DAFX chapter 5
AE chapter 6

Dynamics processing

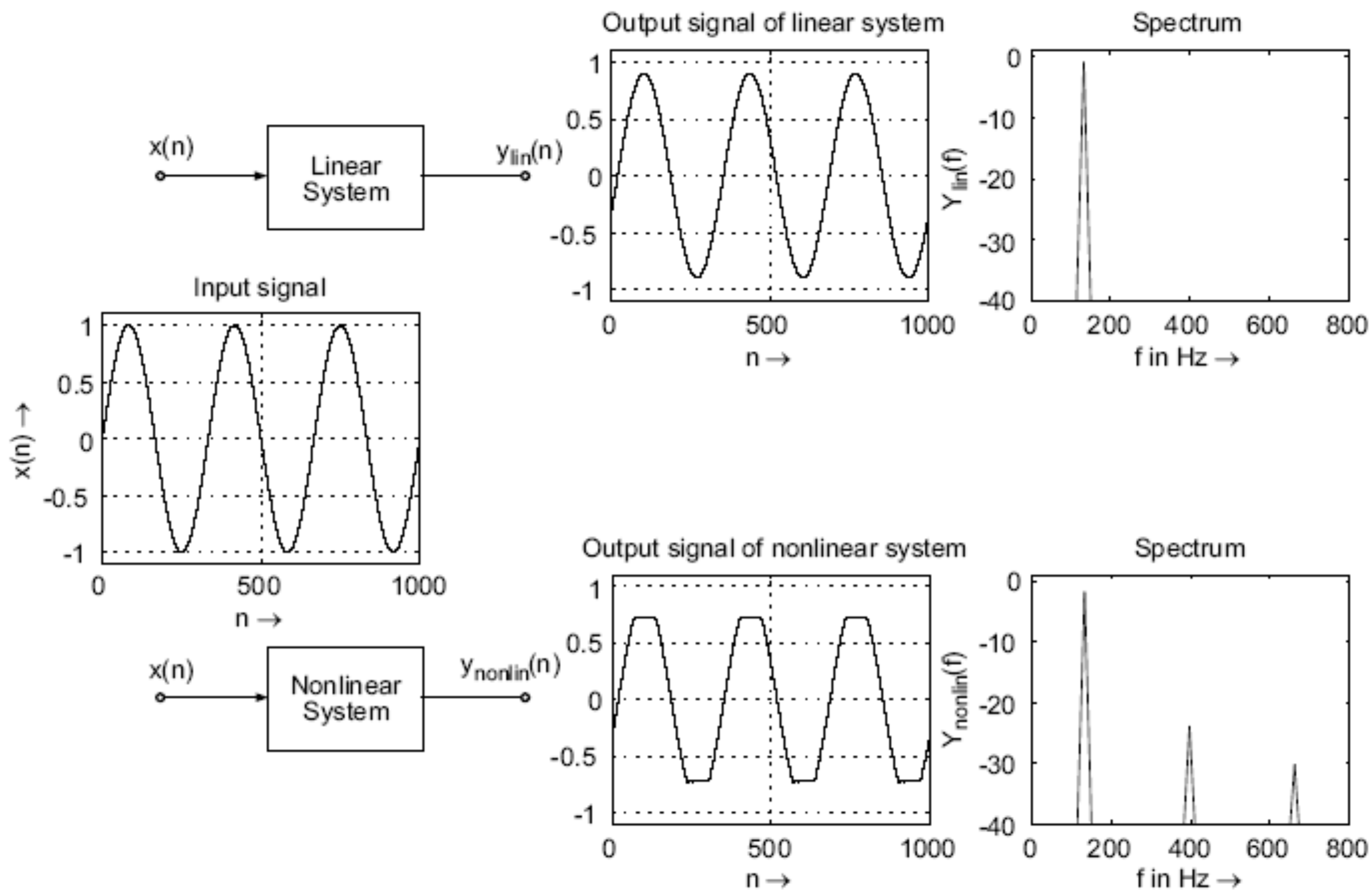


Figure 5.1 Input and output signals of a linear and nonlinear system. The output signal of the linear system is changed in amplitude and phase. The output signal of the nonlinear system is strongly shaped by the nonlinearity and consists of a sum of harmonics, as shown by the spectrum.

Non-linear system with input x(n) has output y(n) and total harmonic distortion (THD) as shown

$$x(n) = A\sin(2\pi f_1 T n)$$

$$y(n) = A_0 + A_1 \sin(2\pi f_1 T n) + A_2 \sin(2 \cdot 2\pi f_1 T n) + \ldots$$

$$\mathrm{THD} = \sqrt{\frac{A_2^2 + A_3^2 + \cdots + A_N^2}{A_1^2 + A_2^2 + \cdots + A_N^2}}$$

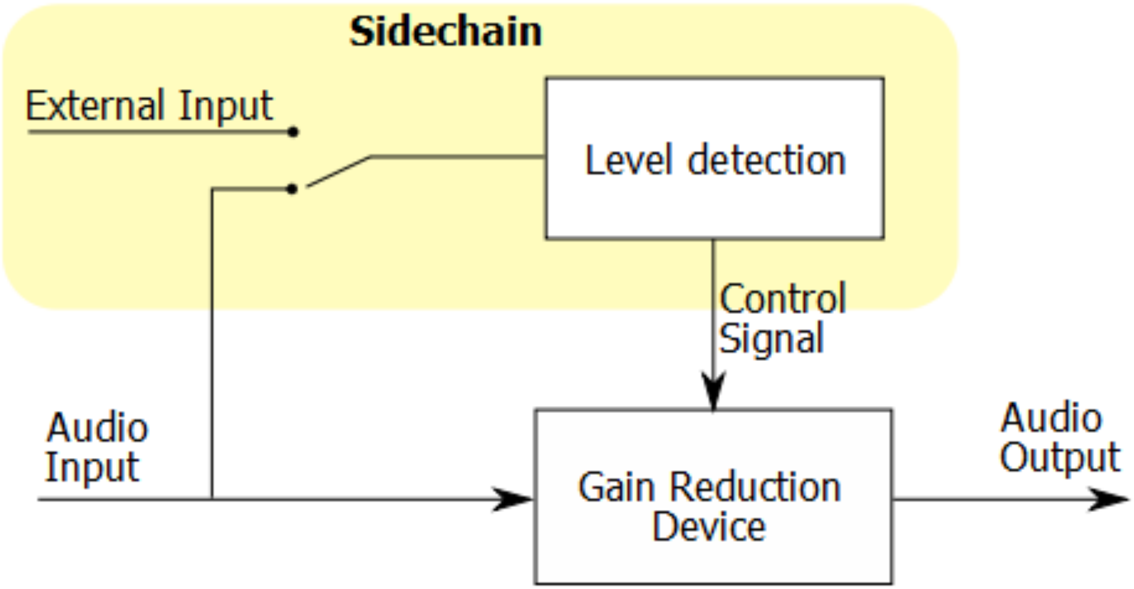
Categories of non-linear processing

- Dynamic range controllers
  - Control of signal envelope
  - harmonic distortion as low as possible
- Harmonic distortion for guitar
  - Linear and non-linear part
  - High harmonic distortion
- Exciters and enhancers
  - Create additional harmonics for subtle improvement
  - Low harmonic distortion

Compressor features

- 3.1 Threshold
- 3.2 Ratio
- 3.3 Attack and release
- 3.4 Soft and hard knees
- 3.5 Peak vs RMS sensing
- 3.6 Stereo Linking
- 3.7 Makeup gain
- 3.8 Look-ahead

Other aspects



- 6 Side-chaining
- 7 Parallel compression
- 8 Multiband compression
- 9 Serial compression

Common uses

- Public spaces
- Music production
- Voice
- Broadcasting
- Marketing

General guidelines for use

- **Vocals:** fast attack and release, ratio depends on the recording and vocal style. usually a soft knee.
  Guitars: fast attack usually somewhat fast release.
  Bass: bit slower attack and slower release, so you leave or accentuate the transient of the hit. Of course if you want to smooth out the bass and bury your bass in the track by getting rid of the attack, have a fast attack on the compressor.

Drums

- **Drums:** Compressing drums is an art to say the least. The different amounts and styles of compression can completely and utterly change the way the drums sound. Whether you're going for those HUGE snare cracks or a more subtle tightness, knowing how to compress can save you from a weak sounding mix. The attack and how big you make the transient peak is the most identifiable part of a hit.

Drums 2

- On the compressor if you have too fast an attack the transient peak will be cut and your drum won't hit hard, but if you have a slower attack that initiates the compressor right after the transient peak it'll accentuate the hit. The compression after initiating and bringing down part of the sustain, the signal falls below the threshold and slowly releases bringing up the decay making the drum last longer and sound larger and more full

Dynamics processing

- Based on
  - Envelope follower
  - Algorithm to derive gain from envelope
  - Multiplier to adjust gain
- Types
  - Limiter
  - Compressor
  - Expandor
  - Noise gate

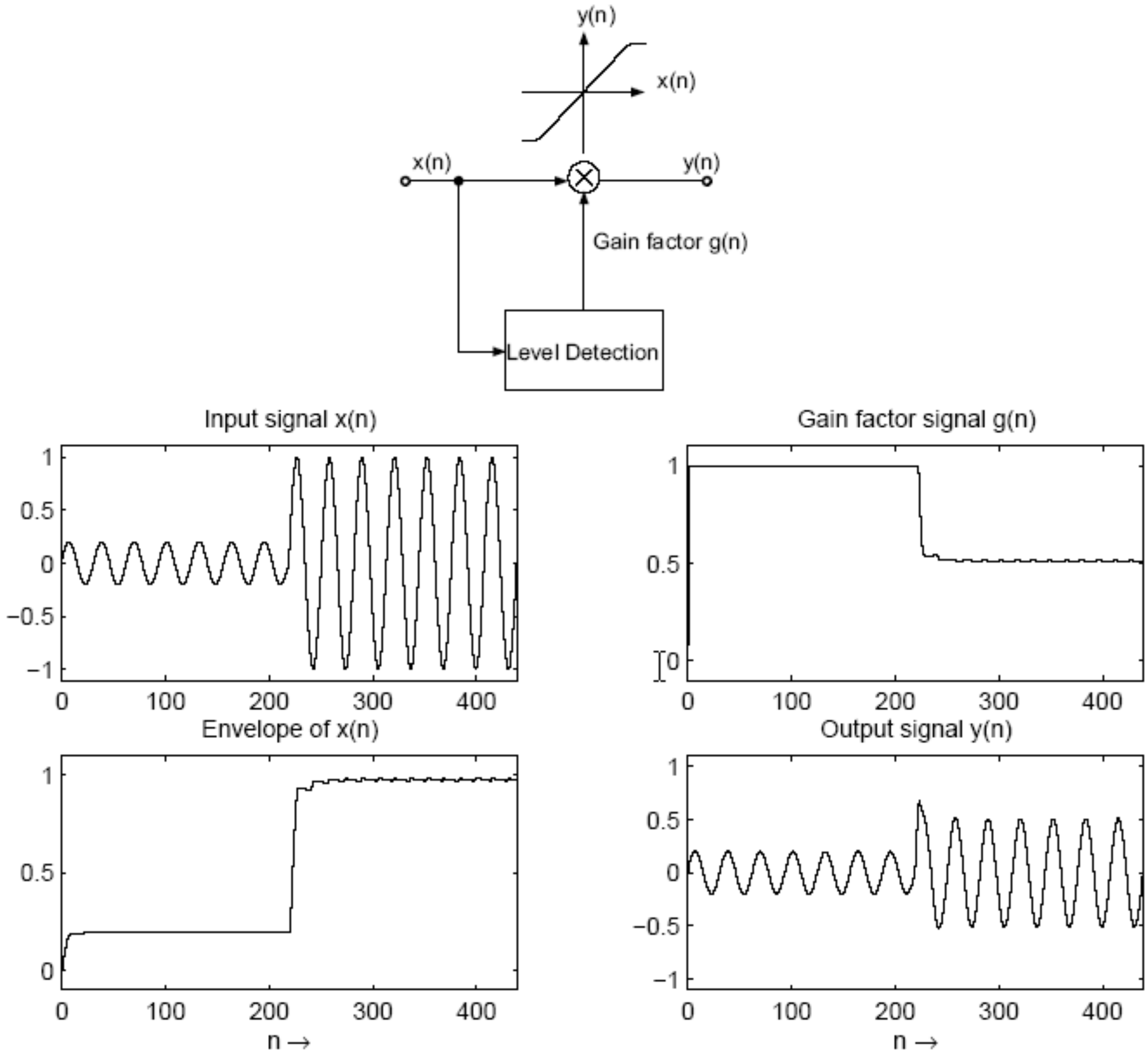
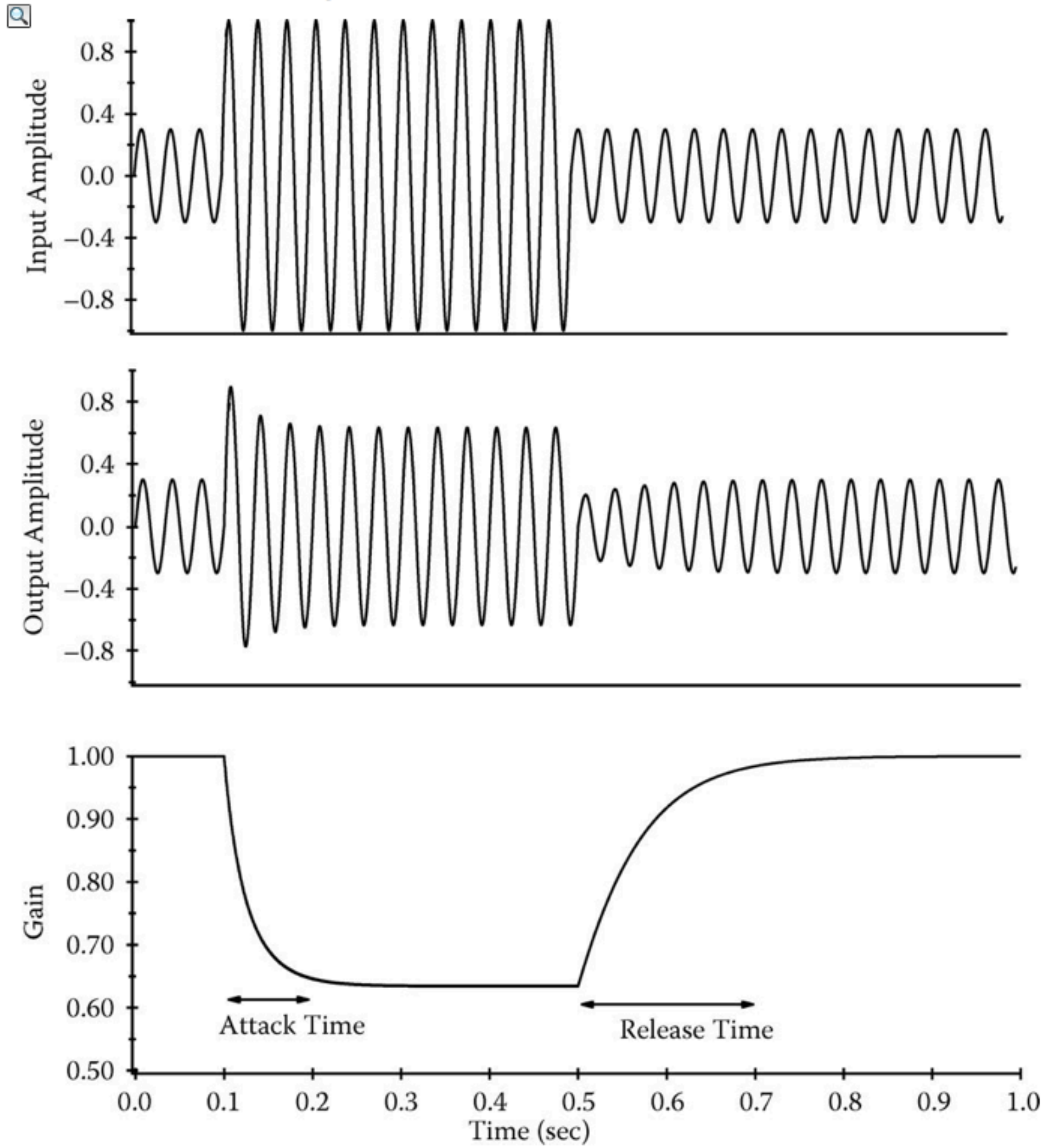
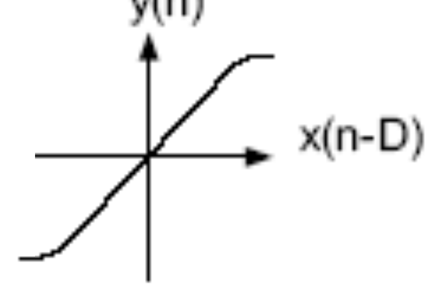


Figure 5.2 Block diagram of a nonlinear signal processing device with envelope detector.

FIGURE 6.3 Effect of a compressor on a signal. Only the middle portion of input is above the compressor's threshold.



representing the signals in either the linear or decibel domains, where M is the makeup gain,



AE text
c(n)=g(n)

$$y[n] = x[n] \cdot c[n] \cdot M$$
$$y_{dB}[n] = x_{dB}[n] + c_{dB}[n] + M_{dB} \tag{6.1}$$

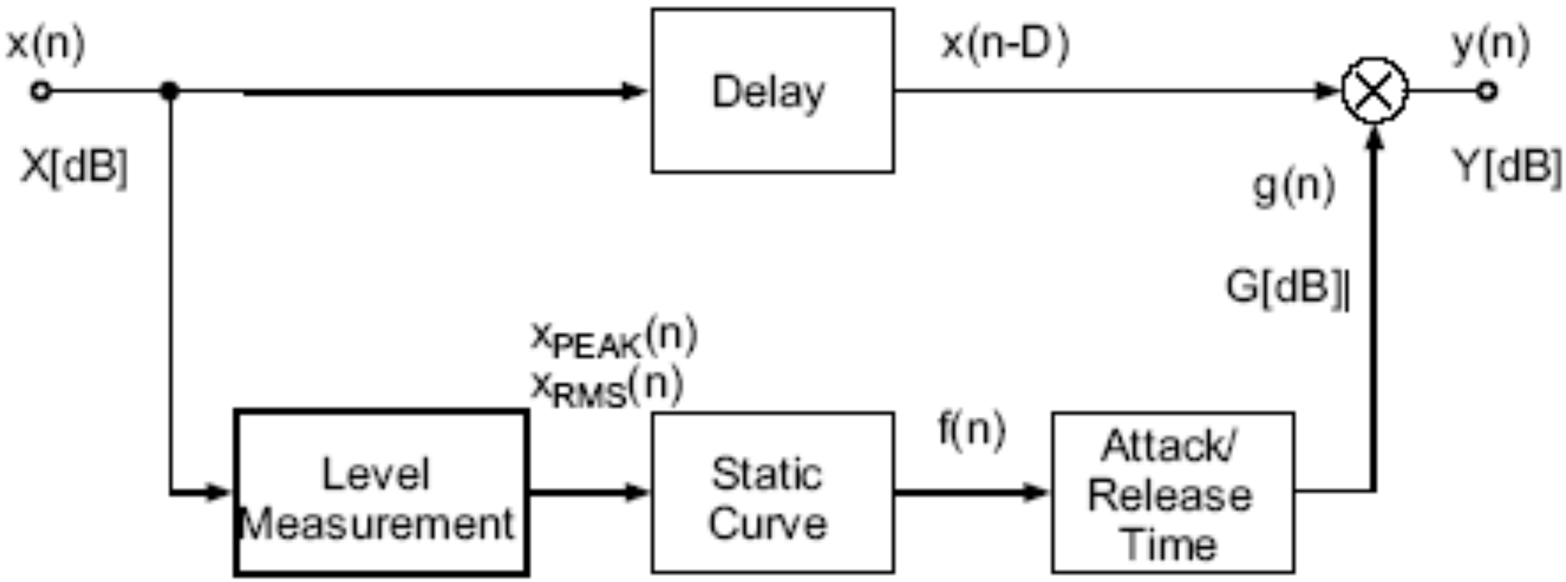
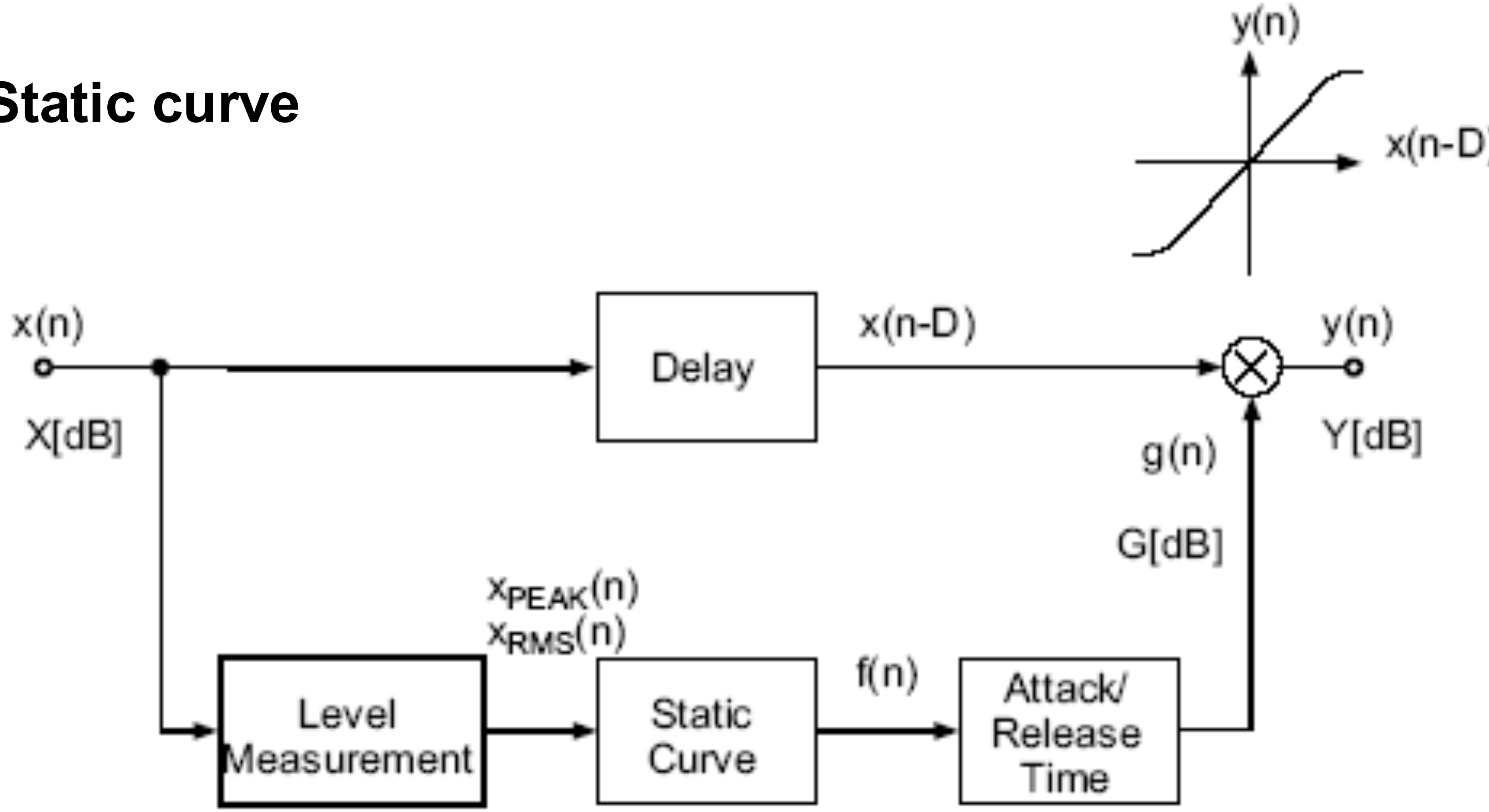


Figure 5.3 Block diagram of a dynamic range controller [Zöl97].

Besides the time signals $x(n)$, $f(n)$, $g(n)$ and $y(n)$ the corresponding signal levels X, G and Y are denoted. These level values are the logarithm of the root mean square $x_{\mathrm{rms}}(n)$ (RMS value) or peak value $x_{\mathrm{peak}}(n)$ of the time signals according to $X = 20 \cdot \log_{10}(x)$. The multiplication $y(n) = g(n) \cdot x(n - D)$ at the output of the dynamic range controller can be regarded as an addition in the logarithmic domain. This means $Y = X + G$ in dB.

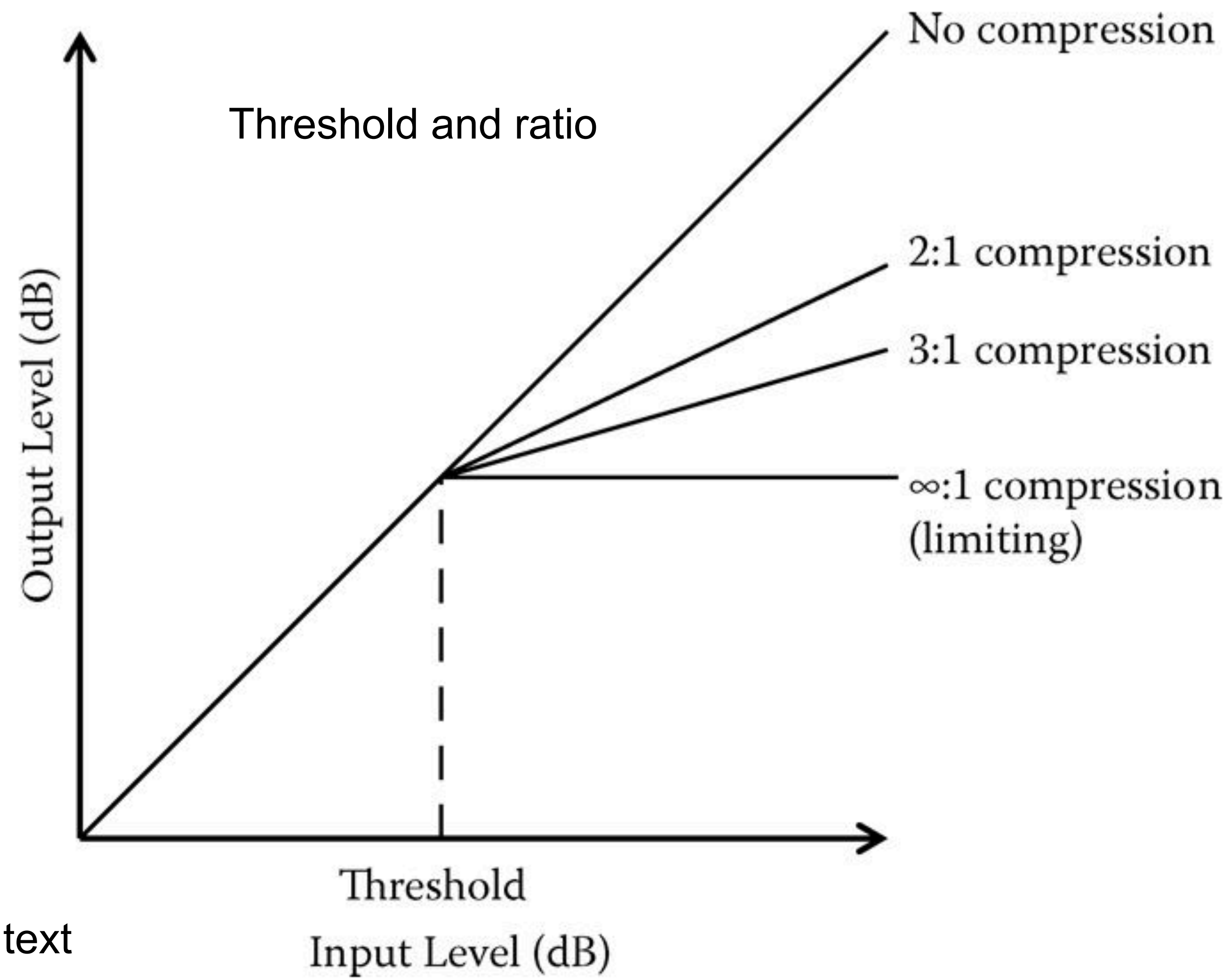
In what follows, we describe each of the 3 stages:
-Static curve
-Level measurement
-Attack/release time

Static curve



Compressor input/output characteristic. The compressor weakens the signal only when it is above the threshold. Above that threshold, a change in the input level produces a smaller change in the output level.

Threshold and ratio



AE text

Static curve

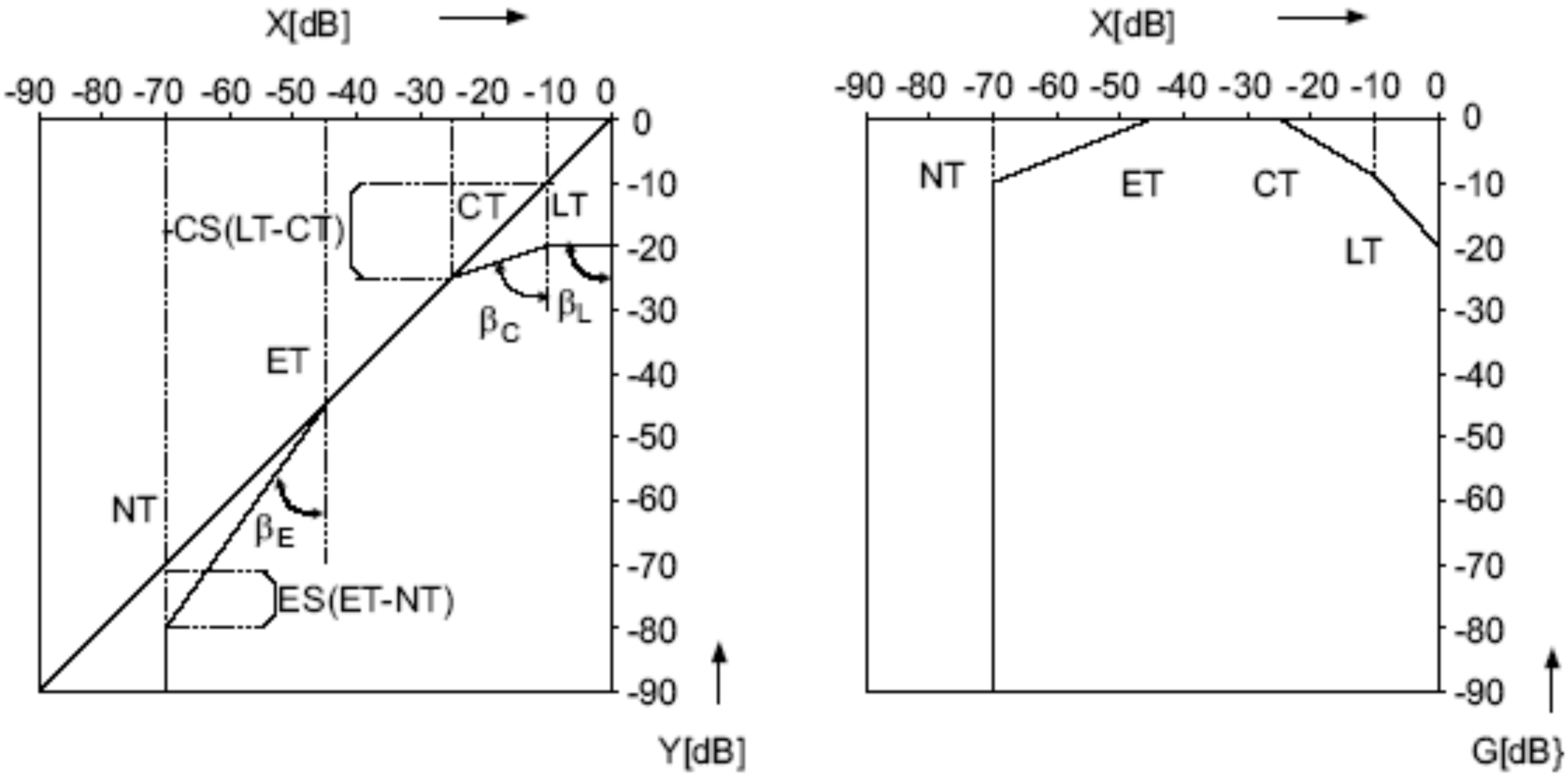
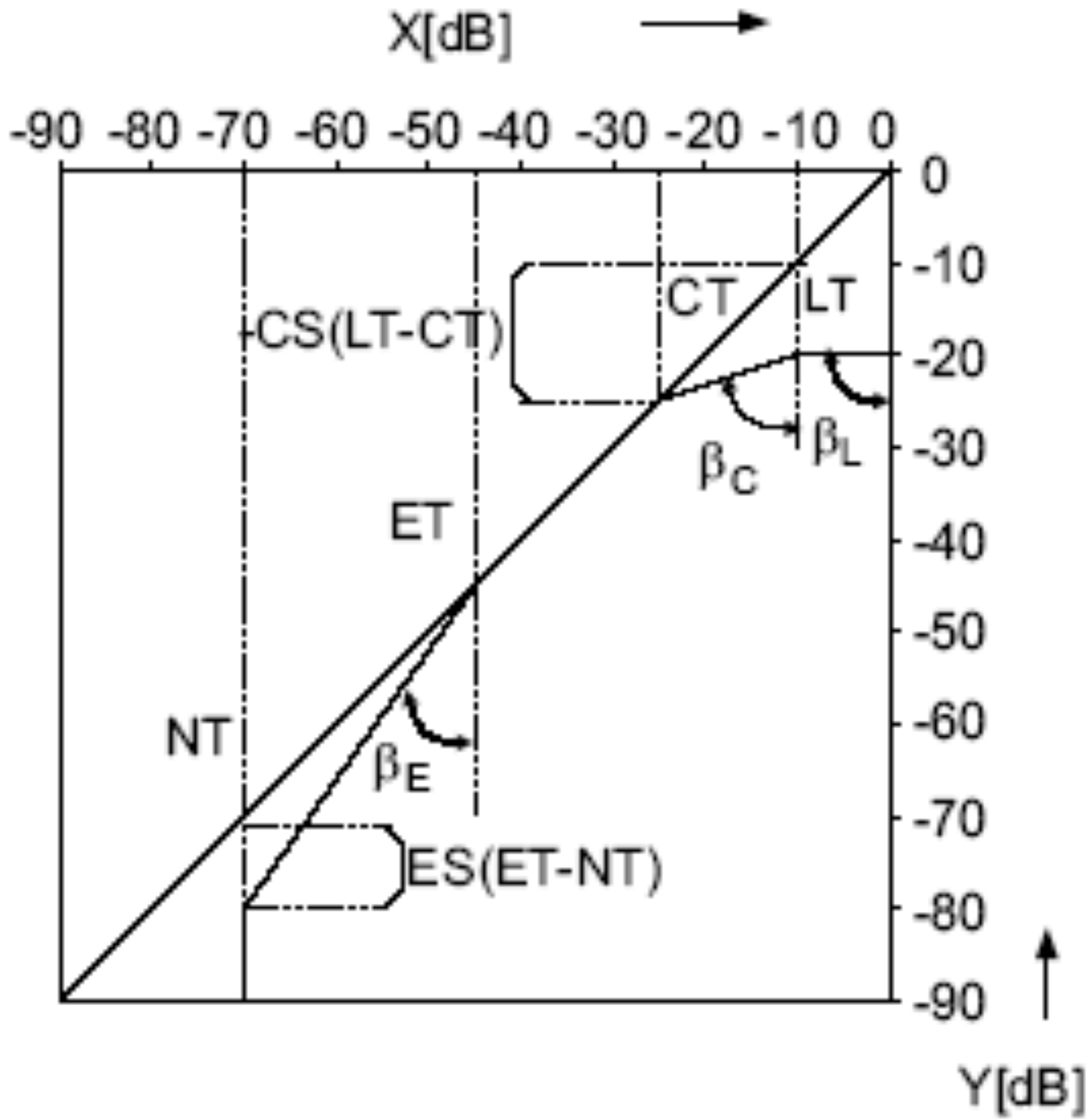
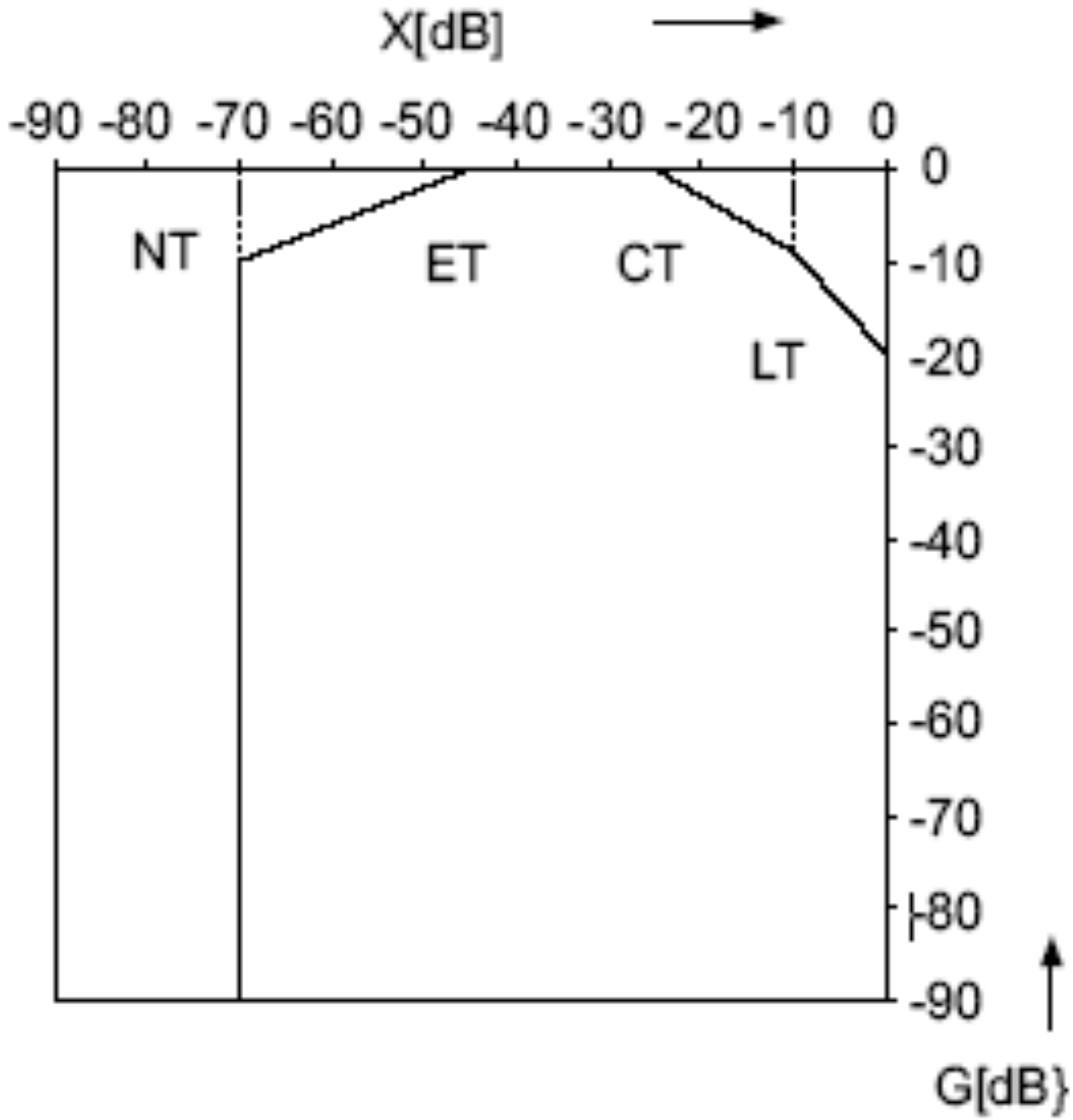
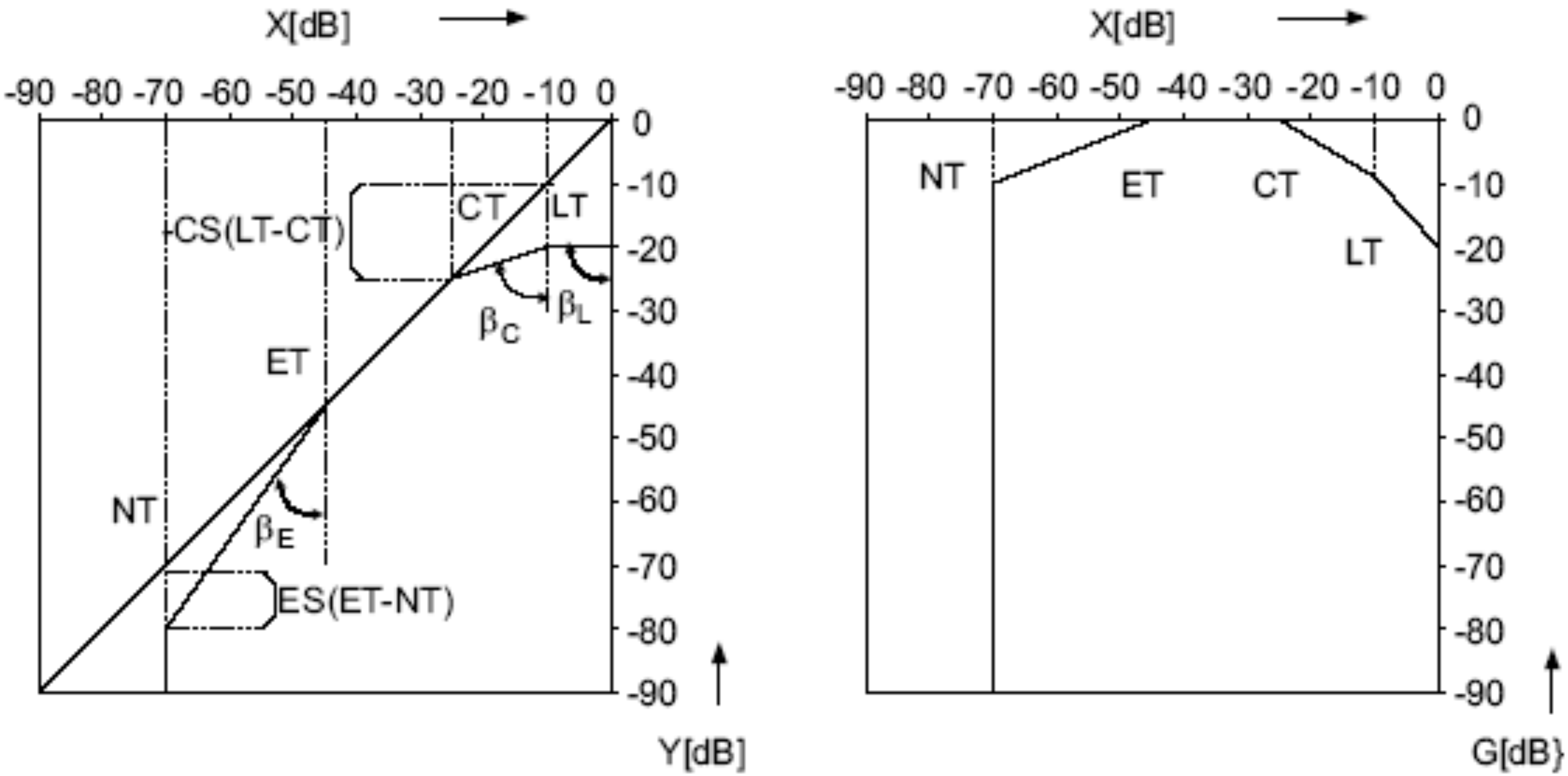


Figure 5.4 Static characteristic of a dynamic range controller [Zöl97].

Figure 7.2 Static curve with the parameters LT=*Limiter threshold*, CT=*Compressor threshold*, ET=*Expander threshold* and NT=*Noise gate threshold*.


X[dB]
-90
-80
-70
-60
-50
-40
-30
-20
-10
0
0
-10
-20
-30
-40
-50
-60
-70
-80
-90
CT
LT
CS(LT-CT)
βC
βL
ET
NT
βE
ES(ET-NT)
Y[dB]


X[dB]
-90 -80 -70 -60 -50 -40 -30 -20 -10 0
0
-10
-20
-30
-40
-50
-60
-70
-80
-90
NT
ET
CT
LT
G[dB}



$$
\begin{array}{llcl}
\text{Limiter} & F_{\mathrm{L}} & = & -LS(X-LT)+CS(CT-LT) \\
\text{Compressor} & F_{\mathrm{C}} & = & -CS(X-CT) \\
\text{Linear part} & F_{\mathrm{lin}} & = & 0 \\
\text{Expander} & F_{\mathrm{E}} & = & -ES(X-ET) \\
\text{Noise gate} & F_{\mathrm{NG}} & = & -NS(X-NT)+ES(ET-NT)
\end{array}
$$

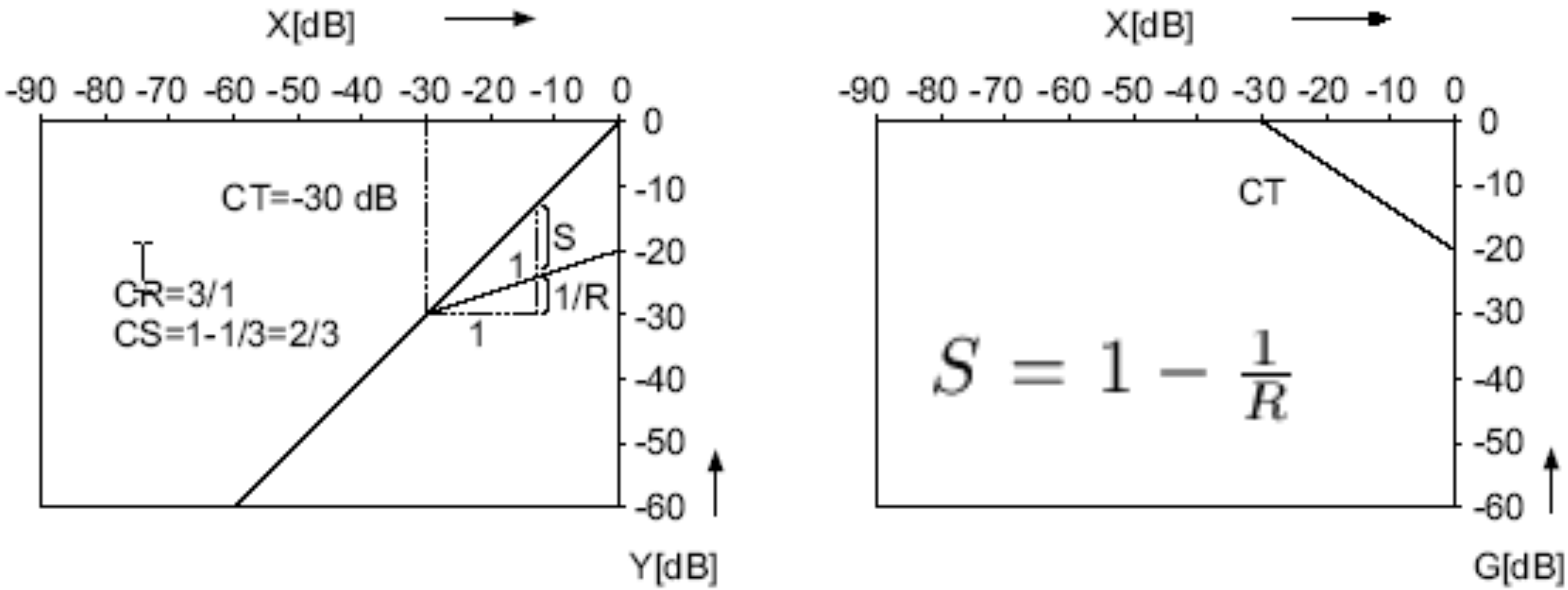


Figure 5.5 Static characteristic: definition of slope S and ratio R [Zöl97].

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

Limiter		R	$= \infty$		S	$= 1$
Compressor	$1 <$	R	$< \infty$	$0 <$	S	< 1
Linear part		R	$= 1$		S	$= 0$
Expander	$0 <$	R	< 1	$-\infty <$	S	< 0
Noise gate		R	$= 0$		S	$= -\infty$

AE text

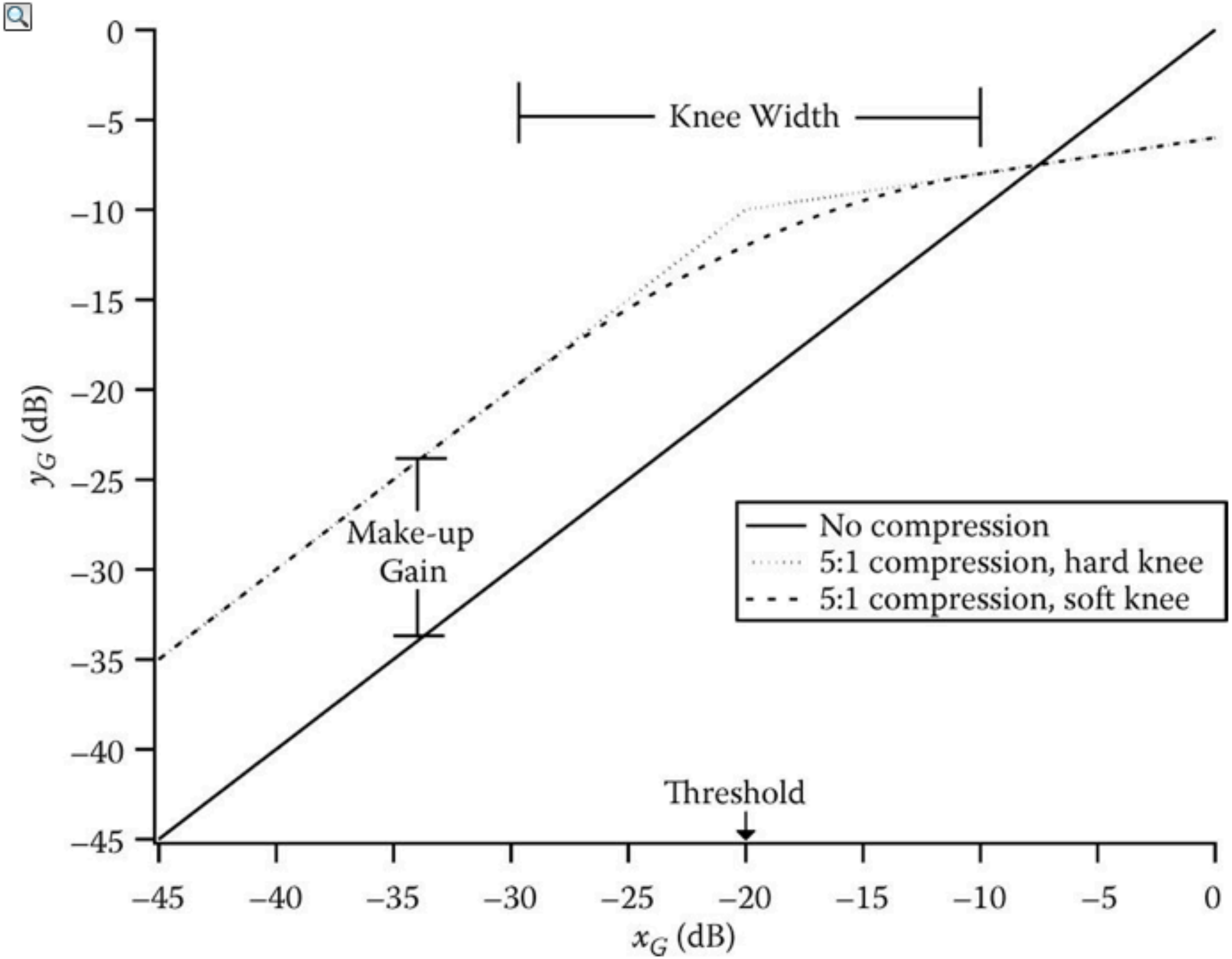
The compression ratio is defined as the reciprocal of the slope of the line segment above the threshold,

$$R = \frac{x_G - T}{y_G - T} \quad \text{for} \quad x_G > T \tag{6.2}$$

where the input and output to the gain computer, x_G and y_G, and the threshold T are all given in decibels. The static compression characteristic is described by the following relationship:

$$y_G = \begin{cases} x_G & x_G \leq T \\ T + (x_G - T)/R & x_G > T \end{cases} \tag{6.3}$$

FIGURE 6.4 Static compression characteristic with makeup gain and hard or soft knee.



Soft and hard knee

$$y_G = \begin{cases} x_G & x_G \le T \\ T + (x_G - T)/R & x_G > T \end{cases} \qquad (6.3)$$

In order to smooth the transition between compression and no compression at the threshold point, we can soften the compressor's knee. The width *W* of the knee (in decibels) is equally distributed on both sides of the threshold. Figure 6.4 presents a compression gain curve with a soft knee.

To implement this, we replace Equation (6.3) with the following piecewise, continuous function:

$$y_G = \begin{cases} x_G & 2(x_G - T) < -W \\ x_G + (1/R - 1)(x_G - T + W/2)^2/(2W) & 2|(x_G - T)| \le W \\ T + (x_G - T)/R & 2(x_G - T) > W \end{cases} \qquad (6.4)$$

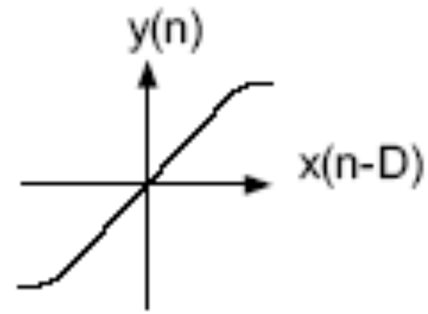
When the knee width is set to zero, the soft knee becomes a hard knee.

Level measurement (peak or RMS)

Peak level measurement has attack/release time

RMS level measurement has averaging time

These are different from the attack/release time used for gain factor smoothing, acting on f(n) to yield g(n)



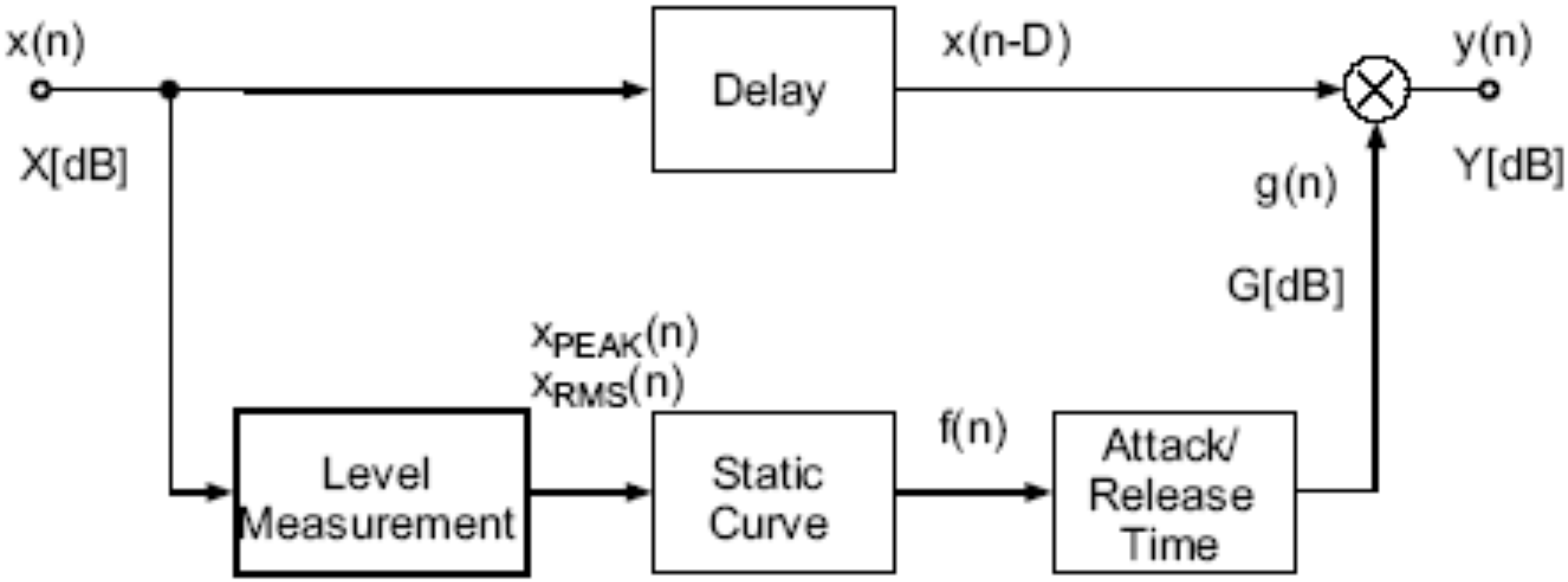


Figure 5.3 Block diagram of a dynamic range controller [Zöl97].

Attack and release times (from AE text)

The attack and the release times are usually introduced through a smoothing detector filter. We can simulate the time domain behavior of the filter in the digital domain with a digital one-pole filter,

$$y[n] = \alpha y[n-1] + (1-\alpha)x[n] \tag{6.5}$$

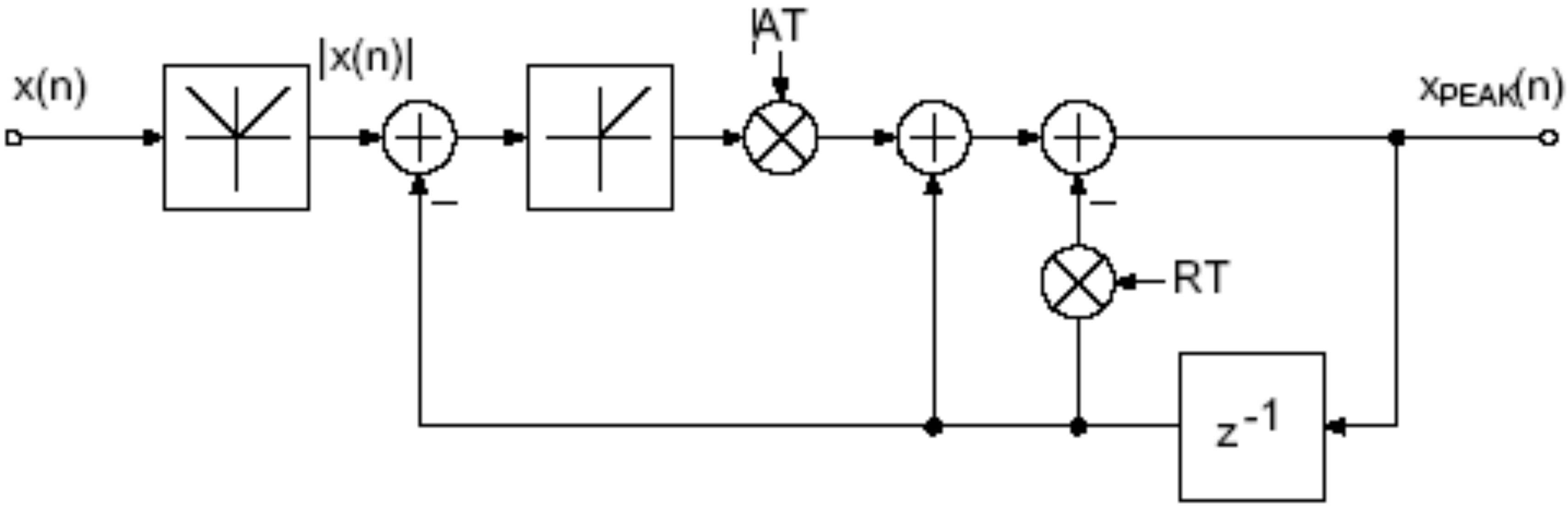
where α is the filter coefficient, $x[n]$ is the input, and $y[n]$ is the output. The step response of this filter is

$$y[n] = 1 - \alpha^n \quad \text{for} \quad x[n] = 1, n \geq 0 \tag{6.6}$$

The time constant τ is defined as the time it takes for this system to reach $1 - 1/e$ of its final value, i.e., $y[\tau f_S] = 1 - 1/e$. Thus, from (6.6) we have

$$\alpha = e^{-1/(\tau f_s)} \tag{6.7}$$

Peak measurement



$$x_{\mathrm{PEAK}}(n) = (1 - \mathrm{AT} - \mathrm{RT}) \cdot x_{\mathrm{PEAK}}(n-1) + \mathrm{AT} \cdot |x(n)|$$

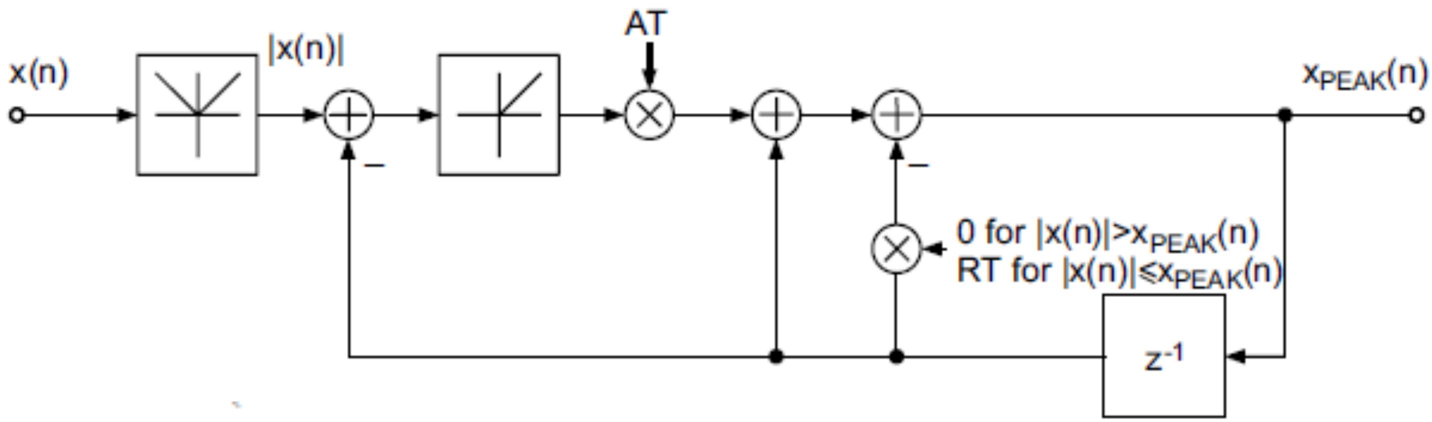
with the transfer function

$$H(z) = \frac{\mathrm{AT}}{1 - (1 - \mathrm{AT} - \mathrm{RT})z^{-1}}.$$

To find H(z) = Y(z)/X(x),

relabel |x(n)| as x(n) and xPEAK(n) as y(n)

Peak measurement



$|x(n)| > x_{\mathrm{PEAK}}(n-1)$

$$x_{\mathrm{PEAK}}(n) = (1-AT)\cdot x_{\mathrm{PEAK}}(n-1) + AT\cdot|x(n)|$$

$$H(z) = \frac{AT}{1-(1-AT)z^{-1}}.$$

$|x(n)| \leq x_{\mathrm{PEAK}}(n-1)$

$$x_{\mathrm{PEAK}}(n) = (1-RT)\cdot x_{\mathrm{PEAK}}(n-1)$$

$$H(z) = \frac{1}{1-(1-RT)z^{-1}}$$

To find H(z) = Y(z)/X(x),

relabel |x(n)| as x(n) and xPEAK(n) as y(n)

RMS measurement

$$x_{\mathrm{RMS}}(n) = (1 - \mathrm{TAV}) \cdot x_{\mathrm{RMS}}(n-1) + \mathrm{TAV} \cdot x^2(n)$$

with the transfer function

$$H(z) = \frac{\mathrm{TAV}}{1 - (1 - \mathrm{TAV})z^{-1}}.$$

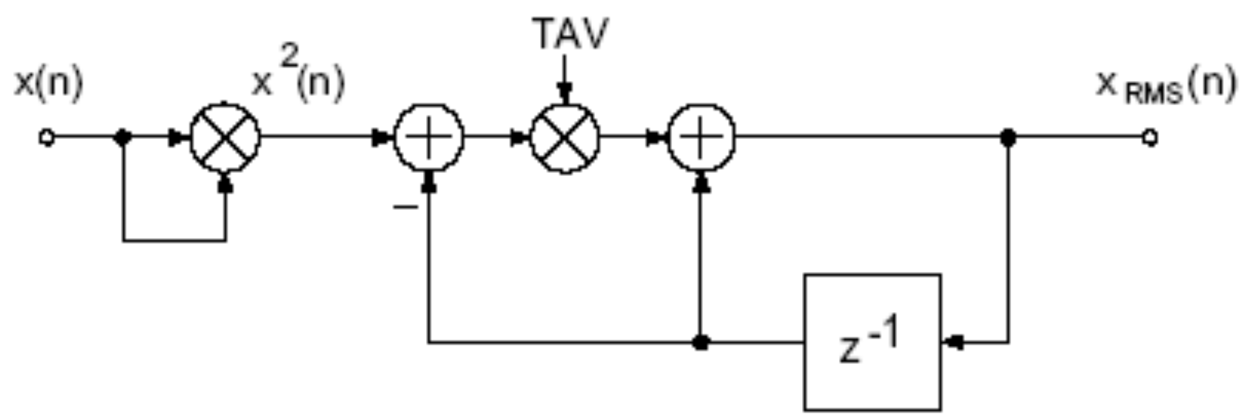
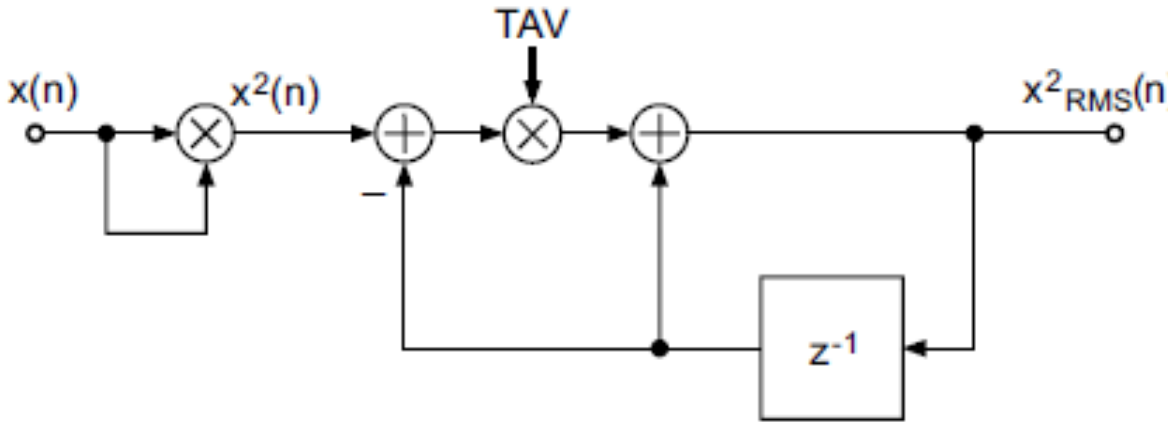


Figure 7.5 RMS measurement (TAV = averaging coefficient).

To find H(z)=Y(z)/X(z),

relabel x^2(n) as x(n) and xRMS(n) as y(n)

RMS measurement



$$x^2_{\mathrm{RMS}}(n) = (1 - \mathrm{TAV}) \cdot x^2_{\mathrm{RMS}}(n-1) + \mathrm{TAV} \cdot x^2(n)$$

$$y^2[n] = \alpha y^2[n-1] + (1-\alpha)x^2[n] \qquad (6.10)$$

AE text

$$H(z) = \frac{\mathrm{TAV}}{1 - (1 - \mathrm{TAV})z^{-1}}.$$

To find H(z)=Y(z)/X(z),

relabel x^2(n) as x(n) and xRMS(n) as y(n)

Peak level measurement has attack/release time AT/RT

RMS level measurement has averaging time TAV

These are different from the attack/release time used for gain factor smoothing, acting on $f(n)$ to yield $g(n)$

Gain factor smoothing (attack/release)

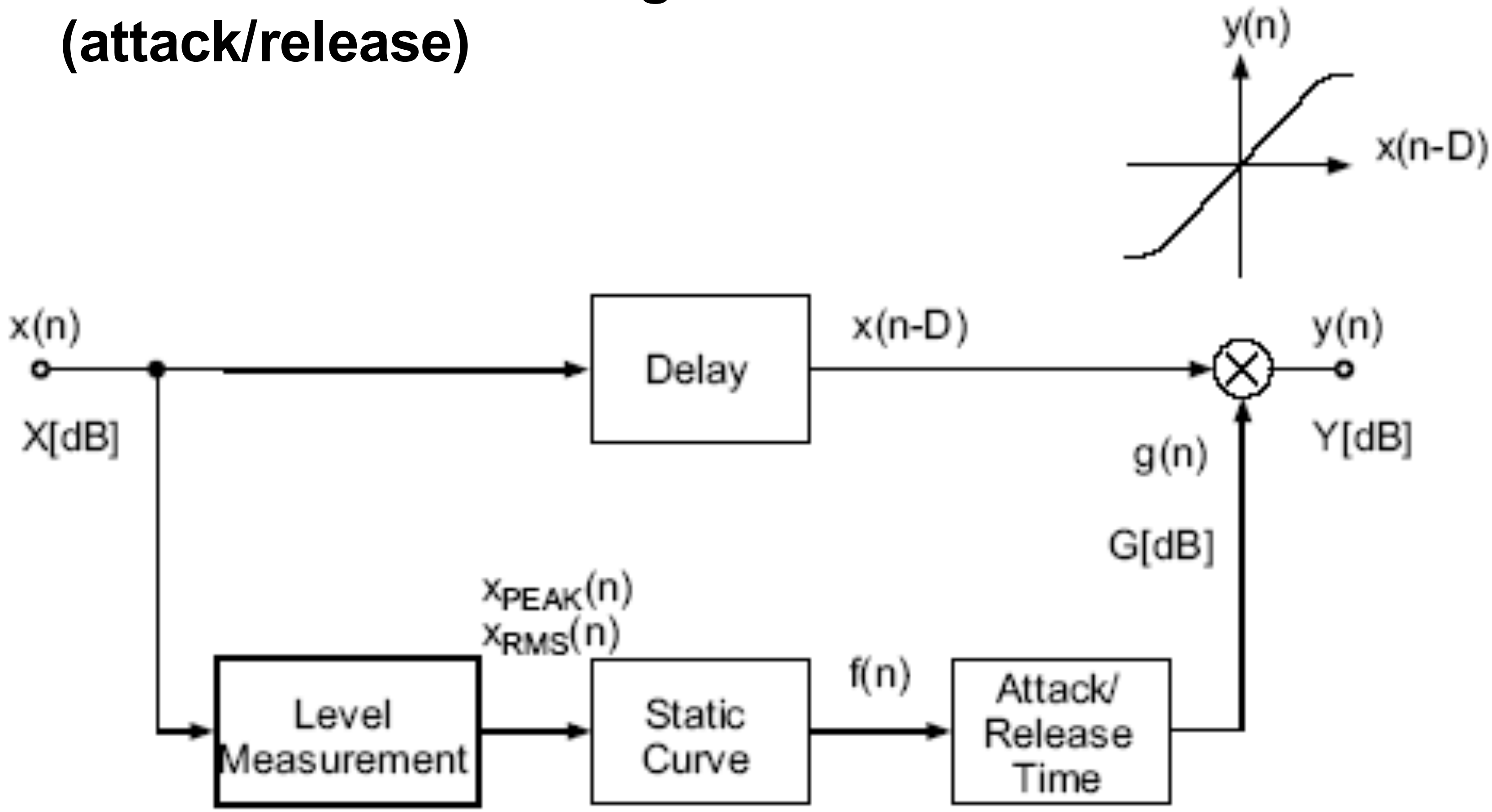
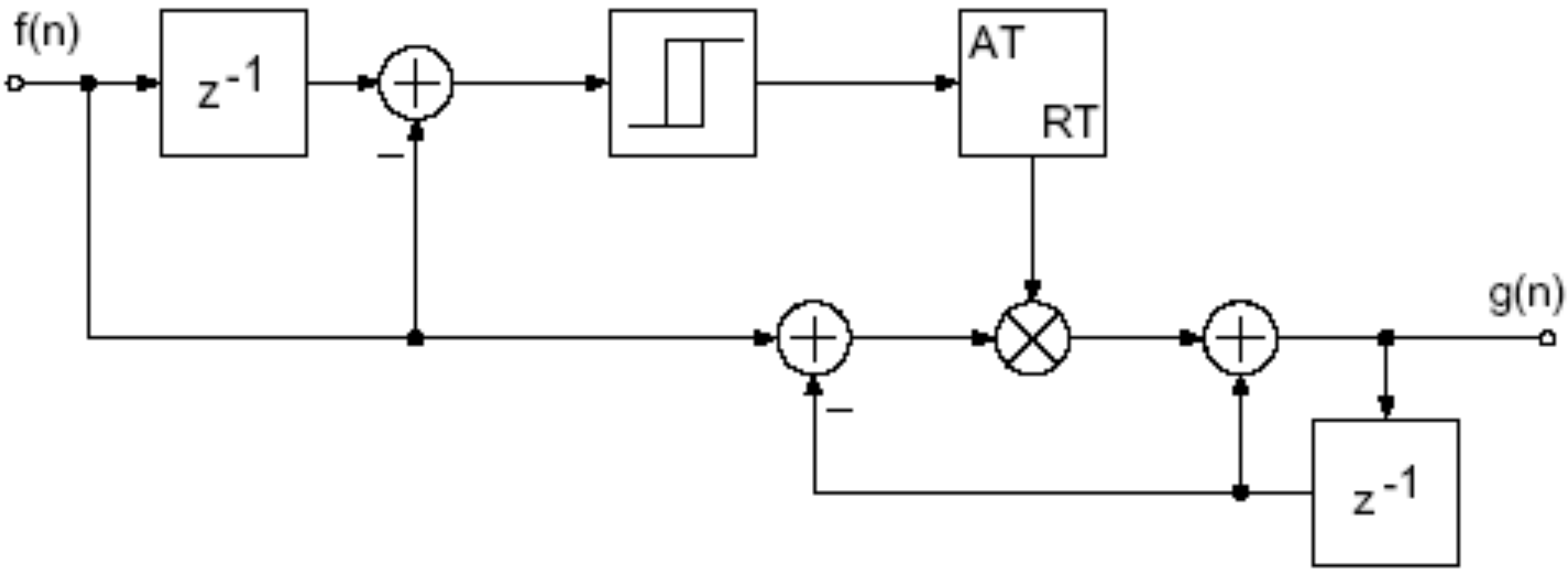


Figure 5.3 Block diagram of a dynamic range controller [Zöl97].

Gain factor smoothing

f(n) = static gain, g(n)= dynamic gain



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

with $k = \mathrm{AT}$ or $k = \mathrm{RT}$ and the corresponding transfer function leads to

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

Simplified implementation of attack/release gain factor smoothing

- Replace AT/RT with low pass filter
- AT and RT will be the same

5.2.1 Limiter

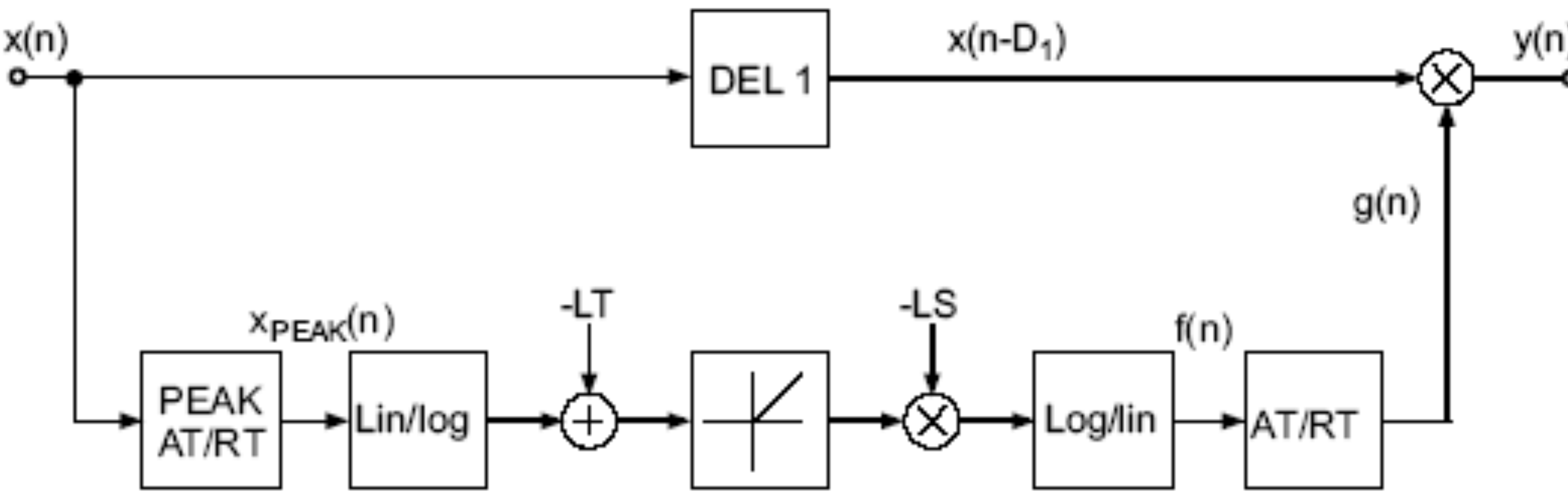
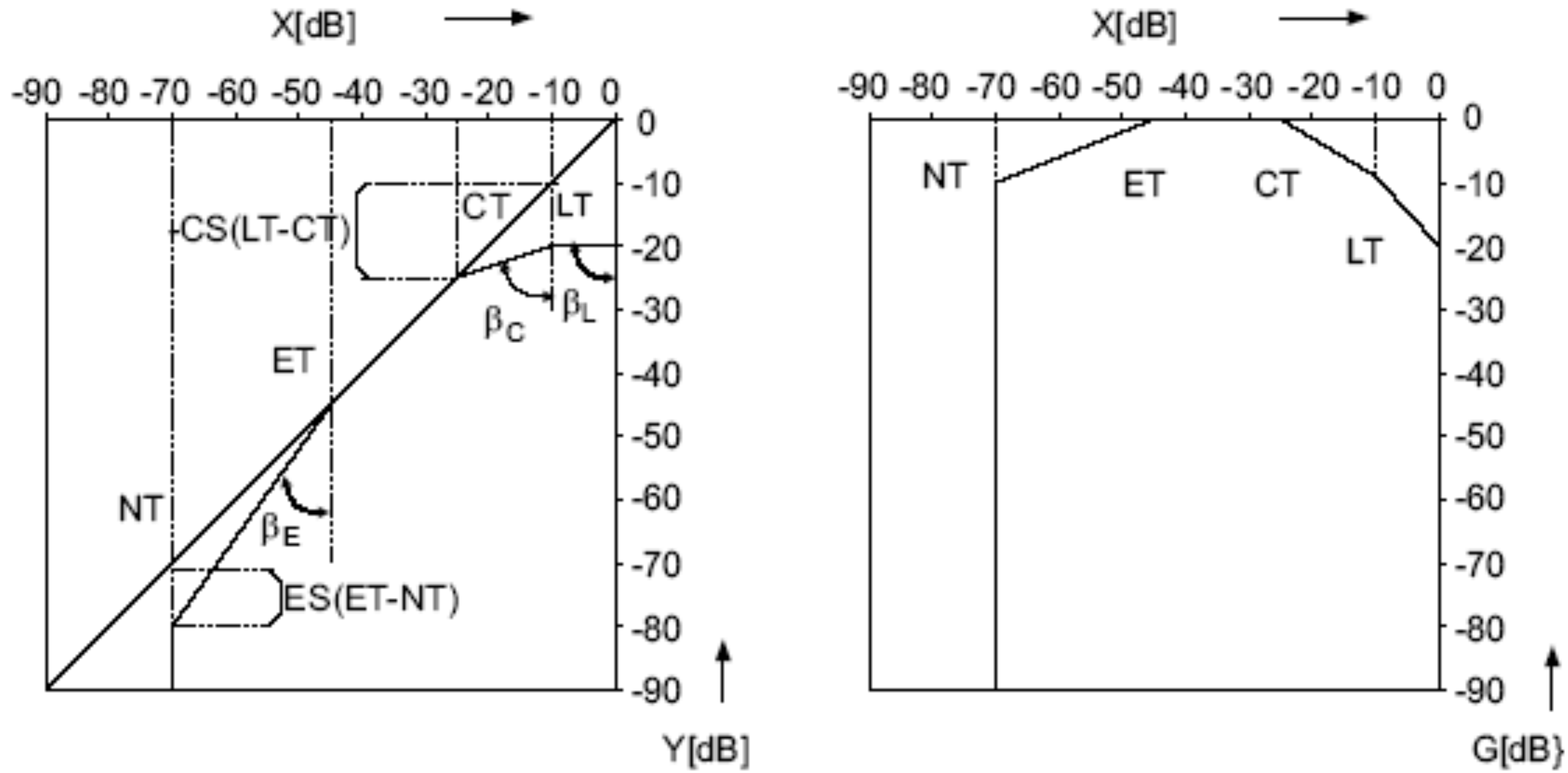
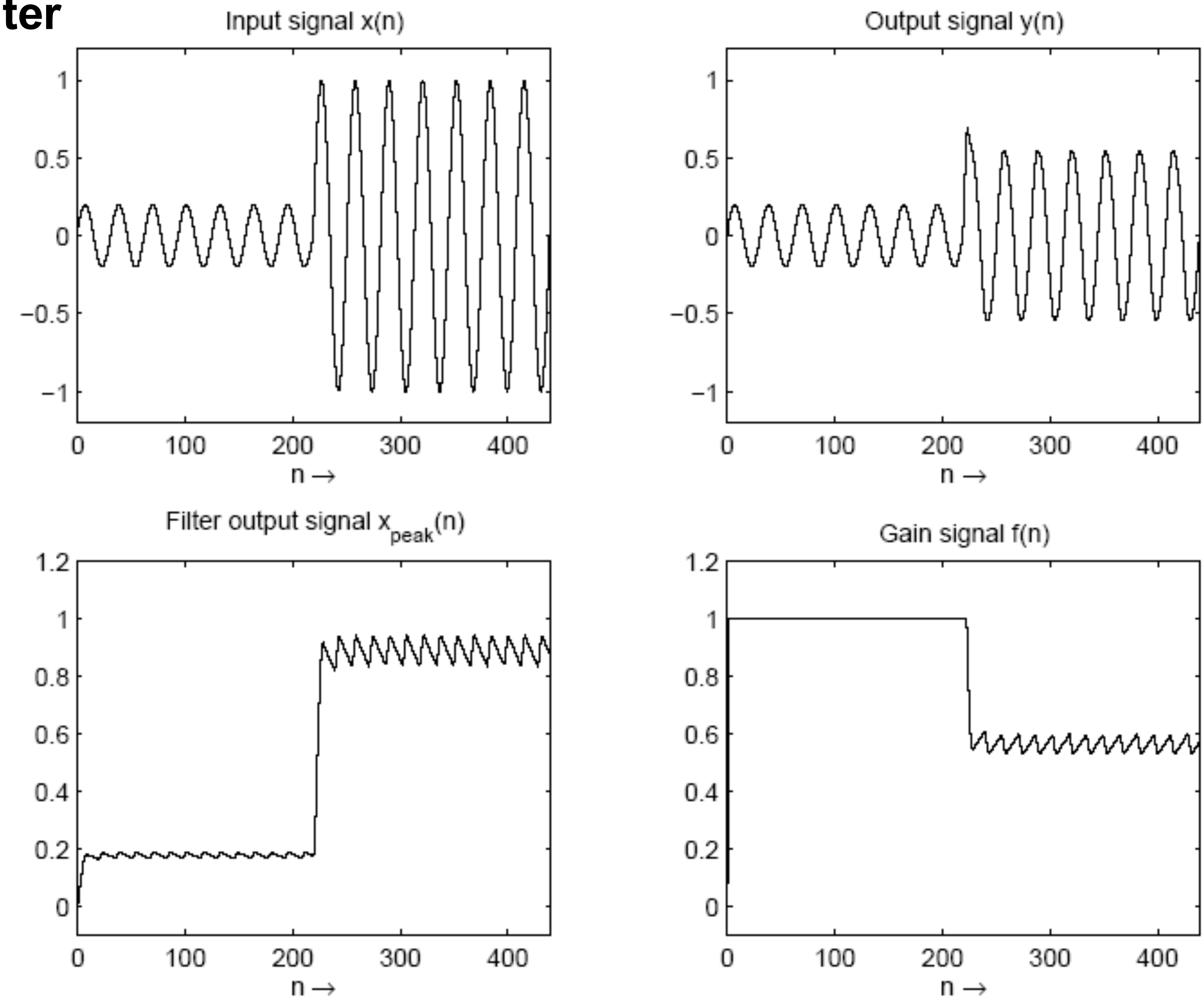


Figure 5.8 Block diagram of a limiter [Zöl97].



Limiter	F_{L}	$=$	$-LS(X-LT)+CS(CT-LT)$
Compressor	F_{C}	$=$	$-CS(X-CT)$
Linear part	F_{lin}	$=$	0
Expander	F_{E}	$=$	$-ES(X-ET)$
Noise gate	F_{NG}	$=$	$-NS(X-NT)+ES(ET-NT)$

limiter



Input signal x(n)
Output signal y(n)
Filter output signal $x_{peak}(n)$
Gain signal f(n)
n →

5.2.2 Compressor and Expander

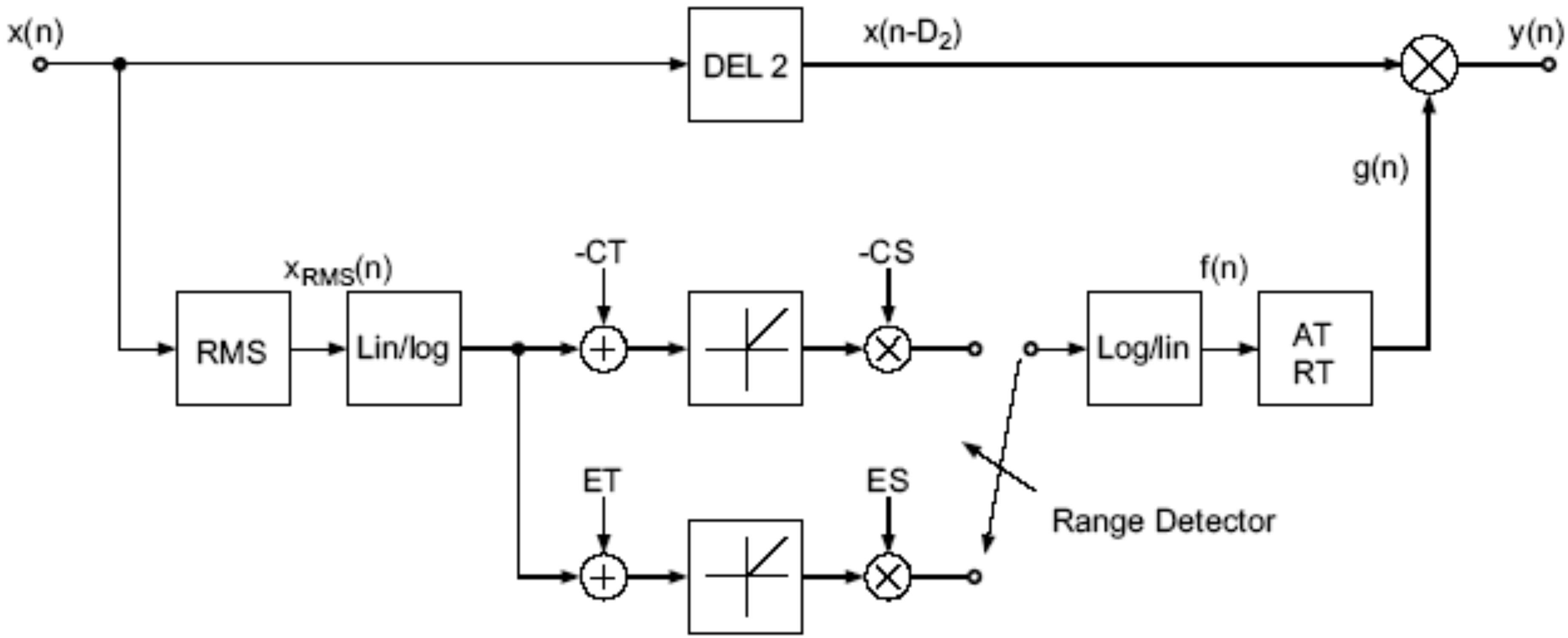
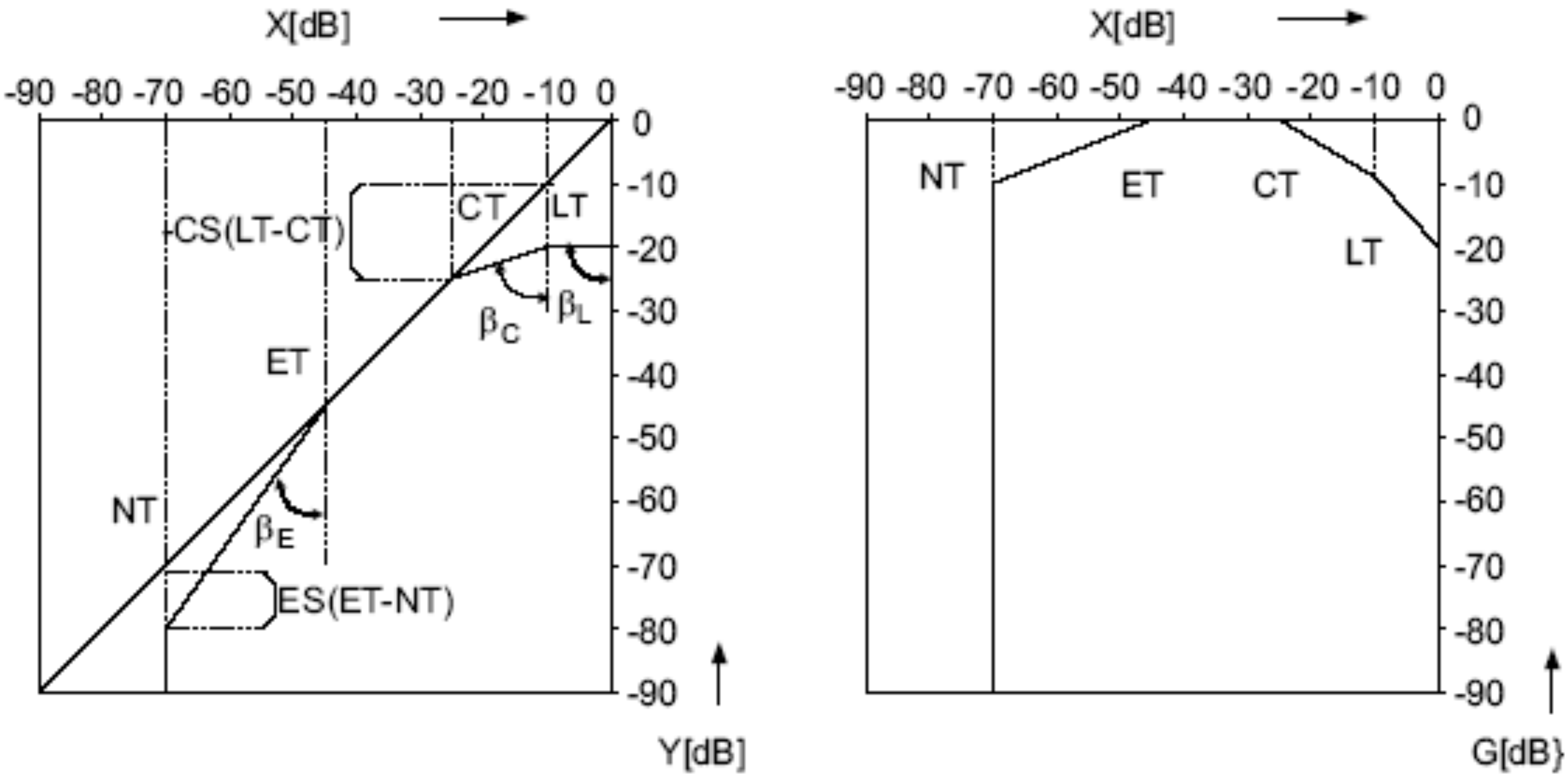


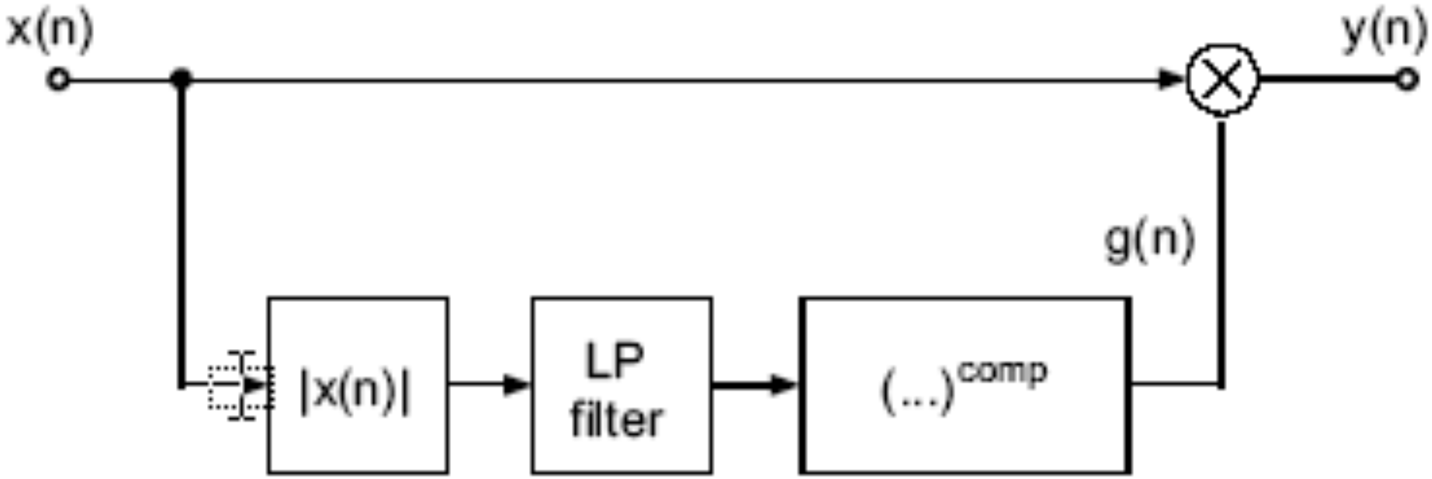
Figure 5.10 Block diagram of a compressor/expander [Zöl97].

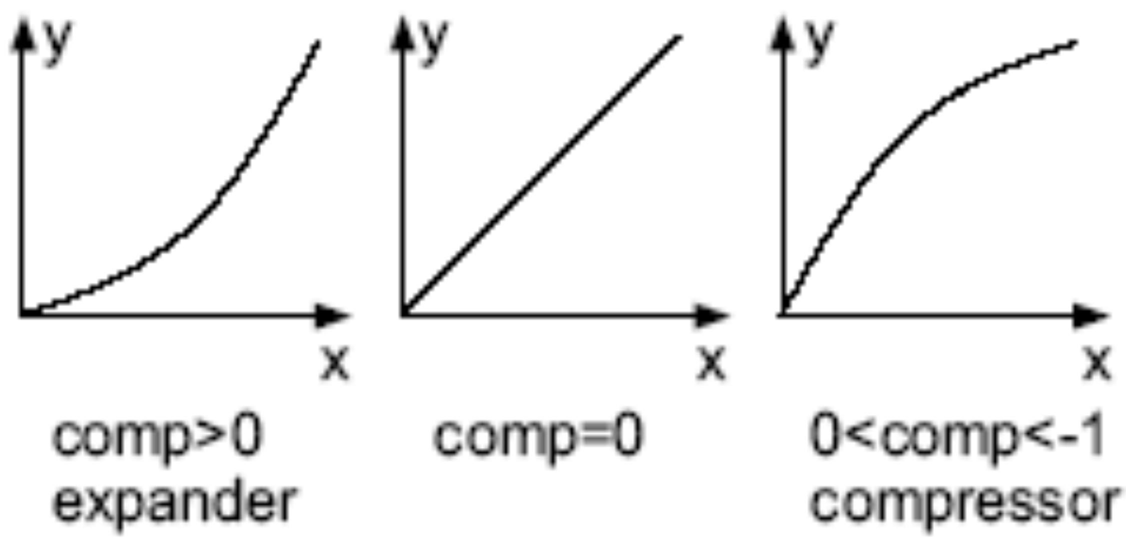


$$
\begin{array}{llcl}
\text{Limiter} & F_{\mathrm{L}} & = & -LS(X - LT) + CS(CT - LT) \\
\text{Compressor} & F_{\mathrm{C}} & = & -CS(X - CT) \\
\text{Linear part} & F_{\mathrm{lin}} & = & 0 \\
\text{Expander} & F_{\mathrm{E}} & = & -ES(X - ET) \\
\text{Noise gate} & F_{\mathrm{NG}} & = & -NS(X - NT) + ES(ET - NT)
\end{array}
$$

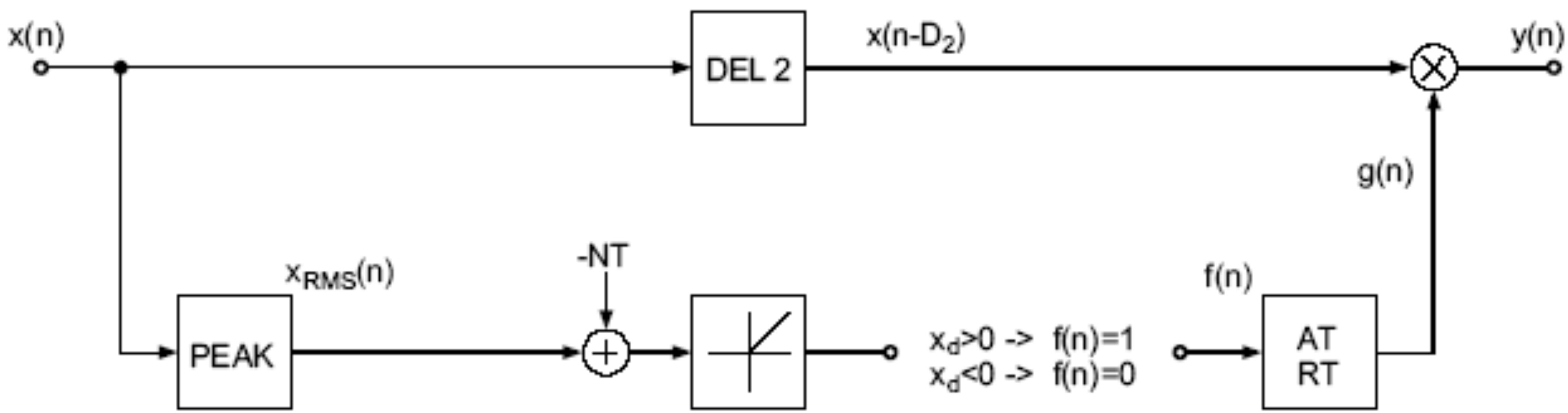
Simplified compressor and expandor

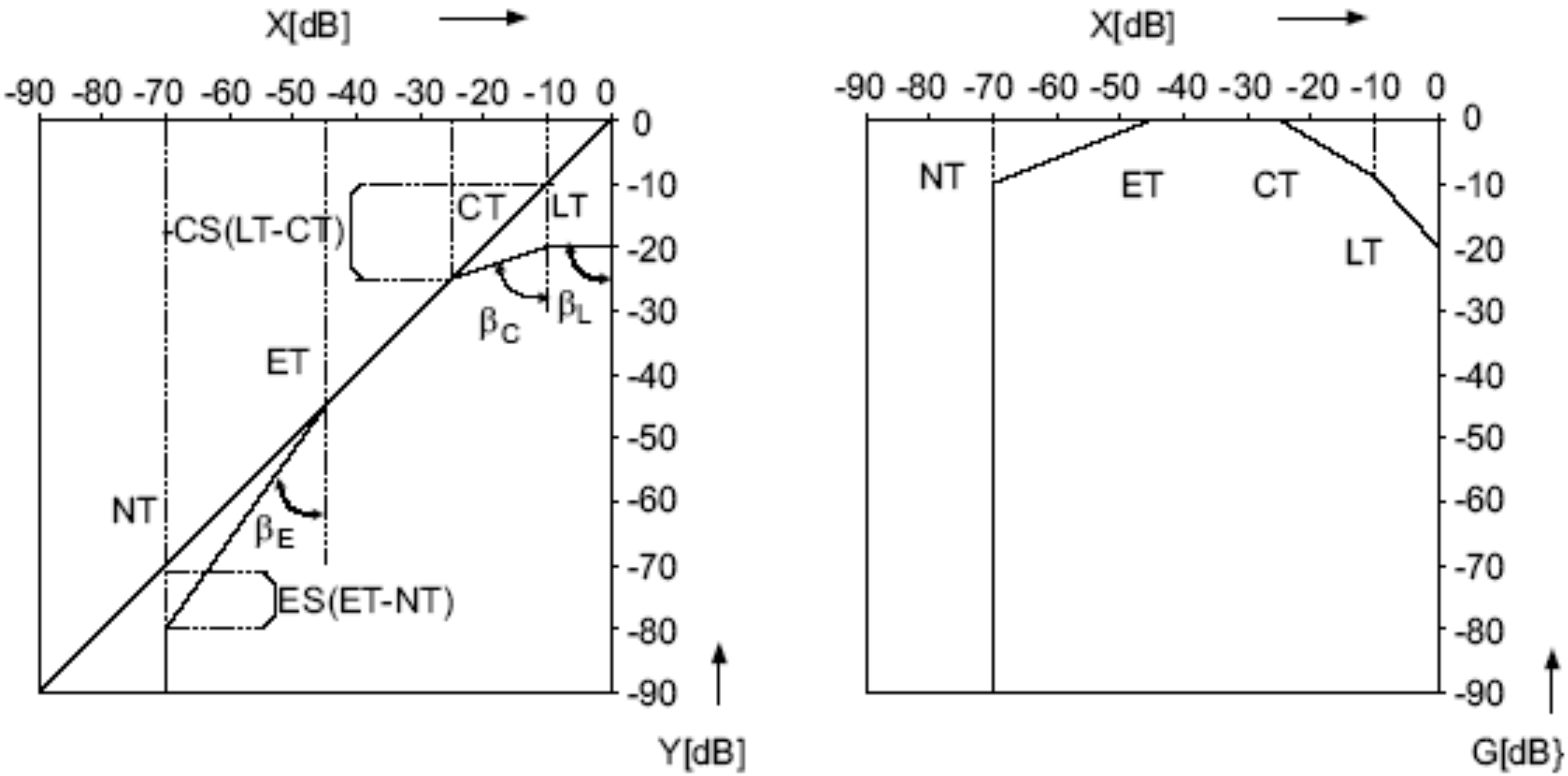
Replace AT/RT with LPF
Replace CT/ET line equations with power law





5.2.3 Noise Gate





Limiter	F_{L}	$=$	$-LS(X - LT) + CS(CT - LT)$
Compressor	F_{C}	$=$	$-CS(X - CT)$
Linear part	F_{lin}	$=$	0
Expander	F_{E}	$=$	$-ES(X - ET)$
Noise gate	F_{NG}	$=$	$-NS(X - NT) + ES(ET - NT)$

Derivation of attack and release times

$$AT = 1 - \exp\left(\frac{-2.2T_S}{t_a/1000}\right),$$

$$RT = 1 - \exp\left(\frac{-2.2T_S}{t_r/1000}\right),$$

$$\mathrm{TAV} = 1 - \exp\left(\frac{-2.2T_A}{t_M/1000}\right)$$

Derivation of AT, RT TAV

If the step response of a continuous-time system is

$$g(t) = 1 - e^{-t/\tau}, \qquad \tau = \text{time constant},$$

then sampling (step-invariant transform) the step response gives the discrete response

$$g(nT_S) = \varepsilon(nT_S) - e^{-nT_S/\tau} = 1 - z_\infty^n, \qquad z_\infty = e^{-T_S/\tau}.$$

The Z-transform leads to

$$G(z) = \frac{z}{z-1} - \frac{1}{1 - z_\infty z^{-1}} = \frac{1 - z_\infty}{(z-1)(1 - z_\infty z^{-1})}.$$

With the definition of attack time $t_a = t_{90} - t_{10}$, we derive

$$0.1 = 1 - e^{-t_{10}/\tau} \quad \leftarrow t_{10} = 0.1\tau,$$
$$0.9 = 1 - e^{-t_{90}/\tau} \quad \leftarrow t_{90} = 0.9\tau.$$

if one considers rise time for the step response to go from 10 to 90% of the final value,

$$0.1 = 1 - \alpha^{\tau_1 f_s},\ 0.9 = 1 - \alpha^{\tau_2 f_s} \rightarrow \tau_2 - \tau_1 = \tau \ln 9 \qquad (6.8)$$

The relationship between attack time t_a and the time constant τ obtained as follows:

$$\begin{aligned} 0.9/0.1 &= e^{(t_{90}-t_{10})/\tau} \\ \ln(0.9/0.1) &= (t_{90} - t_{10})/\tau \\ t_a &= t_{90} - t_{10} = 2.2\tau. \end{aligned}$$

Hence, the pole is calculated as

$$\boxed{z_\infty = e^{-2.2T_S/t_a}.}$$

Attack release time

A system for implementing the given step response is obtained by the relationship b
the Z-transform of the impulse response and the Z-transform of the step response:

$$H(z) = \frac{z-1}{z} G(z).$$

The transfer function can now be written as

$$H(z) = \frac{(1 - z_{\infty})z^{-1}}{1 - z_{\infty} z^{-1}}$$

with the pole $z_{\infty} = e^{-2.2Ts/t_a}$ adjusting the attack, release or averaging time. For

$$H(z) = \frac{(1 - z_\infty)z^{-1}}{1 - z_\infty z^{-1}} \qquad z_\infty = e^{-2.2T_S/t_a}$$

$$H(z) = \frac{AT}{1 - (1 - AT)z^{-1}}. \qquad AT = 1 - \exp\left(\frac{-2.2T_S}{t_a/1000}\right),$$

$$H(z) = \frac{1}{1 - (1 - RT)z^{-1}} \qquad RT = 1 - \exp\left(\frac{-2.2T_S}{t_r/1000}\right),$$

$$H(z) = \frac{\text{TAV}}{1 - (1 - \text{TAV})z^{-1}}. \qquad \text{TAV} = 1 - \exp\left(\frac{-2.2T_A}{t_M/1000}\right)$$

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

with $k = \mathrm{AT}$ or $k = \mathrm{RT}$ and the corresponding transfer function leads to

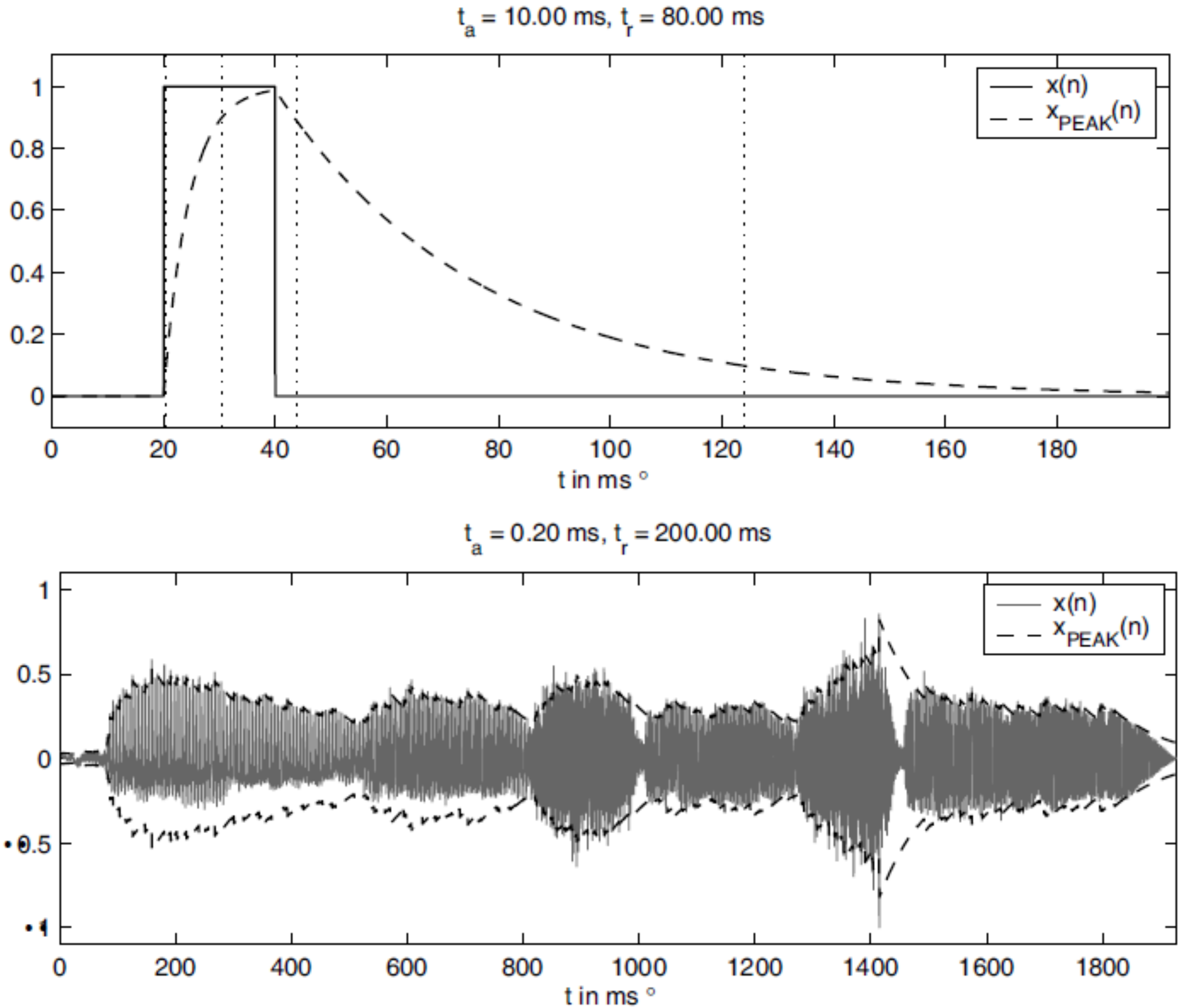
$$H(z) = \frac{k}{1 - (1 - k)z^{-1}}.$$

Attack and release times

$$AT = 1 - \exp\left(\frac{-2.2T_S}{t_a/1000}\right),$$

$$RT = 1 - \exp\left(\frac{-2.2T_S}{t_r/1000}\right),$$

$$\mathrm{TAV} = 1 - \exp\left(\frac{-2.2T_A}{t_M/1000}\right)$$


t_a = 10.00 ms, t_r = 80.00 ms
x(n)
x_PEAK(n)
t in ms
t_a = 0.20 ms, t_r = 200.00 ms
x(n)
x_PEAK(n)
t in ms

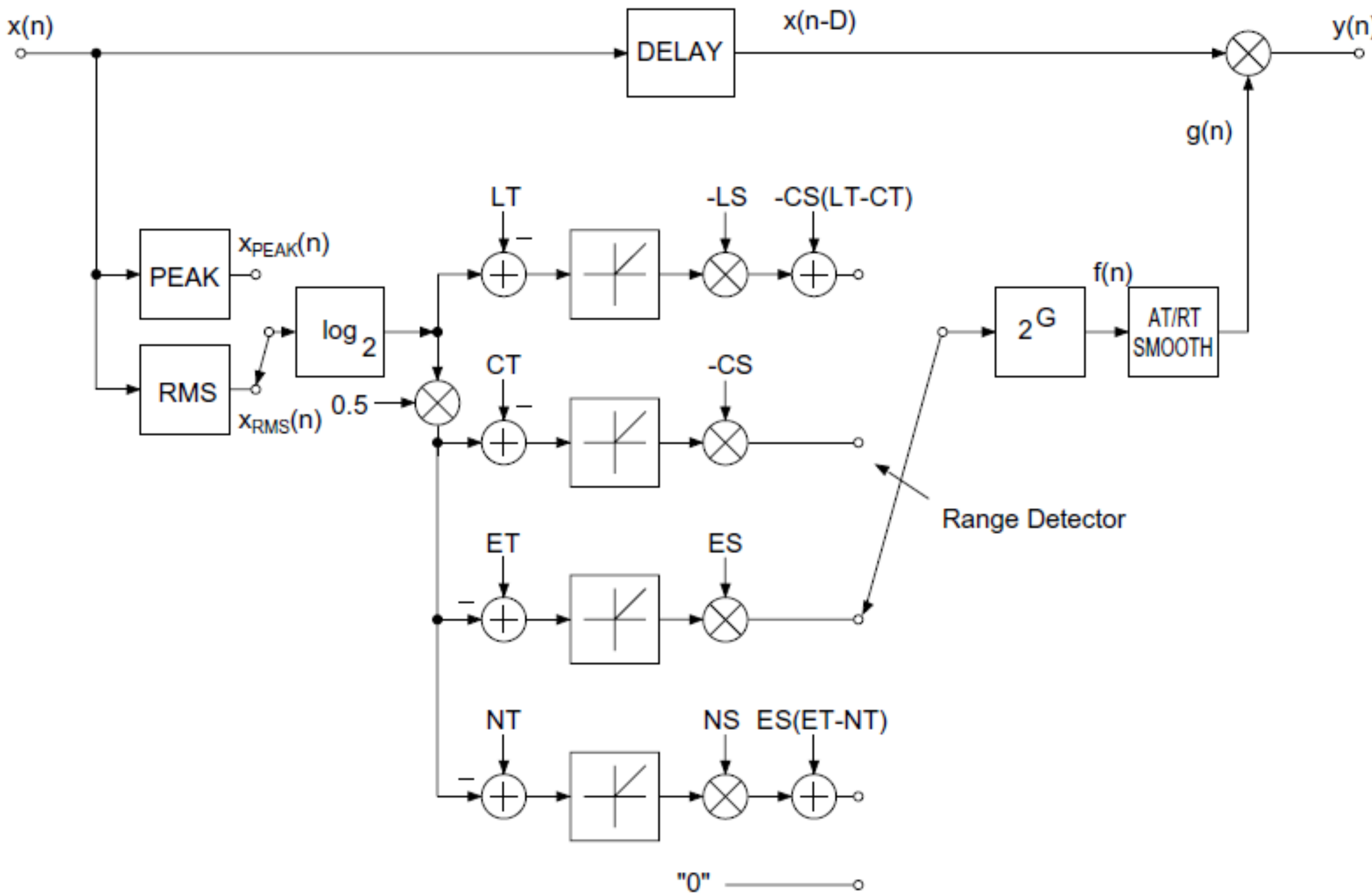


Figure 7.10 Limiter/compressor/expander/noise gate.