

OFDM for VLC with probabilistic constellation shaping

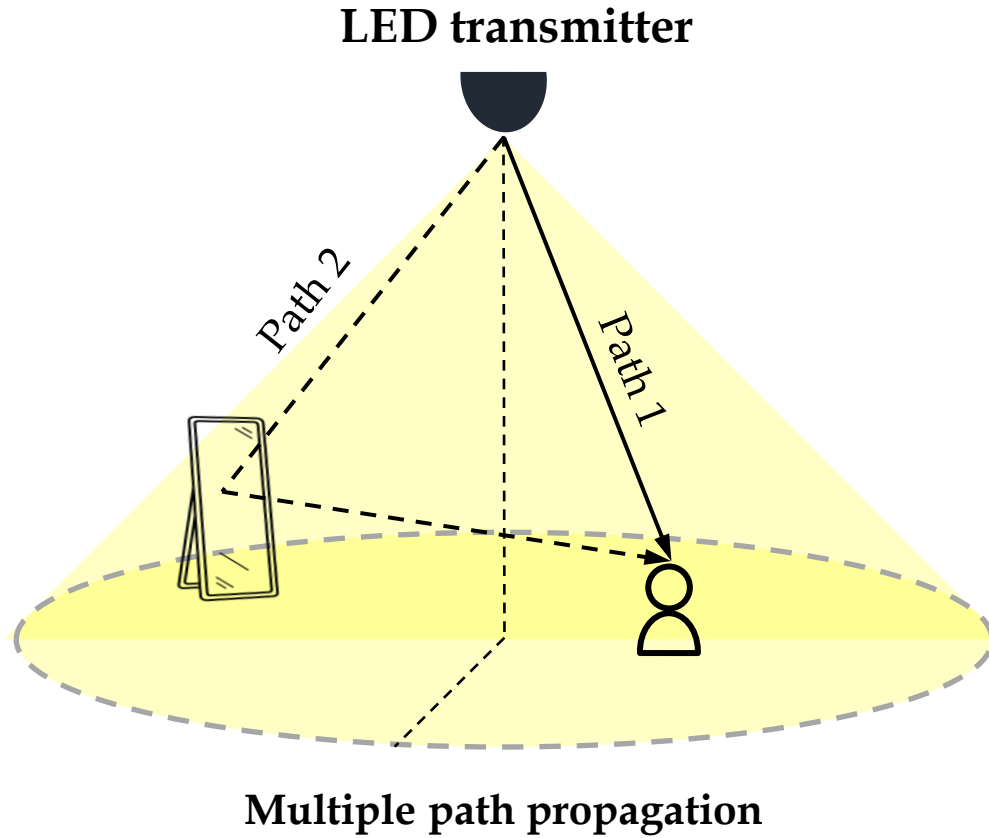
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OFDM basic idea



- In wireless channel (RF, VLC, ...), the signal can reach a user using multiple path component
- Each path has different attenuation, frequency, phase and time delay
- At the receiver, the signal from these multiple paths can get added constructively or destructively based on the phase alignment

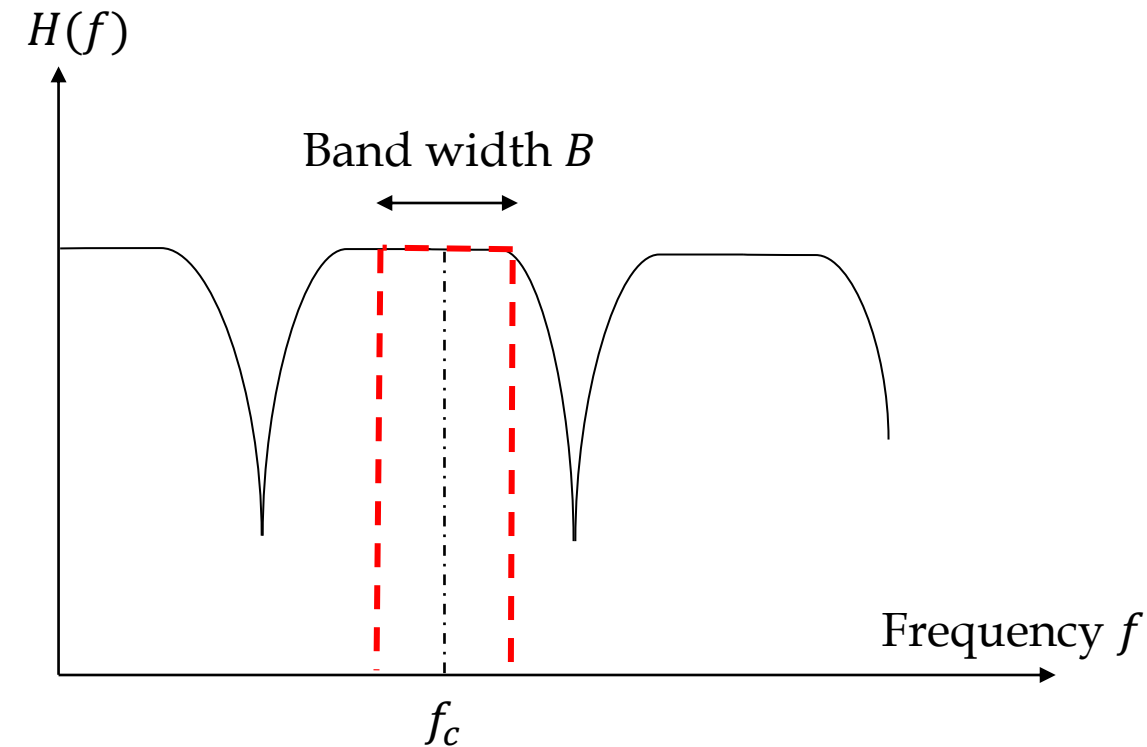


Multipath fading

OFDM basic idea

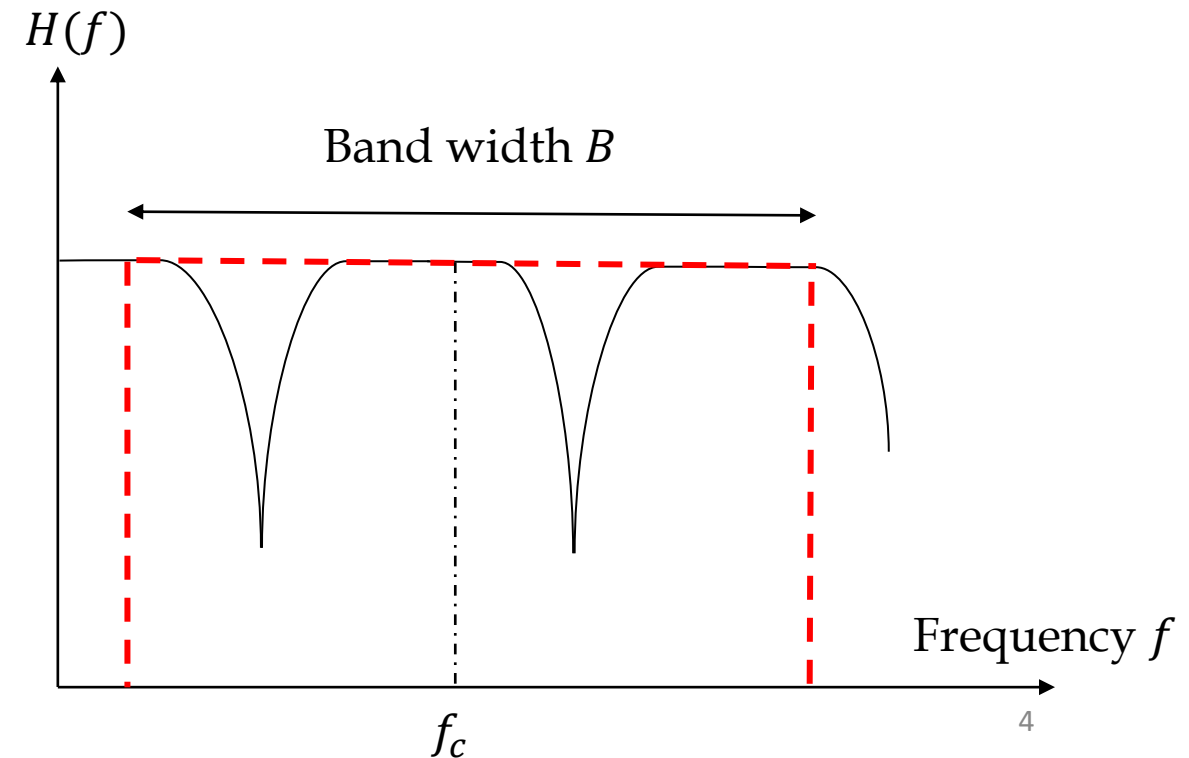
Flat fading

- Occurs when the signal's bandwidth is **narrow** enough that all frequencies experience roughly the same channel
- Multiple path signals experiences the same fading level

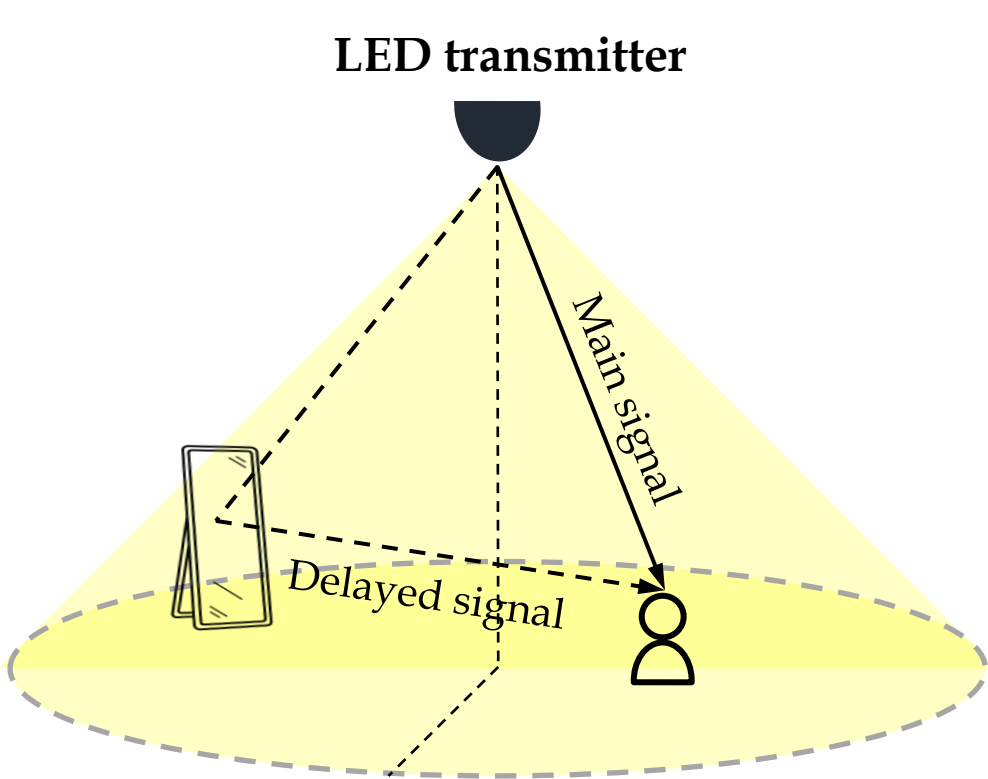


Frequency selective fading

- Occurs when the signal's bandwidth is **large** and spans a wide frequency range
- Multiple path signals experience different fading levels



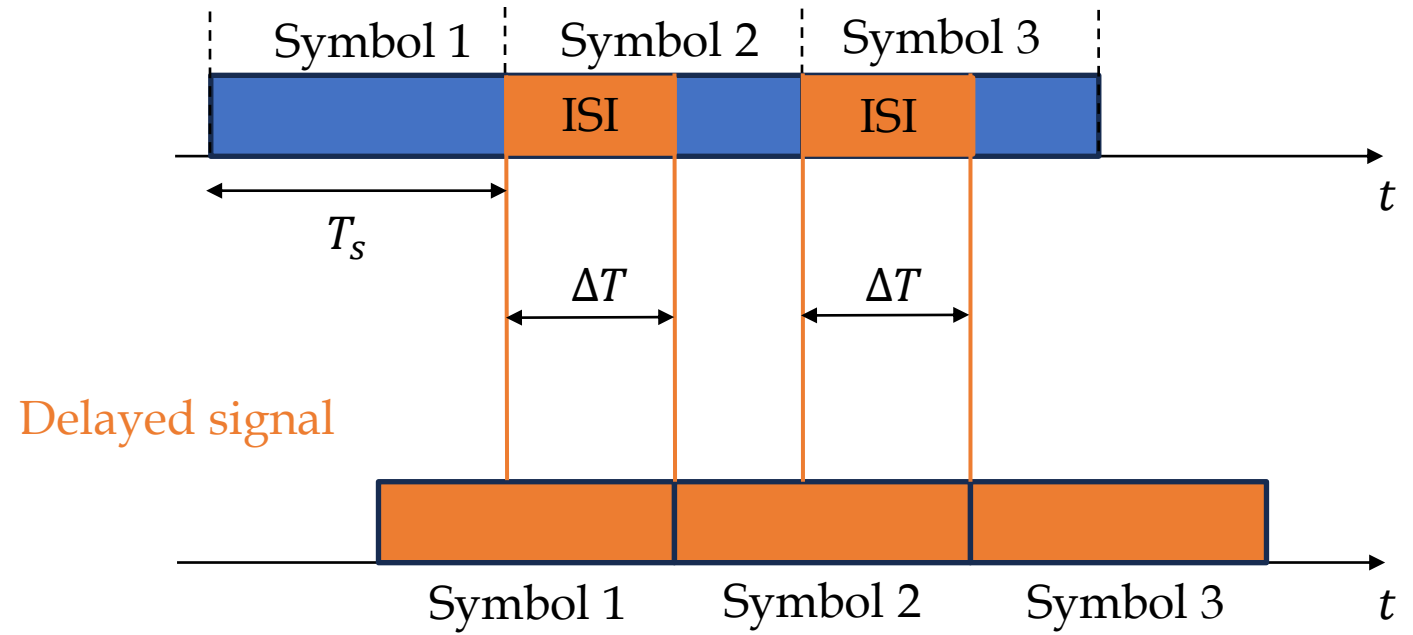
OFDM basic idea



Main signal

ΔT : Delay spread

T_s : Symbol duration



- Due to the multipath components arriving at different time (because of **frequency selective fading**), the symbols are overlapping and leads to **Inter Symbol Interference (ISI)**
- The effect ISI depends on the relationship between the delay spread and the symbol duration:

$\Delta T \approx T_s$: More severe

$\Delta T \ll T_s$: Less severe

OFDM basic idea

Single carrier transmission

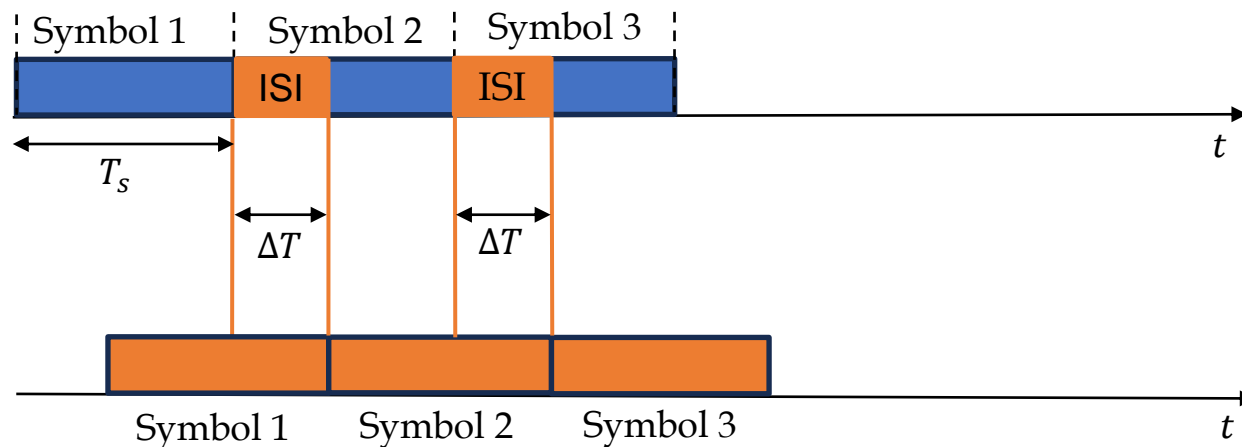
Bandwidth B

Single carrier

Frequency f

ΔT : Delay spread
 $T_s = \frac{1}{B}$: Symbol duration

Main signal



Delayed signal

$\Delta T \approx T_s$: More severe ISI

Multiple sub-carriers transmission

Bandwidth B

SC 1

SC 2

SC 3

...

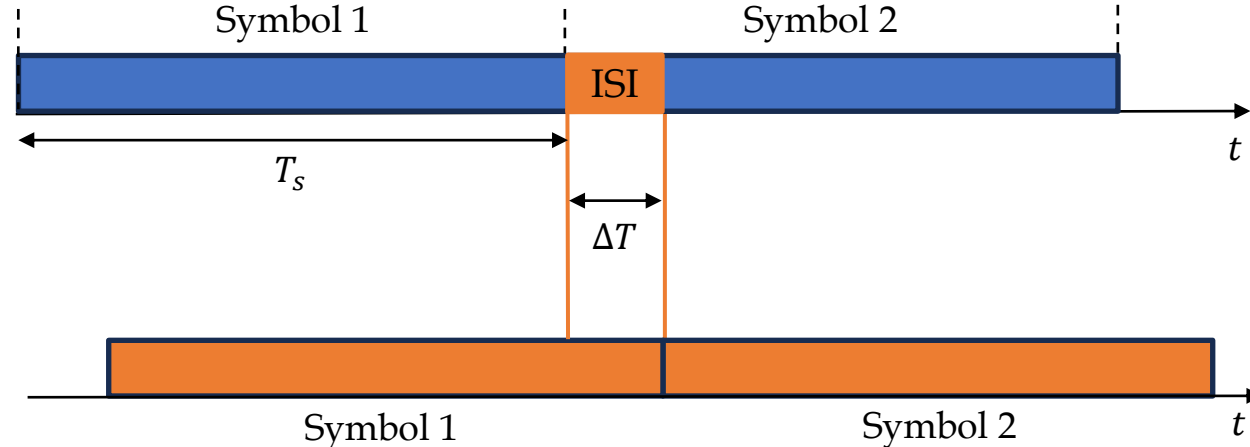
SC N-1

SC N

Frequency f

ΔT : Delay spread
 $T_s = \frac{N}{B}$: Symbol duration

SC 1 main signal



SC 1 Delayed signal

$\Delta T \ll T_s$: Less severe ISI

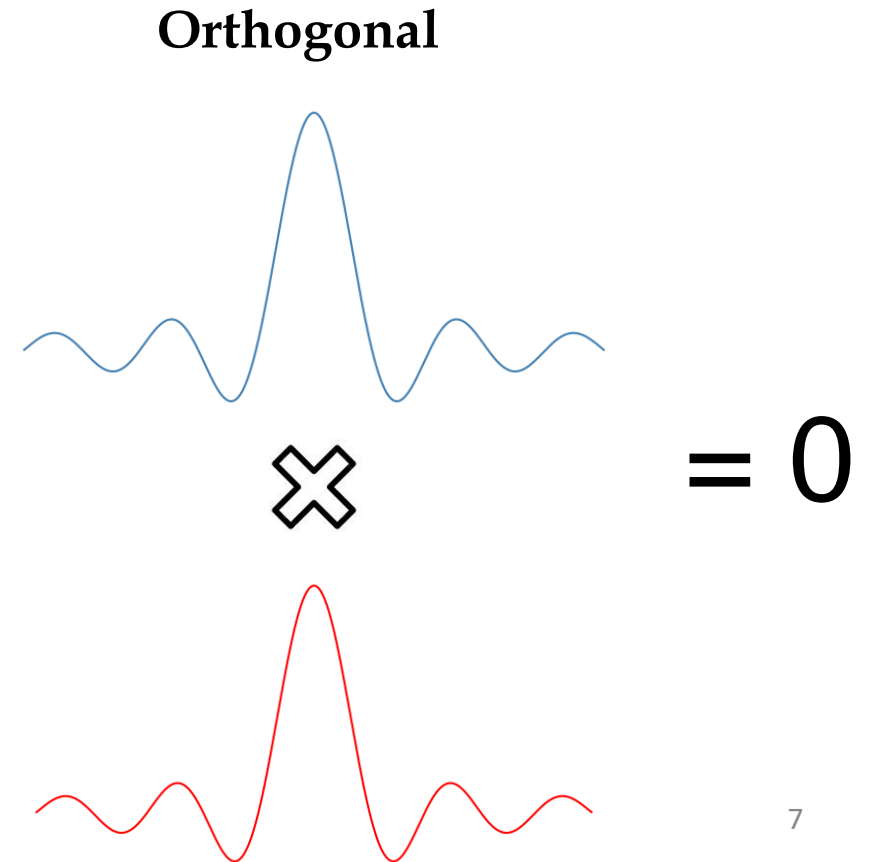
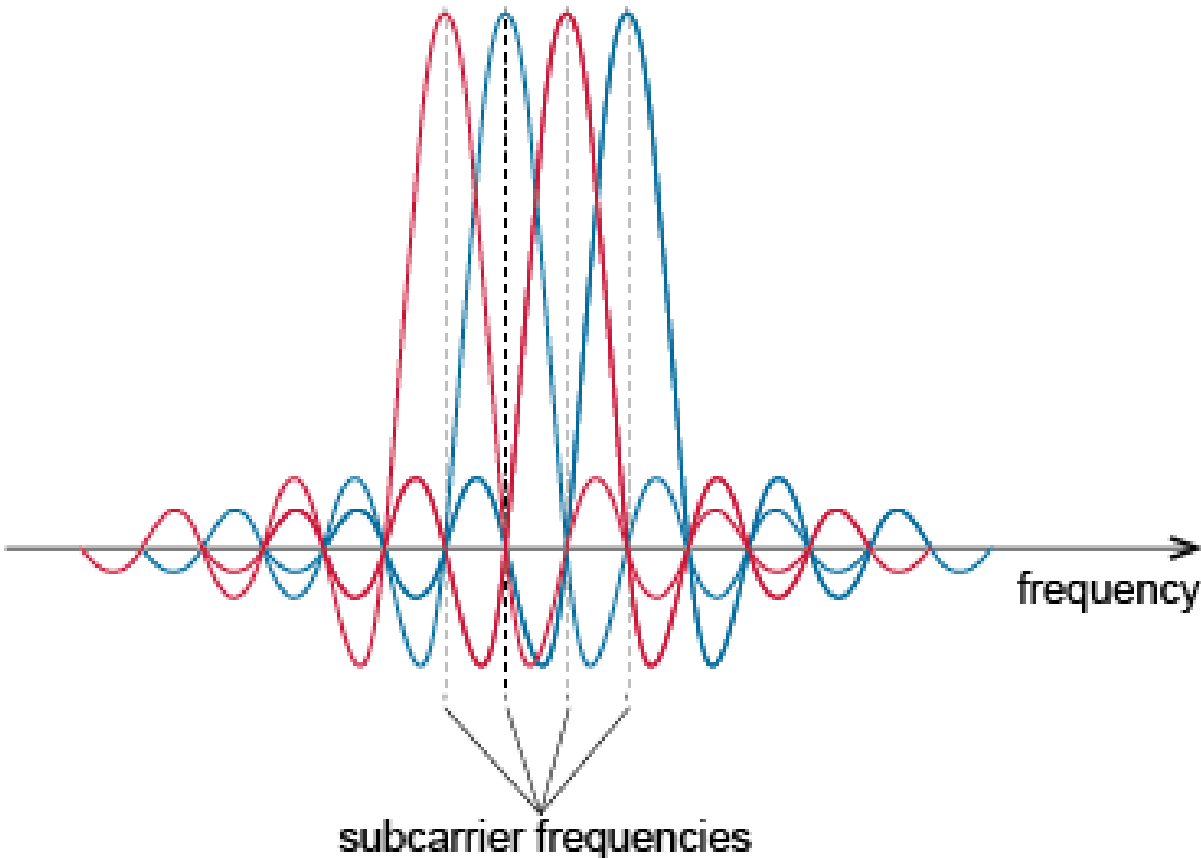
→ Frequency division multiplexing (FDM)

OFDM basic idea

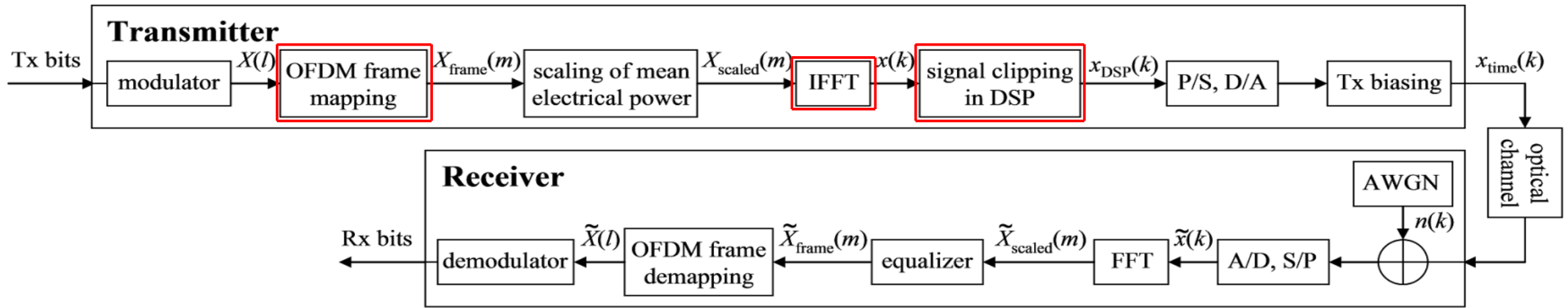
$$\text{OFDM} = \text{O} + \text{FDM}$$

- FDM can deal with delay spread and ISI, but the subcarriers can interfere to others and cause **Inter Carrier Interference (ICI)**

→ Design the subcarriers **orthogonal (O)** to each other, which allows them to occupy the same bandwidth without any interference



OFDM-VLC



- OFDM frame mapping:
 - Form an OFDM frame from the transmitted complex QAM symbol
 - Impose Hermitian symmetry to ensure a real-valued time domain signal $x(k)$ (different to RF transmission)
- IFFT:
 - Convert the frequency-domain data into a time-domain signal that can be transmitted over the communication channel.
 - Maintains the orthogonality of subcarriers
- Signal clipping in DSP:
 - Guarantee normal operation of the LEDs

OFDM-VLC

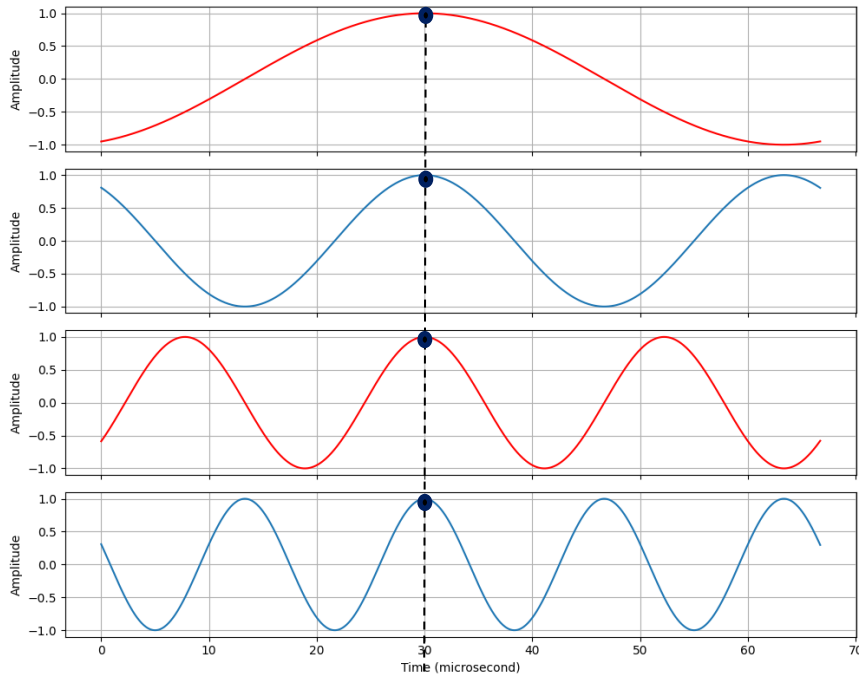
Advantage

- Resilience to Frequency Selective Fading
- Mitigation of Inter-symbol Interference (ISI)
- Offer high data rate transmission
- Adaptive Modulation and Coding
- Efficient Spectrum Utilization
- Multiple access capability (OFDMA)

Issue

- Implementation complexity
- Complex synchronization requirements
- **High peak-to-average power ratio (PAPR)**

PAPR problem



Subcarrier 1 (symbol C_1)

+

Subcarrier 2 (symbol C_2)

+

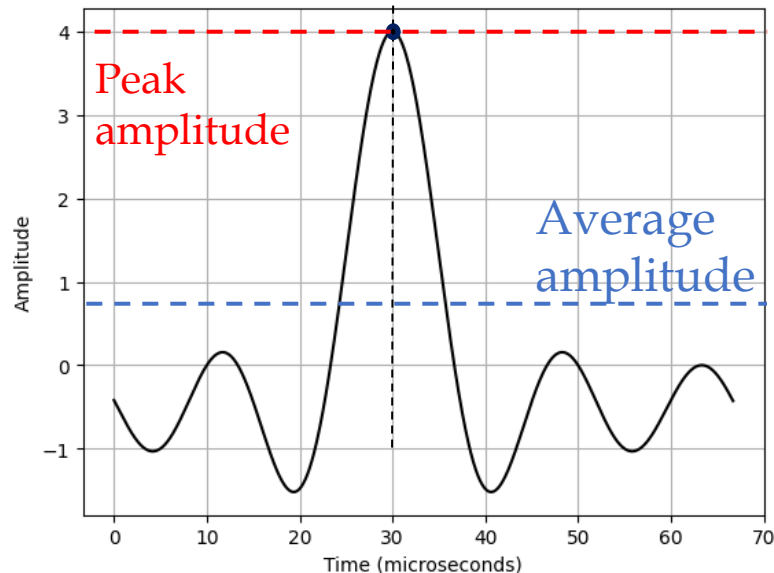
Subcarrier 3 (symbol C_3)

+

Subcarrier 4 (symbol C_4)



Transmitted signal in time domain



- By using IFFT, the transmitted signal in time domain is the **sum** of waveform from N subcarriers
- At a **particular time**, there would be a **peak amplitude** in each of these subcarrier waveforms and add up to a **very big amplitude** in transmitted signal waveform
- A high peak to average power ratio (PAPR) can appear

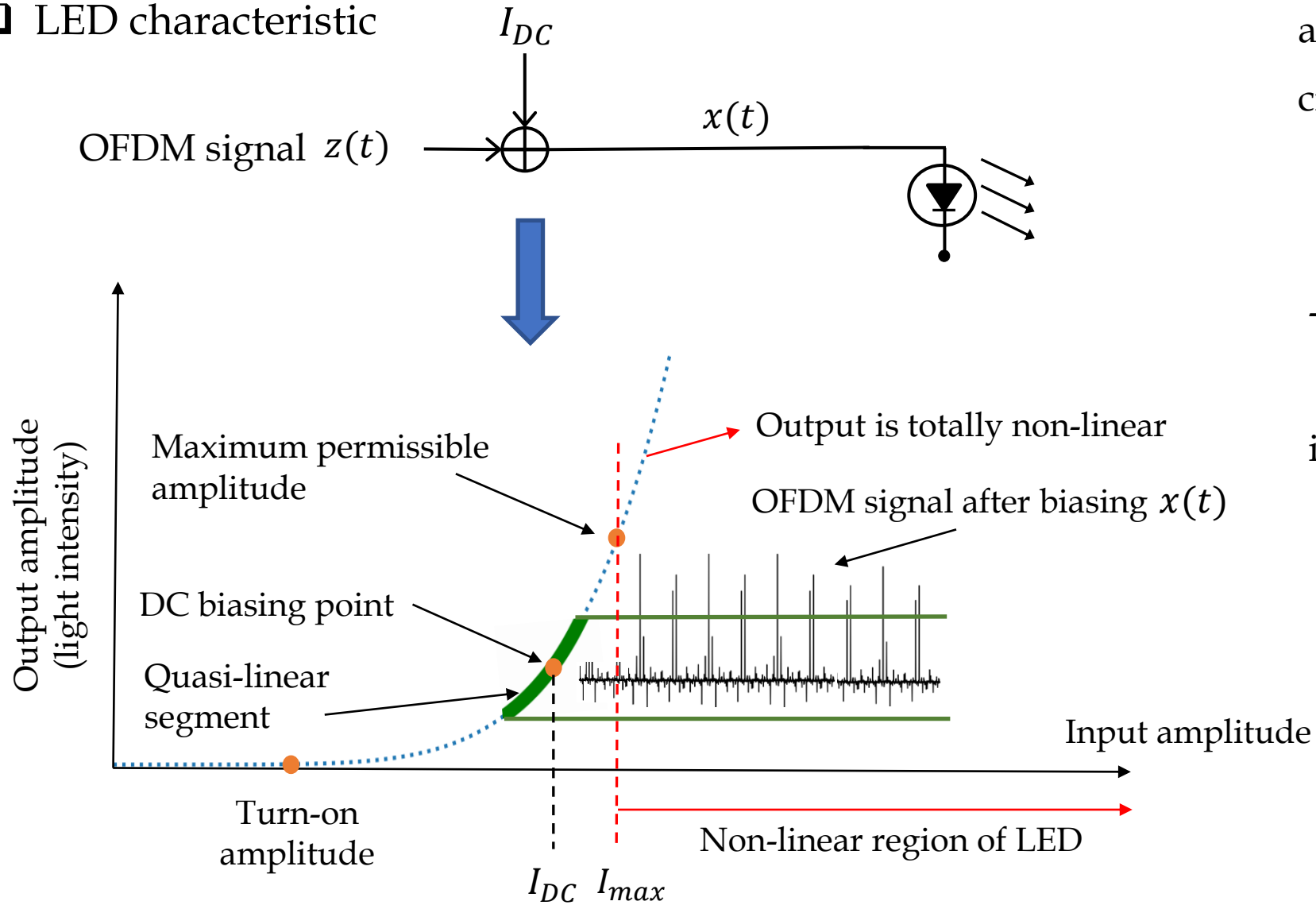
$$PAPR = \frac{P_{peak}}{P_{average}}$$

- The PAPR rises with the number of subcarriers N

PAPR problem

What is the effect of high PAPR in OFDM-VLC system ?

❑ LED characteristic



- Due to high PAPR. the peak amplitude of $x(t)$ is very high and it cross over non-linear region.

- The output OFDM signal $x(t)$ is distorted and the orthogonality is lost

Severe ISI and high BER

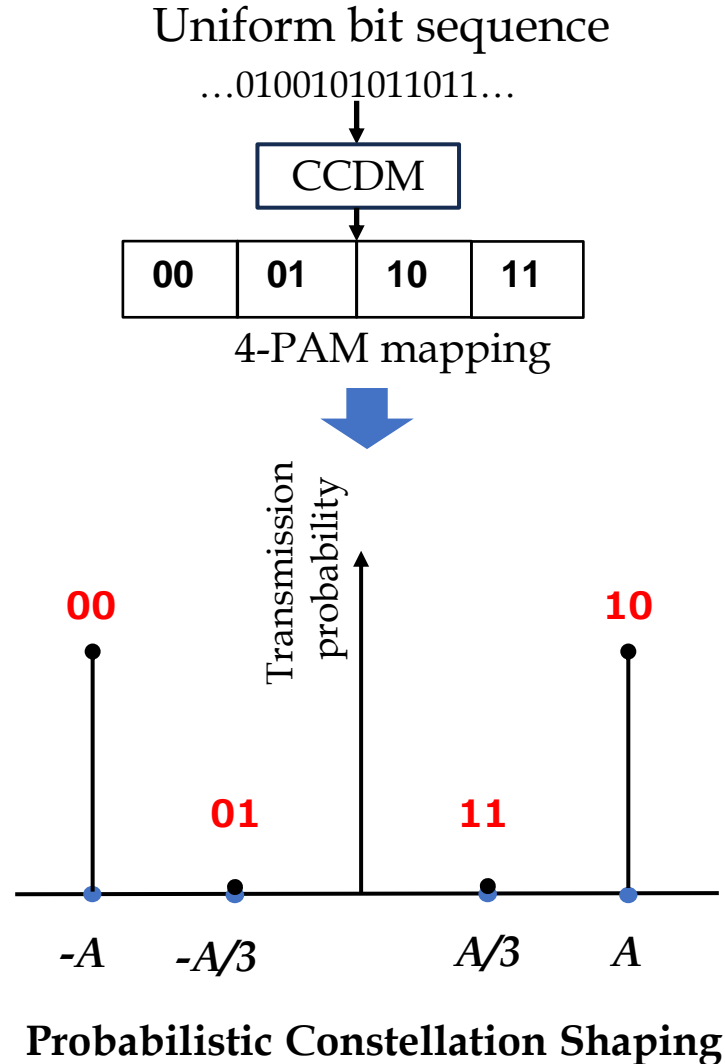
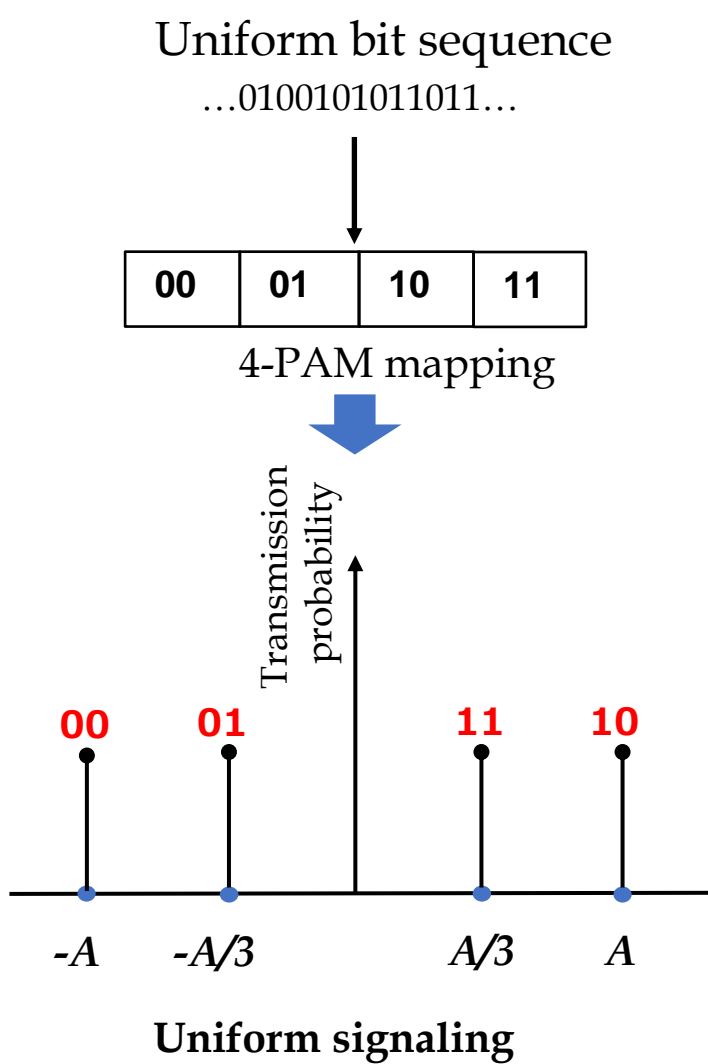
PAPR problem

How to reduce PAPR in OFDM-VLC system ?

Clipping signal	Selective mapping	Geometric constellation shaping
<ul style="list-style-type: none">• Limits the peak amplitude of the OFDM signal to a predetermined threshold• Pros: Simple and effective• Cons: Introduce signal distortion and BER	<ul style="list-style-type: none">• Generates multiple OFDM signals with different phase sequences and selects the one with the lowest PAPR• Pros: Simple and without significant signal distortion• Cons: Increase computational complexity and require the transmission of side information.	<ul style="list-style-type: none">• Adjust the constellation point positions to reduce the probability of high peaks occurrence• Pros: Without significant signal distortion.• Cons: Increase complexity of receiver block, require the transmission of side information and increase BER

Draft idea

How to reduce PAPR in OFDM-VLC system ? \longrightarrow Probabilistic constellation shaping



- **Design the occurrence of constellation points** to reduce the PAPR
- **Pros:**
 - Simple implementation
 - Not introduce signal distortion
 - Probably reduce BER
- **Cons:**
 - Require transmission of side information



Thank you for listening!

Q & A