Orthogonal Frequency Division Multiplexing (OFDM): Concept and System-Modeling

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VL: Mobile Radio Systems, Ch. 5: "Wideband Systems"
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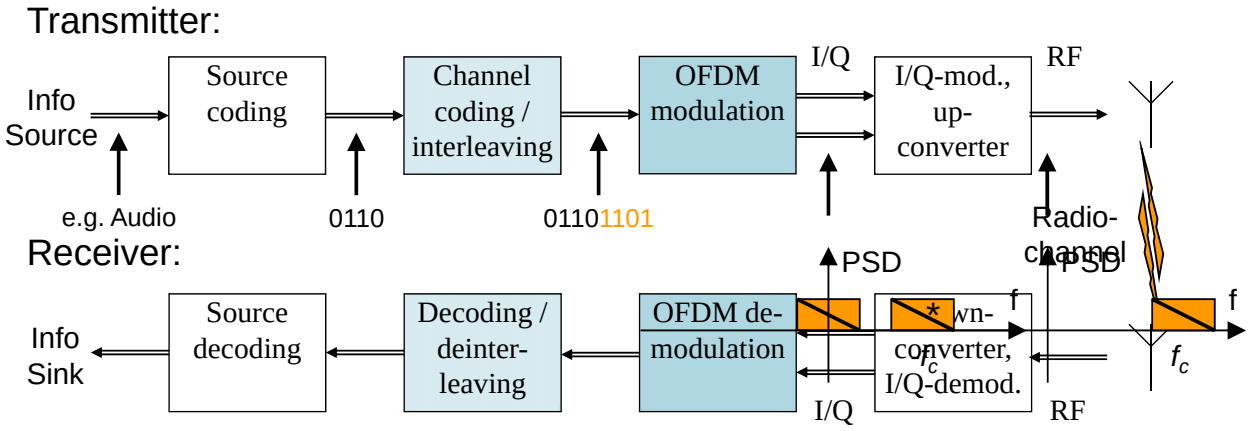
Outline

- Introduction
  - What is OFDM?
  - Multipath fading radio-channel
- Principle of OFDM
- OFDM Implementation and System Model
- Advantages and Disadvantages
- OFDM in Practice
- Summary

What is OFDM?

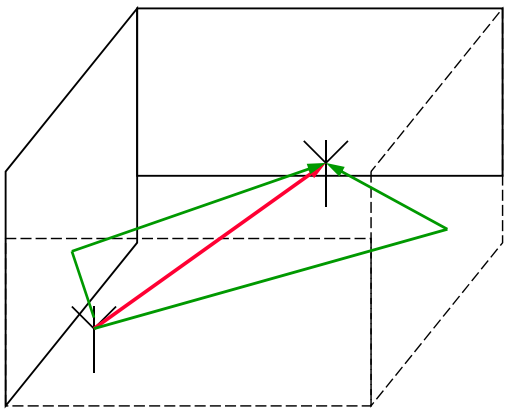
- Modulation technique
  - Requires channel coding
  - Solves multipath problems



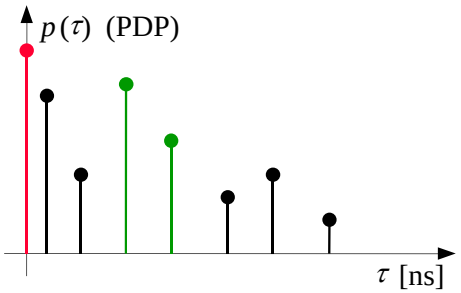
TUG

Multipath Propagation

- Reflections from walls, etc.

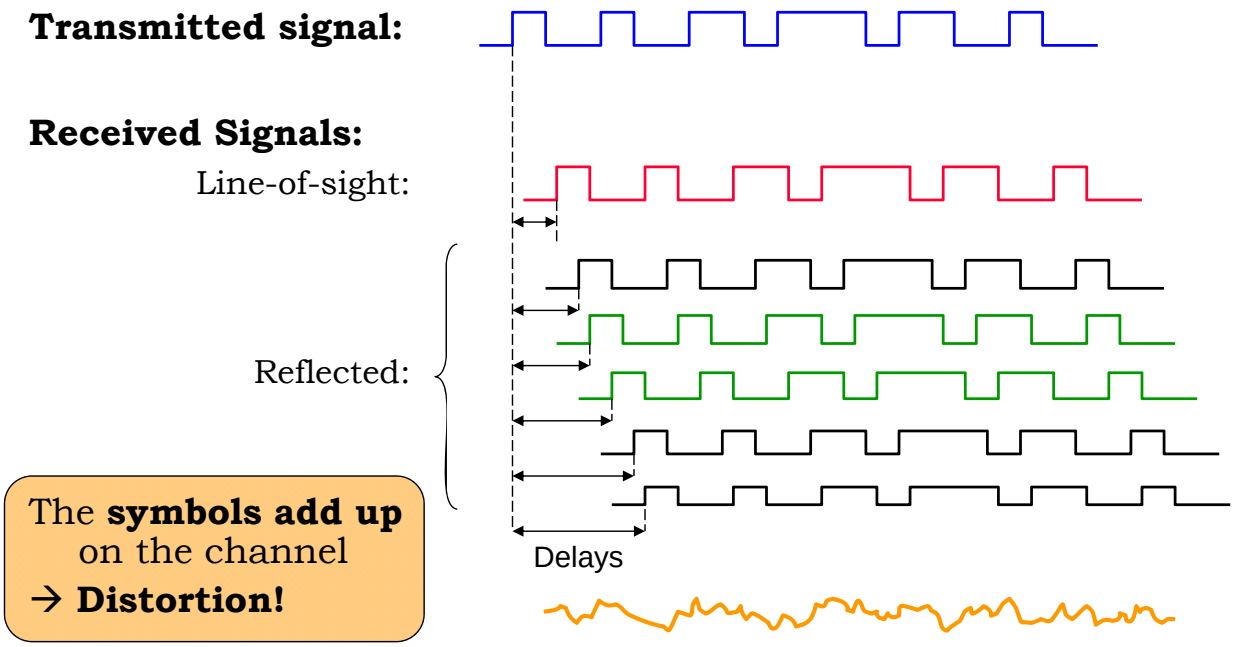


- Time dispersive channel
  - Impulse response:



- Problem with high rate data transmission:
  - inter-symbol-interference

Inter-Symbol-Interference



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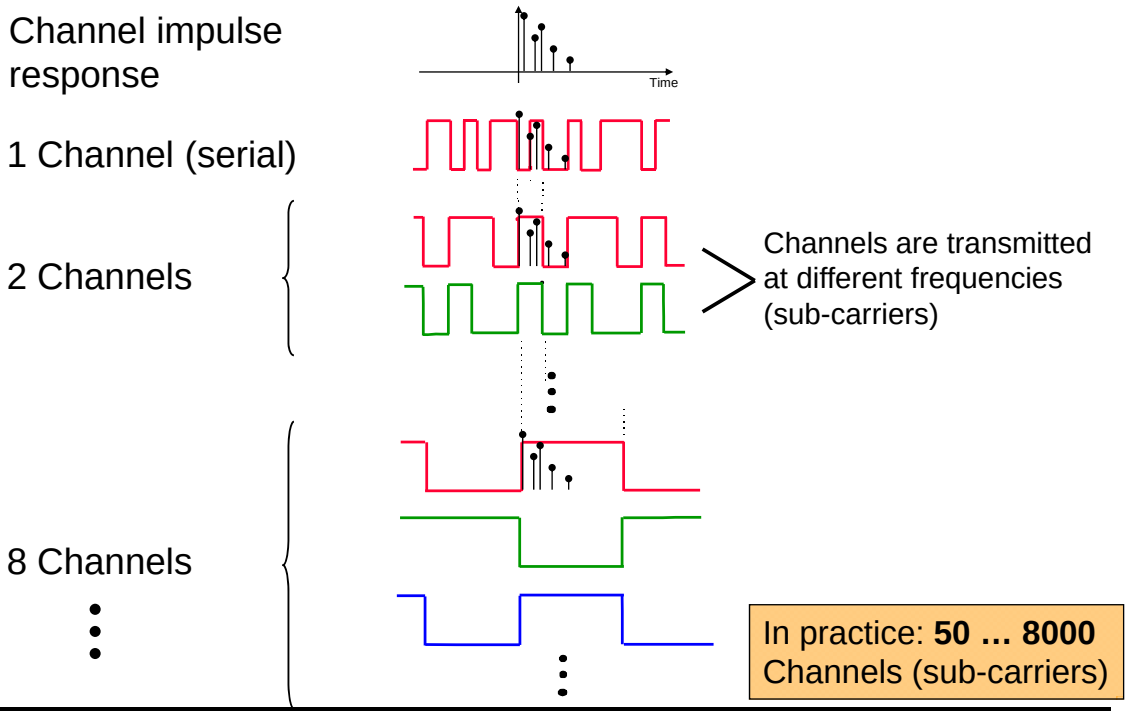
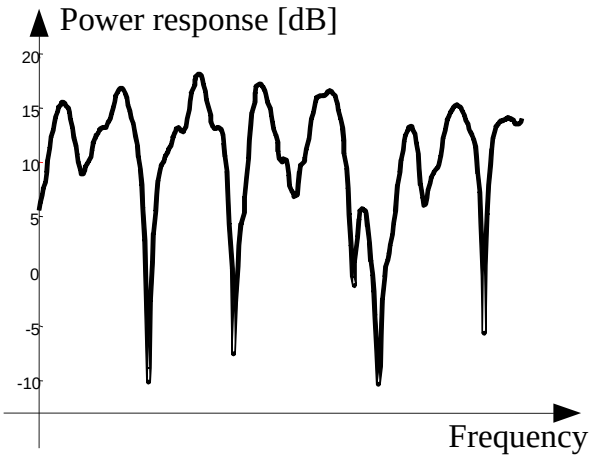
Concept of parallel transmission (1)

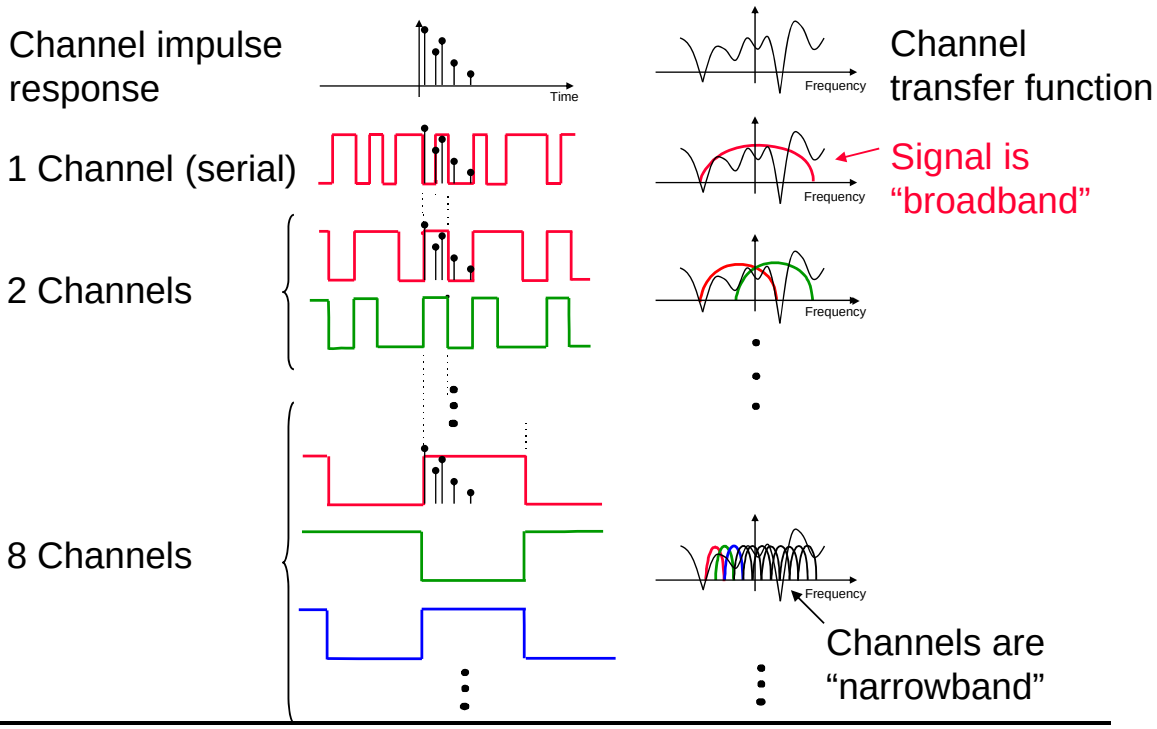


The Frequency-Selective Radio Channel

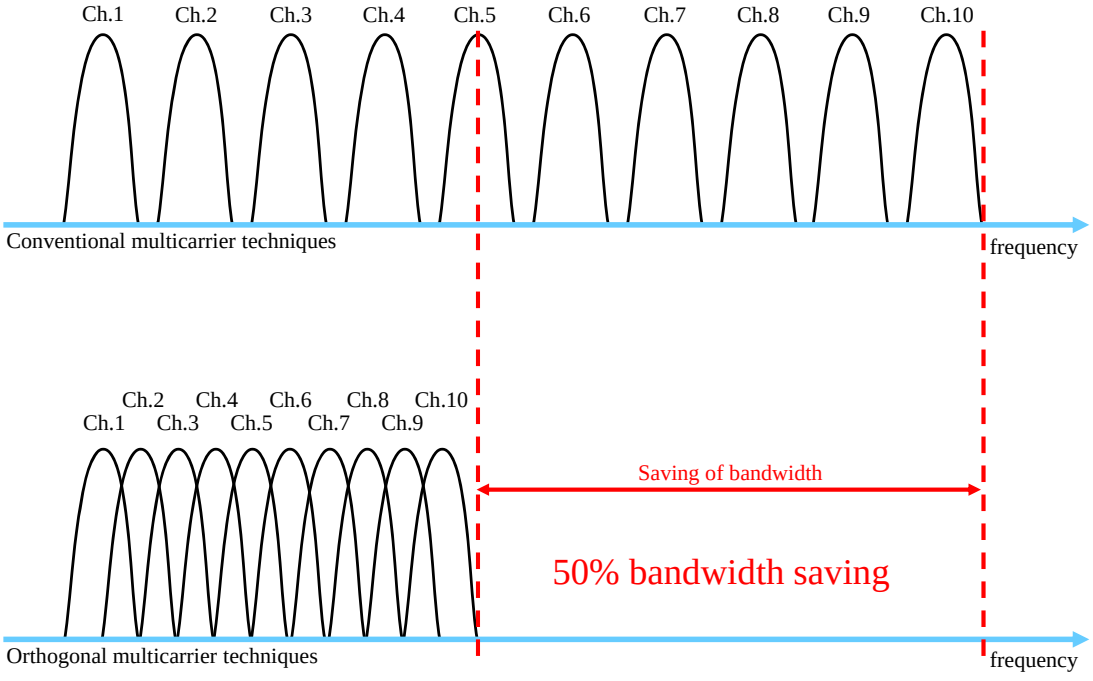


- Interference of reflected (and LOS) radio waves
  - Frequency-dependent fading

Concept of parallel transmission (2)



Concept of an OFDM signal



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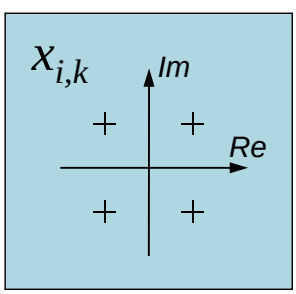
Generating the OFDM signal (1)

- Symbol (QPSK) of sub-carrier i at time k
  - Other symbol-alphabets can be used as well (BPSK, m-QAM)
- Baseband signal is generated by DSP

$$s_{BB,i,k}(t) = w(t - kT) \cdot x_{i,k} \cdot \exp\left[j 2\pi i \Delta f \, (t - kT)\right]$$

Window function

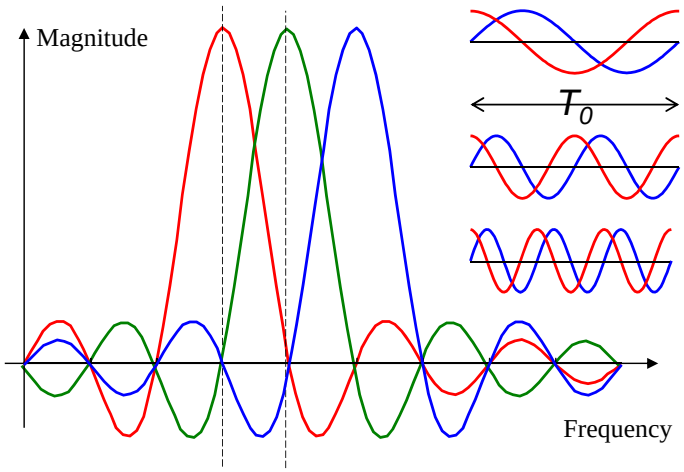
Sub-carrier



Spectrum of the modulated data symbols

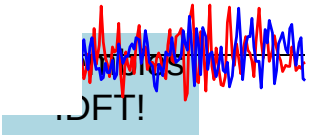
- Rectangular Window of duration T_0
- Has a sinc-spectrum with zeros at $1/T_0$

- Other carriers are put in these zeros
- → sub-carriers are orthogonal

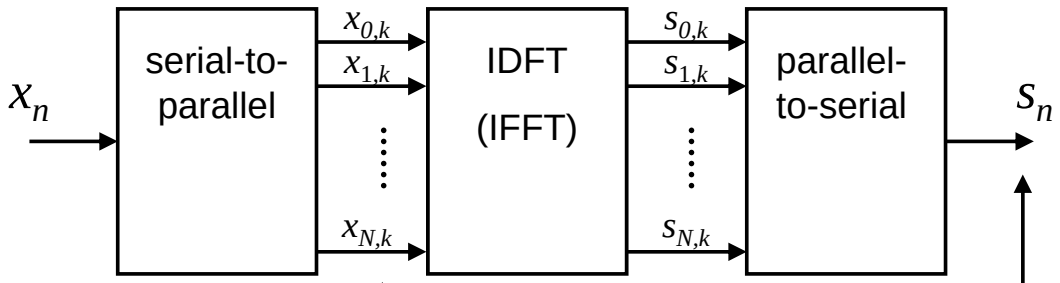


N sub-carriers:

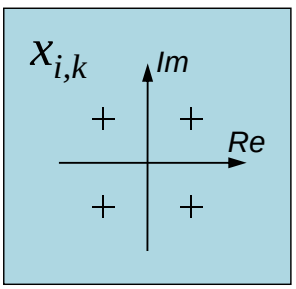
$$s_{BB,k}(t) = w(t-kT)\sum_{i=0}^{N-1} x_{i,k} e^{j2\pi i\Delta f (t-kT)}$$



Generating the OFDM signal (2)



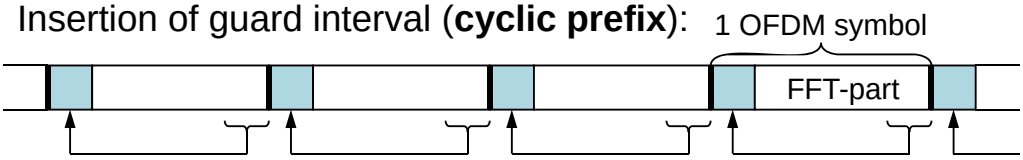
N data symbols:
(in frequency-domain)



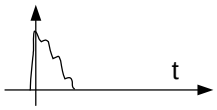
Base-band signal
(time-domain)

Idea of Guard Interval (GI)

Insertion of guard interval (**cyclic prefix**):

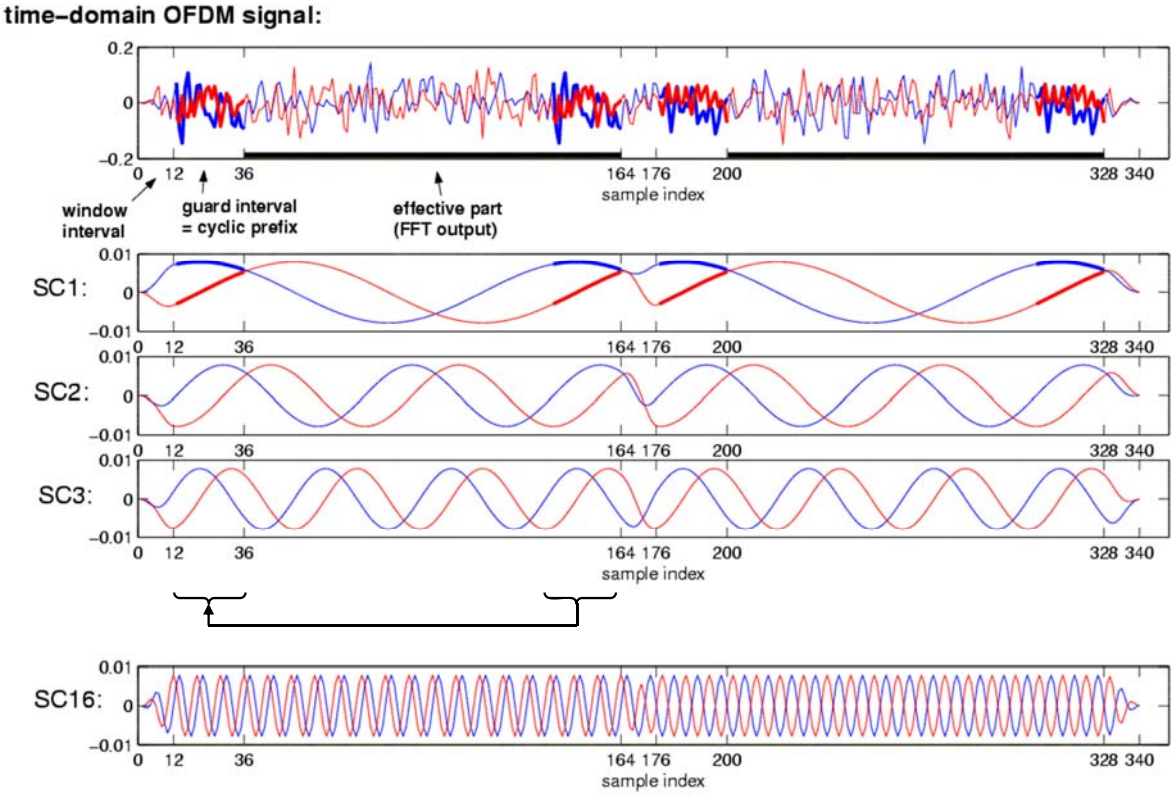


Channel impulse response (shorter than GI):



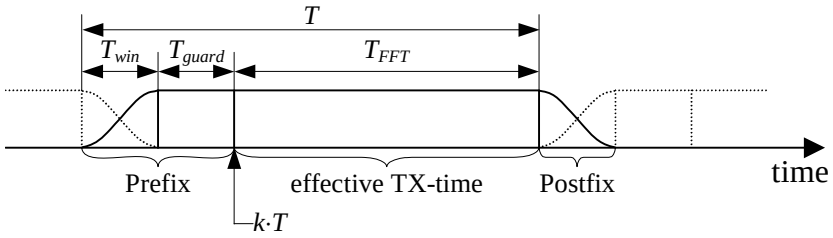
Cyclic convolution of transmitted signal with channel impulse response
→ **multiplication** in frequency-domain

Guard interval (2) - Cyclic extension

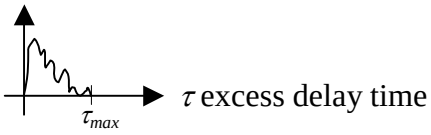


OFDM Symbol Configuration (1)

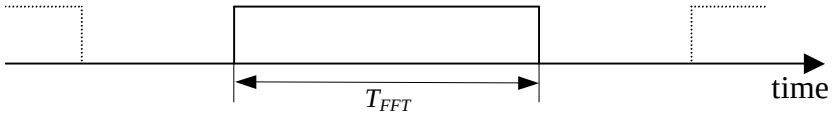
Transmitter pulse prototype $w(t)$



Channel impulse response

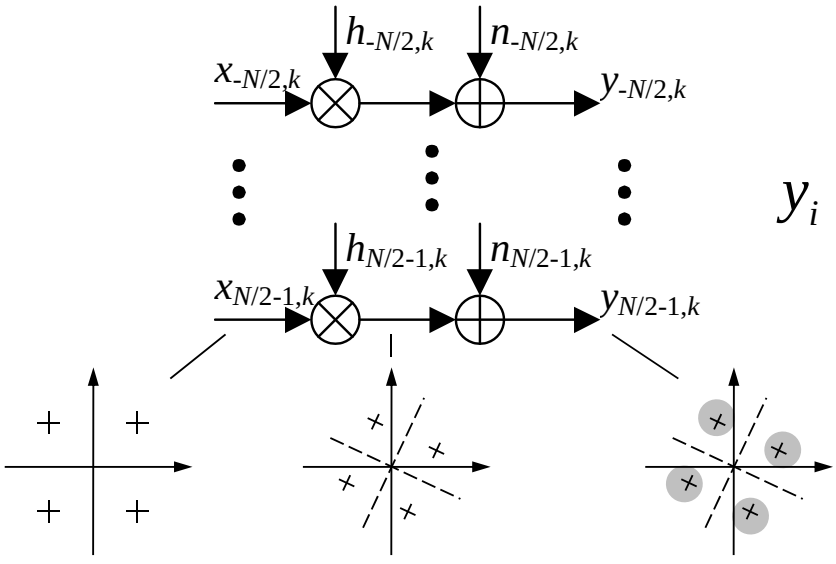


Receiver filter (implemented by FFT)



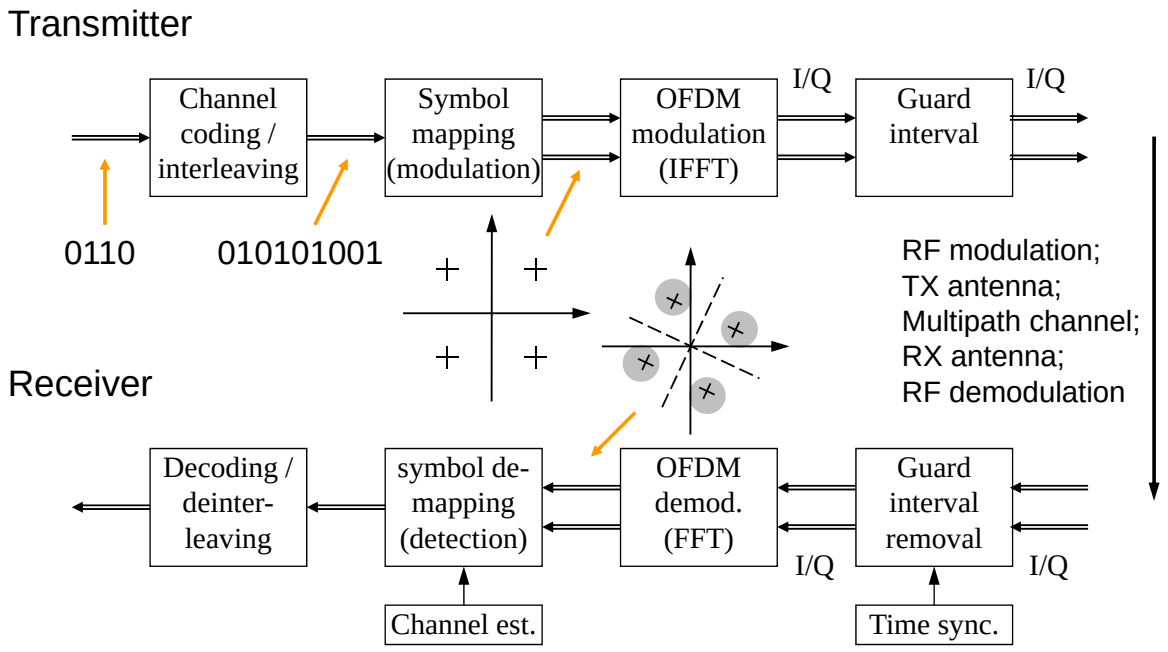
OFDM System Model

- Multiplication of data symbols with (complex-valued) channel transfer-function:



$$y_i = x_i h_i + n_i$$

OFDM Block Diagram



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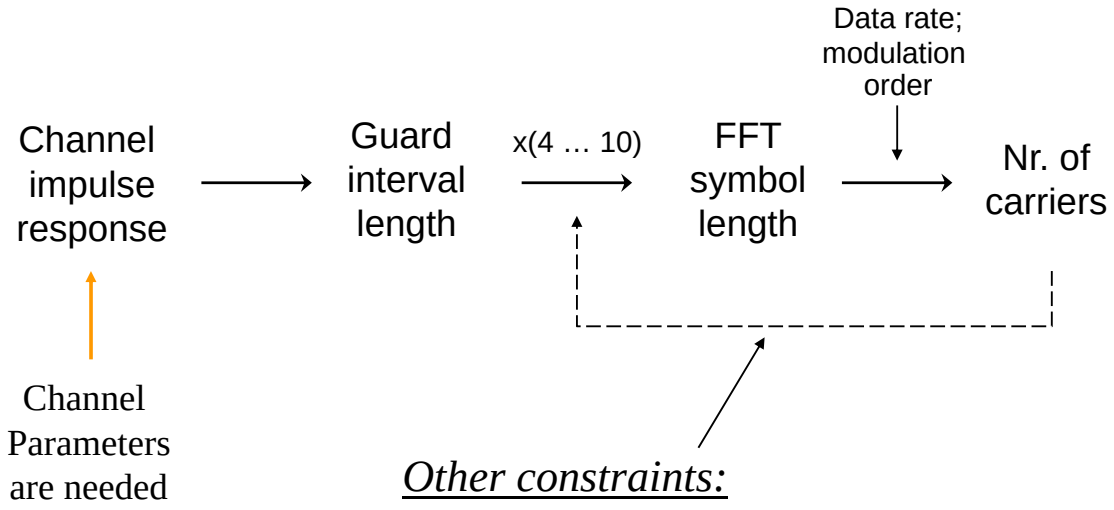
- Principle of OFDM
- OFDM Implementation and System Model
- Advantages and Disadvantages
- **OFDM System Design**
  - **Parameter selection**
  - **Implementation Issues**
- Summary and Applications

Design of an OFDM System

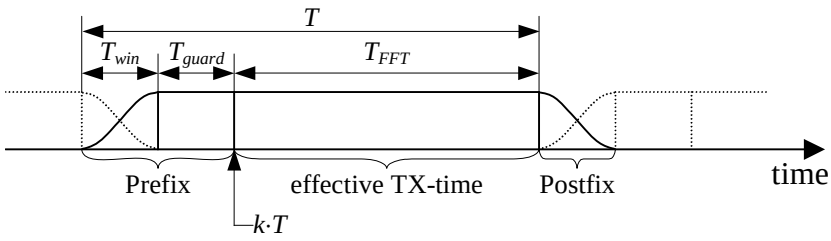


Other constraints:

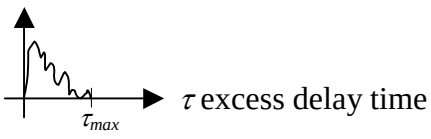
- Nr. of carriers should match FFT size and data packet length
- considering coding and modulation schemes

OFDM Symbol Configuration (1)

Transmitter pulse prototype $w(t)$

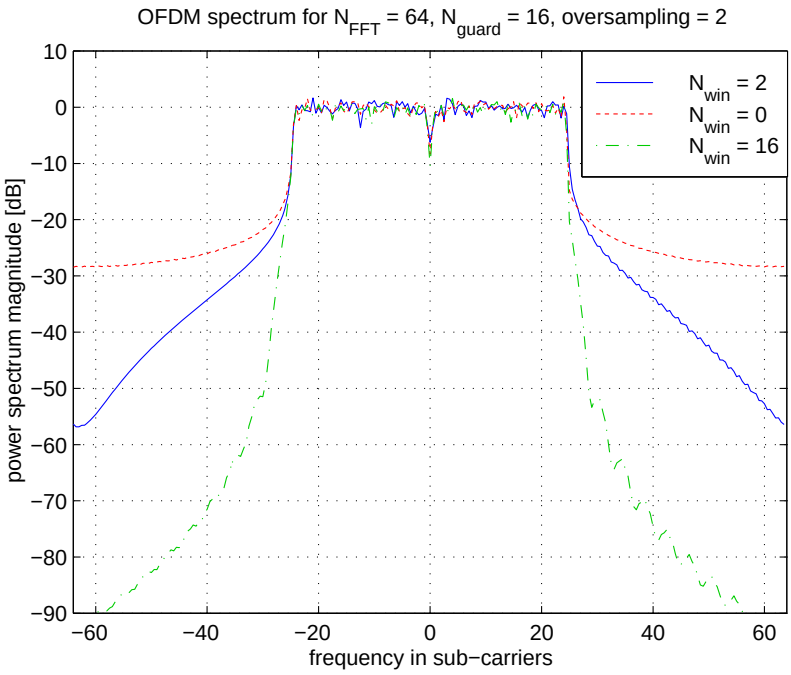


Channel impulse response



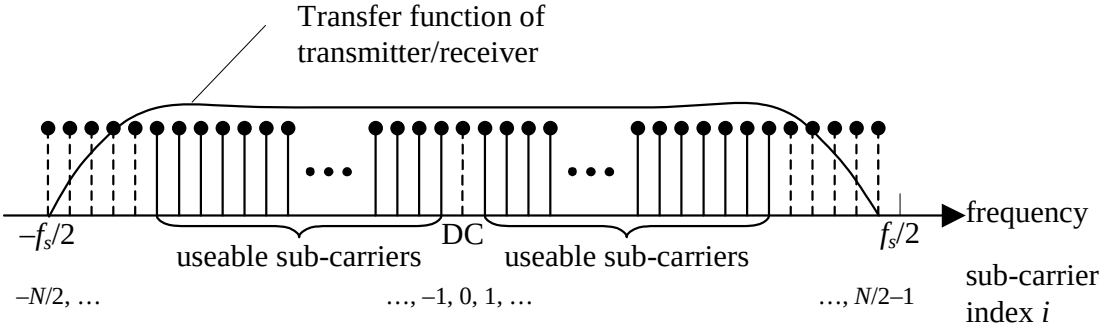
Receiver filter (implemented by FFT)

Spectral Shaping by Windowing



OFDM Symbol Configuration (2)

- Not all FFT-points can be used for data carriers
  - Lowpass filters for AD- and DA-conversion
    - oversampling required
  - DC offsets; carrier feedtrough; etc.



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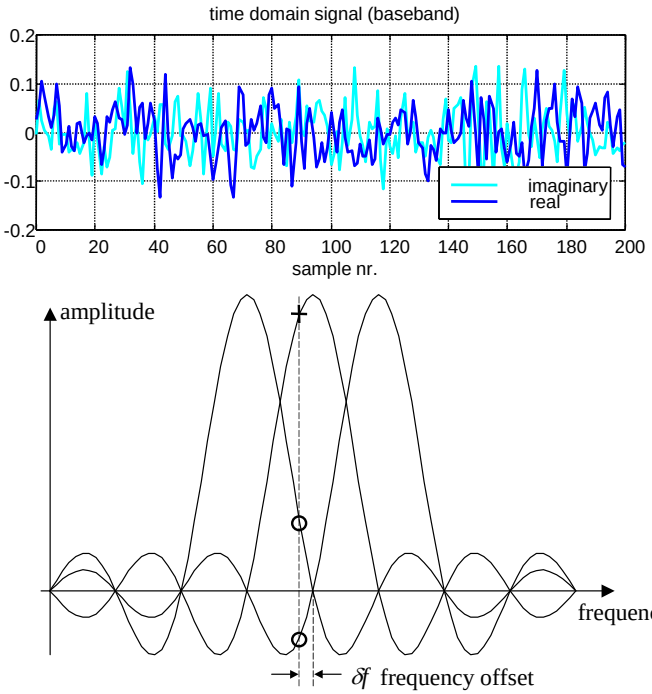
Advantages of OFDM

- Solves the multipath-propagation problem
  - Simple equalization at receiver
- Computationally efficient
  - For broadband systems more efficient than SC
- Supports several multiple access schemes
  - TDMA, FDMA, MC-CDMA, etc.
- Supports various modulation schemes
  - Adaptability to SNR of sub-carriers is possible
- Elegant framework for MIMO-systems
  - Any interference among symbols is removed

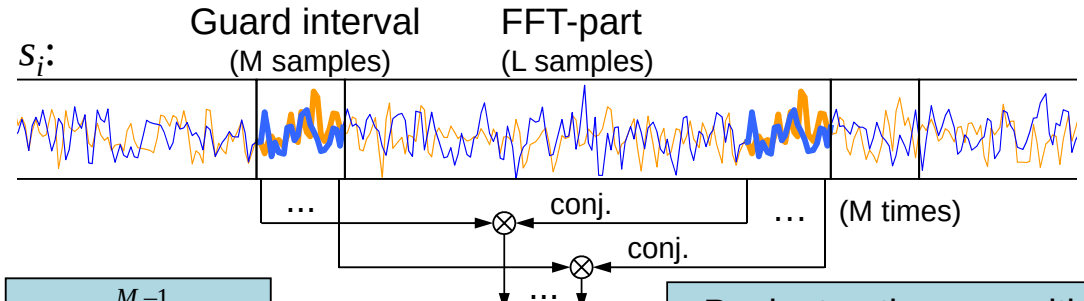
Problems of OFDM (Research Topics)

- Synchronization issues:
  - **Time synchronization**
    - Find start of symbols
  - **Frequency synchr.**
    - Find sub-carrier positions
- Non-constant power envelope
  - Linear amplifiers needed
- Channel estimation:
  - To retrieve data
  - **Channel** is **time-variant**



Correlation-based Frequency-sync.

- Correlation of duplicated parts of OFDM signal
  - e.g.: Cyclic prefix (Guard interval - GI):



$$P_{opt} = \sum_{i=0}^{M-1} r_i^* r_{i+L}$$

- Peak at optimum position
- Phase ∝ frequency-offset

- Received signal with f-offset: $r_i = s_i \exp(j2\pi \delta f\, i / N)$
  - Constant phase offset between samples spaced by L

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Applications of OFDM

- **Wireless LAN**
  - IEEE802.11a/g
  - HYPERLAN
- DAB, DVB, etc.
  - Digital Audio/Video **Broadcasting**
- xDSL (**Digital Subscriber Line**)
  - uses Discrete Multitone (DMT)

Summary – Essential "Ingredients"

- IFFT & FFT
  - For efficient implementation
- Guard interval insertion
  - Obtaining simple equalization
  - Removing all IS- & IC-interferences
- Error correction coding
  - To restore bits that are lost on weak sub-carriers