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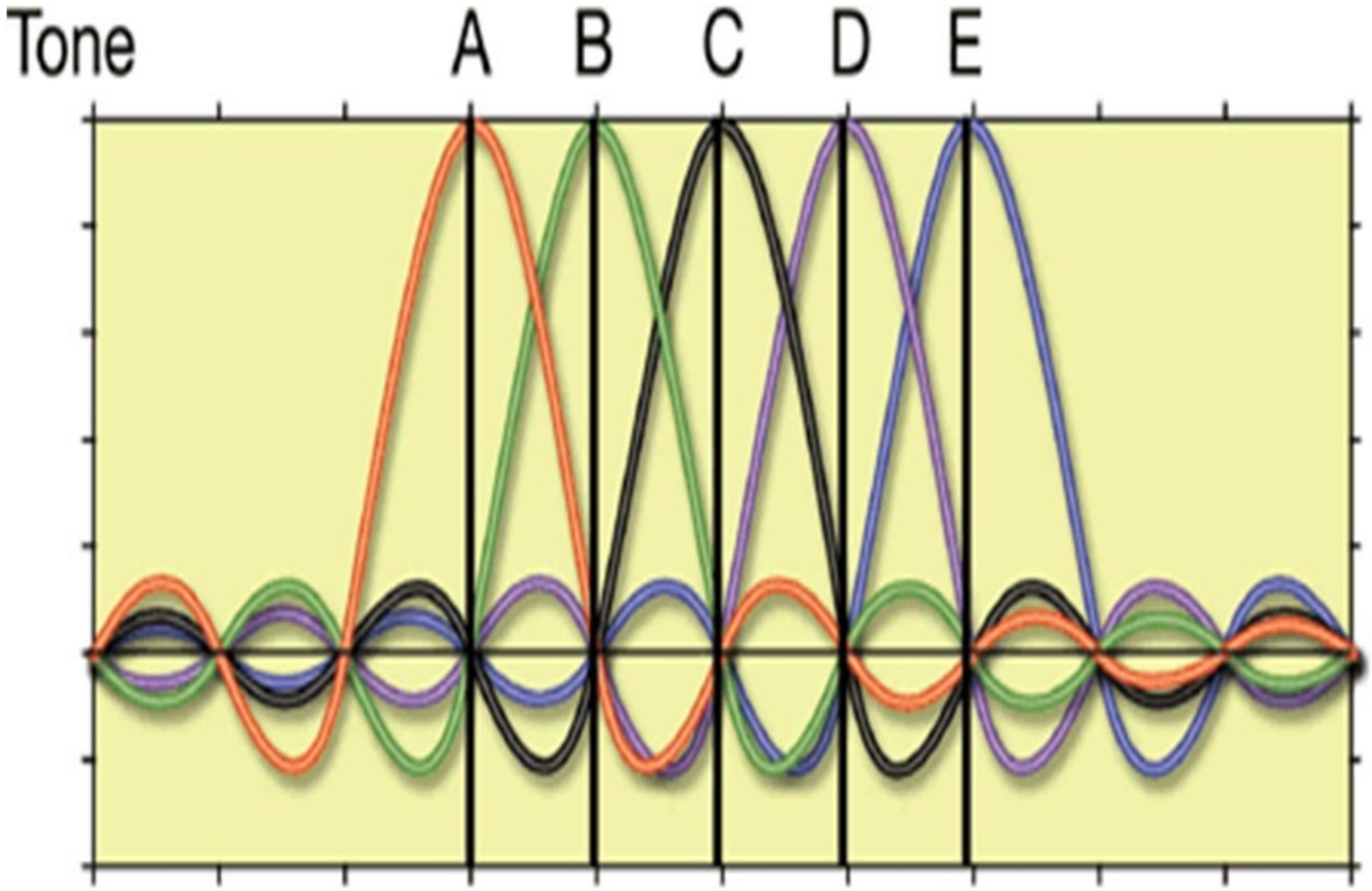
UESTC4004
Digital Communications

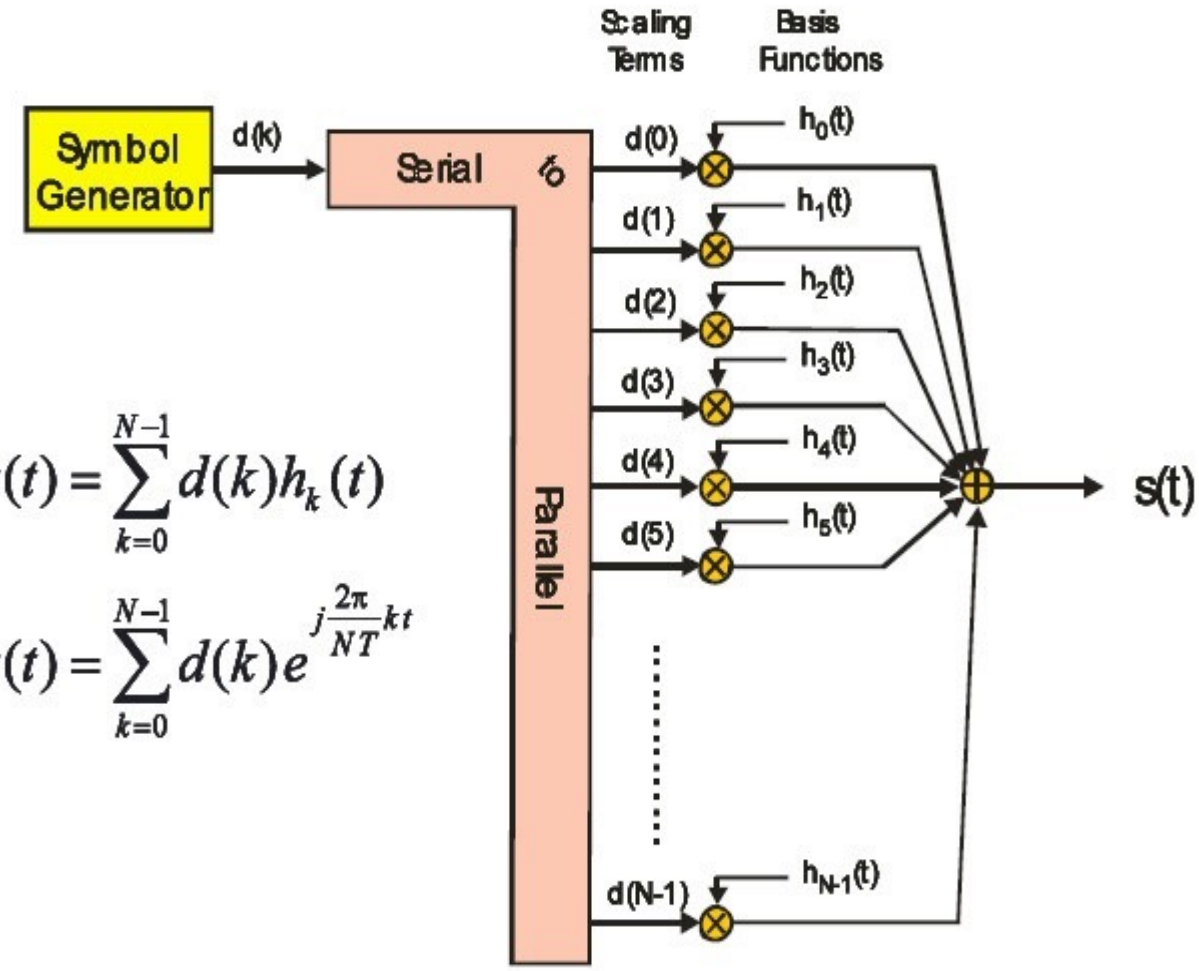
Orthogonal Frequency Division Multiplexing (OFDM)

Disclaimer: Parts of the slide material is taken from external resources



OFDM Spectrum

OFDM Modulator



$$s(t) = \sum_{k=0}^{N-1} d(k) h_k(t)$$

$$s(t) = \sum_{k=0}^{N-1} d(k) e^{j\frac{2\pi}{NT}kt}$$

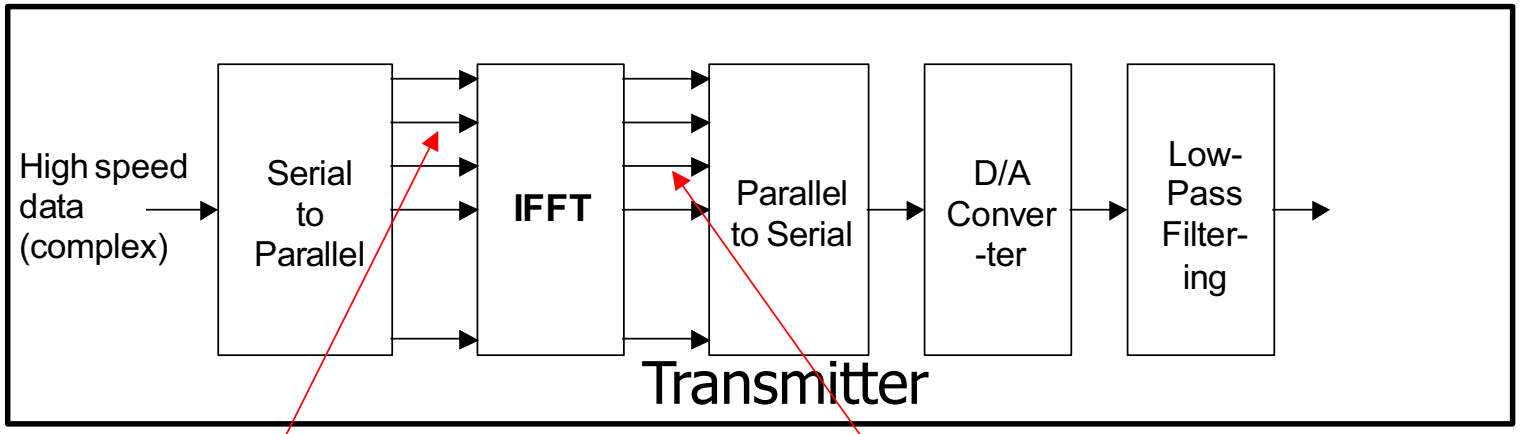
How are OFDM signals generated?

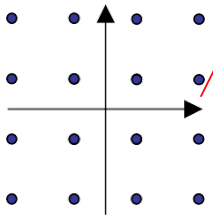
Typical IFFT Output Samples

Signal values at the output of the IFFT are the sum of many samples of many sinusoids - looks random

- Parallel data streams are used as inputs to an IFFT
- IFFT output is sum of signal samples
- IFFT does modulation and multiplexing in one step
- Filtering and D/A of samples results in baseband signal

Signals at Input and Output of Transmitter IFFT





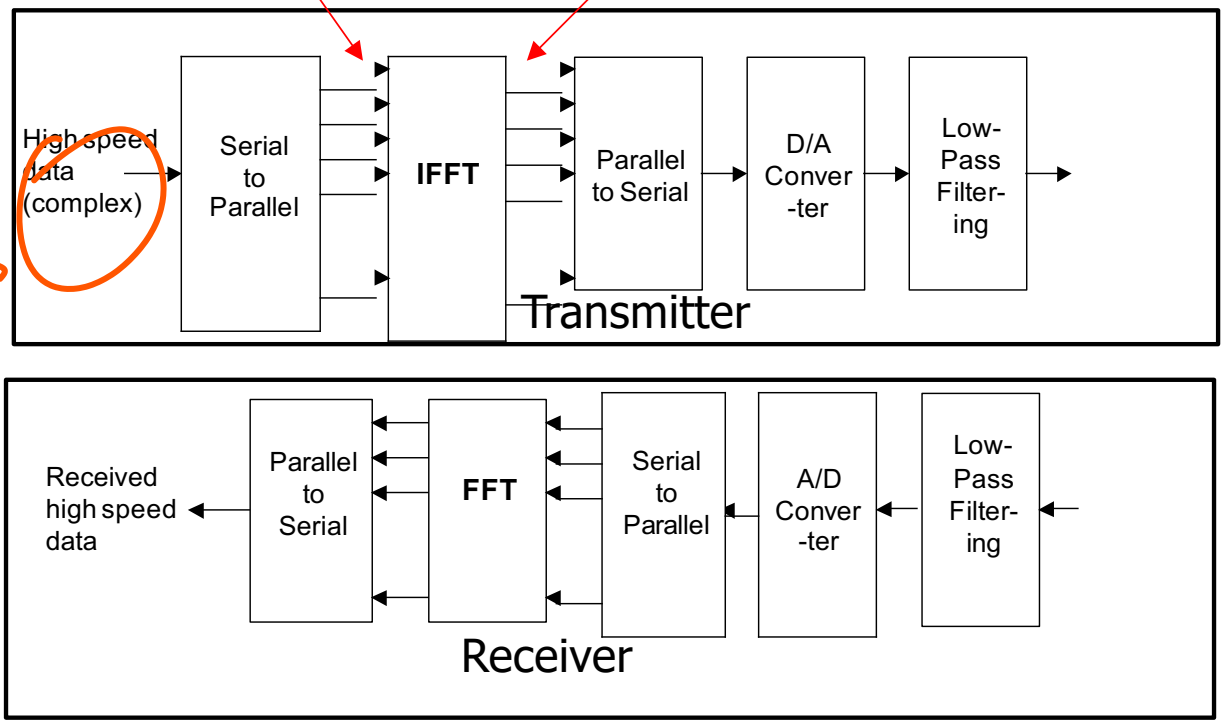
Complex value representing data is input to IFFT

IFFT output gives samples of modulated multiplexed signal

Baseband OFDM system

Discrete frequency domain
Each input controls signal at one frequency

Discrete Time Domain
Samples of modulated and multiplexed signals



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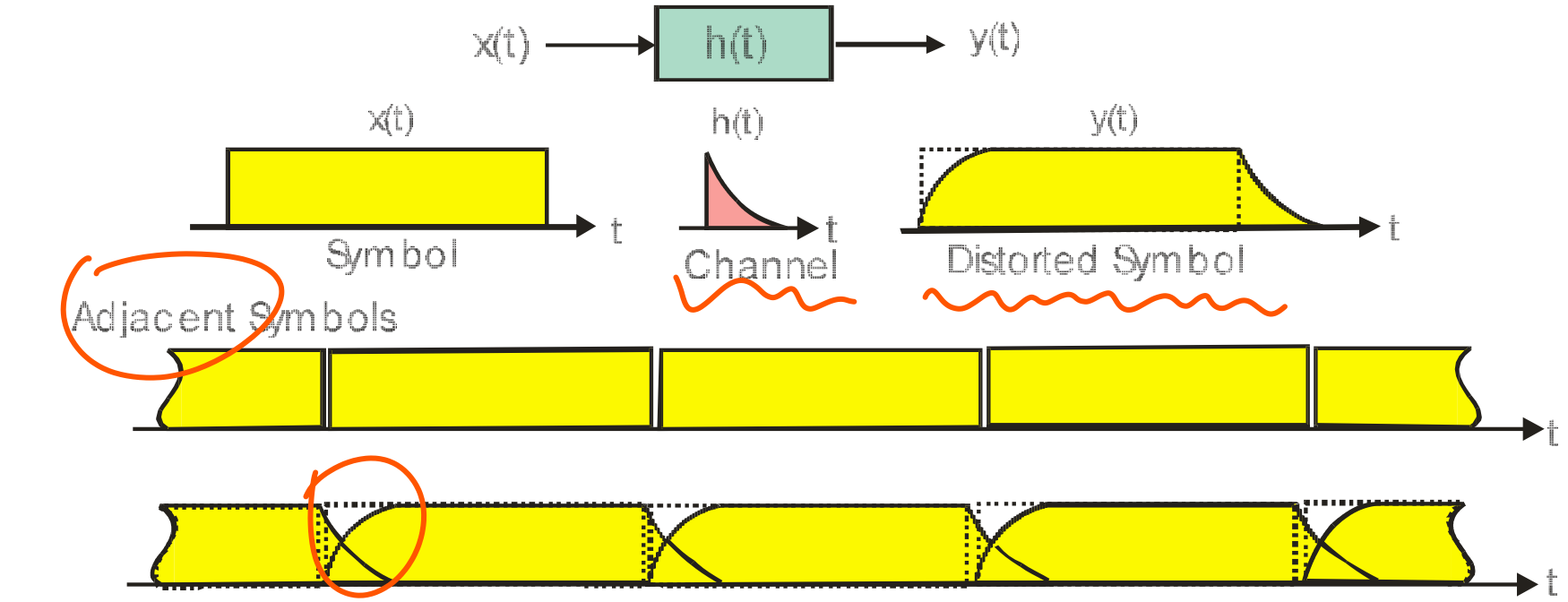
So how does OFDM solve the multipath problem?

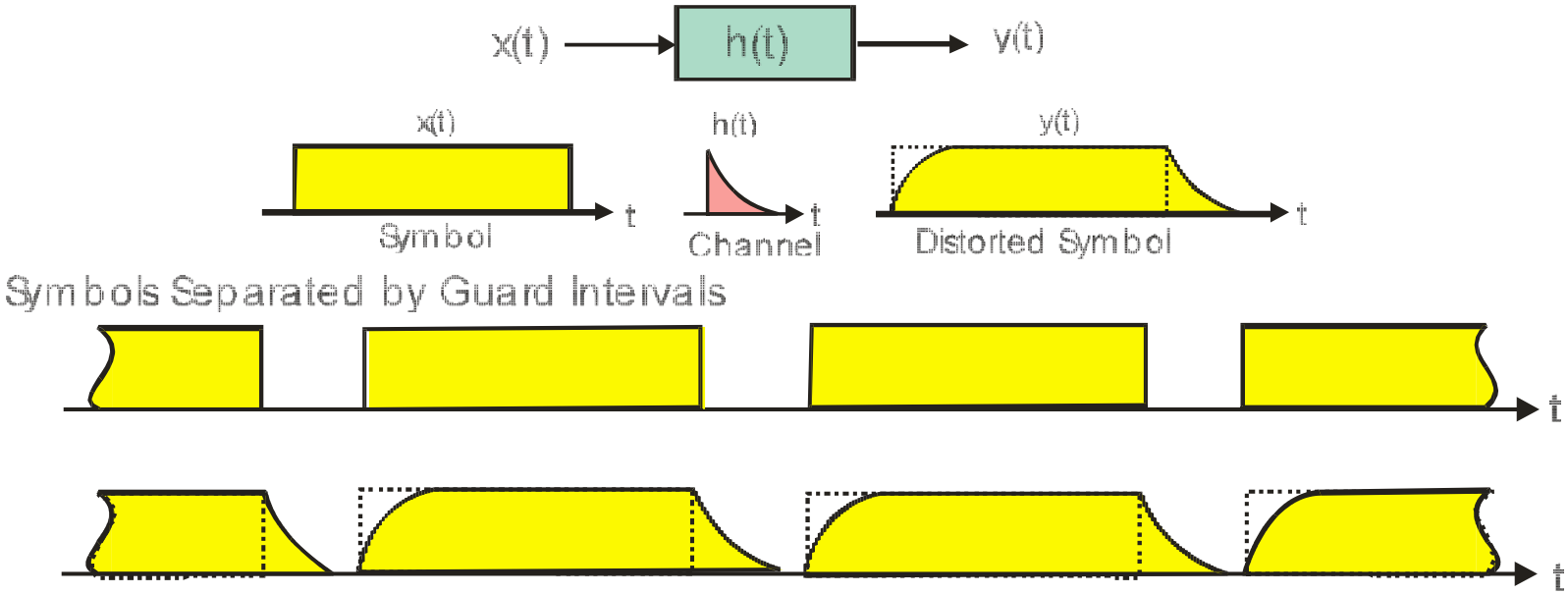
- Data is transmitted in parallel
  - longer symbol period
  - e.g. for *N* parallel streams, symbol period is *N* times as long
- Cyclic prefix
  - trick to avoid residual ISI

Inter Symbol Interference (ISI)

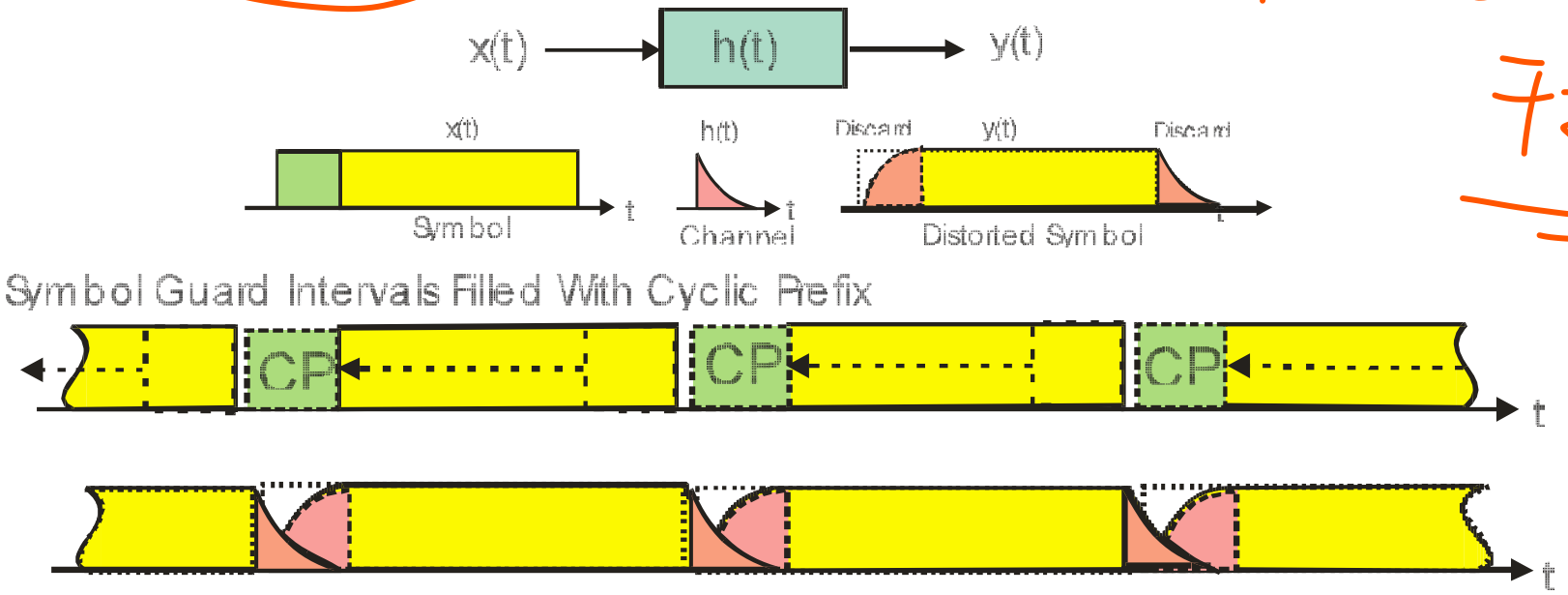
Symbol Smearing Due to Channel



Guard Interval Inserted Between Adjacent Symbols to Suppress ISI



Cyclic Prefix Inserted in Guard Interval to Suppress IS



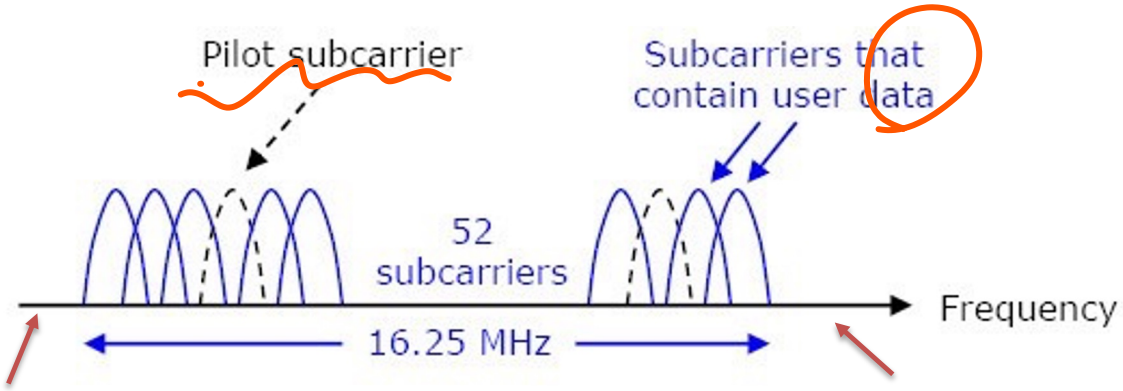
- Longer the Delay Spread (D) of the channel, larger the length of Cyclic Prefix and vice versa

So why is OFDM so popular for new broadband systems?

- Most broadband systems are subject to multipath transmission
- Conventional solution to multipath is an equalizer in the receiver
  - high data rates - equalizers too complicated
- With OFDM there is a simple way of dealing with multipath
  - relatively simple DSP algorithms
- OFDM is used in WiFi, Digital TV, 4G and 5G

Hiperlan-2 - Wireless LAN

- 64 point FFT, 52 subcarriers used – 48 to carry data and 4 as pilots
- The remaining 12 subcarriers are used as Guard bands
- Different modes
  - signal constellation, error coding, cyclic prefix



6 subcarriers spacing on each side of the OFDM channel is kept 'empty' as Guard Bands
The purpose of Guard bands is to avoid inter channel interference

ICI

OFDM Problems

- High peak-to-average power ratio
  - peak signals power much greater than average signal power
  - need very linear amplifiers with large dynamic range
- Very sensitive to frequency errors
  - tight specifications for local oscillators
  - Doppler limitation

OFDM Data rate calculations: Example

HyperLAN2 uses OFDM as the modulation scheme. The FFT size used is 64 where 48 carriers are used to carry data while the remaining carriers are used as pilot and guard bands. If QPSK modulated symbols are transmitted over the data subcarriers, what is the data rate that would be achieved in HyperLAN2 for an OFDM channel with bandwidth of 20 MHz? There is a guard interval of 0.8µsec in between adjacent OFDM symbols.

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-For HyperLAN2 which has total carriers N_t=64 out of which N_d=48 are data carriers while the rest don't carry any data.

-The channel bandwidth is W=20 MHz

Thus, channel spacing Δf would be,

$\Delta f = W/N_t$ = 20MHz/64=312.5 kHz

-Which means that the symbol duration, T_s,

$T_s = 1/\Delta f$ =1/312.5kHz=3.2µsec

-If we add a guard interval of 0.8µsec, this would make total symbol duration equal to 4µse.

Thus data rate R=1/4µsec=0.25Msymbols/sec.

-Each OFDM symbol has 96 data bits – 2 bits in one QPSK symbol and a total of 48 QPSK symbols on 48 data carriers

-This makes data rate of 24Mbits/s (96x0.25Msymbols/sec).

OFDM Example

Consider a channel with a delay spread of 10 msec. To experience flat fading over each of the 512 subcarriers of an OFDM system, what must be the total OFDM system bandwidth to have ISI-free communication?

$T_D = 10$ msec

$T_{symbol} > T_D \Rightarrow B < B_C = \frac{1}{T_D} = \frac{1}{10 \times 10^{-3}}$

$= 100$ Hz

$B_{total} = 100 \times 512 = 51200$ Hz $= 5.12 \times 10^4$ Hz

Course Evaluation

You are requested to participate in a very short survey (2 Questions Only)

The survey is available at Course/Instructor Feedback section of Moodle course page

https://moodle.gla.ac.uk/mod/feedback/view.php?id=3226783

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Thanks!

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