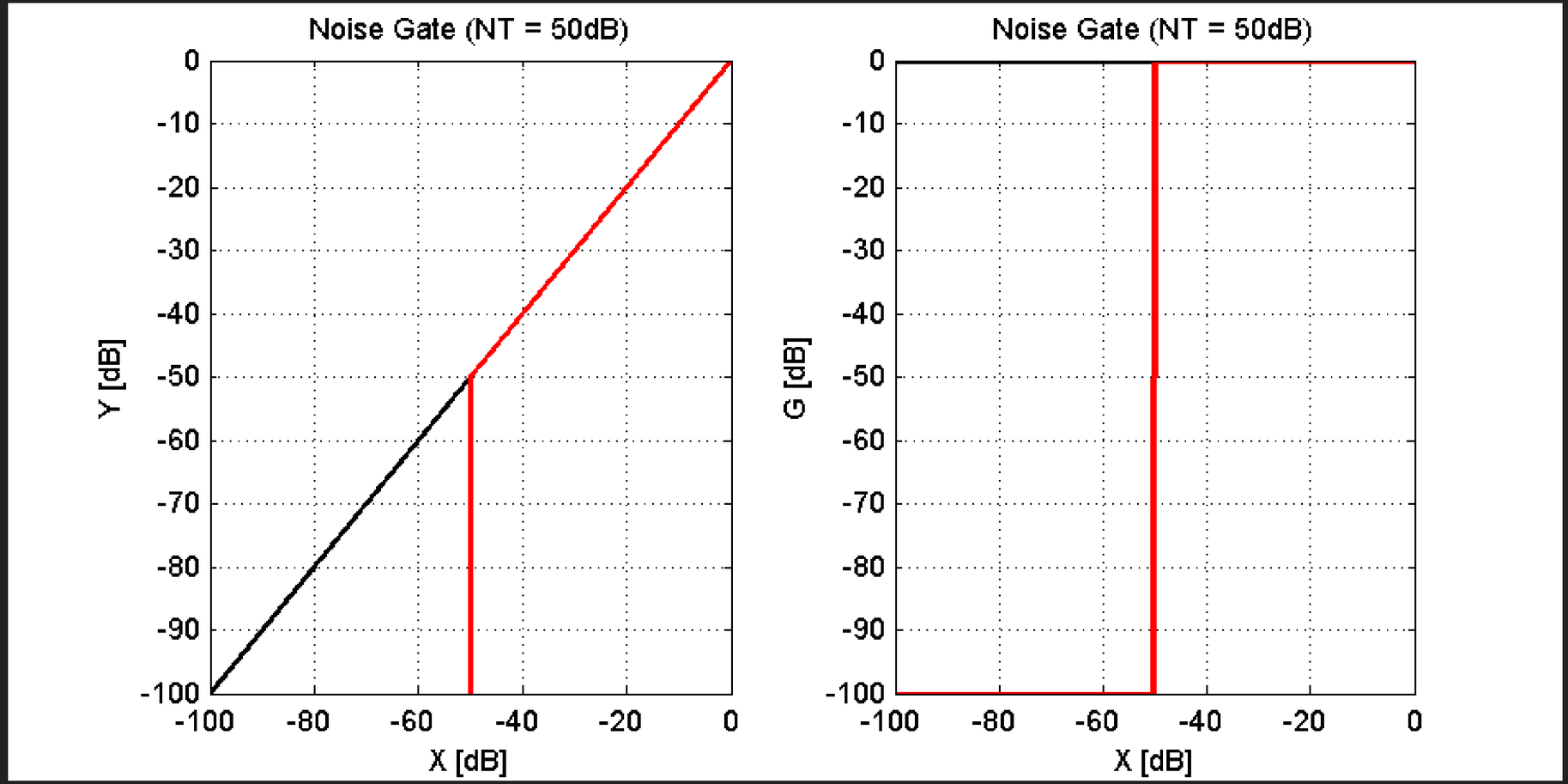



Param *ET* = -6 dB

0:00 / 0:20

# Response Curve: Noise Gate






Param *NT* = -12 dB:

0:00 / 0:20

# Compressor: Mathematical Description

Logarithmic description, nonlinear part

# Mathematical Description: Limiter vs Compressor

Logarithmic description, nonlinear part

## Limiter

$$R = \infty$$
$$Y = LT$$
$$g = LT - X$$

## Compressor

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

# Mathematical Description: Expander vs Gate

Logarithmic description, nonlinear part

## » Expander

$$R < 1$$

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

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

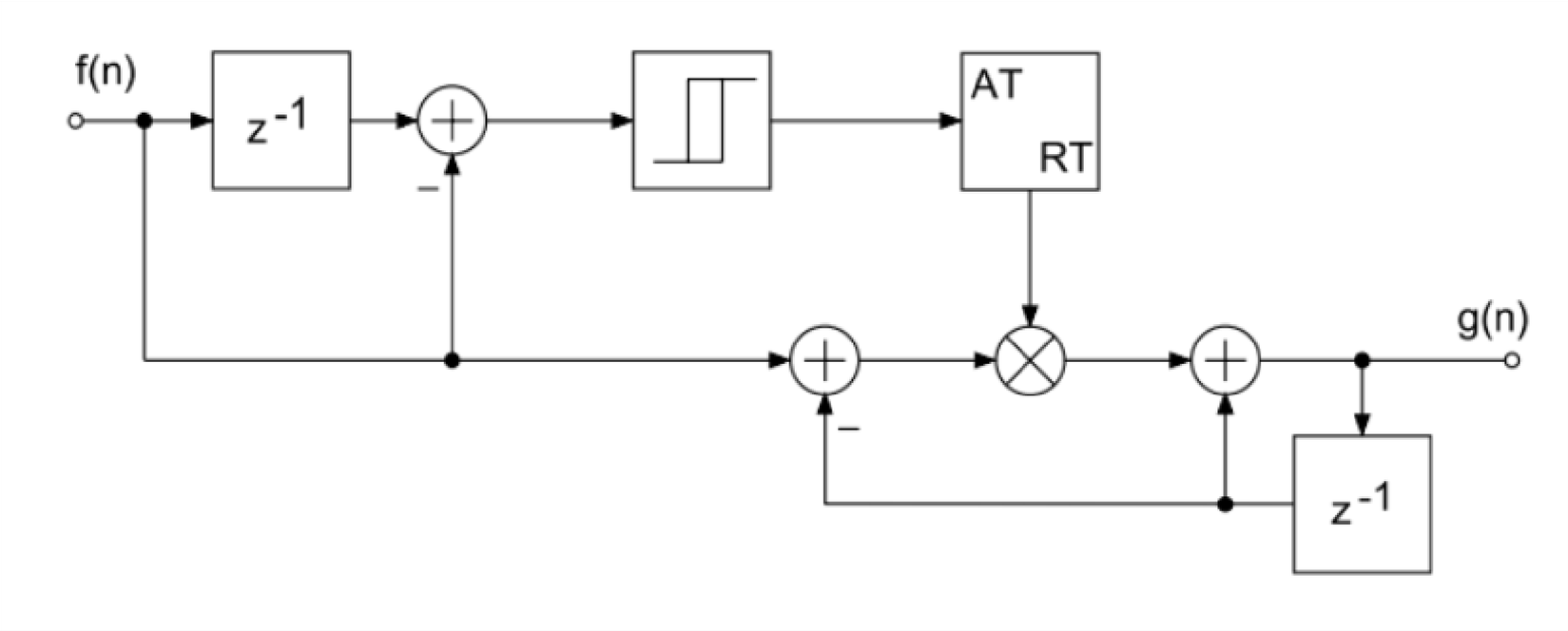
## » Gate

$$R = 0$$

$$Y = -\infty$$

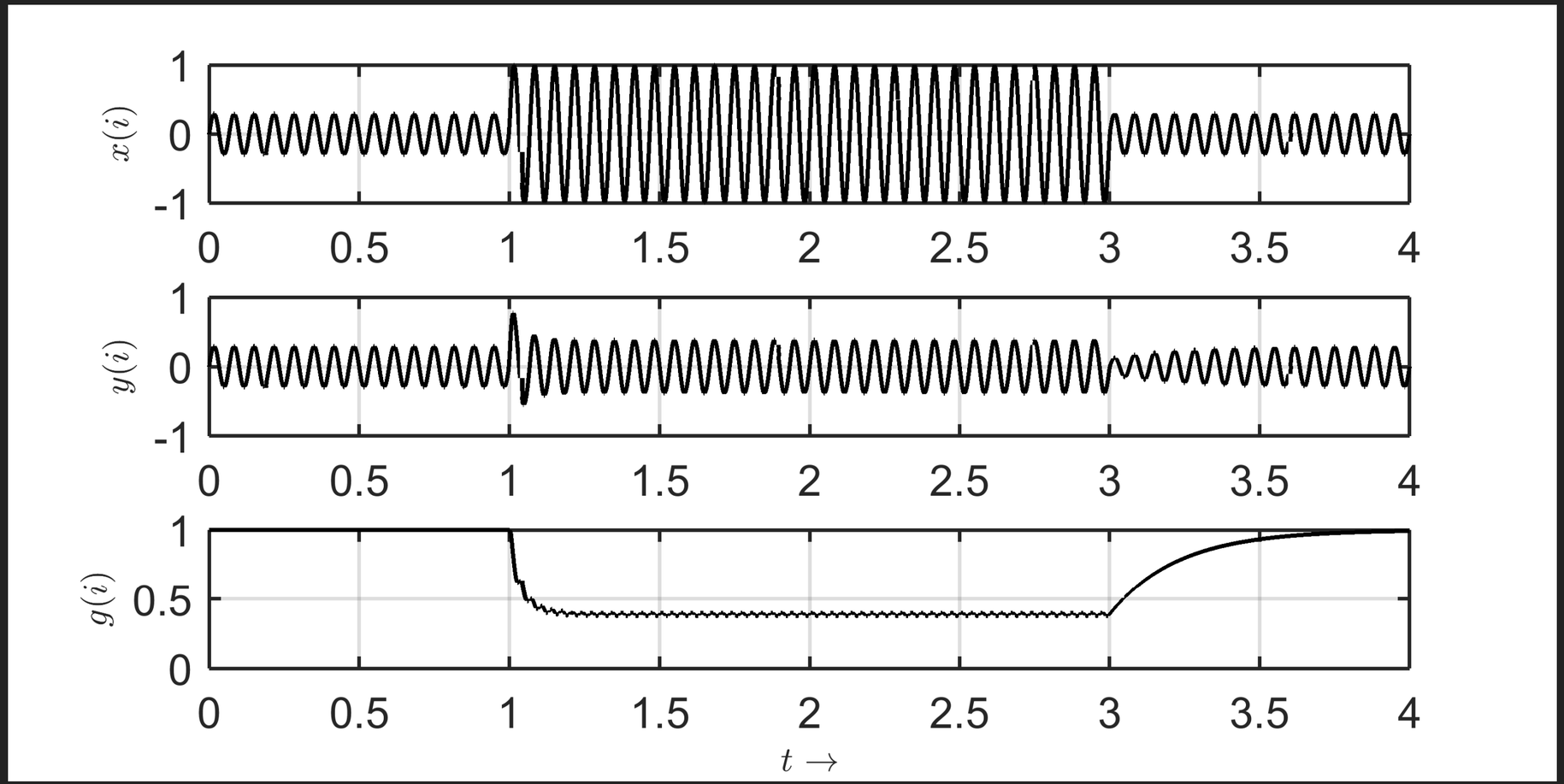
$$g = -\infty$$

# Smoothing: Attack and Release



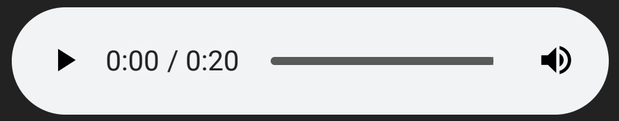

- $\alpha_{AT}$: Attack constant
- $\alpha_{RT}$: Release constant

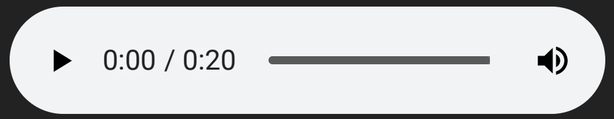
$$g(n) = \alpha \cdot (f(n) - g(n-1)) + g(n-1)$$
$$= \alpha f(n) + (1-\alpha) \cdot g(n-1)$$

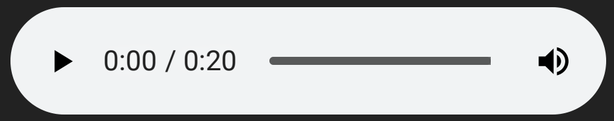

$x(i)$
1
0
-1
0
0.5
1
1.5
2
2.5
3
3.5
4
$y(i)$
1
0
-1
0
0.5
1
1.5
2
2.5
3
3.5
4
$g(i)$
1
0.5
0
0
0.5
1
1.5
2
2.5
3
3.5
4
$t \rightarrow$

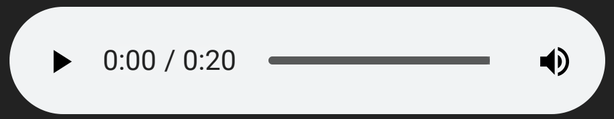
# Gain Visualization: Compressor + Expander

# Audio Examples

- Gate: 

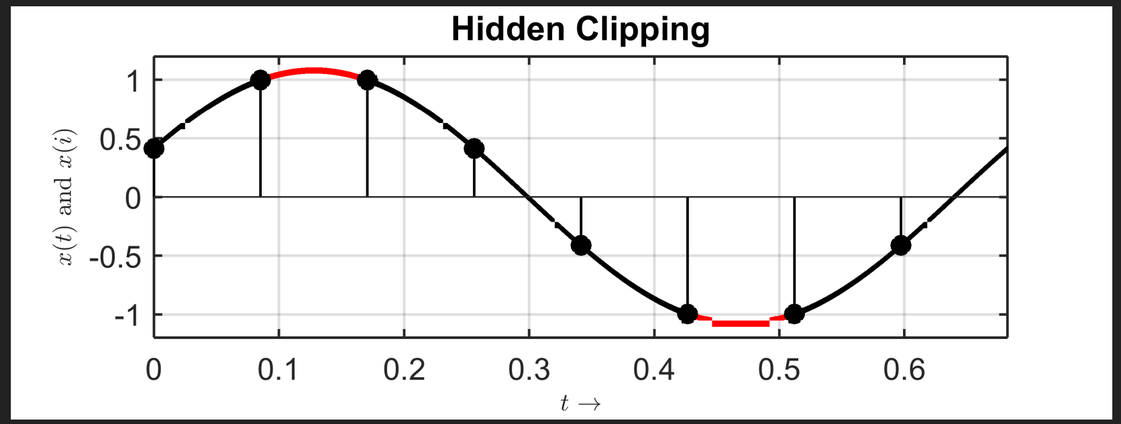
- Expander: 

- Compressor: 

- Limiter: 

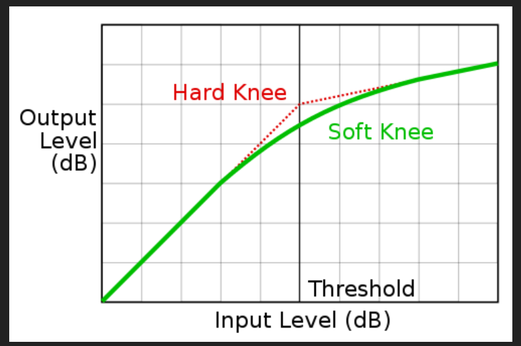
# Variants, I

- **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



# Variants, II

- **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 notcieable with very short attack times, high compression ratios



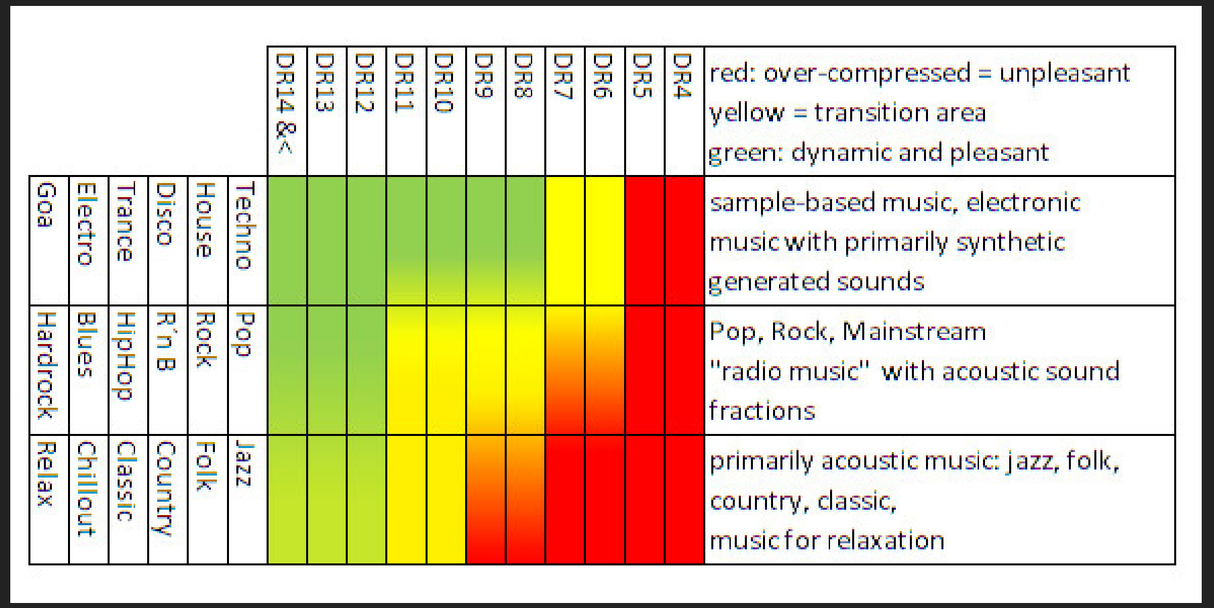
# Variants, III

- **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

# 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**: 0 … 500 ms

# Dynamic Range Target



| | DR14 &< | DR13 | DR12 | DR11 | DR10 | DR9 | DR8 | DR7 | DR6 | DR5 | DR4 | red: over-compressed = unpleasant<br>yellow = transition area<br>green: dynamic and pleasant |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Techno<br>House<br>Disco<br>Trance<br>Electro<br>Goa | | | | | | | | | | | | sample-based music, electronic music with primarily synthetic generated sounds |
| Pop<br>Rock<br>R'n B<br>HipHop<br>Blues<br>Hardrock | | | | | | | | | | | | Pop, Rock, Mainstream "radio music" with acoustic sound fractions |
| Jazz<br>Folk<br>Country<br>Classic<br>Chillout<br>Relax | | | | | | | | | | | | primarily acoustic music: jazz, folk, country, classic, music for relaxation |

# Dynamic Range DB

## 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)