Constrained Clipping for PAPR Reduction in VLC Systems with Dimming Control

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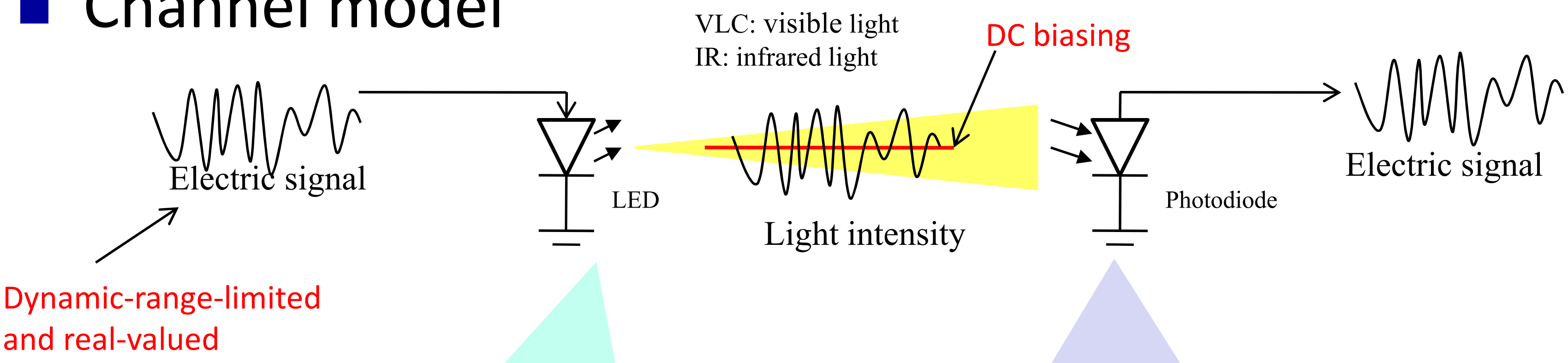
Outline

- Introduction
- Double-sided Clipping
- Constrained Clipping
- Numerical Results

Intensity Modulation/Direct Detection (IM/DD)

- Channel model



Transmitter:
light emitting diode (LED) converts the amplitude of the electric signal into the intensity of the optical signal.

Receiver :
A photodetector (PD) or an image sensor generates an electric signal proportional to the intensity of the received optical signal.

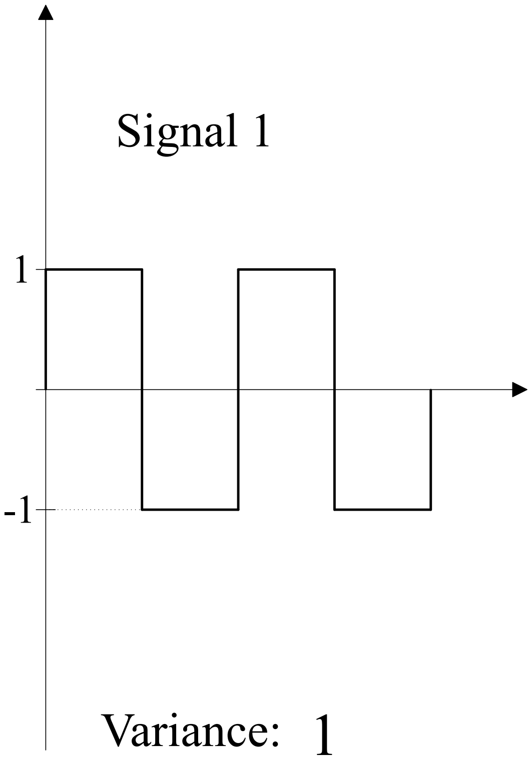
- Differences from Radio Frequency (RF)
  - Real-valued
  - Dynamic-range-limited (turn-on/saturation)
  - DC biasing required

PAPR Reduction

- Motivation of peak-to-average power ratio (PAPR) reduction
  - *Considering signals with the same variance*

High PAPR/peaks → Low amplifier → Low power → Low signal-to-noise-plus-distortion ratio

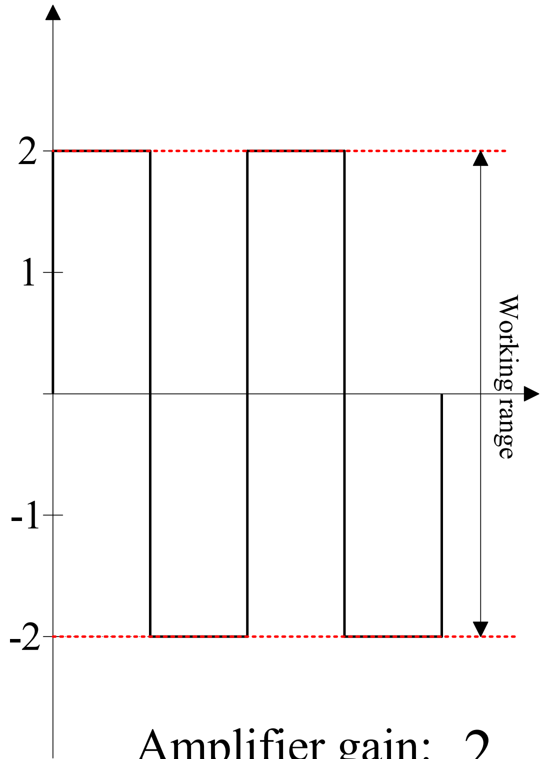
High PAPR/peaks → More Clipping → Distortion → Low signal-to-noise-plus-distortion ratio



Variance: 1

PAPR: 1

$\Rightarrow$



Amplifier gain: 2

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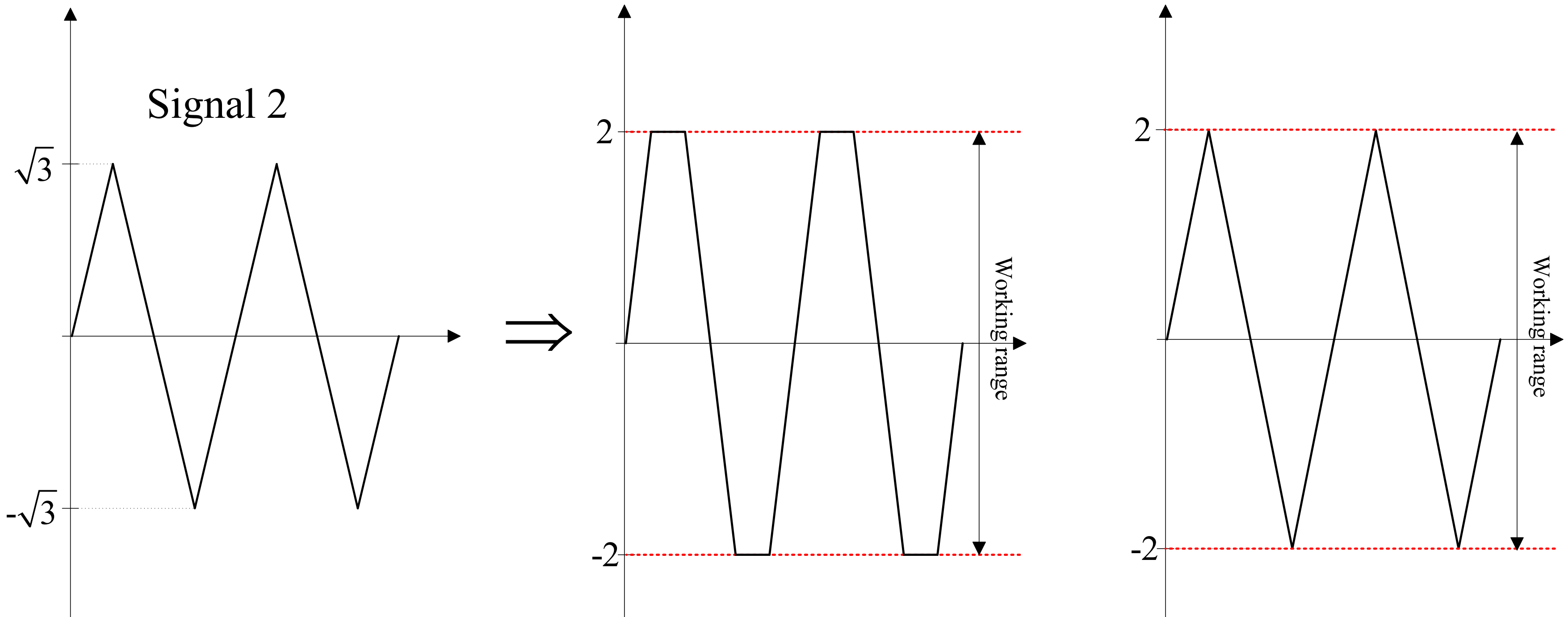


Variance: 1

PAPR: 3

Amplifier gain: 2

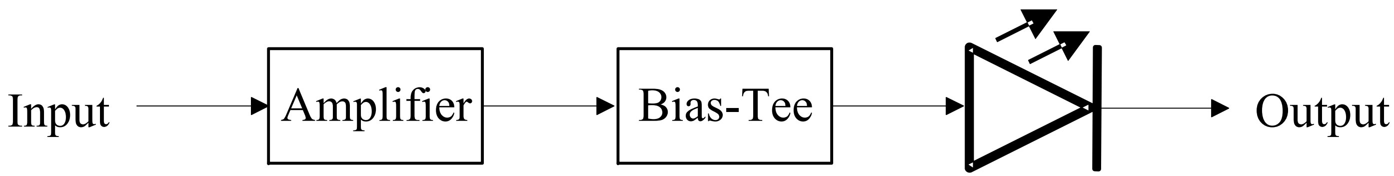
Clipping distortion

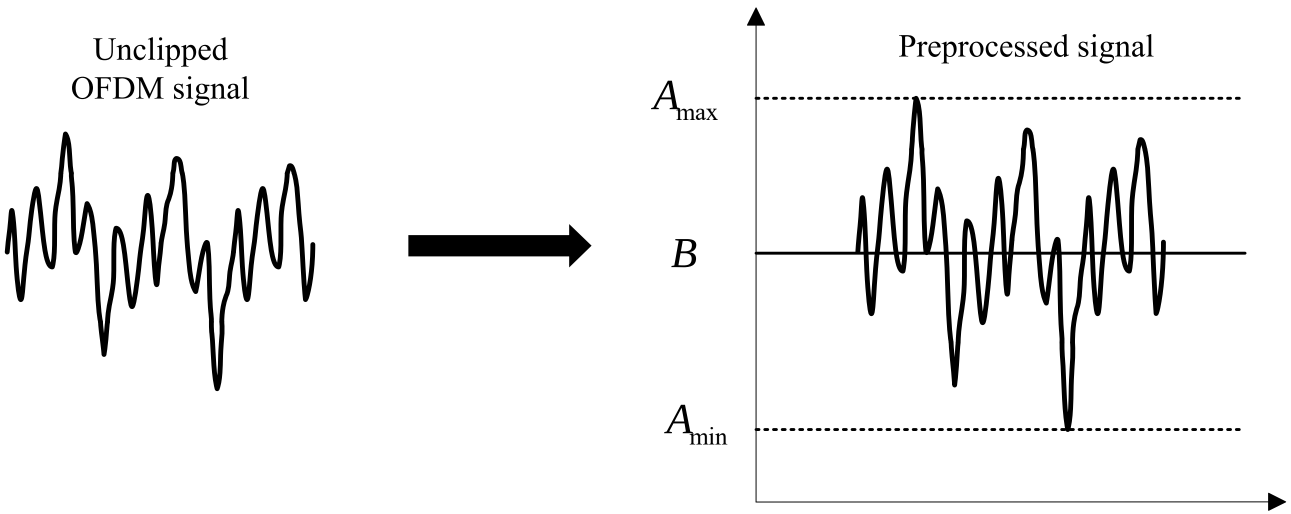
Amplifier gain: 1.1547

Lower signal power

Double-sided Clipping

- Clipping is the simplest way to reduce PAPR
- Motivation of clipping
  - *Tradeoff between clipping distortion and signal power*





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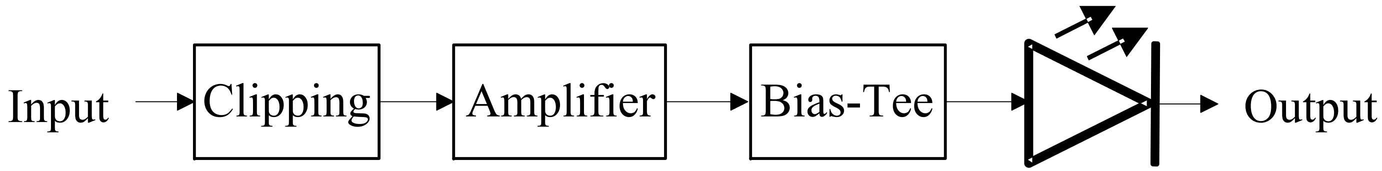
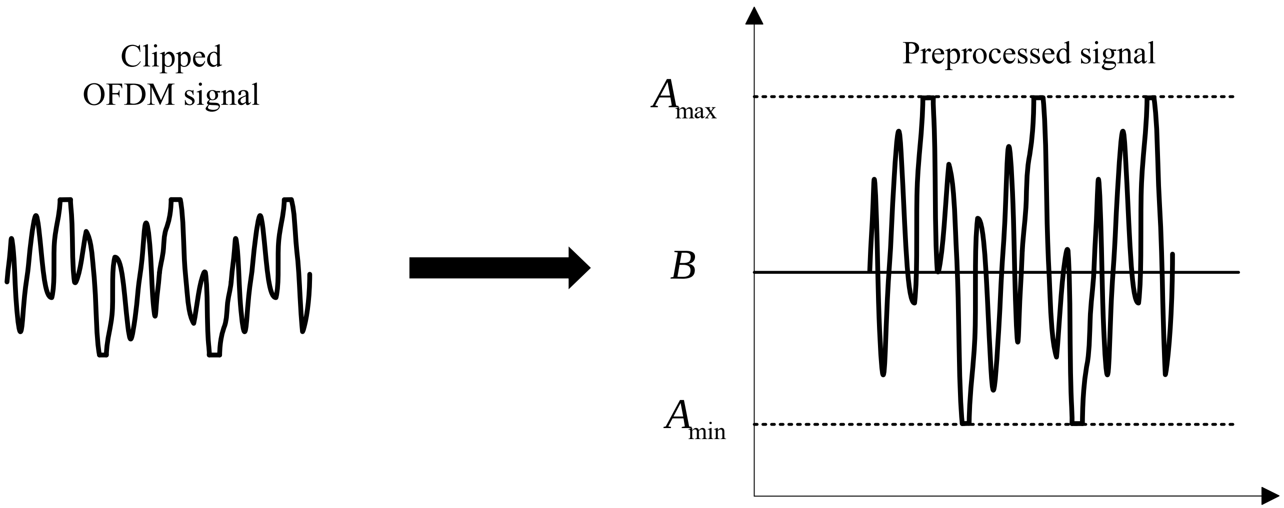
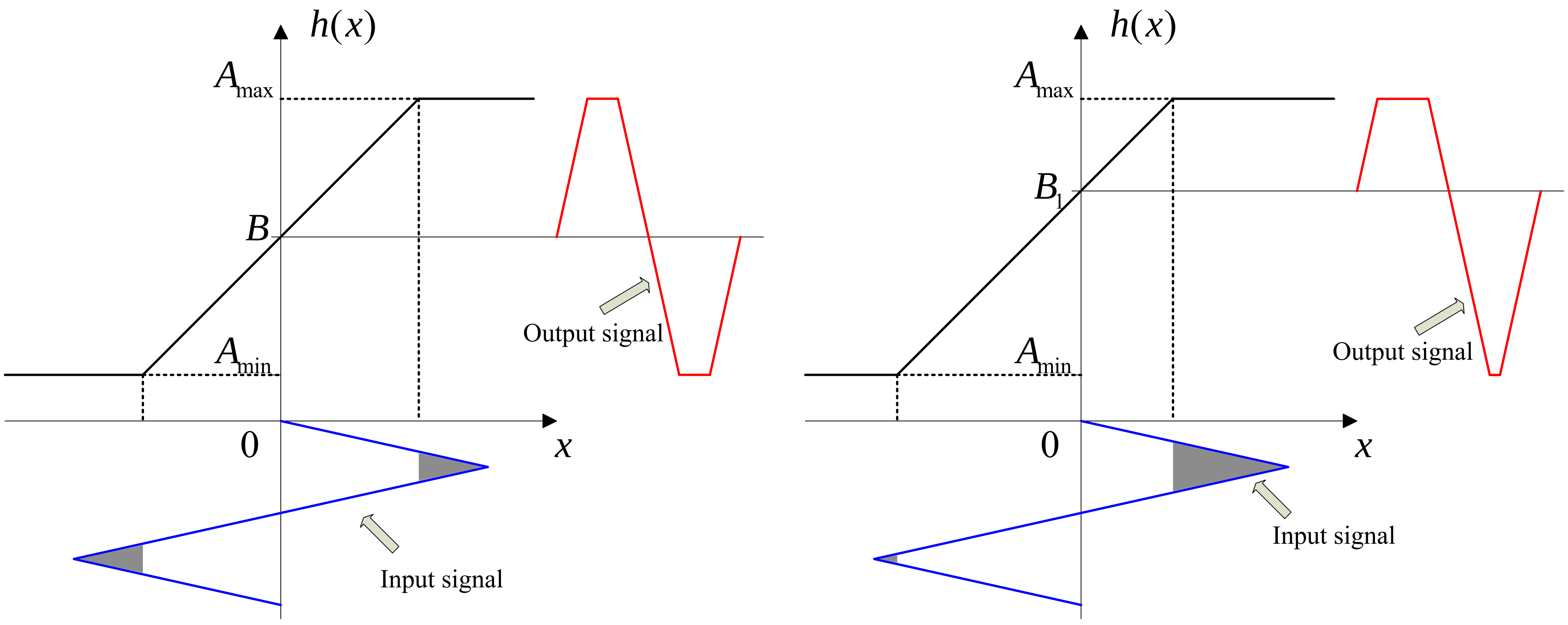




Double-sided Clipping

- Difference from amplitude-limited system
  - *Double-sided clipping*
  - *Clipping ratio is impacted by both gain and bias*



$G=1,\ \ B=(A_{max}+A_{min})/2$

$G=1,\ \ B_1 > B$

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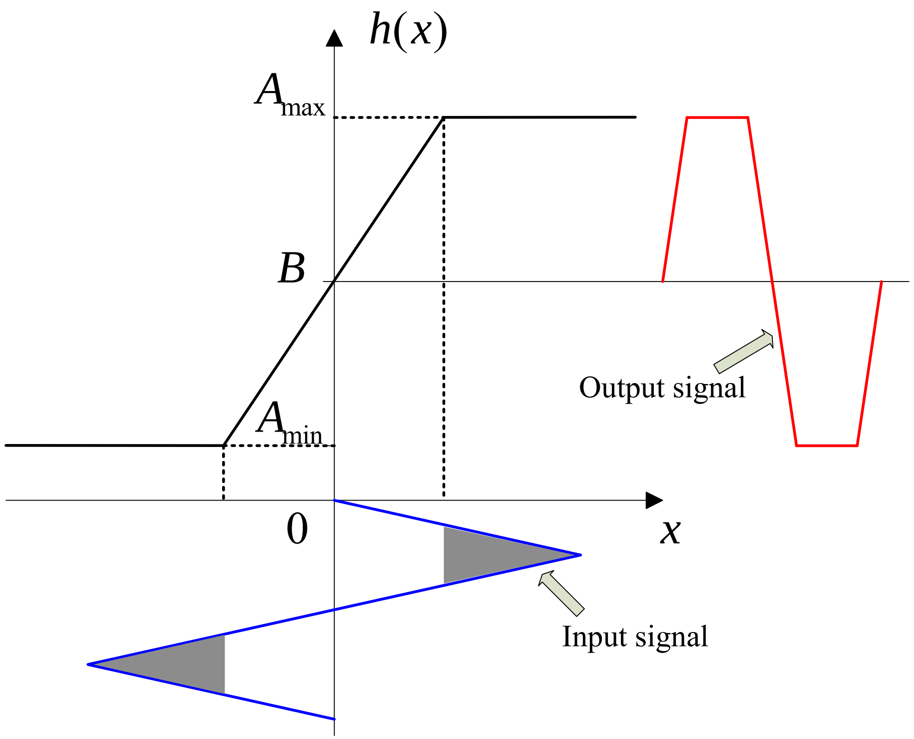
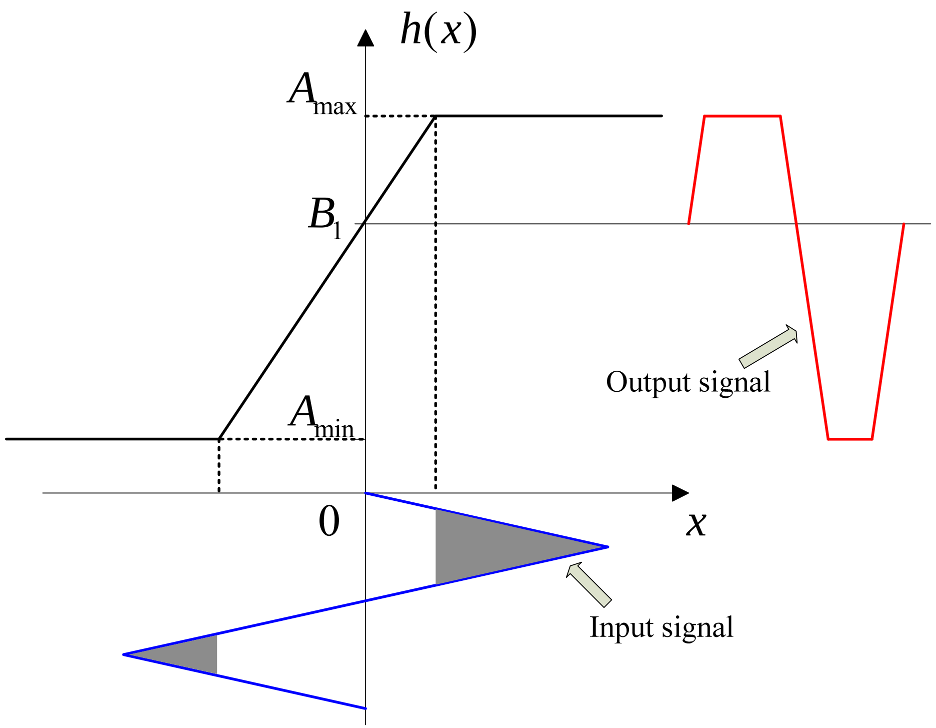


$$G_1 > G, \quad B = (A_{max} + A_{min})/2$$



$$G_1 > G, \quad B_1 > B$$

Double-sided PAPR

- Orthogonal frequency division multiplexing (OFDM)
  - *Time domain:* x_n **Real-valued**
  - *Frequency domain:* $X_k = X^*_{-k}, 1 \leq k \leq N/2 - 1$ **Hermitian symmetry**
- PAPR on both sides
  - *Upper PAPR (UPAPR):*

$$\mathcal{U}(x_n) \triangleq \frac{\left(\max_{0 \leq n \leq N-1} x_n\right)^2}{\sigma_x^2}$$

  - *Lower PAPR (LPAPR):*

$$\mathcal{L}(x_n) \triangleq \frac{\left(\min_{0 \leq n \leq N-1} x_n\right)^2}{\sigma_x^2}$$

- Asymmetric factor

$$\rho \triangleq \frac{(A_{max} - B)^2}{(A_{min} - B)^2}$$

- Joint CCDF of UPAPR and LPAPR

$$\begin{aligned} &\mathrm{CCDF}\{\mathcal{U}(x_n), \mathcal{L}(x_n), \gamma, \rho\} \\ &\triangleq 1 - Pr\{\mathcal{U}(x_n) \leq \gamma, \mathcal{L}(x_n) \leq \gamma/\rho\} \end{aligned}$$

Simple Clipping

- Clipping in time domain

$$\bar{x}_n = \begin{cases} x_{max}, & x_n > x_{max}, \\ x_n, & x_{min} \le x_n \le x_{max}, \\ x_{min}, & x_n < x_{min}. \end{cases}$$

$$x_{max} = \frac{A_{max} - B}{G}$$

$$x_{min} = \frac{A_{min} - B}{G}$$

- Distortion in frequency domain

$$E_k = \bar{X}_k - X_k$$

- Error vector magnitude (EVM)

$$\mathrm{EVM} \triangleq \frac{1}{\sigma_X} \sqrt{\frac{1}{N} \sum_{k \in \mathcal{I}} |E_k|^2}$$

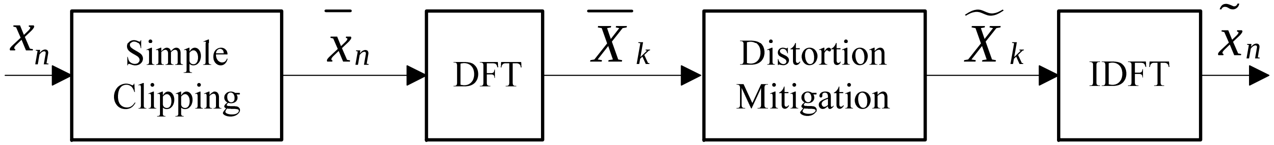
- Clipping ratio / Normalized clipping levels
  - *Upper side:* $\lambda_{upper} = \frac{x_{max}}{\sigma_x}$
  - *Lower side:* $\lambda_{lower} = -\frac{x_{min}}{\sigma_x}$
  - *To satisfy the EVM requirement, clipping levels cannot be very low.*

$$\lambda_{upper} = \sqrt{\rho} \lambda_{lower}$$

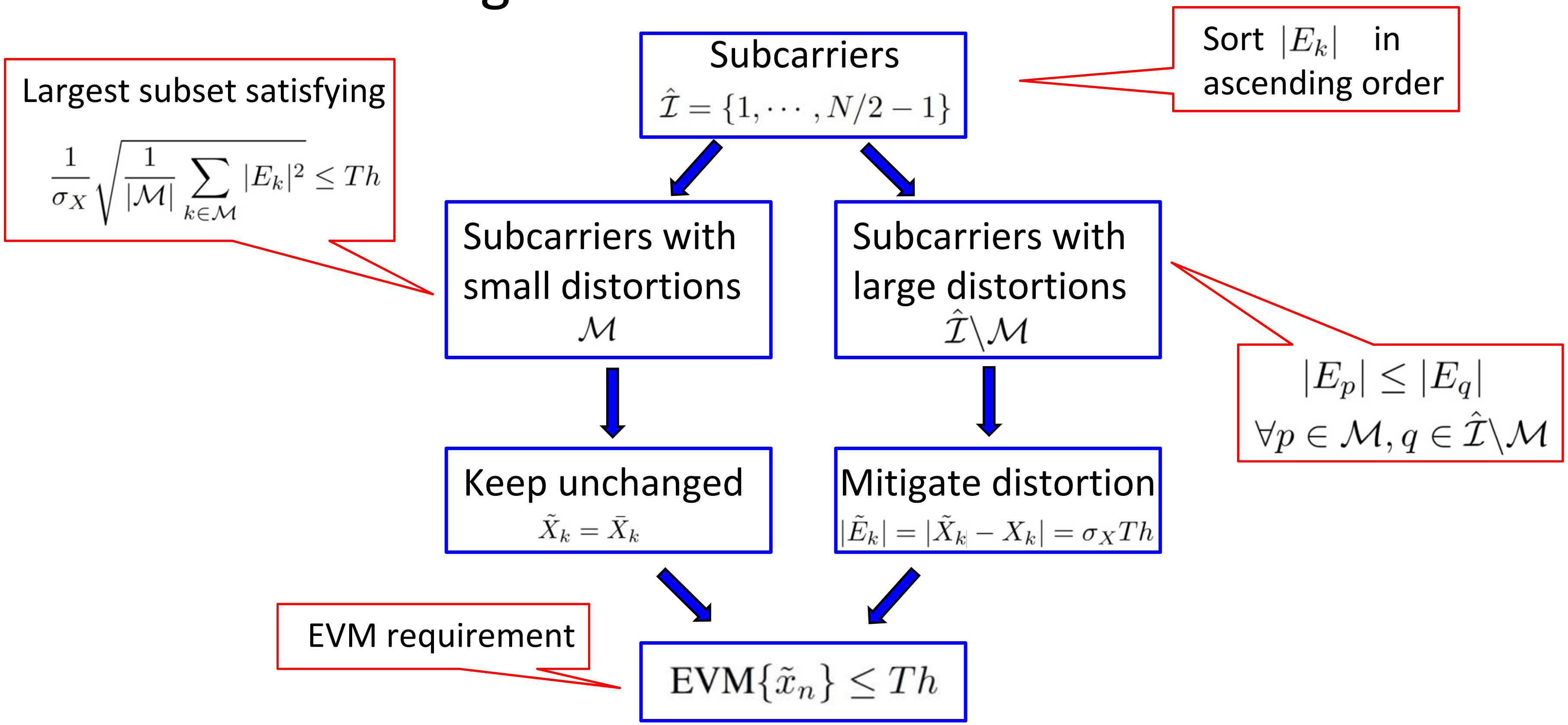
Too conservative!

Constrained Clipping

- Block diagram



- Distortion Mitigation



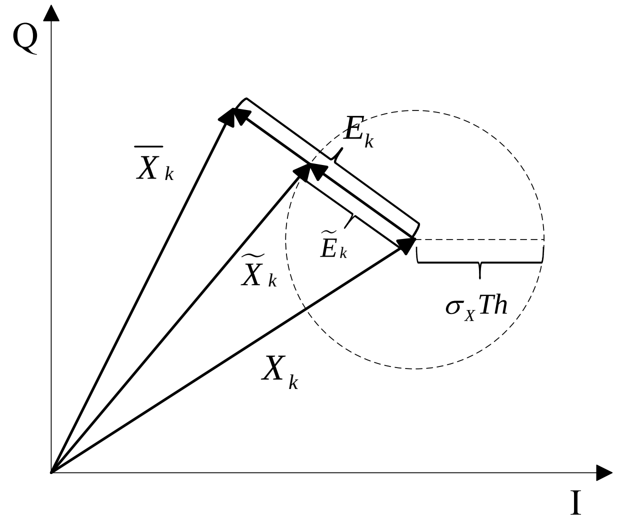
Constrained Clipping

- How to revise subcarriers with large distortions
  - *Modifying frequency domain symbols will change the time domain signals. We make the change as small as possible.*
  - *Parseval's Theorem*

$$\sum_{n=0}^{N-1} |\tilde{x}_n - \bar{x}_n|^2 = \sum_{k \in \mathcal{I}} |\tilde{X}_k - \bar{X}_k|^2$$

  - *Minimize the change in frequency domain*

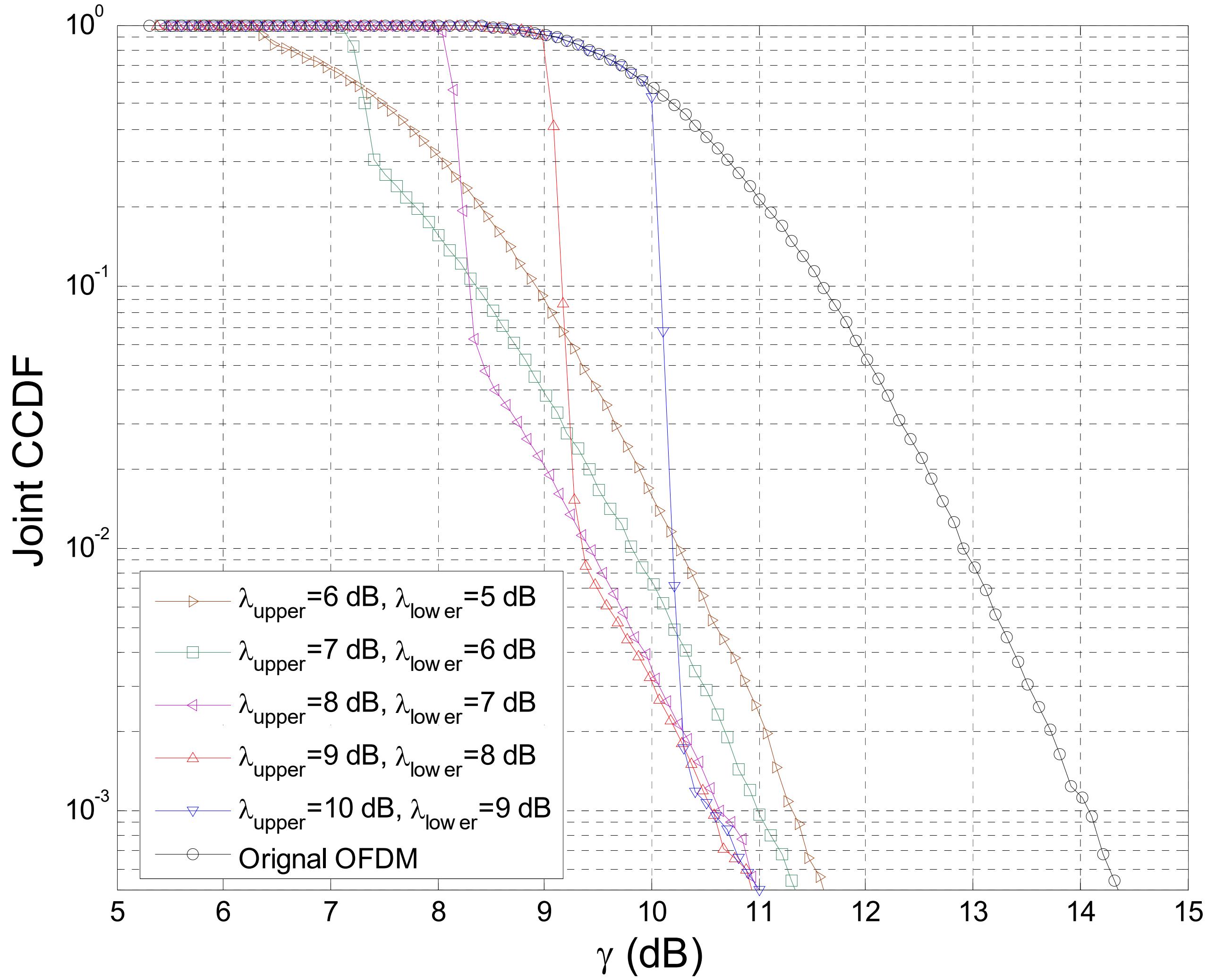
$$\tilde{X}_k = X_k + Th \cdot \sigma_X e^{j \angle E_k}, \quad k \in \hat{\mathcal{I}} \backslash \mathcal{M}$$



R. J. Baxley, et al., Constrained clipping for crest factor reduction in OFDM, IEEE Transactions on Broadcasting, vol. 52, no. 4, pp. 570-575, Dec. 2006.

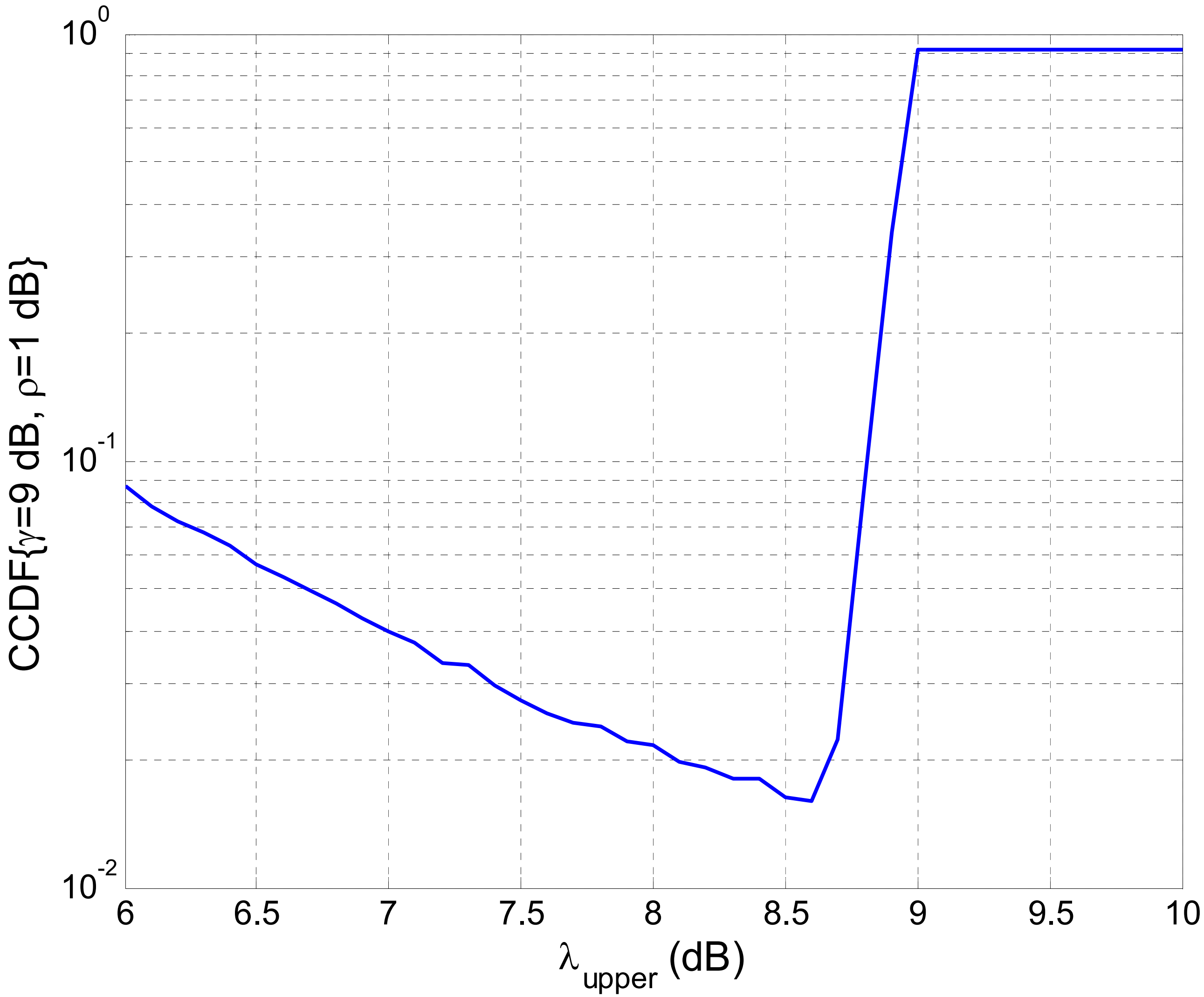
Numerical Results

- PAPR reduction with various clipping levels



Numerical Results

- Probability that signal exceeds 9 dB in UPAPR or 8 dB in LPAPR



Thank you!

Q&A