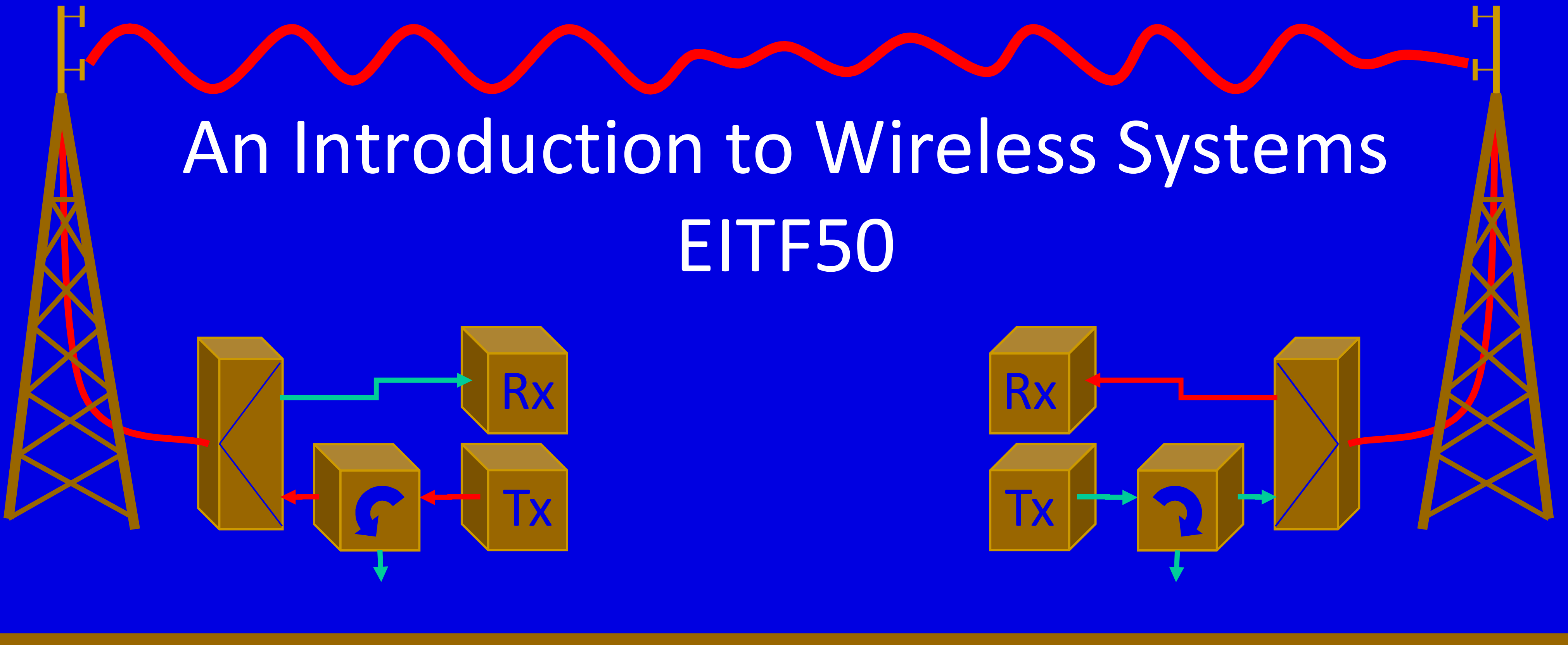
Lecture 8

An Introduction to Wireless Systems
EITF50



Johan Wernehag

Electrical and Information Technology

Slides 21-34 by Ove Edfors

Contents

- Digital Modulation
  - FSK, PSK and ASK
  - Noise and Bit Error Ratio (BER)
- Multi-User System (multiple access)
  - FDMA, TDMA, CDMA
- Spreading Technique
- Multi-carrier Technique
  - History and evolution
  - Transmitters and receivers

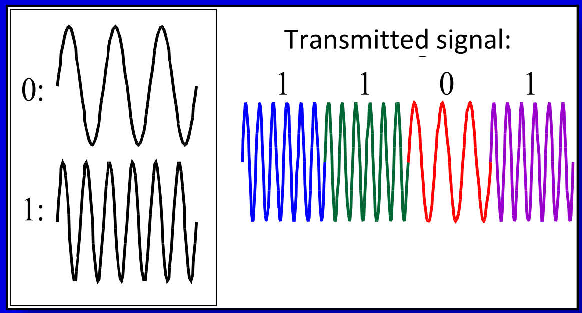
Digital Modulation

- A general radio signal may be written $$s(t) = A\cos(\omega t + \theta)$$

  there are three parameters to alternate: the amplitude A, frequency ω, and phase θ, these leads to three basic forms of digital modulation:

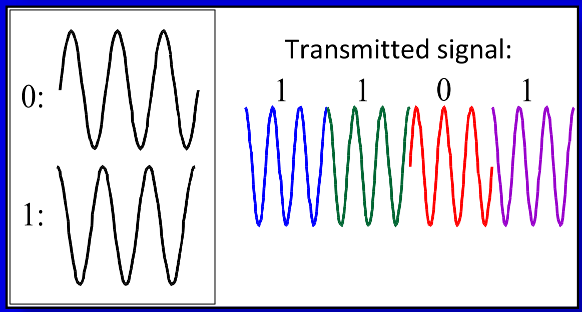
  - **FSK** (Frequency Shift Keying)
    The frequency carries the information.

Example:



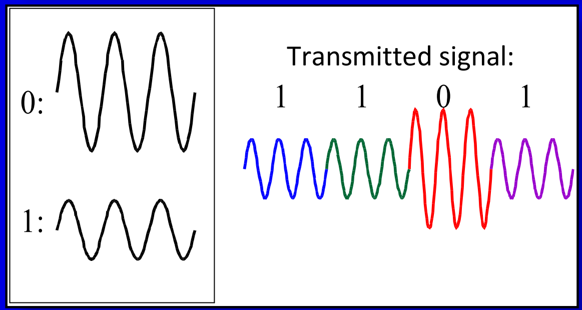
  - **PSK** (Phase Shift Keying)
    The phase carries the information.

Example:



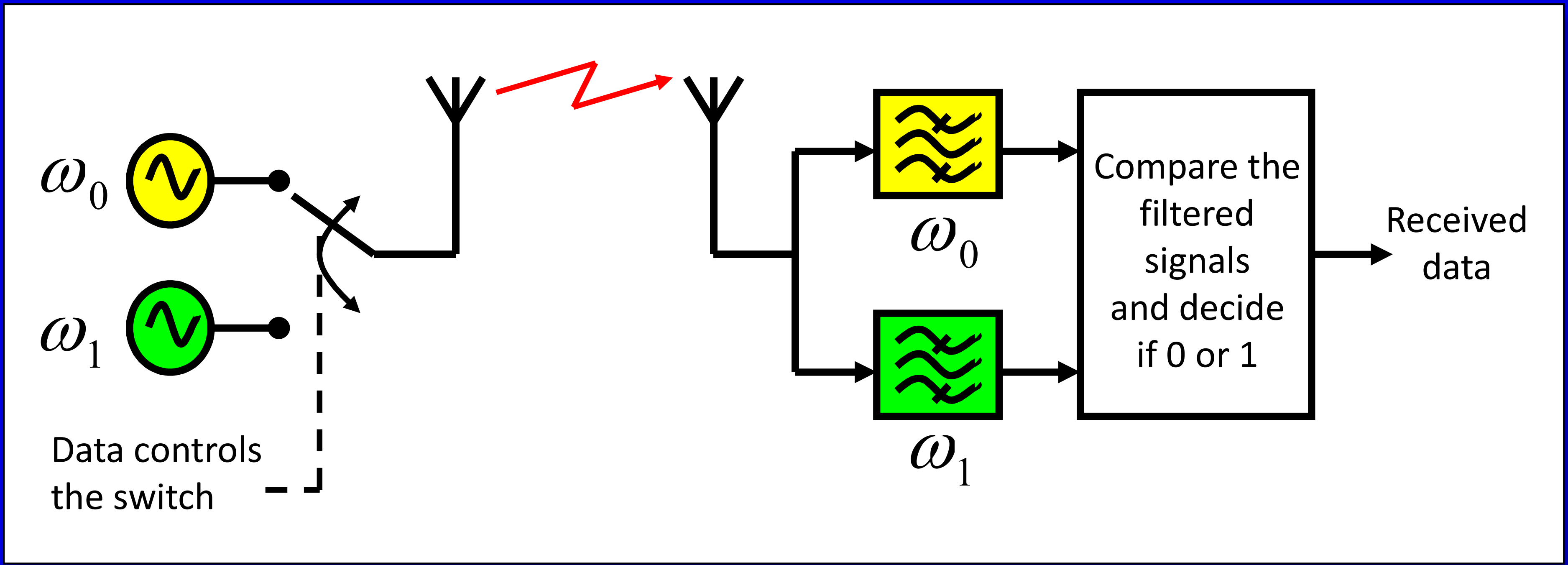
  - **ASK** (Amplitude Shift Keying)
    The amplitude carries the information.

Example:



FSK - Frequency Shift Keying

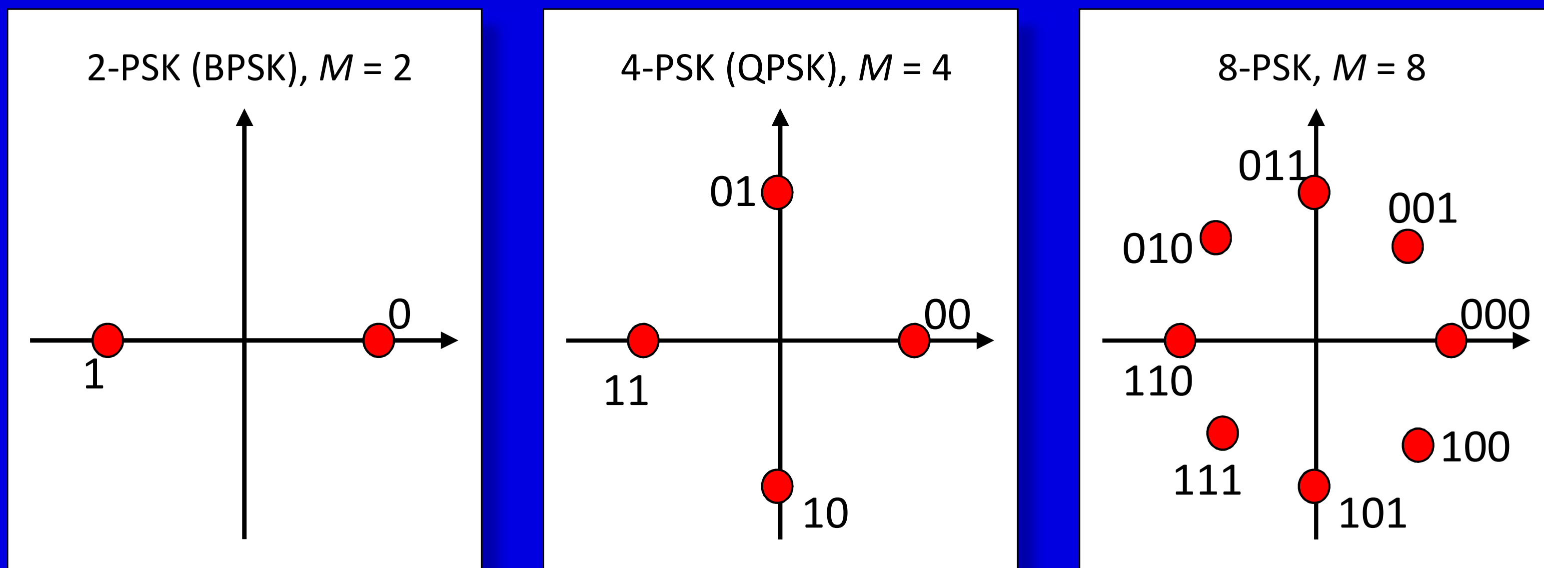
- At binary FSK 0 and 1 are represented by radio signals of different frequencies:



- Neither phase- nor amplitude references are needed in the receiver.
- Simple modulation and demodulation, but poor performance!

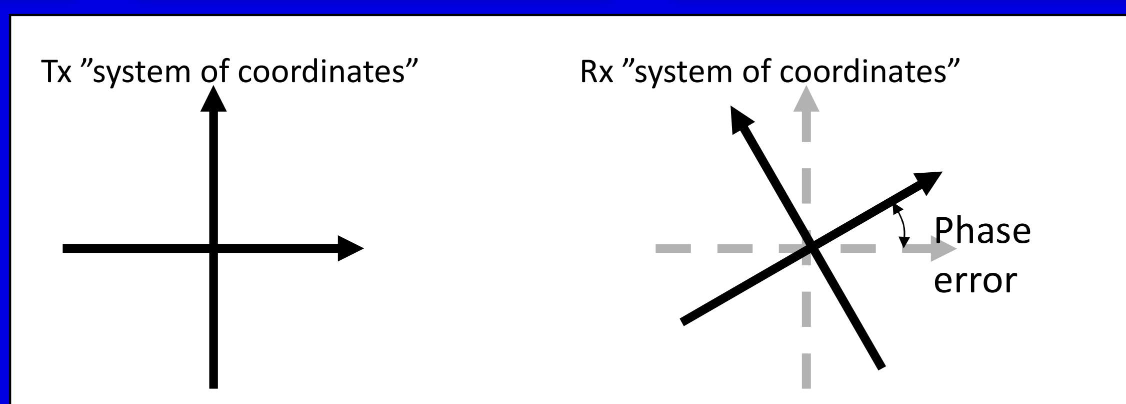
PSK - Phase shift keying

- A PSK symbol with $M = 2^n$ discrete phases may carry n information bits.



Does PSK show any problems?

- Absolute phase reference is required in the receiver.



Can we find any ”smart” cure?

DPSK - Differential PSK

- Idea: Let the phase difference between two subsequent PSK symbols carry the information (instead of absolute phase).

- What is the effect of a phase error $\Delta\theta$ between transmitter and receiver?
  - The phase of two subsequent PSK symbols are θ_1 and θ_2.
  - The information is carried by the difference $\theta_1 - \theta_2$.

Transmitted radio signal at phase: | Phase after demodulation in the receiver

$$\theta_1 \longrightarrow \theta_1 - \Delta\theta$$
$$\theta_2 \longrightarrow \theta_2 - \Delta\theta$$

Information = phase difference:

$$\boxed{\theta_2 - \theta_1} \qquad (\theta_2 - \Delta\theta) - (\theta_1 - \Delta\theta) = \boxed{\theta_2 - \theta_1}$$

Equal, despite of phase error between Tx and Rx

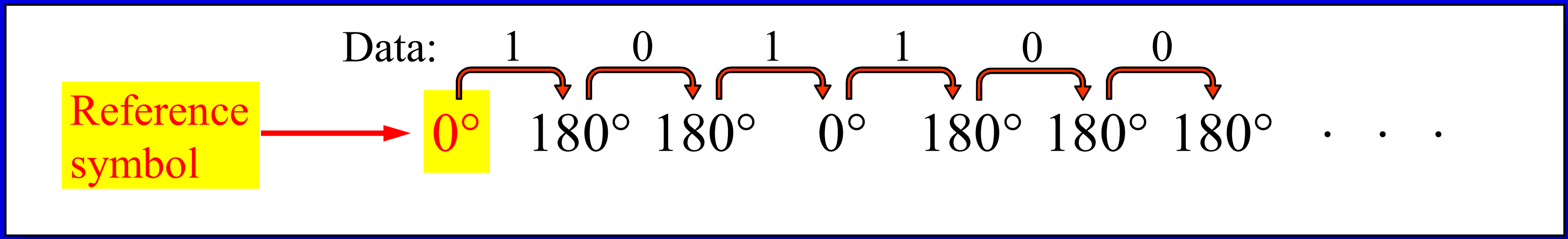
- Differential PSK (DPSK) eliminates the need for absolute phase reference!

Example: Differential BPSK (DBPSK)

- DPSK uses two phases, 0° and 180°.
- The transmission starts with a reference symbol at an arbitrary phase angle (for example 0°).

- The binary information then controls the phase of the next symbol as:
  - If input data is 1, change the phase by 180°.
  - If input data is 0, keep the phase unchanged.

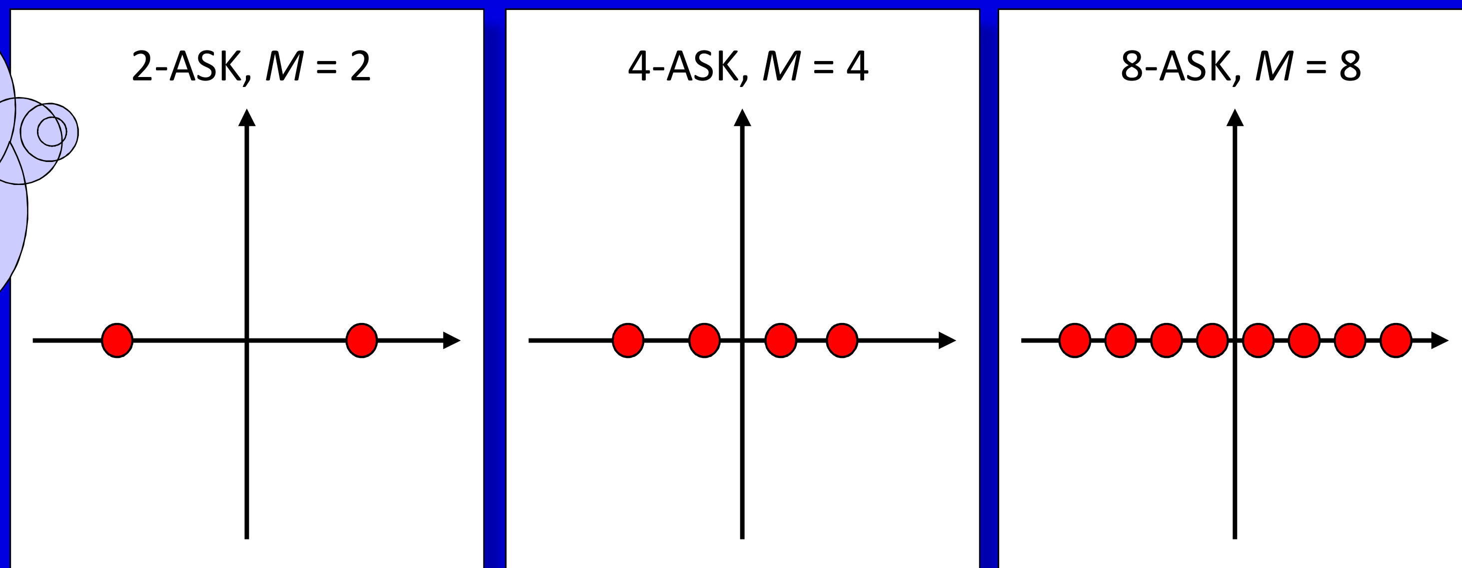
- The data sequence 101100... will be transmitted as BPSK symbols at phase angels as:



ASK - Amplitude Shift Keying

- An ASK symbol with $M = 2^n$ discrete amplitude levels may carry n information bits.

NOTE the similarity to 2PSK!
Change of the sign in the amplitude corresponds to a 180° phase shift.
2ASK and 2PSK are in principle equal!

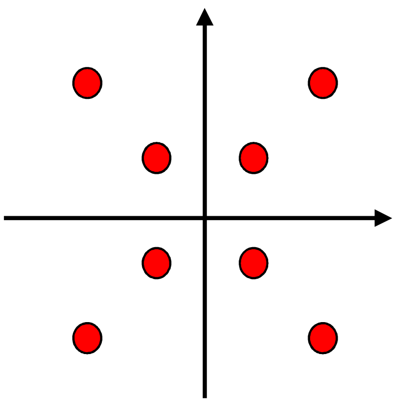


- Does ASK has any drawbacks?
  - Amplitude reference is required in the receiver (doesn’t apply to 2ASK).
  - Requires linear amplifiers due to the changes in level.
- Are there tricks similar to PSK ⇨ DPSK to avoid the amplitude reference?
  - NO, generally it’s not possible to use differential modulation in amplitude shifts.

QAM - Quadrature Amplitude Modulation

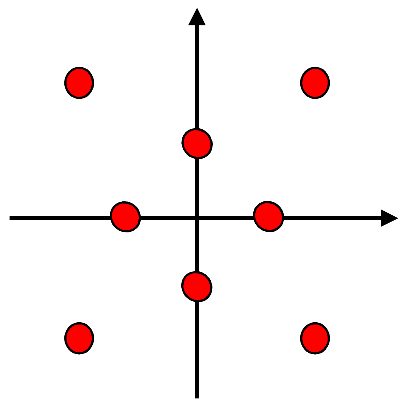
- By combining both phase- and amplitude changes it is possible to accomplish more complex modulating methods.

8-QAM (i)



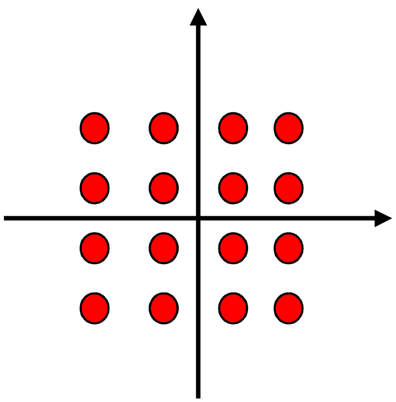
4 different phases
2 different levels

8-QAM (ii)



8 different phases
2 different levels

16-QAM



12 different phases
3 different levels
(4ASK at both I- and Q channels simultaneously)

Are there any drawbacks by using QAM?

- Phase- and amplitude references are required in the receiver.
- Due to change in the level there are no (simple) methods to avoid the references.

Why care about QAM?

- Increased number of bits per modulation symbol.
- Leads to increased data rate and better use of the channel bandwidth.

Bandwidth Efficiency

- Bandwidth efficiency / information density:

$$\boxed{D_i = \frac{f_i}{B_i} \quad [\text{bit/sek/Hz}]}$$

where f_i is the information rate (bit/s) and
B_i the corresponding modulation bandwidth (Hz).

- Ideal (minimal) bandwidth at *M*-PSK/*M*-QAM:

$$\boxed{B_i = \frac{f_i}{\log_2 M}}$$

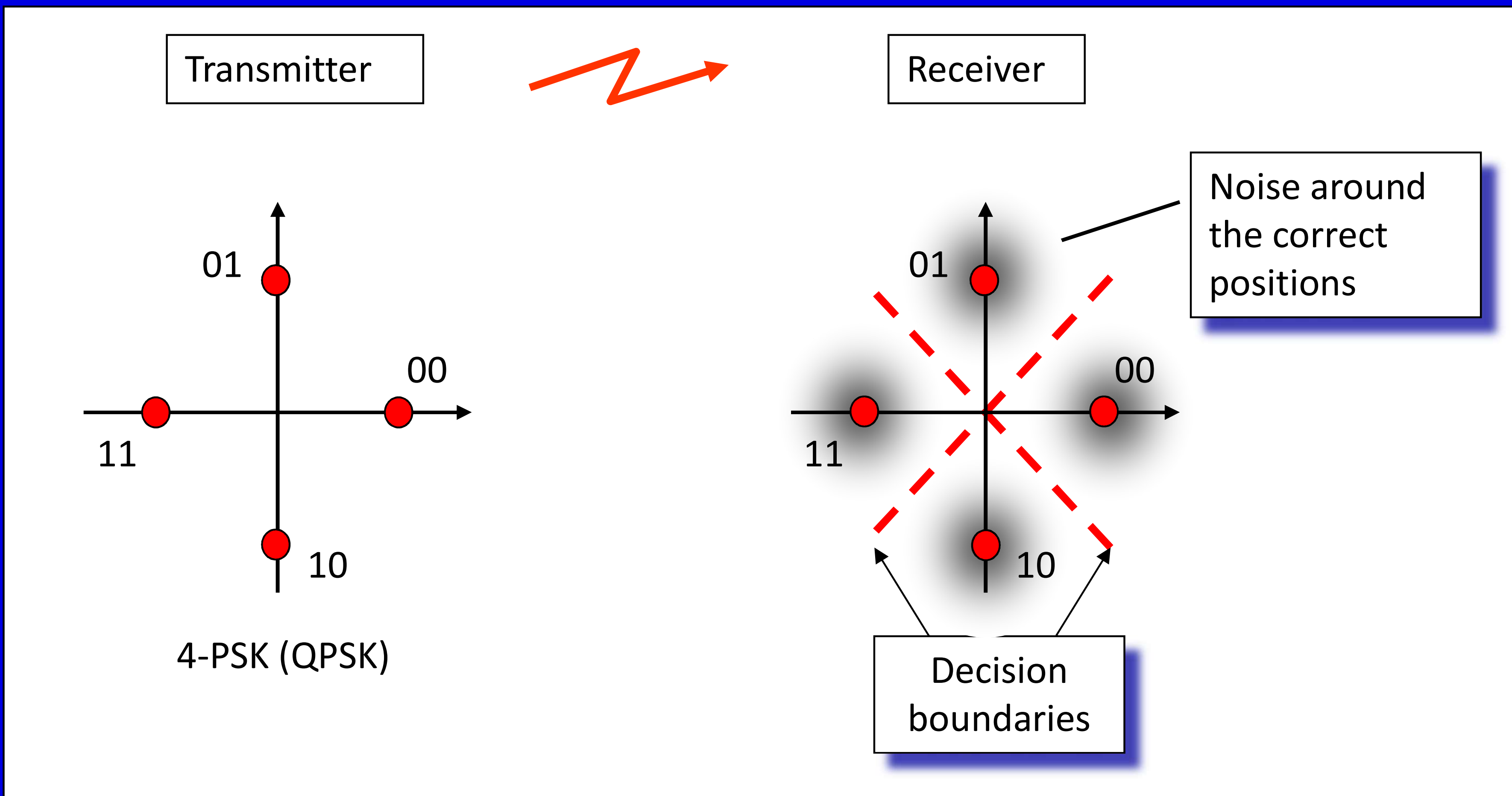
- Combine these equations and we get:

$$\boxed{D_i = \log_2 M \quad [\text{bit/sek/Hz}]}$$

The bandwidth efficiency increases with an increasing M !

Noise and Bit Error Rate

- Noise in the receiver system leads to an amount of incorrect detection, a bit error ratio.



Noise and Bit Error Rate

compare to the modulation gain!

- The detector characteristics states the relation between the signal quality before the detector and the effective bit error rate (BER).

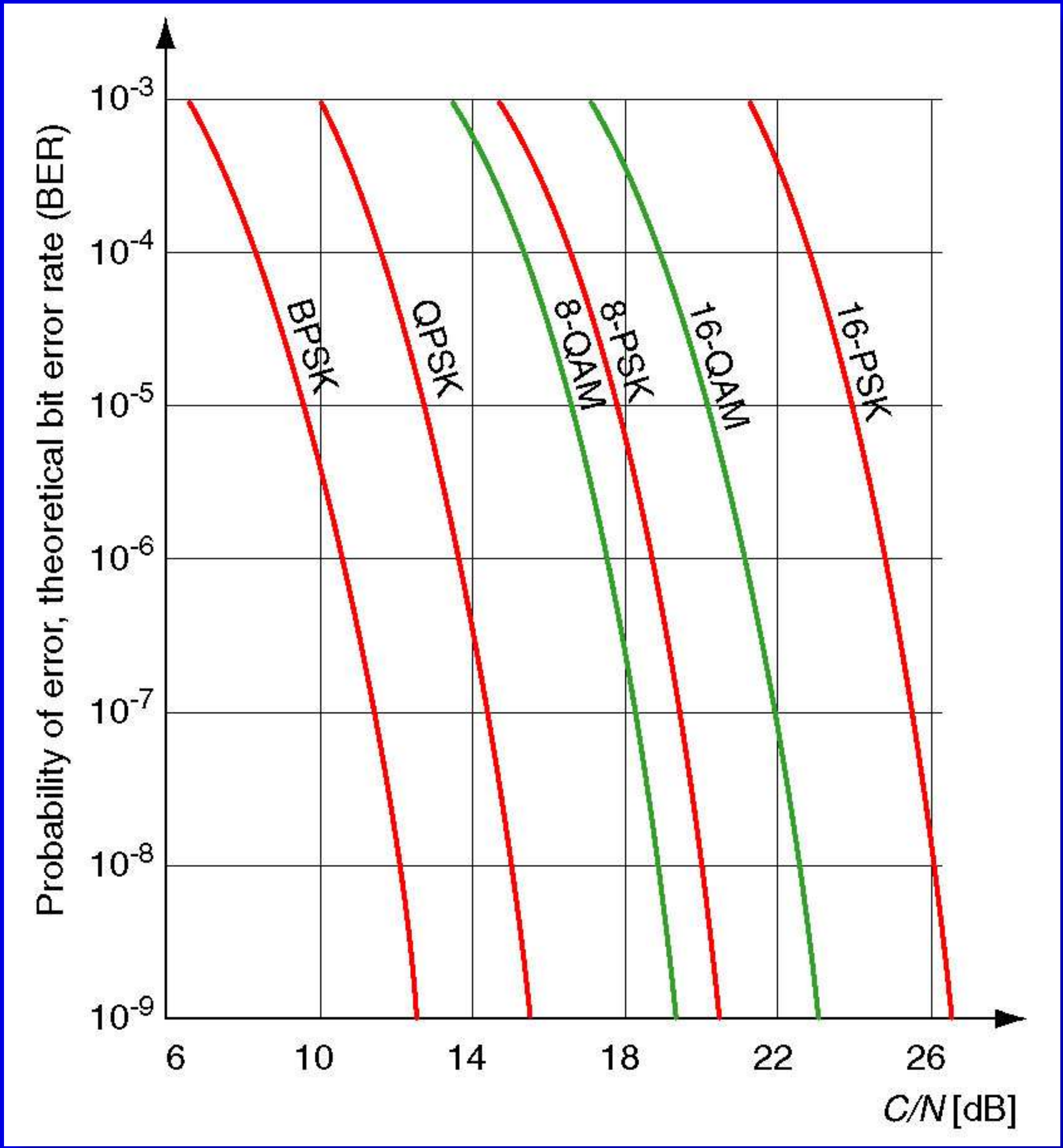
- The received signal quality is either stated as
  C/N, C/N_0 or E_b/N_0, where
  C is the received power [Watt],
  E_b is the received energi per bit [Joule/bit] and
  N_0 is the noise density [Watt/Hz].

- By using the notation from the bandwidth efficiency we get:

$$C = E_b f_i \qquad N = N_0 B_i \quad \Rightarrow \quad \frac{C}{N} = \frac{E_b}{N_0}\frac{f_i}{B_i} \qquad \frac{C}{N_0} = \frac{E_b}{N_0} f_i$$

These equations states the relation between E_b/N_o that is common in BER charts and the corresponding received power C.

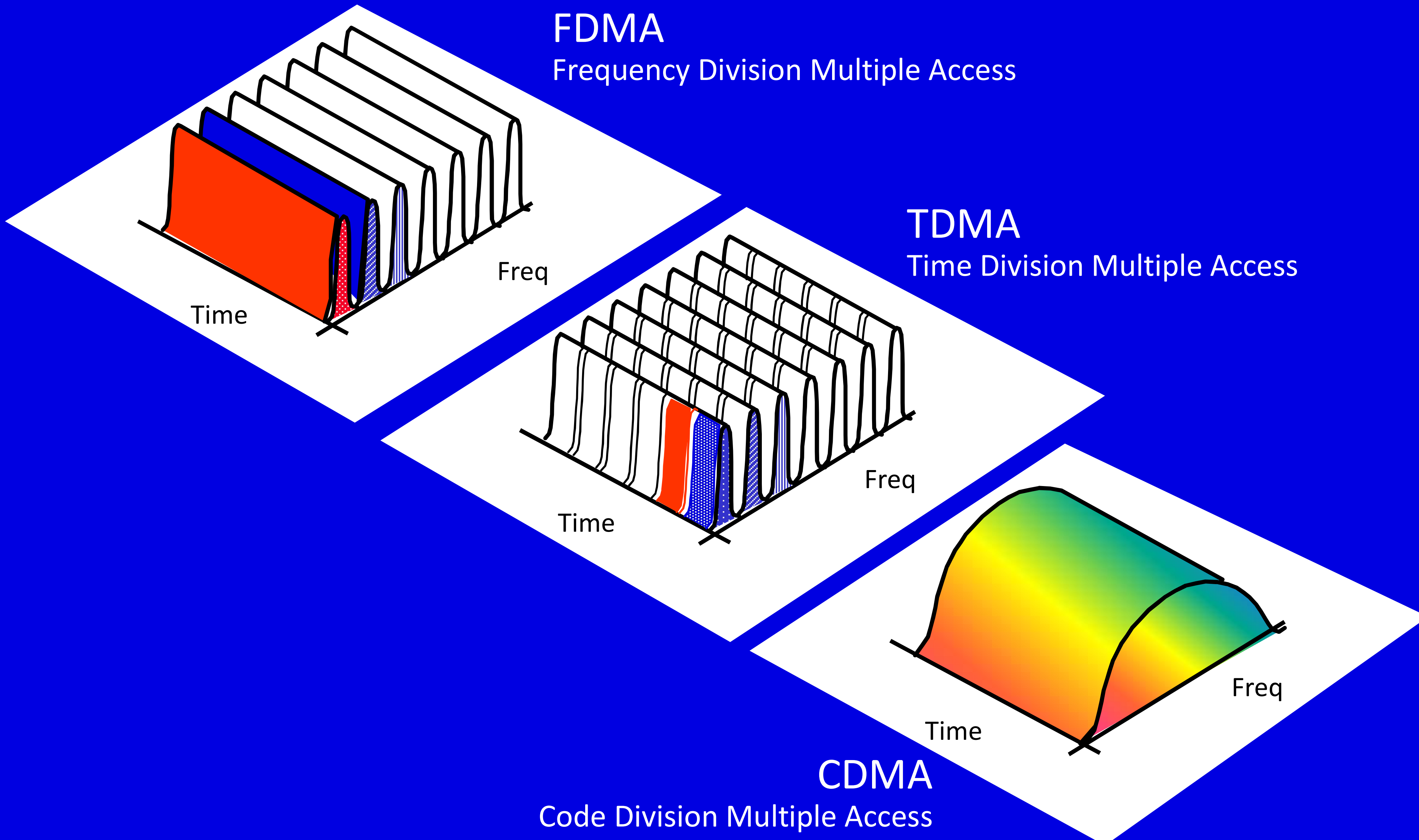
Noise and Bit Error Rate



Multiple-Access Techniques

FDMA
Frequency Division Multiple Access

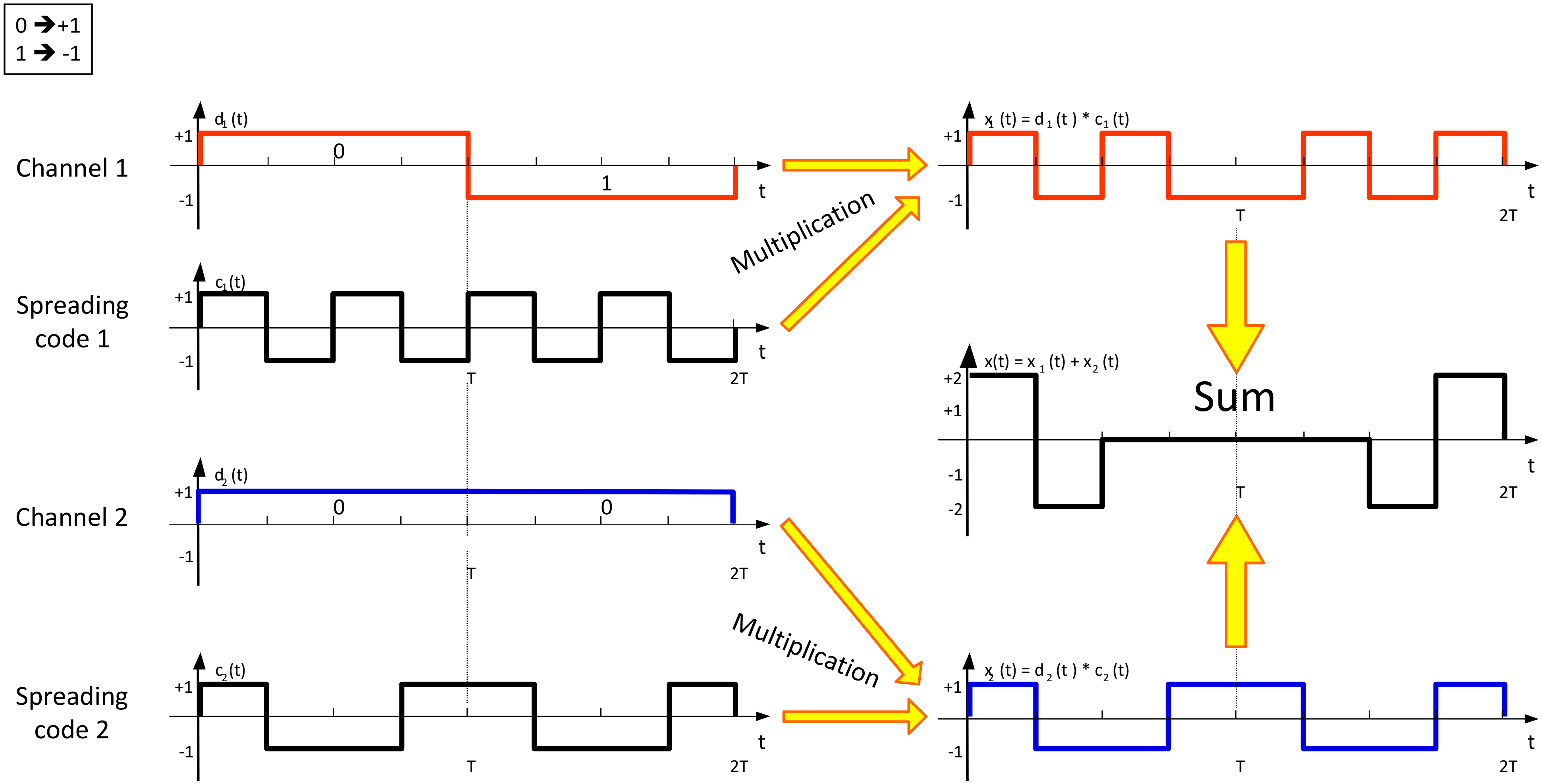
TDMA
Time Division Multiple Access



CDMA
Code Division Multiple Access

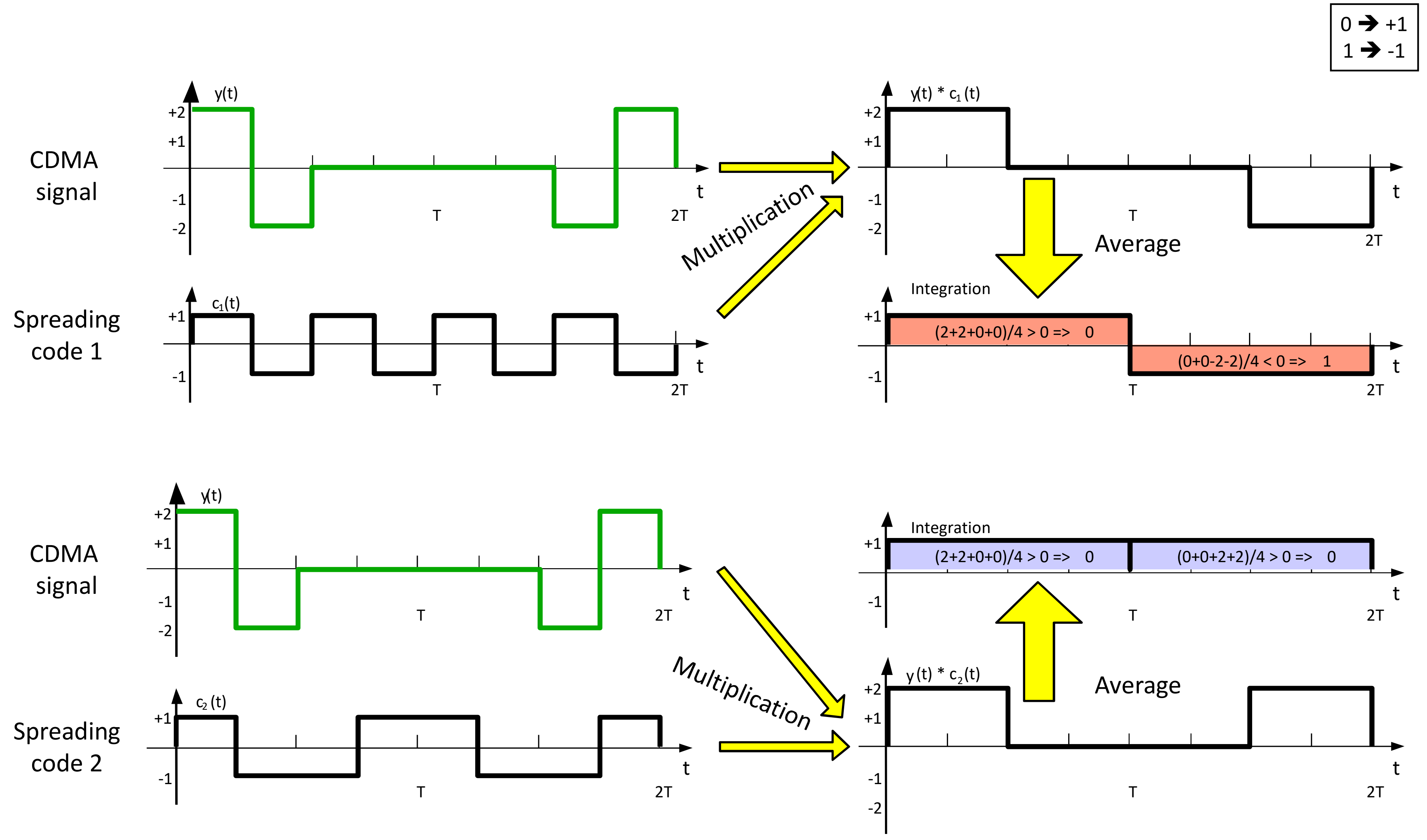
Spreading of Two Sources

Example of a transmitter



De-Spreading of Two Sources

Example of a receiver



Spreading Code

3GPP* chip rate: 3.84 Mcps

Example: 60 kbps data rate

Data bit

1

Intermediate stage

1111111111111111111111111111111111111111111111111111111111111111

XOR

OVSF code**

0110011010011001100110010110011010011001011001100110011010011010

Tx spreaded symbol

1001100101100110011001101001100101100110100110011001100101100101

Pattern generated

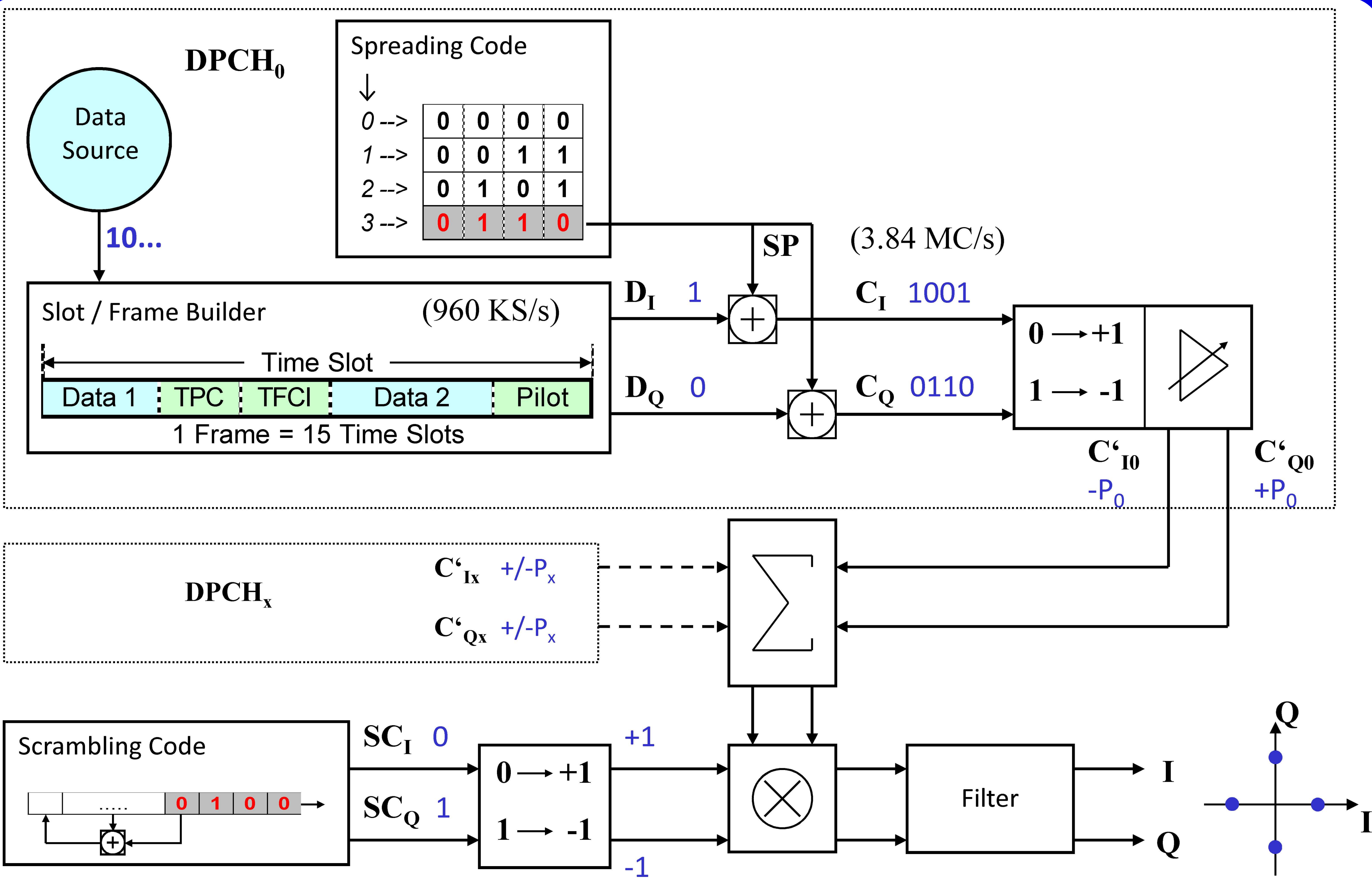
60 kbps * spreading factor of 64 = 3.84 Mcps

* 3rd Generation Partnership Project

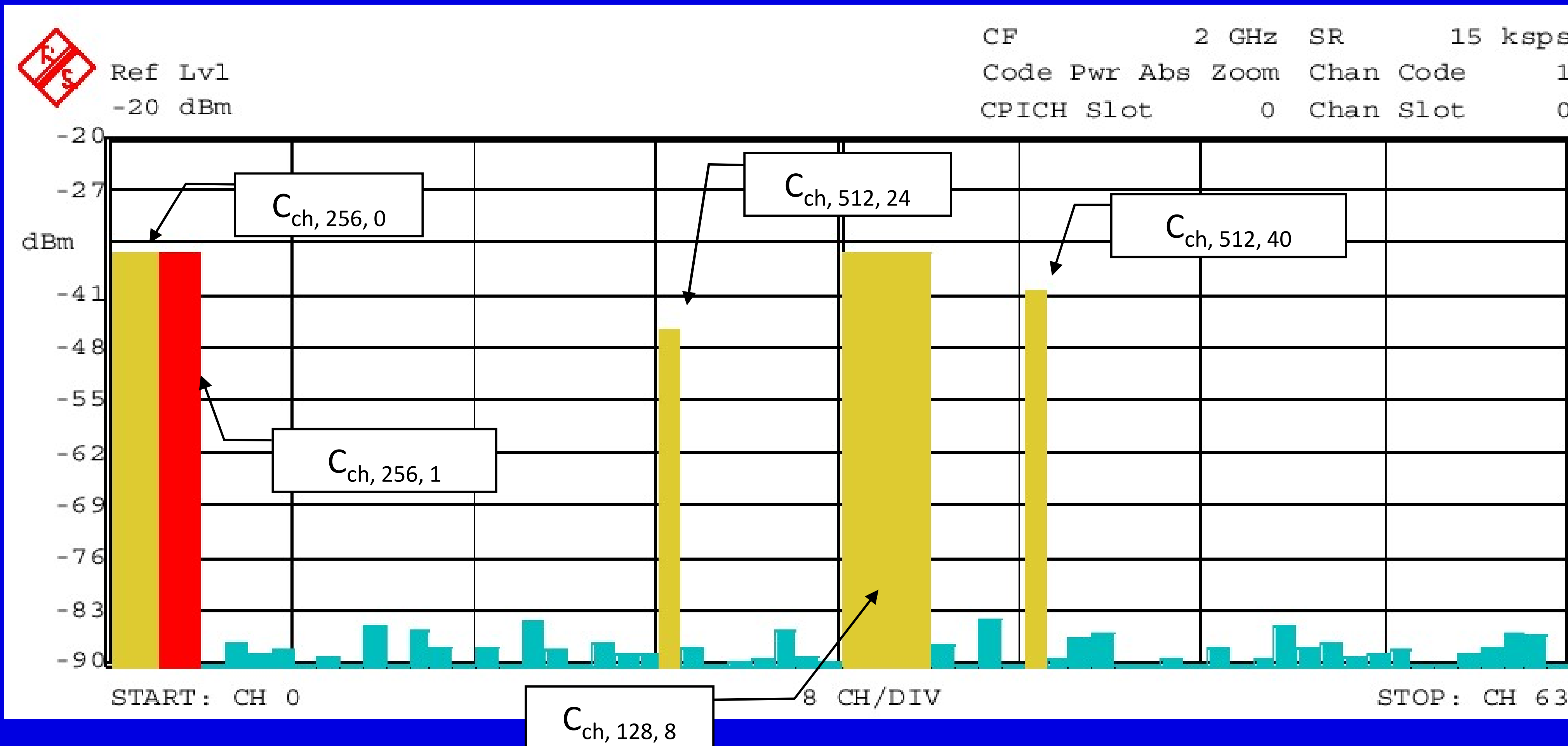
** Orthogonal Variable Spreading Factor

It needs 64 bits (1 symbol) to transmit 1 original bit!

Channel Coding

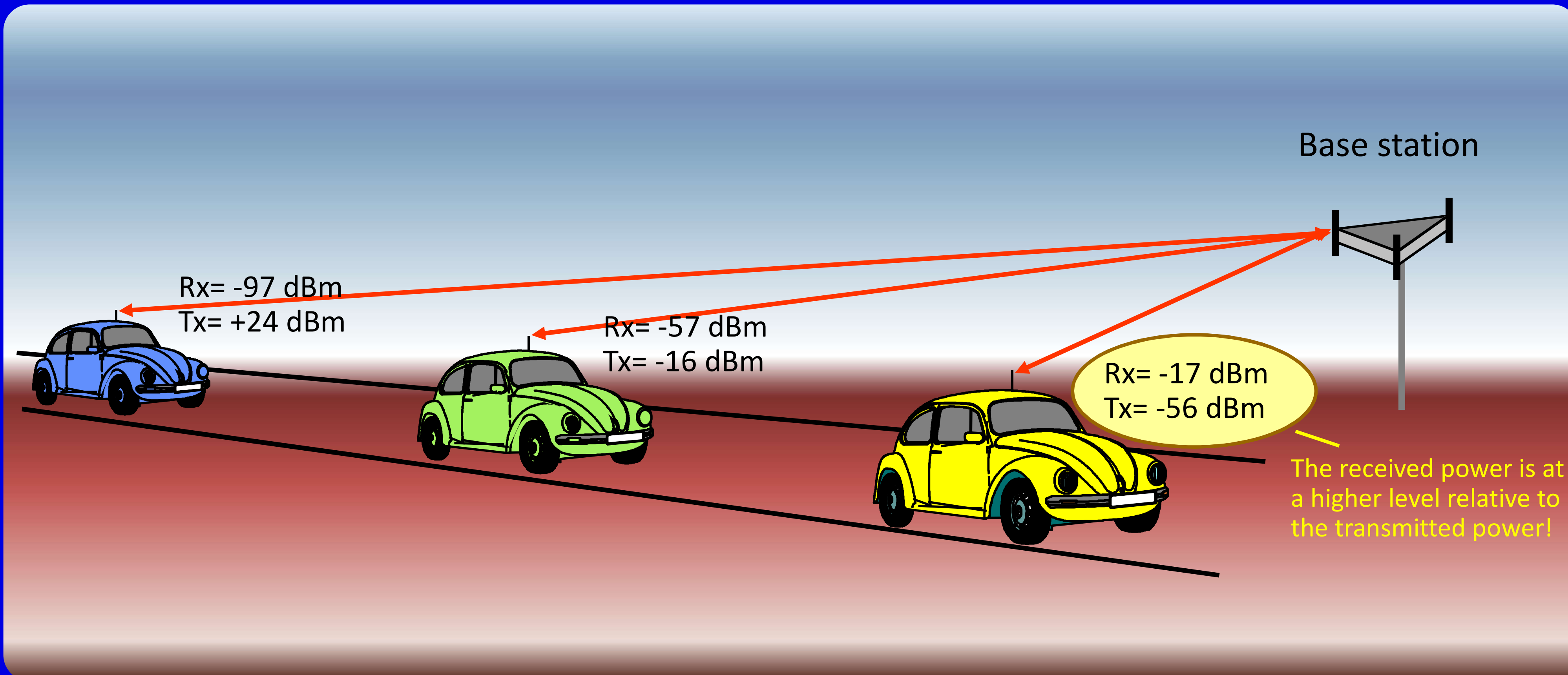


Code Domain Measurements



- At CDMA it is important that all channels in the code domain are received at equal levels
- Therefore is a dynamic power control required in the transmitter

“Open Loop” Power Control



- Fast control: 10 dB setting at 10 - 100 ms
- A “closed loop” power control is also used that is more accurate but causes some delay

Multi-carrier **OFDM**... Why?

ECHO

- What happens if you speak rapidly in a large open stone building?

ECHOES ... ECHOES ... ECHOES !

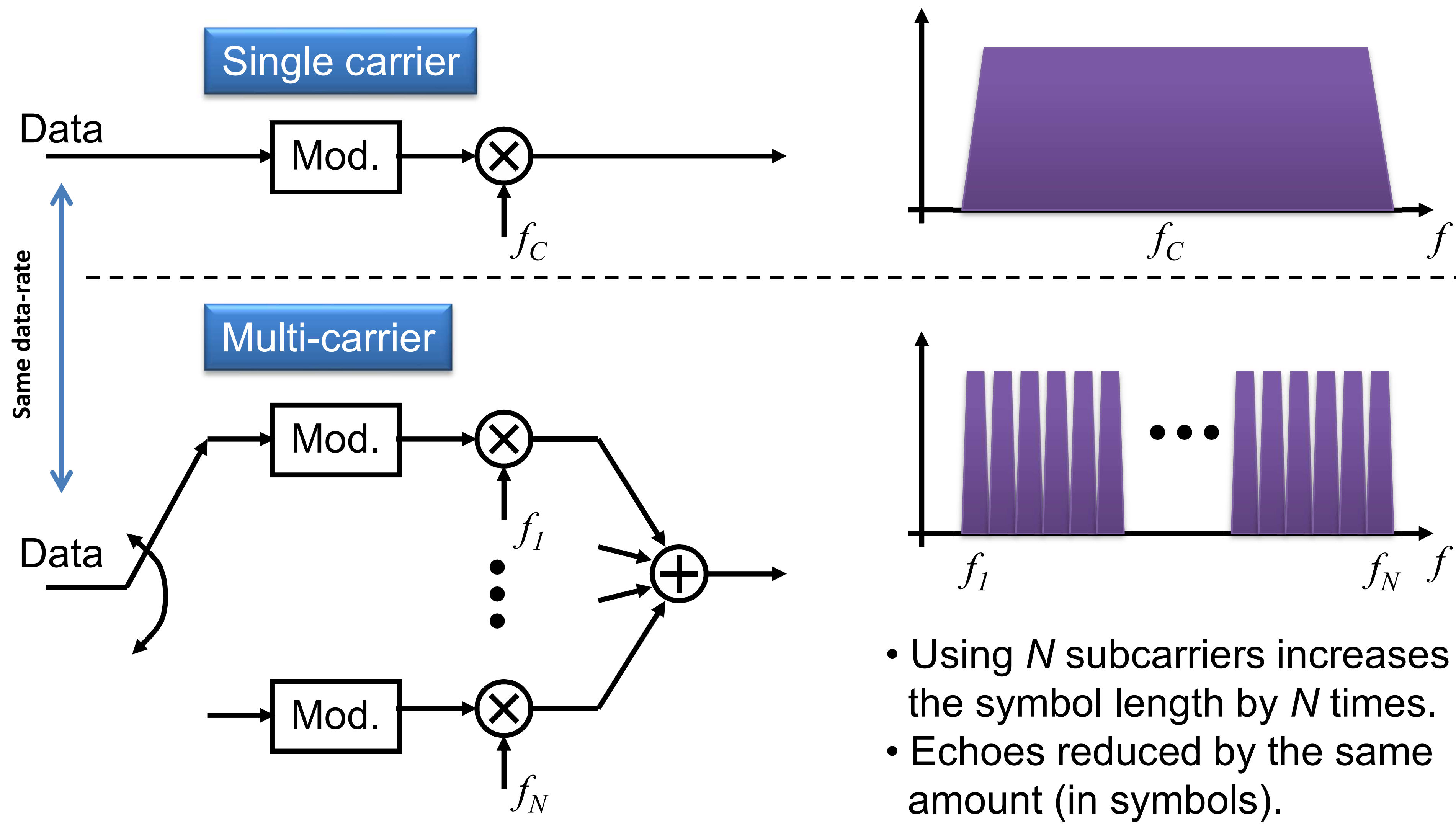
ECHO

How do you solve the problem?

SPEAK SLOWER!

THIS IS THE ESSENCE OF MULTI-CARRIER!
Slower transmission on each carrier, but use many carriers

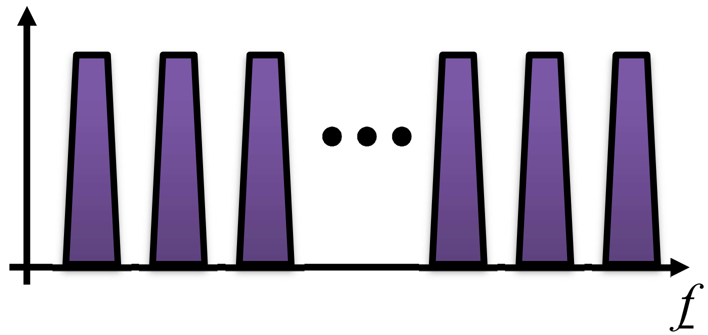
Single/multi-carrier



- Using N subcarriers increases the symbol length by N times.
- Echoes reduced by the same amount (in symbols).

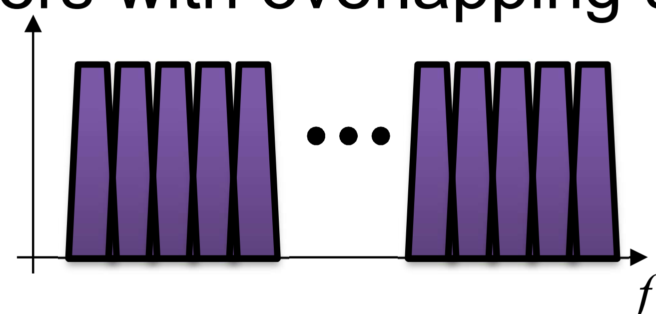
History and evolution [1]

1950's: Few subcarriers, with non-overlapping spectra



- Military systems, e.g. the Kineplex-modem

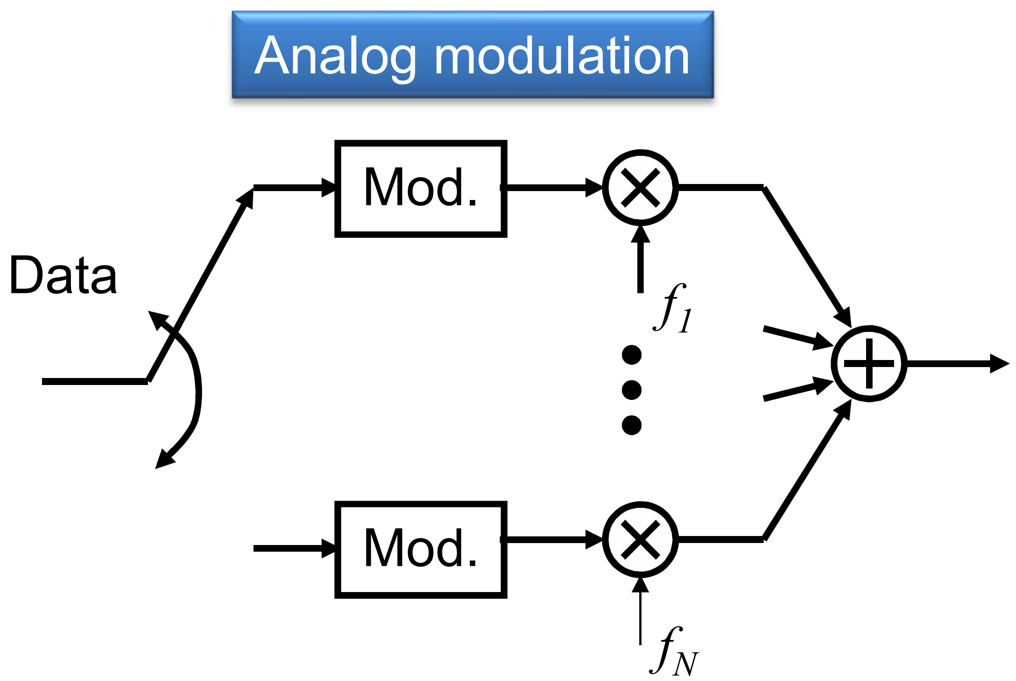
1960's: Subcarriers with overlapping spectra

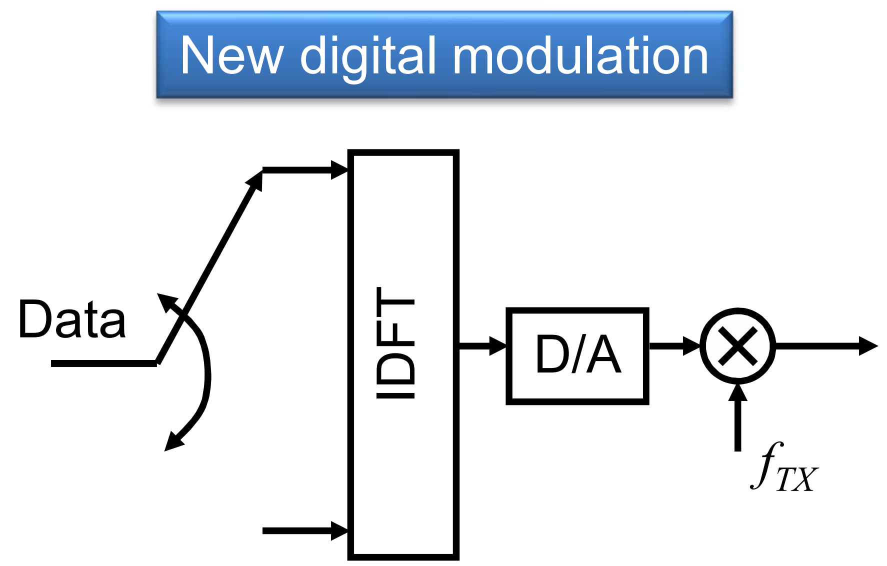


Increased subchannel density and increased data rate.

History and evolution [2]

1970's: Digital modulation of subcarriers

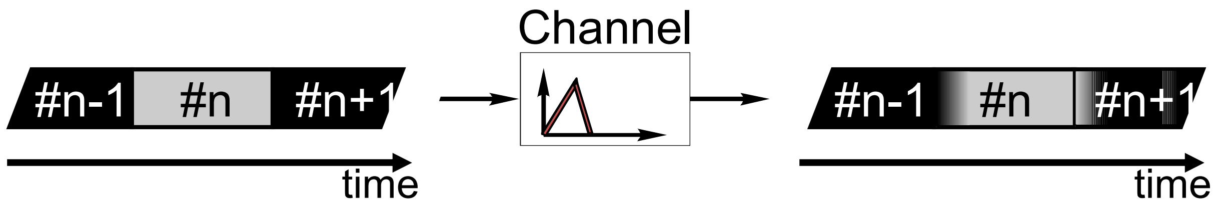




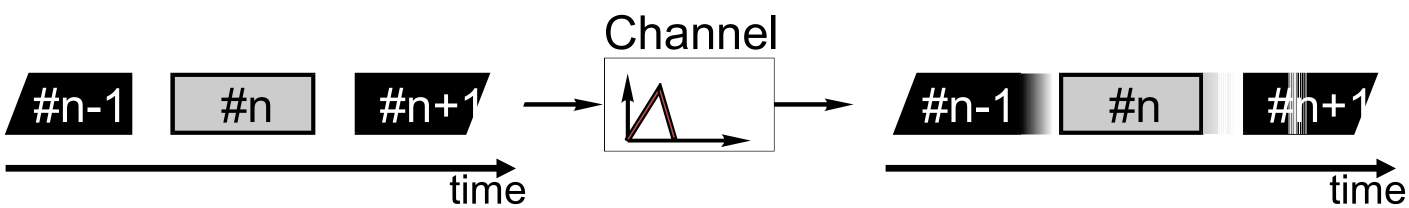
History and evolution [3]

1980's: Improved digital circuits increses interest

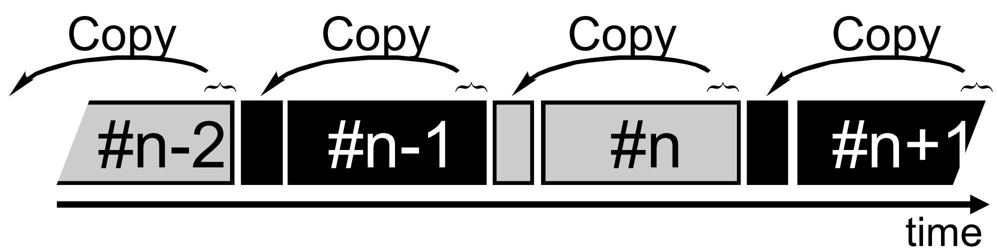
No guard interval => Interference between both subcarriers and symbols



Guard interval => No interference between symbols



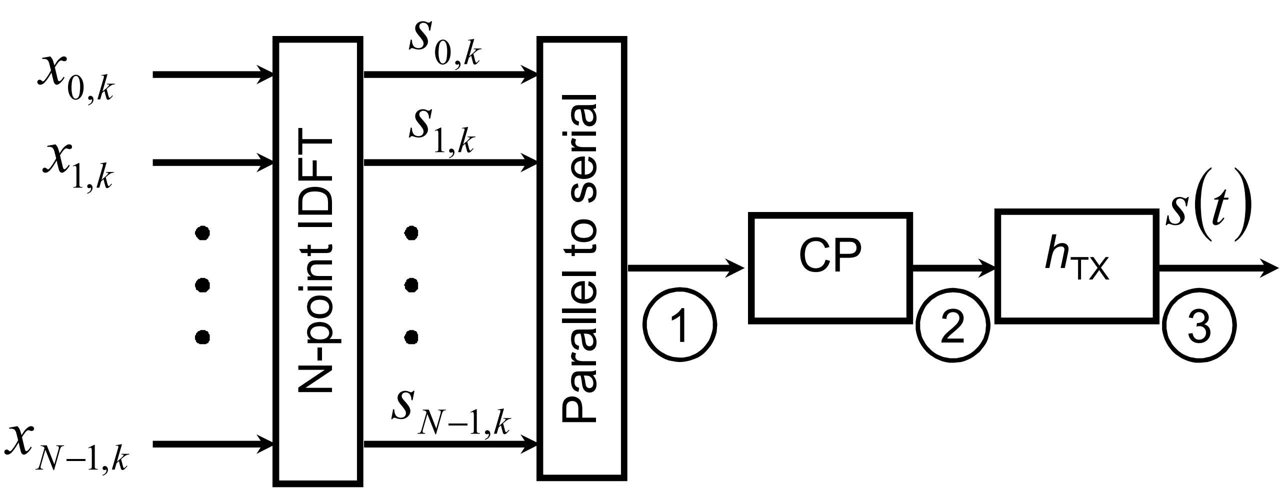
Cyclic prefix => No interference between neither subcarriers nor symbols



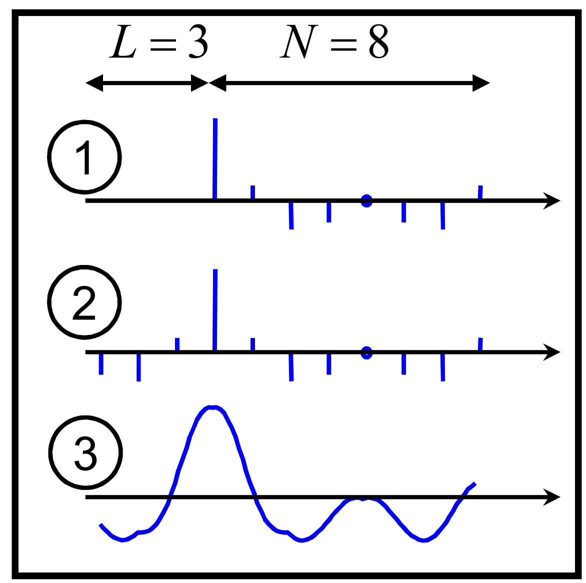
History and evolution [4]

- **1990's**: Commercial applications appear
  - Increased interest for OFDM in wireless applications
  - First applications in broadcasting (Audio/Video)
  - One of the candidates for UMTS (Beta proposal)
  - Applied in wireless LANs
- **2000's**: One of the really hot technologies
  - > 50 Mbps WLANs (based on OFDM) hit the mass market
  - OFDM is one of the candidate technologies when improving and moving beyond current 3G systems – LTE!

An N-subcarrier transmitter



k – symbol
m – sample
n – subcarrier
L – CP length
T_{samp} – sampling period
h_{TX} – TX filter



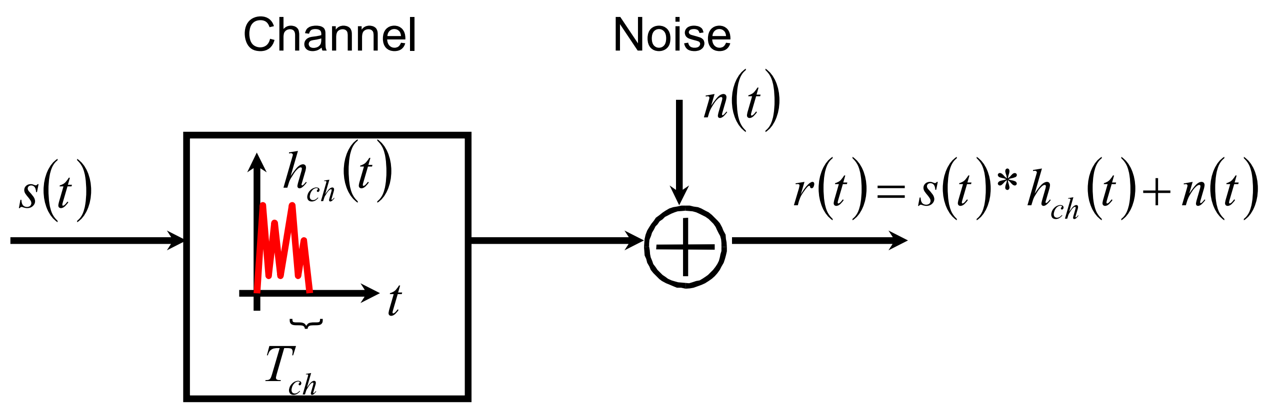
N-point IDFT: $s_{m,k} = \frac{1}{\sqrt{N}} \sum_{n=0}^{N-1} x_{n,k} \exp\left(j2\pi \frac{mn}{N} \right)$ for $0 \le m \le N-1$

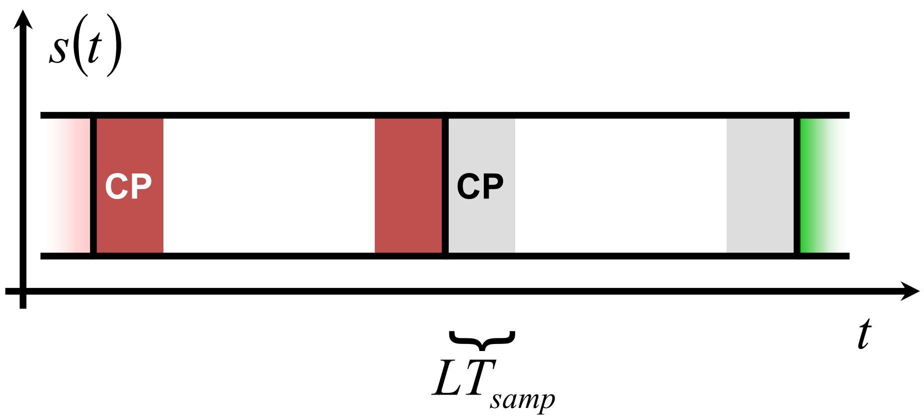
Adding CP: $s_{m,k} = s_{N+m,k}$ for $-L \le m \le -1$

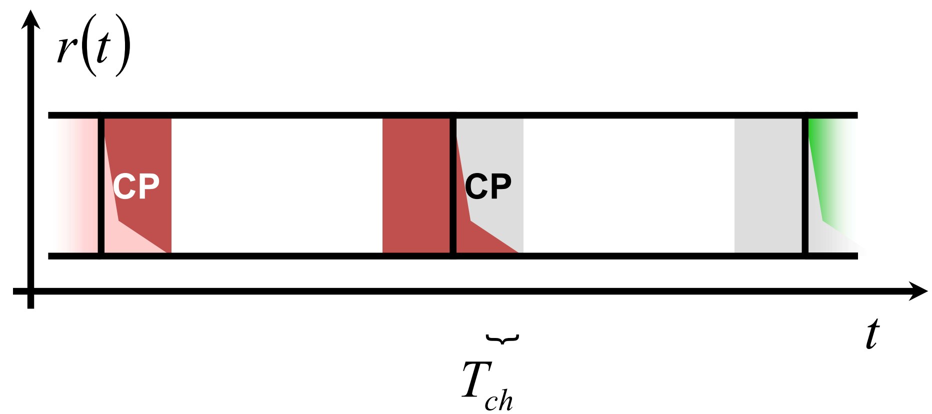
TX filtering: $s(t) = h_{TX}(t) * \left(\sum_{k} \sum_{m=-L}^{N-1} s_{m,k} \delta\left(t - k(N+L)T_{samp} - mT_{samp}\right) \right)$

Transmitters and receivers

… through the channel …



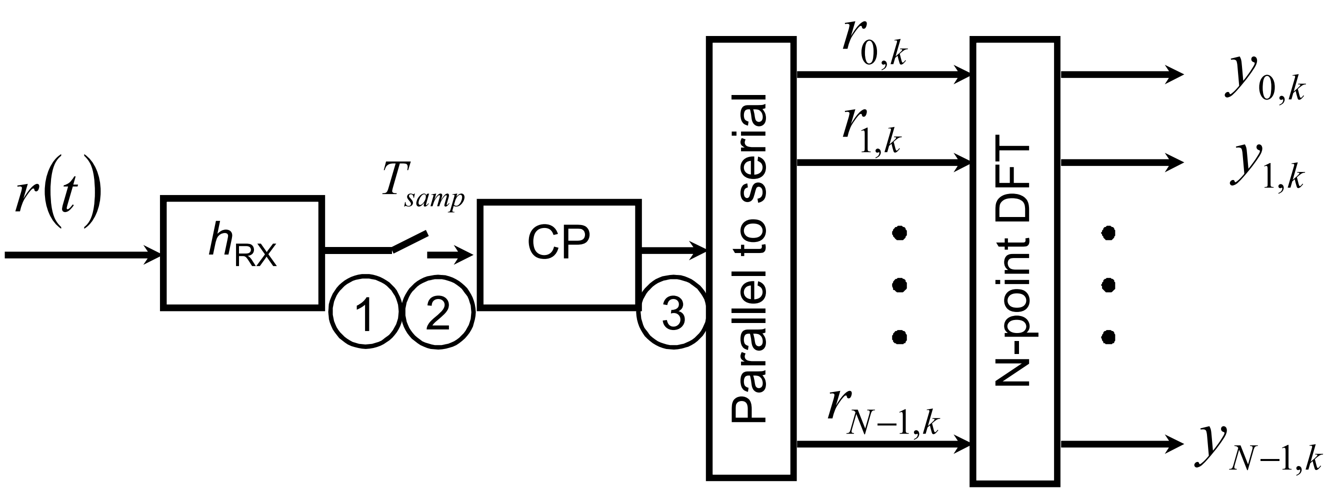




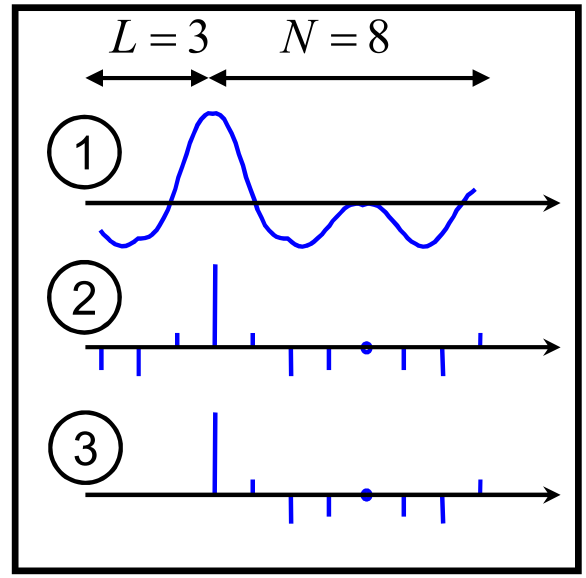
As long as the CP is longer than the delay spread of the channel, $LT_{samp} > T_{ch}$, it will absorb the ISI.

By removing the CP in the receiver, the transmission becomes ISI free.

N-subcarrier receiver



q – symbol
p – sample
n – subcarrier
L – CP length
T_{samp} – sampling period
h_{RX} – RX filter



RX filtering: $z'(t) = h_{RX}(t) * r(t)$

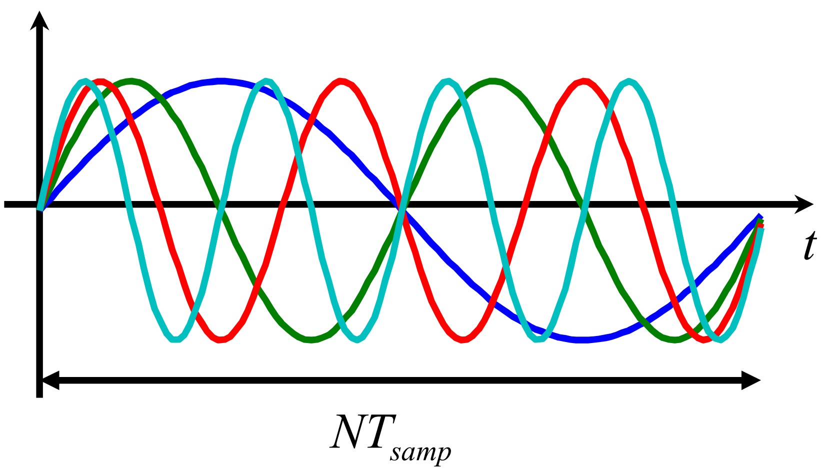
Sampling: $z'_k = z'(kT_{samp})$

Removing CP: $r_{p,q} = z'_{q(N+L)+p}$ for $0 \le p \le N-1$

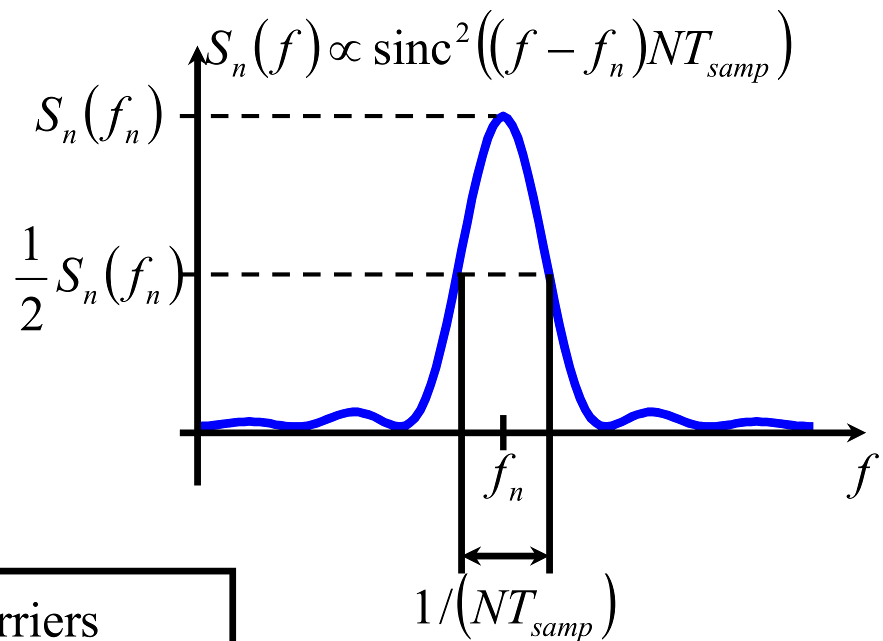
N-point DFT: $$y_{n,q} = \frac{1}{\sqrt{N}} \sum_{p=0}^{N-1} r_{p,q} \exp\left(-j2\pi \frac{np}{N}\right) \text{ for } 0 \le n \le N-1$$

Modulation spectrum [1]

Transmitted OFDM symbol decomposed into different subcarriers (ideal case, 4 subcarriers shown, no CP)



Power spectrum of one subcarrier transmitted at f_n Hz.



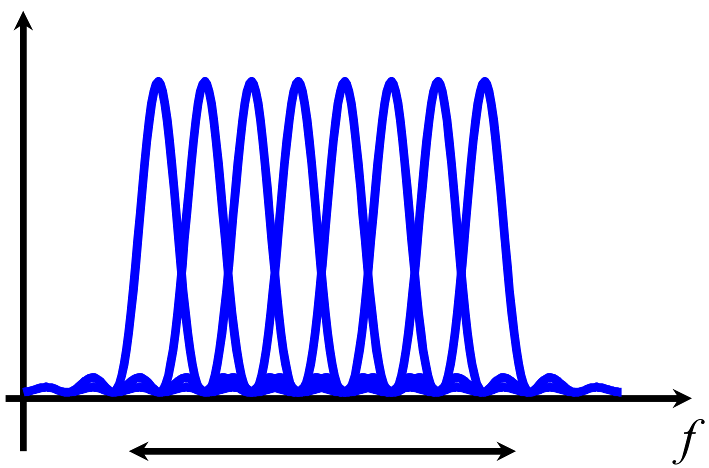
N – Subcarriers

T_{samp} – Sampling period

$$\mathrm{sinc}(x) = \frac{\sin \pi x}{\pi x}$$

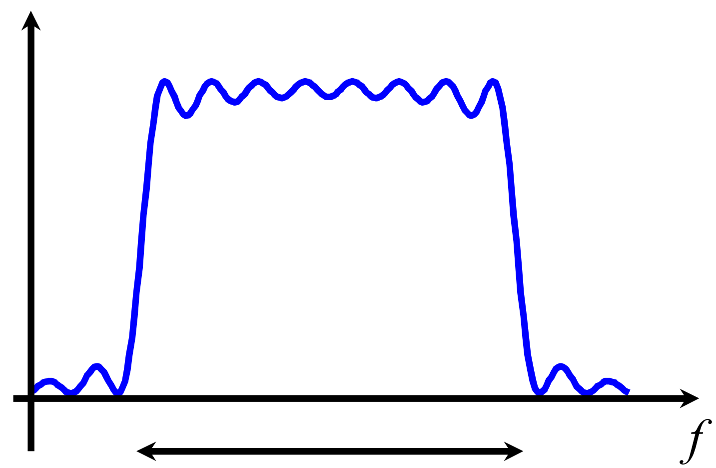
Modulation spectrum [2]

The distance between each subcarrier becomes $1/(NT_{samp})$ which is the same as the 3 dB bandwidth of the individual subcarriers. Using all *N* subcarriers (8 in this case) we get:



$$B = N \times 1/(NT_{samp}) = 1/T_{samp}$$

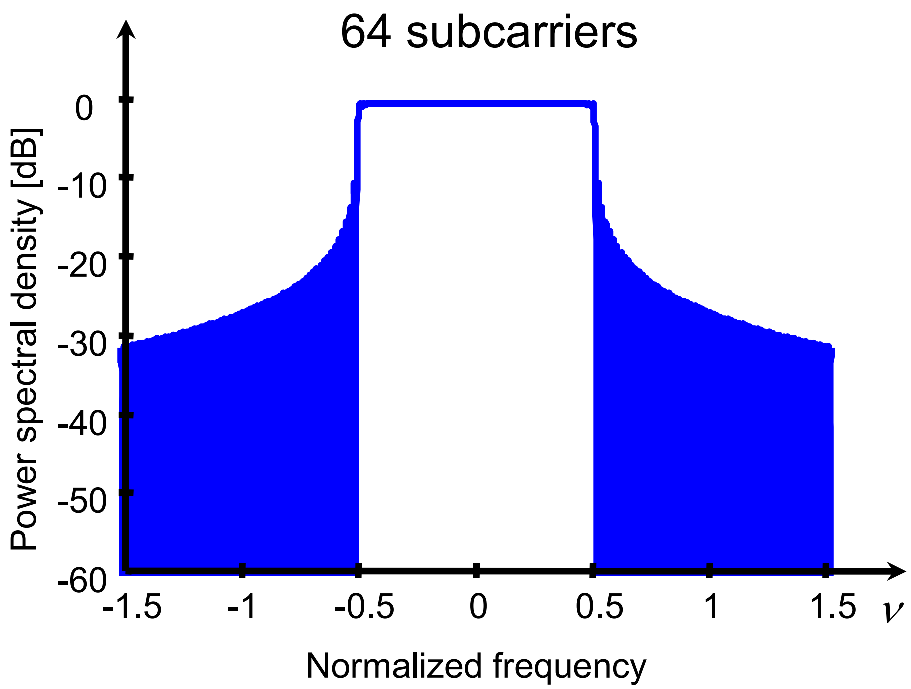
The total modulation spectrum is a sum of the individual subcarrier spectra (assuming independent data on them).

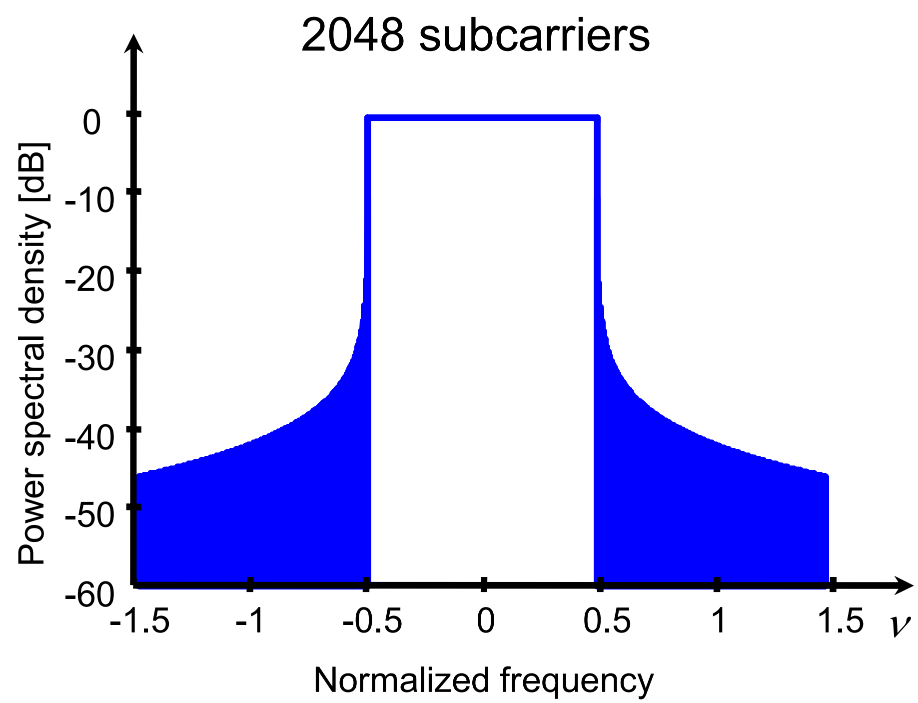


$$B = 1/T_{samp}$$

Transmitters and receivers

Modulation spectrum [3]



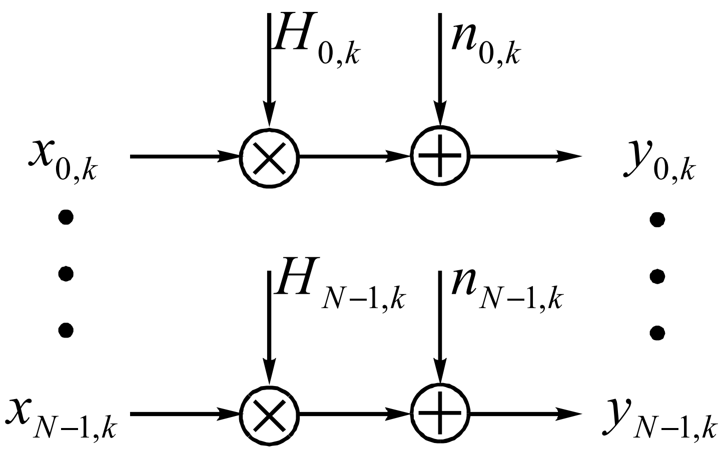


Normalized freq.:

$$\nu = T_{samp} f = f / B$$

Simplified model

Simplified model under ideal conditions
(no fading and sufficient CP)



Total filter in the signal path:

$$h_{signal}(t) = h_{TX}(t) * h(t) * h_{RX}(t)$$

$$H_{signal}(f) = H_{TX}(f) * H(f) * H_{RX}(f)$$

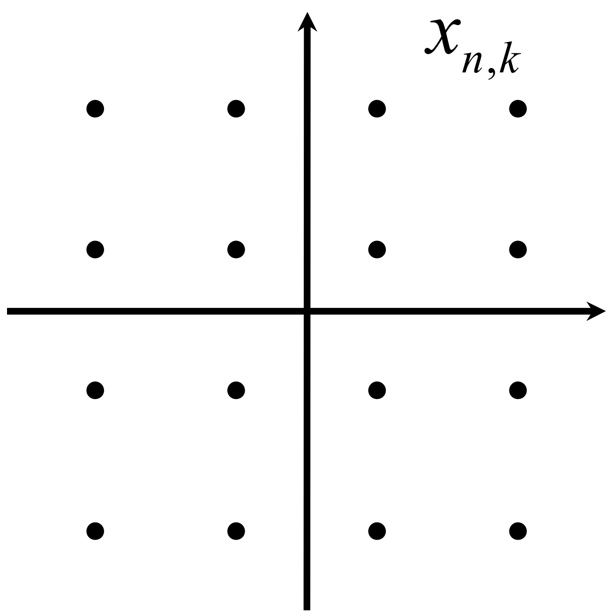
Given that subcarrier *n* is transmitted at frequency f_n the attenuations become:

$$H_{n,k} = H_{signal}(f_n)$$

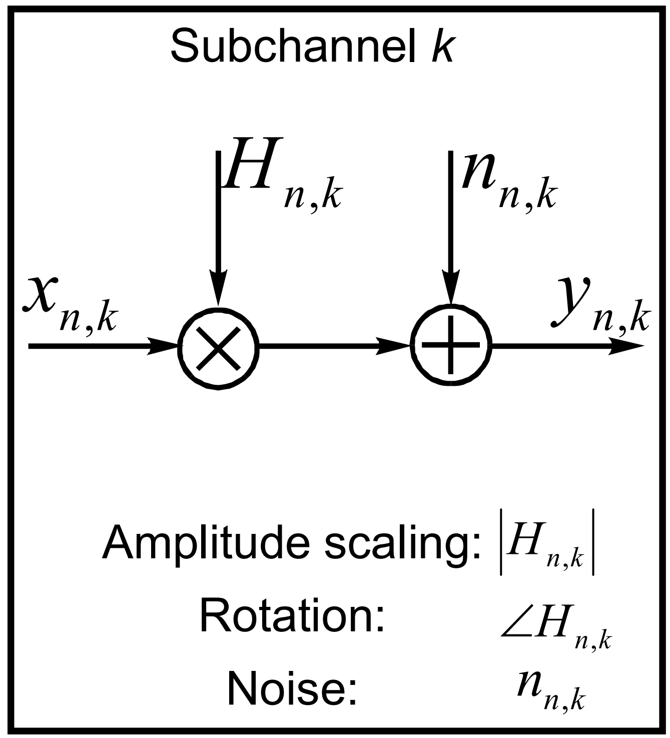
Focus on one subchannel

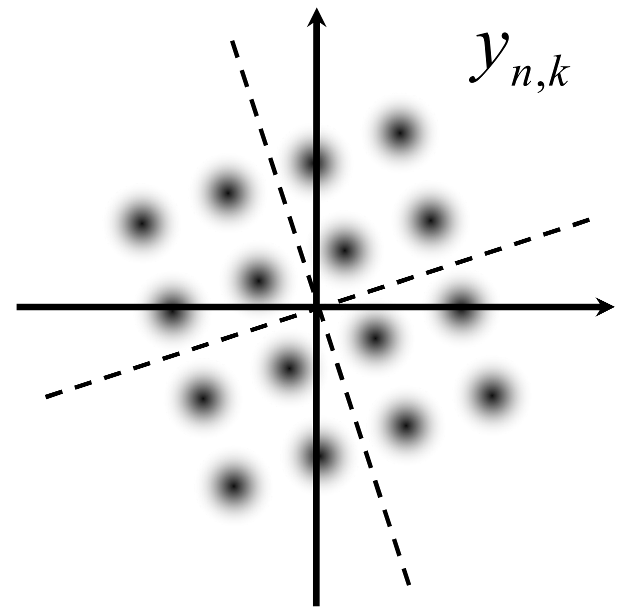
Before IDFT in TX

After DFT in RX



(16QAM)





- Simple equalization of each subchannel: Back-rotate and scale